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Step by Step in 3D printing Handbook

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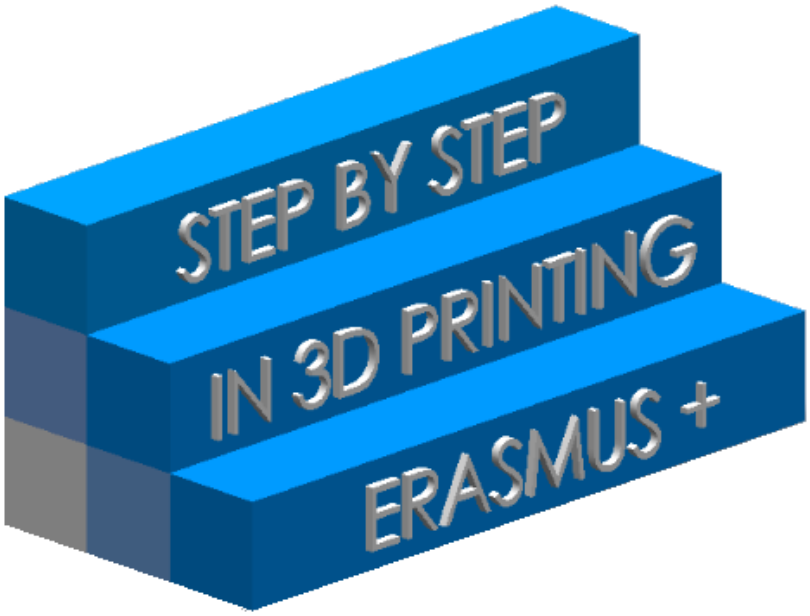

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ΕΠΑΛ ΕΛΕΥΘΕΡΟΥΠΟΛΗΣ

ТЕХНИЧКА ШКОЛА ПИРОТ

СРЕДНО ОПШТИНСКО УЧИЛИШТЕ • СРЕДНО ОПШТИНСКО УЧИЛИШТЕ ГОЦЕ ДЕЛЧЕВ

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Part 1: All about the 3D printing

Introduction

The manual "Step by Step in 3D Printing" was created as part of the approved European Erasmus+ Program, KA2 Small-scale Partnerships in the field of Vocational Education and Training, under contract number 2023-1-RS01-KA210-VET-00015403.

It is the result of a collaboration between the vocational schools Tehnička škola from Pirot, Serbia, SOU Goce Delchev from Valandovo, North Macedonia, and 1st EPAL of Eleftheroupoli from Greece, all of which actively participated in the design and development of its content. Authors are vocational teachers in these schools: Aleksić Vojislav (Srbia), Pilipovikj Vladimir (North Macedonia) i Violeta Samioti (Greece). The assosiates on this project are: Olivera Petrović, translator i Emilija Zafirova Petkov, author of the Easy read version of this handbook.

The main objective of the manual is to provide a clear, detailed, and accessible guide to the process of 3D printing. It is intended for teachers, students, and anyone interested in familiarizing themselves with the fundamental principles and steps of 3D printing. Through its pages, the manual aims to introduce readers to the concepts and techniques of 3D printing, explain the step-by-step process from design to production, enhance creativity, innovation, and digital skills, and support interdisciplinary learning by integrating 3D printing into various fields of science.

This manual serves as both a learning tool and a source of inspiration for those who wish to explore the potential of this technology. It contributes to the development of digital skills and the promotion of creative thinking. It is provided free of charge to all members of the student community of the three schools and is not for sale. Additionally, reproduction for profit is strictly prohibited.

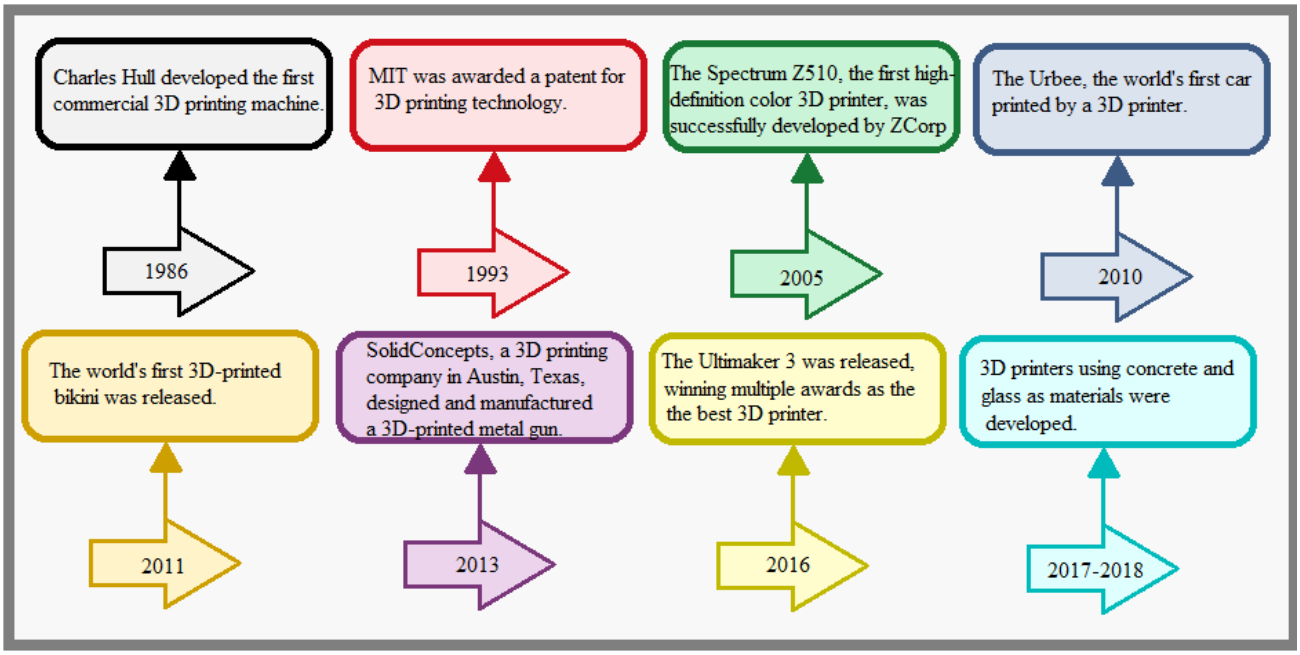
1. What is 3D printing and how does it work?

3D printing (or additive manufacturing) is a technology that enables the creation of physical objects from digital files by adding material layer by layer. Unlike traditional manufacturing methods, such as cutting or subtracting material, 3D printing builds the object with precise dimensions and geometries, offering flexibility and the ability to create complex designs. This technology is used in various fields, allowing the

production of components, models, prosthetics, and other products with enhanced accuracy and adaptability to user needs.

1.1. Historical overview of 3D printing.

- In 1986, Charles Hull developed the first commercial 3D printing machine.
- In 1993, MIT was awarded a patent for 3D printing technology.
- In 1995, the American company ZCorp obtained the exclusive license from the Massachusetts Institute of Technology and developed 3D printers.
- In 2005, the Spectrum Z510, the first high-definition color 3D printer, was successfully developed by ZCorp.
- In November 2010, the Urbee, the world's first car printed by a 3D printer.
- On June 6, 2011, the world's first 3D-printed bikini was released.
- In July 2011, British researchers developed the world's first 3D chocolate printer.
- In August 2011, engineers at the University of Southampton developed the world's first 3D-printed airplane.
- In November 2012, Scottish scientists used human cells to print artificial liver tissue using a 3D printer for the first time.
- In November 2013, SolidConcepts, a 3D printing company in Austin, Texas, designed and manufactured a 3D-printed metal gun.
- In 2015, the Swedish company Cellink introduced the first standardized commercial bio-ink on the market, made from non-cellulose alginate material derived from seaweed.
- In 2016, the Ultimaker 3 was released, winning multiple awards as the best 3D printer.
- In the years 2017-2018, 3D printers using concrete and glass as materials were developed.
- In the years that followed, the development of 3D printer technology was rapid. Today, there are over 170 manufacturers of 3D printing systems worldwide. This list includes: 3D Systems, Stratasys, Fusion3, Formlabs, Desktop Metal, Prusa, and Voxel8, among many others.



***Picture 1**: Timetable of 3D printing.*

1.2 How does a 3D printer work?

The basic operation cycle of a 3D printer includes the following steps:

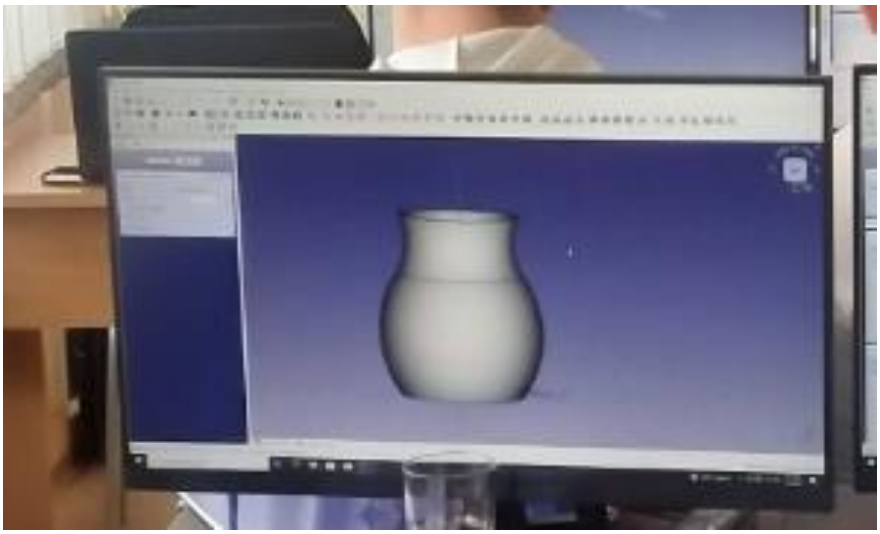
1. **Designing the Model**: The first step is to create a digital 3D model of the object you wish to print, using a design program.

2. **Model Preparation**: The 3D model is 'sliced' into thin horizontal layers, this process called "slicing". Each layer is then converted into code suitable for the printer.

3. **Printing:** During the printing process, the printer uses a material, usually plastic, which melts and is deposited at the desired location of each layer. The printer moves along two axes (X and Y) to place the material in specified positions, while the print bed moves each time a layer is completed (Z axis).

4. **Layer by Layer:** The printer repeats the layering and printing process for each layer until the final object is complete. The additive manufacturing capability allows for the creation of complex geometries and internal structures.

5. **Cooling:** Once the printing is complete, the object is cooled. Subsequently, some post-processing may be required, such as removing residues or applying paint, to achieve the desired aesthetic result.

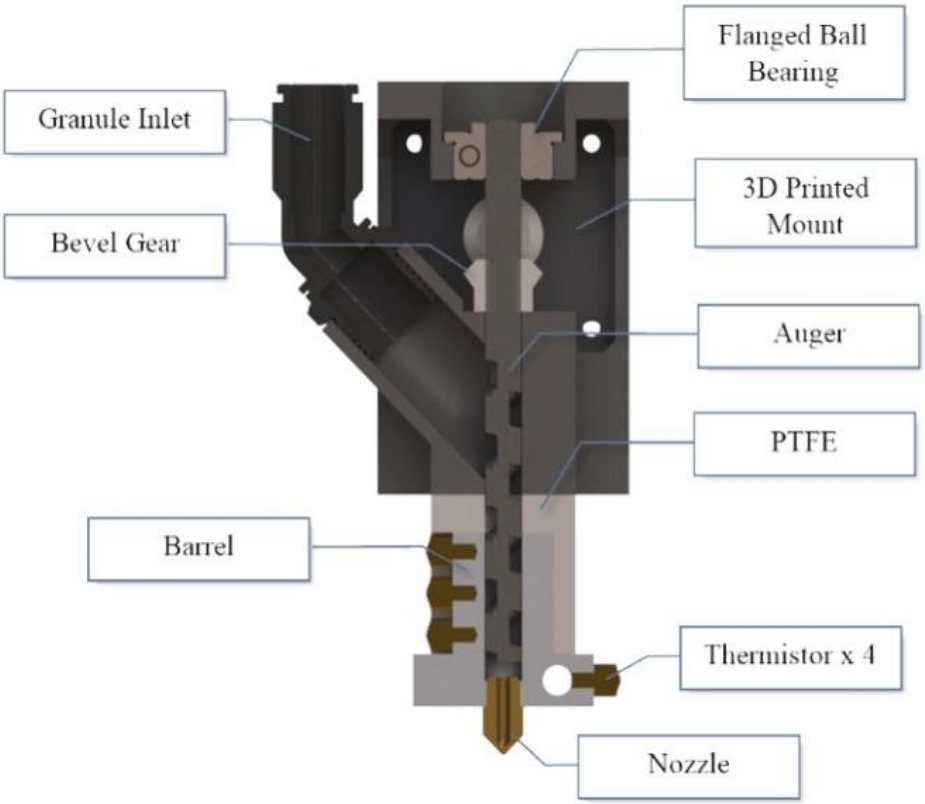


***Picture 2**: Object design process*

1.3 Components of a 3D printer

To operate a 3D printer, certain essential components are required, and it must have the necessary equipment. The list of these components may vary depending on the type of 3D printer, but all of them have the following basic elements.

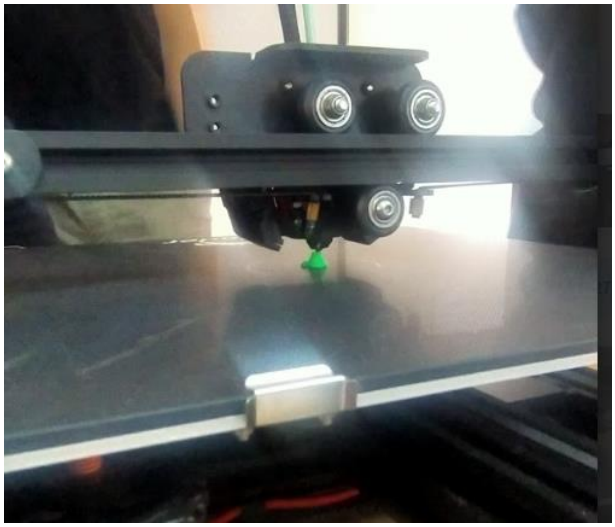
Extruder: The print head is responsible for handling the material (such as plastic or metal) and depositing it in the 3D space. Some printers use multiple print heads for multicolored prints or prints with different materials.



***Picture 3**: Experimental 3D printer extruder*

(Source: Potential of recycled PLA in 3D printing: A review:Mohammad Raquibul Hasan a,, Ian J. Davies b…)

Build Plate: The build plate is the surface where the object is constructed layer by layer. Some print beds are heated to improve material adhesion.



***Picture 4:** Build plate of 3D printer*

Axis System: The moving axes allow the printer to move in various directions. Typically, there are three main axes: X, Y, and Z. The X and Y axes are responsible for the movement of the print head, while the Z axis adjusts the height of the head during printing.

Filament: The printing material is usually in the form of spools in various colors and can include different materials, which will be discussed in detail in section 2.5 of this chapter.

Picture 5: *Filaments for 3D printers*

(Source: https://3pitech.com/cdn/shop/products/3D-Filament-Family.jpg?v=1686258344)

Filament Feed System: The plastic conduit transfers the printing material from the spool to the print head. Typically, this includes a printing mechanism, known as an extruder, which feeds the material into the print head.

Motherboard: 3D printers require a control system and a computer to receive the instructions for printing.

Control Software: The control software is responsible for converting the 3D model into commands that the printer understands. It also provides settings options for parameters such as print speed, temperature, and others. Control software varies depending on the manufacturer and model of the 3D printer.

1.4 Printing materials

The printing material, or filament, is the primary material used in a 3D printer to create objects. There are various types of printing materials, and the choice depends on the project requirements and the user's preferences.

PLA (Polylactic Acid):

Characteristics: PLA is environmentally friendly, produced from plant-based materials (usually from corn), and is biodegradable. It is suitable for prints that do not require high temperature resistance.

Uses: Various applications, such as decorative items, toys, and prototypes.

ABS (Acrylonitrile-Butadiene-Styrene):

Characteristics: ABS is strong and durable, with good resistance to high temperatures.

Uses: Functional objects, applications that require durability and heat resistance.

PETG (Polyethylene Terephthalate Glycol):

Characteristics: PETG combines the transparency of PET with the strength of ABS. It is a durable and flexible material.

Uses: Functional objects, bottles, protective cases.

Nylon:

Characteristics: Nylon is lightweight, durable, and highly absorbent. It requires special preparation for printing.

Uses: Recommended for applications that require abrasion resistance and exceptional strength.

TPE (Thermoplastic Elastomer):

Characteristics: TPE is flexible, elastic, and highly impact-resistant. It is suitable for prints that require elasticity.

Uses: Commonly used for creating rubber objects, such as tires and seals.

Ceramic materials

To achieve the additive method using ceramic materials, a 3D printer adapted to the specific task must be used.

The printing of ceramic materials is mainly done using four technologies: fused deposition modeling (FDM), Powder Bed Fusion, Selective Laser Sintering, and photopolymerization.

The FDM method for printing ceramic materials requires specialized printers that are fed with clay in a liquid state, which is extruded using an appropriate pressure mechanism. The application of this method requires two additional steps compared to the traditional method, which uses polymers. Specifically, suitable preprocessing of the clay is required before extrusion, as well as post-processing of the final print, which involves firing the final product in a kiln for hardening. Post-processing also applies to other printing methods. Therefore, a major limitation of applying 3D printing of ceramics is the cost of specialized printers and the need for a kiln.

Picture 6: *Ceramic objects made by a 3D printer.*

Before purchasing filament, always take the following into consideration.

1. Material Properties

One of the most important factors to consider when choosing the right filament is the material's properties. Its mechanical, thermal, and chemical characteristics determine the performance and suitability of the object you will create for its intended application.

2. Color and finish

The color and finish of the filament are also important factors to consider. Filaments are available in a wide range of colors and finishes, from opaque and translucent to metallic. Consider the desired aesthetics of your project and choose a filament that will highlight the appearance you envision and desire for your object.

3. Manufacturer and Quality

Choose a reliable manufacturer of high-quality filaments. Lower-quality filament can result in poor print quality, nozzle clogging, unwanted print detachment, and a variety of other problems.

4. Compatibility with your printer

Some printers may only be compatible with specific materials or require specialized hardware upgrades to print certain filaments.
Additionally, some materials may require a specific nozzle diameter or adjustments to printing speeds. Make sure to research the compatibility of the filament with your printer before making any purchase.

2. 3D design software

The design and visualization of three-dimensional objects is a specific category of graphics that typically targets graphic designers. However, this does not mean that a regular user cannot work with them, provided that they have some basic knowledge of the subject and a willingness to learn.

3D design programs are an essential tool for professional designers, architects, engineers, and generally for anyone who needs to work with such applications. Advanced 3D technology allows us to create realistic visualizations, develop original ideas, and communicate our creations clearly and accurately.

In today's world, where technology is evolving rapidly, there is a plethora of free 3D programs with excellent features that come without high costs or complicated learning curves. These tools consist of high-quality software that enables their users to express their creativity and create impressive works.

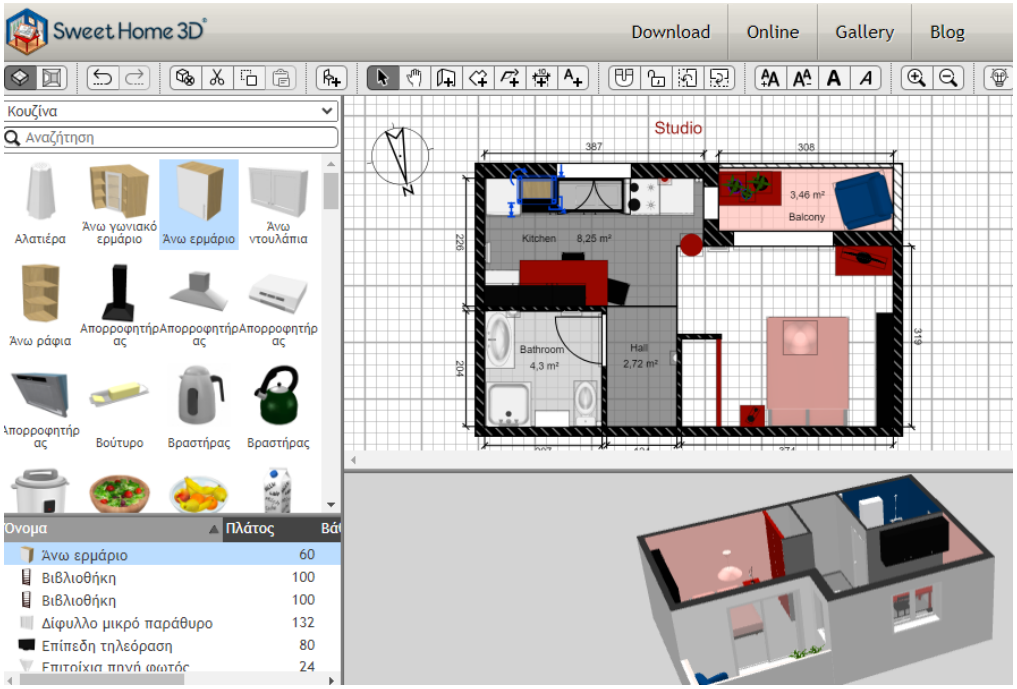
Next, we will examine some of the best free 3D design and modeling programs available to the general public. Each of these offers unique features and tools that can meet the needs and expectations of their users.

From applications that are ideal for beginners, students, and amateur technology enthusiasts to advanced programs aimed at professionals, this list covers a wide range of needs, highlighting the capabilities and performance of each.

2.1 Sweet Home 3D

Sweet Home 3D is aimed at those who want to design their home rooms on their own. It provides you with the ability to create the walls of your rooms, change their colors, dimensions, and add furniture. You can also import 3D models that you have created or find corresponding ones on various websites, resize and orient each piece of furniture, and view the changes in the design simultaneously in the 3D view. Additionally, you can print the design.

Official website: https://www.sweethome3d.com/



Picture 7: *Sweet Home Software*

(Source:https://encryptedtbn1.gstatic.com/images?q=tbn:ANd9GcSNF2fPcgxESyfQw3Qt52K5lPxsCcHqyVJE2zdKG9TeeNbKe50t)

2.2 DreamPlan Home Design Software

Your dream home can be designed and visualized with a realistic three-dimensional model. Design the floor of your space and customize the colors, textures, furniture, and anything else you can imagine to create a space that fully meets your needs and aesthetics.

The software allows you to switch between 3D and 2D viewing modes to perfect the floor plans, use the scanning function, utilize existing designs from the provided libraries, design outdoor spaces (e.g., yards, gardens, garages), and many other features.

The software is not online; it requires installation on your computer. You can download the free version from the following link.

https://www.nchsoftware.com/design/designsetup.exe

No registration is required.

Picture 8: *DreamPlan Home Design Software*

(Source: https://www.nchsoftware.com/design/images/webp/kitchen4.webp)

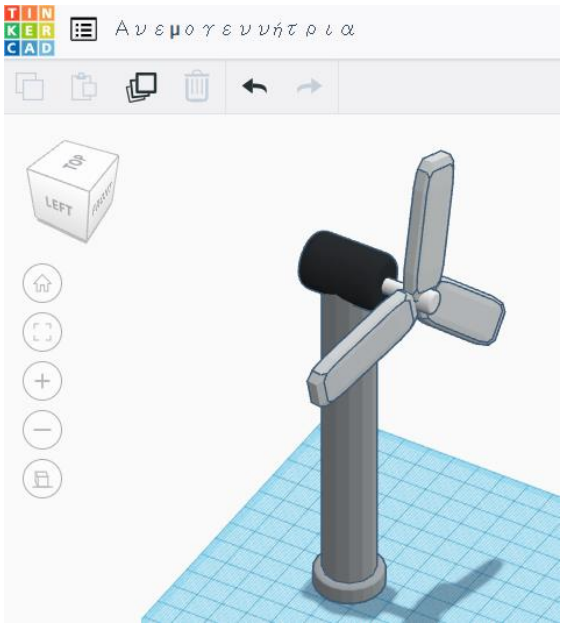
2.3 TinkerCAD

Tinkercad is a free online 3D modeling program that runs in a web browser, known for its simplicity and ease of use. Due to these features, it quickly became popular in schools. Teachers around the world use Tinkercad to help students become familiar with 3D design before training on software for professional use. Although it is ideal for beginners, this does not mean that more experienced users cannot use it to create impressive models.

Tinkercad is available online, and to use it, you simply need to create an account. The process is quick and easy, following the steps displayed on your screen.

You can enjoy the features of TinkerCAD at the following link:

https://www.tinkercad.com/join



Picture 9: *TinkerCAD*

2.4 FreeCAD

FreeCAD is a parametric, feature-based 3D modeling tool for general-purpose use in CAD, MCAD, CAx, CAE, and PLM. It is primarily aimed at engineering and product design, but also fits a wide range of engineering applications, such as architecture and other engineering specialties. It is 100% open-source and highly modular, allowing for advanced extension and customization.

Its simplicity has made it quite popular in schools, where it is mainly used in vocational education, bringing students closer to professional design.

Chapters 1 and 2 of this handbook focus on learning the FreeCAD software.

2.5 Onshape

Onshape is a computer-aided design (CAD) software, delivered over the internet using a software-as-a-service (SaaS) model. It extensively utilizes cloud computing, with processing and rendering that require high computational power being performed on internet-based servers, while users can interact with the system through a web browser or via iOS and Android apps. As a SaaS system, Onshape updates are released directly to the web interface, and the software does not require maintenance by the user.

It is quite easy to learn and closely resembles the functionality and handling of FreeCAD. Its main advantage is the ability for self-learning. Through a series of lessons provided by the program itself, users, even complete beginners, have the opportunity to start on their own and develop into capable designers. Upon completing the courses, the user can print a certificate at a low cost, which immediately qualifies them as a professional designer and allows them to entry in the job market.

Create your account at the following link: https://www.onshape.com/en/products/free

Picture 10: *Certified Onshape Professional*

(Source:https://d36ai2hkxl16us.cloudfront.net/thoughtindustries/image/upload/a_exif,c_fill,w_800,h_450/v1/course-uploads/6e557ed6-d03d-4c48-9492-4d18d145d7a1/tkifcukd7h2d-certprobadge800x450-01.png)

2.6 Make Human

MakeHuman is an open-source software for creating 3D models of human characters. It primarily focuses on the quick and easy creation of customized human forms, which can be used for various purposes, such as 3D modeling, graphics, games, movies, and scientific research.

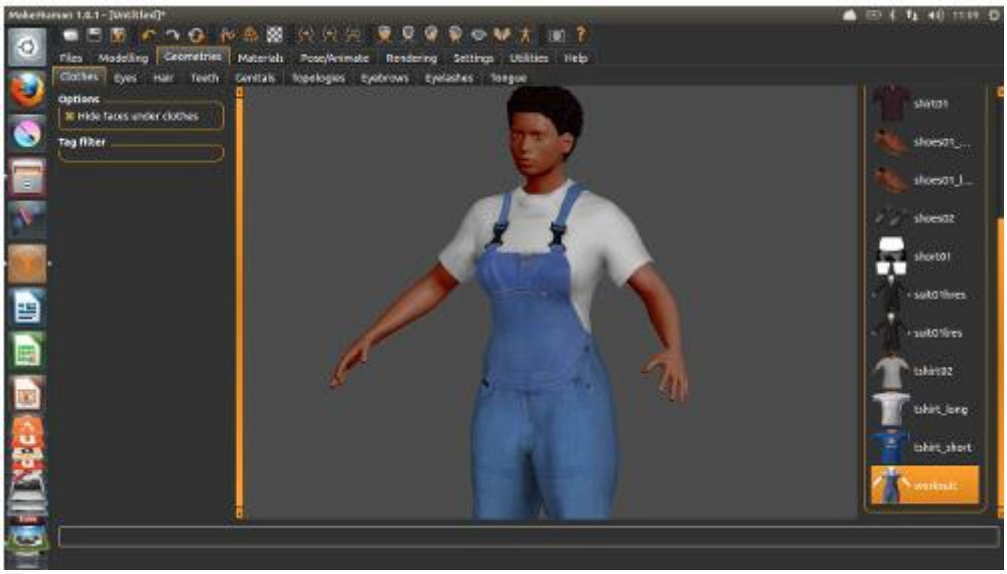
It allows users to modify parameters such as gender, age, ethnicity, body shape, and facial features. Additionally, it enables the selection and application of different clothing, hairstyles, accessories, and styles for the models.

The created models can be exported with a fully customized skeletal system . It also supports exporting models in popular file formats such as OBJ, FBX, DAE, and STL, making them compatible with other design and 3D editing software for further refinement of objects . Its user-friendly interface facilitates quick model customization without requiring specialized knowledge.

It is available for Windows and Mac OS X. To run the application, after downloading the file, extract it and run the executable file "makehuman”.

You can download the application from the follow link:

https://makehuman.en.softonic.com/



Picture 11: *The MakeHuman Software*

(Source: https://www.studiorola.com/wp-content/uploads/2014/07/makehuman.jpg)

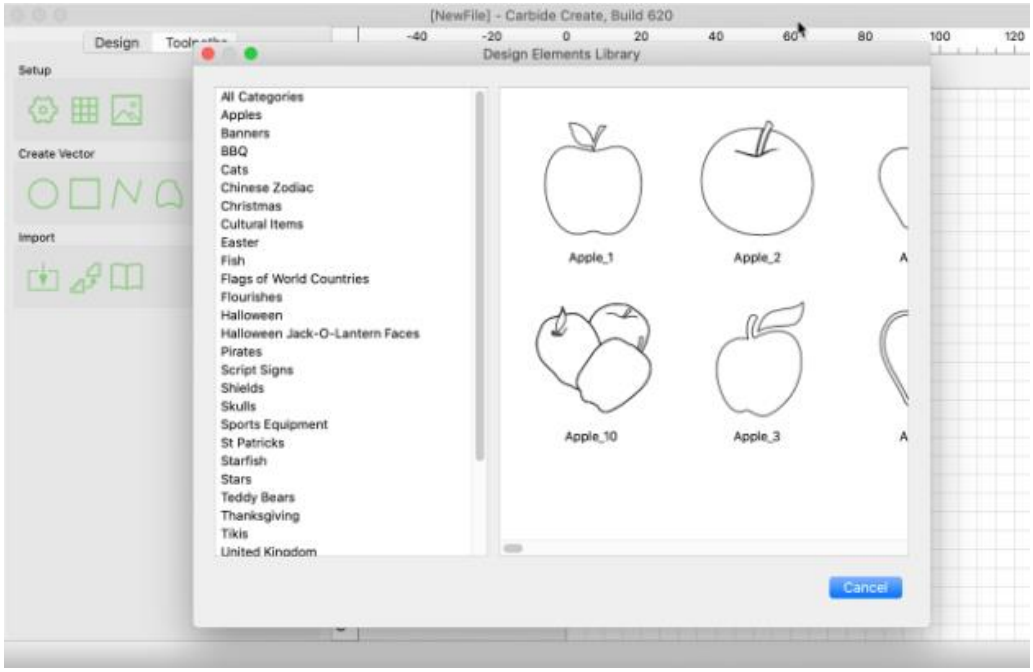
2.7 Carbide Create

Combine the power of 2D design and editing with 3D simulation and watch your designs come to life. Carbide Create, developed by Carbide 3D, is designed to simplify the creation and manufacturing of 2D and 3D objects for CNC machines. It is particularly popular among both beginners and experienced users working with CNC machines for cutting and engraving projects, and it is also ideal for those involved in 3D printing.

Carbide Create is downloadable software compatible with Windows and macOS. Notably, it is the only cross-platform CAD/CAM software that does not rely on "The Cloud." Most importantly, it is offered for free—not just to Carbide 3D customers, but to everyone.

To access it, registration is required. Once registered, you will receive an email containing a download link for the software, along with explanatory videos to guide you through its use.

Official link: https://carbide3d.com/



Picture 12: *The Carbide Create Software*

(Source: https://carbide3d.com/images/blog/cc620.png)

2.8 Blender

One of the best freeware programs for creating 3D objects. It is used for 3D modeling, offering tools for creating and editing complex 3D objects with features like polygonal modeling, sculpting, and surface modeling. It supports character and object animation through advanced animation and rigging tools. It includes the powerful Cycles rendering engine, as well as Eevee, a real-time rendering engine that delivers high-quality results. It also features an integrated video editor that allows for cutting, adding effects, and managing audio. Additionally, it supports the creation of visual effects and motion tracking, making it ideal for use in the film industry. It is available for all major operating systems, including Windows, Linux, and macOS.

Official link: https://www.blender.org/

Picture 13: *The Blender Software*

*(Source:https://miro.medium.com/v2/resize:fit:720/format:webp/1*kHCirek7ELBS_tfulA_agg.jpeg)*

2.9 Potter Draw

PotterDraw is a free design software that enables the creation of 3D ceramic objects and vessels through an intuitive and creative interface. It primarily targets users who wish to design and customize ceramic patterns without requiring prior experience with CAD or 3D modeling software.

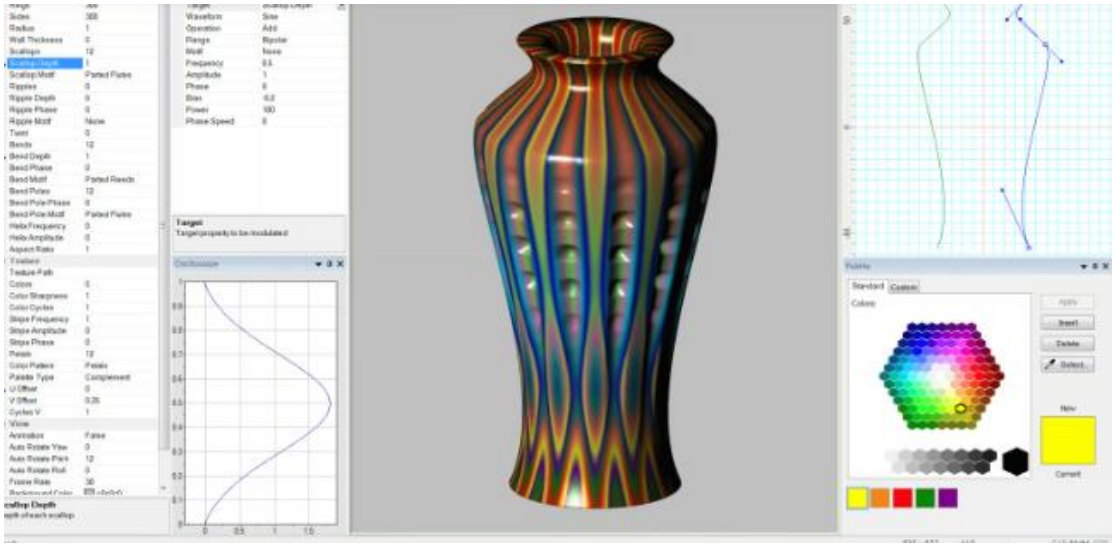
PotterDraw is based on the use of rotationally symmetric shapes. Users can create a profile, and the software automatically transforms it into a 3D object. Designs can be exported in file formats like STL, suitable for use with 3D printers. It also allows the application of materials, colors, and textures to objects to simulate ceramic surfaces.

The software is compatible with Windows systems and is offered free of charge, making it accessible to amateur creators and hobbyists.

Due to its user-friendly nature, PotterDraw is often used for educational purposes, enabling students and beginners to experiment with the art of ceramics and 3D design.

You can download the application from the follow link:

https://potterdraw.sourceforge.io/download.html



Picture 14: *The PotterDraw Software*

(Source:https://i.all3dp.com/workers/images/fit=scaledown,w=1536,h=864,gravity=0.5x0.5,format=auto/wp-content/uploads/2017/08/27005927/PotterDraw-screenshot.png)

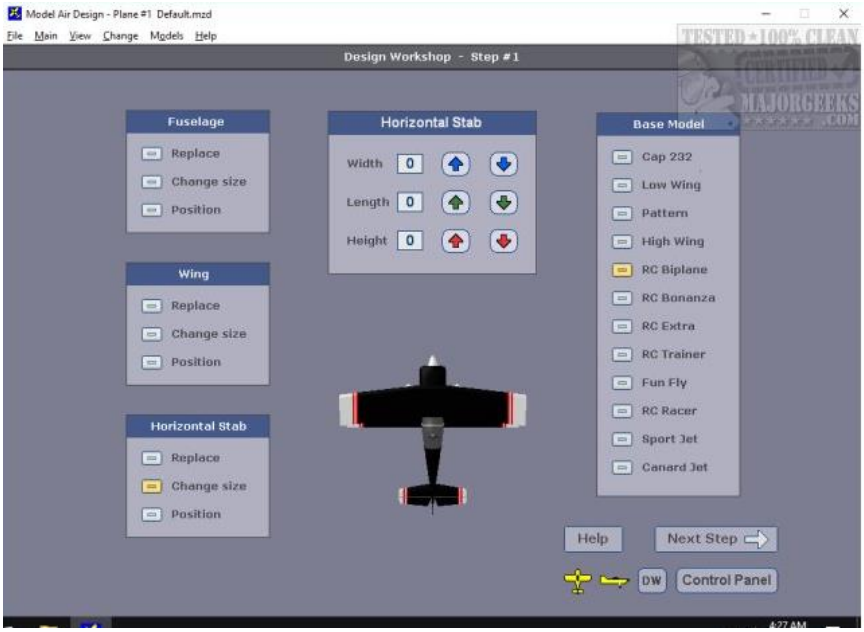
2.10 Model Air Design

Model Air Design is a user-friendly, freeware application designed for creating 3D models of airplanes. It's a great tool for hobbyists and those interested in designing aircraft models without needing advanced CAD software skills. The software provides templates and step-by-step guidance for designing a variety of airplane components, such as fuselages, wings, engines, and wheels. You can choose from various predefined designs and adjust their size, position, and other characteristics.

Model Air Design features an intuitive interface that simplifies the modeling process, making it accessible to beginners, while also offering enough flexibility for more experienced users. The program allows you to preview your designs in 3D, rotating them in all directions, and even simulates basic flight behavior to give you a sense of how your model would perform. It also includes customization options for colors, patterns, and other design elements.

This tool is suitable for both physical model creators and those who simply want to explore the art of aircraft design digitally. Model Air Design is available for Windows and can be downloaded for free.

Official link: https://modelairdesign.com/



Picture 15: *The Model Air Design Software*

(Source: https://www.majorgeeks.com)

2.11 Wings 3D

Wings 3D is a free and open-source 3D modeling software specializing in polygon-based modeling. It is designed to be user-friendly, offering a workspace focused on simplicity and usability. At the same time, it provides powerful tools that facilitate the creation of 3D models, making it ideal for artists and designers seeking an easy-to-use tool with a well-organized workflow.

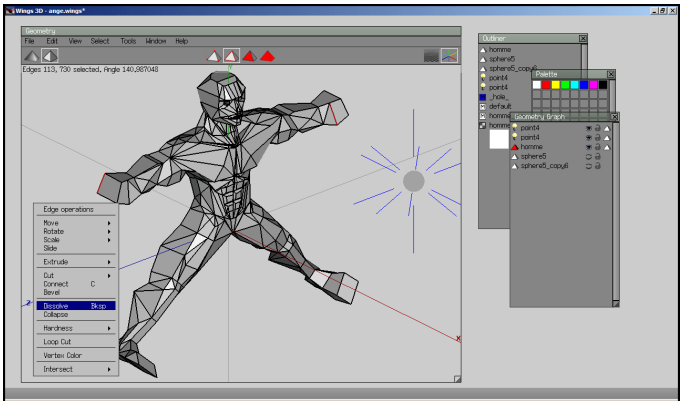
The software provides basic support for applying materials and texture mapping, allowing users to prepare their models for more specialized applications. Although it does not include advanced rendering tools, it supports integration with other 3D software through exporting to various file formats. Wings 3D is written in the Erlang programming language, known for its reliability, and is available for Windows, macOS, and Linux, covering all major platforms.

One of the key advantages of Wings 3D is that it is lightweight and fast to use. It is ideal for beginners who want to learn the basics of 3D modeling, while its simplicity makes it easy to learn. However, the software also has some limitations. It does not include built-in tools for rendering or animation, as it focuses exclusively on

modeling. Additionally, it lacks advanced features such as procedural modeling or sculpting, which would be useful for more demanding creations.

Overall, Wings 3D is an excellent choice for artists and creators looking to design low to medium complexity models. It is suitable for use in games, simulations, or other 3D applications, providing the essential tools for efficient and creative work.

You can download the application from the follow link:
https://www.wings3d.com/download-2/



Picture 16: *The Wings 3D Software*

(Source: https://www.tromjaro.com/wp-content/uploads/2020/03/wings3d-14.png)

The list is extensive, and it is impossible to document all the 3D design programs in this handbook. However, those who are interested can further explore and discover a wealth of tools and applications online that will meet their needs and preferences.

The latest advancements in technology allow for the printing of three-dimensional objects without requiring a prior design process. This is achieved through the use of 3D scanners.

3D scanning refers to the process of capturing three-dimensional objects or environments using specialized systems or devices that can detect and record their geometry and appearance in three dimensions. This technique is useful in many fields, such as industry, architecture, archaeology, medicine, and art.

There are various ways to carry out this process, including the use of lasers, photography, or even sensors that perceive the distance and shape of the object.

Advanced techniques are often employed to create digital models that can be used for analysis, design, documentation, or even reproduction of objects.

Picture 17: *3D Scanner*

3. Advantages and disadvantages of 3D printing

Just as every technological achievement presents both positive and negative aspects, so too does 3D printing technology, which, while having several advantages, also displays a relatively significant number of disadvantages.

By way of example, we mention.

3.1 Advantages

1. Smaller value chains:

The value of the final product does not increase significantly during the production stages, as is common in traditional value chains. Due to the short production chain of 3D objects, the value of the products changes minimally because of the added value during production.

2. Cost Reduction in Production:

This occurs primarily due to the raw materials. The raw materials used are easy to find and quite affordable. There is no need for large production chains, as the only tools required are a printer and a computer.

3. Direct Producer-Consumer Contact:

Due to the unique nature of this technology, the interaction between consumers and manufacturers is more direct than in a traditional production chain. Here, prospective customers choose the item to be printed and immediately contact the company, which then passes the order to the designer, initiating the creation process.

4. Fewer Products in Stock:

A key feature of 3D printing is on-demand production. This is why there are no physical stores and, consequently, no stock in warehouses.

5. Less Complexity in the Production Process:

There aren't many different machines that could create confusion in the production process. The steps are simple and followed in the same way each time.

6. Objects Can Be Easily Modified:

When creating an object in the digital file, it is easy to make modifications, even when the object is in the final design stage.

7. Faster production process:

There is no need for large order quantities to initiate the production of an object, which makes the process simpler and quicker compared to traditional production methods.

8. Easier replication and redesign of products:

Digital files are stored in databases after the completion of production, making the redesign of an object a very simple process.

9. Variety in shape production:

A 3D printer can create objects with many different shapes each time it prints. Traditional machines are less flexible and have a more limited range of formations.

3.2 Disadvantages

1. High equipment acquisition costs:

The purchase prices of 3D printers used for professional purposes are quite high. They start from €500 for small-scale businesses with limited production and can go up to €10,000. These prices are constantly changing as 3D printing technology evolves.

2. Repetitive processes until object perfection:

The ability of a designer to edit the digital file at any stage, based on the client's preferences, is something not typically found in traditional production chains. However, this can sometimes cause delays in the creation of the object and may result in repeating the same processes more than twice.

3. Small production quantities:

In a large production chain, it is possible to simultaneously produce large quantities. This is not the case with 3D production. Here, if the object is large, only one product is created at a time, with a duration ranging from one hour to 5-6 hours, depending on the printer's speed. Although technology has advanced, and there are printers capable of simultaneously printing several models, we have not yet reached the quantities produced by traditional manufacturing methods.

4. Inability to produce large object parts:

Most 3D printers, especially those designed for home use, can print products up to a specific size, usually not much larger than their own dimensions. In the 3D printing industry, large objects are printed in sections and then assembled.

5. Protection of intellectual property:

The presence of online stores for ordering various objects forces most companies to showcase the items they design on various online platforms. As a result, the designer's personal data is not protected. In simple terms, the intellectual property of the object is not secured.

6. Lack of physical stores:

So far, stores selling products derived from 3D printing are exclusively online. This presents the disadvantage of limited awareness among potential consumers. However, from a professional perspective, this can be seen as an advantage, as it reduces the expenses associated with operating a physical store.

7. High energy consumption:

In 2009, the Massachusetts Institute of Technology (MIT) conducted research on the electrical energy consumption of metal powder fusion technology, and it was found that it uses hundreds of times more energy than traditional casting or metalworking. Because of this, 3D printers are more suitable for small batch production.

4. The 3D printing in Industry

Additive manufacturing (3D printing) has found applications in many industrial sectors, offering new possibilities and improvements in production processes. From the automotive and aerospace industries, where it is used to produce high-precision and lightweight components, to the medical field, where it is utilized for the creation of personalized prosthetics and medical devices, 3D printing has revolutionized traditional manufacturing methods. Additionally, it is widely used in architecture for model production and in the consumer industry for creating small batch products. The flexibility, accuracy, and ability to create complex geometries have made additive manufacturing a key tool for innovation and advancement in various sectors.

Next, we will attempt to analyze the industrial sectors where 3D printing is applied and present as many practical applications as possible, even exploring fields that initially seem impossible to benefit from this technology.

4.1 Aerospace

3D printing has many applications in aerospace, significantly contributing to the evolution of technology and manufacturing processes. It is used to create lightweight and durable components, reducing the weight of aircraft and spacecraft, which enhances efficiency and energy performance. Additionally, 3D printing allows for the production of complex geometric designs that are not possible with traditional methods, improving the performance of engines, aircraft systems, and spacecraft structural elements. This technology also provides the ability for rapid prototyping and testing, reducing production time and costs, while offering greater flexibility in design and manufacturing.

Picture 18: *3D printing in aerospace*

(Source:https://www.indiaherald.com/cdncgi/image/width=750/imagestore/images/politics/politics_latestnews/3d4k-415x250.jpg)

4.2 Automotive

In the automotive industry, 3D printing technology offers the capability for rapid manufacturing with high precision, shortening the development cycle and reducing production costs. These advantages make it a highly valued solution among car manufacturers. Furthermore, the use of a wide variety of materials enhances vehicle quality, while simultaneously avoiding the high resource consumption caused by design errors and reducing dependence on traditional mold-based production methods.

The application of 3D printing in the automotive industry has surpassed the phase of creating simple conceptual prototypes and is now expanding to functional components, impacting every aspect of parts manufacturing.

Applications of 3D Printing in Automotive Parts:

In the development process:
3D printing accelerates the research and development phase by enabling the rapid creation of prototypes and testing of complex designs, saving both time and resources.

Manufacturing of complex structures and components:
It facilitates the production of intricate geometries, lightweight structures, and customized components that meet the specific requirements of modern vehicles.

In mold manufacturing:
3D printing enhances the mold production process, shortening the development cycle and allowing the creation of complex and precise designs at a lower cost and in less time.

The first electric car entirely manufactured using 3D printing technology was the X-EV, developed by the Chinese company Polymaker, which specializes in the production of 3D-printed components. The two-seater vehicle is composed of 57 parts, nearly all of which are 3D-printed, except for the chassis, windows, and seats. The manufacturing time, including the production of its components, did not exceed three days.

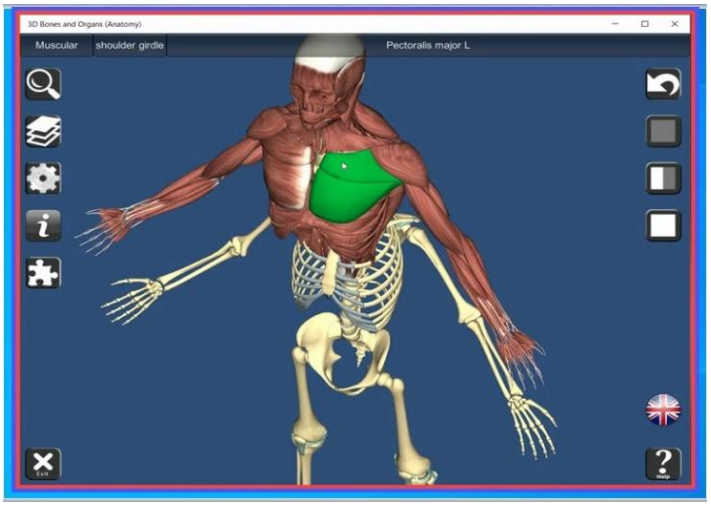
Picture 19: *The first 3D printing car*

(Source:https://encryptedtbn0.gstatic.com/images?q=tbn:ANd9GcS2i3PEPyNkxQSzlALiKy7VFo4eLBu1lKlw7Q&s

4.3 Medicine

Medicine is yet another scientific field that has significantly benefited from the advantages of 3D printing. This technology finds applications in general medical education, surgical training, and patient education. Three-dimensional human models are used in teaching and learning, offering students a clearer understanding of organ anatomy and related diseases.

At the same time, 3D imaging has proven to be a valuable tool in planning and performing surgical procedures. By creating a personalized 3D model for each patient, surgical teams can accurately assess the patient's anatomy and design optimal surgical approaches. This contributes to more efficient and faster surgeries while reducing the risk of complications. Additionally, this process minimizes surgery time, ultimately improving the overall quality of medical care.



Picture20: *3D human model design process*

(Source:https://lens.usercontent.google.com/image?vsrid=CLuR3rzwEQAhgBIiRlYjUxYTU4Zi1jNTg2LTQ3NGYtOGU1NS0xOGUzMTBkM2E5Njk&gsessionid=PJm0lLqcsj0bIMGvnHJasu8HlnRy2jRwggC8aKqUfO6uWDULQE39aw

3D printing is also effectively applied in the field of regenerative medicine, which aims to replace diseased tissues or organs. The precision and reproducibility of tissues and organs created using techniques available just a few years ago were difficult to control. 3D printing has combined the complexity of living tissue with high precision, producing exceptionally effective models. The creation of 3D-printed skin tissues, cardiac tissues, bones, cartilage, and numerous other grafts is now a reality, leading to significant advancements in medicine. It has enabled the development of personalized treatments, reduced the need for donors, and improved patients' quality of life.

Picture21: *3D human model design process*
(Source:https://lens.usercontent.google.com/image?vsrid=CNT7l50CEAIYASIkYWMzMjgyNzAtNjU4ZC00OTg0LTk2YmEtODg4YzQ3OGJlMmY4&gsessionid=LRm5r_KyqhjiTQn1pCxqSkT2Nu-OTip9y97bljIZCnD9RPVn2_sjlQ)

Another application of 3D printing that has gained public trust is the field of prosthetics. A range of 3D-printed components, manufactured using methods such as deposition modeling and material fusion, are widely used to meet the needs of patients in orthopedics, dentistry, oncology, and plastic surgery. Prosthetic models stand out for their precision, customization, and adaptability, providing solutions that enhance functionality and improve patients' quality of life.

Picture22: *3D printing of a prosthetic hand*

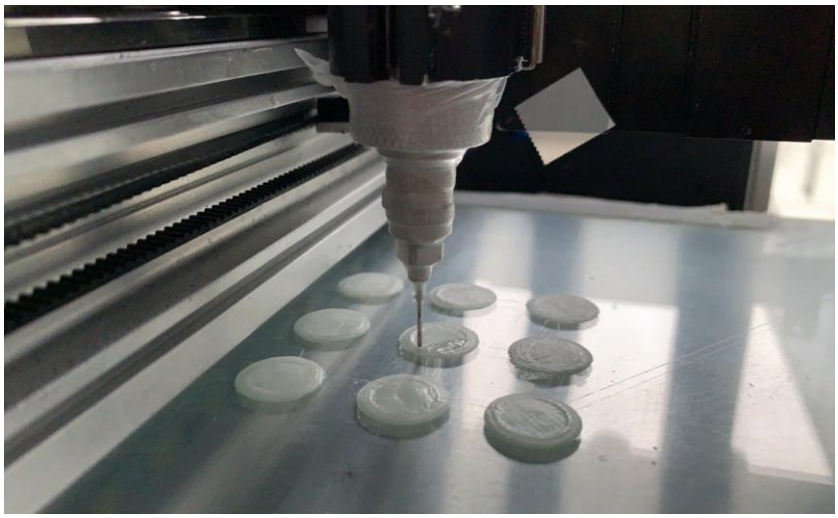
(Source:https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.jaguar-kktc.com%2Fabout-jaguar%2Fjag-style%2Fjag-tech%2Fteknoloji-gelecek-geldi-3d-yazicilar-evimizde&psig=AOvVaw2HyVIRRYOsnfBT-zlhIXXU&ust=1732906056247000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCMDglsza_4kDFQAAAAAdAAAAABAS

4.4 Pharmaceutical

3D printing has also made its way into the field of pharmaceuticals. Until 2022, it remained in an experimental phase, but it is now being actively utilized, bringing the sector closer to personalized medicine. 3D printers manufacture pharmaceutical formulations and enable the customization of pill shapes and coatings, allowing the active ingredients to be released according to each patient's specific needs. There is also the possibility of combining multiple active ingredients. An entire medication regimen for a patient can even be administered in the form of a single tablet, in any required dosage.

The main advantages of this technology are ease of use, unlimited options, speed, and precision in the production of pharmaceutical formulations. It is also an environmentally friendly technology and, of course, much more cost-effective than traditional drug manufacturing methods, as it significantly reduces production quantities. In terms of the geometric characteristics of oral medications, it offers the advantage of altering the shape and size according to the specific needs of each patient. This ability is particularly useful in pediatric and geriatric medicines.

Finally, the direct production of a pharmaceutical formulation is extremely useful in surgeries, ambulances, or crisis zones, as well as crucial for the use of medications with a short shelf life or stability.



Picture23: *Manufacture of pharmaceutical tablets with a 3D printer.*

(Source: https://www.voria.gr/article/i-trisdiastati-ektiposi-anaschediazi-to-mellon-tis-farmakeftikis)

4.5 Food Industry

Although it may seem unbelievable to many, 3D printing has found applications in the field of food technology. Given that consumer choices in the food market are influenced by criteria such as taste, quality, and the ingredients of the products, 3D printing meets these demands by enabling the creation of personalized food products. This innovation is particularly beneficial for specific consumer groups, such as children, the elderly, patients, and athletes, as it customizes food to meet their unique needs. Furthermore, its applications in the field of dietary management are

remarkable, with companies utilizing it to develop personalized meals that support goals such as weight loss or athletic performance, tailored to the individual needs of each customer.

Beyond the ability to create high-quality foods with superior nutritional value and unique flavors, 3D printers have introduced an artistic dimension to food preparation. Chefs now have the opportunity to experiment with innovative designs and intricate shapes, raising the bar for creativity and aesthetics in haute cuisine. At the same time, results that were impossible to achieve using traditional methods are now attainable, while the meal preparation process becomes more efficient, saving valuable time.

Although 3D food printing is steadily gaining ground and emerging as an innovative solution in the field of nutrition, it still faces the challenge of consumer acceptance. Many consumers remain skeptical about this new technology, either due to a lack of information or concerns about the quality, safety, or even the naturalness of printed foods. Overcoming this obstacle requires greater awareness, education, and trust to ensure that the potential of this technology is widely embraced.

Picture 24: *Digital gastronomy*

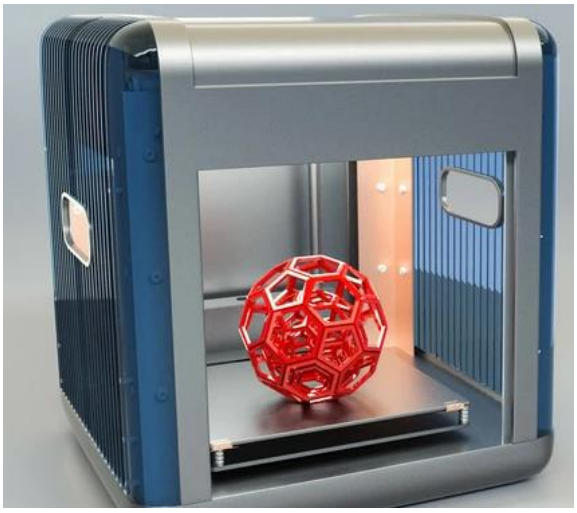
(Source:https://www.nutri-book.gr/images/article_images/nutri-book-psifiaki-gastronomia-3d-trofima-stin-ypiresia-tis-diaitologias.jpg)

4.6 Packing

3D printing has become a valuable ally in the packaging industry, introducing a new way of designing and manufacturing that is radically transforming the field. One of its most significant advantages is the ability to create customized packaging tailored to the needs of consumers or products.Whether it involves an innovative design that reflects a product's identity or functional packaging that provides greater protection for its contents, 3D printing offers precision and a variety of materials to meet even the most demanding applications. The cosmetics and perfume industry, known for its emphasis on originality and the uniqueness of its packaging, is one of the strongest advocates of 3D printing. Thanks to this technology, companies can create impressive designs that stand out, enhancing the identity and luxury of their products. Moreover, 3D printing allows for the rapid development of prototypes and the testing of new ideas, saving time and resources, while also enabling the production of small batches for exclusive collections. In this way, the packaging of cosmetics and perfumes becomes even more striking and tailored to customer preferences.

Another significant advantage of 3D printing is the reduction of production costs and time. The technology enables the rapid creation of prototypes, minimizing the need for traditional molds or large-scale manufacturing processes. This not only accelerates the launch of new products to the market but also reduces waste, as only the necessary parts are printed. Additionally, companies can quickly adapt their packaging to respond to market trends or customer demands.

Sustainability is another area where 3D printing in packaging proves to be exceptionally useful. By using eco-friendly and recyclable materials, companies can reduce their environmental footprint, aligning with the demand for more "green" solutions. Furthermore, the ability to print lighter yet equally durable packaging helps lower transportation costs and energy consumption. Thus, 3D printing combines innovation with sustainability, making it one of the most promising technologies in the packaging industry.



Picture 25: *3D perfume packing design*

(Source:https://icdn.tradew.com/file/202011/1574707/jpg/7467918.jpg?x-oss-process=image/quality,Q_90/format,webp)

4.7 Architecture and construction

Architects were the first to use 3D printing in the construction industry, leveraging the technology to create impressive and precise models of buildings. With the ability to print 3D designs and scale models, architectural design has evolved significantly, allowing professionals to present their projects with greater accuracy and detail, while also offering clients a more comprehensive view of the final result.

3D printing allowed architects to experiment with more complex and bold architectural forms that would be difficult to achieve with traditional methods. The ability to create intricate geometries and material combinations opened new horizons for modern architecture, enabling the design and construction of buildings that are not only functional but also aesthetically striking.

Next came the construction industry, which took advantage of the possibilities offered by 3D printing, revolutionizing the way buildings are constructed. Today, this technology allows for the printing of entire houses with great precision and in a very short time. This development enables the creation of structures that are more durable, cost-effective, and sustainable, compared to traditional construction methods.

The ability to print entire houses with 3D printers also allows for the use of new materials, which provide better thermal and sound insulation, while simultaneously

reducing waste during construction. This method can significantly reduce construction costs, as it requires less labor and materials, while also speeding up the completion process. Thus, the construction sector is being upgraded, offering more affordable and sustainable solutions for the construction of homes and other buildings.

In Mexico, a giant 3D printer, standing 33 feet tall, was used to create an entire neighborhood for families in need. This innovative initiative, a collaboration between organizations such as New Story and ICON, aimed to address the housing shortage in rural areas. The 3D printed homes were designed to withstand the region's seismic activity and flood risks, and were built using advanced materials that offer better durability and insulation than traditional homes. The construction of each house took approximately 24 hours.

The process of constructing 3D-printed houses represents an innovative and revolutionary development in the construction field, as it allows for the rapid and cost-effective creation of homes. However, this technology also carries a significant risk: the potential loss of many jobs. The automation of the construction process using 3D printers could reduce the need for traditional manual labor, threatening jobs related to hands-on construction, such as workers, builders, and craftsmen. While innovative technologies undoubtedly offer advantages, they also create the need for careful balance between progress and social impact.

***Picture 26**: House made by 3D printer*

(Source: https://i.ytimg.com/vi/K3N7kA7bxeI/maxresdefault.jpg)

4.8 Game Industry

Miniatures for tabletop games are among the most dynamic segments of the entertainment industry, with increasing demand from gaming enthusiasts, collectors, and creators. They are utilized in a variety of games, from board and strategy games to card games and even digital media like video games. These tiny works of art enhance storytelling and gaming experiences, creating a more immersive interaction for users.

The traditional method of crafting miniatures involves sculpting, casting, and reproduction through molds—processes that require significant manual labor and time. Despite the high quality that can be achieved, these methods are often expensive and not flexible enough for mass production or customized designs. 3D printing has revolutionized this field by enabling the creation of miniatures with greater speed, precision, and reduced costs.

By utilizing 3D printing, game designers can create prototypes and final products with intricate details that would be challenging to achieve through traditional methods. This technology also paves the way for producing customized miniatures, allowing users to design unique characters or items for their games. Consequently, 3D printing not only enhances the efficiency of the industry but also enriches the player experience, making miniatures an integral part of creative and entertainment production.

***Picture 27**: 3D printing in game Industry*

(Source:https://gr.china3dprinting.com/Content/uploads/2022850312/20221025094929ed146c8221cd4b7a9d92d6861c169bb9.jpg)

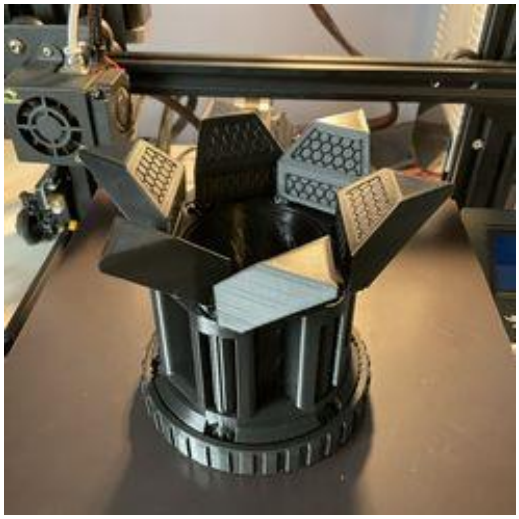
4.9 Art

3D printing is, among other things, a means of expression and creation, and for this reason, it could not be absent from the world of art. Through this technology, artists have been given the opportunity to create works with precise details and complexity something that in the past seemed impossible or, if achievable, was incredibly time-consuming.

The use of 3D printing in art has allowed for experimental exploration of new materials and forms. Artists now have the ability to examine novel ways of combining materials such as plastics, metals, and even biological substances to create artworks with unique properties. The ability to precisely replicate and adapt printed forms has introduced a new dimension to the production and collection of art, enabling artists to recreate the same forms in different scales or with different materials—something that was impossible with traditional art techniques.

3D printing in art has also opened up new possibilities in the field of personalized art. Artists now have the ability to create pieces that perfectly match their clients' preferences, such as customized sculptures and busts that accurately capture the features of a person’s face, as well as artworks that reflect individual tastes or interests. This has brought a new level of popularity to art, as collectors and enthusiasts increasingly seek unique pieces that reflect their personal identity.

Finally, 3D printing has contributed to the evolution of the digital world of art by allowing artists to transfer their digital creations into the physical world. The integration of digital technologies with traditional art has given rise to a new form of "digital sculpture," where artists can design their works using software and then print them with 3D printers. This new field enables the arts to evolve and express themselves in ways that were unimaginable until recently.



***Picture 28**: House made by 3D printer*

(Source:https://images.cults3d.com/9sisYYV1EQPCloQySU4I1zb9lw=/246x246/filters:no_upscale()/https://fbi.cults3d.com/uploaders/26846188/illustration-file/892e8726-4d60-4986-9554 49d6c986dca8/image.jpg)

Websites for Expanding Knowledge on 3D Printing Technologies

Below is a list of websites that highlight various applications of 3D printing in industry, with the aim of enhancing the knowledge of the readers of this manual and promoting the understanding of innovative technologies.

1. Bambu Lab X1 Series | Introduction
https://youtu.be/Eci4iFoyoS4
2. 3D Printed Metal vs CNC Machined - How Strong? https://youtu.be/Js3bJ1B8ySM
3. 3D Printing Food and Cooking It With Lasers
https://youtu.be/5IpqV15frb4
4. 3D printing in Automotive: How Škoda Auto made it
https://youtu.be/d606FD9cItc
5. 3D printing in the auto industry
https://youtu.be/ylRn40wDkr8
6. 3D Printing Is Changing the World
https://youtu.be/GV8zPtqOyqg
7. 10 AMAZING 3D Printing Projects: Rocky Mountain RepRap Festival 2023
https://youtu.be/ZXg_Ml6xJGU
8. Developing 3D Printed Drugs for Personalized Medicine with FabRx | 3D Interviews | 3Dnatives

https://youtu.be/nyJReEPmcow

9. How 3D Printed Food Can Change the Way We Look at Eating

https://youtu.be/TeeSYhPeCLw

10. How 3D printing is spurring revolutionary advances in manufacturing and design.

https://youtu.be/Adl1Sn86ojs

11. How Good are Professional 3D Printed Metal Parts?

https://youtu.be/o1vrfEl1uc8

12. How medical 3D printing could solve the shortage of organ donations.

https://youtu.be/LTwHsiCbbgs

13. MATT Architecture: Rapid model making with 3D printing - Ultimaker: 3D Printing Story

https://youtu.be/mMU_FG-KuX4

14. Metal 3D Printing | The Future of Manufacturing?

https://youtu.be/NkMRzpobmQQ

15. Next Generation of 3D Printed Surgical Instruments

https://youtu.be/2XlHMR01NYA

16. Prusa XL at Volkswagen Academy - How 3D Printing Is Used There

https://youtu.be/q9-ut8EgUHs

17. The 3D printing revolution | DW Documentary

https://youtu.be/k0poVtBhIsQ

18. The Genius of 3D Printed Rockets

https://youtu.be/kz165f1g8-E

19. Can 3D Printing be Art?

https://www.youtube.com/shorts/fz7LXsJb_-o?feature=share

20. 3D Printing Transforming the Gaming Industry

https://youtu.be/axTJXnojuIY

The internet hosts a wealth of videos showcasing impressive applications of 3D printing in the industry, offering viewers a unique opportunity to explore this innovative technology. Through these videos, one can observe how 3D printing is used for prototyping, creating customized products, or producing high-precision components. Viewers gain the ability to understand the technology's functionality, draw inspiration from its creative applications, and identify ways to utilize it in their own fields. These videos serve as educational tools, providing practical ideas and examples that can inspire students to innovate or improve professional activities they may develop in the future by leveraging 3D design and printing.

Part 2 : The FreeCAD software

Introduction

The part 2 follows a step by step methodology and teaches you to use FreeCAD design software for building parametric 3D solid components as well as creating 2D drawings. This handbook not only focuses on the usage of the tools and commands of FreeCAD but also the concept of design. Every chapter in this handbook contains tutorials that provide users with step by step instructions for creating designs and drawings with ease. Every chapter ends with hands-on test that allow users to experience the user friendly and powerful capabilities of FreeCAD to enhance the skills at the end of every chapter and additional notes and tips. The instructions to perform any action are provided by maximum number of illustrations so that the user can perform the actions discussed in the book easily and effectively. There are a lot of illustrations that make the learning process effective. Moreover most of the tools in this handbook are discussed in the form of step by step tutorials. Starting with the basics, you'll explore the FreeCAD interface and terminology, setting a strong foundation for your 3D modeling adventure.

1. What is FreeCAD?

FreeCAD is an open-source parametric 3D modeling application, made primarily to design real-life objects. Parametric modeling describes a certain type of modeling, where the shape of the 3D objects you design are controlled by parameters. For example, the shape of a brick might be controlled by three parameters: height, width and length. In FreeCAD, as in other parametric modelers, these parameters are part of the object, and stay modifiable at any time, after the object has been created. Some objects can have other objects as parameters, for example you could have an object that takes our brick as input, and creates a column from it. You could think of a parametric object as a small program that creates geometry from parameters. FreeCAD is not designed for a particular kind of work, or to make a certain kind of objects. Instead, it allows a wide range of uses, and permits users to produce models

of all sizes and purposes, from small electronic components to 3D-printable pieces and all the way up to buildings. Each of these tasks have different dedicated sets of tools and workflows available.

FreeCAD is also multiplatform (it runs exactly the same way on Windows, Mac OS and Linux platforms), and it is open-source. Being open-source, FreeCAD benefits from the contributions and efforts of a large community of programmers, enthusiasts and users worldwide. FreeCAD is essentially an application built by the people who use it, instead of being made by a company trying to sell you a product. And of course, it also means that FreeCAD is free, not only to use, but also to distribute, copy, modify, or even sell.

1.1 Installing

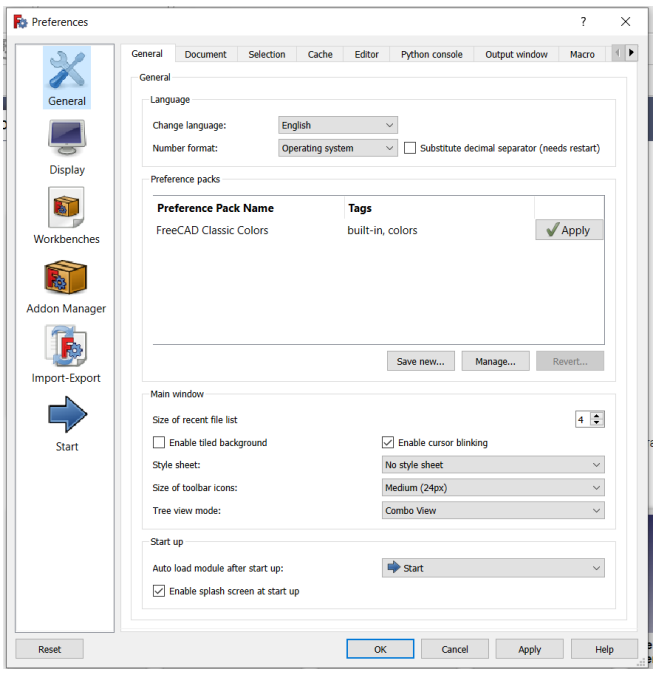
FreeCAD uses the LGPL license, which means you are free to download, install, redistribute and use FreeCAD the way you want, regardless of the type of work you'll do with it (commercial or non-commercial). You are not bound to any clause or restriction, and the files you produce with it are fully yours. The only thing that the license prohibits, really, is to claim that you programmed FreeCAD yourself!

Setting basic preferences

Once FreeCAD is installed, you might want to open it and set a couple of preferences. Preferences settings in FreeCAD are located under menu **Edit – Preferences-General**.

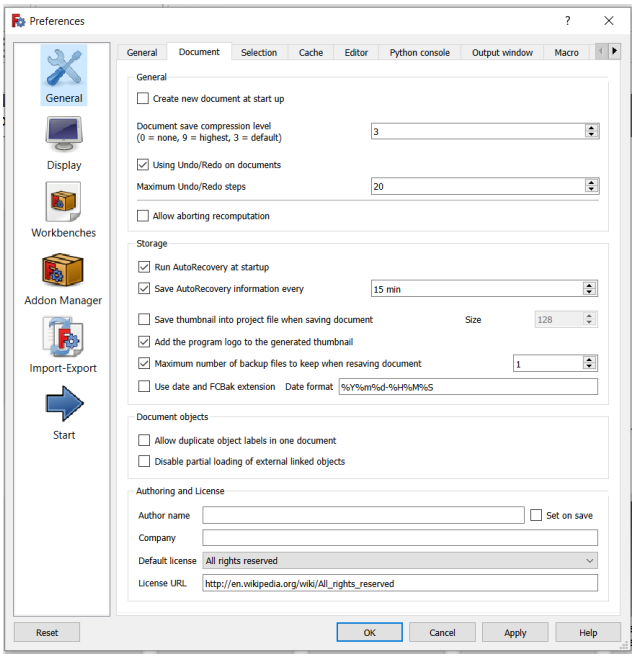
Language: FreeCAD will automatically pick the language of your operating system, but you might want to change that.

General – Language - Change language

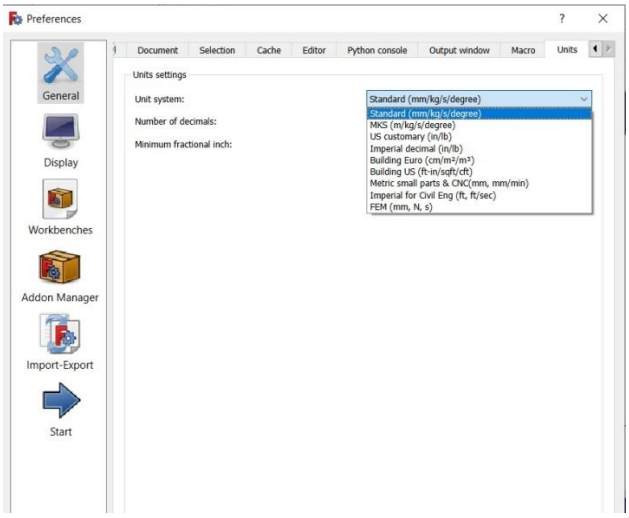


Storage options: As any complex application, FreeCAD might crash from time to time. Here you can configure a few options that will help you to recover your work in case of a crash.

Document - Save AutoRecovery information every (type 10min)

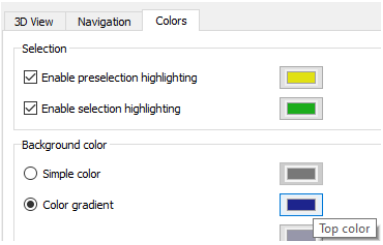


Units: Here you can set the default units you wish to use. It will be easier to work on the examples later, to stay in **mm/kg/s/degree**.

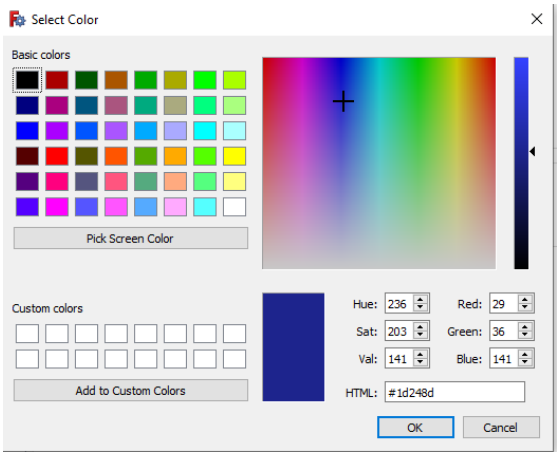


Change of the color of the background:

Edit – Preferences-Display-Colors-Color gradient



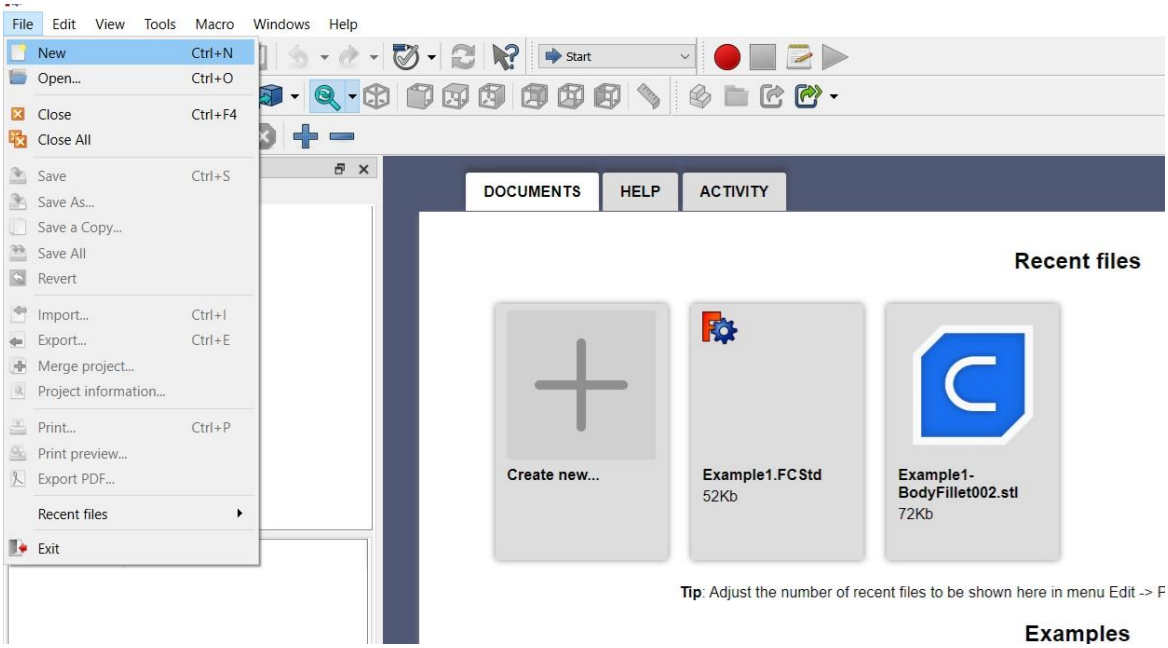
Click on the frame **Top color** and the new window will be opened in which you can choose the colour of the background.



You can choose the colour by scrolling the basic colour and you can choose the shade of the colour vertically.

2. 2D drawing

To create the new **FreeCAD** document click on **File→New**.



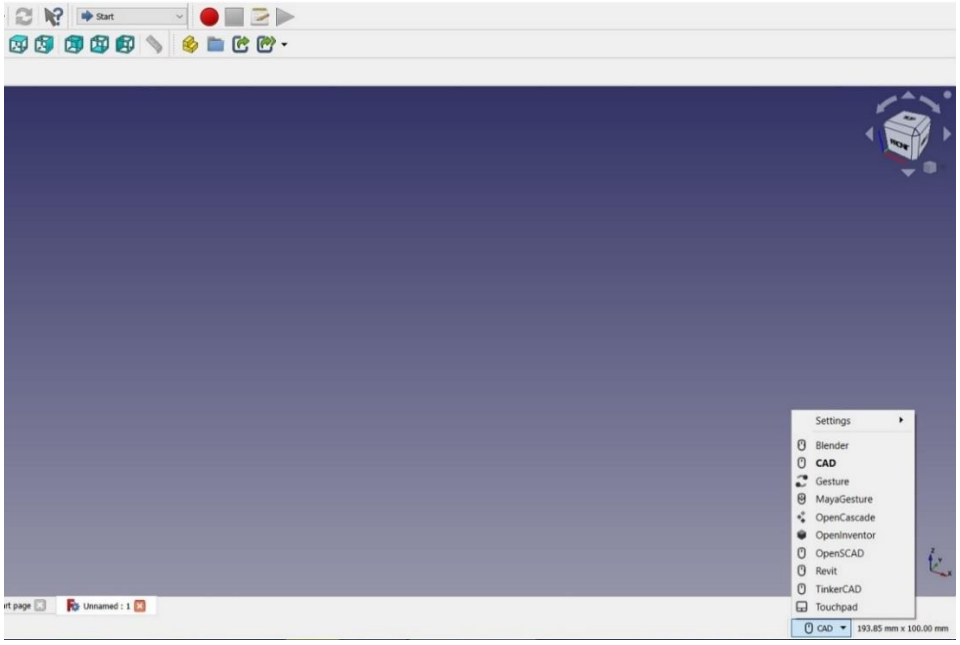
Picture 2-01

After creating new document, it is needed to choose the right navigation. After opening the new document, it is needed to choose the right navigation (manipulation) using the mouse.

By choosing the option CAD, there are different possibilities of navigation (manipulation).

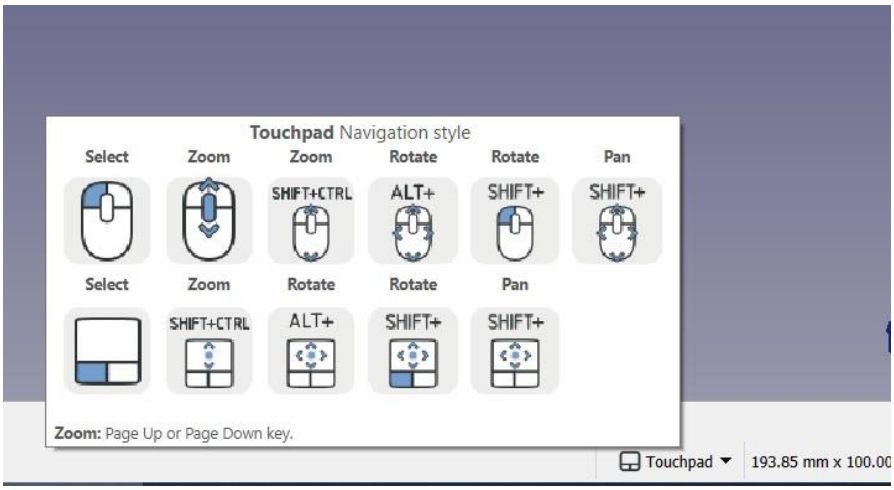
After opening a new document, it is necessary to choose the way of navigation (manipulation) using the mouse.

By opening the CAD tab, various navigation (manipulation) options appear.



Picture 2-02

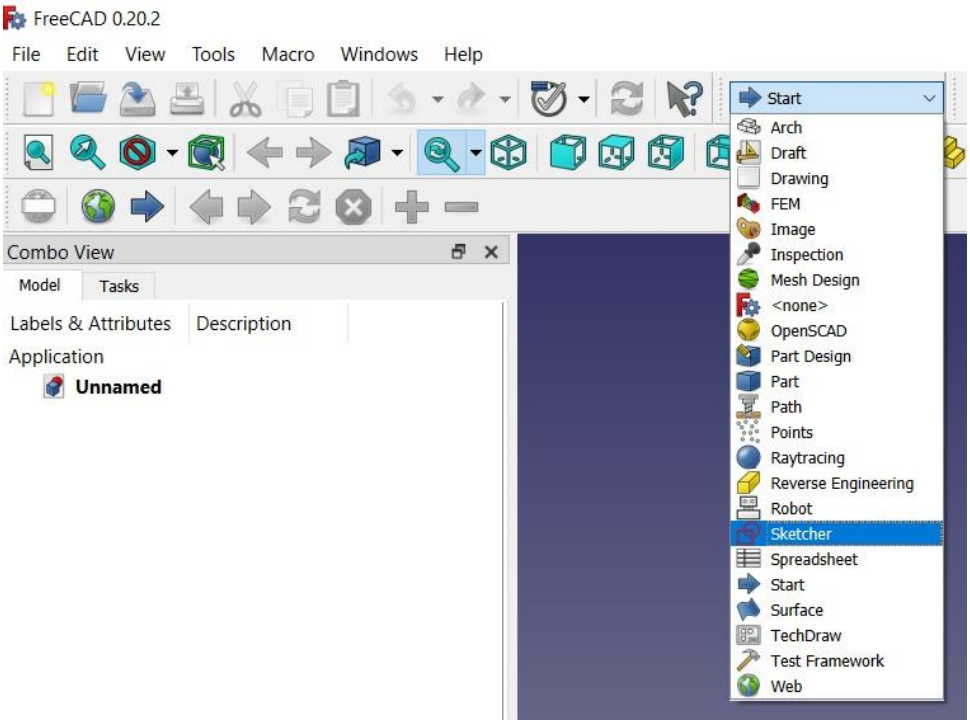
We select the Touchpad tab. After opening it, keep the mouse cursor on it so that the Touchpad navigation style appears. We see that there are about 10 styles of navigation. In this tutorial, we will use the Touchpad style of navigation because it can be used by users who only use the Touchpad on their laptops. Here is a pictorial presentation of instructions for selecting, zooming, rotating and moving. Both for operating the touchpad and for operating the mouse.



Picture 2-03

In order to test how it practically works, we will draw a simple drawing and practically try out all the possibilities on it.

The procedure for activating the window in which we will draw our drawing is as follows: by clicking on the drop-down menu **Start→Sketcher**

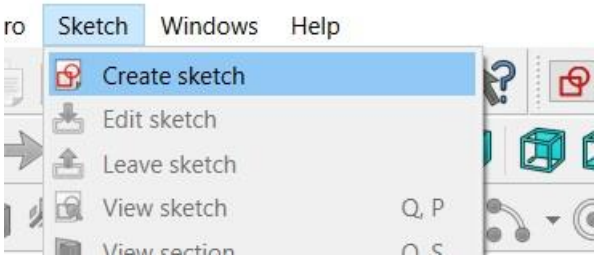


Picture 2-04

By clicking on the Sketcher tab, a number of icons appear, as in the following figure 2-05:

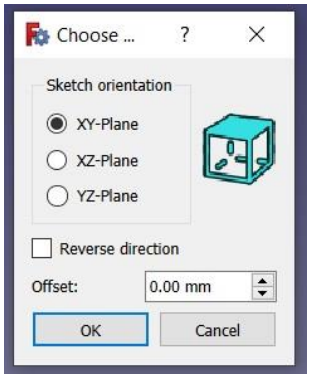
Picture 2-05

By clicking on the menu **Sketch→Create sketch**



Picture 2-06

The following window appears for selecting the plane in which we want to draw our drawing. Here the XY plane is offered, which we accept by clicking OK.

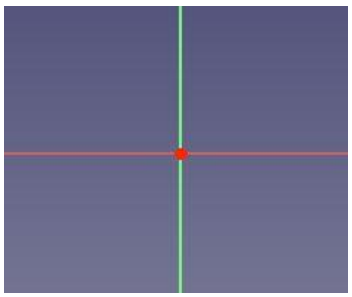


Picture 2-08

As we can see, many of the drawing icons have now become active.

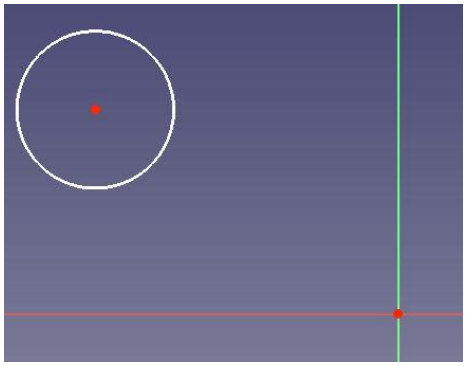
Picture 2-09

Also, a coordinate system with **X** (red line) and **Y** (green line) appears, and **the center of the coordinate system** (red point, hereinafter **CCS**)



Picture 2-08

First we will draw a circle. By clicking on the circle drawing command (left click with the mouse, we move away from the center of the circle as much as we want and then left click with the mouse again).

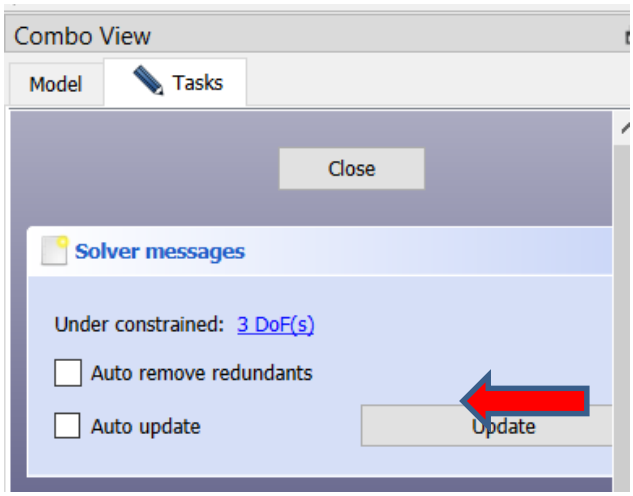


Picture 2-10

NOTE: After drawing a circle, the draw command is still active so we can draw the next circle. When we no longer need it, we turn it off using the ESC key on the computer keyboard or right-clicking the mouse.

In the left part of the screen in the window **Combo View→Solver messages →Under constrained** there is a message **3 Dof(s)** (*degree of freedom*), which means that we need to define 3 parameters for our circle: the distance of the center in the X and Y directions and the diameter of the circle.

In the left part of the screen in the window, which means that we need to define 3 parameters for our circle: the distance of the center in the X and Y directions and the diameter of the circle.



Picture 2-11

NOTE: A *degree of freedom* (DOF) indicates a possible movement of one element. For example, a point can be moved both in horizontal and vertical directions, so it has two degrees of freedom. If a line is defined by two points, therefore in total it has four degrees of freedom. If we fix one of those points, then the entire system has only two degrees of freedom available; if we additionally fix the horizontal movement of the remaining point, we only have one degree of freedom left; and if we also fix the vertical movement of this point, then the last degree of freedom disappears, and the line cannot move from its position any more.

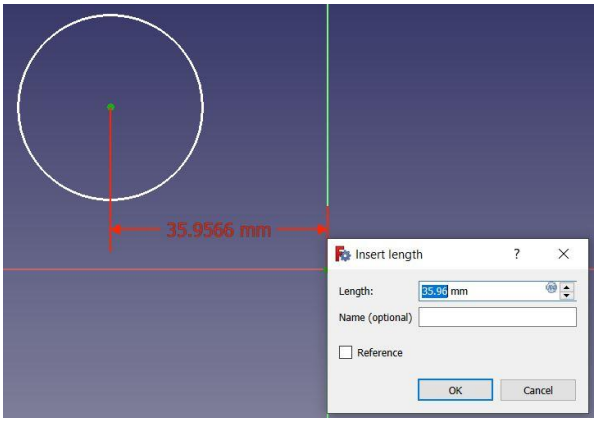
Constraints are "rules" that tell us under which conditions a geometrical object can move and by how much. They are used to eliminate the degrees of freedom so that the sketch has a stable shape. If we eliminate all degrees of freedom, then the sketch is **fully constrained**, and has a fixed shape, which means that its points cannot move at all. In general, it is a good idea to fully constrain sketches because this will result in stable models.

There are **two principal types of constraints**:

Geometric constraints define characteristics of the shapes without specifying exact dimensions, for example, horizontality, verticality, parallelism, perpendicularity, and tangency.

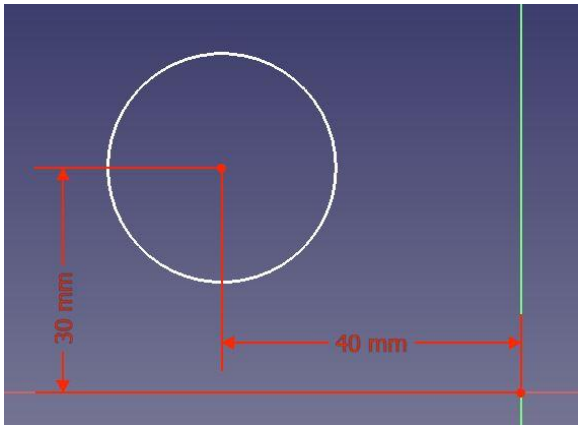
Datum constraints define characteristics of the shapes by specifying dimensions, for example, a numeric length or an angle.

Now we will dimension our circle so that it is completely defined in our workspace. By clicking on the **Constrain horizontal distance** command , and then selecting the center of the circle and then selecting CCS, the **Insert Length** window appears in which we enter the desired value along the X axis (eg 40mm).



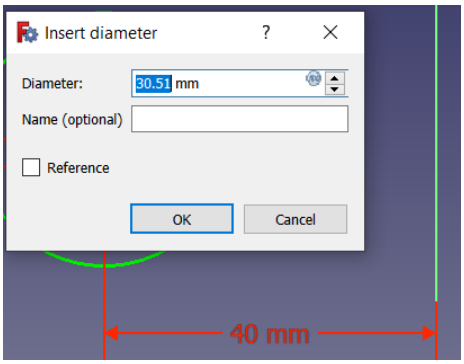
Picture 2-12

The procedure is repeated to define the center of the circle in the Y direction of the coordinate system using the command , first select the center of the circle, and then select CCS. Here we can enter a value of 30mm.



Picture 2-14

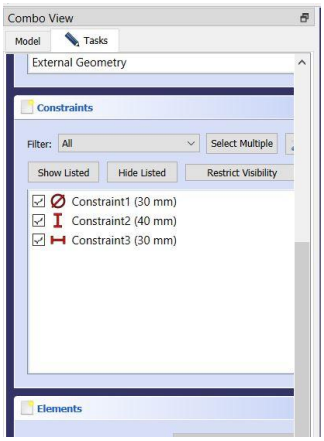
Now we only have to define the diameter of the circle by clicking on the command **Constrain arc or circle** , and then by clicking on the circle, after which the window **Insert diameter** appears, where we enter the desired diameter of the circle, e.g. 45mm (Picture 2-16).



Picture 2-16

NOTE: If we happen to enter the wrong value for the dimensions or later want to change it, move the mouse pointer to the desired dimension (e.g. the diameter of the circle) until it changes color (turns yellow) and double-click to activate the Insert diameter window in which we enter the desired changes.

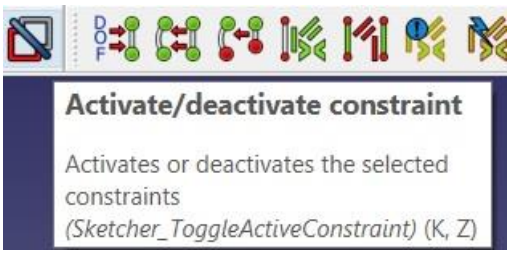
NOTE: Another way to change dimensions is by using the Combo View window in which we find the Constraints window. Here we see the 3 dimensions of the circle. By double-clicking on one of them, the Insert window appears again, in which we enter the desired changes. (Picture 2-16a).



Picture 2-16a

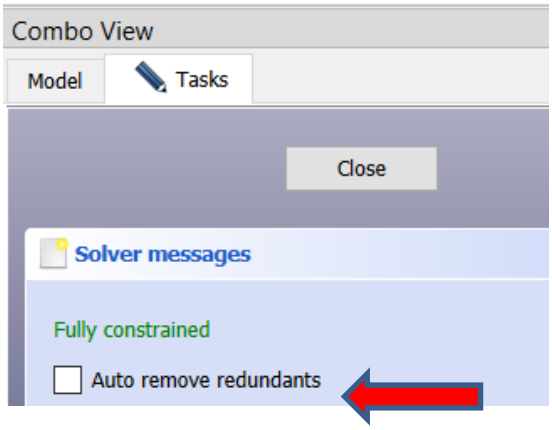
NOTE: Also, if the elevations (dimensions) overlap, we can move them left, right, up, down to make them visible. We also approach with the mouse pointer until the dimension changes color (turns yellow), click on it and move in the desired direction.

NOTE: If you wish to temporarily disable the constraint, you may select it and press **Activate/deactivate constraint.** When you want to apply it again, press again the same button (Picture 2-16b).



(Picture 2-16b)

In this way, we have completely defined our circle in relation to CCS, and in the window **Combo View→Solver messages** it is now **Fully constrained**, which means that the circle, that is our sketch, is completely defined

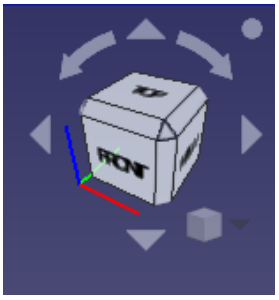


Picture 2-17

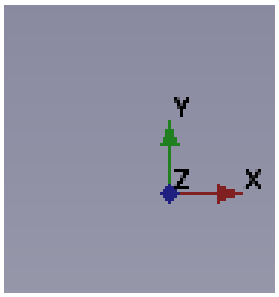
Now in the **Combo View** window, go to **Close**, which exits the active drawing window and sees our drawing and isometry.

On the right side in the upper corner of the screen (Picture 2-20) we see a navigation cube. By clicking on one of the arrows, we rotate our drawing. We can also click on the page of the cube itself, let's say the TOP page, to see the view of the drawing in

the XY plane in which we drew. Parallel to the rotation of our drawing, the coordinate system that can be seen in the lower right corner of the screen is also rotated (Picture 2-21).



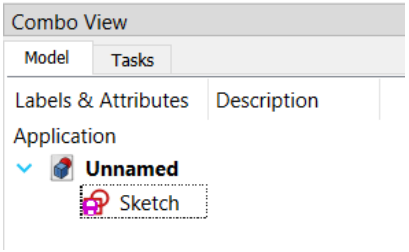
Picture 2-20



Picture 2-21

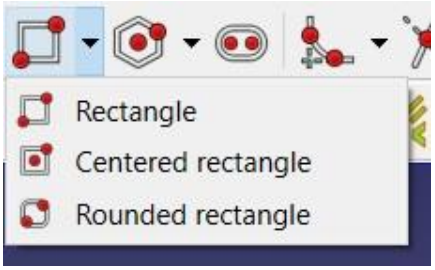
The commands for the second way of manipulating the drawing are shown in Picture 2-03. By combining the SHIFT, CTRL and ALT keys with the mouse keys, various combinations of selecting, rotating, zooming and moving the drawing are possible depending on our needs. These commands need to be practiced well so that we can set up the drawing or later the 3D model the way we want.

Now, we are going to draw a rectangle measuring 60x40mm, which is 20mm in the X direction from the CCS and 25mm in the Y direction from the CCS. In order to do that, we need to return to the workspace where it is possible to draw. In the **Combo View** window, activate **Sketch** by double-clicking (picture 2-22),



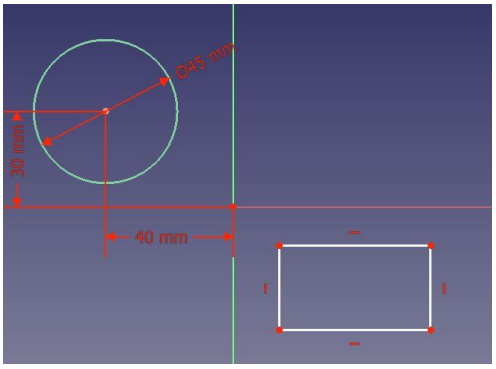
Picture 2-22

and then we use the **Create rectangles** command, which has several options. We will select the **Rectangle** option (picture 2-23).



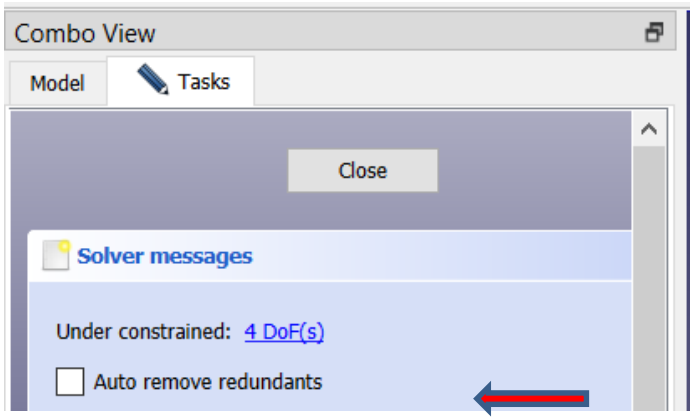
Picture 2-23

Then we draw a rectangle.



Picture 2-24

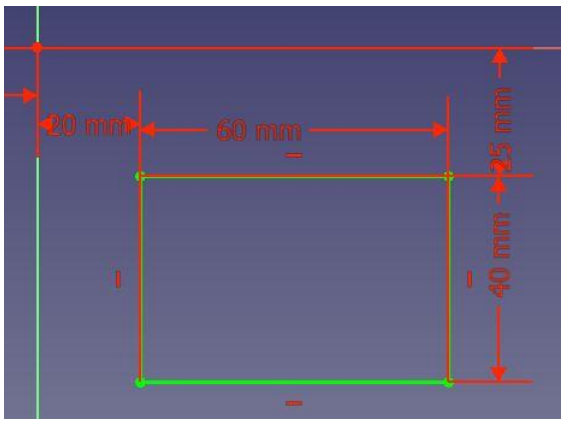
In the **Combo view** window, we see that 4 undefined parameters of the rectangle **4DoF(s)** appear (red arrow, picture 2-25).



Picture 2-25

These are the following parameters**: width and length of the rectangle, position of the rectangle in the X and Y directions in relation to the CCS**. Now we will define those parameters with the help of the commands described when defining the circle. When we enter these parameters in the drawing in the **Combo View** window, the message **Fully constrained** will appear, which means that we have successfully defined everything.

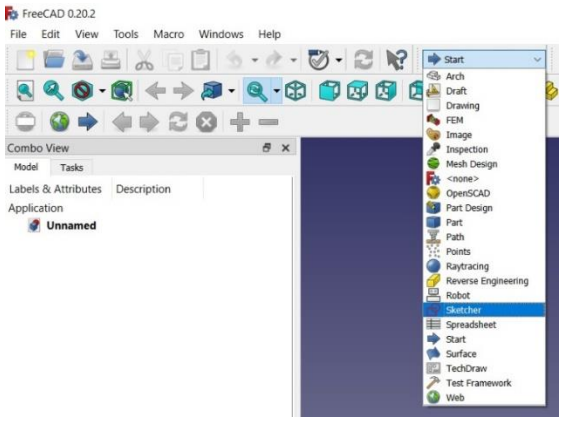
These horizontal and vertical dashes next to the sides of the rectangle indicate that those sides are parallel to the X and Y axis of the coordinate system.



Picture 2-26

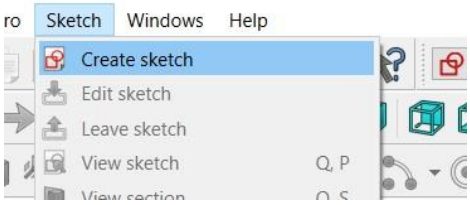
Now, we will draw another circle, 30mm in diameter, 30mm away from CCS in the +X direction and 40mm in the +Y direction, but in the new drawing workspace.

The procedure for activating the window in which we will draw our new drawing is described at the beginning of the tutorial (picture 2-04): by clicking on the drop-down menu **Start→Sketcher**



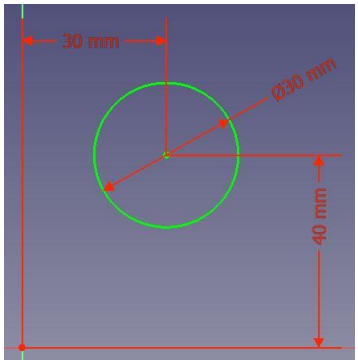
Picture 2-27

Then by clicking on the menu **Sketch→Create sketch**



Picture 2-28

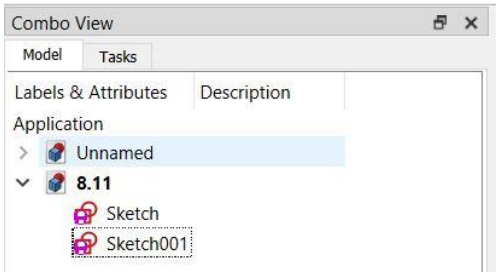
A window appears for selecting the plane in which we want to draw our new drawing. Again, the XY plane is offered, which we accept by clicking OK and draw our circle with the given parameters.



Picture 2-29

NOTE: Here we also use the ESC key on the keyboard to exit some active command, e.g. for horizontal or vertical dimensioning of a circle or for defining the diameter of a circle.

When we have finished drawing our new circle, again in the **Combo View** window we go to **Close**, after which we see our two drawing workspaces, Sketches.



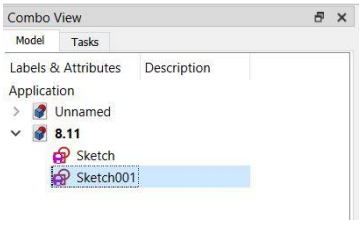
Picture 2-30

In the Sketch workspace we drew our first circle and rectangle, and in Sketch001 we drew our second circle.

With the **Fit all** command (picture 2-31), we zoom in on all drawings on the workspace, and with the **Fit selection** command we zoom only the selected Sketch, which we select in the **Combo View** window (picture 2-33), e.g. Sketch001

Picture 2-31

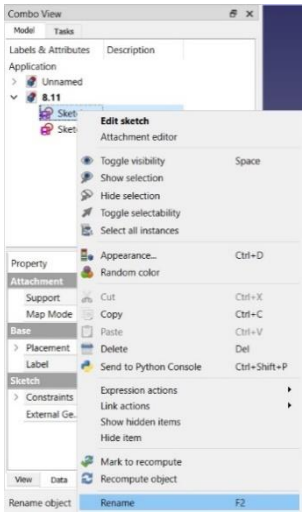
Picture 2-32



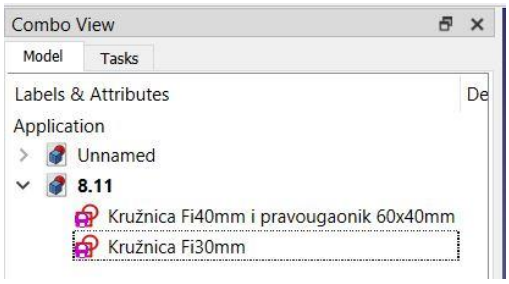
Picture 2-33

In the **Combo View** window, by right-clicking the mouse and selecting Rename (picture 2-34), we change the name of our first Sketch to: Circle Fi45mm and Rectangle 60x40mm.

In the same way, change the name of the second drawing, Sketch001 to: Circle Fi30mm (picture 2-35)

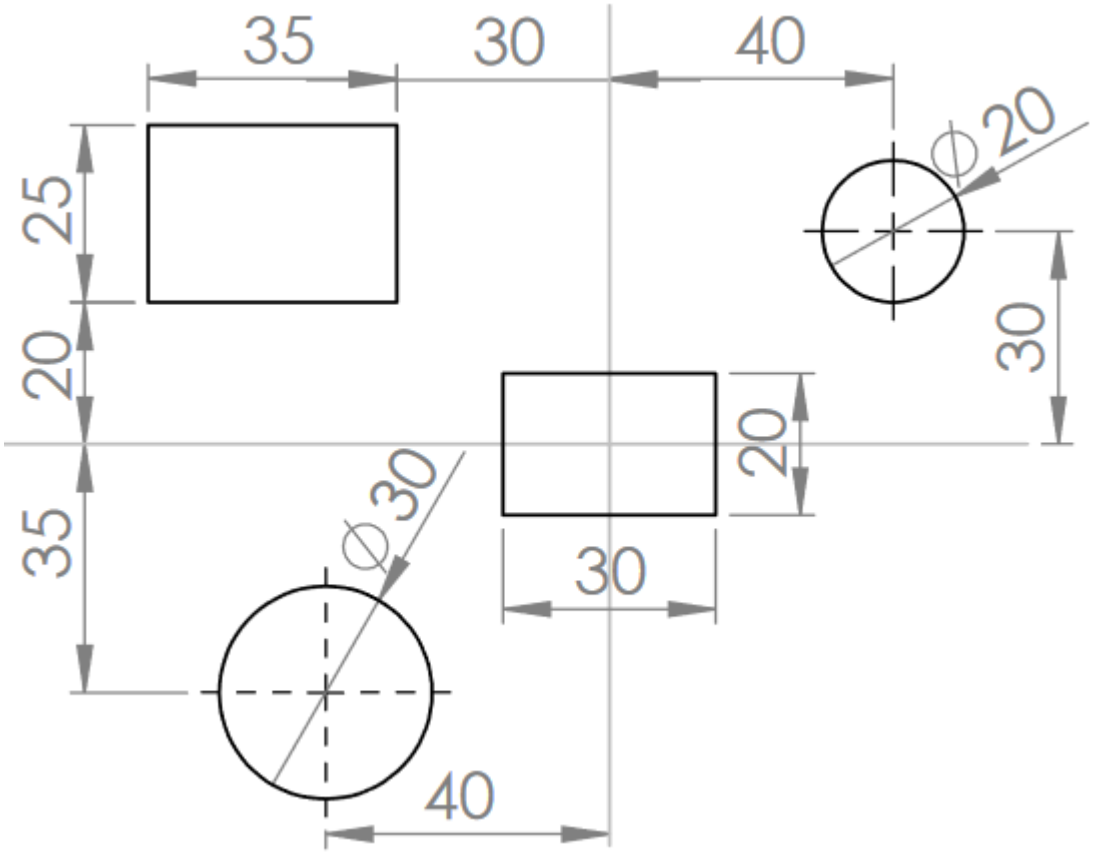


Picture 2-34



Picture 2-35

Exercise task



The task is to draw 2 rectangles and 2 circles. Draw the 35x25mm rectangle and the Ø20 circle in Sketch, and the 30x20 rectangle and the Ø30 circle in Sketch001, and then change their names in "Drawing01" and "Drawing02".

3. 2D drawing: defining constraints, drawing geometric shapes

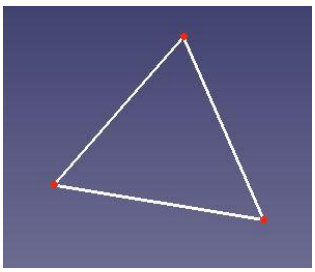
Now we will draw, a triangle, a pentagon, a circular arc (a quarter of a circle) that intersects a straight line, the use of the rounding commands and the use of the command to draw multiple connected lines

1. We should draw an equilateral triangle, whose side is 20 mm long. This triangle should be 20mm away from the CCS in the -X and Y directions.

We open a new document and, also, we open Sketcher. We select the **Create line** command and then draw an arbitrary triangle.

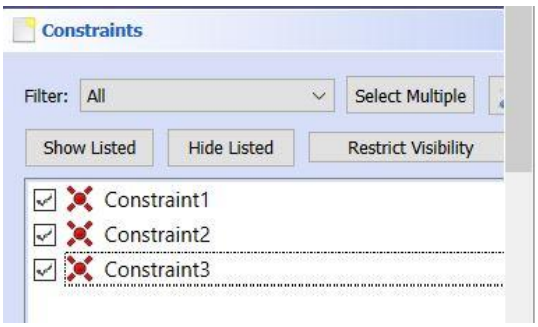
Picture 3-01

NOTE: By selecting this command, we notice that the mouse cursor has turned into a white cross. After the first line is drawn, we approach the end point of the first long one with a cross, and then a red cross appears. Then click with the mouse and draw another line. This way we ensure that the lines are connected. Then we move on to drawing 3 lines.



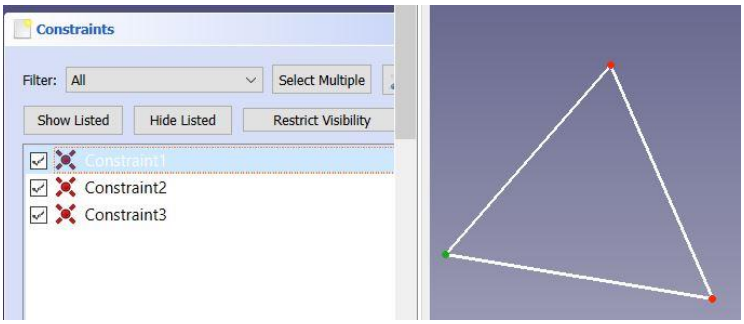
Picture 3-02

On the left side in the **Combo View** we see that within the Constrains window we have 3 constraints: Constrains1, Constrains2 and Constrains3



Picture 3-03

By clicking on one of the Constraints, we will see the green theme of the triangle on the triangle. This means that the two longer triangles are joined at that point. In the following case, Constrains1 is selected, which shows the left theme of the triangle. In the **Combo View→ Constrains** window, we will see all the constraints that we will assign to our drawing.

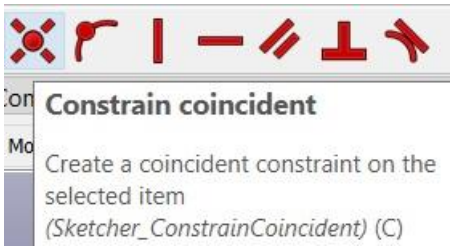


Picture 3-04

The following picture shows the possible limitations.

Picture 3-05

We will explain some of them.

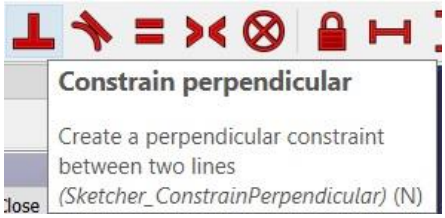


Picture: 3-06

Picture: 3-07

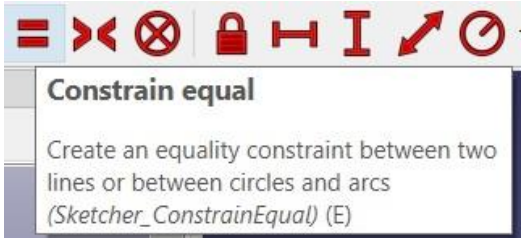
Picture: 3-08

Picture: 3-09

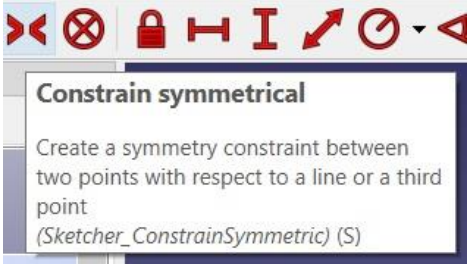


Picture: 3-10

Picture: 3-11



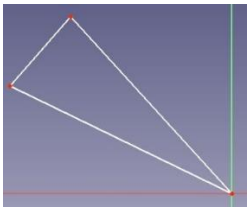
Picture: 3-12



Picture: 3-13

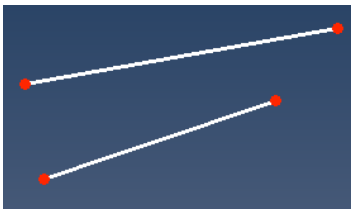
Picture: 3-14

Constrain coincident (picture 3-06) – this constraint allows 2 points to coincide. After that, the vertex will move to CCS (picture 3-15). After the tried command, go to **Edit→Undo** to go back one step.



Picture 3-15

We will draw two random lines.



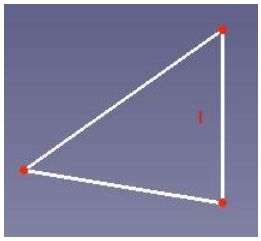
After that, we should activate **Constrain coincident** by clicking on the right end of the first line, and the clicking on the end of the second line. We will se that our lines joined in one point.

NOTE: The point that was selcted first will be fixed, and the second point will be fixed to the first one.

Constrain verticaly – setting the vertical limit of a line (picture 3-7). Select the command, then click on the right side of the triangle. We notice that it has become vertical and that there is a small red line next to it that indicates verticality. We can

see that in **Combo View→ Constrains** (picture 3-17). By clicking on Constraint 4, the small red line indicating verticality will turn green. After the tried command, go to **Edit→Undo** to go back one step

.



Picture 3-16

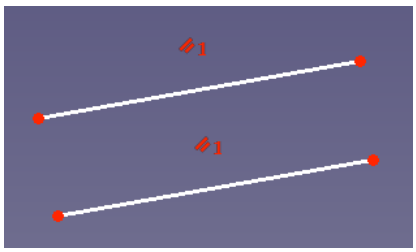
Picture 3-17

Constrain horizontally - setting the horizontal limit of a line (picture 3-8).

Constrain parallel – setting parallelism constraints (picture 3-9). We use this constraint when we want two lines to be parallel.

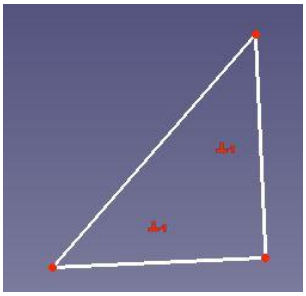
Picture 3-17a

We will draw two random lines. Click on **Constrain parallel** , then click on those two lines. The lines will become parallel.



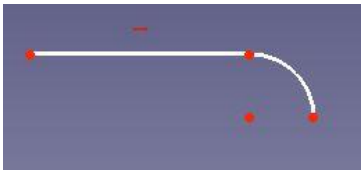
Picture 3-17b

Constrain parpandicular – setting the perpendicularity constraint (pictures 3-10) when we want 2 lines to be at an angle of 90 degrees. In the following picture, we see that the bottom and right sides of the triangle are perpendicular (picture 2-18).



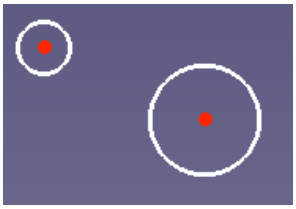
Picture 3-18

Constrain tangent – setting the tangency constraint (picture 3-11) when we want, for example, a longitudinal and a circular tangent (picture 3-19).



Picture 3-19

Constrain equal - setting an equality constraint (picture 3-12) when we want two or more lines, circles or any geometric shapes to be equal.
We will draw 3 random circles like the ones on the picture.

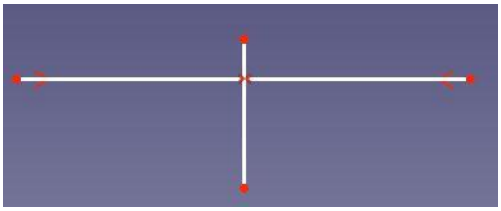


Picture 3-19b

You should click on the command **Constrain equal** **.** Then click on the first circle and after that on the second one.

NOTE: The dimensions of every next cirlce will depend on the circle we selected first.

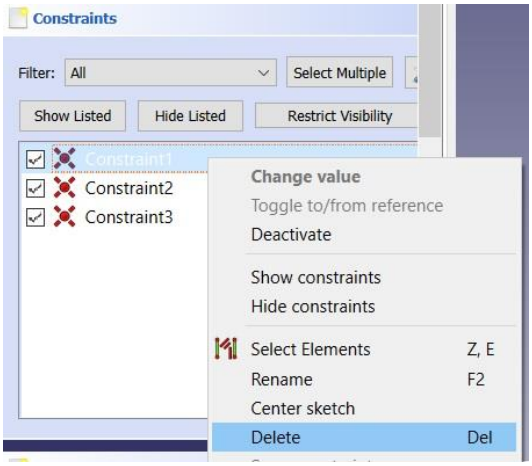
Constrain symmetrical - setting a symmetry constraint (picture 3-13) when we want, for example, 2 points of length (or length) to be at a symmetrical distance in relation to the given length. Picture 3-20 shows that by using this command, the vertical length became the bisector of the horizontal length. The procedure is as follows: we first select one point of the horizontal length, then another and finally the vertical length and then the command Constrain symmetrical.



Picture 3-20

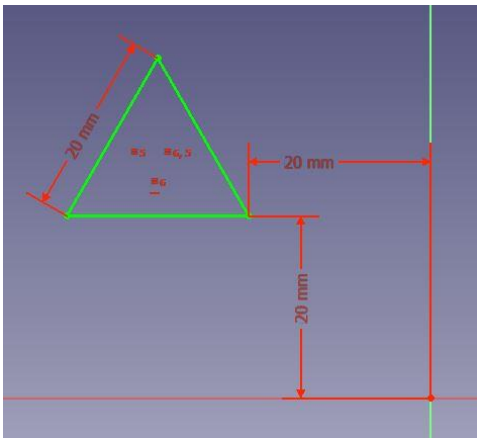
Constrain block – setting the limitation of fixing one or more lines (picture 3-14). After using this restriction, it is not possible to move selected lines or geometric shapes.

NOTE: All the constraints we set can be seen in **Combo View→ Constrains.** If we no longer need a restriction, select it by right-clicking the mouse and then **Delete** in the menu that appears. (picture 3-21).



Picture 3-21

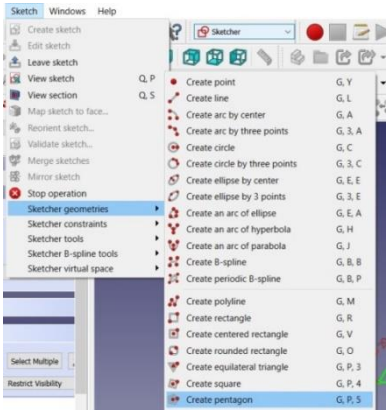
Now we can draw our equilateral triangle, whose side is 20mm long. This triangle should be 20mm away from the CCS in the -X and Y directions. For the lower side of the triangle, set the limit that it is horizontal, and all three sides should be equal (20mm each). The triangle should look like the following picture.



Picture 3-22

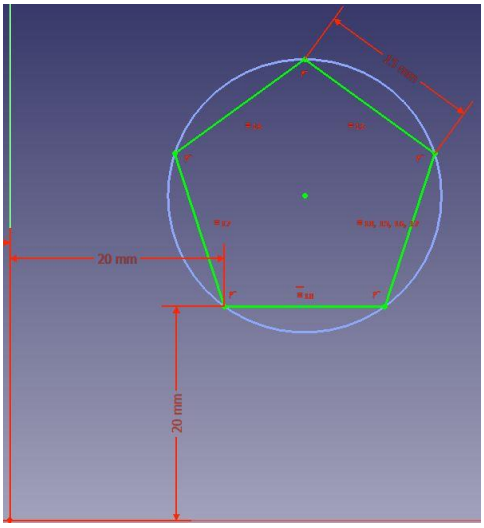
In this way we learned the use of some restrictions. We could have drawn our triangle very easily using the command **Sketch→Sketch geometries→Create equilateral triangle**

2. Now we are going to draw a pentagon in the XY part, whose bottom side is horizontal, and its sides are 15mm each. Distanced from CCS by 20mm in the direction of the X and Y axes. To select the pentagon drawing command, go to **Sketch→Sketch geometries→Create pentagon**. (picture 3-23). As we can see, here are the commands for drawing all the geometric shapes we need: point, line, circle, circular arc, ellipse, hyperbola, rectangle, square, etc.



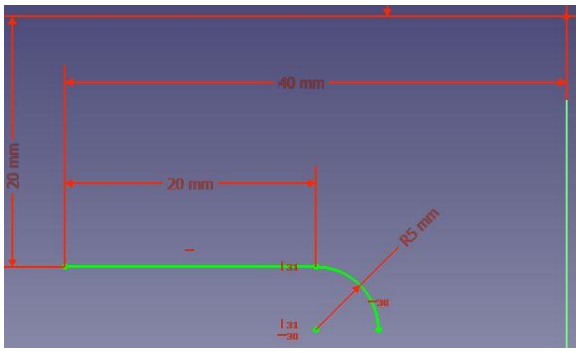
Picture 3-23

The drawing should look like the picture 3-24.



Picture 3-24

3.Our next drawing is a circular arc (a quarter of a circle) that creates a tangent with a straight line in the –X-Y part of the coordinate system. The drawing should look like the following image.



Picture 3-25

The procedure is as follows: we draw along 20mm, the beginning of which is 40mm away in the -X direction, 20mm in the -Y direction. Then **Sketch→Sketch geometries→Create arc by center**.

We click under the right end of the length and use the cross to approach the right end of the length. When the red cross appears, we click so that our circular arc is connected to the longitudinal one. Then we draw about a quarter of the circle. To

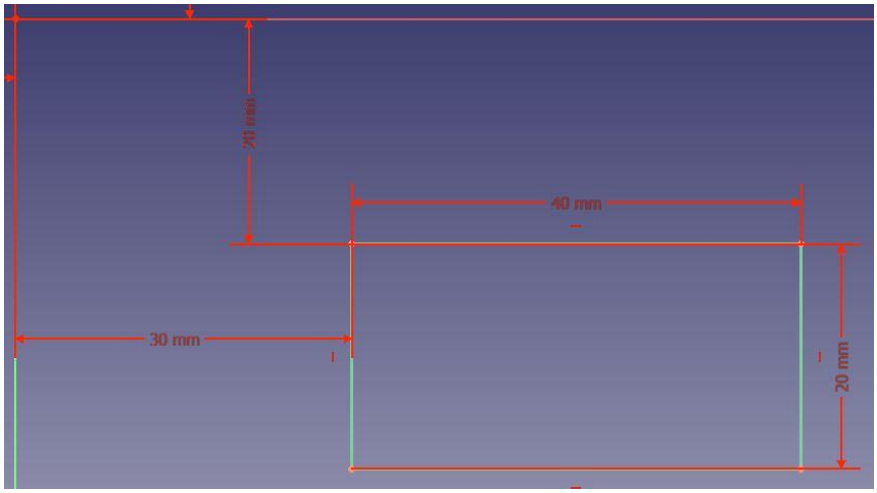
make sure it's the right quarter, we have to introduce restrictions by clicking on the center of the circle and the right point of the circle and then on the horizontal limit. Then, left click with the mouse or ESC on the keyboard to exit the command.

By clicking on the center of the circle and the upper point of the circle and then on the vertical constraint.

Now we are sure that there is a quarter of the circle in the pie. And to make sure that the tangent is along, we will also introduce the **Constrain tangent** constraint. We click on the length and then on the circular arc and then on this boundary. Then **OK** to the pop-up notification window and that's how we finish our drawing.

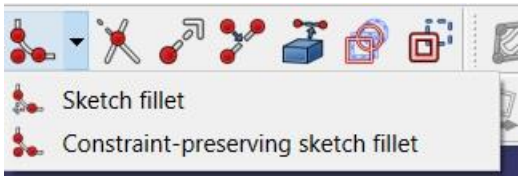
4. Using the rounding commands

We draw a 60x40mm rectangle that is 20mm in the direction of the X axis and 30mm in the direction of the -Y axis.



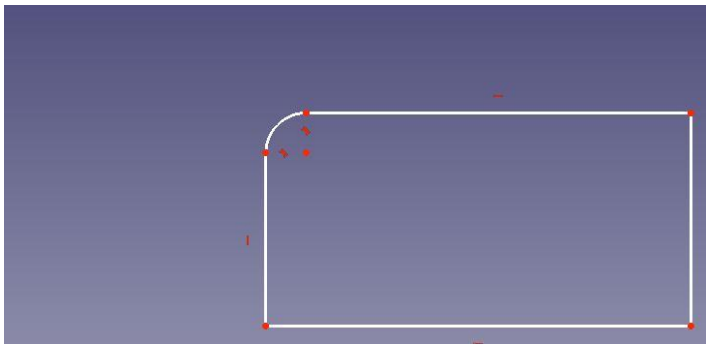
Picture 3-26

Here we have two rounding commands: **Sketch fillet** i **Constraint-preserving sketch fillet**



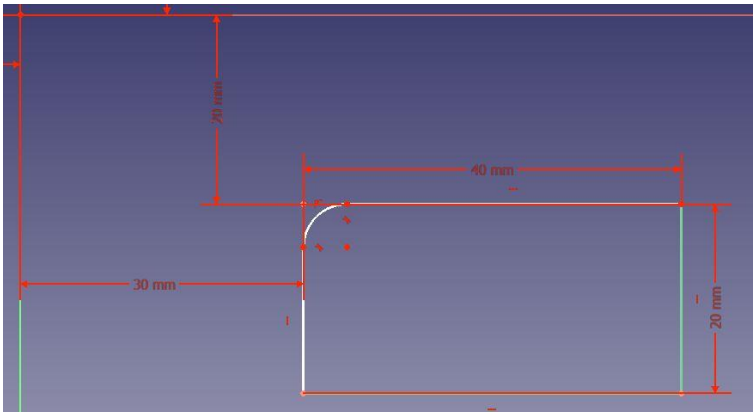
Picture 3-27

We will round the upper left corner of the rectangle first with one command and then with another command to see the difference. We first activate the **Sketch fillet** and then select the left and upper sides of our rectangle. We will get a rounding like in the next picture.



Picture 3-28

Now we go back a step **Edit→Undo**, then select the second command **Constraint - preserving sketch fillet** and repeat the process. We will get rounding as in picture 3-29.

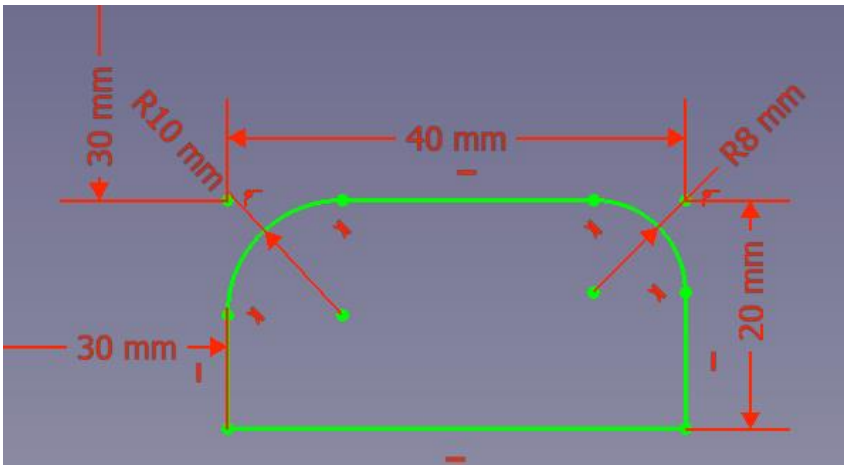


Picture 3-29

We notice that by using the second command, we saved all the dimensions of our drawing, as the name of the command suggests.

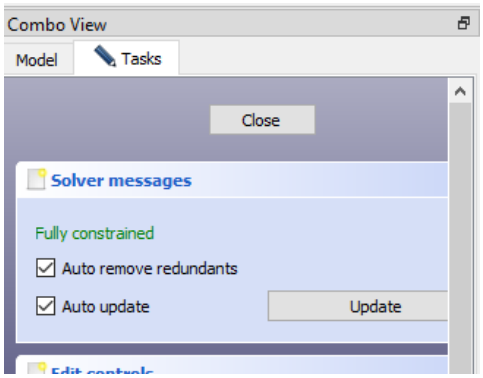
We will now define dimensions for the arc using the command **Constrain arc or circle** and we will type in the value of 10mm. Then, we will draw another

arc using the same command with the dimension of 8 mm as it can be seen on the picture.



Picture 3-29.2

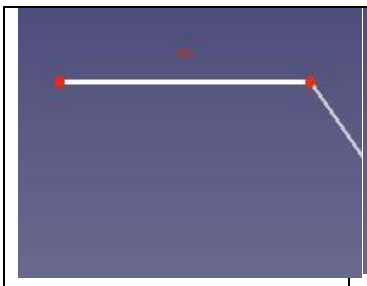
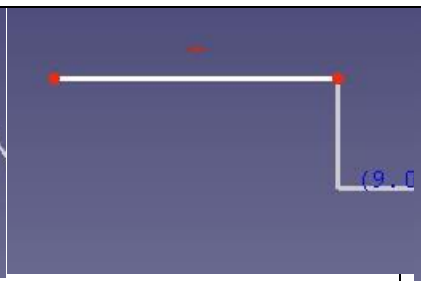
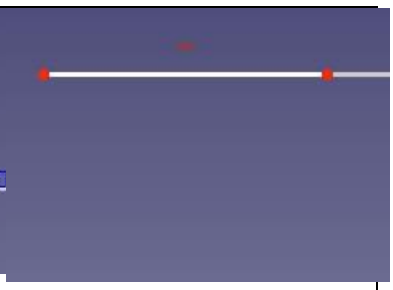
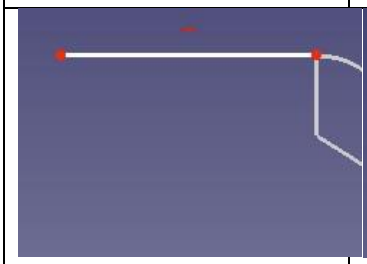
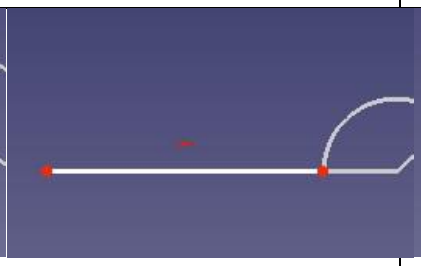
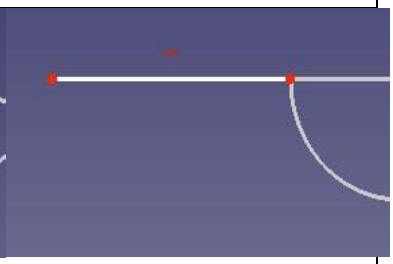
On the left side in the **Combo View** window, we can see that our drawing is totally defined by dimensioning both arcs (Fully constrained).



Picture 3.29.3

5. Using the command to draw multiple connected lines - **Create polyline**

This command is very useful for drawing, especially using the magic letter M on our computer keyboard. We activate it with **Create polyline**.

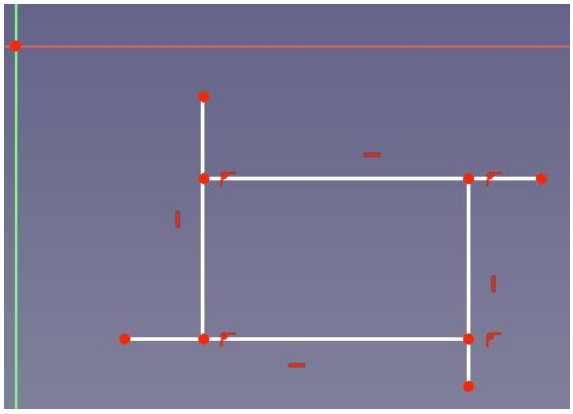
		
Activating command	Pressing a key M, the first time	Pressing a key M, the second time
		
Pressing a key M, the third time	Pressing a key M, the fourth time	Pressing a key M, the fifth time

Picture 30

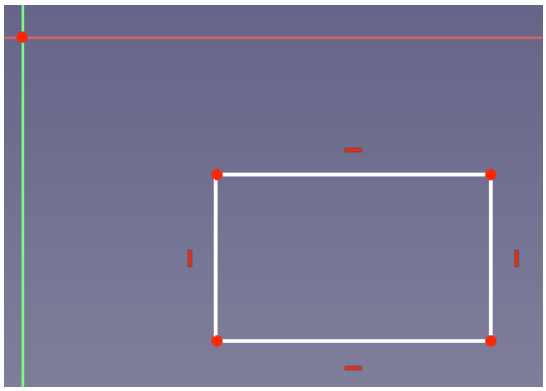
- By activating the command after the drawn line, we draw the next line arbitrarily at any angle
- By pressing the M key for the first time, we draw a parallel line in the first one that is joined by a cross line
- By pressing the M key a second time, we draw a straight line tangential to the first and perpendicular to it
- By pressing the M key a third time, we draw a tangential circular arc that is connected to the first one
- By pressing the M key for the fourth time, we draw a circular arc normal to the previous line on the left
- By pressing the M key for the fifth time, we draw a circular arc normal to the previous line on the right

6. Korišćenje komande za isecanje linija - **Trim edge**

You need to make a drawing which is similar to the one on the picture with constraints so that lines are horizontal and vertical.

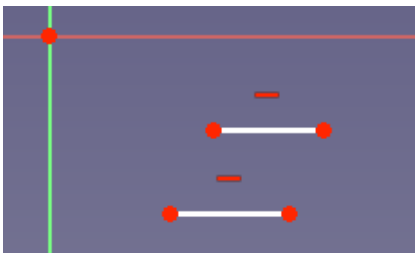


After that you need to activate the command **Trim edge** and to select the lines apart from the rectangle like on the picture. Then click on each line to erase them because they are not needed. After that, there should be only only rectangle on the picture.

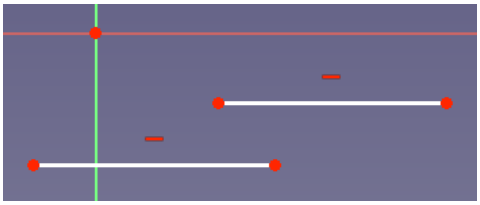


- Using the command for extending the lines- **Extend edge**

It is needed to draw 2 lines as similar as it is shown on the picture with the constraints to be horizontal.



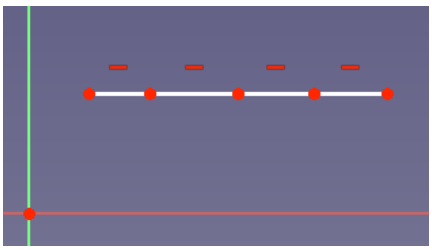
After that we can activate the command **Extend edge** and we should select the first line, click on it and then move the cursor to the right in order to extend it. After that, click once more in order to finish elongating the line. We should do the same with the second line but it should be elongated to the X-axe. The lines should look as it is shown on the picture.



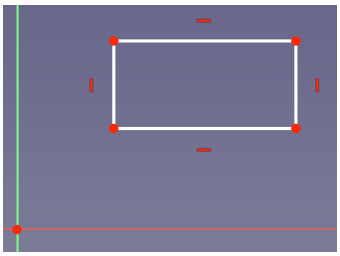
8. Using the command for spliting lines- **Split edge**

You need to draw one line like it is on the picture with the contraint for the horizontal line.

Next, activate the command **Split edge** , move cursor to the line, click anywhere on it, and then move cursor to the right. After that click on the line and repeat the action once again. The line should be devided on 4 lines like on the picture.

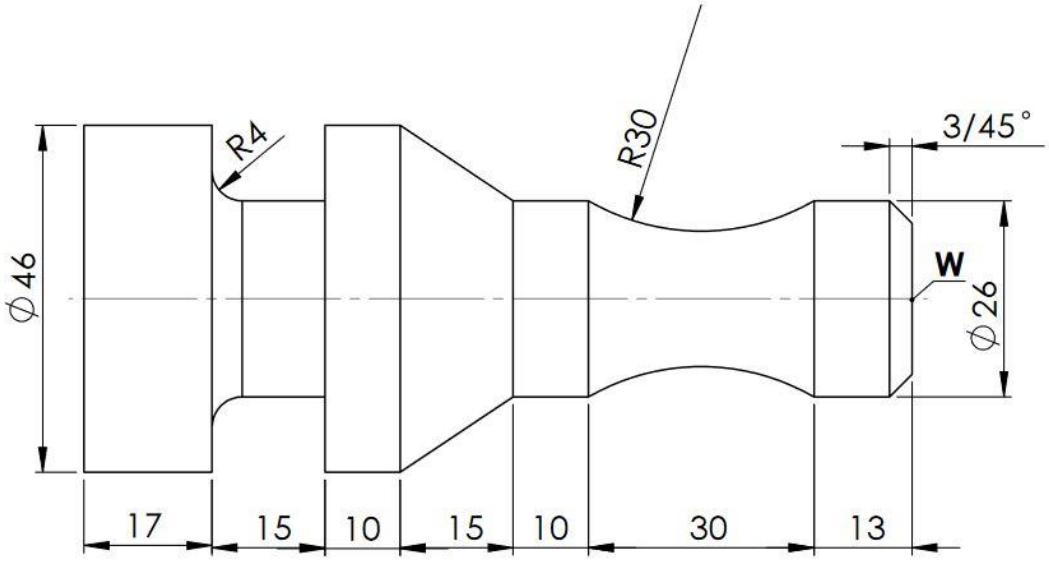


As you can see these is still the horizontal constraint. If we erase these constraints and add new ones, such as vertical contraints in two lines, it is possible to make the rectangle from the first line.



Exercise task

It is necessary to make a drawing as in the following picture. Make sure that point W on the drawing coincides with CCS.

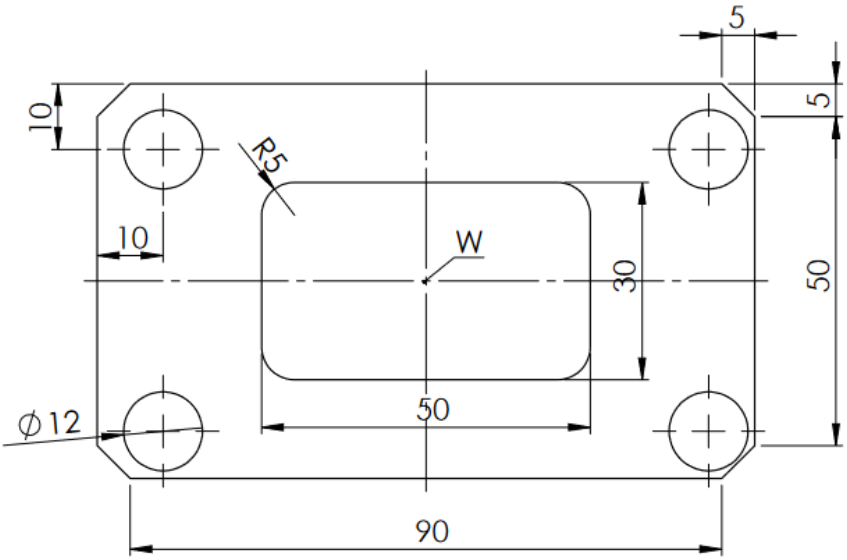


Picture 3-31

Make your own example of a drawing for the object of your choice.

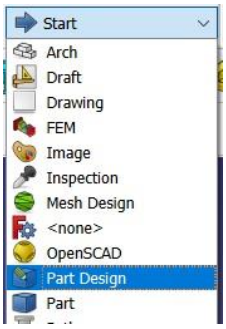
Task for exercising

You should make a drawing as it is shown on the picture. Take care that point W on the drawing coincides with CCS.



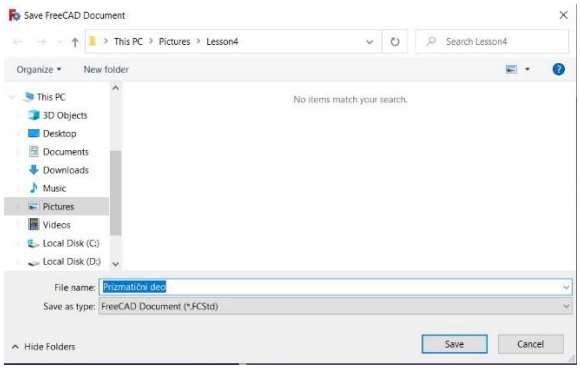
4. 3D model: Prismatic parts

From the drop-down menu, select **Part Design**



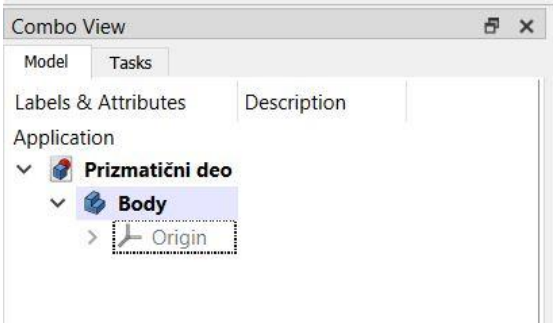
Then we **Save** our future file.

We give a name to our future model. For example, **Prismatic part.**



We click on the **Create body** icon**.**

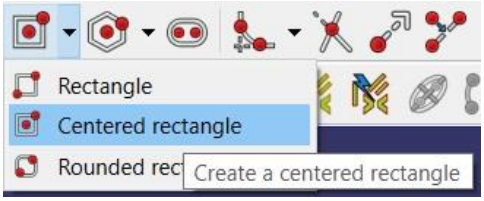
We can see an active icon **Body** in the Combo view window.



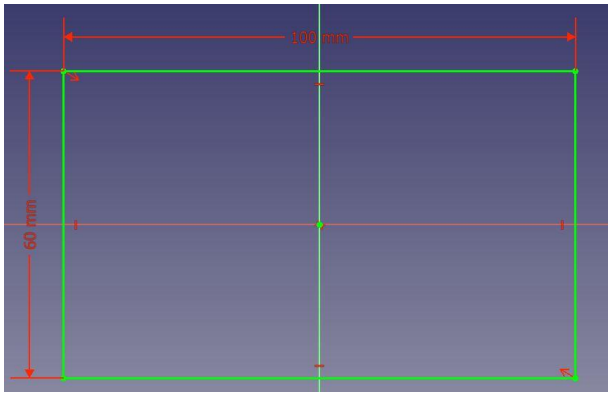
Now, we choose **Create sketch**

We select the desired plane either in the **Combo view** window or on the desktop by selecting the desired plane (Shift+LCM key by moving the mouse to rotate the plane). We choose the XY plane in which we will make our drawing. We will draw a rectangle with dimensions 100x60mm whose center coincides with CCS.

Select the **Centered rectangle** command and then draw our rectangle.

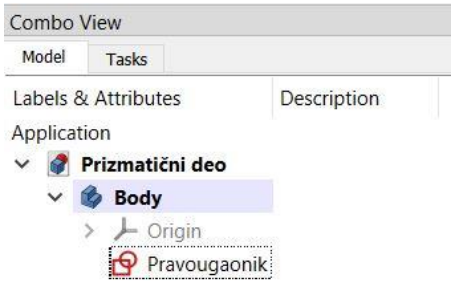


We start drawing from the center of the coordinate system so that the center of the rectangle coincides with the center of the coordinate system (red point, hereinafter CCS). After drawing, we add the desired dimensions to our drawing.



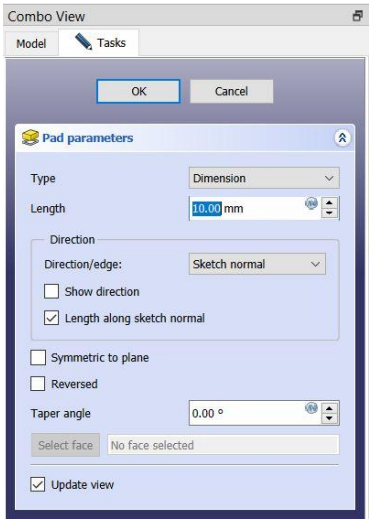
We can see that the drawing is green after dimensioning which means that it is fully defined.

We click on **Close** in the **Combo View** window, then right click on **Sketch→Rename** to change the name of our drawing to "Rectangle".



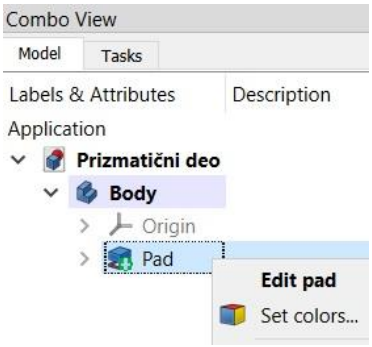
To get a 3D prismatic model from our drawing, we use the **Pad** command

We see that the **Pad parameters** window appears in the Combo View window where we can change various parameters of our 3D model.

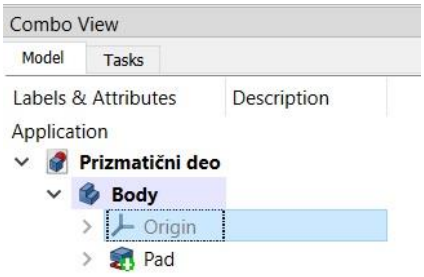


In Length, enter 30mm and left click on the mouse outside the Combo View window to see the change. If we press **Enter** on the keyboard, we exit the **Pad parameters** window. If we want to make some changes to our 3D model, in the Combo View use right click of the mouse, go to **Pad→Edit pad**.

Now we can again change the parameters according to our model's wishes



We click on **Enter** or OK in the Combo View window when we finish the changes. In order to see where our 3D model is in the coordinate system, we need to make it visible. We do it as follows: we select **Origin** and then press the **Space** button on the keyboard.

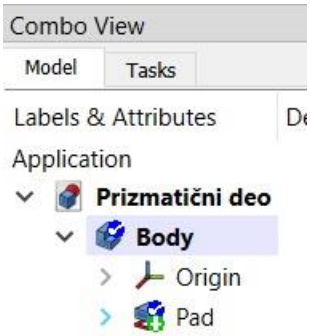


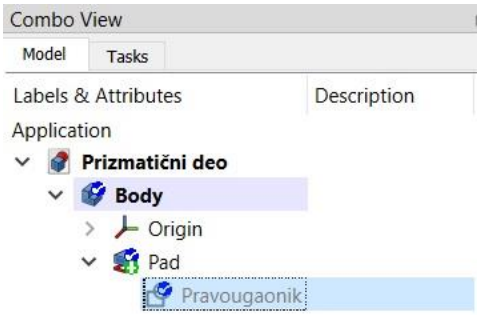
We can see that all 3 planes (XY, XZ, YZ) have become visible.

In order to understand the possibilities of changing the parameters, activate the Pad parameters window again (right click on **Pad→Edit pad**). After experimenting, we return to our model.

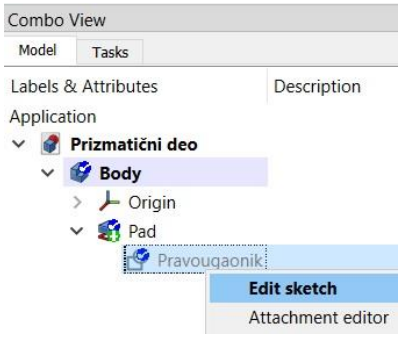
If we want to change something on our model regarding the dimensions of the basic drawing, we do it as follows:

By clicking on the arrow to the left of Pad, our basic drawing "Rectangle" appears.



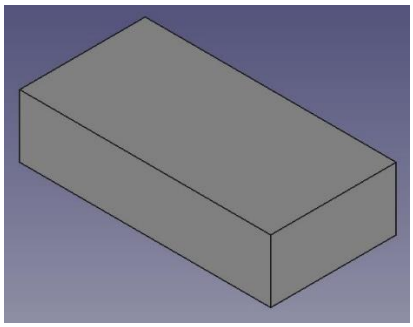


Right click to the Rectangle and then **Edit sketch.**

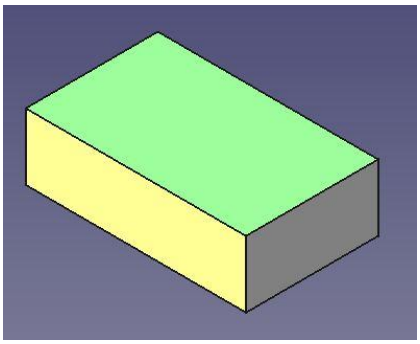


Now we can change our basic drawing based on which we get a 3D model. We will change the width of the rectangle to 120mm (we move the cursor to the dimension, when it turns yellow we should do the left double-click on the mouse, change the dimension and choose OK).

By pressing Close in the Combo View window, we close our Sketch "Rectangle" and see that our 3D model has also changed. It is now 120x60x30mm.

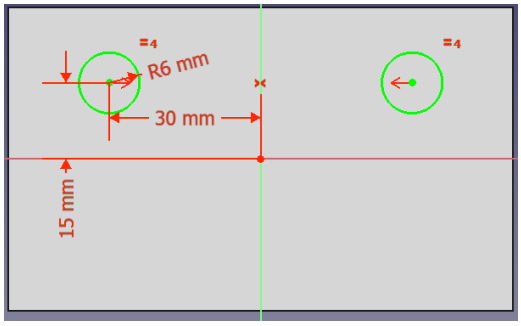


Now we are going to create 2 circular pockets on the 3D model. Let's check that we are in **Part Design** mode, and then select the upper surface of the 3D model



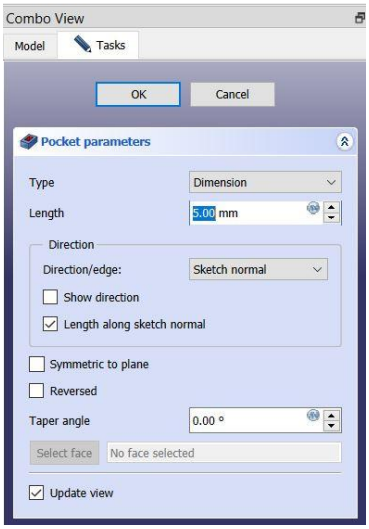
Then we choose **Create Sketch**

Now we draw 2 circles on the selected surface as in the following image, 30mm and 15mm away from CCS, diameter 12mm

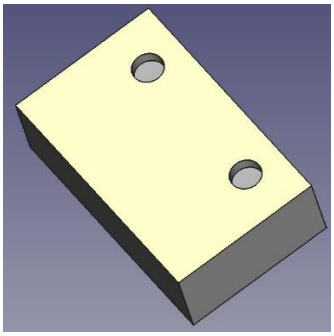


Choose **Close** in the **Combo View** window, and then select the **Pocket** command.

A new **Pocket** parameters window appears in which we have various options for changing the parameters of our 2 circular pockets.



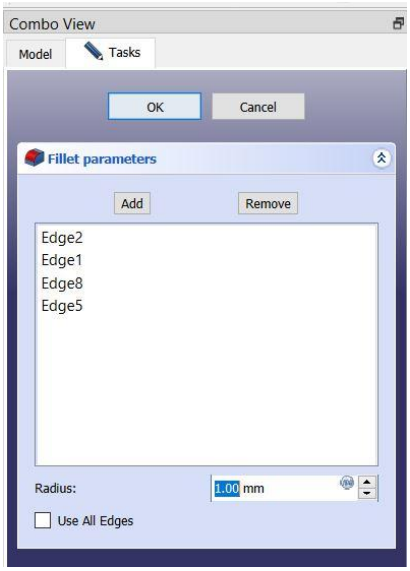
Enter dimension 5mm in **Lengh** and press **OK** in the Combo View window. In this way we created 2 circular pockets on our model.



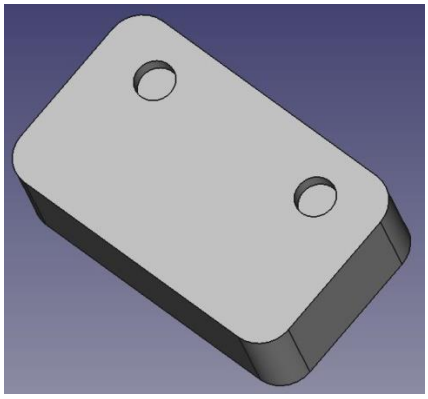
Now we will fill the 4 vertical edges of our model using the **Fillet** command.

We first select the four vertical edges of our model. Press the **Ctrl** key on the keyboard and use the left click on the mouse to select one edge at a time while rotating the model. When we have selected all 4 edges, click on the **Fillet** command

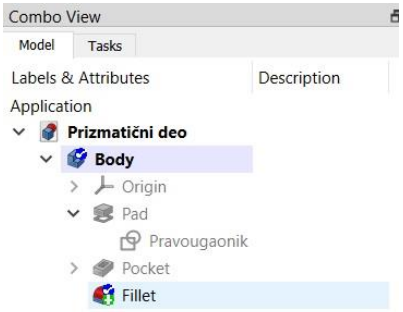
A new window **Fillet parameters** appears.



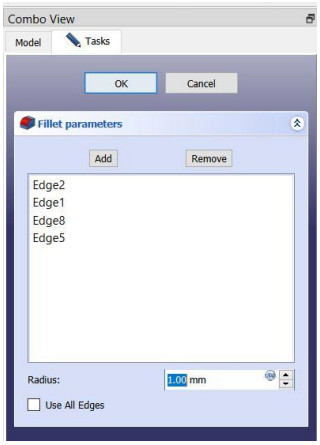
Enter 10mm in **Radius**, then press **OK**. In this way, we rounded the selected edges.



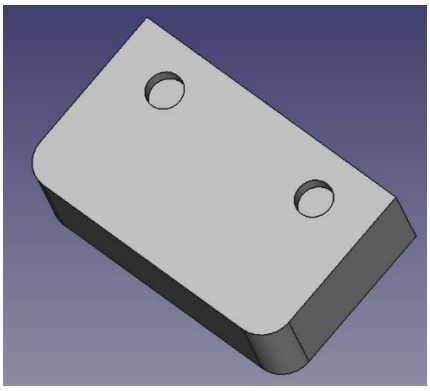
If we want to make some changes to the model, let's say that the upper 2 edges are not rounded in the Combo View window, by double-clicking on **Fillet**, we activate the **Fillet parameters** window again.



In this window, we select the edges in the next order: Edge2, Edge1, Edge8 and Edge5 to determine which are the upper edges (the selected edge is green on the model). When we determine which 2 edges are the top, we delete them by pressing the **Delete** key on the keyboard.



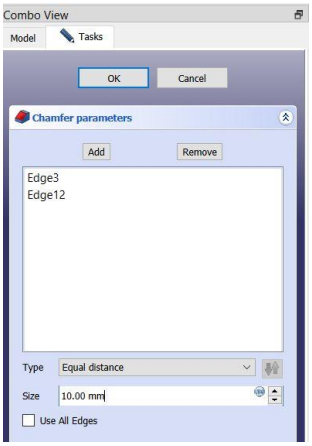
By deleting those 2 edges, our model should now look like the following image:



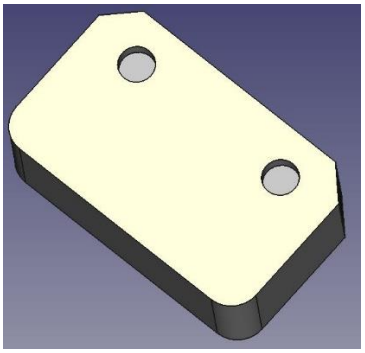
Now we will tilt the 2 top vertical edges of our model using the **Chamfer** command.

First, select the upper edges, then activate the **Chamfer** command.

A new window **Chamfer parameters** appears.

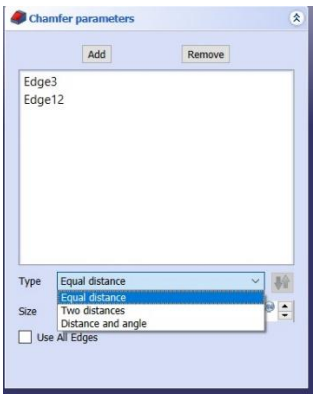


In **Size**, we enter a value, e.g. 10mm and click on **OK**. Now our model should look like the following image:



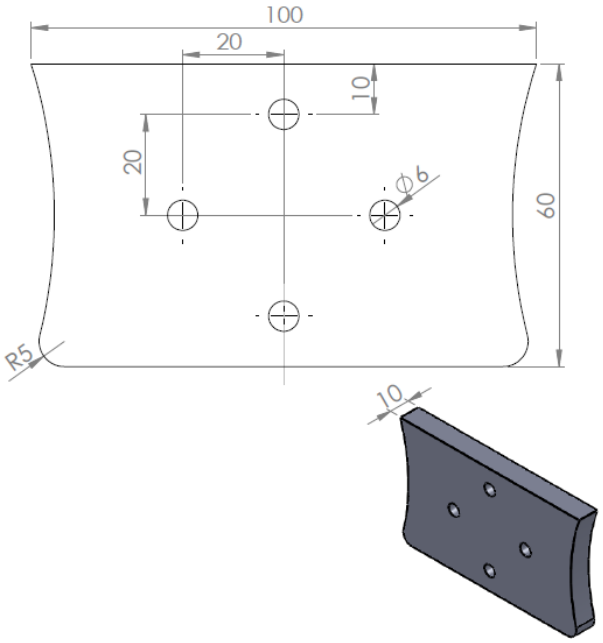
Now by double-clicking **Chamfer** in the Combo View window, we activate the Chamfer parameter again.

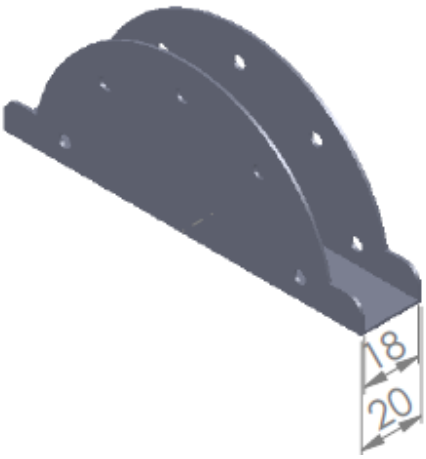
In the **Chamfer parameter→Type** window, we notice different possibilities for cutting edges.

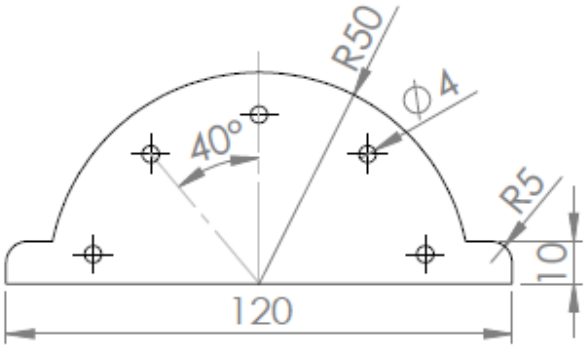


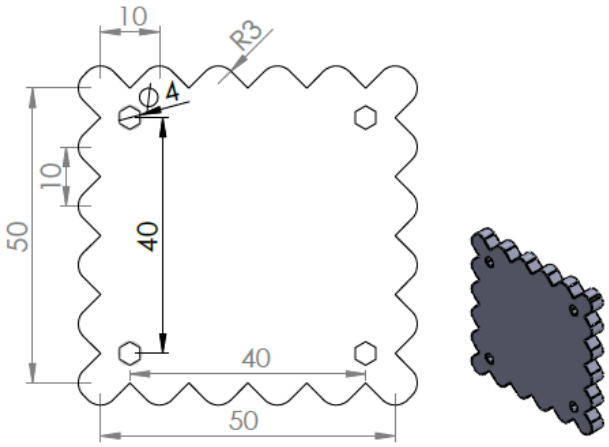
Here we should experiment a bit with these possibilities.

Exercise task



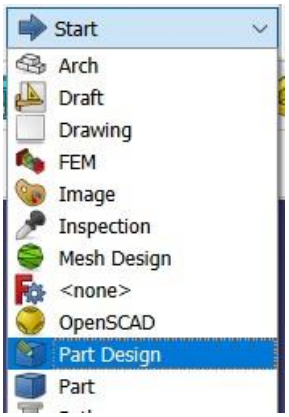




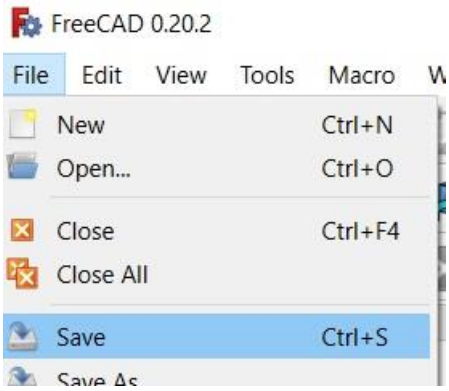


5. 3D model: Axisymmetric parts

From the drop-down menu, select **Part Design**



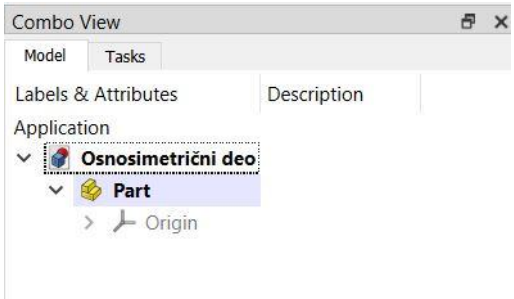
Then we **Save** our future file.



We give a name to our future model. For example, axisymmetric part.

We click on the icon **Create part.**

Now, we can see an active icon **Part** in the Combo view window.



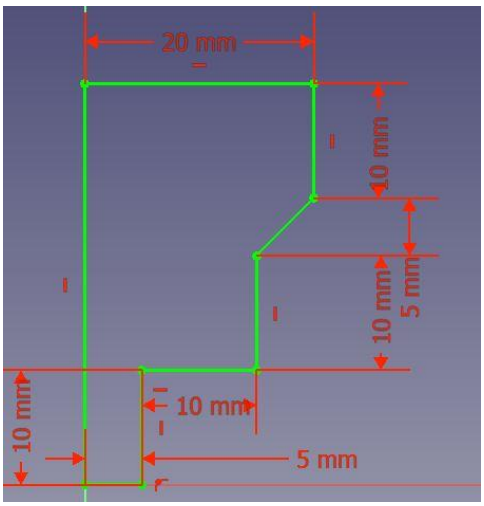
Select Part, then activate the command **Create Body.**

After that we activate the command **Create Sketch**.

We select the desired plane either in the **Combo view** window or on the desktop by selecting the desired plane (Shift+left click on the mouse key by moving the mouse to rotate 3 planes).

Here we do not choose the XY plane as when drawing prismatic parts, but the **XZ** plane in which axisymmetric parts are drawn.

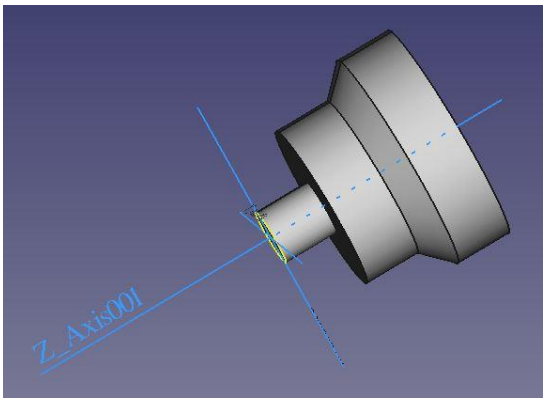
We will now draw a drawing as in the following picture. CCS is in the lower left corner.



Then choose **Close**.

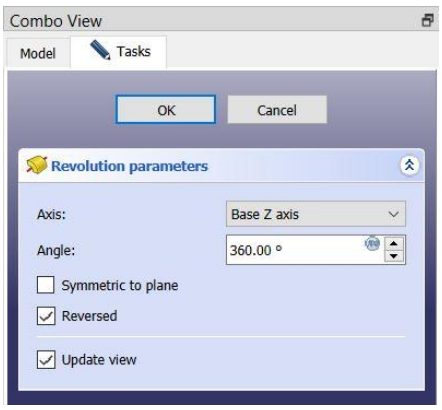
Then, we select the command **Revolution**

After that our axisymmetric 3D model appears as in the following image:

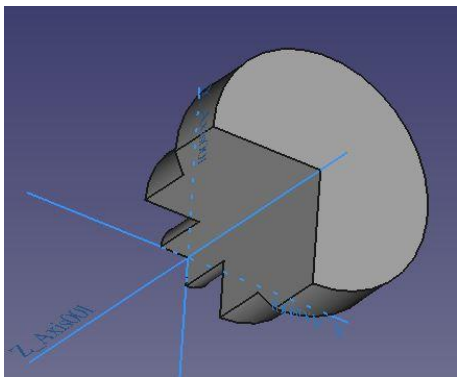


NOTE: When drawing axisymmetric parts, it is very important to select the XZ plane when drawing the sketch, so that the axis of symmetry coincides with the Z axis, both for printing on a 3D printer and for making such parts on CNC lathes.

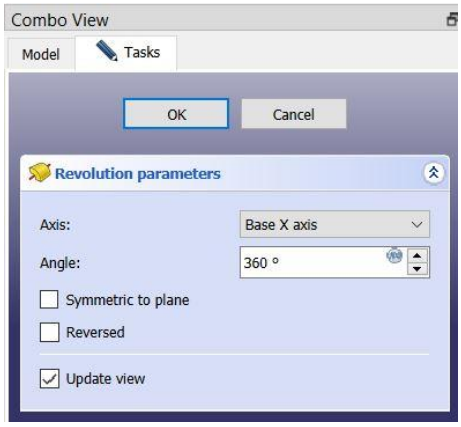
We can see that **Revolution parameters** has opened in the Combo View window**.**



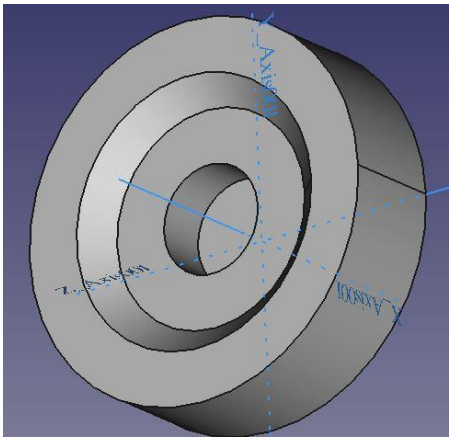
Here we can change, for example, the angle of rotation around the Z axis, e.g. 270º and we will get the following model:



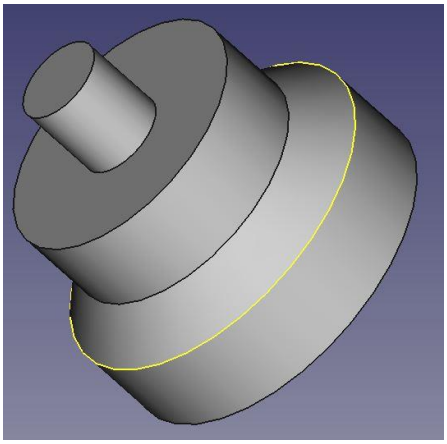
Or change the axis of rotation of our sketch e.g. Base X Axis (rotating our sketch around the X axis)



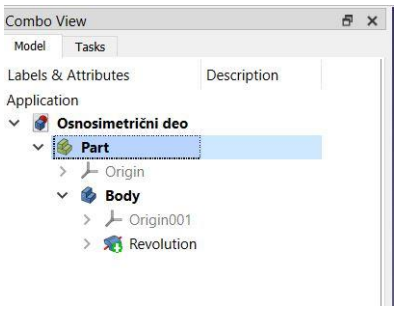
So we get a model like in the next sketch:



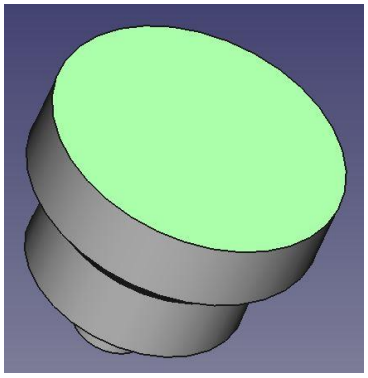
The possibilities are different, but let's go back to our required 3D model where the axis of rotation is the Z axis.



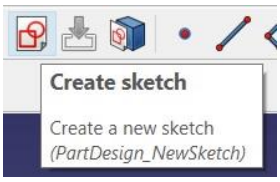
Now,let’s select **Part** in the Combo View window,



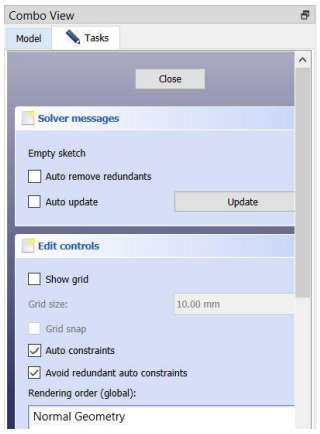
Then we select the surface on which we want to draw, which is the upper surface,



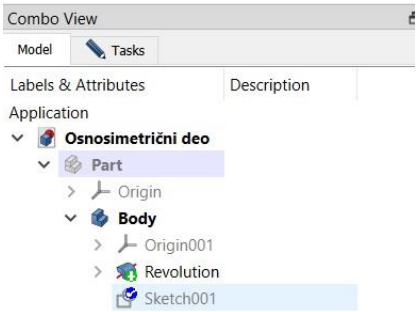
And then we choose **Create sketch.**



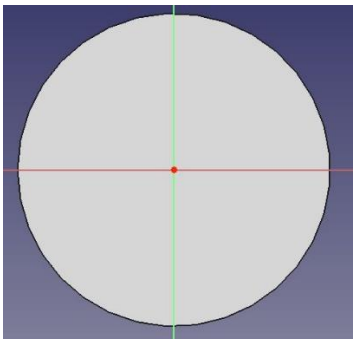
Then, in the window Combo View we choose **Model**



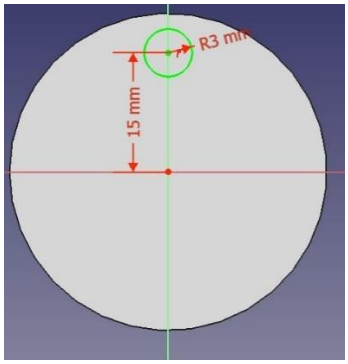
Then, double click on Sketch001



Now we have the opportunity to draw on the selected surface

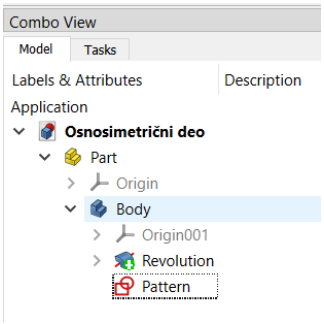


We draw a circle as in the following picture:

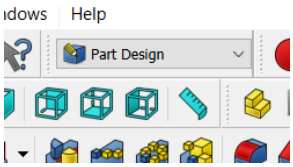


Then, choose **Close** in Combo View window.

Afterwards, we will rename Sketch001 into **Pattern**

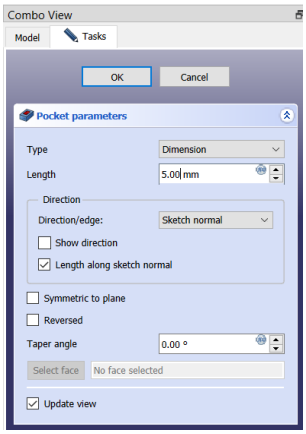


We will check if **Part Design** is active

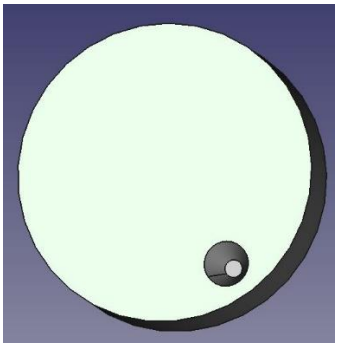


And select the command **Pocket**

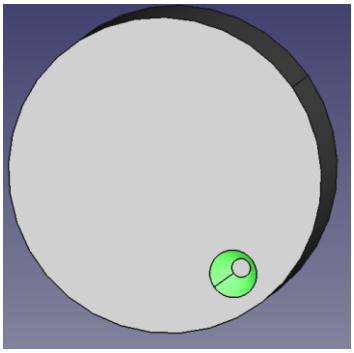
A new window opens in the Combo View window, **Pocket parameters.**



Here we adjust the depth of the pocket, e.g. 5mm (Length) and the angle at which our pocket is hollowed out e.g. -20º (Taper Angle). Then click OK.
Our pocket should look like the one in the following picture:

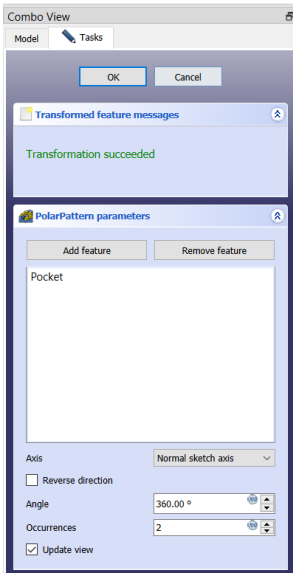


We can see that the bottom of the pocket is hollowed out at an angle of 20º.
In order to copy this pocket in a circle, first select the side of the pocket so that it turns green.

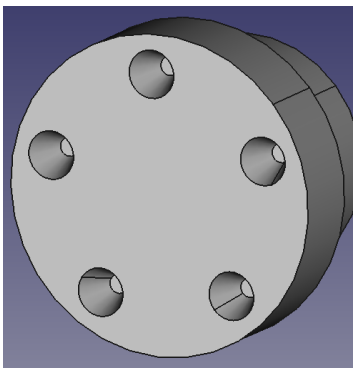


Then click on the command **Polar Pattern**

And then a new window opens in the Combo View window, **Polar Pattern parameters**

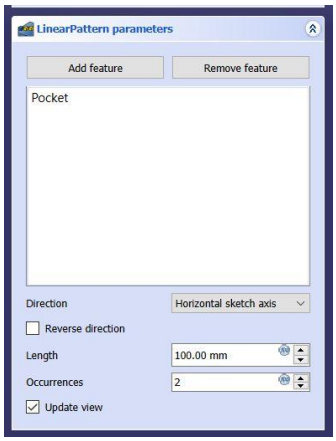


In this window, we can now change the angle. If, for example,it is 360º, the pocket will be copied around the entire circle. Also, here we determine the total number of pockets (**Occurrences**). Let's fill in with number 5, then click OK. We can see that we have 5 pockets evenly distributed.

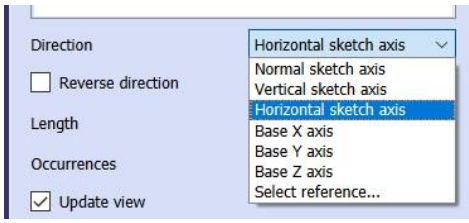


The **Linear Pattern** command is used in a similar way. First, in the Combo View window, delete the **Polar Pattern** (RCM→Delete). Let's press button 2 on the keyboard to have a TOP view. Now select the pocket and activate the command

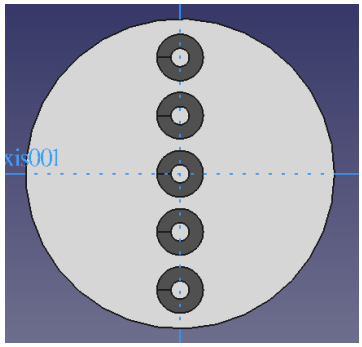
After which a new window **Linear Pattern parameter** appears in the Combo View window.



In the **Length** field, we define the distance at which the pockets will be multiplied (enter, for example, 30mm), and in the **Occurrences** field, where it is shown the total number of pockets (enter, for example, 5). In **Direction**, there is a drop-down menu in which we choose the direction in which the pockets will be multiplied.

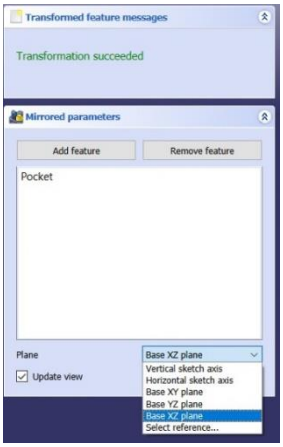


Here we select the **Vertical sketch axis**, and check the **Reverse** direction so that the copies of the pocket go up, then click **OK** in the Combo View window. Now the linearly multiplied pockets should look like the following image:



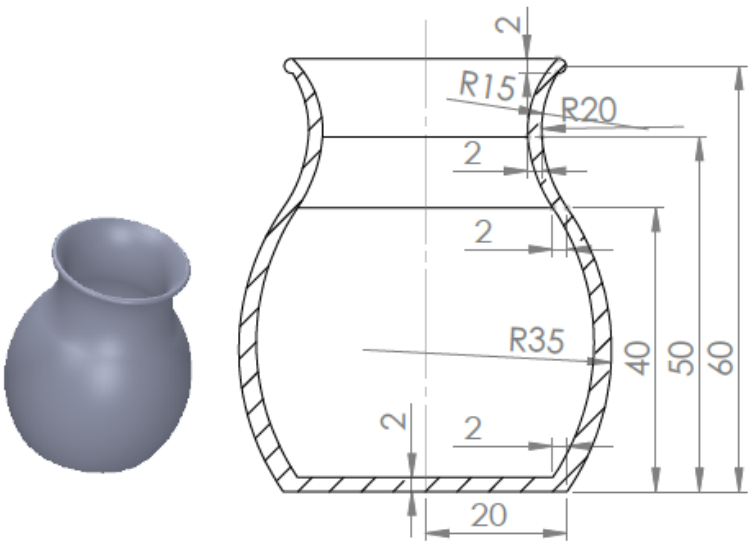
The command **Mirrored** is used in a very similar way:

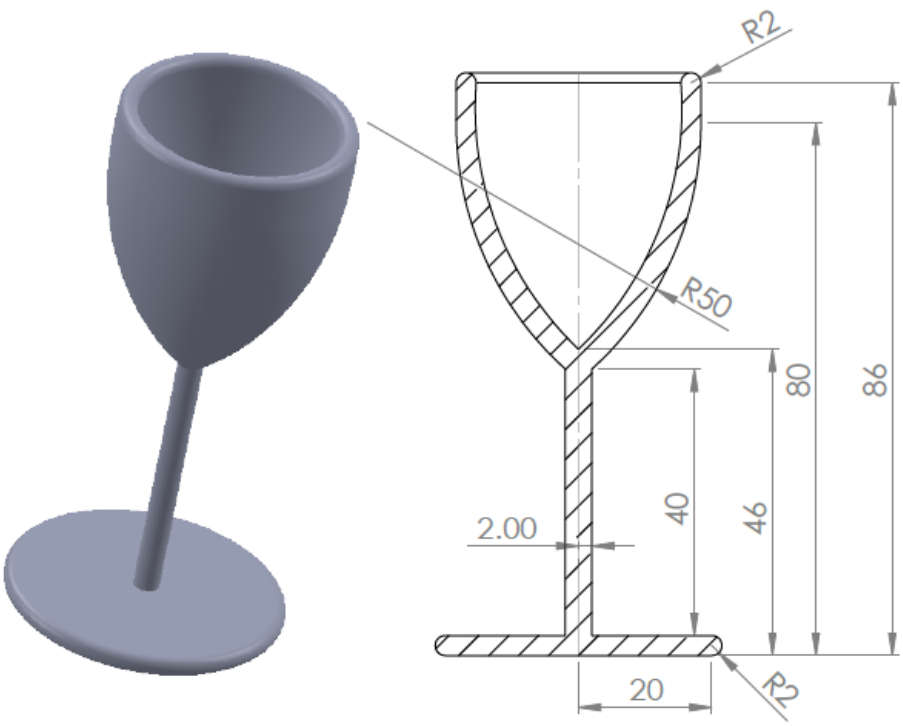
By activating the command, a new window **Mirrored parameters** opens:

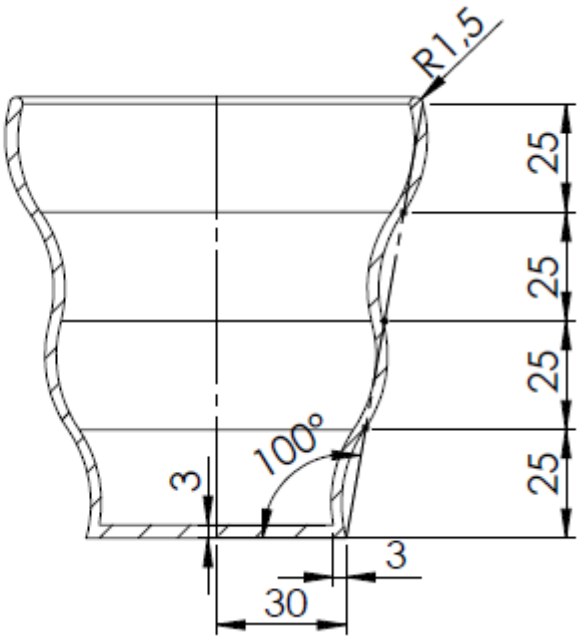


In the window within the **Plane** drop-down menu, we choose around which plane or axis the pocket will be copied.

Exercise task






R1,5
25
25
25
25
100°
3
3
30

6. 3D model: Creation of typical shapes by pouring sections (Loft)

We will create a new document and save it, giving it a name as desired.

Let's go to **Part Design**

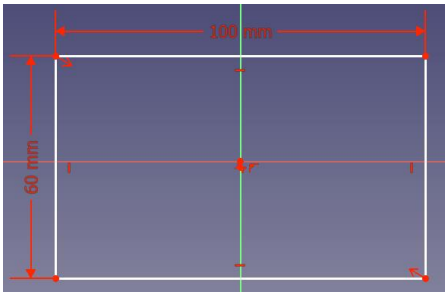
and **Create part**

And then, **Create body**

Then choose **Create Cketch**

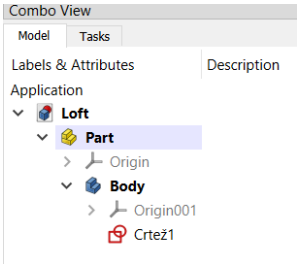
Select XY plane, and click **OK**.

Now we draw a rectangle with dimensions 100x60mm whose center coincides with CCS.

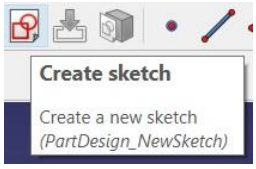


Then we choose **Close.**

In the Combo View window, change the name of our Sketch to Drawing1 (RCM→Rename→Drawing1),

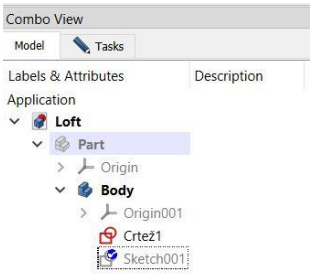


Now we will create another drawing→**Create Sketch**



Select XY plane, and click **OK** in Combo View window.

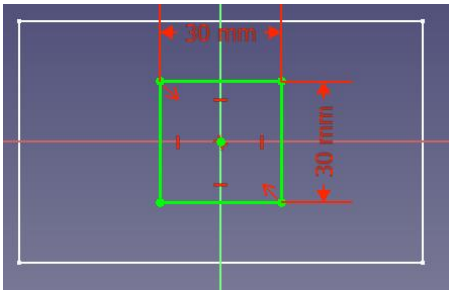
We can see that our previous drawing - the rectangle - is not visible on the desktop. In the Combo View window, click on **Model**



Here we notice that **Part** is inactive. Select it, then press SPACE on the computer keyboard to make it active. Now our drawn rectangle appears.

We change the name of Sketch001 to Drawing2, select it, and then return to the **Tasks** window in the Combo View window.

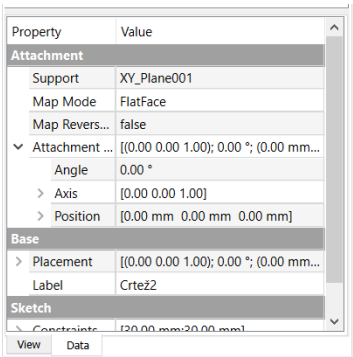
Now we draw a 30x30mm square.



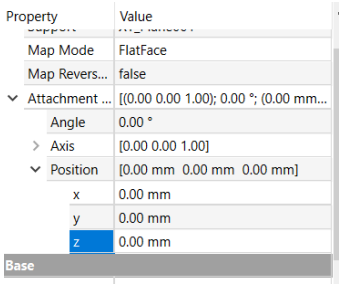
And then choose **Close.**

Now we need to move this square in the Z direction to the desired distance, e.g. 60mm.

Select Drawing 2, then in the window below, in the **Attachment Offset** frame, click on the arrow > in front of **Position**

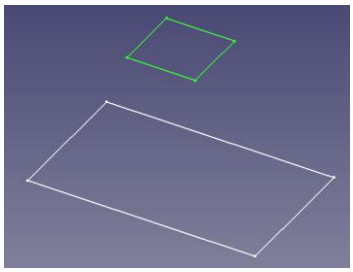


A new possibility for changing the Z distance opens up.



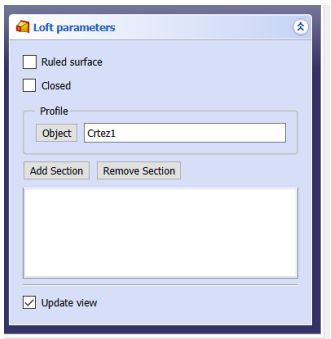
Now click on 0.00mm next to the Z direction and enter a value of eg 60mm.

We see that our square has moved by 60mm in the direction of the +Z axis.

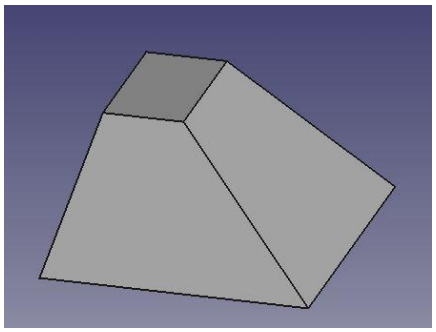


Now select Drawing1, then activate the command

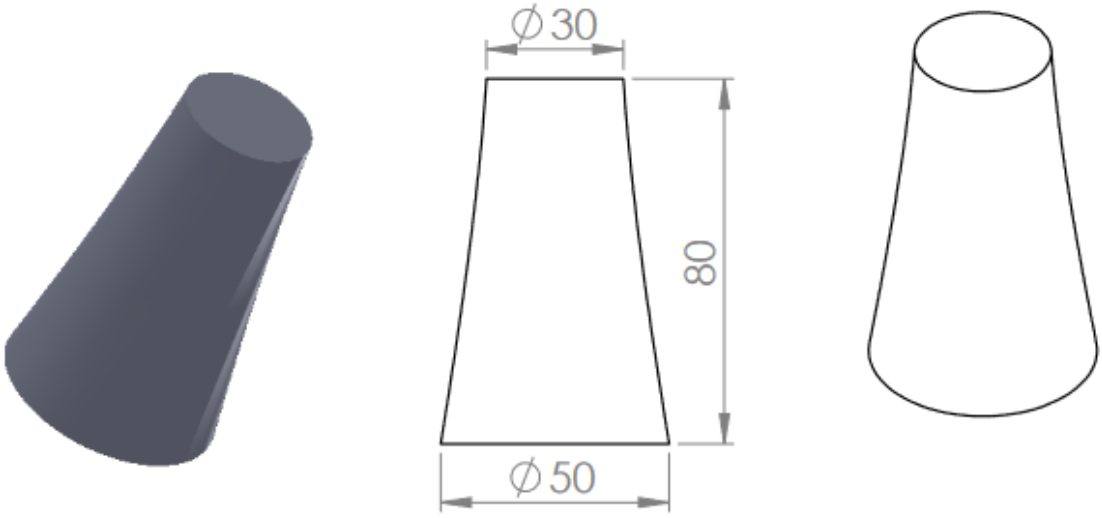
Then, in the **Loft** parameters window, click on **Add Section** and select a square in the workspace.

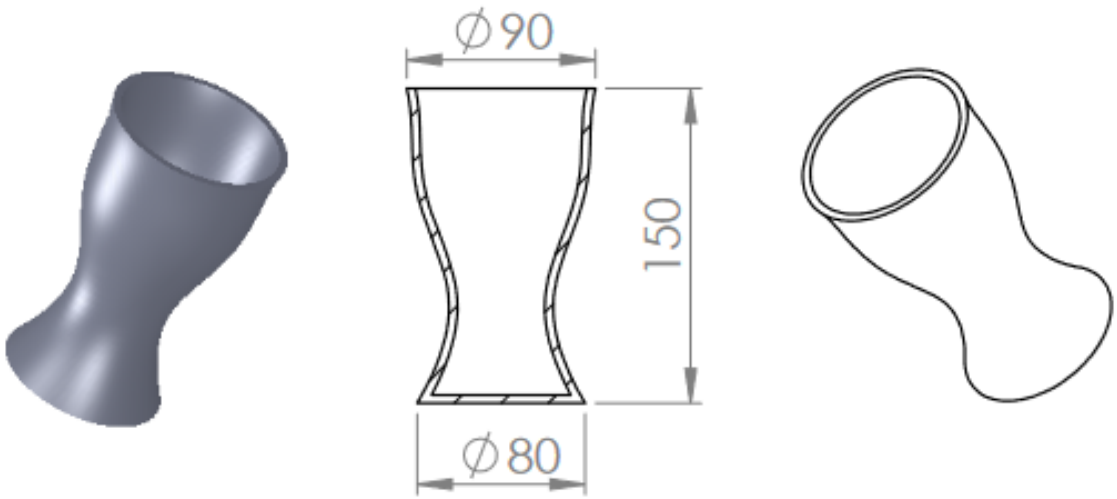


Now we have our 3D model obtained by merging the intersections of rectangles and squares.



Exercise task





Height of plane: XY, 50, 100, 150mm

Diameter: 80, 50, 100, 90mm

Thickness: 3mm

7. 3D model: Creation of typical shapes by drawing along a curve (Additive pipe)

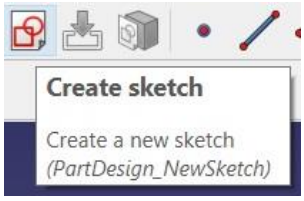
We create a new document and save it, giving it a name as desired (Additive pipe)

Let's choose **Part Design**

and **Create part**

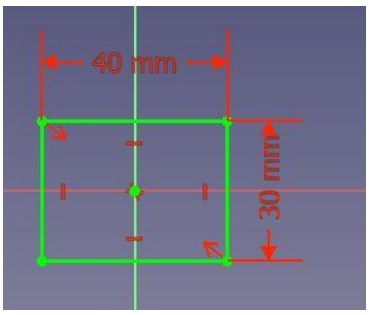
And then **Create body**

Then click on **Create Cketch**



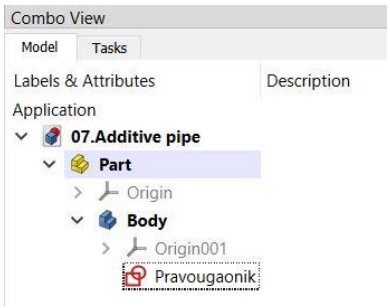
Select XY plane, and then choose **OK**.

Now we will draw, for example, a rectangle with dimensions 40x30mm whose center coincides with CCS.

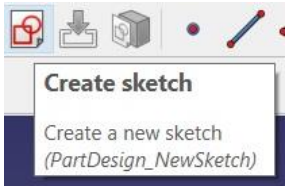


Then we click on **Close.**

In the Combo View window, change the name of our Sketch to Rectangle (**RCM→Rename→Rectangle**),

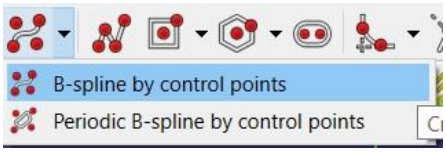


Now we are going to create another drawing: select **Body→Create Sketch**



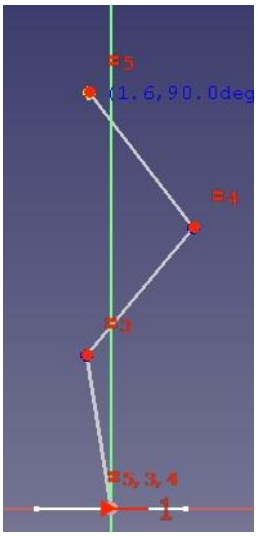
Choose YZ plane, and then **OK** in Combo View window.

Choose **B-spline by control points**

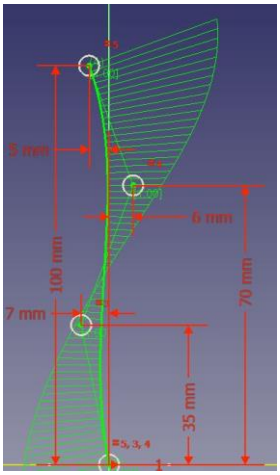


And then we draw a broken line approximately as in the picture, then Esc on the keyboard or RCM.

The bottom white line is actually our rectangle but in the XY plane (now we are in the YZ plane).



Then we dimension these three points as in the following picture.

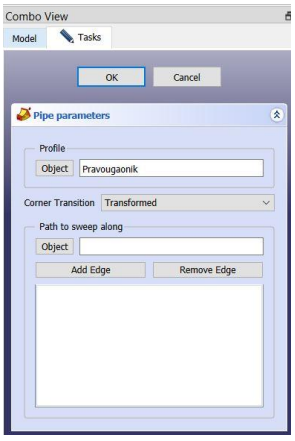


So Close in the Combo View window.

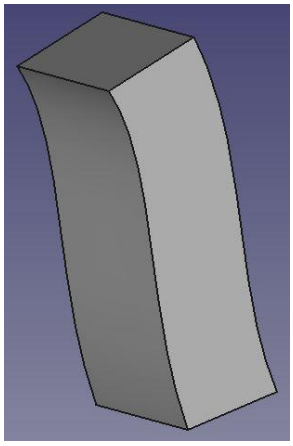
Now we see both a rectangle in the XY plane and a curved line in the YZ plane. Rename Sketch001 to **Curved Line**.

Select the Rectangle drawing in the Combo View window and activate the **Additive pipe** command

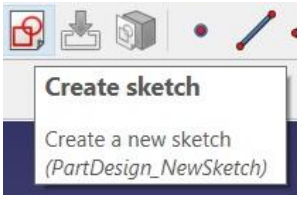
We notice that a new window has opened.



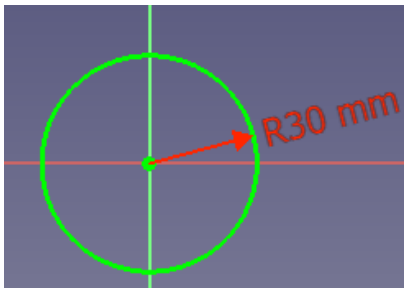
In order to move the selected rectangle along our curved line, we click on **Add Edge** and then select the curved line in the workspace, then click **OK** in the Combo View window and we get our 3D model as in the following image.



If we want to convert one shape along the line into another, we will need another drawing. We select **Additivepipe** and activate another Sketch

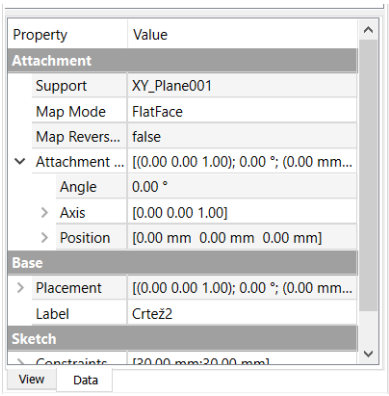


Now,we select the XY plane and OK in the Combo View program. Then we draw a circle with a diameter of 30mm.

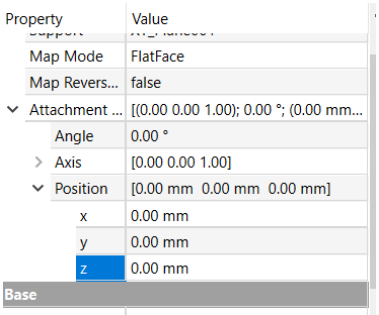


Then **Close** in the Combo View window. Rename **Sketch002** to **Circle**. We move this circle in the Z direction by 100mm, which is the length of our curved line.

We select **Circle**, then in the window below, in the **Attachment Offset** frame, click on the arrow > in front of **Position**

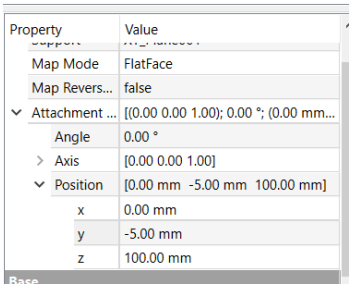


A new possibility for changing the Z distance opens up.



Now click on 0.00mm next to the Z direction and enter the value 100mm.

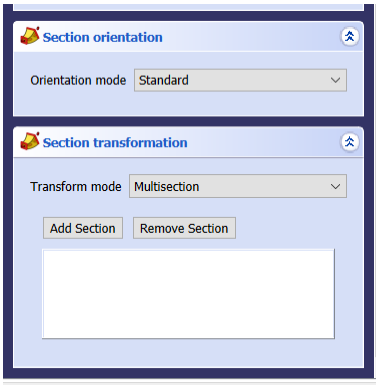
We see that our rectangle has moved by 100mm in the direction of the +Z axis. In order to move our circle so that its center coincides with the end point of the curved line by moving it by -5mm in the Y direction (we look at the dimensions of the end point of the curved line in relation to CCS).



To get our 3D model, select the **Additivepipe** in the Combo View window by double clicking.

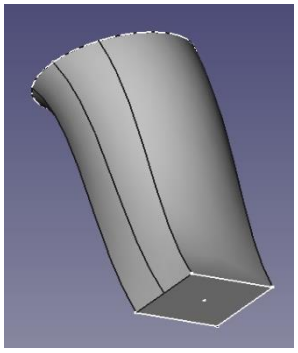
Now select the **Rectangle**, then activate the **Additive Pipe** command.

In the Combo View window, in the **Section transformation**, change the **Transform mode** to **Multisection**. Then click on **Add Section** and select **Circle**.

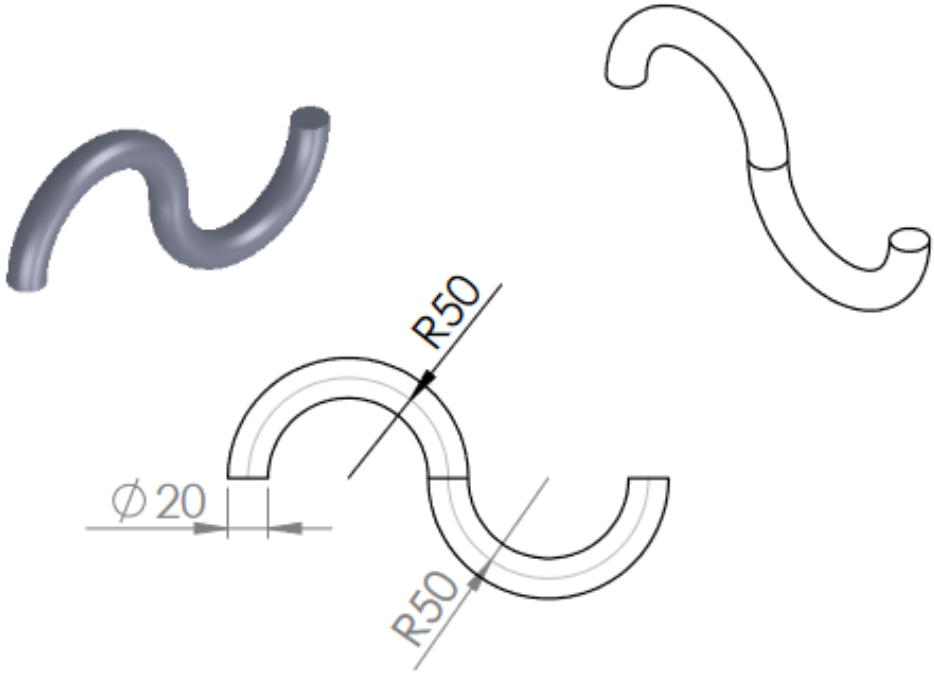


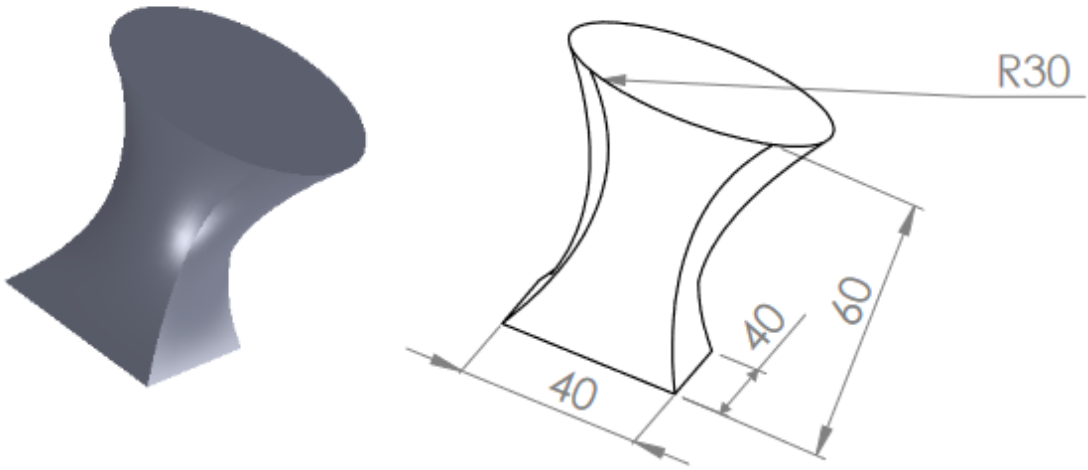
Then click OK in the Combo View window.

In this way, we got our 3D model that turns from a rectangle into a circle guided by a curved line.



Exercise task





Part 3 : The Cura software

Introduction

This handbook provides detailed instructions (including pictures) for installing the software and configuring it according to the user's specific 3D printer and printing requirements. Additionally, it explains various features and functionalities of the software, including importing 3D models, adjusting print settings, and optimizing the printing process for different materials and desired outcomes. This handbook is designed for the needs of the project "Step by Step in 3D printing".

1. What is Cura?

Cura is an open source slicing application for 3D printers.

Ultimaker Cura works by slicing the user's model file into layers and generating the printer-specific g-code.Users can prepare and slice 3D models for printing, as well as customize and optimize print settings for a variety of 3D printers and materials. Once finished, the g-code can be sent to the printer for the manufacture of the physical object. Cura is a powerful and user-friendly 3D printing software with numerous useful features and capabilities.

Cura is available under LGPLv3 license. Cura was initially released under the open source Affero General Public License version 3, but on 28 September 2017 the license was changed to LGPLv3. This is the preferred 3D printing software for Ultimaker 3D printers, but it can be used with other printers as well.

The open source software, compatible with most desktop 3D printers, can work with files in the most common 3D formats such as STL, OBJ, X3D, 3MF as well as image file formats such as BMP, GIF, JPG, and PNG.

Ultimaker Cura is supported by operating systems that are actively maintained by their software manufacturer or community. This currently means that 'Windows 7' and 'MacOS 10.14' are no longer supported.

Compatible operating systems:

Windows 10 or higher, 64-bit

Mac OSX 11 Big Sur or higher, 64-bit

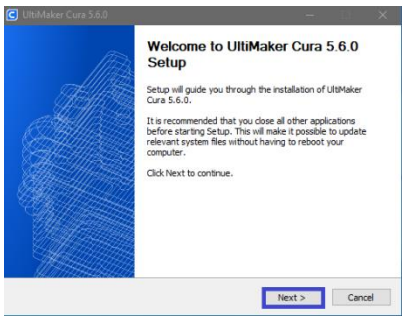
Linux, 64-bit

2. Installation

Cura is free software and you can download it directly from the Ultimaker website at the following link https://ultimaker.com/software/ultimaker-cura/. As I mentioned in the software description, it works on multiple operating systems, so you should choose an installation that matches your operating system.

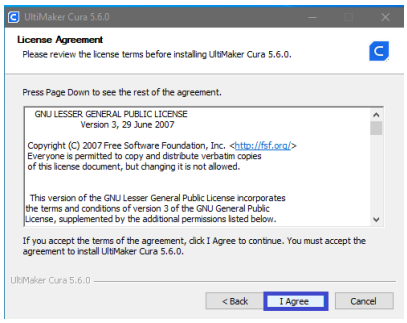
After downloading the installation follow the following steps.

Step 1



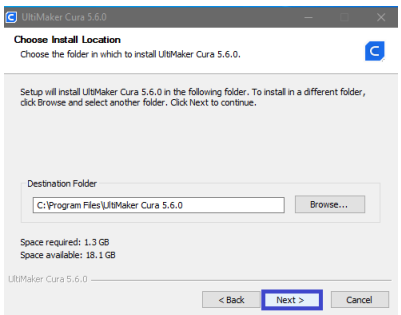
After starting the installation a welcome window will appear and it is recommended to firstly close the other applications before starting the installation. After closing the other applications click **"Next"**

Step 2



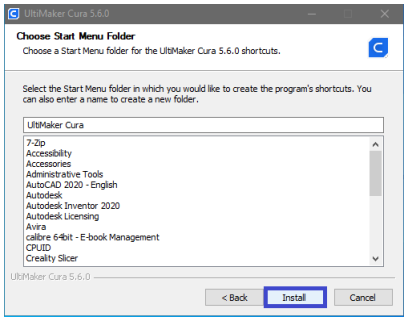
If you agree with the terms of use of the software, click **"I Agree"**

Step 3



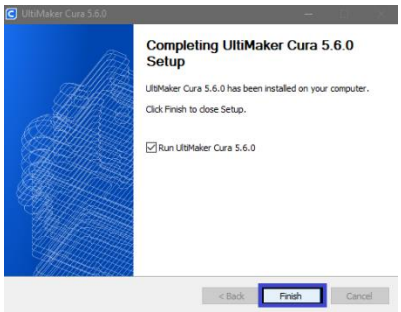
Choose the location and folder in which you want to install the software, than press **"Next"**

Step 4



Select Start Menu Folder and click "**Install**"

Step 5

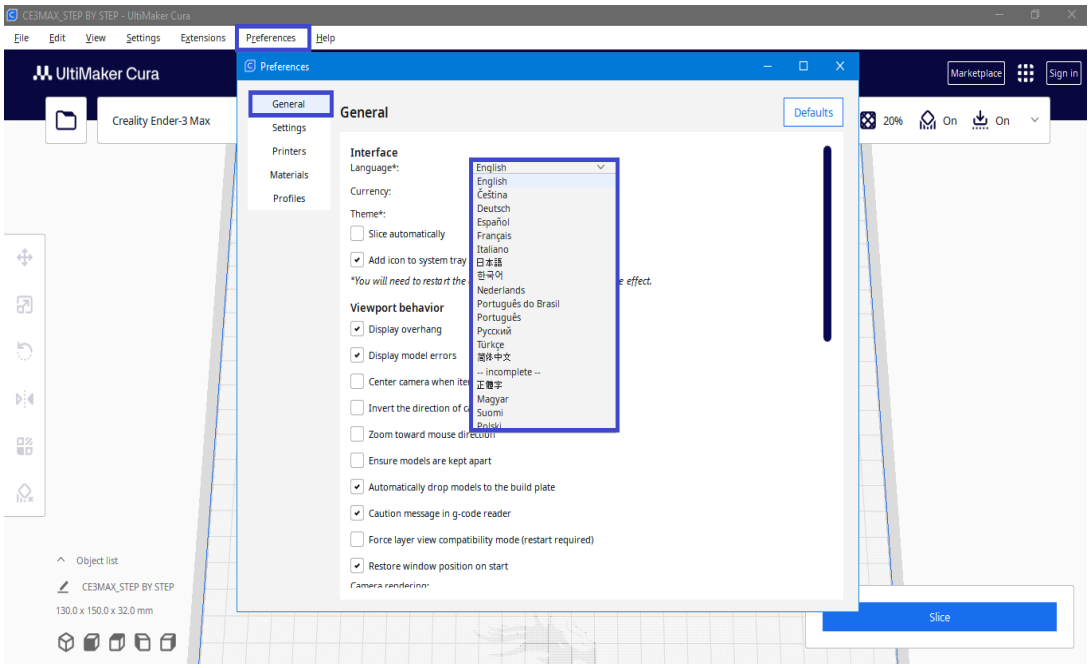


At the end, you will receive an information confirming that the installation is complete.You will also have the option to immediately start the software, depending on whether Run Ultimaker 5.6.0 is selected for you.

Click **"Finish"**

3. Language setting

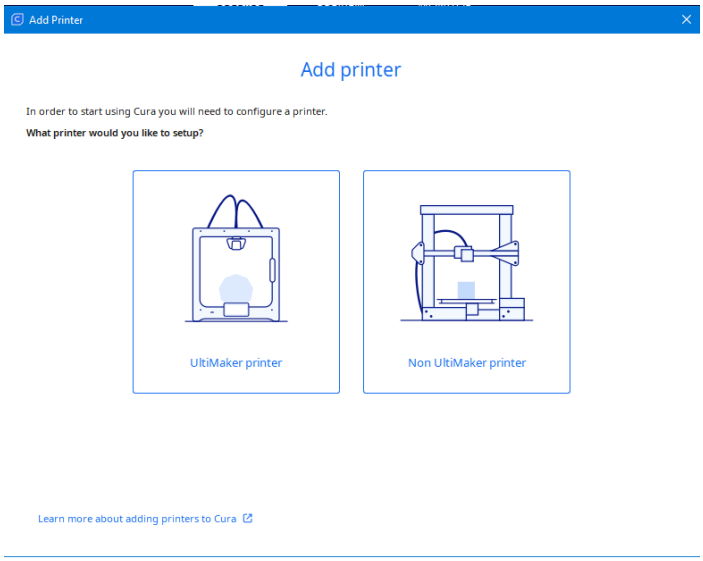
Cura will automaticly pick the language of your operating system, but you can change it.



Configure the Cura software settings according to our 3D printer.

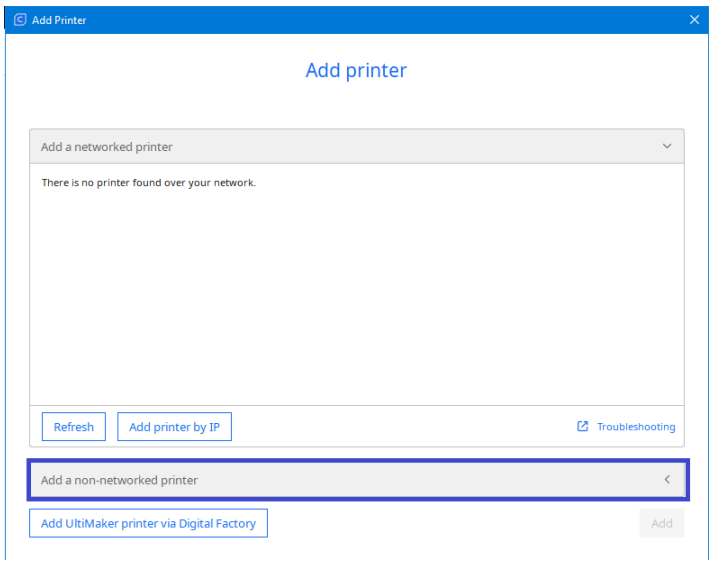
After starting the software you need to select your 3D printer. Cura offers you a wide range of FDM 3D printers from different manufacturers, but if you don't find your 3D printer, you can make a configuration yourself according to the parameters of the printer you have.

Step 1: Select the manufacturer of your 3D printer



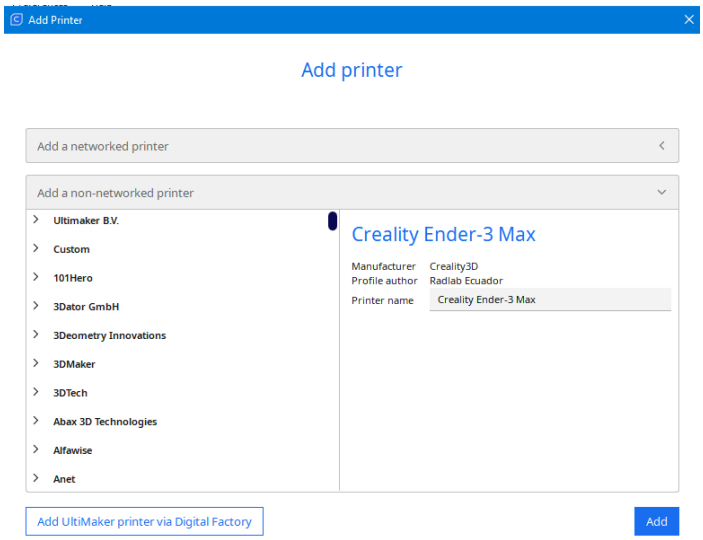
If your 3D printer is manufactured by Ultimaker, then select Ultimaker printer, if not, select Non Ultimaker printer.

Note: The printer we are going to deal with in this manual is non Ultimaker printer.



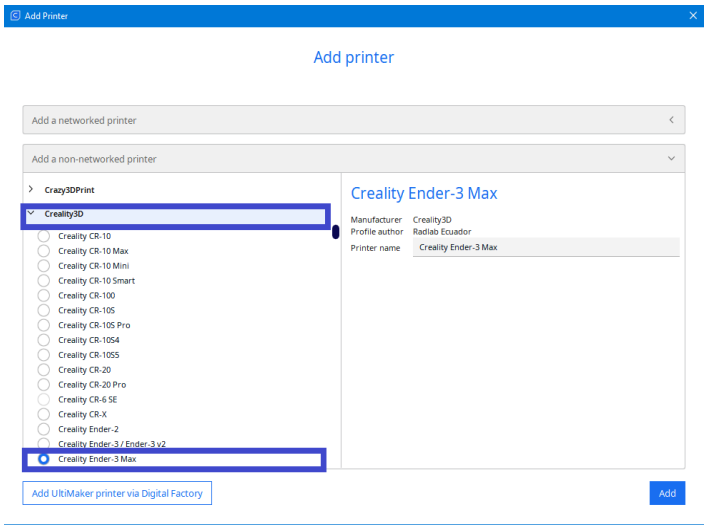
If your printer is networked with your computer then it will appear automatically.

If it is not, then select **"Add a non-networked printer"**



On the left side are the manufacturers of 3D printers and on the right side you have the name of the 3D printer.

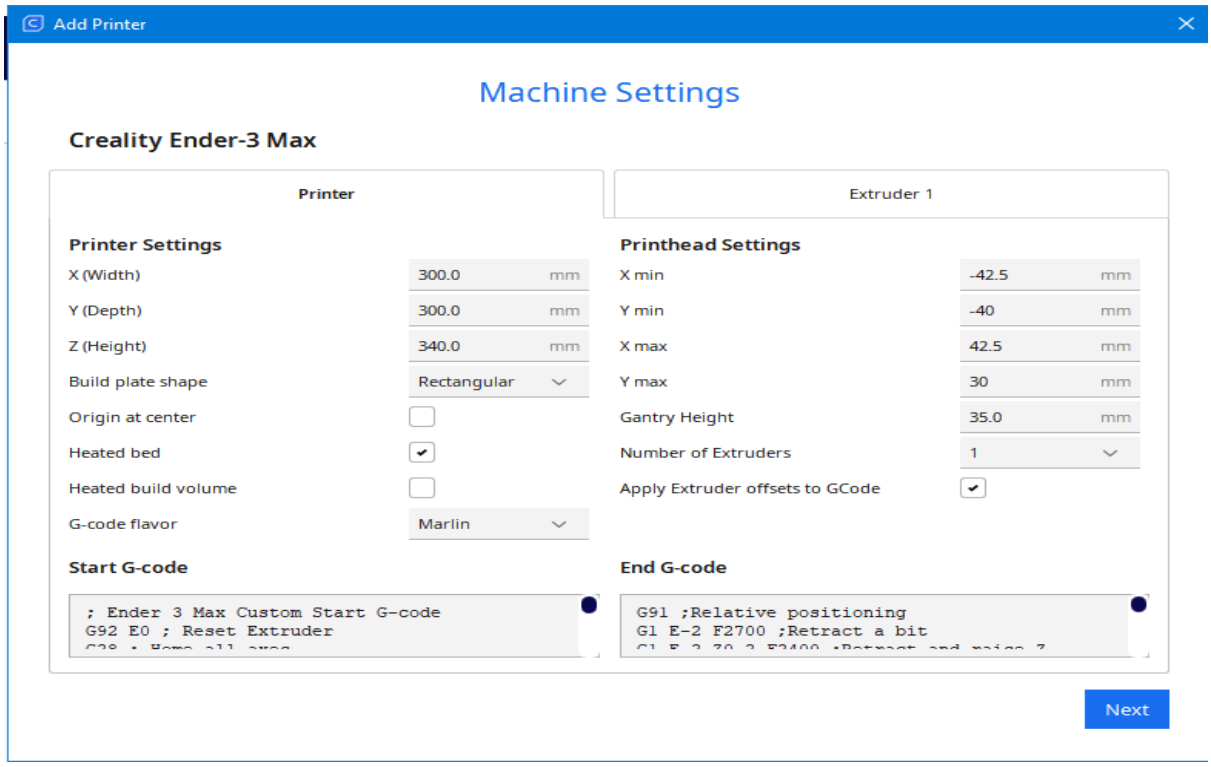
Step 2: Choose your 3D printer



We select our 3D printer and click **"Add"**

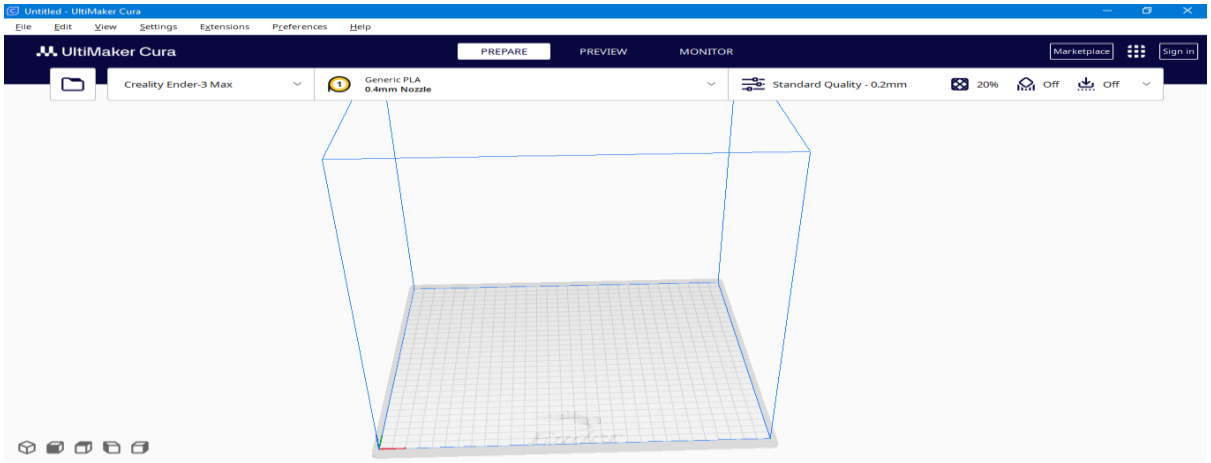
Note: The printer we are going to deal with in this manual, is Crealiti Ender 3 max

Step 3: Configuration of your 3D printer



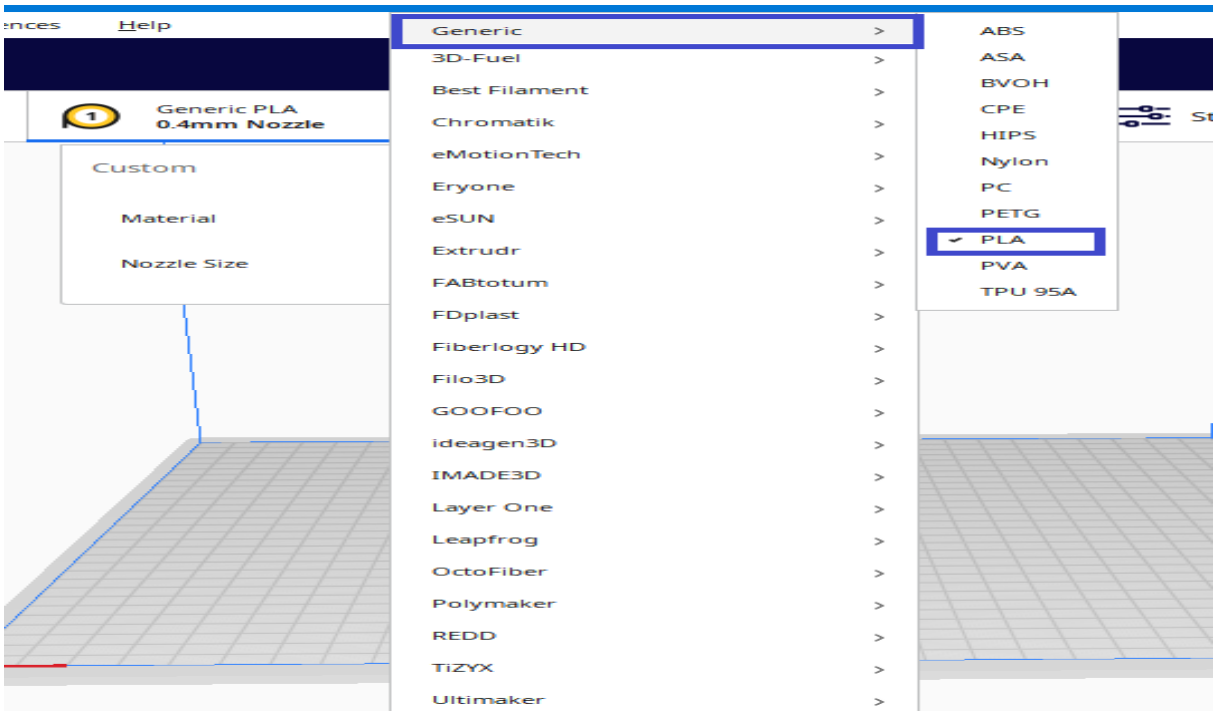
The software automatically displays the parameters for your 3D printer. If, by chance, they do not match the parameters given by the manufacturer, you have the opportunity to change them. If everything is fine, click **"Next"**

Note: The dimensions for the X,Y and Z axis should never be larger than the actual values of the 3D printer.



Step 4: Selection of material for printing.

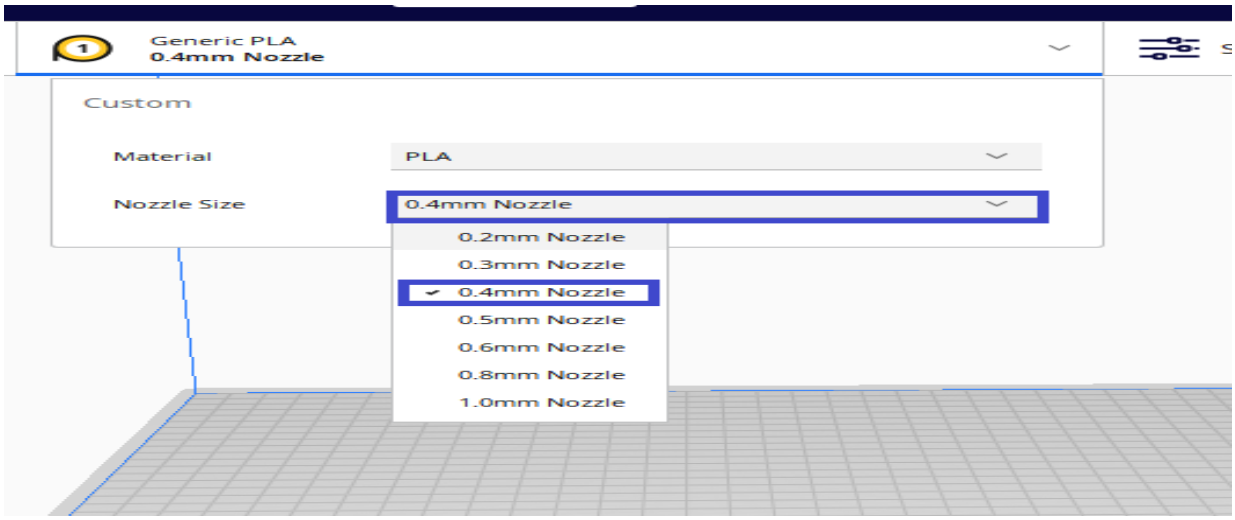
After starting the software, you need to select the material you will print with. Cura offers you a large selection of printing material such as ABS, PLA, PETG, TPU, PVA



Note: We use PLA filament.

Step 5: Selection of nozzle size

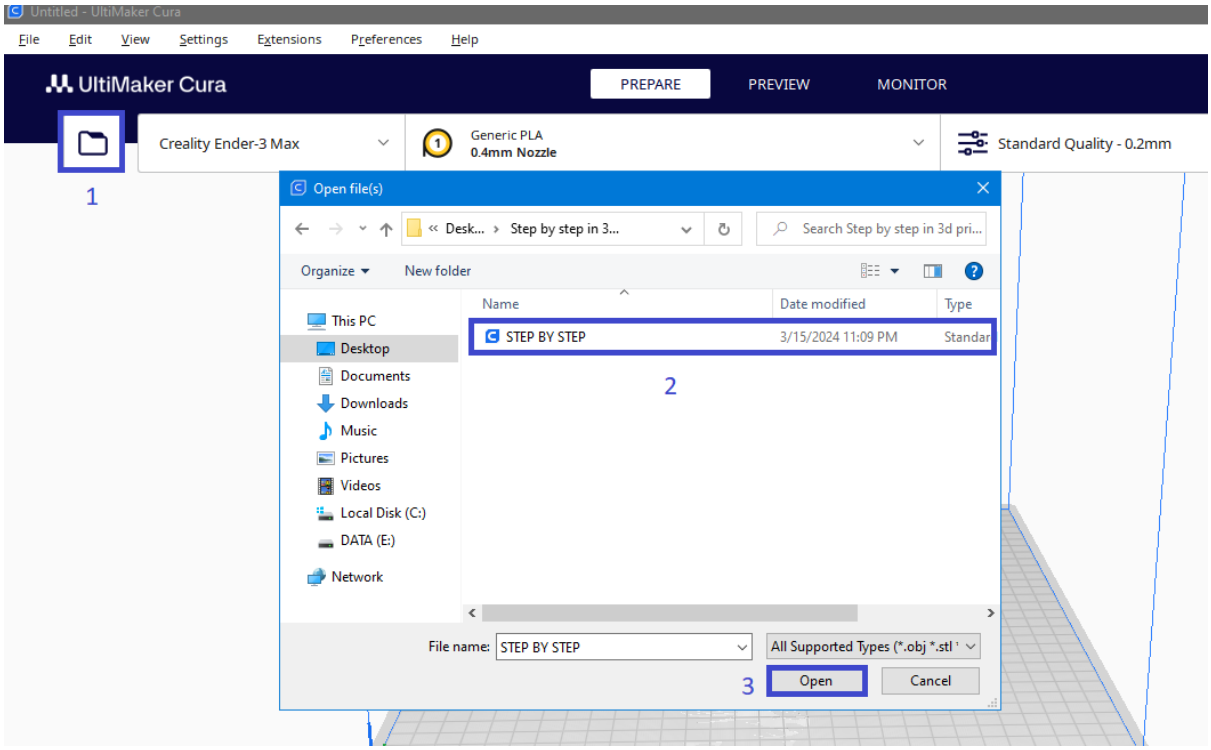
Select the size of the nozzle from your 3d printer.

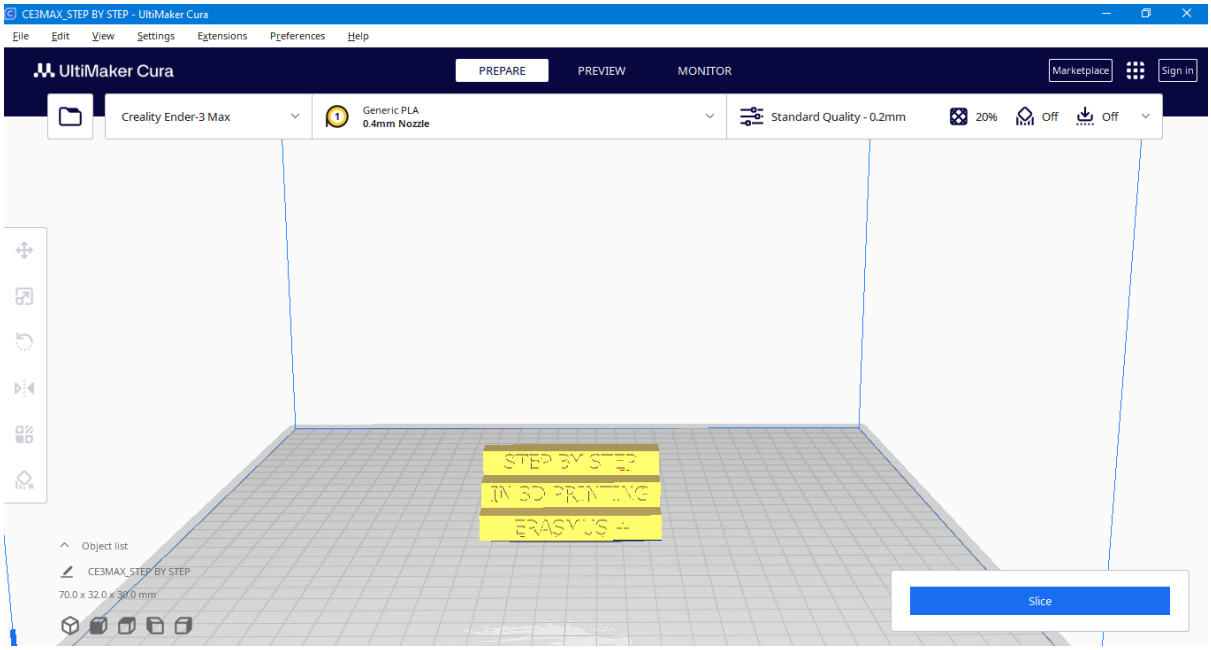


Note: The nozzle of our 3D printer is 0.4mm

4. Import the 3D model into Cura.

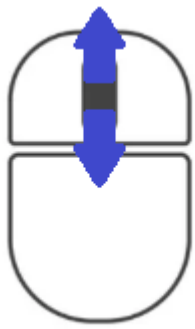
Before importing the 3D model into the software, ensure that your model has been converted to one of the following formats: STL, OBJ, X3D or 3MF. These are the formats supported by Cura.





After you see the 3D model on the platform, you can start preparing it for 3D printing

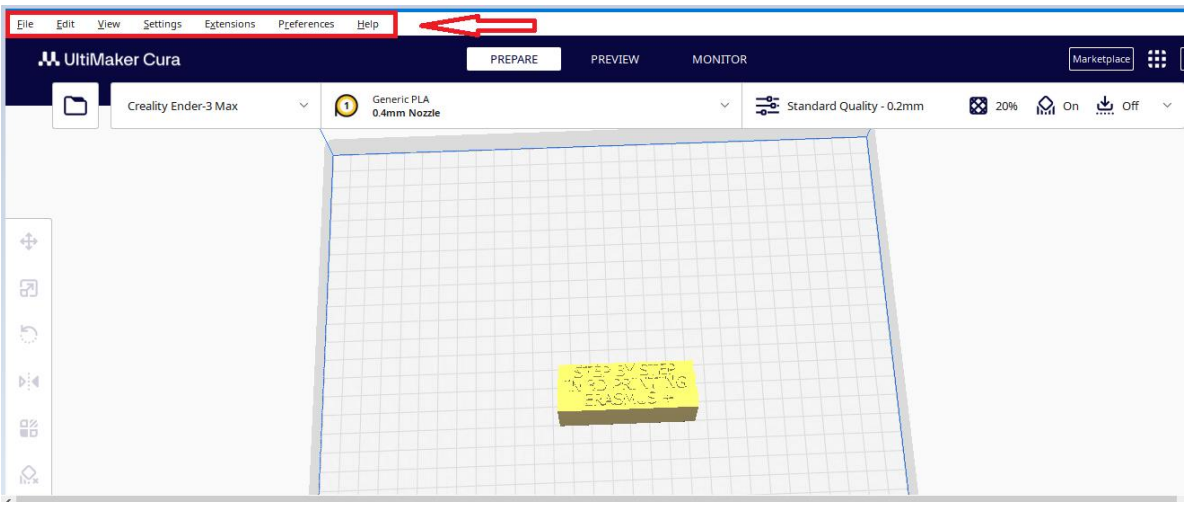
Navigation

Left Click – Select model	**Right click- Orbit around scene**	**Middle mouse Button- Pan the viewport**	**Scroll in/out- Zoom the viewport**
			

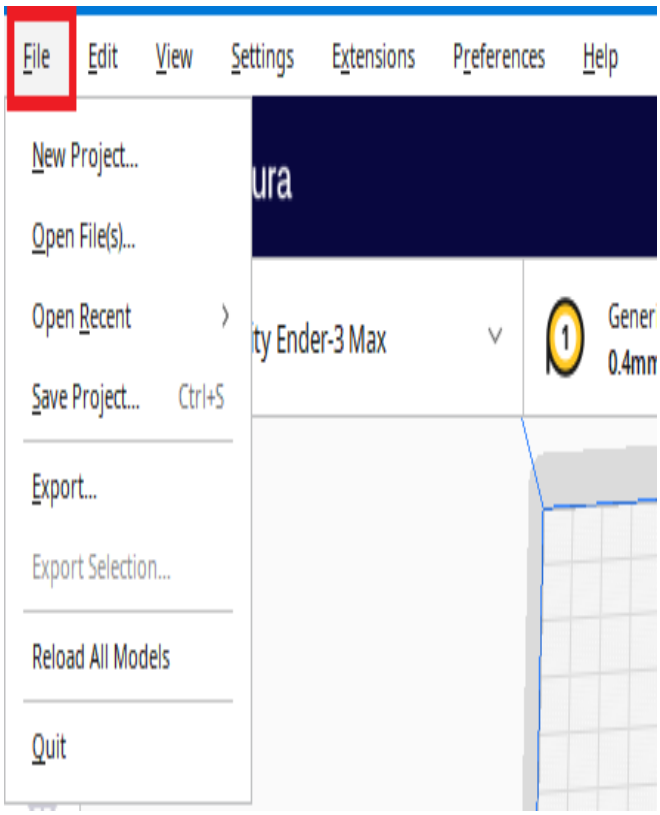
5. Command in the window

5.1 Top menu bar

The top menu bar includes the following options: File, Edit, View, Settings, Extension, Preferences and Help



File



Clicking on File will open commands such as:

New Project- if you want to start a new project

Open files- if you want to open an already existing model

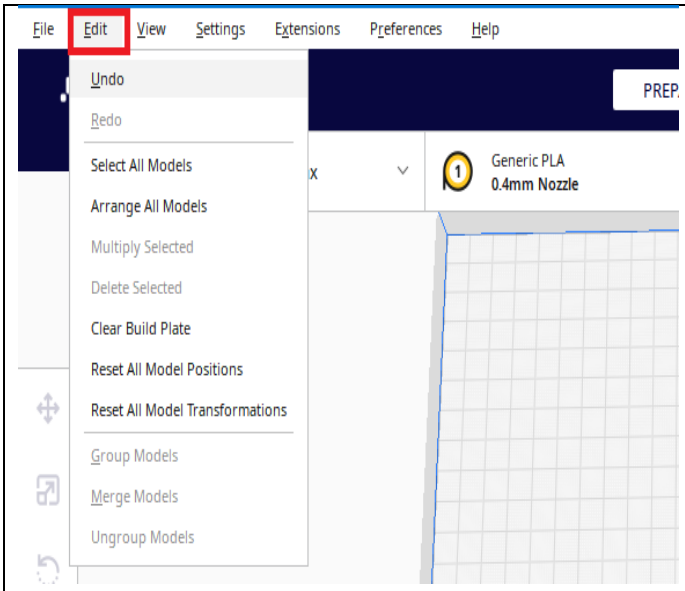
Open recent- if you want to open a model you have previously worked on

Save project- if you want to save the project you are currently working on

Export-if you want to export the model in another format

Quit- if you want to exit the program

Edit

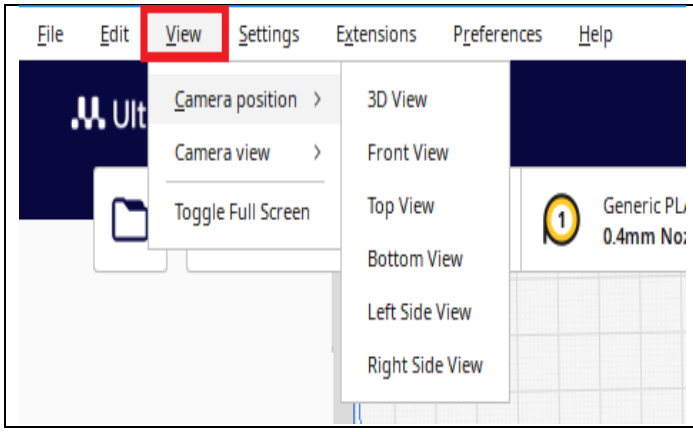


Clicking on Edit opens up options such as (undo) canceling a given command and returning to the previous state of the model.

("Undo" can also be done by pressing ctrl+z on the keyboard.)

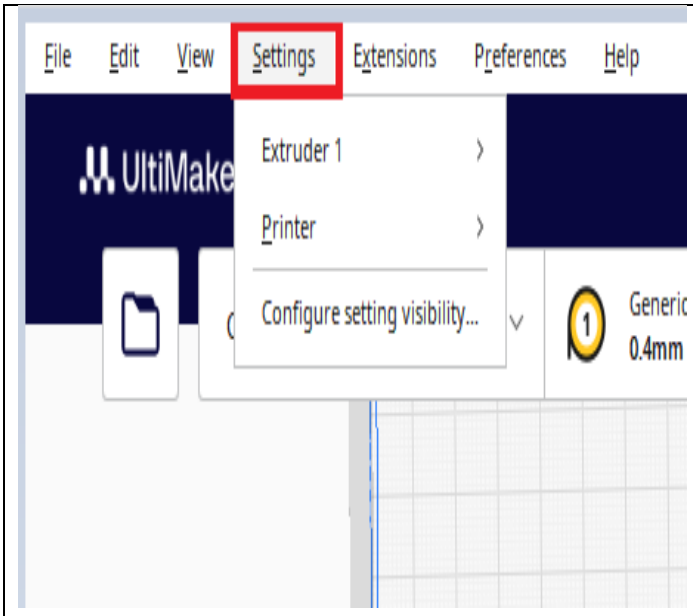
Other options are described below in the section **: left-click menu**

View



By clicking on **view** you have the opportunity to choose how to view the model, choose a position from which you will have the best view of the model

Settings



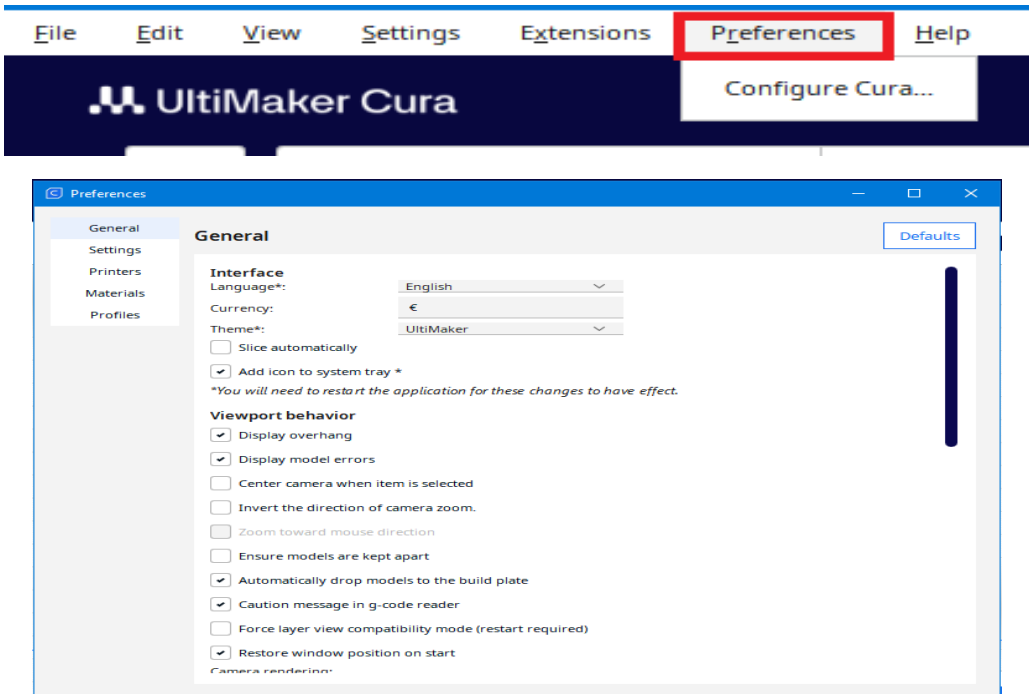
By clicking on Settings:

-In the **Extruder 1** field you have the opportunity to change the size of the nozzle and change the material you are going to print with.

-In the **Printer** field, you can choose the printer you will work with (if you have several printers available, then you should choose the printer with which you will print the model you are working on)

Preferences

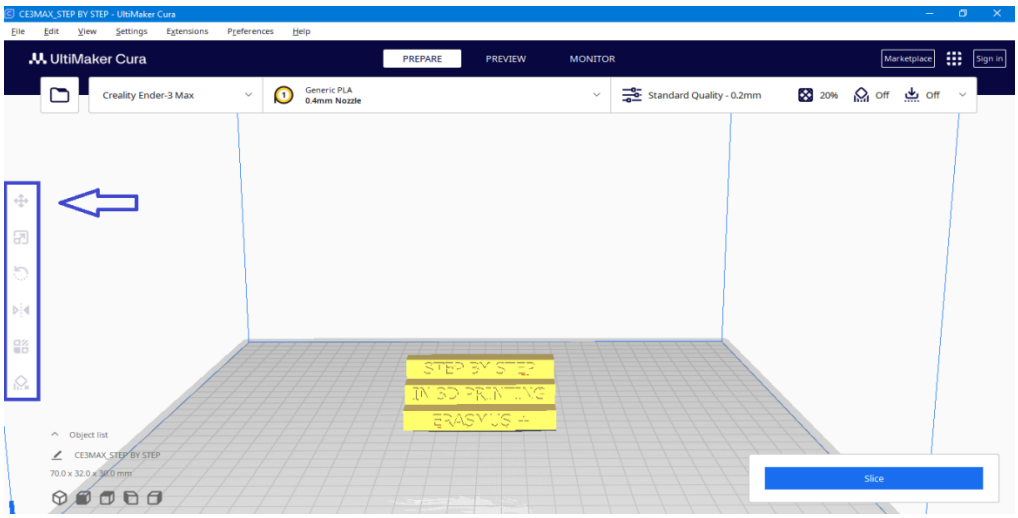
By clicking Preferences and Configure Cura you have the ability to make all the changes described so far, on an advanced level.



5.2 Operation bar

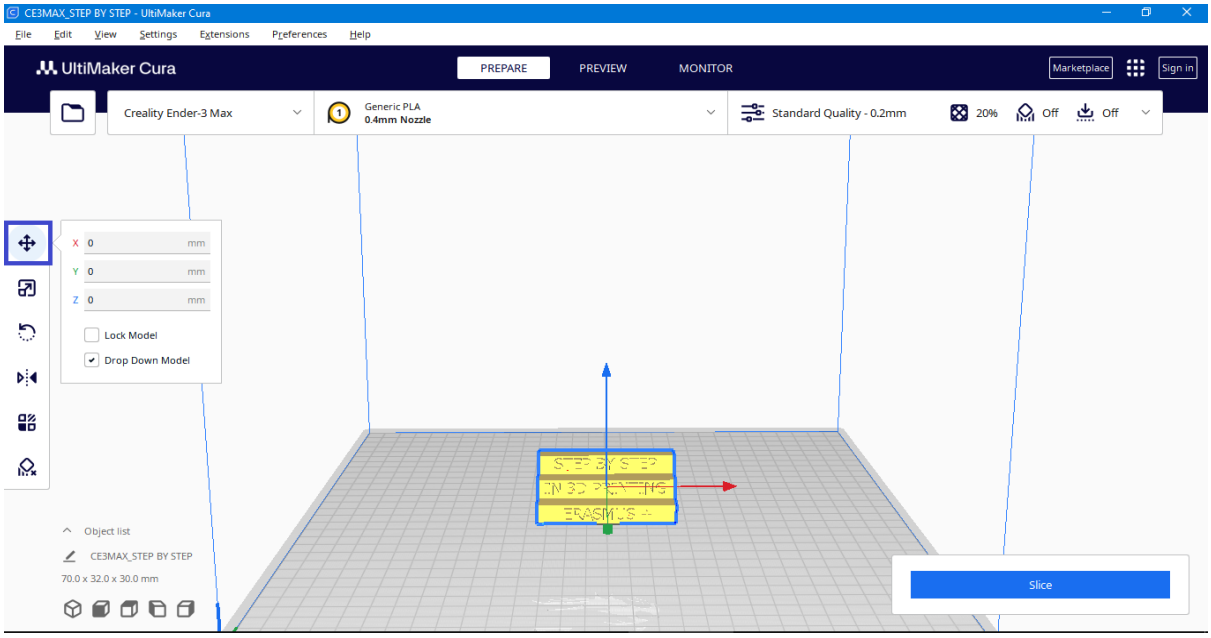
The operation bar includes the following functions: Move, Scale, Rotate, Mirror, Per Model Settings, and Support Blocker.

Before you can use these functions, the model must be selected.



Move

Perform moving operations on the selected model, including X/Y/Z movement



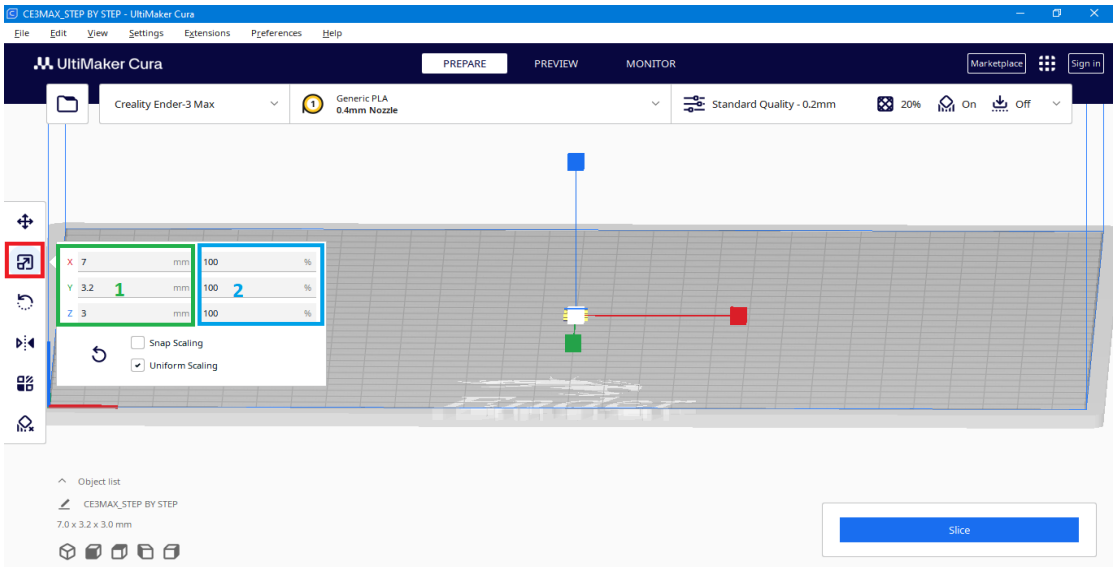
Scale

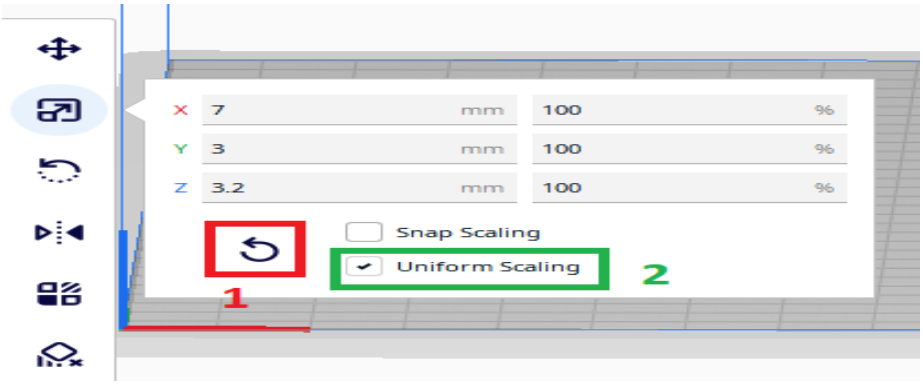
Perform scaling operations on the selected model, including scaling in the X/Y/Z directions, switch or lock the Uniform for scaling, and reset operation.

NOTE: When importing models into Cura, it's important to check the scale settings. Sometimes, the default scale might be different, (10x smaller) causing the model to appear smaller. You can adjust the scale in Cura to match the size of your model in the 3D modeling program you were using.

First select the model, then click on the Scale command (the box marked in red below the image). After you have done the previous steps, you have the option to resize the model in two ways. The first way, is to change the dimensions of the model in millimeters, while the second way is through changing the dimensions in percentages. The two ways of changing are related to each other, this means that if you change the

dimension of the model in millimeters, the percentage value will automatically change, and vice versa.

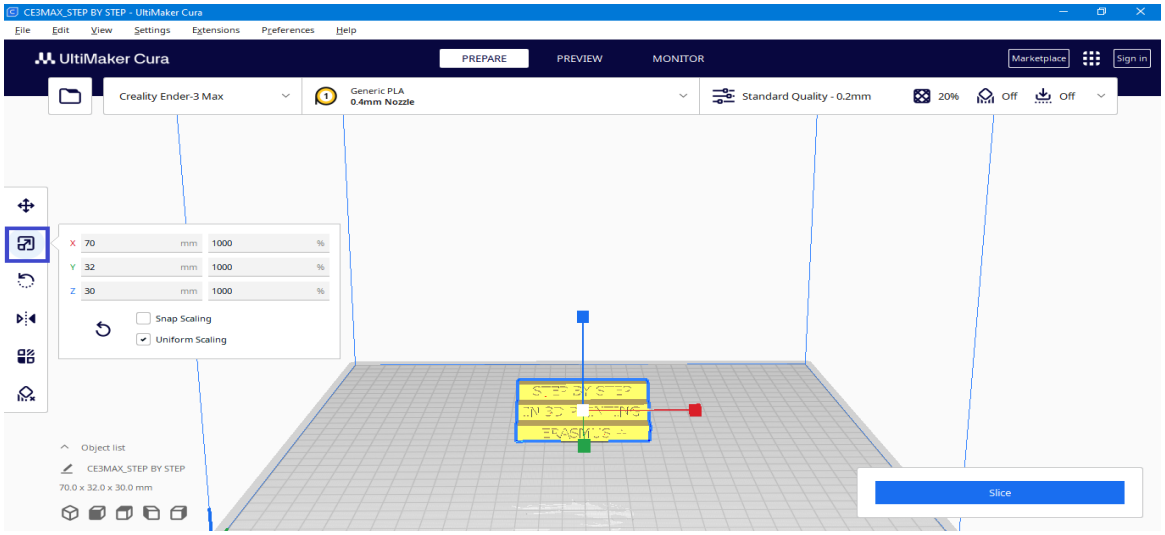




Reset- Command for resetting the dimensions of the model, i.e. returning to the original dimensions of the model.

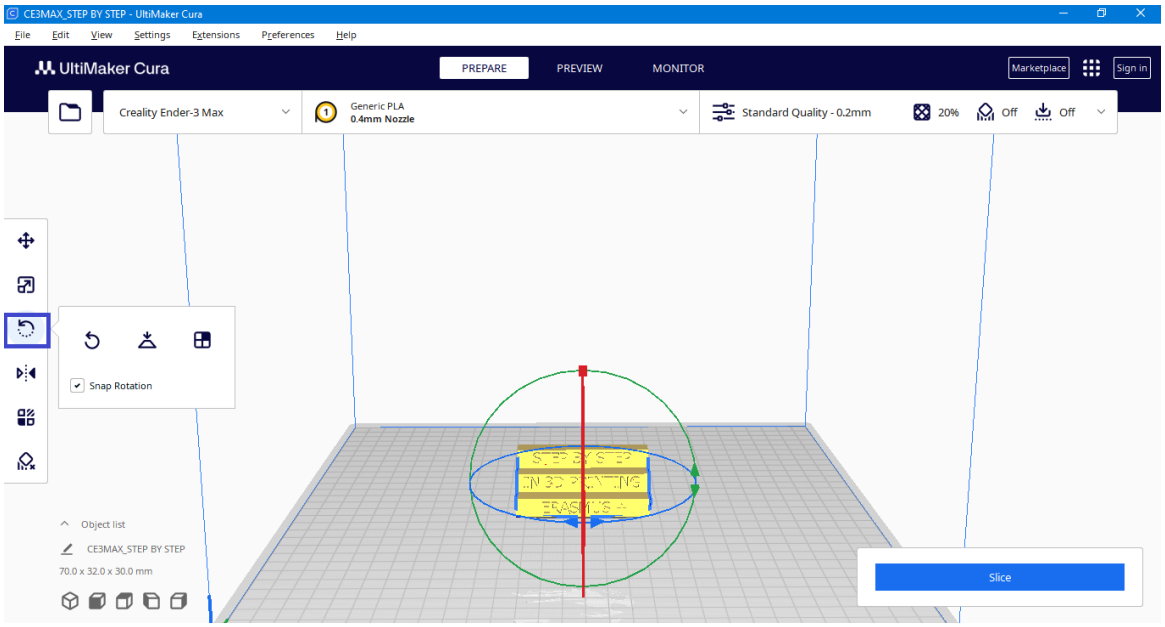
Uniform Scaling - By selecting the uniform Scaling command when changing one dimension, the other dimensions will change linearly with the same amount as previously choosen, if the command is not selected then you can change the dimensions of the model for each size separately (X, Y or Z)

NOTE: Our model is 10 times smaller than the original one, so we will use the option to change the dimensions in percentages (100x10=1000%) with the Uniform Scaling field selected.



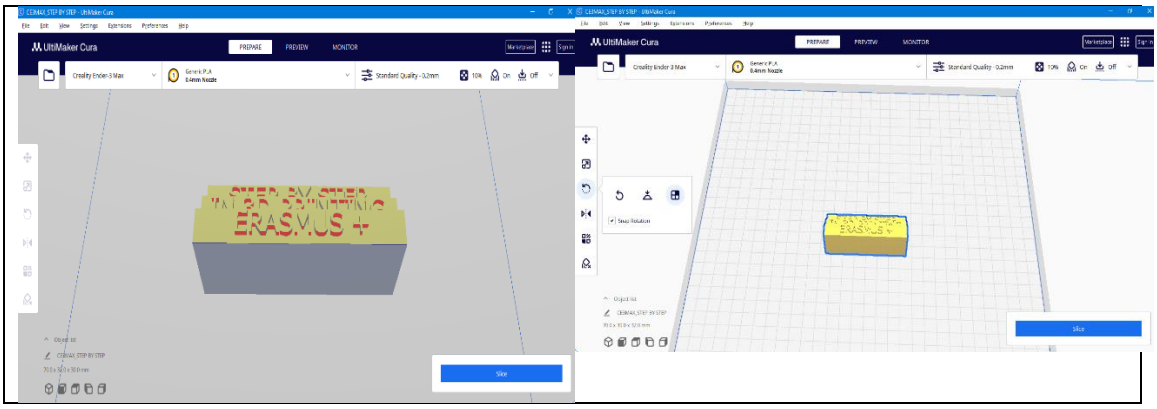
Rotate

Allows you to rotate the model as you wish, avoiding the need for support.



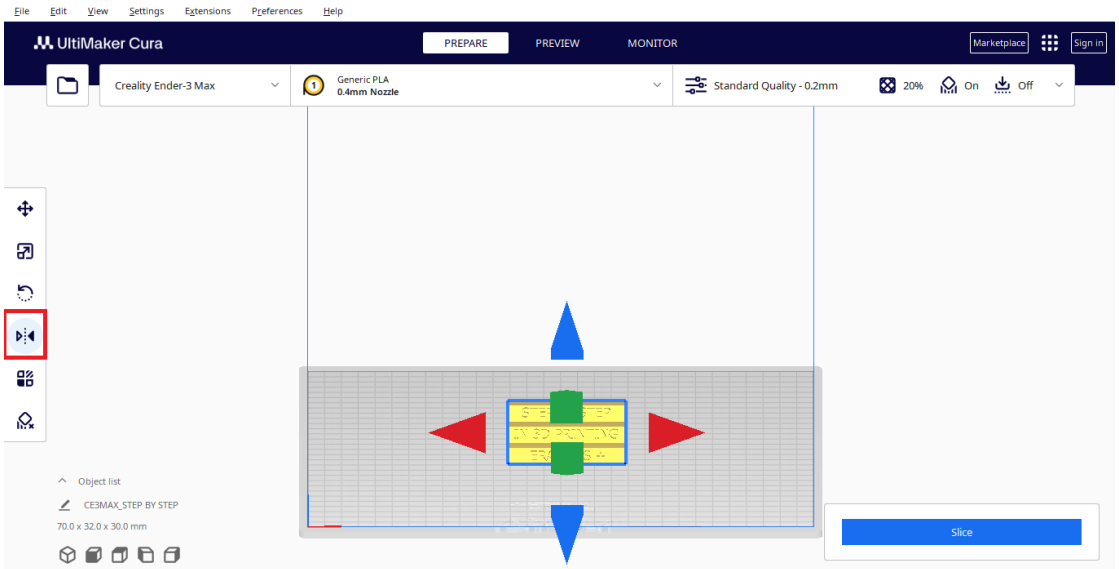
NOTE: If the model has some red colored parts, it indicates that those areas require support structures. To minimize the need for supports, adjust the model either by eliminating the red areas or minimize their presence.

If you rotate this model you will notice that the letters on the bottom side are red colored, so we will flip this model so that there are no red parts on it.



Mirror

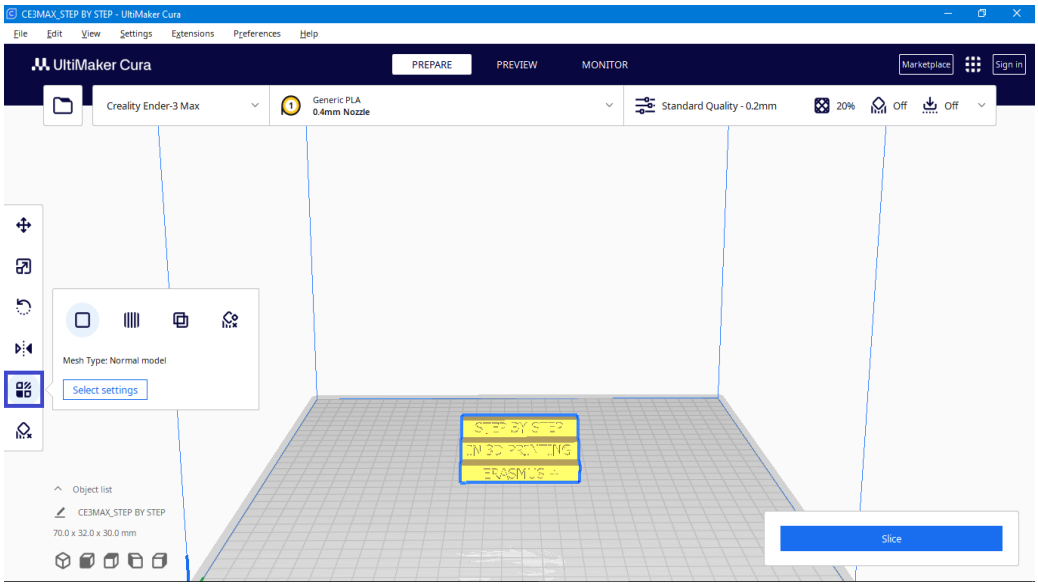
Allows you to mirror the model on all different axis.



With this command you can flip the models, and, for example make them suitable for stamp.

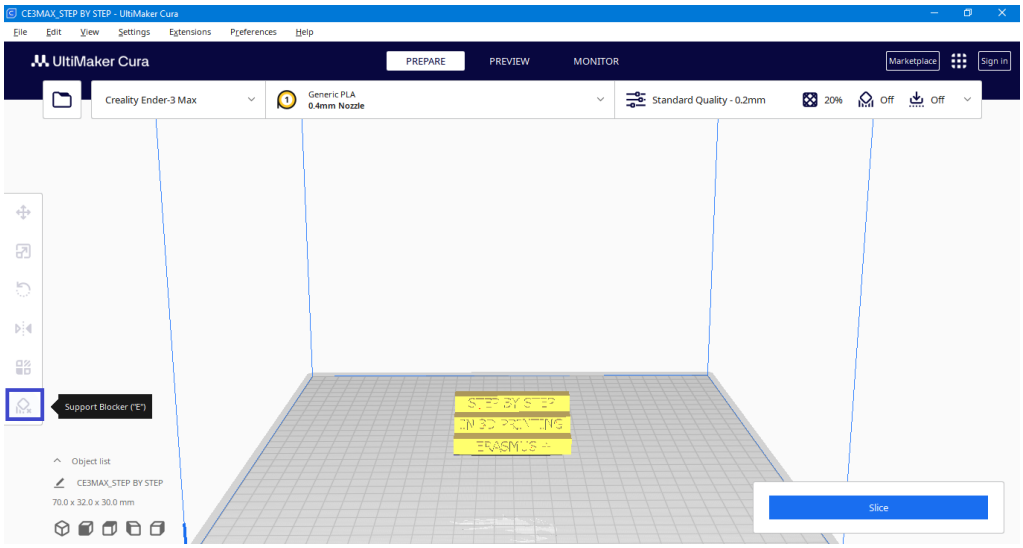
5.3 Per model settings

Allows you to change the mesh type and settings of the models



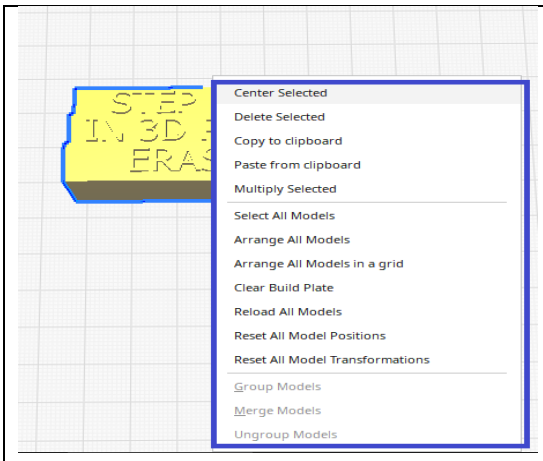
Support blocker

Allows you to block an area so that supports will not be generated.



Right click menu

Right-clicking on the model opens a menu in which you have several options



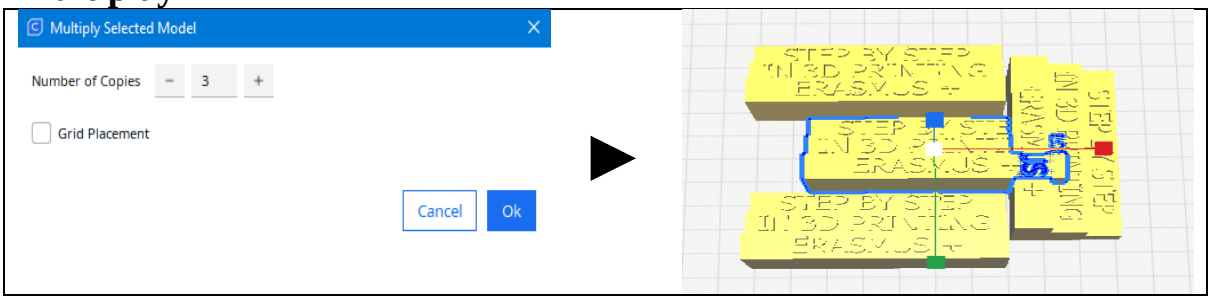
Center selected-positions the selected model in the middle of the printing plate

Multiply selected- number of copies of the model

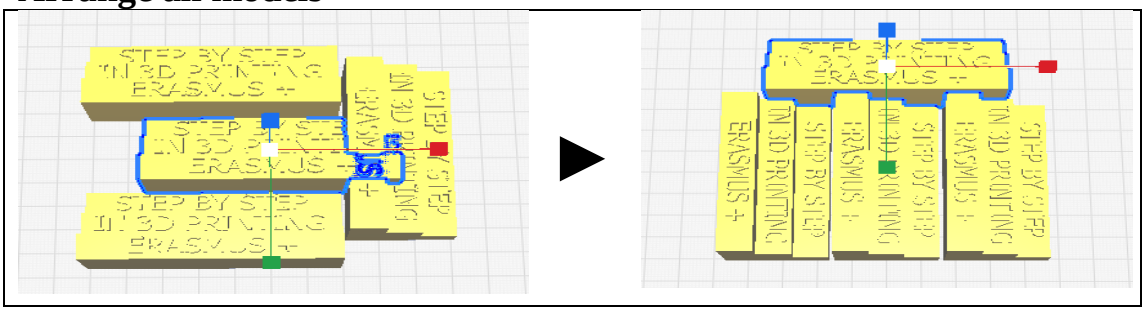
Arrange all models-arranges models next to each other to save

Arrange all models in a grid- arranges the models at a certain distance from each other in a grid

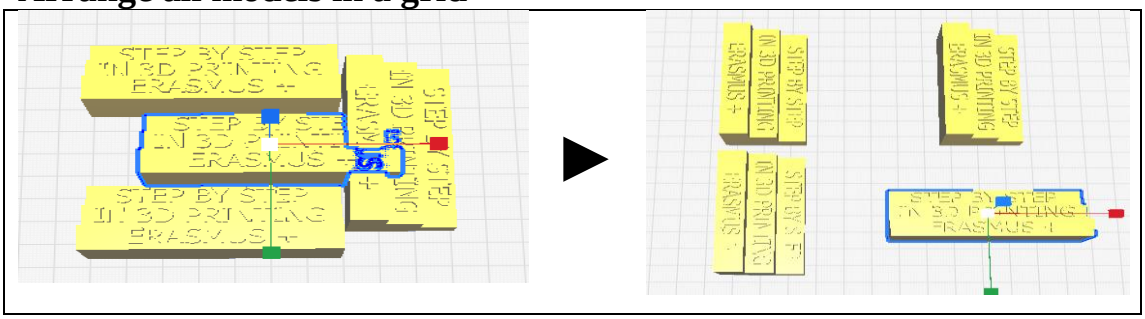
Multiplay



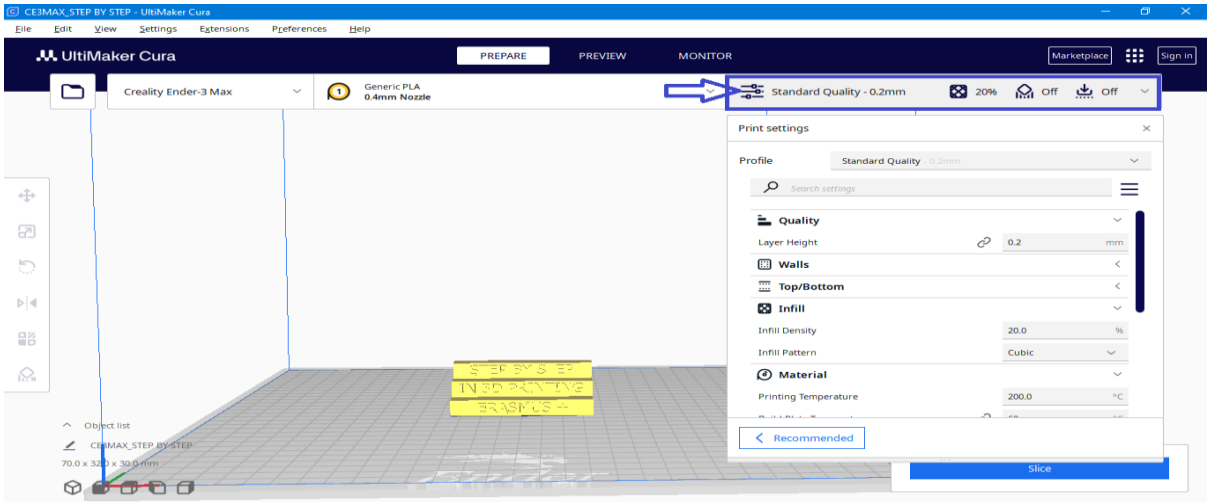
Arrange all models



Arrange all models in a grid



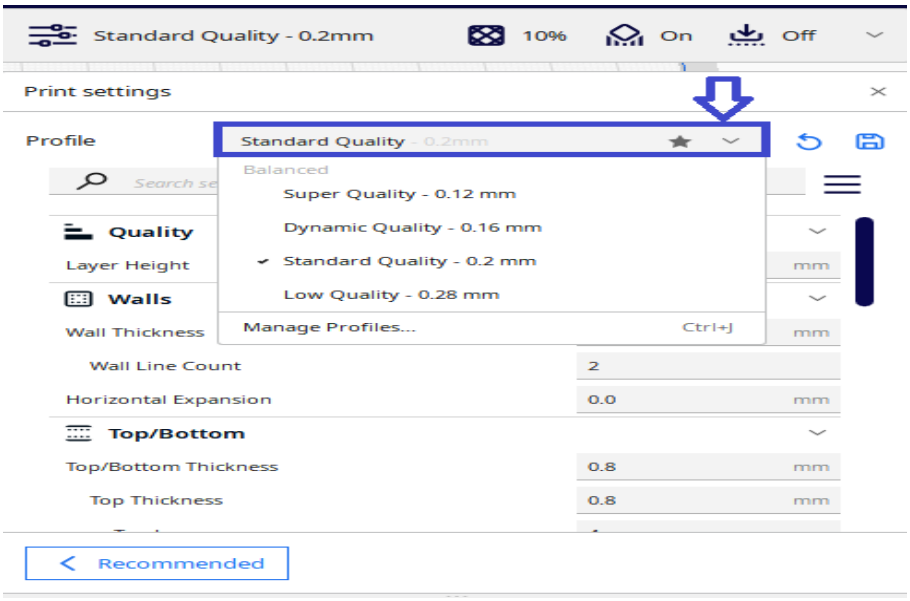
5.4 Print settings



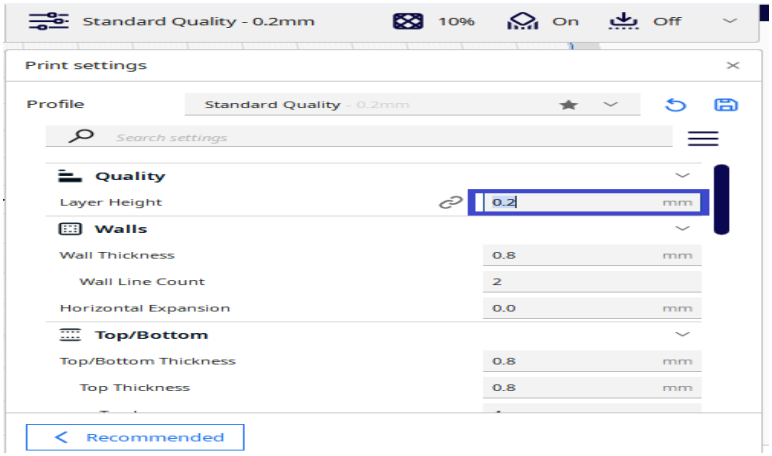
This is the field where you adjust the printing according to your needs.

Print Quality.

Here, you select the printing quality for your model, i.e., the layer height. You can choose from existing profiles where your previous print settings are saved, or create new ones with custom parameters.



You can also enter the layer height manually in the "layer height" field.



NOTE: Higher values produce faster prints in lower resolution, lower values produce slower prints in higher resolution.

For our model we use Standard Quality 0.2mm

5.5. Walls

This is a field in which the thickness of the walls ars given before it starts to fill the inner part of the model, that is, the number of lines made by the extruder along the ends of the model. The two fields are dependent on each other, while both are dependent on the width of a layer.

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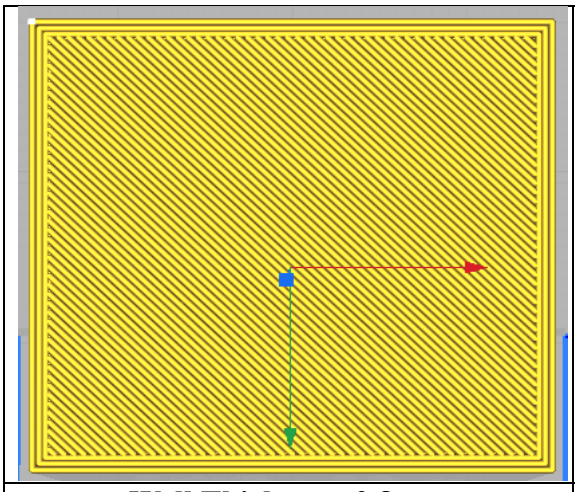
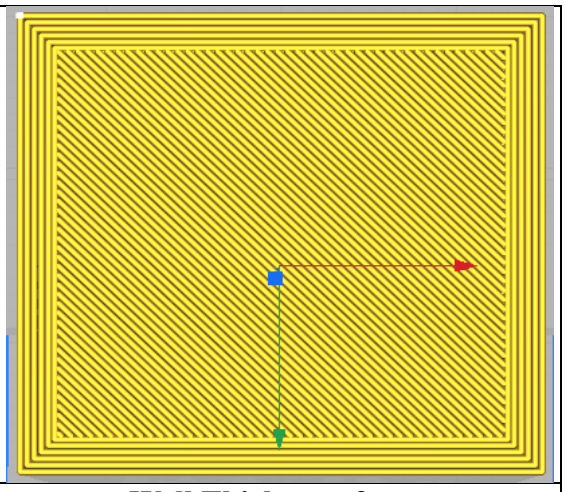
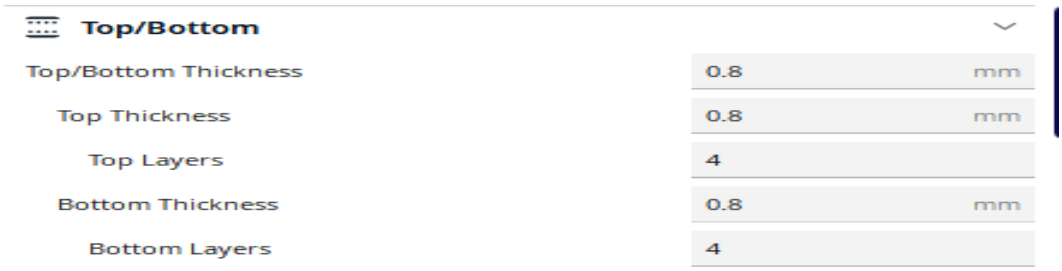
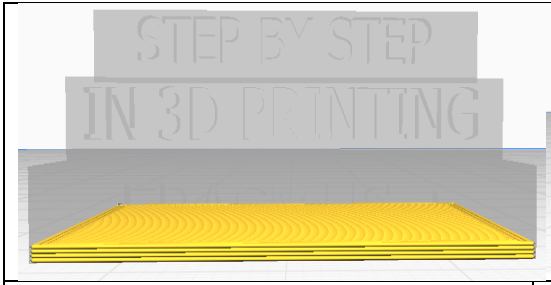
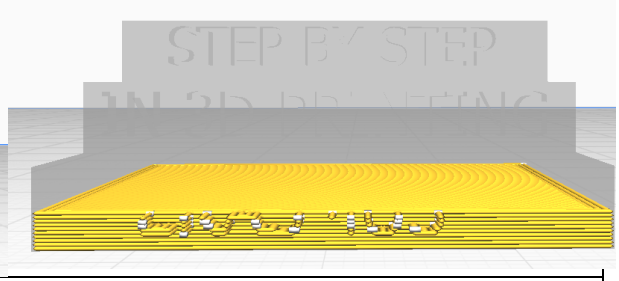
	
Wall Thickness 0.8mm **Wall Line count 2**	**Wall Thickness 2mm** **Wall Line count 5**

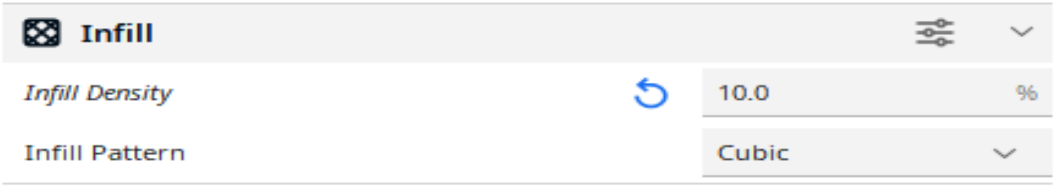
Top/Bottom



In this field you specify the thickness of the bottom and top of the model, that is, how many layers to make before the model starts to be filled. You have the option to set them with the same value, but also with different values for the top and the bottom.

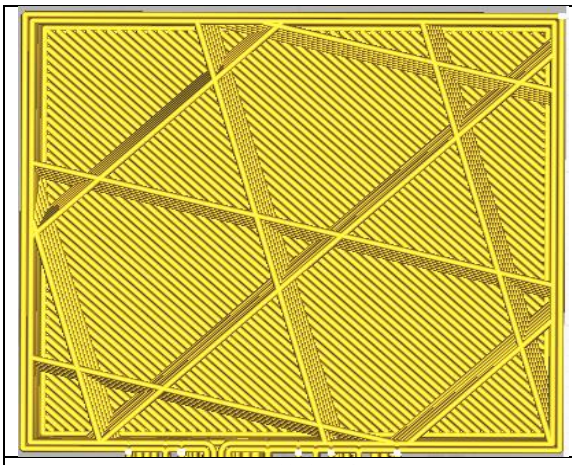
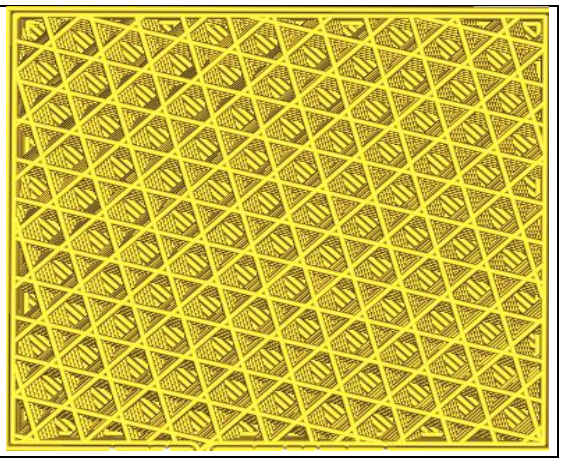
	
Bottom thickness 0.8mm **Bottom layers 4**	**Bottom thickness 2mm** **Bottom layers 10**

Infill



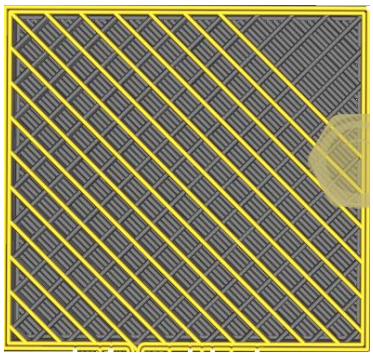
In this field you specify the infill density of the model in percent, and the shape of the fill. You have a choice of several patterns.

NOTE: The higher the percentage of infill, the more solid the model, it takes more material and more time to make, a lower percentage means less material (lighter model), and less time to make.

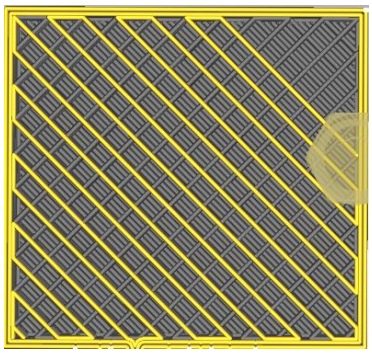
	
Infill 10%	***Infill 50%***

Infill pattern

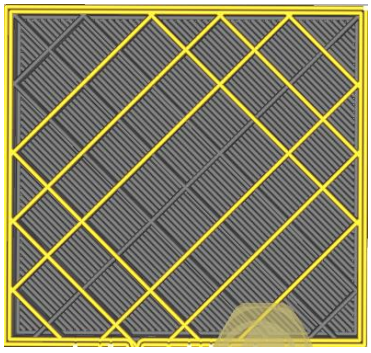
Grid Lines Triangles Tri-Hexagon Cubic Cubic Subdivision Octet Quarter Cubic Concentric Zig Zag Cross Cross 3D Gyroid Lightning Cubic	**The pattern of the infill material of the print.** • **The line and zig zag infill swap direction on alternate layers, reducing material cost.** • **The grid, triangle, tri-hexagon, cubic, octet, quartet cubic, cross and concentric patterns are fully printed in every layer.** • **Gyroid, cubic, quarter cubic and octet infill change with every layer to provide a more equal distribution of strength over each direction.** • **Lighting infill tries to minimize the infill, by only supporting the celling of the object.**



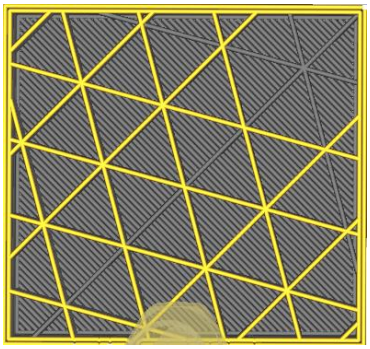
Lines



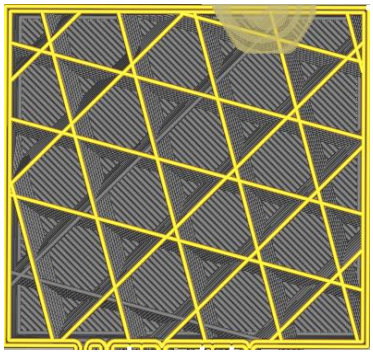
Zig-Zag



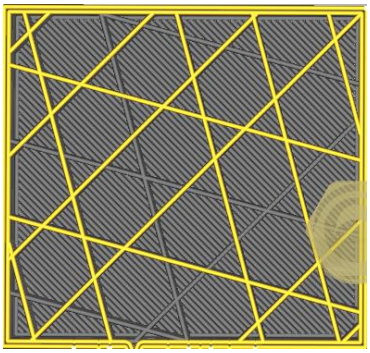
Grid



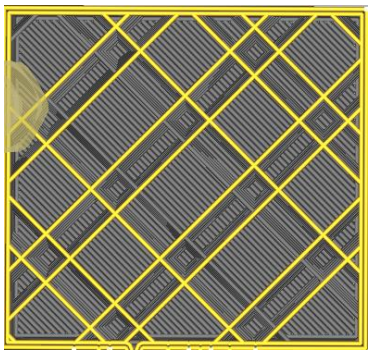
Triangles



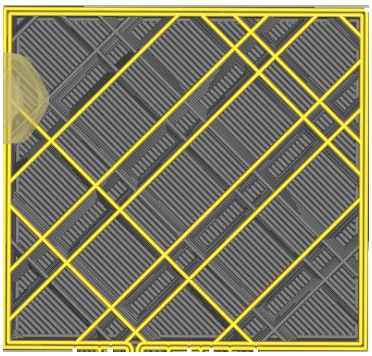
Cubic



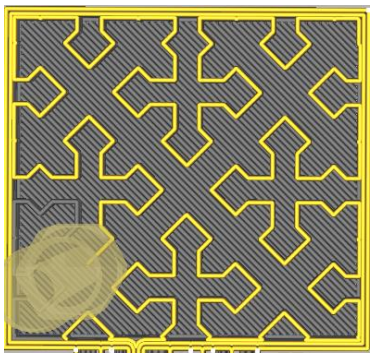
Tri-Hexagon



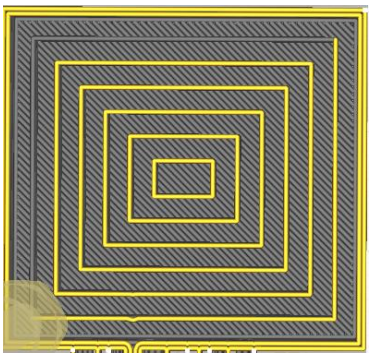
Octet



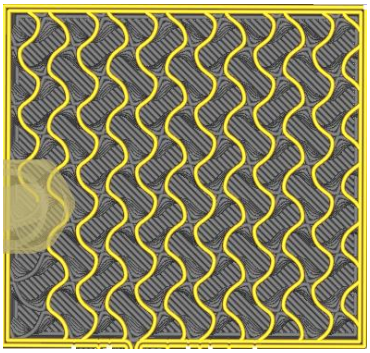
Quartet Cubic



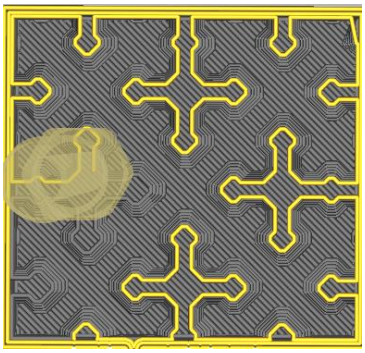
Cross



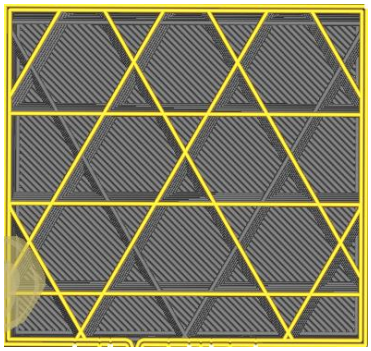
Concentric



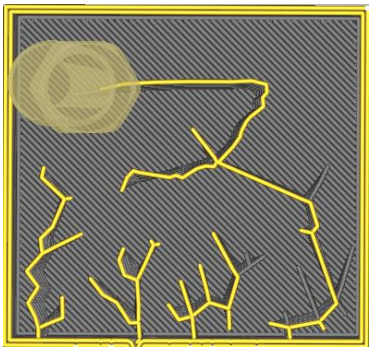
Gyroid



Cross 3D

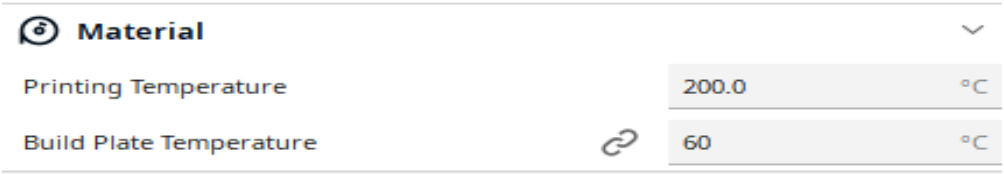


Cubic Subdivision



Lighting

5.6 Materials



In this field you enter the temperature of the nozzle and the temperature of the bed (if the 3D printer you are working with has a heated bed).

The temperature of the nozzle and bed depends on the type of material you are printing with.

Material	**PLA**	**TPU**	**ABS**
Printing temperature	**180 ºC to 230 ºC**	**210 ºC to 230 ºC**	**240 ºC to 260 ºC**
Build Plate Temperature	**40 ºC to 60 ºC**	**30 ºC to 60 ºC**	**95 ºC to 110 ºC**

Note: The temperature depends on the conditions in which you print.

Note: The 3D printer we will print on is not closed. Since we will print in conditions where there will be movement of people, the maximum temperatures are recommended because there is a flow of air that cools the filament and deformation of the printed object can occur.

Speed

The speed at which printing happens

The optimal print speed for your object depends on your priorities, preferences, and printer's capabilities.Lower print speeds can improve surface quality, dimensional accuracy, and precision, but they also increase the printing time and the risk of clogging and jamming. Higher print speeds can reduce printing time and material consumption, but they also degrade surface quality, dimensional accuracy, and precision.

Travel

Retract the filament when the nozzle is moving over a non-printed area

Retraction is a feature meant to eliminate stringing by pulling back filament when the printhead moves to a new location.

Cooling

Enables the print cooling fans while printing. The fans improve print quality on layers with short layers times and bridging/overhangs.

Support

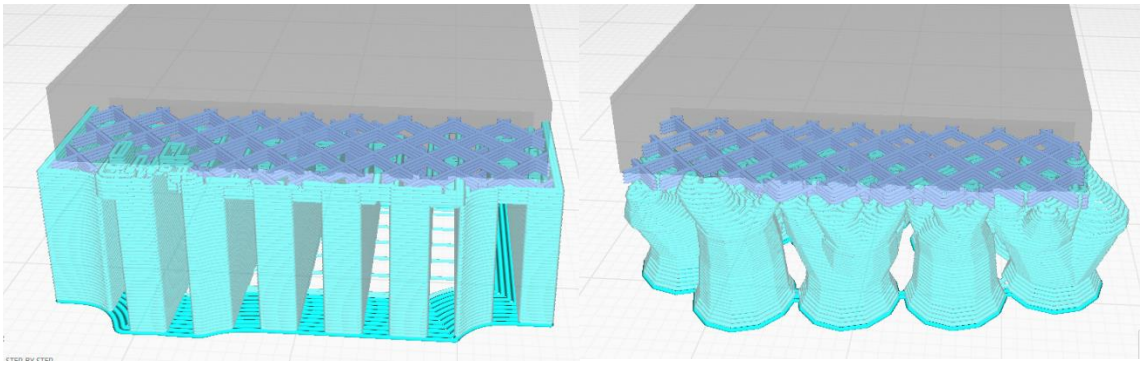
Generate structures to support parts of the model which have overhangs. Without these structures, such parts would collapse during printing. The software will color in red, the part that is hanging, and that needs a support.

Support structure

Chooses between the techniques available to generate support.

Normal support creates a support structure directly below the overhanging parts and drops those areas straight down.

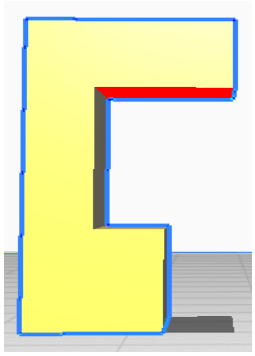
Tree support creates branches towards the overhanging areas that support the model on the tips of those branches, and allows the branches to crawl around the model to support it from the build plate as much as possible.



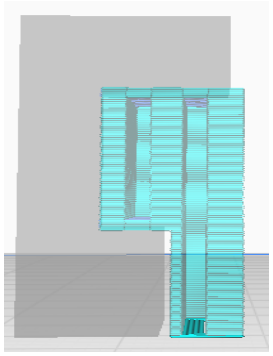
Normal support ***Tree suport***

Support placement

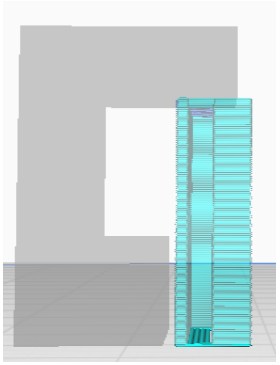
Adjust the placement of the support structures. The placement can be set to touching build plate or everywhere. When set to everywhere the support structures will also be printed on the model.



Without support

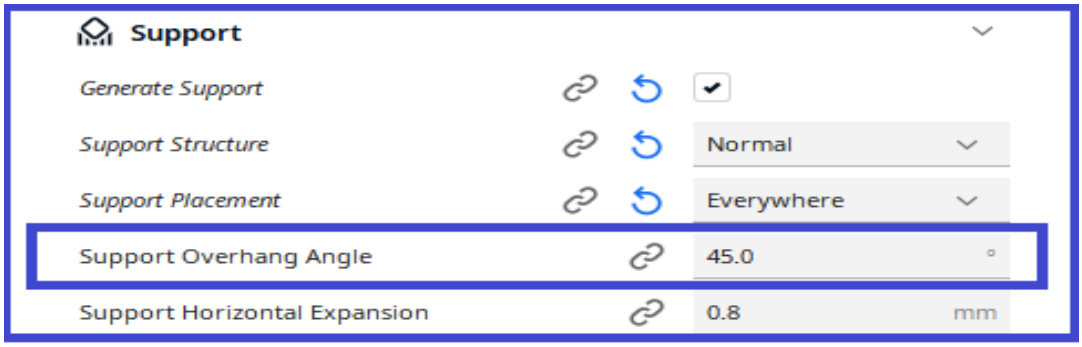


Everywnare



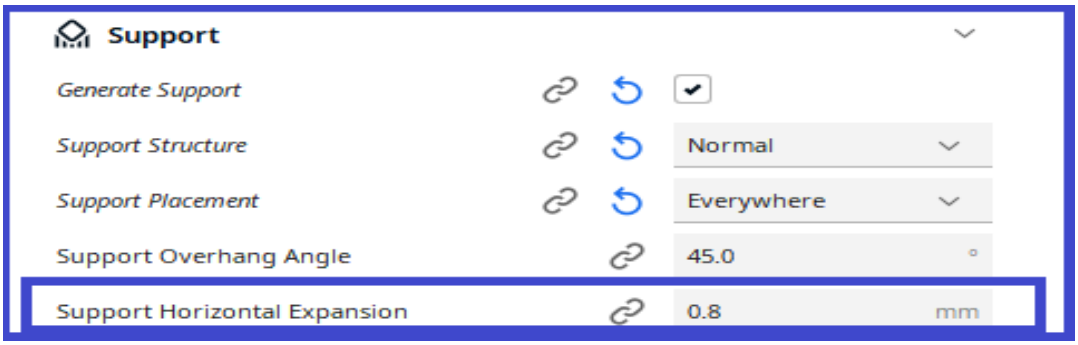
TuchingBuildplate

Support Overhang Angle

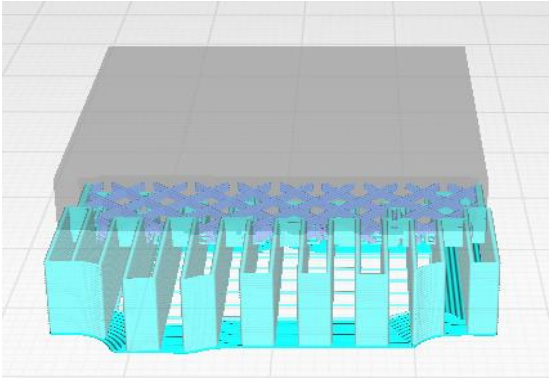


The minimum angle of overhangs for which support is added. At a value of 0º all overhangs are supported, 90º will not provide any support.

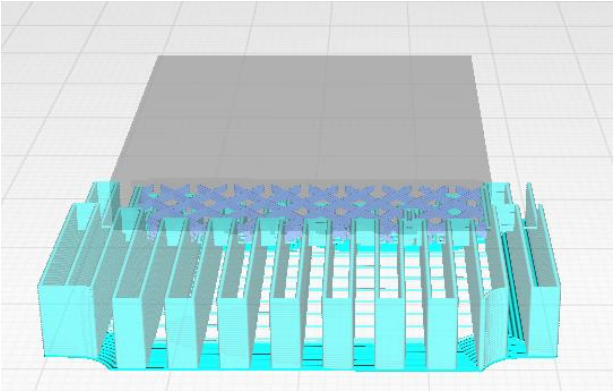
Support Horizontal Expansion



Amount of offset applied to all support polygons in each layer. Positive values can smooth out the support areas and result in more sturdy support.



Support Horizontal Expansion 0.8mm



Support Horizontal Expansion 5mm

5.7 Build Plate Adhesion

This option is suitable if you are printing a larger object.

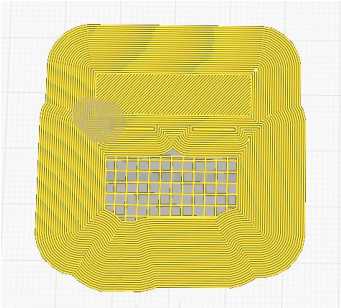
When larger objects are printed, larger temperature shocks occur, which tend to twist the object and detach it from the printing platform. In order to avoid these problems, Build plate Adhesion is used, with which the object covers a larger area with the build (printing) plate and avoids the object from detaching.

Different options that help to improve both priming your extrusion and adhesion to the build plate.

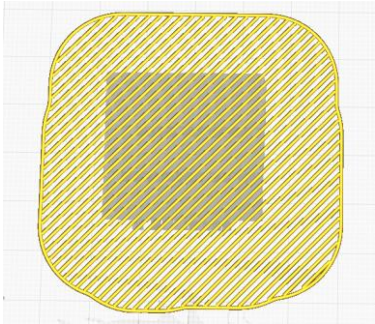
Brim adds a single layer flat area around the base of your model to prevent warping.

Raft adds a thick grid with a roof below the model.

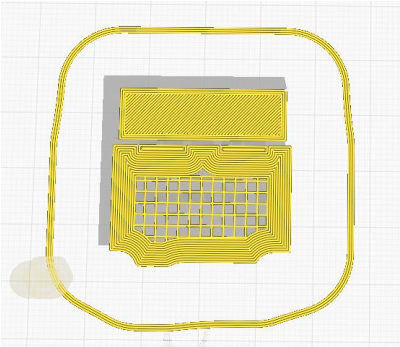
Skirt is line printed around the model, but not connected to the model.



Brim



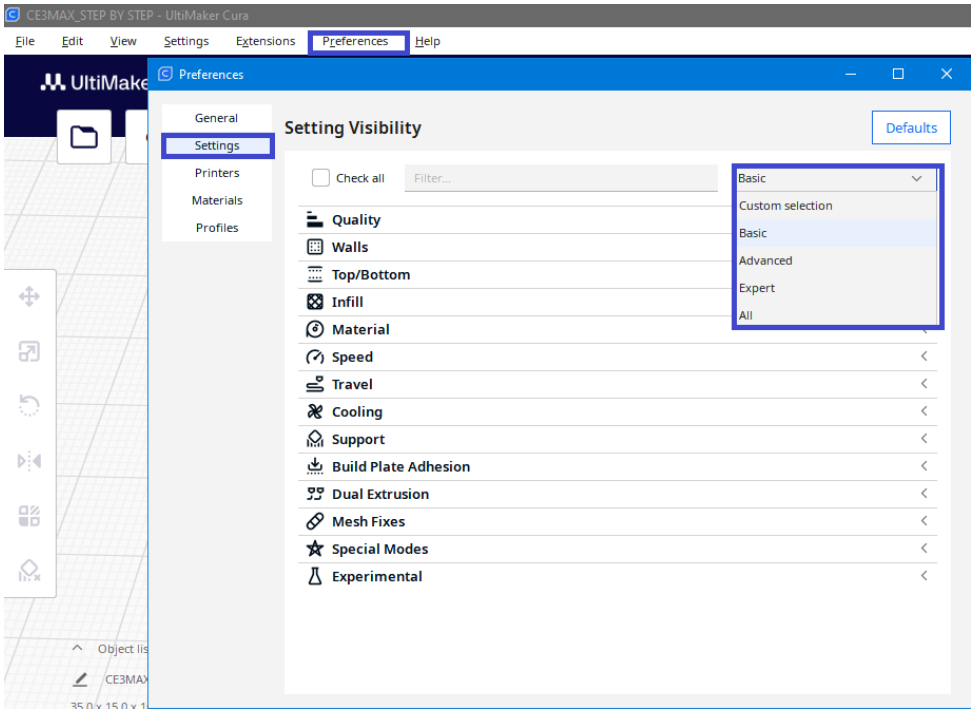
Raft



Skirt

5.8 Advanced settings

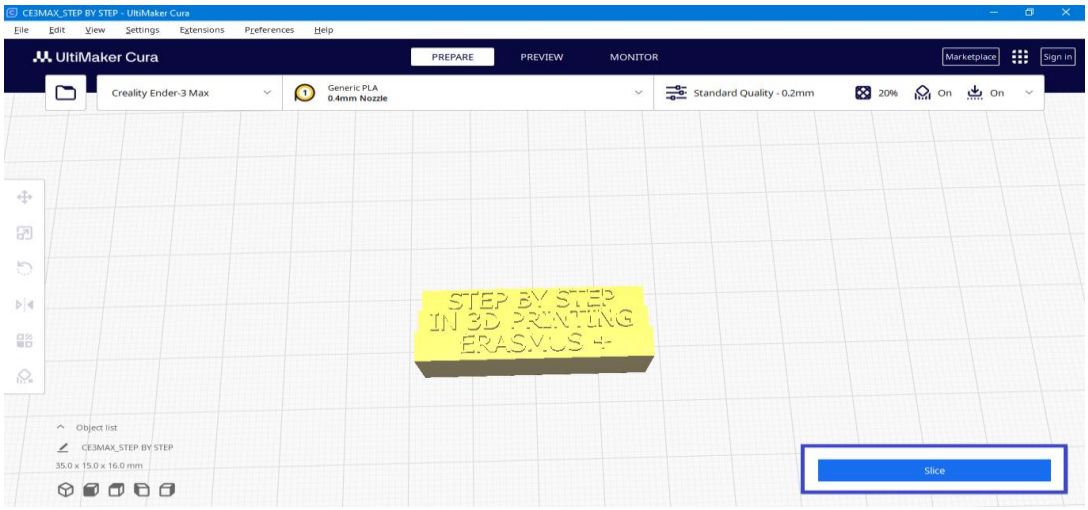
The previously mentioned settings are basic, if you need more settings you can always include additional options.



To turn on the additional options, click preferences, then select the Settings,and you will see all the settings available in Cura. You can choose from already existing profiles, or you can configure yourself with selection of the setting. After you select the settings they will appear in the print settings.

Slice

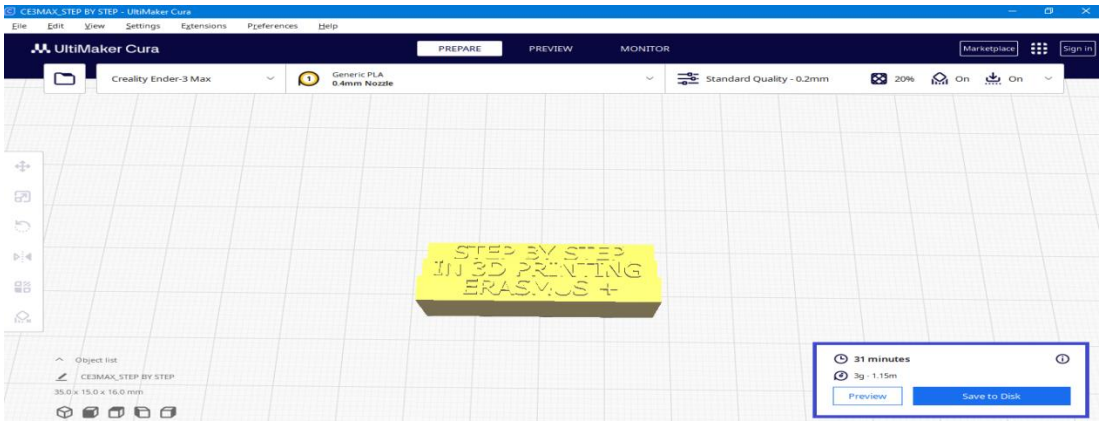
After you have made all the necessary settings for your model click **slice.**



By clicking on slice, the model is divided into layers and is ready for printing. You are shown the duration of printing and how much material will be consumed during printing. The model is converted to G-code and you can save the G-code to your computer or USB stick to transfer it to your 3D printer.

Note: You cannot open the G-code in Cura, so if you want to save the project with all changes, save it with the Save Project option located in the Top menu bar-File-Save project.

Before saving the G code from the model, it is recommended to review the print simulation to avoid errors that may occur during the setup.



Preview

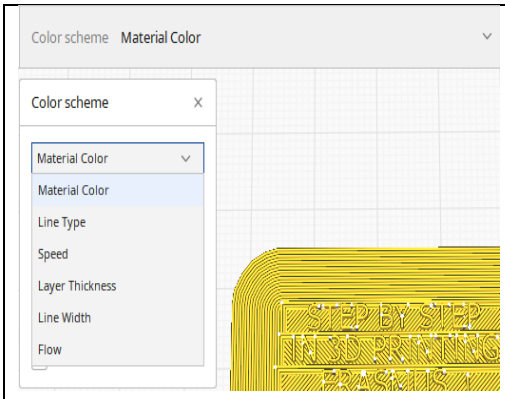
The preview option gives you the option to preview the printout. To be able to preview the printout you need to make a slice.

*On the right side (marked with red color in this manual) is a scale for each layer of the print, allowing you to always know which layer you are reviewing.

*On the bottom (marked with blue color in this manual) is the play button to turn on the preview (simulation)

You can always go back to print settings if you want to adjust some settings, but with each change you lose the ability to preview, which means you have to click slice again.

Preview colors

	In this field you can change the colors of the preview -such as choosing a support color, -choosing a color for exterior walls, -viewing the speed of different layers

If you are satisfied with the results, you can save the G code and upload it to the 3D printer. **Enjoy printing**

Examples

Example 1

Following the handbook, make the settings for the model " STAMP”:

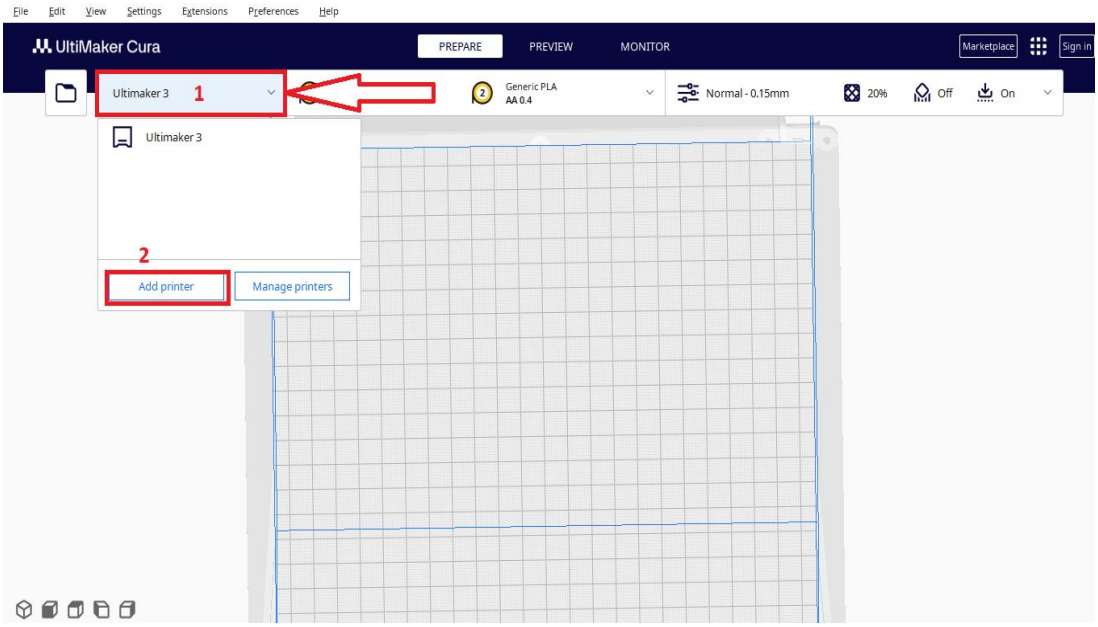
The 3D printer we print with is: Ender 3 Max
Material: PLA 1.75mm

1. Import the 3D model
2. Size of the model should be 60x40x5 mm.
3. The model does not need to be supported
4. Infill 20%
5. Make the model to be used as a stamp
6. Save the project

First we choose the printer with which we are going to print the model, in this case Creality Ender 3 Max

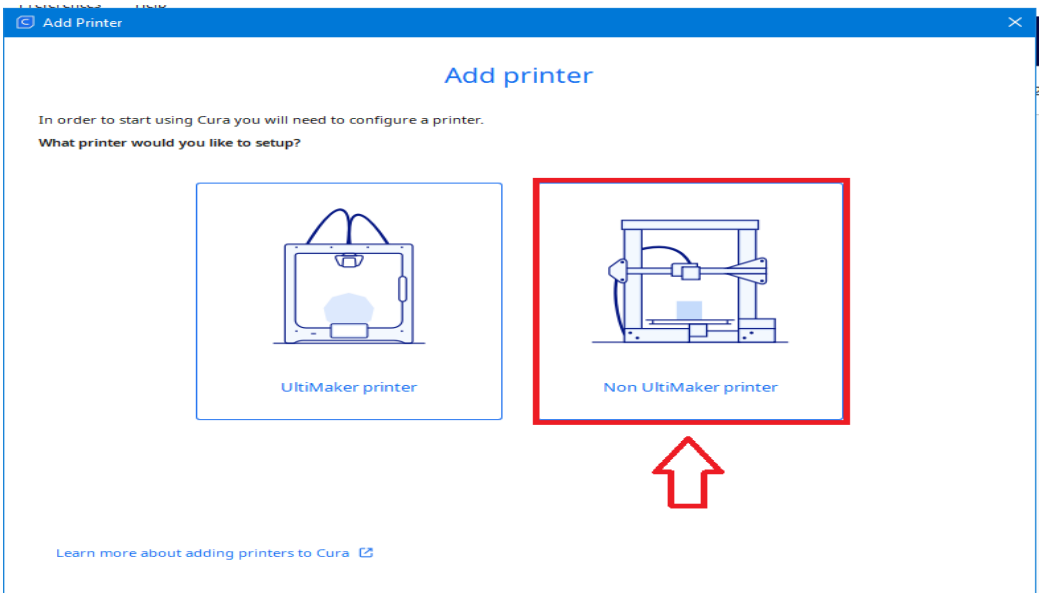
Our printer is not on the list, we need to add it with the Add printer command.

Step 1

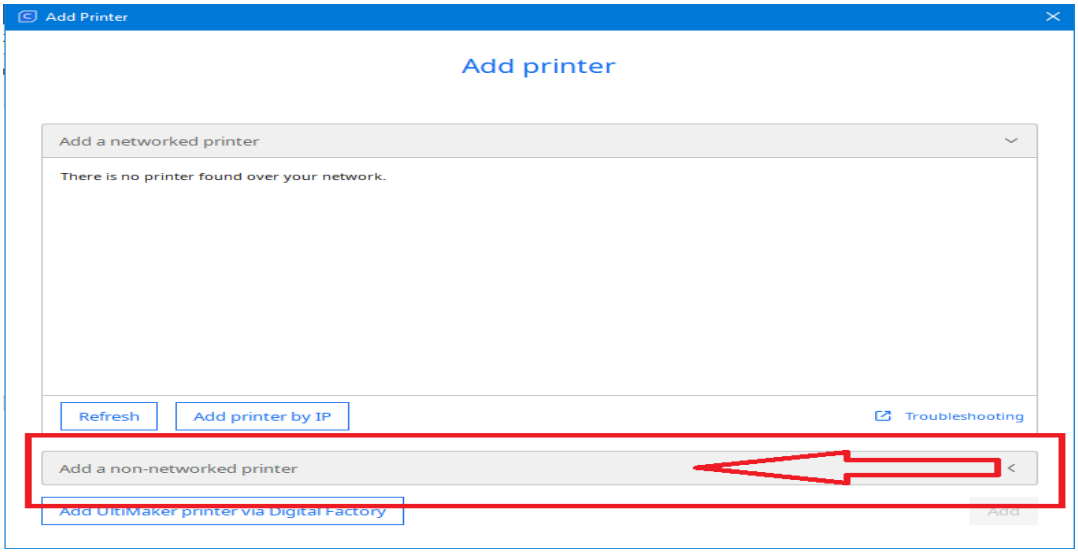


A window will open where we have to choose a printer that is not manufactured by Ultimaker

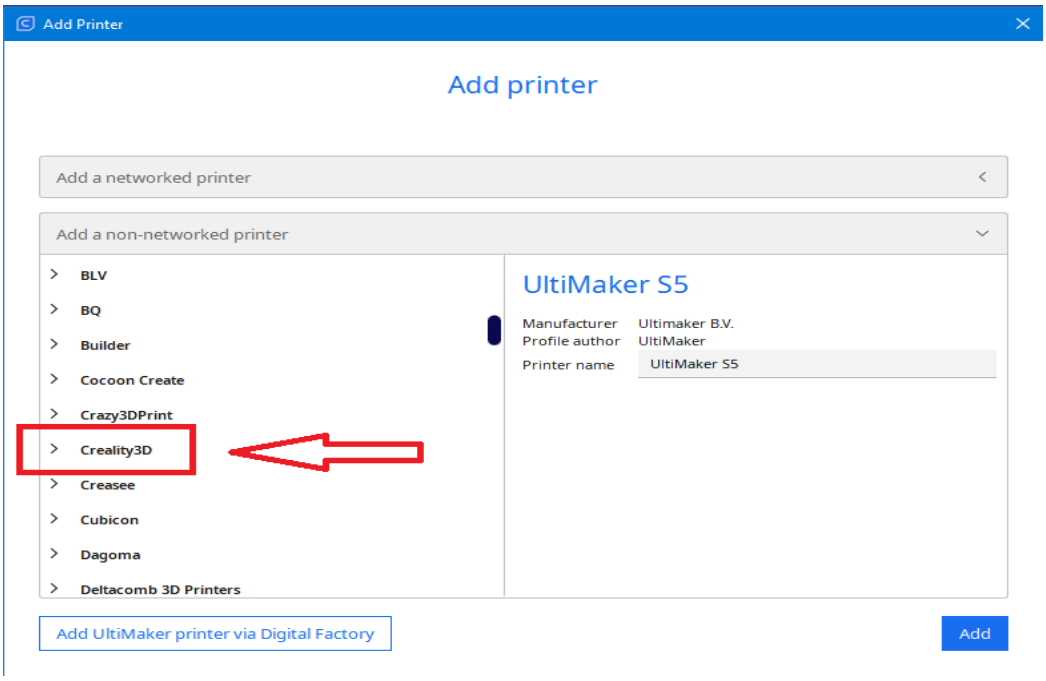
Step 2


Add Printer
Add printer
In order to start using Cura you will need to configure a printer.
What printer would you like to setup?
UltiMaker printer
Non UltiMaker printer
Learn more about adding printers to Cura

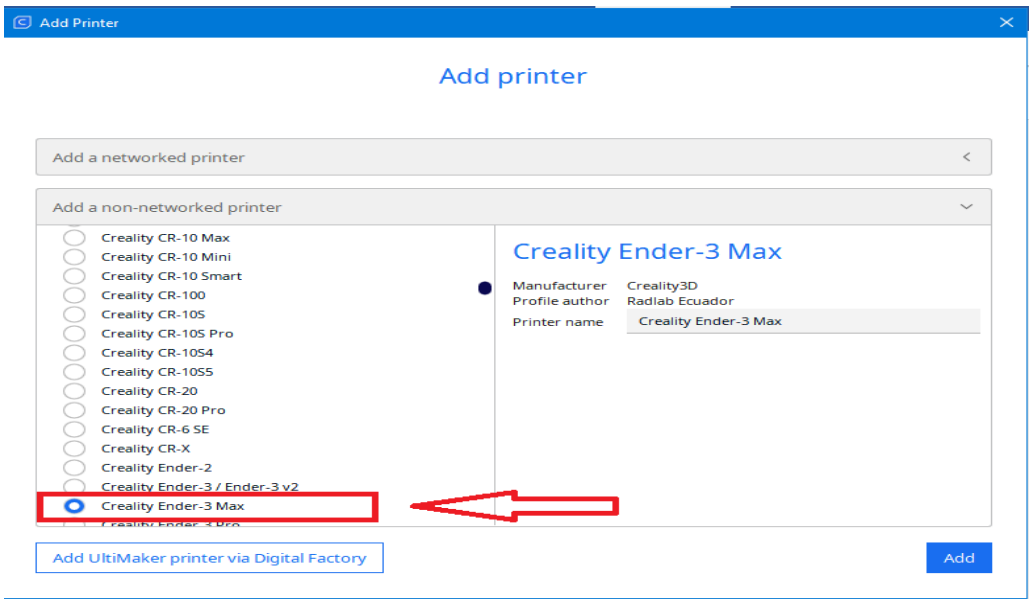
Step 3


Add Printer
Add printer
Add a networked printer
There is no printer found over your network.
Refresh
Add printer by IP
Troubleshooting
Add a non-networked printer
Add UltiMaker printer via Digital Factory
Add

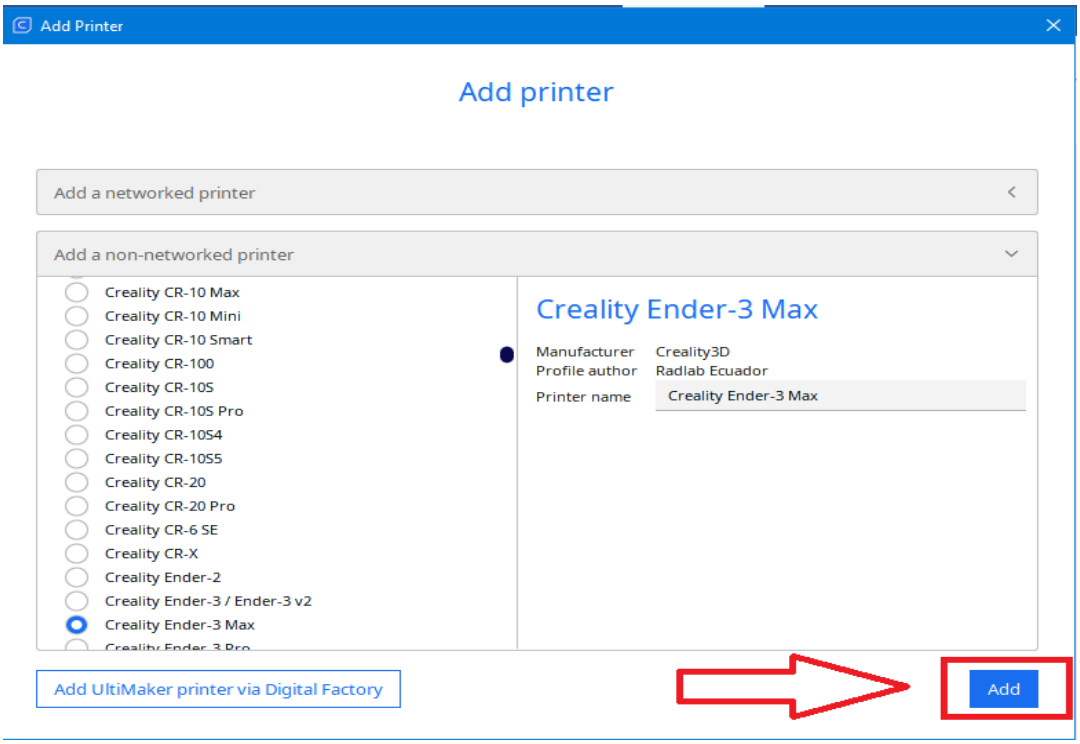
Step 4


Add Printer
Add printer
Add a networked printer
Add a non-networked printer
BLV
BQ
Builder
Cocoon Create
Crazy3DPrint
Creality3D
Creasee
Cubicon
Dagoma
Deltacomb 3D Printers
UltiMaker S5
Manufacturer Ultimaker B.V.
Profile author UltiMaker
Printer name UltiMaker S5
Add UltiMaker printer via Digital Factory
Add

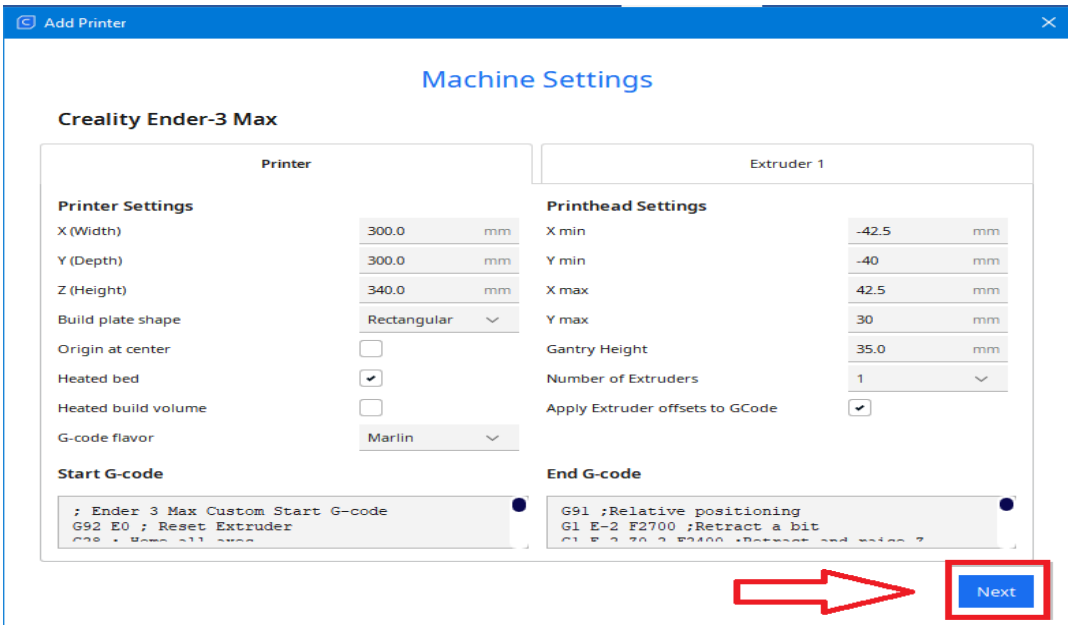
Step 5


Add Printer
Add printer
Add a networked printer
Add a non-networked printer
Creality CR-10 Max
Creality CR-10 Mini
Creality CR-10 Smart
Creality CR-100
Creality CR-10S
Creality CR-10S Pro
Creality CR-10S4
Creality CR-10S5
Creality CR-20
Creality CR-20 Pro
Creality CR-6 SE
Creality CR-X
Creality Ender-2
Creality Ender-3 / Ender-3 v2
Creality Ender-3 Max
Creality Ender-3 Max
Manufacturer Creality3D
Profile author Radlab Ecuador
Printer name Creality Ender-3 Max
Add UltiMaker printer via Digital Factory
Add

Step 6



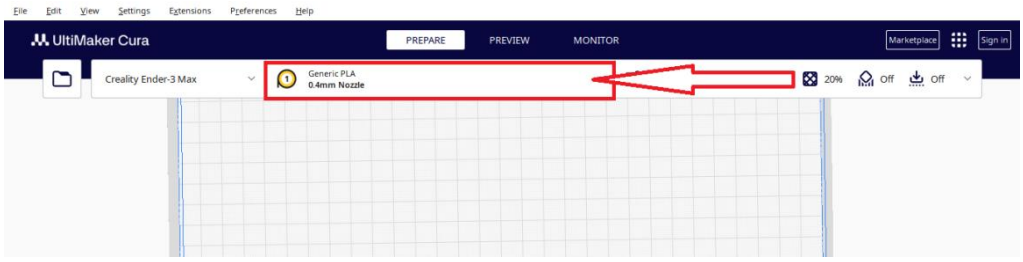
Step 7

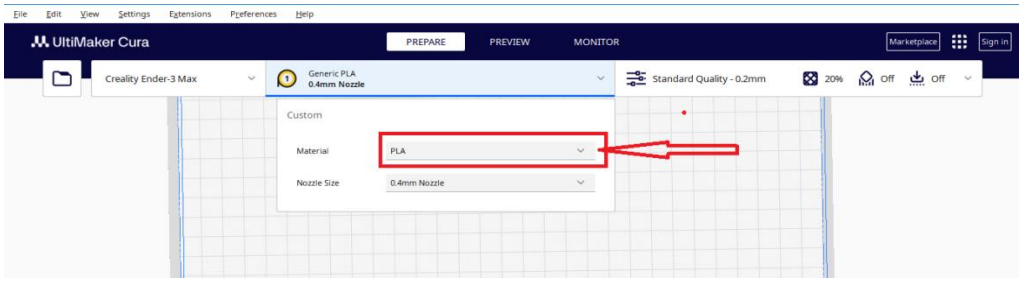


Step 7 completes the selection of a 3D printer

Next , we need to choose the material (PLA) that we are going to use for printing the object:

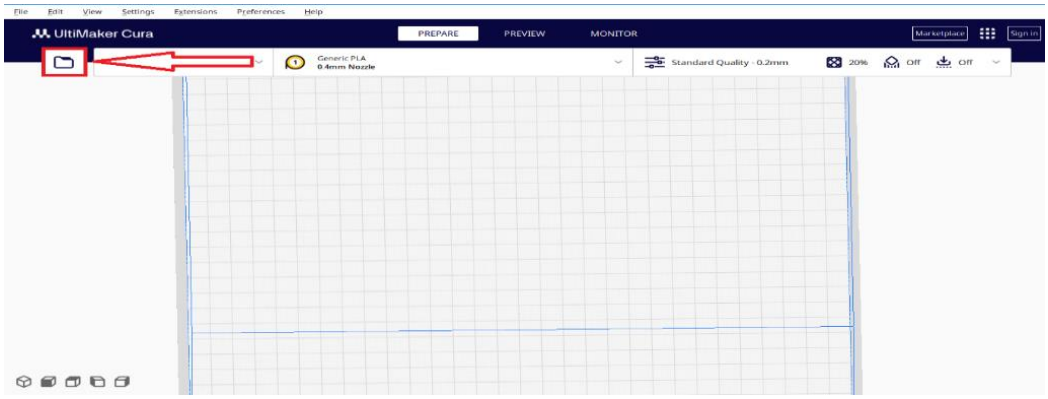
Step 8



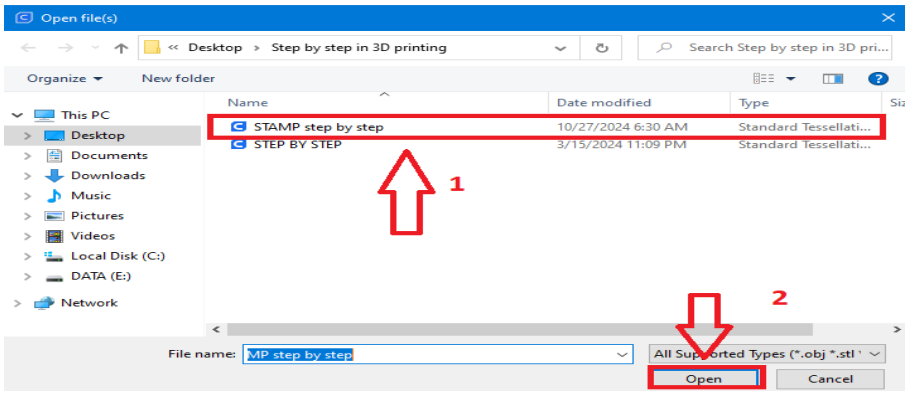


1. **Now we can import the model we want to adjust and print**

Step 9



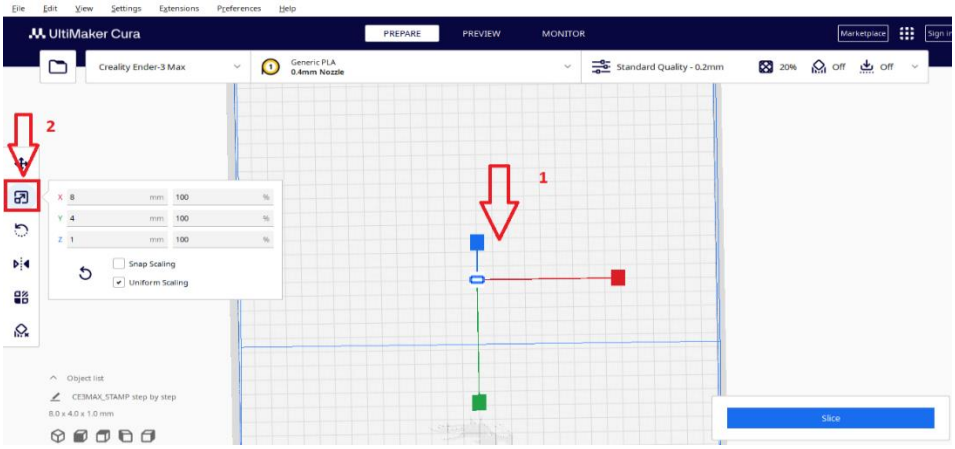
Step 10



2. **Setting the dimensions of the object 60x40x5mm**

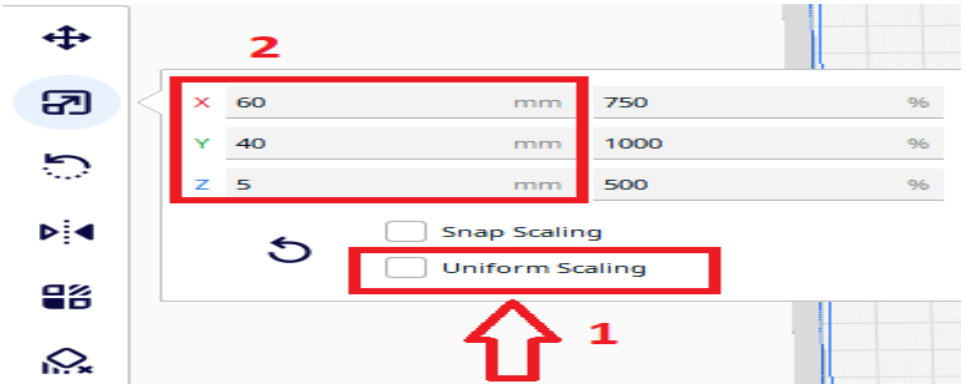
Step 11

Select the model and choose the SCALE command



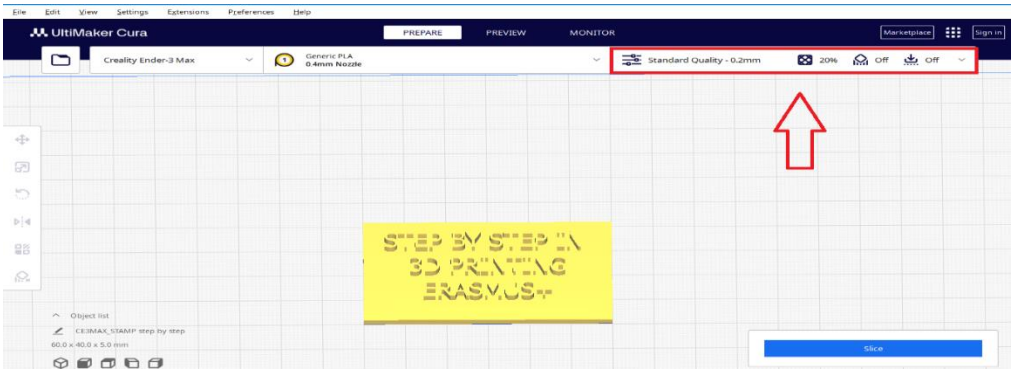
Step 12

Unselect **uniform scaling** and enter the desired dimensions for x, y and z

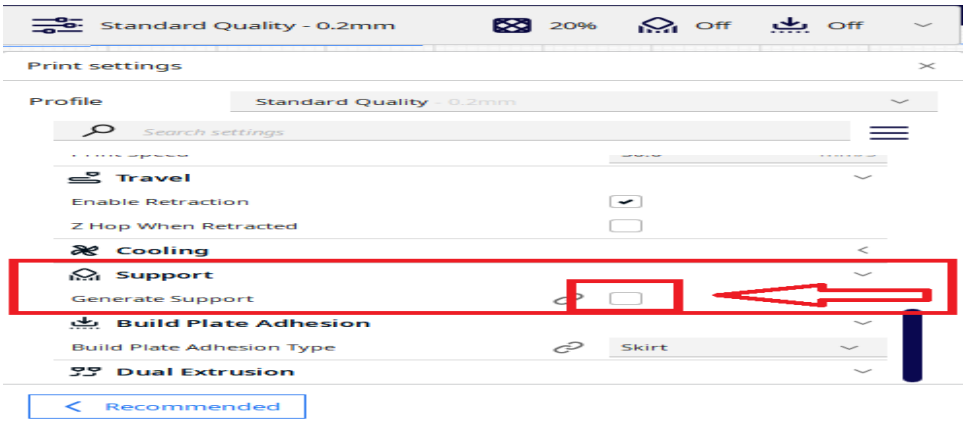


3. **Turn off the support option**

Step 13

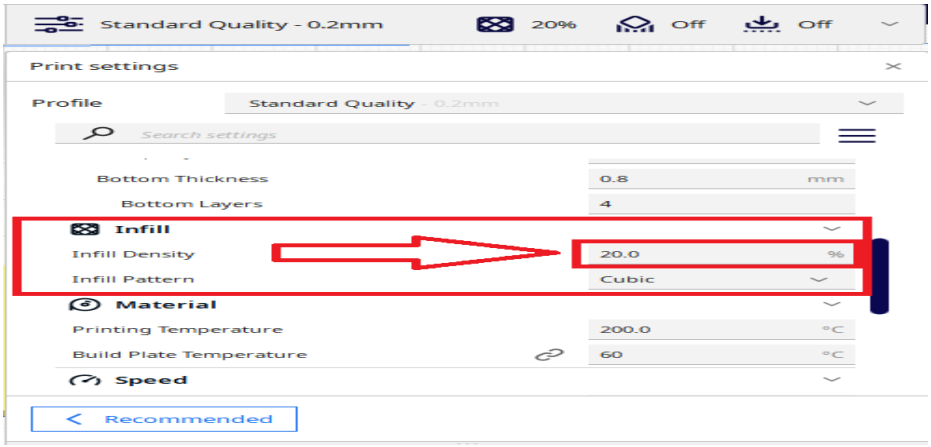


Step 14



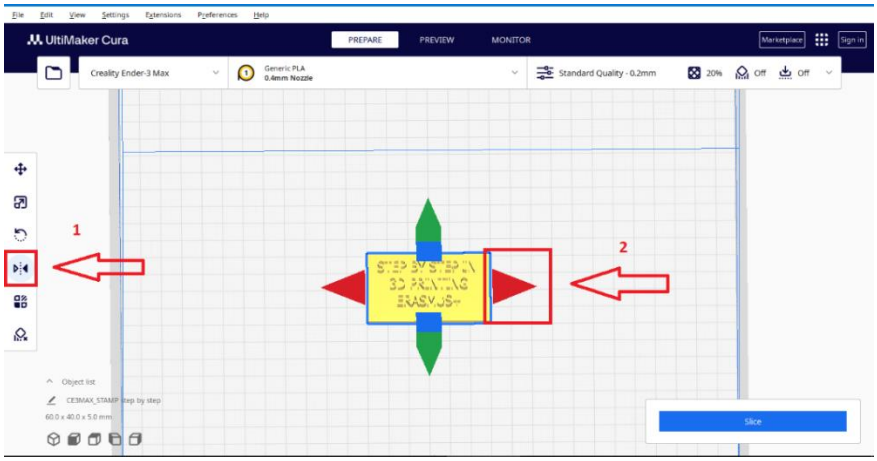
4. **Model infill 20%**

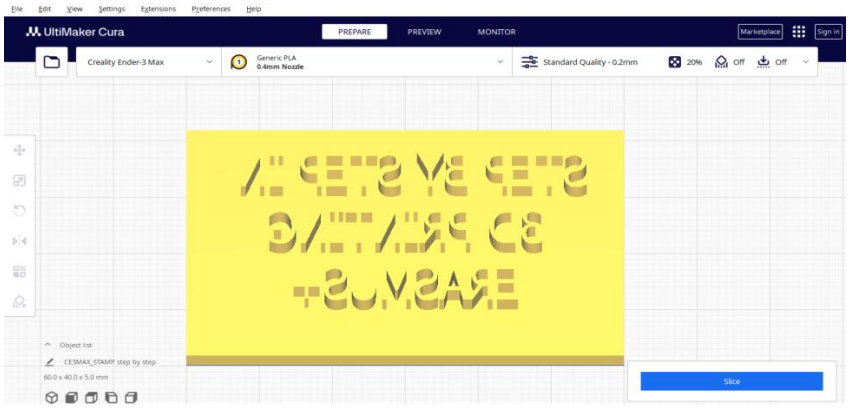
Step 15



5. **Making the model suitable for use as a stamp.**

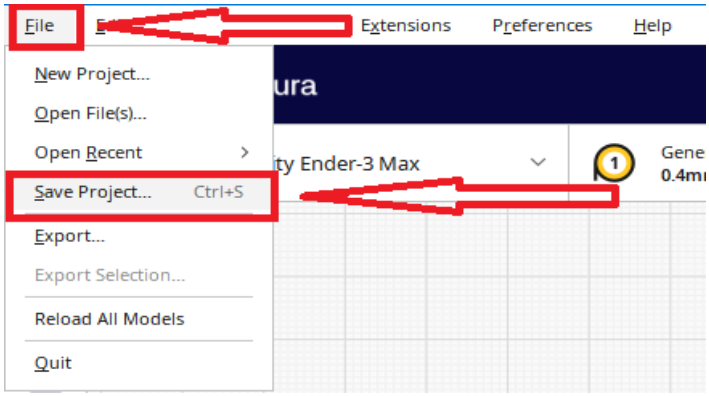
Step 16





6. **Saving the project**

Step 18


File
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Preferences
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New Project...
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Quit
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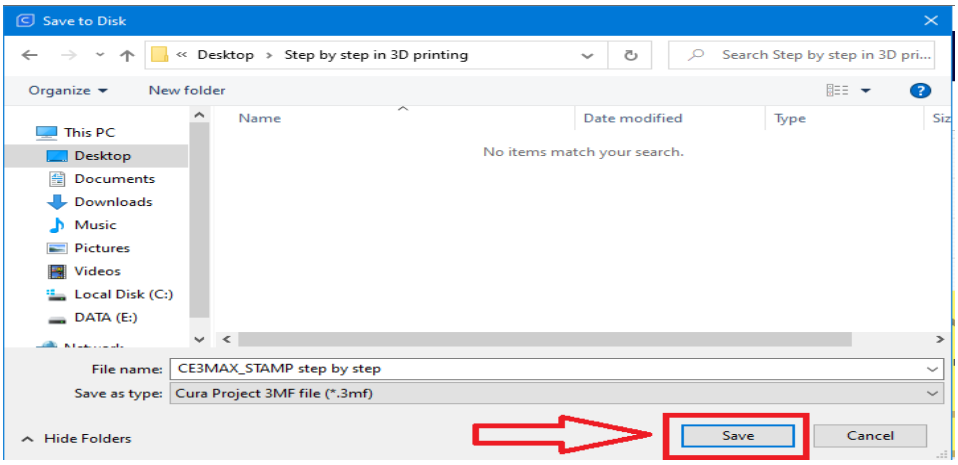
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Desktop
Documents
Downloads
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Pictures
Videos
Local Disk (C:)
DATA (E:)
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Type
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File name: CE3MAX_STAMP step by step
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Hide Folders
Save
Cancel

Example 2

Following the handbook, make the settings for the model "Figure 1":

The 3D printer used is: Ender 3 Max

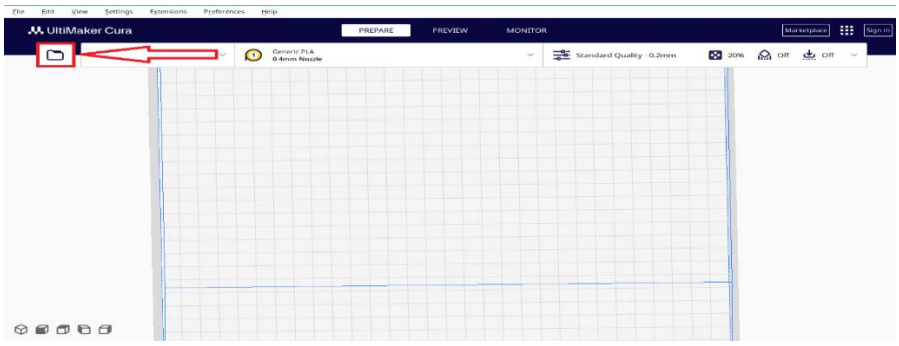
Material: PLA 1.75mm

1. Import the 3D model
2. Size of the 1 figure should be 10mm wide and 20mm high.
3. Make 4 figures that will be arranged on a grid.
4. Move the figures to the lower left corner of the platform.
5. Make the printing parameters in conditions where there is movement of people near the printer
6. Generate G code

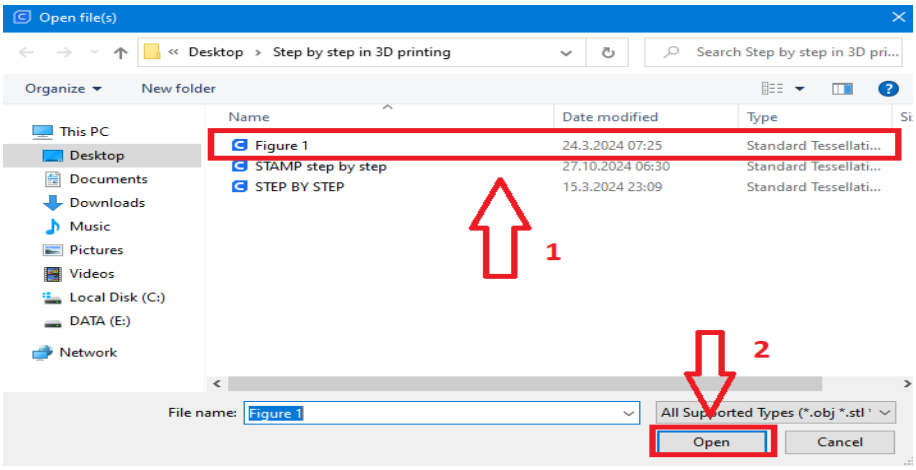
Since we have selected the same printer and material in the previous task, we can move on to the parameters of the model.

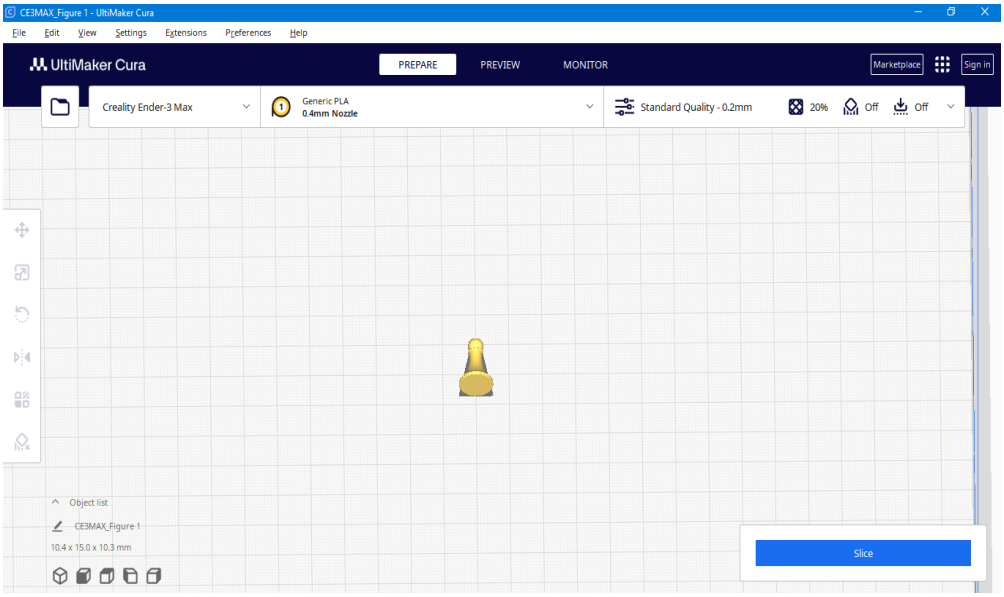
1. **Import the 3D model**

Step 1



Step 2

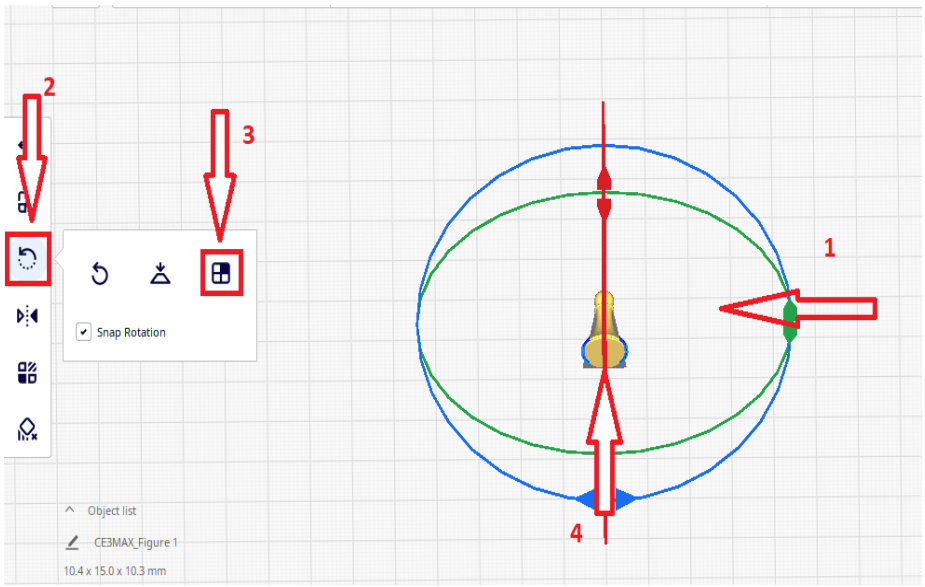




We have imported the model but we see that the model is lying down, we need to straighten it

Select the model and click on the **Rotate command** – **select face to align to the build plate,** than select the bottom of the model.

Step 3

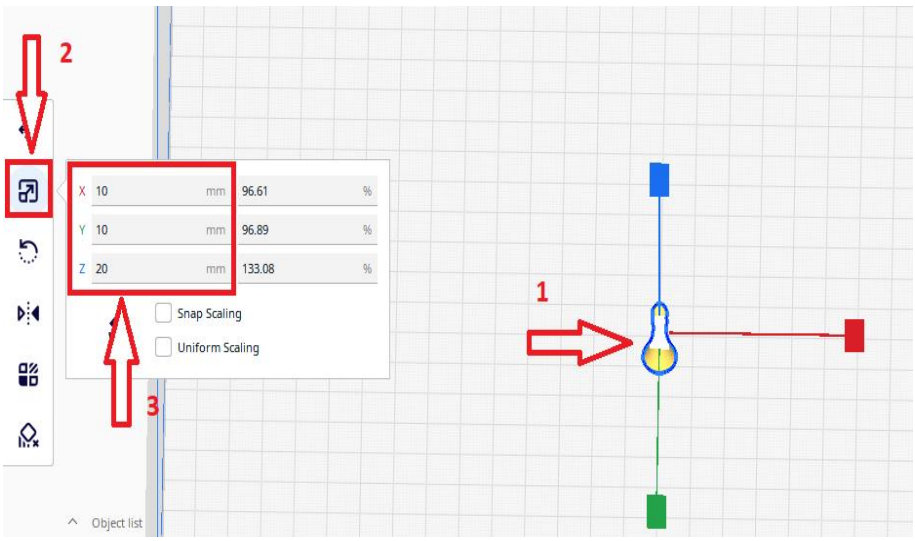


Now we can move on to the next step.

2. **The size of the 1 figure should be 10mm wide and 20mm high.**

Step 4

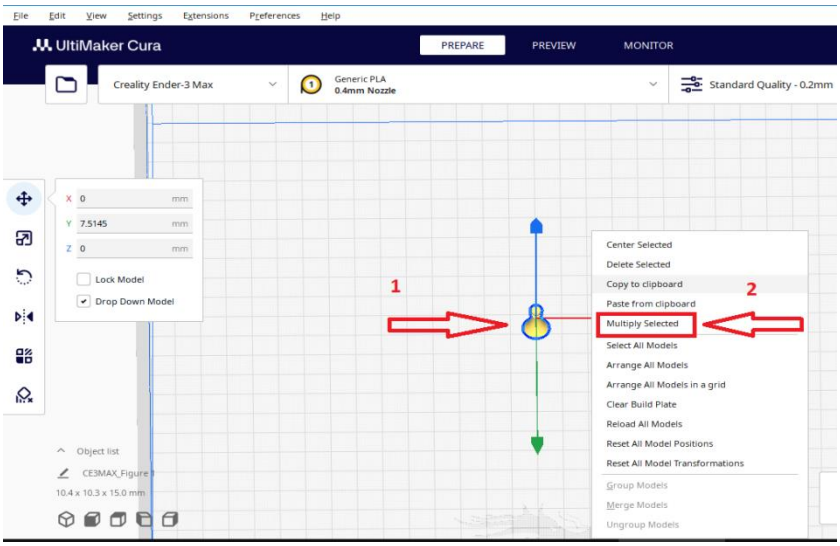
Select the model, click the Scale command and change the **X,Y and Z** values



3. **Make 4 figures that will be arranged on a grid.**

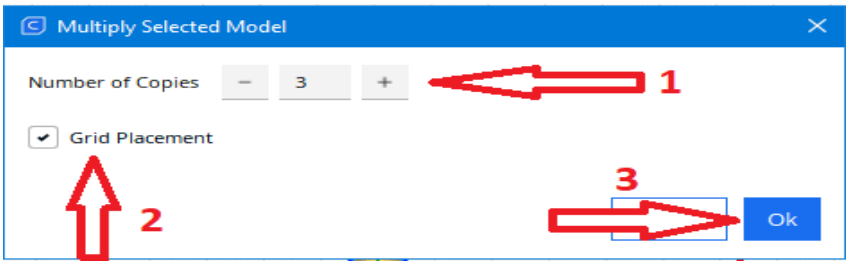
Step 5

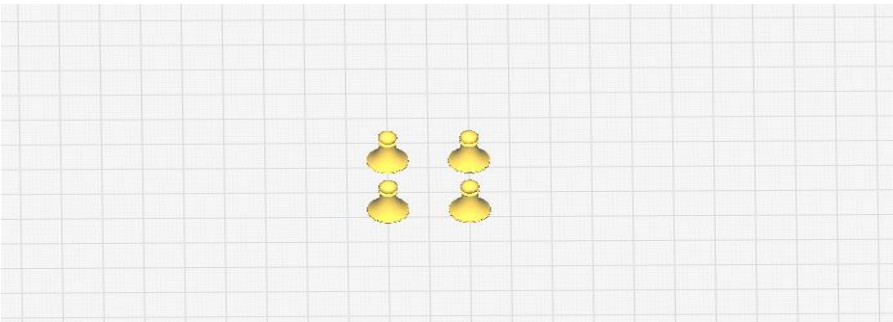
Right-click on the model and choose the **multiply selected** command



Step 6

Select the **number of copies** (in our case 3), select the field **grid placement** and press **OK**

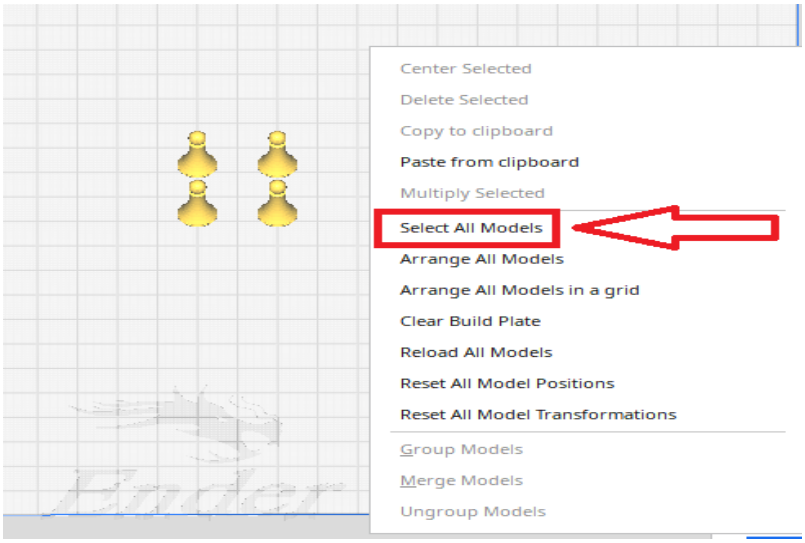




4. **Move the figures to the lower left corner of the platform.**

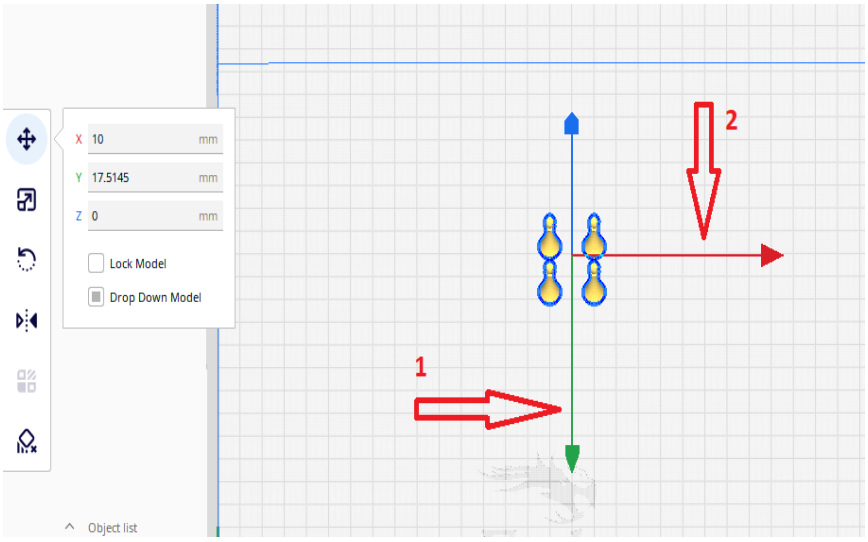
Step 7

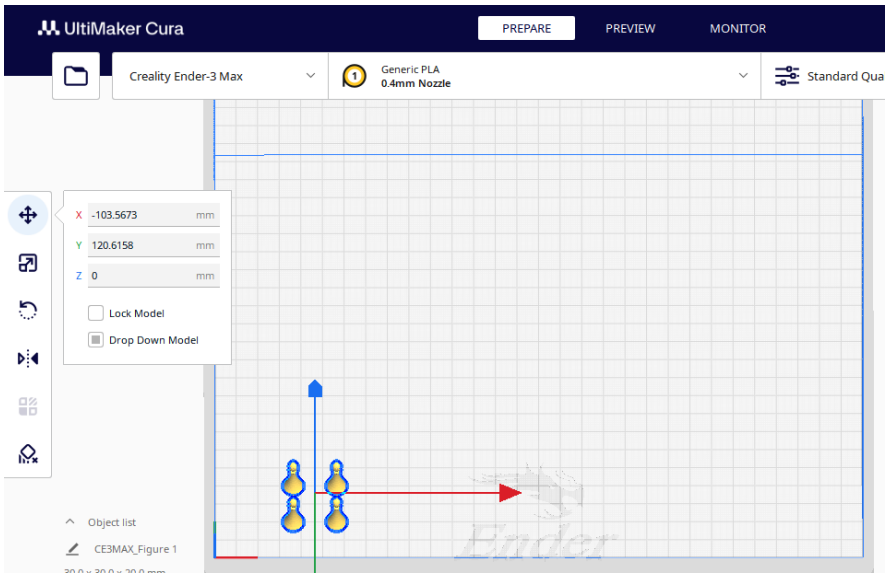
Right-click anywhere on the field and click **select all models**



Step 8

First click on the green arrow and **drag down** to move the models down, then on the red arrow and **drag to the left**, in order to move the models to the left.





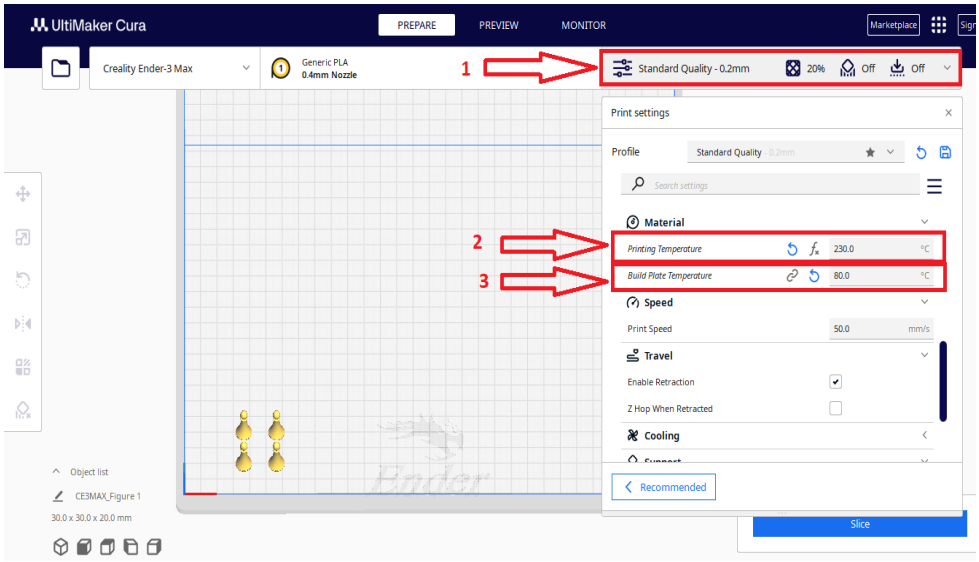
5. **Make the printing parameters in conditions where there is movement of people near the printer**

   Because when we print, a larger number of people will pass by the printer, so they will create a larger air flow, that can detach the object from the printing platform. To

avoid detachment we need to **raise the printing temperature** and the **Build Plate temperature** as well as turn on the **build plate adhesion**.

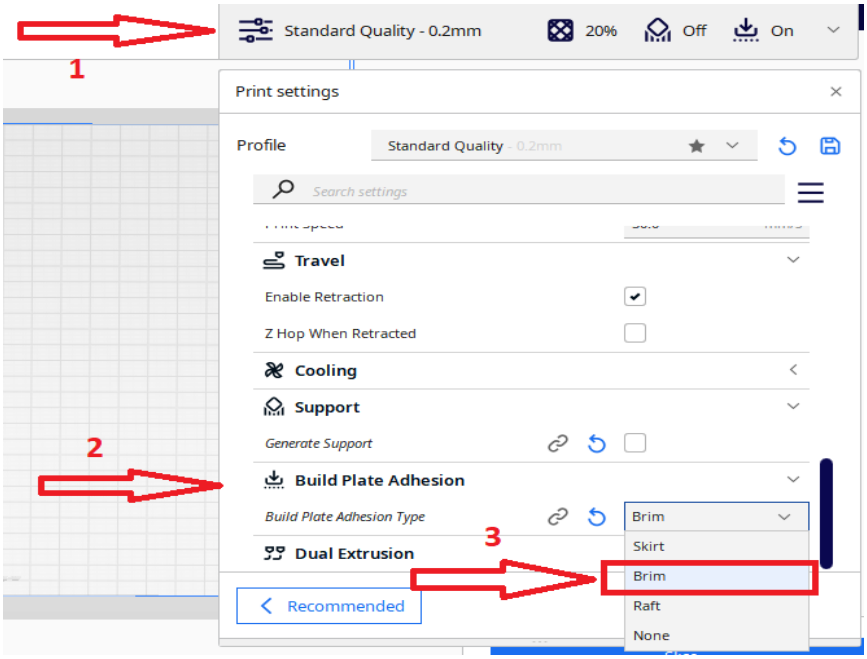
Step 9

Printing temperature: 220°C Build Plate Temperature: 80°C



Step 10

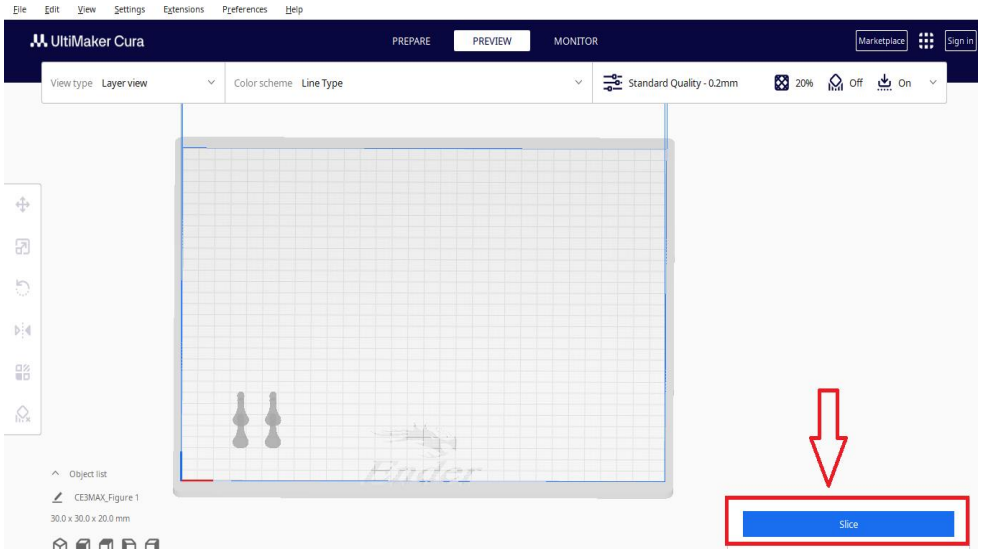
Select the **Brim** option in the **Build Plate Adhesion** section



6. Generate G code

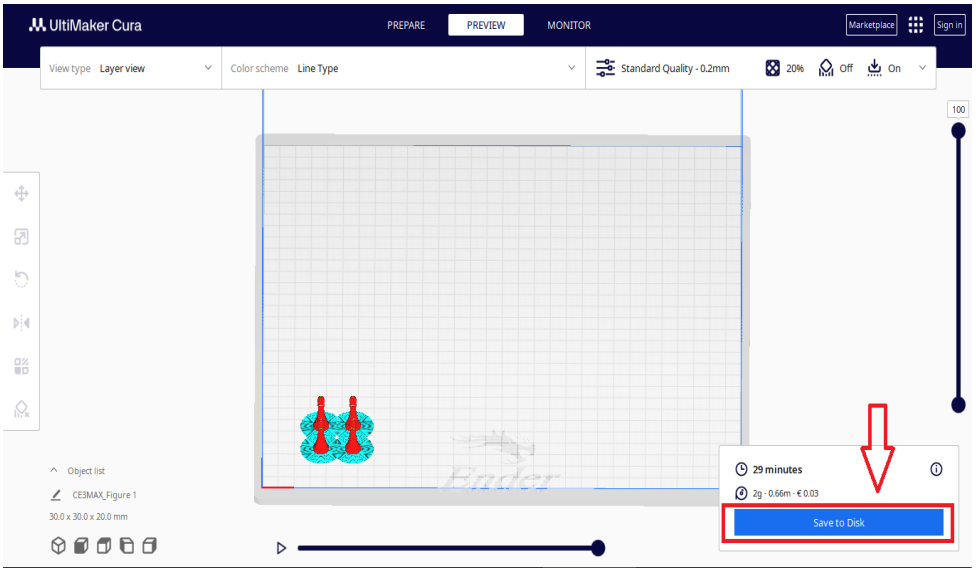
After making all the settings, click on **Slice** to generate G-code

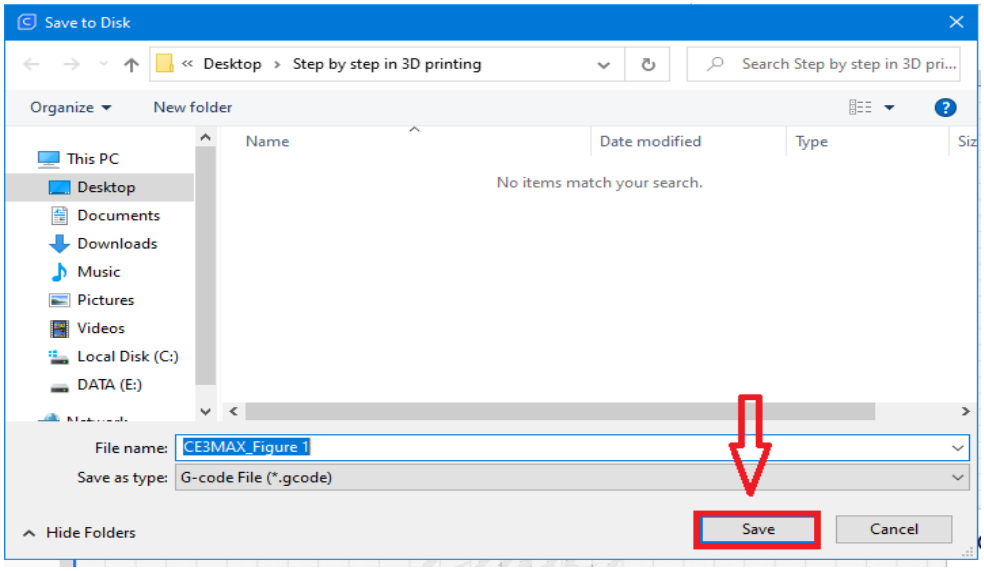
Step 11



Step 12

Click **save to Disk** and save the G-Code under a name of your choice





Now you can enter the G-code into the printer and start printing.

Conclusion

3D Printing in Industry has proven its ability to revolutionize and foster innovation, impacting a wide range of sectors. The capability to create specialized items with the desired precision, even with complex geometries that are impossible to produce using traditional methods, enhances productivity and reduces errors. This, in turn, boosts flexibility and speed in production processes, enabling faster development of new products and technologies, while also contributing to sustainability by minimizing waste and optimizing the use of raw materials.

Although this technology offers numerous advantages, it is not without challenges. One of the major obstacles is the need for specialized training and the adaptation of workers to new production methods. The automation and use of 3D printers raise concerns about job losses, as certain processes that once required manual labor are now replaced by machines. Despite these concerns, the advantageous possibilities offered by 3D printing make this technology a cornerstone for the industry of the future.

Overall, 3D printing can bring about a true transformation in manufacturing and creation sectors, improving resource management and increasing efficiency. At the same time, it presents new opportunities to enhance the quality of life, whether through personalized products or by offering more affordable and sustainable solutions. With the right strategy and adaptation to the challenges that may arise, 3D printing can play a central role in building a more advanced and greener future for industries.

Sources

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