



3D Printing Guide

Best Practices and Policy



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The 3D Printing Guide

Introduction

3D printing is a method of prosthetic construction in which objects are made by the successive addition of overlapping layers of material. Various types of material can be used in 3D printing, mainly ceramics and polymers. Compared to other prosthetic technologies and equipment, 3D printers are usually faster, cheaper, and easier to use. For this reason, many believe that in the coming years, the world production of goods will turn in this direction, gradually replacing traditional techniques. There are many who believe that 3D printing will be a "new industrial revolution", as it will bring decentralization. Production processes, paving the way for local and small-scale production, adapted to current needs.

In the 1980s, 3D printing techniques were considered suitable only for the production of functional or aesthetic prototypes, and a more appropriate term for it at the time was rapid prototyping. As of 2019, the precision, repeatability, and material range of 3D printing have increased to the point that some 3D printing processes are considered viable as an industrial-production technology, whereby the term *additive manufacturing* can be used synonymously with 3D printing. One of the key advantages of 3D printing is the ability to produce very complex shapes or geometries that would be otherwise impossible to construct by hand, including hollow parts or parts with internal truss structures to reduce weight. Fused Filament Fabrication (FFF), which uses a continuous filament of a thermoplastic material, is the most common 3D printing process in use as of 2020. [1]

Characteristic is the fact that the layering technique for 3D printing is in turn based on the technology of InkJet printers. InkJet printers use ink layers. Similarly, 3D

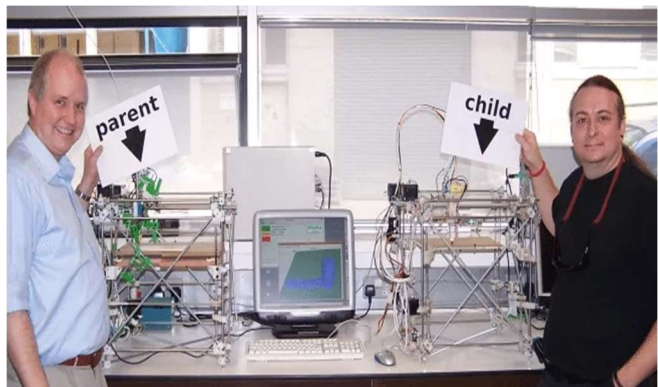


Figure 1. Dr. Adrian Bowyer, left, and Vik Olliver with a parent RepRap machine and its child, made by a RepRap (2005) [15]



printers use layers of other materials with greater mass, resulting in the 3D format. Therefore, we can consider that the foundation for 3D printing was the creation of the first InkJet printer in 1976.

Figure 2. In 2005, Dr. Andrian Bowyer designed and built a 3D printer that could make its own pieces to be assembled as a new printer.

As of 2020, 3D printers have reached the level of quality and price that allows most people to enter the world of 3D printing. In 2021, decent quality printers can be found for less than US\$200 for entry level machines. These more affordable printers are usually FFF (Fused Filament Fabrication).

General principles

The basic idea behind 3D printing is found in rock formations at great depths below the ground (water droplets deposit thin layers of metal forming stalactites and stalagmites). Prosthetics technology applies to printers of various sizes and shapes; however, regardless of the type of 3D printer or the material used, the 3D printing process follows the same basic steps: it starts with creating a 3D drawing of the object you want to print, using digital CAD (Computer Aided Design) software. The digital model can also be obtained by using a 3D scanner or simply by downloading a file from the online marketplace. We will already find thousands of free and paid CAD designs on the Internet for a variety of items, from simple decorative or utility items to intricate devices in assembled parts. Thingiverse is one of the most popular related websites.

Preparing the printer first involves filling it with raw materials (such as plastics or metal powders). In fact, one must choose the material with which he will best achieve the specific properties required for the object he wants to produce. The variety of materials used in 3D printers is very large: it includes plastics, ceramics, resin, metals, sand, fabrics, biomaterials, glass and even food.

In addition, preparation of the construction platform is required (in some cases, an adhesive may need to be cleaned or applied to prevent the object from moving and warping from heat during the printing process). Once the digital model is loaded on the printer, the machine automatically creates the desired object. While printing processes vary depending on the type of 3D printer technology, material extraction (which includes a number of different types of processes) is the most common method used in desktop 3D printers.

Material extrusion works like a glue gun. The printing material, typically a plastic thread, is heated until it liquefies and is extruded through the **printing nozzle** (the end from which the filament is ejected). Using information from the digital file, the design is divided into thin two-dimensional sections so that the printer knows exactly where to place the plastic material (polymer) through the nozzle in thin layers, often 0.1 mm thick. The polymer solidifies quickly and binds to the bottom layer of the material. Once the first layer is completed, the **base** on which it is placed moves downwards, so that a new one is created on

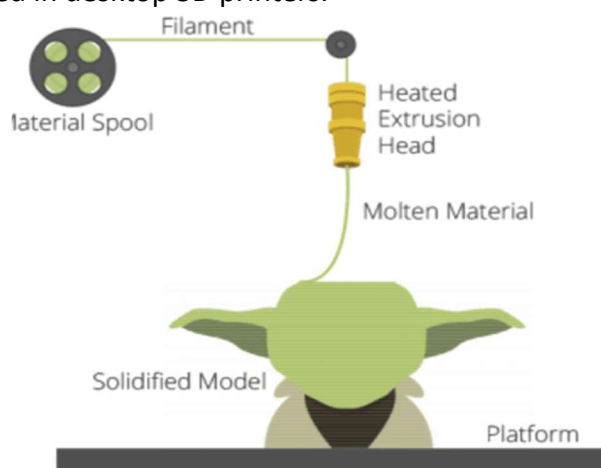


Figure 3. The basic principle of 3D printing operation

top of the existing layer. Depending on the size and complexity of the item, the whole process can take minutes to days.

The **Fused Deposition Modelling (FDM)** and **Fused Filament Fabrication (FFF)** methods are essentially the same method. Just the name Fused Deposition Modeling and the abbreviation FDM have been patented by Stratasys. The name Fused Filament Fabrication and the abbreviation FFF were created by the RepRap Project and can be used freely and without restrictions by third-party 3D printers.

Once printing is complete, each item requires a minimal post-processing, which includes a variety of practices (simple or more complex), from simply detaching the item from the printing platform to removing support structures from the item (temporary material printed for the protrusion on the object), brushing, finishing, etc. This step often requires specialized skills and materials. When the item is original, it can often not be used immediately or completed until it is sanded, varnished or painted to complete its original design.

FFF printers's typology

“**Cartesian** 3D printer is named after the XYZ dimensional coordinate system. The extruder moves in two directions (X and Z), while the print bed moves along the Y-axis. It also means that the print bed is usually square- or rectangle-shaped. Original Prusa i3 MK3S is a Cartesian printer.” [12].

These types of FFF 3D printers follow the same mathematical pattern: they rely on X, Y and Z coordinates to place a print head in the correct place to print the plastic filament.

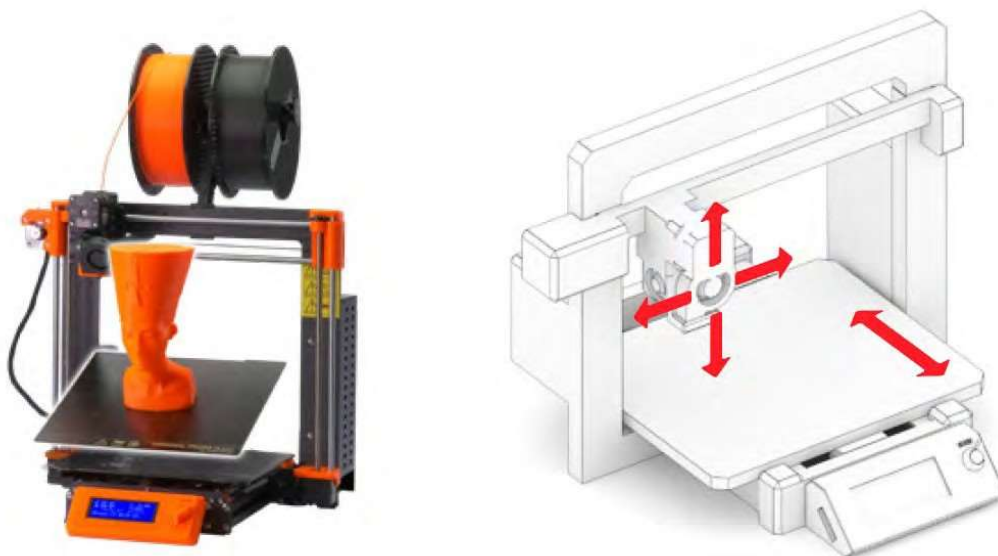


Figure 4. Cartesian type 3D printer

“**Delta 3D printers** have their extruder movements controlled by three moving arms, which meet in the extruder. Two of the biggest advantages are the speed of printing and large

printing volumes. However, the printer requires extremely precise assembly and calibration. The printer's geometry requires complex calculations for movements of stepper motors in each of the arms". [12]

Delta FFF printers, however, use a different system of movement. Instead of XYZ rods, delta printers support the extruder with three arms, which are attached to three vertical posts arranged in a triangle [13].

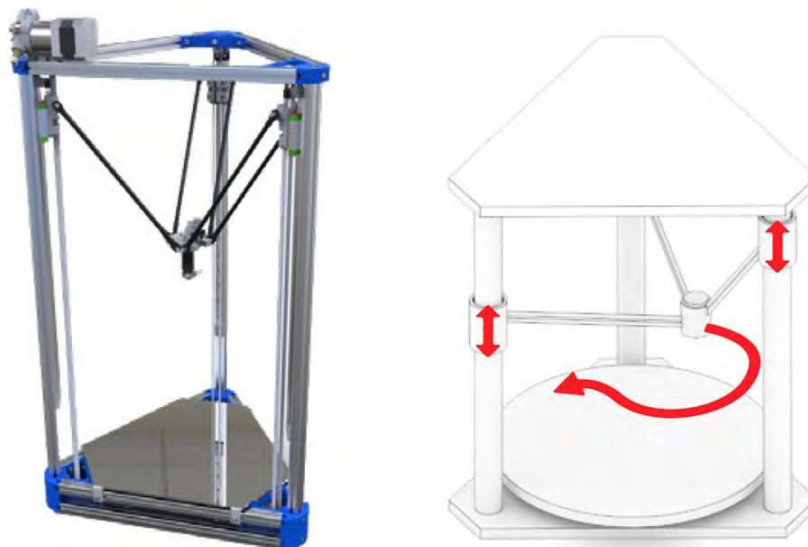


Figure 5. Delta printer

Applications

3D printer technology is also used in the fields of jewelry, footwear, industrial design, architecture, engineering and construction (AEC), in the automotive, aerospace, dental and medical industries, education, information mapping systems, civil engineering projects, and more. With the use of plastic and 3D drawings, which are freely available on the internet, or which one can create on one's own, it can very easily be made from the smallest component, to the whole construction piece by piece. Also, a feature of 3D printers is that they can reproduce themselves as they can print the parts that make them up.

A strategic advantage of 3D printing is the ability to produce more personalized and complex objects using just as much material as needed. Also, 3D printing helps to localize production by reducing the need for a production line and helps reduce CO2 emissions due to less travel (logistics). 3D printing, like almost any technology, can be used for dangerous purposes, such as easy weapon construction.

The invention of 3D printing reduces the production time of the first version of a product and frees us from the various obstacles we encounter in traditional production methods. For example, it is possible to print complex geometric shapes and intertwine parts without a bond. It is also possible to produce unique items, in small quantities, with low cost and fast distribution. The design, production and control cycle are accelerated allowing the

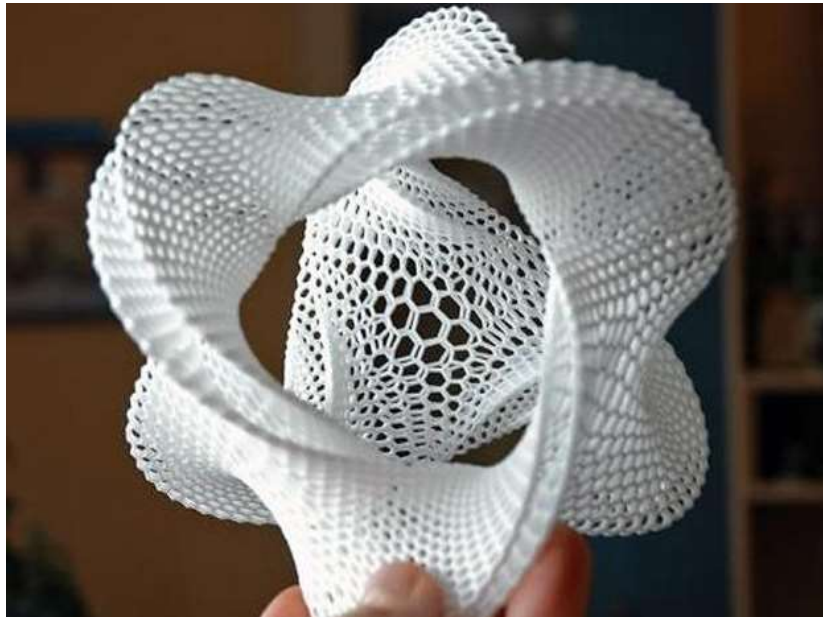


Figure 6. The applications of 3D printing are endless

designer to directly assess the viability of a product and incorporate design changes where required. The ability to modify a design online and immediately create the object - without wasting casting or drilling - makes prosthetic construction an economical way to create individual objects, small batches. Objects can be manufactured once the 3D digital model is created, eliminating the need for expensive and time-consuming tool equipment and prototype construction. Prosthetic technology allows rapid reaction in the markets and creates new production facilities outside the factories, such as mobile units that can be placed near the source of local materials. This technology also helps to reduce material loss during production. By building objects in successive layers, instead of the traditional processing methods where the material is cut, the needs and costs of the materials are reduced by up to 90%. These techniques save energy by eliminating the production stages, using virtually less material, allowing the by-products to be reused, and producing lighter products. 3D printing makes sense for high-tech products with complex designs, but is less effective for producing simple products that are produced in large quantities, such as stadium seats or trash cans.

Other 3D Printing techniques

- Selective Laser Sintering (SLS)
- Stereolithography (SLA)
- Digital Light Process (DLP)
- Multi Jet Fusion (MJF)
- PolyJet
- Direct Metal Laser Sintering (DMLS)
- Electron Beam Melting (EBM)

More info about these techniques can be found here:

<https://www.protolabs.com/resources/blog/types-of-3d-printing/>



Industrial and Personal 3D Printers

Three-dimensional (3D) printing is admittedly a great revolution and its presence is becoming more and more intense in many fields. It's actively used, not only on a personal level but also on an industrial scale, in production sector, engineering, medicine, education, science and elsewhere.

On a personal level, 3D printing allows to create models -even complex original objects- or to adapt existing products very quickly, in small quantities, with accuracy. This is especially important, as there is no need for specialized tools and equipment to make a prototype or to create, for example, an artistic object. On the other hand, this technology is also gaining ground at the industrial level where, of course, the requirements are different both in terms of the quantity of objects and their reliability, properties and reproducibility.

The obvious advantages of additive technology, e.g. production speed, safety, cost reduction and product quality, make the complete transition to it only a matter of time. Thanks to digital design and easy data transmission, everyone can minimize the time from the conception of an idea to its implementation, with safety both in the printing process and the resulting products.

What is certain is that 3D printing is a technology that has come to stay and we will see it applied more and more to many areas of our lives. It is now one of the technologies included in most academic and public Libraries due to its cost-effectiveness and ease of availability, helping in the education and development of know-how, always with safety in their use. [(3)]

The use of 3D printing technologies in industry

The term Industrial 3D Printing is presented as a revolutionary technology that is going to change production methods as we know them, especially when we refer to mass production and mass personalization customization. The way, the speed and the result of the adoption of additive manufacturing technologies, depends on the industry and the strategy of each company. In any case, the application of 3D printing technologies in the industry is a future challenge to achieve more flexible systems which will be based on internet and IT technologies. With the future of production in mind, the key question is whether additive technologies will be able to replace classic production lines. [(11)]

Table 1: Pros and Cons of 3D printing technologies in industry

Pros	Cons
The additive construction allows design freedom and complexity does not limit production.	Technologies have a lower rate of production than traditional methods.
Machining processes are to be eliminated, saving the relevant costs and time.	In complex cases, a significant effort is required in the definition of the parameters, the preparation and the general design.

<p>The possibility of optimal design is given, for low weight constructions, which would be impossible with the classical production methods.</p>	<p>Many times, the production process is not completed by the end of printing, as additional processing may be required for surface quality and dimensional accuracy.</p>
	<p>There is often a limit to the size that can be printed, based on the capabilities of the 3D printing machine, and economies of scale are not achieved due to discontinuous production.</p>

A very detailed and systematic study is required to determine the effectiveness of 3D printing technologies and to what extent it will transform production.

Economies of scale

3D printing technologies are currently lagging behind in this area. Nevertheless, additive construction is an industry that is constantly evolving and improving, in order to be able to replace the traditional production methods at some point. [7]

On demand manufacturing

3D printing technologies allow to significantly reduce the life cycle of products, especially in the design part. In addition, new supply chain management models will be created, reducing the risk posed by conventional inventory management models.

Product Personalization

3D printing allows the creation of personalized products, tailored to the personal needs of their users. In addition, new models are to emerge, in which customers will play an active role in the product design and production process.

Flexibility

The development of the supply chain on the basis of 3D printing will create more flexible networks, bringing production closer to the final consumer. The reduction of transports of finished products will have a significant impact on the distribution channels and more generally in the sector of distribution and distribution of products.

Differences between industrial and home desktop 3D printers

What Makes a Printer Industrial?

Industrial FFF printers are designed for repeatability and reliability. To ensure this, they feature closer control of the processing parameters during printing. These are the key elements that differentiate the home 3D printer from the Industrial [8,9]:

- **Large-enough volume** to print large pieces or dozens of smaller parts (300+ mm)
- **Extruder temperature** upwards of 350 °C to print reliably with engineering-grade filaments, such as PEEK, Ultem, and carbon-fiber infused polymers

- **Heated build chamber** that can hold a consistent temperature (at least 80 °C) for long durations to prevent part warping or cracking
- **Automation** of process variables for consistency and less manual calibration [(15)]



Figure 7. One of the largest format industrial 3D printers

Accuracy

Generally, the geometric tolerances and part accuracy are dependent upon printer calibration and model complexity.

Typically, **industrial FFF 3D printers** produce parts of higher accuracy than desktop FFF machines, because of the closer control of the processing parameters during printing. Industrial machines run calibration algorithms before each print, include a heated chamber to minimize the effects of rapid cooling of the molten plastic (e.g. warping) and can operate at higher printing temperatures. Most of these machines support dual extrusion. This allows for the deposition of **water-soluble support material**, which is removed in post-processing and results in smoother surfaces and makes it easier to print complex parts. [(14),(16)]



Figure 8. Accuracy is frequently a crucial factor

On the other hand, **desktop FFF 3D printers** are now catching up and there are machines that support these advanced features (i.e. calibration algorithms, heated chamber, higher printing temperatures and dual extrusion). A well calibrated basic desktop FFF machine can produce parts with fairly high **dimensional accuracy** (typically with tolerances of ± 0.5 mm) and with the same **minimum feature size** as industrial FFF machines (i.e. approx. 1 mm). This accuracy is sufficient for most applications. Most materials used in desktop FFF printing allow for critical dimensions (e.g. holes) or detailed features (e.g. threads) to be machined accurately in a post-processing step. [(15)]

Materials

The material most commonly used on desktop FFF 3D printers is PLA. When higher strength, ductility and thermal stability is needed, ABS is commonly used, which is more prone to warping (due to shrinkage) and the geometry of the printed part can prohibit its use, especially in machines that do not have a heated chamber. Another alternative material that is rising in popularity is PETG, which has material characteristics comparable to ABS and is easy to print with.



Figure 9. Rolls of plastic filaments is the main material used on 3D Printers

Industrial FFF 3D printers use mainly engineering plastics ABS, polycarbonate (PC) or Ultem). These materials are usually loaded with certain additives that alter their properties and make them particularly useful for a certain industrial need (e.g. high impact strength, thermal stability, chemical resistance and biocompatibility). Some materials printed with industrial FFF have similar material properties to injection molded parts and often times can be 'good enough' for creating functional end-parts. The temperature resistant properties of these materials also mean that they are suitable for mold-printing for low run injection molding. [(5), (7), (10), (13), (19)]

Production capabilities and cost

The **production capabilities** of an industrial FFF 3D printer are typically greater than that of a desktop 3D printer, meaning that an industrial FFF machine can complete a **large order faster** than a desktop 3D printer. Industrial 3D printers also have a **larger printing area**, which means that they can produce larger parts in one print or print more models at the same time.

Industrial FFF printers are also designed for **repeatability** and **reliability**. They can often produce the same part over and over again. Desktop FFF printers require a high level of user maintenance and regular calibration. [10]

Table 2. The most important differences between 3D printers for home use (desktop) and industrial models

Type	Desktop 3D printer	Industrial 3D printer
Amount of handled materials	Mostly 1	Usually 1-2 for build and 1-2 for water-soluble support material
Dimensional accuracy	0.5%-1% (~1mm for a 10cm item)	~0.2% (0.2mm for a 10cm item)
Build volume	<10 lit	>100 lit~1000lit
Chamber	Usually open	Closed and heated, allowing precise control of material properties
Printing speed	~50mm/sec	>100mm/sec
Material types	Mostly PLA, PET-G (also ABS but difficult to use in open chambers)	ABS, PC, Ultem, etc Taking into account Durability, Thermal stability, Flexibility, Resistance to chemical agents, Biocompatibility, etc
Typical layer thickness	0.10 - 0.25 mm	0.18 - 0.5 mm
Machine cost	400€ - 4.000€	>20.000€

Advantages of 3D Printing

1. Faster production

Let's say you are still using the traditional manufacturing method and you are okay with it. However, when it comes to comparing it with 3D manufacturing, you will notice the differences.

Comparing the two is the same as comparing a sports car vs a horse-drawn cart. Both will reach their goal, however, the time difference is altogether tremendous. From a model to the last item, 3D printing tests ideas and designs quickly.

Quicker model development and design will eventually translate to more opportunity to emphasize the model and discover item showcase the prototype before contenders. 3D printing creation takes only hours. On the other hand, testing thoughts and designs with traditional assembling strategies can take up days, if not weeks and months.

2. High quality designs and products

Conventional manufacturing strategies can without much of a stretch result in poor designs, and in this way poor quality models. Envision a situation where somebody needs to bake a cake by mixing all the ingredients together, blending them up, and placing them in the oven

Poorly done mixture will definitely result to a poorly done cake. This is not something that you would like to have.

You can experience such issues with injection and subtractive methods of manufacturing.

You are not guaranteed of quality 100 per cent of the time. 3D printing follows step by step patching of different components, which ensures upgraded designs and in the long run better quality articles.

3. Easy to test and iterate

3D printing provides room for testing the model. It is conceivable to encounter the touch and feel of the item prototype to truly test. From there, you will be in a position to unravel all the design flaws. On the off chance that an issue is discovered, you can alter the CAD document and print out another model early enough.

4. Easy to customize

Conventional manufacturing strategies are ideal for making a great many duplicates of something very similar. It brings about the same dull and exhausting designs without any significant improvements. Making each design special or unique with these strategies is phenomenally hard.

3D printing takes into consideration unending personalization, which makes it a lot more straightforward to the satisfaction of your customers. Creative mind is the main restriction. You can make a product that is accurately designed to fit in somebody's specific needs. This eliminates the numerous visits that a client needs to ensure they have an appropriate product.

5. Allows different sizes and shapes

The good thing about 3D printing is the flexibility that it provides. You can create models of different shapes, sizes and geometry.

Old techniques for assembling depend on molds and slicing techniques to create the ideal shapes. Designing geometrically complex shapes can be hard and costly with these technologies. 3D printing takes on this task effortlessly and there's very little the technology can't do with the use of the correct material.

6. Can be used on different materials

3D printing effectively suits a differing scope of crude material, including metal glass, plastic, paper, ceramics, diamond, and a plethora of other options. Most conventional alternatives are very limited. [4]



Limitations of 3D Printing

Expensive: 3D printing is more expensive than most of the traditional methods of manufacturing.

3D printing hardware and materials cost make the innovation costly. Modern evaluation 3D printers are quite expensive, costing a huge amount of capital investment, which makes the underlying costs of utilizing the innovation extremely high.

The good news is you can avoid the issue of the high cost of 3D printing. Simply outsource the service, and you will be able to save yourself from incurring high expenses. Just find affordable 3D printing services in China.

High energy consumption: It is always believed that 3D printers are energy-thirsty. They consume high energy, and this will force you to spend more on electricity bills.

While such claims are true, there is a special way of avoiding high energy costs is by paying 3D printing companies in China to do the job for you.

Toxic emissions: In the past, the first generation of 3D printers were known to emit toxic gases and chemicals to the environment. You don't have to worry about this as the latest LED printers are more environment-friendly.[4]

Basic 3D printer selection criteria

How big are the objects?

One of the characteristics of 3D printers is the print size or useful print volume and refer to the three dimensions of the largest object that can be printed on this machine.

Base: From 200mm to 300mm for each side, which is not necessarily square.

Height: Can range from 180mm to 200mm

On what surface will you print?

The printing platform (the surface on which the printing is done) may seem insignificant to a beginner, but it can prove to be very critical in practice. A good platform will ensure the stability of the print and will allow the object to be easily detached after the process is completed.

Open or closed frame?

There are 3D printers that are enclosed by walls, possibly with a lid or a removable lid, but there are also some 3D printers that are not enclosed somewhere. The advantage with "open" printers is that there is more comfortable visual contact with the process and object of 3D-printing. On the contrary, a closed type 3D Printer provides greater security for both users and the process, provides sound insulation and is suitable when the raw material is ABS.

Print in one or more colors?

Some 3D printers using multiple nozzles can export objects in two or more colors. Each nozzle is supplied with a material of a different color. The colors are not mixed, however there is already a fairly wide range of colors available.



How high resolution is needed?

A 3D printer spreads layers of molten material according to instructions it receives from a digital file to form the final object. For 3D printing, the resolution is equivalent to the thickness / height of each layer. This resolution is measured in microns and each micron is 0.001mm, so the smaller this size the higher the resolution and the better the details are rendered to the object. This of course has the corresponding cost at the time of completion of the process. Printers on sale today have different levels of resolution at which they can print, from 50 microns to 800+ microns.

The Anatomy of a 3D Printer

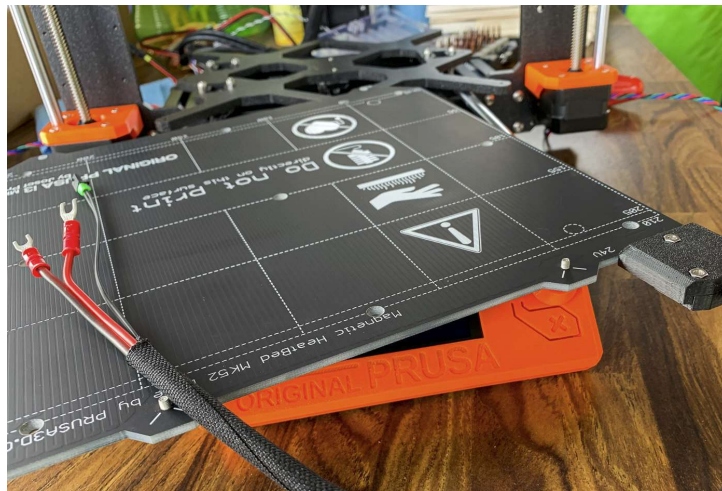


Figure 10. The print bed [33]

There are various types and methods employed by 3D printers to create objects, but our emphasis will be on **Fused Filament Fabrication** technique that is the most common among desktop 3D printers used at home. This method can be considered to be the same as the 'glue-gun' method. The glue-gun method consists of heating up a filament to a point where it melts – this melting filament is then placed in thin layers and the object is created layer-by-layer.

The printer parts

Print Bed

The print bed is the flat surface where the objects are created layer by layer by the printer. It is usually a few millimeters of aluminum, glass or magnetic foil, with or without coating. The printing surface is usually heated for better adhesion of the material and is recommended for most materials. In this case, it is important to keep the print bed warm during the whole process in order to prevent warping. Temperatures between 40 degrees to 110 degrees Celsius are maintained during the entire printing process.

Stepper Motors

Motors that we use for the movement of the X, Y and Z axes. They carry the movement with belts or cables providing millimeter accuracy. We will find another one in the extruder, the mechanism that is responsible for the proper flow of the material.

Extruder

The extruder is a part that is responsible for pulling and feeding the filament to a part called the **hot end**. Typically, extruders are integrated within hot ends. In other cases, they may be located away from the hot end from where they push the filament to the hot end through a tube called the Bowden Cable. A printer with a dual extruder can print using two different colors and materials at the same time. This does come at an extra cost because an extra extruder and a hot end is required.

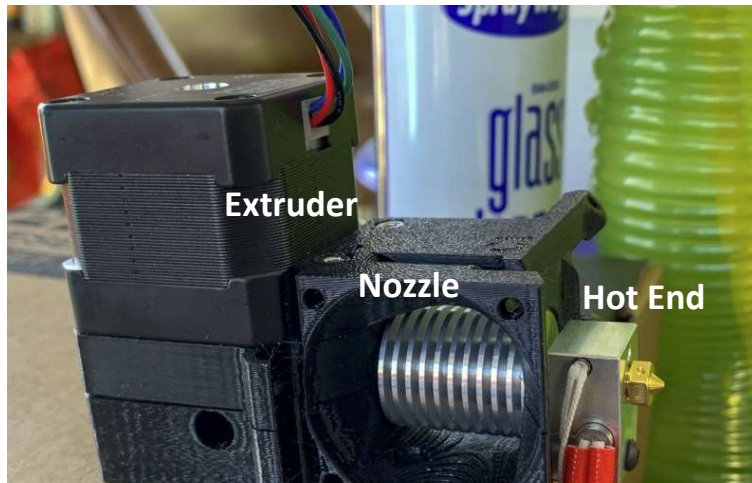


Figure 11. The Extruder [34]

Hot End

The Hot End in a 3D printer comprises of a heater, a temperature sensor and an extrusion tip through which the filament is fed. Just as their name implies, they can get extremely hot and should never be handled directly. There are holes in the nozzle that range in size between 0.2 mm and 0.8 mm. The smaller the nozzle of the hot end, the finer the print will be; However, the time taken to print the object will also be greater.

Part Cooling Fan - Print cooling fan

The fan that freezes the object during printing. Usually, we do not operate it in the first layers and adjust its speed by the slicer program we use.

Hot End Cooling Fan - Head cooling fan

The fan that keeps the printhead heatsink cool and operates permanently without stopping. It does not affect whether it is open or not and it is recommended to leave it until the head cools down, before closing our printer.

Nozzle or nose

The nozzle is where the molten filament comes from. Depending on its diameter we have different results in terms of quality and time. There are different sizes, with the most common being 0.4mm in most printers, but one can easily find from 0.1mm up to 1mm.

Each nozzle type requires different filament, so be careful if you choose to get a new one.

Linear Motion Control

A belt, pulley, servo, or actuator-controlled portion of a machine frame that moves the head or the bed of the 3D printer in the X-, Y-, or Z-axis. Most printers may move the print head in X and Y directions, while the build bed moves vertically in the Z direction. Others may use linear controls to deposit material in the build area or remove excess material to overflow bins.



Figure 12. The actuator-controlled portion on the XY axis

The belts are the parts of the 3D printer one must take special care of. Over time, the belts may lose the tightness and become loose; that's when it is time to be replaced.

Filament Materials

The two most common materials are by far ABS (acrylonitrile butadiene styrene) and PLA (poly-lactic acid). These two materials have some slight differences in their properties. For example, ABS is more elastic than PLA and melts at higher temperatures, but it emits an odor during processing and the printing platform needs to be preheated. PLA has a finer texture but is less durable. Prices from 15 to 40 EURO per kilo (also affects the density of the material) ABS (Acrylonitrile Butadiene Styrene) is an oil derivative and is one of the most popular 3D printing materials along with PLA. Compared to PLA, ABS is more flexible and impact resistant, it also has a higher melting point and longer life. Its texture is more matte than PLA and can be processed, sanded and painted. It is also soluble in acetone, which helps us to bond prints together or to smooth them out.

Table 3. Main attributes of the most common FFF Filament Materials [(8)]

Material	Extrusion Temperature	Positives	Negatives	Uses
ABS (Acrylonitrile Butadiene Styrene)	210–250°C	Strong, flexible, smooth surface, withstands higher temperatures, easy to sand and paint	Strong odor, warps easily, requires heated build plate, may require fume hood, not biodegradable	Same plastic as LEGOs
PLA (Polylactic Acid)	190–240°C	Low warping, doesn't require heated build plate, recyclable, sweet odor	Less flexible, can be brittle, softens at 60°C	
HIPS (High Impact Polystyrene)	230–265°C	Dissolves only in limonene-D so good for support material		Preferred material for LulzBot 3D printers
PET(E/T/G) (Polyethylene Terephthalate)	210–250°C	Recyclable, strong, transparent surface		Same plastic as soda bottles, preferred filament for Cube's Ekocycle
PVA (Polyvinyl Alcohol)	190–210°C	Dissolvable in water	Filament susceptible to humidity	Useful as support material
Nylon	245°C	Absorbs color well (see Horne, 2013)	Filament susceptible to humidity	
NinjaFlex	210–240°C	Prints are flexible	Expensive, adhesion to build plate can be difficult	
Lay Brick and Lay Wood	Varies by intended texture effect	Achieve look of brick or wood using FFF printer	Particles can damage extruder	Mixture of PLA and brick or pine shavings

ABS is used in many products that we find in our daily lives, car parts, utensils, and even toys such as Legos. In 3D printing, the ABS filament requires a heated platform for better traction of the models but also to minimize their distortion as the ABS has the property of shrinking when it cools down. When printing, it leaves a slight plastic odor, from annoying to poor quality consumables to almost invisible to the best (like Z-ABS).

PLA (Polylactic Acid) is the other popular 3D printing filament after ABS and is very popular due to its ease of use. It is produced from renewable sources such as sugar beets, corn and soy and is biodegradable and ecological. The extrusion temperature required for printing is lower than ABS and has a low shrinkage rate so it does not suffer from distortion as much as other consumables. PLA has very good adhesion to cold platform and it is usually



Figure 13. Filament Types and colors [35]

enough to cover it with blue tape. Due to its lower printing temperature and easier cooling, it has an advantage over models with small details and sharp edges. Its surface is relatively glossy and can normally accept external treatment. It is harder than ABS but also more fragile.

HIPS (High Impact Polystyrene) is a general-purpose consumable that has become famous for its ability to dissolve in Limonene. HIPS and ABS have similar printing characteristics as temperature printing, and therefore adhere well to each other. Thus arose its use in parallel with ABS in 2-head printers, with HIPS being used exclusively for brackets which are then dissolved by immersion in Limonene, thus enabling complex prints of models that previously could not be printed with it. method it is now possible to remove supports from difficult internal points and complex internal structures without marks and damage to the model.

PVA (Polyvinyl Alcohol) is another water-soluble material. It is mainly used as a support structure, and dissolves completely in water. It was the first filament in this capacity and opened the doors to water-soluble prints. The types of products that can be printed using PVA range from simple prints to scientific or biotechnological applications. It is relatively easy to print and has good adhesion to the blue tape.

Wood filament is a revolutionary 3D printing material. This filament contains usually 30% recycled wood and the rest is usually a PLA base. Therefore, its printing behavior, cold platform adhesion and printing temperatures are properties that it shares with PLA. The impressive thing is that the printed objects have a texture very close to that of wood, up to its smell. In fact, playing with different printing temperatures, we slightly affect



Figure 14. Wooden 3D printed object

its hue, which gives a lot of creative possibilities. Printed models are easy to process, cut, sand, grind or even paint, but keep in mind that their strength is less than that of the common PLA as mixing with wood makes it more vulnerable to breakage.

Nylon consumables have recently become a popular alternative as a 3D printing material as this material offers flexibility and high durability, while being extremely lightweight. Nylon models are not as fragile as those printed with either ABS or PLA, in fact a 3D object made of Nylon can be up to ten times stronger. It is therefore an excellent choice for printing objects such as tools, gears or even prostheses. Nylon is more demanding and difficult to print and as it tends to absorb a lot of moisture, it needs a lot of attention to how it is stored and good dehumidification in a heating chamber before use.



Figure 15. Nylon 3D printed artefact

PETG (Polyethylene Terephthalate Glycol-modified) is an upgraded version of the popular PET filament. The difference between PET and PETG is the addition of glycol which prevents crystallization and makes the filament less brittle. One of the most important characteristics of PETG is its impact resistance. It also has very high optical clarity and compared to Acetal and Nylon has better resistance to acid conditions, wear and abrasion resistance. Due to these properties PETG has many uses and applications in products ranging from medical equipment, food packaging, labeling, and more.

What affects the filament selection?

The quality of the filament and its cost is something that influences the choice of the filament company. But sometimes we have to look at some details to make the right choice! Whether we are interested in low cost or quality, we need to look at some parameters to make the right choice.

Country of production: The country of production of the filament is directly related to quality. By choosing an advanced factory with the latest technology production line, we ensure the best production conditions of our filament. There are countries that have a tradition in filament production such as European countries with the largest manufacturer in the Netherlands.

Density: The density of the filament has to do with the final cost of the material. The plastic is always bought in packages that have weight as a unit of measurement. (1kg, 0.75kg, 0.5kg, 0.25kg) However, the consumption of the 3d printer is measured in meters of material. In the following example we see two identical PLA materials with different densities. The consumption of PLA which has 1.24gr / cc and costs 25 €, in a construction that needs 317m of material is 25 € (1000gr of material). In the second case the PLA which is 1.43gr / cc and has the same purchase cost of 25 €, in the same construction with 317m of material we have a

final cost of 28.84 € (1150gr of material) We observe that our density makes the object heavier with result that we do not have enough of a filament of 1kg but we need more.

Properties: All filament companies have detailed measurements to their yarns. There you can see important information such as impact strength, tensile strength, hardness and more. By comparing this information we can see how much better a filament really is. Many times for marketing reasons companies write 10x, 20x louder but it does not result from the measurements. If you do not find the detailed measurements you should ask the manufacturer.

Packaging: Many do not care, but the right packaging is what will protect our filament. A strong filament made of ABS will protect our material from falling. The transparent filament will help us to see at any time how much we have left. Also, the material should ideally be closed in a vacuum package to always come fresh to your door! Finally, the box will protect it during transport



Figure 16. Proper packaging is crucial

Stability: The main goal of a 3d printer user should be stability. Trust a company because it knows it will find consistent performance in its prints. So, every 3d print with every filament that will make it have the same results. Many times, we observe cheap filaments to differ from batch to batch of construction resulting in different settings being needed and printing failures. So practically our material becomes more expensive because we will make repetitive prints.

Fused Filament Fabrication (FFF) Printers

Fused Filament Fabrication is the most common type of 3D printing process, and is used by most of desktop 3D printers in the consumer market. The filament is fed into the extruder of the printer, where it is heated to a high enough temperature to melt it. This melted filament is then extruded from the nozzles to create each layer.

Advantages of FFF Printers:

- ✓ These 3D printers are usually the cheapest and can be bought between \$1000 and \$5000.
- ✓ The filament used is affordable.
- ✓ They use a large variety of materials.
- ✓ They are easy to maintain and parts can also be replaced conveniently.
- ✓ They can print quite fast.

Disadvantages of FFF Printers:

- ☒ Their nozzles can frequently clog
- ☒ Supports can be problematic to clean up
- ☒ The individual layers can be visible in the end product (striping)

Storage

Thermoplastic materials, such as ABS and PLA work best if they are previously **sealed** to prevent absorbing moisture from the air. However, this does not imply that the filament will necessarily be spoiled if the reel of your filament is left to sit around for a week or so before used. Still, extended exposure to the atmosphere can have detrimental effects on the quality of the material as well as the end product. The filament comes wrapped up in plastic to prevent absorption of moisture. Here is a comparison of the effects of storing ABS and PLA:

ABS – If ABS is exposed to the atmosphere and it absorbs unacceptable amounts of **moisture**, then it will tend to bubble and gush from the nozzle tip when being used to print an object. This will lead to a reduced visual quality, accuracy, strength and will be more likely to clog the nozzle. By using a source of heat such as a food dehydrator, you can easily dry ABS prior to use.

PLA – PLA reacts in different ways when exposed to **moisture**. In addition to forming bubbles and gushing from the nozzle during printing process, a slight discoloration and numerous other changes in its properties will also be seen.

At high temperatures, **PLA** is known to **react with water** and this can lead to depolymerization. Depolymerization is a process in which a material undergoes decomposition into simpler compounds.

You can also **dry PLA using a food dehydrator**, but keep in mind that this can lead to a change in the crystallinity ratio of the material and will probably alter extrusion characteristics. Nonetheless, this isn't a major problem for most of the 3D printers out there.

Smell

ABS – When ABS is heated, a **notable odor** of hot plastic is pretty evident. For some, this is nothing more than a nuisance, while there are some people who do not even notice it. Regardless of whether you notice the smell or not, it is imperative that you ensure proper ventilation of the room where ABS is being used. Also, make sure that the ABS you use is free of contaminants. A reliable extruder also plays an important role as heating the material to the proper temperature goes a long way in controlling the smell.

PLA – Due to the fact that PLA is made from sugar, it gives off a **semi-sweet odor** equal to that of cooking oil when heated. It definitely won't bring back memories of those delicious home-cooked meals; however, some consider its odor to be better than that given off by ABS.

Part Accuracy

ABS and PLA both have characteristics that allow them to create dimensionally-accurate parts and products. Still, the following points are worth mentioning when it comes to discussing accuracy of parts.

ABS – One of the major challenges involving use of ABS is the upward curling of the surface that is in direct contact with your printer's print bed. By heating up the print bed and by making sure that the bed is clean, flat and smooth, you can really help to eliminate this issue. Some people find it better to apply a number of solutions including ABS/Acetone mixture or simple hair spray onto the print surface prior to printing. At 3D Insider we have experimented with

hair spray on the print bed with some success (just remember that hair spray is highly flammable!)

Certain features such as sharp corners usually end up being round. A small fan can be used to cool the area around the nozzle to improve such corners; however, excessive cooling can lead to a reduction in the adhesion between the layers, and may eventually cause the final product to crack.

PLA – PLA warps less than ABS. This is exactly why it can be used to print objects without the need of a heated bed. If cooled actively, PLA can be used to create sharper details including sharp corners without the material cracking or warping. The increased airflow can also assist by strengthening the object by binding the layers strongly together. [2]

General Material Properties

ABS can take numerous forms and can also be engineered to have various properties. In essence, it is a strong plastic with moderate flexibility. Before colors are added to ABS, it milky-beige. The mild flexibility of the material makes it easy for it to be sanded and machined. Also, it is much easier to recycle as compared to PLA.

Engineers usually prefer ABS due to its high strength, flexibility and machinability.

PLA – The origin of PLA includes sugar-beets, corn and potatoes. This is why PLA is thought of as being more environmentally friendly than ABS. It is commonly used to package food and to make containers foodstuff. In its original form, it is transparent but can be colored to varying degrees of opacity and translucency. It is much stronger than ABS as well as rigid. Objects printed using PLA carry a glossy look and are smooth to the touch. Nonetheless, it is slightly more complicated to work with due to its complex interlocking assembly and pin-joints.

Thickness of the Filament

ABS and PLA filaments come in two different diameters: 1.75 mm and 3 mm

Each extruder is designed to work with a certain thickness of filament. The diameters of the filaments may vary slightly from one manufacturer to another. However, if a filament is labeled as 3 mm, then it must not exceed that value; it can, however, be slightly less than 3 mm (say, 2.88 mm).

Maintenance Guidelines

A 3D printer that is well-cared for will give you years of flawless service while functioning optimally and delivering better quality prints. The following guidelines will help you keep your precious printer in the best condition possible.

Oil the Rods

The X, Y and Z axes provide movement paths for the extruder head. It is essential that the movement is smooth and unrestricted for the finished product to be created as accurately as possible. This is why you should periodically oil your X, Y and Z rods after cleaning up any residue that you may find on them. In most cases, once a month would suffice.

Tighten the Nuts and Bolts

The mechanism of a 3D printer is designed to move, and this movement can cause the nuts and bolts to become loose overtime. If they get too loose, your printer will start to shake when being used and this will reduce the accuracy considerably. Again, tighten all the nuts and bolts on a monthly basis. Just remember not to over tighten them!

Test and Adjust Belt Tension

There's no harm in testing the belt tension to ensure it is correct. Any deviation from the correct tension will lead to a decrease in print quality. Adjust the tension as required. You can refer to your printer's manual for detailed guidance on tightening belt tension.

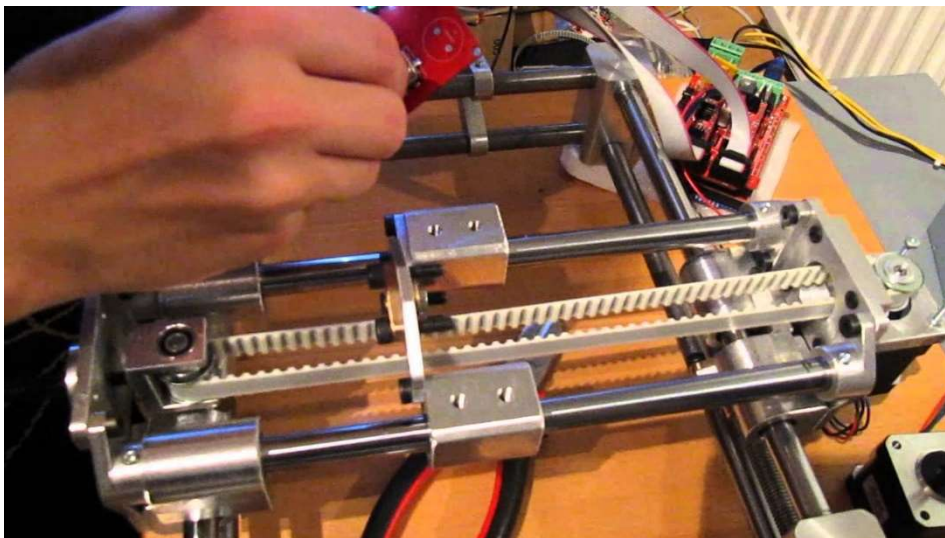


Figure 17. Belt tension testing

Floss the Extruder Gear

With time, some small pieces of plastic may accumulate in the extruder gear and prevent smooth rotation of the gear. Take a pointy object (such as a toothpick) to remove such bits and bobs from the gear's teeth.

Update Your Firmware

Maintenance isn't just limited to the hardware portion of your printer; it also involves the firmware. Keep checking for any available updates for your extruder. Firmware of 3D printers has improved drastically over the past few years, and it will continue to do so.

Keep Your Software Updated

The software that you use to control the printer must also be updated whenever one is available. A lot of bugs and errors may have been removed in the newer versions.

Replace Build Surfaces If Necessary

In order to create perfect, flat builds, you need to make sure that you replace your build surfaces if they become warped.

Things to avoid with a 3D Printer

Don't Rush

You will definitely be really excited when you have your 3D printer delivered. DON'T RUSH to start using it as quickly as possible. You may mess up something while doing so. The best way is to start off slowly, read the enclosed documentation and proceed one step at a time.

Don't Forget the Hot Nozzle

The nozzle of the extruder has to be hot in order to melt the plastic filament. The temperatures can exceed 150 degrees Celsius. If during printing, you have to re-adjust the bed height, don't forget that the nozzle would be hot – you don't want a small indentation in the printer bed!

Don't Presume That It's Calibrated Correctly

While it is true that printers now come pre-calibrated, things can shift during transportation. Make sure you check the following to ensure everything is as it should be:

- ✓ Clearance of Nozzle from Print Bed
- ✓ Printer Correctly Configured in Software
- ✓ Print Bed Dimensions Properly Loaded in the Software

How to Store Printer Filament Correctly

Whether it is wood, ceramic or any other material, most of them will absorb water content to some extent. By definition, absorption is a condition in which something takes in another substance.

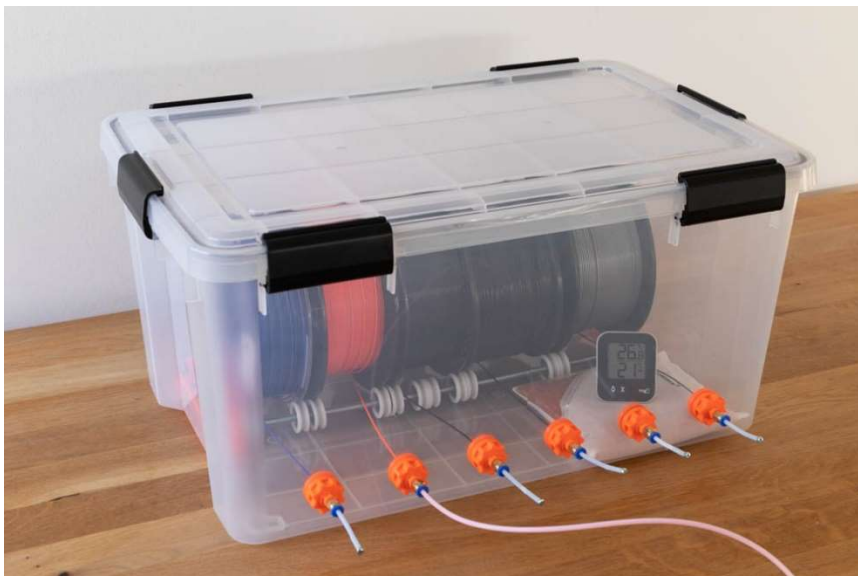


Figure 18. Innovative storage boxes ensure good filament quality for a long time

When it comes to the most popular plastic filaments used in 3D printing, both ABS and PLA have water-absorbent properties. If allowed to absorb moisture, their quality is drastically reduced.

Small water bubbles will be created within the filaments as a result of the absorption of moisture, and this makes proper storage absolutely necessary. As soon as the filament is heated during the printing process, the bubbles will cause the material to be spewed out rather than being laid down precisely.

PLA cartridges and spools are also known to get brittle if they absorb a lot of water content. A number of people have experienced this after their filament simply snapped while being processed by the extruder.

The only thing you can do to prevent the moisture from being absorbed by the plastic filament is to store them in airtight plastic bags and containers.

You could always opt for custom cases that are especially designed for storing ABS and PLA filament reels and spools. However, there's a cheaper method to keep your feedstock free from moisture:

Get a large airtight plastic bin and place the plastic filament reels in it. Place a bucket of uncooked rice as a desiccant and you will have perfectly dry plastic filaments at your disposal!

A dryer can be used to remove the moisture from ABS; however, you cannot dry out PLA and this is why it should never be allowed to absorb moisture in the first place. Almost all renowned companies ship the plastic filaments in vacuum-sealed packs along with desiccants. Desiccants work best when they are in a closed-system. You should only open the pack when you actually need to use it. After using it, wrap it up in a plastic bag and drop in a few desiccants to absorb any moisture.

Design Best Practices

Minimum Wall Thickness

It is recommended that features of any design are above 0.6 mm (0.024") on self-supporting features, like X-, T-, O-, or C-like shapes. At least 1.2 mm (0.048") is recommended for unsupported or load bearing features like I-like shapes, pins, or tabs.

Clearance between Features

To ensure part features have a usable gap, it is important to design at least a 0.5 mm (0.020") gap.

Remove Confined Hollows

Most commercial 3D printing processes will have trapped material or support structure in confined hollows. Line-of-sight access to clean or drain these areas is necessary. These access areas are often called "escape holes," because they allow for material to escape during post processing. Any cavities with a depth beyond 50.8 mm with only one access point, such as a boss, may require multiple escape holes for cleaning.

Fillet Everything

Fillets, or rounded internal and external corners, are preferred in every 3D printing process to mitigate transitions between features and reduce acute stress points. Generous filleting can increase the end-use performance of a printed part.

Be Mindful of Cantilevers

3D printing offers significant freedom of design. Features like cantilevers and “lollipop heads” can be delicate compared to the rest of the part. It is important to be mindful of these features while designing, especially if they are critical for function. It sometimes makes sense to make these features replaceable, or use off-the-shelf pins to produce these features on large parts where they can be crushed or damaged by the part’s weight.

Design with Even Wall Thickness

3D printed parts share many design tips with injection molding, including uniform wall thicknesses. A uniform wall thickness will help mitigate any thermal deviations between thick and thin transitions on a part. These can be caused by uneven cooling of the part as it is growing or curing. Adding ribs, coring, and lattice structures can build strength without increasing thickness to a part. One exception is Fused Filament Fabrication (FFF), where infills can be modified to sparse, lattice-like, cross sections which provide similar results. [3]

Ways to reduce the cost of 3D printing

Optimize Print Settings

When preparing your print on slicing software, it’s important to enter the best possible settings for your printer and selected filament. This is a process that will require trial-and-error on your own, but there are also various resources out there (like Filaments directory) that will share print settings with you. Not only do the correct settings ensure higher quality prints, it also reduces the chance of print failures, clogged nozzles, and other frustrating errors that will have you restarting prints and reaching into your wallet. By making sure you have the right print setting, you can preserve material, thus cutting down on the cost of 3D printing.

Hollow Your 3D Model

You can save material (and thereby cut your cost of 3D printing) if you hollow out the inside of your design. But be careful how slim you make the model, because the printing material you use will require a minimum wall thickness to maintain structural integrity. This value can

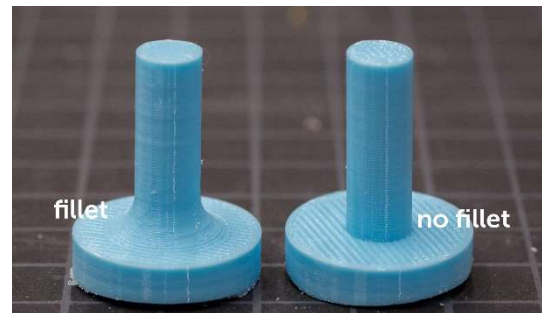


Figure 19. Filleting Explained

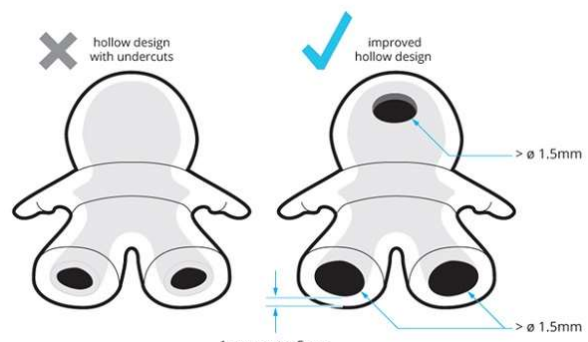


Figure 20. Hollowing helps reduce the total cost

range from 3mm to 1mm for plastics and ceramics, and all the way down to 0.2mm for titanium.

Reduce the Size of Your Print

The saying that “bigger is better” might ring true in some situations, but not when it comes to reducing the cost of 3D printing. If you are simply printing a model of something in real life, the size might not be of functional importance. In this case, it would make sense to reduce the size of your design. However, at the end of the day, this is a question of personal preference and general needs. Still, if you’re able to make your model smaller, the printing process will require less material, thus resulting in much lower costs of 3D printing.

Reduce Infill Percentage

Another way to save the cost of 3D printing is to reduce the percentage of infill used when able. Not only will you preserve more material this way, your prints will also finish much faster. Of course, there may be instances where higher percentages of infill are needed to meet certain structural or mechanical needs. But when you don’t need to create a solid object, reducing the infill percentage is a great way to reduce the cost of 3D printing while also speeding up the overall process.

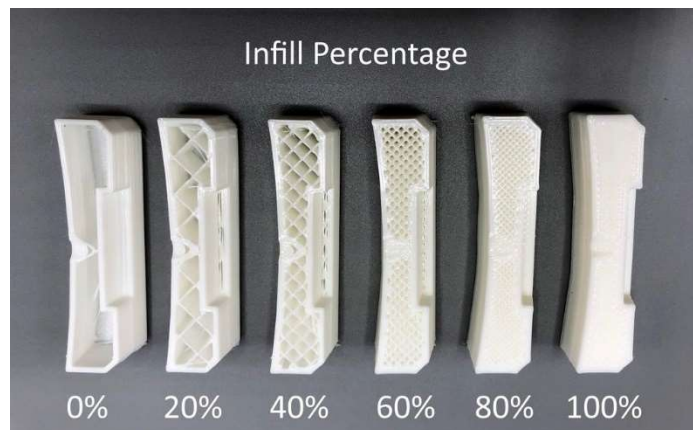


Figure 21. Use infill with care

Choose a Greater Layer Height and Resolution

All 3D files are sliced into layers can be printed one by one to form the physical object. The height of these layers determines the resolution of the printed item (think of it as the pixels on your computer screen). A low layer height will result in a smooth surface, but it will also drastically increase the time it takes to print your 3D file.

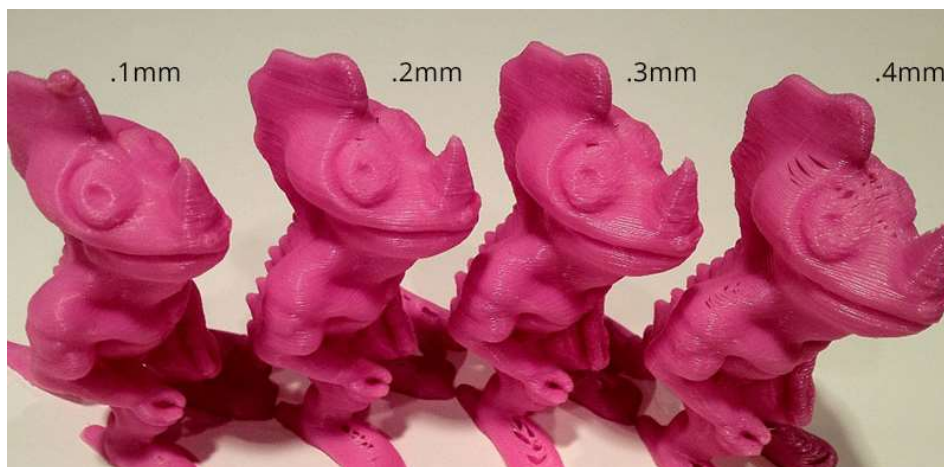


Figure 22. The final product depends widely on Accuracy

Since 3D printing services make their money by printing as high a volume of material in as short a time as possible, the time your part spends in the 3D printer is directly reflected in your overall cost of 3D printing. While increasing the layer height will result in a lower cost of 3D printing, you should consider the impact on the appearance and functionality of the printed object. Especially if your part requires sharp edges to function or has to fit exactly with other parts, a smaller layer height is preferable.

Similarly, with desktop 3D printing, you can slightly reduce the cost of 3D printing by increasing the layer height. This will reduce the time and material used to print your creation. However, there are certainly times when print quality is the most important aspect, and thus layer height should be set on a case-by-case basis.

Select the Right Materials

Within the range of commonly used ABS and PLA plastics, the price can range anywhere from \$19 and \$175/Kg (obviously, picking a cheaper filament will help reduce the cost of 3D printing). This is the result of varying attributes like color, translucency, and special properties like glow in the dark.

For desktop 3D printing, it's also important to select a material that is affordable but also matches your needs. PLA should work well for normal prototypes, but something like PETG will offer more durability for prints that will encounter stress.

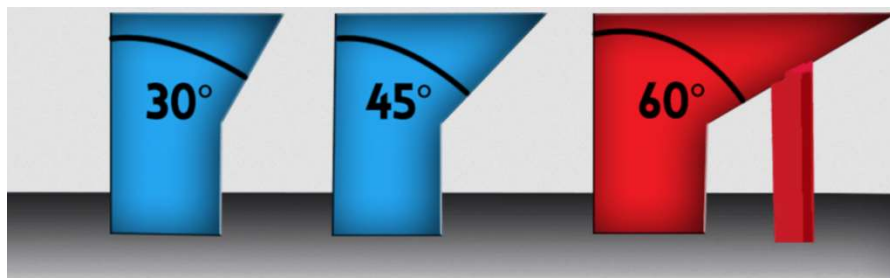


Figure 23. Support can be avoided

Avoid Support Structures and Rafts (When Possible)

The cost of 3D printing through materials could be saved by eliminating or reducing support structures and rafts. Similarly, to the infill percentage tip, there will always be projects that require support structures. But a lot of the time, just reorienting your object on slicing software can help rid your print of unnecessary plastic waste. Not only can the removal of support structures reduce the cost of 3D printing and overall time spent, but it will also help produce cleaner prints. Anyone with desktop 3D printing experience knows how painful it can be to remove support structures at times, and could leave you with lackluster print quality and rough surfaces.

Take Advantage of Complex Shapes

In general, one of the biggest advantages of additive manufacturing over traditional methods of fabrication is the ability to replicate complex shapes and structures that are found in nature, such as honeycombs. With 3D printing, it's easy to design lean 3D shapes that have been

trimmed down to the minimum amount of required material, yet can still be stronger and more lightweight than traditionally manufactured parts. Using biological concepts, you can cut your cost of 3D printing for material. If you want to experiment with this concept, check out the free 3D modeling tools like Meshmixer.

Use or Modify a Free Design

There’s a ton of great designs out there, so you don’t have to necessarily reinvent the wheel yourself. 3D printing marketplaces like Thingiverse has over 1 million free designs for you to choose and 3D print for personal use.

Free 3D Modeling Software

There is no need to spend a dime on 3D modeling software, as there are many great free 3D modeling tools available. Freely available programs like TinkerCAD or SculptGL will turn you into a 3D modeling artist in no time. While more advanced options like FreeCAD and Autodesk Fusion 360 will even match the needs of industry professionals. Because choosing the right 3D modeling software is difficult, we have compiled a list of tools for you to sort through. Find the right 3D modeling software for your creative endeavors here and save on the cost of 3D printing software. (<https://all3dp.com/1/best-free-3d-modeling-software-3d-cad-3d-design-software/>)

DESIGN RULES FOR 3D PRINTING



	Supported walls	Unsupported walls	Support & overhangs	Embossed & engraved details	Horizontal bridges	Holes	Connecting /moving parts	Escape holes	Minimum features	Pin diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
Fused deposition modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective laser sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct metal Laser sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm

Figure 24. This is the 3D hubs design guide. [11]



Keep Filament Properly Stored

While certain systems that will keep your spools safe are already on the market, they can be bulky and oftentimes expensive. Instead, you can use vacuum bags that you are able to compress the air out of. By sealing your filament in such an environment, you can prevent the material from bubbling or becoming brittle, which in turn means less money spent on filament. [5]

Workflow

Having received the specifications for each technology, we initially alienate ourselves from the starting point of the AM processes so that we can create the 3D-CAD model. So based on the design requirements we complete the data and are stored in a specific format that is manageable by the AM machine.

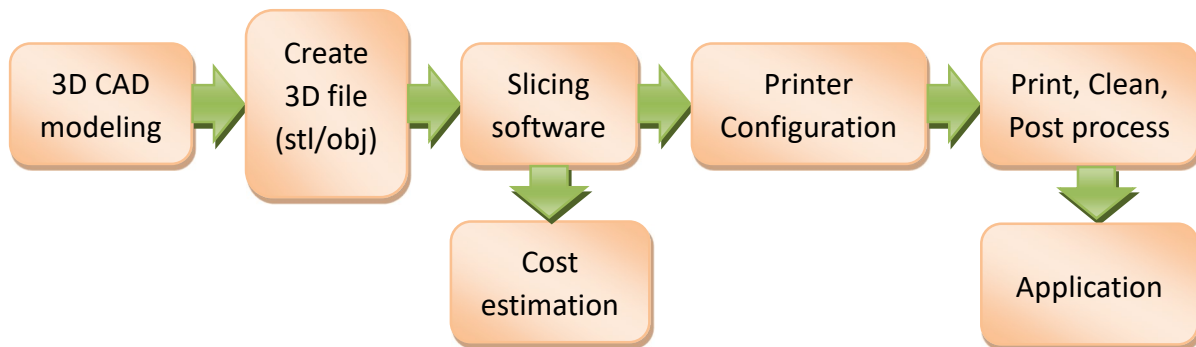


Figure 25. AM - process steps

Usually for 3D printers FFF is the format of the file is initially STL or in OBJ format etc. The name for the STL format is "STereoLithographic", "Standard Tessellation Language" and "Standard Triangle Language" [(9)]. The STL file format models a 3D object by drawing a layer of surface mesh using connected triangles. The Surface Tessellation Language (STL) format is the de facto industry standard, despite recent data formats such as "Additive Manufacturing File Format"



Figure 26. STL example

(AMF) or the "3D Manufacturing Format" (3MF). STL is the interface between the CAD program and the AM machines. In this case, the surface geometry of an object is represented as a tessellation of triangles (Figure 26. STL example. The resolution of an STL can be adjusted by specifying the number of its triangular facets. A low resolution forms the model no longer correctly and therefore the accuracy of the object produced is reduced. On the other hand,

high resolutions mean a higher memory storage and usage, which makes the handling of the data sometimes difficult. [(1)]

The OBJ object format is also considered a universal 3D file format and describes 3D models using polygons. [(25)]

Once the STL data is loaded on a machine, the pre-processing stage can start fix and repair the STL data, enhance it, and slice the data. Each manufactures have its own software already on the machine installed, which allows the user to make the mentioned operations. However, there are also companies that are directly providing these tools (e.g., Magics software platform from Materialise).

Depending on the machine type and the technology, various machine set-up operations are necessary: e.g., adjusting the corresponding parameter, selecting the right feedstock, preparing the build platform. The actual manufacturing of the part follows this step. Once executed, the excess material or support material must be removed. The nature and scope of the post-processing step are depending directly on the technical and quality requirements of the final part.

Looking at the production process, so it is important, to be aware about the fact that additive processes have their own process steps to be mandatory complied. [(22)]

Below in Table 4. Most Common Abbreviations, 3D File Formats and Software, we list some of the possible formats for 3D models that are more common file extensions along with their software. Knowing the software that was used to create the model, some errors can be detected in the model but also a suggestion can be made for some alternative software to make the file compatible with the 3D printer.

Table 4. Most Common Abbreviations, 3D File Formats and Software

FILE EXTENSION	ASSOCIATED SOFTWARE & NOTES	
.stl	Standard Tessellation Language	Universal file type, common in most software, also known as stereolithographic (Bourke, 3 1999)
.obj	Object	Universal file type (Bourke, 2015a)
.3ds		Autodesk software format (www.autodesk.com)
.blend		Blender (www.blender.org)
.dae	Digital Asset Exchange	3D image files based on the COLLADA format (www.khronos.org/collada/)
.dwf	Design Web Format	Autodesk software format (www.autodesk.com)

.fbx	Filmbox	Autodesk software format (www.autodesk.com)
.lwo	Lightwave Object	Lightwave (www.lightwave3d.com)
.ply	Polygon File Format	Common to many software (Bourke, 2015b)
.skp	Sketchup	Sketchup (www.sketchup.com)
.shp	Shape	Developed by ESRI for storing spatial data, can be converted to .stl file to 3D print (McCune, 2014)
.thing		MakerBot (www.makerbot.com)
.vrmf	Virtual Reality Modeling Language	Created as web-based 3D format in 1995 (Web3D Consortium, 2015)
.x3d	X3D	XML encoding of VRML format (Web3D Consortium, 2015)
.ply	Polygon File Format	Common to many software (Bourke, 2015b)
.skp	Sketchup	Sketchup (www.sketchup.com)

How Create 3D File

To create a 3d file object this can usually be done in 4 ways:

- 1) Find existing models
- 2) Scanning of an object
- 3) Starter Sites
- 4) Designing Your Own Model

Find existing models

It is the easy way for a quick print if the 3D object we want to print already exists, ie it has already been designed by someone and is available for download. They are usually stored in repositories specifically for 3D printing but many manufacturers have their own items ready to be tested by them for 3D printing (eg Tingiverse.com from MakerBot and Youmagine from Ultimaker). Beware of files that may have been transformed and created by some modeling software but have never been printed, there may be errors in the printing process.

In addition to the printability, staff and visitors should consider whether there is a charge for downloading a model from a storage facility or if the design is licensed under a Creative



Commons (<http://creativecommons.org>) or other license. While noting if a designer is protecting a model, library staff may need to observe if a model is a fax of a design, such as an animated character, that may be protected from copyright or trademark reproduction. Your

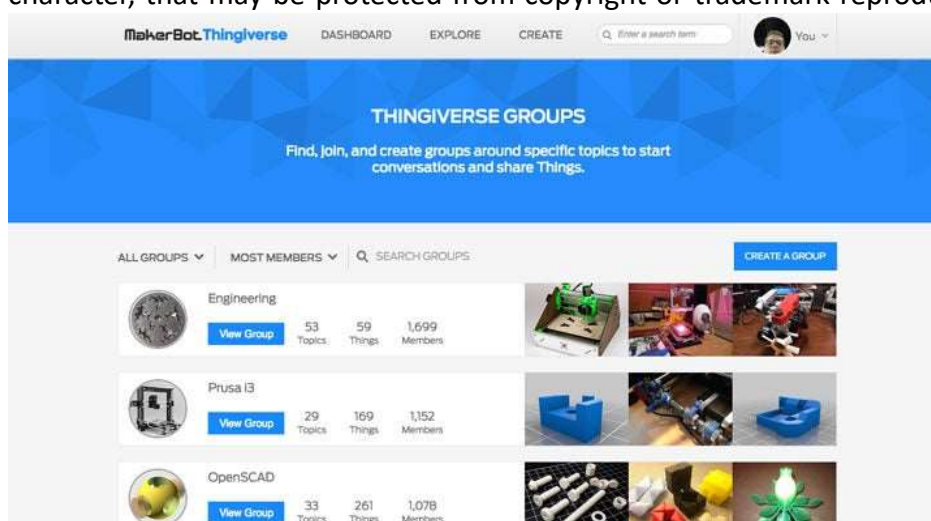


Figure 27. Thingiverse.com from MakerBot

library policy may restrict printing, especially to a limited number of protected models. See the chapter for more details on establishing a political library that balances freedom of expression and intellectual property rights.

Table 5. Sites for Free STL Files & 3D Printer Files/Models

	Site	Type	Free/Paid
Thingiverse	https://www.thingiverse.com/	Repository	Free
Cults	https://cults3d.com/en	Marketplace	Free, Paid
CGTrader	https://www.cgtrader.com/	Marketplace	Free, Paid
MyMiniFactory	https://www.myminifactory.com/	Marketplace	Free, Paid
Pinshape	https://pinshape.com/	Marketplace	Free, Paid
Turbosquid	https://www.turbosquid.com/Search/3D-Models/free/stl	Repository	Free, Paid
PrusaPrinters	https://www.prusaprinters.org/prints	Repository	Free
3DExport	https://3dexport.com/	Marketplace	Free, Paid
YouMagine	https://www.youmagine.com/	Repository	Free
NIH 3D Print Exchange	http://3dprint.nih.gov/	Repository	Free
Threeding	https://www.threeding.com/index.php	Marketplace	Free, Paid

Free3D	https://free3d.com/free-3d-models/3d-printable?	Repository	Free, Paid
GrabCAD Library	https://grabcad.com/	Repository	Free
Redpah	https://www.redpah.com/	Marketplace	Free, Paid
3DShook	http://www.3dshook.com/	Subscription Service	Free, Paid
XYZprinting 3D Gallery	https://3d-gallery.xyzprinting.com/en-US/gallery/	Marketplace	Free, Paid
Libre3D	http://libre3d.com/	Repository	Free
Fab365	https://fab365.net/	Marketplace	Free, Paid
NASA	http://nasa3d.arc.nasa.gov/models/printable	Repository	Free
Dremel Lesson Plans	https://digilab.dremel.com/resources/lesson-plans	Repository	Free
Instructables	https://www.instructables.com/	Repository	Free
Yeggi	https://www.yeggi.com/	Search Engine	Free, Paid
STLfinder	http://www.stlfinder.com/	Search Engine	Free, Paid
3DFindIt	https://www.3dfindit.com/?lang=en_GB	Search Engine	Free, Paid
Thangs	https://thangs.com/	Search Engine	Free, Paid

Scanning of an object

In addition to the classic paper document scanner (2D), there are scanners that do 3D printing of an existing physical object. They have the ability to create a similar object in a 3-dimensional representation using laser sensors or with sharp images so that there are appropriate measurements for the external rigidity of the object. After the scan of the object is completed, the model should be processed in order to make the correct impression by removing possible holes, to clean the surfaces, in general, there are no foreign parts that do not correspond to the existing object. For the processing it will be done with a suitable 3D processing software and it will be possible to produce the appropriate file so that the 3D printing can be done (STL file, OBJ etc). The whole process costs a lot of time and requires relative specialization in a program suitable for editing, but this way it is possible to produce a faithful copy of the object but also to replace it in a part that is missing or worn.

3D scanners have characteristics depending on their cost, size, the surface they need to scan, ease of use, etc. The quality of 3D scanning depends mainly on the characteristics of the object such as the size of the surface but also its location, the ambient light and the extent to which it has shadows or gloss in some places, in general anything that may not provide a good scan of the product model. For the analysis of the scan, the machine itself has a primary role with its construction possibilities but also the ease of use, taking into account the abilities of the person who does the scan. We must also take into account the digital processing that will be needed after the end of the process in order for the final model to be more accurate in the real one. [(23)]

Several varieties of 3D scanners are available. They can be characterized by their portability, either desktop or mobile. Scanners can also be characterized by their method of modeling an object's surface, either using laser sensors or photographic images. Typically, desktop scanners tend to use lasers and mobile scanners tend to use photos, but this distinction is not always valid.

Desktop scanners are stationary and may require a direct connection to a computer with sufficient memory and processing power. An item must be brought to a desktop scanner to be scanned, so its use is restricted to portable items. If you supply a desktop scanner in your library, you must identify a location for its placement, perhaps dedicate a computer for accessing its software, and provide some level of staff or patron training in its use.



Figure 28. Desktop scanner

Mobile scanners come in several varieties and provide solutions for taking a scanner to an object. For large and unmovable items, mobile scanning is the only way (besides using a camera, repeatedly) to gather the digital data needed to construct a model. Mobile scanners are a viable solution for libraries that cannot afford or provide space for a larger and pricier desktop scanner, but that wish to provide some sort of scanning options for users. They can be circulated for use within or beyond the library.



Figure 29. Mobile scanner

If a 3D scanner is not available, a 3D scan of an object can be created through the use of just a tablet or smartphone. Autodesk's free 123D Catch app (www.123dapp.com/catch) works with still photos taken using a smartphone running the app or up-loaded from a digital camera. Users take twenty to seventy photos of an object from all angles, preferably by adding newspaper or sticky notes to serve as reference points near the object. Then they upload those photos, process and clean up if desired, and then the app returns a 3D model.



Figure 30. Smartphone App

Table 6. Scanners and Apps outlines some of the 3D desktop and mobile scanners that are commonly used. It also identifies some apps that can substitute for scanning devices.

Table 6. Scanners and Apps

DESKTOP SCANNERS		
MakerBot digitizer	http://store.makerbot.com/digitizer	Scan objects 8" x 8", includes digitizer software, resolution 0.5 mm
NextEngine	http://www.nextengine.com/	Resolution 0.1 mm, no preset size limit. (base, requires software and accessories); educational discount
Matter and Form	https://matterandform.net/scanner	Desktop but portable, scan objects 7" x 9.8", resolution 0.43mm, includes software
Shining 3D EinScan Pro+	https://www.einscan.com/handheld-3d-scanner/einscan-pro-plus/	-Resolution: 0.1 mm -Scan Volume: 200 X 200 X 200 mm -Technology: White light 3D scanning technology
Crealty CR-Scan 01	https://www.crealty.com/goods-detail/creality-scanner-cr-scan-01	Accuracy 0.1mm, Technology Structured Light
MOBILE SCANNERS		
Structure Sensor	http://www.structure.io/	Mobile scanner attachment for iPads
iSense	http://cubify.com/products/isense	Mobile scanner attachment for iPads

Skanect	http://skanect.occiptal.com/	Free (but limited) version, Software that turns a user's Structure Sensor, Microsoft Kinect, or Asus Xtion camera into a mobile 3D scanner
iPhone 12 Pro, iPhone 12 Pro Max and iPad Pro	https://www.apple.com/iphone/	The Light Detection and Ranging (LiDAR) scanner in these devices accurately measures distances to map out three-dimensional spaces. This technology is meant to enhance the phone camera's low-light photo ability, but it is also compatible with a growing array of mobile apps to enable you to 3D scan rooms and objects.
Xperia 1, Xperia XZ1, Xperia XZ1 Compact, Xperia XZ2, Xperia XZ2 Compact, Xperia XZ2 Premium, and Xperia XZ3	https://electronics.sony.com/c/mobile	The 3D Creator was developed by Sony to allow you to capture objects and people on your smartphone and directly turn them into high-resolution 3D models. There are five scanning modes on the 3D Creator, selfie, face, head, food and freeform. Depending on what you want to scan, the app will guide you to choose the correct mode.
SCANNING APPS		
Autodesk 123D Catch	http://www.123dapp.com/catch	Free mobile and web app, Upload photos, process as desired, and get a 3D model
Trnio	https://www.trnio.com/	Allows scans to be exported as OBJ files. In order to use other file formats, users can use a program like MeshLab to convert files to STL or PLY format. Files can also be used for 3D printing by touching them up with Meshmixer or Blender.
Sony 3D Creator	https://www.sony.com/electronics/support/articles/SX606201	The 3D Creator was developed by Sony to allow you to capture objects and people on your smartphone and directly turn them into high-resolution 3D models. There are five scanning modes on the 3D Creator, selfie, face, head, food and freeform. Depending on what you want to scan, the app will guide you to choose the correct mode.
Scandy Pro	https://www.scandy.co/apps/scandy-pro	Free for iPhones and iPads
Qlone	https://www.qlone.pro/	Available for both iOS and Android. The all-in-one app allows the user to scan an image, edit it, and export the digital file. It's a fast process but without compromising on quality, as the app can even scan in 4K.

Starter Sites

There are many online repositories where users can search by keyword, or browse through the categories in each repository. It is possible to download any file that exists for free either after some registration or with some payment. In most cases, anyone can post files without any control over the proper operation of the final object. There is also the possibility that these files can be modified for customization needs with corresponding software tools that are often provided in the repository itself or the user enters to do so externally. Most of them are with open source software and support various features such as photos of the produced object, comments from users, etc. The most popular of these is Thingiverse.com linked to MakerBot, YouMagine, linked to Ultimaker spearheaded a new open source license for 3D models, called 3DPL [(21)] more in the relevant table below.

Table 7. Online Repositories of 3D Models for Printing

REPOSITORY	WEB	AFFILIATION	DESCRIPTION & NOTES
Thingiverse	https://www.thingiverse.com/	MakerBot http://www.makerbot.com	Over 100,000 models; best-known model repository.
YouMagine	https://www.youmagine.com/	Ultimaker https://ultimaker.com	Over 10,000 models. Building a community for sharing and collaboration.
Sketchfab	https://sketchfab.com		300,000 models
3Dagogo	https://www.3dprint.com	AstroPrint https://astroprint.com	Models verified to be printable. Has a communal storefront. Personal, business, and commercial level licenses may available for each model. Some free, some cost to download.
3D Warehouse	https://3dwarehouse.sketchup.com	Trimble & SketchUp	Large repository of 3D objects, not all designed for printing.
MakerHome	https://makerhome.blogspot.com and https://mathgrrl.com/hacktastic/	Dr. Laura Taalman	365 (more or less) models on MakerHome. Most designs are math oriented. Completed project of one model per day for a year. Blog continued on Hacktastic.
NIH 3D Print Exchange	https://3dprint.nih.gov/	NIH (National Institutes of Health) http://nih.gov	For downloading and sharing biomedical 3D print files, modeling tutorials, educational materials. Special collections: prosthetics,

			neuroscience, heart library, molecule of the month. Files are free.
Smithsonian X3D	https://3d.si.edu/explore/	Smithsonian Institution http://si.edu	Files created to serve as use cases to highlight collections and explore the Smithsonian’s digital collection. Files are free.
Yeggi	https://www.yeggi.com		300,000 models. Search engine. Mouse-over shows repository and cost (if any). Ad driven.
NASA	https://nasa3d.arc.nasa.gov	Additional U.S. federal agencies	Free, public domain. Vary in number or models and 3D printable models available.

Designing A Model

At the level of avarice users in 3D model design they can start with files that have already been created and can make simple adjustments to them through online repositories (eg with the Customizer function in the Thingiverse repository) but also various other software programs. These are different levels of software programs for creating models, ranging from beginners to experts. Someone with little experience can use beginner programs several of them are available online for free with free versions. For more advanced users there are advanced options available for a fee. Intermediate programs are less intuitive and have a longer learning curve than beginner programs. However, they can be attractive to users who are willing to invest time due to additional features and capabilities. Software programs aimed at professional users, such as engineers, tend to require local computer installation and licenses for individual or business use (institution level). Licensed editions may have an educational discount option.

Artists as well as engineers usually need to have different designs and functional needs for the objects they create. Engineers want precision in measurements to determine the size and application of the 3D object; on the contrary, artists often have a more abstract concept and develop smooth curves as they rely on sculptural techniques to create organic models. Some examples of parametric modeling software, such as Autodesk’s Inventor and SolidWorks, allow the user to start with predefined 3D shapes or a digital sketch that is extruded into 3D. By resizing, rotating and grouping shapes, a designer can create three-dimensional objects with exactly the required dimensions. Digital design software, such as Blender or Maya, also allows for more organic modeling capabilities along with texture. 3D models are created through a process similar to the work of a sculptor with a piece of clay. There are several different digital tools used to stretch and texture the model, allowing the development of natural models such as human faces and vegetation.

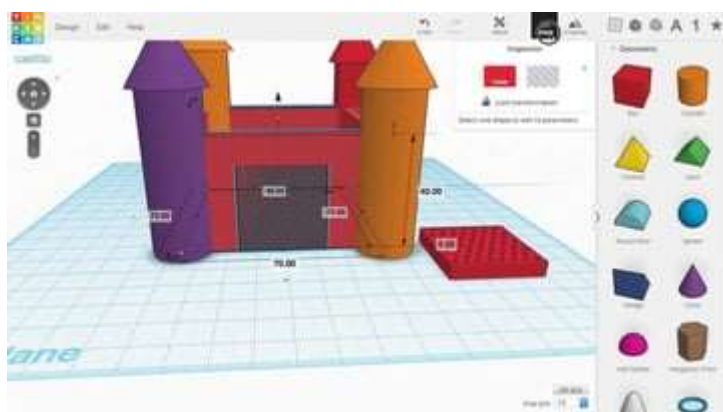


Figure 31. TinkerCAD

Finally, there are the open source modeling software that contains a programming style user interface where the shapes are entered using equations and then a modeling code is compiled to render the 3D object (eg. OpenSCAD (e.g., MakerBot Industries [(17)]). Mainly they need to know good programming but also to be skilled in creating 3D models by removing and adding blocks of different sizes. The new user needs to be careful

when designing a 3D model from the beginning to take into account the concept of scale. The representation on the screen of the PC may differ depending on the dimensions that the user will use with the final 3D printing that he realizes.

Table 8. Popular Software for Creating 3D Models

SOFTWARE	WEB SITE	FEATURES	FREE/PAID
BEGINNER			
Tinkercad	https://tinkercad.com	Recommended introductory software	FREE (Age+13)
3D Builder	https://www.microsoft.com/en-us/p/3d-builder/9wzdnrcfj3t6	Microsoft released a simple CAD software	FREE
3DSLASH	https://www.3dslash.net/index.php	Available as both a browser-based application, or as a desktop app for Windows, macOS, Linux, and Raspberry Pi.	FREE
Meshmixer	https://www.meshmixer.com	Meshmixer is a lightweight 3D modeling software developed by Autodesk	FREE
MagicaVoxel	https://ephtracy.github.io	Open Source Voxel Editor for Windows, Mac, Linux, iOS, and Android	FREE
INTERMEDIATE			
SketchUp	https://www.sketchup.com/plans-and-pricing/sketchup-free	Make version is free, Pro version requires license, ed-	FREE / PAID

		educational discounts available	
123D Design	https://www.autodesk.com/solutions/123d-apps	Part of Autodesk 123D, free suite from Autodesk. http://123dapp.com	FREE
Vectary	https://www.vectary.com	No download, all in the browser	FREE
FOR DIGITAL ARTISTS			
Blender	https://www.blender.org	Good for rendering, sculpting, and animation	FREE
Maya	https://www.autodesk.com/products/maya/overview	Supports animation, special effects, rendering, and shading	PAID, Desktop subscriptions; from Autodesk
SculptGL	https://stephaneginier.com/sculptgl	freely accessible, open-source, browser-based sculpting program.	FREE
FOR ENGINEERS			
Autodesk Inventor	https://www.autodesk.com/products/inventor/overview	Intended for mechanical design	FREE trials, desktop subscriptions, FREE for qualifying educational institutions
Fusion 360	https://www.autodesk.com/products/fusion	A professional 3D CAD program by Autodesk	PAID
OpenSCAD	https://openscad.org	Intended for engineers creating machine parts	FREE, open source
Onshape	https://www.onshape.com	Full cloud (web browser) CAD system for collaborators on open-source projects via a powerful, browser-based parametric design program	FREE (student), professional, and enterprise levels
Solidworks	https://www.solidworks.com	Core for engineers	PAID, Requires purchase but educational discounts

Using Model Checking or Repair Software

For the best possible quality for a printable 3D model this can be done by special computer software and not by human eye. In this way the modeling process can be controlled if it does not develop smoothly with the result that the generated model is not completed correctly. To ensure this all models should perform a check / repair software before printing any 3D model. This will save you time, don't spent money in filament and man-hours by putting an end to the agony that everything will be done right.

So when there is a problem model then redesign can be done to correct the errors or use software to repair the model. There are many options for ordinary users up to the most specialized with various software programs for this ((see Table 9. Model Checking and Repair Software). It is a good idea for ordinary users to start with the software from Microsoft Model Repair Service. It is cloud-based and requires only one user to upload an STL file and then download the repaired file. Several other programs (such as Simplify3D) include some functionality for testing the model and fixing some or all of the surface grid problems. So it is a good idea most of the time to use the editing software that includes the option of checking or repairing for the correct printing of the 3D model.

Table 9. Model Checking and Repair Software [38, 39]

SOFTWARE	WEB SITE	FEATURES
Microsoft Model Repair Service	https://tools3d.azurewebsites.net	Free cloud service; requires Microsoft account. Repairs the 3D mesh by closing holes and fixing geometry to create a water-tight 3D mesh suitable for 3D printing. Reduce simplifies the 3D mesh to reduce file size and improve processing. Convert.
Meshmixer	https://www.meshmixer.com	Free software powered by Autodesk. Offers many capabilities alongside its STL repair tool.
MeshLab	https://www.meshlab.net	Open source system designed for processing and editing unstructured 3D meshes; an issue that can happen with 3D scans; capable of automatically filling holes in meshes; tools allow editing, inspecting and repairing of STL files.
Netfabb	https://www.autodesk.com/products/netfabb/overview	Private, Professional/Enterprise, Cloud, and other paid levels. Fusion 360 with Netfabb, Connected software for additive manufacturing, design, and simulation.

Magics	https://www.materialise.com/en/software/magics	Materialise Magics is a professional 3D print data preparation tool that allows extensive manual control over meshes, including wall thickness analysis, hollowing, remeshing, smoothing, Boolean, and cutting operations, as well as fixing holes, bad edges, and the most complicated triangle errors.
Blender	https://www.blender.org	Blender is a free and open-source mesh creation environment, including 3D modeling, rigging, rendering, and animation. Several STL repair functions are available in Edit Mode on the Mesh menu on the lower toolbar
Make Printable	https://makeprintable.com	Web service that checks STL files for any mistakes that might be corrupting the file.

Cost Calculation tools

There are several ways to calculate the cost of the 3D artifact to be printed. We can find online tools, spreadsheets, download software to run locally or use the built-in tool of the PrusaSlicer.

The image shows a screenshot of the PrusaSlicer software interface. On the left, a 3D model of a keyboard is visible. On the right, the software's control panel is shown, featuring a 'Sliced Info' section with the following data:

Sliced Info	
Used Filament (m)	29.86
Used Filament (mm ³)	71827.33
Used Filament (g)	89.07
Cost	2.26
Estimated printing time :	
- normal mode	11h 5m 55s
- stealth mode	11h 12m 33s

Two red arrows point from text labels to the 'Used Filament (g)' and 'Estimated printing time' rows in the table. The label 'Filament calculations' points to the 'Used Filament (g)' row, and the label 'Printing time estimation' points to the 'Estimated printing time' row.

Input material data Price on PrusaSlicer

PrusaSlicer-2.1.1-win64-201912101512 based on Slic3r

File Edit Window View Configuration Help

Plater Print Settings Filament Settings Printer Settings

Generic PLA

Filament

- Color:
- Diameter: mm
- Extrusion multiplier:
- Density: g/cm³ ← Filament density
- Cost: money/kg ← Filament cost/kg

Temperature °C

- Extruder: First layer: Other layers:
- Bed: First layer: Other layers:

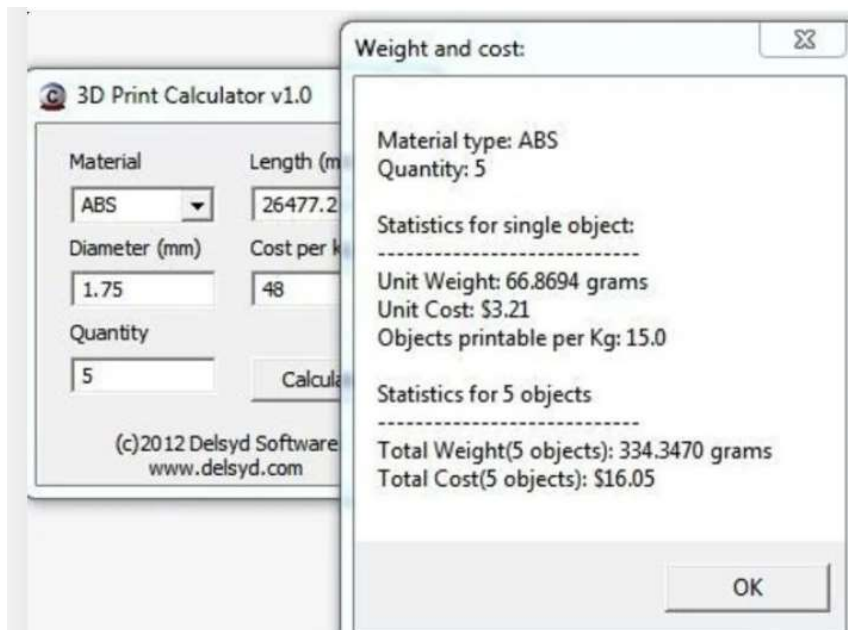
3D Printing Cost Calculator Spreadsheet MS-EXCEL Jason King

Source: <https://www.e-junkie.com/ecom/gb.php?c=cart&i=1421722&cl=229974&ejc=2>

Energy		Repairs	
Electricity Tariff (£/kWh)	0,16	Repair Costs (%)	10,00
Printer Power (Watts)	50,00	Lifetime (h)	3650,00
kWh (1 hr)	0,05	Repairs/hr	0,04
£/hr	0,01	COST (€)	0,22
COST (€)	0,04		
Filament		Other	
Filament Cost (€/kg)	34,19	Other Costs (€)	0,10
COST (€)	3,42	COST (€)	0,10
Depreciation		Failures	
Printer Purchase (€)	1576,00	Failure Rate (%)	10,00
Printer Lifetime (years)	5,00	Costs so far	5,93
Daily Usage (hours)	2,00	COST (€)	0,59
Hours in Life	3650,00		
Depreciation/hr	0,43	TOTAL	
COST (€)	2,16	Total Cost (€)	6,53
		Yellow cells are changeable	
		Blue cells are calculations	
		Grey cells are text	

3D Printer Calculator

Source: <https://www.thingiverse.com/thing:29310>



Prusa Calculator

Source: https://blog.prusaprinters.org/calculator_3416/

Hi I'm Calculator

Hi, I am a calculator. I will help you to calculate the real price of the filament converted to printing volume (in cubic centimetres), the number of steps per millimetre and the acceleration needed to reach a certain printer speed.

Filament

Real filament price

WORK IN PROGRESS! Great tool to compare real price of filament. Only measurement, which accurately tells you how much you can print with your purchased filament, is volume in cm^3 . Filament vendors should provide price per cm^3 which doesn't happen now. So I made this simple tool for you to calculate it.

Example: You are offered 100m of PLA both in 3mm and 1.75mm for \$25. With 3mm you will buy 2827cm^3 but with 1.75mm just 962cm^3 of plastic. That renders 1.75mm deal pretty awful as you will get just one third for the same price.

Sold by weight

Sold by meter

Filament name

Weight

Material - presets the density for calculations

Density

Package price

3D Printing Cost Calculator Web Application

Source: <http://3dprinthq.com/cost/desktop.php>

Welcome to Your FREE 3D Printing Cost Calculator Web Application

"Accurately calculate how much it costs you to 3D print anything..."

Object Weight (grams):	<input type="text" value="100"/>
Printing Time (hours):	<input type="text" value="5"/>
Electricity Tariff (£/kWh):	<input type="text" value="0.1568"/>
Printer Power (Watts):	<input type="text" value="50"/>
Filament Cost (£/kg):	<input type="text" value="34.19"/>
Printer Purchase (£):	<input type="text" value="1576"/>
Printer Lifetime (years):	<input type="text" value="5"/>
Daily Usage (hours):	<input type="text" value="2"/>
Repairs Costs (%):	<input type="text" value="10"/>
Other Costs (£):	<input type="text" value="0.1"/>
Failure Rate (%):	<input type="text" value="10"/>
Total Cost (£):	6.53

Note: £ is GBP but use any currency, it makes no difference to the calculations as long as you use the same currency throughout.

3DPEC - 3D Print Estimation Calculator

Source: <https://www.thingiverse.com/thing:1217337>

3D Print Estimation Calculator (3DPEC) - Standards Electronics

File Change Log Help / Updates Share Donate Legal

Material: ABS (1.08 g/cm³) PLA (1.30 g/cm³) g/cm³

Diameter: 1.75 mm 3.00 mm mm

Spool Weight: / Kg

Spool Cost:

Job Part Qty:

Machine Cost: / Hour

Technician Cost: / Hour

Material Mark Up: %

Est. Setup Time: Minutes

Est. Build Time: HH:MM

Filament Length Part Volume Part Weight

mm - OR - mm³ - OR - grams

Choose one of the above - The rest will calculate based off the selected field

Total material cost per part	<input type="text"/>	\$/€/£
Total material cost for job	<input type="text"/>	\$/€/£
Machine cost per part	<input type="text"/>	\$/€/£
Machine cost for job	<input type="text"/>	\$/€/£
Setup cost for job	<input type="text"/>	\$/€/£
Customer cost per part	<input type="text"/>	\$/€/£
Customer cost for job	<input type="text"/>	\$/€/£
Parts possible per spool	<input type="text"/>	Parts
Setup + build time for job	<input type="text"/>	Hours

© Standards Electronics 2015

Version 1.0.0 Released 12/21/2015 FOR ESTIMATION PURPOSES ONLY standardselectronics.com

SELECTED FIELD HELP - No Field Selected.

Instructions:

- Fill in all the fields with a value, letters and strange characters will throw an error.
- Select one of the three main inputs, and fill in the corresponding input. The other two can be left blank (they will auto populate).
- Any currency can be used, but note that what you use for the costs above will be the output below (numbers are just numbers to the calculator)
- Read the hints and tips under the help menu for a good crash course on everything this does.



Shatter-Box 3D Printing Cost Calculator – No Internet, No Problem!

Source: <https://shatter-box.com/knowledgebase/3d-print-cost-calculator/>



Shatter-Box is a knowledge base website which was born around game developing, but also hosts other stuff like a 3D printing cost calculation tool!

It's a [free piece of software](#) available to download directly from Shatter-Box. In terms of how the tool itself works, there's nothing new here. You can manipulate the usual parameters which play a role in price calculation for 3D printing like print duration, material cost, profit margin and others you've surely been introduced to up to this point. All in all, there's no lack of important parameters – it's all there!

Now then, it's finally time we tell you what exactly drew our attention to this piece of software: You may have noticed that it's the first calculator on the list which doesn't require an internet connection. Instead, it's a downloadable tool which you can use offline, if needed.

The other feature which earned this calculator a place in this article is the possibility to have multiple profiles for different printers. This is a very important feature for 3D printing businesses which use several different 3D printers for their work. This feature saves time since it stores the following information for each printer profile:

- Printer power consumption
- Electricity price
- Profit
- Pieces
- Currency

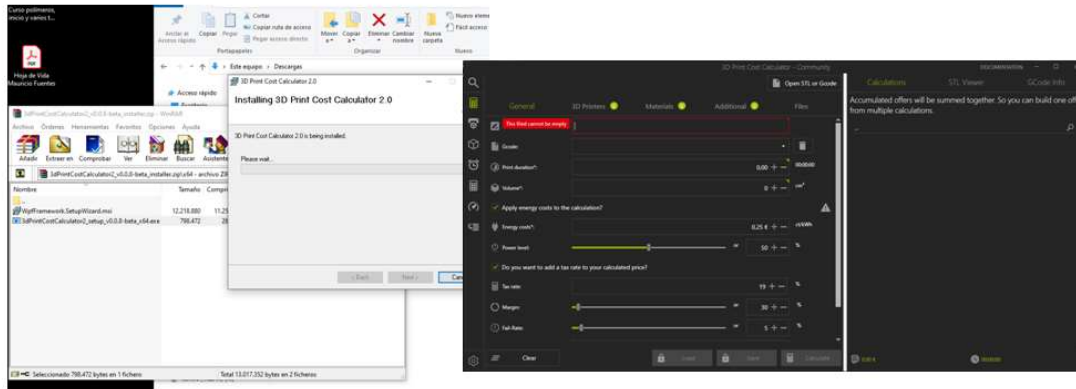
There is an even [more enhanced version of this software](#), but it's not free. The paid version of this 3D print cost calculator comes with additional features like two additional interfaces: the **Manage** and the **Print Jobs** interface

The manage interface is here to give you an organized look at the materials, diameters, and printers with the worksteps included, while the print jobs interface gives the user the ability to easily track multiple ongoing print jobs and their statuses.

3D Print Cost Calculator 2.0 - Beta

Source: <https://shatter-box.com/download/3d-print-cost-calculator-2-0/#>

The tool gives you a small overview of the price parts, like the energy costs, the material costs and the pure profit. If you figure out some calculating issues, please open a topic in the support forum.



Omni - Looks Great, Easy to Use

Source: <https://www.omnicalculator.com/other/3d-printing>



[Omni](https://www.omnicalculator.com/other/3d-printing) is an online platform with hundreds of calculators for different purposes, like science and finance. To be exact, the platform hosts 825 calculators. And one of those is for calculating the cost of 3D printing.

The user interface is modern and easy to use. The calculator itself is rather simple, but at the same time effective. In the first section, the user enters the price of the filament and the length of filament used to make the part. Your slicer software estimates the length of filament needed to complete a certain part, so just copy that value and paste it in the calculator.

The second section is used for calculating the price of labor based on print time, while the final section is where the markup percentage is added.

MORE: <https://all3dp.com/2/3d-printing-cost-calculator-great-websites/>



The practical 3D printing guide

The most important thing to remember while designing for 3D printing is the fact that your digital design will become a physical object.

General design consideration for 3D printing, must be

- Overhangs. All 3D printing processes build parts layer-by-layer. Material cannot be deposited onto thin air, so every layer must be printed over some underline material
- Wall thickness
- Warping
- Detail's level

Platform Management

These are the components of the Prusa MK3S 3D printer:

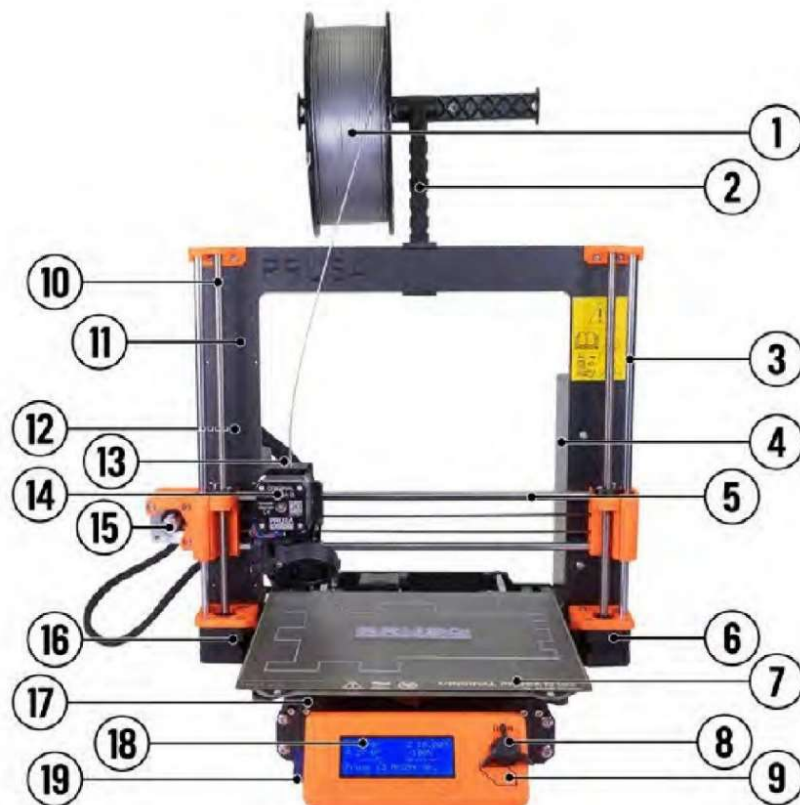


Figure 32. Prusa MK3S components

Original Prusa i3 MK3S+ printer description: (1) Filament spool; (2) Spool holder; (3) Z- Axis; (4) Power supply; (5) X-Axis; (6) Z2 Stepper; (7) Heatbed with spring steel sheet; (8) LCD Knob; (9) Reset Button; (10) Threaded Rod; (11) Printer Frame; (12) USB Port; (13) Einsy Rambo Board; (14) Extruder Stepper; (15) X-Stepper; (16) Z1 Stepper; (17) Y-Axis; (18) LCD Panel; (19) SD Card Slot

Preparation of the export file using PrusaSlicer

When running the software, we will see the following parts:

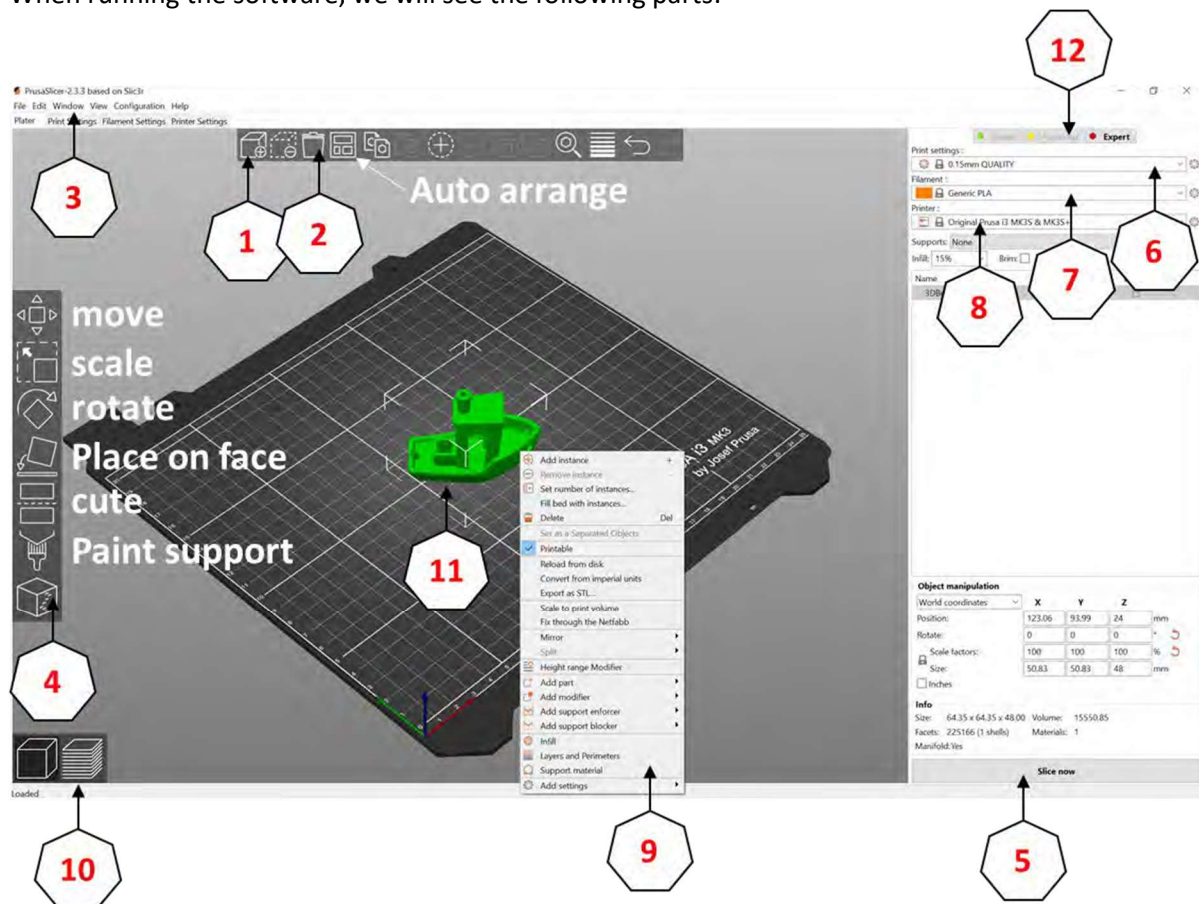


Figure 33. The PrusaSlicer software GUI

PrusaSlicer has a fairly simple user interface. The majority of the screen is dedicated to the 3D view, which is used to manipulate 3D models [14].

1. The Add button loads models into PrusaSlicer
2. Delete and Delete All buttons remove the model(s) from PrusaSlicer
3. Opens detailed settings of print, filament and printer
4. Move, Scale, Rotate, Place on Face and Cut tools
5. Slice and generate G-code button
6. Quality / Speed setting of a print
7. Material selection
8. Printer selection
9. Right-click on model opens a context menu
10. Switch between 3D editor and layers preview
11. Model preview
12. Switch between Simple / Advanced / Expert mode

Using the “Set number of instances”, we can duplicate or triplicate our part, as we like.

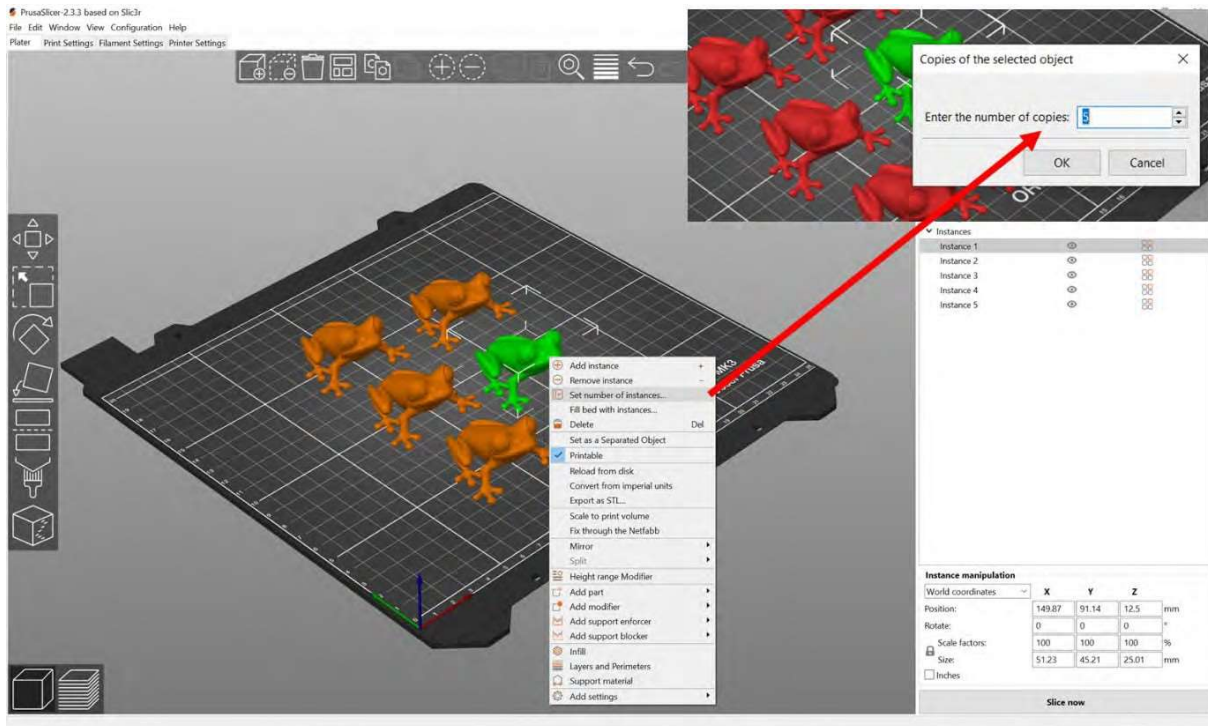


Figure 34. Using the pocket menu

We find the cutting plane option, to divide the part in two other independent parts

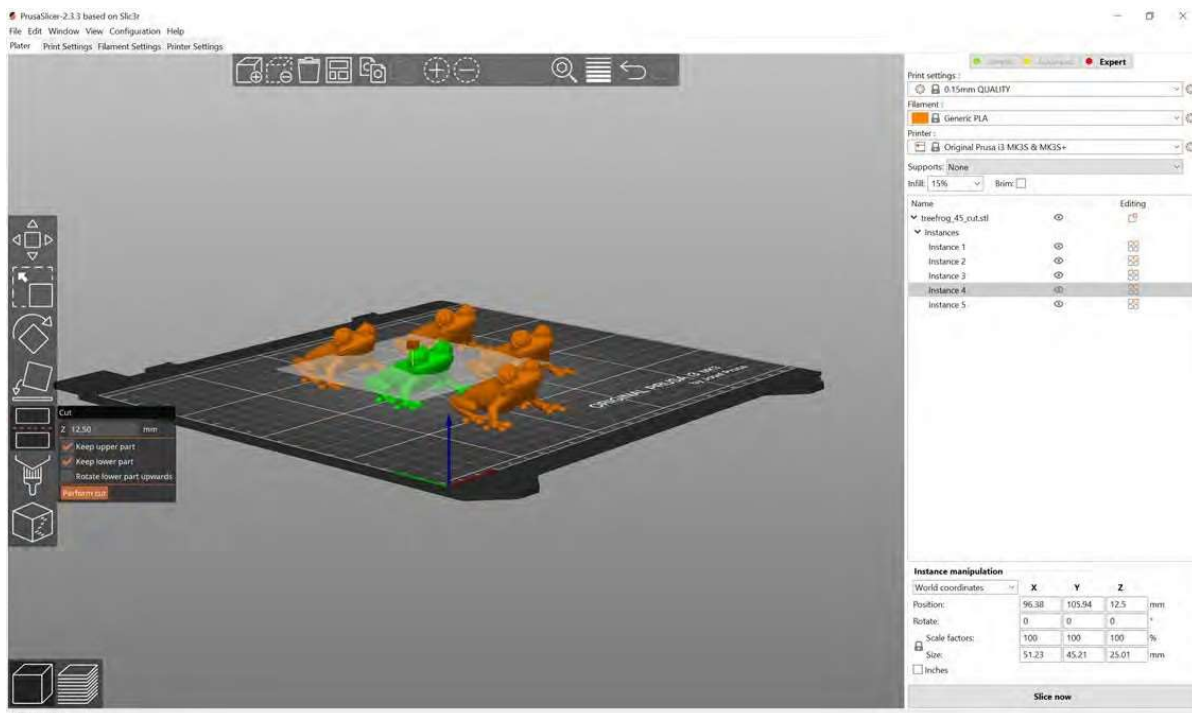


Figure 35. Cutting plane at 12.50 mm height

When we have finished the load printing preparation, we could slice the parts

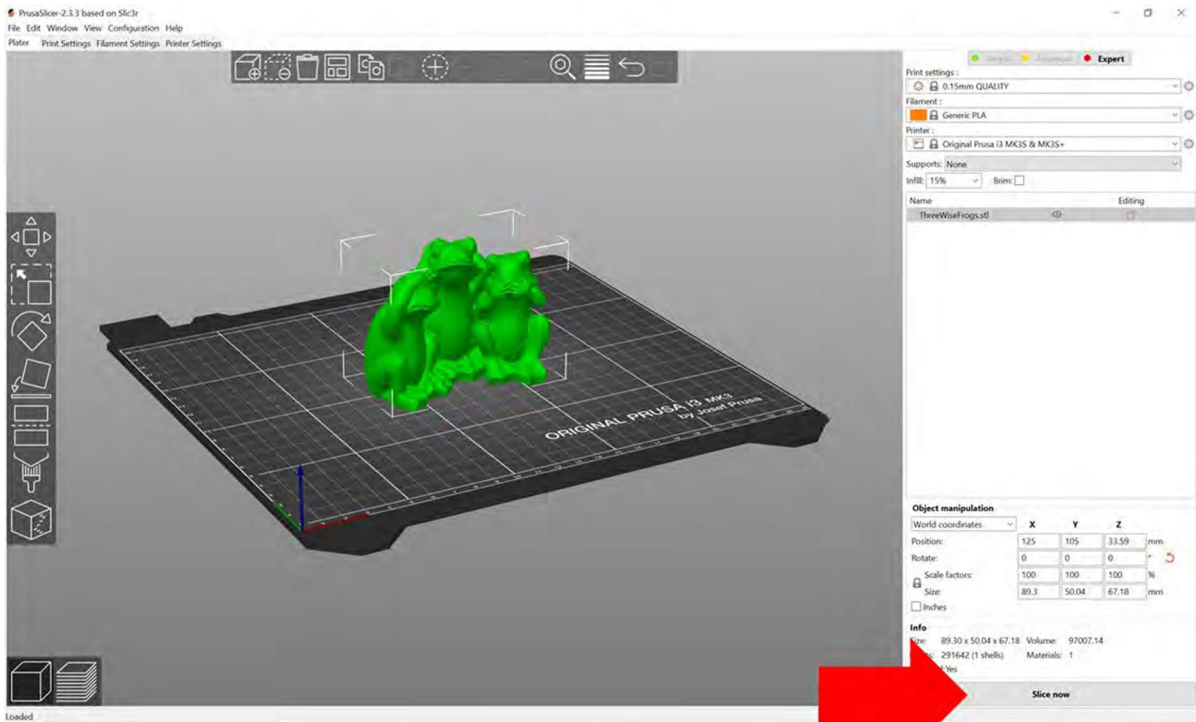


Figure 36. Slicing function

When the software finishes his calculation, it displays the following information

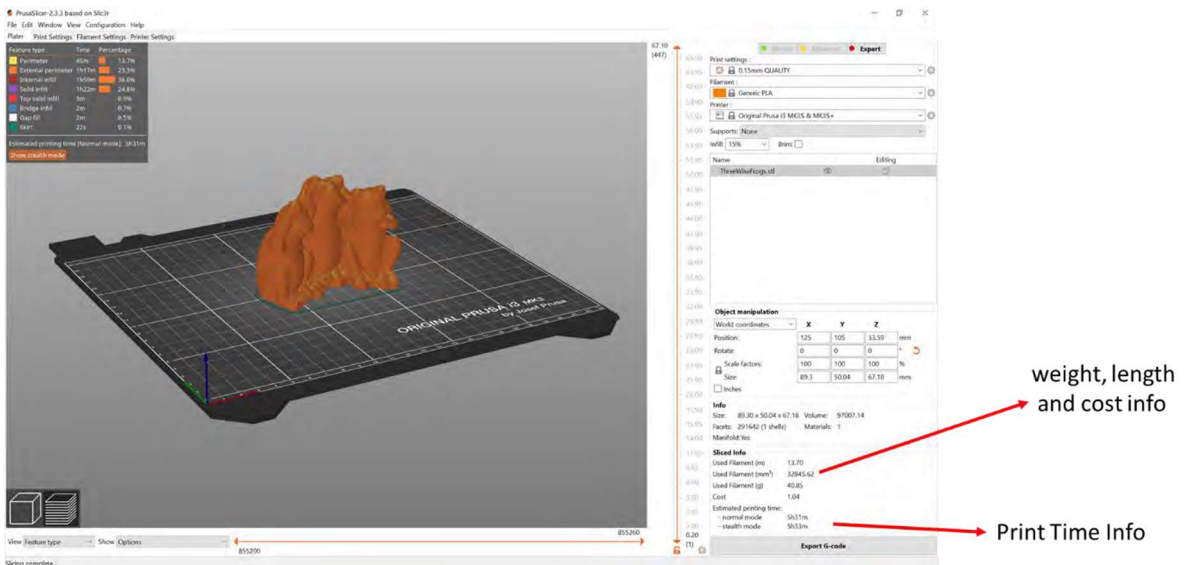


Figure 37. Display slicing info

Print Configuration

FFF parts are not printed solid to reduce the print time and save material. Instead, the outer perimeter is traced using several passes, called the shell/perimeter and the interior is filled with an internal, low-density (programmable) structure, called the infill.

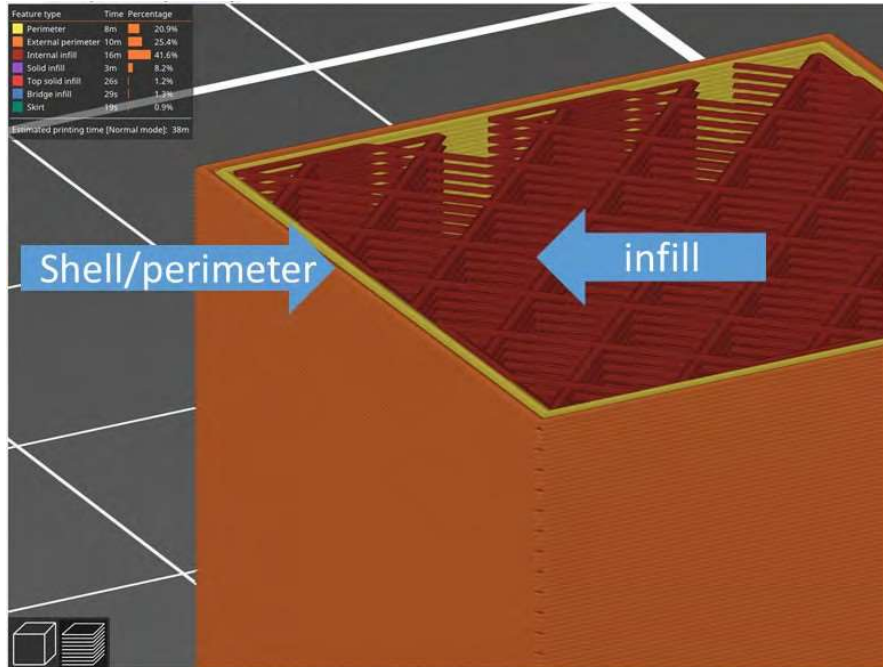


Figure 38. Perimeter (wall) and infill definition

The infill patterns will be programmed as follows:

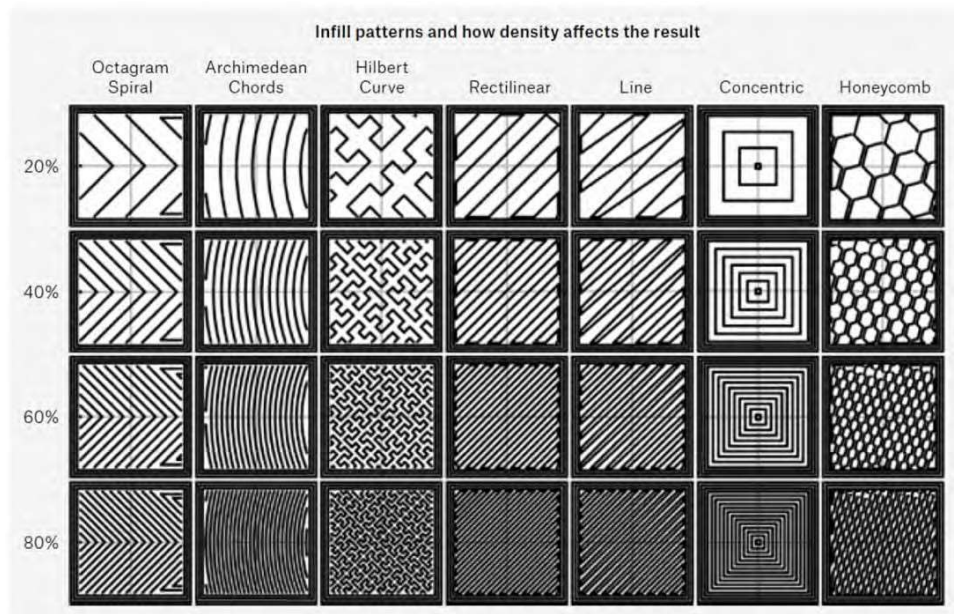


Figure 39. Infill patterns and densities [15]

The infill parameter can be found on the print settings tab.

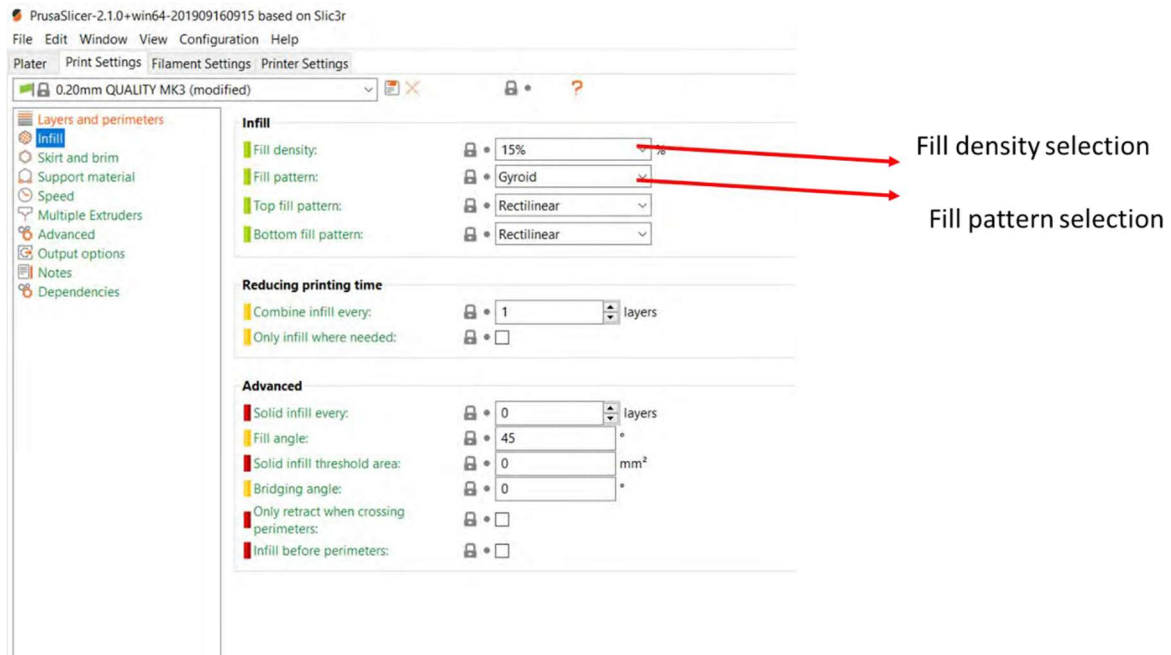


Figure 40. Infill and density tab

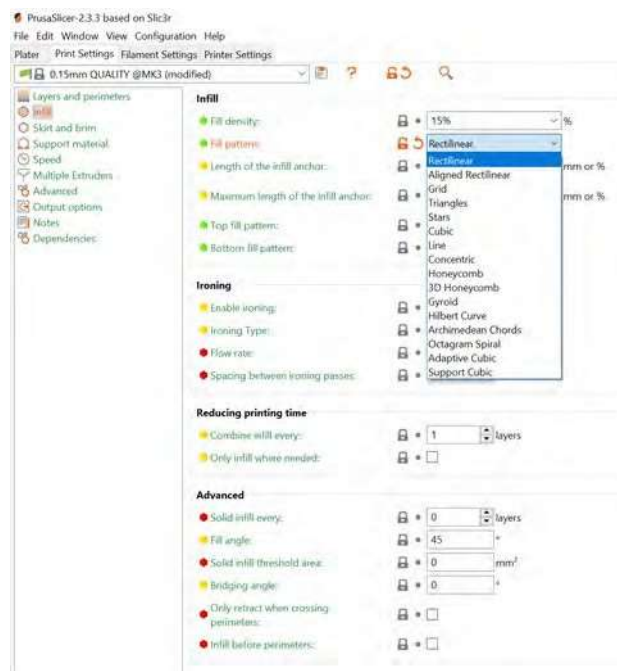


Figure 41. PrusaSlicer Infill patterns

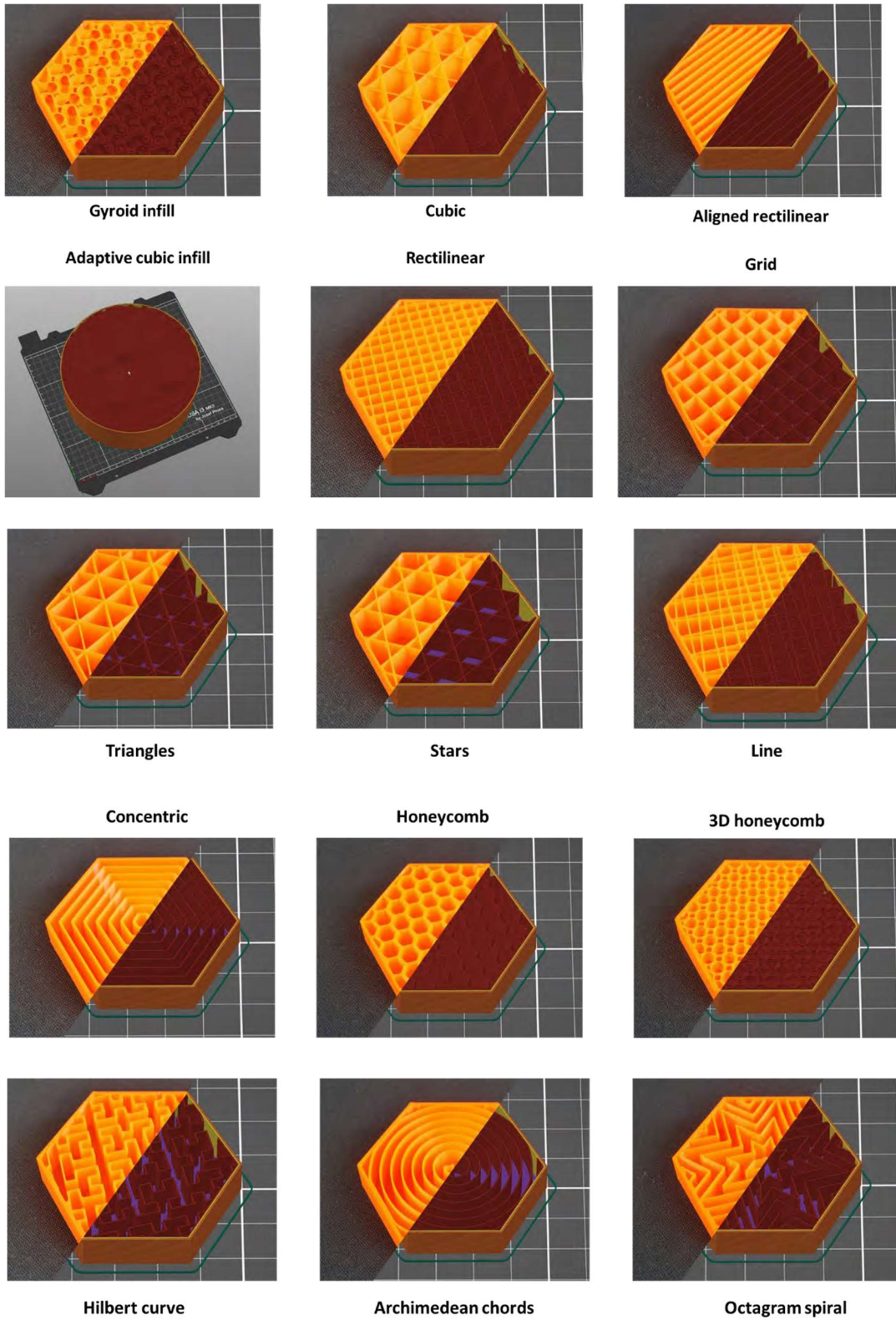


Figure 42. Infill patterns [16]

As a printing aid, we can use the skirt, brim and raft [17].

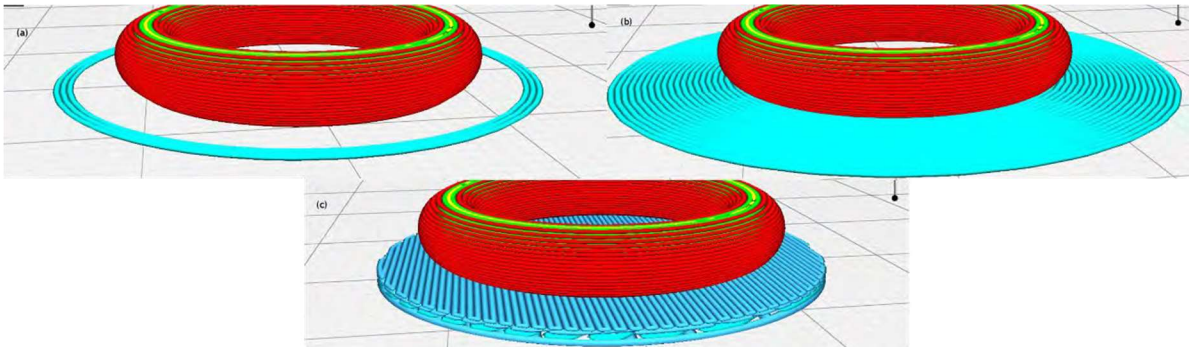


Figure 43. (a) Skirt, (b) Brim, and (c) Raft [17]

The skirt is a printed outline of all the models on the print bed. It's printed before any of the models, and its purpose is mainly to stabilize the flow of the filament through the nozzle. The skirt is also useful to verify the adhesion of the first layer to the print bed [18].

A Brim is a special type of skirt that is actually attached to the edges of your model. Typically, the brim is printed with an increased number of outlines to create a large ring around your part, similar to the brim of a hat. Brims are often used to hold down the edges of your part, which can prevent warping and help with bed adhesion [19].

A Raft is a horizontal latticework of filament that is located underneath your part. Your 3D-printed part will be printed on top of this raft, instead of directly on the build platform surface. Rafts are primarily used with ABS to help with warping and bed adhesion, but they can also be used to help stabilize models with small footprints, or to create a strong foundation on which to build the upper layers of your part [19].

We could be programming this help, on PrusaSlicer menu. By default, the software programme skirt configuration.

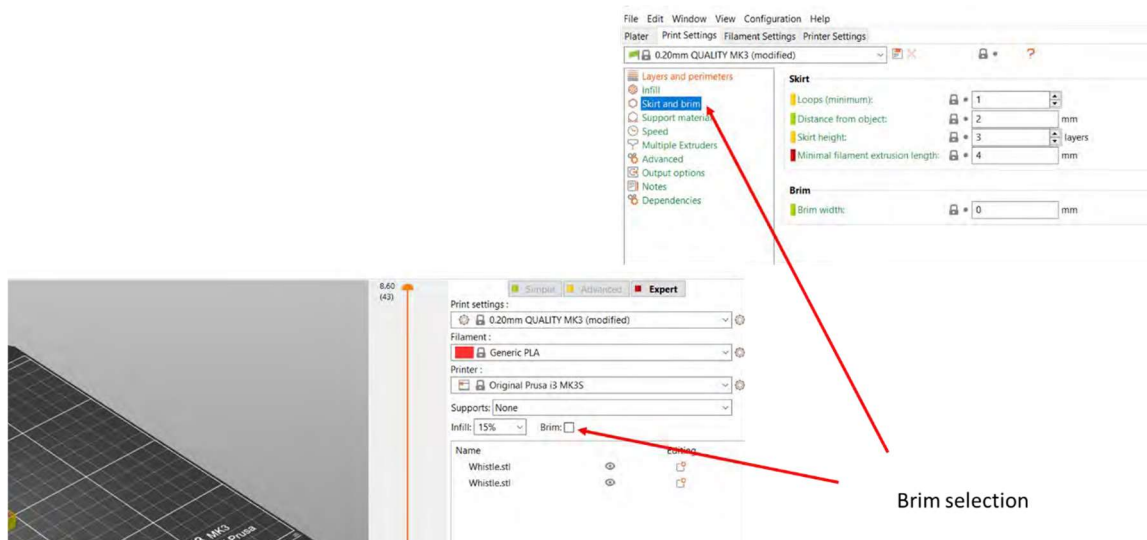


Figure 44. Brim and skirt on print settings

An important thing when slicing a 3D model is the support's generation. This function is located at the print setting tab.

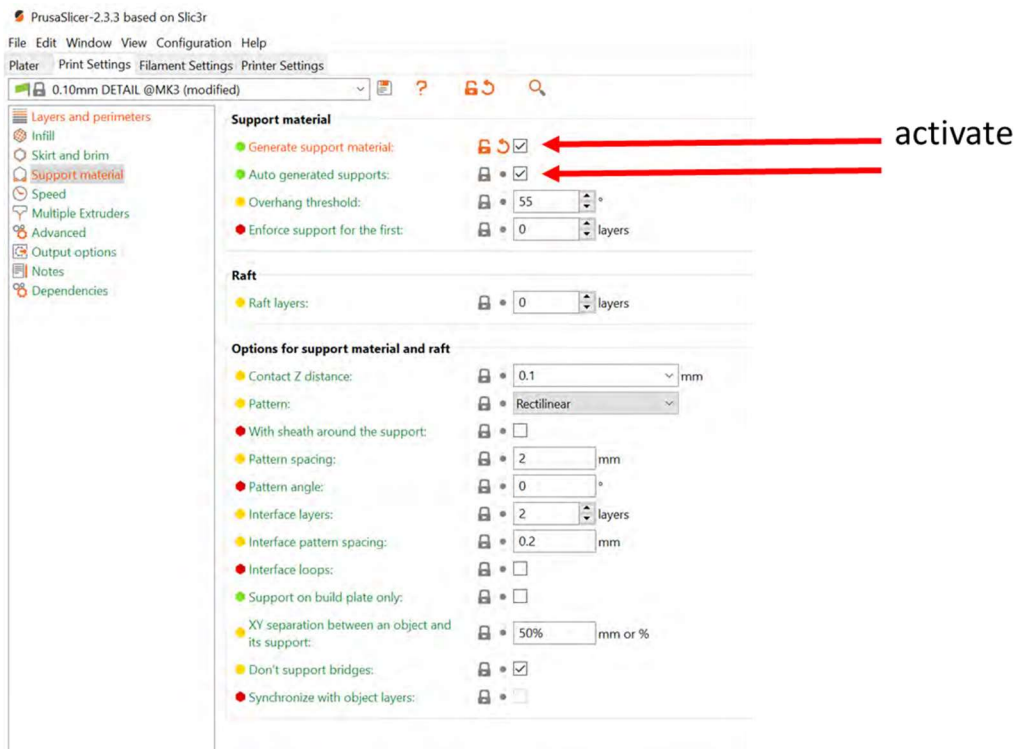


Figure 45. Print setting supports tab

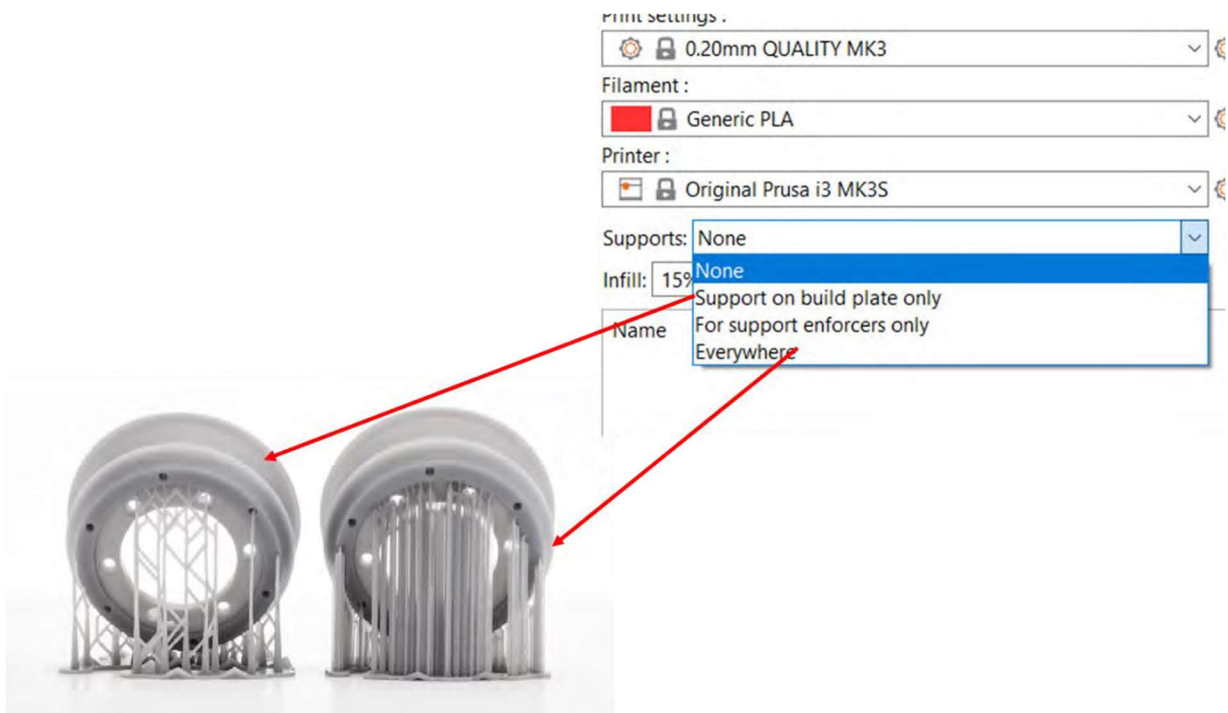


Figure 46. Supports typology

Select supports everywhere. Supports can grow from both the print bed and any model surface when necessary. This ensures that every overhang and parts starting mid-air will get supported. However, small imperfections may appear on the surface where supports started growing from.

Select supports from build plate only. Creates only supports that have their base at the print bed.

Select for support enforcers only. Automatic support generation is enabled only for areas marked with a support enforcer [20].

About the supports angle criteria generation, we use the following information.

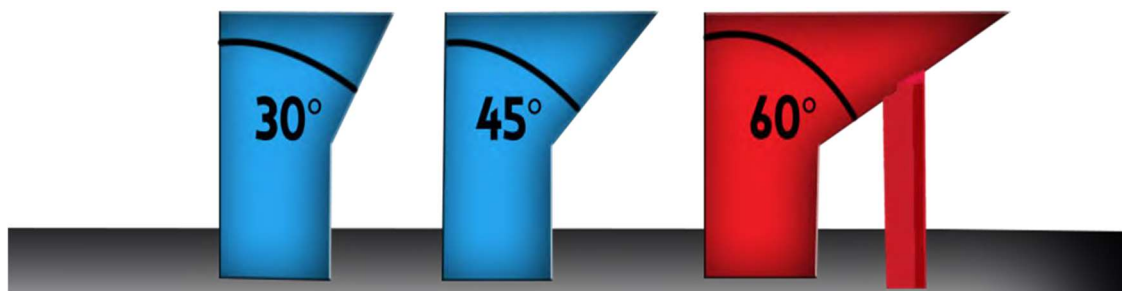


Figure 47. Support angle generation [21]

Overhang angles are extremely important to take into consideration when designing a part to be 3D printed. Without understanding how support structures work, it is easy to think that any structure can be easily printed with a clean surface quality.

As mentioned above, a fine quality print will not result in any better surface quality over a draft quality print when in reference to the scarring resulting in support for extreme overhangs.

This scarring is just about impossible to get rid of 100%, even on our specialty printer. This scarring is worse on some unique materials, especially on the flexible options. That is why complex flexible models are very difficult to print, and you should be warned of such before moving forward printing with a unique material.

If you have a part with angles roughly 45° or more, then you will require support. This support will leave scarring such as you can see from the image on the right. The more extreme the angle and the closer to the build plate that angle is, the more difficult this support material gets to remove cleanly [22].

Also, you can decrease (or increase) the print speed in two ways. The easiest way to do it is by rotating the knob next to the LCD screen during the printing process. Counterclockwise = slow down, Clockwise = speed up. The percentage shown on your LCD is relative to the speeds set in PrusaSlicer [23].

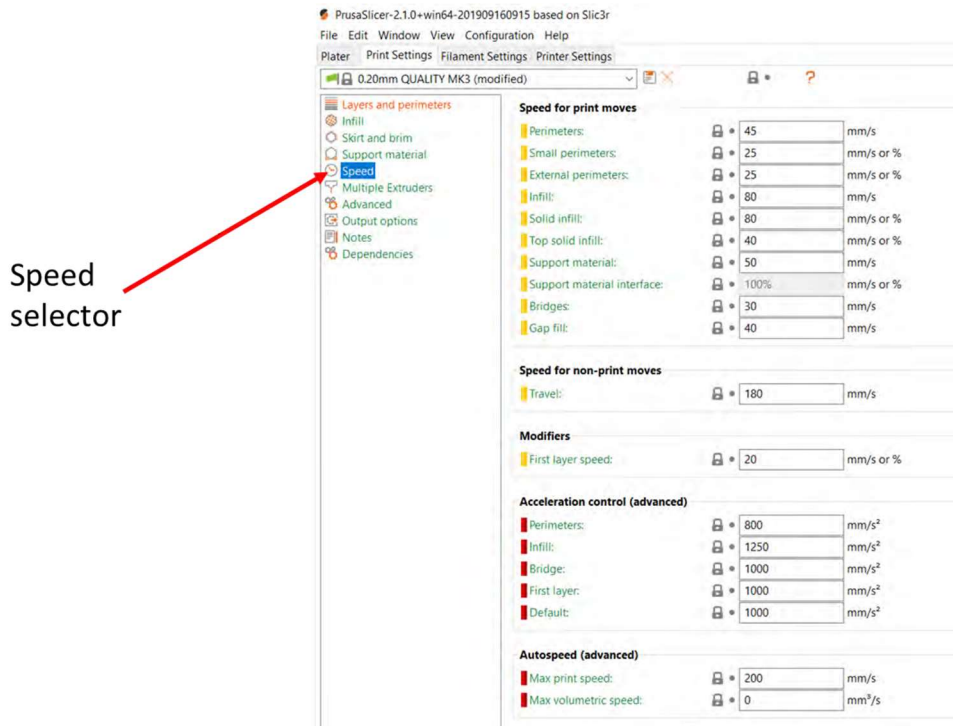


Figure 48. Speed menu tab

Makers, must know the relation between speed and printed quality. Speed menu tab

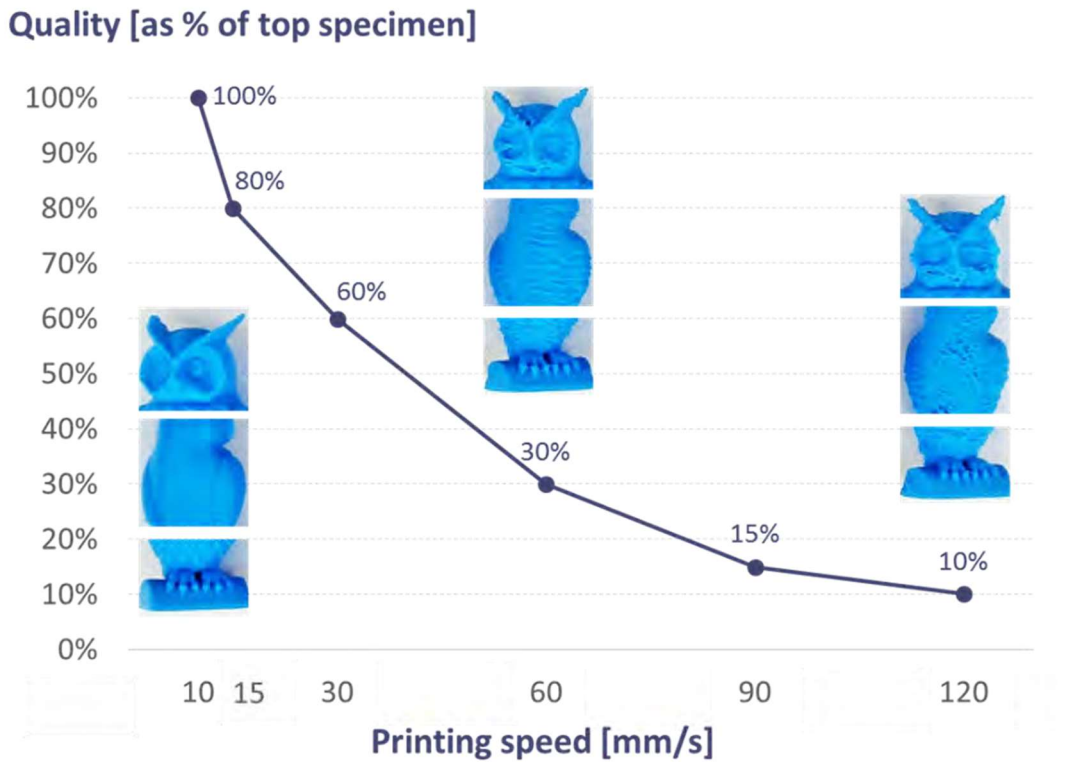


Figure 49. Quality and printing speed [24]

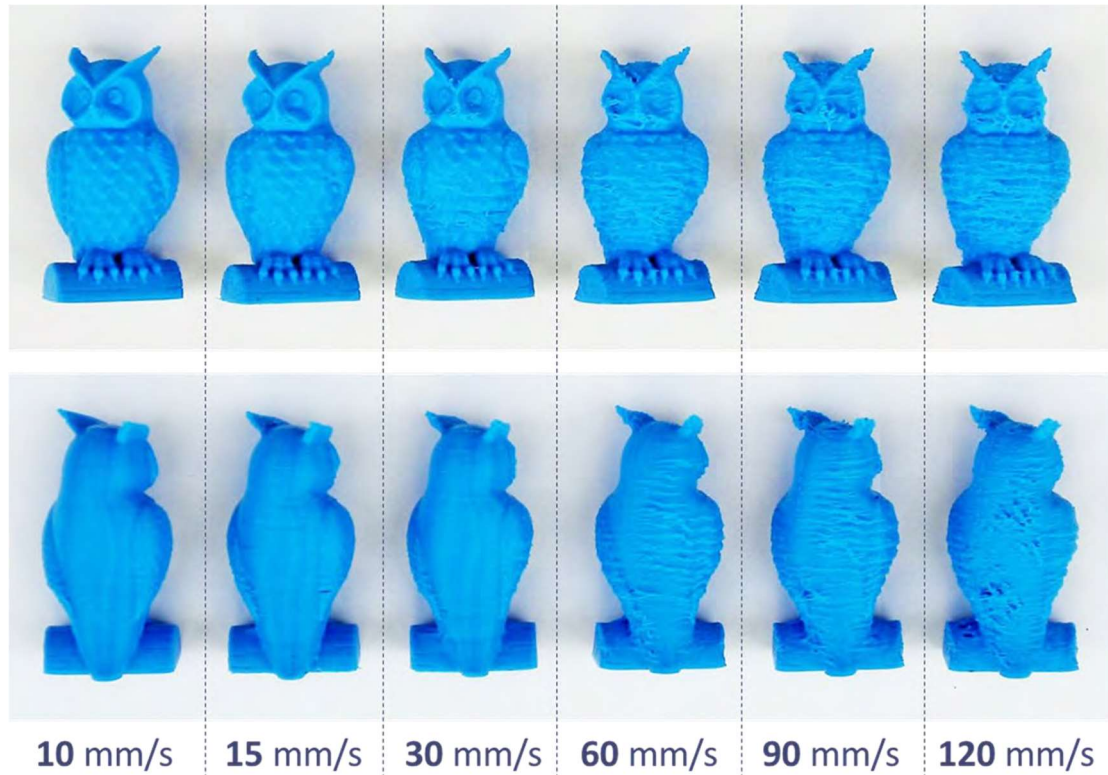


Figure 50. Figures of printing speed [25]

Also, we will set the layer height and print quality. The height of the individual slices/thickness of each layer. Layer height is the main factor affecting both the print time and the vertical resolution.

Layer height selection

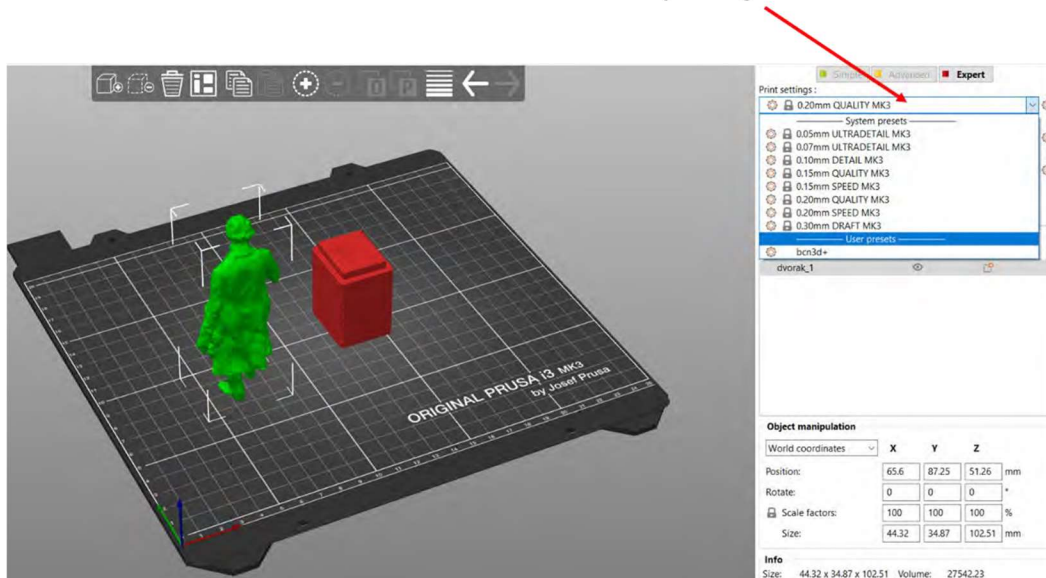


Figure 51. Layer programming

By choosing taller layer heights, you can significantly shorten the print time at the cost of more visible layers. On the other hand, choosing small layer height (e.g. 0.10 mm) will result in extra detail at the cost of longer print times.

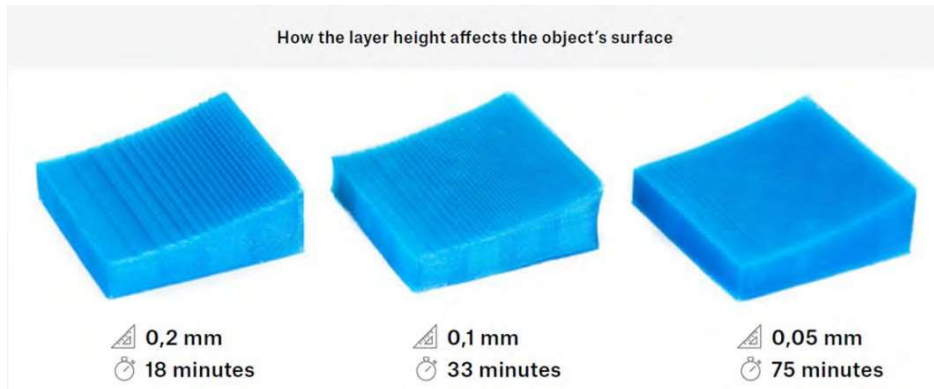


Figure 52. Layer and quality [26]

Layer height – sometimes also called the “Z-axis resolution” has a major impact on both print times and overall surface finish of the printed object. Higher values lead to faster prints and layers that are more visible on the surface of the object. This effect is especially prominent on surfaces that are nearly parallel to the print bed. Most of the time, layer heights of 0.15 – 1.20mm are preferred [26].



Figure 53. Layer and printing time [27]

Filament Settings

We select the printing material that we will use

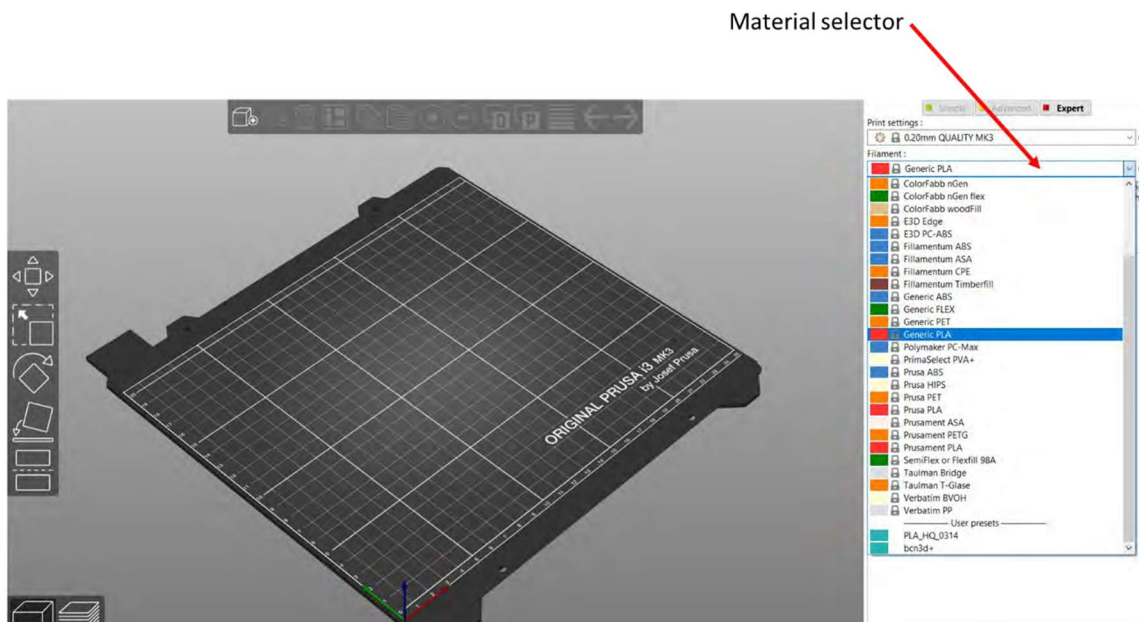


Figure 54. Selection of material

We find all information about material with the filament provider

ABOUT PLA

PLA melts at a relatively low temperature of about 175 degrees Celsius. Unlike so-called thermoset materials, PLA can be heated past its melting point multiple times with very little degradation. It's a hard material, but that also means it's somewhat brittle, and once it breaks, it likes to shatter. **Only this material is proven for 50 microns layer height.**

However, PLA is not a perfect material and, just like every other plastic, has some disadvantages. The low melting temperature also means **low-temperature resistance**. Parts start to lose mechanical strength at temperatures **over 60 °C**.

The combination of being both biodegradable and having low-temperature resistance means that it's **not ideal for outdoor use**, not to mention low UV-resistance. Also, PLA is only soluble in chemicals like chloroform or hot benzene. So when connecting multiple pieces, you're better off using just glue.

Even though PLA is biodegradable, and the material on its own is food safe, we do not suggest to repeatedly **drink or eat from your 3D prints**. Because of the small fractures on the print surface, bacteria can build up in there over time. You can prevent this by applying a food-safe coating. When **post-processing PLA**, it's better to use wet sanding. Without water you'll quickly start heating the plastic by friction, it will melt locally and make it hard to keep sanding.

PRINTING SETUP

Nozzle	215 °C	Heatbed	50-60 °C
--------	--------	---------	----------

BASIC ATTRIBUTES

<input checked="" type="checkbox"/>	Easy to print	<input type="checkbox"/>	Brittle
<input checked="" type="checkbox"/>	Can print tiny parts	<input type="checkbox"/>	Low temperature resistance
<input checked="" type="checkbox"/>	Can print huge objects	<input type="checkbox"/>	Difficult post-processing
<input checked="" type="checkbox"/>	Hard and tough		
<input checked="" type="checkbox"/>	Low warping		

Figure 55. Filament information [28]

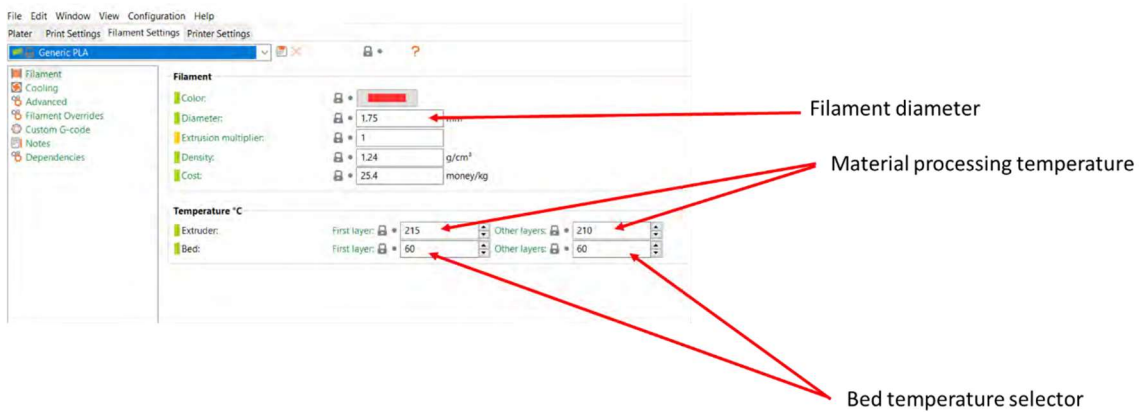


Figure 56. Material settings, diameter, material temperature, bed temperature

The material, in this case, is generally a thermoplastic filament, which is melted and then extruded layer by layer onto the print bed. The most common filaments are made of the thermoplastics PLA, ABS, and PETG, but there are so many more out there that expand what you can create with your FFF printer.

	ABS	Flexible	PLA	HIPS	PETG	Nylon	Carbon Fiber Filled	ASA	Polycarbonate	Polypropylene	Metal Filled	Wood Filled	PVA
Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More
Compare Selected	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ultimate Strength	40 MPa	25-43 MPa	65 MPa	32 MPa	53 MPa	40-85 MPa	45-48 MPa	55 MPa	72 MPa	32 MPa	20-30 MPa	46 MPa	78 MPa
Stiffness	5 GPa	1 GPa	2.5 GPa	10 GPa	3 GPa	3 GPa	10 GPa	5 GPa	6 GPa	4 GPa	10 GPa	6 GPa	3 GPa
Durability	8/10	9/10	4/10	7/10	8/10	10/10	3/10	10/10	10/10	9/10	4/10	3/10	7/10
Maximum Service Temperature	98 °C	60-74 °C	52 °C	100 °C	73 °C	80-95 °C	52 °C	95 °C	121 °C	100 °C	52 °C	52 °C	75 °C
Coefficient of Thermal Expansion	90 µm/m°C	157 µm/m°C	68 µm/m°C	80 µm/m°C	60 µm/m°C	95 µm/m°C	57.5 µm/m°C	98 µm/m°C	69 µm/m°C	150 µm/m°C	33.75 µm/m°C	30.5 µm/m°C	85 µm/m°C
Density	1.04 g/cm ³	1.19-1.23 g/cm ³	1.24 g/cm ³	1.03-1.04 g/cm ³	1.23 g/cm ³	1.06-1.14 g/cm ³	1.3 g/cm ³	1.07 g/cm ³	1.2 g/cm ³	0.9 g/cm ³	2-4 g/cm ³	1.15-1.25 g/cm ³	1.23 g/cm ³
Price (per kg)	\$10- \$40	\$30- \$70	\$10- \$40	\$24- \$32	\$20- \$60	\$25- \$65	\$30- \$80	\$38- \$40	\$40- \$75	\$60- \$120	\$50- \$120	\$25- \$55	\$40- \$110
Printability	8/10	6/10	9/10	6/10	9/10	8/10	8/10	7/10	6/10	4/10	7/10	8/10	5/10
Extruder Temperature	220-250 °C	225-245 °C	190-220 °C	230-245 °C	230-250 °C	220-270 °C	200-230 °C	235-255 °C	260-310 °C	220-250 °C	190-220 °C	190-220 °C	185-200 °C
Bed temperature	95-110 °C	45-60 °C	45-60 °C	100-115 °C	75-90 °C	70-90 °C	45-60 °C	90-110 °C	80-120 °C	85-100 °C	45-60 °C	45-60 °C	45-60 °C
Heated Bed	Required	Optional	Optional	Required	Required	Required	Optional	Required	Required	Required	Optional	Optional	Required

Figure 57. Filament characteristics [21]

Although 3D printing technology has been evolving at quite impressive pace, beginner 3D printer users still face numerous challenges that they have to overcome in order to get results that satisfy their expectations. There are several crucial things that can influence whether the print will succeed or not [30].

Another just as important part is choosing the appropriate settings for your print. 3D printing has not yet reached the stage when all you have to do is just to click the “print” button and wait. Choosing settings that are not proper is one of the most common reasons why prints fail. Even good quality filament printed with inappropriate settings will generate bad result, therefore you should pay them attention.

The most important setting is described as follows.

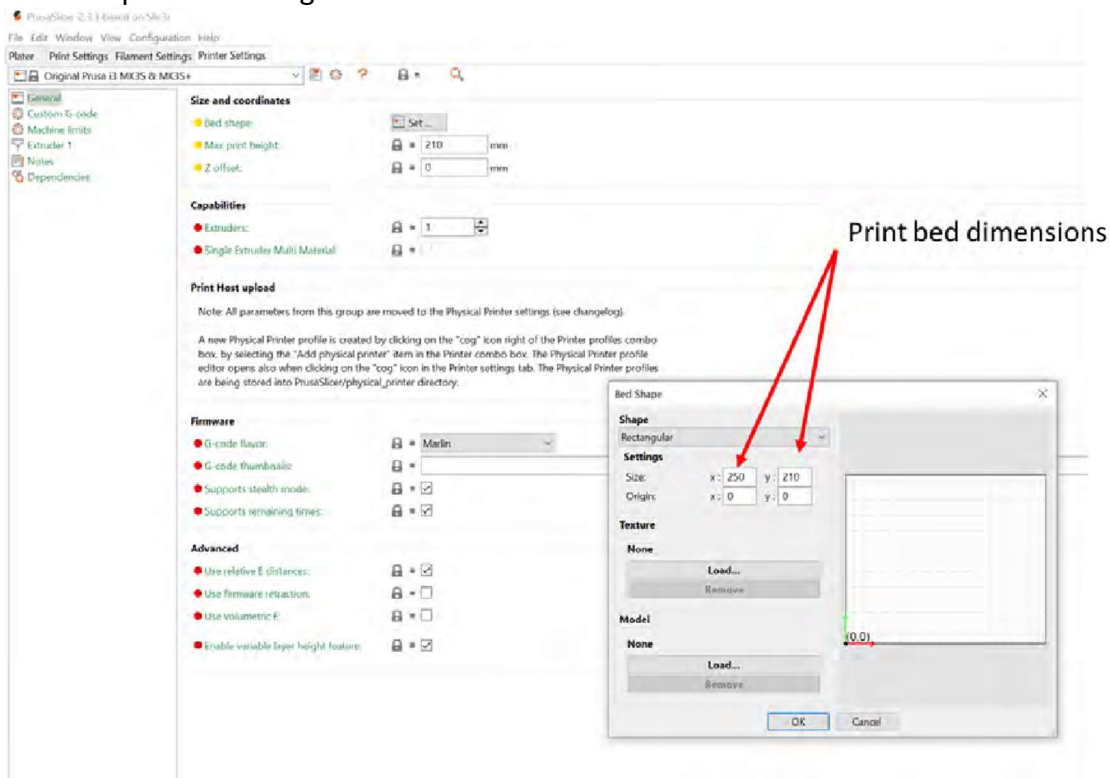


Figure 58. Print bed dimensions

Another parameter to consider is the nozzle diameter. Can be found in printer settings tab.

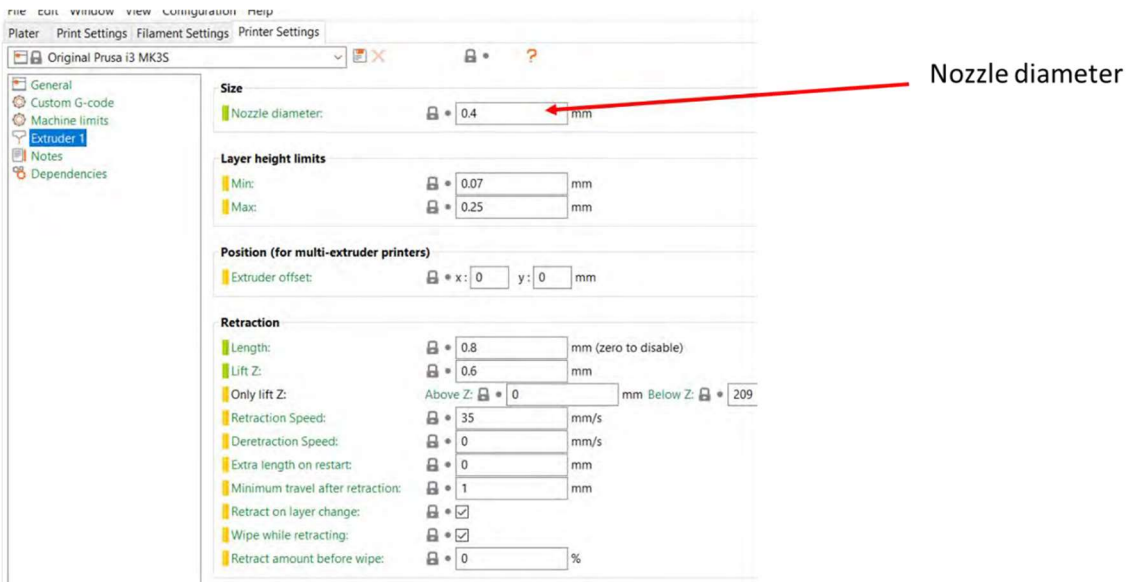


Figure 59. Nozzle diameter input

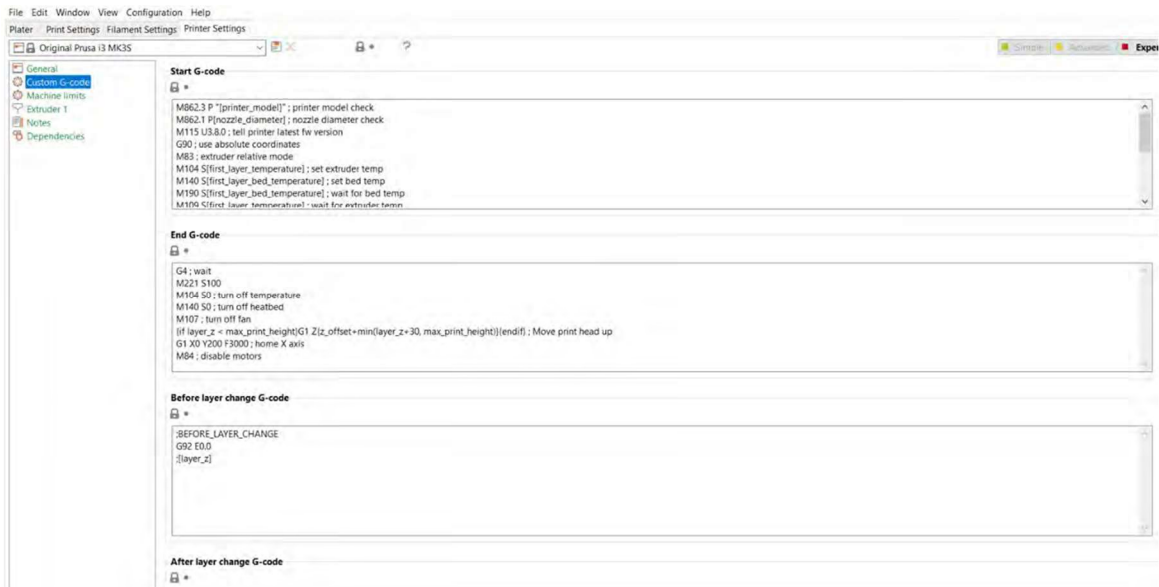


Figure 60. Other g code parameters to consider

Brass has excellent heat conductivity and is tough enough to print most "every day" filaments. It is also accessible and reasonable to manufacture, which is probably why many 3D printers are supplied with brass nozzle.

Besides the standard 0.4 mm diameter, we provide configurations for 0.25 mm, 0.6 mm, and 0.8 nozzle diameters. On top of that, you can always create and customize your own profiles. To achieve fine detail, you can use a 0.25 mm nozzle. We recommend using it only for very small objects, a few centimetres in size, as the print times are considerably longer compared to 0.4mm nozzles. By contrast, if you want to speed up the print and the details are not as important, you can try using the 0.6 or 0.8 mm nozzle [31].

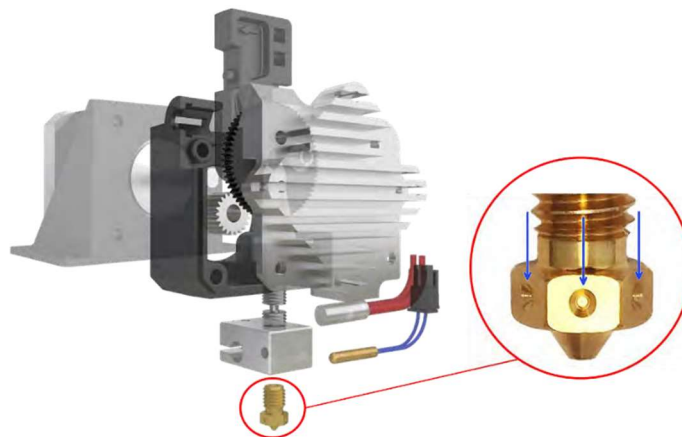


Figure 61. Nozzle eschema [32, 33]

Slicing

The last step is the slicing process.

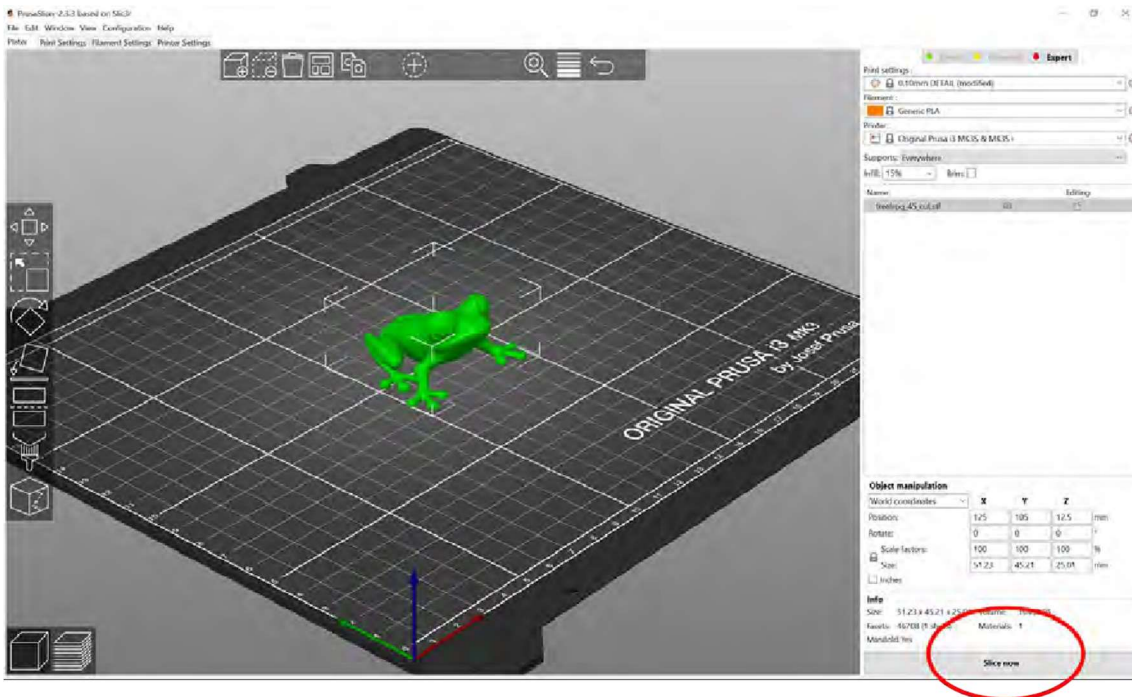


Figure 62. Slicing

The information displayed about the sliced info is the length and weight of the used filament in mm and g. Finally, it displays the estimated printing time. Finally, we generate the g-code and export it to ssd card.

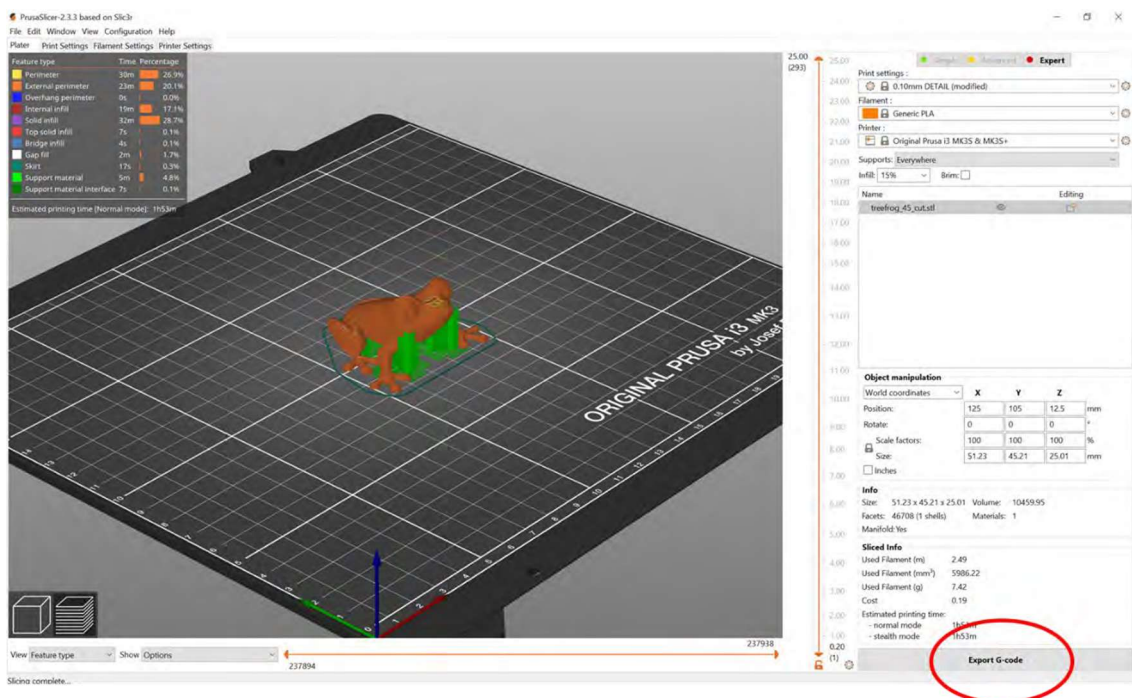


Figure 63. G code generation

Preparation of the 3D printer (Prusa MK3S)

Original print surfaces by Prusa Research are coated from both sides.

Double-sided textured PEI powder-coated spring steel sheet

Scratchproof, hard to damage	PLA prints with a small contact area may need a brim
Transfers texture to prints	PLA prints with a huge footprint (one side 18cm+) may warp
More forgiving Live Adjust Z setting	Need to change Live Adjust Z if you also own Smooth PEI sheet
No need for Windex with PETG	Never clean with acetone
No need for glue stick with FLEX	
Prints automatically detach after sheet cools down	
First layer can be more squished compared to smooth sheets	

Perfect for PLA	Do not clean with IPA before PETG. Release agent might be necessary
Great adhesion with almost all materials	You must apply glue stick when printing Flex
Smooth bottom of prints	Need to change Live Adjust Z if you also own the textured PEI sheet
Tiny details will stick great	
Rejuvenate with acetone from time to time	



Figure 64. Steel print sheets - smooth PEI sheet and textured powder-coated PEI

Selftest

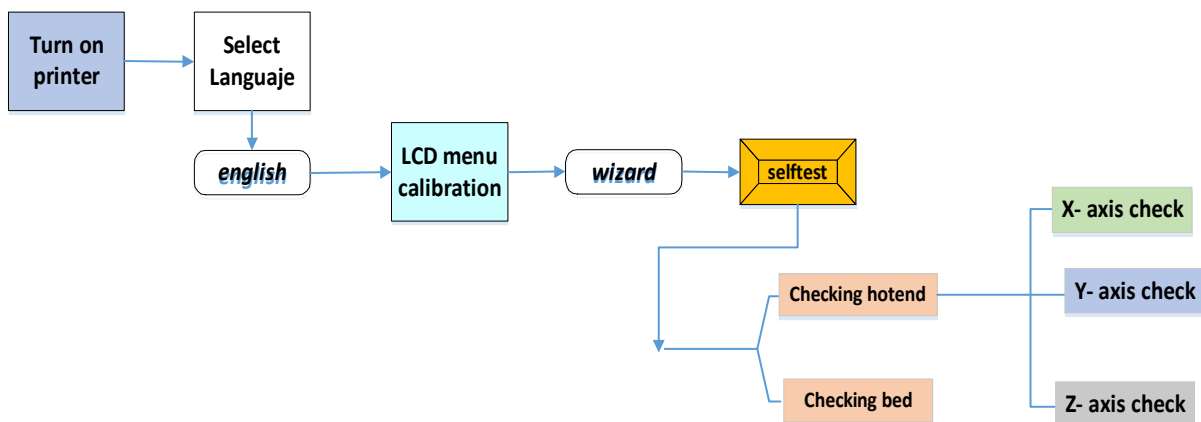


Figure 65. The Self Test of the Prusa MK3S 3D printer

The purpose of the selftest routine is to check the most common errors. You can run the Selftest from **Calibration** menu on the LCD panel. The test consists of:

- Extruder and print fan test
- Heatbed and hotend proper wiring
- XYZ motors proper wiring and functionality
- XY axis length
- XY belts tension
- Loose belt pulley test
- Filament sensor test

Increasing the adhesion

On some special occasions, such as printing a tall object with a very small contact area (with the print surface), you might need to increase the adhesion. Fortunately, PEI is a very chemically resistant polymer and you can temporarily apply various adhesion solutions without damaging it. This also applies to materials that would not stick to PEI otherwise, like Nylon, etc. Before applying anything onto the bed, consider using the Brim option in PrusaSlicer which increases the surface area of the first layer.

For ABS prints, ABS juice can be used and later cleaned with pure acetone. Be very gentle when applying the juice and do so while the bed is cold. Prints will attach strongly. **Do not use ABS juice on the powder-coated spring steel sheet!**

Calibrate XYZ

We do this when we need to calibrate the distance between the tip of the nozzle and the SuperPINDA (Prusa INDuction Autoleveling) probe. The purpose of the X/Y/Z calibration routine is to measure the skew of the X/Y/Z axes and to find the position of the 4 calibration

points on the print bed for proper bed leveling. You can run the XYZ calibration from the **Calibration** menu on the LCD panel.

Place a sheet of a regular office paper (for example, the checklist shipped with every order) and hold it under the nozzle during the first round (first 4 points being checked) of calibration. **If the nozzle catches on the paper during the process, power off the printer** and lower the SuperPINDA probe slightly.

Initiating this routine performs a series of measurements in three rounds: In the first round, **without the steel sheet** installed, 4 sensor points on the print bed are searched for carefully, so as not to touch the print bed with the nozzle. In the second round, the point locations are being improved. In the last round, **with the steel sheet on**, the height above the 9 sensor points is measured and stored in non-volatile memory for reference. This finishes the Z-axis calibration.

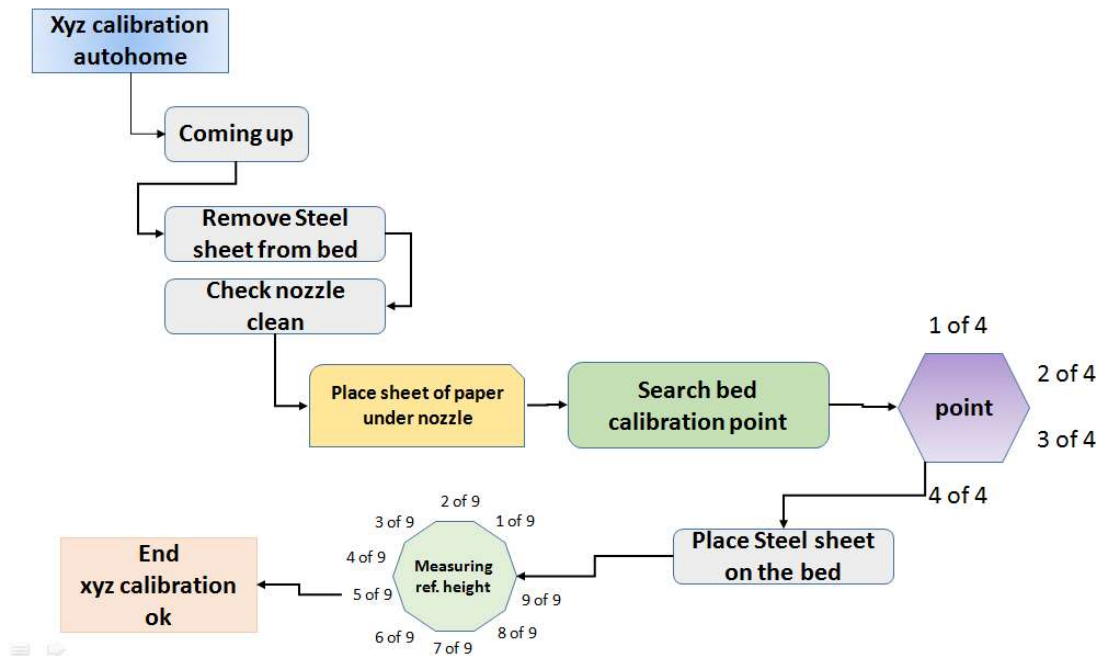


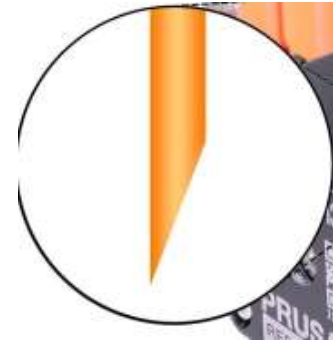
Figure 66. The XYZ calibration diagram

Calibrate Z

Calibrate Z is located in the LCD Menu - **Calibration - Calibrate Z**. It is always done with the steel sheet on. It should be performed whenever you move the printer to a different location. It saves the heights of all 9 calibration points in non-volatile memory.

Loading the filament into the extruder

If you have the filament sensor and **autoloading enabled**, preheat the printer and simply insert the filament into the extruder. Everything is automated from this point. Make sure that the filament tip is nice and pointy.



If you have the filament sensor or **autoloading disabled** in the settings, you can manually start the loading process from the LCD menu. Insert the filament into the extruder and choose the **Load filament** option in the menu and press the button to confirm.

If your **filament is running out** during a print, you can easily replace it with a new spool. Just go to the LCD menu, select **Tune** submenu and press **Change filament**

Unloading the filament

This procedure is similar to the loading operation. Select **Unload filament** option from the menu. If the nozzle is not preheated, the preheat menu will be automatically shown. Select the filament type and confirm your selection by pressing the control knob. After the printer reaches the target temperature, press the knob to unload the filament. If the nozzle was preheated, the filament is unloaded immediately.

First layer calibration

You can launch the calibration from LCD Menu - **Calibration - First layer cal.**

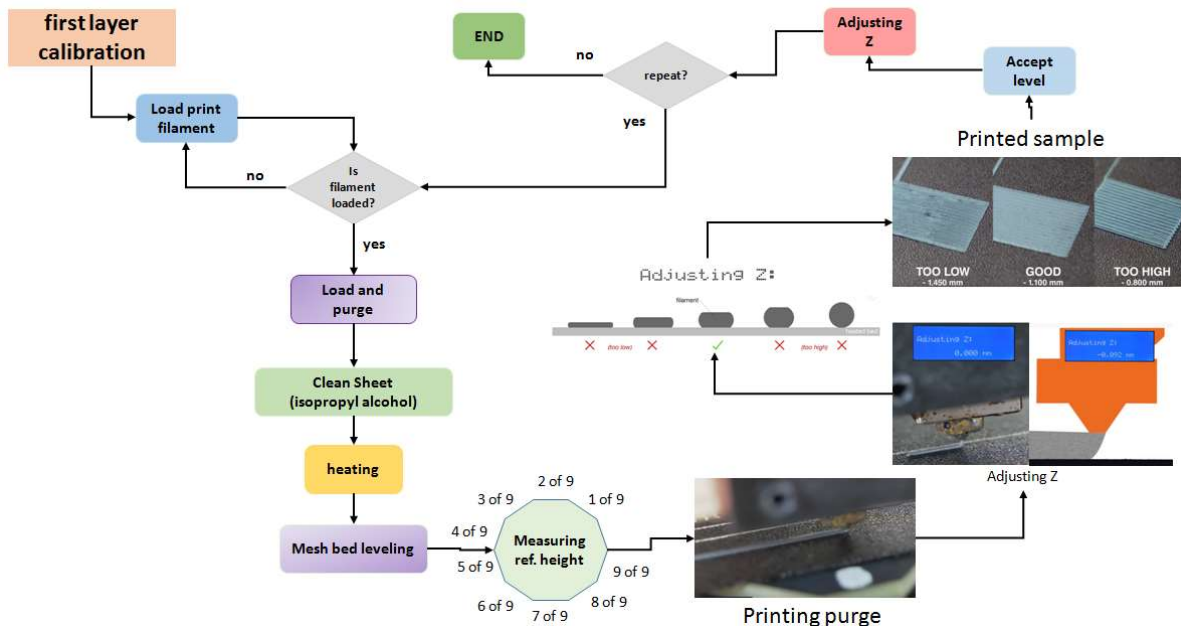


Figure 67. The Z-calibration diagram

The printer will probe the bed and start printing a zig-zag pattern on the print surface. The nozzle will be at the height based on the SuperPINDA probe setting, **it must not by any means touch** the printing surface.



Figure 68. First layer calibration



Observe the line which is being extruded on the print surface. A new menu will automatically show up where you can tune the nozzle height in real time by turning the knob. The aim is to adjust the nozzle height until the extruded plastic sticks nicely to the bed and you can see that it is being slightly squished. The value should not exceed -2.000 mm. **If you have to adjust it more** (e.g. -2.500), move the SuperPINDA probe slightly higher.

3D PRINTING AND INTELLECTUAL PROPERTY RIGHTS

Many institutions and libraries are considering or already providing 3D printing services. These are becoming increasingly prevalent and the interest in such technology is growing as the associated cost for the equipment and the final production is declining. But liability could arise for the copyright infringement, depending on how the services are provided. If the Library prints items on its own initiative it could become entangled in direct infringement but may face secondary liability, if it provides the instruments for 3D printing at the request of patrons.

Academic Libraries can manage the risks by implementing written policies governing the use of 3D printing and educating users on it. That means that librarians need to know how copyright applies to 3D printing and what limits and exclusions of copyrightable elements exist. It should be noted, however, that it is not always clear - on the contrary, it is often complicated. In practice, it is difficult for staff to recognize potentially infringing printing requests.

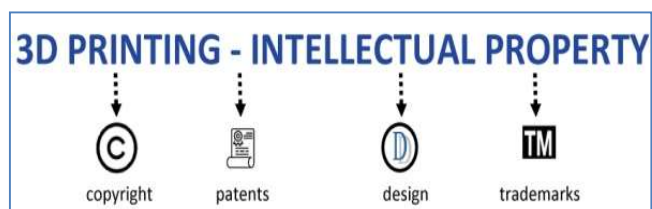
Library policies on 3D printing contribute to its credibility and it's important not to be based on fear and not to be overly restrictive.

Intellectual Property Rights

“Intellectual property (IP) refers to creations of the mind – everything from works of art to inventions, computer programs to trademarks and other commercial signs”

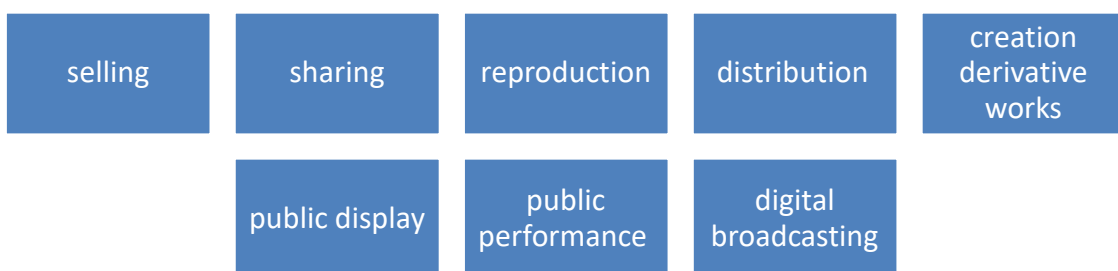
Undoubtedly, the role of the IP rights system in promoting innovation in 3D printing is a complex one. In some instances it has a beneficial role but in others it can play neutral or harmful. It benefits creators but has the opposite impact on content available free by the public.

The 3D printing IP issues cut across **copyrights**, **patents**, **design** and **trademarks** but the majority of legal challenges related to 3D printed objects are rooted in copyright.



It is true that some users of 3D printing may not always intentionally but unintentionally violate these rights.

Exclusive rights to copyright owners



What is often protected by law in 3D printing?

- CAD file - The design of a CAD file is protected, either it is through software tools or by scanning
- CAD file's code - Protection pertaining to design data generated by designing a CAD file or through scanning
- the printed object - Protection pertaining to printing such as materials and hardware (e.g., 3D printing machines and scanners)
- CAD and slicer software

Relevant legislation

Ownership-related legislation for 3D printing is partly regulated by IP Rights and types of them such as the sui generis database right regime, soft types of IP, trade secrets and others that play a crucial role in the protection of rights. Most important is the role of:

- International, European and National laws
- European Regulations
- Directives of the European Parliament and of the Council
- General contractual agreements
- Berne Convention
- WIPO Copyright Treaty

Industrial 3D Printing

A complete industrial 3D printing system is associated with various copyrights.

Patent protection and legal protection of inventions have played an important role in the sector of industrial 3D printing. Based on it, 3D printers are protected as well as their components, the processes of making 3D printing and the raw materials used (powders, liquids, yarns, sheets).

A powerful tool also for the protection of the 3D printing industry is the protection of trade secrets. It is well known that 3D printers and 3D objects do not always reveal the details of the manufacturing process.

Personal 3D Printing

A major challenge for intellectual property owners is to enforce their rights in the sector of personal 3D printing which differs from that of industrial 3D in this matter. Questions are also raised about incentives for innovation in 3D printing.

3D printing: EXCEPTIONS AND LIMITATIONS

3D printing copyright exceptions and limitations are particularly important in order to maintain the necessary balance between the interests of copyright holders and users of protected items. These exceptions may vary from country to country but everywhere permits the use of



protected works without the permission of the rights holders and exempt from financial compensation **in certain circumstances**.

The most common types of exceptions and limitations to IP rights are **private** and **non-commercial** use and copying, fair use, as well as issues of repair, reuse and recycling of protected products in relation to the doctrine of exhaustion. Additional factors taken into account in these exceptions are the Public Sector and the duration of rights.



Copyright Exception for Libraries

National copyright laws state exceptions specific to Libraries by allowing them to provide reproduction devices such as printers, computers, photocopiers and scanners. They are not responsible for any copyright infringement committed by the users as long as a reminder and warning exist in a visible place near the equipment to protect the copyright of the authors.

Protection Strategies

Owners of 3D printers can feed them with 3D design files which they may have obtained from the Internet, modified, and reproduced. Such files are legally protected by various types of copyright laws, such as copyright, design protection, reproduction and modification rights, etc. They also can share 3D design files and print designs to their own 3D printers.

In such cases patent owners face new challenges too. Whether the above actions constitute an infringement depends on the legal framework of the individual country and whether this allows the specific action for private use. In the patent laws of some countries, there isn't an exception for private or non-commercial use, while in other countries, such as many European, the relevant laws have special provisions that exclude private and non-commercial uses from the exclusive rights of patent holders.

Theoretically, where reproduction for personal use is prohibited, intellectual property holders can seek redress. In practice, however, this is very complicated as it is not clear what exactly constitutes an infringement in the world of patents where many issues have emerged such as the distinction between repair and reconstruction. Therefore, going to court may not be a wise practice for the above. The same goes for the 3D designs and 3D design files protection.

As IP rights are difficult to enforce in the world of personal 3D printing, right holders often target those who indirectly facilitate or encourage such infringements. These are the so-called "intermediaries" and they have the intermediate responsibility while a lot of discussion is emerging around them.

Particular attention should be paid here as intermediaries help to promote 3D printing and create a new digital marketplace. Barriers to the free flow of data run the risk of hindering innovation and incentives.

Specific exemptions from liability for intermediaries have been created, which include notification and removal procedures and provocation standards.

Open-Source 3D Printing

One of the main reasons that 3D printing has thrived in last years is undoubtedly the open-source approach. The relevant expiration of the basic patents obviously contributed to this. Other factors that have contributed to the emergence of the open-source 3D printing community are the availability of easy-to-use 3D design software, the advent of state-of-the-art communication technologies, open-source versions, internet broadband penetration and more that led to a collaborative system which the open-source 3D printing community was built on.

Digital rights management in 3D printing

In order to effectively manage the rights in 3D printing, protection mechanisms must be integrated in the design files, 3D printer, 3D scanner and final product. An example of a restraint mechanism is a kind of digital watermark in the object design file that would indicate that it is copyrighted. Then the printer should be able to identify the specific digital watermark.

Fortunately, none of the known 3D file online repositories encourages counterfeiting.

Copyright and 3D digital object designs

Many questions arise about rights in 3D digital object designs.

A fundamental tenet of copyright law is originality. But what does this mean in the context of 3D printing and how easy is it to define originality when a large number of 3D printing users openly share an object design file? What happens when the user intervenes in the original design and a varied work results? Are we talking about a "collaboration" work that includes new intellectual property rights? Alternatively, users may not have access to the design files of the objects they want. Will it be considered copyright infringement if they use a 3D scanner to create new design files with modifications to them?

Creative commons for 3D printing

Digital object designs are often modified and redistributed to the 3D printing community. Many of the original authors of CAD files use CC licenses to encourage individuals to create derivative works in a way that secures their credit. It would be ideal for the creators to be able to monitor all the derivatives of their work, how their original designs evolve and whether they are used on the internet in accordance with the provisions set by the CC licenses.



Widespread use of object designs would be desirable, but conditional.

POLICIES AND BEST PRACTICES TO GUIDE USERS ON 3D PRINTING

(ACCORDING TO THE LIBRARIES MISSION)

Academic libraries have always protected intellectual property rights and especially copyright. They are now called upon to extend this role to 3D printing as well. They must proactively formulate and implement acceptable and effective policies of using the service of the new technology concerned about secure and legal access to the 3D printer. Those must include

copyright, patent, trademark and other laws and written statements by users who accept their terms and confirm that all uses of the 3D printer will be for lawful purposes only. Thus they provide the Libraries with the necessary flexibility in case of abuse, but also the freedom to design and create new works.

It goes without saying that not all Libraries will have the same binding rules, which will also depend on their decision as to who will actually print. On the other hand, a policy based on legality is not easy as legality is not easy to define too.

Policies can be reviewed based on the problems and issues that arise over time.

Developing 3D Printing Services - Suggested workflows

1. Very important decision right from the start is **to whom the 3D printer is available** (students, university staff and faculty, external users) and who is allowed to access the 3D printer (e.g. only authorised University staff)

2. One of the first basic considerations is the explicit definition of **who** will be responsible for the printing process (e.g., CAD files, starting printing, printer management). It can be fully staff managed, be entirely open to users or in collaboration with staff and users. Of course, there is the possibility of combining the above and creating multiple types of service.

For each of the service styles there are advantages and disadvantages which are related to the types of libraries.

3D PRINTING SERVICE TYPE	PROS	CONS
Staff-Managed	<ul style="list-style-type: none"> There is no concern for printer safety. Staff members have the option to refuse a 3D print request for reasons as legality, safety, and intellectual property issues. Printing has more chances of success. 	<ul style="list-style-type: none"> Waste of staff time. Users do not acquire printer usability.
Users-Managed	<ul style="list-style-type: none"> Users take responsibility for the print failures and their cost. There is no burden on staff time. 	<ul style="list-style-type: none"> It is not certain that users will follow the Library's instructions. Users can print items that are not allowed. Users may damage library equipment. Users may not be able to solve problems (e.g. in the printer queue).

		<ul style="list-style-type: none"> • There is no proper time management and there is a possibility of long delays for next users. • Other users' jobs may be changed or canceled.
<p>Staff and Users collaboration</p>	<ul style="list-style-type: none"> • Permits users who have some skills to use 3D printers to work on their printing. • Allows staff to deal with different users in parallel if there is more than one printer. 	<ul style="list-style-type: none"> • Moderate burden on staff time. • Many printers may be required.

Service options depend on the number of employees and the specialization of the Library staff, type of the printer, available space for it, chances of replacing the printing presses in case of mismanagement, type of users (registered, external, different ages), skills and interest of the users, requirements of the users (large and complex models), the possibility of training the users in the use of the printer.

3. Special care needs to be taken in defining **what is allowed and what is forbidden to print**.

Library policies for 3D printing should be as simple as possible and it is necessary to use language carefully and find the right words. A notice that covers a wide range of issues is "illegal activity is prohibited". This can affect both the content of the printing and the use of the printer. The word "illegal" is a legal term and has more weight, for example, than the word "inappropriate" or "objectionable".

Libraries should advise their users if obtain a CAD file from a source to look for a copyright indication or terms of use. In this way they will be able to know what is allowed and what is forbidden to do with it.

Libraries should require users to read the policy and confirm that their requested print material complies with the terms of it and there isn't any infringement on one's intellectual property rights.

Another procedure that makes clear how the service operates and prevents accidents is the definition of printing **time** which affects a number of other issues. The Library - depending on the available staff, its level and the type of equipment- decides whether to permit the printers operating unattended, during hours that are closed to the public. If, of course, the equipment is not sufficiently checked or there is concern about disasters (e.g. overheating and fire), loss of time in case of a problem (phenomenon of "spaghetti"),

software malfunctions that destroy the objects and other unwanted, the decision leans towards the provision of the service during the opening hours of the Library.

It is obvious that the decision on the hours of service operation affects the type and size of objects that the Library accepts for printing.

4. If a Library needs to handle a large number of 3D printing requests it must **prioritize** its jobs and develop a hierarchy system considering several factors and preferences. For example, faculty prioritized over other users, smaller objects over large ones -that require a lot of time- or monochrome models have priority over colorful ones to save time swapping filament spools etc. Some Libraries based on the time that requests submitted, processed and approved, but this must be done very carefully to anticipate potential problems.

All these of course depending on the deadline set by the users and the guarantee that all users are serviced equally.

A fairly good practice that will solve many problems is to assign a task manager, exclusively for prioritizing and managing the printer queue. This is even more necessary when multiple printers are added and jobs increase exponentially.

5. A **workflow** adjustment is absolutely necessary with the start of the 3D service. This flow will be evolved as staff gain experience on the requirements and difficulties of the service. The flow will vary depending on the service styles chosen by the Library.
6. The only way to verify the success of such a library service is the **assessment**. Libraries must evaluate their services and workflow continually, based on user opinions mainly (e.g. gathering feedback from users, giving them the opportunity to capture their view of the service by filling out a questionnaire).

Policies should be clearly communicated to users.

KEY POINTS

Libraries...

- ▶ in addition to not allowing the printing of objects that may infringe the IP rights of creators, must ensure that no one will print dangerous, obscene or harmful to the environment material,
- ▶ reserve the right to reject a 3D printing request,
- ▶ must give step by step instructions for 3D printing and estimate the wait time, the cost, possible imperfections etc. (tip: only time estimate and no promise or guarantee for completion time),
- ▶ must post on their website (and/or print) detailed guides and training material suitable for both users and staff. Pictures are suggested instead of text –wherever is possible- for more vivid and immediate information to readers. A FAQ section of basic troubleshooting and links to help is desired,
- ▶ must inform users of the exact printing procedures -depicting the roles involved in the process- but also provide for exceptions such as, for example, users denying staff involvement in the case of fragile objects or staff denying user involvement in the event of sharp edges, etc,



- ▶ ensure an automated communication with users, regardless of the Library service style,
- ▶ can serve patrons via social media,
- ▶ can manage workflow developing effective tools (in-house or open source) as the staff skills or library's budget permit,
- ▶ is convenient to align the 3D printing service with other services with similar procedures and requirements (e.g. the service time, the necessary presence of a "specialist", the advance fixing appointments, etc.),
- ▶ decide, depending on who manages the prints, how users will bring the 3D files (e.g. via USB, email or storage),
- ▶ set the charge for the final object (if the decision is to charge). This should be made logically and based on the material used and the time required for its production. A charge that prevents patrons from using the service should be avoided,
- ▶ can determine an appropriate length of time and the manner of receiving the printed product. In case of non-response of the users, Libraries should have the right to impose a penalty,
- ▶ need to develop a policy if the printer fails, either through carelessness or intent,
- ▶ in case users bring their own materials, it must be ensured that they are approved for the specific printer, in order to avoid problems,
- ▶ must provide proof of delivery/receipt at each stage of the service (e.g., CAD files, final products, etc). It is helpful to exist a tracking slip for each job throughout the process,
- ▶ should consider participating in 3D printers' networks, sign up for discussion lists etc.,
- ▶ need to keep and process 3D printing statistics,
- ▶ may ask users to have an image of the printed object (e.g., for 3D printing service marketing).

Adequate and ongoing staff training

When the number of employees of a Library is large, there should be trained specialized staff that supports the 3D printing service. This way ensure success and the service is in harmony with the mission of the Library that foster -except knowledge- creativity, discovery, innovation, and collaboration. Even then, however, all staff should have a basic knowledge and be able to answer the initial questions about the service, direct users to experienced staff, and provide them with printed and/or online guides.

The need for staff training is more pressing if modeling services are provided. But even if they are not, staff must have a basic knowledge of identifying a good or a bad model.

Undoubtedly as technology evolves staff will need to be constantly trained to meet the ever-increasing demands of users.

3D printing service patron education

Libraries can provide their users -in addition to the appropriate equipment- the necessary expertise in 3D printing. Information on CAD software, its use and from which reputable sources they can find such files available for free download or purchase is undoubtedly necessary. Patron training helps expected use of the service and ensures the correct process



from the beginning to the completion of the printing job. It is also an opportunity for detailed information on intellectual property and encouraging users to develop their own designs and print original work. In the latter case, users are educated about their rights as copyright holders, choose whether to share their designs, or set out circumstances in which others can use their work. In short, the Library should educate users on how to use 3D printing tools, promoting information literacy and giving them more power and rights over their creations.

Many Libraries allow printing by users only if they have received special training and have relevant certification.

It is possible - for the benefit of the Library - that these trained users voluntarily help others, reducing the workload for staff.

Conclusion

The vast majority of Libraries have advanced forward, continually monitoring developments and adapting their policies to new services, new forms of information and interactions between librarians and patrons.

3D printing services -an integral to the ever-changing face of education- provides new opportunities for innovation and creativity and Libraries need to offer such services to a wider audience. As there is little case law that deals specifically with 3D printing services and leads to decision-making and good practice, we can refer to existing laws and guidelines relating to reproduction services and copyright in general.



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