# Green STEAM Incubator

# Module on 3D Modelling: 20 hours lessons
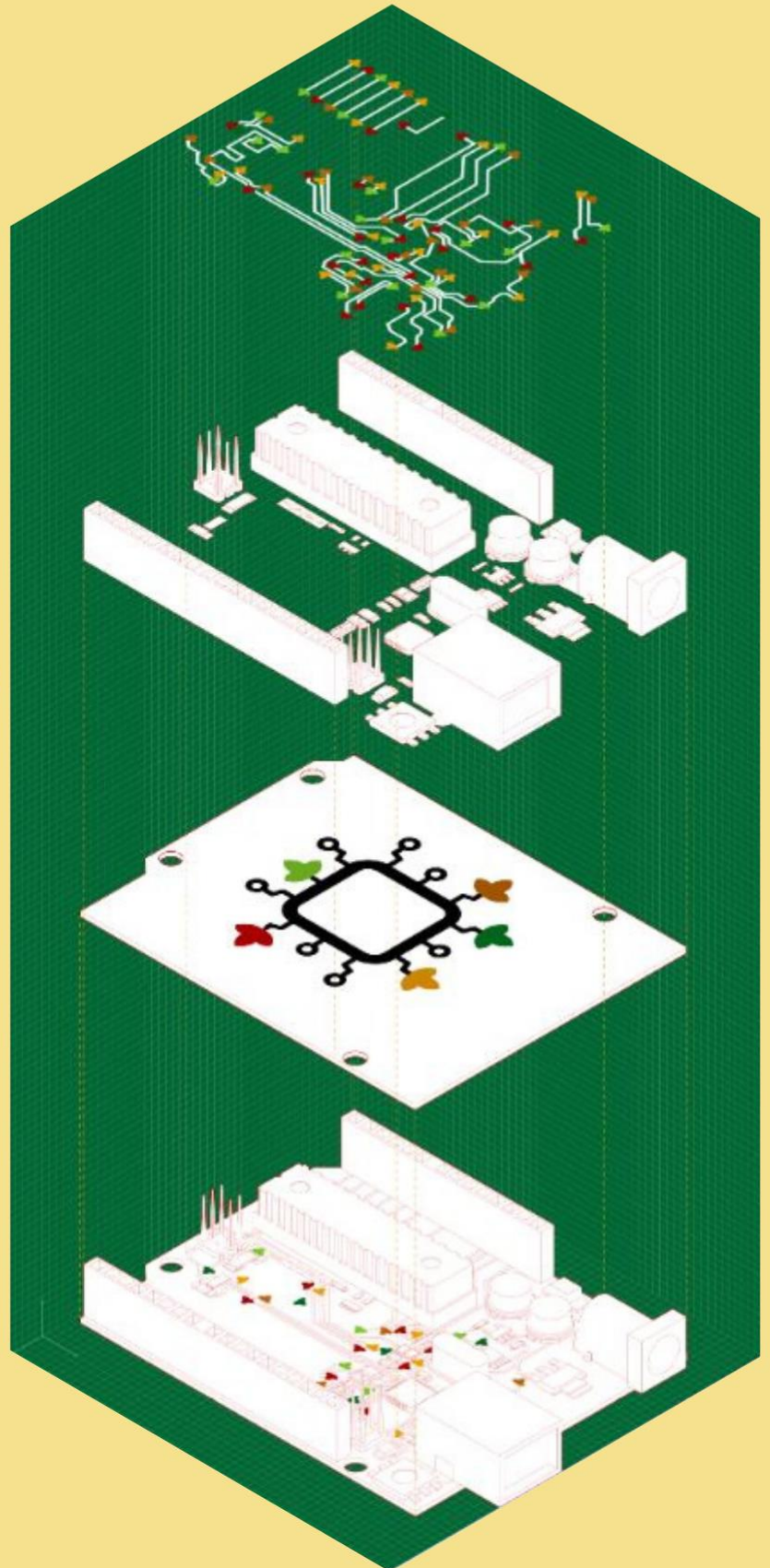
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# INTRODUCTION

This module was written within the scope of Intellectual Output 4 of the Green STEAM Incubator project, and it contains chapters regarding 3D modeling. The material was created in order to provide participants with STEAM-oriented knowledge, capacities, and skills.

Every consortium partner worked on the different chapters that make up this module, from the research phase to the writing one. The objective was to devise learning material that focuses on 3D modeling and the various possibilities that come with it.

The module has two main chapters, and in each one, there is a subchapter that contains themes that serve as a lesson, and in total, there are 20 hours of lessons formulated in a logical order.

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# LESSON - INTRODUCTION TO DESIGN AND 3D PRINTING, AND INITIAL CONCEPTS

- **Study section:** 3D Modelling

- **Lesson duration:** 1:00h

- **Educational objectives:**

    o Understand what design is and its history

    o Understanding the emergence of 3D printing

- **Learning outcomes and acquired competencies:**

    o Gain basic knowledge about design and 3D printing.

- **Main Keyword(s):** technical drawing, design, CAD

- **Required material and resources:** none

## Several definitions of DESIGN

- Discipline aimed at **harmonizing** the human environment, from the design of everyday objects to town planning. (Definition from Larousse)

- **Industrial aesthetics** applied to the search for new forms adapted to their **function**.

- Cambridge Dictionary:

    - a drawing or set of drawings showing how a building or product is to be made and how it will work and look.

    - the art of making plans or drawings for something:

    - the way in which something is planned and made:

> **Brief definition of 3D Printing**
>
> the process of printing a solid object from a digital model by printing many separate layers of the object:
>
> 3D printing is changing the way we produce objects, from tools to toys, and even body parts.
>
> Definition from Cambridge dictionary

To understand design and 3D printing, the facilitator should start by introducing historical concepts such as industrial design, standardized, and automated manufacturing processes.

## History of design

The history of design as we understand it today is very much linked to the period of the Industrial Revolution: 1760 - 1840.

Thanks to the steam engine and technical progress, countries became industrialized and modernized their manufacturing processes, developing standardized methods at a larger scale.

Production moved from a craft mode, tailor-made by artists and craftsmen, to mechanized, automated production, and all objects and production processes were reviewed in order to be optimized and standardized.

One famous example is Paxton's Crystal Palace, which was developed in record time (8 months) for the 1851 London World's Fair.

*Figure 1: The Crystal Palace at Sydenham Hill, London. It was destroyed in 1936.*
*BBC Hulton Picture Library*

Beyond the development of construction (see the New York skyscrapers) and railway networks, it is also the production processes of everyday objects that are designed differently:

For example, the bistro chair was developed by Michaël Thonet in 1859 and sold 50 million copies from 1859 to 1930.



*Figure 2: Chair Thonet no 14, 1859.*

In the years that followed and up to the present day, design and manufacturing processes have never ceased to be rethought and reinvented to respond to different and sometimes incompatible logics: comfort, aesthetics, simplicity, artistic, economic...

Generally speaking, the arrival of the design and industrial revolution has opened a debate between the supporters of technology, industry, and those who advocate the beauty of the unique and original object.

## Initial concepts

- **Design and CAD**

The creation and design of plans to develop objects and the way they are made have always existed. However, from the moment that the descriptive geometry of the 16th and 17th centuries was developed, we speak of design. The Italian word Disegno stands for drawing a project, and it carries a more complex meaning in art, involving both the ability to make the drawing and the intellectual capacity to invent the design.

In the 50s, technical drawing methods improved with the introduction of computerized drawing machines and real-time computing, which allowed for even more automation of technical design.

From the 1950s onwards, Patrick Hanratty and Ivan Sutherland made a major contribution to developing what is now called CAD or Computer-Aided Design.

In 1957, P.Hanratty developed the first numerical control programming language, and I.Sutherland designed the first computer-aided design program; it is the graphic interface and 3D modeling that we know today.

The development and improvement of CAD systems have, in a sense, enabled the development of 3D printing.

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# Development of 3D Printing

3D printing has gone through 3 major phases:

- its creation (1981-1999)

- its development (1999-2010)

- its widespread use (2010-nowadays)

- **Beginnings of 3D printing (1981 – 1999)**

The introduction of the first Personal Computer by IBM in 1981 paved the way for the widespread use of Computer-Aided Design.

Then in the 1980s, there were multiple projects and research topics that focused on 3D printing, originally called Stereolithography (SLA), in 1986.



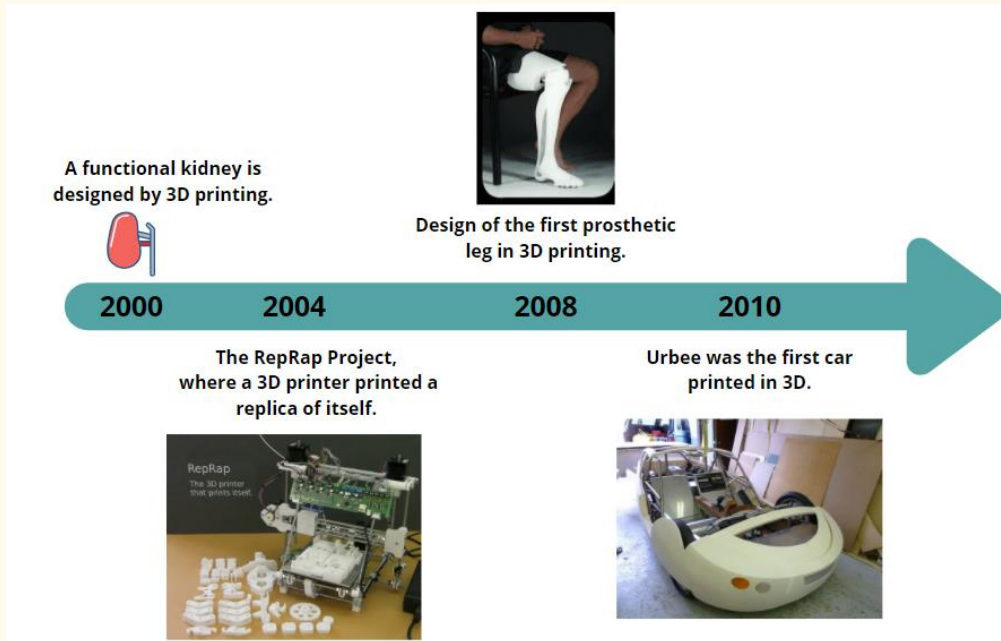*Figure 3: The first 3D printer ever created was made in 1983 by Chuck Hull.*

In less than 10 years, three different methods were patented, marking the birth of 3D printing.

The 1990s saw the development of the first industrial prototyping system and the production of applications for 3D printing. Medical research is also looking at 3D printing for medical applications (1999: Artificial organ design).

- **Improvement of 3D Printing (1999 – 2010)**

Since the 2000s, 3D printing has continued to develop in many sectors of activity and has greatly increased in terms of visibility, and accessibility and has become widely available.

Here are a few examples:



A functional kidney is designed by 3D printing.

Design of the first prosthetic leg in 3D printing.

2000    2004    2008    2010

The RepRap Project, where a 3D printer printed a replica of itself.

Urbee was the first car printed in 3D.

Towards the end of the 2000s (in 2006), 3D printing has been gaining more and more enthusiasm in the industrial sector with new processes, materials, and many new opportunities.

At this time, the 3D printing market opened up to the general public as it became more accessible, more affordable, and more documented.

- **2011 to nowadays**

3D Printing technology continues to develop, and more and more companies understand the benefits that additive manufacturing can offer them. Companies consider the low-cost prototyping advantages that 3D printing allows and have fully integrated it into their iterations, innovations, and production processes.

3D printing has also become accessible and affordable with home printers and many open-source programs for the general public.

Today it is possible to print with many materials: metals, glass, paper, concrete, and wood, among others, and there is a lot of available open-source documentation.

The various fields of application are extremely varied: medicine, industry, retail, construction, musical instruments, jewelry, household articles, clothing accessories, vehicles, food, parts of the human body... at present, there seems to be no limit.

See a couple of examples below:



*Figure 4: Europe's first 3D-printed two-story house in Belgium, alongside the BOD2 printer that created it.*
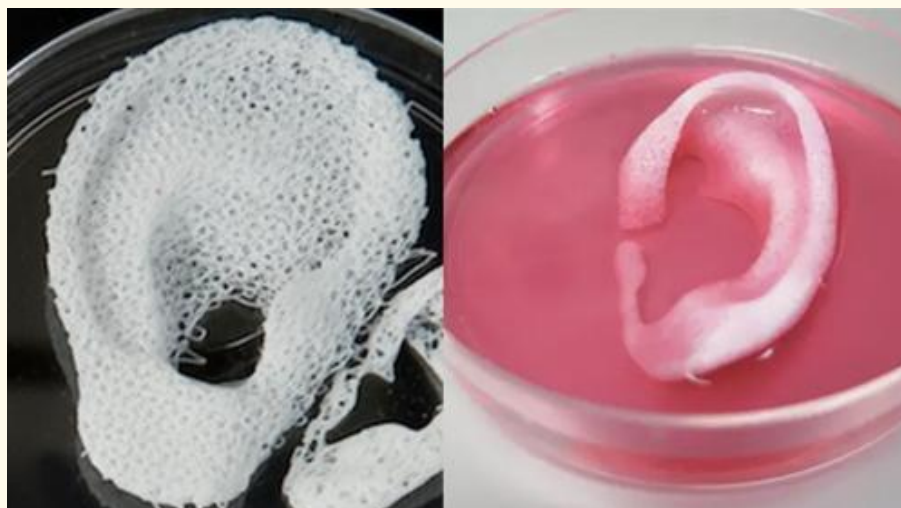


*Figure 5: Regenerative medicine researchers at the North Carolina hospital have announced that they have printed ear, bone and muscle structures and successfully implanted them into animals.*

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*Figure 6: tibia prosthesis developed in 3D printing*



*Figure 7: Re-Spire: a printable and laser cuttable Mask Spacer*

And many more examples.

Here, the facilitator can encourage students to talk about 3D printing projects they know or have heard about to widen the scope of applications

## To go further:

This video presents the 10 dates that have changed 3D printing:

## https://youtu.be/HIztrNM_ejc

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- **Bibliographic (references):**

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https://www.sculpteo.com/fr/centre-apprentissage/les-bases-impression-3d/histoire-impression-3d/#:~:text=The%20SLA%201-,Les%20ann%C3%A9es%2090%20%3A%20%C3%89mergence%20des%20premiers%20fabricants%20d'imprimantes%203D,et%20des%20outils%20de%20CAO&text=En%201992%2C%20le%20brevet%20du,%C3%A0%20usage%20professionnel%20et%20individuel

https://www.journaldunet.com/solutions/cloud-computing/1150875-la-cao-une-histoire-ancienne/

Figures:

Figure 1 : https://www.britannica.com/topic/Crystal-Palace-building-London
Figure 2 : https://fr.wikipedia.org/wiki/Chaise_n%C2%B0_14
Figure 3 : https://3dinsider.com/3d-printing-history/#:~:text=The%20first%203D%20printer%20ever,public%20in%20a%20big%20way.
Figure 4 : https://www.cnet.com/news/europes-largest-3d-printer-just-made-its-first-two-story-house/
Figure 5 : https://3dprint.com/119885/wake-forest-3d-printed-tissue/
Figure 6 : http://www.ufunk.net/en/tech/exo-prosthetic-leg/
Figure 7 : https://www.thingiverse.com/thing:4616510

**LESSON – INTRODUCTION TO TECHNICAL DRAWING AND SYMBOLS USED**

- **Study section:** 3D Printing

- **Lesson duration:** 2:00h

- **Educational objectives:**

  o Understand the basics of visualization and drawing;

  o Get acquainted with the symbols used for technical drawing;

- **Learning outcomes and acquired competencies:**

  o Identify what a technical drawing and its purpose is

  o Recognize symbols and understand how to use them

- **Main Keyword(s):** technical drawing, visualization, CAD, symbols.

- **Required material and resources:** none

> **Brief definitions of TECHNICAL DRAWING**
>
> Technical drawing, drafting or drawing, is the act and discipline of **composing drawings** that **visually communicate** how something **functions** or is **constructed**.
>
> Definition from Wikipedia

To understand technical drawings and their symbols, the facilitator should explain the use and purpose of technical drawings and then show the different symbols used to make technical drawings easy to read and understand.

## Introduction to technical drawing:

- **What is it?**

The technical drawing is an essential and codified element to ensure that the plans and drawings developed are understood and communicated without error in the world of industry and engineering.

Indeed, how to render on paper the reality of an object. Let's take a pencil as an example.

Depending on how it will be drawn and represented, it can be complicated to understand that we are dealing with the same pencil. It is always a matter of PERSPECTIVE.
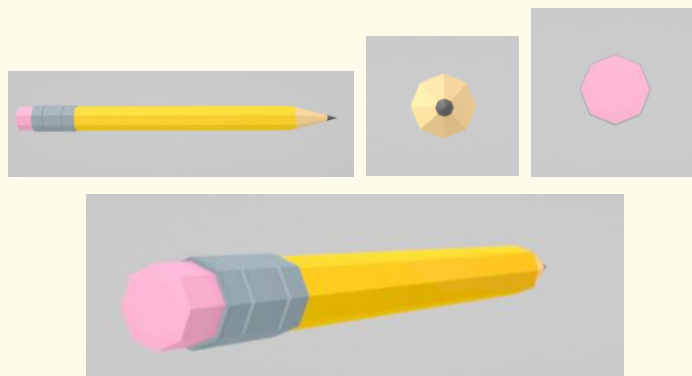


*Figure 1: several views of the same pencil in a 3D view*

Technical drawing, therefore, involves standards, codes, symbols, and protocols so that those developing technical drawings and those interpreting/analyzing them can understand views, scales, perspectives, units of measurement, scoring systems without ambiguity.

Technical drawings include dimensions, geometry, tolerances, material type, finish, hardware.

In addition, technical drawings always have an information block that contains essential information about the assembly and are most often located in the lower right-hand corner.

A professional drafter who makes technical drawings is sometimes called a drafting technician, engineer, architect, and scientist. Nowadays, the creation of a technical drawing is usually associated with the computer (CAD).

- **Some important concepts**

For technical drawing, the terms used are:

Visualization – ability to create and manipulate the mental image.

Drawing – ability to put it on paper.

In order for the drawing to be understandable and give a maximum of information, it is necessary to present different views from different directions (like the example of the pencil). It is also often essential to offer cut views to make all the drawing elements visible and understandable.

In technical drawings, there are different types of lines to indicate the visible and hidden planes of the element:
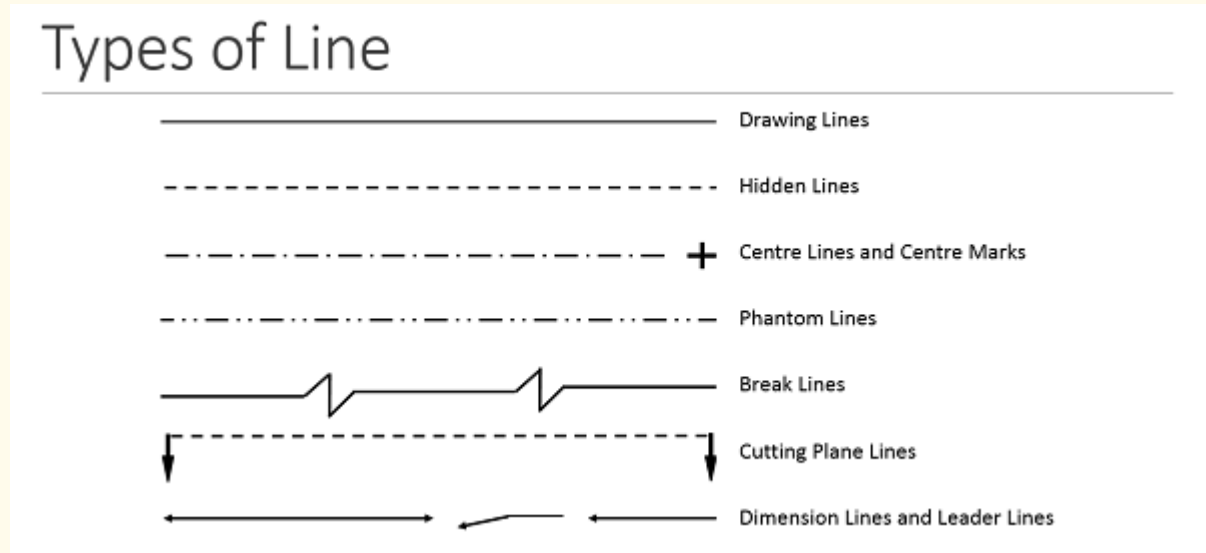


## Types of Line

| | |
|---|---|
| ───────────── | Drawing Lines |
| ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ | Hidden Lines |
| ─ · ─ · ─ · ─ · ─ · ─ ─╋─ | Centre Lines and Centre Marks |
| ─ ·· ─ ·· ─ · ─ · ─ ·· ─ | Phantom Lines |
| ───/\/───/\/─── | Break Lines |
| ↓ ─ ─ ─ ─ ─ ─ ↓ | Cutting Plane Lines |
| ←──────→  ←──── | Dimension Lines and Leader Lines |

*Figure 2: the different types of lines*

Below is an example of a technical drawing of a mug with different angle projection and the information block in the lower right-hand corner:
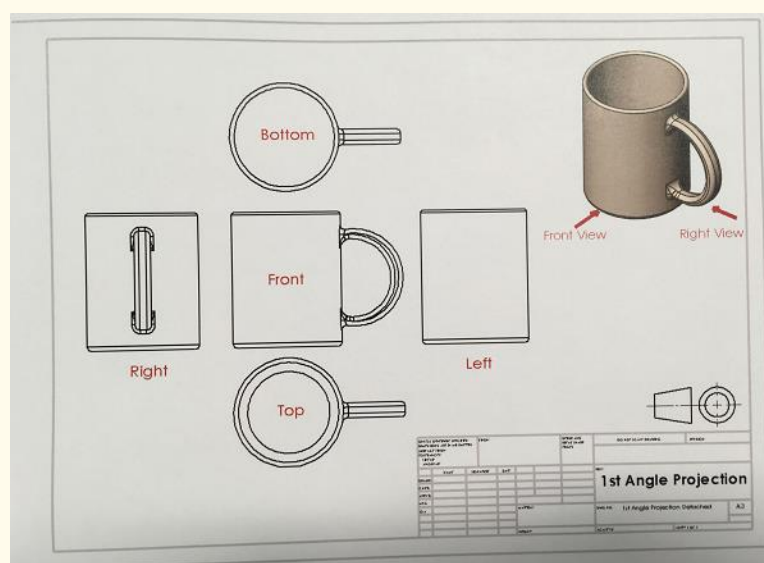


*Figure 3: technical drawing of a cup*

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## Symbols used in technical drawing

To ensure that a drawing is legible and understandable, it is necessary to use symbols and abbreviations.

Indeed, there is not much space on a drawing, so engineers and scientists have developed a series of standardized symbols and abbreviations that can be understood in all languages rather than putting explanatory text on it.

So, a good drawing should be understandable by anyone, whatever the language.If you need to find the meaning of a symbol or abbreviation, you should consult the Australian standard AS 1100.101-1992, which defines the general principles of technical drawing and lists tables of symbols, abbreviations, and their meanings.

See below some examples:

| Symbol | Meaning | Symbol | Meaning |
|---|---|---|---|
| Ⓛ | LMC – Least Material Condition | ◄⊕ | Dimension Origin |
| Ⓜ | MMC – Maximum Material Condition | ⌴ | Counterbore |
| Ⓣ | Tangent Plane | ⌄ | Countersink |
| Ⓟ | Projected Tolerance Zone | ⏃ | Depth |
| Ⓕ | Free State | ⌀ | All Around |
| ∅ | Diameter | ◄► | Between |
| R | Radius | ✕ | Target Point |
| SR | Spherical Radius | ▷ | Conical Taper |
| S∅ | Spherical Diameter | ▷ | Slope |
| CR | Controlled Radius | □ | Square |
| ⟨ST⟩ | Statistical Tolerance | | |
| 77 | Basic Dimension | | |
| (77) | Reference Dimension | | |
| 5X | Places | | |

*Figure 4: common symbols for technical drawing*

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To know more about **Engineering drawing abbreviations and symbols**, you can consult the complete list  here:

https://en.wikipedia.org/wiki/Engineering_drawing_abbreviations_and_symbols

- **Bibliographic (references):**

https://design.tutsplus.com/articles/technical-drawing-for-beginners-an-introduction-to-perspective--vector-21707

http://www.en.technisches-zeichnen.net/technical-drawing/basics-01/technical-drawing-01.php

https://www.houghton.edu/wp-content/uploads/2020/01/LABLEC1-Introduction-to-technical-drawing.pdf

https://sielearning.tafensw.edu.au/toolboxes/toolbox905/2_draw/draw_t4/htm/draw4_2_1.htm

Figures:

Figure 1: https://poly.google.com/view/5R0mBgid5-k

Figure 2: https://www.makeuk.org/insights/blogs/how-to-read-engineering-drawings-a-simple-guide

Figure 3:https://www.makeuk.org/insights/blogs/how-to-read-engineering-drawings-a-simple-guide

Figure 4:  https://www.pinterest.com/pin/142356038195471525/

# LESSON – PROJECTION OR VIEWS

- **Study section:** 3D Printing

- **Lesson duration:** 1:00h

- **Educational objectives:**

  o Identify and understand the different projections/views needed and used in technical drawing

- **Learning outcomes and acquired competencies:**

  o Understand the different projections purposes;

  o Identify which view is more relevant given a specific need;

- **Main Keyword(s):** views, projections, perspective, visualization.

- **Required material and resources:** none

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### Brief definitions of **PROJECTIONS/VIEWS**

What is projection in technical drawing?

A projection is a drawing or a representation of an object or a concept that is reproduced by visually projecting it onto one or more imaginary planes. The planes of this projection that are used to develop technical drawings are much the same type of process as when a projector shows a film on a screen.

There are two types of projections: Parallel projection and Perspective projection.

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In the previous section, the facilitator explained the principles of technical drawings and symbols, and they addressed the importance of having several views to understand an object or a component. In this lesson, the facilitator will explain the different projections to visualize an object and understand a technical drawing.

# The different projections/views used for technical drawings

When we create or read a technical drawing, we need to refer to projections or views. To understand the drawing properly and for the machine to do the expected action (cutting, folding, printing...), it requires a full view of the drawing.

Several types of views are used for different purposes in the manufacturing drawing. One important tip with views: use/give only the necessary views that will contribute to a better understanding of the drawing.
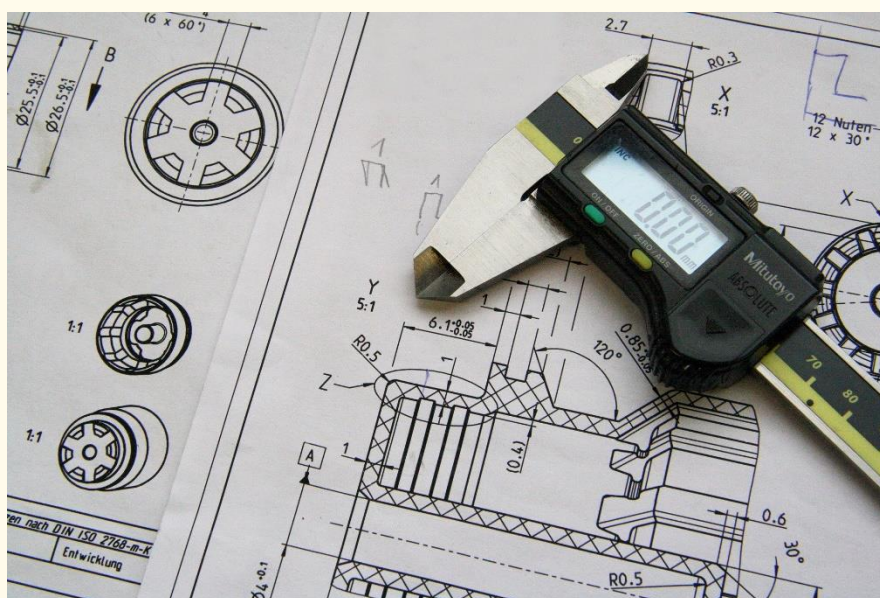


*Figure1: Example of technical drawing*

A projection in the context of technical drawing involves four components:

1. The real object that the drawing or projection represents

2. The eye of the spectator looking at the object

3. The imaginary projection plane

4. Imaginary lines of sight called projectors

The two main types of projections, both of which have several sub-classifications, are the **parallel projection** and the **perspective projection**.

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- **PARALLEL PROJECTION**

Parallel projection is a type of projection where the line of sight or projectors are parallel and are perpendicular to the picture planes. It is subdivided into the following three categories: Orthographic, Oblique and Axonometric Projections

- o **Orthographic projection**

Orthographic projection is a way to represent a 3D object into 2 dimensions. Orthographic views are created by projecting a view of an object onto a plane, which is usually positioned so that it is parallel to one of the object's planes. This kind of representation prevents the viewer from having a distortion of lengths.

The orthographic view is the most commonly used projection for engineering drawing and communicating all the needed information about the object. It provides three different views in a **multi-view drawing**, that is to say

- **front view**,
- **top view**
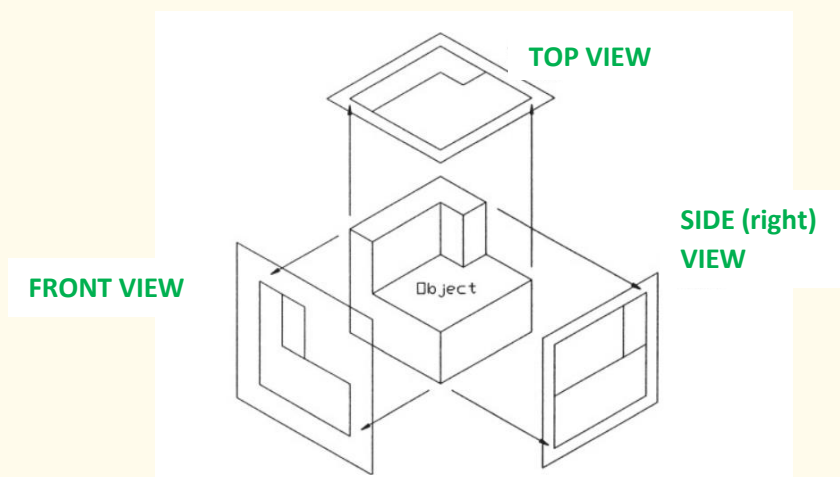- and **side (left or right) view.**



*Figure 2: Orthographic projection planes*

Useful information:

Sometimes, there are differences in the positioning of the views, depending on the region: Europe (ISO) or the USA.

o **Oblique Projections**

The oblique projection shows the full size of one specific view, it is simpler than other projections, but it requires traditional drawing equipment.

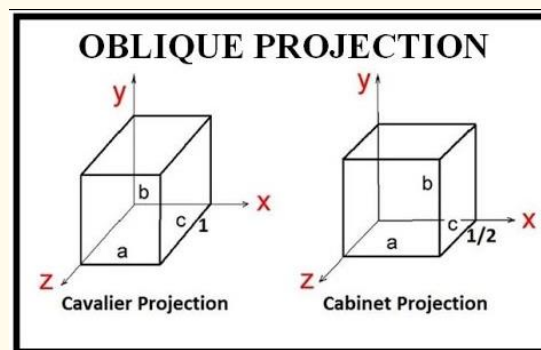Oblique projection can be of two sorts: Cavalier projection or Cabinet Projection.



*Figure 3 : Oblique Projections*

o **Axonometric Projections**

Is a way to create a pictorial drawing of an object where the lines of sight are perpendicular to the plane of projection, and the object is rotated around one or more of its axes to reveal multiple sides. Definition from Wikipedia.

Axonometric projections include three different varieties: Isometric, Dimetric and Trimetric:

**Isometric** projection is a method for visually representing three-dimensional objects in two dimensions in technical and engineering drawings. It is an axonometric projection in which the three coordinate axes appear equally foreshortened, and the angle between any two of them is 120 degrees. (Source Wikipedia)

The vertical lines remain vertical (compared with the front view) while parallel lines are pictured at a 30° angle. The length of vertical and parallel lines are the real measures; that is to say, it is possible to take a ruler and the scaling of the drawing to have the real measurement of the length directly from the drawing. The same cannot apply to angled lines.
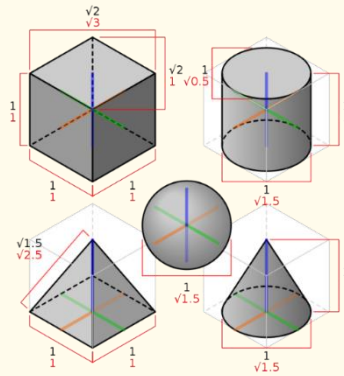
*Figure 4: A cube, sphere, pyramid, and cylinder in isometric projection. Black labels denote dimensions of the 3D object, while red labels denote dimensions of the 2D projection (drawing).*

Important note:

It is important to distinguish the isometric view from a perspective view. The perspective view is an artistic one that represents an object as it seems to the eye. Engineers stay true to the dimensions rather than optical illusions.

**Dimetric projection** is an axonometric projection where two of the three axes of an object make equal angles with the plane of projection, and the third angle is larger or smaller than the other two.

Dimetric projections are not used as often as isometric projections, and Dimensional approximations are common in dimetric drawings.
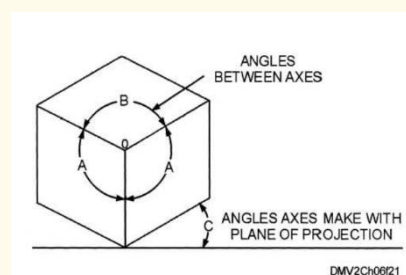


*Figure 5: A dimetric projection*

**Trimetric Projection**

In trimetric projection, the direction of viewing is that all three axes of space appear unequally foreshortened. The scale along each of the three axes and the angles among them are determined separately as dictated by the viewing angle.
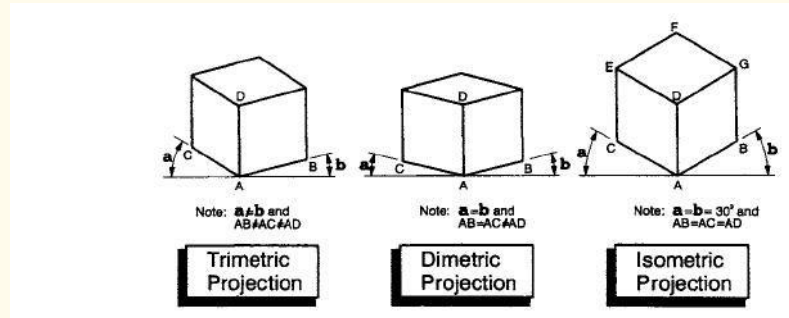


*Figure 6: The three types of axonometric projections*

- **PERSPECTIVE PROJECTION**

Perspective projections are drawings that seek to reproduce what the human eye really sees when looking at a specific object. There are three types of perspective projections: **one-point, two-point,** and **three-point projections.**
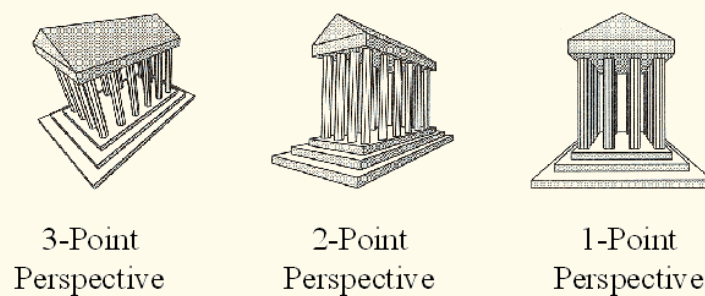
The perspective points are called vanishing points.



*Figure 7: The three types of axonometric projections*
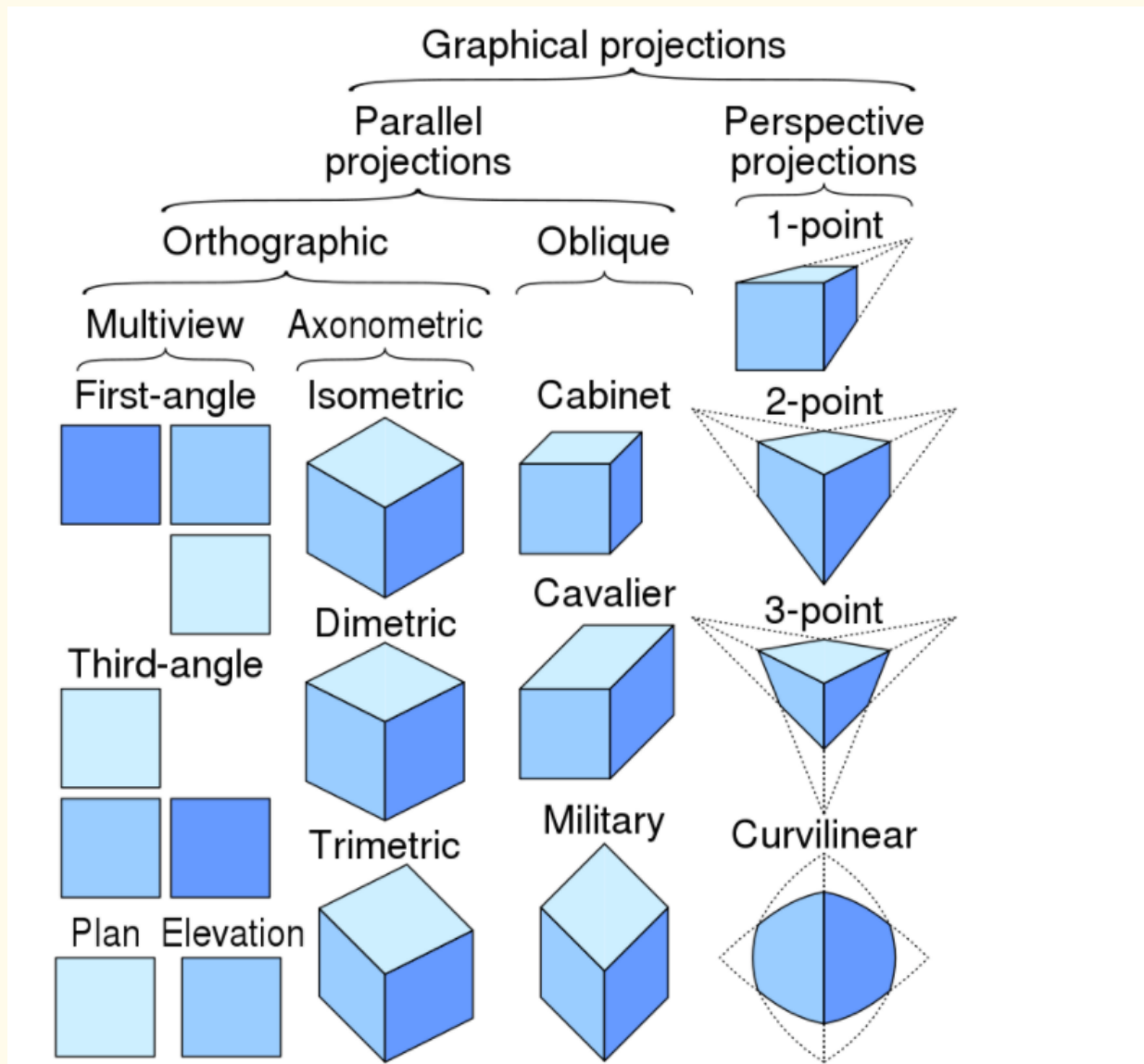
**TO WRAP IT UP:**



*Figure 8: Taxonomy of projection*

## The views used for technical drawing:

- **FLAT PATTERN**

Flat-pattern view, as its name mentions it, is a method used when the object or pattern is entirely drawn on a flat surface.

This view is mostly used for folded sheet metal parts, for instance. Because the cutting job comes before the bending job, it is important to have all the information visible by the machine before it does the cutout and bending.
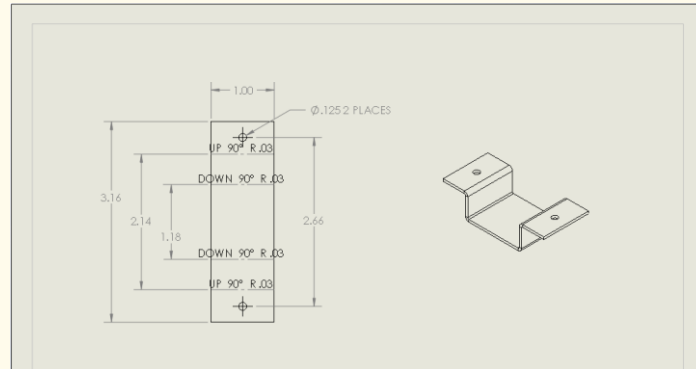


*Figure 9: flat pattern view*

- **SECTION VIEW**

The section view is an additional view aiming at displaying parts of the 3D object or features that are not easily understood when looking only from the outset.

A cross-section is the preferred option compared to hidden lines as it brings more clarity. The cross-hatching feature is an indicator for cross-sectional views.
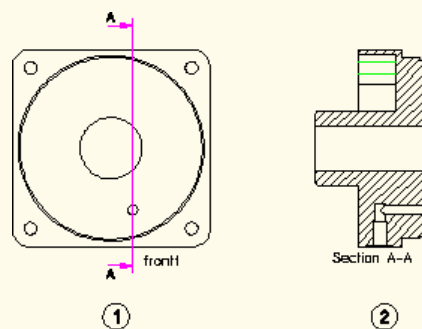


*Figure 10: section views*

- **CUTOUT VIEW**

The cutout view is more or less similar to section views, but it also includes cutouts.
Generally speaking, if there are cutouts, it is preferable to use cutout views including all the information instead of having 2 views, one section, and one cutout.
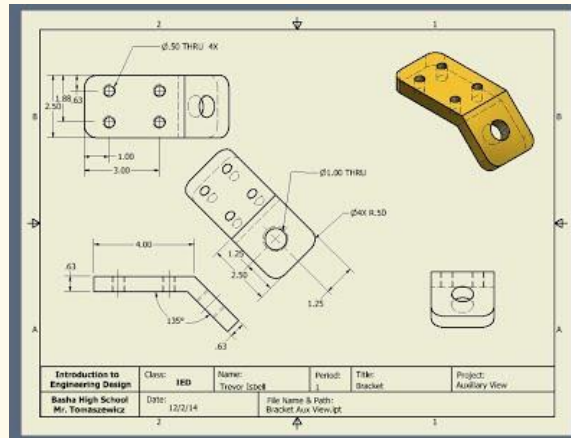
*Figure 11: Cutout views*

- **DETAIL VIEW**

The detail view is used to give more details of a drawing. It is a kind of focus, from a larger view to a selected close-up of a selected section. This view is very useful for improving the readability of many small measurements included on a large part and located in small areas.



*Figure 12: Detail views*

- **AUXILARY VIEW**

Auxiliary views are very frequently found on many types of industrial drawing. This method is considered as a "helper view" showing inclined surface without distortion. This view represents (projects) the object so the true size and shape of the surface can be seen as it actually is.

Depending on the needs, the auxiliary view can be projected from the front, the top, or the side views.

*Figure 13: Auxiliary views*

- **Bibliographic (references):**

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https://www.oreilly.com/library/view/engineering-graphics-with/9780134271019/ch05.html#:~:text=Orthographic%20views%20are%20two%2Ddimensional,the%20planes%20of%20the%20object.

https://en.wikipedia.org/wiki/Axonometric_projection

https://technologystudent.com/despro2/obli1.htm

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Figures :

Figure 1 : Image by Anja Heidsiek from Pixabay

Figure 2 : https://www.oreilly.com/library/view/engineering-graphics-with/9780134271019/ch05.html#:~:text=Orthographic%20views%20are%20two%2Ddimensional,the%20planes%20of%20the%20object.

Figure 3 : https://www.youtube.com/watch?app=desktop&v=i64rhlCtjWg

Figure 4 : https://en.wikipedia.org/wiki/Isometric_projection#/media/File:3D_shapes_in_isometric_projection.svg

Figure 5 : http://draftingmanuals.tpub.com/14276/css/Dimetric-Projections-326.htm

Figure 6 : https://imeulia.blogspot.com/2011/07/axonometric-projection.html

Figure 7 : https://www.cs.princeton.edu/courses/archive/fall00/cs426/lectures/pipeline/sld032.htm

Figure 8 : https://en.wikipedia.org/wiki/File:Comparison_of_graphical_projections.svg

Figure 9 : https://www.cati.com/blog/2017/01/what-happened-to-my-flat-pattern-1-1/

Figure 10 :

https://support.ptc.com/help/creo/ced_modeling/r20.2.0.0/en/ced_modeling/OSDM_Annotation/am_viewp6.html

Figure 11 :

https://www.google.com/search?q=cut+out+views+technical+drawing&tbm=isch&ved=2ahUKEwj9nf-6_b7uAhWVEGMBHQHiC8QQ2-cCegQIABAA&oq=cut+out+views+technical+drawing&gs_lcp=CgNpbWcQA1C9lwJYo6kCYNmqAmgAcAB4AIABSYgBvQiSAQIxOJgBAKABAaoBC2d3cy13aXotaW1nwAEB&sclient=img&ei=LN0SYP3XPJWhjLsPgcSvoAw&bih=712&biw=807#imgrc=bDG_k8pq3LPEeM

Figure 12 : https://blogs.rand.com/manufacturing/2013/01/attachment-to-detail-its-the-little-things.html

Figure 13 : https://sites.google.com/site/trevorsengineeringportfolio/auxiliary-view

**LESSON – CUTS AND SECTION VIEW**

- **Study section:** 3D Modelling

- **Lesson duration:** 1:00h

- **Educational objectives:** being able to identify the different section views of a model.

- **Learning outcomes and acquired competencies:**

  o   Gain knowledge about the different views.

- **Main Keyword(s):** Section View, Full Section, Half/Offset/Revolving/Broken View

- **Required material and resources:**

> **Brief definition of Section/Full/Half/Offset/Revolving/Broken View**
>
> **Section View –** view which shows the internal parts of a 3D model in a design.
>
> **Full View** – view which shows the interior of the object.
>
> **Half View** – view which removes the quarter of the object.
>
> **Offset View** – when particular features of a model need to be viewed. Reveals the interior components.
>
> **Revolving View** – view which shows the shape of an object by rotating the section 90 degrees.
>
> **Broken View** - when only a part of the model needs viewing.

## Cuts and Section View

The facilitator will start the lesson by explaining to the participants what is a section view. The facilitator begins as follows:

A section view can be defined as the view which shows the internal parts of a 3D model in a design. In other words, the section view looks as if you cut through the entire length of the design. This view can be used to look at and modify the internal parts of the 3D model. (*What Is Section View?,* n.d.)
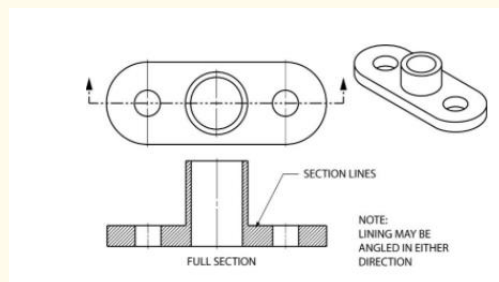


Source:
https://technologystudent.com/prddes1/orthogrp2.html
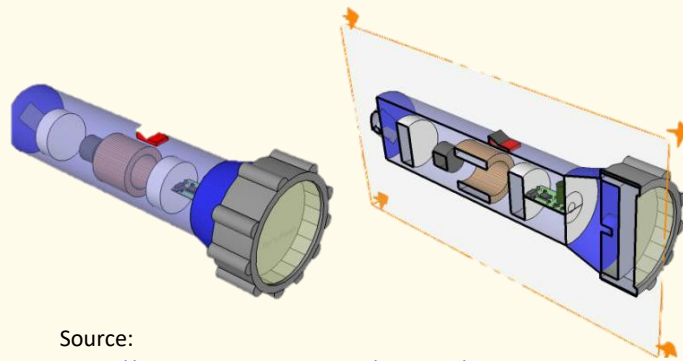
Furthermore, the facilitator mentions some characteristics of a 3D Section View:

- Encourages the cutting of material (of pieces) from a 3D model to help us see its interior features. This view is useful when creating sectioned views of a model for presentation purposes instead of physically modifying the parts.

- Can be commentated, measured, and used in providing documentation for PMI, Product Manufacturing Information purposes.

- It can be used in the automatic generation of drawings. (*3D Section Views of Models*, n.d.)

Therefore, a sectional view reveals the hidden details of a model and is used in helping civil engineers, airplane designers, and architects to communicate their ideas. The lesson continues with the facilitator describing the **different types of sectional views,** which include:

1. **Full section:** when the imaginary cutting plane crosses the entire model, splitting the model in two. The interior of the model is revealed.



Source: https://openoregon.pressbooks.pub/blueprint/chapter/unit-7-sectional-views/

2.  **Half view:** when the cutting plane is expected to curve at a right angle and cuts through only half of the represented model, not its full length, the quarter of the model is removed. This view is only effective on symmetrical models and has the main target to show an object's internal and external construction in the same drawing.
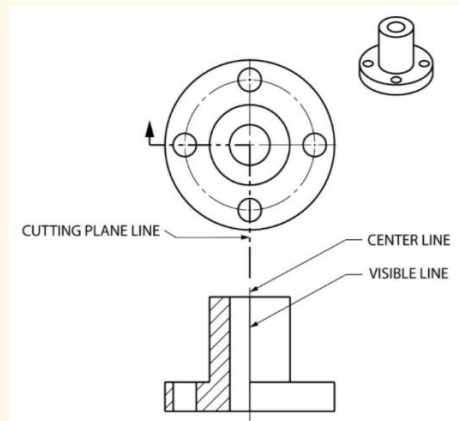


3.  **Offset view:** effective on complex objects. When particular features of a model need to be highlighted but are not located on the straight line of the cutting plane, then the cutting plane line is bent and is imagined cutting the model and reveals the interior components. [Note: the curves in the imaginary cutting plane are always 90 degrees]
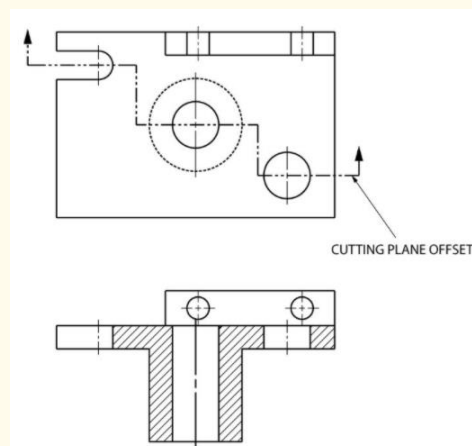
4. **Revolving view:** is effective for "extended" models or sections of models, and other model projections can be featured. When the cutting plane cuts the model at an angle, the drawing is rotated for a better view.
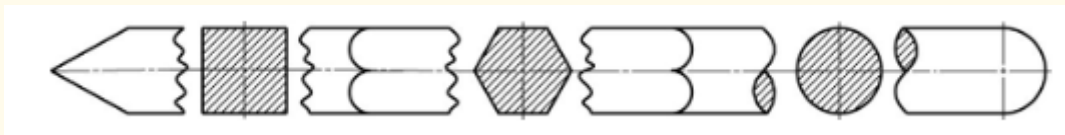


5. **Broken view:** when only a part of the model needs viewing. For this view, we do not use the cutting plane but an irregular cut line that removes the section of the model at a specific depth. This is helpful when particular interior details at a particular part of the model need to be featured.
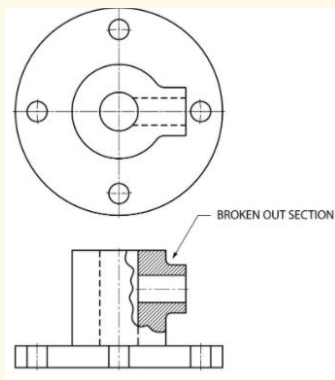


(*Types of Sectional Views*, n.d.)

Before the end of the lesson, the facilitator can show the participants – already printed – pictures of the different types of section views. The participants will have to match the pictures with the 5 different section views.

- **Bibliographic (references):**

*3D section views of models*. (n.d.). Retrieved November 25, 2020, from https://www.soliddna.com/SEHelp/ST5/EN/a_h/cutawy1a.htm

*Types of Sectional Views*. (n.d.). Bizfluent. Retrieved November 25, 2020, from https://bizfluent.com/list-5968217-types-sectional-views.html

*What is Section view?* (n.d.). Shapr3D Help Desk. Retrieved November 25, 2020, from https://support.shapr3d.com/hc/en-us/articles/360008543033-What-is-Section-view-

# LESSON – AXONOMETRIC PROJECTION, COMPUTER AIDED DESIGN (CAD) AND SOFTWARE

- **Study section:** 3D Modelling

- **Lesson duration:** 2:00h

- **Educational objectives:**

  - being able to understand what is an Axonometric Projection

  - being able to understand a Computer-Aided Design Software

- **Learning outcomes and acquired competencies:**

  - Have a good understanding of different projections and CAD;

- **Main Keyword(s):** axonometric projection, isometric/dimetric/trimetric projection, Computer-Aided Design (CAD), raster graphics, vector-based graphics

- **Required material and resources:**

| **Brief definition of Axonometric Projection, Isometric/Dimetric/Trimetric Projection, CAD, raster/vector-based graphics** |
|---|
| **Axonometric Projection** – used in creating pictorial drawings, where the plane of projection is perpendicular to the lines of sight. |
| **Isometric Projection** – all contractions are the same. |
| **Dimetric Projection** – two contractions are the same |
| **Trimetric Projection** – no contraction is the same |
| **Computer Aided Design** - design process supported by the use of a computer software |

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> **Raster Graphics** - a type of digital image that uses tiny rectangular pixels, or picture elements, arranged in a grid formation to represent an image.
>
> **Vector-based Graphics** - are computer graphics images that are defined in terms of points on a Cartesian plane, connected by lines and curves to form polygons and other shapes.
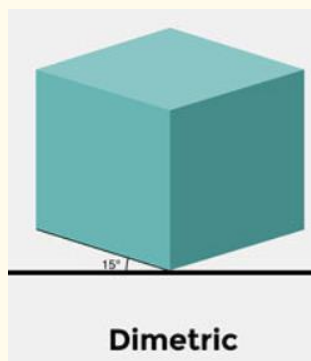
## Axonometric Projection

The facilitator starts the lesson by explaining to the participants the term Axonometric projection. Axonometric projection is used for creating a graphic drawing of an object, where the "lines of sight" are perpendicular to the plane of projection, and for revealing multiple sides, the object is rotated around its axes. Axonometric projection allows for the representation of more than one "side" of an object and may portray a thing such that no principle axes of the model is perpendicular to the projection plane, and therefore, more than one "side" of the model may be denoted concurrently (*Axonometric Projection*, n.d.). The facilitator continues by distinguishing the three types of axonometric projection:

1. **Isometric projection:** is when the direction of viewing is such that the three axes of space appear equally contracted, and there is a shared angle of 120 degrees between them (as shown in the picture). The proportionality of all sides and lengths is conserved, and the axes have a shared scale.



**Isometric**
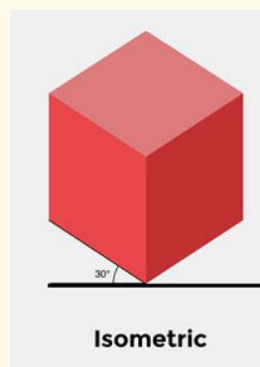
2. **Dimetric projection:** direction of viewing is such that two of the three axes (x-axis and z-axis) are equally contracted, of which the attendant scale and angles of presentation are determined according to the angle of viewing; and separately determine the scale of the third (vertical – y-axis) direction.

**Dimetric**

Source: https://www.qpractice.com/ncidq-glossary/axonometric-drawings/

3. **Trimetric projection:** direction of viewing is such that all three axes appear unevenly contracted. The scale passing the three axes and the angles among them is determined separately by the angle of viewing (Lockhart et al., 2018).



**Trimetric**
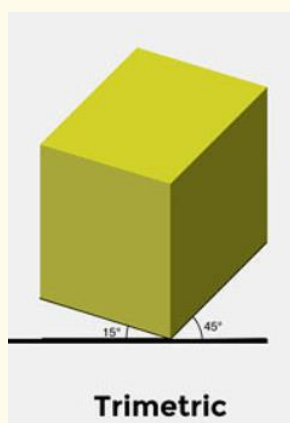
The facilitator can use the – already printed – pictures for participants to match.

## Computer-Aided Design (CAD)

The facilitator continues the lesson by moving on to the next topic; Computer-Aided Design. Computer-Aided Design (CAD) can be defined as the design process supported by computer software. The CAD software helps us produce, analyze, modify and enhance a design. Many participants may believe that a CAD refers only to the drawings; therefore, the facilitator should explain that CAD refers to the use of software to help in the design process. For example, instead of drafting by hand, the software replaces it with an automated process. CAD software has an important role in the modern market. One example includes the people working in architecture who undoubtedly use 2D or 3D CAD programs ("What Is Computer-Aided Design (CAD)?," n.d.).

Furthermore, CAD includes creating computer models defined by geometrical parameters. That is a model on a computer monitor as a 3D representation of a part of a system of parts, which can be promptly altered by changing relevant parameters. Designers can view the created objects under a variety of representations as well as test them by simulating real-world conditions (*Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM)*, n.d.).



Source: https://www.designtechcadacademy.com/knowledge-base/introduction-to-cad

## Software

The facilitator continues with the last topic of this lesson; Software. S/he explains to participants that the CAD software is broadly used for industrial products, animated movies, and other applications. CAD programs use either raster graphics or vector-based graphics (defines and vector-based graphics using the above definitions) to show how an object will look. The software enables:

- Efficiency in the quality of design;
- Increase in an Engineer's productivity;
- Improve record keeping through better communication and documentation.

The CAD software can be classified as follows (*Introduction to CAD, Background, Uses, and Types of CAD Software.*, n.d.):

- 2D CAD
- 3D CAD
- 3D wireframe and surface modeling

- Solid modeling

Best general-purpose CAD software includes:

| AutoCAD | SketchUp | Onshape | Inventor | BricsCAD | SolidWorks |
|---------|----------|---------|----------|----------|------------|

(*Best 40+ General-Purpose CAD Software & Programs in 2020*, n.d.)

The facilitator explains that in this case, they will be using Onshape. Onshape is considered the only product development platform that combines CAD, incorporated data management, real-time association tools, and business analytics. (*Onshape | Product Development Platform*, n.d.)

The participants need to follow the subsequent steps:

**Step 1:** Use the following link https://www.onshape.com/en/products/free to Sign Up on Onshape. Click on the 'Get Started' button and sign up using your personal information.

**Step 2:** Once you sign up, you'll be able to create a new document. Click on the 'Create' button at the top left corner and select 'Public' or 'Private' (please note that you will be able to create only 10 free 'Private' documents).

**Step 3:** Once you are redirected to the 'Part Studio,' select the sketch icon and create a sketch. (*How to Use Onshape and Assembly*, n.d.)

- **Bibliographic (references):**

*Axonometric projection*. (n.d.). Engineering. Retrieved November 25, 2020, from
https://engineering.fandom.com/wiki/Axonometric_projection

*Best 40+ General-Purpose CAD Software & Programs in 2020*. (n.d.). G2. Retrieved
November 26, 2020, from https://www.g2.com/categories/general-purpose-cad

*Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM)*. (n.d.). Inc.Com.
Retrieved November 26, 2020, from https://www.inc.com/encyclopedia/computer-aided-design-cad-and-computer-aided-cam.html

*How to Use Onshape and Assembly* . (n.d.). Instructables. Retrieved March 12, 2021, from
https://www.instructables.com/How-to-Use-Onshape-and-Assembly/

*Introduction to CAD, Background, Uses and Types of CAD Software.* (n.d.). Retrieved
November 26, 2020, from https://www.designtechcadacademy.com/knowledge-base/introduction-to-cad

Lockhart, S., Goodman, M., & Johnson, C. (2018). *Modern Graphics Communication, 5th
Edition*. https://www.peachpit.com/store/modern-graphics-communication-9780134848716?w_ptgrevartcl=Visualization+and+Sketching_2873372

*Onshape | Product Development Platform*. (n.d.). Retrieved March 12, 2021, from
http://www.onshape.com/en/

What is computer-aided design (CAD)? - Definition and meaning. (n.d.). *Market Business
News*. Retrieved November 26, 2020, from https://marketbusinessnews.com/financial-glossary/computer-aided-design-cad/

## LESSON – CREATING A PART/OBJECTION ONSHAPE, VERIFYING THE OBJECT, AND EXPORTING IT

- **Study section:** 3D Modelling

- **Lesson duration:** 3:00h

- **Educational objectives:**

  o Learn how to use the tools of the software;

  o Learn how to verify the object;

  o Learn how to export the object.

- **Learning outcomes and acquired competencies:**

  o Be able to replicate the vase step by step.

- **Main Keyword(s):** Onshape, features: Sketch 1/ Revolve 1, Tools: Corner rectangle/ Revolve/ Construction/ Spline/ Chamfer/ Fillet/ Shell, Valid mesh, STL

- **Required material and resources:** Computer (SketchUp on the web)

> **Brief definition of Onshape, Valid Mesh, STL file**
>
> **Onshape** – is a Computer Aided Design software system
>
> **Valid mesh** - a model that has a complete surface, also called manifold
>
> **STL File** - converts the object into a map of triangles which can then be imported to a 3D printer software

## Create a part/object on Onshape

The facilitator opens the Onshape software and starts creating the vase using the following steps:

**Step 1:** In Onshape everything starts with a Sketch. The participants should select the Front plane and click on Sketch. Participants should then use the Corner Rectangle tool to draw a 150 (height) x 90 (width) rectangle on the Front view. See **Figure 1**.
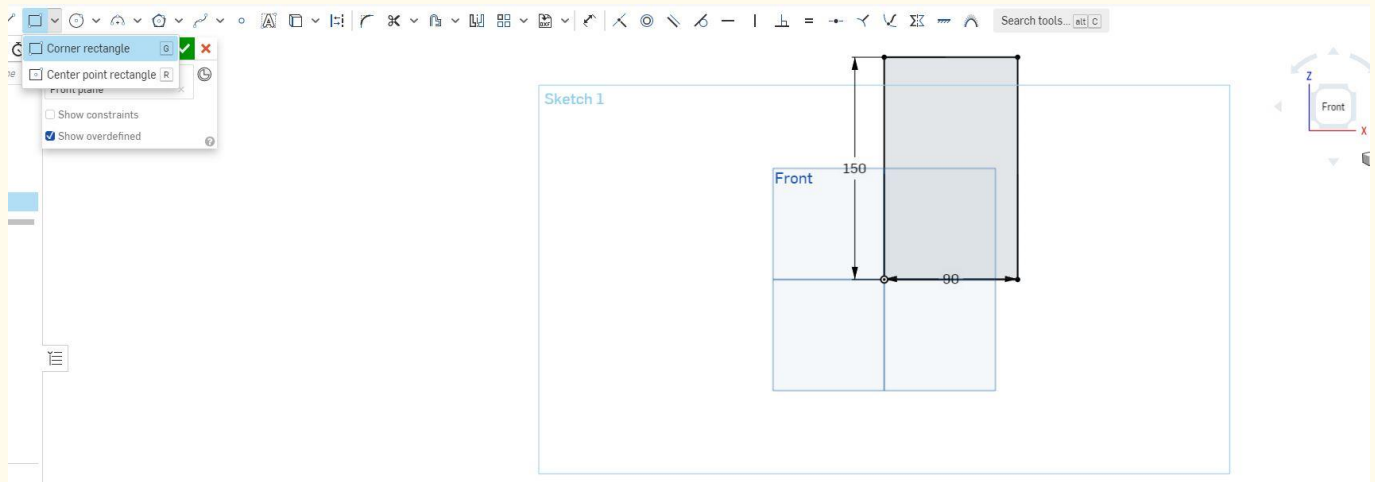


Figure 1

**Step 2:** The participants should use the Revolve tool and select the vertical axis. Participants should get the shape shown in **Figure 2**.
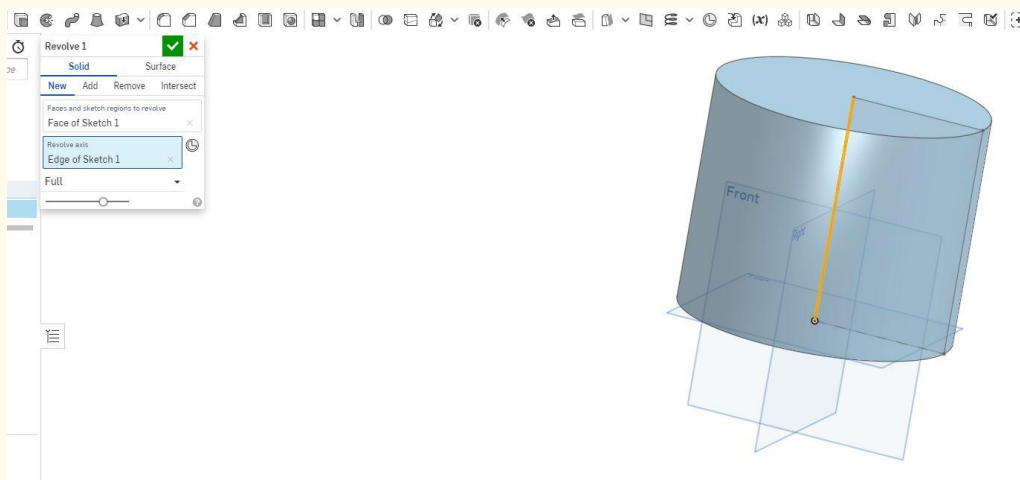


Figure 2

**Step 3:** Double click on Sketch 1 (on the left-hand-side). Participants should select the Construction tool and then select the right vertical line. The selected line will be replaced with a dotted line. Select the line tool and draw a diagonal line, as shown in **Figure 3**.
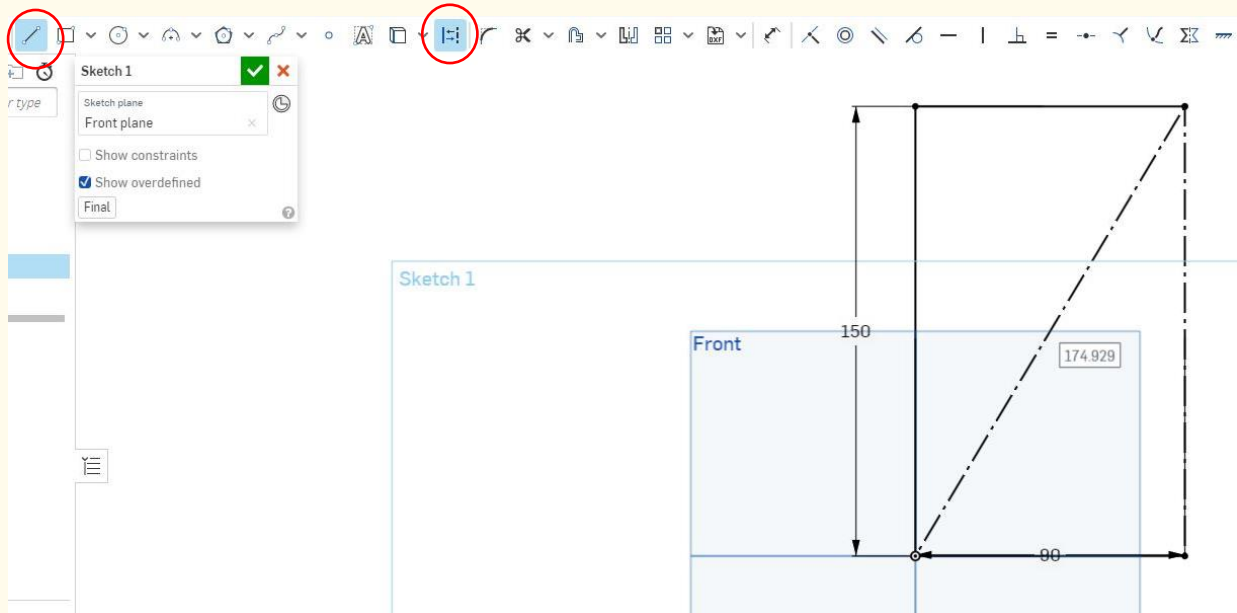


Figure 3

**Step 4:** Double click on Revolve 1 (left-hand-side). Participants should then select the upper triangle, remove 'Face of Sketch 1', and add the new face (upper triangle). See **Figure 4**.
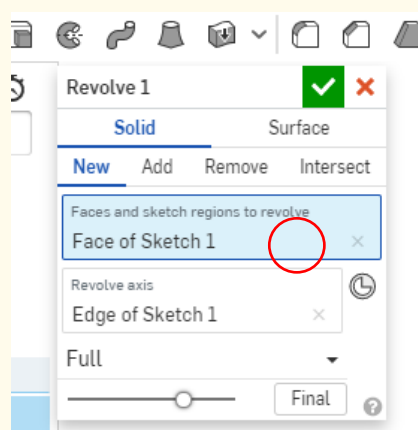


Figure 4

Participants should get a cone.

**Step 5:** Double click on Sketch 1 and delete the diagonal line. Participants should select the Spline tool and draw an outline for the vase, as in **Figure 5**. Before clicking on the green check, you should adjust the shape of the vase.
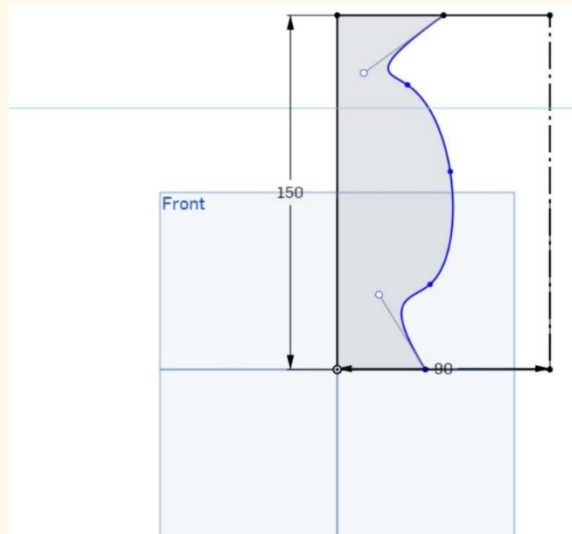


Figure 5

**Step 6:** Select the Chamfer tool and the base of the vase; adjust the distance to 2mm as in **Figure 6**. Repeat the same step for the top edge. For the top edge, also use the Fillet 2 tool to soften the edge.
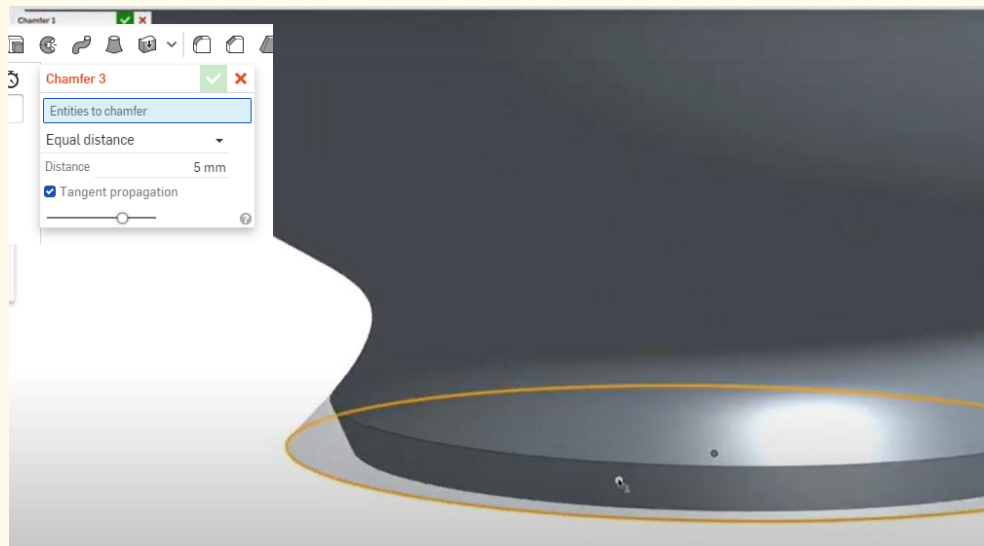


Figure 6

**Step 7:** Participants will use the Shell 2 tool to create hollowness. Select the top surface and adjust shell thickness to 5mm. Click on the green check. The vase is created, and participants and the facilitator should get something similar to **Figure 7**.
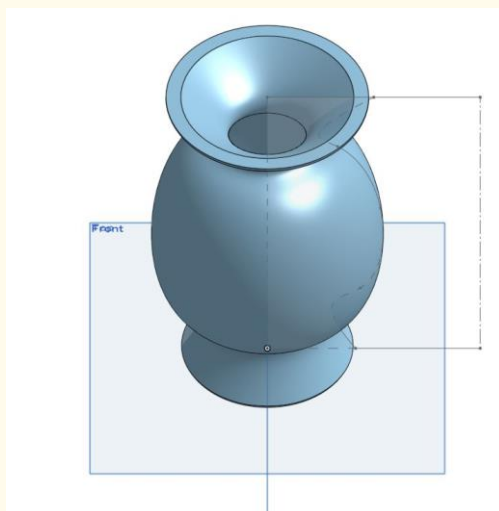


Figure 7

**Step 8:** Participants can edit the appearance of the vase by selecting Part 1. Right-click on Part 1 and select edit appearance. Participants may choose a color for their vase. See **Figure 8**.
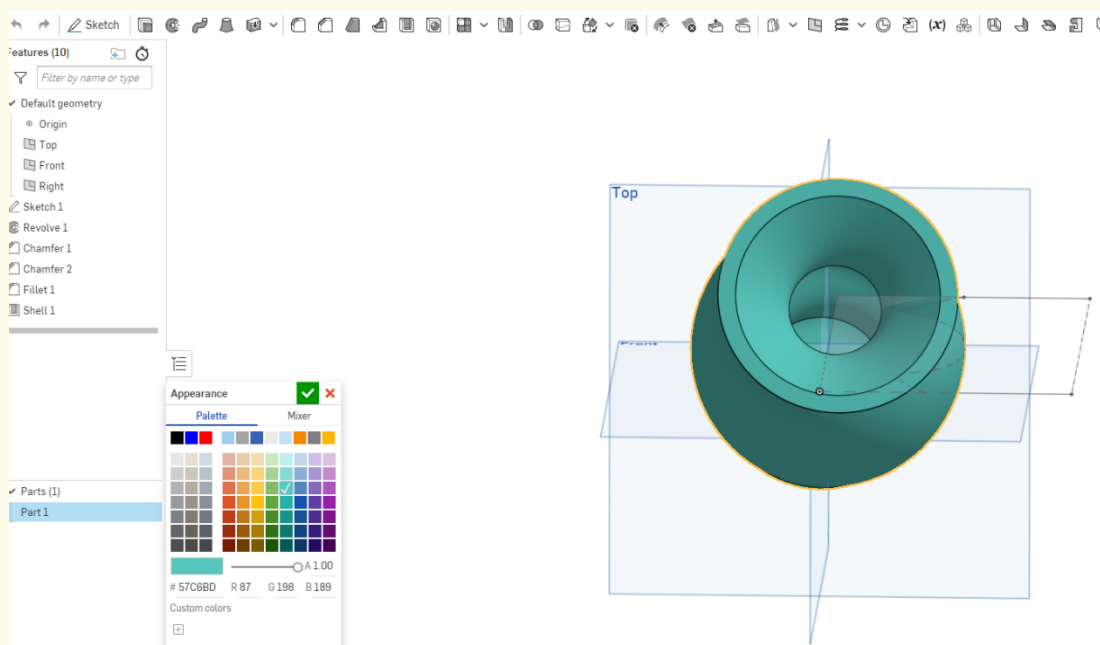


Figure 8

# Verifying the object

Once the vase is created/modeled, the facilitator makes sure that all participants understand the process. The facilitator moves on with the next topic; Verifying the object.

The word verification refers to confirming that a part is physically made to the object specifications within the given tolerance. (Odeh et al., 2019)

If the shapes in the participants' model intersect other shapes, this will create an invalid mesh that will cause problems when trying to 3D print the model. Therefore, before printing the object using a 3D printer, participants must verify that their model is exported as a valid mesh. In 3D printing, a valid mesh is a complete surface model, also called a manifold. All STL 3D models for 3D printing are exported as hollow shells. If you think of it, the model has both an outer and an inner surface defined by many connected triangles that form the surface. If there was a hole in the model, then the structure would not be viable. One of the most common export errors occurs with triangles that are not joined as a surface but intersecting each other, causing confusion when trying to 3D print. One of the final steps is to check that the 3D model has the correct orientation for 3D printing and has the required size ("Verifying 3D Printing Models," n.d.).



Source: https://www.dummies.com/computers/pcs/printers/verifying-3d-printing-models-netfabb/
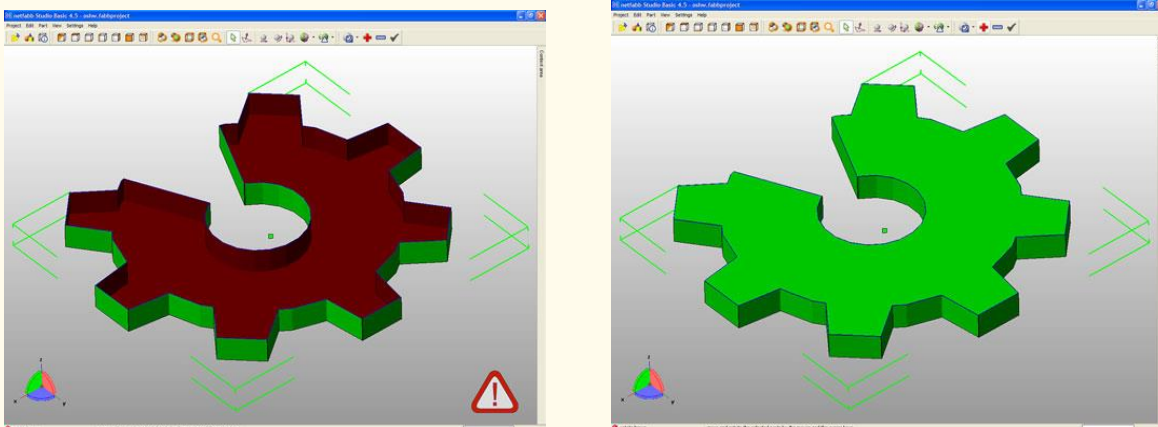
The facilitator shows the above images to the participants and explains:

The left image shows that the exported object has an invalid mesh (highlighted red). It is invalid since the object is hollow. For the object to be verified, it needs to be filled in as shown on the right image.

## Exporting the object

The facilitator continues the lesson by Exporting the object. S/he starts by explaining to the participants that when using a 3D Modelling Software – in this case, Onshape – the objects can be exported in several file types. The facilitator will discuss that in this case, they will explain how to export 3D objects/designs from Onshape to STL file that can then be used by the 3D printers.

An STL file converts the object into a map of triangles so that participants can then take that STL file and import it into the 3D printer software.

It is important to export to the STL file and then import the STL files to correct the units. In other words, the units the participants are shipping need to match units that the 3D printer software uses to import the models. The participants may get scaling issues if the units are mismatched between the export and the import process.

Remember: it is very difficult to edit STL files.

The export command can be accessed in many places. Examples include:

- the participants can right-click on the part they want to export and select export;
- Right-click on the part in the workspace and select export;
- Right-click on the whole part studio and choose export

Using Onshape software, participants can export a single part as well as a group of parts. Once the participants click on export, they will get the following options:
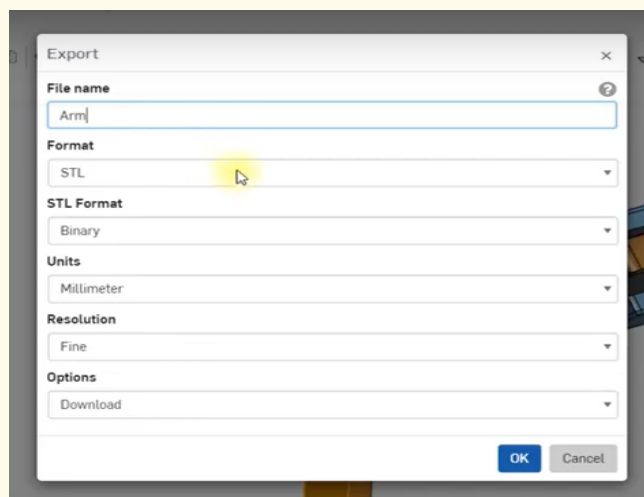
There are several formats to export in, as shown in the picture:
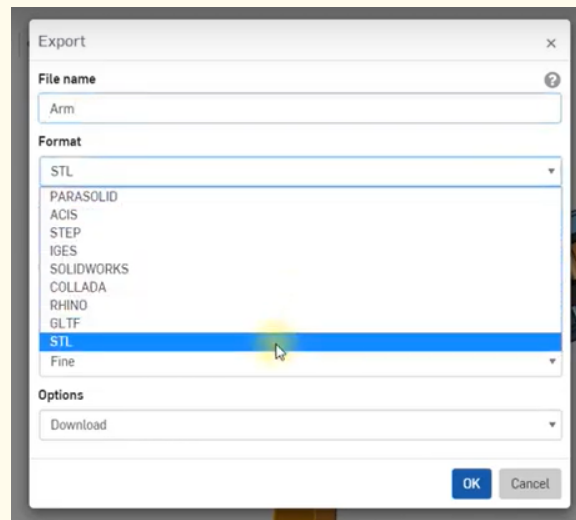


Keep the STL format to binary, Units to millimeters, and Resolution to Fine. Click okay and check that your browser is downloading the file. The participants can use this downloaded file and import it to the 3D printer.

- **Bibliographic (references):**

*Exporting Files*. (n.d.). Retrieved December 4, 2020, from https://cad.onshape.com/help/Content/exporting-files.htm

Odeh, M., Levin, D., Inziello, J., Lobo Fenoglietto, F., Mathur, M., Hermsen, J., Stubbs, J., & Ripley, B. (2019). Methods for verification of 3D printed anatomic model accuracy. *3D Printing in Medicine*, *5*(1), 6. https://doi.org/10.1186/s41205-019-0043-1

Verifying 3D Printing Models with Netfabb. (n.d.). *Dummies*. Retrieved November 30, 2020, from https://www.dummies.com/computers/pcs/printers/verifying-3d-printing-models-netfabb/

Video with instructions on how to create a vase: https://youtu.be/ZDZWrZ4CLxM

Video with instruction on how to export an object:

https://www.youtube.com/watch?v=dYo6kzmtLw0&feature=youtu.be

# 3D PRINTING

## LESSON – INTRODUCTION TO 3D PRINTING AND TYPES OF PRINTERS

- **Study section:** 3D Printing Fundamentals

- **Lesson duration:** 1:00h

- **Educational objectives:**

    o   Know what 3D printing is.

- **Learning outcomes and acquired competencies:**
    o   Know what 3D printing is and what it can be used for;
    o   Know the various types of 3D printers and materials they use;
    o   Plan and structure tasks;
    o   Communicate concepts and ideas clearly;
    o   Act with initiative and demonstrate analytical capacity;
    o   Recommend solutions for problem-solving;
    o   Demonstrate creativity, autonomy, and innovative spirit.

- **Main Keyword(s):**

    o   3D Printing
    o   3D Printer
    o   Filament
    o   Cura

- **Required material and resources:**

    o   3D printer
    o   Computer
    o   Internet

---

### Brief definition of 3D Printing

3D printing, or additive manufacturing, is the construction of a three-dimensional object from a CAD model or a digital 3D model. The term "3D printing" can refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three-dimensional object.

---

## Introduction to 3D Printing

3D Printing is a process used to create three-dimensional objects in which layers of material are formed under computer control.

These objects can have almost any shape or geometry. They are usually made by 3D modeling software and are created as physical objects by having a 3D Printer successively adding material layer by layer.

3D printing is not only used as a hobby. It can be used for many areas, such as medicine, prototyping, building houses, for academic purposes, art, decoration, spare parts, and many others.



*Picture 1 - 3D Printed Calibration Cube*

## Types of 3D printers

There are several types of 3D printers in the market; some are more expensive than others. Usually, they are known by the printing method. Bellow will be presented the most common types of 3D printers and their main characteristics.

### Fused Deposition Modeling (FDM)

FDM is the most common 3D printing method used in desktop 3D printing. It uses a thermoplastic filament that is heated and extruded. The object is printed layer by layer from the bottom up. The color of the printed object is the same as the thermoplastic filament.

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Co-funded by the Erasmus+ Programme of the European Union
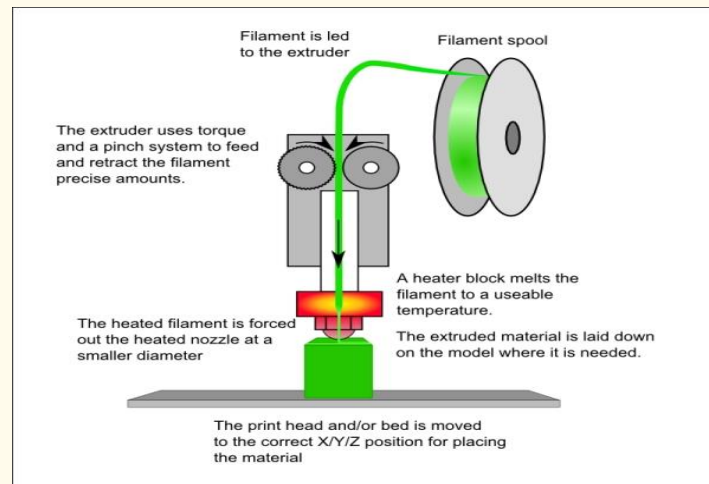
*Picture 1 – Fused Deposition Modeling 3D Printing Mechanism*

Source: https://www.safaribooksonline.com/library/view/3d-printing-
for/9781783550753/graphics/0753OT_01_03.jpg

## Stereolithography (SLA)

SLA exposes a layer of photosensitive liquid resin to a UV-laser beam so that the resin hardens and becomes solid. The object is printed layer by layer, and each layer is built on top of the preceding one.
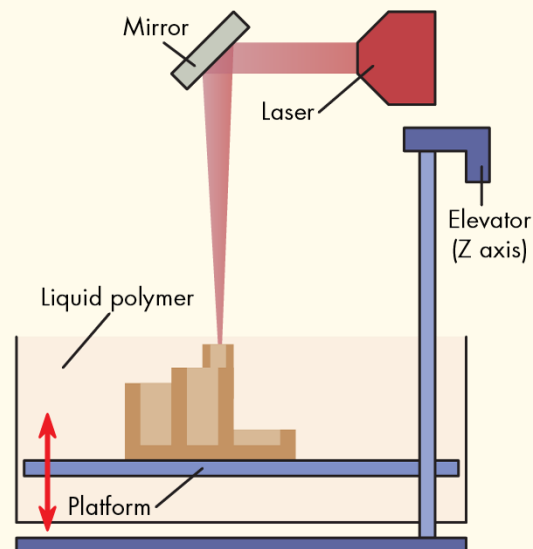


Picture 2 – Stereolithography 3D Printing Mechanism

http://www.machinedesign.com/sites/machinedesign.com/files/uploads/2015/03/SLA.png

## Digital Light Processing (DLP)

Digital Light Processing (DLP) and Stereolithography have a lot in common. Both use photosensitive liquid resin. The object is printed layer by layer, from top to bottom, and with a special light projector.
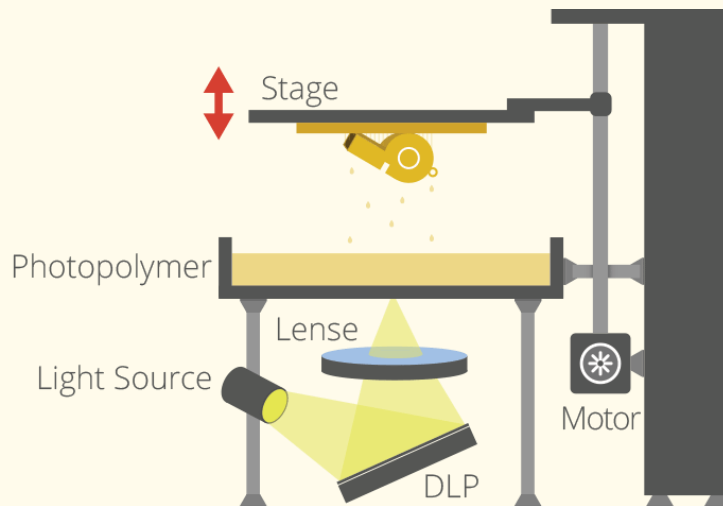
Picture 3 –Digital Light Processing 3D Printing Mechanism

## SLM (Selective Laser Melting)

SLM uses a high-powered laser beam to fully melt metallic powders into solid three-dimensional objects. The object is printed layer by layer. Typical materials used are stainless steel, aluminum, titanium, and cobalt chrome.
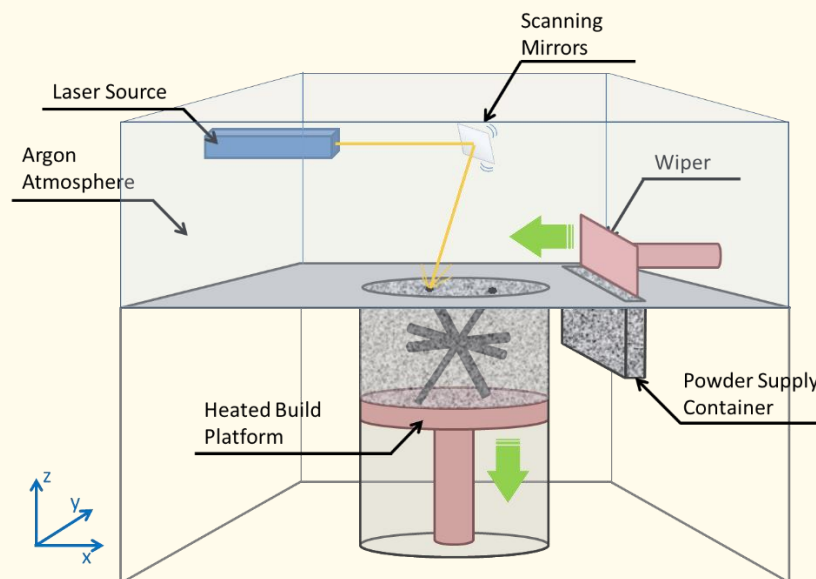


Picture 4 – Selective Laser Melting 3D Printing Mechanism

http://blogs.nottingham.ac.uk/innovate/files/2015/08/SLM_schematic_pic_mod.png

## Electron Beam Melting (EBM)

EBM uses an electron beam under a high vacuum to fully melt the metallic powder at elevated temperatures of 1000 °C. The object is printed layer by layer. This 3D printer can use metals like pure titanium, Inconel718, and Inconel625 to fabricate aerospace parts and medical implants. This type of technology is slower and more expensive than the previous ones.

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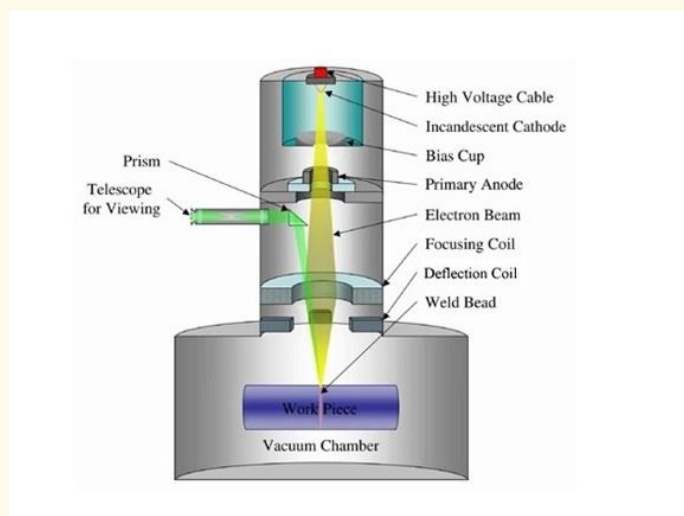
Picture 5 – Electron Beam Melting 3D Printing Mechanism

https://media.licdn.com/mpr/mpr/shrinknp_800_800/AAEAAQAAAAAAAi1AAAAJGEwZWVhYWFlLWVhZGQt
NDVmNy1hYjFhLWZlMzg5ZjFjODBiOQ.jpg

# LESSON – CHOOSING A SLICER

- **Study section:** 3D Printing Fundamentals

- **Lesson duration:** 1:00h
- **Educational objectives:**

    o How to choose a slicer.
    o Know some slicers.

- **Learning outcomes and acquired competencies:**
    o Know how to choose a slicer;
    o Install the Cura software;
    o Plan and structure tasks
    o Communicate concepts and ideas clearly
    o Act with initiative and demonstrate the analytical capacity
    o Recommend solutions for problem-solving
    o Demonstrate creativity, autonomy, and innovative spirit

- **Main Keyword(s):**

    o 3D Printing
    o 3D Printer

o  Filament
o  Cura

- **Required material and resources:**

    o  3D printer
    o  Computer
    o  Internet

## Choosing a Slicer

In 3D printing, it is necessary to have a file with a 3D Model (the drawing in 3D format). The most common files are STL and OBJ. Afterward, it is necessary to convert the file into a special code (G-code) that allows the 3D printer to read it. This type of coding is done by slicer software, and the process is called slicing.

At the end of the slicing process, the user can send the file directly to a 3D printer or have it saved on an SD card or a flash drive; for example, we can send the file with Wi-Fi. The user has a lot of options to choose from since there are several slicing software to 3D print. Below are some examples of slicers:

| Cura | Slic3r | Simplify 3D | Repetier |
|------|--------|-------------|----------|
|  |  |  |  |
| *Picture 6 – Cura software* | *Picture 7 – Slic3r Software* | *Picture 8 – Simplify 3D software* | *Picture 9 – Repetier Software* |

The Slicer that we choose is Cura. The pictures that illustrate the installation process are from version 2.7.0. Yet, it is constantly being updated, and the user may find other versions. The process is the same, no matter the version. Below are the instructions for installing the software.

**STEP 1**

Copy and paste the link ([https://ultimaker.com/en/products/cura-software](https://ultimaker.com/en/products/cura-software)) on your browser to download Cura Software.
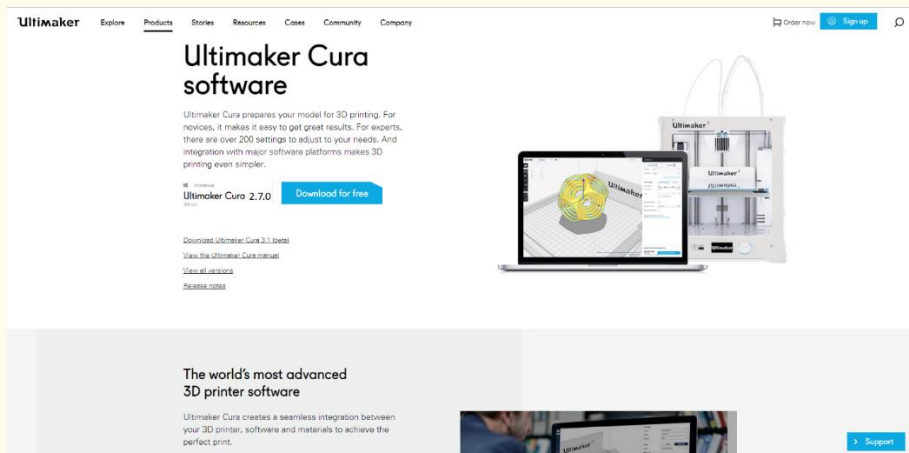


*Picture 10 - Cura's homepage*

**STEP 2**

Locate your downloaded installer and execute it. After doing that, the following image should apear, just press **Next**.
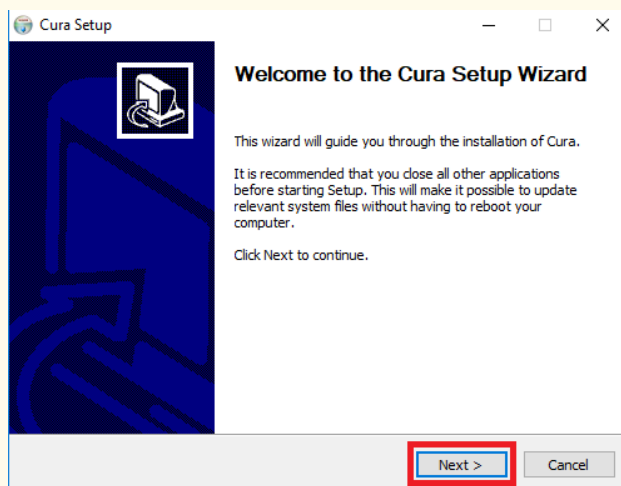


*Picture 11 - Cura's setup wizard*

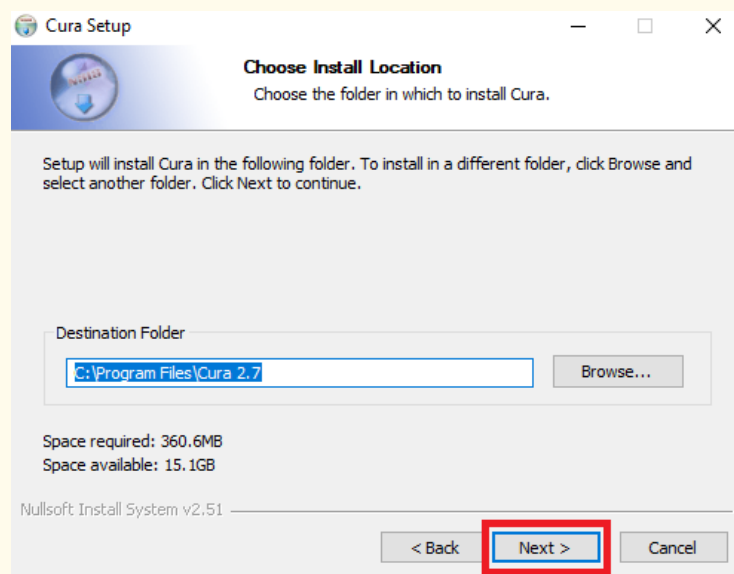Co-funded by the
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Agree to the license terms.
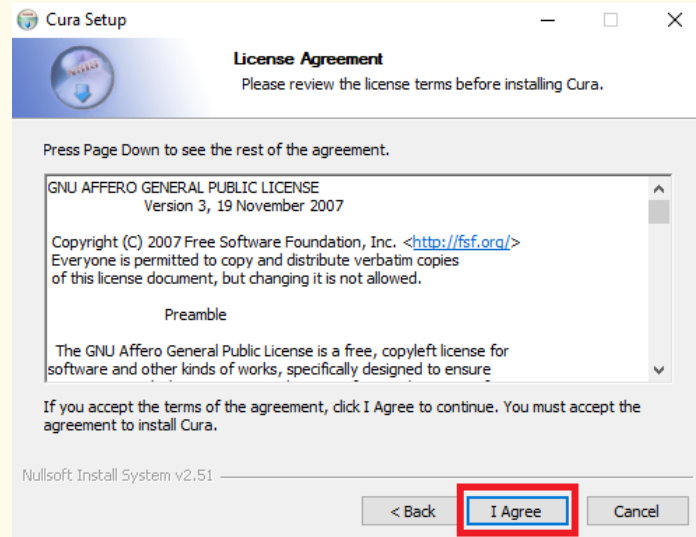


*Picture 12 – Cura's License Agreement*

STEP 4

Choose your desired install location, and then **Next**.



*Picture 13 – Installation folder*

STEP 5

Select **Next** again.
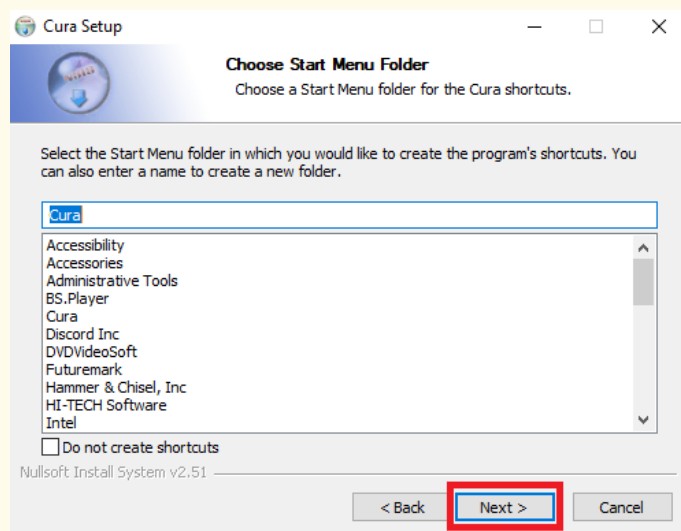


*Picture 14 – Start Menu Folder*

**STEP 6**

The user can add more options if desired, although they are not mandatory. Press **Install**.
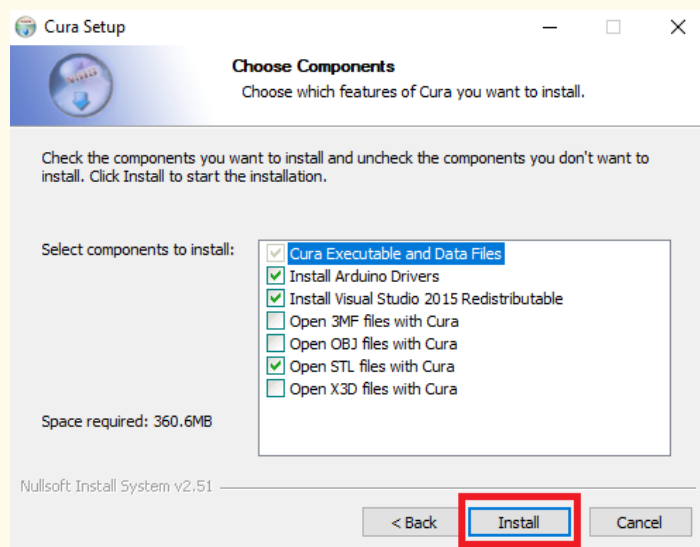


*Picture 15 – Choice of components*

**STEP 7**

Wait for the installation to be over.



*Picture 16- Installation process*

**STEP 8**

Click on finish. Cura is now installed.

# LESSON – ADDING YOUR PRINTER TO CURA

- **Study section:** 3D Printing Fundamentals

- **Lesson duration:** 1:00h

- **Educational objectives:**

  o How to add a printer to Cura.

- **Learning outcomes and acquired competencies:**
  o Plan and structure tasks;
  o Communicate concepts and ideas clearly;
  o Act with initiative and demonstrate analytical capacity;
  o Recommend solutions for problem-solving;
  o Demonstrate creativity, autonomy, and innovative spirit.

- **Main Keyword(s):**

  o 3D Printing
  o 3D Printer
  o Filament
  o Cura

- **Required material and resources:**

  o 3D printer
  o Computer
  o Internet

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## Adding your printer to Cura

**STEP 1**

After opening Cura, this workspace should be shown. Note that the version used is Cura 2.7.0. There may be some differences after updating to a new version.
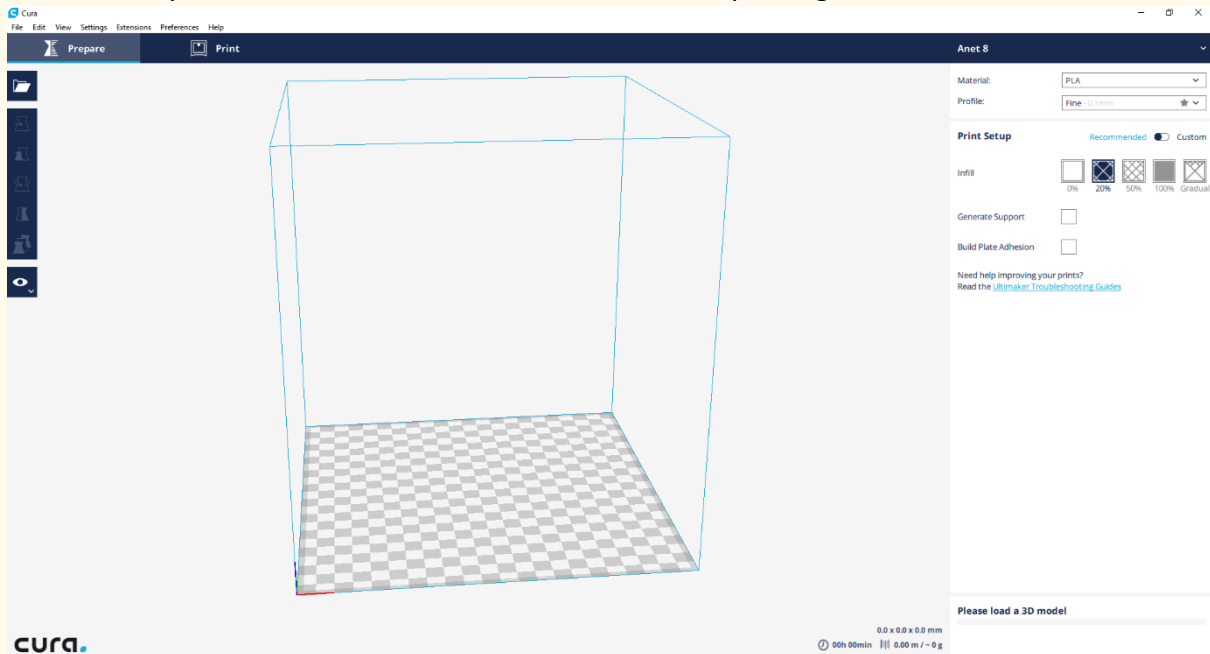


*Picture 17 – Cura's workspace*

**STEP 2**

Press **Preferences**, and then **Configure Cura.**
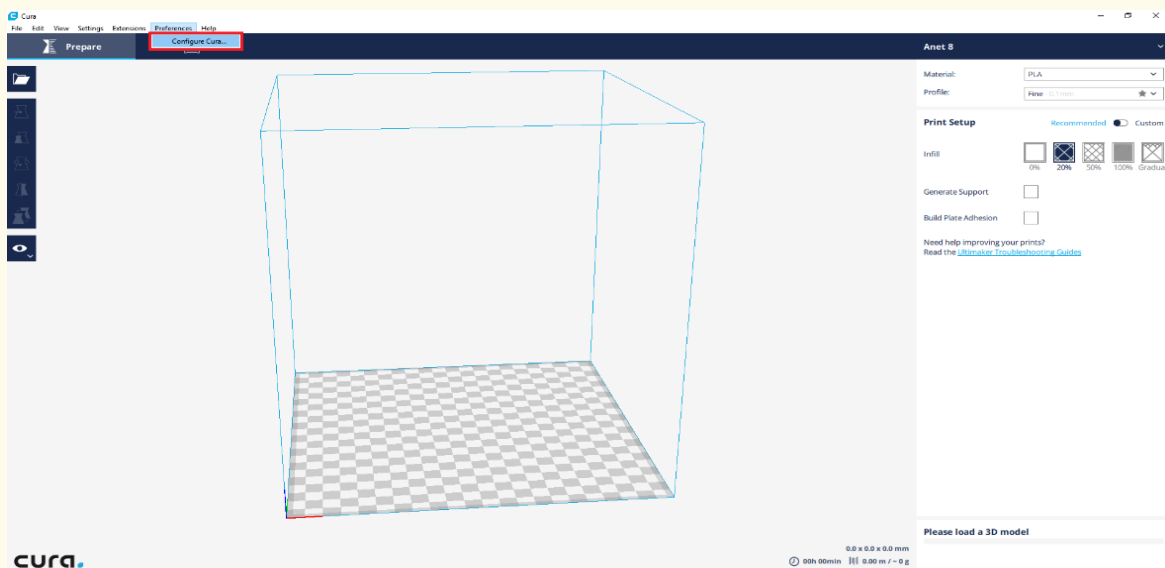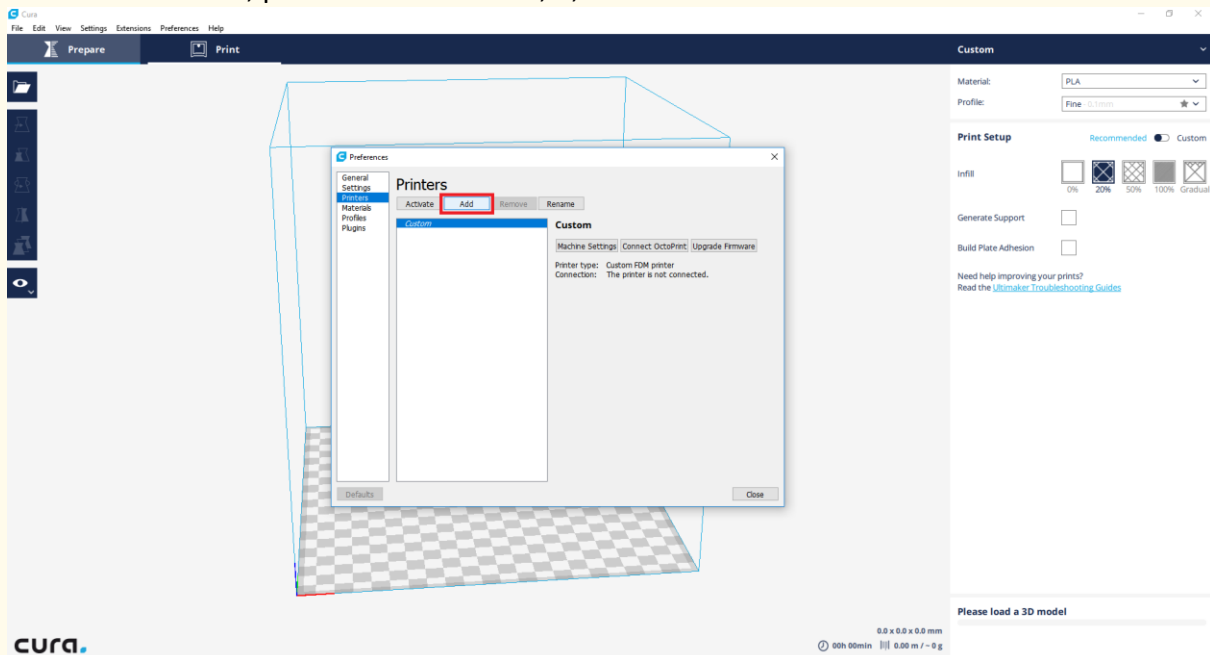


*Picture 18 – Cura's preferences menu*

**STEP 3**

Click on **Printers** tab.
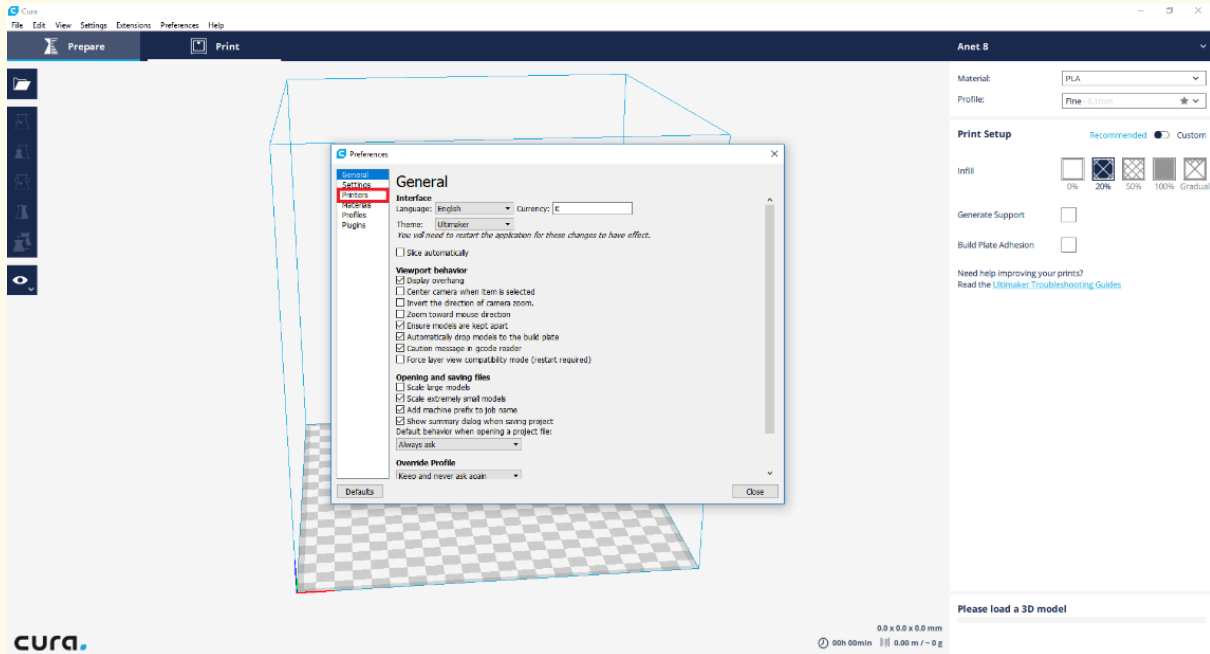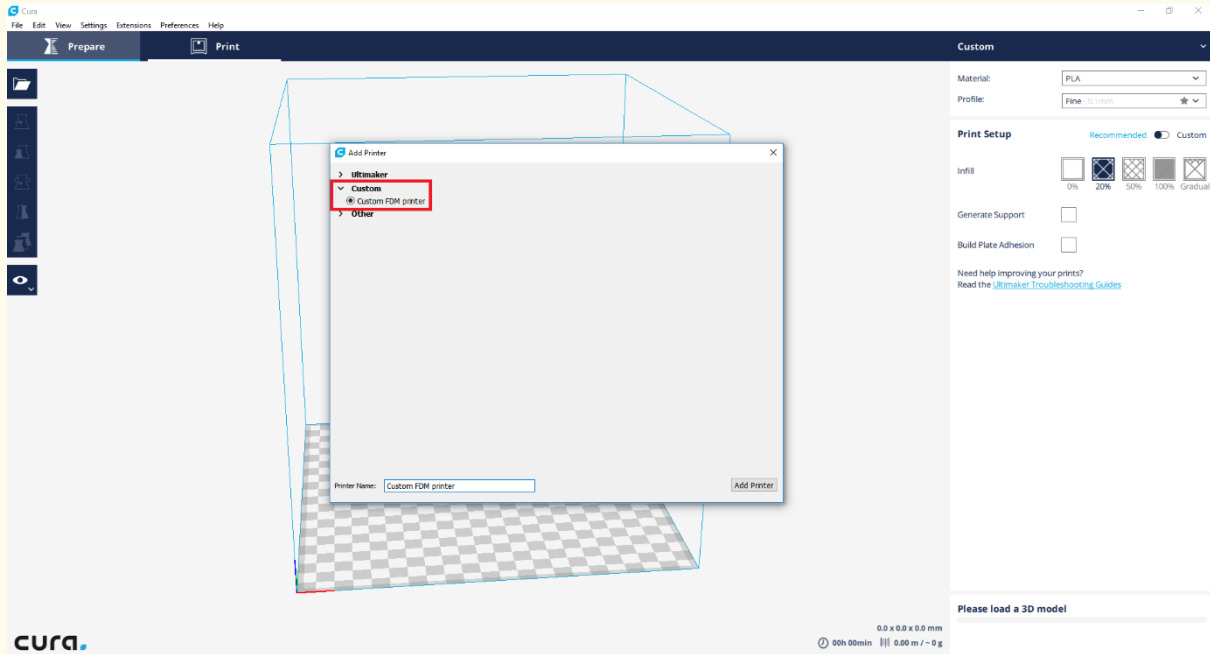


*Picture 19- Cura's configurations*

**STEP 4**

Click on **Add** and look for the name of the printer you will use. Then, click on **Add Printer**.
If it does not show, please follow STEPs 5, 6, and 7.


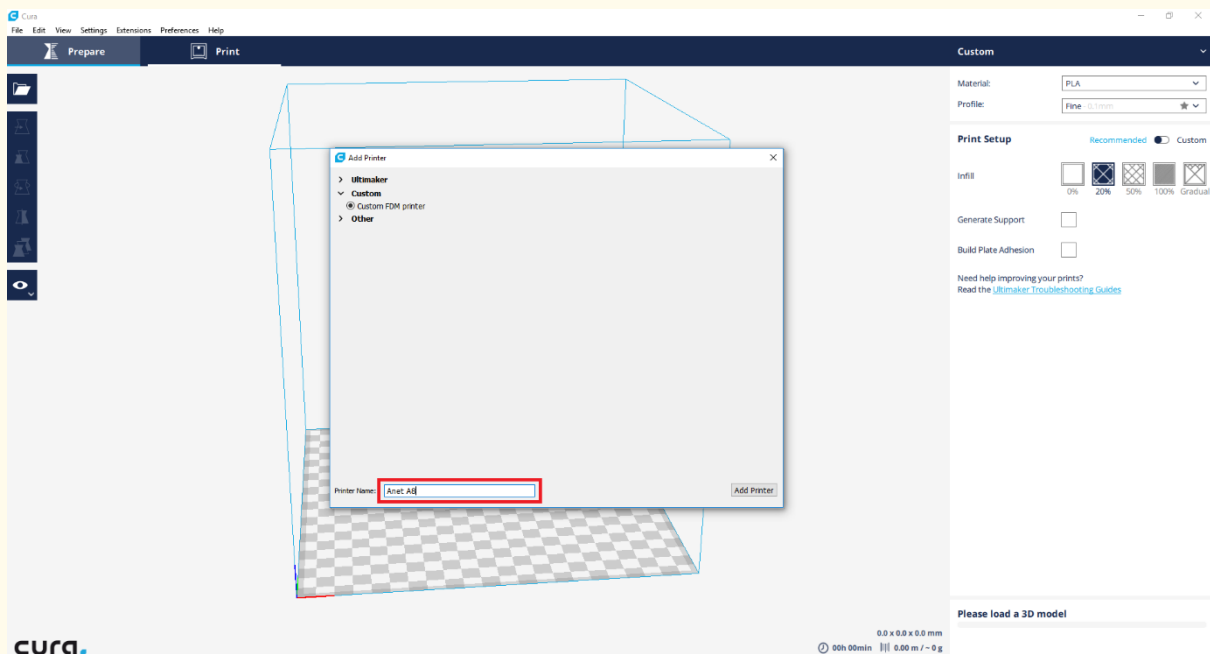
*Picture 20 – Adding a printer to Cura*

**STEP 5**

If the desired printer is not on the listed ones, choose the **Custom** option.
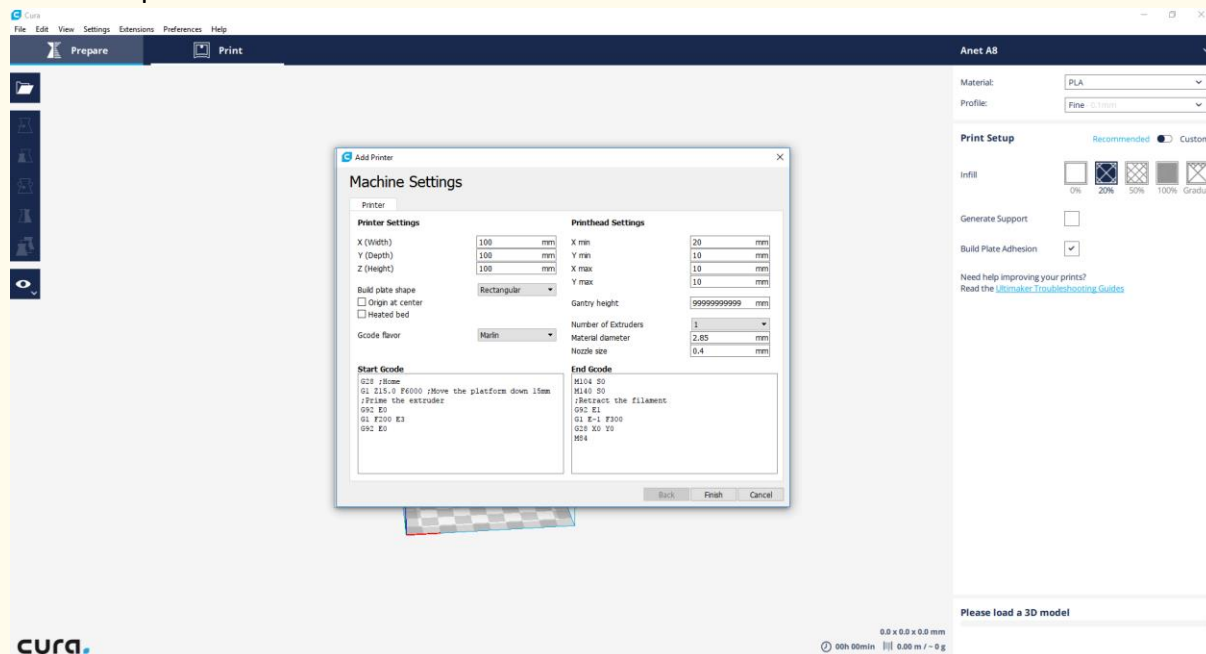


*Picture 21 – Finding a printer*

**STEP 6**

Choose one name for the printer you will be using.
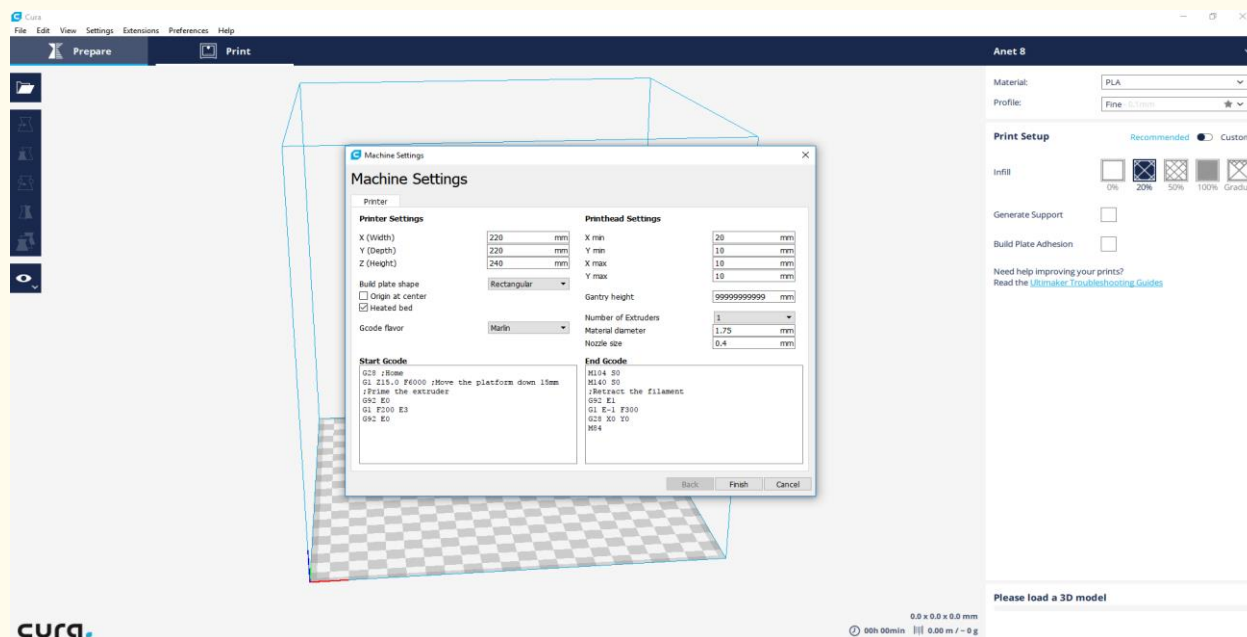


*Picture 22 – Naming the printer*

**STEP 7**

Choose the settings of your printer and then press **Finish**. You may find this information in the printer's documents or on the brand website.



*Picture 23 – Choosing the settings of the printer*

The printer used will be **Anet A8**, which is not part of the list of available printers yet.  So, settings need to be changed according to this printer. If the user intends to use this same printer, they may find the Machine Settings in the picture below.



*Picture 24 – Anet's A8 settings*

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# LESSON – CREATING AND IMPORTING STL FILES

- **Study section:** 3D Printing Fundamentals

- **Lesson duration:** 1:00h

- **Educational objectives:**

    o How to import STL files to Cura.
    o What is an STL file.

- **Learning outcomes and acquired competencies:**
    o Plan and structure tasks;
    o Communicate concepts and ideas clearly
    o Act with initiative and demonstrate an analytical capacity
    o Recommend solutions for problem-solving
    o Demonstrate creativity, autonomy, and innovative spirit.

- **Main Keyword(s):**

    o 3D Printing
    o 3D Printer
    o Filament
    o Cura

- **Required material and resources:**

    o 3D printer
    o Computer
    o Internet

## Importing STL files

For the user to implement the slicing process, they have to import the file. The most common files are STL and OBJ. In this module, the chosen file will be the STL one.

**STL** (**ST**ereo**L**ithography) is a file format from CAD software adequate to 3D systems. Many software support this format, and it is widely used in rapid prototyping, 3D printing, and computer-aided manufacturing. STL files describe only the surface geometry of a three-dimensional object without representing color, texture, or other common CAD model attributes.

The steps below show the user how to import the file to Cura.

**STEP 1**

Choose 1 file that is with STL.

**STEP 2**

To import an STL file to Cura, you can drag the file into the software or click on File > Open
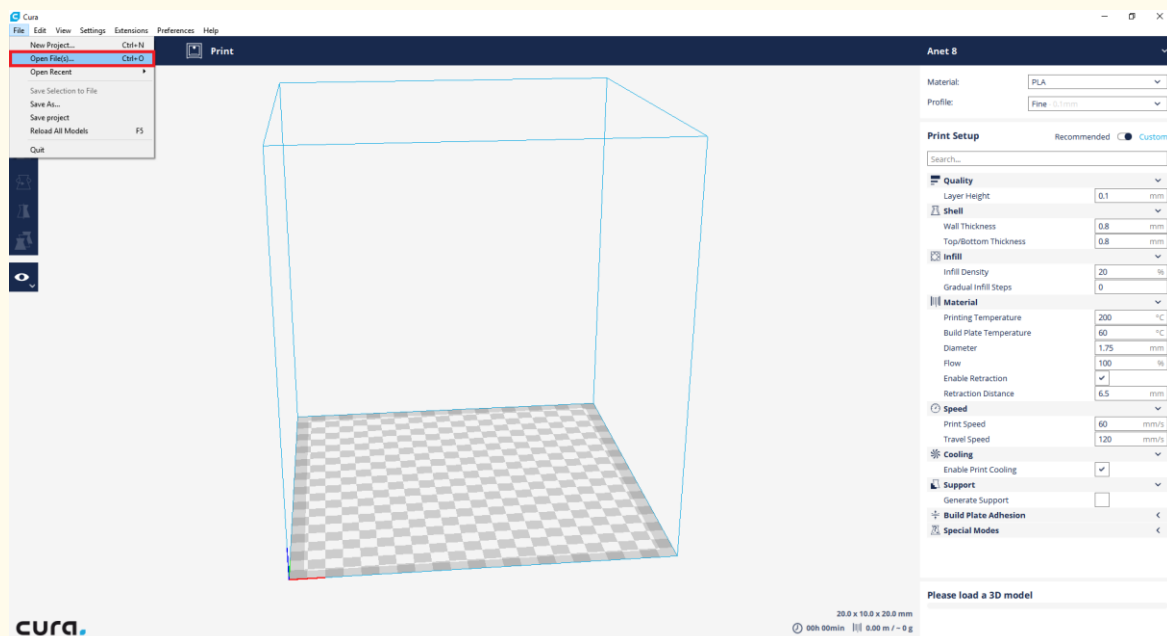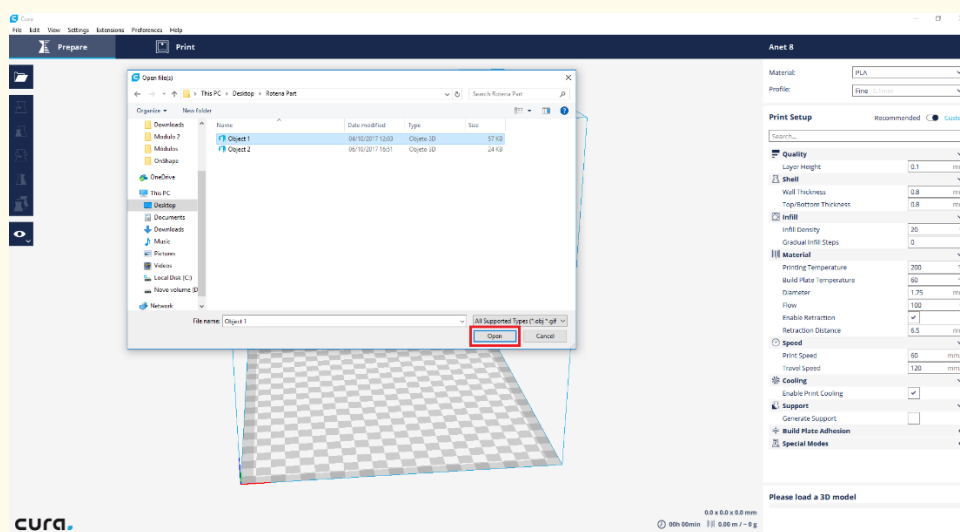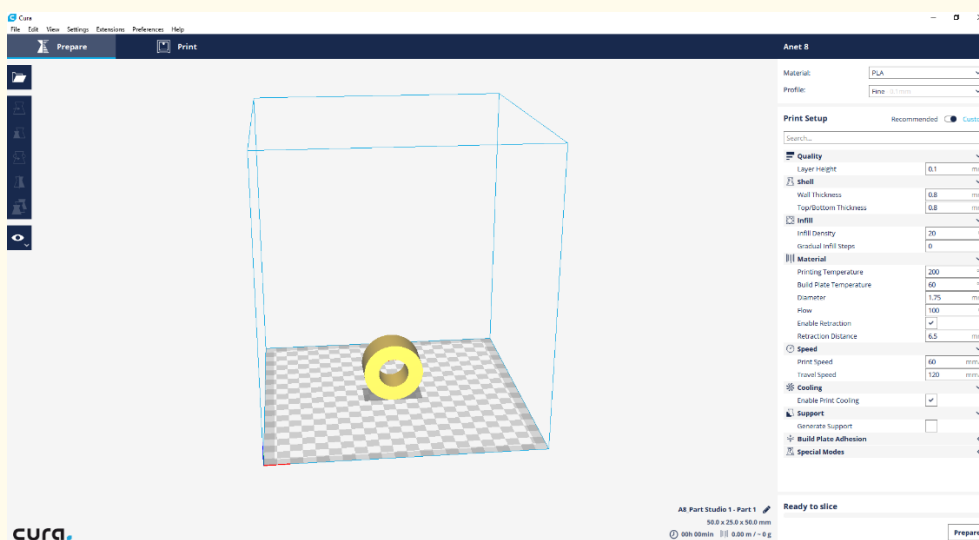


File.

*Picture 25*

**STEP 3**

Search for your downloaded STL file and click on the Open button.



*Picture 26*

The file has successfully been uploaded to Cura.



*Picture 27*

# LESSON – PLACING YOUR PART/OBJECT, AND SUPPORT STRUCTURES

- **Study section:** 3D Printing Fundamentals

- **Lesson duration:** 1:00h

- **Educational objectives:**

  - Strategies for a good 3D printing;
  - Know how to place a part in Cura;
  - Distinguish between a good placement and a bad one;
  - Know various types of supports for 3D printers and what they are used for;

- **Learning outcomes and acquired competences:**
  - Plan and structure tasks;
  - Communicate concepts and ideas clearly;
  - Act with initiative and demonstrate analytical capacity;
  - Recommend solutions for problem-solving;
  - Demonstrate creativity, autonomy and innovative spirit.

- **Main Keyword(s):**

  - 3D Printing
  - 3D Printer
  - Filament
  - Cura

- **Required material and resources:**

  - 3D printer
  - Computer
  - Internet

## Placing your part/object

Placing a part/ object into a slicer is a process that requires attention because, due to gravity, a thing cannot be printed at any given angle. Gravity should always be considered because this type of printing deposits filament layer by layer, and the selected printer operates from the bottom up. For example, if the object is printed in the position illustrated in Picture 30, the result will not be expected. This will happen because it will be flat on one area, as shown in Picture 31:
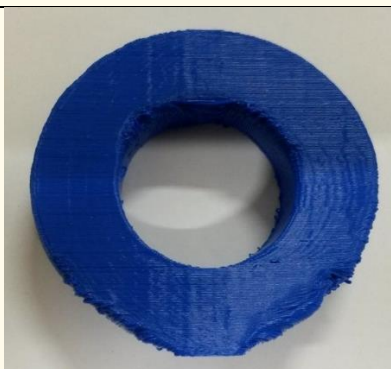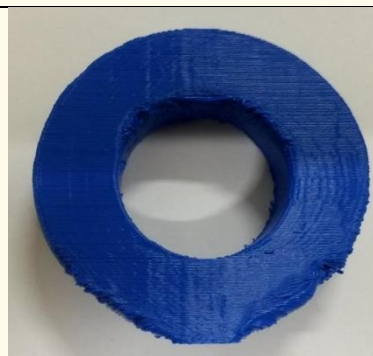


*Picture 29*



Flat Area
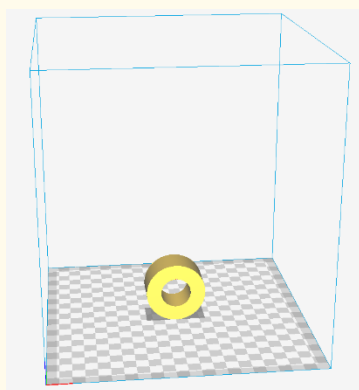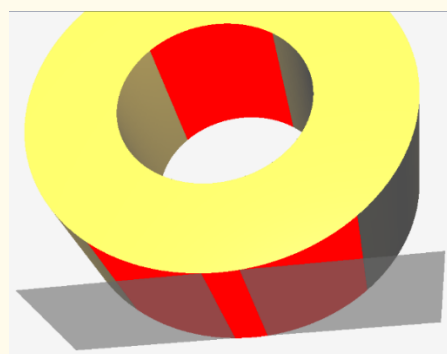
*Picture 30*

The part/object printed will look like this:



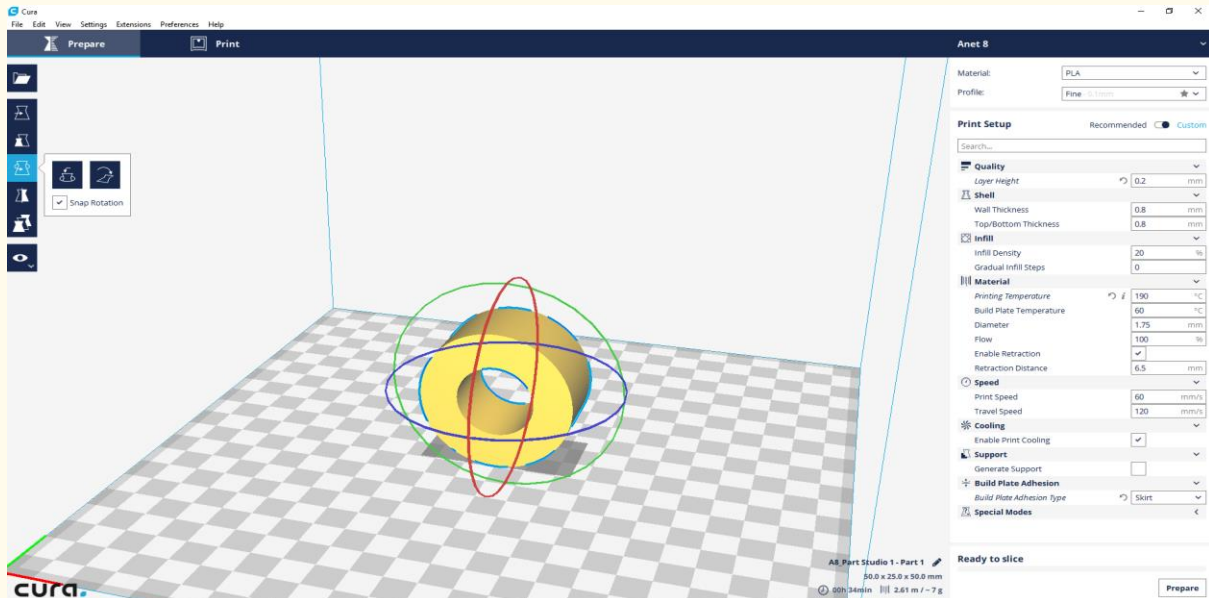*Picture 28 – Failed 3D Printed Object*



*Picture 29 – Failed 3D Printed Object*

So, to have the object in a higher quality, the user needs to rotate it, following the next steps:
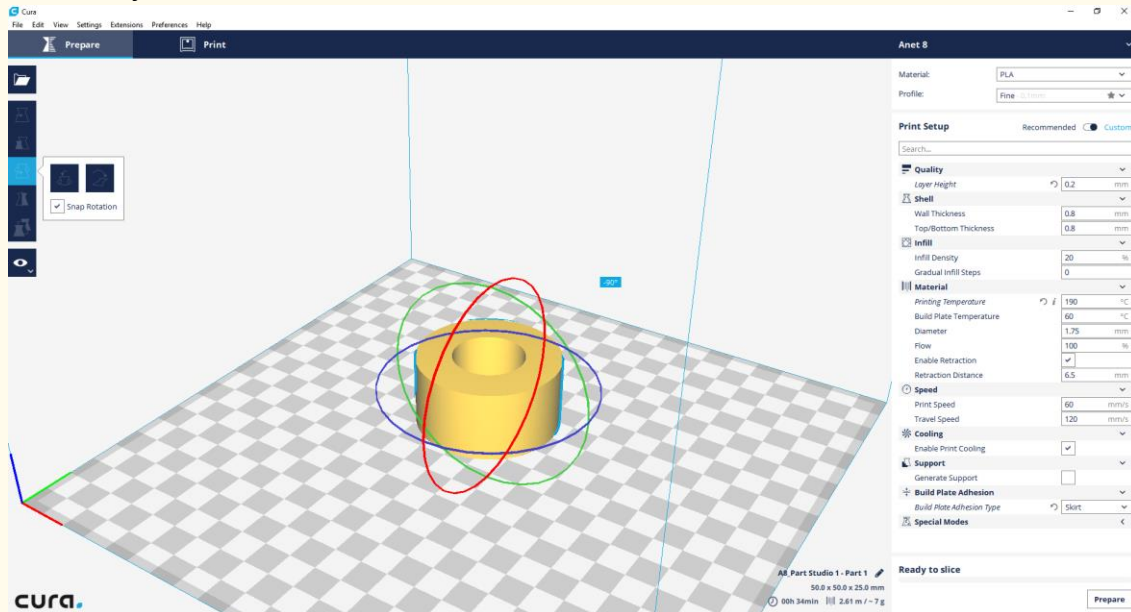
**STEP 1**

The user needs to click on the object with the **left mouse button**, click **rotate**, and choose one of the axes to rotate.
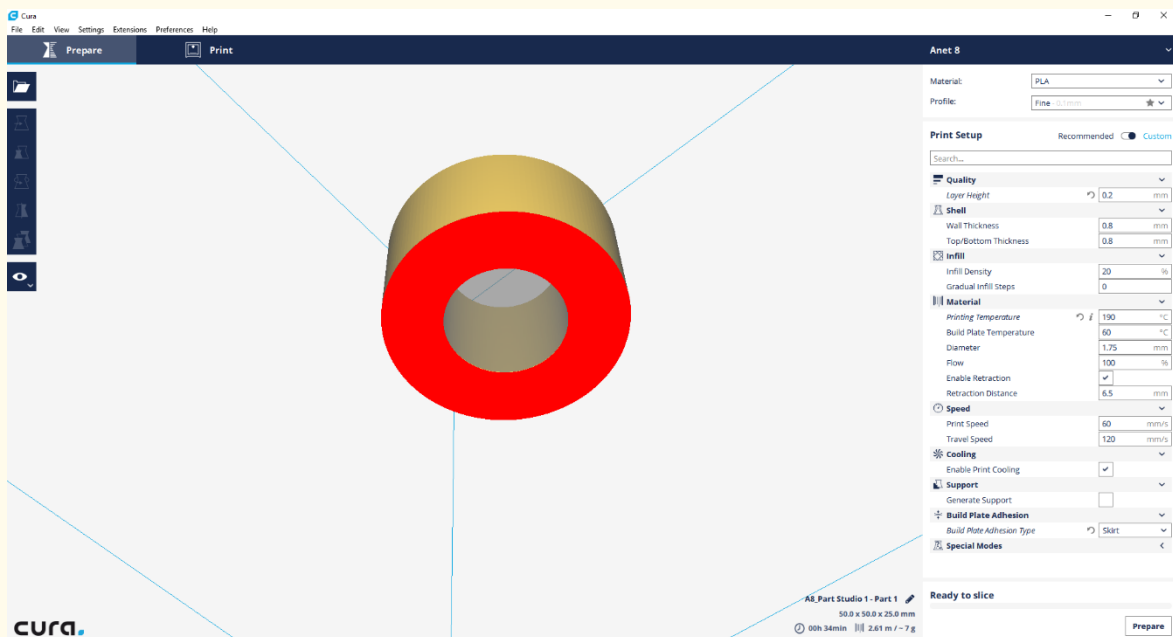


*Picture 30*

**STEP 2**

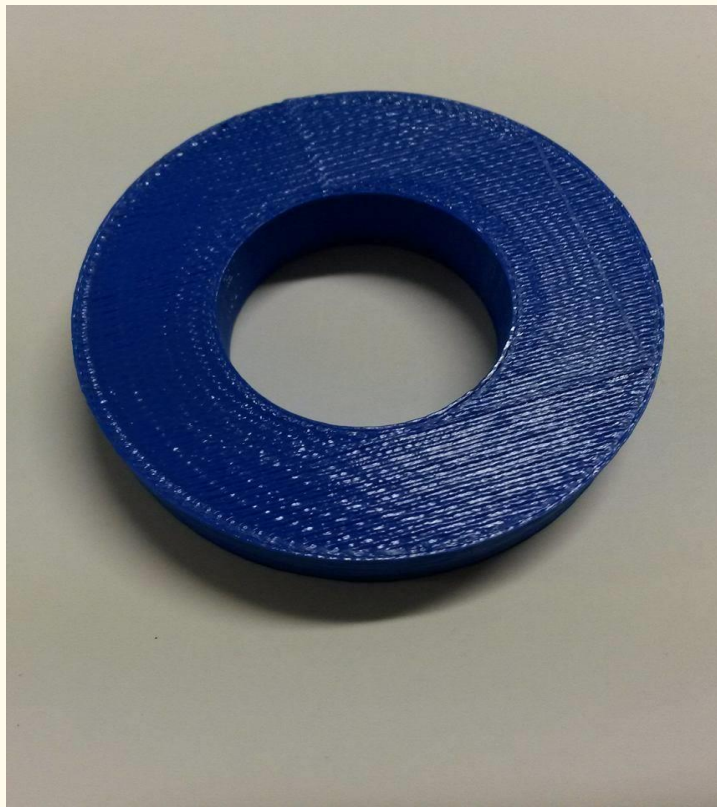Rotate the object 90º in the X axis.



*Picture 31*

Now the object can be printed with no gravity issues and no flat areas where they should

not be.



*Picture 32*

The printed part/object will then look like this:

*Picture 33 - Correctly 3D Printed Object*

## Support structures

A support structure is an auxiliary to successful 3D printing when the part's surface contact is insufficient.  This causes bad printing quality. To overcome that, support structures can be added to the original object, which will then be removed.
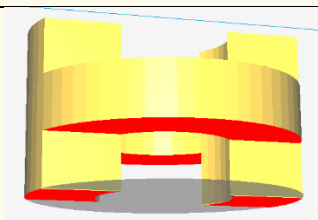


*Picture 34 – Original part/object*
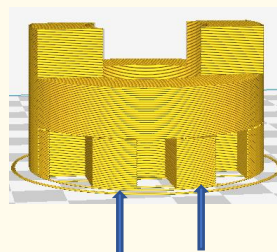


*Picture 35 – Already with the support.*

Next will be explained how to create and add the support structures.

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To add support structures, upload into Cura the file "Object 2.stl "and do the following steps:

**STEP 1**

Make sure the settings option is switched to **Custom**.
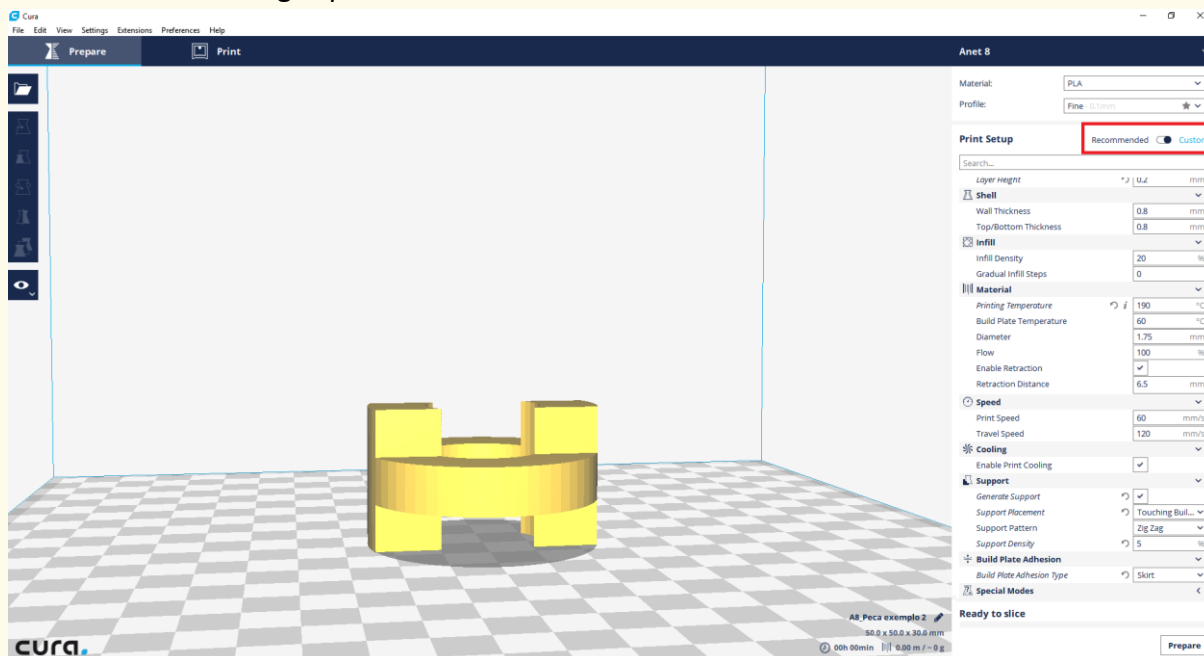


*Picture 36*

**STEP 2**

Tick the Generate support box.



*Picture 37*

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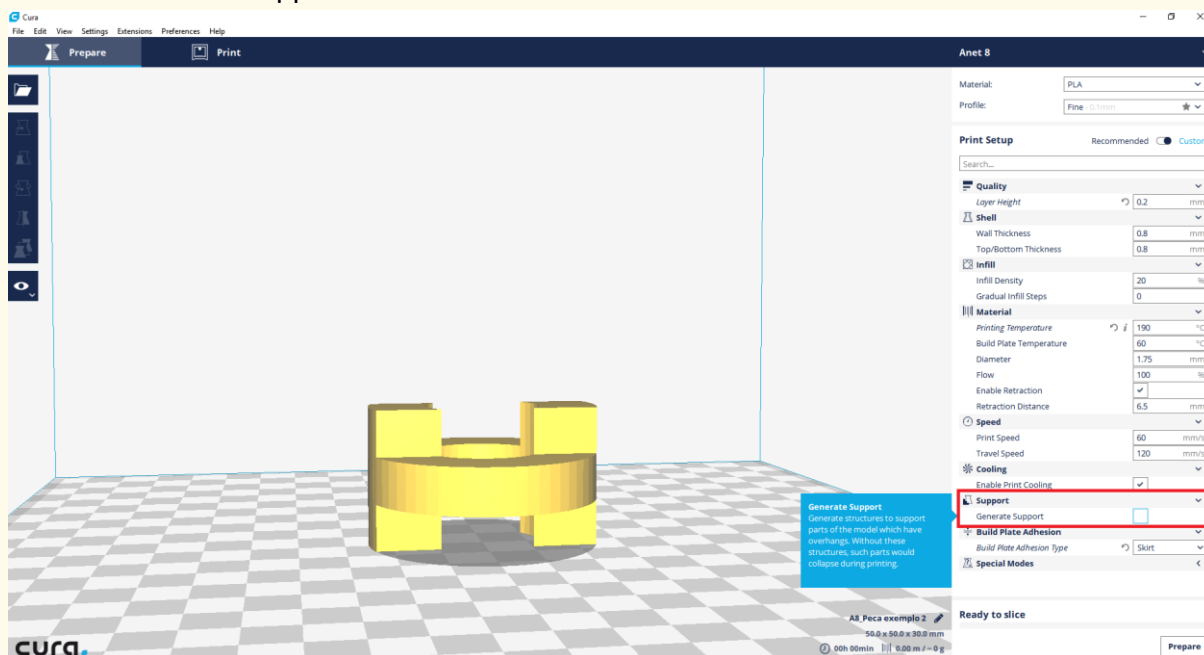
**STEP 3**

Select the support placement and choose **touching build plate only**. If the object requires support in areas other than touching build plate zones, unlike the selected object, choose then everywhere.
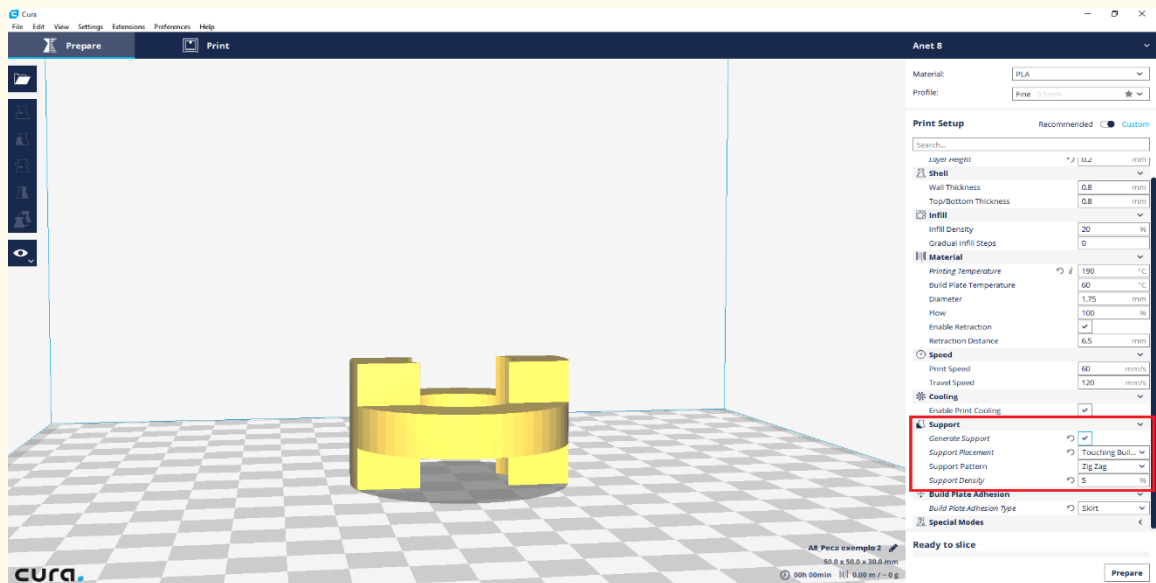


*Picture 38*

To check out how the support structure will be built, it is possible to change the view mode from **Solid** to **Layers**.
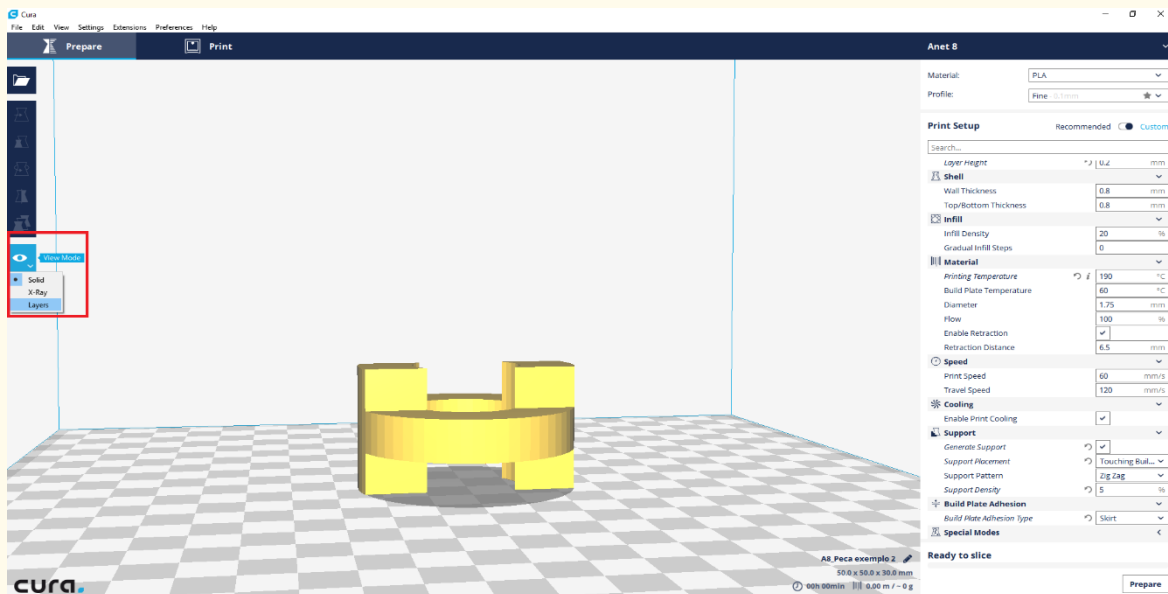


*Picture 39*

The result will be the following:



*Picture 40*

**STEP 4**

Rotate to see the support structure.



*Picture 41*

## Types of thermoplastic filaments

To print, it is necessary to have a thermoplastic filament. There are several types of thermoplastic filaments. The table presents some of the most common ones, with the respective pros and cons and the recommended printing temperatures.

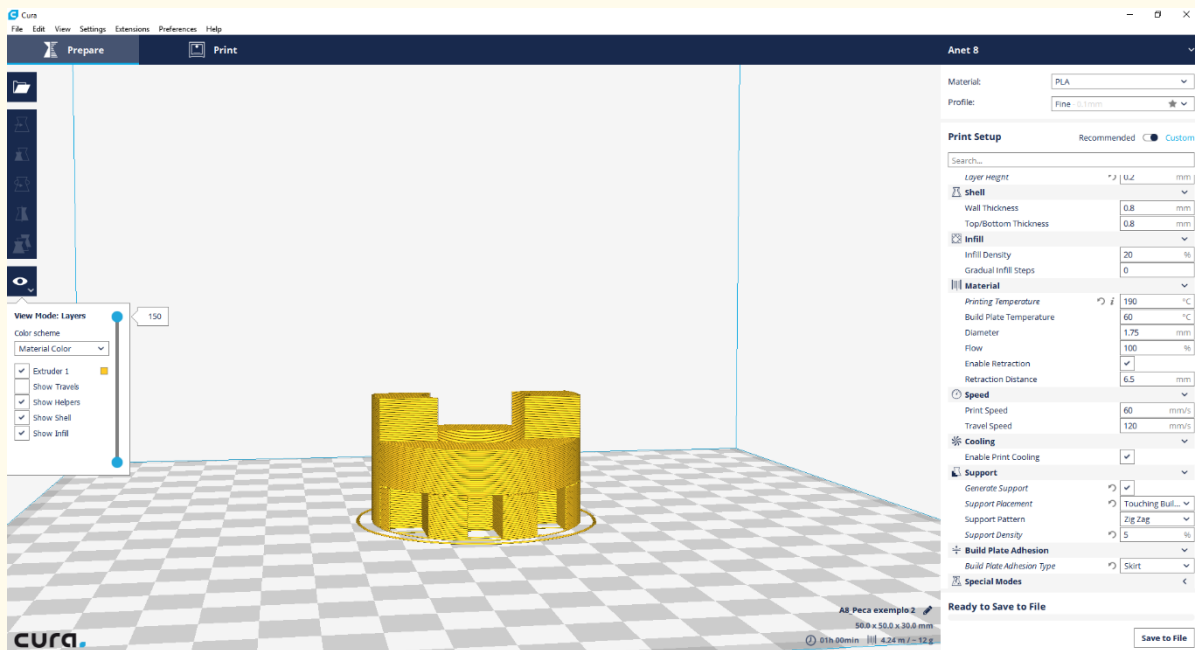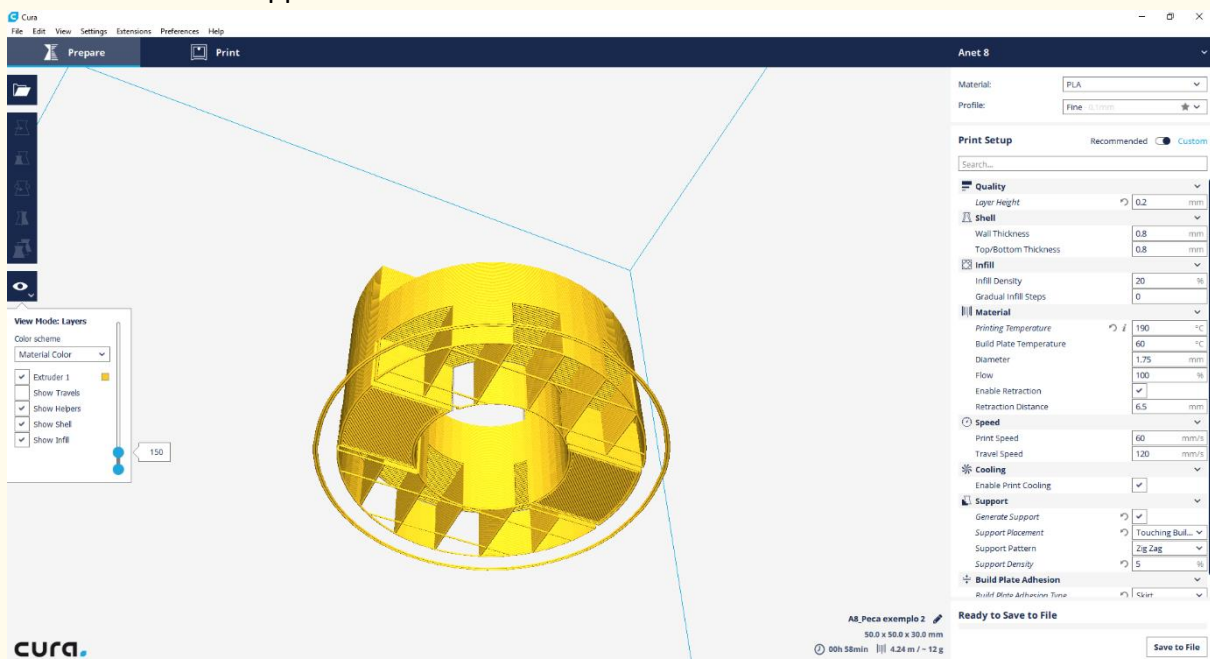| Material | Pros | Cons | Print Temperature | Build Plate Temperature |
|---|---|---|---|---|
| **PLA – Polyactic Acid** | -Easiest material to work with;<br><br>-Less prone to warping compared to ABS;<br><br>-Good for beginners; | -Prone to clogging the printer nozzle;<br>-Attract water molecules, making it difficult to print; | 190ºC-220ºC | 50ºC-70ºC |
| **ABS – Acrylonitrile Butadiene Styrene** | -Very durable and strong;<br><br>-Cheapest thermoplastic in the market; | -Petroleum-based non-biodegradable plastic;<br>-High temperature needed to print;<br><br>-Creates mild fumes that can irritate users and surrounding people; | 210ºC-250ºC | 70ºC-100ºC |
| **PVA – Polyvinyl Alcohol** | -Non-toxic and biodegradable;<br><br>-Soluble in water;<br><br>-Low flexibility and safe for food; | -Not easy to use;<br><br>-Costly compared to other materials; | 180ºC-230ºC | 45ºC-50ºC |
| **PET – Polyethylene Terephthalate** | -Easy to print;<br>-Hard and shockproof;<br>-Wide temperature print range; | -Stores a water from ambient, needs to be stored very well. | 230ºC-255ºC | 45ºC-50ºC |
| **Nylon** | -High strength, durability and flexibility;<br>-Can re-melt and use again without losing bonding properties; | -Very high melting temperature;<br>-When heated will break down and emit toxic fumes; | 240ºC-250ºC | 60ºC-80ºC |
| **Wood** | -Contain real wood fibres;<br>-Can change shades of brown with temperature; | -Softer and weaker compared to PLA;<br>-Reduced flexibility and tensile length,<br>-Breaks easily; | 200ºC-260ºC | 90ºC-110ºC |

*Table 1 - Types of filament*

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# LESSON – TYPES OF FILAMENT

- **Study section:** 3D Modelling

- **Lesson duration:** 1:00h

- **Educational objectives:**

  o Understand what a 3D printing filament is

  o Get to know about different types of filament

- **Learning outcomes and acquired competencies:**

  o Have a good understanding of the different types of filaments and what they

  are for.

- **Main Keyword(s):** filament

- **Required material and resources:**

> **Brief definition of a 3D Printing Filament**
>
> 3D printing filament is the thermoplastic feedstock for fused deposition modeling 3D printers.

## Filaments in 3D Printing

The facilitator starts the lesson by explaining to the participants what are filaments and how they can be used in 3D printing. The following text is provided:

The filament is the raw material that is used in 3D printing. Filaments used in 3D printing are thermoplastics, plastics (aka polymers) that melt rather than burn when heated, can be shaped and molded, and solidify when cooled. The process of printing with plastic filament is called either fused filament fabrication (FFF) or fused deposition modeling (FDM). The filament is fed into a heating chamber in the printer's extruder assembly, where it is heated to its melting point and then extruded (squirted) through a metal nozzle as the extruder

assembly moves, tracing a path programmed into a 3D object file to create, layer by layer, the printed 3D object. Although most 3D printers have a single extruder, some dual-extruder models can print an object in different colors or with varying filament types.
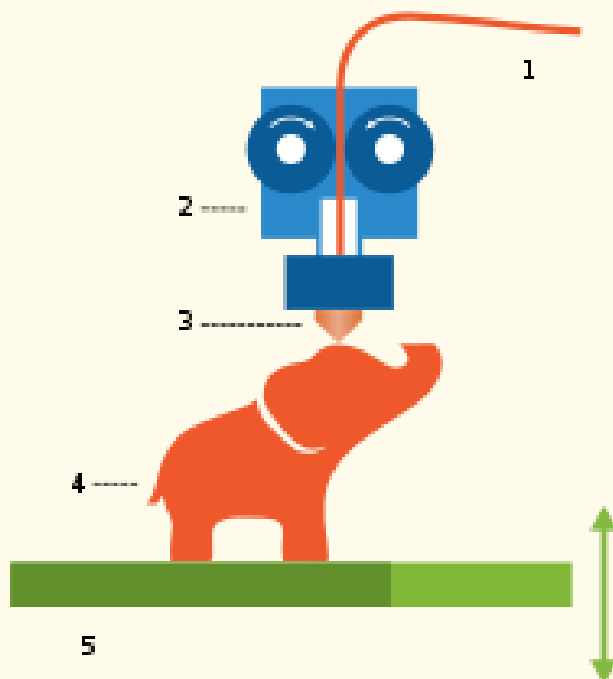


*Figure 1 The process of turning 3D printing filament into a 3D model, source: https://en.wikipedia.org/wiki/3D_printing_filament#/media/File:Filament_Driver_diagram.svg*

## Types of filaments

Several types of filaments are available in the market based on the raw material used, with different properties, requiring different temperatures to print, setting aside the numerous colors they come in.

Filaments may be comprised of polylactic acid, polyvinyl alcohol, carbon fiber, and tongue-twisty thermoplastic elastomers. Various acronyms are used for filaments, such as ABS, PLA, HIPS, CPE, PET, PETT, TPE, PVA, and PCTPE.

*Figure 2 Types of 3D Printing Materials, source:* [https://3dinsider.com/3d-printing-materials/](https://3dinsider.com/3d-printing-materials/)

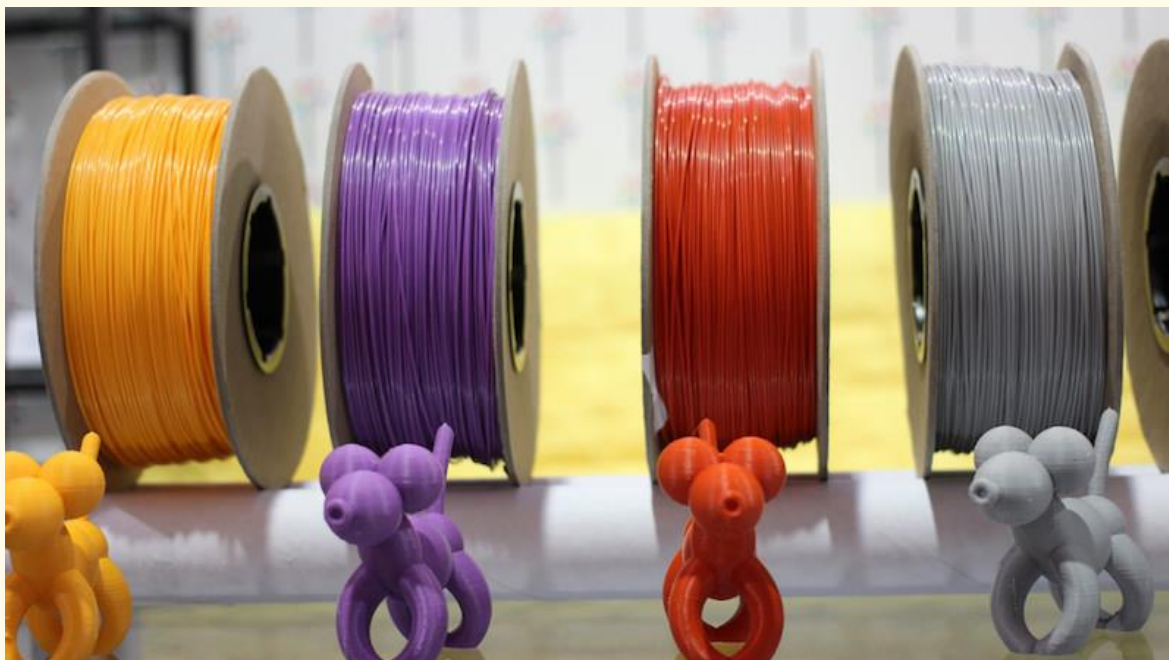The most common filament types are acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), Polyethylene Terephthalate (PET), and a Glycol Modified version of PET (PETG).

Objects printed from ABS are tough, durable, and non-toxic. It has a relatively high melting point, with a print temperature ranging from 210 degrees to 250 degrees Celsius.

PLA has a relatively low melting point, with usable temperatures between 180 degrees and 230 degrees Celsius. It is plant-based and biodegradable. It's harder than ABS, prints without warping, and is generally easy to work with.

PET and PETG filaments are known for their ease of printability, smooth surface finish, and water resistance. PETG is commonly used to manufacture water bottles. It is a semi-rigid material with good impact resistance, but it has a slightly softer surface, making it prone to wear. The material also benefits from great thermal characteristics, allowing the plastic to cool efficiently with almost negligible warpage. There are several variations of this material in the market, including PETG, PETE, and PETT, which will not be analyzed further.

In addition to the thermoplastics that comprise the common 3D printer filament types (such as the PLA mentioned above, ABS, PET, and PETG), 3D printer filament can be (or consist of) the likes of nylon, polycarbonate, carbon fiber, polypropylene.

Nylon is an incredibly versatile synthetic material developed in the 1930s that can also be used as a 3D printer filament. It is strong and durable yet flexible and among the lowest-priced 3D printing filaments. It melts at a higher temperature (about 240 degrees Celsius) than most filaments.

Polycarbonate (PC) 3D Printer Filament, also known as PC filament, is a strong thermoplastic material used in 3D printing. It is a really strong material while still maintaining temperature resistance. Polycarbonate does not shatter like plexiglass. It tends to bend and deform, similar to hard rubber, until it eventually breaks. It also has high optical clarity.

Carbon Fiber filament contains short fibers infused into a PLA or ABS base material to help increase strength and stiffness.

Polypropylene, abbreviated PP, is a common household plastic prized for its unique set of properties. For 3D printing, PP filament is excellent for applications that need to be light, water-tight, or durable.

- **Bibliographic (references):**

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**LESSON – SAFETY RULES WHILE 3D PRINTING**

- **Study section:** 3D Modelling

- **Lesson duration:** 2:00h

- **Educational objectives:**

  o Become aware of possible 3D printer hazards;

  o Become aware of basic safety rules that should be kept while 3D printing.

- **Learning outcomes and acquired competencies:**

  o Be aware of errors to avoid and good practices to follow to maintain safety.

- **Main Keyword(s):** 3D printing, safety rules

- **Required material and resources:**

> **Brief definition of Safety rules**
>
> A principle or regulation governing actions, procedures or devices intended to lower the occurrence or risk of injury, loss and danger to persons, property or the environment (GEMET, 2021).

## 3D Printer hazards and EC standards for machinery

The facilitator starts the lesson by explaining to the participants first the possible 3D printer hazards and then the importance of keeping some safety rules while 3D printing. The following text is provided:

While 3D printing, it is important to be aware of the possible 3D printer hazards, which include but are not limited to:

- The generation of ultrafine/nano-sized particles;

- Heat;

- Mechanical hazards from moving parts;

- High voltage;

- Ultraviolet light; and

- Depending on the media being used, chemical vapors (ex. styrene, acrylonitrile, or formaldehyde, etc.) depending on the media being used.

The user should make sure that the manufacturer of the 3D printer or his authorized representative has carried out a risk assessment that determines the health and safety requirements that apply to the particular 3D printer and is in alignment with harmonized standards that have been set by the European Commission (European Commission, 2018).

## Safety rules while 3D printing

To ensure that none of the participants will be endangered for any of the above reasons or others, we must keep in mind the following safety rules while 3D printing:

- When 3D printers are running, users should not congregate around the printing operation to minimize the inhalation of particulates being created.

- When possible, 3D printers should be placed in areas designed as labs and/or in appropriate areas for their use, increasing ventilation rates (6-12 air exchanges per hour).

- There shall be no eating, drinking, applying cosmetics, chewing gum, or handling contact lenses in rooms that contain 3D printing operations.

- Wash hands thoroughly after 3D printing.

- All work surfaces must be cleaned by a wet method. Sweeping and other dry methods can create airborne particles.

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# LESSON – HAVING A SUCCESSFUL PRINT

- **Study section:** 3D Modelling

- **Lesson duration:** 2:00h

- **Educational objectives:**

  o To safeguard a successful 3D printing by becoming aware of potential risks

  and failures during the 3D printing process.

- **Learning outcomes and acquired competencies:**

  o Know when a print was made without any problem.

- **Main Keyword(s):** successful, 3D printing

- **Required material and resources:**

> ### Brief definition of 3D filament moisture saturation
>
> Some 3D printing filaments are hygroscopic, meaning that they absorb moisture from the air, prolonged exposure to even moderately humid room air causes moisture saturation.

> ### Brief definition of Bed adhesion
>
> Bed adhesion is the ability of 3D printed plastic to "stick" to the build plate while printing. When 3D prints do not stick to the build plate, you can get curled, shifted, and disastrous results.

## Introduction

3D printing has already become a key technology multidisciplinary educational tool and has many applications, spanning education levels and subjects, potentially helping students and youth of today to become the innovators of tomorrow.

## How to ensure a successful 3D print

Green STEAM Incubator

First, the facilitators need to familiarize themselves with 3D printing and acquire basic knowledge of scanning and design, print preparation, printing, and post-processing. Specific topics with which facilitators should familiarize with are:

- Unboxing, printing, and post-processing.
- Making 3D models printable.
- Implementation advise and curriculum examples.

The next step is to design a curriculum that incorporates 3D printing. The Green STEAM Incubator has carefully designed such a curriculum, with lessons and specific practical examples, which can be used. Overall, a multidisciplinary understanding of key Additive Manufacturing (AM) is required (related knowledge areas—material science, design, engineering, etc., along with a broader, more creative, and innovative mindset.

## Tips for a successful 3D print in practice

For securing a successful 3D print in practice, here are some tips that you can consider while 3D printing.

**Moisture affects 3D printing filaments**

Some 3D printing filaments are hygroscopic; that is, they absorb moisture from the air. Therefore, prolonged exposure to even moderately humid room air causes moisture saturation. If that happens, you need to ensure that the filament has not been exposed to moisture before the print. If that happens, an increased filament diameter of even 20 – 40 microns (roughly the width of a human hair) can derail a build before it ever begins. Indications of possible moisture Content in failed 3D printing products:

- Filament cracks or makes a popping noise as the filament is pushed through the extruded
- Holes in the top of parts
- Extruder tip bubbles with a tiny burst of steam, stringy or drooly
- The filament will not adhere to the print bed
- Repeated builds seem inconsistent or fail no changes in variables
- Extruder motor stops, but filament keeps coming out
- Extruder motor starts, but filament extrusion is delayed

- Parts become soft, fragile, and break easily
- Extruder jams

For preventing all the above, it is suggested that 3D printing filaments are stored in storage spaces/cabinets.
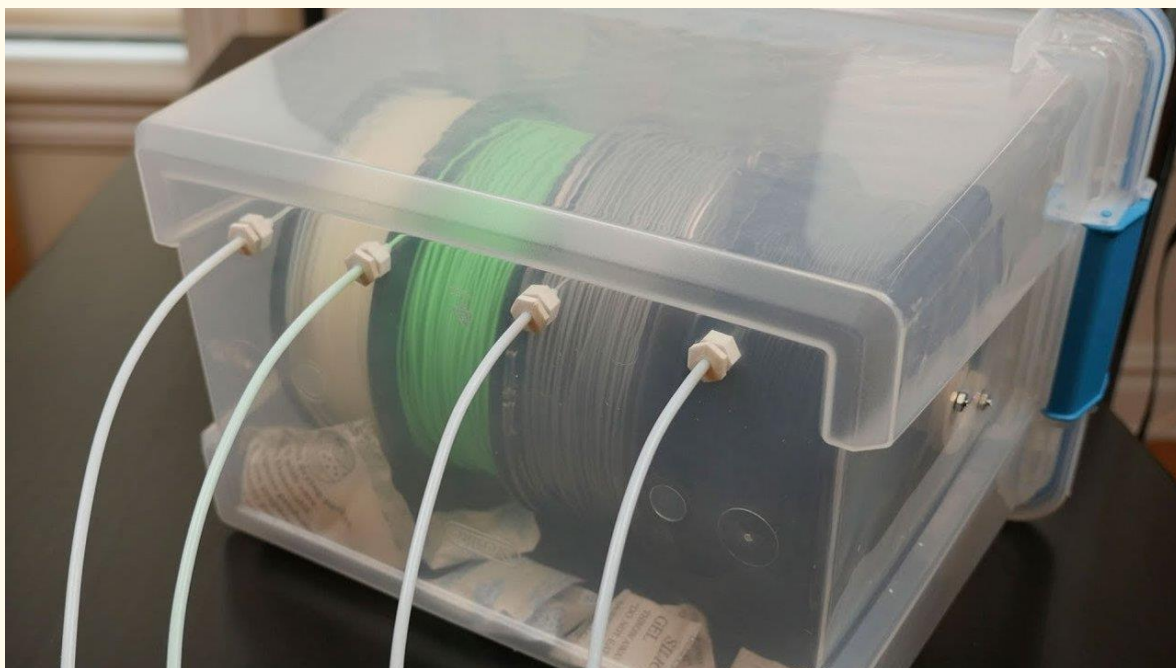


*Figure 1 3D Printer Filament Storage, source: https://all3dp.com/2/filament-storage-3d-printer/*

**3D Printer Bed Adhesion**

Bed adhesion is the ability of 3D printed plastic to "stick" to the build plate while printing. However, there is a possibility that the 3D prints do not stick to the build plate, which results in curled, shifted, and disastrous results. For avoiding such a failure, you can use varying types of 3D printing surfaces to get objects to stick to the plate while 3D printing. Usually, 3D printers use aluminum, stainless steel, glass, Buildtak, kapton tape, PET tape, masking tape, or PEI film to this end.

Tips for improving adhesion:

- add brims to the base of prints in order to increase the contact surface area.
- adjust nozzle temperature and avoid thermal expansion taking appropriate precautions during 3D printing.
- alter fan speed since the fan's speed during the first layer and the entire print can have an effect on print adhesion. The longer the plastic is molten, the better it will adhere.

- adhere filament to the bed so that the nozzle is at a consistent and reasonable distance from the build plate. For doing so, level the build plate to ensure that the molten filament is close enough to the build plate to stick.

- use a 3D printed brim to increase the surface area that the print has with the build surface.

- clean the build plate with rubbing alcohol and a microfiber cloth each time before printing.

- cut your model in half, and then bond the halves together with glue. With the use of this technique, your model will not have an artificial flat surface but will have a glue seam.
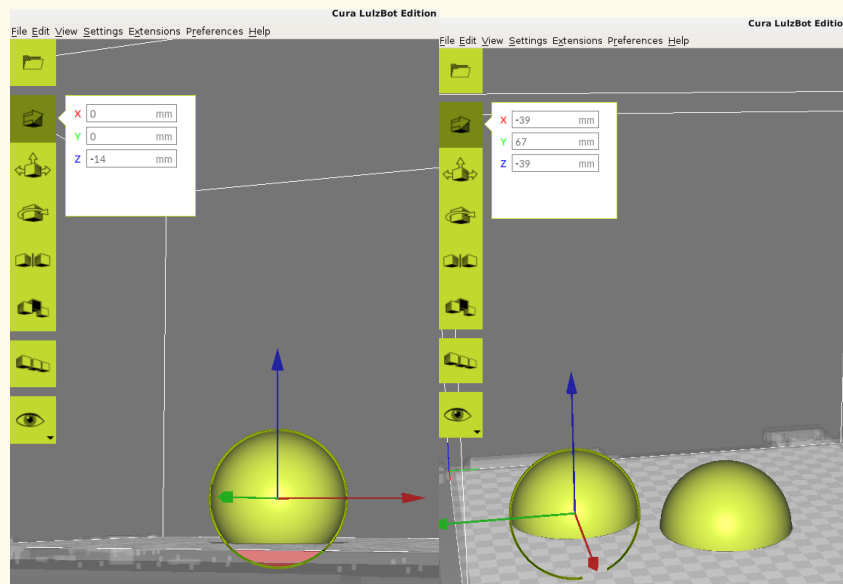


*Figure 2 Maximizing Bed Adhesion, drop the base (left), divide the object in two halves (right) source: https://bit.ly/3oHNWmq*

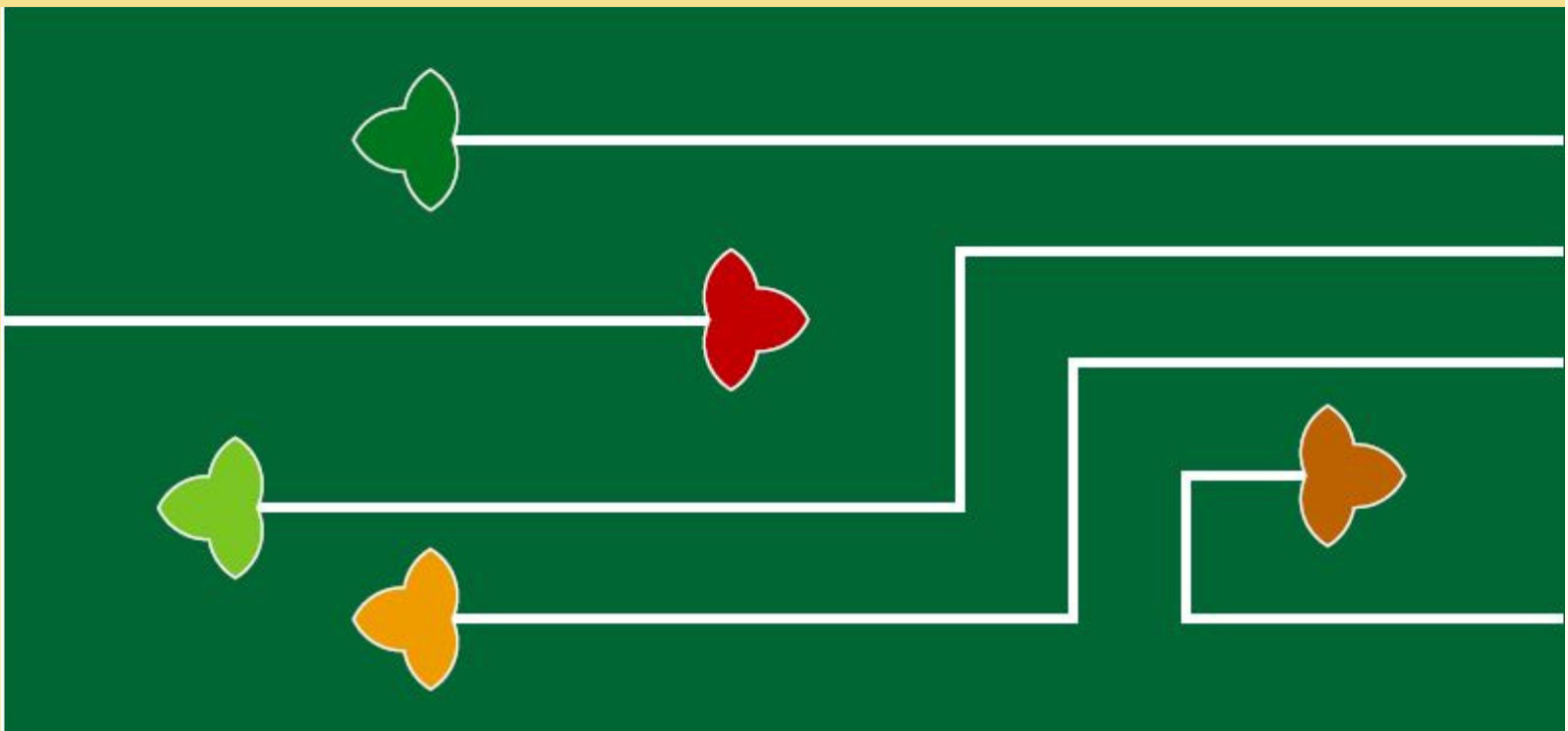- **Bibliographic (references):**

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