

**3D Printing Technologies**

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**3D printing technologies**

3D printing refers to processes in which material is joined or solidified under computer control to create a three-dimensional object, with material being added together (such as liquid molecules or powder grains being fused together). 3D printing is used in both rapid prototyping and additive manufacturing (AM). Objects can be of almost any shape or geometry and typically are produced using digital model data from a 3D model or another electronic data source such as an Additive Manufacturing File (AMF) file (usually in sequential layers). There are many different technologies, like stereolithography (STL) or fused deposit modeling (FDM). Thus, unlike material removed from a stock in the conventional machining process, 3D printing or AM builds a three-dimensional object from computer-aided design (CAD) model or AMF file, usually by successively adding material layer by layer.

The term "3D printing" originally referred to a process that deposits a binder material onto a powder bed with inkjet printer heads layer by layer. More recently, the term is being used in popular vernacular to encompass a wider variety of additive manufacturing techniques. United States and global technical standards use the official term additive manufacturing for this broader sense, since the final goal of additive manufacturing is to achieve mass-production, which greatly differs from 3D printing for Rapid prototyping.

**Terminology**

The umbrella term additive manufacturing (AM) gained wide currency in the 2000s,[3] inspired by the theme of material being added together (in any of various ways). In contrast, the term subtractive manufacturing appeared as a retronym for the large family of machining processes with material removal as their common theme. The term 3D printing still referred only to the polymer technologies in most minds, and the term AM was likelier to be used in metalworking and end use part production contexts than among polymer, inkjet, or stereolithography enthusiasts.

By the early 2010s, the terms 3D printing and additive manufacturing evolved senses in which they were alternate umbrella terms for AM technologies, one being used in popular vernacular by consumer-maker communities and the media, and the other used more formally by industrial AM end-use part producers, AM machine manufacturers, and global technical standards organizations. Until recently, the term 3D printing has been associated with machines low-end in price or in capability.[4] Both terms reflect that the technologies share the theme of material addition or joining throughout a 3D work envelope under automated control. Peter Zelinski, the editor-in-chief of Additive Manufacturing magazine, pointed out in 2017 that the terms are still often synonymous in casual usage[5] but that some manufacturing industry experts are increasingly making a sense distinction whereby AM comprises 3D printing plus other technologies or other aspects of a manufacturing process.

Other terms that have been used as AM synonyms or hypernyms have included desktop manufacturing, rapid manufacturing (as the logical production-level successor to rapid prototyping), and on-demand manufacturing (which echoes on-demand printing in the 2D sense of printing). That such application of the adjectives rapid and on-demand to the noun manufacturing was novel in the 2000s reveals the prevailing mental model of the long industrial era in which almost all production manufacturing involved long lead times for laborious tooling development. Today, the term subtractive has not replaced the term machining, instead complementing it when a term that covers any removal method is needed. Agile tooling is the use of modular means to design tooling that is produced by additive manufacturing or 3D printing methods, to enable quick prototyping and responses to tooling and fixture needs. Agile tooling uses a cost effective and high quality method to quickly respond to customer and market needs, and it can be used in hydro-forming, stamping, injection molding and other manufacturing processes.

**History**

Early additive manufacturing equipment and materials were developed in the 1980s.[6] In 1981, Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two additive methods for fabricating three-dimensional plastic models with photo-hardening thermoset polymer, where the UV exposure area is controlled by a mask pattern or a scanning fiber transmitter.[7][8]

On 16 July 1984, Alain Le Méhauté, Olivier de Witte, and Jean Claude André filed their patent for the stereolithography process.[9] The application of the French inventors was abandoned by the French General Electric Company (now Alcatel-Alsthom) and CILAS (The Laser Consortium).[10] The claimed reason was "for lack of business perspective".

Three weeks later in 1984, Chuck Hull of 3D Systems Corporation[12] filed his own patent for a stereolithography fabrication system, in which layers are added by curing photopolymers with ultraviolet light lasers. Hull defined the process as a "system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed,".[13][14] Hull's contribution was the STL (Stereolithography) file format and the digital slicing and infill strategies common to many processes today.

The technology used by most 3D printers to date—especially hobbyist and consumer-oriented models—is fused deposition modeling, a special application of plastic extrusion, developed in 1988 by S. Scott Crump and commercialized by his company Stratasys, which marketed its first FDM machine in 1992.

The term 3D printing originally referred to a powder bed process employing standard and custom inkjet print heads, developed at MIT in 1993 and commercialized by Soligen Technologies, Extrude Hone Corporation, and Z Corporation.

The year 1993 also saw the start of a company called Solidscape, introducing a high-precision polymer jet fabrication system with soluble support structures, (categorized as a "dot-on-dot" technique)

AM processes for metal sintering or melting (such as selective laser sintering, direct metal laser sintering, and selective laser melting) usually went by their own individual names in the 1980s and 1990s. At the time, all metalworking was done by processes that we now call non-additive (casting, fabrication, stamping, and machining); although plenty of automation was applied to those technologies (such as by robot welding and CNC), the idea of a tool or head moving through a 3D work envelope transforming a mass of raw material into a desired shape with a toolpath was associated in metalworking only with processes that removed metal (rather than adding it), such as CNC milling, CNC EDM, and many others. But the automated techniques that added metal, which would later be called additive manufacturing, were beginning to challenge that assumption. By the mid-1990s, new techniques for material deposition were developed at Stanford and Carnegie Mellon University, including microcasting[15] and sprayed materials.[16] Sacrificial and support materials had also become more common, enabling new object geometries.

As the various additive processes matured, it became clear that soon metal removal would no longer be the only metalworking process done through a tool or head moving through a 3D work envelope transforming a mass of raw material into a desired shape layer by layer. The 2010s were the first decade in which metal end use parts such as engine brackets[18] and large nuts[19] would be grown (either before or instead of machining) in job production rather than obligately being machined from bar stock or plate. It is still the case that casting, fabrication, stamping, and machining are more prevalent than AM in metalworking, but AM is now beginning to make significant inroads, and with the advantages of design for additive manufacturing, it is clear to engineers that much more is to come.

As technology matured, several authors had begun to speculate that 3D printing could aid in sustainable development in the developing world.

**General principles**

**Modeling**

3D models are generated from 2D pictures taken at the Fantasitron 3D photo booth at Madurodam

Main article: 3D modeling

3D printable models may be created with a computer-aided design (CAD) package, via a 3D scanner, or by a plain digital camera and photogrammetry software. 3D printed models created with CAD result in reduced errors and can be corrected before printing, allowing verification in the design of the object before it is printed.[22] 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 collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

**Printing**

File:Hyperboloid Print.ogv

Timelapse video of a hyperboloid object (designed by George W. Hart) made of PLA using a RepRap "Prusa Mendel" 3D printer for molten polymer deposition

Before printing a 3D model from an STL file, it must first be examined for errors. Most CAD applications produce errors in output STL files,of the following types:

* holes;
* faces normals;
* self-intersections;
* noise shells;

**manifold errors.**

A step in the STL generation known as "repair" fixes such problems in the original model. Generally STLs that have been produced from a model obtained through 3D scanning often have more of these errors. This is due to how 3D scanning works-as it is often by point to point acquisition, reconstruction will include errors in most cases]

Once completed, 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 G-code file containing instructions tailored to a specific type of 3D printer (FDM printers).[citation needed] This G-code file can then be printed with 3D printing client software (which loads the G-code, and uses it to instruct the 3D printer during the 3D printing process)

Printer resolution describes layer thickness and X–Y resolution in dots per inch (dpi) or micrometers (µm). Typical layer thickness is around 100 μm (250 DPI), although some machines can print layers as thin as 16 μm (1,600 DPI).X–Y resolution is comparable to that of laser printers. The particles (3D dots) are around 50 to 100 μm (510 to 250 DPI) in diameter.[citation needed] For that printer resolution, specifying a mesh resolution of 0.01–0.03 mm and a chord length ≤ 0.016 mm generate an optimal STL output file for a given model input file.[31] Specifying higher resolution results in larger files without increase in print quality.

Construction of a model with contemporary methods can take anywhere from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems can typically reduce this time to a few hours, although it varies widely depending on the type of machine used and the size and number of models being produced simultaneously.

Traditional techniques like injection moulding can be less expensive for manufacturing polymer products in high quantities, but additive manufacturing can be faster, more flexible and less expensive when producing relatively small quantities of parts. 3D printers give designers and concept development teams the ability to produce parts and concept models using a desktop size printer.

Seemingly paradoxic, more complex objects can be cheaper for 3D printing production than less complex objects.[citation needed]

**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[34] with a higher-resolution subtractive process can achieve greater precision.

Some printable polymers such as ABS, allow the surface finish to be smoothed and improved using chemical vapor processes based on acetone or similar solvents.

Some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts. These techniques are able to print in multiple colors and color combinations simultaneously, and would not necessarily require painting.

Some printing techniques require internal supports to be built for overhanging features during construction. These supports must be mechanically removed or dissolved upon completion of the print.

All of the commercialized metal 3D printers involve cutting the metal component off the metal substrate after deposition. A new process for the GMAW 3D printing allows for substrate surface modifications to remove aluminum[36] or steel.

**Processes and printers**

This section should include only a brief summary of 3D printing processes. See Wikipedia:Summary style for information on how to properly incorporate it into this article's main text. (August 2017)

Schematic representation of the 3D printing technique known as Fused Filament Fabrication; a filament a) of plastic material is fed through a heated moving head b) that melts and extrudes it depositing it, layer after layer, in the desired shape c). A moving platform e) lowers after each layer is deposited. For this kind of technology additional vertical support structures d) are needed to sustain overhanging parts

A timelapse video of a robot model (logo of Make magazine) being printed using FDM on a RepRapPro Fisher printer.

A large number of additive processes are available. The main differences between processes are in the way layers are deposited to create parts and in the materials that are used. Each method has its own advantages and drawbacks, which is why some companies offer a choice of powder and polymer for the material used to build the object.[38] Others sometimes use standard, off-the-shelf business paper as the build material to produce a durable prototype. The main considerations in choosing a machine are generally speed, costs of the 3D printer, of the printed prototype, choice and cost of the materials, and color capabilities.[39] Printers that work directly with metals are generally expensive. However less expensive printers can be used to make a mold, which is then used to make metal parts.

ISO/ASTM52900-15 defines seven categories of Additive Manufacturing (AM) processes within its meaning: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat photopolymerization.

Some methods melt or soften the material to produce the layers. In Fused filament fabrication, also known as Fused deposition modeling (FDM), the model or part is produced by extruding small beads or streams of material which harden immediately to form layers. A filament of thermoplastic, metal wire, or other material is fed into an extrusion nozzle head (3D printer extruder), which heats the material and turns the flow on and off. FDM is somewhat restricted in the variation of shapes that may be fabricated. Another technique fuses parts of the layer and then moves upward 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.

Laser sintering techniques include selective laser sintering, with both metals and polymers, and direct metal laser sintering. Selective laser melting 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. Electron beam melting is a similar type of additive manufacturing technology for metal parts (e.g. titanium alloys). EBM manufactures parts by melting metal powder layer by layer with an electron beam in a high vacuum.[44][45] Another method consists of an inkjet 3D printing system, which creates the model one layer at a time by spreading a layer of powder (plaster, or resins) and printing a binder in the cross-section of the part using an inkjet-like process. With laminated object manufacturing, thin layers are cut to shape and joined together.

Schematic representation of Stereolithography; a light-emitting device a) (laser or DLP) selectively illuminate the transparent bottom c) of a tank b) filled with a liquid photo-polymerizing resin; the solidified resin d) is progressively dragged up by a lifting platform e)

Other methods cure liquid materials using different sophisticated technologies, such as stereolithography. Photopolymerization is primarily used in stereolithography to produce a solid part from a liquid. 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 cured with UV light after it is jetted, producing fully cured models that can be handled and used immediately, without post-curing. Ultra-small features can be made with the 3D micro-fabrication technique used in multiphoton photopolymerisation. Due to the nonlinear nature of photo excitation, the gel is cured to a solid only in the places where the laser was focused while the remaining gel is then washed away. Feature sizes of under 100 nm are easily produced, as well as complex structures with moving and interlocked parts. Yet another approach uses a synthetic resin that is solidified using LED.

In Mask-image-projection-based stereolithography, a 3D digital model is sliced by a set of horizontal planes. Each slice is converted into a two-dimensional mask image. The mask image is then projected onto a photocurable liquid resin surface and light is projected onto the resin to cure it in the shape of the layer. Continuous liquid interface production begins with a pool of liquid photopolymer resin. Part of the pool bottom is transparent to ultraviolet light (the "window"), which causes the resin to solidify. The object rises slowly enough to allow resin to flow under and maintain contact with the bottom of the object. In powder-fed directed-energy deposition, a high-power laser is used to melt metal powder supplied to the focus of the laser beam. The powder fed directed energy process is similar to Selective Laser Sintering, but the metal powder is applied only where material is being added to the part at that moment.