Seven 3D Printing Technologies
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Summary

3D printing (3DP) also known as additive manufacturing (AM) is a process of making three-dimensional objects through an additive process in which successive layers of material are laid one on another to form the desired geometry. AM can be traced back to the 1980s when the first forms of the equipment and process came to life, such as Chuck Hull's Stereolithography apparatus (SLA) which formed 3D Systems. As with any technology, new and better techniques are developed constantly and 3D printing is no exception. A few 3D printing technologies that are still in their infancy are High Speed Sintering (HSS), Voxel Printing and Bio Printing just to name a few. Even current technologies and processes are changing at a rapid pace. With such a great movement happening in the 3D printing space its future is bright.

The technology can be currently categorized into seven distinct types of 3D Printer:

- Material Extrusion
- Light Photopolymerization
- Material Jetting
- Binder Jetting
- Powder Bed Fusion
- Direct Energy Deposition
- Sheet Lamination

Material Extrusion

Material extrusion's technology referred to as Fused Deposition Modelling (FDM) but also Fused Filament Fabrication (FFF) or Plastic Jet Printing (PJP) [for legal reasons] has been a popular choice for the DIY/hobbyist community and was invented in the late 80s by Scott Crump, founder of Stratasys. The FDM process starts with software to determine how the filament extruder(s) will draw out each layer to build up the model, preparing it for the building process. Printers with two or more print heads can print out multiple colours and/or use scaffolding materials to support the overhanging parts of complex prints. In either case, FDM printers use only one print head at a time, switching between them for multi-material prints.

The actual printing process works by using a motor to feed the filament through a heating element. The filament emerges molten and quickly hardens to bond with the layer below it. The print head and/or the build platform moves in the X-Y (horizontal) plane before moving in the Z-axis (vertically) once each layer is complete. In this way, the object is built one layer at a time from the bottom upwards. Keep in mind that, while FDM is a very flexible printing process, it can have trouble printing sharp angles and overhangs. Choosing an efficient orientation for the model on the printing bed can make a big difference. If the object was printed using support material or rafts, after the printing process is complete, they are snapped off or dissolved in solvent leaving behind the finished object. Post-processing steps can greatly improve the surface. Acetone baths can be used leave the part with a glossy shine.
FDM printers can be categorized into 3 designs; Cartesian, Delta and Polar. Cartesian style move the build platform in the X and Y coordinate and Z is accomplished by raising the Z carriage. Delta’s have a stationary build platform but instead use 3 towers rotated 120 degrees from each other and lifts and lowers each towers attached carriage to achieve movement about the X, Y and Z coordinates. The last is a Polar design is which the build platform moves in the Z axis while the extruder moves about the polar coordinate system r and φ. Material selection is growing weekly but typical forms include Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA).

**Light Photopolymerization**

Light Photopolymerization can be divided into 2 technologies, Stereolithography (SLA/SL) and Digital Light Processing (DLP). SLA works by using a laser to draw each layer of a model into a UV curable resin (photopolymer). Exposure to the UV light causes the liquid resin to solidify and attach to the layer below. SLA can have slower build speeds compared with Digital Light Processing (DLP) because each layer must be drawn out by the laser beam as opposed to DLP’s process with which a single layer is created by projecting an entire image. Depending on machine manufacturer, designs can vary drastically. Machines like the Form1 by Formlabs, directs the laser with a galvanometer while machines such as Old World Laboratories Nano keep the laser perpendicular to the print surface similar to FDM printers hotend. Varying designs are also adopted concerning the build plate and the printed objects can be lifted or submerged from the Vat. For DLP a digital micro-mirror device (DMD) is the core component. The DMD projects a light pattern of each cross-sectional slice of the object through an imaging lens and onto the photopolymer resin. The projected light causes the resin to harden and form the corresponding layer which fuses it to the adjacent layer of the model. The B9Creator was one of the first projector based printers to hit to market. Just like FDM objects with steep angles and overhangs will require support structures.

Unlike FDM, finished prints tend to not have distinct visible layers. Post-processing typically entails washing away excess resin and cutting or sanding supports. Support removal is usually carried out after the model has had time to fully cure. Curing time can be shortened by setting the object under a UV lamp. Current materials are limited and pricier but mimic ABS, polypropylene and wax. When comparing FDM printers with photopolymerization printers, photopolymerization gives higher resolution prints but at a cost significantly higher than FDM. Photopolymerization is also limited to single colour printing.

**Material Jetting**

Material Jetting machines have close resemblances to traditional paper printers. In Material Jetting a photopolymer material is funnelled into a liquid stream which is jetted out of the printhead onto the build plate. A UV light surrounding the printhead cures each successive layer immediately. With material being jetted on demand, multi-material prints are possible. The advantages of multi-material prints are multi-colour prints and also prints with superior mechanical properties when creating “plastic alloys”. As in the other technologies listed above, support material is required. Machines that fall into this category are very high resolution down to about 16 microns but priced significantly higher than the any of the above technologies.
**Binder Jetting**

Binder Jetting also called Drop-on-powder or Inkjet Powder Printing was developed in 1993 at the Massachusetts Institute of Technology (MIT). It works by using an automated piston fed roller to spread a layer of densely backed powder onto the build platform. A printhead then applies a binder to form a cross-section of the object. The process is repeated until the object is complete. Unlike the previous technologies, binder jetting can have full colour prints. Full colour printing is accomplished using a process similar to paper inkjet printing. Once the binder is laid down, the inkjet print-head follows and deposits colour where required. Support structures are rarely needed as each slice is supported by the previous layer(s) of powder. Post-processing work is required which entails blowing excess powder with pressurized air. The leftover material blown from the object during post-processing is reusable. Materials can range in properties from smooth to porous to rigid or elastic. The major disadvantage to this process is poor mechanical properties but can be overcome by infusing the object with additional materials. With the ability to print large full colour objects, binder jetting is favoured by the architecture, engineering and construction (AEC) industry.

**Powder Bed Fusion**

Powder Bed Fusion can be subdivided into Direct Metal Laser Sintering (DMLS), Direct Metal Printing (DMP), Electron Beam Melting (EBM), Selective Heat Sintering (SHS), Selective Laser Melting (SLM) and Selective Laser Sintering (SLS)

Direct Metal Laser Sintering (DMLS) was developed by EOS, a German based company in the 90’s. DMLS and SLS are often used interchangeably but a distinction is made by the fact that DMLS refers specifically to metal sintering and is not used with plastics. The process starts with an automated roller spreading a thin metal layer of powder onto a bed encapsulated in a chamber of inert gas (argon or nitrogen). Gas is used in mitigating the effects of oxidation as sintering occurs. The powder bed must be held at an optimal temperature for sintering to occur. A laser starts to move across the powder, sintering a cross section of the object. This process is then repeated. Like with Binder Jetting, support material is rarely required as the unsintered powder beneath the active layer acts as support. The left over material can be recycled for future use. Since DMLS takes place at such high temperatures the parts produced are almost free from distortion and residual stress at the micro level, but are subject to thermal stress or warping as cooling occurs. Resolutions can get as little as 10 microns.

Electron Beam Melting (EBM) was developed by Arcam, a Sweden based company in 1997. EBM starts with a bed of metal powder enclosed in a vacuum chamber in order to reduce the damaging effects of oxidation as melting takes place. An automated roller then spreads a thin layer of metal powder across a bed that is kept at optimal temperature for melting to occur. An electromagnetically controlled electron beam then starts to move across the powder melting a cross section of the object. When the layer is finished the bed drops down and the process is repeated. When printing is completed, the model and excess material is left to cool. All leftover material can be recycled. Finished objects produced will have the same properties as objects created using DMLS.

Selective Heat Sintering (SHS) is manufactured exclusively by Blueprinter, a Denmark based company. The process starts by an automated roller spreading a thin layer of powder across an encapsulated temperature optimized bed. A printhead then moves across the bed applying heat to bring the powder to just below its melting point causing solidification to occur. The bed is lowered and followed by a piston spreading a new layer of powder which is followed by another pass of the thermal printhead.
The process is repeated until the object is printed. As with other powder bed printers, the excess material cradles the object in the printing process eliminating the need for supports. After printing is completed very little post-processing is required except removing excess powder. The excess powder is reusable in future prints. SHS’s downfall is its small build volume and limited material selection.

Selective Laser Melting (SLM) was developed in 1995 when Fraunhofer Institute for Laser Technology researchers teamed up with F&S Stereolithographietechnik GmbH researchers. SLM is a metal additive manufacturing technique similar to Selective Laser Sintering (SLS). The main difference being that SLS sinters the material, heating to just below melting point, while SLM melts the material, creating a melt pool in which material is consolidated before cooling to form a solid structure. The process takes place on a bed of powder enclosed in a chamber of inert gas (argon or nitrogen) in order to reduce the effects of oxidation. The powder bed is held at an optimized temperature for melting. During printing, a thin layer of powder is spread across the build chamber by an automated roller. The laser starts to move across the powder and melts a cross section of the object. A new layer of powder is then spread over the top of the previous layer and the laser then begins to form the next layer. In rare occasions is support structures required as the excess powder cradles the object in the printing process. Once the process is complete the object is left to cool and the leftover material is recovered and recycled for future use. Objects created using SLM are ideal for applications where high strength or high temperatures are required as it results in extremely dense and strong parts. The high temperature required in SLM can cause residual stresses formed from the high thermal gradients within the material.

Selective Laser Sintering (SLS) was developed in the mid-1980s at the University of Texas at Austin. SLS starts with a controlled chamber encapsulating a heated bed of powder (just below melting point) producing ideal conditions for sintering. A thin layer of powder is spread across the bed by an automated roller. A laser starts to move across the chamber and sinters a cross section of the object. Since finished part density depends on laser power, rather than laser duration, typical SLS machines use pulsed lasers. The bed drops and another layer of powder is added followed by a pass of the laser. The process is repeated forming completed object. Once complete the object and unsintered material is left to cool followed by material recovery and recycling. As with all powder bed technologies the unsintered powder cradles the object during printing eliminating the need for supports. Materials range from polymers to metals and depending on materials, finished products can resemble that of object produced in conventional manufacturing.

**Direct Energy Deposition**

Direct Energy Deposition can be broken down into Electron Beam Direct Manufacturing (EBDM) / Electron Beam Freeform Fabrication (EBF3) and Laser Powder Forming (LPF). Electron Beam Direct Manufacturing (EBDM) / Electron Beam Freeform Fabrication (EBF3) are basically the same process, but developed by different people. With the EBDM/EBF3 process, a computer controlled electron beam gun provides the energy source used for melting metallic material, typically in wire form. The highly efficient electron beam can be both precisely focused and deflected using electromagnetic coils. The deposition mechanism deposits the material just where it is needed, solidifying immediately to form a layer of the object. The sequence is repeated to produce a near-net-shape part needing only finish machining.
A contamination-free work zone is produced since the process is conducted within a high vacuum environment, which does not require the use of additional inert gasses that are commonly used with laser and arc based processes. EBDM/EBF3 currently has one of the largest build capacities of any 3D printing process.

Laser Powder Forming (LPF) nicknamed Direct Metal Deposition (DMD) or Direct Metal Printing (DMP) is an additive manufacturing technology used to repair and rebuild worn or damaged components, to manufacture new components, and to apply wear and corrosion resistant coatings. A high power laser is used as an energy source to melt a highly focused metallic powder stream onto the melt pool via a powder feeding system which is all performed in a sealed chamber to reduce oxidation. The laser head is controlled by a multi axis joint and the object is built upon a rotary build platform, allowing a variety of angles to produce complex geometries. Depending on the machine used, objects can be near net shape requiring minimal post-processing. A negative aspect of LPF is that the machinery is big and expensive, but also that it requires large amounts of power. This process can use a wide variety of materials such as nickel, iron, cobalt and titanium based alloys, as well as refractory metals and cermet (ceramic-metal composites). Objects produced can have as good or better mechanical properties than cast or wrought objects.

Sheet Lamination

The last type is Sheet Lamination which is categorized into Laminated Object Manufacturing (LOM) and UltraSonic Additive Manufacturing (UAM). Laminated Object Manufacturing (LOM) was developed and patented in 1996 by Helisys Inc (now Cubic Technologies) a California based company. LOM works by laying a sheet of material down followed by a glue mechanism that deposits varying amount of glue depending if the area is part of the object or outside it’s bound. A hot compression plate follows ensuring tight bonding between layers. The next step depends on the printers’ ability to print with full colour, but a print head similar to that on a standard ink-jet printer would print the required coloured outline before the sheet is laid down for bonding. After bonding and colouring is complete a knife or laser follows, tracing the 2D outline of the model’s cross section. The build plate lowers and the process is started over. Post-processing entails peeling or removing excess material. LOM is slightly less accurate then SLA and SLS but considerably less expensive. While not as prevalent as other methods of additive manufacturing, LOM is starting to get traction thanks to the Architectural sector. The most common materials are plastic and paper sheets.

UltraSonic Additive Manufacturing (UAM) also known as Ultrasonic Consolidation (UC) was developed and patented by Dawn White. UAM is similar in process as LOM; In fact it’s a hybrid process that combines additive and subtractive manufacturing. Thin strips of metal are laid down side to side followed by a welding process that’s composed of ultrasonic energy delivered at a high-frequency (20,000 Hertz) and the compressive force generated by heavy machine rollers. The welding process is followed by a CNC mill to remove the excess strips of material. These steps are repeated to form the finished object. Selectively applying the strips of metal where material is needed results in significant waste reduction compared with traditional subtractive manufacturing. UAM’s ability to create objects with multiple metal selections with tight bonds makes it ideal for high-value end-use components. Advantages of using UAM over traditional manufacturing are that more complex internal structures are possible and UAM parts will exhibit better mechanical properties. Current material selection includes copper, nickel, silver and stainless steel.