# 3D Printing

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***Abstract:*** **3D printing is any of various processes to make a object. In 3D printing, additive processes are used, in which successive layers of material are laid down under computer control. These objects can be of almost any shape or geometry, and are produced from a or other electronic data source. A 3D printer is a type of 3D printing in the term's original and technically precise refers to processes that sequentially deposit material onto a powder bed with inkjet printer heads. More recently the meaning of the term has expanded to encompass a wider variety of techniques such as and based processes use the term additive manufacturing (AM) for this broader sense.**

## I. INTRODUCTION

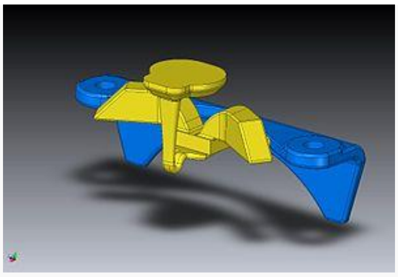

Fig 1. CAD Model used for 3D Printing

Early AM equipment and materials were developed in the 1980s. In 1984, of invented a process known as , in which layers are added by curing. Hull defined the process as a "system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed He also developed the widely accepted by 3D printing software as well as the digital slicing and infill strategies common to many processes today. The term *3D printing* originally referred to a process employing standard and print heads. The technology used by most 3D printers to date—especially hobbyist and consumer-oriented models—is , a special application of plastic .

AM processes for metal sintering or melting, and usually went by their own individual names in the 1980s and 1990s. Nearly all metalworking production at the time was by , and was applied to those technologies the idea of a tool or head moving through a 3D work envelope transforming a mass of raw material into a desired shape layer by layer was associated by most people only with processes that removed metal (rather than adding it), such as CNC by others. But AM-type sintering was beginning to challenge that assumption. By the mid 1990s, new techniques for material deposition were developed at, including micro casting and sprayed materials. Sacrificial and support materials had also become more common, enabling new object geometries.

By the early 2010s, the terms *3D printing* and *additive manufacturing* developed umbrella terms for all AM technologies. Although this was a departure from their earlier technically narrower senses, it reflects the simple fact that the technologies all share the common theme of sequential-layer material addition/joining throughout a 3D work envelope under automated control. Other terms that have appeared, which are usually used as AM synonyms (although sometimes as , have been *desktop manufacturing*, *rapid manufacturing* [as the logical production-level successor and *on-demand manufacturing* The 2010s were the first decade in which metal parts such as engine brackets and large nuts would be grown (either before or instead of machining) in or plate.

In 2005, a rapidly expanding hobbyist and home-use market was established with the inauguration of the projects. Virtually all home-use 3D printers released to-date have their technical roots in the on-going RepRap Project and associated open-source software initiatives. In distributed manufacturing, one study has found that 3D printing could become a mass market product enabling consumers to save money associated with purchasing common household objects. For example, instead of going to a store to buy an object made in a factory by or a , a person might instead print it at home from a downloaded 3D model.

## II. GENERAL PRINCIPLES

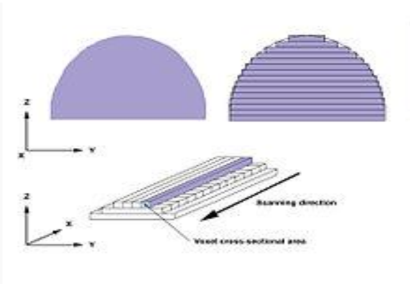

Fig 2. 3D model slicing

*MODELING*

3D printable models may be created with a (CAD) package or via a or via a plain digital camera and software.

The manual modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning is a process of analysing and collecting digital data on the shape and appearance of a real object. Based on this data, three-dimensional models of the scanned object can then be produced.

Regardless of the 3D modelling software used, the 3D model (often in .skp, .dae, .3ds or some other format) then needs to be converted to either a.STL or a .OBJ format, to allow the printing (a.k.a. "CAM") software to be able to read it.

*PRINTING*

Before printing a 3D model from an file, it must first be examined for "manifold errors", this step being called the "fixup". Especially STL's that have been produced from a model obtained through often have many manifold errors in them that need to be fixed. Examples of manifold errors are surfaces that do not connect, gaps in the models, Examples of software that can be used to fix these errors are , or even Cura, or Slic3r.

Once that's done, the .STL file needs to be processed by a piece of software called a "slicer" which converts the model into a series of thin layers and produces a containing instructions tailored to a specific type of 3D printer. This G-code file can then be printed with software (which loads the G-code, and uses it to instruct the 3D printer during the 3D printing process. It should be noted here that often, the client software and the slicer are combined into one software program in practice. Several open source slicer programs exist, including Skeinforge, Slic3r, and Cura as well as closed source programs including Simplify3D and KISSlicer. Examples of 3D printing clients include , Printrun/Pronterface.


FIG 3. Scanned skull of printed in two sizes

Note that there is one other piece of software that is often used by people using 3D printing, namely a . This software lets one examine the route of travel of the printer nozzle. By examining this, the user can decide to modify the GCode to print the model a different way (for example in a different position, e.g. standing versus lying down) so as to save plastic (depending on the position and nozzle travel, more or less support material may be needed). Examples of GCode viewers are .

*FINISHING*

Though the printer-produced resolution is sufficient for many applications, printing a slightly oversized version of the desired object in standard resolution and then removing material with a higher-resolution subtractive process can achieve greater precision.

Some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts. Some are able to print in multiple colors and color combinations simultaneously. Some also utilize supports when building. Supports are removable or dissolvable upon completion of the print, and are used to support overhanging features during construction.

## III. PROCESSES

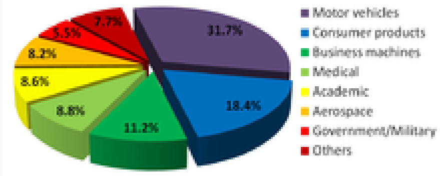


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Fig 4. Extrusion deposition

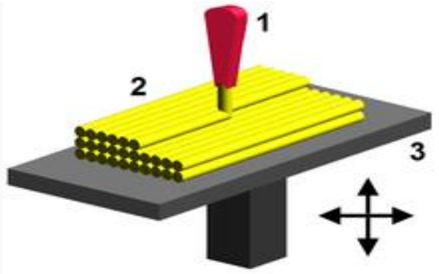


Fig 5. Fused deposition modeling: 1 – nozzle ejecting molten plastic, 2 – deposited material (modeled part), 3 – controlled movable table

Fused deposition modeling (FDM) was developed by in the late 1980s and was commercialized in 1990 by After the patent on this technology expired, a large open-source development community developed and both commercial and variants utilizing this type of 3D printer appeared. As a result, the price of this technology has dropped by two orders of magnitude since its creation.

In fused deposition modeling the model or part is produced by extruding small beads of material which harden immediately to form layers. A filament or metal wire that is wound on a coil is unreeled to supply material to an nozzle head. The nozzle head heats the material and turns the flow on and off. Typically or are employed to move the extrusion head and adjust the flow. The head can be moved in both horizontal and vertical directions, and control of the mechanism is typically done by a (CAM) software package running on a various polymers are used, including (PC), (HDPE), PC/ABS, In general, the polymer is in the form of a filament fabricated from virgin resins. There are multiple projects in the open-sourced community aimed at processing post-consumer plastic waste into filament. These involve machines used to shred and extrude the plastic material into filament.

BINDING OF GRANULAR MATERIALS

Fig 6. The granular printing system uses heated air and granulated sugar to produce food-grade art objects

Another 3D printing approach is the selective fusing of materials in a granular bed. The technique fuses parts of the layer and then moves downward in the working area, adding another layer of granules and repeating the process until the piece has built up. This process uses the unfused media to support overhangs and thin walls in the part being produced, which reduces the need for temporary auxiliary supports for the piece. A laser is typically used to the media into a solid. Examples include (SLS), with both metals and polymers (e.g. PA, PA-GF, Rigid GF, PEEK, PS,

(SLM) does not use sintering for the fusion of powder granules but will completely melt the powder using a high-energy laser to create fully dense materials in a layer-wise method that has mechanical properties similar to those of conventional manufactured metals.

This is repeated until every layer has been printed. This technology allows the printing of full color prototypes, overhangs, and elastomer parts. The strength of bonded powder prints can be enhanced with wax or impregnation.

*LAMINATION*

In some printers, paper can be used as the build material, resulting in a lower cost to print. During the 1990s some companies marketed printers that cut cross sections out of special adhesive coated paper using a carbon dioxide laser and then laminated them together.

In 2005 developed a different process using ordinary sheets of office paper, a blade to cut the shape, and selective deposition of adhesive and pressure to bond the prototype.

There are also a number of companies selling printers that print laminated objects using thin plastic and metal sheets.

*PHOTOPOLYMERIZATION*

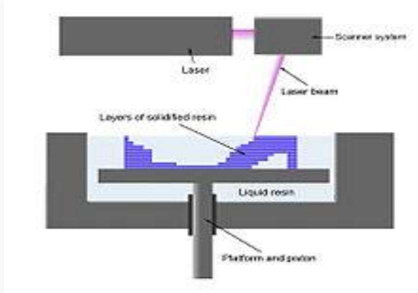


Fig 7. Stereolithography apparatus

Stereolithography was patented in 1986 by Photopolymerization is primarily used in stereolithography (SLA) to produce a solid part from a liquid. This process dramatically redefined previous efforts, from the "photosculpture" method of François Willème (1830–1905) in 1860 through the photopolymerization of Mitsubishi's Matsubara in 1974. The "photosculpture" method consisted of photographing a subject from a variety of equidistant angles and projecting each photograph onto a screen, where a was used to trace the outline onto modeling clay In photo-polymerization, a vat of liquid polymer is exposed to controlled lighting under conditions. The exposed liquid polymer hardens. The build plate then moves down in small increments and the liquid polymer is again exposed to light. The process repeats until the model has been built. The liquid polymer is then drained from the vat, leaving the solid model. The is an example of a DLP rapid prototyping system.

Inkjet printer systems like the *Objet PolyJet* system spray photopolymer materials onto a build tray in ultra-thin layers (between 16 and 30 µm) until the part is completed. Each photopolymer layer is with UV light after it is jetted, producing fully cured models that can be handled and used immediately, without post-curing. The gel-like support material, which is designed to support complicated geometries, is removed by hand and water jetting. It is also suitable for elastomers.

*BIOPRINTING*

3D bioprinting is the process of generating 3D structures and geometries utilizing cells and an encapsulation material. The medical applications of 3D bioprinting are numerous, and are thus the subject of intensive research at academic institutions such as . One major application area of bioprinting is in the tissue engineering field of regenerative medicine. In addition to the complexities associated with 3D printing in general, extra considerations must be taken regarding material, cell type, and growth factor selection involving researchers from the fields of materials science, cell biology, engineering of all kinds, and medicine.

3D bioprinting has seen much preliminary success in terms of generation of several different kinds of tissues. These include skin, bone, cartilage, trachea, and heart tissue. While preliminary success has been attained in these noncritically functional tissue structures, significant research effort is directed towards the generation of fully functional replacement organs and tissues, such as aortic heart valves.

*NANOSCALE 3D PRINTING*

3D printing techniques can be employed to construct nanoscale-size objects. Such printed objects are typically grown on a solid substrate, e.g. silicon wafer, to which they adhere after printing as they're too small and fragile to be manipulated post-construction. While 2D nanostructures are usually created by depositing material through some sort of static stencil mask, 3D nanostructures can be printed by physically moving a stencil mask during the material deposition process. Programmable-height nanostructures with widths as small as 10 nm have been produced by metallic physical vapor deposition through a piezo-actuator controlled stencil mask having a milled nanopore in a silicon nitride membrane. This metal-vapor technique is also advantageous because it can be used on surfaces that are too sensitive to heat or chemicals for traditional lithography to be used on.

LARGE 3D PRINTERS

Fig 8. Large scale industrial 3D printing

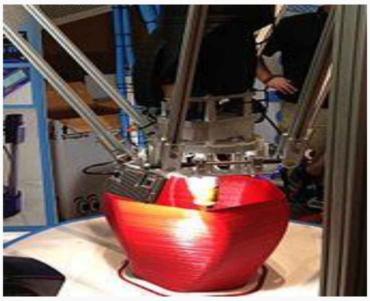

Fig 9. Large delta-style 3D printer

Large 3D printers have been developed for industrial, education, and demonstrative uses. A large 3D printer was built in 2014 by SeeMeCNC. The printer is capable of making an object with diameter of up to 4 feet (1.2 m) and up to 10 feet (3.0 m) in height. It also uses plastic pellets as the raw material instead of the typical plastic filaments used in other 3D printers. Another type of large printer is Big Area Additive Manufacturing (BAAM). The goal is to develop printers that can produce a large object in high speed. A BAAM machine of Cincinnati Incorporated can produce an object at the speeds 200-500 times faster than typical 3D printers available in 2014. Another BAAM machine is being developed by with an aim to print long objects of up to 100 feet (30 m) to be used in aerospace industries.

*EFFICIENCY*

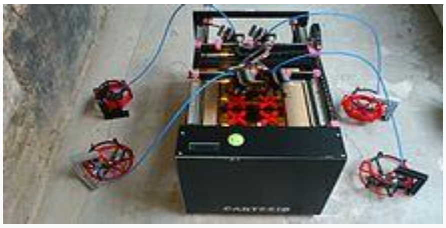

Fig 10. CartesioLDMP mass production 3Dprinter

The current slow print speed of 3D printers limits their use for . To reduce this overhead, several fused filament machines now offer multiple heads. These can be used to print in multiple colours, with different polymers, or to make multiple prints simultaneously. This increases their overall print speed during multiple instance production, while requiring less capital cost than duplicate machines since they can share a single controller.

Distinct from the use of multiple machines, multi-material machines are restricted to making identical copies of the same part, but can offer multi-color and multi-material features when needed. The print speed increases proportionately to the number of heads. Furthermore, the energy cost is reduced due to the fact that they share the same heated print volume. Together, these two features reduce overhead costs.

Printers are made with twin print heads, used to manufacture single (sets of) parts in multiple colours or materials.

## IV. MANUFACTURING APPLICATIONS

Fig 11. component created using 3D printing


Fig 12. Printing 3D house project at Amsterdam

Earliest Applications have been on the and cost of developing prototypes of new parts and devices, which was earlier only done with subtractive toolroom methods (typically slowly and expensively). With technological advances in additive manufacturing, however, and the dissemination of those advances into the business world, additive methods are moving ever further into the production end of manufacturing in creative and sometimes unexpected ways. Parts that were formerly the sole province of subtractive methods can now in some cases be made more profitably via additive ones.

*DISTRIBUTED MANUFACTURING*

Additive manufacturing in combination with technologies allows decentralized and geographically independent distributed production. as such is carried out by some enterprises; there is also a service to put people needing 3D printing in contact with owners of printers.

Some companies offer on-line 3D printing services to both commercial and private customers, working from 3D designs uploaded to the company website. 3D-printed designs are either shipped to the customer or picked up from the service provider.

*RAPID MANUFACTURING*

Advances in RP technology have introduced materials that are appropriate for final manufacture, which has in turn introduced the possibility of directly manufacturing finished components. One advantage of 3D printing for rapid manufacturing lies in the relatively inexpensive production of small numbers of parts.

*INDUSTRIAL APPLICATIONS*

Apparel

3D printing has spread into the world of clothing with fashion designers experimenting with 3D-printed bikinis, shoes, and dresses. In commercial production Nike is using 3D printing to prototype and manufacture the 2012 Vapor Laser Talon football shoe for players of American football, and New Balance is 3D manufacturing custom-fit shoes for athletes.

3D printing has come to the point where companies are printing consumer grade eyewear with on demand custom fit and styling (although they cannot print the lenses). On demand customization of glasses is possible with rapid prototyping.

Automobiles

In early 2014, the Swedish , announced the One:1, a supercar that utilises many components that were 3D printed. In the limited run of vehicles Koenigsegg produces, the One:1 has side-mirror internals, air ducts, titanium exhaust components, and even complete turbocharger assembles that have been 3D printed as part of the manufacturing process.

Technology Show. "Produced from a new fiber-reinforced thermoplastic strong enough for use in an automotive application, the chassis and body without drivetrain, wheels and brakes weighs a scant 450 pounds and the

Construction

An additional use being developed is , or using 3D printing to build buildings. This could allow faster construction for lower costs, and has been investigated for construction of off-Earth habitats. For example, the Sinterhab project is researching a lunar base constructed by 3D printing using as a base material. Instead of adding a binding agent to the regolith, researchers are experimenting with microwave.

Electric motors and generators

The magnetic cores of electric machines (motors and generators) require thin laminations of special preprocessed electrical steel that are insulated from each other to reduce core iron losses. 3D printing of any product that requires core materials with special properties or forms that must be preserved during the manufacturing process, such as the material density, non-crystalline or nano-crystalline atomic structures, etc. or material isolation, may only be compatible with a hybrid 3D printing method which does not use core material altering methods, such as sintering, fusing, deposition, etc.

Medical

3D printing has been used to print patient specific implant and device for medical use. Successful operations include a titanium implanted into a British patient, titanium lower splint for an American infant. The hearing aid and dental industries are expected to be the biggest area of future development using the custom 3D printing technology. In March 2014, surgeons in Swansea used 3D printed parts to rebuild the face of a motorcyclist who had been seriously injured in a road accident. Research is also being conducted on methods to bio-print replacements for lost tissue due to arthritis and cancer.

Computers

3D printing can be used to make laptops and other computers, including cases, as and . I.e. a motherboard can be bought and be used in a printed VIA OpenBook case.

*OPENSOURCE 3D PRINTERS*

Impact

Additive manufacturing, starting with today's infancy period, requires manufacturing firms to be flexible, users of all available technologies to remain competitive. Advocates of additive manufacturing also predict that this arc of technological development will counter , as end users will do much of their own manufacturing rather than engage in trade to buy products from other people and corporations. The real integration of the newer additive technologies into commercial production, however, is more a matter of complementing traditional subtractive methods rather than displacing them entirely.

Social change

Since the 1950s, a number of writers and social commentators have speculated in some depth about the social and cultural changes that might result from the advent of commercially affordable additive manufacturing technology. Amongst the more notable ideas to have emerged from these inquiries has been the suggestion that, as more and more 3D printers start to enter people's homes, so the conventional relationship between the home and the workplace might get further eroded. Likewise, it has also been suggested that, as it becomes easier for businesses to transmit designs for new objects around the globe, so the need for high-speed freight services might also become less. Finally, given the ease with which certain objects can now be replicated, it remains to be seen whether changes will be made to current copyright legislation so as to protect intellectual property rights with the new technology widely available.

As 3D printers became more accessible to consumers, online social platforms have developed to support the community. This includes websites that allow users to access information such as how to build a 3D printer, as well as social forums that discuss how to improve 3D print quality and discuss 3D printing news, as well as social media websites that are dedicated to share 3D models. RepRap is a wiki based website that was created to hold all information on 3d printing, and has developed into a community that aims to bring 3D printing to everyone. Furthermore, there are other sites such as Thingiverse, which was created initially to allow users to post 3D files for anyone to print, allowing for decreased transaction cost of sharing 3D files. These websites have allowed for greater social interaction between users, creating communities dedicated around 3D printing.

3D printing technology declines, it is "easy to imagine" that production may become "extremely" local and customized. Moreover, production may occur in response to actual demand, not anticipated or forecast demand. Spence believes that labor, no matter how inexpensive, will become a less important asset for growth and employment expansion, with labor-intensive, process-oriented manufacturing becoming less effective, and that re-localization will appear in both developed and developing countries. In his view, production will not disappear, but it will be less labor-intensive, and all countries will eventually need to rebuild their growth models around digital technologies and the human capital supporting their deployment and expansion. Spence writes that "the world we are entering is one in which the most powerful global flows will be ideas and digital capital, not goods, services, and traditional capital. Adapting to this will require shifts in mindsets, policies, investments (especially in human capital), and quite possibly models of employment and distribution investment pundits have predicted that 3D printing may lead to a resurgence of American Manufacturing, citing the small, creative companies that compromise the current industry landscape, and the lack of the necessary complex infrastructure in typical outsource markets.

## V.CONCLUSIONS

I hope that this instructable has provided a useful foundation for your future 3D design and 3D printing endeavors. Remember that there are many more techniques than I have covered here; these are just basics to get you started. 3D is limited only by your imagination, so go exploring, and make something awesome.

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