2015

BEGINNER'S GUIDE TO 3D PRINTING

VERSION 0.1

THINK3D TEAM

Welcome to **think3D**'s Beginner's Guide to 3D Printing. This document is for people who are completely new to 3D printing technology or who are looking at gaining additional information on 3D printing technology. It is very imperative that 3D printing technology is going to change the world. Experts claim 3D printing is a much bigger revolution than internet. We at **think3D**, completely agree to those viewpoints. In this document, we shall be providing data to illustrate the true revolutionary nature of 3D printing.

This document is structured into 6 chapters, (a) Introduction of 3D printing (b) History of 3D printing (c) 3D Printing Technology (d) 3D Printing Processes (e) 3D Printing Materials (f) 3D Printing Applications (g) 3D Printing Glossary.

"3D printing" is an umbrella term for a host of processes and technologies that offer a full spectrum of capabilities for the production of parts and products in different materials. One thing common in all these processes is the manner in which production is carried out – layer by layer in an additive process. That is why "3D Printing" is also called additive manufacturing in contrast to traditional methods of production that are primarily subtractive in nature, also called as "subtractive manufacturing" or molding/casting processes.

Applications of 3D printing are emerging almost by the day, and, as this technology continues to penetrate more widely and deeply across industrial, maker and consumer sectors, this is only set to increase. Most reputable commentators on this technology sector agree that, as of today, we are only just beginning to see the true potential of 3D printing.

About think3D:

think3D is India's largest 3D printing platform covering all aspects of 3D printing technology like "Latest News", "3D Printers", "Print On Demand Services", "3D Design Store" & "3D Scanning Services". This document is an attempt to provide the readers a reliable authentic information on various terms and terminologies involved in 3D printing, its history, application areas and benefits.

If you wish to contact us and gain more information on 3D printing technology, you can always reach us at 040-3091 1007 or email us at info@think3d.in

CHAPTER 01

What is 3D Printing?

In the 20th century, no other invention affected the mankind more than technology did. With the advent of computers in 1950s and internet in 1990s, the fundamental way of doing things has through a massive changes. These technologies made our lives better, opened up new avenues and possibilities and gave us a hope for the future. But it generally decades for an ecosystem to be built across a particular technology to take it to masses and achieve the truly disruptive nature of that technology.

It is widely believed that 3D printing or additive manufacturing (AM) has the vast potential to become one of these technologies. There is a lot of coverage on 3D printing across many television channels, newspapers and online resources. What really is this 3D printing that some have claimed will put an end to traditional manufacturing as we know it, revolutionize design and impose geopolitical, economic, social, demographic and environmental and security implications to our everyday lives?

The most basic, differentiating principle behind 3D printing technology is that it is an additive manufacturing process. And this is indeed the key because 3D printing is a radically different manufacturing method based on advanced technology that builds up parts, additively, in layers at the sub mm scale. This is fundamentally different from any other existing traditional manufacturing techniques.

Traditional manufacturing process has evolved a lot over time from hand based manufacturing to the automated processes such as machining, casting, forming and molding. Yet these technologies all demand subtracting material from a larger block – whether to achieve the end product itself or to produce a tool for casting or molding processes — and this is a serious limitation within the overall manufacturing process.

For many applications traditional design and production processes impose a number of unacceptable constraints, including the expensive tooling, fixtures and the need for assembly for complex parts. In addition, the subtractive manufacturing processes, such as machining can result in up to 90% of the original block of material being wasted.

In contrast, 3D printing process can create objects directly by adding material layer by layer in a variety of ways, depending on the technology used. Simplifying the ideology behind 3D printing, for anyone that is still trying to understand the concept, it could be likened to the process of building something with Lego blocks automatically.

3D printing is an enabling technology that encourages and drives innovation with unprecedented design freedom while being a tool-less process that reduces prohibitive costs and lead times. Components can be designed specifically to avoid assembly requirements with intricate geometry and complex features created at no extra cost. 3D printing is also emerging as an energy efficient technology that can provide environmental efficiencies in terms of both the manufacturing process itself, utilizing up to 90% of standard materials and throughout the product's operating life through lighter and stronger design.

In recent years, 3D printing has gone beyond being an industrial prototyping and manufacturing process as the technology has become more accessible to small companies and even individuals. Previously, only big corporates used to own 3D printers as the scale and economics of owning 3D printer make it prohibitive for smaller companies to own one. But with the rapid decline of the printer cost, the technology has become more affordable. Now a days, smaller and less capable 3D printers can be acquired for under $1000.

This has opened up the technology to a much wider audience, and as the exponential adoption rate continues apace on all fronts, more and more systems, materials, applications, services and ancillaries are emerging.

CHAPTER 02

History of 3D Printing

The earliest 3D printing technologies first became visible in the late 1980's, at which time they were called Rapid Prototyping (RP) technologies. This is because the processes were originally conceived as a fast and more cost-effective method for creating prototypes for product development within industry. As an interesting side note, the first patent application for RP technology was filed by Dr. Kodama in Japan in May 1980. But the full patent specification was not filed before the one year deadline after the application thus voiding the patent application.

The first patent for 3D printing technology was issued in 1986 to Mr. Charles Hull for stereolithography apparatus (SLA). He invented the machine in 1983 and went on to cofound 3D Systems Corporation — one of the largest and most prolific organizations operating in the 3D printing sector today.

3D Systems' first commercial RP system, the SLA-1, was introduced in 1987. As with every new technology, there were lot of researchers working on various ways to attain additive manufacturing in 1980s. In 1987, Mr. Carl Deckard, who was working at the University of Texas, filed a patent in the US for the Selective Laser Sintering (SLS) RP process. This patent was issued in 1989 and SLS was later licensed to DTM Inc, which was later acquired by 3D Systems.

In 1989, one Mr. Scott Crump also filed a patent for Fused Deposition Modeling (FDM). He went to co-found another major 3D printing company called Stratasys Inc. As of 2015, FDM has become the most popular 3D printing technology for entry level machines. This technology is based on open source RepRap model. The FDM patent was issued to Stratasys in 1992. In Europe, 1989 also saw the formation of EOS GmbH in Germany, founded by Hans Langer. After a dalliance with SL processes, EOS' R&D focus was placed heavily on the laser sintering (LS) process, which has continued to go from strength to strength. Today, the EOS systems are recognized around the world for their quality output for industrial prototyping and production applications of 3D printing. EOS sold its first 'Stereos' system in 1990. The company's direct metal laser sintering (DMLS) process resulted from an initial project with a division of Electrolux Finland, which was later acquired by EOS.

Other 3D printing technologies and processes also emerged during these years, namely Ballistic Particle Manufacturing (BPM) originally patented by William Masters, Laminated Object Manufacturing (LOM) originally patented by Michael Feygin, Solid Ground Curing (SGC) originally patented by Itzchak Pomerantz and 'three dimensional printing' (3DP) originally patented by Emanuel Sachs. And so the early nineties witnessed a growing number of competing companies in the RP market but only three of the originals remain today — 3D Systems, EOS and Stratasys.

Throughout the 1990's and early 2000's a host of new technologies continued to be introduced, still focused wholly on industrial applications and while they were still largely processes for prototyping applications, R&D was also being conducted by the more advanced technology providers for specific tooling, casting and direct manufacturing applications. This saw the emergence of new terminology, namely Rapid Tooling (RT), Rapid Casting and Rapid Manufacturing (RM) respectively.

In terms of commercial operations, Sanders Prototype (later Solidscape) and ZCorporation were set up in 1996, Arcam was established in 1997, Objet Geometries launched in 1998, MCP Technologies (an established vacuum casting OEM) introduced the SLM technology in 2000, EnvisionTec was founded in 2002, ExOne was established in 2005 as a spinoff from the Extrude Hone Corporation and Sciaky Inc was pioneering its own additive process based on its proprietary electron beam welding technology. These companies all served to swell the ranks of Western companies operating across a global market. The terminology had also evolved with a proliferation of manufacturing applications and the accepted umbrella term for all of the processes was Additive Manufacturing (AM). Notably, there were many parallel developments taking place in the Eastern hemisphere. These technologies enjoyed some local success but couldn't really impact the global market around that time.

During the mid-nineties, the sector started to show signs of distinct diversification with two specific areas of emphasis that are much more clearly defined today. First, there was the high end of 3D printing, still very expensive systems, which were geared towards part production for high value, highly engineered, complex parts. At the other end of the spectrum, some of the 3D printing system manufacturers were developing and advancing 3D printers that kept the focus on improving concept development and functional prototyping. These were built to be cost-effective systems. These machines are prelude to today's desktop machines. However, these systems were all still very much for industrial applications. Looking back, this was really the calm before the storm.

In 2007, the market saw the first system under $10,000 from 3D Systems, but this never quite hit the mark that it was supposed to. This was partly due to the system itself, but also other market influences. The holy grail at that time was to get a 3D printer under $5000 — this was seen by many industry insiders, users and commentators as the key to opening up 3D printing technology to a much wider audience. For much of that year, the arrival of the highly anticipated Desktop Factory was heralded as the one to watch. It came to nothing as the organization faltered in the run up to production. Desktop Factory and its leader, Cathy Lewis, were acquired, along with the IP, by 3D Systems in 2008 and all but vanished. As it turned out though, 2007 was actually the year that did mark the turning point for accessible 3D printing technology — even though few realized it at the time. Dr Bowyer conceived a concept called RepRap. RepRap concept is to build an open source self-replicating 3D printer. The idea occurred in 2004 and the seed was germinated in the following years with some heavy slog from his team at Bath, most notably Vik Oliver and Rhys Jones, who developed the concept and built a working prototype of 3D printer using the deposition process. 2007 was the year the shoots started to show through and this embryonic, open source 3D printing movement started to gain visibility.

But it wasn't until January 2009 that the first commercially available 3D printer – in kit form and based on the RepRap concept – was offered for sale. This was the BfB RapMan 3D printer. Closely followed by Makerbot Industries in April the same year, the founders of which were heavily involved in the development of RepRap until they departed from the Open Source philosophy following extensive investment. Since 2009, a host of similar deposition printers have emerged with marginal unique selling points (USPs) and they continue to do so. The interesting dichotomy here is that, while the RepRap phenomenon has given rise to a whole new sector of commercial, entry-level 3D printers, the ethos of the RepRap community is all about Open Source developments for 3D printing and keeping commercialization at bay.

2012 was the year that alternative 3D printing processes were introduced at the entry level of the market. The B9Creator (utilizing DLP technology) came first in June, followed by the Form 1 (utilizing stereolithography) in December. Both were launched via the funding site Kickstarter — and both enjoyed huge success.

As a result of the market divergence, significant advances at the industrial level with capabilities and applications, dramatic increase in awareness and uptake across a growing maker movement, 2012 was also the year that many different mainstream media channels picked up on the technology. 2013 was a year of significant growth and consolidation. One of the most notable moves was the acquisition of Makerbot by Stratasys.

Heralded as the 2nd, 3rd and, sometimes even, 4th Industrial Revolution by some, what cannot be denied is the impact that 3D printing is having on the industrial sector and the huge potential that 3D printing is demonstrating for the future of consumers. What shape that potential will take is still unfolding before us.

CHAPTER 03

3D Printing Technology

The entire 3D printing technology can be divided into 3 steps – (a) 3D Design (b) Slicing (c) 3D Printing. 3D digital model is the starting point for any 3D printing process. This digital model can be created using various 3D design softwares or can also can be created using 3D scanning. Once the 3D model is created, it is then sliced into layers thereby converting the design into a file readable by 3D printer. 3D printer will then print this file layer by layer using the material given as input to the 3D printer. As stated, there are a number of different types of 3D printing technologies, which process different materials in different ways to create the final object. Functional plastics, metals, ceramics and sand are all routinely used for industrial prototyping and production applications. Research is also being conducted for 3D printing bio materials and different types of food.

Generally speaking though, at the entry level of the market, materials are much more limited. Plastic is currently the only widely used material — usually ABS or PLA. There is also a growing number of entry level machines that have been adapted for foodstuffs, such as sugar and chocolate.

The different types of 3D printers each employ a different technology that processes different materials in different ways. It is important to understand that one of the most basic limitations of 3D printing — in terms of materials and applications — is that there is no 'one solution fits all'. For example some 3D printers process powdered materials (nylon, plastic, ceramic, metal), which utilize a light/heat source to sinter/melt/fuse layers of the powder together in the defined shape. Others process polymer resin materials and again utilize a light/laser to solidify the resin in ultra-thin layers. Jetting of fine droplets is another 3D printing process, reminiscent of 2D inkjet printing, but with superior materials to ink and a binder to fix the layers.

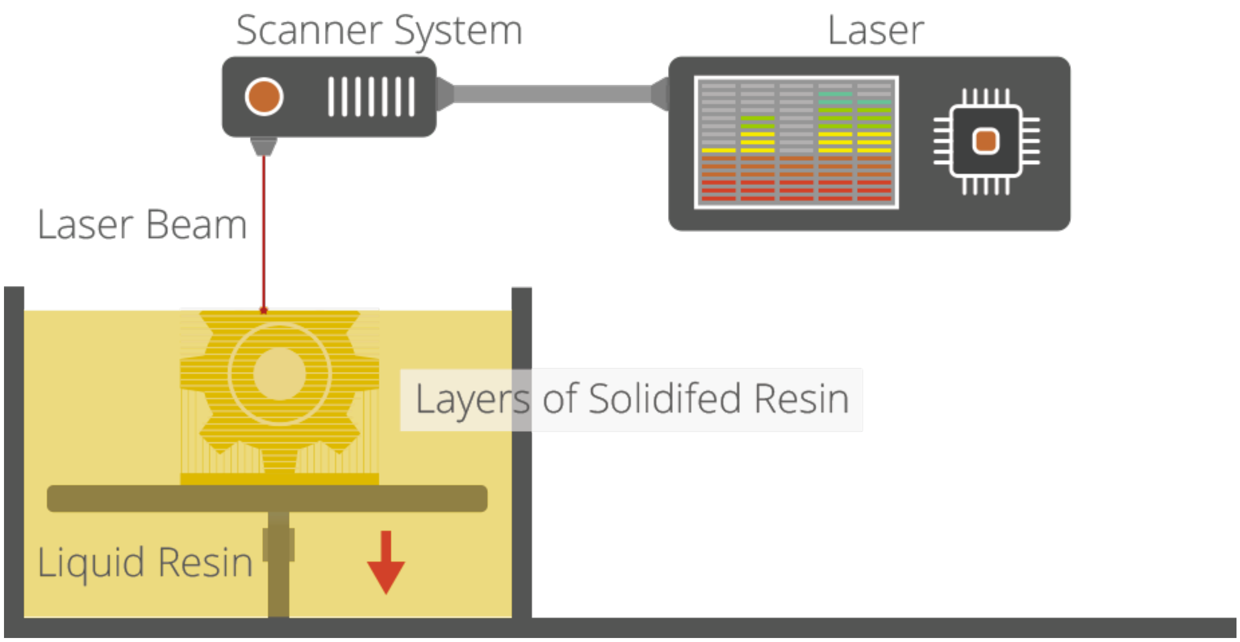
Perhaps the most common and easily recognized process is deposition, and this is the process employed by the majority of entry-level 3D printers. This process extrudes plastics, commonly PLA or ABS, in filament form through a heated extruder to form layers and create the predetermined shape. Because parts can be printed directly, it is possible to produce very detailed and intricate objects, often with functionality built in and negating the need for assembly.

However, another important point to stress is that none of the 3D printing processes come as plug and play options as of today. There are many steps prior to pressing print and many more steps after the print is done. Apart from the realities of designing for 3D printing, which can be demanding, file preparation and conversion can also prove time-consuming and complicated, particularly for parts that demand intricate supports during the build process. However there are continual updates and upgrades of software for these functions and the situation is improving. Furthermore, once the object is 3D printed, it needs to undergo finishing operations. Support removal is an obvious one for processes that demand support, but others include sanding, lacquer, paint or other types of traditional finishing touches, which all typically need to be done by hand and require skill, time and patience.

CHAPTER 04

3D Printing Processes

SLA

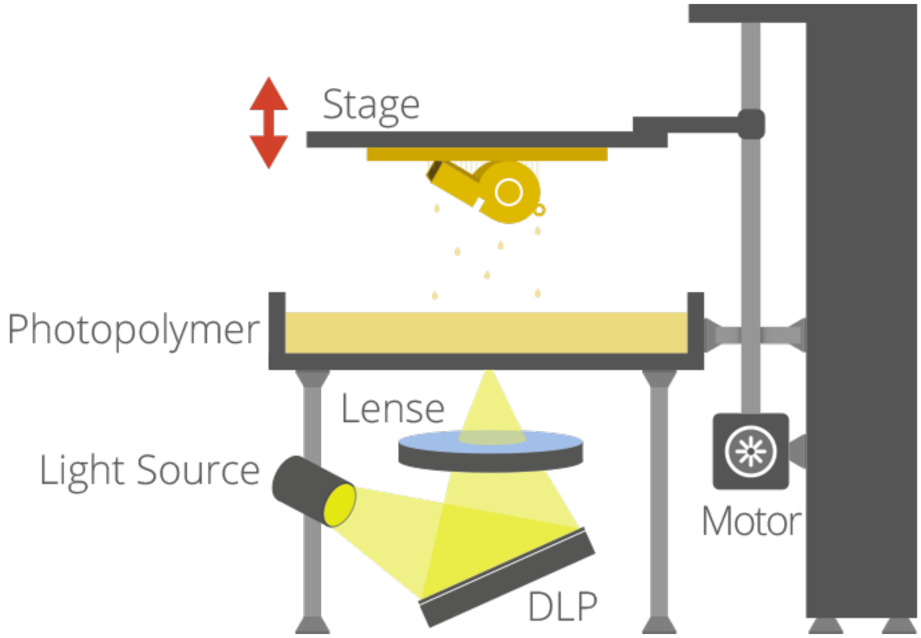


Stereolithography (SL) is widely recognized as the first 3D printing process. It was certainly the first to be commercialized. SL is a laser-based process that works with photopolymer resins that react with the laser and cure to form a solid in a very precise way. It is a complex process but simply put the photopolymer resin is held in a vat with a movable platform inside. A laser beam is directed in the X-Y axes across the surface of the resin according to the 3D data supplied to the machine (the .stl file), whereby the resin hardens precisely where the laser hits the surface. Once the layer is completed, the platform within the vat drops down by a fraction (in the Z axis) and the subsequent layer is traced out by the laser. This continues until the entire object is completed and the platform can be raised out of the vat for removal.

Because of the nature of the SL process, it requires support structures for some parts, specifically those with overhangs or undercuts. These structures need to be manually removed. In terms of other post processing steps, many objects 3D printed using SL need to be cleaned and cured. Curing involves subjecting the part to intense light in an oven-like machine to fully harden the resin.

Stereolithography is generally accepted as being one of the most accurate 3D printing processes with excellent surface finish. However limiting factors include the post-processing steps required and the stability of the materials over time, which can become more brittle.

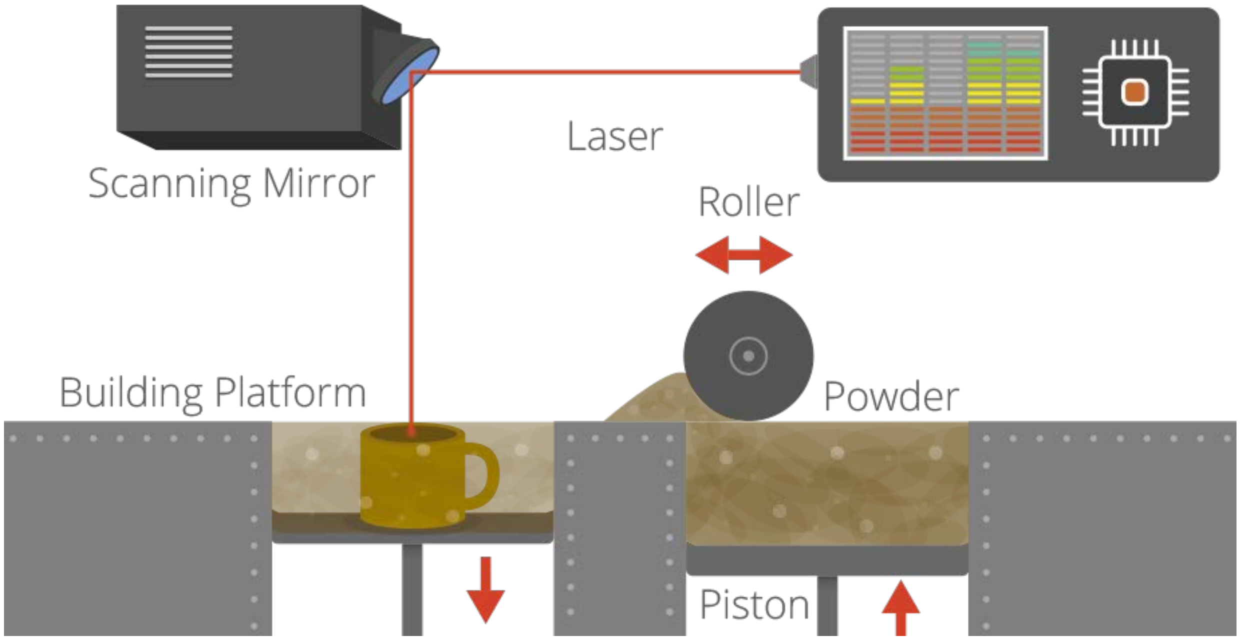
DLP



DLP (Digital Light Processing) is a similar process to stereolithography in that it is a 3D printing process that works with photopolymers. The major difference is the light source. DLP uses a more conventional light source, such as an arc lamp with a liquid crystal display panel, which is applied to the entire surface of the vat of photopolymer resin in a single pass, generally making it faster than SL.

Also like SL, DLP produces highly accurate parts with excellent resolution, but its similarities also include the same requirements for support structures and post-curing. However, one advantage of DLP over SL is that only a shallow vat of resin is required to facilitate the process, which generally results in less waste and lower running costs.

Laser Sintering / Laser Melting



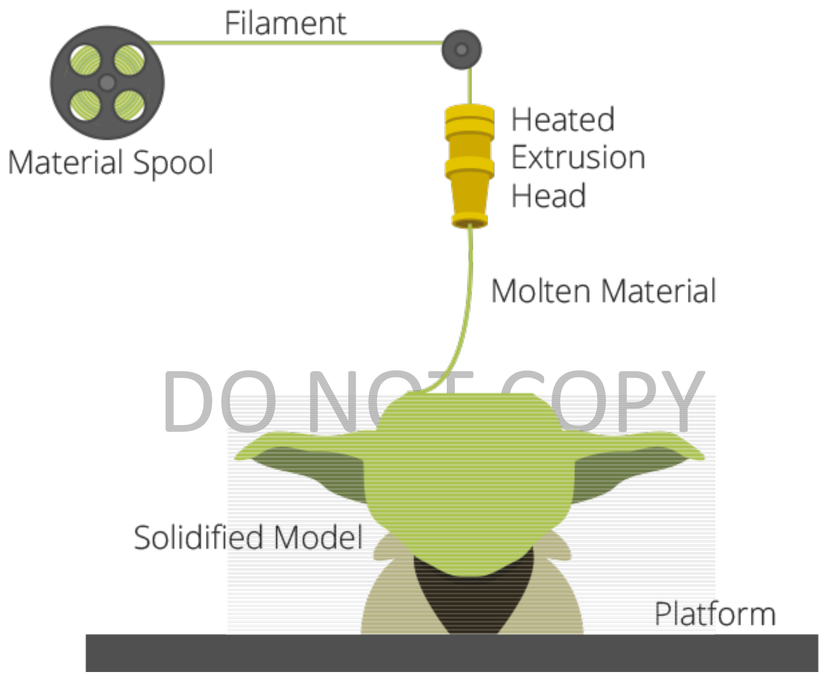
Laser sintering and laser melting are interchangeable terms that refer to a laser based 3D printing process that works with powdered materials. The laser is traced across a powder bed of tightly compacted powdered material, according to the 3D data fed to the machine, in the X-Y axes. As the laser interacts with the surface of the powdered material it sinters, or fuses, the particles to each other forming a solid. As each layer is completed the powder bed drops incrementally and a roller smoothens the powder over the surface of the bed prior to the next pass of the laser for the subsequent layer to be formed and fused with the previous layer.

The build chamber is completely sealed as it is necessary to maintain a precise temperature during the process specific to the melting point of the powdered material of choice. Once finished, the entire powder bed is removed from the machine and the excess powder can be removed to leave the 'printed' parts. One of the key advantages of this process is that the powder bed serves as an in-process support structure for overhangs and undercuts, and therefore complex shapes that could not be manufactured in any other way are possible with this process. However, on the downside, because of the high temperatures required for laser sintering, cooling times can be considerable.

Furthermore, porosity has been an historical issue with this process and while there have been significant improvements towards fully dense parts, some applications still necessitate infiltration with another material to improve mechanical characteristics.

Laser sintering can process plastic and metal materials, although metal sintering does require a much higher powered laser and higher in-process temperatures. Parts produced with this process are much stronger than with SL or DLP, although generally the surface finish and accuracy is not as good.

Extrusion / FDM / FFF



3D printing utilizing the extrusion of thermoplastic material is easily the most common and recognizable 3DP process. The most popular name for the process is Fused Deposition Modelling (FDM). However this is a trade name, registered by Stratasys, the company that originally developed it. Stratasys' FDM technology has been around since the early 1990's and today is an industrial grade 3D printing process. However, the proliferation of entry-level 3D printers that have emerged since 2009 largely utilize a similar process, generally referred to as Freeform Fabrication (FFF), but in a more basic form due to patents still held by Stratasys. The earliest RepRap machines and all subsequent evolutions employ extrusion methodology. However, following Stratasys' patent infringement filing against Afinia there is a question mark over how the entry-level end of the market will develop now, with all of the machines potentially in Stratasys' firing line for patent infringements.

The process works by melting plastic filament that is deposited, via a heated extruder, a layer at a time, onto a build platform according to the 3D data supplied to the printer. Each layer hardens as it is deposited and bonds to the previous layer.

Stratasys has developed a range of proprietary industrial grade materials for its FDM process that are suitable for some production applications. At the entry-level end of the market, materials are more limited, but the range is growing. The most common materials for entry-level FFF 3D printers are ABS and
PLA.

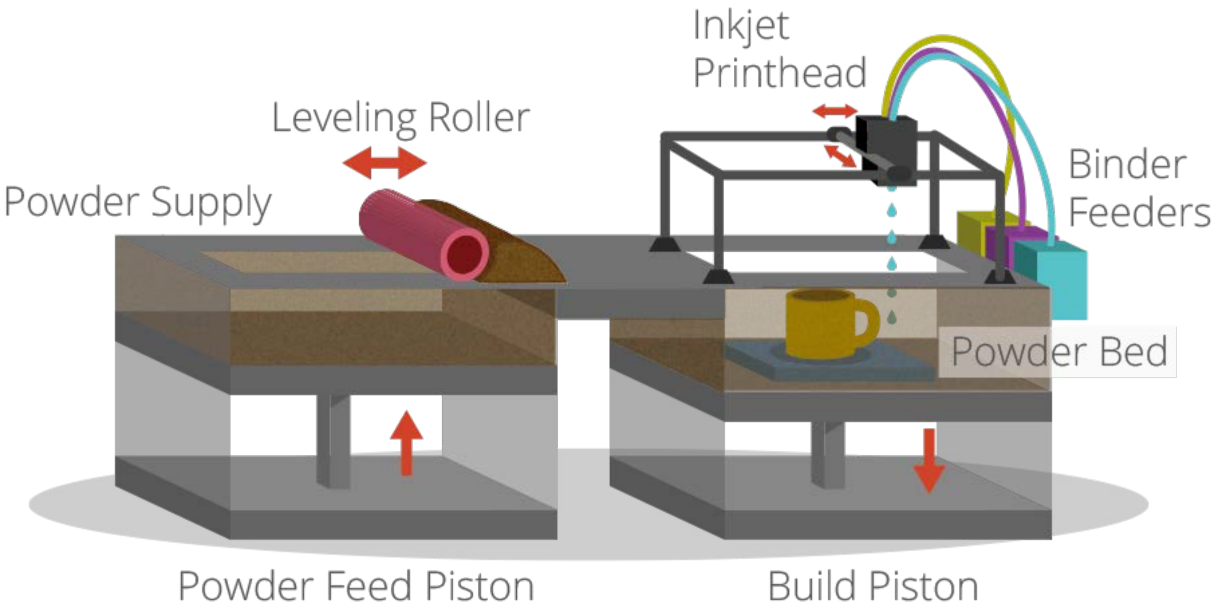
The FDM/FFF processes require support structures for any applications with overhanging geometries. For FDM, this entails a second, water-soluble material, which allows support structures to be relatively easily washed away, once the print is complete. Alternatively, breakaway support materials are also possible, which can be removed by manually snapping them off the part. Support structures, or lack thereof, have generally been a limitation of the entry level FFF 3D printers. However, as the systems have evolved and improved to incorporate dual extrusion heads, it has become less of an issue.

In terms of models produced, the FDM process from Stratasys is an accurate and reliable process that is relatively office/studio friendly, although extensive post-processing can be required. At the entry-level, as would be expected, the FFF process produces much less accurate models, but things are constantly improving.

The process can be slow for some part geometries and layer-to-layer adhesion can be a problem, resulting in parts that are not watertight. Again, post-processing using Acetone can resolve these issues.

Inkjet: Binder Jetting

There are two 3D printing process that utilize a jetting technique.

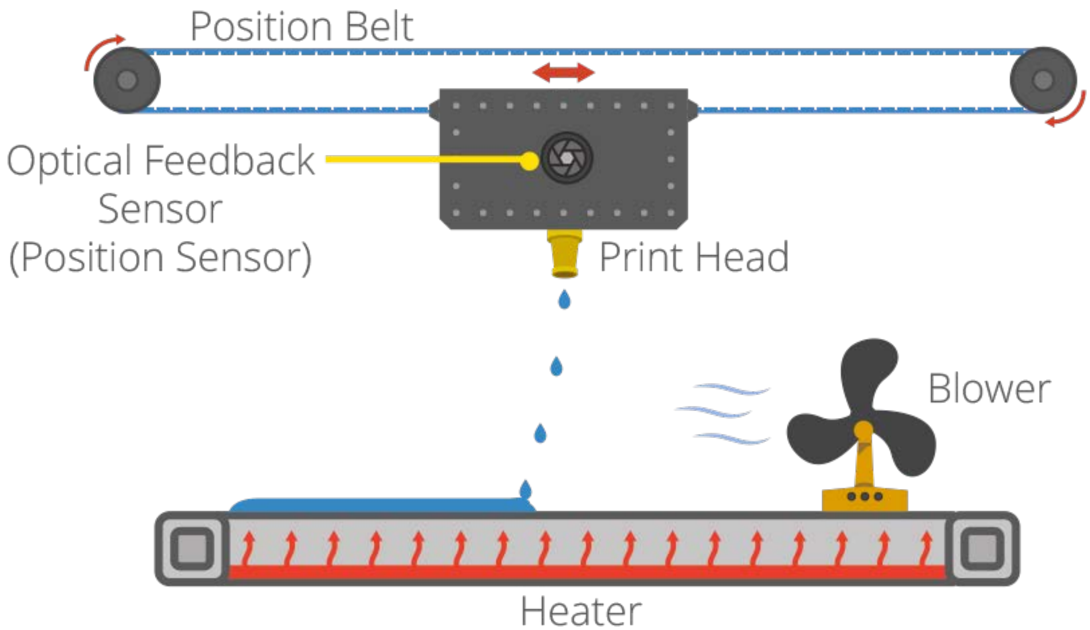


Binder jetting: Where the material being jetted is a binder, and is selectively sprayed into a powder bed of the part material to fuse it a layer at a time to create/print the required part. As is the case with other powder bed systems, once a layer is completed, the powder bed drops incrementally and a roller or blade smoothens the powder over the surface of the bed, prior to the next pass of the jet heads, with the binder for the subsequent layer to be formed and fused with the previous layer.

Advantages of this process, like with SLS, include the fact that the need for supports is negated because the powder bed itself provides this functionality. Furthermore, a range of different materials can be used, including ceramics and food. A further distinctive advantage of the process is the ability to easily add a full color palette which can be added to the binder.

The parts resulting directly from the machine, however, are not as strong as with the sintering process and require post-processing to ensure durability.

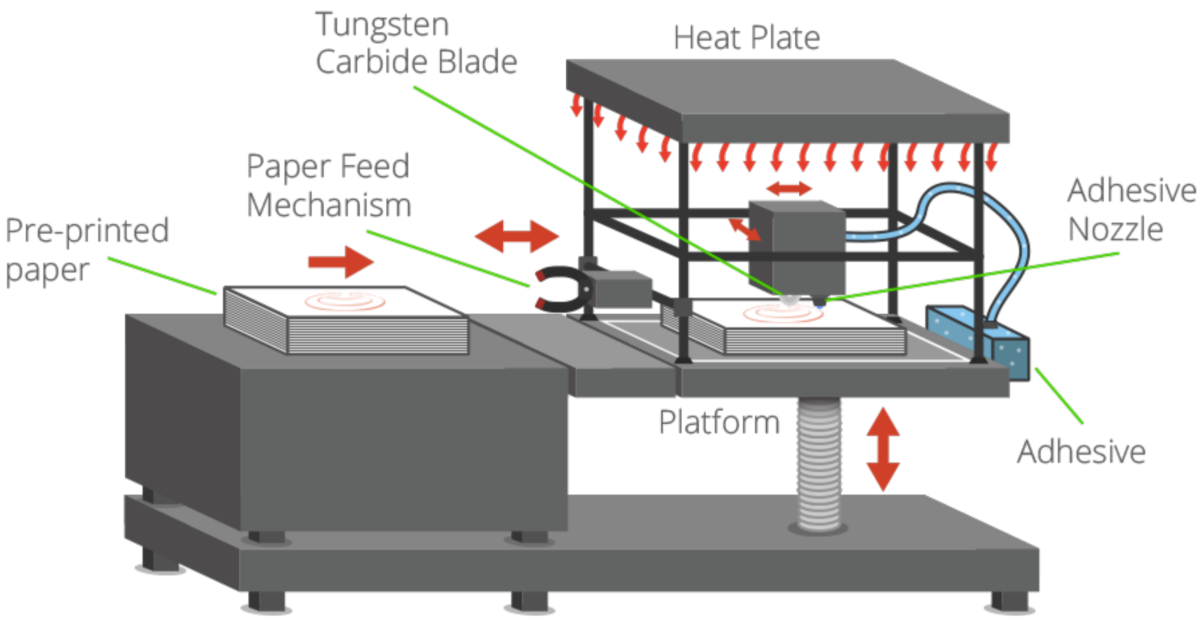
Inkjet: Material Jetting



Material jetting: a 3D printing process whereby the actual build materials (in liquid or molten state) are selectively jetted through multiple jet heads (with others simultaneously jetting support materials). However, the materials tend to be liquid photopolymers, which are cured with a pass of UV light as each layer is deposited.

The nature of this product allows for the simultaneous deposition of a range of materials, which means that a single part can be produced from multiple materials with different characteristics and properties. Material jetting is a very precise 3D printing method, producing accurate parts with a very smooth finish.

Selective Deposition Lamination (SDL)



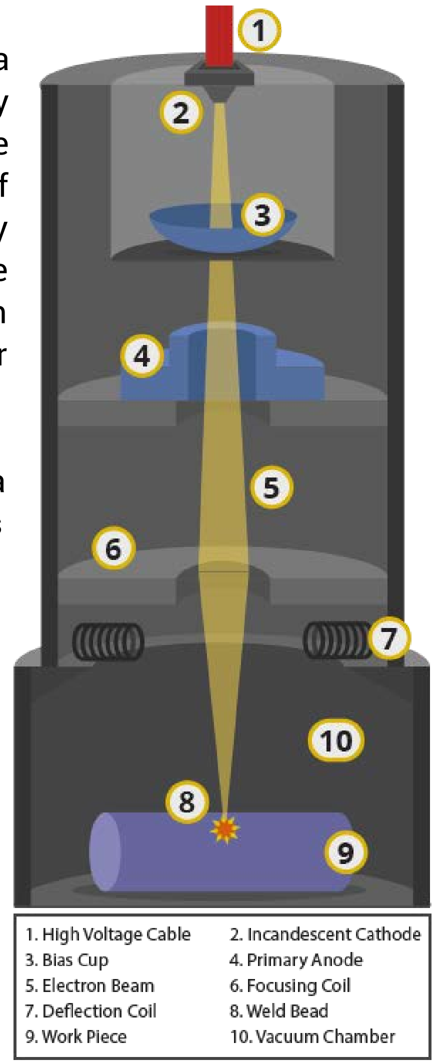
SDL is a proprietary 3D printing process developed and manufactured by Mcor Technologies. There is a temptation to compare this process with the Laminated Object Manufacturing (LOM) process developed by Helisys in the 1990's due to similarities in layering and shaping paper to form the final part. However, that is where any similarity ends.

The SDL 3D printing process builds parts layer by layer using standard copier paper. Each new layer is fixed to the previous layer using an adhesive, which is applied selectively according to the 3D data supplied to the machine. This means that a much higher density of adhesive is deposited in the area that will become the part, and a much lower density of adhesive is applied in the surrounding area that will serve as the support, ensuring relatively easy "weeding," or support removal.

After a new sheet of paper is fed into the 3D printer from the paper feed mechanism and placed on top of the selectively applied adhesive on the previous layer, the build plate is moved up to a heat plate and pressure is applied. This pressure ensures a positive bond between the two sheets of paper. The build plate then returns to the build height where an adjustable Tungsten carbide blade cuts one sheet of paper at a time, tracing the object outline to create the edges of the part. When this cutting sequence is complete, the 3D printer deposits the next layer of adhesive and so on until the part is complete. SDL is one of the very few 3D printing processes that can produce full colour 3D printed parts, using a CYMK colour palette. And because the parts are standard paper, which require no post-

EBM

The Electron Beam Melting 3D printing technique is a proprietary process developed by Swedish company Arcam. This metal printing method is very similar to the Direct Metal Laser Sintering (DMLS) process in terms of the formation of parts from metal powder. The key difference is the heat source, which, as the name suggests is an electron beam, rather than a laser, which necessitates that the procedure is carried out under vacuum conditions.



EBM has the capability of creating fully dense parts in a variety of metal alloys and as a result the technique has been particularly successful for a range of production applications in the medical industry, particularly for implants. However, other hi-tech sectors such as aerospace and automotive have also looked to EBM technology for manufacturing fulfillment.

CHAPTER 05

3D Printing Materials

The materials available for 3D printing have come a long way since the early days of the technology. There is now a wide variety of different material types that are supplied in different states (powder, filament, pellets, granules, resin etc.)

Specific materials are now generally developed for specific platforms performing dedicated applications (an example would be the dental sector) with material properties that more precisely suit the application. There are way too many such proprietary materials from many different 3D printer vendors. In this article, we shall look at the most popular types of generic materials available.

Plastics

Nylon, or Polyamide, is commonly used in powder form with the sintering process or in filament form with the FDM process. It is a strong, flexible and durable plastic material that has proved reliable for 3D printing. It is naturally white in color but it can be colored - pre or post printing. This material can also be combined (in powder format) with powdered aluminum to produce another common 3D printing material for sintering — Alumide.

ABS is another common plastic used for 3D printing, and is widely used on the entry-level FDM 3D printers in filament form. It is a particularly strong plastic and comes in a wide range of colors. ABS can be bought in filament form from a number of nonproprietary sources. This made the filament very popular in the market.

PLA is a bio-degradable plastic material that has gained traction with 3D printing for this very reason. It can be utilized in resin format for DLP/SL processes as well as in filament form for the FDM process. It is offered in a variety of colors, including transparent, which has proven to be a useful option for some applications of 3D printing. However it is not as durable or as flexible as ABS.

LayWood is a specially developed 3D printing material for entry level extrusion 3D printers. It comes in filament form and is a wood/polymer composite.

Metals

A growing number of metals and metal composites are used for industrial grade 3D printing. Two of the most common are aluminum and cobalt derivatives.

One of the strongest and therefore most commonly used metals for 3D printing is Stainless Steel in powder form for the sintering/ melting/EBM processes. It is naturally silver, but can be plated with other materials to give a gold or bronze effect.

In the last couple of years Gold and Silver have been added to the range of metal materials that can be 3D printed directly, with obvious applications across the jewelry sector. These are both very strong materials and are processed in powder form. Titanium is one of the strongest possible metal materials and has been used for 3D printing industrial applications for some time.

Other 3D Printing Materials

Ceramics

Ceramics are a relatively new group of materials that can be used for 3D printing with various levels of success. The particular thing to note with these materials is that, post printing, the ceramic parts need to undergo the same processes as any ceramic part made using traditional methods of production — namely firing and glazing.

Paper

Standard A4 copier paper is a 3D printing material employed by the proprietary SDL process supplied by Mcor Technologies. The capital outlay for the machine is in the mid-range but the emphasis is very much on an easily obtainable, cost-effective material supply that can be bought locally. 3D printed models made with paper are safe, environmentally friendly, easily recyclable and require no post-processing.

Bio Materials

There is a huge amount of research being conducted into the potential of 3D printing bio materials for a host of medical applications. Living tissue is being investigated at a number of leading institutions with a view to developing applications that include printing human organs for transplant, as well as external tissues for replacement body parts. Other research in this area is focused on developing food stuffs — meat being the prime example.

Food

Experiments with extruders for 3D printing food substances has increased dramatically over the last couple of years. Chocolate is the most common one. There are also printers that work with sugar and some experiments with pasta and meat are undergoing.

Chapter 06

3D Printing Applications

The origins of 3D printing in 'Rapid Prototyping' were founded on the principles of industrial prototyping as a means of speeding up the earliest stages of product development. This saves time and money at the outset of the entire product development process and ensures confidence ahead of production tooling. Prototyping is still probably the largest application of 3D printing today.

The developments and improvements of the process and the materials since the emergence of 3D printing for prototyping saw the processes being taken up for applications further down the product development process chain. Tooling and casting applications were developed utilizing the advantages of the different processes. Again, these applications are increasingly being used and adopted across industrial sectors.

Similarly for final manufacturing operations, the improvements are continuing to facilitate uptake. In terms of the industrial vertical markets that are benefitting greatly from industrial 3D printing across all of these broad spectrum applications, the following is a basic breakdown:

The medical sector is viewed as being one that was an early adopter of 3D printing, but also a sector with huge potential for growth, due to the customization and personalization capabilities of the technologies and the ability to improve people's lives as the processes improve and materials are developed that meet medical grade standards.

3D printing technologies are being used for a host of different applications. In addition to making prototypes to support new product development for the medical and dental industries, the technologies are also utilized to make patterns for the downstream metal casting of dental crowns and in the manufacture of tools over which plastic is being vacuum formed to make dental aligners. The technology is being used to directly manufacture both stock items, such as hip and knee implants, and bespoke patient-specific products, such as hearing aids, orthotic insoles for shoes, personalized prosthetics and one-off implants for patients suffering from diseases such as osteoarthritis, osteoporosis and cancer. 3D printed surgical guides for specific operations are also an emerging application that is aiding surgeons in their work and patients in their recovery. Technology is also being developed for the 3D printing of skin, bone, tissue, pharmaceuticals and even human organs. However, these technologies remain largely decades away from commercialization.

Like the medical sector, the aerospace sector was an early adopter of 3D printing technologies in their earliest forms for product development and prototyping. These companies, typically working in partnership with academic and research institutes, have been at the sharp end in terms or pushing the boundaries of the technologies for manufacturing applications.

Because of the critical nature of aircraft development, the R&D is demanding and strenuous, standards are critical and industrial grade 3D printing systems are put through their paces. Process and materials development have seen a number of key applications developed for the aerospace sector and some non-critical parts are all-ready flying on aircraft.

High profile users include GE / Morris Technologies, Airbus / EADS, Rolls-Royce, BAE Systems and Boeing. While most of these companies do take a realistic approach in terms of what they are doing now with the technologies, some do get quite bullish about the future.

Another general early adopter of Rapid Prototying technologies was the automotive sector. Many automotive companies — particularly those at the cutting edge of motor sport and F1 — have followed a similar trajectory to the aerospace companies. First using the technologies for prototyping applications, but developing and adapting their manufacturing processes to incorporate the benefits of improved materials and end results for automotive parts.

Many automotive companies are now also looking at the potential of 3D printing to fulfill after sales functions in terms of production of spare/replacement parts on demand, rather than holding huge inventories.

Traditionally, the design and manufacturing process for jewelry has always required high levels of expertise and knowledge involving specific disciplines like fabrication, mold-making, casting, electroplating, forging, silver/gold smithing, stonecutting, engraving and polishing. Each of these disciplines evolved over many years and each requires technical knowledge. Just one example is investment casting — the origins of which can be traced back more than 4000 years.

For the jewelry sector, 3D printing has proved to be particularly disruptive. There is a great deal of interest and uptake based on how 3D printing can, and will, contribute to the further development of this industry. From new design freedoms enabled by 3D CAD and 3D printing, through improving traditional processes for jewelry production all the way to direct 3D printed production eliminating many of the traditional steps, 3D printing had and continues to have a tremendous impact in this sector.

Artists and Sculptors are engaging with 3D printing in myriad of different ways to explore form and function in ways previously impossible. Whether purely to find new original expression or to learn from old masters this is a highly charged sector that is increasingly finding new ways of working with 3D printing and introducing the results to the world. There are numerous artists that have now made a name for themselves by working specifically with 3D modelling, 3D scanning and 3D printing technologies.

Architectural models have long been a staple application of 3D printing processes, for producing accurate demonstration models of an architect's vision. 3D printing offers a relatively fast, easy and economically viable method of producing detailed models directly from 3D CAD, BIM or other digital data that architects use. Many successful architectural firms, now commonly use 3D printing (in house or as a service) as a critical part of their workflow for increased innovation and improved communication.

More recently some visionary architects are looking to 3D printing as a direct construction method. Research is being conducted at a number of organizations on this front, most notably Loughborough University, Contour Crafting and Universe Architecture.

As 3D printing processes have improved in terms of resolution and more flexible materials, one industry, renowned for experimentation and outrageous statements, has come to the fore.

3D printed accessories including shoes, head-pieces, hats and bags have all made their way on to global catwalks. And some even more visionary fashion designers have demonstrated the capabilities of the tech for haute couture — dresses, capes, full-length gowns and even some under wear have debuted at different fashion venues around the world.

Iris van Herpen should get a special mention as the leading pioneer in this vein. She has produced a number of collections — modelled on the catwalks of Paris and Milan — that incorporate 3D printing to blow up the 'normal rules' that no longer apply to fashion design. Many have followed, and continue to follow, in her footsteps, often with wholly original results.

Although a late-comer to 3D printing, food is one emerging application that is getting people very excited and has the potential to truly take the technology into the mainstream. 3D printing is emerging as a new way of preparing and presenting food.

Initial forays into 3D printing food were with chocolate and sugar and these developments have continued apace with specific 3D printers hitting the market. Some other early experiments with food include the 3D printing of “meat” at the cellular protein level. More recently pasta is another food group that is being researched for 3D printing food.

Looking to the future 3D printing is also being considered as a complete food preparation method and a way of balancing nutrients in a comprehensive and healthy way.

The holy grail for 3D printing vendors is consumer 3D printing. There is a widespread debate as to whether this is feasible in future. Currently, consumer uptake is low due to the accessibility and application issues that exist with entry level machines. There is headway being made in this direction by the larger 3D printing companies such as 3D Systems and Makerbot, as a subsidiary of Stratasys as they try to make the 3D printing process and the ancillary components (software, digital content etc) more accessible and user-friendly.

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