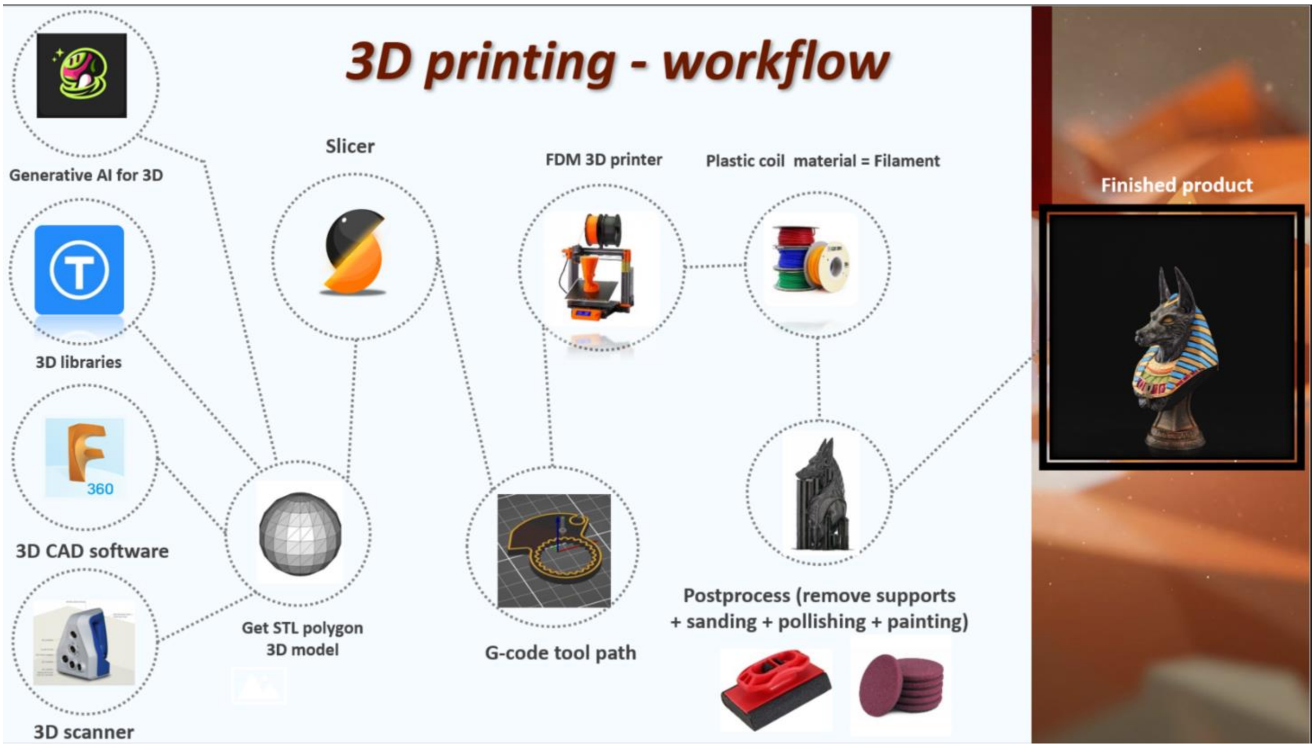
1 *The workflow of FDM 3D printing process*



1.1 Online library full of 3D models

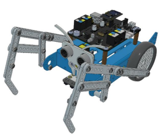
The most common way to start with 3D printing is to ***download models from the internet.***

A ***large number of 3D models are available for free*** created by enthusiasts from all over the world.

Here is a list of libraries full of useful 3D models from mechanical parts, various accessories, household items to DND figures and more :

- https://www.printables.com/
- https://www.thingiverse.com/
- https://cults3d.com/
- https://www.myminifactory.com/

Place for notes

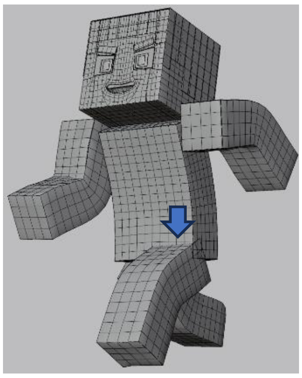


1.2 3D Software modeling techniques

There are many advanced ways to create a 3D model, here are some of the techniques :

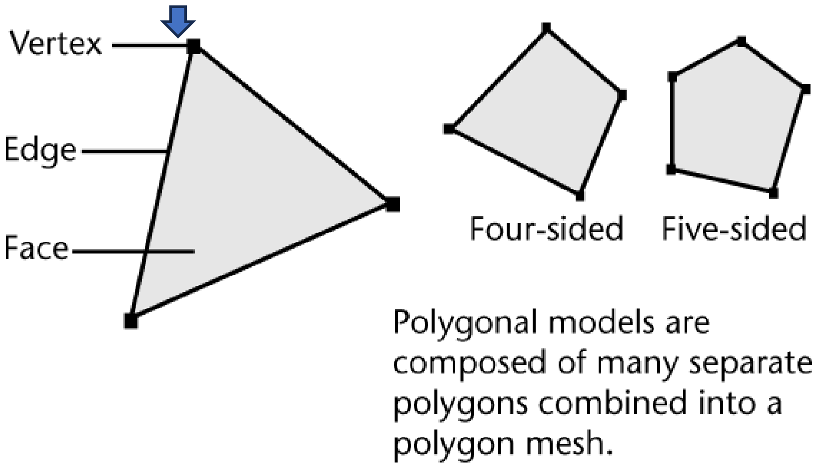
1. **Polygonal modeling**
2. **NURBS**
3. **CAD**
4. **Digital sculpting**

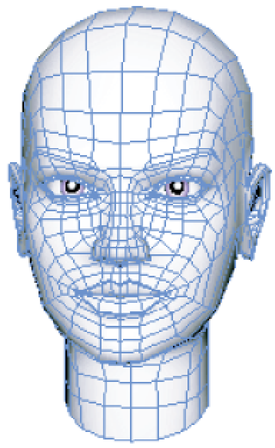
1. Polygonal modeling



Polygonal modeling involves creating a 3D polygonal ***mesh (a patchwork of polygons – triangles** or other simple digital geometric figures).*

Essentially a polygon 3D model starts as a very simple shape, and details are eventually added by splitting it into many pieces and deforming their position





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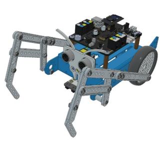
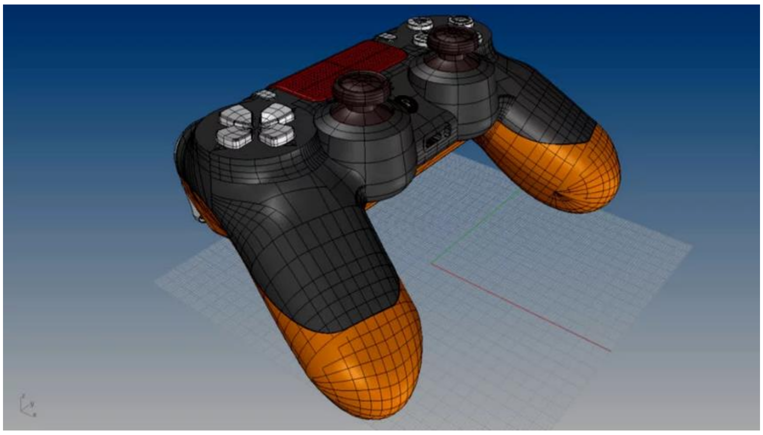
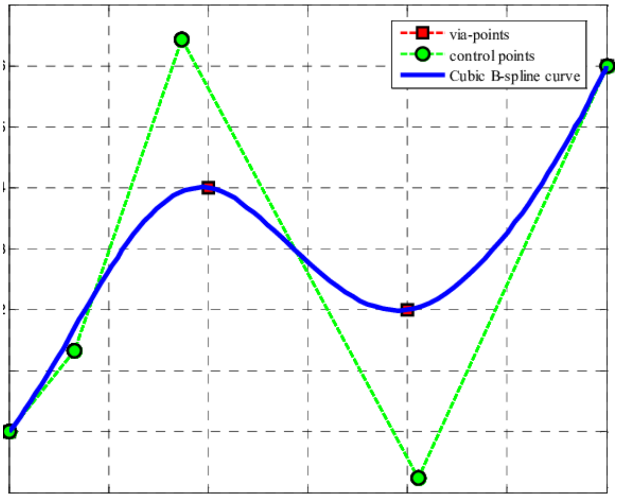


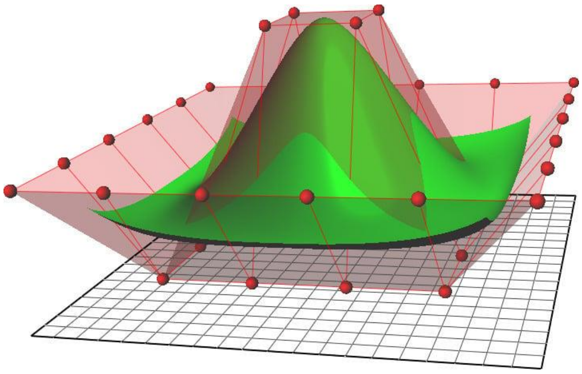
2. NURBS



When comparing polygonal modeling vs NURBS, you should understand that ***NURBS** (Non-Uniform Rational B-splines) relies on a polygonal mesh* to form a model.

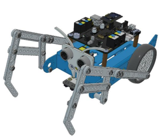
The ***mesh formation is more automated than manual***, allowing the curves and surfaces to be more accurate and lifelike, beholden to an ***established algorithm*** and ***not the whims of a designer.***



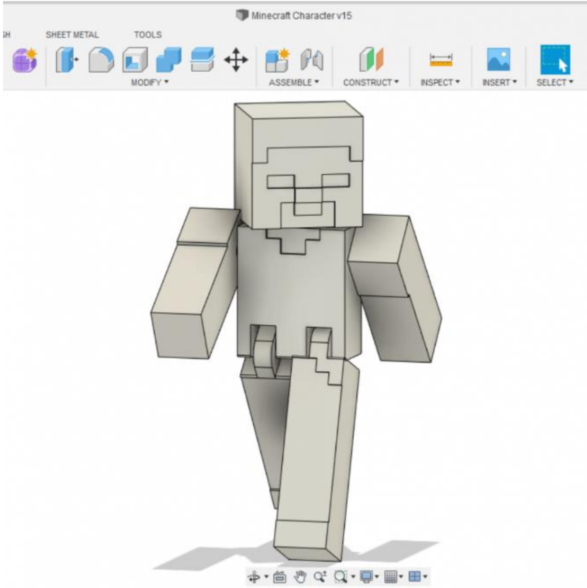


Instead of polygons, precise file formats use surfaces formed using ***non-uniform rational basis spline*** (NURBS), a computer-generated mathematical model. Nurbs are ***being controlled by control points.***

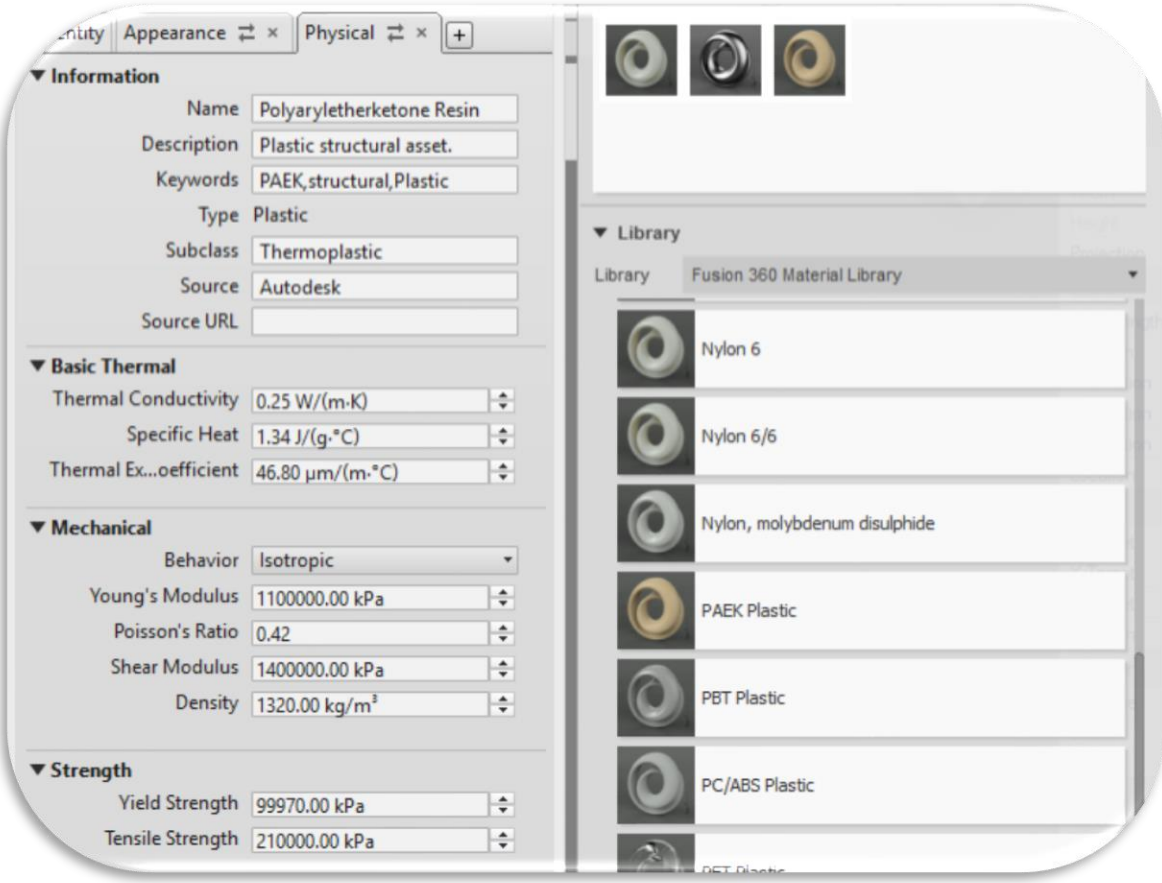
Place for notes



3. CAD

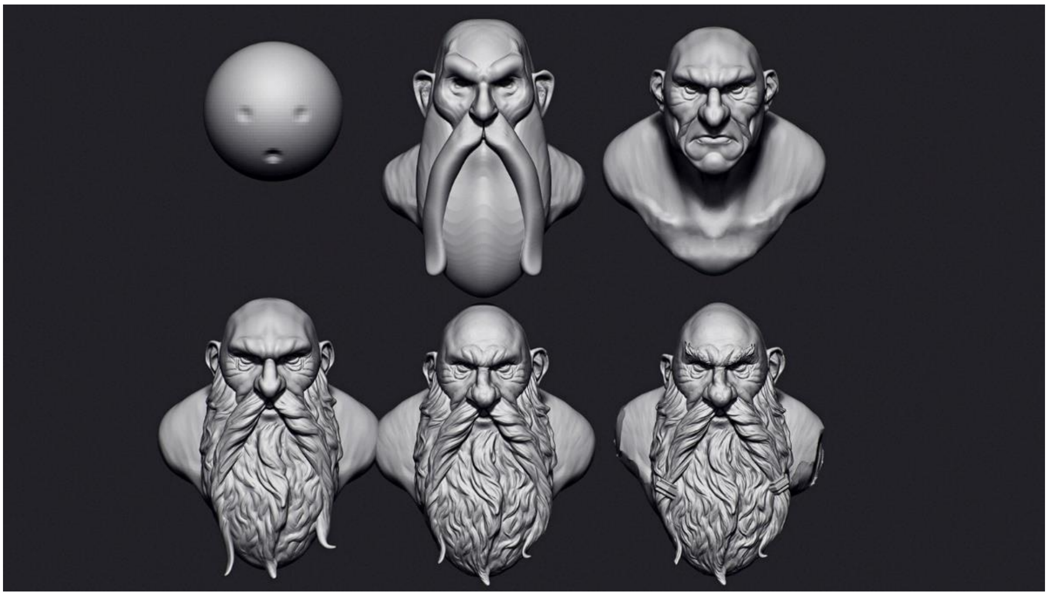


CAD stands for ***computer-aided design***, and is characterized by a major reliance on traditional geometric figures. In other words, ***CAD models have plenty of lines, angles, and symmetrical figures,*** but relatively few curves and abstract shapes. Another major ***difference between CAD and 3D modeling*** of the regular type is that CAD models often contain additional data about the object, such as ***materials, weight, and other types of properties.***

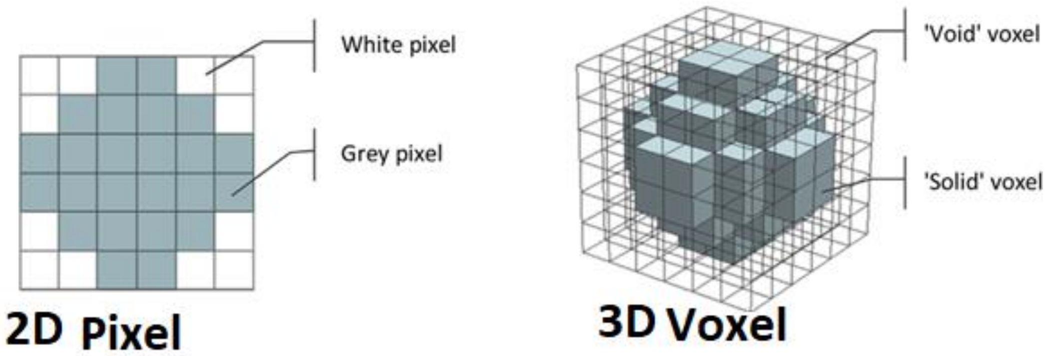


4. *Digital Sculpting*

<u>3D sculpting</u> is a time-intensive and careful technique that is often used for ***characters and organic objects***. It is focused on taking a ***flat block (resembling a piece of clay) and deforming it*** until it has the form and details resembling the target.



Interestingly, this technique uses ***voxels instead of polygons, and provides great freedom for adding details large and small.***

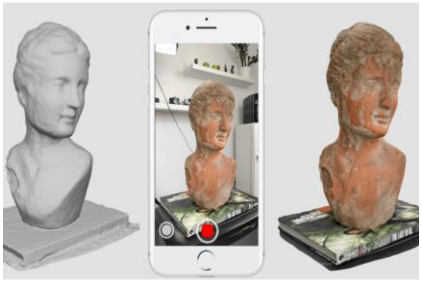


Place for notes

1.3 Scanner based modeling & Photogrammetry & Lidar

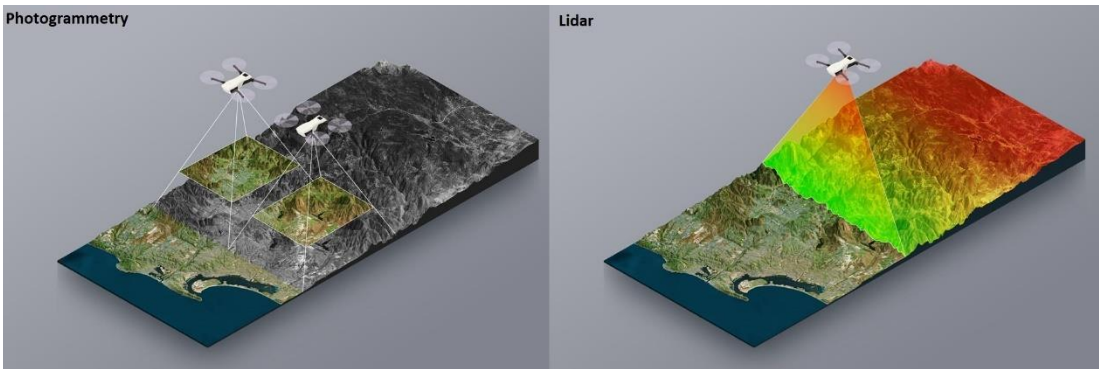
3Dscanning or ***active sensing*** is used to ***collect data*** about the form and structure of existing objects. The sensing system generates light or laser and uses a camera to capture generated pattern on real object.

With the help of software, this ***data is then converted into a complete 3D model.***



Photogrammetry has a lot to do with photos. They are imported into modeling software, with the application then using algorithms to establish the dimensions and shape of the object, despite the photo being in 2D. A 3D model is then generated based on this data.

LiDAR



Uses ***laser pulses to measure distances and is an active remote sensing system***. This means that the system itself generates energy (light). Photogrammetry uses passive sensing with photographic images. Passive sensors detect energy remitted or reflected from an object.

Place for notes

1.4 Generative AI for 3D

<u>The 3 Major AI 3D Modeling Techniques :</u>

1. **Text-to-3D models**
   Enter concise and straightforward text in the text box to generate 3D models. Try to avoid abstract descriptive words to get 3D models you desire.

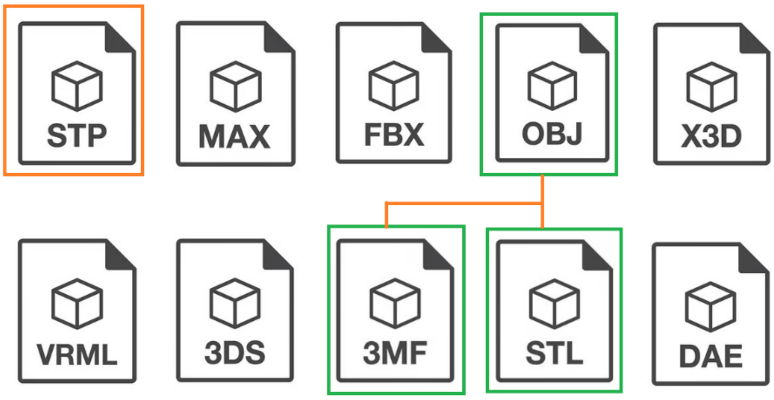
2. **Image-to-3D models**
   Upload flat 2D images and let AI do its thing. Witness pixels turning into polygon, commonly used in the tech industry.

3. **Video-to-3D models**
   Enhance your 3D model extraction success by uploading videos featuring clearly visible objects.

Place for notes

1.5 3D printable model formats

Neutral file formats work cross-platform, meaning you can create a file in one program, send it to someone who uses different software, and they would be able to work with the same file! Neutral formats work around the cross-platform compatibility issue. Neutral file formats ***include STL, OBJ, 3MF***, and many more.



STL (stereolithography) is a widely used 3D file format in 3D printing, rapid prototyping, and CAM, storing approximate surface geometry as a triangular mesh without color or material data. It supports ASCII and binary formats (binary being more common) and remains the industry standard, though newer formats like OBJ, 3MF, and AMF may eventually replace it.

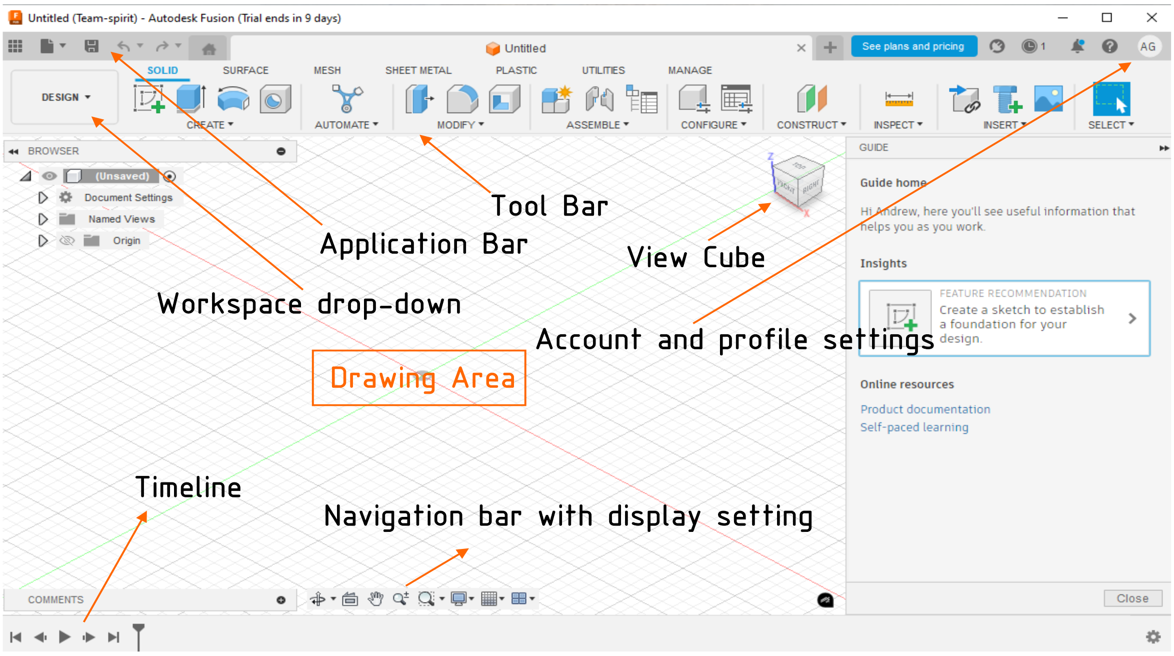
The OBJ file format, by virtue of being neutral, is one of the most popular interchange formats for 3D graphics. It is also gaining traction in the 3D printing industry as the industry moves towards full-color printing.

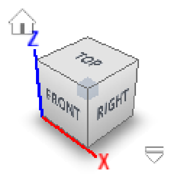
3MF (3D Manufacturing Format) is a compressed, open-source file format developed by the 3MF consortium to overcome STL's limitations. **Unlike STL, it stores geometry, printer profiles, supports, G-code commands, thumbnails, and modifiers, all in a smaller file size**, making it a strong candidate for the new 3D printing standard.

STEP (ISO 10303) is a successor to IGES, widely used in engineering fields like automotive, aerospace, and construction. It ***enables comprehensive product data exchange, supporting topology, tolerances, materials, and textures via .stp/.step files***. While IGES remains more universally compatible, STEP is preferred for detailed CAD, CAM, and CAE applications.

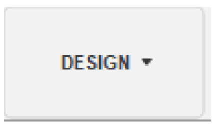
2 *3D modelling in CAD software using Fusion 360*

Autodesk Fusion 360 Design application Window & user interface, please use physical mouse hardware



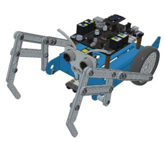


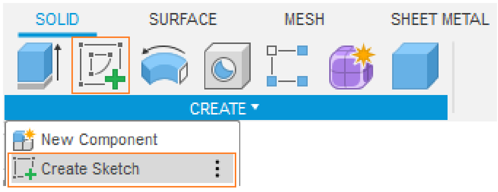
*The **ViewCube** is a crucial tool for navigating 3D models, allowing users to easily rotate and access different faces such as **Top, Bottom, Front, Back, Right,** and **Left** for precise orientation. By clicking, dragging, or right-clicking the **ViewCube**, users can smoothly adjust their view, enabling efficient modeling and seamless transitions between **perspective** and **orthographic mode.** House icon represents home button, by pressing it resets the view to the center of **drawing area.***



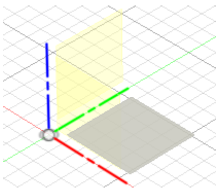
*The **Design** button is used to activate workspace in which you can create **solid bodies**.*

*The **Toolbar** lets you choose a workspace (for example Design), with tools that vary by workspace and are further organized into logical groupings within tabs. As you start to discover your own common workflows you can customize and rearrange your toolbar features.*

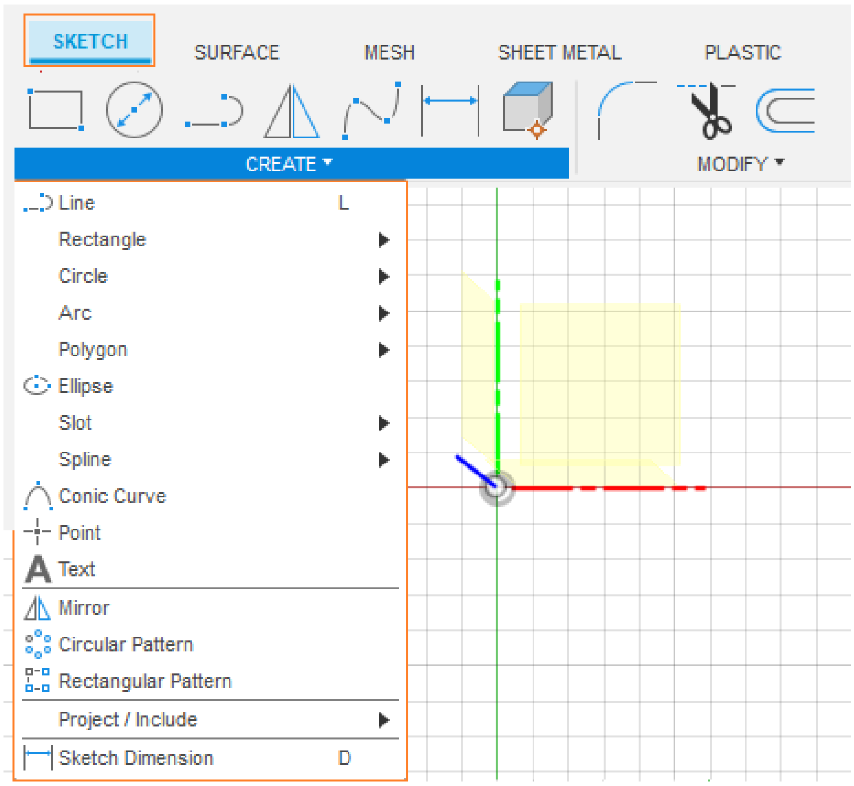




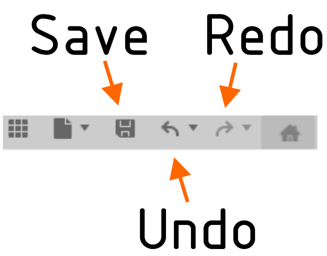
Create Sketch *to start a new sketch from the drop-down in* ***Toolbar****. The three primary* ***planes*** *will be displayed on the canvas screen, select a* ***Plane*** *for Sketch. click on the desired* ***plane*** *from the canvas screen. The selected* ***plane*** *will become parallel to the screen and act as the current sketching* ***plane****. Now, we are ready to draw a sketch on the selected* ***plane****.*



By clicking on the desired ***plane*** *from the canvas screen the selected* ***plane*** *will become* ***parallel*** *to the screen and act as the current sketching* ***plane****. Now, we are ready to draw a sketch on the selected* ***plane.***



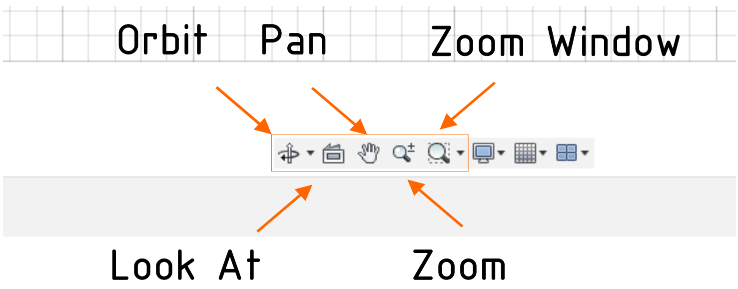
In ***Sketch*** *drop-down, there are various tools for creating sketch entities, which will be discussed during the workshop .*



In the ***application bar*** *the* ***save, undo and redo*** *options are available.*

Mouse Functions *these shortcuts are essential for efficient navigation and manipulation of 3D models and designs within the software.*

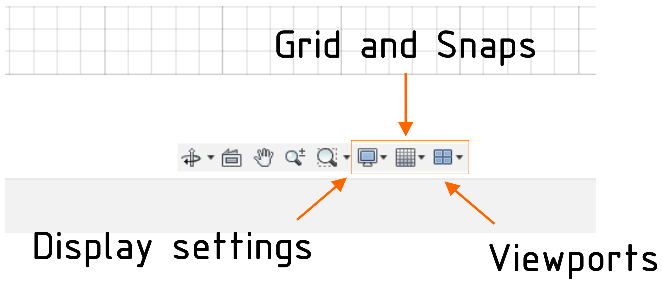
- ***Zoom In/Out****: Scroll the middle mouse button downward to zoom out and upward to zoom in.*
- ***Pan the View****: Click and hold the middle mouse button to pan the view.*
- ***Orbit the View****: Use Shift + middle mouse button to orbit the view.*
- ***Select Objects or Tools****: Click the left mouse button to select any object or tool.*
- ***Access Shortcut Menus****: Right-click to access shortcut menus in the software.*



The ***Navigation Bar*** *is available at the bottom of the graphics window of Fusion 360. It provides access to navigation commands for design*

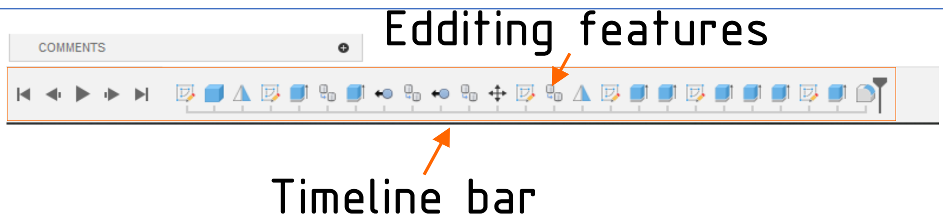
- ***Orbit*** *– Rotates the model view freely or in a constrained manner.*
- ***Free Orbit*** *– Allows unrestricted rotation of the model.*
- ***Constrained Orbit*** *– Rotates the model with movement restrictions.*
- ***Look At*** *– Aligns the selected face parallel to the screen.*
- ***Navigation Bar*** *– Provides access to navigation tools.*
- ***Pan*** *– Moves the model parallel to the screen.*
- ***Zoom*** *– Adjusts the magnification of the view.*
- ***Zoom Window*** *– Magnifies a selected area of the model.*
- ***Fit*** *– Centers and fits the model on the screen.*

Place for notes



*In **Display bar** are essential tools for visualizing and manipulating designs in Autodesk Fusion 360, providing flexibility and control over the design environment.*

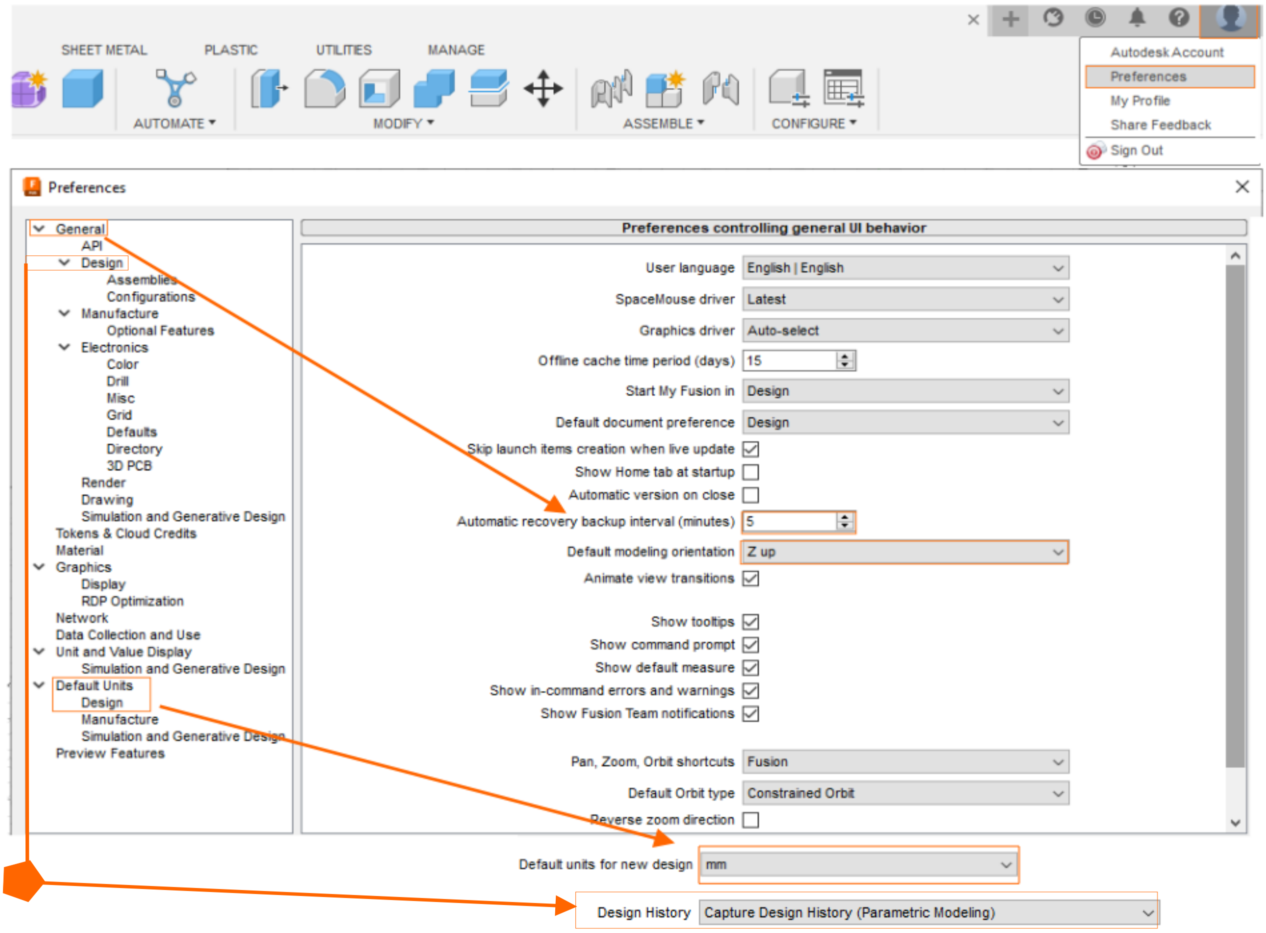
- ***Display Setting Tool**: This tool allows users to enable or disable commands related to visual style, object visibility, and camera settings. It also provides a shortcut (CTRL+SHIFT+F) to run Fusion 360 in full-screen mode.*
- ***Grid and Snaps Flyout**: This feature is used to activate or deactivate interface objects such as the Layout Grid, Layout Grid Lock, and Snap to Grid. Users can also customize grid size and snapping increments using the Grid Settings and Set Increments tools.*
- ***Viewports Tool**: This tool enables users to display the model in four viewports simultaneously. Users can set these views to be asynchronous by deselecting the Synchronize Views check box. The Single View tool allows users to return to a single viewport, and the SHIFT+! shortcut toggles between single and multiple viewport modes.*



- ***Timeline Bar**: The Timeline bar records design features in chronological order, making it easier to edit and manage the design process. The Timeline bar is a powerful tool for efficient and time-saving editing, allowing users to revisit and modify previous design steps easily.*
- ***Editing Features**: To edit any feature of the model, double-click on the respective feature in the Timeline bar. After making the desired changes and applying the parameters, the final design will automatically update to reflect the changes.*

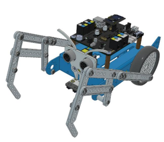
Place for notes

*In user account drop down click on **Preferences,** here we can specify various parameters for our application.*

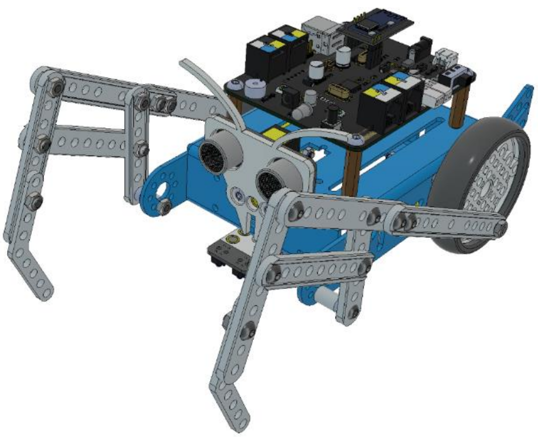


- *In **General** we set up **Automatic recovery backup interval** for 5 minutes, it specify the desired time in minute after which recovery copy of your model will be created*
- *Click the **Default modeling orientation** drop – down to define default model orientation which is in most of CAD software **Z axis upwards.***
- *In **Default Units Design** select **Default units for new design** in **mm**.*
- *Select the **Capture Design History** option from **Design** drop-down, to keep detail of every operation you perform on the model.*

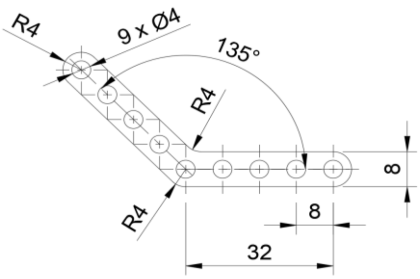
Place for notes

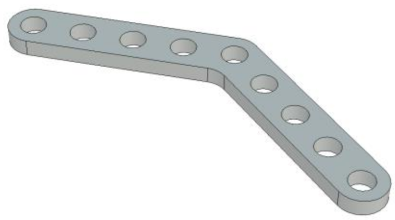


Assembly design of the Mantis kit probe & linkages

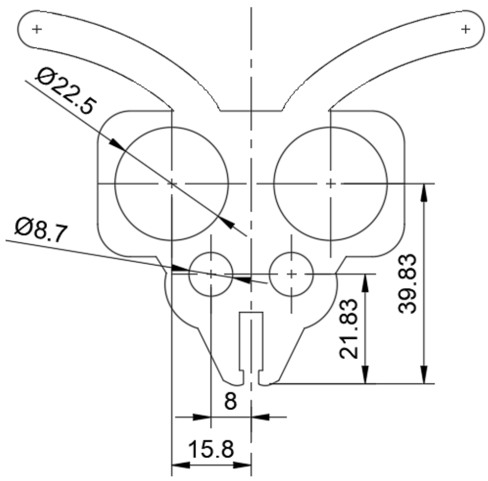


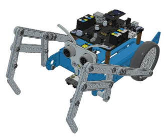
Example part of a linkage : sketch & solid



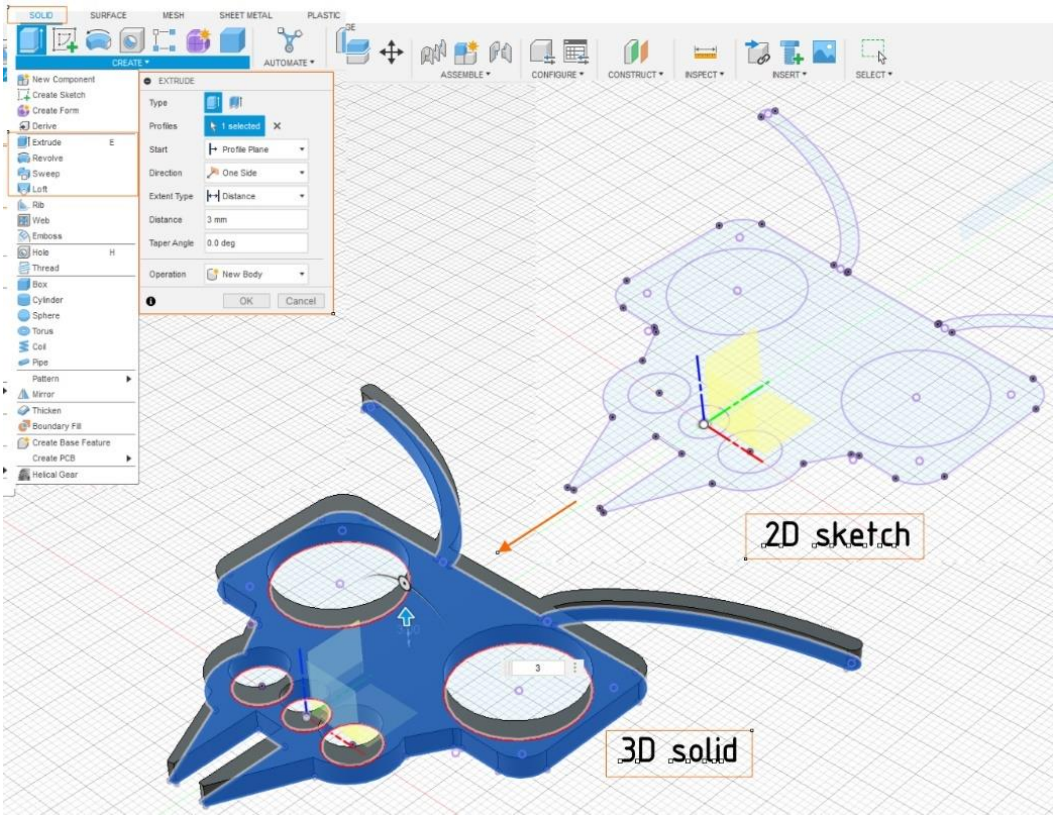


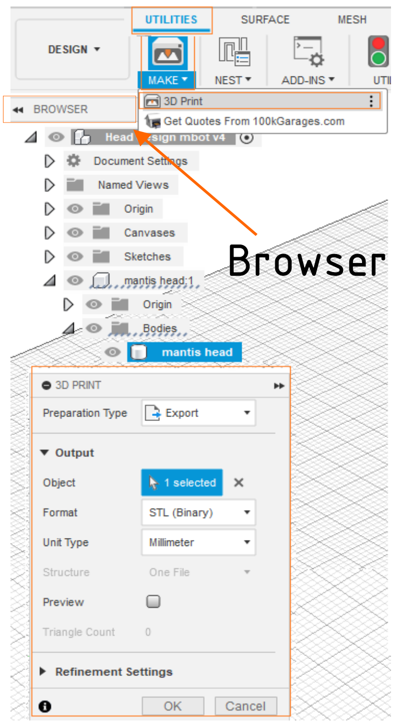
Custom probe design – dimensions required for recommended design





*The **Solid drop down tab** contains traditional solid modeling tools within the **Design** workspace in Fusion, and supports both **parametric** and **solid modeling modes**. You can use the solid modeling tools to create and modify **3D solid bodies** from **sketches** or **primitives**. There are various tools for creating solid entities and primitives, which will be discussed during the workshop.*



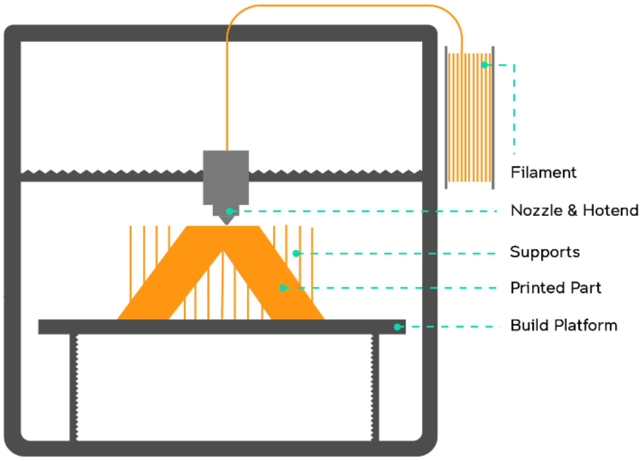


Export to a 3D priting file

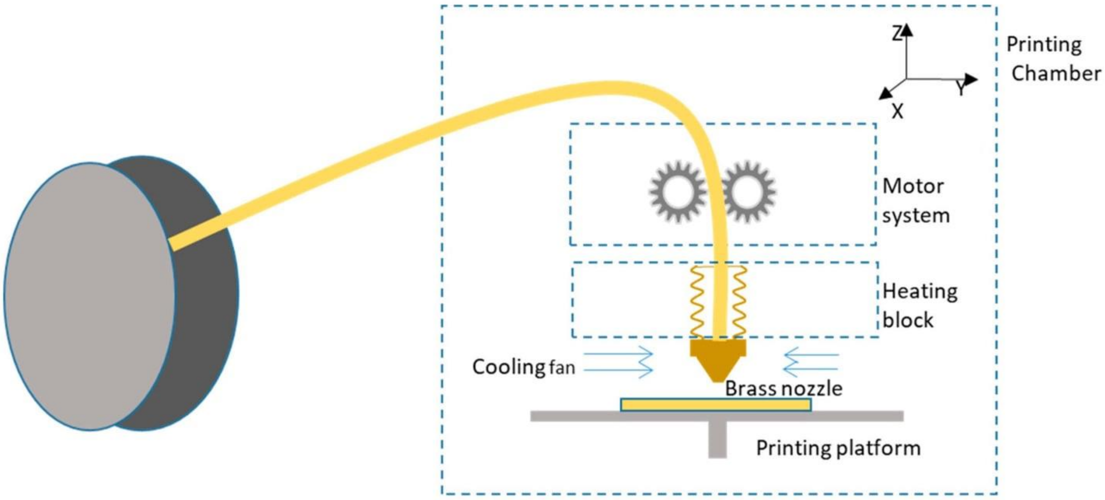
- *In the Design workspace toolbar, go **to Utilities > Make > 3D Print**, select **Preparation Type Export**.*
- *As object choose the **body** in the **browser**.*
- *Export in 3MF (includes geometry, colors, and textures), STL (Binary/ASCII) (triangulated surface for scanning and prototyping), or OBJ (similar to STL but supports color and texture).*

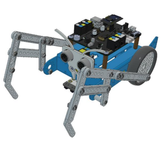
3 *FDM 3D printing process*

Fused Deposition Modeling (FDM) *is a material extrusion 3D printing method that melts and deposits thermoplastic filaments layer by layer to create objects. Known for its simplicity, affordability, and accessibility, FDM dominates the current market.*



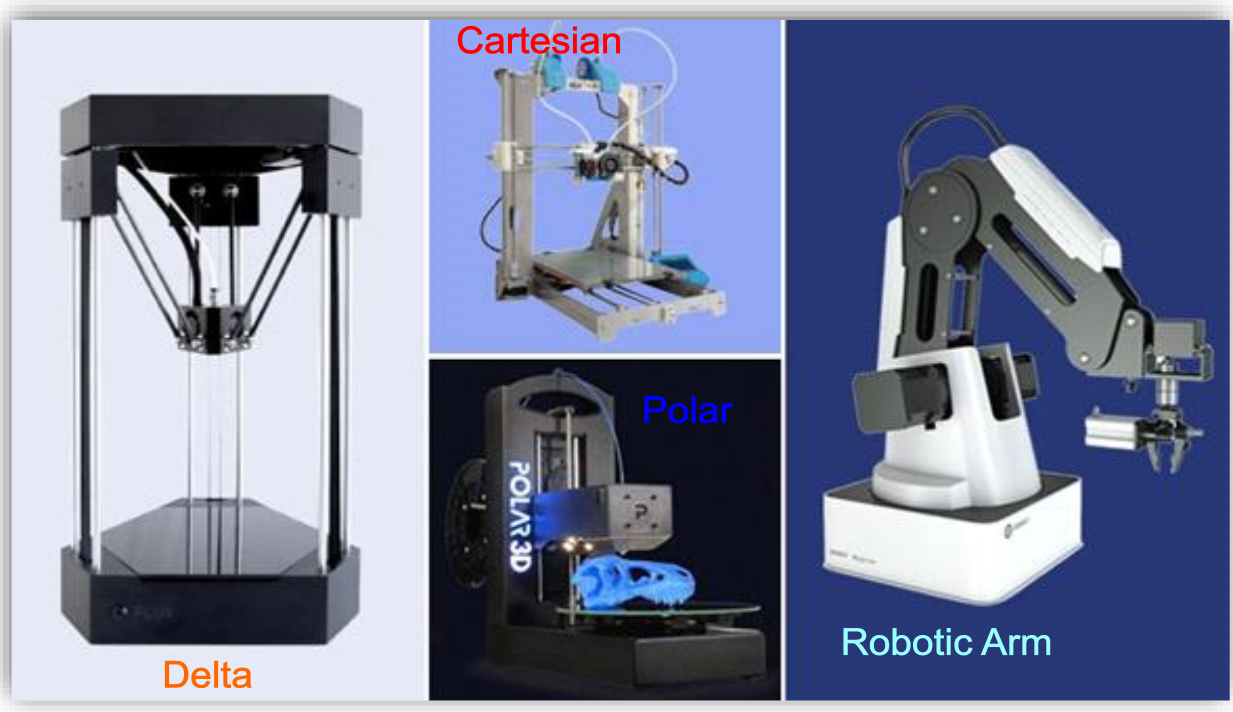
The extrusion system *in FDM 3D printing consists of the* ***cold end****, which feeds filament and controls flow* ***(motor system*** *), and the* ***hot end (heating block with nozzle)****, which heats and extrudes material through a nozzle. Both work together to ensure precise* ***deposition for proper layer stacking onto the priting platform.***

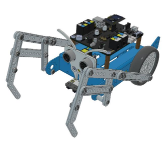




3.1 Types of FDM printers

- *Cartesian* ***FDM 3D printers****, the most common type, use the Cartesian coordinate system with X, Y, and Z axes to position the print head, allowing user-defined or preset Z-axis settings, and offer affordable, often DIY-assembled models*
- *Polar* ***FDM 3D printers*** *use a circular coordinate system where the build plate rotates and moves while the extruder shifts vertically, making them efficient with fewer motors and ideal for spiral designs, though* ***they have less accuracy toward the edges***
- *Delta* ***FDM printers*** *use Cartesian coordinates with a circular print plate and an extruder suspended by three moving arms, allowing fast printing and scalable designs, though they can be challenging to calibrate.*
- *Robotic arm* ***FDM printers****, still in development, offer* ***mobility and flexibility for creating large, complex structures*** *without a fixed print plate, though their print quality lags behind Cartesian printers, with major manufacturers like* ***Kuka*** *and* ***ABB*** *driving advancements*





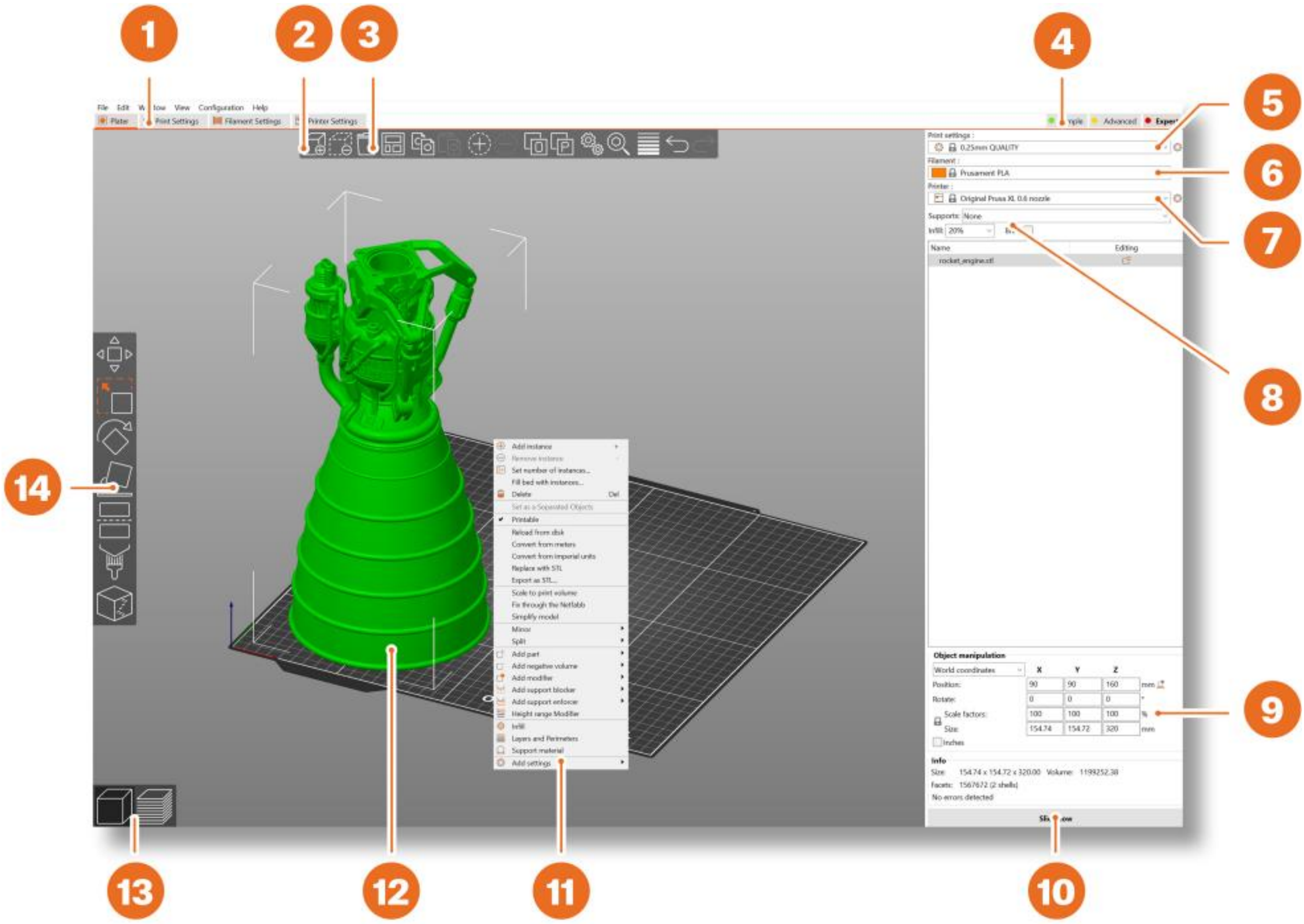
3.2 FDM 3D printing standart materials – filaments

Filaments : *used in 3D printing are thermoplastics, which are plastics (aka polymers) that melt rather than burn when heated, can be shaped and molded, and solidify when cooled.*

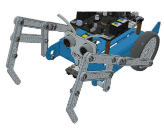
MATERIAL	FEATURES	APPLICATIONS
ABS (acrylonitrile butadiene styrene)	Tough and durable Heat and impact resistant Requires a heated bed to print Requires ventilation	Functional prototypes
PLA (polylactic acid)	The easiest FDM materials to print Rigid, strong, but brittle Less resistant to heat and chemicals Biodegradable Odorless	Concept models Looks-like prototypes
PETG (polyethylene terephthalate glycol)	Compatible with lower printing temperatures for faster production Humidity and chemical resistant High transparency Can be food safe	Waterproof applications Snap-fit components

3.3 Prusaslicer Interface

Prusaslicer in 3D Printing *is a free to use 3D printing software that acts as a link between the digital model (generated on a computer) and the actual model (constructed by the 3D printer itself).*



1. Opens detailed Print, Filament and Printer settings
2. The Add button is used to import a 3D model into the scene
3. The Delete and Delete All buttons remove the model(s) from PrusaSlicer
4. Switching between Simple, Advanced and Expert modes
5. Settings for printing speed and quality
6. Material selection
7. Printer selection
8. Quick settings for Infill density, Supports and Brim



9. Information about model size / printing time (after slicing)

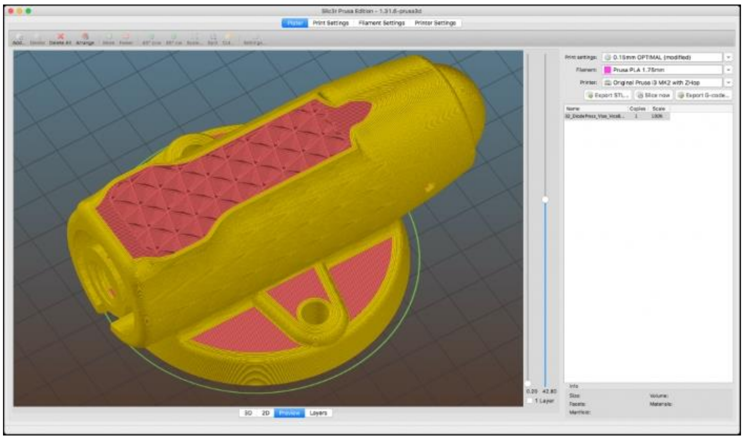
10. Slice / Export button

11. Right-click the model to open a context menu

12. Model preview in 3D

13. Switch between 3D editor and Preview mode

14. Move, Scale, Rotate, Cut, Paint-on Supports, Seam Painting tools



*The 3D printing slicer software transforms the digital model into printing instructions, called **G-code which are** instructions for the printer in the form of **tool path code.***

***G-code** is a programming language for CNC (Computer Numerical Control) machines. G-code stands for "Geometric Code". We use this language to tell a machine what to do or how to do something. The G-code commands instruct the machine where to move, how fast to move and what path to follow.In case of additive manufacturing or 3D printers, the G-code commands instruct the machine to deposit material, layer upon layer, forming a precise geometric shape.*

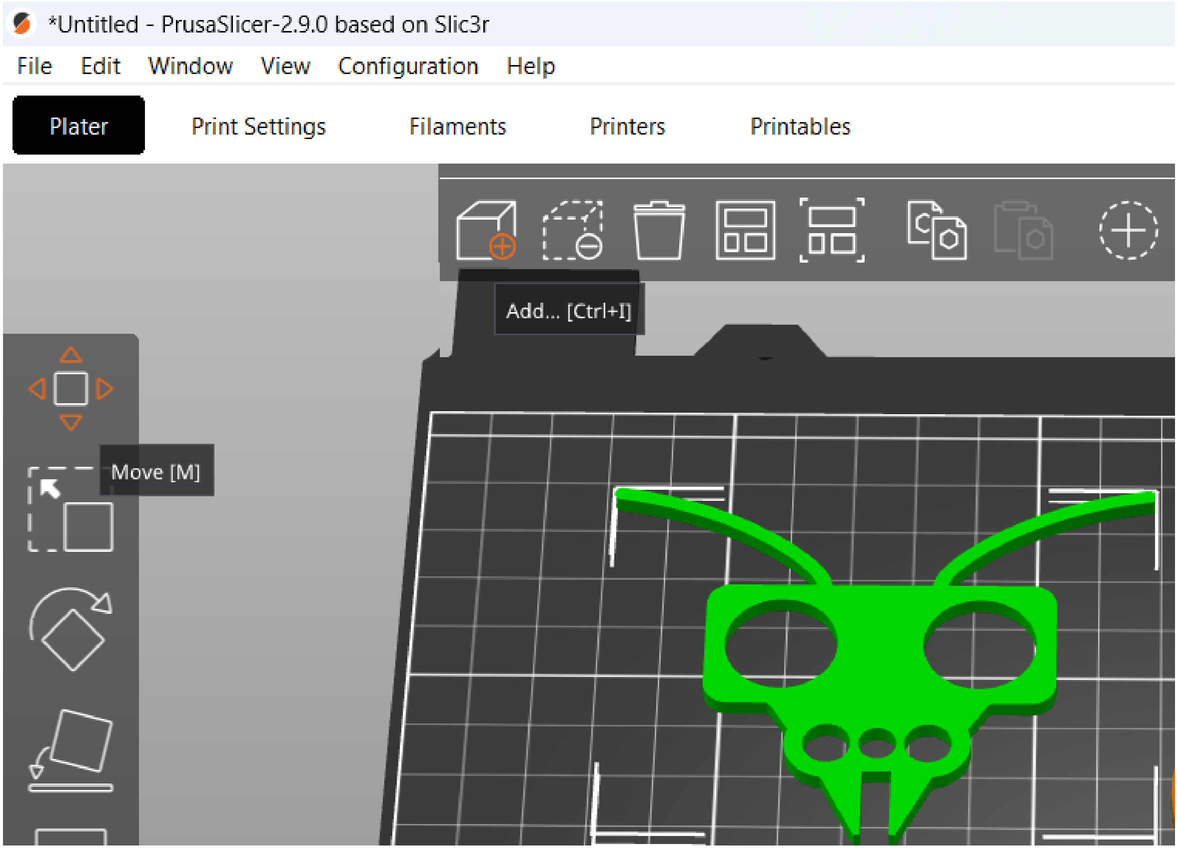
```
G00 Z5.000000
G00 X33.655106 Y11.817060

G01 Z-1.000000 F100.0(Penetrate)
G01 X247.951560 Y11.817060 Z-1.000000 F400.000000
G01 X247.951560 Y30.935930 Z-1.000000
G01 X106.963450 Y30.935930 Z-1.000000
G03 X106.587404 Y32.243414 Z-1.000000 I-7.576860 J-1.471361
G03 X105.974610 Y33.458880 Z-1.000000 I-6.445333 J-2.487300
G03 X104.697090 Y35.083261 Z-1.000000 I-7.601246 J-4.663564
G03 X103.141830 Y36.435630 Z-1.000000 I-10.087550 J-10.030472
G03 X102.969400 Y38.107779 Z-1.000000 I-20.252028 J-1.243405
G03 X102.369430 Y39.685740 Z-1.000000 I-3.842423 J-0.557919
G03 X100.419761 Y41.664361 Z-1.000000 I-6.181245 J-4.140917
G02 X98.333794 Y43.482560 Z-1.000000 I7.045018 J10.188229
G02 X95.783544 Y47.017541 Z-1.000000 I9.647185 J9.647199
G02 X94.101654 Y51.024620 Z-1.000000 I28.957871 J14.510988
G03 X92.872672 Y54.561719 Z-1.000000 I-340.631289 J-116.371936
```


3.4 Basic parameters setup in Prusaslicer

Initial Setup & Workflow

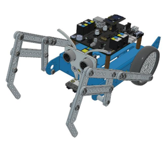
PrusaSlicer allows you to import objects in ***STL, OBJ, AMF, STEP and 3MF*** *formats - these are the most common types of 3D files you can find on the internet. You can either* ***drag them directly into the 3D editor window*** *or use the* ***Add… button*** *from the top bar.*



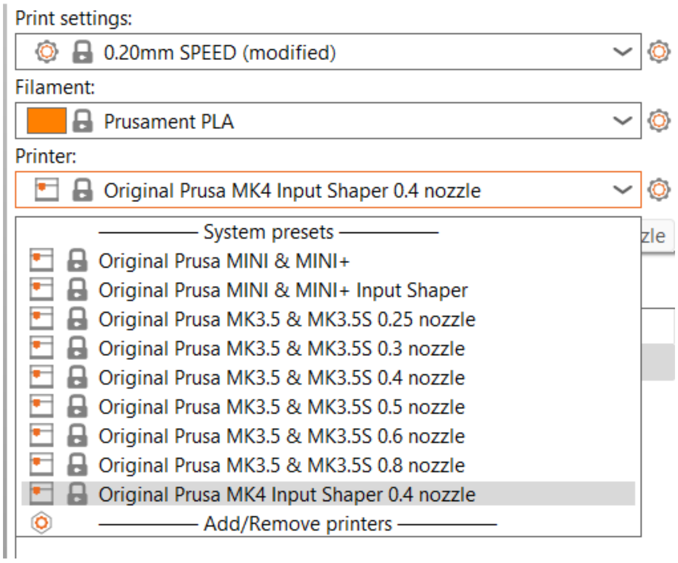
To ***modify the model****, use the tools* ***on the left sidebar, i.e. Move, Scale and Rotate****.*

If an object is blue, it means it does not fit into the print bed and it needs to be moved or scaled down.

There is no universal way to place the model on the bed*, it always depends on the specific shape. However, a general rule is that the bigger the flat surface of the model that touches the bed, the better it will hold - so try to position the largest flat surface of the model downwards. You can use the Place on Face (F key) function to do it quickly.*

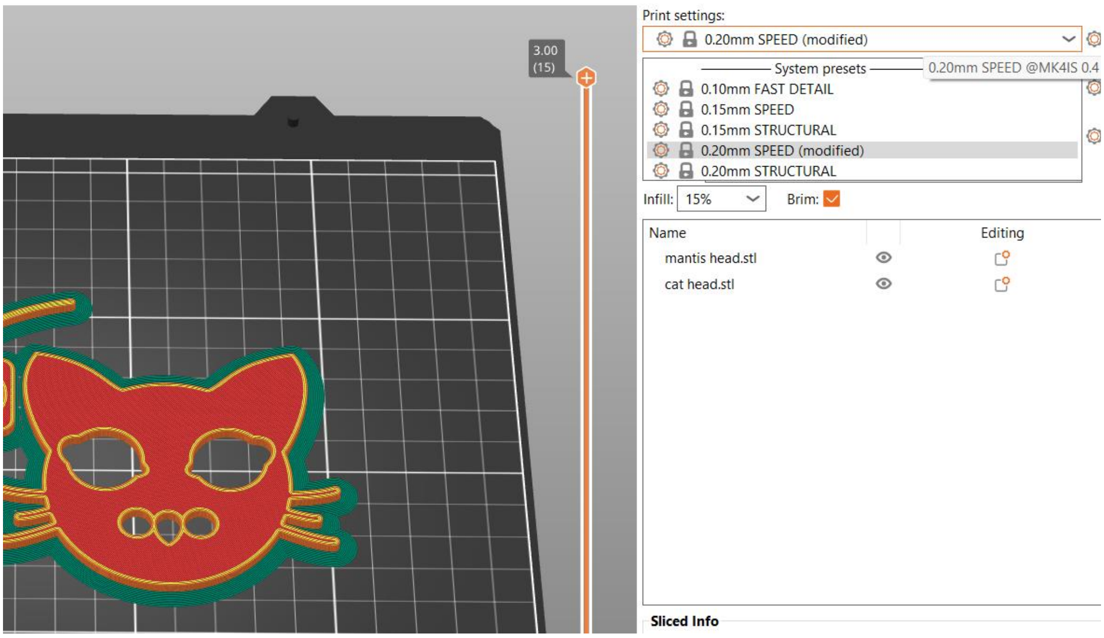


You can select a Printer from the drop-down menu on the right*.*



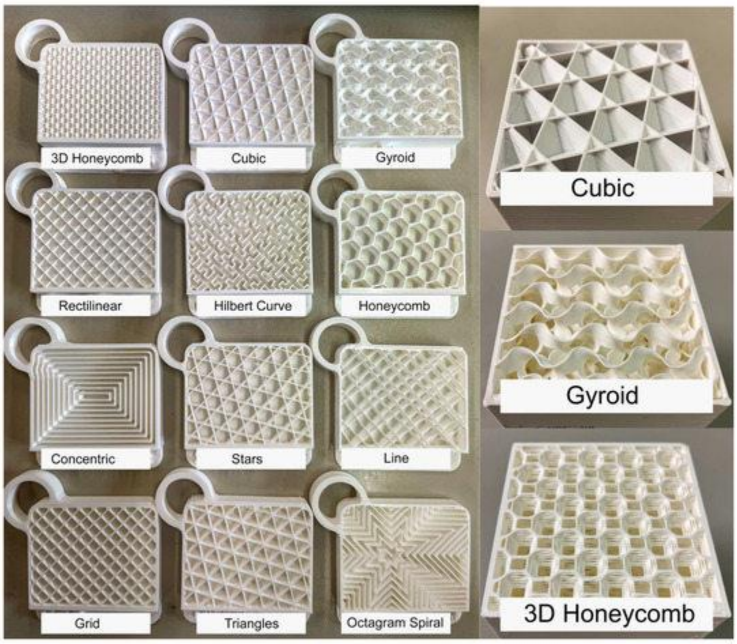
If you don't see the Original Prusa MK4 printer in the list or lower, you need to add it either by using Add Printer-Add Presets menu item (in the same menu), or by using Configuration - Configuration Wizard from the top menu bar.

Then select the layer height, infill and the material you intend to use. If you are not sure about the ***layer height, stick with 0.15mm profiles as they give generally good results****.*

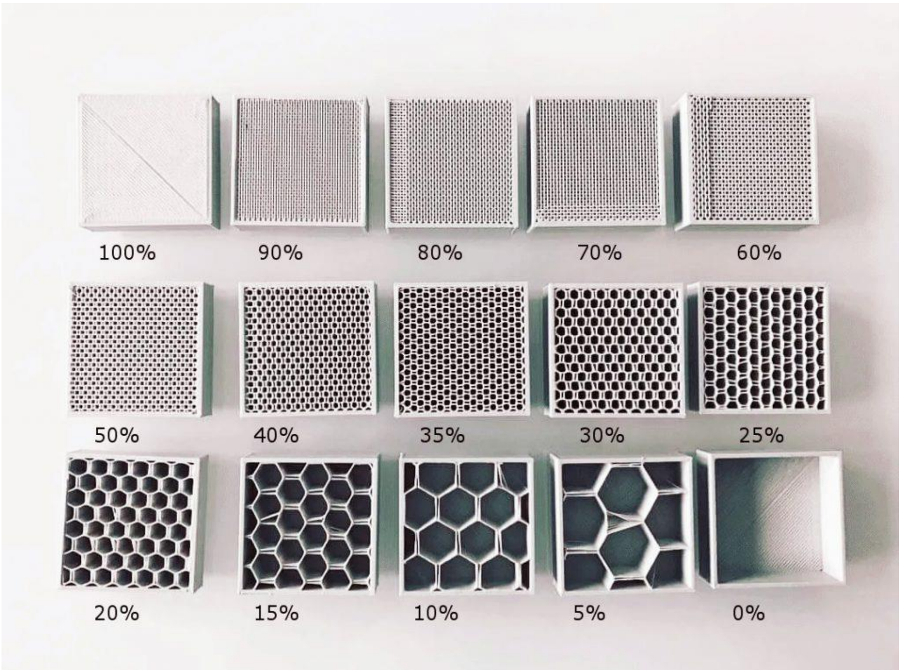


Recommended infill values are between 5-20 % *but it heavily depends on the model and how durable it needs to be. More infill means a more durable model, however, it will take longer to print and more material will be consumed. For general use, there is no point in going above 40% infill, unless your project really requires it.*

Infill *is the* ***internal structure*** *of the part, and it can have a* ***range of patterns*** *and* ***densitie****s, which can be adjusted in the slicer software and applied automatically to the g-code (the coded instructions sent to the 3D printer in order to commence a print). Infill has a big impact on how a part turns out.* ***The purpose of the infill is to stiffen the object from the inside.***



Example of infill patterns



Example of infill densities, higher density equals more solid structure.

***Shells**, also known as **perimeters**, are the printed outlines defining the shape of the object. Every object you print must have at least one shell. Additional shells add to an object's strength, weight, and print time. Two or three shells are sufficient for most*

Shell thickness

***Print Quality** mainly affected by **the thickness of each layer** of a 3D printed object. A finer layer gives higher details and less visible layer line but longer print time. A thicker layer will reduce print time but with a lower details and more visible layer line in the end result. Typically 0.2mm thickness per layer is good for most applications*

Print quality = layerheight

Additive Support Structures

An FDM 3D printer works by depositing layer over layer of thermoplastics to create a 3D object. Thus, ***each new layer must be supported by the layer beneath it.***

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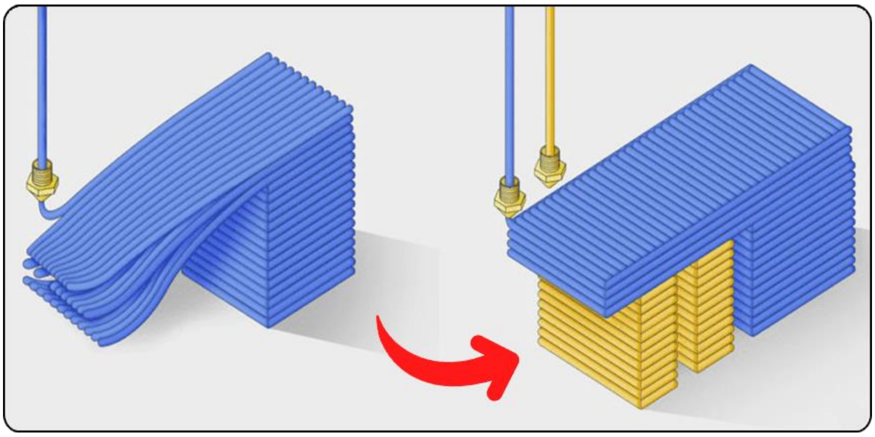
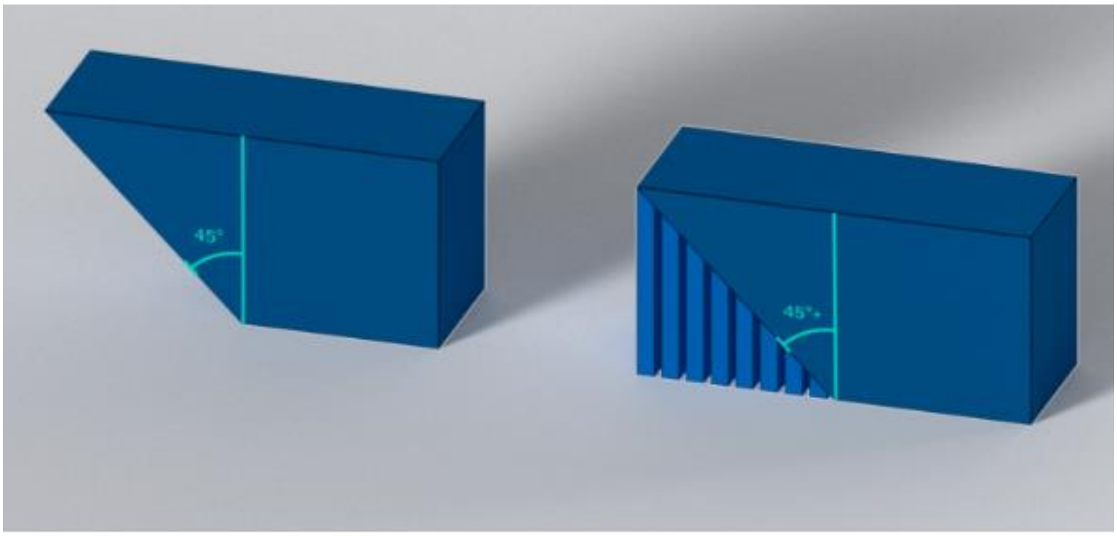
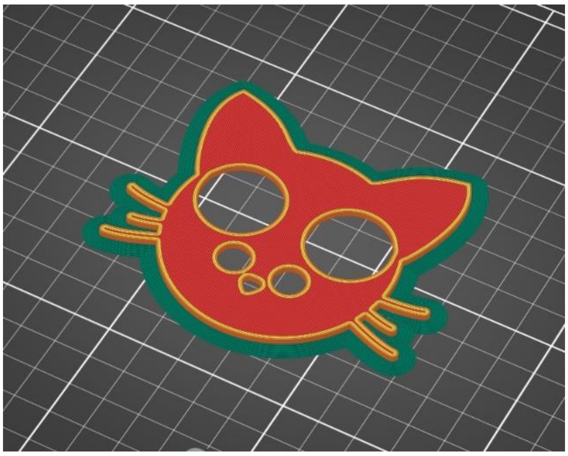


If your model has an overhang that is not supported by anything below, there's a possibility it will drop or fall. For a successful print you'll need additional 3D printed support structures

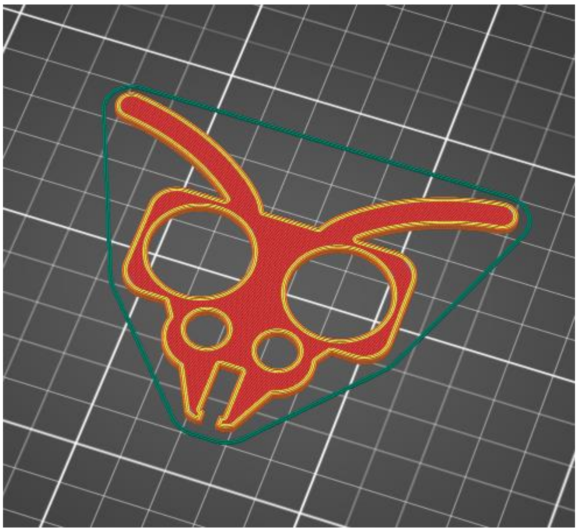


Left: *If the overhang is 45° or less taken from the vertical, support are generally not needed*
Right: *If the overhang is greater than 45° taken from the vertical, supports are generally needed*

Brim & Skirt



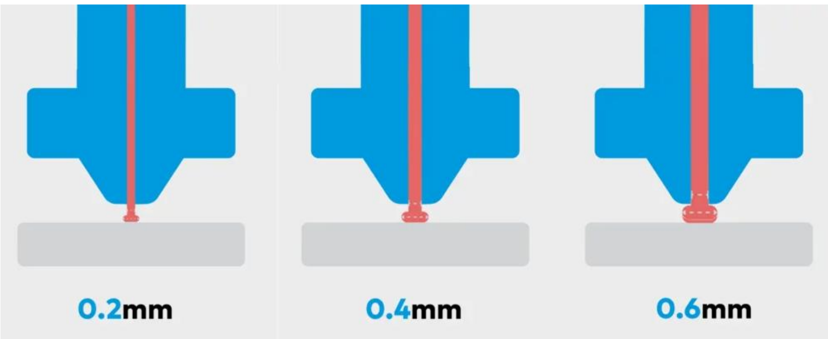
The brim serves to ***increase adhesion to the bed***, ***reducing the risk of warping***. A wider first layer is printed around the model. This makes sense especially if the model only touches the bed in a small area. This function can be enabled in PrusaSlicer by checking the "Brim" box in the menu in the right column. After the printing is finished, the brim can usually be removed easily by hand, or you can use a knife or scalpel.



*A **3D printing skirt** is a **thin outline*** printed around a model to **prime the extruder** and check **material flow, adhesion, and first-layer quality**. While it doesn’t prevent failures, it helps identify issues early, allowing users to **adjust settings before the main print** begins.

Nozzle Diameter & Its Importance

Nozzles are an important component of the 3D printing process, responsible for extruding the material onto the build plate layer by layer.



https://blog.zaxe.com/picking-a-3d-printer-nozzle-things-to-consider/

*The **nozzle diameter** directly affects **filament extrusion, precision, and print speed**, making it a key factor in 3D printing.*

- ***>0.4mm Nozzles**: Larger diameters increase speed and reduce clogging but sacrifice fine details.*
- ***0.4mm Nozzles**: The industry standard, balancing **speed and detail**, though newer software allows **0.6mm** nozzles to achieve similar precision.*
- ***<0.4mm Nozzles**: Provide **high precision and better overhangs**, but significantly increase **print time** and require lower **layer heights** (~80% of nozzle diameter).*

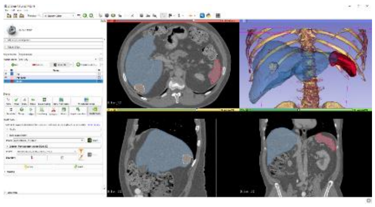
*Choosing the right nozzle depends on whether you prioritize **speed or detail** in your prints*

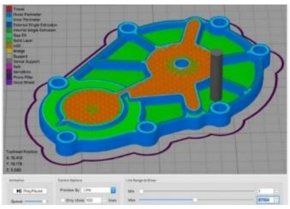
Various metal materials that nozzles are made of, depending what kind of abrasive material they print and how often.

Self assessment

1. *Which pricture describe a Slicer for 3D printing?*

A **B** **C**





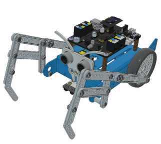
2. *What is 3D mesh made of?*
    - ***A** Corner points*
    - ***B** Edges*
    - ***C** Polygons*
    - ***D** All above*

3. Which model has higher polygon count ?

A Steve Minecraft **B** Lara Croft Tomb Raider **C** Neither of them

D both of them

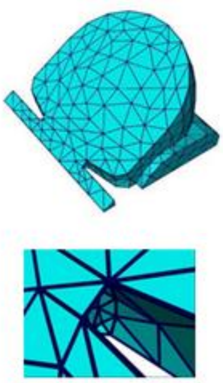
4. How can we obtain a 3D model ?
    - ***A** By 3D modeling in a CAD*
    - ***B** By 3D scanning*
    - ***C** Download from virtual library*
    - ***D** Generate by AI*
    - ***E** All above*



5. How does FDM 3D printing create an object ?

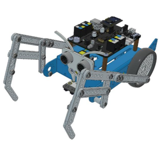
- ***A*** *By cutting through material,*
- ***B*** *By substracting material,*
- ***C*** *Adding layers of material*
- ***D*** *Melting layers of material*

6. Which picture represents a mesh ?



A **B**

7. Choose various option , which materials can be used for FDM 3D printing ?

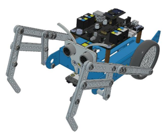


8. What is g-code
    - ***A*** *code line in python*
    - ***B*** *predirect path on which tool of a machine moves*
    - ***C*** *code generated by Artificial inteligence*
9. What kind of tool does a FDM 3D printer use for extruding filament layer on to print bed ?

10. Which component is the most important in the 3D printing process, responsible for extruding the material onto the build plate layer by layer.
    - ***A*** *Nozzle*
    - ***B*** *Extruder*
    - ***C*** *hotend*
    - ***D*** *filament*
    - ***E*** *bowden tube*

11. What do we use Fusion 360 for ?

- ***A*** *3D modeling*
- ***B*** *Simulation*
- ***C*** *Schematic design*
- ***D*** *Computer aided manufacturing*
- ***E*** *All above*



Vocabulary list

CAD: *Computer Aided Design is an advanced software for creating designs and generate technical drawings in 2D and 3D by architects, engineers, drafters & artists. It is a mixture of hardware and software that allows designing and producing anything simpler for a designer.*

G-code : *Are Instructions provided to a machine controller (industrial computer) that tells the motors where to move, how fast to move, and what path to follow.*

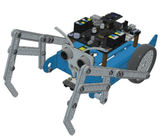
The nozzle: *The component of a 3D printer that deposits the molten filament into the build area.*

A 3D printer extruder : *is a filament feeding mechanism used in many fused filament fabrication (FFF) 3D printers.*

Fused deposition modeling (FDM) 3D printing *:, also known as fused filament fabrication (FFF), is an additive manufacturing (AM) process within the realm of material extrusion. FDM builds parts layer by layer by selectively depositing melted material in a predetermined path. It uses thermoplastic polymers that come in filaments to form the final physical objects.*

3D mesh *is a structural build of a three-dimensional model consisting of polygons. 3D meshes use reference points in X, Y and Z axes to define shapes with height, width and depth.*

Polygons in 3D modeling *are the geometrical foundations or forms of 3D models. To build detailed 3D objects, designers start with polygons or shapes like cubes, cylinders, spheres, etc. As they are easily modifiable,* ***CG artists and animators often use this to deform and form their 3D digital objects****. Usually,* ***polygons can be three-sided or four-sided.*** *The tris or* ***triangular polygon*** *models are famous for making gaming models.*



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