BASICS OF 3D PRINTING

with Josef Prusa

Third edition

INTRODUCTION

You may have heard about 3D printing on TV, or read about it on the internet. Like all new technologies, 3D printing draws the attention of mainstream media, but the topic is often covered in shallow or sensational ways. There are many myths floating around about 3D printing – including the common misconception that it's a new technology. In fact, this type of manufacturing method has been known since the 1980s and it's now quite commonly used in all sorts of industries, and even by hobbyists at home.

You will find out that 3D printing is not some kind of futuristic, complicated and super-expensive technology available only to a handful of mortals. On the contrary! The principles are pretty straightforward and simple. There are a number of industry-specific words and abbreviations that could, perhaps, frighten you at first – don't worry about that! Actually, there are not too many of them and you will soon wrap your head around them.

This book will help you understand what kinds of 3D printing technologies are currently available and how they work. We will take you through the whole process of 3D printing, starting with obtaining a printable 3D model, through the pre-printing preparations, to the final post-processing of a printed object. You will learn what an extruder is, as well as slicing, perimeters or infill. We're going to explain the differences between commonly used materials, and how to utilize 3D printing for practical application.

This book will give you a very good understanding of 3D printing and also provide you with all the basic knowledge required to start. The only thing remaining will be to buy a 3D printer and start printing!

Josef Průša

Josef Prusa

Josef Prusa (*23. 2. 1990) became interested in 3D printing before joining Prague's University of Economics in 2009. Soon, Josef grew into one of the leading developers of Adrien Bowyer's international open-source RepRap project. Today, you can see the Prusa design in different variations all around the world. It's one of the most popular 3D printers and it's one of the reasons why the knowledge of 3D printing has increased among the public. In 2012, Josef established Prusa Research, which produces the Original Prusa 3D printers and delivers more than 10.000 of them to customers worldwide. With more than 400.000 units sold, the Original Prusa i3 is the world's most widely used 3D printer design.

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WHAT IS 3D PRINTING?

3D printing is an automated additive manufacturing process, where a 3D printer creates a physical model based on digital data (a 3D object). There are a number of various 3D printing technologies, but the most commonly used one, called FFF (Fused Filament Fabrication), is simple: an object is created layer by layer by melting a strand of plastic. Imagine that you would take a 3D object and slice it into thin pieces – like a potato into potato chips. Then, you would take a glue gun and "draw" each layer with hot glue. This is generally how objects are printed – it's an additive method, because we're adding material. It's directly opposite to the subtractive method, which consists of machining of existing material.

3D printing is expanding and evolving rapidly. There's a constant and ongoing development of 3D printers and printing materials. 3D printers first successfully expanded from the professional sphere into the hobby/maker world. And now, the hobbyists' popularity helped it expand into various new industries.

History of 3D printing

At first, 3D printing was called Rapid Prototyping – and this term is still used today, although rarely. Before affordable 3D printers became commonplace, this technology had been used for prototyping only.

A typical job for rapid prototyping would be the development and production of a TV remote. Preparatory works for production can cost even tens of thousands of dollars (manufacturing the molds, the manufacturing process itself, testing...), so the manufacturer needs to be perfectly certain that their TV remote fits well into users' hands and all buttons can be reached comfortably. That's where prototyping comes in. Even though the prices of 3D printers were really high, the cost for manufacturing a single prototype using the old methods was around a thousand dollars, which would still save a lot of money. However, due to the costs of the machines, there was no chance they could get into the hands of ordinary users – fortunately, this situation has changed.

Discovery of Stereolithography

3D printing, as we know it today, was discovered in 1984, when the founder of 3D Systems, Charles W. Hull, applied for a patent for his invention – stereolithography. Hull was the first to print digital 3D data. This technology, commonly abbreviated as SLA, is used to this day. You can learn more about it in the chapter describing various 3D printing methods.

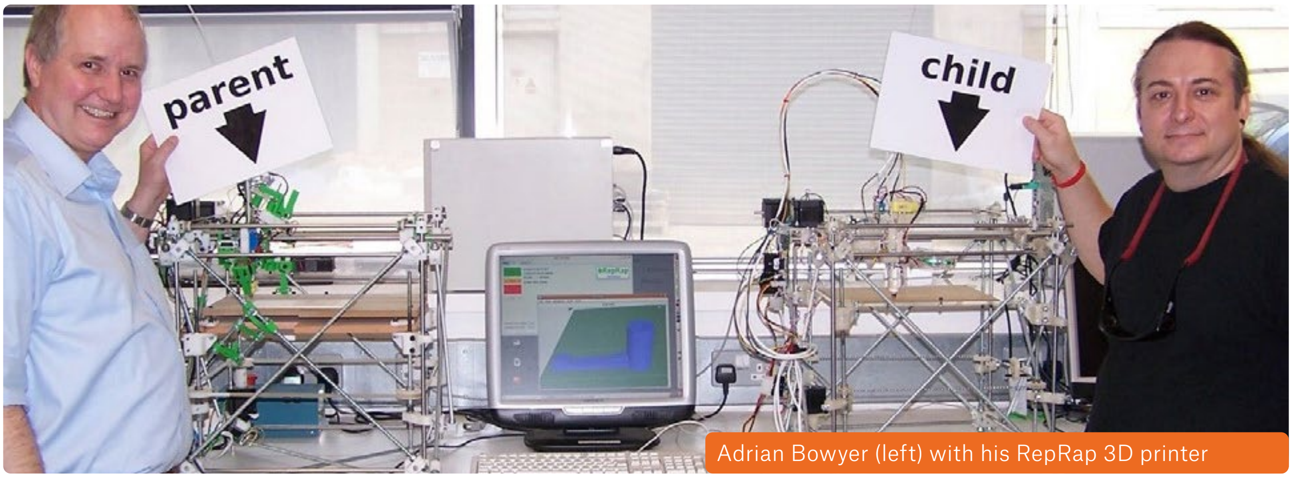
First commercial 3D printer

In 1992, 3D Systems began to produce and sell the first commercially available 3D printer based on the SLA technology.

The RepRap Project

2005 was probably the most important year in the history of modern 3D printing: the RepRap project was created by Dr. Adrian Bowyer at the University of Bath. The idea was to develop a 3D printer that is capable of printing as many of its own parts as possible. The project was conceived as open-source from the very beginning, which means that all source codes are available publicly for free and they are open to further modifications and improvements. This was an important decision that allowed enthusiasts from the whole world to take part in the project. And it's the main reason why the RepRap machines are currently the most widespread 3D printers in the world. Thanks to RepRap, we can now buy 3D printers for the DIY/maker and semi-professional markets – these are usually machines under 4,000 USD.

The community around RepRap printers is huge. If you want to understand how 3D printers work (or you want to try various upgrades, mods and experiments), RepRap is the perfect solution for you. These 3D printers can be purchased either as calibrated and fully assembled machines, or as DIY assembly kits, which are pretty fun to build – and actually less complicated than you might think.



Adrian Bowyer (left) with his RepRap 3D printer

The use of 3D printing

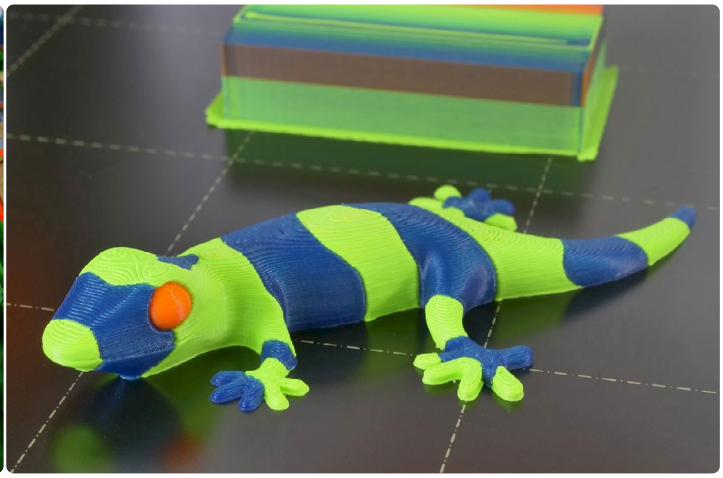
3D printing was, at first, used as a means for creating cheap and quick prototypes. As technologies became less expensive, 3D printers found their uses in other industries.

One such example is small-series productions. There are companies manufacturing low volumes of their products and the high costs related to high-volume production would not be justified in such cases. Therefore, 3D printing comes in as a more suitable solution. Another useful aspect is the fact that when you come up with an improved design, you can start producing it immediately, which means you can introduce new and improved products at a much faster rate than usual.

We have embraced this approach with the production of our Original Prusa i3 3D printers. Our in-house 3D printing farm now has over 700 printers. When there's a redesigned or improved part, all we need to do is to test it and then upload it to the printing farm system – the production can start pretty much immediately. Plus, we can also send the data to our customers, so they can print the parts themselves right away. The possibility of quick iterations is one of the biggest strengths of 3D printing.


Prusa Research print farm

Personalized production enables manufacturers to produce customized items based on customers' requests. This can be, for example, a smartphone case with an individual motif, a customizable keychain or various marketing items modified to suit the customer's needs.



A 3D printer is also great for producing **toys and figures**. You can find thousands of free or paid models on the internet, ranging from simple toys to meticulously crafted tabletop games.

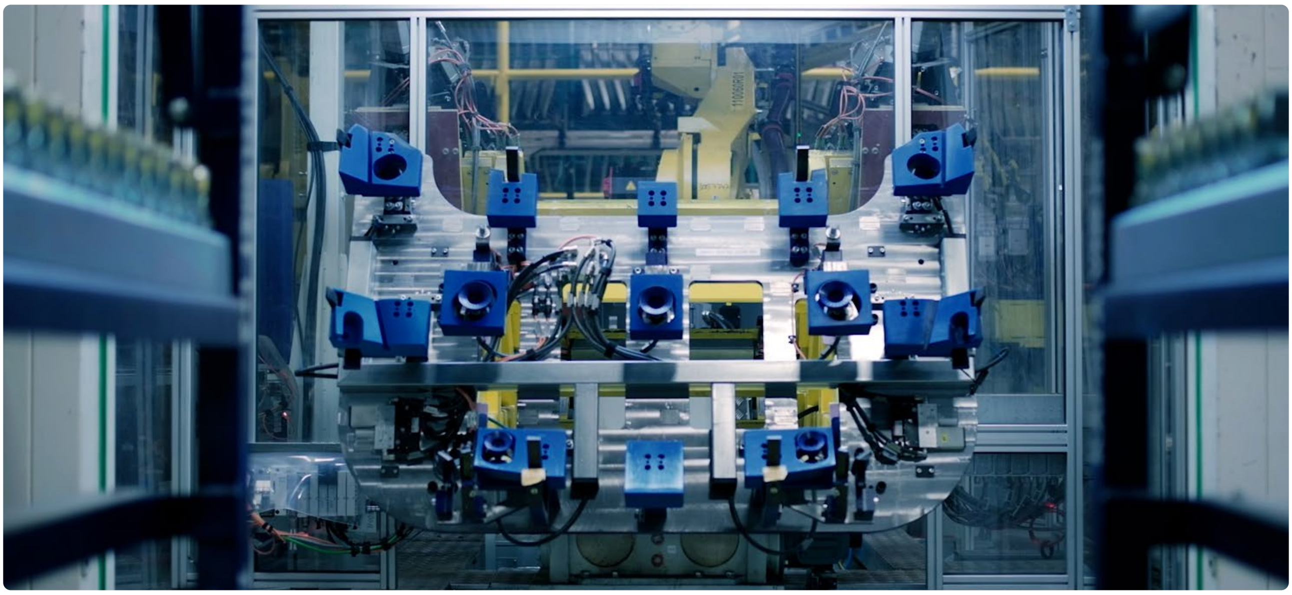
Cosplay* fans will find 3D printers especially useful, because they can be used to produce masks, equipment, accessories and other items that can be easily post-processed (sanded and painted) to give them an authentic look.

* Cosplay – portmanteau of the words 'costume play'. It's a performance art in which the participants (cosplayers) wear costumes to represent a specific character from books, films or video games

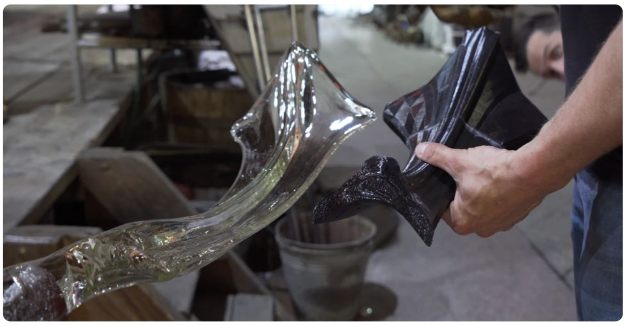


Another area where 3D printers really shine is the production of **spare parts** – either those that are no longer available through official channels or the ones provided directly by manufacturers. The number of printable parts officially available for home appliances is on the rise as the manufacturers support this trend. You can find many useful examples from various brands at printables.com/brands!

When we look for examples in the professional sphere, we'll find exciting use cases of 3D printing in various industries. Automotive companies use 3D printers for various **custom tools** for production lines to save costs and time. Some printed parts even last longer than the metal ones!



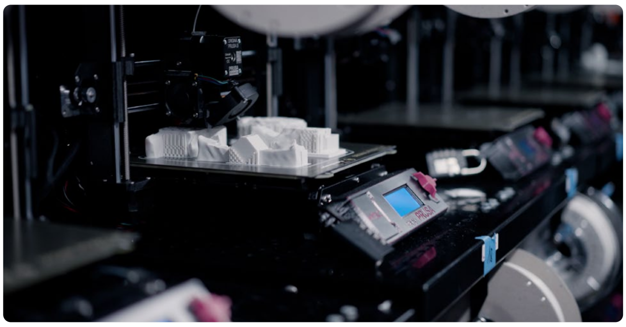
The fastest ultralight airplane, the **Shark**, has over one hundred 3D-printed parts under the hood!



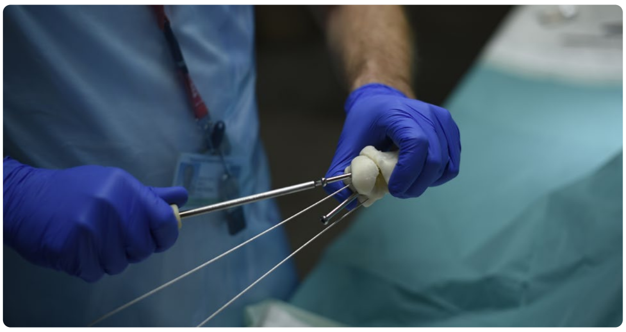
Designers use 3D printers for prototyping and fine-tuning their ideas before sending them to production.

Some of the greatest scientific minds work on the mysteries of the universe at **CERN**. And 3D printers help them make custom equipment and various tools.

3D printers are very popular among special effects artists in the movie industry. Various props, costumes, and models were created thanks to 3D printing.



3D printers are a huge thing in architecture and construction. One of the most important parts of architectural projects is model visualization. Also, 3D printing dramatically simplifies the creation of detailed concept models and client presentations. The world's most renowned universities even teach 3D printing for architects.



3D printing is quickly spreading into healthcare, finding various use cases in teaching future doctors the basics of anatomy or helping surgeons prepare for operations – all thanks to 1:1 3D printed models based on CT scans of the patient. Thanks to better preparation, the treatment takes less time and leads to better results, saving lives even!

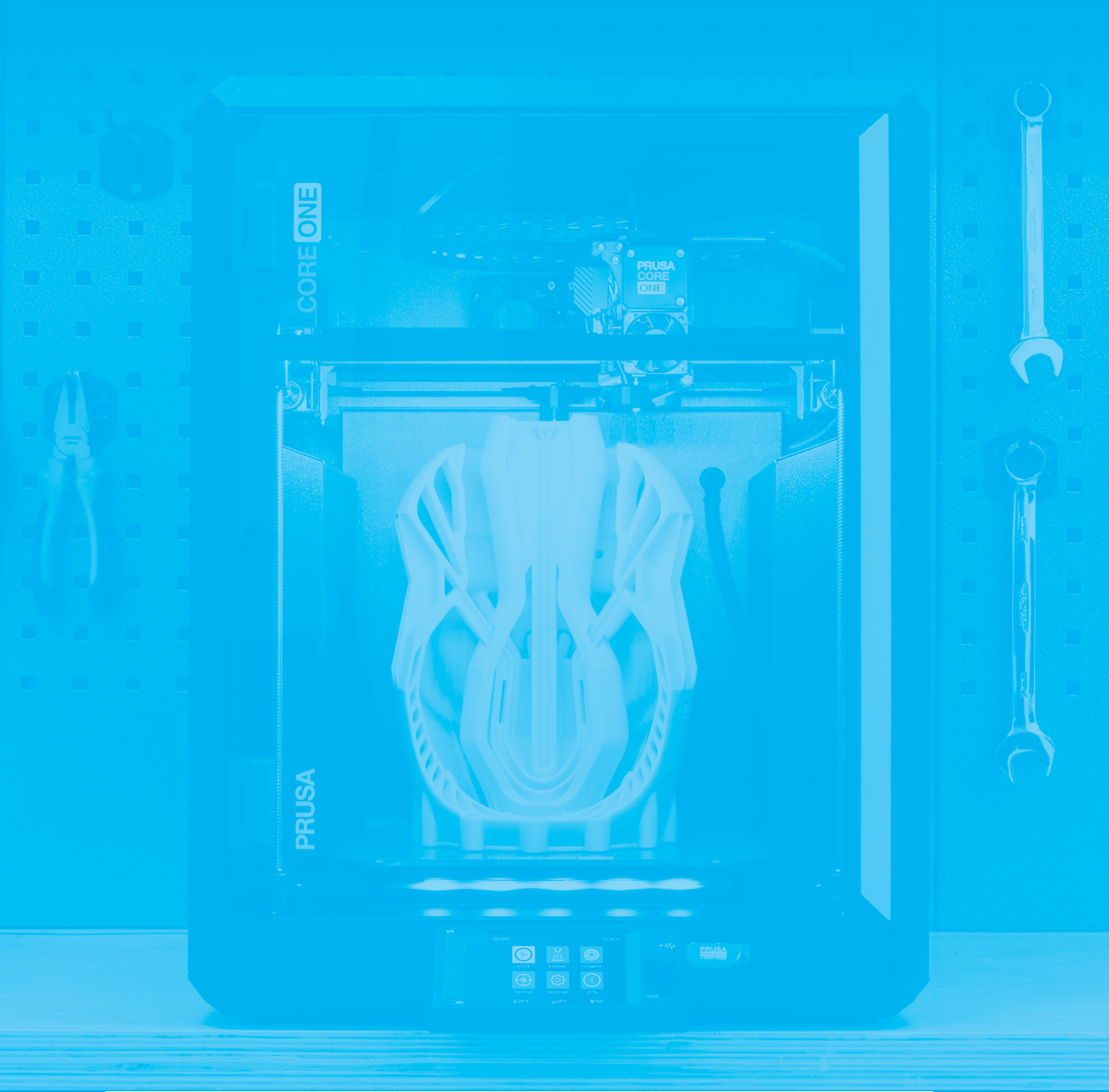
3D printing in education

As 3D printing becomes more popular and accessible, it's making its way into classrooms worldwide. Technology allows teachers to create custom educational tools – and students to develop creativity and practical thinking. With little effort, education can be much more than books and notes.

Students create various experiments and projects, learn to collaborate, and actively research information.

Join Prusa Education!

For all schools, universities, and other educational institutions, we offer the Prusa Education Program to help you get up to speed with 3D printing. Check education.prusa3d.com to find out what the program has to offer for you and your school.



3D PRINTING TECHNOLOGIES

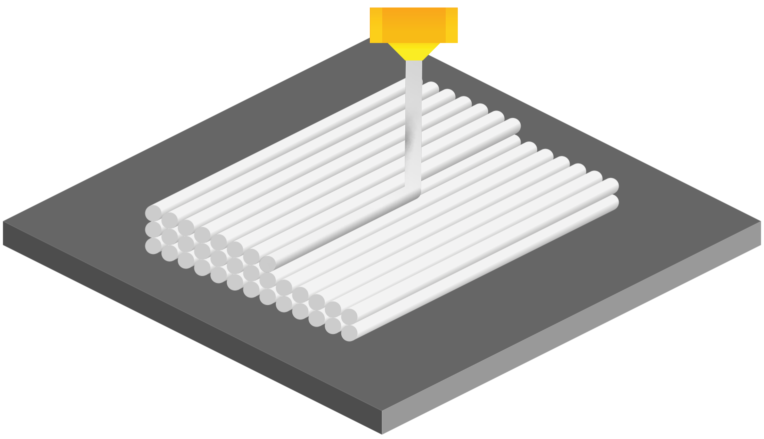
All types of 3D printing are based on the same principle: creating objects by adding layers on top of existing layers. As of this moment, there is no 3D printing technology that would be completely universal and suitable for every purpose. This is why it's important to decide how and for what purpose you are going to use the printer. To make things easier, let's divide 3D printer types into three main categories:

1. A strand of plastic melted by a heating element and extruded by a printing head (extruder) through a nozzle. This is a typical description of the FFF (Fused Filament Fabrication) / FDM (Fused Deposition Modelling) technologies. These terms can be considered to be synonyms. FDM is a trademark of Stratasys.
2. Liquid material solidified into layers in pre-defined areas. This is what we usually call SLA – Stereolithography Apparatus. The liquid material (resin) is cured by a ray of light (UV laser or LED panel, DLP projector).
3. Fine powder sintered (compacted and formed, not melted) by a laser. The technology is called SLS (Selective Laser Sintering) and compared to the previous two, it's much more expensive.

FDM/FFF

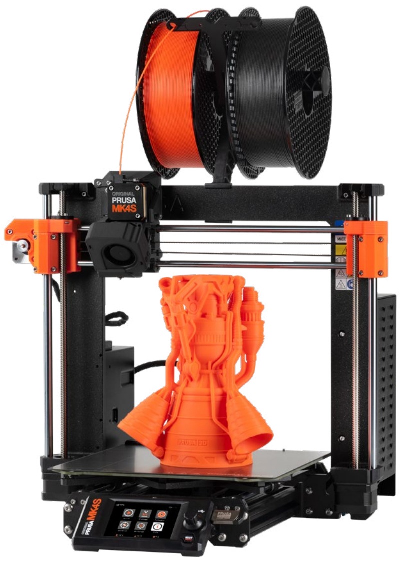
The most widespread and most affordable 3D printing technology, suitable for printing functional/ mechanical parts and prototypes. The printer uses strands of plastics as the main resource. The spool of plastic is called filament and it is usually available with a diameter of 1.75 mm. There are still some 3 mm filaments on the market, however, their printing accuracy is quite low, and using them is not recommended. Compared to liquid resins or powdered materials, filaments are safe and easy to work with. The downside is that the layers on the printed objects are visible to the naked eye. The usual layer height (when using a 0.4 mm nozzle) is between 0.05 to 0.3 mm.

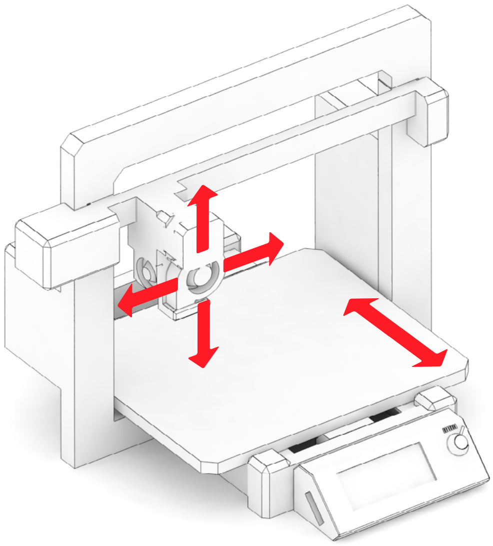
The price range of FFF 3D printers starts at around 150 USD for the cheapest models from China and it can go way beyond 100.000 USD for professional machines. The Original Prusa MK4S 3D printer starts at 729 USD / 819 EUR and it represents an ideal price/quality ratio.



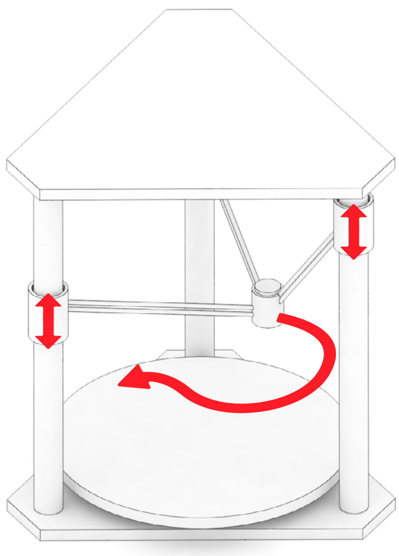
We can divide FDM / FFF 3D printers into sub-categories based on the movement of their axes in three-dimensional space.

1. **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 MK4S is a cartesian printer.





2. **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.



Delta 3D printers are popular in industrial applications for a number of reasons. They are capable of producing very tall objects with consistent quality because the heatbed is fixed in place. The extruder is lightweight which leads to reduced inertia and thus higher accuracy. Delta 3D printers by Prusa Research are also equipped with an actively-heated print chamber which makes working with advanced materials much easier.

3. **CoreXY 3D printers** are becoming increasingly popular. They use a cube-shaped design and incorporate a system of belts and pulleys with two stepper motors that move the extruder in the X and Y axes. The print bed is mounted on the Z-axis and moves up and down. This brings a number of benefits, such as higher printing speeds and good print quality because the bed doesn't move back and forth. Prusa Core ONE and Original Prusa XL are CoreXY 3D printers.

FFF 3D printers components

All FFF 3D printers are quite similar construction-wise. They usually consist of the following parts:

Extruder

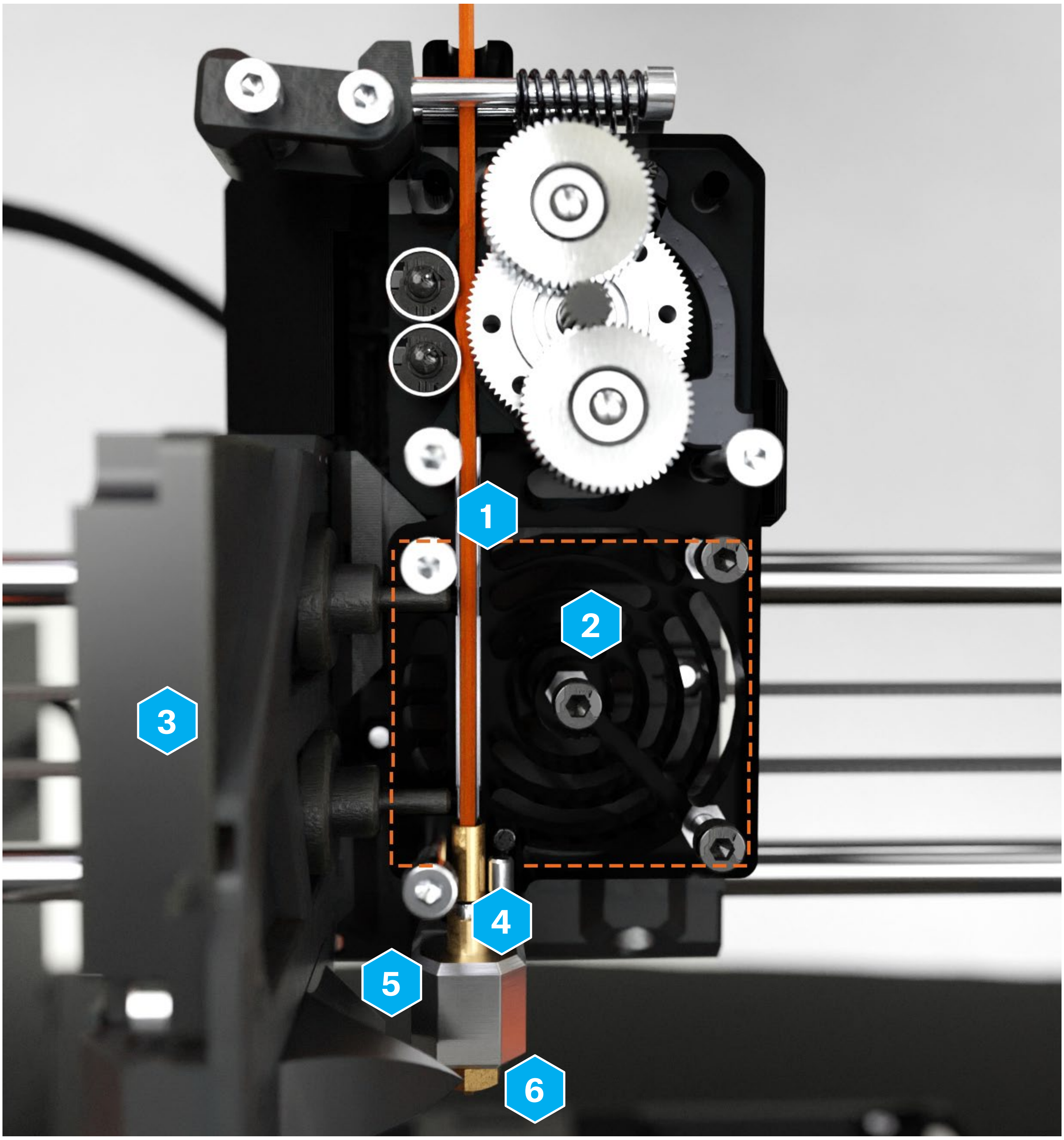
An extruder, or a print head, is designed to lay down printed layers by extruding melted plastic.

First, the filament enters the extruder – at this point, the filament is a solid plastic strand and is at room temperature. It goes through a heatsink which is a part designed to dissipate the heat coming from the heatbreak and minimize the transition area between solid and melted filament. Usually, the heatsink has a fan mounted on its side to increase the cooling efficiency. The heatbreak is essentially a piece of a tube with an outer thread that is narrower on one end to minimize the diameter as much as possible, so there's less heat rising up towards the area where the filament should remain solid.

The heater block is made of heat-conducting materials, usually aluminum, and contains a small electric heating element along with a thermistor for measuring the temperature. The material is melted in the heater block and it is pushed further and out through the nozzle. The nozzle can have different diameters and many printers allow the users to change the nozzle to a new one with a different diameter. Modern extruders are also packed with additional sensors and hardware with advanced features to make the experience more user-friendly. For example, the Original Prusa 3D printers equipped with Nextruder, use Loadcell technology to perform a fully automatic calibration and achieve an always perfect first layer. You can read more about nozzles with various diameters and their benefits in an article at prusa.io/nozzles.

Extruder

1 PTFE tube
2 Heatsink
3 Print fan
4 Heatbreak
5 Heater Block
6 Nozzle



Heated bed

A heated bed or heatbed is an important part of every modern 3D printer that should be compatible with as many materials as possible. The heated bed stops printed objects from bending, warping or detaching from the surface.

Frame

The frame is the supporting structure of the printer. Rigid and precisely manufactured frames have a positive impact on the printing quality. A robust and firm frame minimizes vibrations and allows for a faster print without noticeable quality issues on produced prints.

Stepper motors

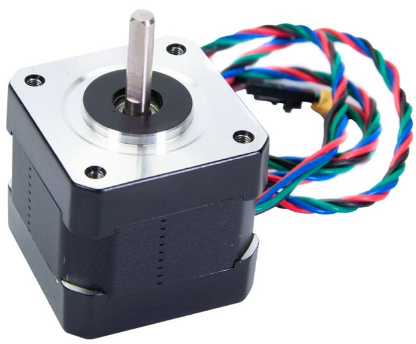
Stepper motors take care of movements in all axes – this includes the extruder and the heated bed, while another motor controls the movement of the filament string. The advantage of stepper motors is the fact that the steps can be precisely controlled.

Mainboard

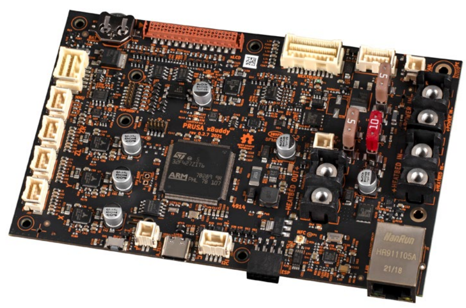
The mainboard is an electronic component with integrated circuits that controls the whole printer. Its primary function consists of reading instruction files (G-codes) and controlling the motors, heatbed and heater based on the instructions found within the G-code.

Heated bed

Frame



Stepper motors

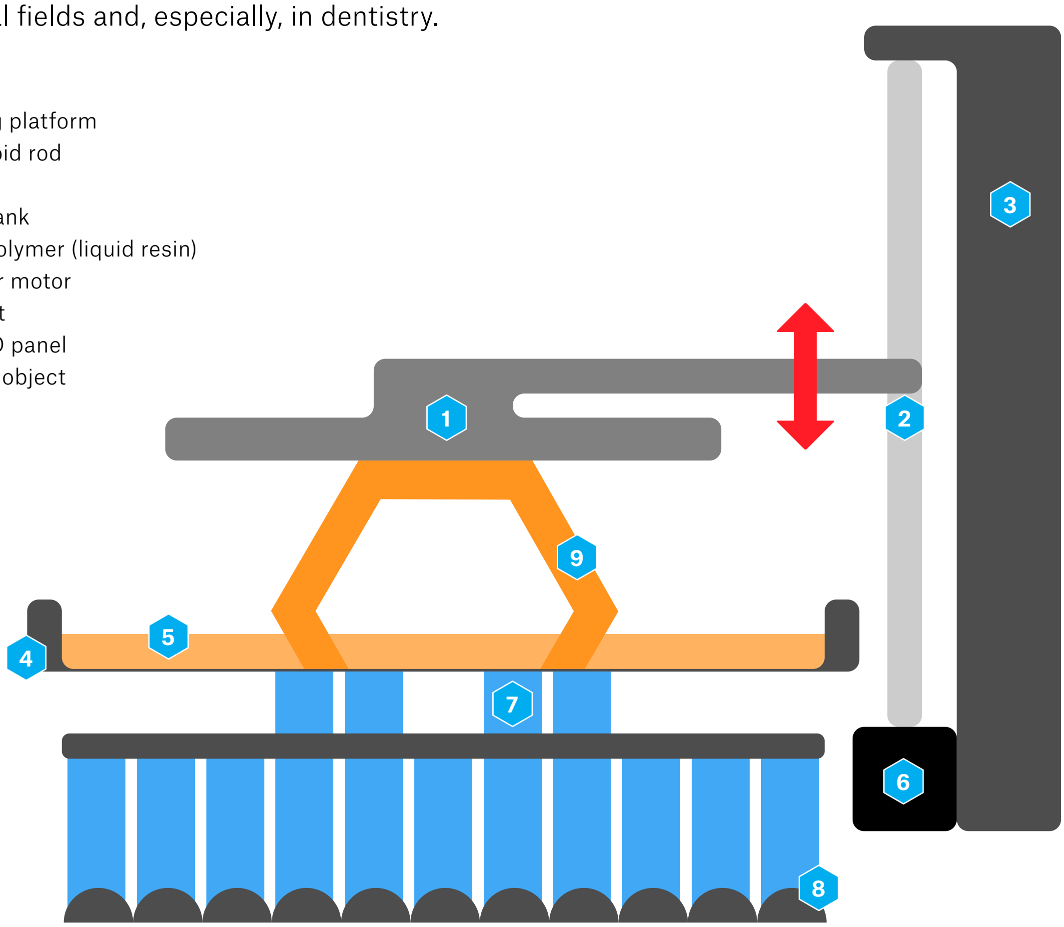


Mainboard

SLA (Stereolithography)

The SLA technology is based on curing (solidifying) photosensitive liquid resins by exposing them to UV light. SLA 3D printers are equipped with a platform that moves once a single layer is solidified to create space for a new layer that adheres to the previous one. The resin tank has a transparent bottom with an LCD panel mounted directly under it. The LCD displays a mask of a single layer while a source of UV light shines through the mask, exposing (and solidifying) resin in an exact shape. This leads to incredibly detailed and smooth 3D prints with layers nearly invisible to the human eye. SLA 3D printers are perfect for miniatures and prototypes, but they are also highly praised in various industrial fields and, especially, in dentistry.

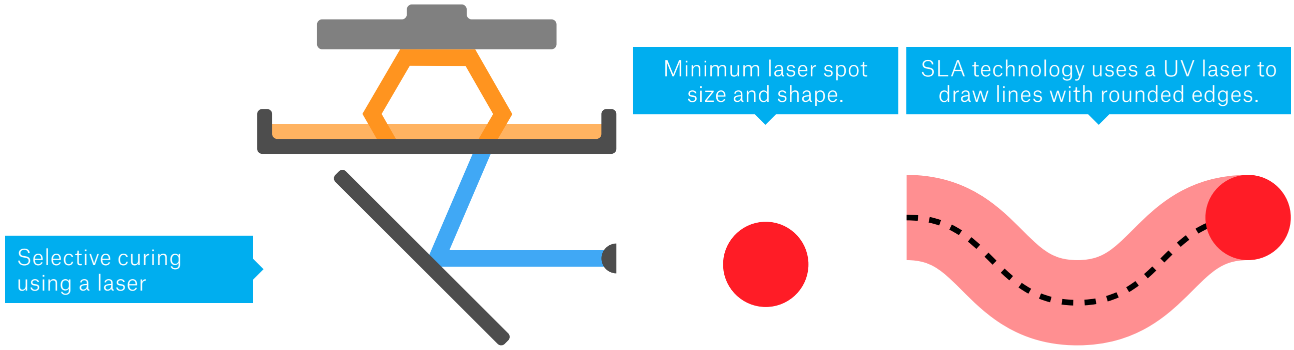
1 Printing platform
2 Trapezoid rod
3 Z-Axis
4 Resin tank
5 Photopolymer (liquid resin)
6 Stepper motor
7 UV light
8 UV LED panel
9 Printed object



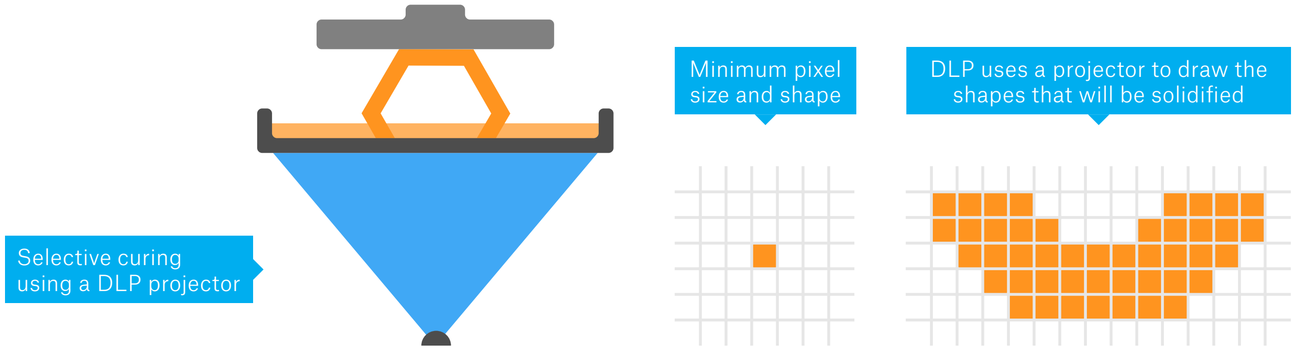
However, SLA machines are slightly more complex to use compared to their FFF/FDM counterparts. Resins are liquids and are often easy to spill, plus, it's important that they won't come into contact with your skin or eyes. Objects printed with the SLA technology tend to be wet and sticky because they are pulled from a tank filled with liquid resin. Usually, it is required to wash the objects in isopropyl alcohol and cure them using UV light. This, somewhat tedious process can be made substantially easier by using specialized equipment – we have developed the Curing and Washing Machine (CW1S) as an all-in-one accessory to our Original Prusa SL1S SPEED. The CW1S can preheat resin to working temperatures, and also wash, dry and cure resin-based 3D prints within a couple of minutes and with minimum effort.

There are three main types of SLA printers. They differ based on the exposure methods. Even though they may seem similar, the printing quality can differ greatly.

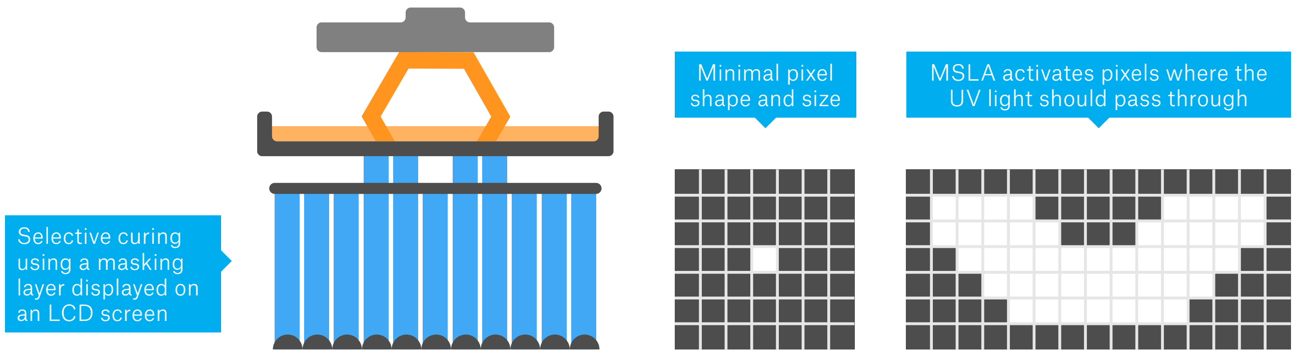
1. **SLA – Laser** – exposure is performed with a ray of UV laser. The ray is controlled by two mirrors and it "draws" each layer gradually. The time required to solidify a single layer depends on the size of the area which needs to be solidified. Simply put: the more objects there are on the print platform, the longer the print takes.



2. **SLA – DLP (Digital Light Processing)** – the whole layer is solidified at once because the digital projector inside the printer exposes the entire print area. The advantage of this method is obvious – each layer is solidified in the same amount of time, no matter how many objects there are on the print platform.



3. **MSLA (Masked Stereolithography)** – exposure of liquid resin is done by a high-performance UV LED panel and the layer shape is displayed on a high-resolution LCD. UV light can only pass through disabled pixels. Since LCDs have a fixed resolution, it also means that printed objects have a fixed XY resolution and the only aspect affecting their look is the layer height. MSLA printers also cure a whole layer at once, meaning it doesn't matter how many objects there are on the printing platform. The Original Prusa SL1S SPEED 3D printer adds a special tilting mechanism for increased reliability and speed.



The pictures above are a simplified representation of each of the technologies. The depictions of DLP and MSLA technologies are not taking into account such features as anti-aliasing. Without AA, the edges of the mask would be noticeably pixelated. In layman's terms, anti-aliasing can smooth out the sharp edges by averaging colour from nearby pixels. So in our case, there's in fact not just a black and white edge, but the anti-aliasing method actually creates a gradient transition, resulting in smoother lines.

MSLA printer components

The situation with SLA 3D printers is similar to FFF/FDM models – there are different designs, different configurations, depending on how the SLA 3D printer solidifies resins. We would like to focus on MSLA machines, since our own Original Prusa SL1S uses masked stereolithography.

UV LED panel

High-performance UV LED panels are used to solidify liquid resin in the resin tank. The SL1S SPEED uses a large panel instead of a single LED, so the distribution of UV light is more evenly distributed. This, combined with a high-quality lens array, leads to extremely low exposure times and faster printing.

LCD panel

Currently, the most desired LCD type for SLA printing is a monochrome display. It is used for “masking.” Basically, the UV LED panel shines light through the display into the tank with resin. Without a mask, the resulting object would be a solid block. This is why the LCD panel displays a mask (a picture of a single layer) by turning individual pixels on or off. Disabled pixels allow UV light to pass through, and enabled (black) pixels block the light. The resolution of the display affects the quality of the print.

Touch screen

This is the printer’s second LCD screen, however, this one is not used for the printing itself. Instead, the user can easily configure and control the printer using an easy-to-use interface.

Tank (vat) and tilt

The tank, sometimes called a vat, is the container for liquid resin. It has a transparent bottom which allows UV light to pass through. The Original Prusa SL1S SPEED 3D printer even has a special tank tilting mechanism for faster printing and increased print quality. How does it work? After each layer is cured (solidified), it needs to adhere to the rest of the printed object, but it also has a tendency to stick to the bottom of the tank. Most 3D printers use a simple upward motion and try to detach the layer from the bottom with a vertical motion. The tilting mechanism enables a much more gentle “peeling” motion, so the layer is separated gradually. It is also much faster compared to regular vertical motion.

Z-axis tower

The only mechanical movement of the printing platform is in the Z-axis (up and down). Thanks to the masking LCD screen with fixed X-Y resolution, no other movements are necessary.

Acrylic lid

The SL1S features a semi-transparent orange-tinted acrylic lid. It blocks a large portion of UV light coming from the outside (e.g. sunlight), which would otherwise cure the resin in the tank. It also blocks the UV light emitted by the UV LED from leaking out of the printer.

Air filtration

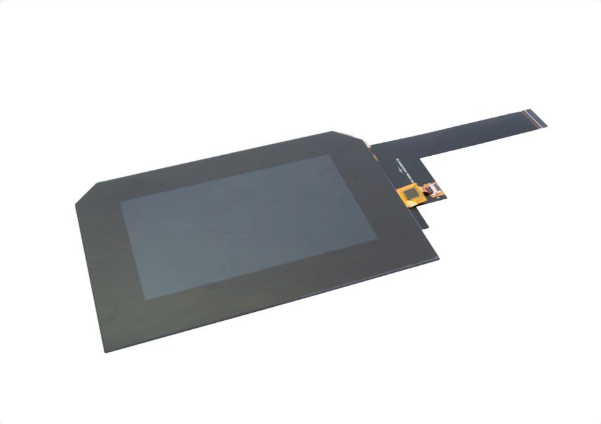
Most of commercially available resins produce prominent odors. This is why the SL1S has a built-in filter.

Solid aluminum frame

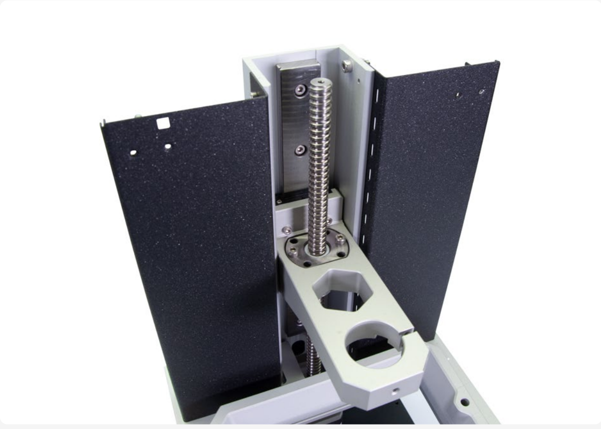
The frame ensures that the machine is solid and stable. Softer frames are prone to warping or oscillation, which results in poor print quality.


UV LED panel


LCD screen


Touch screen


Tank (Vat)


Z-axis tower


Acrylic lid


Air filtration


Solid aluminum frame

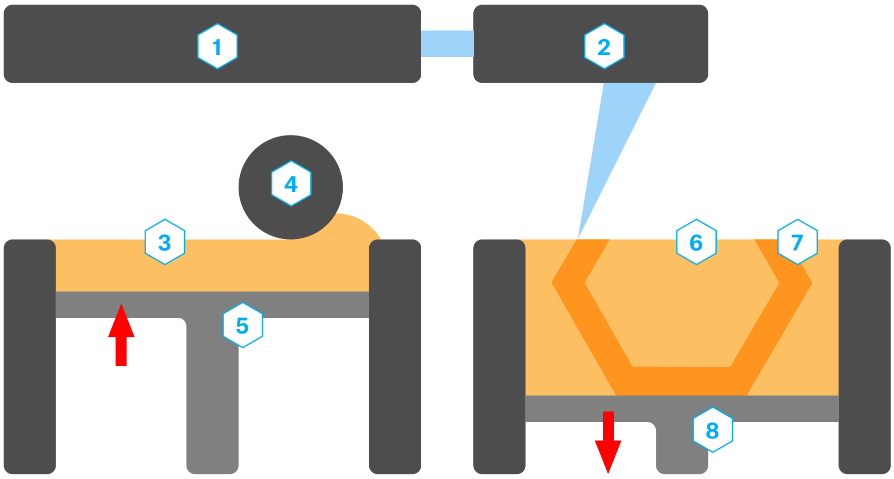
SLA 3D printers are, generally, more expensive than FFF machines. The cheapest useable SLA 3D printers start at around 250 USD, professional machines are well over a hundred thousand dollars. The Original Prusa SL1S SPEED starts at 1,979 EUR / 1,999 USD. Also, when choosing an SLA 3D printer, it's recommended to choose a model that is compatible with 3rd-party resins, so you are not locked to a single manufacturer.

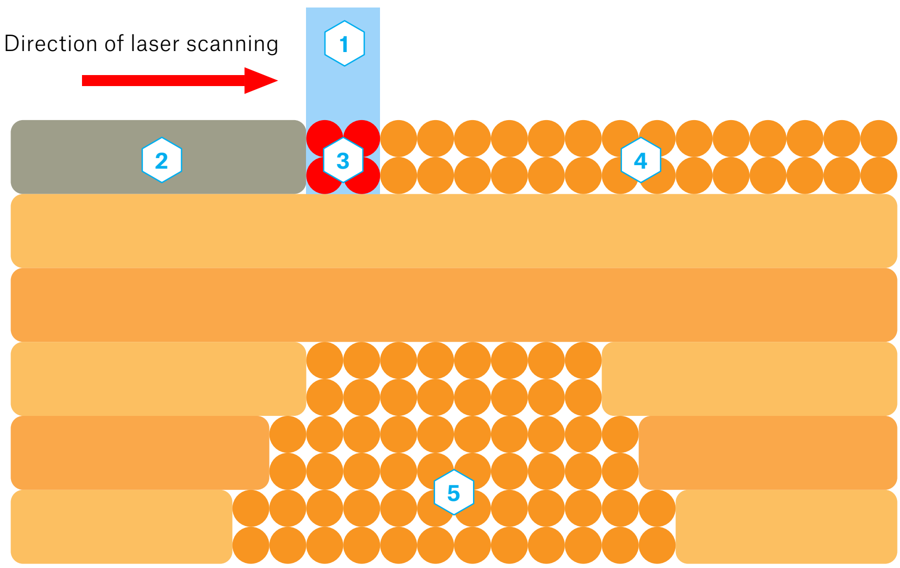
SLS / DMLS

Another type of 3D printing technologies are SLS and DMLS, which use a process called sintering. Essentially, every time a new layer is printed, a cylinder spreads a thin layer of fine powder across the platform, which is then sintered with a laser into the required shape. When the print finishes, the whole object is covered with the printing powder. Due to how this method works, the printed objects must have holes, through which the excessive powder is poured out. Unsintered material can be reused for next prints, which means that very little material is wasted. Another advantage is the fact that the layers are nearly invisible.

These printers are not massively widespread among the common public. Due to their main use in various industries, the prices are noticeably higher – the cheapest machines start at around 6,000 USD.

1 Laser
2 Scanning system
3 Powder container
4 Cylinder
5 Powder loading mechanism
6 Powder bed
7 Printed object
8 Motorized platform





1 Laser beam
2 Sintered powder particle
3 Laser sintering
4 Powder bed
5 Unsintered material in previous layers

CHOOSING A 3D PRINTER

Once you start choosing a 3D printer, it's always important to decide how and for what purpose it is going to be used. Maybe you were expecting a long list of printers sorted from the best to the worst – but that's pretty much impossible to do without oversimplifying things to extremes. Instead, we would like to present you with a set of questions you should ask yourself before buying a 3D printer. Answering these will help you select the right machine for your purposes.

What price range are you aiming for? Expensive professional printers or cheap Chinese products?

The price reflects the quality of the build and the lifespan of the printer along with other nice-to-have features. Some cheaper printers often come with a long list of required user modifications that are recommended to carry out before you even start using the machine. If you're looking for something that works right out of the box, you may need to adjust your preferences.

What is the customer support for the printer? Is there an active community, which could potentially help me in case I run into trouble? Is the printer open-source? What about spare parts and upgrades?

Community support is a key factor when choosing a 3D printer. Like smartphones, where active communities extend device life through updates, open-source 3D printers benefit from engaged users who develop upgrades and spare parts, enhancing longevity.

What are the running costs?

Certain manufacturers only allow use of their own branded materials and spare parts. This increases the running costs and also limits the range of supported materials.

Does speed matter?

When choosing a 3D printer, you can get easily lost in incredible numbers describing various speeds and information. Although the numbers might look decisive, most data is theoretical. In reality, the printhead has to make various stops, turns, and moves, never reaching the proclaimed tens of thousands of mm/s. The thermal properties of your printing material and model shape are also limiting. With ultra-high printing speed, your layers might not stick together, and you'll have a failed print. Instead of proclaimed speed numbers, you should focus more on reliability and the community around the printer.

How large printing surface do you really need?

It may look like it's better to have a huge printing surface, however, in most cases it's just a huge money waster. Objects made from PLA can't be usually larger than 20 cm in one axis, due to thermal expansion, which causes larger objects to warp and detach from the print surface. Don't forget that you can always cut the model into multiple pieces and glue them together.

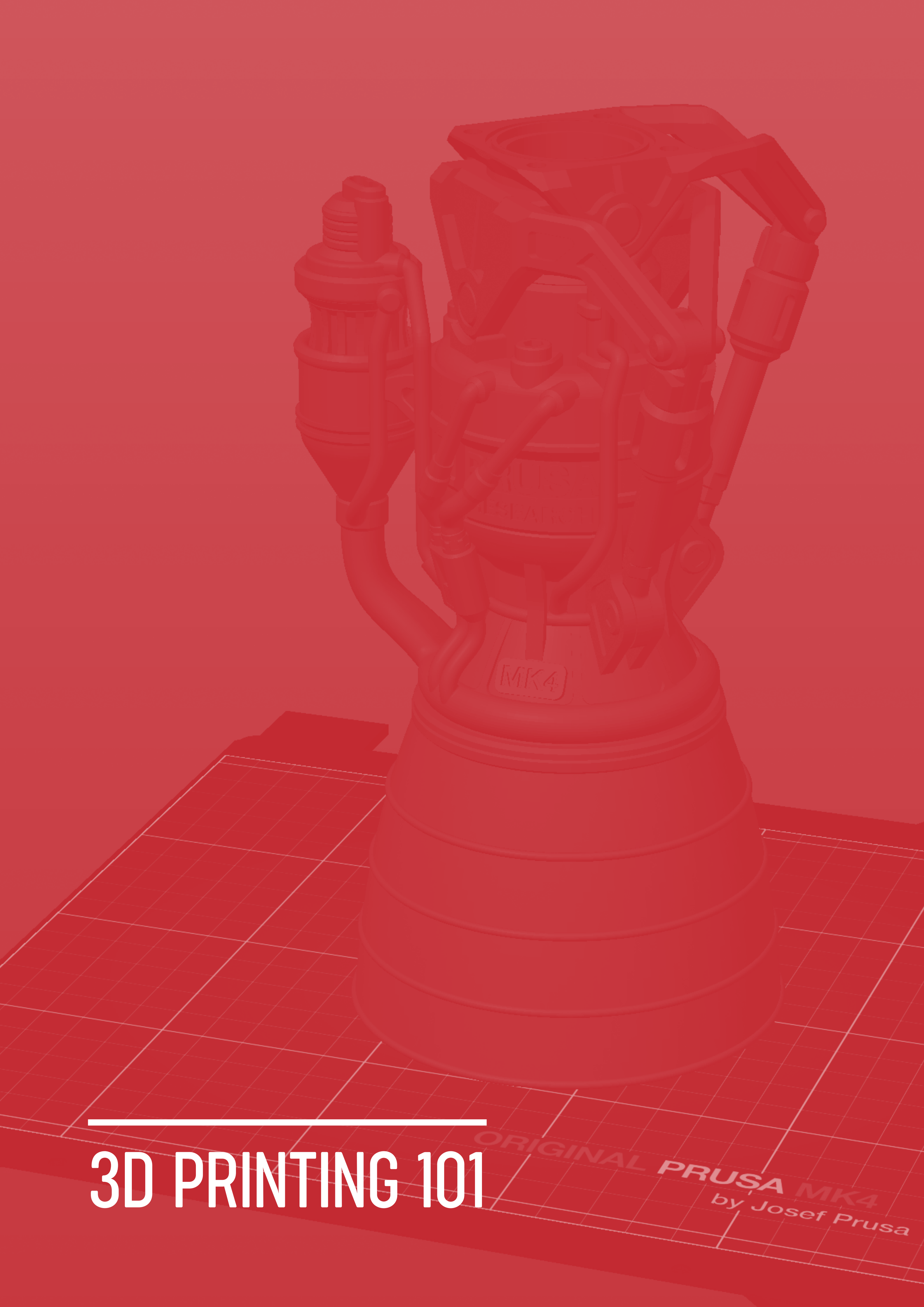
How detailed prints do you need?

The quality and the level of detail of objects printed on an FFF printer can be affected by using a nozzle with a different diameter and by selecting the right materials, speed and temperatures. Although, it's true that the level of detail on FFF printers is lower than on SLA printers.

Is a single-material printer good enough, or do you need a multi-material (or even a full-colored) 3D printer?

You will find out more about multi-colour printing in the next chapter.

We have covered the topic of choosing a 3D printer extensively at prusa3d.com. Navigate to 3D printers – How to choose a 3D printer and take a deep dive into the world of 3D printing!



3D PRINTING 101

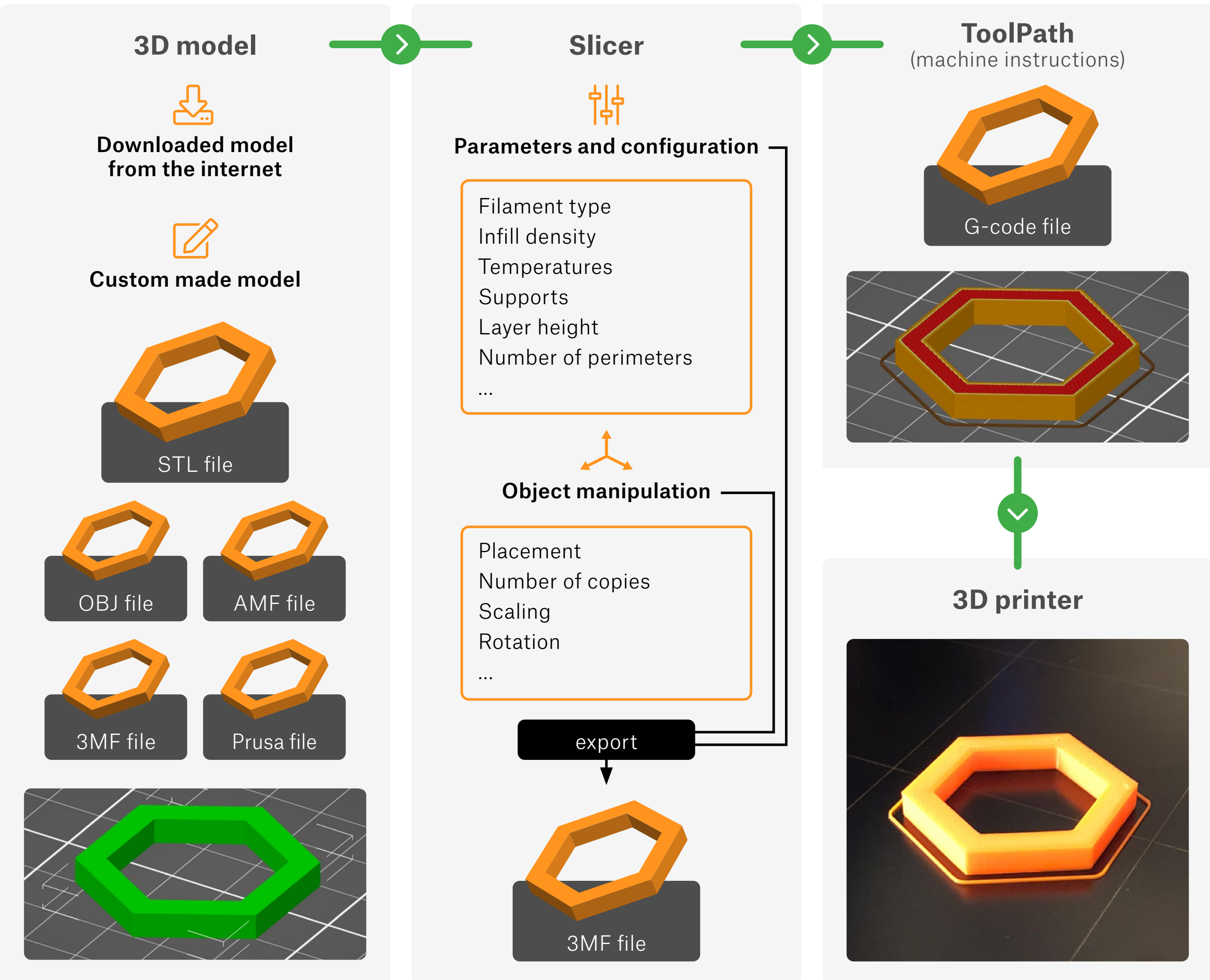
CHECK OUT THE PRUSA ACADEMY COURSE!

This part is but a short summary of the topic. To fully dive into making your own models, we recommend you check out the course Design Principles for 3D Printed Parts in the Academy section at prusa3d.com.

The 3D printing process consists of three main steps. First, you need to obtain a printable 3D model. Then, you should prepare it for printing, and the last step is the printing job itself. Let's take a look at everything from a general perspective. Then, we'll go more into detail.

The first step is to obtain a 3D object, which is typically an STL file. However, this format is not recognized by 3D printers and it is not directly printable. To process an STL file, you need to use a specialized tool, commonly known as 'slicer'. There are different slicers on the market, some are free (PrusaSlicer), others are paid (Simplify3D) and they are usually compatible with a limited range of printers, so you need to choose the right one for your machine. You can import an STL file into the slicer of your choice, configure printing parameters and then export the final result as a 'G-code', which is basically the original 3D object sliced into thin layers and converted into a set of movement commands recognized by 3D printers. Furthermore, slicers insert additional information into G-codes, such as temperature information, cooling settings and others. The resulting G-code is printer-specific, so that's why 3D objects are usually shared as STL files – users can then slice them for their printer / filament individually.

The diagram below depicts the individual steps leading towards a successful 3D print.



Getting a 3D model

Generally speaking, a 3D model can be obtained through one of the following ways:

1. **Downloading a 3D model from the internet**
2. **Creating your own models**
3. **3D scanning a real-world object**

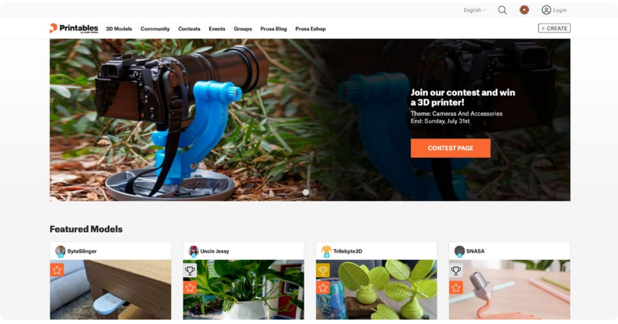
Online libraries and 3D hubs

The easiest way how to get started with 3D printing is to find 3D objects available on the internet for free. They usually come in .stl or .obj file formats. There are several websites that offer a wide range of downloadable models that offer a wide range of downloadable models – the best ones are listed below.

Printables

Free and paid models

www.printables.com

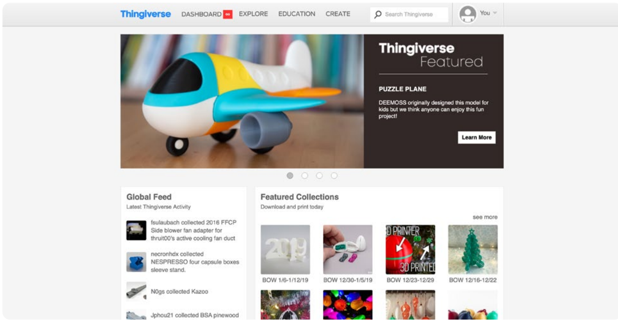


The ultimate online library of models for all 3D printer owners, under continuous development. With features like Community Feed, 3D objects preview, achievements, physical rewards, and community contests, Printables can satisfy all your 3D printing needs!

Thingiverse

Free models

www.thingiverse.com

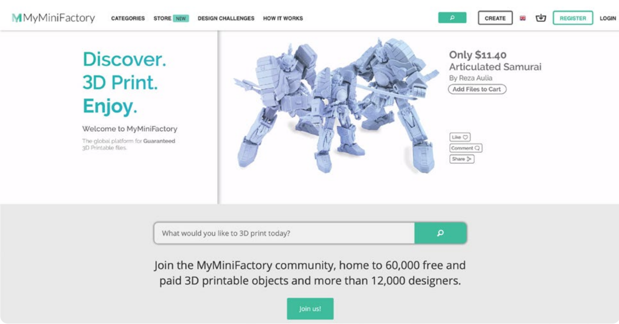


Thingiverse is a popular online library with a large collection of printable models split into a number of different categories, such as Hobby, Learning, Toys and Games and more. New models are being added every day.

MyMiniFactory

Free and paid models

www.myminifactory.com

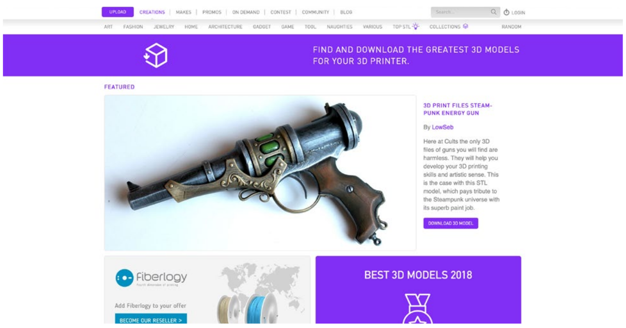


A popular repository with curated 3D printable objects by professional designers. All models are tested before publishing, so you can be sure you're getting quality STLs. The price of paid models is usually between 4 to 40 USD.

Cults

Free and paid models

www.cults3d.com



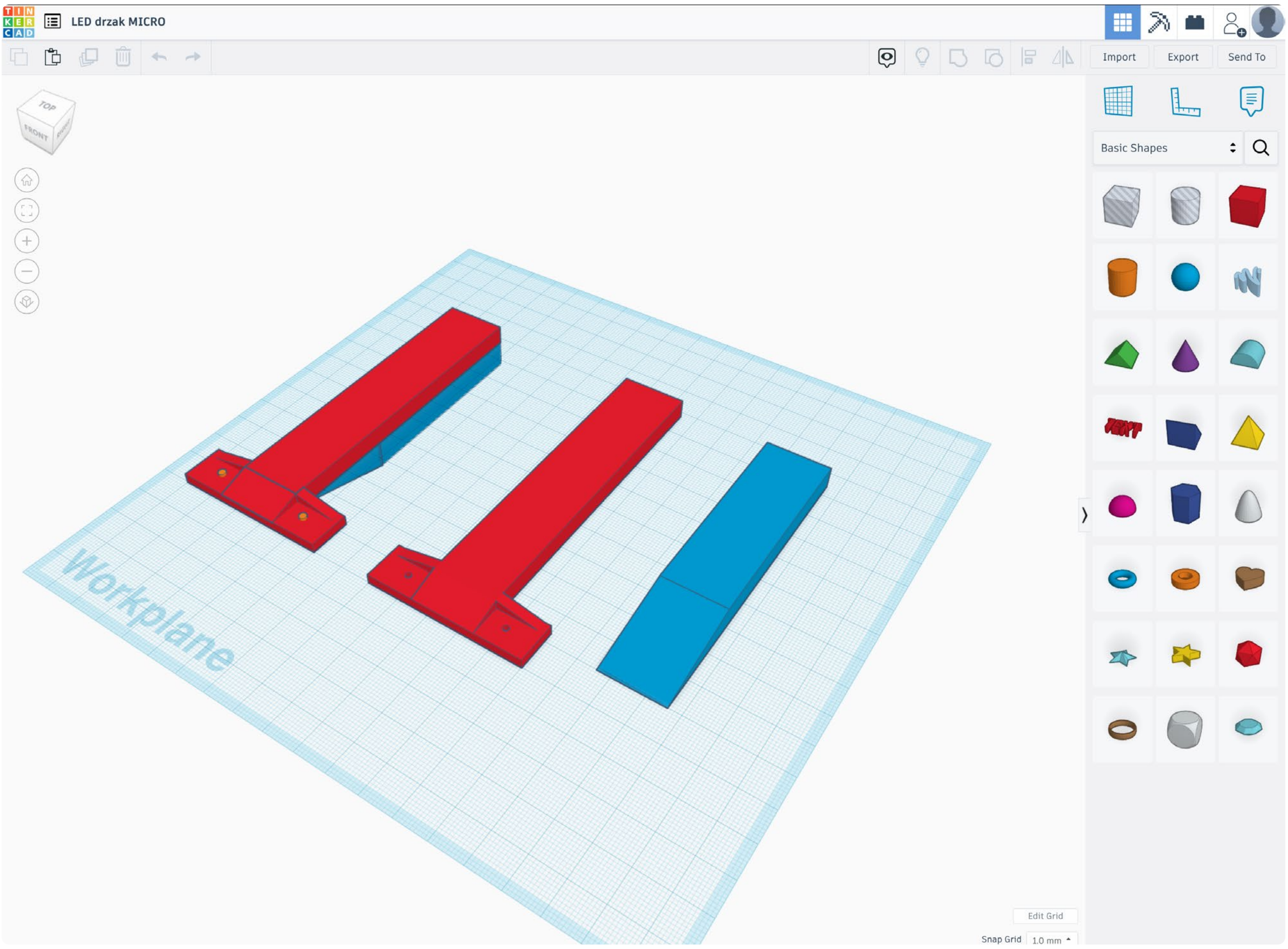
A 3D models file marketplace where makers can share for free or sell their STL files. An interesting difference between this site and the rest are various collections based around popular brands, such as Lego, IKEA or GoPro.

3D modeling software

Nowadays, you can pick from a wide range of various 3D modeling applications. There are simple and easy-to-learn (and often web-based) applications such as Tinkercad. You can try parametric modeling with OpenSCAD, or use a fully professional tool such as the popular Autodesk Fusion. All these applications enable you to create a model and export it as an STL file.

Tinkercad

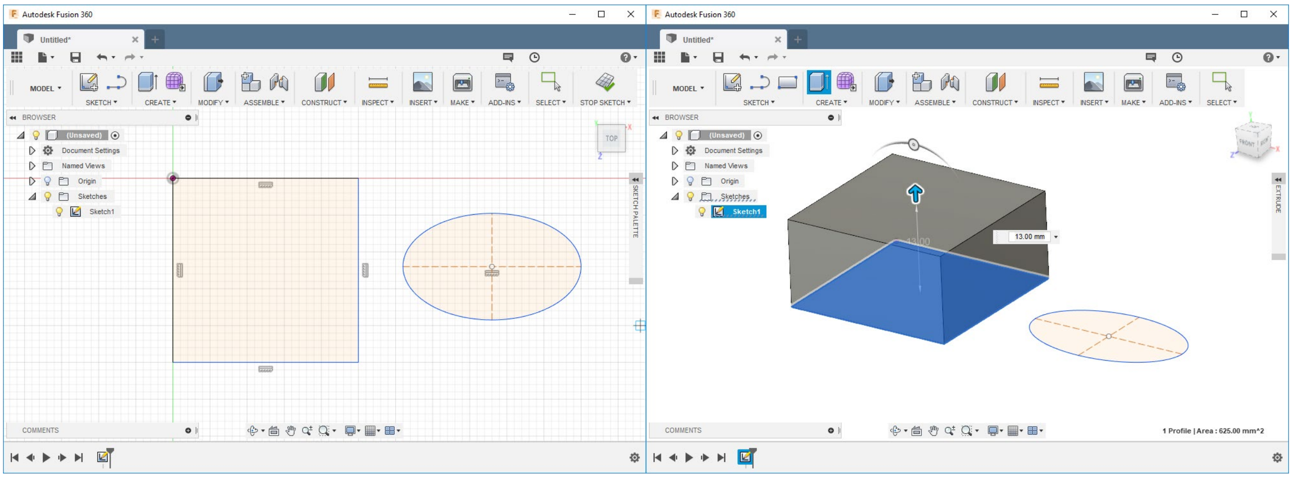
Tinkercad is a great and intuitive tool for beginners. It's free, although a registration is required. You can find plenty of tutorials, guides and tips online. Tinkercad is built around the idea of a basic library with various shapes, which can be dragged into the main window and further modified. The application lacks advanced functions, however, it can import and edit an existing STL file. Tinkercad is available at www.tinkercad.com.



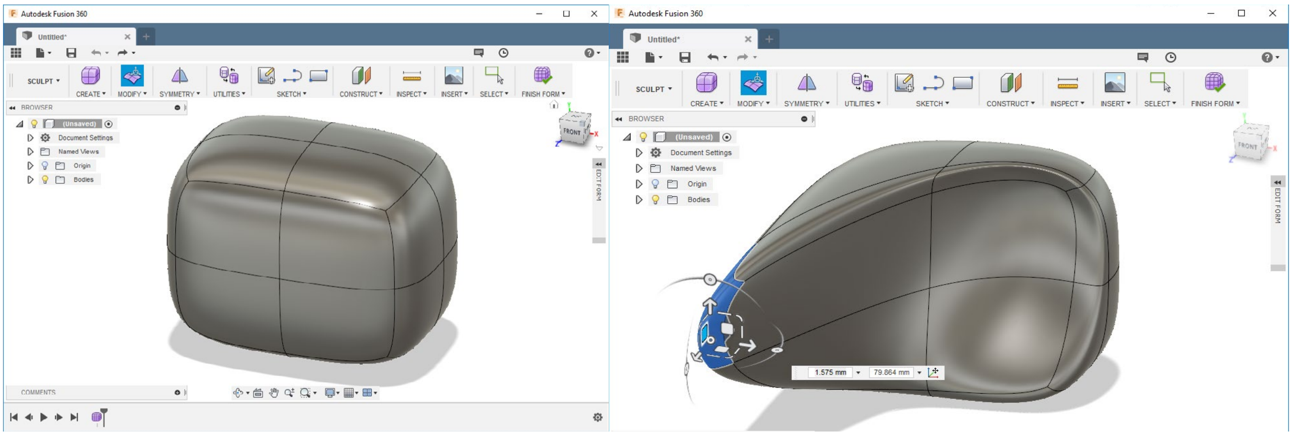
Autodesk Fusion

If you want to start designing more complex objects, or even various components that should fit together, then you need to select a more professional tool. Fusion is a popular option. Users can work in both CAD (Computer-aided Design) and CAM (Computer-aided Manufacturing), strength analysis and visualizations. Autodesk Fusion offers not only parametric modeling but even sculpting as well. We have an extensive course on modeling with Autodesk Fusion in Prusa Academy available at prusa3d.com, so let's take a look at these two methods just briefly.

Parametric modeling is a common way of creating structural models or mechanical parts. The object starts as a 2D shape using basic primitives (such as a line, square, rectangle, point...). Next, the object is extruded, which turns it into a 3D shape.



Now, imagine that we want to create a model of a dog. Using parametric modeling is inefficient and too complicated, because we want to create an organic shape. This is where sculpting steps in. Digital sculpting is somewhat similar to real-world sculpting (e.g. using a sculpey or similar material), however, it has many advantages – such as the undo function. The primitive objects in this case are already 3D objects – cube, sphere, cylinder, toroid and others. These objects can be freely extruded, squished, bent... See the pictures below.

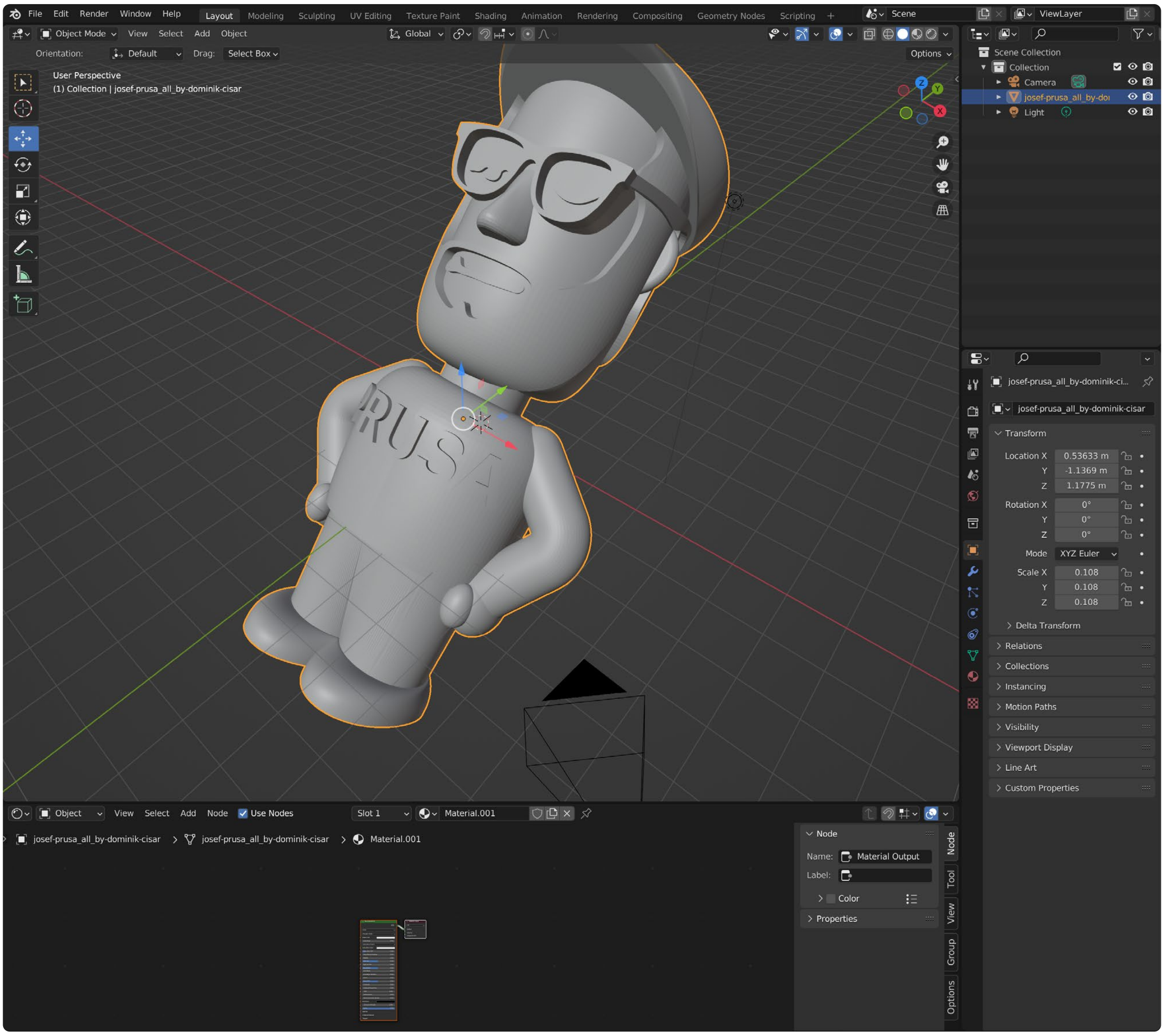


CHECK OUT THE PRUSA ACADEMY COURSE!

If you're interested in making your own models using Autodesk Fusion, we recommend you check out the course 3D Modeling in Fusion in the Academy section at prusa3d.com.

Blender

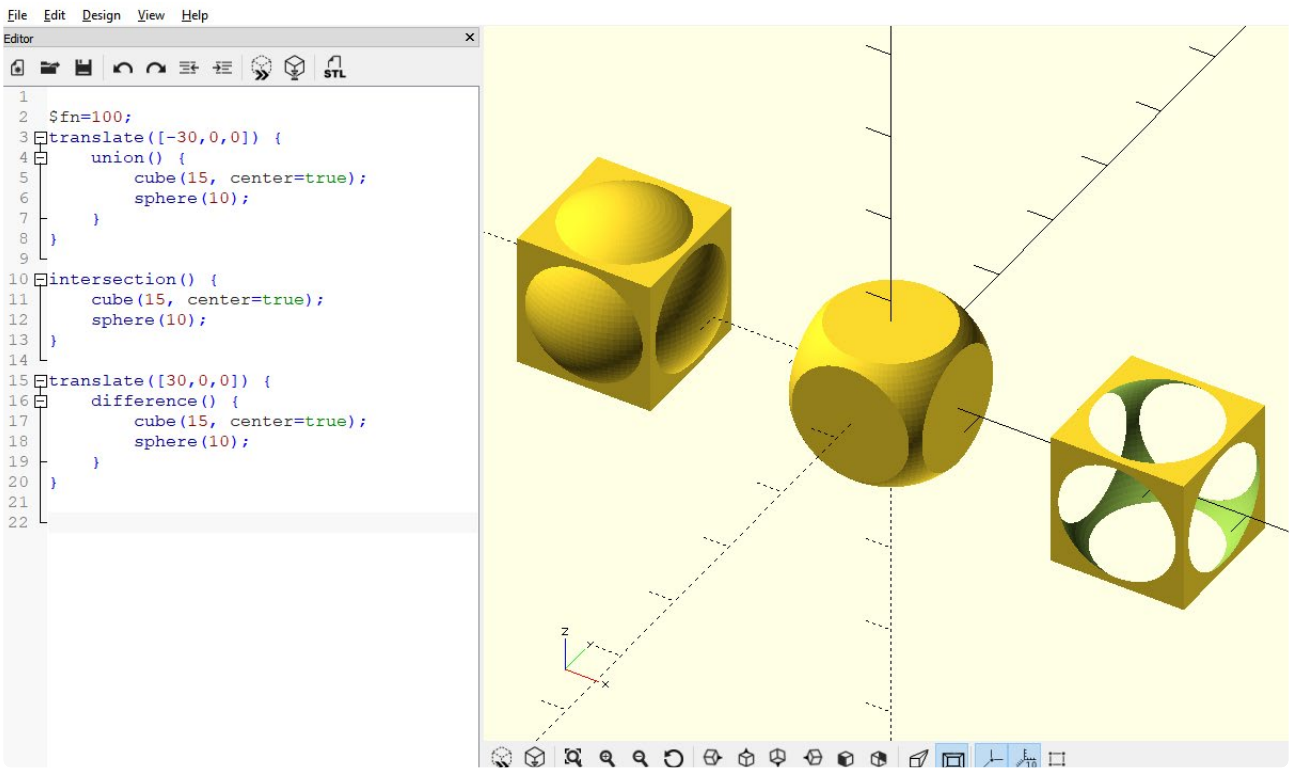
Blender is probably the best free 3D modeling tool available today. It's developed under an open-source license and it's available for Windows, Mac and Linux. It may be a bit too complex for a beginner, chaotic even. However, it has found its way into the hearts of many users. Especially users with artistic ambitions, who don't need precise parametric modeling, found Blender to be an amazing tool. Sculpting, texturing, animations... Blender is a Swiss army knife among 3D modeling applications.



OpenSCAD

OpenSCAD is an open-source project available for free from www.openscad.org. It takes a completely different approach to 3D modeling – everything is done by writing code. The user interface is divided into two parts. In the left section, the user defines 3D objects by 'programming' them, while in the right section, a 3D preview is displayed. The application works mostly with a couple of primitives (cube, cylinder, sphere,...) and basic boolean operations (join, cut, intersection). However, the program also allows for advanced scripting – you can use commonly known operators, such as if, while, for, logical operators and others. If you feel you are more of a programmer than an artist, you may give OpenSCAD a go.

How to start with creating models in OpenSCAD is described in detail at: prusa.io/openscad.



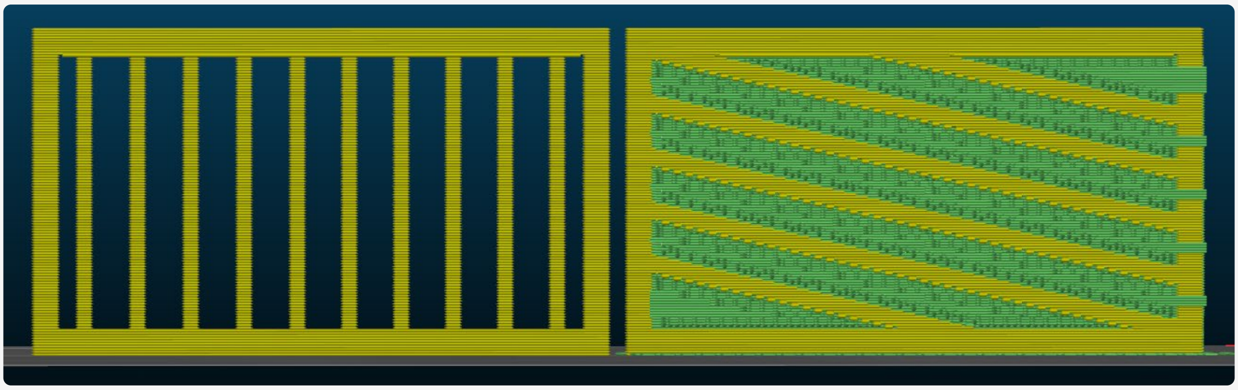
You can also try the following applications:

Microsoft 3D Builder
Meshmixer
Rhinoceros 3D
FreeCAD
Autodesk Inventor
SolidWorks
Autodesk AutoCAD
SketchUp

Things to keep in mind when designing a model

1. Try to minimize the need for supports. 3D printers can't start printing mid-air, and massive overhangs require supports as well. To save time, material and improve the quality of the object's surface, try to design the object in a way that will minimize the need for supports.
Let's take a look at an example – you need to design a part of a fence and it's up to you how the pickets will look. In the pictures below, you can see two ways how to design the fence if we want to print it in a vertical position. The best solution here will be to print the part horizontally.

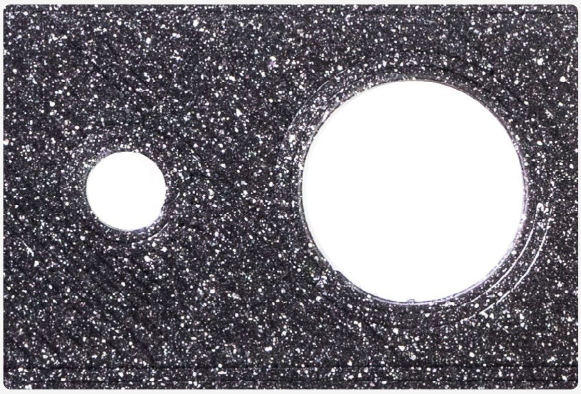
Model preview in PrusaSlicer – support structures are marked green, while the object itself is yellow.



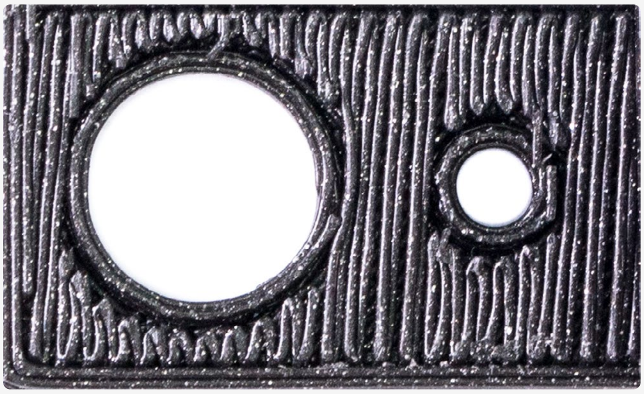
It's possible to print this model without supports.

Supports are required to print this model successfully. However, removing them will be difficult and the surface of the model won't be perfectly smooth.

2. Decide how the model will be positioned on the print bed. Surfaces placed on top of supports won't be as smooth as surfaces placed directly on the print bed.



Surface printed directly on the print bed is perfectly flat and smooth.



Surface printed above supports. The surface is inconsistent and rough. This is the worst case scenario for demonstration purposes. Surfaces with a lower overhang angle look much better even with supports.

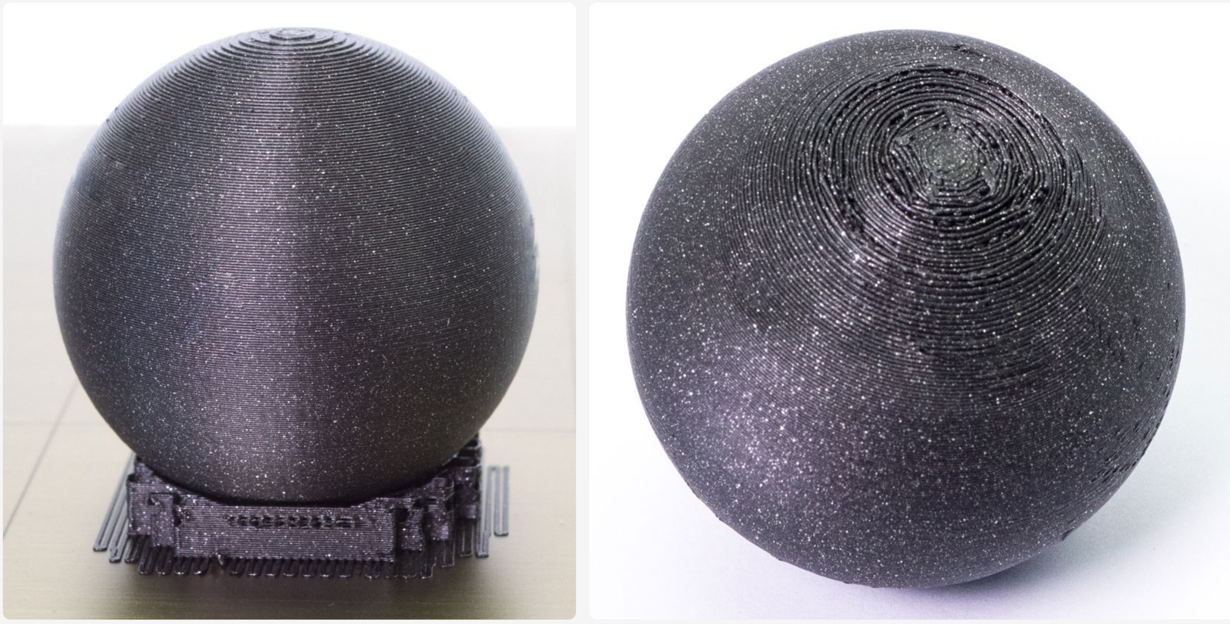
CHECK OUT THE PRUSA ACADEMY COURSE!

There's so much more to learn and discover. To fully dive into making your own models, we recommend you check out the course Design Principles for 3D Printed Parts in the Academy section at prusa3d.com.

3. The print has lower strength in the direction parallel to the printed layers than in direction perpendicular to the printed layers. If you expect that the printed part will have to withstand certain forces, keep this fact in mind.

4. Consider splitting the model into multiple parts, then find the optimal positions for these parts on the print bed. Let's take a simple sphere as an example. Printing it as a single part is quite difficult, because the initial layer that touches the print bed is very small. You can add a brim and supports to remedy this issue. However, the surface quality will suffer (see below). A possible solution is to cut the sphere into two parts. Print them separately and then glue them together.

Printing a sphere as a single object. The layers at the bottom of the object are affected.



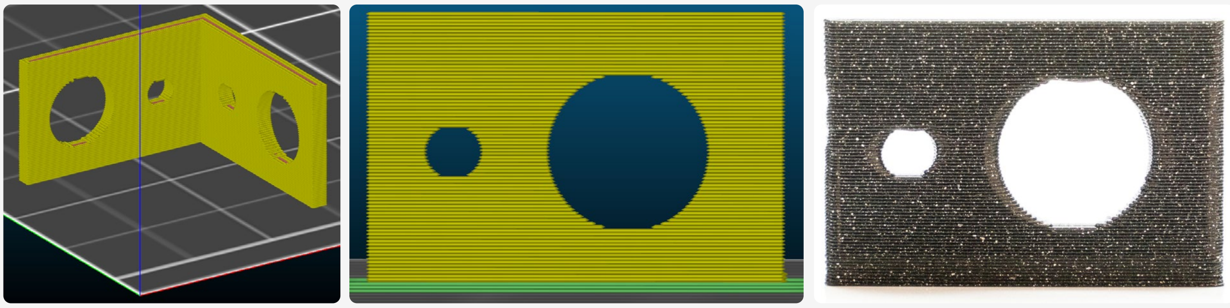
Printing a sphere cut into two hemispheres, which are then glued together.

5. When modelling parts that should fit together, you need to include a certain tolerance. You won't be able to combine two parts with zero-tolerance dimensions. Please keep in mind that you will probably have to tweak the tolerances until you reach an optimal result. There's no single "universal" value – it all depends on the size of the model, horizontal or vertical orientation, shape of the parts that should interlock, calibration, settings, materials and other aspects. So don't worry about not nailing it the first time, it will take a couple of tries to tweak everything – after all, 3D printers are designed to be great prototyping machines, so keep iterating until you find the best result. A quick example: If we want to insert a 10 mm rod into a tube, the tube's diameter should be about 0.15 mm bigger.

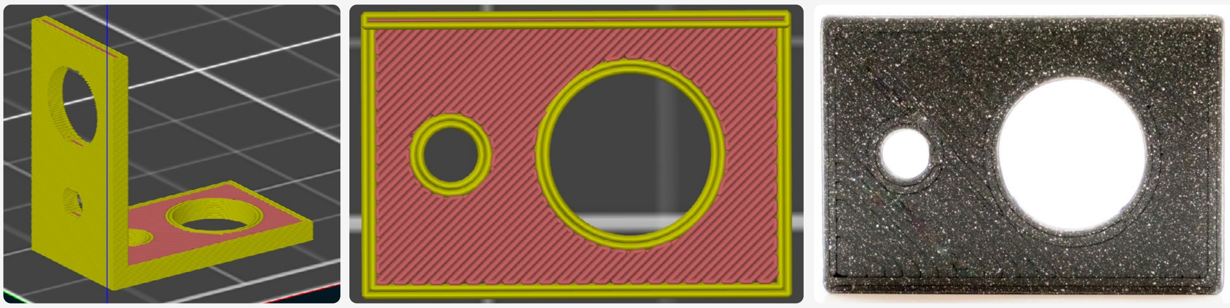
6. A circular hole printed vertically won't be perfectly circular. To achieve a better result, print circular holes horizontally as depicted in the pictures below.

Slic3r PE preview | **Real-life print**

A circular hole printed vertically



A circular hole printed horizontally



7. The width of a single perimeter when printed with a standard 0.4 mm nozzle is about 0.45 mm. This affects the total width of a model's walls.

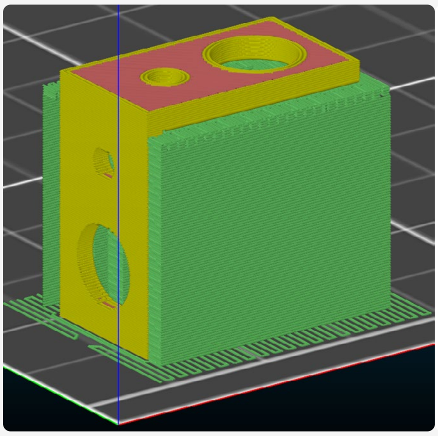
Wall thickness	**Is it possible to print?**
Less than the width of one perimeter	✗
One perimeter	✓
More than the width of one perimeter, but less than two perimeters	✗
More than twice the width of one perimeter	✓

Examples of possible object orientations and how they affect the resulting prints

Let's take a look at a simple L-shaped clamp with two holes on both ends and how the object orientation affects its final look. And it's not only the looks that are affected – the way how an object is oriented has an effect on its structural integrity and toughness as well.

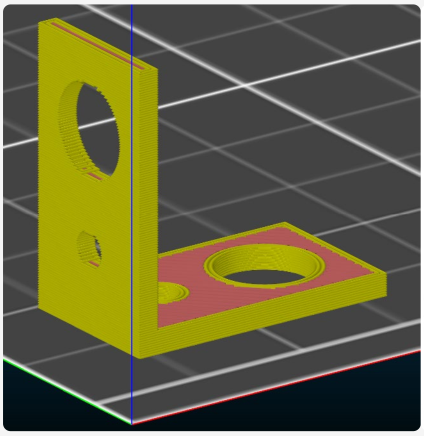
PrusaSlicer preview | **Printed object**

- ⊕ The side parallel to the print bed will have nicely shaped circular holes.
- ⊖ Way too many supports result in a lot of wasted material.
- ⊖ Low material strength in the 90° corner.
- ⊖ The part printed vertically will have a tendency to break in the direction of printed layers.
- ⊖ The part printed vertically won't have perfectly circular holes.
- ⊖ The part above supports will have a slightly rough surface.



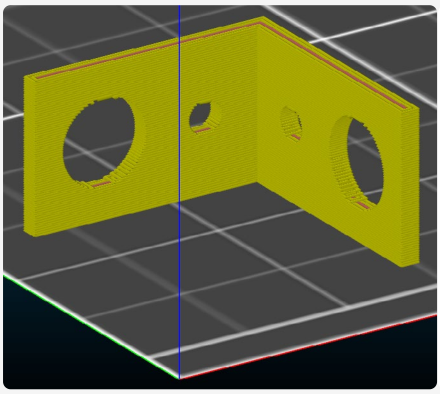

This is not an optimal orientation for this model

- ⊕ The side printed parallel to the print bed will have nicely shaped circular holes.
- ⊕ No supports.
- ⊖ Low material strength in the 90° corner.
- ⊖ The part printed vertically will have a tendency to break in the direction of printed layers.
- ⊖ The part printed vertically won't have perfectly circular holes.




This is not an optimal orientation for this model

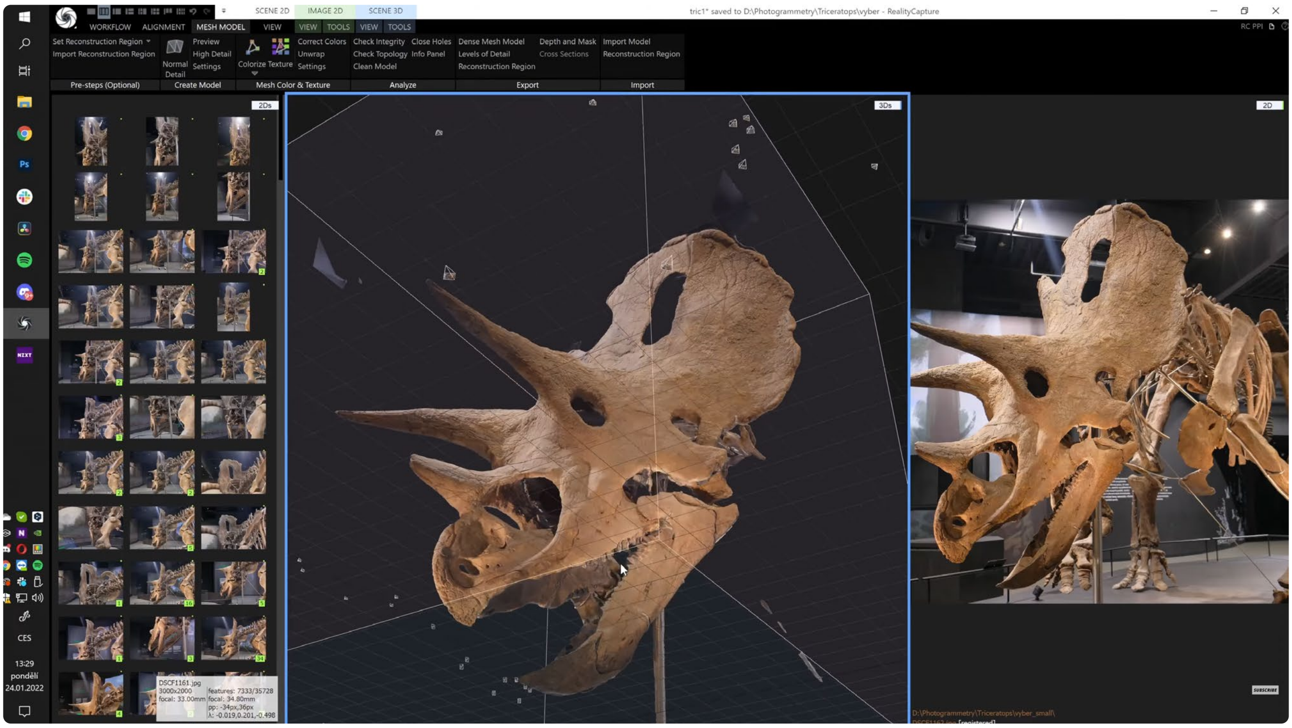
- ⊕ Best possible material strength in the 90° corner.
- ⊕ No supports.
- ⊖ The holes won't be perfectly circular.




This is the optimal orientation for this model

3D Scanning and Photogrammetry

3D scanning and Photogrammetry are two popular options for creating a digital object based on a real one. 3D scanners have been on the market for quite some time, but their high price makes them unavailable to mainstream users. The cheapest scanners can be bought even for less than 300 USD, while the expensive ones can go well beyond 10,000 USD. That's where photogrammetry steps in. It's a much cheaper technology, however, it can still bring amazing results even though it requires a bit of extra work. The whole principle is based around processing dozens, or even hundreds, of photographs of a single object in a specialized software. The good thing is that even your smartphone's camera is enough for the job. You can learn more about photogrammetry at: prusa.io/photogrammetry.



Sense 3D scanner by 3D Systems

Source: https://3dprint.com/58221/3d-systems-sense-plus

Choosing the right printing material

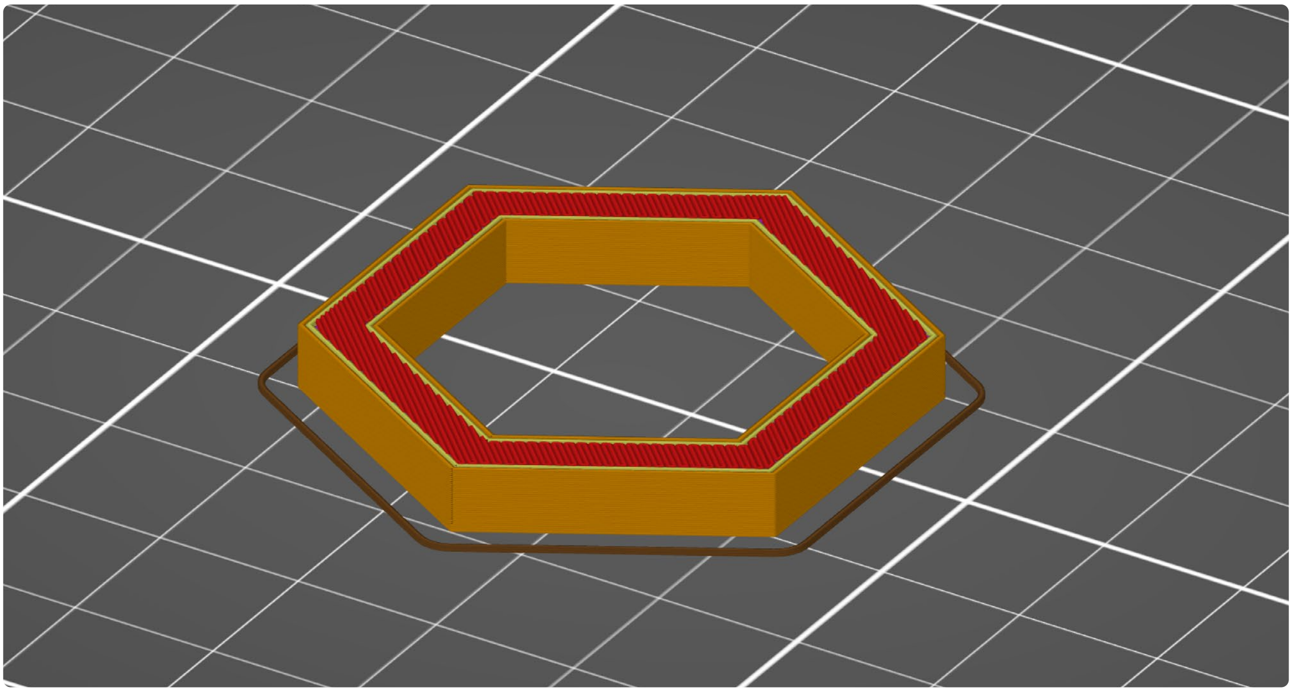
A common misconception is that various filaments are just about different colours. The truth is that there are many different types of filaments with greatly different properties. Some materials are very easy to print and allow for plenty of detail on the printed objects, but their heat resistance is low (PLA). Other materials can be the complete opposite (PC Carbon Fiber).

You can read more about printing materials in the **'Filaments' chapter**.

Slicing

Slicing is the process of turning a 3D object into a machine code called G-code using a software tool called a slicer. The most common slicers are PrusaSlicer, Simplify3D and Cura. The input for the G-code generation is not just a 3D object, but various settings come into play as well. They can affect the G-code / printing process in a number of ways – like the toughness of the model, amount of details or printing speed. It's also possible to modify the objects – scaling, rotating, cutting and other tools are available. Last, but not least – you can use slicers to position the object(s) on the virtual printing surface. The software is as important as hardware, meaning that correct slicing settings are crucial for a good-looking 3D print.

There's a number of available slicers, each of them has its pros and cons. Most of them are available for free. Beginners should stick to slicers that feature tested pre-made slicing profiles for their printers. Once you become comfortable with something that works out-of-the-box, you can download other software packages and try experimenting. Pretty much every major 3D printer manufacturer has its own slicer fine-tuned for their printer lineup. Let's take a look at three slicers that are used by Original Prusa 3D printer owners the most.

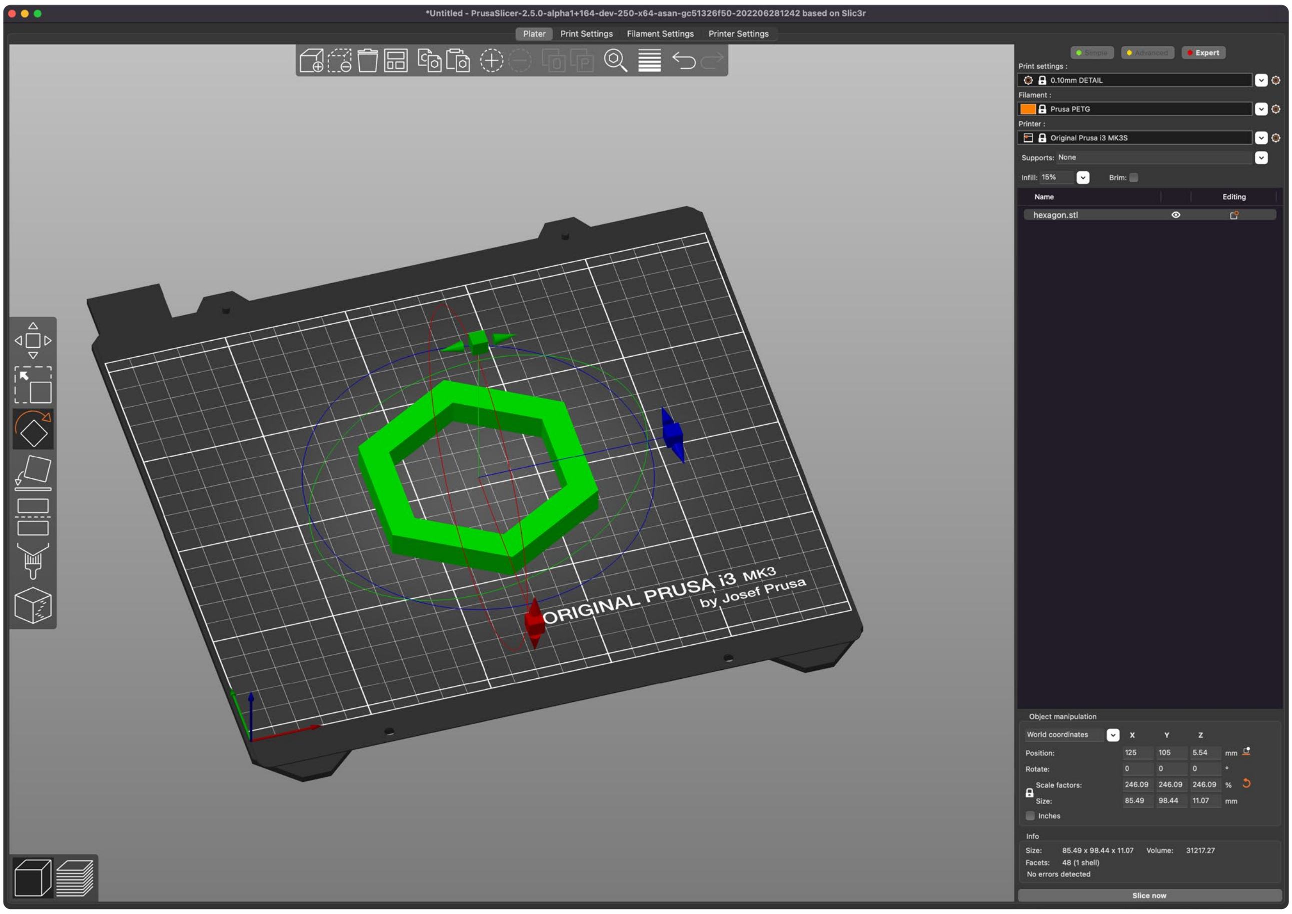


PrusaSlicer

PrusaSlicer is based on, or rather 'forked from', the open-source Slic3r project. PrusaSlicer is our default slicer and you can download stable releases from prusa3d.com/prusaslicer. The application is full of useful features and is regularly updated. It has plenty of improvements and optimizations for Prusa Research products including profiles for multi-material printing and 3rd party 3D printers as well. It also comes with a huge library of pre-made and tested settings for all sorts of materials.

Features:

- **Free and Open-source**
- Features over 300+ tested profiles for various filaments and resins, ranging from the most popular ones to various exotic materials (such as Woodfil and many others). Print profiles are regularly updated.
- Built-in firmware flashing tool for Original Prusa 3D printers
- Multi-material printing support
- OctoPrint, Prusa Connect and Printables.com integration
- Plenty of options for print settings, including special area-based modifiers
- Sliced model preview that shows the object layer-by-layer.
- Variable layer height settings
- Support for SLA 3D printers
- Tree supports generation
- Support for 3rd-party 3D printer profiles

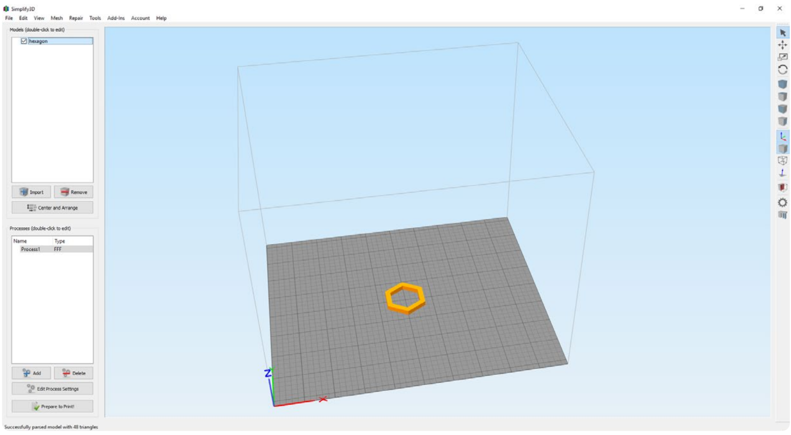


Simplify3D

Simplify3D is a slicing software developed independently – so it's not tied to any 3D printer manufacturer or specific model. It features pre-made profiles for hundreds of various 3D printers. This is especially useful if you have more than just one brand of 3D printers, since you don't have to create printing profiles yourself.

Features:

- **Paid software.**
- Realistic simulation of extruder movements in the preview mode
- Preview of sliced 3D objects in G-code format
- Automatically generated 3D supports with optional user modifications
- Plenty of print settings
- Area-based settings modifiers, object-specific print settings

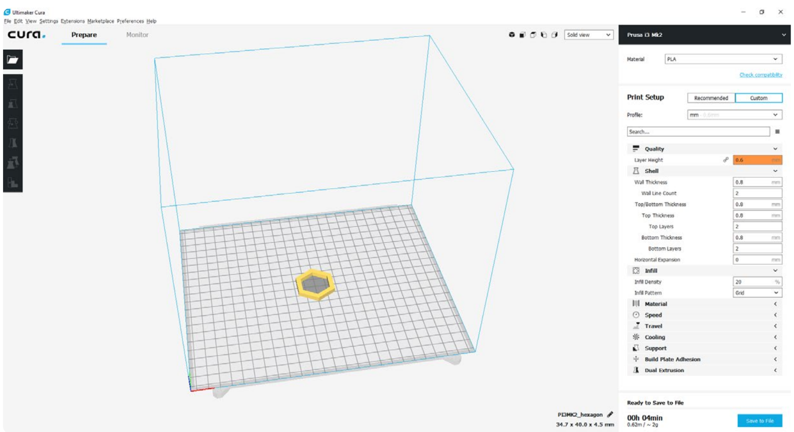


Cura

Cura is a slicing software developed by Ultimaker, a 3D printer manufacturer. It's the most common choice for owners of Ultimaker 3D printers. However, the program features a number of profiles for other brands of 3D printers as well.

Features:

- **Free and Open-source.**
- Simple interface is beginner-friendly, however, there are advanced settings as well.
- Optimized profiles for official materials and Ultimaker 3D printers
- Object-specific printing settings, allowing to position multiple objects on the same print bed, each with different configuration.
- Preview of a sliced 3D model in G-code format
- Shows a detailed breakdown of how long it will take to print each section of the model (perimeters, supports, infill and others).



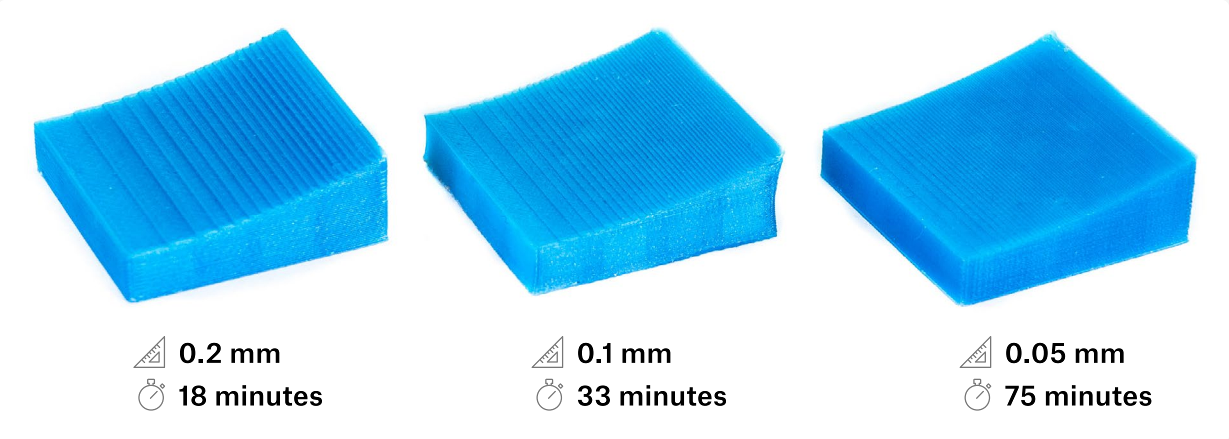
Slicer – basic settings

Filament and print bed temperatures – every filament manufacturer states the optimal temperature range for their filaments. You should stick to the recommended values. Modification of print temperatures leads to changes of the print's visuals. The temperature of the nozzle and print bed usually ranges from 200 °C to 240 °C (392 °F to 464 °F) and 60 °C to 100 °C (140 °F to 212 °F) respectively.

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 more visible layers 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 0.15–0.20 mm are preferred. Lower layer height leads to more detailed prints (less noticeable layers), however, the printing time is extended.

PrusaSlicer has a function for configuring variable layer height – it means users can choose which parts of the object will have lower layers (detailed or sloped parts) and which parts can have increased layer height. Depending on the object's geometry, you can save a lot of print time by using Adaptive layer height and let PrusaSlicer calculate the optimal layer height for different parts of the model – e.g. straight vertical sides will be printed with increased layer height while rounded edges will be smoother when using lower layer height. Click the Variable layer height button to open the menu, then adjust the sliders and see the result by clicking the "Adaptive" button.

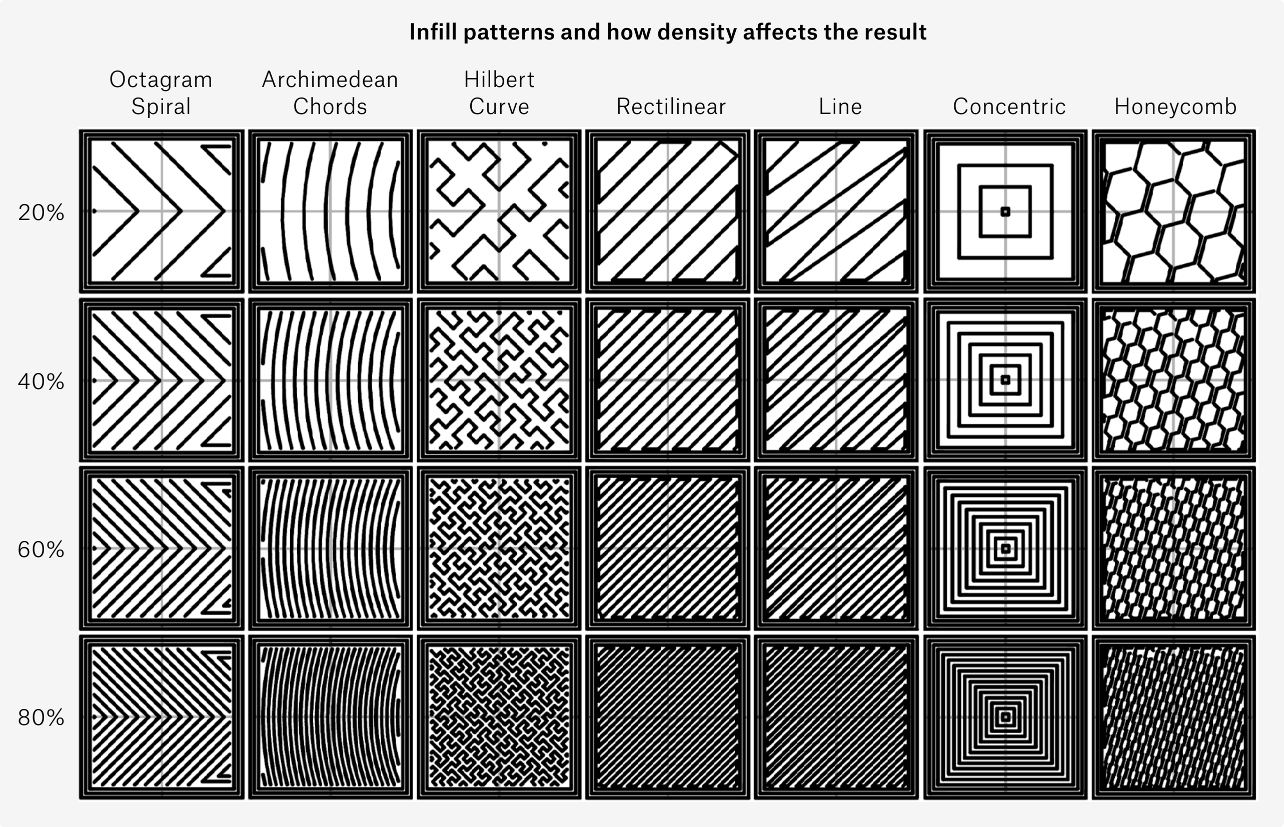
How the layer height affects the object's surface



Vertical shells / Perimeters – these are the outside walls of the model and by setting the Vertical shells, we're adjusting how many perimeters there will be. The resulting thickness of the wall can be roughly calculated as: number of perimeters × nozzle diameter. You can learn more about perimeters in our guide at prusa.io/perimeters.

Horizontal shells / Solid Layers – used to configure the number of top and bottom layers of the model, which will be completely solid (100% infill).

Infill – affects the print time, durability of the printed object and filament consumed. Infill is set as a percentage, while 0% means a completely hollow object. Usually, 10-20% is used. It's also possible to choose the infill pattern (see below).



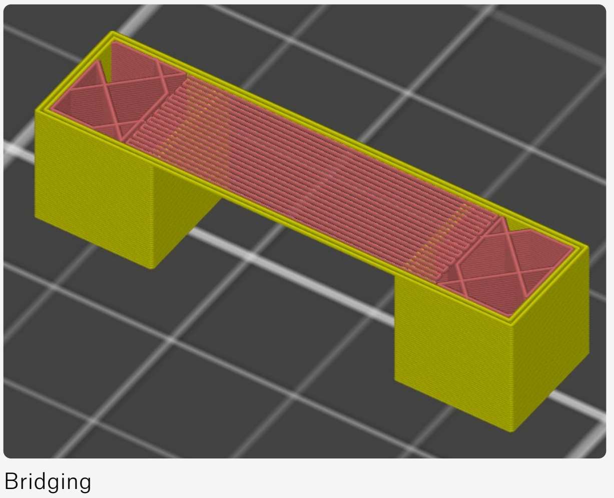
Supports – scaffolding-like structures that support overhangs or parts that start mid-air. Supports are designed to be easy to remove, but they may leave marks on the model. Our goal is to minimize the number of supports by rotating (or even designing) the object to achieve an optimal orientation, where only a few (or none) supports are required. Fewer supports means faster printing and better overall look of the model. In this matter, the introduction of Organic Supports – a significantly improved type of supports that mimics tree growth – helped immensely. Organic Supports allow faster printing and less filament waste while maintaining contact with the overhang.

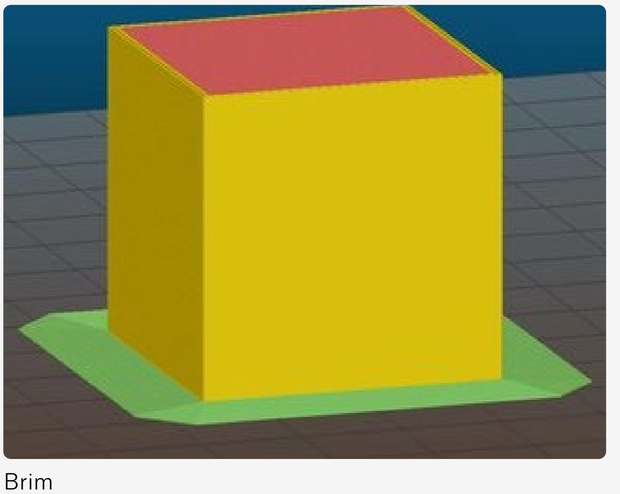
Bridging – this is the only case when the printer can print in the air with no supports underneath the layer. This is a special case, though. The extruder can drag a string of extruded plastic in a straight line between two solid points. This also means the bridge has to be perfectly parallel to the printing platform. The maximum length of the bridged path is also determined by the cooling performance of your 3D printer.

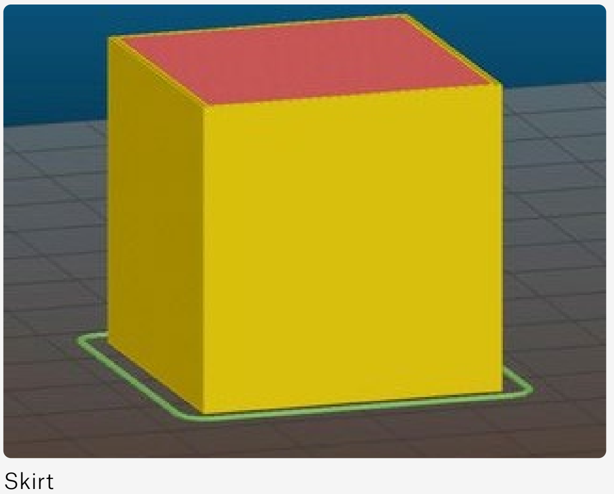
Brim – to increase the adhesion of the printed object to the printbed (e.g. when printing small/thin objects), it's recommended to use a brim. It's an additional flat surface that will prevent the object from warping/detaching mid-print. It can be easily removed when the print job finishes.

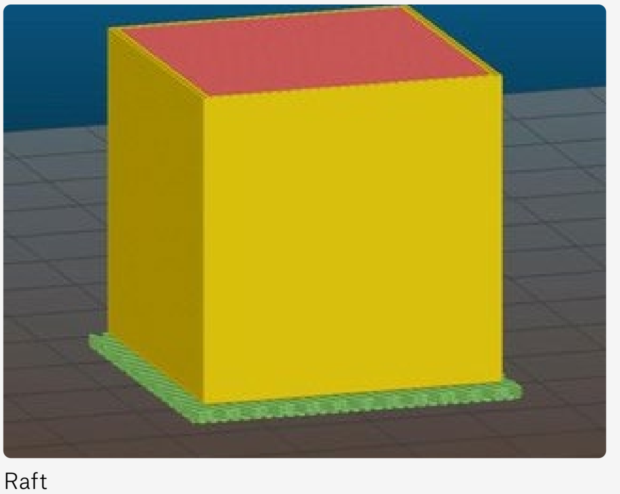
Skirt – is a 3D-printed outline around all the models on the print bed. It's printed at the beginning of the print job before all objects and its purpose is mainly to stabilize the flow of the filament through the nozzle. The skirt is also useful to verify the adhesion of the first layer to the print bed. Since it's printed before the models, you can quickly change the Live Z adjust if you see the first layer not sticking properly or being too squished by the nozzle.

Raft – a special kind of support structure, which lifts the whole printed object above the printing platform. It is used primarily with ABS materials, because it helps to prevent warping / lifting the object from the print surface.


Bridging


Brim


Skirt


Raft

Cooling – it's recommended to actively cool printed objects – especially thin and tall structures, which don't have enough time to cool down on their own, because the extruder tends to stay in one area for extended periods of time.

Advanced settings
Slicing apps offer a whole range of other parameters you can tweak and tune: speed for perimeters, bridges, infill and many others. These settings are usually factory tweaked by default, so there's no need to adjust them further.

You can read more about slicing in our article at prusa.io/prusaslicer.

Preparing the print sur face

Preparing the print surface is key for successful printing. If the printer is not properly calibrated, and the surface does not allow for good adhesion, the print job will fail. Always make sure the first layer sticks to the printing surface well.

The development of 3D printers included also various versions of the print surface. Originally, there were only standard glass or mirror print beds without additional heating. To increase adhesion, ABS juice (tiny bits of ABS dissolved in Acetone) were used. Other options were to use a kapton tape or paper glue (Kores). This also meant that working with the printer had been somewhat messy. Then, the PEI film was discovered – and everything changed. You can find the PEI surface on all Original Prusa 3D printers starting with the MK2 version. This type of surface does not need lengthy and complicated preparation – just keep it clean and degreased. It's compatible with a wide range of materials and the only time when you need to use the Kores glue is when you want to print with PET. In this case, the glue acts as a separator, because PET's adhesion may be way too strong, which makes it difficult to remove from the bed.

Nowadays, there is a number of different print sheets for Original Prusa 3D printers offering various surface properties, making them ideal for different types of materials. Some may even affect the visual aspect of your print – the textured powder-coated sheet transfers its rough texture onto the bottom of your prints.

Starting the print

Starting the print means sending the generated G-code into a 3D printer. As 3D printers evolve, so do options on how to do that.

The 3D printer needs continuous access to sequential G-code instructions throughout the print job. This is why using an SD card or a USB drive is recommended.

Modern 3D printers have Wi-Fi, LAN, and remote print initiation features like most devices. However, the traditional methods, like SD cards and USB connections, are here to stay for some time, at least due to their reliability and ease of use, even in offline environments or closed or restricted networks.

Additional remote printer management options include Prusa Connect or OctoPrint. These platforms broaden the possibilities for controlling and managing 3D printing processes through web browser UI.

Post-processing

3D printed objects are usually ready to be used once you finish printing – this applies to functional parts mostly. If you have extra requirements about the object's surface or the overall look in general, you need to adjust the surface using a variety of tools. This is called post-processing.

Post-processing covers a wide range of techniques, materials, tools and procedures with the aim to make the surface of the printed object smooth, colored and good looking in general. Models made of plastics can be sanded (using electric sanding machines usually leads to damage to the model due to high temperatures created by excessive friction), smoothed out with putty, sprayed with a filler, laminated, colored with acrylics or with a spray... However, adding extra material on the model can cause tiny details to disappear.

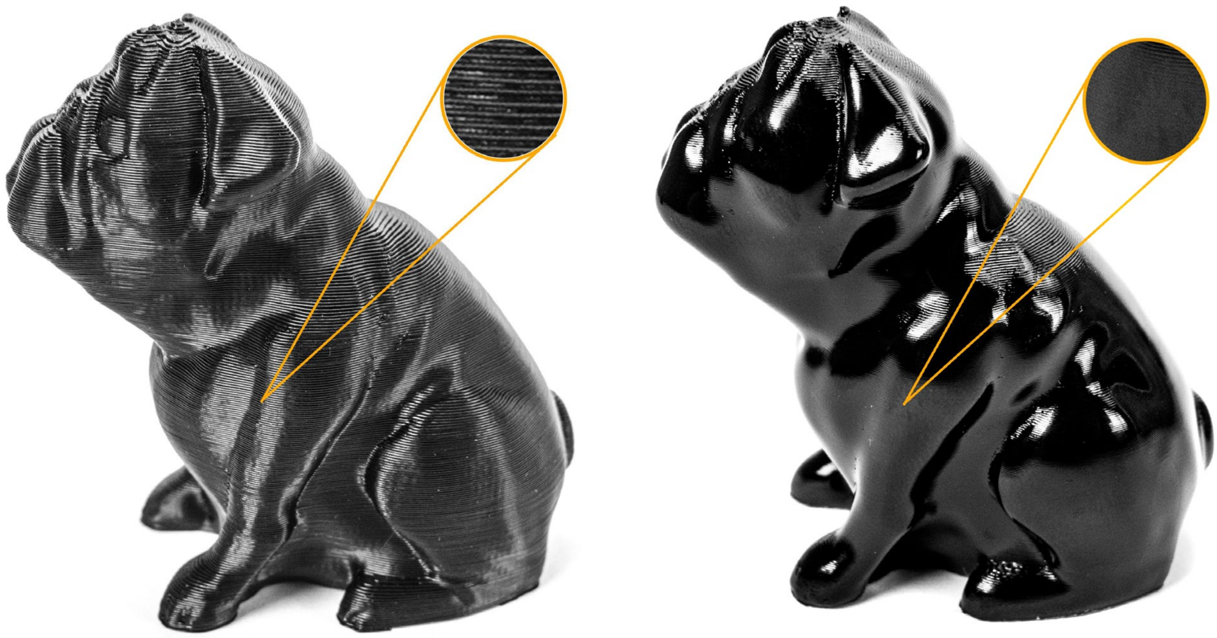
You can learn more about post-processing in our article at: prusa.io/postprocessing.

Gluing and smoothing models using acetone

ABS and ASA are materials soluble in acetone. This can be also used to glue printed models together: smear the surfaces you want to attach with a bit of acetone and push them together.

Acetone can be also used to smooth the surface of 3D printed models. You can either submerge the model into acetone for a short period of time (5-10 seconds), or you can place the model in a sealed container with acetone on the bottom – the object won't touch the surface, but the vapors will smooth out the surface over time. PVB filaments are also soluble – in isopropyl alcohol, which is generally a safer liquid to work with.

Smoothing out the surface leads to the loss of tiny details.



WARNING!
Acetone is a volatile flammable liquid – make sure the room is well-ventilated. Use protective gloves and glasses.

More tips:

- So-called 'stringing' (thin strings on the surface) can be easily removed with a heat gun – however, do it very quickly, otherwise, the object could deform in excessive heat.
- Materials such as PLA and PETG can be glued together using any good superglue. You can use an activator to speed up the process.

PLA is a material soluble in chloroform (trichloromethane). However, chloroform is not suitable for smoothing out the printed objects (like ABS/Acetone combination), because it eats away the surface. Chloroform can be used as a glue to bond parts together, but a common superglue is a much better option. Chloroform is a hazardous substance and it should be handled with caution and in well-ventilated areas.

FILAMENTS

As the popularity of 3D printers grows, manufacturers are also producing new filaments with various colours or special properties. Currently, the range of available filaments is pretty wide and there are plenty of materials to choose from: easily printable and very popular PLA, universal PETG suitable for printing of mechanical parts, very tough and temperature-resistant PC Carbon Fiber, composite materials that imitate the look of wood or bronze, glow-in-the-dark filaments, soft flexible materials and many others.

Every filament needs specific print settings, which also means that the same type of material from two different manufacturers can have different printing requirements. It's even possible that there can be a filament from a single manufacturer that has different printing requirements based on its color (e.g. red vs blue PLA).

To reach the best possible quality levels during printing, always refer to the recommended printing temperatures set by the manufacturer. We have profiles for most of the supported filaments in PrusaSlicer. Only in case the prints have visible issues, you can start tweaking the material profile in PrusaSlicer – this includes temperatures, fan speeds, printing speed, filament flow, retractions and other settings.

The most frequently used filaments are PLA, PETG and ASA. We'll explain how these materials differ and in what situations they perform the best. But there are also other interesting materials on the market – in fact, there are so many materials that the best way how to learn more about them is visiting our Knowledge Base with material guide or the manufacturers' websites.

If you are a 3D printing beginner, the most important thing you should start with is to familiarize yourself with the "basic" materials and learn in which situations they perform the best. The most user-friendly material is PLA. Let's consider PLA filaments the baseline for our guide and see how the other popular materials compare.

PLA

PLA is likely the most used filament in general.

There are a couple reasons why:

- It's easy to print. What does it mean in reality? Very nice surface finish and acceptable surface finish above supports and in large overhangs. Good for printing small and detailed models.
- No unpleasant odor during printing
- Low thermal expansion compared to other materials. It does not warp, and sticks to the printing platform nicely. This is why it's suitable for printing large objects.
- PLA comes in a wide variety of colors.
- One of the cheaper materials

So why do we need other materials?

- PLA is hard and brittle. It has a tendency to break and shatter under pressure.
- PLA is not temperature-resistant, it starts to soften at around 60 °C (140 °C), which makes it a less-than-ideal choice for printing things like car smartphone holder.
- Compared to the rest of popular materials, PLA has the worst weather resistance.

In these three situations, PETG, ASA and polycarbonate are better choices.

PETG, ASA and PC (polycarbonate)

All these three materials are more flexible compared to PLA, which means that they will flex slightly under pressure and won't break immediately. On the scale from the easiest to the most difficult materials to print, PETG sits between PLA and ASA/PC. The problem with ASA and PC is their thermal expansion. These materials tend to bend and warp during printing, which causes them to detach from the print bed – especially larger objects have a higher tendency to warp and bend, making them more difficult to print. Also, ASA produces a very noticeable odor during printing, much stronger than PETG or PLA. Also, compared to PLA, PETG has a shinier surface finish, but also a tendency to create filament strings during extruder movement.

What are ASA/PC good for and what's the difference between them?

ABS was the first widely available material for 3D printing. As the industry evolved, new and improved materials appeared on the market. ASA is considered to be the successor to ABS. Most of their properties are the same, while ASA is better in some ways. ASA is a UV-stable material and it also has lower thermal expansion, which makes it easier to print (compared to ABS).

ASA and polycarbonate are generally considered to be technical materials. ASA is considered the successor to ABS, the first widely available material for 3D printing.

ASA is a UV-stable, heat-resistant material and it has a slightly lower thermal expansion, which makes it easier to print. The most popular thing about ASA is that it can be smoothed out using acetone vapors.

The polycarbonate is slightly harder to print but comes with great mechanical and chemical resistance. It is slightly harder to print than ASA but works much better for printing mechanical and heat-resistant parts than both PETG and ASA.

And that covers PLA, PETG, ASA and PC – these are good materials for 3D printing in general. You might want something extra, though. Let's take a look at some materials that are used less often, but they offer some interesting features – their price tends to be higher, though.

FLEX (TPU/TPE/TPEE)

Flexible materials are a large group of special filaments with flexible properties. These materials are somewhat similar to rubber – when you bend them, they won’t break. Flexible materials are produced with different levels of hardness. The softer (more “bendy”) the material is, the more difficult it is to print with it. Flexible filaments can be used to print wheels for RC models, cell phone cases, silentblocks. However, keep in mind that the printed objects don’t have the same level of adhesion as rubber. In other words, for high-performance RC cars, store-bought tires will perform better.

Filled materials

Composite materials like wood/metal/carbon-filled filaments consist of the main plastic part and a secondary material mixed inside. However, these filaments are usually filled with materials improving their mechanical or aesthetical properties. The most common composite materials are filled with carbon fibers but they can be also found with glass fibers, Kevlar fibers, etc. These fibers help filaments to gain perfect dimensional stability with no warping, increased temperature resistance, abrasion resistance, etc (see our Prusament PC Blend Carbon Fiber). However, these materials are usually more expensive and a hardened steel nozzle is a must.

Woodfill and other metal composites

Polished Bronzefill

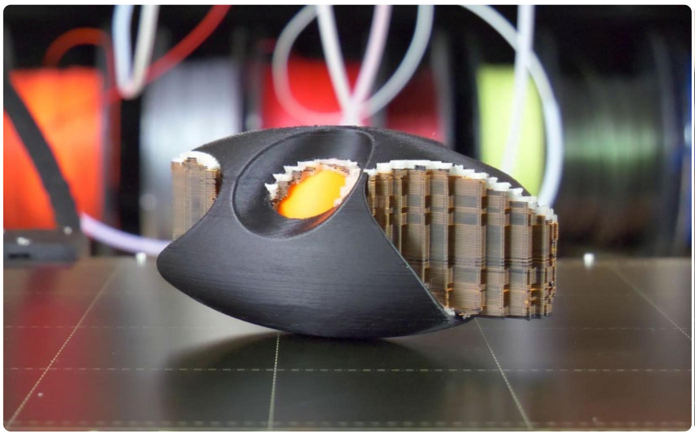
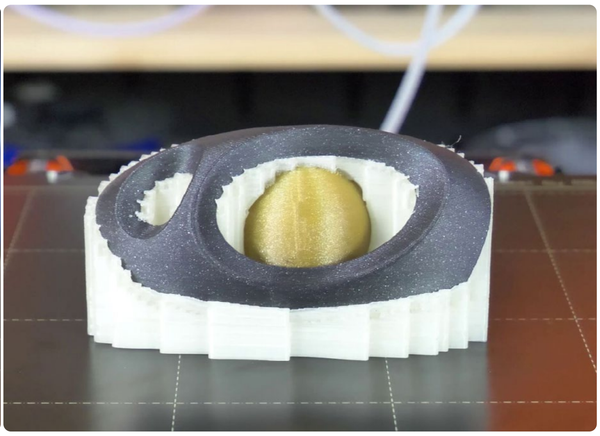
PVA and BVOH for soluble supports

Usually, when printing a model, the best practice is to rotate the model in such a manner that will minimize the number of supports. However, this is not possible at all times. In most cases, the supports are printed with the same type of material as the rest of the model – and eventually, when the print is finished, we can break them off. The surface above supports can often carry traces of the broken-off material, layers can be more visible compared to the rest of the object etc.

There are 3D printers that can print with two or more materials at the same time (e.g. our Original Prusa 3D printer with the Multi Material Upgrade 3 or an Original Prusa XL with multiple print heads, which opens the possibility to use a different material to print supports: this is where soluble materials, such as PVA and BVOH, come in. Thanks to these materials, the support distance parameter (which is used for easier removal of standard supports) is no longer required, because we will simply dissolve the material in water. However, these materials are more expensive than standard filaments. It's possible to reduce the filament consumption by using the soluble materials on the 'interface' only (a couple of layers between supports from a standard material and the object itself).

BVOH and PVA materials work the best in combination with PLA, especially due to the similar printing temperatures. Both BVOH and PVA are water-soluble.

HIPS is a support material soluble in D-limonene (lemonesol) or acetone and works best in combination with PETG.

Other materials

PP – flexible material with excelent chemical and impact resistance. Comes with very high warping and poor surface adhesion.

Nylon – resistant and tough material with great adhesion between layers. Nylon is friction resistant, so it's suitable for printing mechanical parts, but it's also hygroscopic (absorbs air humidity), which has a negative impact on printing.

PVB – easy-to-print material with settings similar to PLA, good for surface smoothing using isopropyl alcohol. PVB has good looks and transparency but poor mechanical properties and temperature resistance.

MULTI-COLOR 3D PRINTING

So far we've discussed only single-color 3D printing. So the obvious question is whether it's possible to print with multiple colors or materials at the same time. Sure it is! There's even more than one option. There are advantages and disadvantages to currently available methods, so let's take a look at them.

What is the difference between multi-colored and fully-colored prints?
In our case, multi-colored print means an object printed with two to five colors. Full-color 3D printers can create any color, because they mix CMYKW colors.

The easiest way how to achieve multi-colored prints is by manually swapping the filament during the printing job. This is a good option for creating e.g. logos, banners or original business cards.

- ⊕ No need to modify your 3D printer.
- ⊕ No wasted material.
- ⊖ Needs to be done manually.
- ⊖ Only one color change per layer, not possible to have more colors in one layer.

If we take the previous method a couple of steps further, we'll end up with the Original Prusa Multi Material Upgrade 3S or Mosaic Palette. Essentially, these devices can swap filaments automatically, and even several times per single layer.

- ⊕ Enable filament changes within one layer.
- ⊕ Use the original (or slightly modified) single extruder – no need to calibrate multiple extruders.
- ⊖ Wasted material – the printer has to 'purge' material from the nozzle during filament changes.
- ⊖ Supports only up to 5 colors.
- ⊖ Not possible to mix colors to create new blends.

Full-color printing can be achieved by mixing filaments directly in the extruder. The principle is similar to regular ink printers, the only difference is that the ink is replaced with filaments. However, a 3D printer needs more than just CMYK filaments – white (W) filament is also required.

- ⊕ 4-5 filaments are enough for full-colored printing.
- ⊕ Saturated colors.
- ⊖ Lots of wasted material.
- ⊖ To achieve good colors, "calibrated" CMYKW filaments are required.

You can also achieve full-color printing with a combination of a 3D printer and a regular (ink) printer. The ink printer combines CMYK colors to achieve the required shade and the color is applied onto white filament, which absorbs the drops of color.

- ⊕ Any color is possible.
- ⊕ Only one filament is enough.
- ⊕ No wasted material.
- ⊖ Not possible to achieve fully saturated colors.

MULTI-MATERIAL 3D PRINTING

Being able to print with multiple colors is one thing, but combining more materials in one print is even more interesting. This way you can create functional parts or print models with breakaway, water-soluble, or easily removable support structures.

Yet, there are limits: Blending 3D printing materials depends on their mechanical and thermal properties. It's a job best suited for experienced designers and printers with multiple print heads, like the Original Prusa XL with a toolchanger. With up to five print heads, it can handle up to five different materials simultaneously with minimal to zero waste.

For example, this durable case for microphone transportation is made out of PETG, PLA, and TPU.

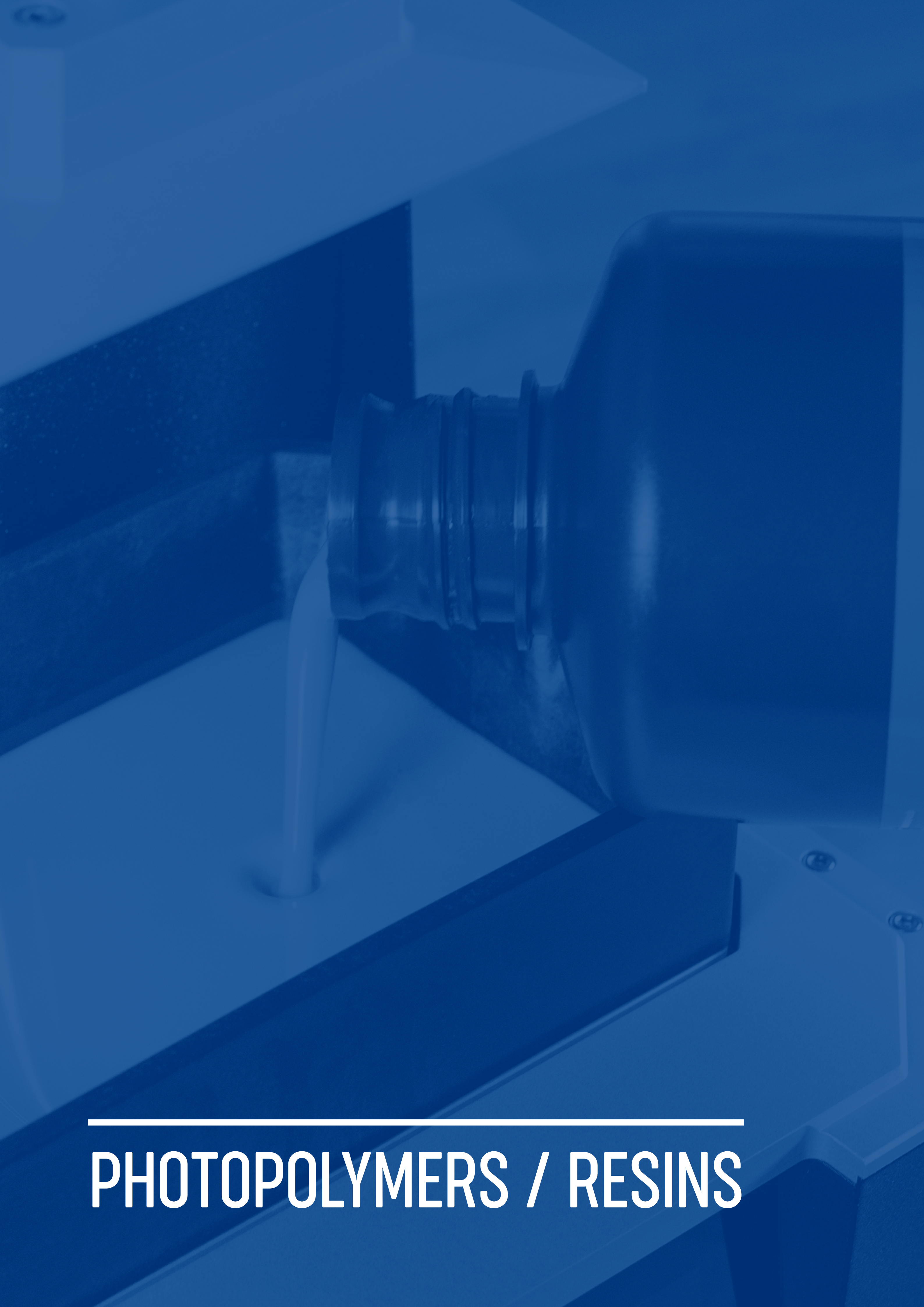
- ⊕ Enables diverse material combinations for unique projects.
- ⊕ Ideal for functional parts with different material properties.
- ⊕ You can make intricate designs with varied support structures.
- ⊕ Visually appealing and detailed designs.
- ⊕ Minimal to no filament waste.
- ⊖ Can be expensive due to specialized printers and materials.
- ⊖ Operation and calibration are more complex.
- ⊖ Limited material compatibility due to varying properties.
- ⊖ It involves a learning curve and is less user-friendly for beginners.
- ⊖ Filament waste.

While multi-color printing produces colorful models and eliminates painting and other post-production steps, it has two significant downsides: longer print times and plastic waste. A single-nozzle 3D printer must switch from one color to another while purging the transition filament containing a mixture of both colors before resuming the print with the new color. That's why multi-color 3D printing methods like the Original Prusa MMU3 rely on wipe towers or purge structures to clear extruders between color changes. Other 3D printers simply dump the purged filament directly on the table. Both are a source of plastic waste, though the latter is more considerable.

There are several ways to reduce plastic waste: using a 3D printer with a toolchanger can limit your waste to zero. Other methods include advanced slicer settings – PrusaSlicer has introduced the option to wipe filament directly into the infill. This integration reduces material consumption by limiting the amount of filament that would otherwise go into the wipe tower. Other efforts to reduce waste in 3D printing extend beyond printer and filament optimization: for example, design tweaks like minimizing supports and print orientation can also play crucial roles.

Sustainability at Prusa Research

We continuously implement measures to reduce our carbon footprint: the spool sides of Prusament are made from recycled plastic, we produce recycled filaments, and we use plastic waste to create experimental prints. We also continuously implement measures to benefit our customers and the environment, like improving our packaging efficiency and choosing low-emission shipping partners. And our printers are upgradeable and fully repairable. Check our progress at Company–Sustainability at Prusa3d.com.



PHOTOPOLYMERS / RESINS

Resins (also called Photopolymers or UV-sensitive resins) are printing materials for SLA 3D printers. Resins are liquids, which are cured (solidified) through exposure to UV light. Resins are usually noticeably more expensive than filaments, but their price can differ based on their properties. The cheapest resins can be bought for around 30 USD/L, while more advanced materials can cost as much as 400 USD/L – these are usually dental or casting resins. Prusament Resins cost around 60 USD and offer a nice price to quality ratio. Generally speaking, SLA prints are more fragile than FFF prints. On the other hand, SLA prints don't break along layer lines – instead, they shatter like glass.

Resins usually consist of three basic components:

- **The core** of the resin (monomers and oligomers).
- **Photoinitiators** – molecules reacting to UV light, which initiate the solidifying process.
- **Additives** – admixtures that change the color and properties of the resin.

> When buying resins, always check at which wavelength the curing process happens to ensure a good compatibility with your 3D printer. Our SL1 and SL1S SPEED work with standard 405 nm resins.

Differences arise only through adding additives and dyes. A typical parameter that can be affected by additives is the degree of hardness and toughness. The following table summarizes the most common types of resins with their advantages and disadvantages.

Material type	Properties
Standard resin	⊕ Smooth surface, lots of details ⊖ Fragile ⊖ Not suitable for mechanical parts
Clear resin	⊕ Can be turned nearly fully transparent through post-processing ⊖ Semi-transparent
Casting resin	⊕ Lots of details ⊕ Great for preparation of casting forms ⊕ Little to no remnants after burning the resin
Hard and resistant resins	⊕ Similar to ABS or PP materials ⊕ Partially flexible ⊕ Suitable for mechanical parts ⊖ Low resistance to high temperatures
Heat-resistant resin	⊕ Highly temperature-resistant ⊕ Used for injection forms ⊖ Expensive
Bio-compatible resins	⊕ Non-toxic ⊕ Suitable for dental implants manufacturing ⊕ Abrasion-resistant ⊖ Expensive
Flexible resins	⊕ Soft material, lots of details ⊕ High print reliability and low viscosity ⊖ Limited deformation ⊖ Non-recyclable material

Please keep in mind that liquid resins are toxic materials. Always use protective equipment such as gloves and safety glasses when working with them. You should know that there are resins on the market that contain various amounts of highly toxic chemicals. We suggest studying the safety data sheet before using the resin. Sometimes resins emit an unpleasant smell and people think that it might be harmful to your health. Unfortunately, there is no specific correlation between bad odor and resin toxicity. There are safe chemicals with bad odor and there are unsafe chemicals with bad odor. Some vendors sell low-odor resins but again, every harmful substance should be mentioned in the safety datasheet.

GLOSSARY

You can find the most commonly used terms and their explanation in the table below.

Term	Description and explanation
AMF/3MF file	File format used by slicer software to save the whole scene (models, placement and print settings).
FDM / FFF	3D printing technologies – additive manufacturing process. A filament string is loaded into an extruder, heated, melted and extruded. The printer has mechanical parts moving in three axes, allowing it to print any 3D object.
G-code	File that includes a list of commands for a 3D printer.
OBJ file	One of 3D object files supported by slicers, similar to STL.
PEI	A film on the surface of the printing sheet – good adhesion and easy maintenance.
RepRap	RepRap is the first open-source 3D printer project. It was founded in 2005 at the University of Bath by Adrian Bowyer. Now, the project is in the hands of the 3D printing community – hundreds of developers and tens of thousands of users.
resin	Liquid material used for printing with SLA 3D printers. Also called photopolymer, because the solidifying process is initiated by UV light.
SLA / DLP	3D printing technologies that are based on curing liquid resin using UV light.
SLS	3D printing technology based on sintering of metal powders using a laser.
STL file	One of the supported file formats for slicers. It defines a set of points (vertices) in 3D space, which are connected to form edges and polygons. It's the most common type of files in the 3D printing industry.
bed, heatbed	Printing surface, usually with a heating unit to improve the adhesion.
bridging	The only case when printing in the air without supports is possible, however, it works only in a specific scenario. Bridging can create a straight line between two points with the same Z-axis height. This means the bridge has to be parallel to the printbed.
brim	Extra material printed around the base of the object to improve adhesion – especially useful for small objects.

extruder	The entire printing head. It usually constists of the hotend, feeding mechanism and a fan.
filament	Printing material used in FDM/FFF 3D printers.
firmware	Software running and controlling 3D printers.
heat break	A part of the hotend in the shape of a tube, which minimizes the transfer of heat between the heater block and the heatsink.
heater block	The lower part of the hotend made of heat-conducting materials. It contains a nozzle, heating module and a thermistor.
heater cartridge	Heating module, which heats the heater block along with the nozzle.
hotend	Part of the extruder that melts filament strings.
infill	Slicing settings, which determine how dense the inner structure of the printed object will be. 100% means a solid object. The usual number is between 10 and 20%. This parameter has a major impact on the printing time and amount of material used.
layer	One layer of the object created though the slicing process. The recommended layer height shouldn't exceed 0.75 × nozzle diameter. It has a major impact on the speed of printing. The lower layer height is used, the higher amount of details will be in the Z-axis.
mesh	A way of representation of a 3D model. A set of vertices, edges and polygons (facets) in three-dimensional cartesian coordinate system.
nozzle	A part of a 3D printer used to extrude melted plastic. It's diameter affects the quality and speed of the print. You can learn more at: prusa.io/nozzles.
overextrusion	A 3D printing error – an excessive amount of filament is pushed through the nozzle which results in an uneven surface of the printed object.
perimeter	Outside "wall" of a 3D printed object. Slicers have the option to change the number of perimeters. The thickness of a perimeter is defined by the nozzle diameter. When using a standard 0.4 mm nozzle, the perimeter thickness is 0.45 mm. The number of perimeters has a major impact on the printing time.
raft	A type of supports which is present under the whole first layer of the printed object.

retraction	An instruction that causes filament to be retracted back into the nozzle when the extruder is moving. By doing this, the melted string of filament is stopped from pouring out onto the model. Incorrect retractions can often manifest as stringing (see 'stringing).
skirt	A line around the printed object, usually several layers tall. It creates a microclima for the printed model and decreases the chance of bending, warping or cracking. Can be also used to calibrate the first layer height.
slicer	Software for converting (slicing) a 3D model into a machine code readable by 3D printers (G-code). There's a number of them on the market, some are free, while other are paid – PrusaSlicer, Cura, Simplify3D etc. Slicer is not a modeling tool.
slicing	The process of converting a 3D model into a machine code readable by 3D printers. The process 'slices' the model into horizontal layers of defined height and creates the movement instructions for the extruder.
stringing	An unwanted effect manifested as thin strings of plastic ('hairs') on the surface of the object. Adjusting the retraction usually helps.
supports	Scaffolding-like structures used to print complex objects with either large overhangs or parts starting mid-air. The supports are printed with special settings, so it's rather easy to break them off from the printed object. However, FFF/FDM supports usually leave marks on the surface.
thermistor	Thermal sensor. Used for checking and adjusting the temperature of the hotend and heatbed.
under-extrusion	A 3D printing issue that occurs when an insufficient amount of filament is pushed through the nozzle, manifested as missing layers/ parts of the printed model. If the temperature settings are correct, the cause is usually a clogged nozzle.

FAQ

What is 3D printing?

3D printing is an automatized process, which enables manufacturing of real physical objects based on digital data (3D model).

How much does it cost to run a 3D printer?

Highest costs come from the material (filaments). The price for printing a single object depends mainly on its weight. 1 kg of filament usually costs around 20-30 USD. The energy consumption is similar to a 100W bulb. Servicing a regular 3D printer is quite cheap and it's usually less than a couple dozen dollars.

What is 3D printing good for?

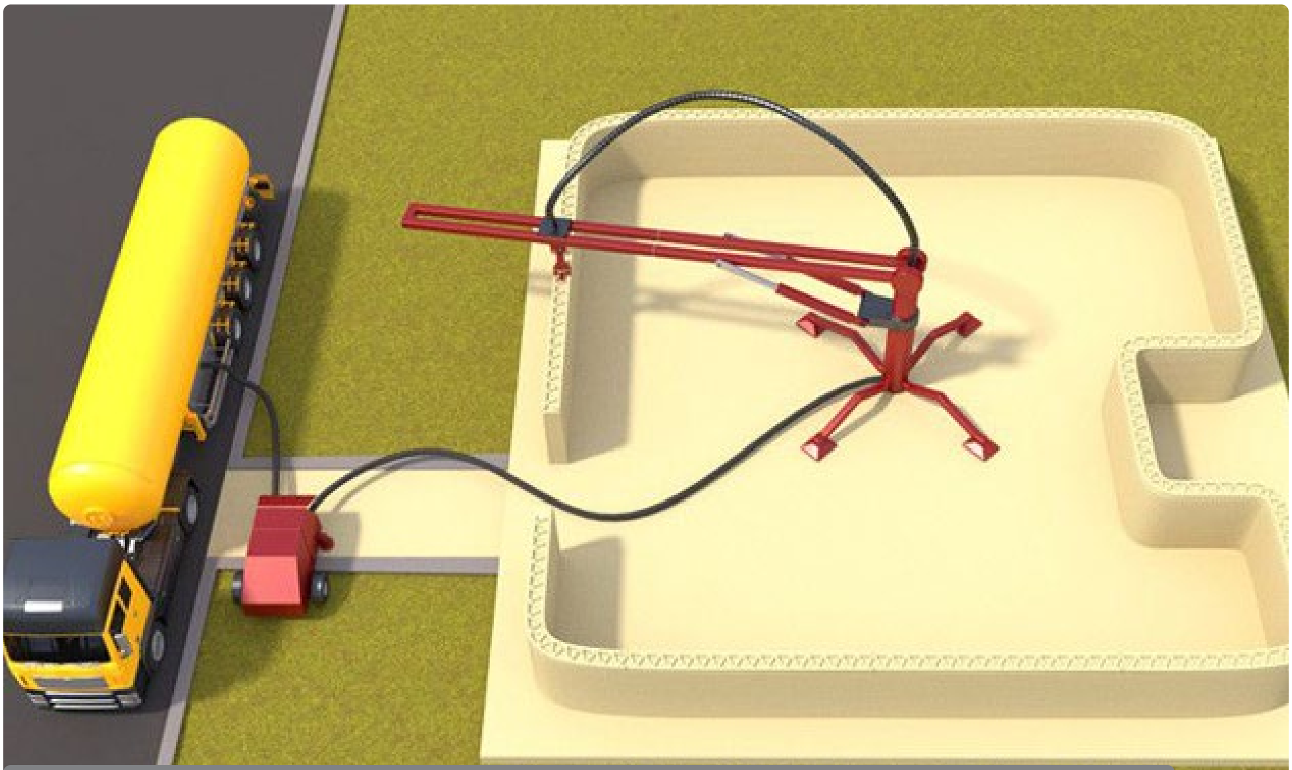
It's difficult to name all the uses – rapid prototyping, customized model manufacturing, small-series production, dentistry, DIY... there are so many fields where 3D printing can be used!

Is FFF 3D printing considered eco-friendly?

3D printing is an additive manufacturing method, which means that material is added onto an empty surface to create an object. The direct opposite is subtractive manufacturing, which is based on removing material from an existing object (e.g., woodworking). This means that 3D printing produces less waste. Another benefit is that using 3D printing, we're able to repair things that would be otherwise thrown away. There are also recycled PLA and PETG materials available that are made from 100% recycled PLA and PETG.

Is it possible to print a house?

Yes, there's already a number of successful attempts using concrete or similar materials. It works the same way as 3D printing with plastics.



Visualization of a 3D printed house. Source: www.3dnatives.com/en/3d-printed-house-companies-120220184

Can 3D printers print human organs?

Not yet. However, scientists from all over the world are working hard to make this possible. There are news published about this topic almost every day. The problem (and the challenge) is the fact that human organs are incredibly complex and dependant on other organs. Scientists are focusing on printing tissues for less-complex organs, for now.

Can I print objects larger than the print surface?

Yes, it's possible to cut the model into pieces and glue them together after printing.

What is the difference between SLA and FFF technologies?

FFF (or FDM) 3D printing uses filament as the source material – a strand of plastic. The material is melted and extruded through the nozzle, which is a part of an extruder. SLA, on the other hand, is based on solidifying of liquid resins using UV light. Objects printed on FFF 3D printers have more visible layers compared to SLA. On the other hand, SLA printing has different disadvantages – such as the use of liquid resins, which are potentially harmful chemicals.

What kind of material is used for FFF 3D printing?

Various kinds of plastics, in some cases with additives. The most popular and commonly used filaments are PLA and PETG. However, you can select from a wide range of advanced (more durable) materials, such as ASA, PC Carbon Fiber and Nylon.

How long does a print job take?

A simple question that is difficult to answer. It depends on many different factors: primarily, it's the size of the printed object, but also the density of the infill, number of perimeters, lower and upper shells, nozzle diameter, layer height, model complexity, number of supports and other factors. Printing a figure 5 cm tall will take about an hour. However, with large and complex objects, you can easily get into dozens of hours of printing. Most slicing apps can estimate the overall printing time.

What to do with empty filament spools?

Dispose of them in the plastic waste bins. Unfortunately, it's not possible (due to a number of reasons) to buy the empty spools back from the customers. If you don't feel like throwing them away, you can use them for a variety of projects – check out our article at: prusa.io/spools.

Is it possible to print food?

Surprisingly, yes! You will need a specially modified 3D printer (there's a number of them in the RepRap family) and you can print with chocolate, or even print pancake dough directly on a pan.

Can I print a cup or a plate and use it for drinking and eating?

Yes, but there's a couple of things to keep in mind! PETG and PLA are harmless plastics that can get in touch with food. However, it's not advised to use the printed objects for eating or drinking without post-processing them first. Tiny gaps in layers are perfect for accumulation of bacteria and it's nearly impossible to clean these parts well. Before you start using a printed cup, use food-safe epoxy to coat the sides.

How do you measure the speed of a 3D printer?

While many 3D printers claim to print at incredible speeds, the reality is that these advertised numbers are primarily theoretical. To assess a 3D printer's speed accurately, it's recommended to download the manufacturer's slicer and check the time it calculates for your preferred settings. The most reliable way to compare 3D printers remains through their track record of reliability and feedback from the community.

Can I print erotic toys?

Yes, but rather just for display only. It’s the same problem as with cutlery (cups, plates) – there are gaps between layers where bacteria tend to accumulate. It’s possible to post-process the object and give it a coating to create a harmless surface.

Is it possible to 3D print a gun?

Theoretically, yes. If you take your time with post-processing, it can even look quite real. Would you put a real bullet in a plastic gun and pull the trigger, though? No? Neither would we! The plastic gun would most likely shatter in your hand and hurt you. Also, it would be impossible to take this gun through a metal detector, because the shell casing of the bullet would trip an alarm anyway. So maybe you’re thinking: “How about using metal powder (SLS printing)?” Yes, that would be theoretically possible. However, this scenario is completely pointless due to the high price of manufacturing. If you, for whatever reason, want to produce a gun at home, a simple lathe is more than enough.

Basics of 3D Printing with Josef Prusa

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