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3D printing technology

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Abstract

There is a discussion of the relevant 3D printing processes and their applications. 3D printing technology is transforming the practice of medicine and making work easier for architects. The aerospace industry employs them because of the possibility of manufacturing lighter structures to reduce weight. 3D printing technology is transforming the practice of medicine and making work easier for architects. Studies are reviewed which were about the products made in additive manufacturing processes. However, there is still a lot of work and research to be accomplished before 3D printing technologies become standard in the manufacturing industry because not every commonly used manufacturing material can be handled. The accuracy needs improvement to eliminate the necessity of a finishing process. The continuous and increasing growth experienced since the early days and the successful results up to the present time allow for optimism that additive manufacturing has a significant place in the future of manufacturing.

Keywords: 3D printing, additive manufacturing, accuracy

1. Introduction

Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material (from the International Committee F42 for Additive Manufacturing Technologies, ASTM) ^[13]. The term "3D printing" is increasingly used as a synonym for AM. However, the latter is more accurate in that it describes a professional production technique which is clearly distinguished from conventional methods of material removal. Instead of milling a workpiece from solid block, for example, AM builds up components layer by layer using materials which are available in fine powder form ^[15]. A range of different metals, plastics and composite materials may be used. It is also known as rapid prototyping, is a mechanized method whereby 3D objects are quickly made on a reasonably sized machine connected to a computer containing blueprints for the object. The 3D printing concept of custom manufacturing is exciting to nearly everyone. This revolutionary method for creating 3D models with the use of inkjet technology saves time and cost by eliminating the need to design; print and glue together separate model parts. Now, you can create a complete model in a single process using 3D printing ^[16]. The basic principles include materials cartridges, flexibility of output, and translation of code into a visible pattern. The inception of 3D printing can be traced back to 1976, when the inkjet printer was invented. In 1984, adaptations and advances on the inkjet concept morphed the technology from printing with ink to printing with materials. In the decades since, a variety of applications of 3D printing technology have been developed across several industries. The following is a brief history of the major milestones along the way. Originally developed at the Massachusetts Institute of Technology (MIT) in 1993, 3DP technology creates 3D physical prototypes by solidifying layers of deposited powder using a liquid binder. By definition 3DP is an extremely versatile and rapid process accommodating geometry of varying complexity in hundreds of different applications, and supporting many types of materials. Utilizing 3DP technology, Z Corp. has developed 3D printers that operate at unprecedented speeds, extremely low costs, and within a broad range of applications. 3D printers are used by leading manufacturers to produce early concept models and product prototypes. 3D Printers are machines that produce physical 3D models from digital data by printing layer by layer. It can make physical models of objects either designed with a CAD program or scanned with a 3D Scanner ^[17, 18].

2. A Brief History of 3D Printing ^[w4]

1984: THE BIRTH OF 3D PRINTING: Charles Hull, later the co-founder of 3D Systems, invents stereolithography, a printing process that enables a tangible 3D object to be created from digital data. The technology is used to create a 3D model from a picture and allows users to test a design before investing in a larger manufacturing program.

1992 BUILDING PARTS, LAYER BY LAYER: The first SLA (stereolithographic apparatus) machine is produced by 3D Systems. The machine's process involves a UV laser solidifying photopolymer, a liquid with the viscosity and color of honey that makes three-dimensional parts layer by layer. Although imperfect, the machine proves that highly complex parts can be manufactured overnight.

1999 ENGINEERED ORGANS BRING NEW ADVANCES TO MEDICINE: The first lab-grown organ is implanted in humans when young patients undergo urinary bladder augmentation using a 3-D synthetic scaffold coated with their own cells. The technology, developed by scientists at the Wake Forest Institute for Regenerative Medicine*, opened the door to developing other strategies for engineering organs, including printing them. Because they are made with a patient's own cells, there is little to no risk of rejection.

2002 A WORKING 3D KIDNEY: Scientists engineer a miniature functional kidney that is able to filter blood and produce diluted urine in an animal. The development led to research at the Wake Forest Institute for Regenerative Medicine that aims to "print" organs and tissues using 3D printing technology.

2005 OPEN-SOURCE COLLABORATION WITH 3D PRINTING: Dr. Adrian Bowyer at University of Bath founds RepRap, an open-source initiative to build a 3D printer that can print most of its own components. The vision of this project is to democratize manufacturing by cheaply distributing RepRap units to individuals everywhere, enabling them to create everyday products on their own.

Z Corp. launched a breakthrough product, named Spectrum Z510, which was the first high definition color 3D Printer in the market.

2006 SLS LEADS TO MASS CUSTOMIZATION IN MANUFACTURING: The first SLS (selective laser sintering) machine becomes viable. This type of machine uses a laser to fuse materials into 3D products. This breakthrough opens the door to mass customization and on-demand manufacturing of industrial parts, and later, prostheses.

That same year Objet, a 3D printing systems and materials provider, creates a machine capable of printing in multiple materials, including elastomers and polymers. The machine permits a single part to be made with a variety of densities and material properties.

2008 THE FIRST SELFREPLICATING PRINTER: Following its launch in 2005, RepRap Project releases Darwin, the first self-replicating printer that is able to print the majority of its own components, allowing users who already have one to make more printers for their friends.

2008 MAJOR BREAKTHROUGH FOR PROSTHETICS: The first person walks on a 3D-printed prosthetic leg, with all parts — knee, foot, socket, etc. — printed in the same complex structure without any assembly. The development guides the creation of Bespoke Innovations, a manufacturer of prosthetic devices which makes customized coverings that surround prosthetic legs.

2009 DIY KITS FOR 3D PRINTERS ENTER THE MARKETPLACE: MakerBot Industries, an open-source hardware company for 3D printers, starts selling DIY kits that allow buyers to make their own 3D printers and products.

2009 FROM CELLS TO BLOOD VESSELS: Bioprinting innovator Organovo, relying on Dr. Gabor Forgacs's technology, uses a 3D bioprinter to print the first blood vessel.

2011 WORLD'S FIRST 3D-PRINTED ROBOTIC AIRCRAFT: Engineers at the University of Southampton design and fly the world's first 3D-printed aircraft. This unmanned aircraft is built in seven days for a budget of £5,000. 3D printing allows the plane to be built with elliptical wings, a normally expensive feature that helps improve aerodynamic efficiency and minimizes induced drag.

2011 WORLD'S FIRST 3D-PRINTED CAR: Kor Ecologic unveils Urbee, a sleek, environmentally friendly prototype car with a complete 3D-printed body at the TEDxWinnipeg conference in Canada. Designed to be fuel efficient and inexpensive, Urbee gets 200 mpg highway and 100 mpg city. It is estimated to retail for \$10,000 to \$50,000 if it becomes commercially viable.

2011 3D PRINTING IN GOLD AND SILVER: i.materialize becomes the first 3D printing service worldwide to offer 14K gold and sterling silver as materials — potentially opening a new and less expensive manufacturing option for jewelry designers.

2012 3D-PRINTED PROSTHETIC JAW IS IMPLANTED: Doctors and engineers in the Netherlands use a 3D printer made by LayerWise to print a customized three-dimensional prosthetic lower jaw, which is subsequently implanted into an 83-year old woman suffering from a chronic bone infection. This technology is currently being explored to promote the growth of new bone tissue.

3. How 3D Printing Works

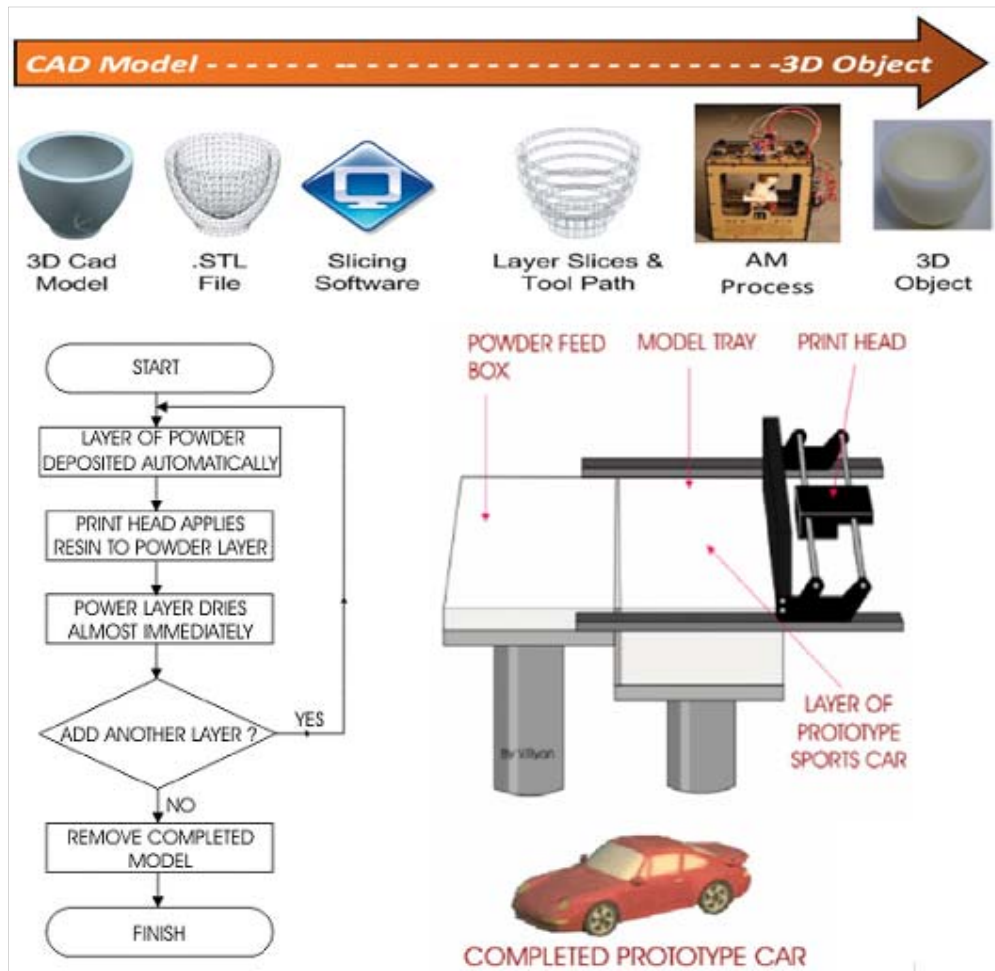


Fig. 1: 3D Printing Technology [10, 11, 12]

3.1 Source Data [2, 10, 12]

3D printing technology leverages 3D source data, which often takes the form of computer-aided design (CAD) models. Mechanical CAD software packages, the first applications to create 3D data, have quickly become the standard for nearly all product development processes. Other industries such as architectural design have also embraced 3D technologies because of the overwhelming advantages they provide, including improved visualization, greater automation, and more cost-effective reuse of 3D data for a variety of critically important applications. Due to the widespread adoption of 3D-based design technologies, most industries today already create 3D design data and are capable of producing physical models with 3D printers. The software that drives the 3D printers accepts all major 3D file formats, including .stl, .wrl, .ply, and .sfx files, which leading 3D software packages can export. In addition to mainstream applications in mechanical and architectural design, 3D printing has expanded into new markets including medical, molecular, and geospatial modeling. Additional sources of data include CT/MRI diagnostic data, protein molecule modeling database data, and digitized 3D-scan data. As designing and modeling with 3D technologies has become more pervasive, developers have created a large number of software packages tailored for use in specific industries. A small sampling of 3D software packages

that are directly compatible with the 3D printers appear in the table below.

Table 1: 3D software packages those are directly compatible with the 3D printers [10, 11, 12]

| | | | |
|----------------|----------|--------------------|----------------|
| SolidWorks® | Maya® | RapidFor™ | 3D Studio Viz® |
| Pro/ENGINEER® | SketchU® | Alias® | Form Z® |
| CATIA® | RasMol | Raindrop GeoMagic® | VectorWorks |
| 3D Studio Max® | Rhino® | Inventor® | Mimics |

After exporting a solid file from a 3D modeling package, users can open the file in ZPrint™, the desktop interface for Z Corp.'s 3D printers. The primary function of ZPrint is to cut the solid object into digital cross sections, or layers, creating a 2D image for each 0.1016mm (0.004") slice along the z axis. In addition to sectioning the model, users can utilize ZPrint to address other production options, such as viewing, orienting, scaling, coloring, and labeling multiple parts. When a user decides to print the job, ZPrint software sends 2D images of the cross sections to the 3D Printer via a standard network, just as other software sends images or documents to a standard 2D printer. Setup takes approximately 10 minutes.

3.2 Block Diagram

The microcomputer is used to create a 3 Dimensional model of the component to be made using well-known CAD techniques. A slicing algorithm is used to identify selected successive slices, i.e., to provide data with respect to selected 2-D layers, of the 3-D model [4].

Once a particular 2-D slice has been selected, the slice is then reduced to a series of one dimensional scan lines. Each of the scan line may comprise of single line segments or two or shorter line segments. Each line segment having a defined starting point on a scan line and a defined line segment length [4, 11, 14].

The microcomputer actuates the powder distribution operation when a particular 2-D slice of the 3-D model which has been created has been selected by supplying a powder "START" signal to a powder distribution controller circuit which is used to actuate a powder distribution system to permit a layer of powder for the selected slice to be deposited as by a powder head device. The powder is deposited over the entire confined region within which the selected slice is located. Once the powder is distributed, the operation of powder distribution controller is stopped when the microcomputer issues a powder "STOP" signal signifying that powder distribution over such region has been completed [4, 12].

Microcomputer then select a scan line i.e., the first scan line of the selected 2-D slice and then select a line segment, e.g., the first 1-D line segment of the selected scan line and supplies data defining the starting point thereof and the length thereof to a binder jet nozzle control circuit. For simplicity in describing the operation it is assumed that a single binder jet nozzle is used and that such nozzle scans the line segment of a slice in a manner such that the overall 2-D slice is scanned in a conventional raster scan operation. When the real time position of the nozzle is at starting point of the selected line segment. Nozzle is turned on at the start of the line segment and turned off at the end of line segment in accordance with the defined starting point and length data supplied from the computer for that line segment. Each successive line segment is similarly scanned for the selected scan line and for each successive scan line of the selected slice in the same manner. For such purpose nozzle carrier system starts its motion with a scan "BEGIN" signal from microcomputer. So that it is moved in both x-axis direction and in the Y-axis direction. Data as to the real time position of the nozzle carrier is supplied to the nozzle control circuit. When the complete slice has been scanned, a scan "STOP" signal signifies an end of the slice scan condition [4, 11, 12].

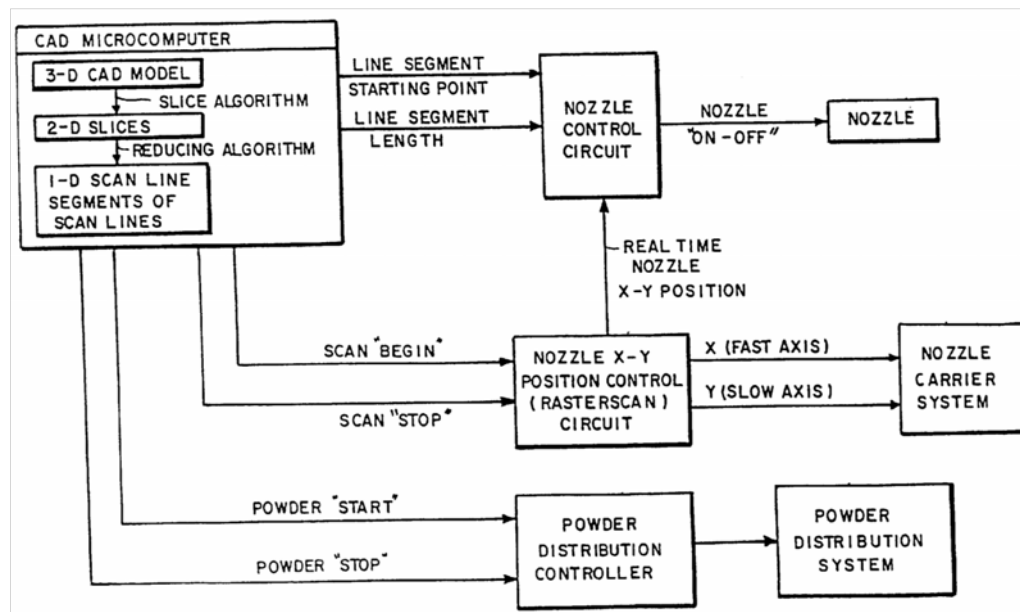


Fig 2: Block Diagram [4, 11, 12]

3.3 3D Printing Working [5]

3D printers use standard inkjet printing technology to create parts layer-by-layer by depositing a liquid binder onto thin layers of powder. Instead of feeding paper under the print heads like a 2D printer, a 3D printer moves the print heads over a bed of powder upon which it prints the cross-sectional data sent from the ZPrint software. The system requires powder to be distributed accurately and evenly across the build platform. 3D Printers accomplish this task by using a feed piston and platform, which rises incrementally for each layer. A roller mechanism spreads powder fed from the feed piston onto the build platform; intentionally spreading approximately 30 percent of extra powder per layer to ensure a full layer of densely packed powder on the build platform. The excess

powder falls down an overflow chute, into a container for reuse in the next build [5, 11, 12, 13].

Once the layer of powder is spread, the inkjet print heads print the cross-sectional area for the first, or bottom slice of the part onto the smooth layer of powder, binding the powder together. A piston then lowers the build platform 0.1016mm (0.004"), and a new layer of powder is spread on top. The print heads apply the data for the next cross section onto the new layer, which binds itself to the previous layer. ZPrint repeats this process for all of the layers of the part. The 3D printing process creates an exact physical model of the geometry represented by 3D data. Process time depends on the height of the part or parts being built. Typically, 3D printers build at a vertical rate of 25mm – 50mm (1" – 2") per hour [5, 14, 15, 18].

When the 3D printing process completes, loose powder surrounds and supports the part in the build chamber. Users can remove the part from the build chamber after the materials have had time to set, and return unprinted, loose powder back to the feed platform for reuse. Users then use forced air to blow the

excess powder off the printed part, a short process which takes less than 10 minutes. Z Corp. technology does not require the use of solid or attached supports during the printing process, and all unused material is reusable [5, 11, 13].

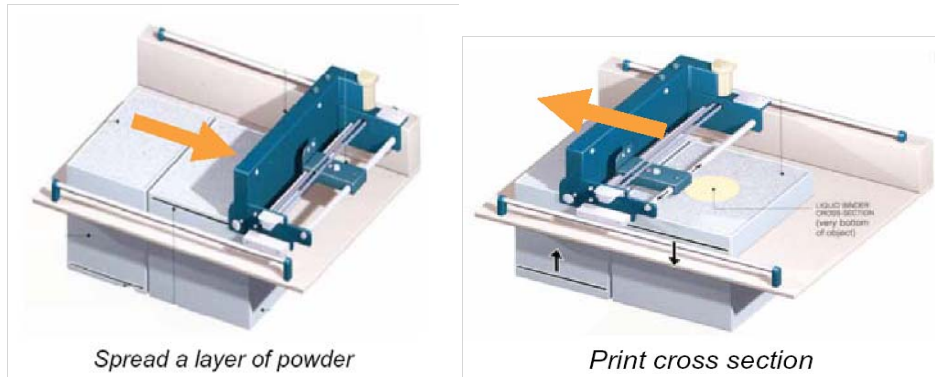


Fig 3: 3D Printing Process [5, 11, 13]

3.5 Building Materials [5-12]

- **Rigid opaque materials:**
 - White (VeroWhitePlus)
 - Black (VeroBlackPlus)
 - Blue (VeroBlue)
 - Gray (VeroGray)
- **Transparent material (VeroClear):** a nearly colorless material (visual simulation of transparent thermoplastic such as PMMA)
- **High Temperature material (RGD525):** for advanced functional testing, hot air/water flow, static applications
- **Polypropylene-like material (DurusWhite):** for snap fit applications

1) High-Performance Composite Material makes strong, high-definition parts and is the material of choice for printing color parts. The most widely used material, high-performance composite material enables color HD3DP on the 600-dpi platform 3D printer. Fine resolution on small features and excellent strength make this material suitable for applications ranging from concept modeling to sand-casting patterns. It consists of a heavily engineered plaster material with numerous additives that maximize surface finish, feature resolution, and part strength. This material is ideal for:

- High-strength requirements
- Delicate or thin-walled parts
- Color printing
- Accurate representation of design details

2) Direct Casting Metal Material creates sand-casting molds for non-ferrous metals. This material is a blend of foundry sand, plaster, and other additives that when combined produce strong molds with good surface finishes. Direct casting metal material can withstand the heat required to cast non-ferrous metals.

Users of this “ZCast®” process can create prototype castings without incurring the costs and lead-time delays of tooling.

3) Investment Casting Material fabricates parts that users dip in wax to produce investment casting patterns without molds or geometric constraints. The material consists of a mix of cellulose, specialty fibers, and other additives that combine to provide an accurate part while maximizing wax absorption and minimizing residue during the burn-out process. Users utilize investment casting material to create high quality castings with excellent surface finishes in a number of industries.

4) Snap-fit material creates Snap- parts with plastic-like, flexural properties, Which are ideal for snap-fit applications. Z Corp. has optimized this material for infiltration with the Z-Snap™ epoxy. Users utilize snap-fit material to create plastic-like parts that snap into other components and assemblies.

5) Elastomeric Material creates parts with rubber-like properties. Optimized for infiltration with an elastomer, this material system consists of a mix of cellulose, specialty fibers, and other additives. Users utilize elastomeric material to produce accurate parts that are capable of absorbing the elastomer, which gives the parts their rubber-like properties.

4. Methods

1. StereoLithography Apparatus: Stereo lithographic 3D printers (known as SLAs or stereo lithography apparatus) position a perforated platform just below the surface of a vat of liquid photo curable polymer. A UV laser beam then traces the first slice of an object on the surface of this liquid, causing a very thin layer of photopolymer to harden. The perforated platform is then lowered very slightly and another slice is traced out and hardened by the laser. Another slice is then created, and then another, until a complete object has been printed and can be removed from the vat of photopolymer, drained of excess liquid, and cured [3, 15].

Principle: converts photo sensitive liquid resins and composites into solids layer-by-layer using light (usually UV)

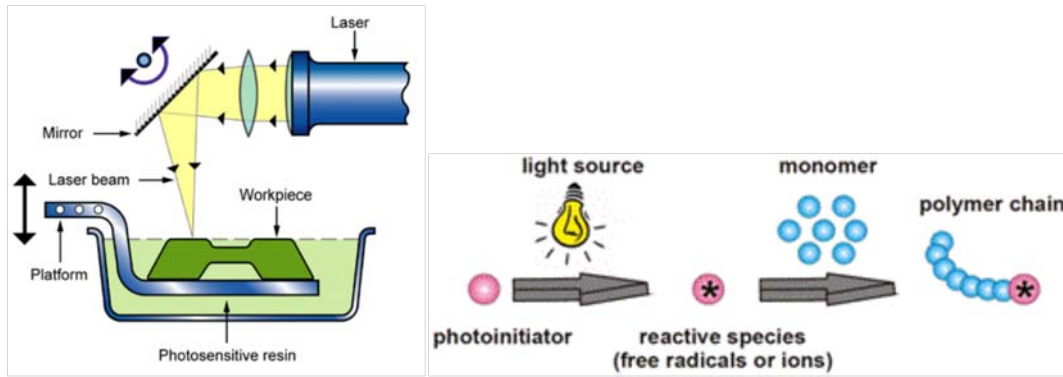


Fig 4: Stereolithography Apparatus [3, 15]

- **Material:** liquid material
- **Building:** UV laser beam that traces each slice of the object on the surface of this liquid, causing a very thin layer of photopolymer to harden

2. Material Extrusion: FDM – Fused Deposition Modeling: Here a hot thermoplastic is extruded from a temperature-controlled print head to produce fairly robust objects to a high degree of accuracy [3, 8, 9].

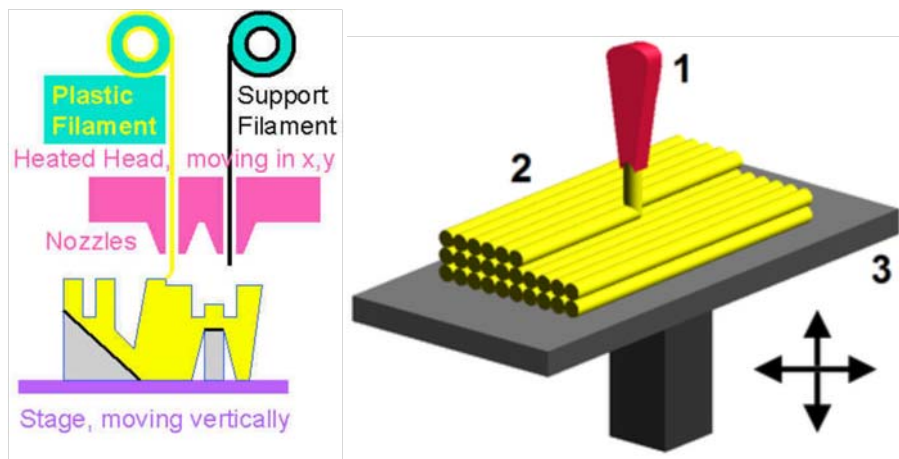


Fig 5: Fused Deposition Modeling [3, 8, 9]

A nozzle deposits molten polymer by an extrusion head onto a support structure or the part layer-by-layer.

- **Material:** semi-liquid material (usually thermoplastic)
- **Building:** material is deposited from a computer-controlled print head

3. SLS - Selective Laser Sintering: This builds objects by using a laser to selectively fuse together successive layers of a cocktail of powdered wax, ceramic, metal, nylon or one of a range of other materials [3, 6, 7].

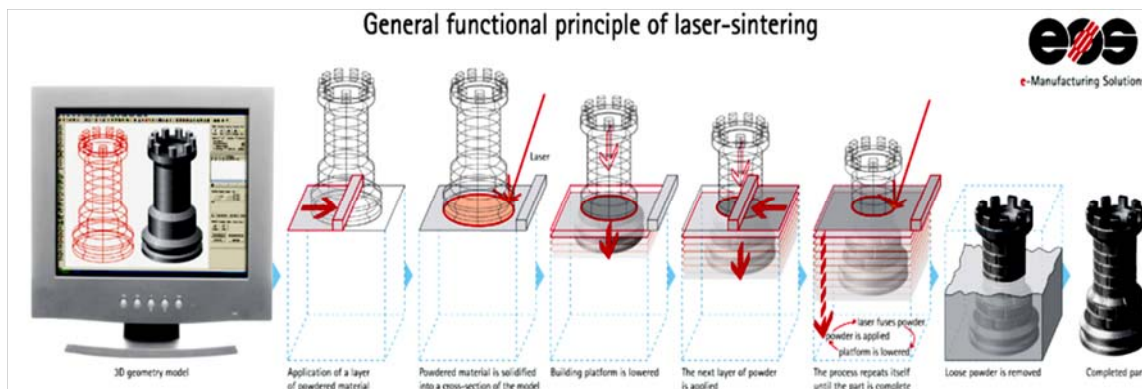


Fig 5: Selective Laser Sintering [3, 12]

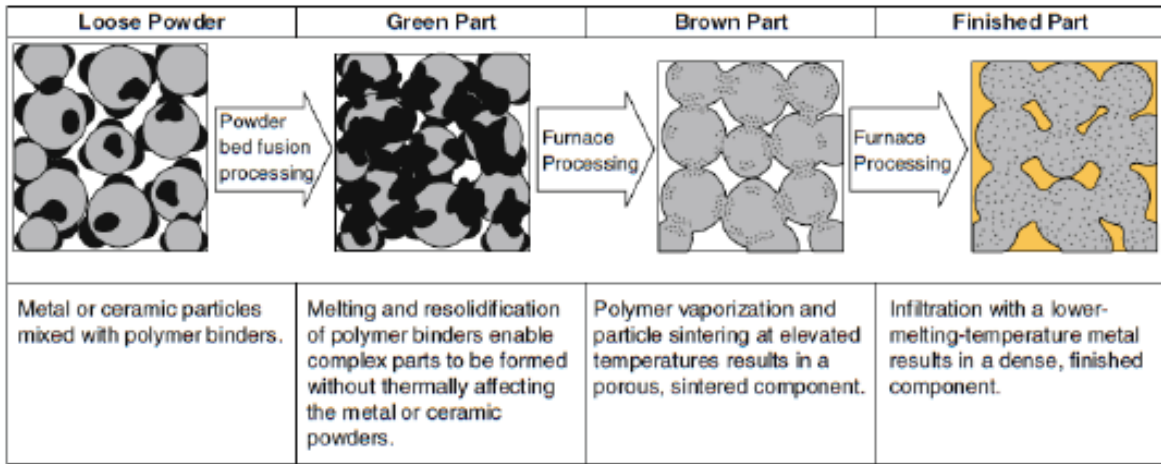


Fig 6: Infiltration after sintering [3, 15]

- **Material:** fine layer of powder (wax, polystyrene, nylon, glass, ceramics, stainless steel, titanium, aluminium, polymers)
- **Building:** a laser selectively fuse a layer of granules together

4. Material Jetting: This again builds up objects from successive layers of powder, with an inkjet-like print head used to spray on a binder solution that glues only the required granules together^[3, 12].

- **Material:** photo-polimeric material
- **Building:** object layers are created by emitting liquid photopolymer from a print head (like inkjet printers). The layer is cured using UV light.
 - **Polijet technology (Objet Connex printers)**
 - **More than one** photo-polimeric material at a time
 - **Digital materials:**
 - Set resulting object mechanical properties
 - Print two different materials at a time

5. Advantages of 3-D Printing in Comparison to Other Technologies^[1, 16-18]

- Can economically build custom products in small quantities as if mass production were used.

Sources of cost effectiveness include:

- No need for costly tools, molds, or punches
- No scrap, milling, or sanding requirements
- Automated manufacturing
- Use of readily available supplies
- Ability to recycle waste material
- Minimal inventory risk as there is no unsold finished goods inventory
- Improved working capital management as goods are paid for before being manufactured
- According to one source, 3-D printing is cost effective with plastic injection molding on production runs of 50 to 5,000 units
- Ability to easily share designs and outsource manufacturing
- Speed and ease of designing and modifying products

6. Important 3-D Printing Applications^[1, 16-18]

Small Production Run Applications of 3-D Printing

- Mass-customized products
- Prototypes
- Replacement parts
- Medical/Dental applications

Medium Production Run Applications of 3-D Printing

- Bridge manufacturing

Industries: Automotive, Manufacturing, Medical, Recreational (Do-it-yourself), Jewelry, Aerospace, Education, Dental, architecture, construction (AEC), industrial design, military, biotech (human tissue replacement), fashion, footwear, eyewear, geographic information systems, food, and many other fields.

7. Current Limitations of 3-D Printing^[1, 16, 18]

- Higher costs for large production runs relative to injection molding and other technologies
- Reduced choice for materials, colors, and surface finishes
- Lower precision relative to other technologies
- Limited strength, resistance to heat and moisture, and color stability

8. Conclusions

This paper describes the different methods of 3D printing technology. 3D Printing is the method of converting virtual 3D models into physical model. After the arrival of 3D Printing futurist predicted that we'd soon see them in every home. In future consumers will probably make what they want at home with their own 3D Printers. Different applications as 3D printing technology is explained.

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