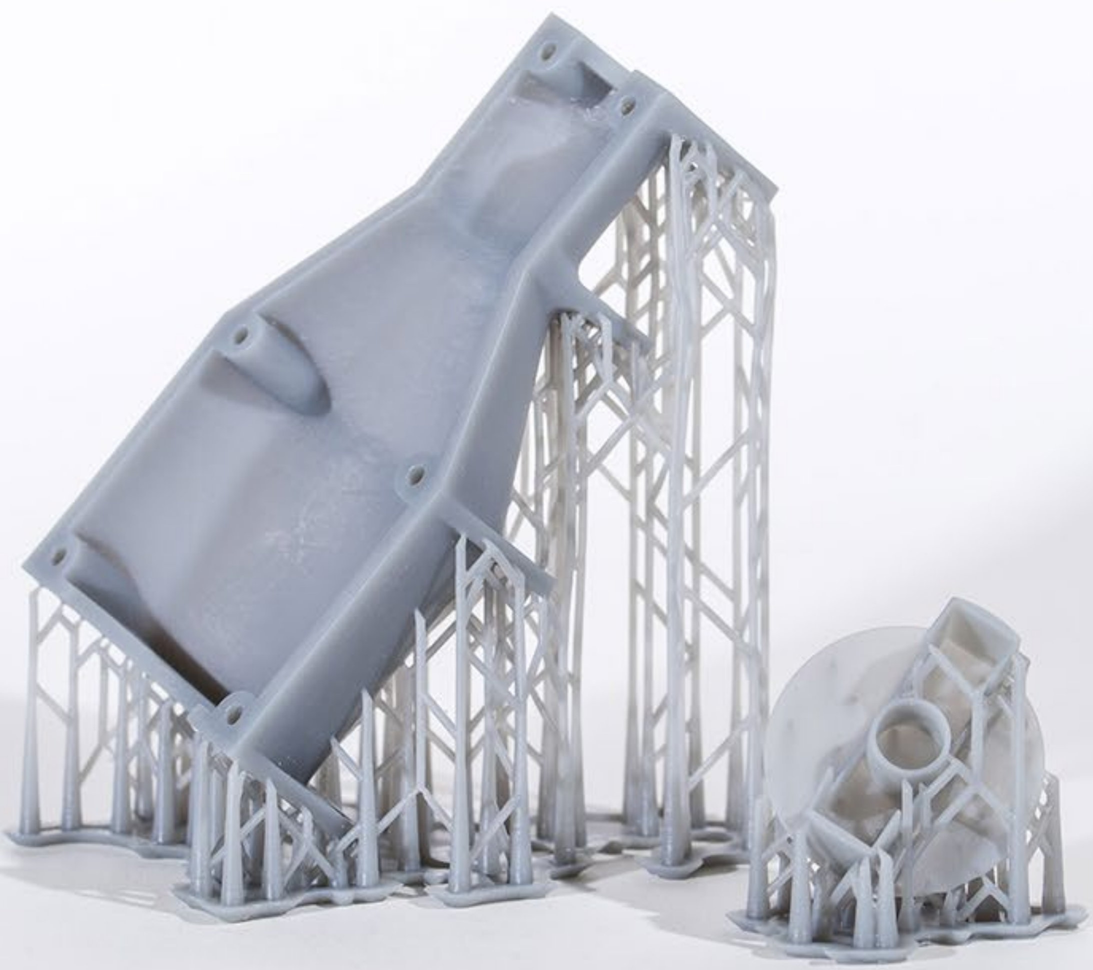


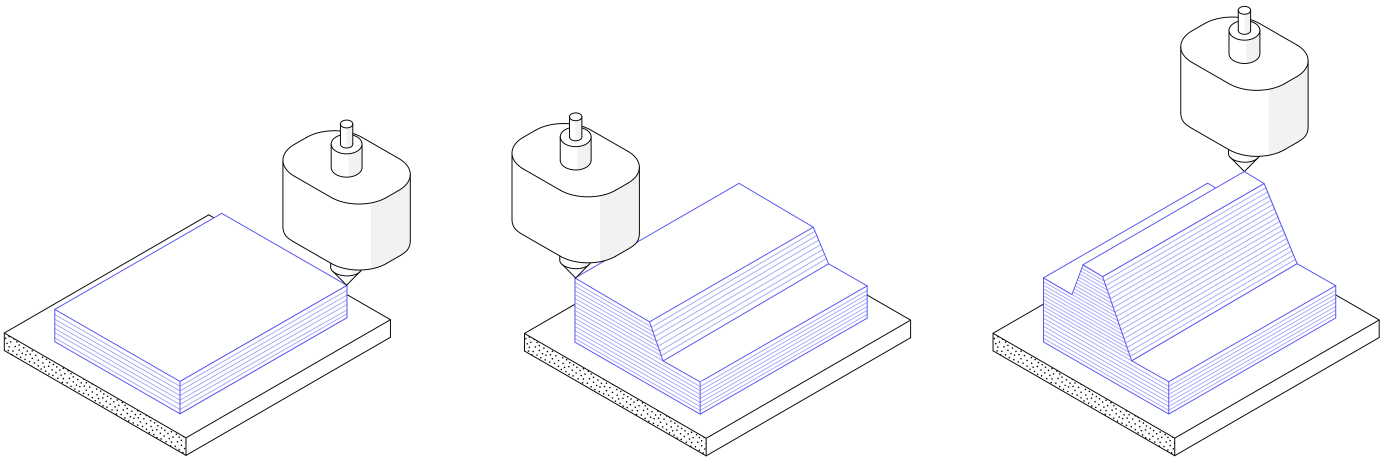
Part 1

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.

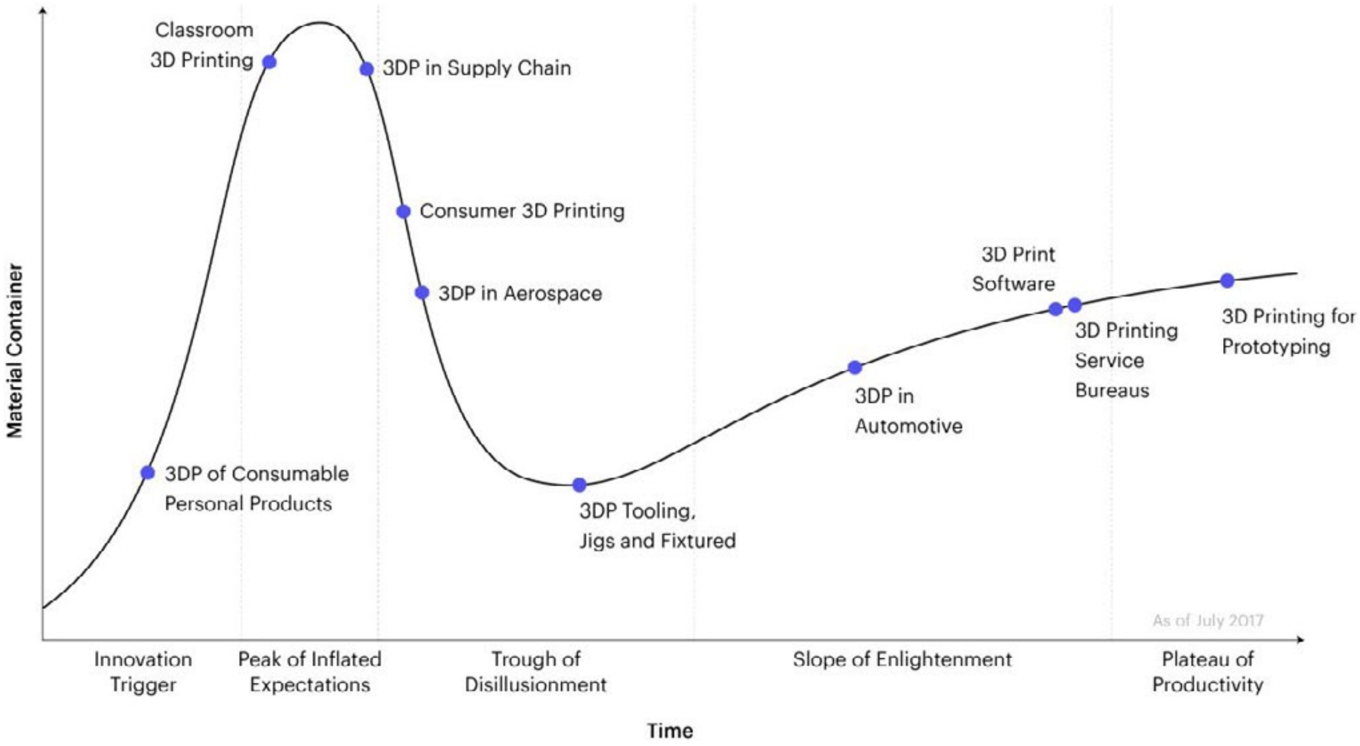
> In the 90’s and 00’s other 3D printing technologies were released, including FDM by Stratasys and SLS by 3D Systems. These printers were expensive and mainly used for industrial prototyping.

> 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

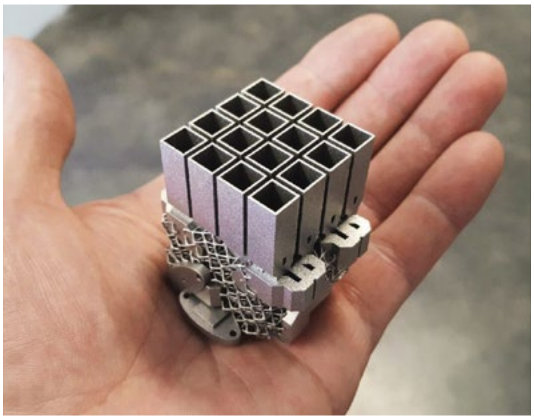
The development of new 3D printing materials with high heat resistance and stiffness, combined with the ability to create custom parts quickly and at a low cost, pushed 3D printing to find multiple applications around industrial tooling. For example, 3D printing is used today to manufacture low-run injection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

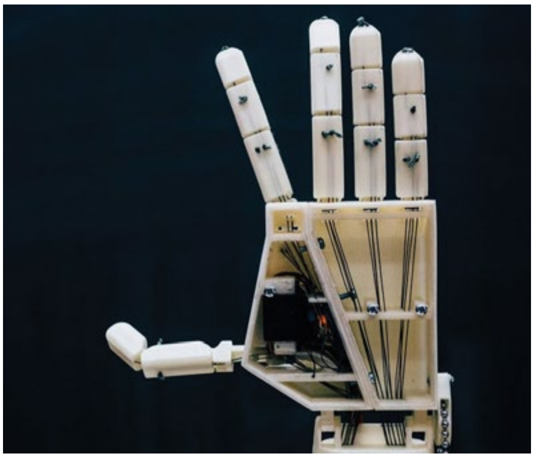
Custom shapes, such as hearing aids, no longer need to be made through manual labor. With 3D printing, they can be manufactured quickly from a digital file (by 3D scanning the patient's body, for instance). This brings substantial lower costs and lower production times.



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 →