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3D Printing Laboratory Manual: Practical Tips and Safety Rules

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Introduction

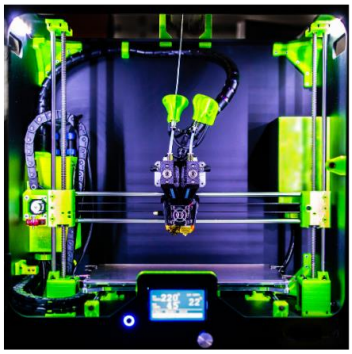
Through the 20-hour STEM Module on 3D Modelling developed under the context of the Numeric[All] project, we learned the basics of 3D Modelling and how to prepare your 3D model to be printed. However, knowing 3D printing safety requirements and processes is also essential. As such, this **Laboratory Manual** presents information on the technical functions and setup of 3D printers to ensure the best possible outcome.

Types of 3D Printers

There are many types of 3D Printers that are used according to the industry and intended usage. In the training materials of the Numeric[All] project and specifically in this manual, we will focus on Fused Deposition Modelling (FDM). The figure below demonstrates other types of 3D Printers and their usage.

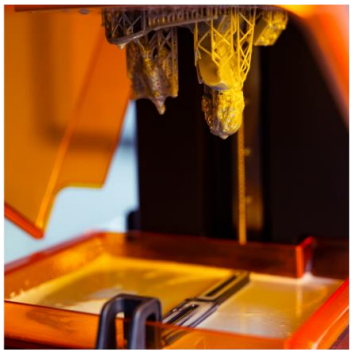
Fused Deposition Modeling (FDM)

It creates the object by melting and depositing the filament layer by layer.



Stereolithography (SLA)

It creates the object with a laser that solidifies the liquid photopolymer resin layer by layer.



Selective Laser Sintering (SLS)

It creates the object by using a high-power laser to fuse grains of ceramic, glass or plastic into layers.

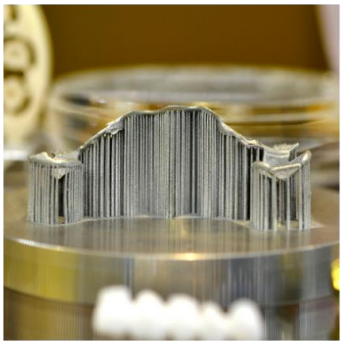


Figure 1. Summary of main types of 3D Printers

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Components of a 3D Printer

In order to be able to spot any discrepancies in your 3D printing, it is essential to know the most important components of a 3D printer. There are many types of 3D printers, but the Fused Deposition Modelling (FDM) 3D printer is the most used, especially for beginners. The following components are commonly found in most 3D printers.

Axes of 3D printer: How the 3D printer moves to construct a three-dimensional item

Similar to 3D Modelling, a 3D printer moves in a three-dimensional space to create an item. As such, its movements are within the x, y, and z axes. The x and y axes move within the horizontal sphere, whereas the z-axis moves within the vertical one.

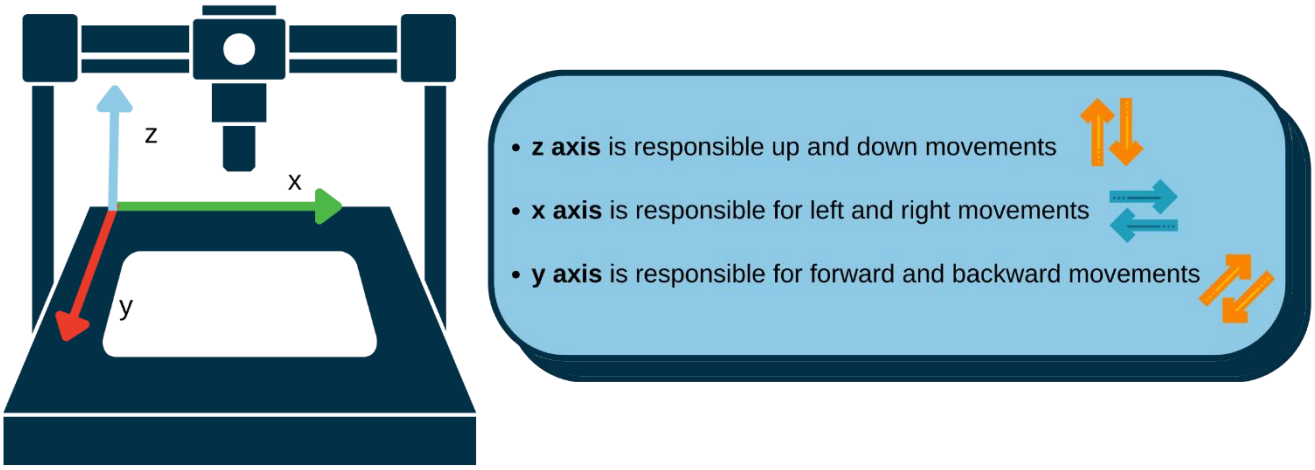

Figure 2. x, y and z axes on 3D printer

3D Printing Filament: The material used to print a 3D item

Depending on your needs, many different types of raw materials are used to print 3D items. The most popular 3D filament is Polylactic Acid (PLA). Some of the reasons behind this are that it doesn't require high temperatures or a heated print bed, which minimises shrinkage. In addition, it is inexpensive, easy to print, comes in various colours and has many applications in different fields, such as manufacturing and prototyping.

Figure 3. PLA Filament (Source: Canva)

If you are interested, follow for a thorough list of 3D Printing Filaments, their pros and cons.

Extruder and Hot end: Interconnected

These two parts are commonly referred to together as the extruder. Even though they are interconnected, they have two very important roles. On the one hand, the extruder is used to pass the filament from the reel to the hot end. On the other, the hot end melts the filament and pushes it through the nozzle, which is attached at the bottom of the hot end.

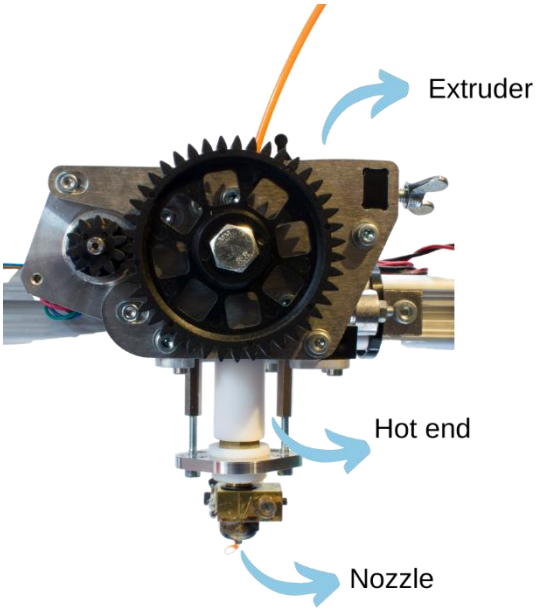

Figure 4. Extruder, Hot end and Nozzle parts

Nozzle diameter: Trade-off between precision and print speed

The nozzle is attached to your hot end and is responsible for the extrusion of the 3D filament. The diameter of the nozzle primarily affects the resolution of your 3D item, which is based on layer height and printing speed. The range of diameters starts from 0.1mm to 1.0mm, shown in the figure below. The standard diameter used in 3D printers is 0.4mm as it balances quality and print speed.

Figure 5. Nozzle diameter range (Source: https://top3dshop.com/blog/3d-printer-nozzle-guide)

Tip: The layer height value should be at most 80% of the nozzle diameter. For instance, 0.32mm is the recommended maximum layer height for a 0.4mm nozzle diameter.

Print Bed: Layering the 3D item

The print bed of a 3D printer refers to a solid and flat surface where the layers of melted plastic form the 3D item. Depending on your 3D printer, the surface is either stationary or moves in a specific direction. From the first layer applied on the print bed, you can see if there is something wrong to avoid your item moving in the middle of printing.

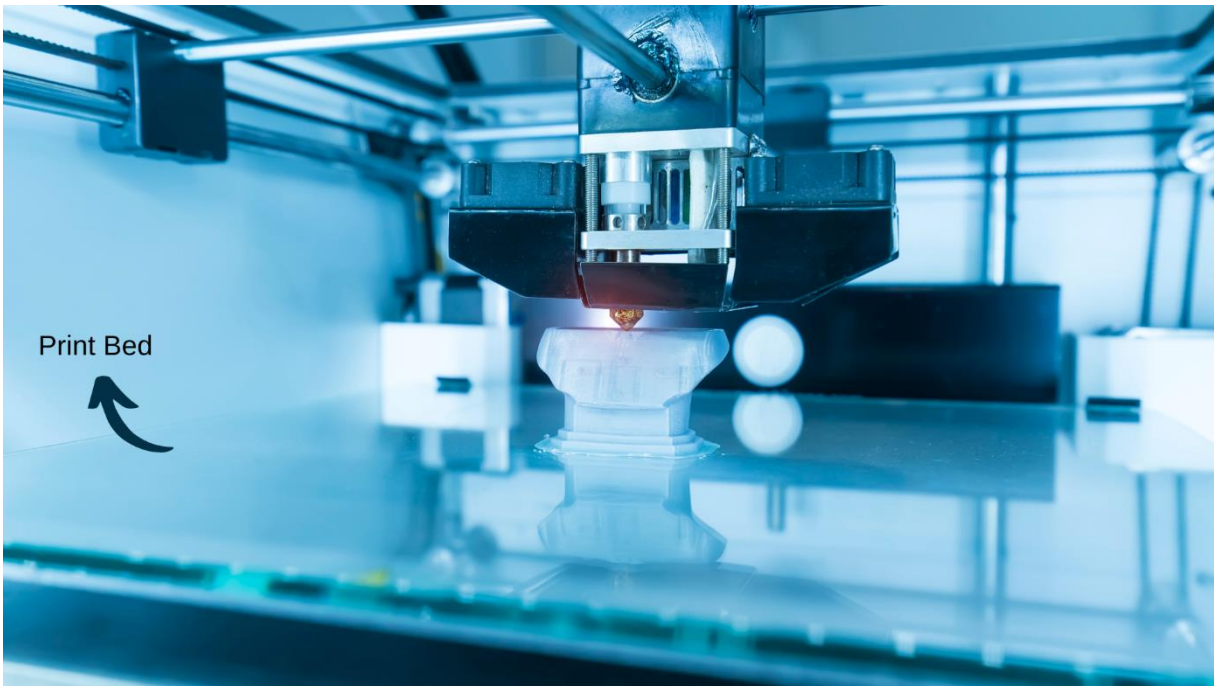

Figure 6. Print Bed of 3D Printer

Two important things to look out for are:

- **Heating of the build surface** to ensure first-layer adhesion and warping.
- **The material of the build plate** to ensure its performance under heat and filament sticking to the surface.

Print Display: Human Machine Interface

The print display allows users to communicate with the 3D printer directly. This way, you can start, pause, and stop the printer and load your 3D files from a USB or SD card. This is all dependent on the firmware of your 3D printer.

In addition, it can contain the power supply unit, motherboard, USB ports and Wi-Fi connectivity.

Setting up and using your 3D Printer: Important things to consider

In this part of the Manual, we will go through a few essential things you should consider to ensure you can make the most out of your 3D printer.

1. Where to place your 3D printer

The three main things to consider when deciding where to place your 3D printer are: ventilation, who has access to it, and its surroundings. The ideal location would be in a well-ventilated room, in case of fumes, that is inaccessible to pets and children to avoid injuries. The space surrounding the 3D printer should be clear and away from flammable objects. A few more factors to consider are the location of the room due to the noise made by the printer and keeping a storage space for its materials. In any case, do not leave the 3D printer unattended for an extended period of time.

2. Choosing your 3D Printing Material

As we have already mentioned, Polylactic Acid (PLA) is the most popular 3D filament due to its ease of use. Some other benefits of PLA are that it is biodegradable, odourless and cheap to buy, which makes it ideal for educational purposes.

3. Provide adequate training

In many cases, whenever a new technological object is bought in an educational setting, it largely goes unused unless there is proper training. The reason is that educators might feel uneasy using something they have yet to receive training on and need help understanding its applicability in their lessons. Training is essential in enhancing the pedagogical and methodological usage of 3D printing in education.

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4. Which tools and supplies are needed

Since 3D printing can be pretty messy, there are a few tools and supplies that can make maintaining your printer and 3D items easier. These include:

- **USB sticks**: to transfer 3D files to the printer in case of limited internet connectivity at your institution.
- **Flush Cutters and Needle Nose Pliers**: to safely remove support material from your 3D item easily and effectively.
- **Craft Spatula**: to remove prints from build plates using glue.

5. Calibration: Levelling and Nozzle Height

You can spot if something is wrong with your 3D printing from the first layer that comes off. Sometimes, that is that the print bed is unlevelled.

Figure 7. Unlevelled print bed

You might be wondering how you can spot an unlevelled bed. Remember to consider all three axes (x, y, z) to ensure successful 3D printing. Here are a few signs to look out for.

You might notice that:

- The filament **doesn't stick to the build surface** in certain areas.
- Filament **stays stuck to the nozzle** in some places.
- The filament's **height and width vary** across the build surface.
- The **gap between the extruded lines varies** across the build plate.

Source: Kivelä, 2022

Figure 8. Signs of an unlevelled print bed

Some printers have an ‘auto-levelling’ function, which automatically adjusts the print bed. Nevertheless, you may have to manually adjust screws with other printers to ensure the print bed is in the correct position. Another important aspect is the distance between the nozzle and the print bed (i.e., the z-axis).

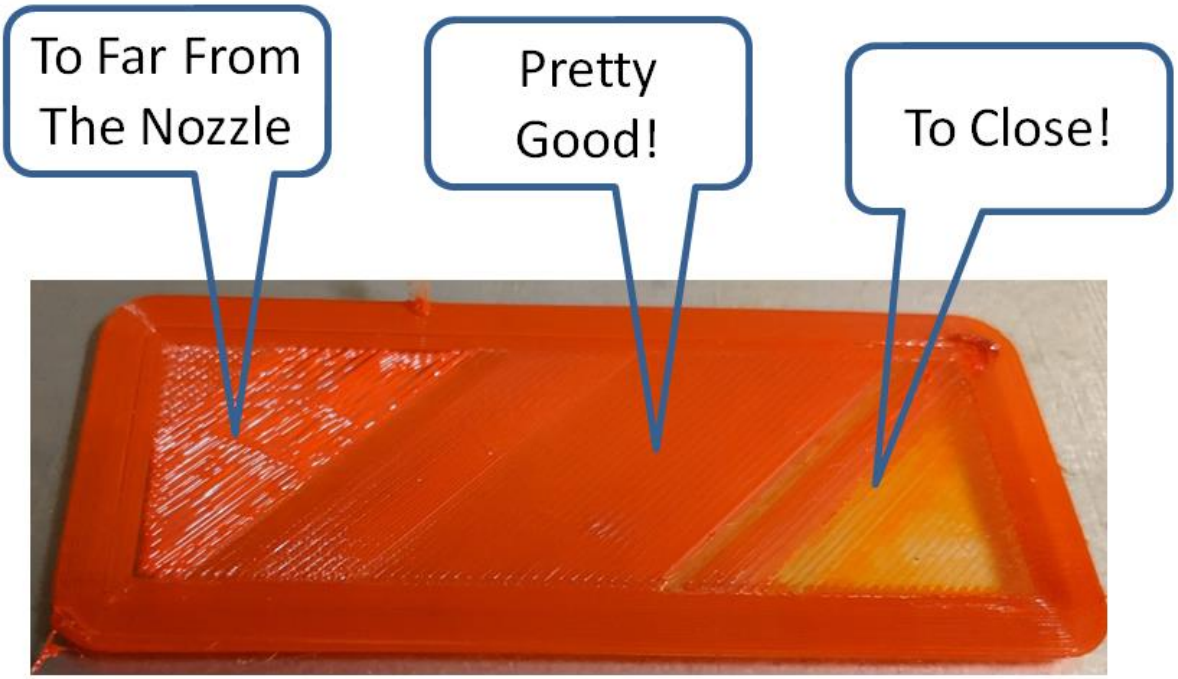


Figure 9. Examples of nozzle height differences on filament extruded.
(Source: https://3dnewb.com/3d-printing-first-layer-problems/)

6. Print Bed and Hot End Temperature Settings

When it comes to temperature, there are two things that you need to consider: the temperature of **1) the print bed** and **2) the hot end**.

Depending on your filament, some temperatures can be **too hot or too cold for the hot end.** There is no exact ideal print temperature for PLA, but a range between 180 and 220 degrees Celsius is recommended. If the layers are not adhering to one another, raise the hot end temperature. Be careful not to raise it too much, as the printed result will be soft and droopy. Consider raising and lowering the temperature little by little to find the perfect temperature for your hot end.

Now, the **print bed temperature** is another crucial component of 3D printing. Although PLA does not require a heated bed, it makes printing easier. Similar to the

hot end, the perfect temperature for PLA requires some experimentation. The recommended range is between 55 and 70 degrees Celsius. Some signs that your print bed is not at its optimal temperature are that:

1) the layers are not sticking to the bed, which means that the bed is too cold, and
2) the sides of your print are expanding and/or shrinking, which means the bed is too hot.

7. Support material

As we have seen, 3D printing involves layering to create a 3D object. This also means that this additive process requires support from one layer to the other. In the case that your model has an overhand and no support is provided, the model will most probably collapse. This is where support material is needed to avoid such incidents. Even though support material is helpful in these cases, it can also be a hustle in the post-processing phase, where you need to remove these structures.

In some instances, support is not needed, but there are some conditions. As a general rule, the support material is required when an angle is more than 45 degrees. In the figure below, you can see the letters Y, H and T. Here, the letter Y has overhands that do not go above 45 degrees in the vertical direction. As such, the support material is not needed.

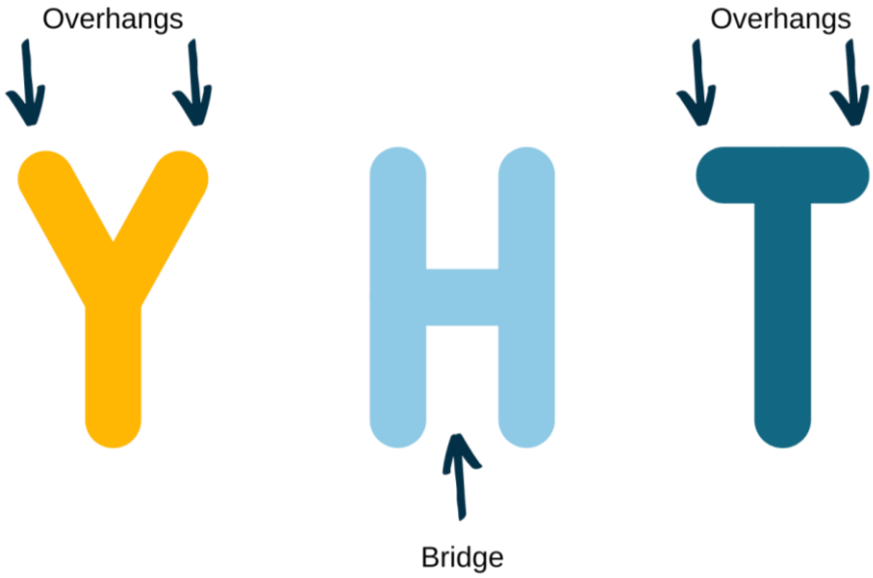


Figure 10. Examples of Overhangs and Bridges using letters Y, H, T

In the case of H, which is a bridge, if the distance surpasses 5mm, support is needed. If the bridge is under 5mm, support structures are not needed.

Figure 11. Letters Y, H, and T printed with support material (Source: https://www.hubs.com/knowledge-base/supports-3d-printing-technology-overview/)

The figure above shows that the letter T was printed with support material. The reason is that it has an overhand of 90 degrees on the vertical, which means you will need to print support structures. Otherwise, you will end up with a messy result.

Figure 12. Letter T printed with and without support material (Source: https://www.hubs.com/knowledge-base/supports-3d-printing-technology-overview/)

8. Post-processing: What happens after you have printed your 3D object

After you have finally printed your first 3D object, it's time to prepare it for use. Depending on the application of your object, different steps are required.

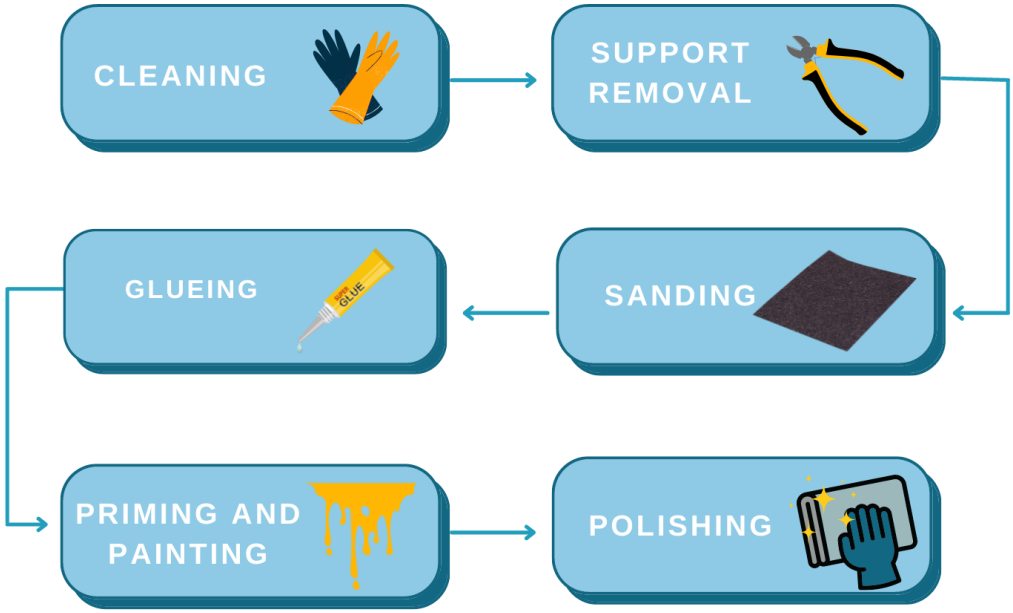
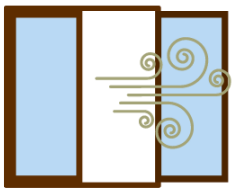


Figure 13. Post-processing steps

1) Cleaning: it would be best if you started by doing some basic cleaning to see any imperfections on the object.
2) Support removal: If your object has support structures, you can remove them using flush cutters and/or needle nose pliers, depending on how delicate the structures are. Be careful not to remove parts of the core of the object accidentally.
3) Sanding: After that, you can do sanding, especially if you notice any blobs left on the surface, to make your object smooth. For FDM parts, sanding in circular motion is recommended to avoid ruining the object's appearance.
4) Glueing: Using super glue can easily join PLA-printed objects. Glueing is an easy solution if you have printed your item in two or more pieces.
5) Priming and Painting: It is recommended to use a primer coat before starting to paint your 3D object as a base layer.
6) Polishing: Plastic polishes are available for 3D prints to make your object as smooth as possible. All you will need is a microfiber cloth and a plastic polisher.

Safety Rules

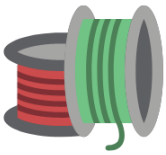


Keep the room well-ventilated to avoid inhaling any toxic or harmful fumes

Do not touch the any parts of 3D printer, especially the extruder or print bed, when it is printing.

Wear safety googles if you want to go near the printer.

Purchase low-emitting filaments. Look for certification that the 3D printer you are buying meets low-emission standards.



Keep away the surrounding of the printer clear and away from flammable objects.

Do not leave the 3D printer unattended for an extended period of time.

Here you can find a list of the most important safety rules to consider when storing and operating a 3D printer in your facilities in order to avoid injuries and health hazards.

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