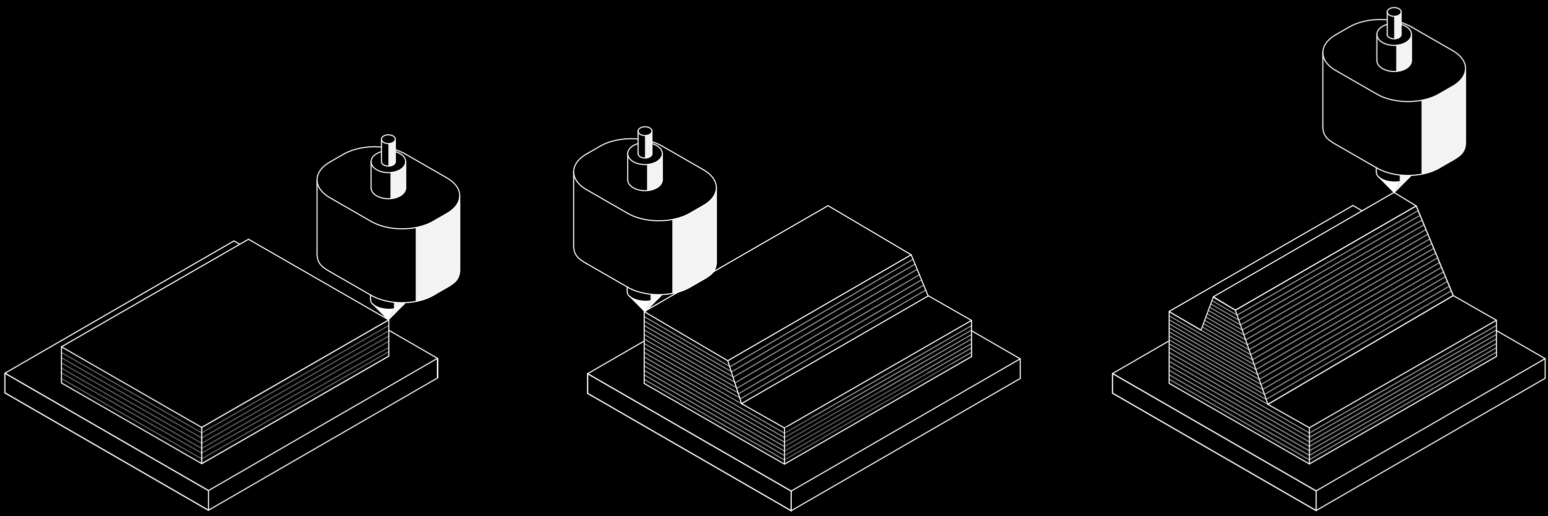

What is 3D printing? The definitive guide

Learn all you need to know about 3D printing in 30 minutes or less. Whether you are just getting started or you’re an experienced engineer, you’ll find this guide packed with useful tips and information.

3D HUBS

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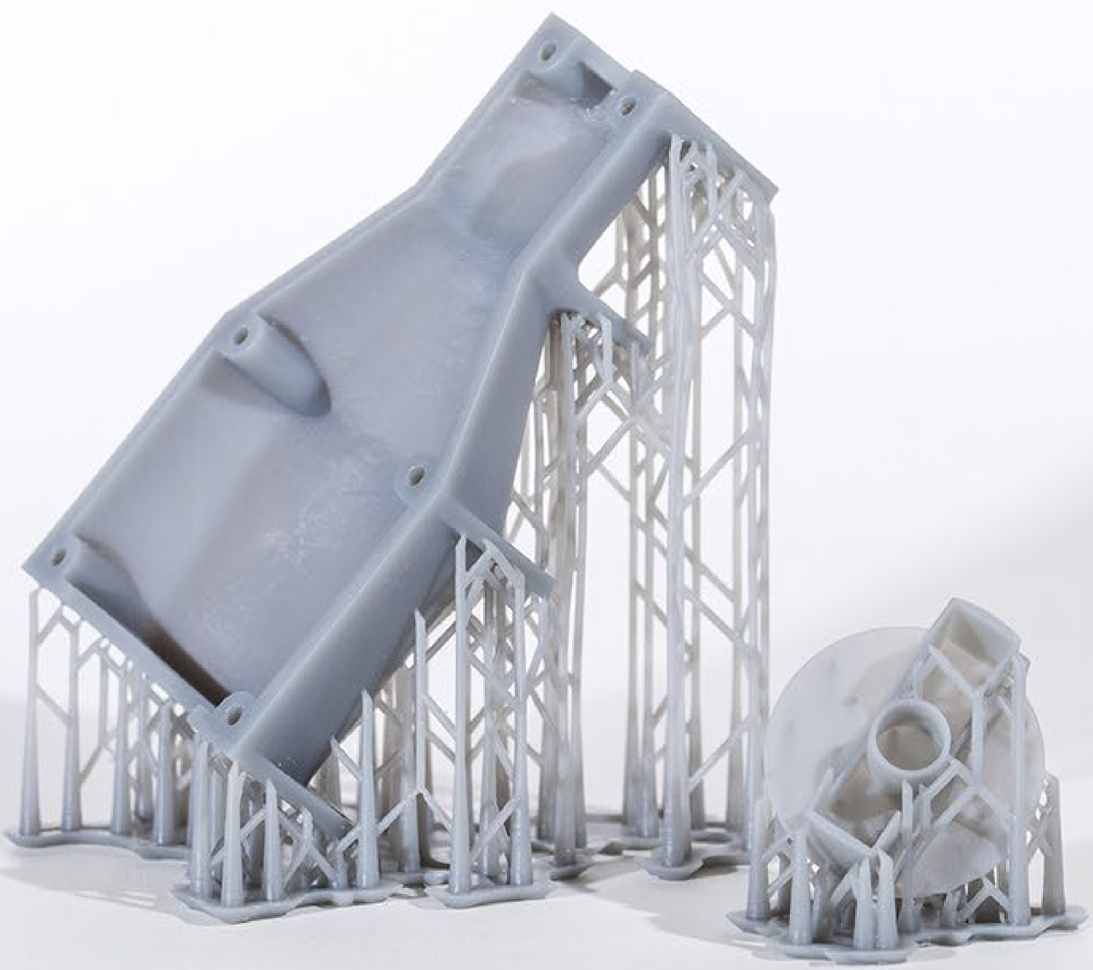


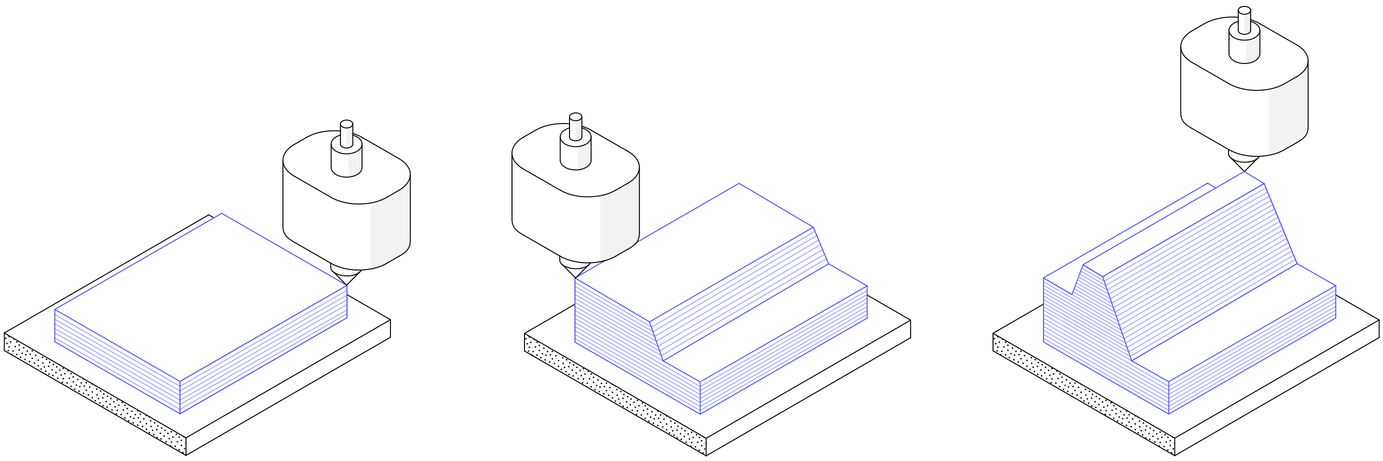
Part 1

The Basics

What is 3D printing? How does it work? What are the key benefits and limitations and main industrial applications? Here, we answer all these questions and examine how 3D printing compares to traditional manufacturing, helping you understand the state of the technology.

How does 3D printing work?

Every 3D printer builds parts based on the same main principle: a digital model is turned into a physical three-dimensional object by adding material a layer at a time.



Every 3D printer builds parts based on the same main principle: a digital model is turned into a physical three-dimensional object by adding material a layer at a time.

This where the alternative term Additive Manufacturing comes from - 3D printing is a fundamentally different way of producing parts compared to traditional subtractive (CNC machining) or formative (Injection molding) manufacturing technologies.

In 3D printing, no special tools are required (for example, a cutting tool with certain geometry or a mold). Instead the part is manufactured directly onto the built platform layer-by-layer, which leads to a unique set of benefits and limitations - more on this below.

The process always begins with a digital 3D model - which is the blueprint of the physical object. This model is sliced by the printer's software into thin 2-dimensional layers and then turned into a set of instructions in machine language (G-code) for the printer to execute. From here, the way a 3D printer works varies by process. For example, desktop FDM printers melt plastic filaments and lay it down onto the print platform through a nozzle (like a high-precision, computer-controlled glue gun). Large industrial SLS machines use a laser to melt (or sinter) thin layers of metal or plastic powders.

The available materials also vary by process. Plastics are by far the most common, but metals can also be 3D printed. The produced parts can also have a wide range of specific physical properties, ranging from optically clear to rubber-like objects.

Depending on the size of the part and the type of printer, a print usually takes about 4 to 18 hours to complete. 3D printed parts are rarely ready-to-use out of the machine though. They sometimes require some post-processing to achieve the desired level of surface finish. These steps take additional time and (usually manual) effort.

A brief history of 3D printing

> The sci-fi author, Arthur C. Clarke, was the first to describe the basic functions of a 3D printer back in 1964.

> The first 3D printer was released in 1987 by Chuck Hull of 3D Systems and it was using the "stereolithography" (SLA) process.

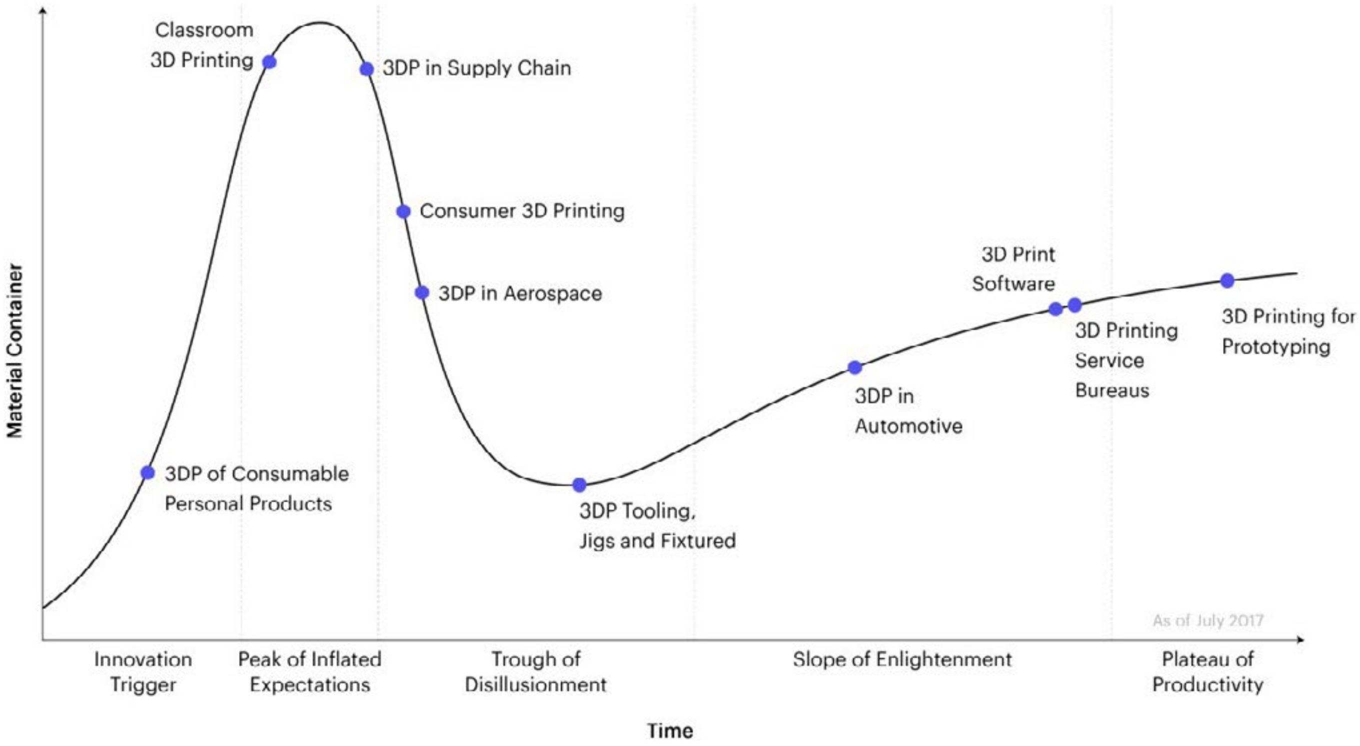
> In the 90's and 00's other 3D printing technologies were released, including FDM by Stratasys and SLS by 3D Systems. These printers were expensive and mainly used for industrial prototyping.

> In 2009, the ASTM Committee F42 published a document containing the standard terminology on Additive Manufacturing. This established 3D printing as an industrial manufacturing technology.

> In the same year, the patents on FDM expired and the first low-cost, desktop 3D printers were born by the RepRap project. What once costed $200,000, suddenly became available for below $2,000.

> According to Wohlers the adoption of 3D printing keeps growing: more than 1 million desktop 3D printers were sold globally between 2015 and 2017 and the sales of industrial metal printers almost doubled in 2017 compared to the previous year.

3D printing: beyond the hype



So where is 3D printing today? Is the hype over? Well, maybe but... The hype of the previous years was based on the idea of widespread consumer adoption. This was (and still is) a misleading interpretation of where the technology actually adds value. 3D printing today has found very specific roles in the world of manufacturing.

The inflated expectations of the previous years have given their place to an increased productivity. Many aspects of the technology are now mainstream and adopted by both professional and hobbyists.

Of course, 3D printing is an evolving technology. Every year new 3D printers are released that can have a significant impact on the industry. For example, HP launched their first 3D printing system relatively late (in 2016), but it proved to be one of the most popular industrial 3D printers already by 2017.

Benefits & Limitations of 3D printing

It is important to understand that 3D printing is a rapidly developing technology. It comes with its unique set of advantages, but also lags behind traditional manufacturing in some ways.

Here we summarize the most important benefits and limitations of 3D printing, taking into account the pro's and con's of all 3D printing technologies currently available. Use them to understand where 3D printing stands today and where it is headed in the near future.

Learn more about the advantages of 3D printing →

Benefits of 3D printing

Low-cost prototyping with very quick turnarounds

One of the main uses of 3D printing today is prototyping - both for form and function. This is done at a fraction of the cost of other processes and at speeds, that no other manufacturing technology can compete with: Parts printed on a desktop 3D printer are usually ready overnight and orders placed to a professional service with large industrial machines are ready for delivery in 2-5 days.

The speed of prototyping greatly accelerates the design cycle (design, test, improve, re-design). Products that would require 8+ months tp develop, now can be ready in only 8-10 weeks.

Very low start-up costs

In formative manufacturing (think Injection Molding and Metal Casting) each part requires a unique mold. These custom tools come at a high price (from thousands to hundreds of thousands each). To recoup these costs identical parts in the thousands are manufactured.

Since 3D printing does not need any specialized tooling, there are essentially no start-up costs. The cost of a 3D printed part depends only on the amount of material used, the time it took the machine to print it and the post-processing - if any - required to achieve the desired finish.

Large range of (speciality) materials

The most common 3D printing materials used today are plastics. Metal 3D printing finds also an increasing number of industrial applications. The 3D printing pallet also includes speciality materials with properties tailored for specific applications.

3D printed parts today can have high heat resistance, high strength or stiffness and even be biocompatible. Composites are also common in 3D printing. The materials can be filled with metal, ceramic, wood or carbon particles, or reinforced with carbon fibers. This results in parts with unique properties suitable for specific applications.

Geometric complexity at no extra cost

3D printing allows easy fabrication of complex shapes, many of which cannot be produced by any other manufacturing method. The additive nature of the technology means that geometric complexity does not come at a higher price.

Parts with complex or organic geometry optimized for performance cost just as much to 3D print as simpler parts designed for traditional manufacturing (sometimes even cheaper since less material is used).

Customization of each and every part

Have you ever wondered why we buy our clothing in standardized sizes? For the reasons we just mentioned, with traditional manufacturing, it is simply cheaper to make and sell identical products to the consumer. 3D printing though allows for easy customization.

Since start-up costs are so low, one only needs to change the digital 3D model to create a custom part. The result? Each and every item can be customized to meet a user's specific needs without impacting the manufacturing costs.

Limitations of 3D printing

Lower strenght & anisotropic material properties

Generally, 3D printed parts have physical properties that are not as good as the bulk material: since they are built layer-by-layer, they are weaker and more brittle in one direction by approximately 10% to 50%.

Because of this, plastic 3D printed parts are most often used for non-critical functional applications. DMLS & SLM though can produce metal 3D printed parts with excellent mechanical properties (often better than the bulk material). For this reason, they have found applications in the most demanding industries, like aerospace.

Post-processing & support removal

Printed parts are rarely ready to use off the printer. These usually require one or more post-processing steps. For example, support removal is needed in most 3D printing processes. 3D printers cannot add material on thin air, so supports are structures that are printed with the part to add material under an overhang or to anchor the printed part on the build platform.

When removed and they often leave marks or blemishes on the surface of the part they came in contact with. These areas need additional operations (sanding, smoothing, painting) to achieve a high quallity surface finish.

Less cost-competitive at higher volumes

3D printing cannot compete with traditional manufacturing processes when it comes to large production runs. The lack of a custom tool or mold means that start-up costs are low, so prototypes and a small number of identical parts (up to ten) can be manufactured economically.

It also means though that the unit price decreases only slightly at higher quantities, so economies of scale cannot kick in. In most cases, this turning point is at around 100 units, depending on the material, 3D printing process and part design. After that, other technologies, like CNC machining and Injection Molding, are more cost effective.

Limited accuracy & tolerances

The accuracy of 3D printed parts depends on the process and the calibration of the machine. Typically, parts printed on a desktop FDM 3D printer have the lowest accuracy and will print with tolerances of ± 0.5 mm. This means that if you design a hole with diameter of 10 mm, its true diameter after printing will something between 9.5 mm to 10.5 mm. Other 3D printing processes offer greater accuracy.

Industrial Material Jetting and SLA printers, for example, are able to produce parts down to ± 0.01 mm. It is important to keep in mind though, that these results can only be achieved after optimisation for specific features in a well-designed part. Metal 3D printed parts for critical applications are often finished via CNC machining or another process after printing, to improve their tolerances and surface finish.

Applications of 3D printing

Here we collected some examples to show how people used 3D printing and why they chose it for their specific use cases.

Automotive

The automotive industry has benefited greatly from the fast turnaround and the ease of customization offered by 3D printing. Volkswagen traditionally used CNC machining to create custom jigs and fixtures. CNC has typically longer production times and higher cost.

The same jigs and fixtures could be 3D printed overnight and tested on the assembly line the next day. Feedback from the operators was incorporated almost immediately and a new jig was ready to test the next day until the perfect tool was created.

Entertainment

3D printing is one of the favorite tools of movie makers today, due its ability to create believable props. The high design flexibillity of 3D printing helps entertainment professionals bring to life objects of their imagination. This can now be done quickly and at a much lower cost than the past.

One example comes from Vitaly Bulgarov, a concept designer whose resume includes working with movie studios. like Paramount and Dreamworks. He used 3D printing to quickly turn his computer sketches into a usable physical objects for a film he was working on.

DIY - Makers

For makers that constantly explore new ideas, 3D printing is the perfect tool. One of its key benefits is the ability to produce unlimited spare parts and new designs without relying on external vendors.

They can develop and customize their designs enabling them to create new and better concepts. Jack Davies, for example, is a product design student from Nottingham Trent University. He created his own electric skateboard using 3D printed parts. His boosted board has capabilities comparable to a commercially available electric skateboards, but for about a third of the price.

Education

The 3D printing technology has great potential in educational environments. With 3D printing, the course subjects can be brought to life through scaled replicas. This equips the students with practical (and very valuable) real-life experience.

Aerospace engineering students from the University of Glasgow worked together with Rolls Royce to create a functional 3D printed jet engine model. The model gives instant feedback to the students about changes they make during it operation, helping them gain very valuable practical experience.

Product design

With the help of 3D printing, product designers can easily customize their products at no extra costs. They can also create high-quality functional prototypes for a new product concept. This accelerates the design cycle and proves that their product idea works before a larger investment is made.

For example, Paul Kohlhaussen designed and created a functional prototype of his ultimate camera. He combined camera parts from different models and merged them together with a custom 3D printed body. He then took his idea to Kickstarter to succesfuly get funding for his project.

Industrial tooling

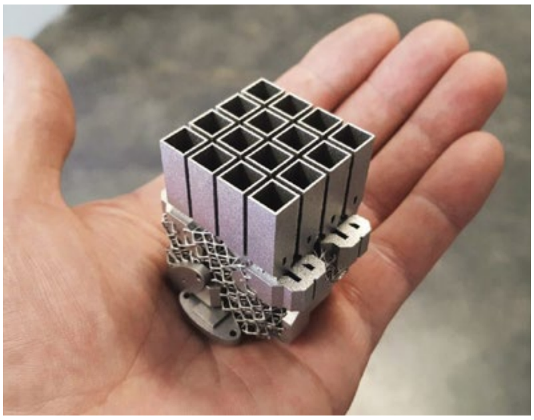
The development of new 3D printing materials with high heat resistance and stiffness, combined with the ability to create custom parts quickly and at a low cost, pushed 3D printing to find multiple applications around industrial tooling. For example, 3D printing is used today to manufacture low-run injection molds.

These molds are used to produce a few hundred parts (compared to the 10.000+ of metal molds), but come at a fraction of the cost of a "traditional" mold and can be manufactured overnight. This makes them ideal for low-volume, low-cost production or small tests runs before full scale manufacturing.

Healthcare

Did you know that today in the US hearing aids are manufactured almost exclusively using 3D printing? In fact, the companies that did not adopt the technology, very fast when out of business, as they could not keep up with the competition. The healthcare and prosthetics field has benefited greatly by adopting 3D printing.

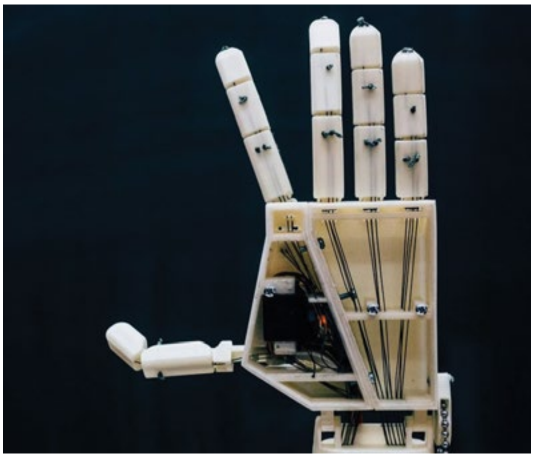
Custom shapes, such as hearing aids, no longer need to be made through manual labor. With 3D printing, they can be manufactured quickly from a digital file (by 3D scanning the patient's body, for instance). This brings substantial lower costs and lower production times.



Aerospace

Engineers in space & aerospace industriy use 3D printing to manufacture high-performance parts. The ability to create topology optimized structures with high strength-to-weight ratio and possibility to consolidate multiple components into a single part are particularly appealing.

Optisys LLC is a provider of micro-antenna products for aerospace and defence applications. They used metal 3D printing to reduce the number of discrete pieces of their tracking antenna arrays from 100 to only 1. With this simplification, Optisys managed to reduce the lead time from 11 to 2 months, while achieving a 95% weight reduction.



Robotics

In the field of robotics & automation, custom one-off parts are very often needed to develop new robotic mechanisms. 3D printing has evolved into one of the main manufacturing technologies of this industry, because of its speed, great design freedom and ease of customization. The large range of material options with unique properties, also allows the creation of unique structures, such as "soft" robots.

A team of engineering students from the University of Antwerp built a humanoid robotic arm that can translate speech into sign language and they used 3D printing almost exclusively to manufacture all custom structural parts of their robot.

3D Printing vs. Traditional Manufacturing

3D printing is an exceptional tool for manufacturing custom parts and prototyping. Due to its unique characteristics though, it is best suited for specific applications. When choosing between an additive (3D printing), subtractive (CNC machining) or formative (Injection Molding) manufacturing technology, then there are a few simple guidelines that can gudie your decision.

As a rule of thumb:

“3D printing is the best option when a single (or only a few) parts are required at a quick turnaround time and a low-cost or when the part geometry cannot be produced with any other manufacturing technology.”

Choosing a subtractive technology (CNC machining) makes more sense in the following scenarios:

> Medium volumes: When producing parts in the 100’s, then CNC machining is typically more economical. This is because the economies of scale start to kick in.

> Relatively simple geometries: Especially for metal parts, when the design can be manufactured easily through a subtractive process then CNC machining is the best option.

> High material requirements: When excellent material properties are essential, then CNC machining is a better option, as 3D printed parts typically have a lower strength.

> High dimensional accuracy: For functional parts with tight tolerances, CNC machining is the best option. For complex geometries, a hybrid approach (printing is done first, CNC machine is done afterwards) is also be a viable option.

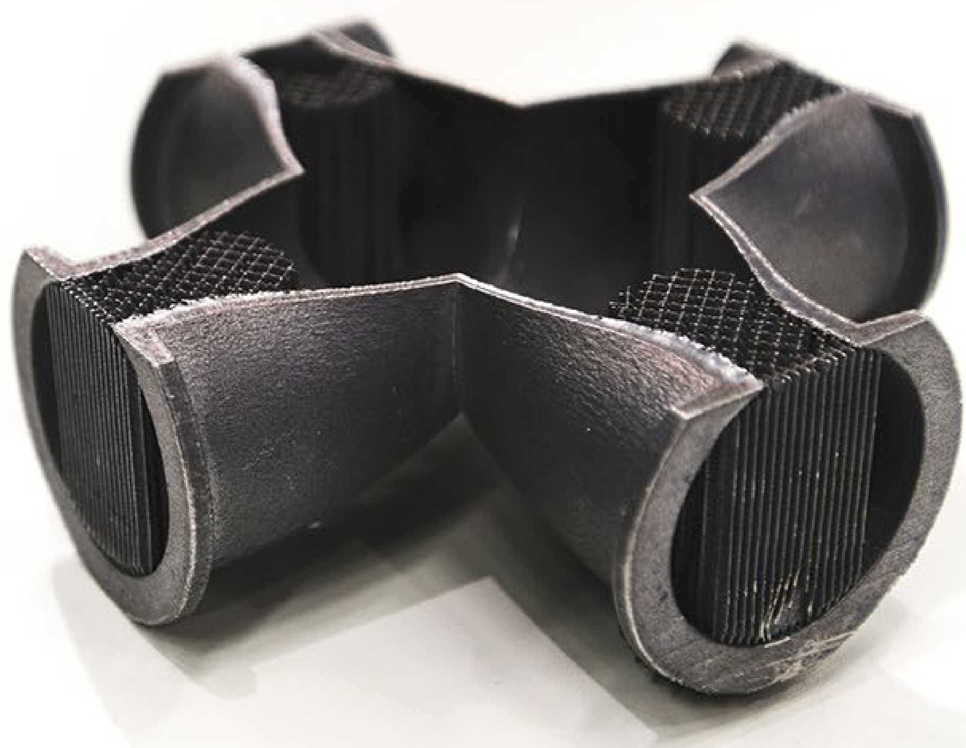
> For larger production (> 1000 parts), formative technologies (like Injection molding) are more cost effective and usually make the most financial sense.

For a quick reference in the unit cost, use the graph below. In this simplification, it was assumed that all technologies can produce the part geometry. When this is not the case, 3D printing is generally the preferred manufacturing solution.

To summarize:

“3D printing offers great geometric flexibility and can produce custom parts and prototypes quickly and at a low-cost, but when large volumes, tight tolerances or demanding material properties are required traditional manufacturing technologies are often a better option.”

Read an extensive article with practical examples →

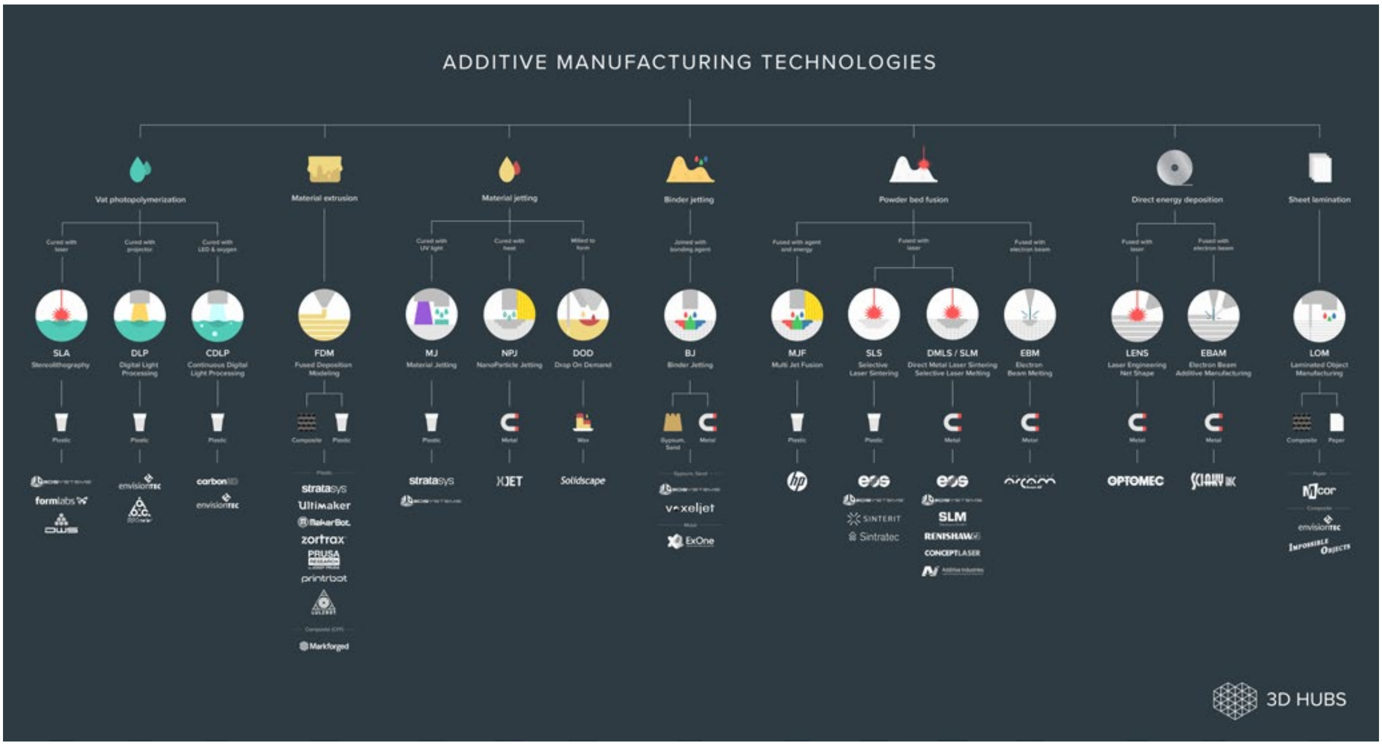


Part 2

3D Printing Processes

After reading this section, you will have a complete overview of today's 3D printing landscape. Quickly learn about the most popular processes and materials, as well as actionable decision making tools to help you select the optimal 3D printing process for your application.

The different types of 3D printing



This infographic illustrates the seven 3D printing categories, the main materials each group can print with and the most popular printer manufacturers. The ISO/ASTM 52900 standard categorized all different types of 3D printing under one of these seven groups:

> Material Extrusion (FDM)
Material is selectively dispensed through a nozzle or orifice

> Vat Polymerization (SLA & DLP)
Liquid photopolymer in a vat is selectively cured by UV light

> Powder Bed Fusion (SLS, DMLS & SLM)
A high-energy source selectively fuses powder particles

> Material Jetting (MJ)
Droplets of material are selectively deposited and cured

> Binder Jetting (BJ)
Liquid bonding agent selectively binds regions of a powder bed

> Direct Energy Deposition (LENS, LBMD)
A high-energy source fuses material as it is deposited

> Sheet Lamination (LOM, UAM)
Sheets of material are bonded and formed layer-by-layer

Download the poster here →

Fused Deposition Modelling (FDM)

In FDM, a spool of filament is loaded into the printer and then fed to the extrusion head, which is equipped with a heated nozzle. Once the nozzle reaches the desired temperature, a motor drives the filament through it, melting it. The printer moves the extrusion head, laying down melted material at precise locations, where it cools and solidifies (like a very precise hot-glue gun).

When a layer is finished, the build platform moves down and the process repeats until the part is complete. After printing is done, the part is usually ready to use but it might require some post-processing, such as removal of the support strucures or surface smoothing.

FDM is the most cost-effective way of producing custom thermoplastic parts and prototypes. It also has the shortest lead times - as fast as next-day-delivery - due to the high availability of the technology.

A wide range of thermoplastic materials is available for FDM, suitable for both prototyping and some functional applications.

As of limitations, FDM has the lowest dimensional accuracy and resolution compared to the other 3D printing technologies. FDM parts are likely to have visible layer lines, so post-processing is often required for a smooth surface finish.

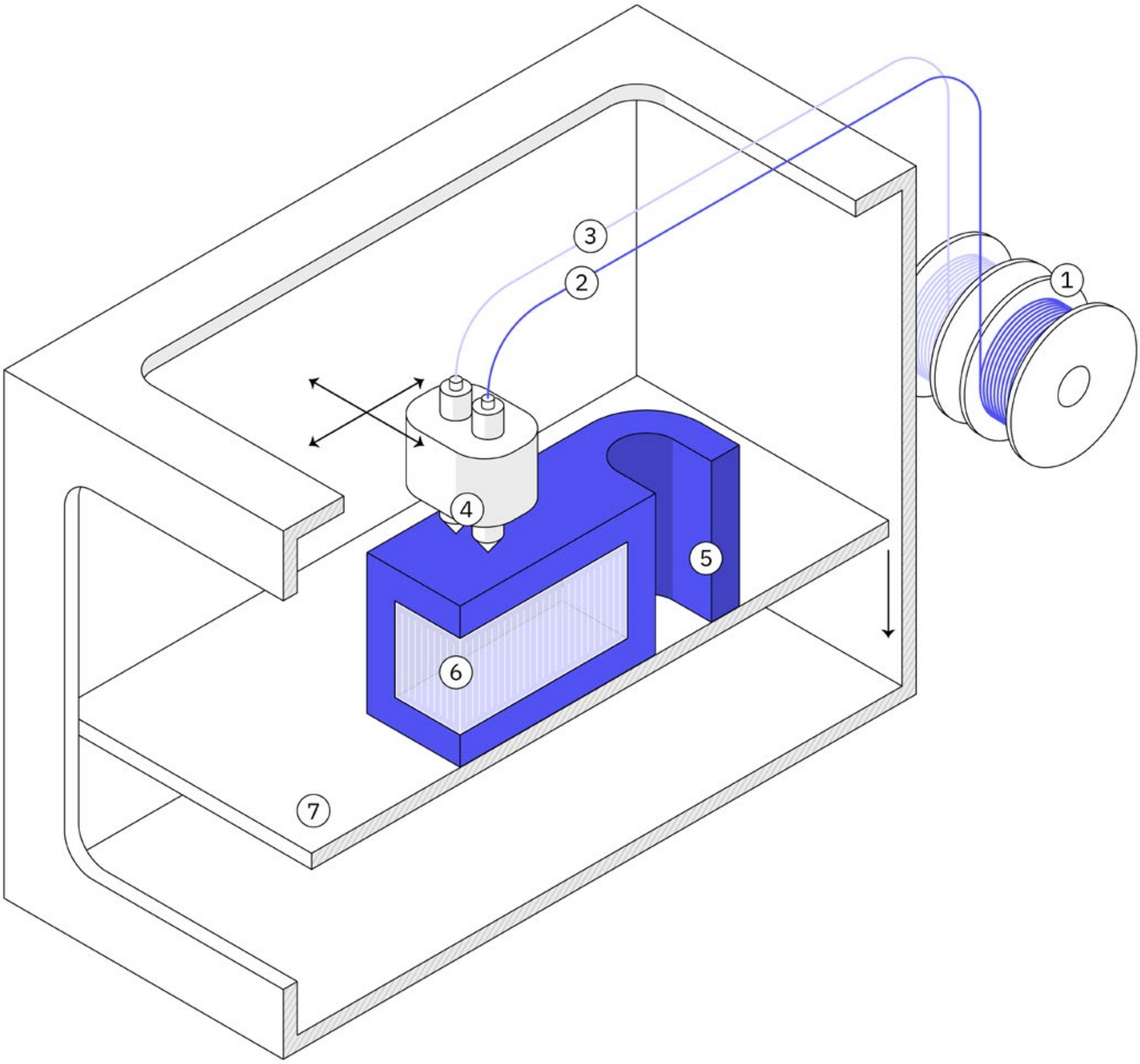
Additionally, the layer adhesion mechanism makes FDM parts inherently anisotropic. This means that they will be weaker in one direction and are generally unsuitable for critical applications.

Learn more about FDM 3D printing →

Popular FDM materials

FDM is the most widely available 3D printing process, mainly used in low-cost prototyping and for design verification with very fast turn around times.

> PLA > ABS > Nylon > TPU > ASA > PEI



1. Filament spools
2. Main filament
3. Support filament
4. Extrusion head
5. Printed part
6. Support structure
7. Build platform

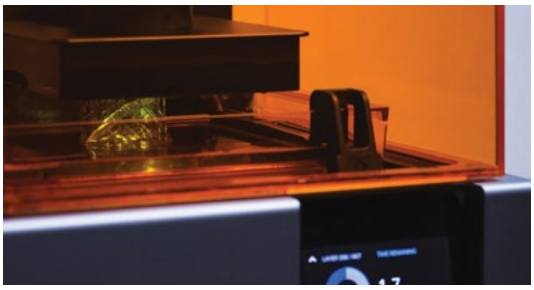
Pros

+ Low-cost prototyping
+ Fast turn-around (less than 24 h)
+ Functional applications (non-critical load)

Cons

- Limited dimensional accuracy
- Visible layer lines (can be post-processed)
- Anisotropic mechanical properties

Stereolithography & Digital Light Processing (SLA & DLP)



SLA and DLP are similar processes that both use a UV light source to cure (solidify) liquid resin in a vat layer-by-layer.

SLA uses a single-point laser to cure the resin, while DLP uses a digital light projector to flash a single image of each layer all at once.

After printing, the part needs to be cleaned from the resin and exposed to a UV source to improve its strength.Next, the support structures are removed and, if a high quality surface finish is required, additional post-processing steps are carried out.

SLA/DLP can produce parts with very high dimensional accuracy, intricate details and a very smooth surface finish ideal that are ideal for visual prototypes. A large range of speciality materials, such as clear, flexible, castable and biocompatible resins, or materials taylored for specific industrial applications, are also available.

Generally, SLA/DLP parts are more brittle than FDM parts, so they are not best suited for functional prototypes. Also, SLA parts must not be used outdoors, as their mechanical properties and color degrades when they are exposed to UV radiation from the sun.

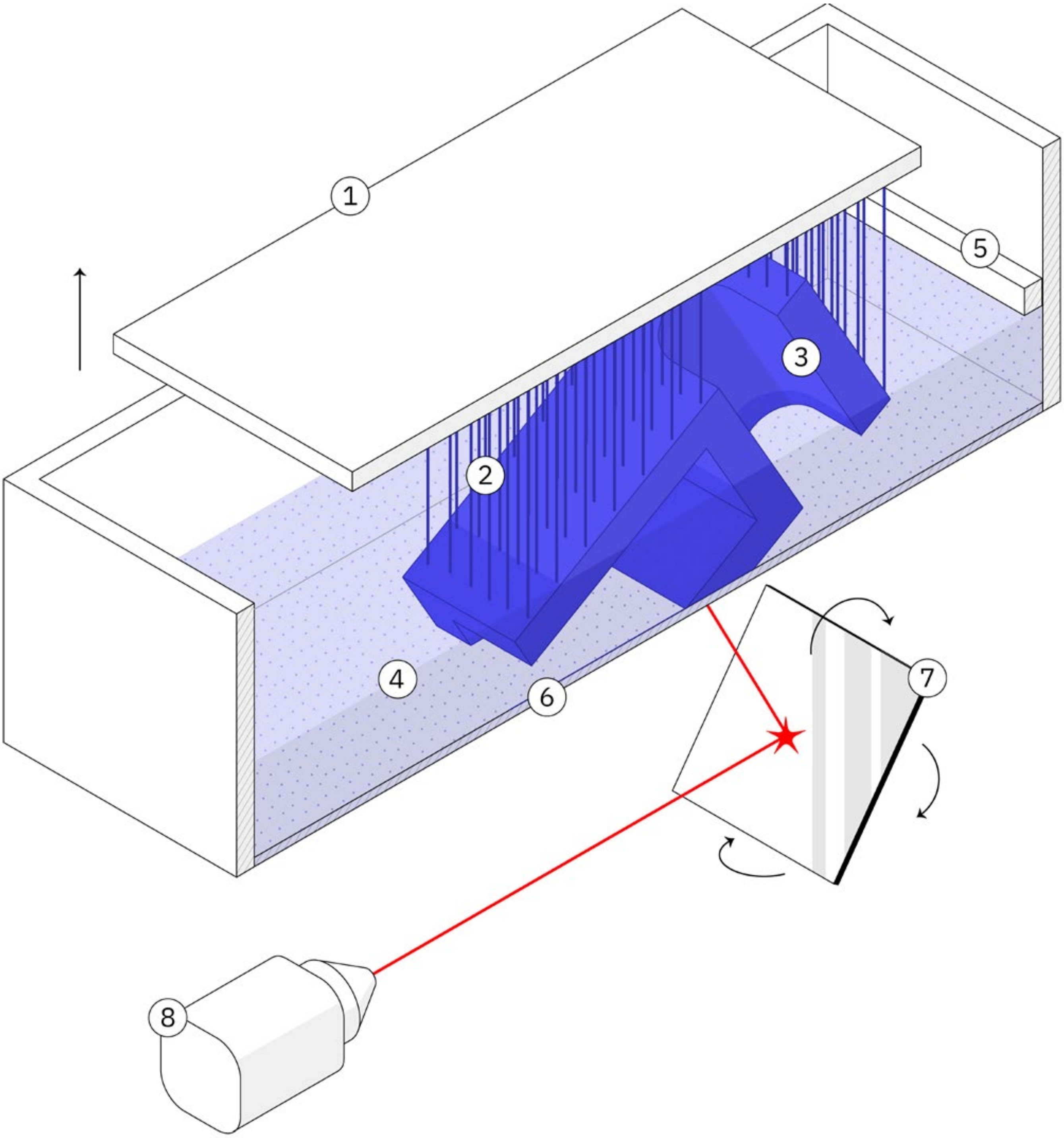
Support structures are always required in SLA/DLP which may leave small blemishes in the surfaces they come in contact with that need extra post-processing to remove.

Learn more about the SLA / DLP 3D printing →

Popular SLA / DLP materials

SLA is most suitable for visual applications where an injection mold-like, smooth surface finish, and a high level of feature detail are required.

> Standard   > Tough   > Durable   > Clear   > Rubber-like



1	Build platform	5	Recoater
2	Support structure	6	Transparent screen
3	Printed part	7	XY scanning mirror
4	Liquid photopolymer	8	UV laser

Pros

+ High accuracy & intricate details
+ Smooth surface ideal for visual prototypes
+ Large range of specialty materials

Cons

- Produces relatively brittle parts
- Degrade with exposure to sunlight
- Removal of support marks required

Selective Laser Sintering (SLS)

The SLS process begins with heating up a bin of polymer powder to a temperature just below the melting point of the material. A recoating blade or roller then deposits a very thin layer of powder - typically 0.1 mm thick - onto the build platform.

A CO2 laser scans the surface of the powder bed and selectively sinters the particles, binding them together. When the entire cross-section is scanned, the building platform moves down one layer and the process repeats.The result is a bin filled with parts surrounded by unsintered powder.

After printing, the bin needs to cool before the parts are removed from the unsintered powder and cleaned. Some post-processing steps can then be employed to improve their visual appearance, such as polishing or dying.

SLS parts have very good, almost-isotropic mechanical properties, so they are ideal for functional parts and prototypes. Since no support structures are required (the unsintered powder acts as support), designs with very complex geometries can be easily manufactured.

SLS is also excellent for small-to-medium batch production (up to 100 parts), since the bin can be filled throughout its volume and multiple parts can be printed at a single production run.

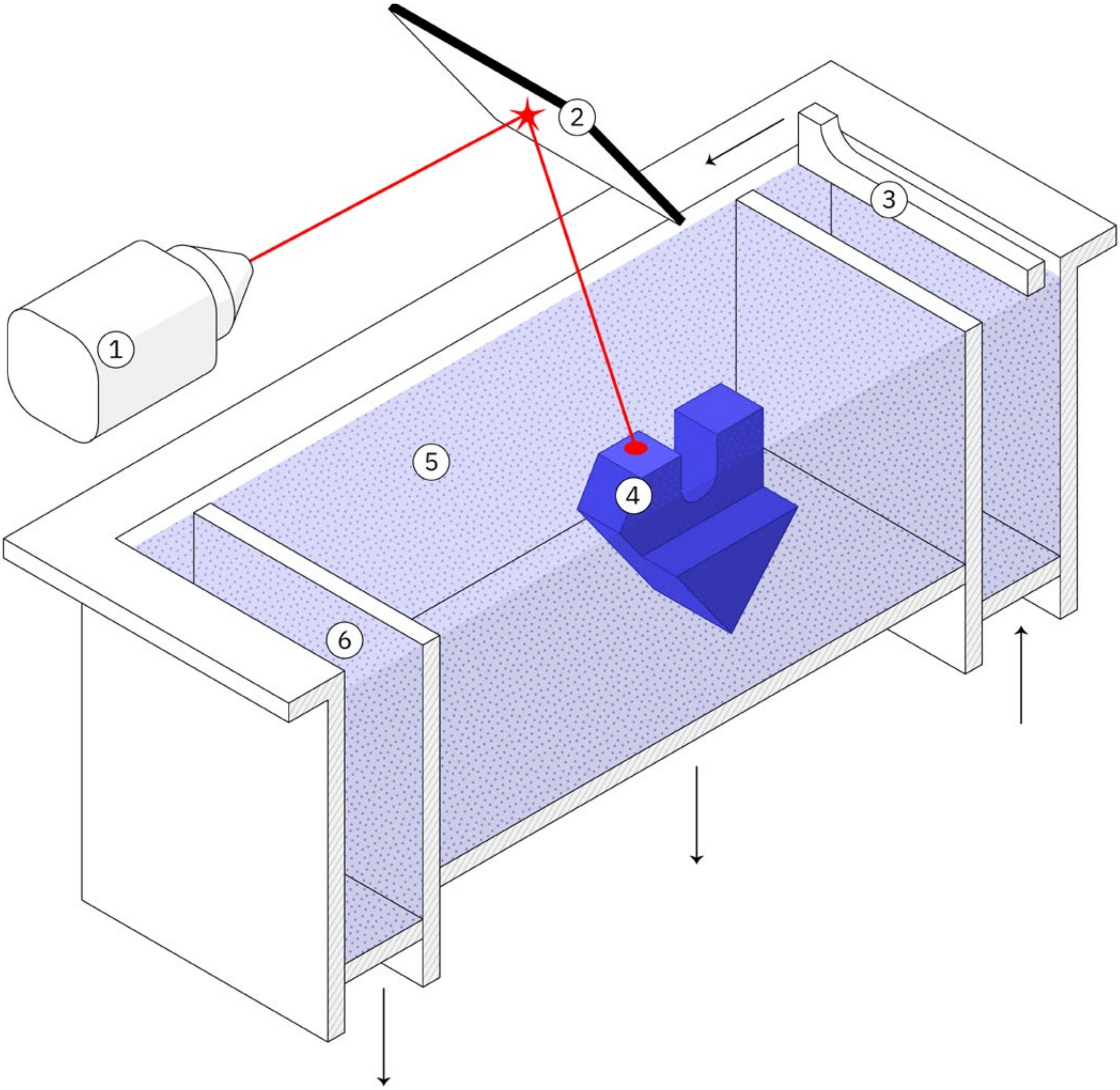
SLS printers are usually high-end industrial systems. This limits the availability of the technology and increases its cost and turn-around times (compared to FDM or SLA, for example). SLS parts have a naturally grainy surface and some internal porosity. If a smooth surface or watertightness is required, additional post-processing steps are needed. Beware that large flat surfaces and small holes need special attention, as they are susceptible to thermal warping and oversintering.

Learn more about the SLS process →

Popular SLA / DLP materials

SLS is used for both prototyping and small-batch production of functional plastic parts with good mechanical properties.

> Nylon > TPU > Carbon filled > Glass filled > PA 11



(1) Laser
(2) XY scanning mirror
(3) Recoater
(4) Printed part
(5) Building platform
(6) Overflow bin

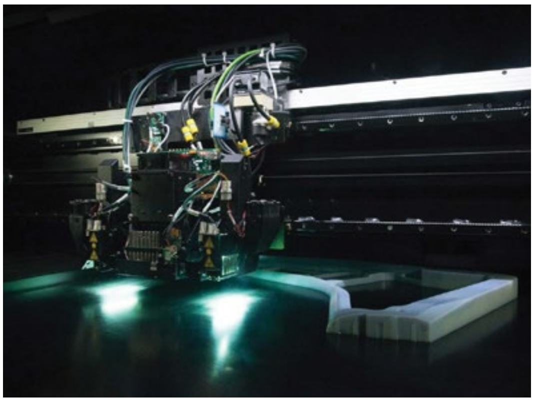
Pros

+ Ideal for functional prototypes
+ Complex geometries - no support needed
+ Small batch production capabilities

Cons

- Higher cost than FDM or SLA
- Slower turn-around due to batch production
- Grainy surface & internal porosity

Material Jetting (PolyJet)



Material Jetting works in a similar way to standard inkjet printing. However, instead of printing a single layer of ink on a piece of paper, multiple layers of material are deposited upon each other to create a solid part. Multiple print heads jet hundreds of tiny droplets of photo-polymer onto the build platform, which are then solidified (cured) by the UV light source.

After a layer is complete, the build platform moves down one layer and the process repeats. Support structures are always required in Material Jetting. A water-soluble material is used as support that can be easily dissolved during post-processing and that is printed at the same time as the structural material.

Material Jetting is the most precise 3D printing technology (with SLA/DLP being a close second). It is one of the few 3D printing processes that offers multi-material and full-color printing capabilities.

Material Jetted parts have a very smooth surface - comparable to injection molding - and very high dimensional accuracy, making them ideal for realistic prototypes and parts that need an excellent visual appearance. Material Jetting is one of the most expensive 3D printing processes and this high cost may make it financially unviable for some applications. Moreover, parts produced with Material Jetting are not best suited for functional applications.

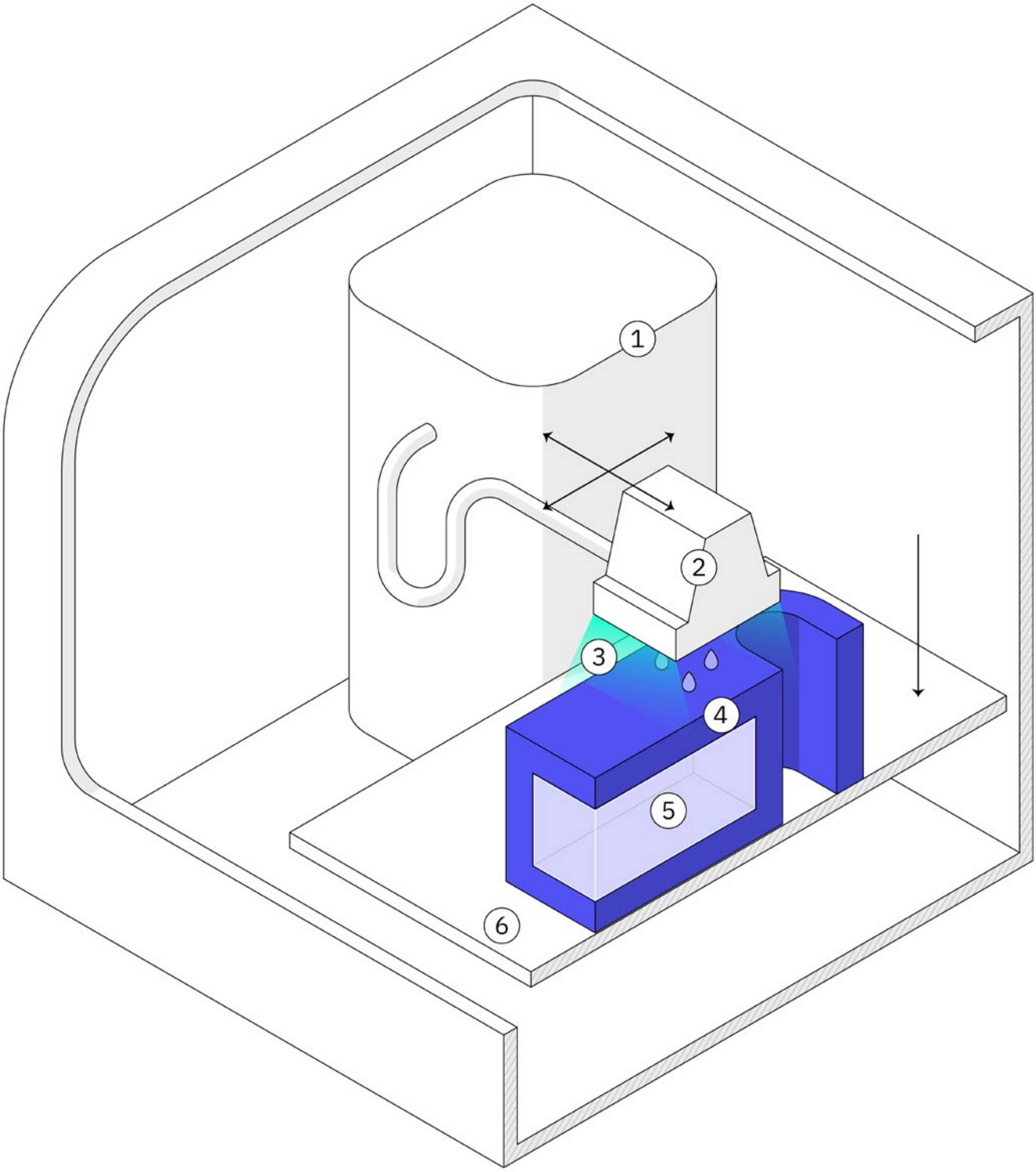
Like SLA/DLP, the materials used with this process are thermosets, so the produced parts tend to be brittle. They are also photosensitive and their properties will degrade over time with exposure to sunlight.

Learn more about the Material Jetting process →

Popular Materials Jetting materials

Material Jetting produces parts of the highest dimensional accuracy with a very smooth surface finish, used for both visual prototypes and tooling manuacturing.

> Standard   > Digital ABS   > Transparent   > Rubber-like



1	Material container	4	Printed part
2	Inkjet print head	5	Support structure
3	UV curing light	6	Building platform

Pros

+ High accuracy & very fine detail
+ Injection molding-like finish
+ Multi-material & full-color capabilities

Cons

- The most expensive plastic 3D printing process
- Mechanical properties degrade over time
- Produces relatively brittle parts

Direct Metal Laser Sintering & Selective Laser Melting (DMLS & SLM)

Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM) produce parts in a similar way to SLS: a laser source selectively bonds together powder particles layer-by-layer. The main difference, of course, is that DMLS and SLM produce parts out of metal.

The difference between the DMLS and SLM processes is subtle: SLM achieves a full melt of the powder particles, while DMLS heats the metal particles to a point that they fuse together on a molecular level instead. Support structures are always required in DMLS and SLM to minimize the distortion caused by the high temperatures required to fuse the metal particles.

After printing, the metal supports need to be removed either manually or through CNC machining. Machining can also be employed to improve the accuracy of critical features (e.g. holes). Finally, the parts are thermally treated to eliminate any residual stresses.

DMLS/SLM is ideal for manufacturing metal parts with complex geometries that traditional manufacturing methods cannot produce. DMLS/SLM parts can be (and should be) topology optimized to maximize their performance while minimizing their weight and amount of material used. DMLS/SLM parts have excellent physical properties, often surpassing the strength of the rough metal. Many metal alloys that are difficult to process with other technologies, such as metal superalloys, are available in DMLS/SLM.

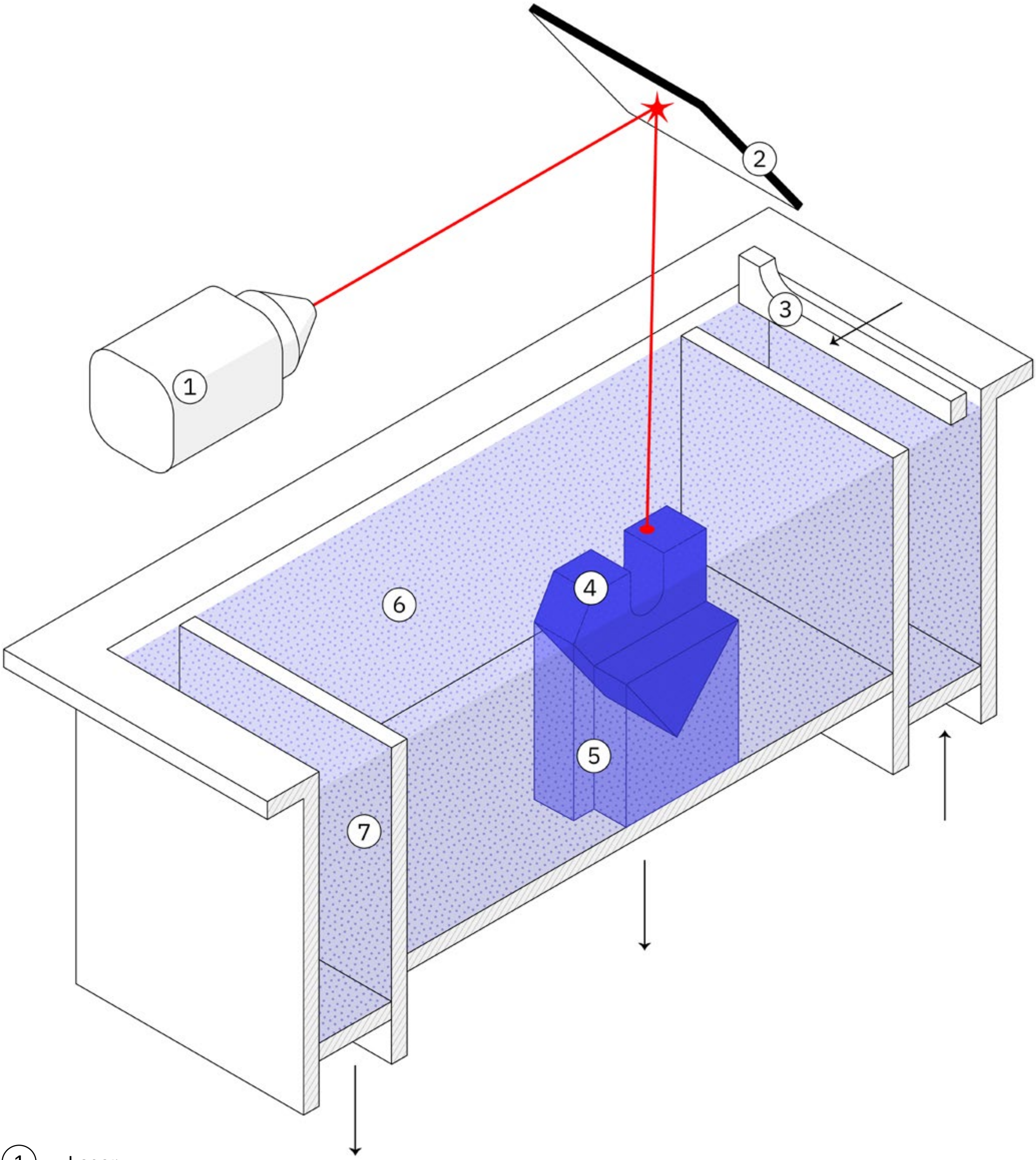
The costs associated with DMLS/SLM 3D printing are high: parts produced with this processes typically cost between $5.000 and $25.000.For this reason, DMLS/SLM should only be used to manufacture parts that cannot be produced with any other method. Moreover, the build size of modern metal 3D printing systems is limited, as the required precise manufacturing conditions are difficult to maintain for bigger build volumes.

Learn more about the DMLS / SLM process →

Popular DMLS / SLM materials

DMLS/SLM produce high performance, end-use metal 3D printed parts for industrial applications in aerospace, automotive and medical.

> Stainless steel   > Aluminum   > Titanium



1 Laser

2 XY scanning mirror

3 Recoater

4 Printed part

5 Support structure

6 Powder bed

7 Overflow bin

Pros

+ Highly complex, topology optimized metal parts
+ Parts with excellent material properties
+ Ideal for high-end engineering applications

Cons

- The most expensive plastic 3D printing process
- Mechanical properties degrade over time
- Produces relatively brittle parts

Binder Jetting

Binder Jetting is a flexible technology with diverse applications, ranging from low-cost metal 3D printing, to full-color prototyping and large sand casting mold production.

In Binder Jetting, a thin layer of powder particles (metal, acrylic or sandstone) is first deposited onto the build platform. Then droplets of adhesive are ejected by a inkjet printhead to selectively bind the powder particles together and build a part layer-by-layer. After the print is complete, the part is removed from the powder and cleaned.

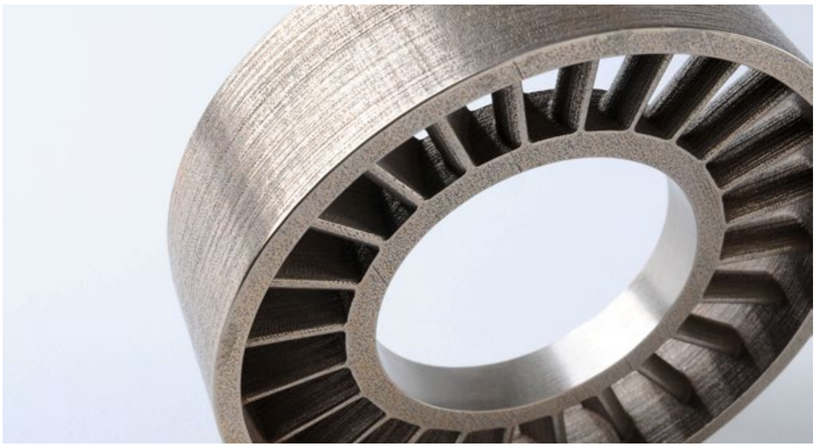
At this stage it is very brittle and additional post-processing is required. For metal parts this involves thermal sintering (similar to Metal Injection Molding) or infiltration with a low melting-point metal (for example, bronze), while for full-color parts are infiltrated with cyanoacrylate adhesive.

Binder Jetting can produce metal parts and full-color prototypes at a fraction of the cost of DMLS/SLM or Material Jetting respectively. Very large sandstone parts can also be manufactured with Binder Jetting, as the process is not limited by thermal effects (for example, warping).

Since no support structures are needed during printing, metal Binder Jetting parts can have very complex geometries and, like SLS, low-to-medium batch production is possible by filling up the whole build volume. Metal Binder Jetting parts have lower mechanical properties than the bulk material though, due to their porosity.

Due to the special post-processing requirements of Binder Jetting, special design restrictions apply. Very small details, for example, cannot be printed, as the parts are very brittle out of the printer and may break. Metal parts might also deform during the sintering or infiltration step if not supported properly.

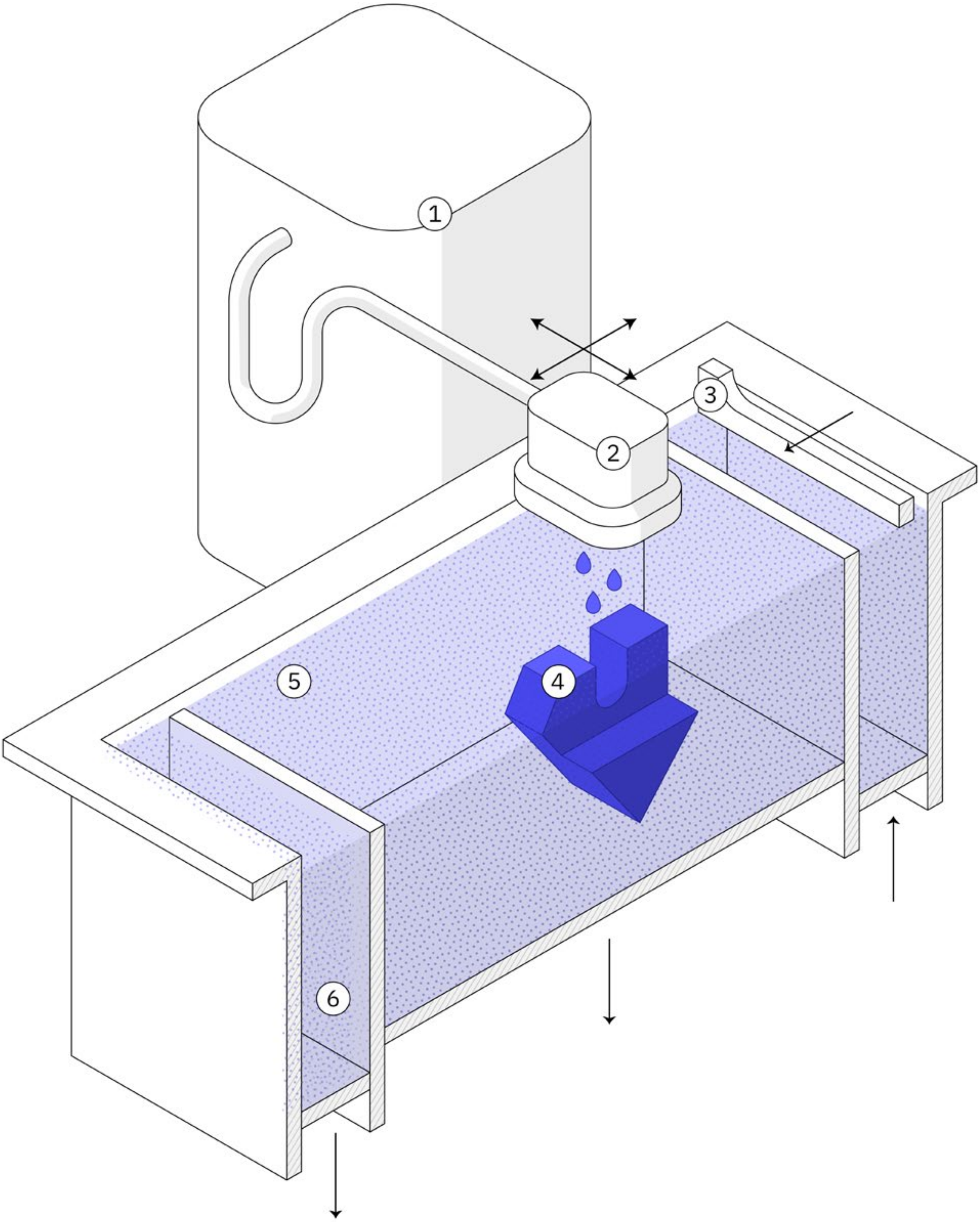
Learn more about the Binder Jetting process →



Popular Binder Jetting materials

Binder Jetting is most commonly used for full-color parts, low-cost metal printing, and large sand casting molds.

> Stainless steel



① Material container
② Inkjet print head
③ Recoater
④ Printed part
⑤ Powder bed
⑥ Overflow bin

Pros

+ Low-cost batch production of metal parts
+ Full-color prototyping in acrylic or sand
+ Very large printing capabilities in sand

Cons

- Inferior material properties to DMLS/SLM
- Design restriction due to post-processing
- Fine details may not be printable

How to select the right 3D printing process

Selecting the optimal 3D printing process for a particular application can be difficult. There are often more than one process that are suitable and each of them offers different benefits, like greater dimensional accuracy, superior material properties or better surface finish.

For this reason, we have prepared decision making tools and generalized guidelines to help you select the right 3D printing process for your project.

Read the full selection guide →

Generally, there are three main things you always need to consider:

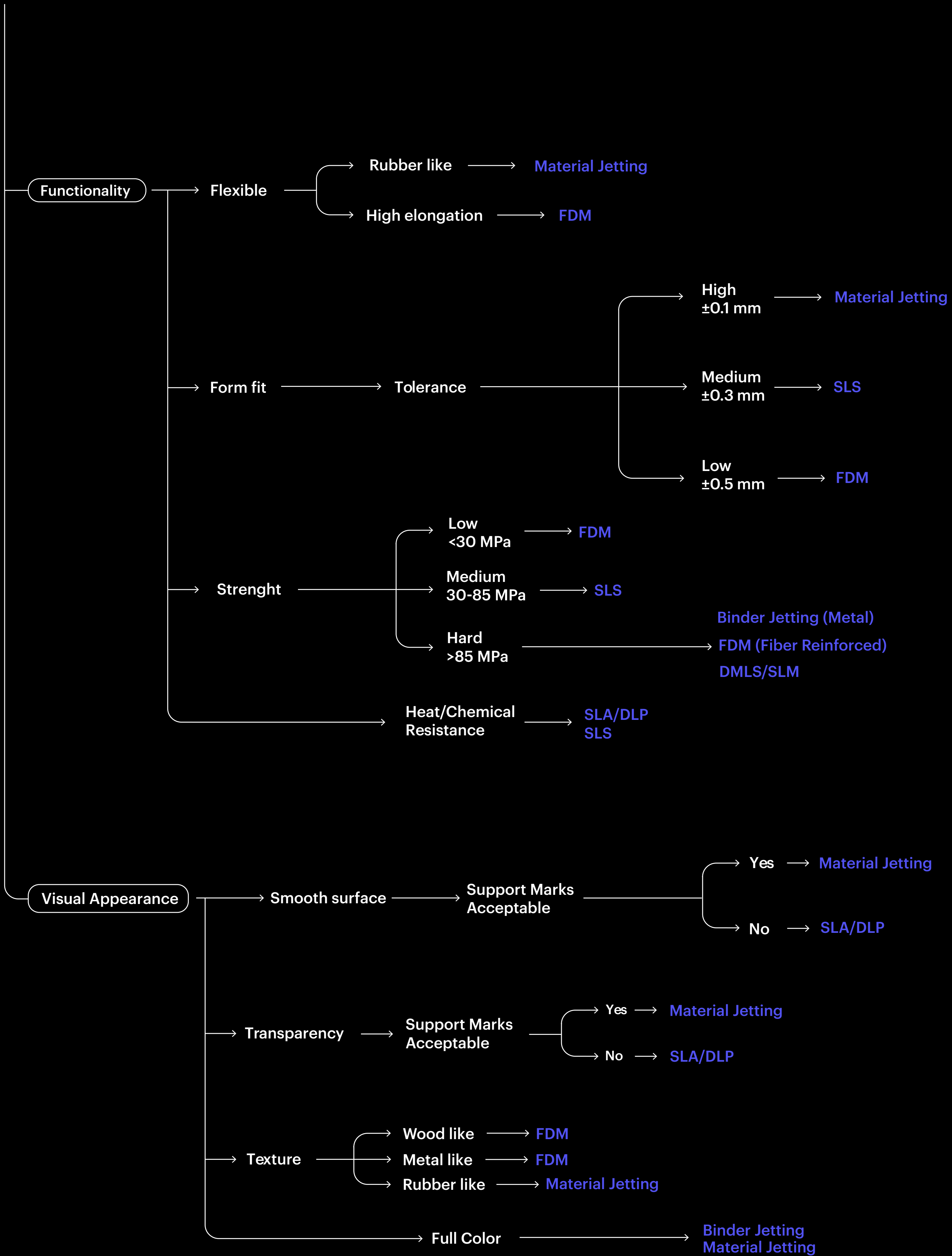
> The required material properties, such as strength, hardness, impact strength, etc.

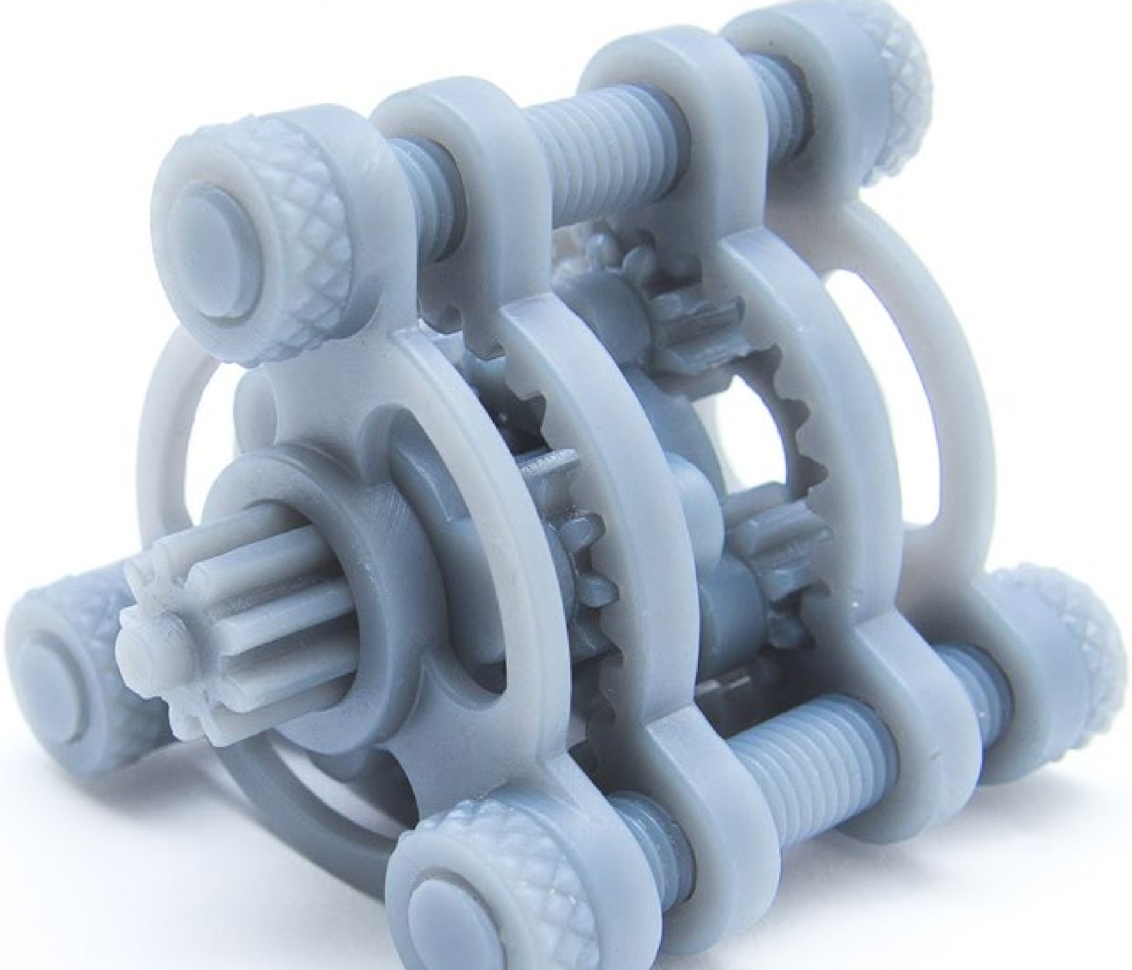
> The functional & visual design requirements, such as smooth surface, strength, heat resistance etc.

> The capabilities of the 3D printing process, such as accuracy, available print volume, layer height etc.

With these considerations in mind, identifying the best solution for your application should become straightforward. We have prepared a detailed guide to help you with the technical details or you can se this decision trees bellow for a quick reference.

What is your main design requirement?





Part 3

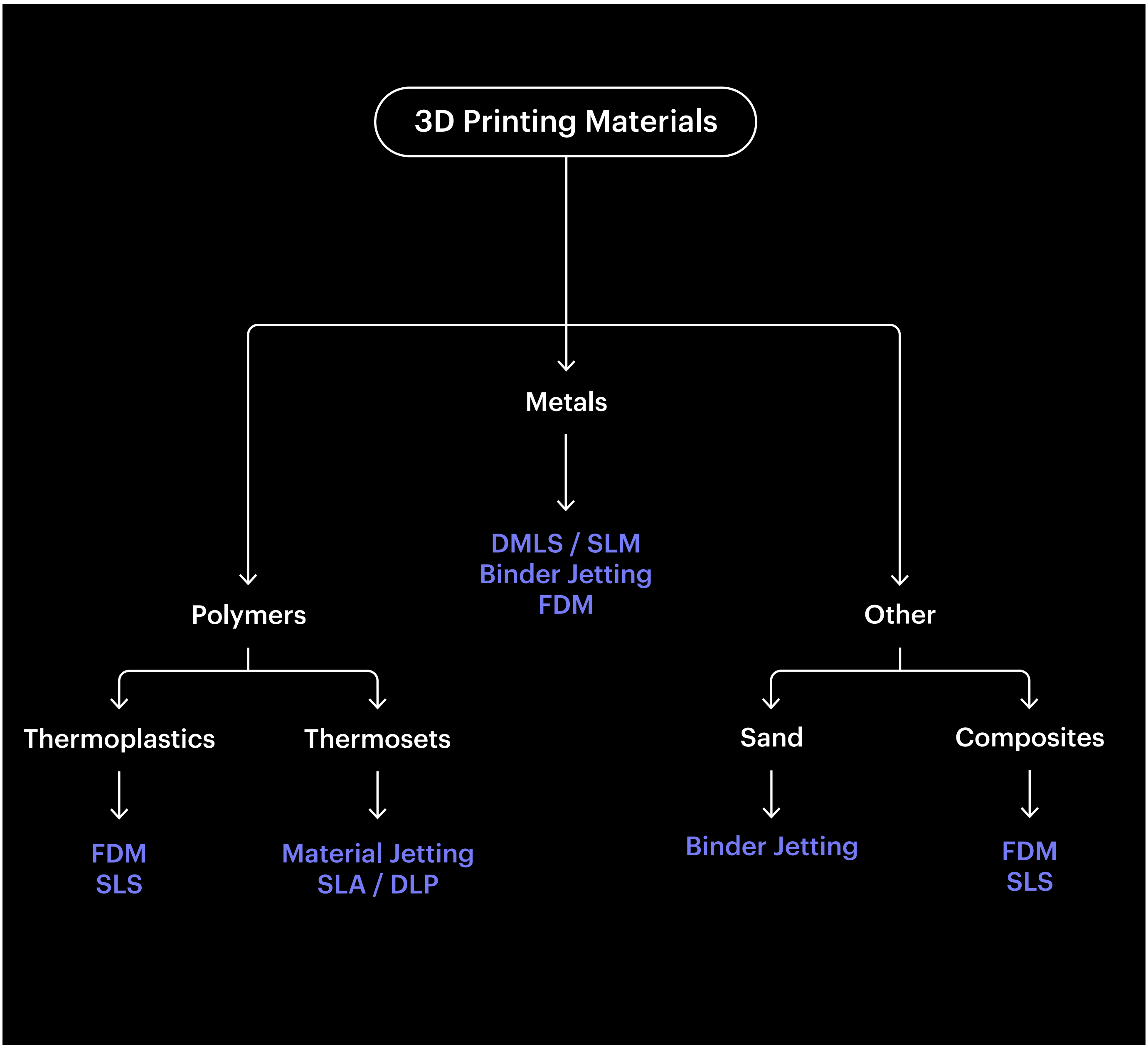
3D Printing Materials

3D printing materials are closely connected to 3D printing processes. In this section, you will learn more about the most popular materials that are used today in 3D printing and their key applications.

3D Printing Materials

3D printing materials are closely connected to 3D printing processes. In this section, you will learn more about the most popular materials that are used today in 3D printing and their key applications. Each 3D printing process is compatible with different materials. Plastics both thermoplastics and thermosets) are by far the most common followed by metals.

Some composites and ceramics can also be 3D printed. In the tables below, the most common plastics and metals used in 3D printing are summarized. If you are looking for a 3D Printing material with specific properties, you will probably find our Material Index useful.



Plastics

3D printing plastics are lightweight materials with a wide range of physical properties, suitable for both prototyping purposes and some functional applications. Plastics are either thermoplastics (with FDM or SLS), which are generally more suited for functional applications, or thermosets (with SLA/DLP or Material Jetting), which are generally more suited for applications that require good visual appearance.

PLA

The most common low-cost 3D printing plastic. Ideal for non-functional prototyping with sharp and precise details. Unsuitable for high temperatures

ABS

Commodity plastic with better mechanical and thermal properties compared to PLA and excellent impact strenght.

Resin

Thermoset polymers that produce high detail parts and smooth, injection mold-like surface. Ideal for prototyping.

Nylon

Nylon or polyamide (PA) is a plastic with excellent mechanical properties and high chemical and abrasion resistance. Perfect for functional applications.

PEI (ULTEM)

PEI is an engineering thermoplastic with good mechanical properties and exceptional heat, chemical and flame resistance.

TPU

TPU is a thermoplastic elastomer with low hardness and a rubber-like feel that can be easily flexed and compressed.

ASA

ASA has mechanical properties similar to ABS, with improved printability and UV stability and high chemical resistance. Commonly used for outdoor applications.

Metals

3D printing metals are mainly used in applications that require high strength, high hardness or high thermal resistance. When 3D printing in metal, topology optimization is critical to maximize part performance and mitigate the high cost of the technology. DMLS/SLM are compatible with the largest range of metals and produces parts for high-end engineering applications.

For less demanding use-cases, Binder Jetting is gaining popularity due to its lower cost with Stainless steel being by far the most used material. Extrusion based metal 3D printing systems (similar to FDM) are being released in 2018 which are expected to drive down the costs of metal 3D printing for prototyping purposes.

Stainless Steel

Stainless steel is a metal alloy with high ductility, wear and corrosion resistance that can be easily welded, machined and polished,

Aluminum

Aluminum is a metal with good strenght-to-weight ration, high thermal and electrical conductivity, low density and natural weather resistance.

Titanium

Titanium is a metal with an excellent strength-to-weight ratio with low thermal expansion and high corrosion resistance that is sterilizable and biocompatible.

Cobalt-chrome

Cobalt-chrome (CoCr) is a metal super-alloy with excellent strenght and outstanding corrosion, wear and temperature resistance.

Nickel Alloys

Nickel alloys (Ni) have excellent strenght and fatigue resistance. Can be used permanently at temperatures above 600°C

Part 4

Design for 3D printing

This section will give you tips on how to correctly prepare your digital files for 3D printing. We will delve deeper in the best design practices and give you recomendations on what software to use. If 3D modeling sounds tough (or if you are simply short in time), we give you a list of the best online model repositories to help you find existing designs.

How to get a printable model

All you need to start 3D printing is a model in the STL file format. Depending on your design skills and the time you want to invest, you can either:

> Design a 3D printable model yourself
> Find it in an online repository

In the next sections we will explore both options, but first let's learn more about STLs.

The STL file format

> STL is the industry standard file format that all 3D printers use.
> STLs use triangles to represent the outer and inner surfaces of a solid 3D object.
> Think of STLs files as the PDFs of 3D printing: they contain all the information needed to print a model, but they are not easy to edit.

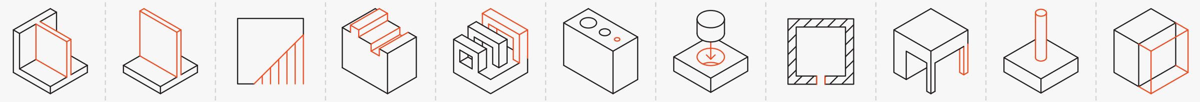
Learn more about the STL file format →

Design for 3D printing

If you are already familiar (or willing to get your hands dirty) with 3D design, then it is easy to create a 3D printable model yourself. Just use your favorite CAD software and simply save your models in the STL file format (all modern CAD software packages can do this). Don't forget that despite the great design freedom offered by 3D printing, some restrictions still do apply: anything can be "drawn" in 3D on a digital canvas, but not everything can be 3D printed.

DESIGN RULES FOR 3D PRINTING

3D HUBS



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

To make your life easier, we created a poster that sums up the most important design rules for each 3D printing process. You can print it and put it on your wall to always have it next to you while designing. If you want to delve deeper, we prepared multiple guides describing the key design consideration for 3D printing, full of actionable tips and advice.

Here are the top 3 things to look out for:

> Overhangs & support: 3D printers cannot deposit material on thin air. Walls at an angle greater than 45° will require support, affecting the surface quality.

> Level of detail: The smallest feature a printer can create depends on the size of the end effector (nozzle or laser) it uses.

> Layer height: The layer height affects the vertical resolution of a part. It’s effects are visible are areas with greater curvature (it appears as stair-stepping).

Follow the links below to read comprehensive design guidelines for each 3D printing process:

- > FDM
- > SLA/DLP
- > Material Jetting
- > SLS
- > DMLS/SLM
- > Binder Jetting

What is the best software for 3D printing?

Different software packages can aid you in each different stage of the design process: from CAD design, to STL repair and preparation. In this section we list the best software for 3D printing to help you get started. You can find below the list with the CAD design software we recommend to use for designing parts for 3D printing.

TinkerCAD
Easy to use online app to get started with 3D modelling.
> Ideal for: Beginners
> Platform: Online
> Price: Free

Solidworks

Professional CAD software used by over 2 million engineers worldwide.
> Ideal for: Professionals
> Platform: Windows
> Price: Paid

Rhinoceros

Multi-use, free-form surface modeler for engineering, architecture and jewelry design.
> Ideal for: Intermediates / Professionals
> Platform: Windows and Mac
> Price: Paid

Fusion360

CAD design, testing, and fabrication in a single collaborative cloud-based tool.
> Ideal for: Intermediates / Professionals
> Platform: Windows and Mac
> Price: Paid / Free (educational version)

Onshape

Collaborative cloud-based tool for professional applications including parts, assemblies, and drawings.
> Ideal for: Professionals
> Platform: Online
> Price: Paid / Free

Modifying / Repairing STL before print

If you are looking for the best tools you can use to modify or repair your STL files before you send them to print, here is a list of the best software currently available:

AUTODESK®
NETFABB®

Netfabb

Powerful additive manufacturing and design software for the most demanding applications.
> Ideal for: Professionals
> Platform: Windows
> Price: Paid / Free (educational version)

Meshmixer

State-of-the-art software for working directly on an STL file. It can clean, repair and modify any mesh.
> Ideal for: Intermediates
> Platform: Windows and Mac
> Price: Free

Slicing Softwares

The process of converting an STL file into machine language (G-code) is called slicing. Here are some of the best and most popular slicing software out there today:

Cura

Easy-to-use slicing software with integrated FDM 3D printer profiles for increased reliability and productivity.
> Ideal for: Beginners / Intermediates
> Platform: Windows / Mac
> Price: Free

SIMPLIFY3D®

Simplify3D

Advanced software for preparing and slicing 3D models with everything you need to work with your 3D printer.
> Ideal for: Intermediates / Professionals
> Platform: Windows , Mac and Linux
> Price: Paid

Find a design online

If you are new to design (or if you are simply looking for something to print fast), then one of the many online repositories might already have what you are looking for.

Here are some websites we recommend:

> Thingiverse - The largest online repository with thousands of free 3D printable files for desktop 3D printing.

> MyMiniFactory - A popular online repository with free 3D models that are tested for quality and are guaranteed to be 3D printable.

> Cults - An online marketplace with high quality 3D printable models by professional designers, and curated collections connected to big-name brands.

> Pinshape - An online marketplace with both free and premium 3D printable files, focusing mainly on hobbyists.

> GrabCAD - An online repository of many 3D models that also includes some 3D printable files, focusing mainly on engineering professionals.

Part 5

Start 3D printing

It is time to put your knowledge into practice. In this section, we will guide you through the basic steps needed to start 3D printing: from choosing what printer to buy to how to use an online service.

Buy a printer or use a 3D printing service?

Once you have your design ready, it is time to print! Again, you have two options here: you can either buy your own 3D printer or use an online service. It is an important decision to make, so we have collected arguments for both sides to help you make the right choice based on your specific needs. No matter how you decide to proceed, we give you tips on what you should do next in the following two sections.

Buy a 3D printer if...

> You need to print regularly (from 10 to 25+ times a week)

> You have one specific application in mind for the printer

> You are ready to make a sizeable investment

> You are prepared to setup, tinker and optimize your machine

> You have the necessary space and time to install and operate the printer

Use an online service if...

> You will need too few (less than 5) or too many (25+) parts printed per month

> You want to print using multiple processes and materials, including industrial printers

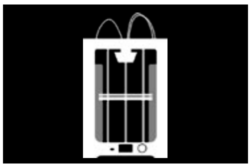
> You want to access the latest technologies at all times

> You prefer to focus your time on designing and perfecting your models

> You want to test and learn first before deciding what printer to buy

What 3D printer should you buy

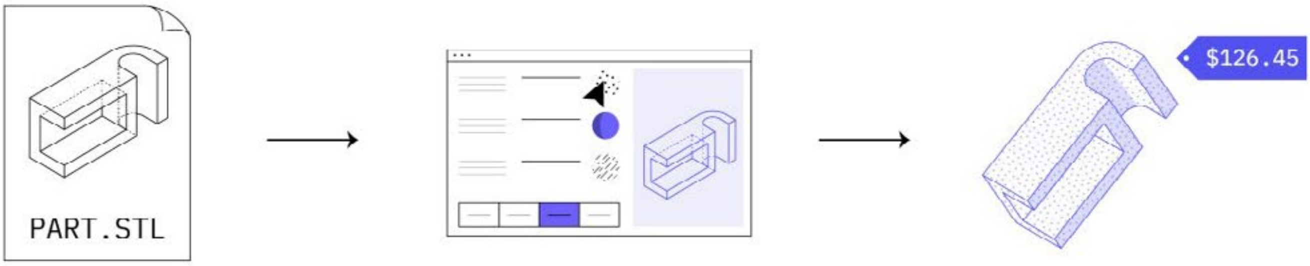
To answer this question, every year we reach out to our global network of 3D printing service providers to learn from their experiences and find out more about the 3D printers they own. With reviews from more than 10 thousand verified 3D printer owners, who have completed about 1.48 million prints on 650+ different 3D printer models, the result of our research is the most comprehensive 3D Printer Guide available.



Find the best printers

Read the full reviews of the best Prosumer, Workhorse, Plug 'n' Play, Budget, and Industrial 3D printers →

How to use a 3D printing service



1

Upload your 3D CAD files
in a supported format

2

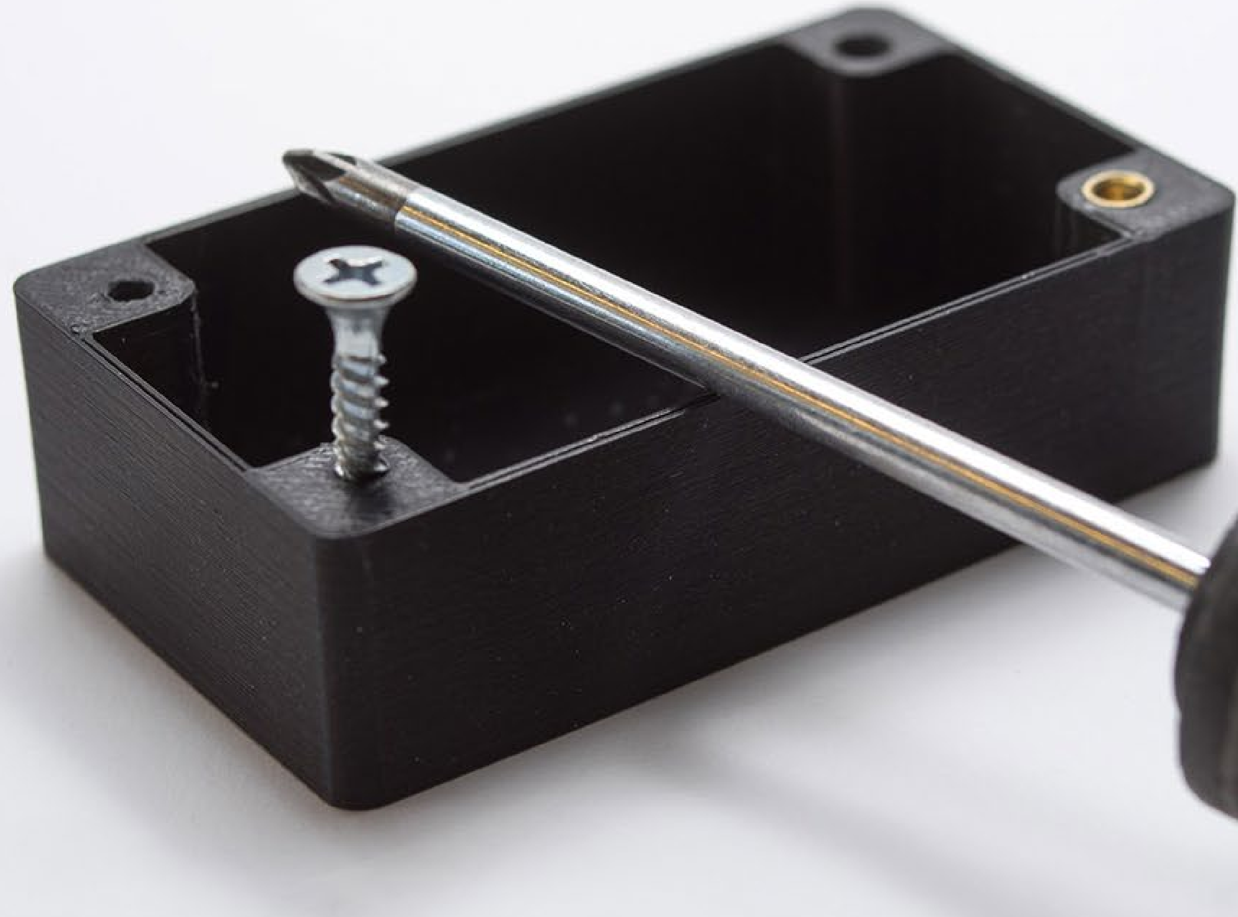
Specify your requirements
Material, process, layer height, lead time...

3

Get an instant quote
and start manufacturing

On 3D Hubs we are building the smartest manufacturing solution on the planet. By combining our global network of manufacturing services with our smart sourcing engine, you can instantly access readily available 3D printing production capacity near your area with the best possible quotes and lead times.

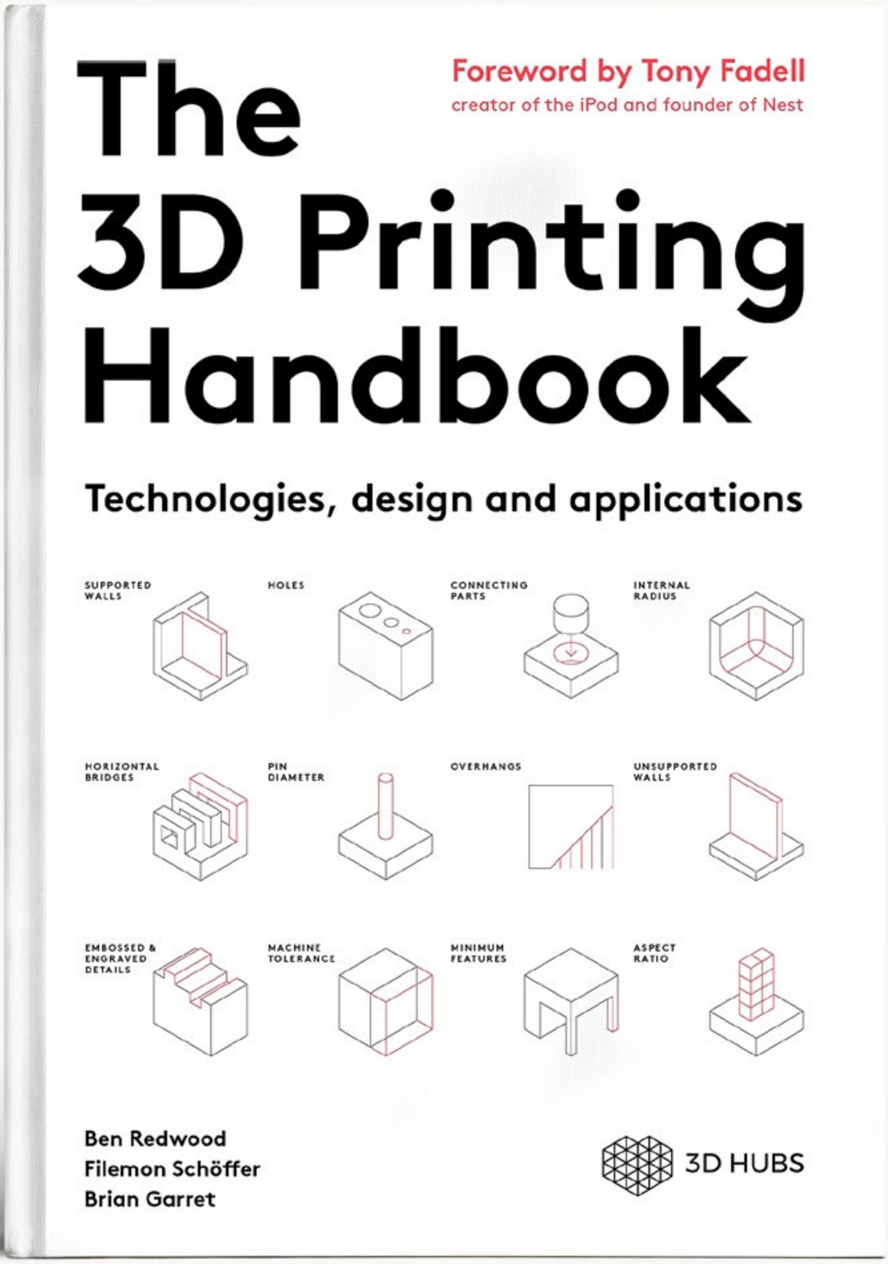
When you upload a part, our proprietary Design for Manufacturing (DFM) software detects any potential design issues before production begins, minimizing cost and delays. This way you can be certain that you always receive the best price possible at the fastest turnaround times for your 3D printed parts.



Part 6

Useful Ressources

In this guide we touched upon all you need to get you started with 3D printing, but there is plenty more to learn. Below we list the best and most useful resources on 3D printing and other digital manufacturing technologies for those who want to delve deeper.



The 3D Printing Handbook

If you're a professional looking to master the key aspects of 3D printing, this book is for you.

What's inside:

> Insights into the mechanism behind all major 3D printing technologies
> An understanding of the benefits and limitations of each technology
> Decision making tools for technology selection
> Actionable design advice and guidelines
> Industry case studies from world-leading brands

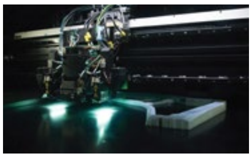
Get the book here →

Knowledge Base

Here, we touched upon all you need to get you started with 3D printing. There is plenty more to learn though in our Knowledge Base - a collection of technical articles on all manufacturing technologies, written by experts from 3D Hubs and the manufacturing industry.

Here is a selection of our most popular articles on 3D printing:

> Supports in 3D Printing: A technology overview
> The Advantages of 3D printing
> PLA vs. ABS: Choosing the right 3D Printing plastic
> Key Design Considerations for 3D printing
> HP MJF vs. SLS: A 3D Printing Technology Comparison



Knowledge Base

Quality articles for engineers and designers to learn about Digital Manufacturing. Written by manufacturing experts, curated by 3D Hubs →

Other Guides

Want to learn more about Digital Manufacturing?
There are more technologies to explore:

The Engineer's guide to CNC machining

Learn all you need to know about CNC machining in 25 minutes or less, wheter you are an experienced design engineer or just getting started with manufacturing, this guide is for you →

Injection Molding: The Complete Engineering Guide

You will know the fundamental mechanics of the Injection Molding process and how these relate to its key benefits & limitations →