ADDITIVE MANUFACTURING TECHNOLOGIES

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What is 3D Printing/Additive Manufacturing?

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the entire object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object.
The process starts with making a virtual design of the object that has to be created. This virtual design is made in a CAD (Computer Aided Design) file using a 3D modelling program (for the creation of a totally new object) or with the use of a 3D scanner (to copy an existing object). This scanner makes a 3D digital copy of an object and puts it into a 3D modelling program. To prepare the digital file created in a 3D modelling program for printing, the software slices the final model into hundreds or thousands of horizontal layers. When this prepared file is uploaded in the 3D printer, the printer creates the object layer by layer. The 3D printer reads every slice (or 2D image) and proceeds to create the object blending each layer together with no sign of the layering visible, resulting in one three dimensional object.

Technologies used for 3D Printing

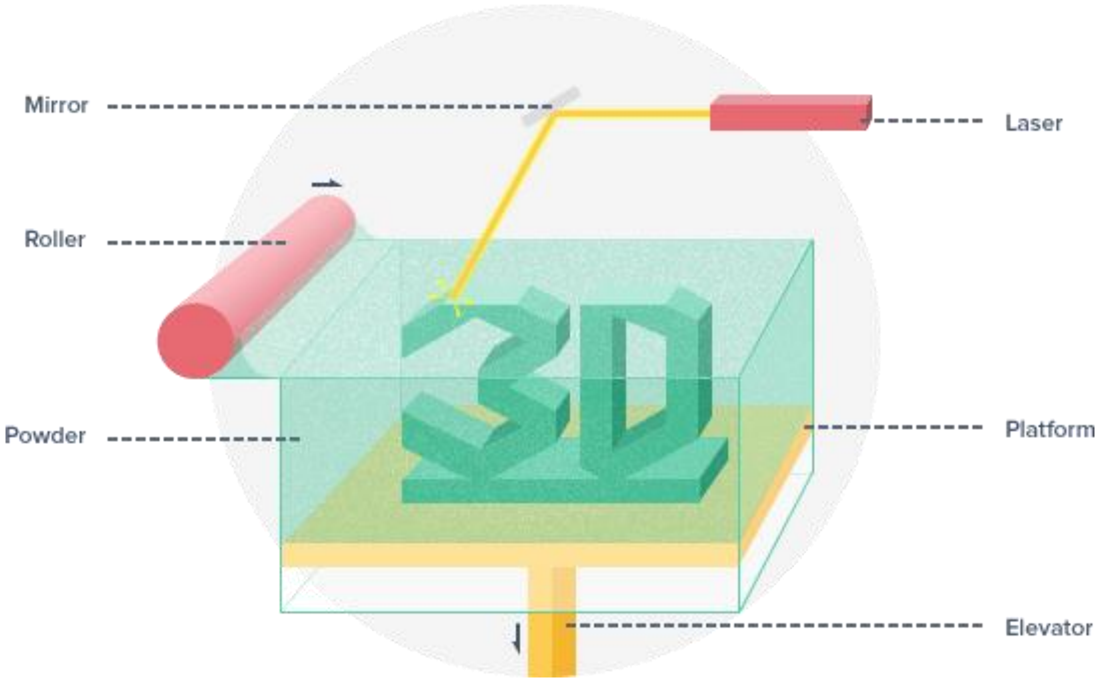
- ### Powder Bed Fusion Technology

1. ### Selective Laser Sintering (SLS)

   Selective Laser Sintering uses lasers to sinter powdered material, binding it together to create a solid structure. When a layer is finished, the build platform moves down and an automated roller adds a new layer of material which is sintered to form the next cross section of the object. Repeating this process builds up the object one layer at a time. SLS is both a cost and time effective technology, making it ideal for prototyping and end use manufacturing.

   How it works?

   The build takes place on a bed of powder encapsulated by controlled chamber in order to keep environment ideal and stable. During production, a thin layer of powdered material is spread evenly across the build chamber by an automated roller. The laser starts to move across the powder and sinters 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 cross section. When fully built, the object is surrounded by non-sintered, excess powder. That excess material cradles the object in the printing process, providing support for complex geometries and overhangs which might require dedicated supports using other 3D printing processes. Once the print is completed, the model and supporting material is left to cool. The leftover material is recovered and recycled, leaving the final model behind. However, since temperatures are very high in the build chamber, the object can be subject to some thermal stress or warping as it cools. This process is able to make high density objects, and post processing, many times, consists of only blasting the object with compressed air to remove excess powder. SLS made objects are often treated to a solution bath or colour dies but not usually machined.



Video showing functioning of the system-
https://www.youtube.com/watch?v=9E5MfBAV_tA

Materials Used

SLS can produce parts from a relatively wide range of commercially available powder materials. These include polymers such as nylon (neat, glass-filled, or combined with other fillers such as carbon fiber) or polystyrene; metals including steel, titanium, alloy mixtures; composites and green sand. While some machines are able to use single-component materials leading to less porous and more high-performance products, most

SLS machines use two-component powders. These are typically either coated powder or a powder mixture comprised of the base material and a compound to facilitate sintering.

Machines

a. EOS M 400 by EOS

b. iPro 8000 MP by 3D Systems

c. ProX 500 by 3D Systems

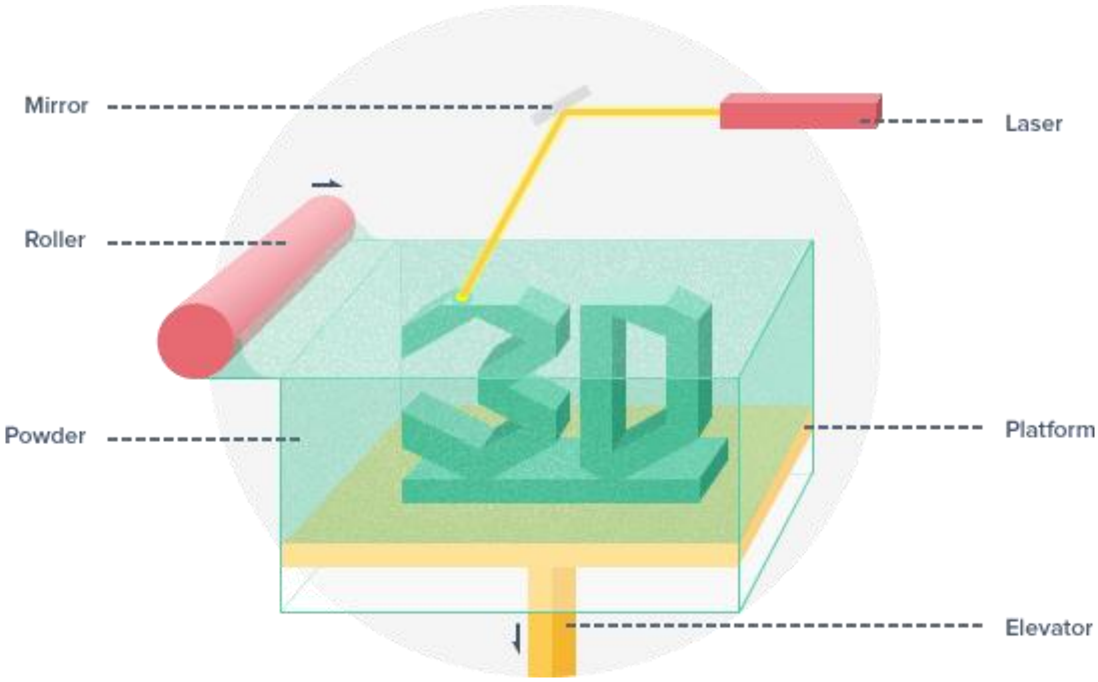
More machines can be found here- https://thre3d.com/category/printers

2. Selective Laser Melting (SLM)

Selective Laser Melting uses a laser to melt powdered metal in chamber of inert gas. When a layer is finished, the powder bed moves down, and an automated roller adds a new layer of material which is melted to form the next cross section of the model. SLM is ideal for applications where high strength or high temperatures are required as it results in extremely dense and strong parts that match characteristics of the target material. SLM is a metal additive manufacturing technique similar to Selective Laser Sintering (SLS). A main difference between them being that SLS sinters the material, i.e heating to below the melting point until the particles merge with one another, while SLM melts the material, creating a melt pool in which material is consolidated before cooling to form a solid structure.

How it works?

SLM specifically differs from SLS because it does not use material with low melting points, and instead, only uses integral powder metal, creating a much higher energy density to fuse the powder. The build takes place on a bed of powder encapsulated by tightly controlled chamber of inert gas (either argon or nitrogen) in order to reduce the damaging effects of oxidation. The powder bed is held at an elevated temperature so the powdered material is at an optimal temperature for melting. During production, a thin layer of plastic powder is spread evenly 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 cross section. When fully built, the object is surrounded by non-sintered, excess powder. That excess material cradles the object in the printing process, providing support for complex geometries and overhangs which might require dedicated supports using other 3D printing processes.Once the print is completed, the model and supporting material is left to cool. The leftover material is recovered and recycled, leaving the final model behind. The process takes place at at a high temperature in order to reach a high density. This is accompanied by residual stresses that derive from high thermal gradients in the material that can cause distortion, cracks or delaminations. However, objects created using SLM are similar to those manufactured by series production, often do not require special surface finishes, and can be easily machined.



Video showing functioning of the system-
https://www.youtube.com/watch?v=bgQvqVq-SQU&list=UUmyUACVV-DdW7F6OEHDa-tg

Materials Used

Unlike SLS, the materials used in SLM can exist in an single component (atomized) form which allows for denser, less porous builds. The types of materials available for this process include stainless steel, tool steel, cobalt chrome, titanium and aluminium. Other materials are currently under development but must exhibit certain flow characteristics in order to be process capable.

Machines

a. SLM 100 by Realizer

b. SLM 125 HL by SLM Solutions

c. SLM 500 HL by SLM Solutions

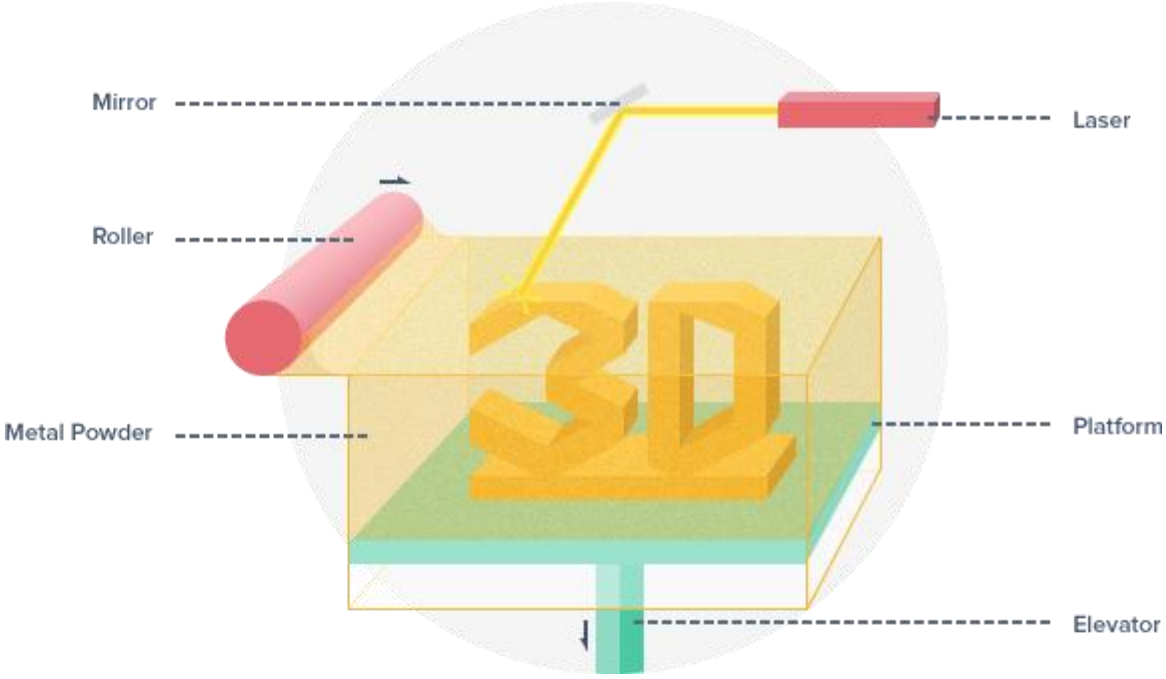
More machines can be found here- https://thre3d.com/category/printers

3. Direct Metal Laser Sintering (DMLS)

Direct Metal Laser Sintering is a process used exclusively by EOS that sinters layers of powdered metal in a chamber of inert gas. When a layer is finished, the powder bed moves down, and an automated roller adds a new layer of material which is sintered to form the next section of the model. Repeating this process builds up the object one layer at a time. DMLS is a metal additive manufacturing technique similar to Selective Laser Sintering (SLS), the main difference being that DMLS refers specifically to metal sintering and is not used for plastics. Nevertheless, the term SLS is often used interchangeably with DMLS. The physical process is different from Selective Laser Melting (SLM) in that it only sinters the powder as opposed to achieving a full melt.

How it works?

The build takes place on a bed of powder encapsulated by tightly controlled chamber of inert gas (either argon or nitrogen) in order to reduce the damaging effects of oxidation. During production, a thin layer of metal powder is spread evenly across the build chamber by an automated roller. The powder bed is held at an elevated temperature so the metal powder is at an optimal temperature for sintering. The laser starts to move across the powder and, as it moves, sinters 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 cross section. When fully built, the object is surrounded by non-sintered, excess powder. That excess material cradles the object in the printing process, providing support for complex geometries and overhangs which might require dedicated supports using other 3D printing processes. When printing is completed, the build chamber, including the model and excess material inside, is left to cool. The leftover material is then recovered and recycled, leaving the final model behind. DMLS takes place at such a high temperature that it produces parts that are practically free from residual stress and distortion at a micro level, eliminating the need for heat treatment post-processing. However, due to high temperatures in the build chamber, the object can be subject to some thermal stress or warping as it cools.



Video showing functioning of the system- https://www.youtube.com/watch?v=cRE-PzI6uZA

Materials Used

DMLS only works with multi-component alloys, but theoretically, almost any metal alloy can be used in DMLS once it has been fully developed and validated. Materials currently available from EOS include alloys containing stainless steel, aluminium, cobalt chrome, maraging steel, Inconel, and titanium.

Machines

a. ProX 300 by 3D Systems

b. ProX 200 by 3D Systems

c. PXM by Phenix Systems

More machines can be found here- https://thre3d.com/category/printers

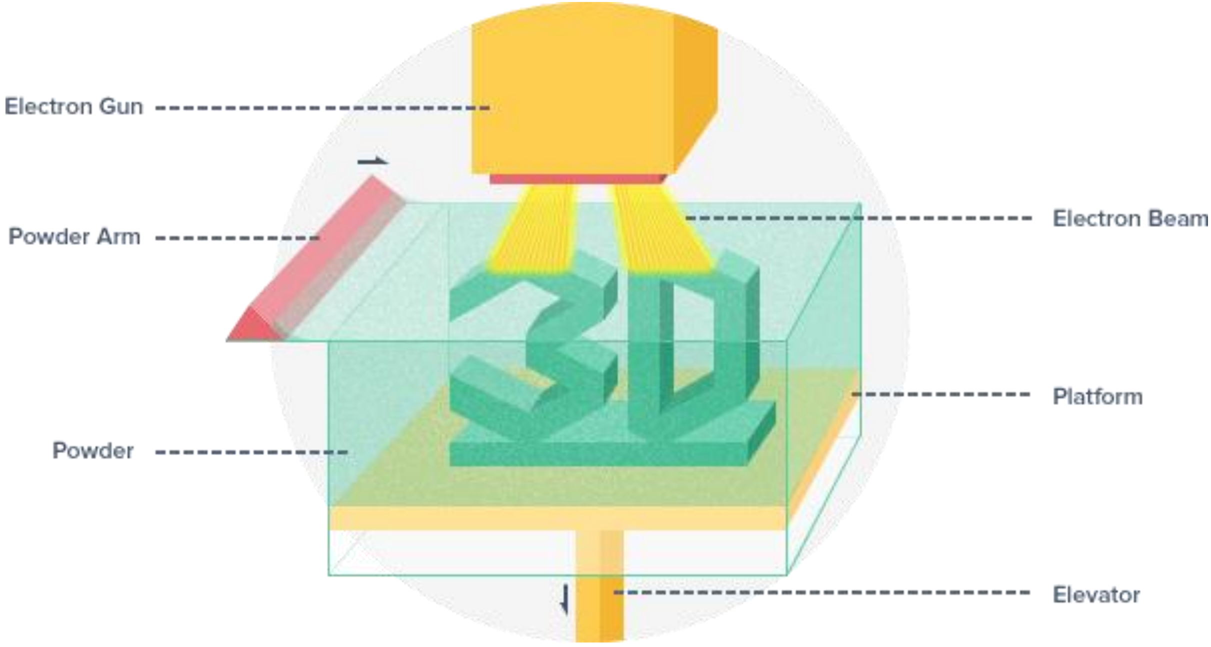
4. Electron Beam Melting (EBM)

Electron Beam Melting is a process used exclusively by Arcam, and works by melting powdered metal inside a vacuum using an electron beam. When a layer is finished, the powder bed moves down, and an automated roller adds a new layer of material which is melted to form the next section of the model. Repeating this process builds up the object one layer at a time. EBM is ideal for applications where high strength or high temperatures are required, as it produces extremely dense and strong objects that match the characteristics of the fully dense target material. EBM is a metal additive manufacturing technique similar to Selective Laser Melting (SLM), the main difference being that EBM uses an electron beam in a vacuum to fully melt the metal powder, instead of a laser in a chamber of inert gas.

How it works?

The build takes place on a bed of powder encapsulated by a vacuum chamber in order to reduce the damaging effects of oxidation. During production, a thin layer of metal powder is spread evenly across the build chamber by an automated roller. The powder bed is held at an elevated temperature so the metal powder is at an optimal temperature for melting. The electron beam starts to move across the powder and, as it moves, melts a cross section of the object. Electromagnetic coils control the electron beam and help provide the fast and accurate beam control that allows several melt pools to be simultaneously maintained. This means that several parts of the object can be built at the same time per layer, leading to faster build speeds. A new layer of powder is then spread over the top of the previous layer and the electron beam then begins to form the next cross section. When fully built, the object is surrounded by unmelted, excess powder. That excess material cradles the object in the printing process, providing support for complex geometries and overhangs which might require dedicated supports using other 3D printing processes.

When printing is completed, the build chamber, including the model and excess material inside, is left to cool. The leftover material is then recovered and recycled, leaving the final model behind. EBM takes place at such a high temperature that it produces parts that are practically free from residual stress and distortion at a micro level, eliminating the need for heat treatment post-processing. However, due to high temperatures in the build chamber, the object can be subject to some thermal stress or warping as it cools.



Materials Used

Available materials for Arcam EBM printers include various forms of titanium in addition to cobalt chrome. Since the process takes place in vacuum at high temperature, it produces objects comparable to wrought material and that have better mechanical qualities than cast titanium or cobalt chrome. Organizations can set aggressive design timetables because they can both prototype and manufacture relatively inexpensive high-quality objects with long lifecycles. EMB has also built certified medical-grade, biocompatible implants.

Machines

a. Q10 by Arcam

b. Q20 by Arcam

5. Selective Heat Sintering (SHS)

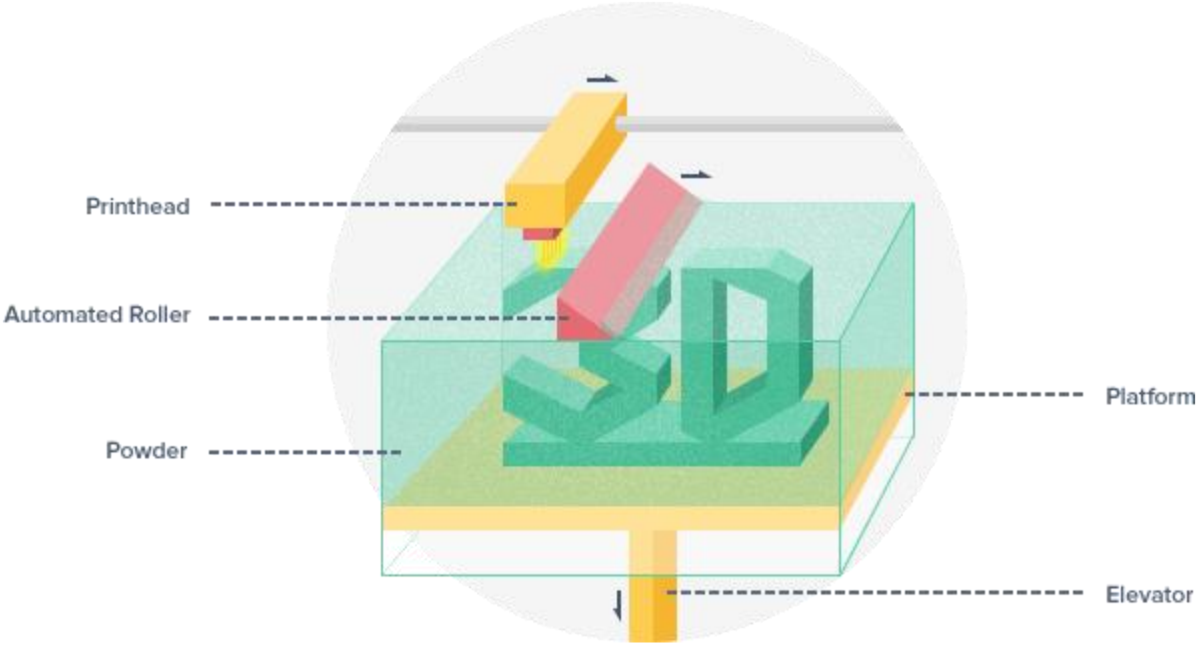
Selective Heat Sintering systems are manufactured by BluePrinter, and work by using a thermal print head to apply heat to layers of powdered thermoplastic. When a layer is finished, the powder bed moves down, and an automated roller adds a new layer of material which is sintered to form the next cross section of the model. SHS is best for manufacturing inexpensive prototypes for concept evaluation, fit/form and functional testing. SHS is a plastics additive manufacturing technique similar to Selective Laser Sintering (SLS), the main difference being that SHS employs a less intense thermal print head instead of a laser, thereby making it a cheaper solution, and able to be scaled down to desktop sizes.

How it works?

The build takes place in a bed of powder encapsulated by a tightly controlled chamber. During production, a thin layer of metal powder is spread evenly across the build chamber by an automated roller. The powder bed is held at an elevated temperature so the plastic powder is at an optimal temperature for sintering. The print head starts to move across the powder and, as it moves, applies heat to bring the material to just below its melting point and solidifies the material to create the object. A new layer of powder is then spread over the top of the previous layer and the thermal print head then begins to form the next cross section. When fully built, the object is surrounded by unmelted, excess powder. That excess material cradles the object in the printing process, providing support for complex geometries and overhangs which might require dedicated supports using other 3D printing processes. After printing is completed, the excess powder must be removed. Powder removal is usually done at a separate powder removal station. This excess powder can then be reused for further prints. SHS is employed in Blue Printer's desktop-sized rapid prototyping machines that come in a very manageable size compared to other powder bed fusion 3D printers. However, a small build volume and limited selection of materials means that SHS prototyping is currently restricted to printing small, white models.

Materials Used

BluePrinter offers thermoplastics in powder form which have properties similar to nylon. They currently only produce a very limited, monochrome selection. However, the amount of materials available for this process does not reflect a technological limitation of the process, but rather, the speed at which BluePrinter can offer a wider selection for their patented process. The finished object's strengths and quality are comparable to those created using Binder Jetting.



Video showing functioning of the system-
https://www.youtube.com/watch?v=Jtgj1yMWyMs

Machines

a. Blueprinter by Blueprinter

- Light Polymerization Technology

1. Stereolithography (SLA)

Stereolithography uses a laser to draw each layer of a model into a photopolymer (light reactive plastic) resin, curing it one layer at a time. A beam of UV light, in the form of a laser, is projected onto a point in the resin, causing it to react and become solid. The laser then draws the cross section of the object to be printed, forming one layer of hardened material. The most recently printed layer is then repositioned to leave room for unhardened photopolymer to fill the newly created space between the print and the laser. Repeating this process builds up the object one layer at a time. Production time depends on the size of the model, but trades off high resolution for relatively slow 3D printing speeds which can sometimes take over 24 hours to print a fist sized object. SLA can typically reach layer thicknesses of under 30 microns, a fraction of a sheet of computer paper. Like Digital Light Processing (DLP), objects printed using SLA are known to have less visible layers than are visible with other techniques, such as Fused Deposition Modeling (FDM). **This technology is also used in consumer level printing.**

How it works?

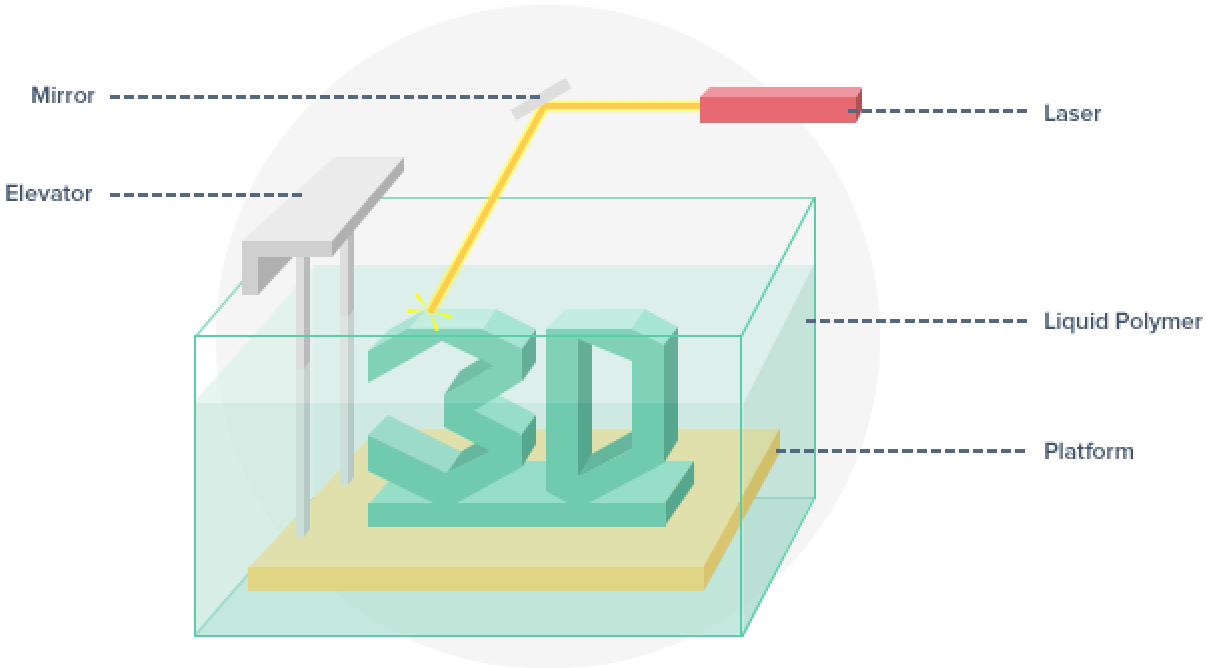
Each cross-section of the sliced CAD model is traced over the liquid material by a laser. Exposure to the UV light causes the liquid resin to solidify and attach to the layer below. Compared with Digital Light Processing (DLP), SLA can have relatively slower build speeds because each layer must be drawn out by the laser beam, as opposed to DLP's process with which a single layer is created by projecting one digital image. SLA can be likened to drawing the layer one motion at a time while DLP is more akin to a stamping process.

There are two styles of printing using SLA. The model can be built by pulling the object out of the resin to create space for uncured resin at the bottom of the tank to form the next layer. The other technique to print using SLA is to build the object by pulling it down into the tank with the newest layer being cured on the top of the photopolymer bath. Because of this, for all instances with sharp angles or overhangs, there must always be vertical supports connecting them to the build platform. Supports are thicker in their columns and base than where they connect to the object in order to withstand the tensions and stresses of mechanical movement; for example, when disconnecting the most recently cured layer from the vat to create room for new resin to flow in. However, the points of contact between the support and the model can be minimized, resulting in an ability to have strong support columns while maintaining easy removal and post processing later, as well as minimizing surface blemishing.

With SLA, layers tend not to form ridges, blending together much more smoothly than plastic filament is able to. When the process is complete, the remaining resin must be washed away with solution, then the supports are removed by snapping or cutting. Sanding or filing away what's left behind by the supports is usually left until later, after the model has had a chance to fully harden, which can be expedited with a short time under UV lamps.

Materials Used

SLA printers can produce objects with a wide variety of properties such as water resistance, flexibility, durability, stiffness, high clarity, thermal resistance and high impact resistance. The photopolymers have been designed to mimic ABS, polypropylene, and wax, making them useful for everything from high quality prototyping to lost wax casting. However, prints using photopolymer can become brittle with increased exposure to light over time. They may begin to show small cracks and become more susceptible to breaking. With this process, only one material can be used at a time because the object is built out of a vat containing a singular photopolymer solution.



Video showing functioning of the system- https://www.youtube.com/watch?v=NM55ct5KwiI&list=PL6ReneqBS2JDFuygm6Yta1iNBMaUds5fq

Machines

a. Form1 by Formlabs

b. Miicraft by Miicraft

c. ProJet 6000 MP by 3D Systems

More machines can be found here- https://thre3d.com/category/printers

2. Digital Light Processing (DLP)

Digital Light Processing uses a projector, like the kind used for office presentations or in home theatres, to project the image of the cross section of an object into a vat of photopolymer (light reactive plastic). The light selectively hardens only the area specified in that image. The most recently printed layer is then repositioned to leave room for unhardened photopolymer to fill the newly created space between the print and the projector. Repeating this process builds up the object one layer at a time. DLP is known for its high resolution, typically able to reach a layer thicknesses of under 30 microns, a fraction of a sheet of copy paper. Like Stereolithography (SLA), objects printed using DLP are known to have less visible layers than are visible with other techniques, such as Fused Deposition Modeling (FDM), at the same resolution. **This technology is also used in consumer level printing.**

How it works?

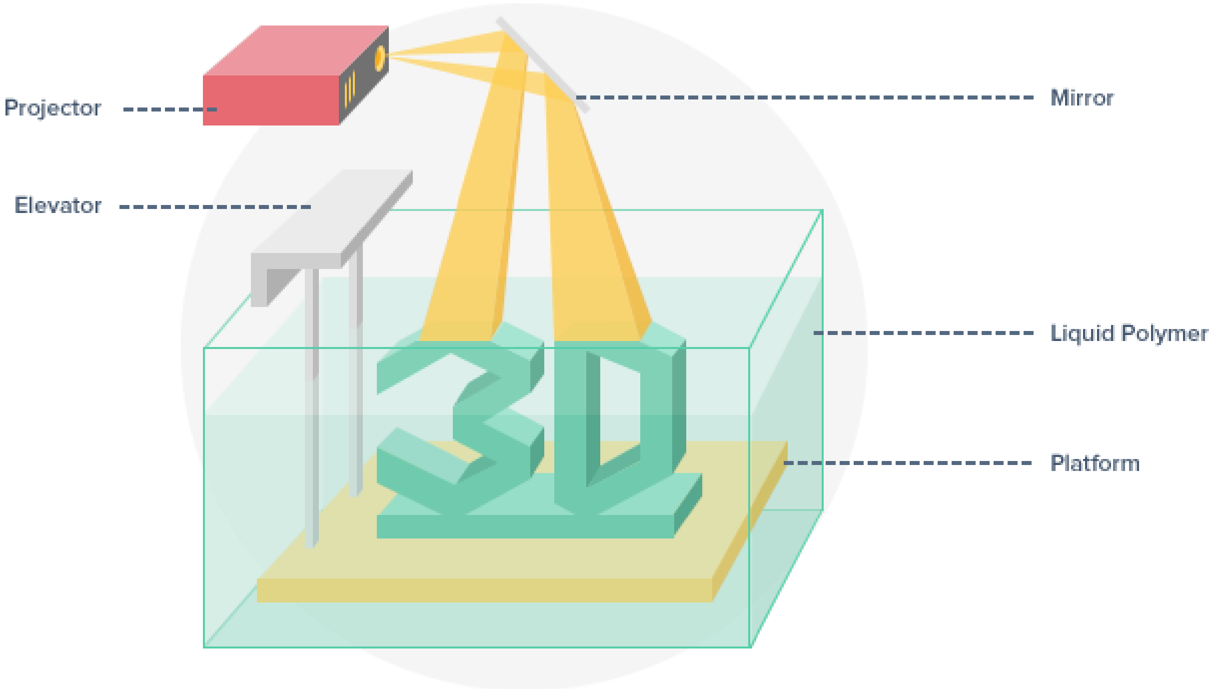
A digital micromirror device (DMD) is the core component of DLP printers. The DMD projects a light pattern of each cross-sectional slice of the object through an imaging lens and onto the photopolymer resin. The projected light causes the resin to harden and form the corresponding layer which fuses it to the adjacent layer of the model. Compared with Stereolithography (SLA), DLP can have relatively faster build speeds. This is because a single layer is created in one digital image, as opposed to SLA's laser process which must scan the vat with a single point. SLA can be likened to drawing the layer one motion at a time while DLP is more akin to a stamping process.

There are two styles of printing using DLP. The model can be built by pulling the object out of the resin to create space for uncured resin at the bottom of the tank to form the next layer. The other technique to print using DLP is to build the object by pulling it down into the tank with the newest layer being cured on the top of the photopolymer bath. Because of this, for all instances of sharp angles or overhangs, there must always be vertical supports connecting them to the build platform. Supports are thicker in their columns and base than where they connect to the object, to withstand the tensions and stresses of mechanical movement; for example, when disconnecting the most recently cured layer from the vat to create room for new resin to flow in. However, the points of contact between the support and the model can be minimized, resulting in an ability to have strong support columns while maintaining easy removal and post processing later, as well as minimizing surface blemishing.

With DLP, layers tend not to form ridges, blending together much more smoothly than plastic filament is able to. When the process is complete, the remaining resin must be washed away with solution, then the supports are removed by snapping or cutting. Sanding or filing away what's left behind by the supports is usually left until later, after the model has had a chance to fully harden, which can be expedited with a short time under UV lamps.

Materials Used

DLP printers can produce objects with a wide variety of properties such as water resistance, flexibility, durability, stiffness, high clarity, thermal resistance and high impact resistance. The photopolymers have been designed to mimic ABS, polypropylene, and wax, making them useful for everything from high quality prototyping to lost wax casting. However, prints using photopolymer can become brittle with increased exposure to light over time. They may begin to show small cracks and become more susceptible to breaking. With this process, only one material can be used at a time because the object is built out of a vat containing a singular photopolymer solution.



Machines

a. T.Black by Trimaker

b. HA 50 uv by Rapidshare

c. S30 by Rapidshare

More machines can be found here- https://thre3d.com/category/printers

- Fused Deposition Modelling (FDM) Technology

  FDM can easily be understood as drawing with a very precise hot glue gun. FDM (rebranded by the open source community as Fused Filament Fabrication, FFF) works by extruding material through a nozzle to print one cross section of an object, then moving up vertically to repeat the process for a new layer. The printer nozzle contains resistive heaters that melt the plastic as it flows through the tip and forms the layers. The extruded plastic then hardens immediately as it bonds to the layer below it. Repeating this process builds up the object one layer at a time. The quality of prints using this technology depends largely on layer height; the thinner the cross sections, the less noticeable they are, and the smoother the printed objects are. The cross section's resolution, typically ranges between 75 microns (slightly thinner than a sheet of copy paper) and 300 microns. FDM technology is common in desktop 3D printers and less expensive professional printers. **This technology is also used in consumer level printing.**

How it works?

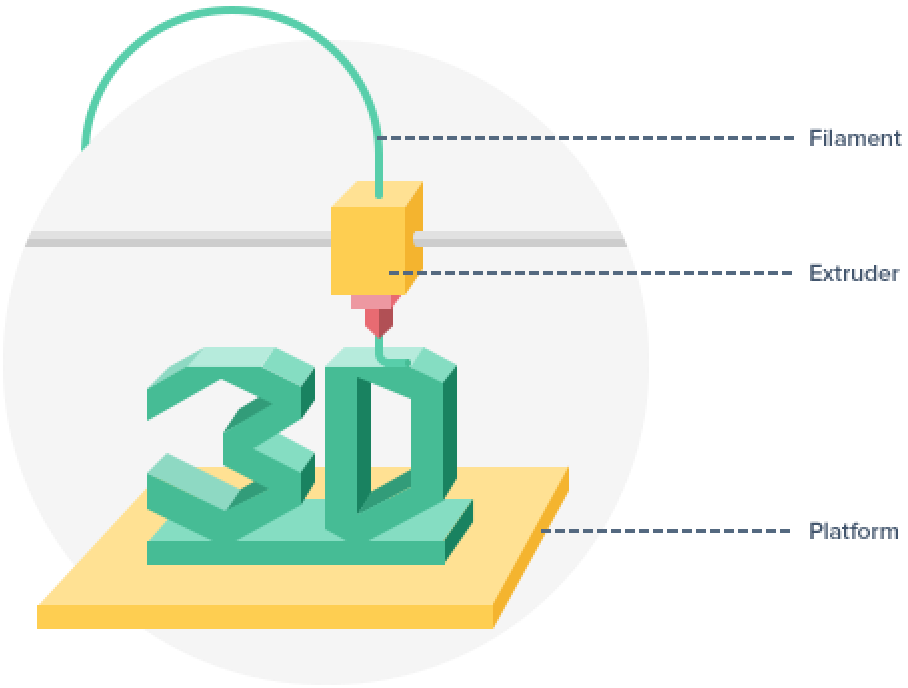
The FDM process begins with software that determines how the filament extruder(s) will draw out each layer to build up the model, preparing it for the building process. Printers with two or more print heads can print out multiple colours and/or use scaffolding materials to support the overhanging parts 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 that melts it at a temperature that typically ranges between 170 and 240 degrees Celsius, depending on the type of material being used. 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. The FDM process uses material for two different purposes, building the object and supporting overhangs in order to avoid extruding material into thin air. 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 quality of even objects printed at low resolutions. Sanding is a common way to reduce or remove the visibly distinct layers of the model. However, sanding prints can be a time consuming process, and it is sometimes impossible to reach every surface on complex shapes. Sanding might not be effective for certain materials. Another option that works well for select plastics such as ABS is an acetone vapour bath. The vapour creates a cloud when heated and smoothens the surface of the object, removing evidence of the distinct layers. Acetone baths leave the part with a glossy shine, similar to glazed ceramics.

Materials Used

FDM printers are fed by filament, usually rolled on a spool, and are mainly thermoplastics or thermoplastic/organic-material blends. The most common materials used in FDM printers are ABS, PLA, and polycarbonate (PC). PLA has been a clear winner for home 3D printing because of it's biodegradability, and because it does not give off unpleasant chemical fumes during the printing process. Dissolvable materials such as PVA are used for scaffolding, and exotic blends containing wood and stone as well as filaments with rubbery characteristics are also becoming popular, as suppliers race to develop new materials. Compared to other 3D printing processes, FDM materials are relatively inexpensive, making them ideal for desktop 3D printing. However, professional FDM printers have the ability to extrude more advanced thermoplastics that demonstrate fire retardant properties.



Video showing the process-
https://www.youtube.com/watch?v=WHO6G67GJbM&list=UUmyUACVV-DdW7F6OEHDa-tg

Machines

a. Cube2 by 3D Systems

b. Prusa i3 complete kit by Mixshop

c. CubeX by 3D Systems

More machines can be found here- https://thre3d.com/category/printers

- Direct Energy Deposition Technology

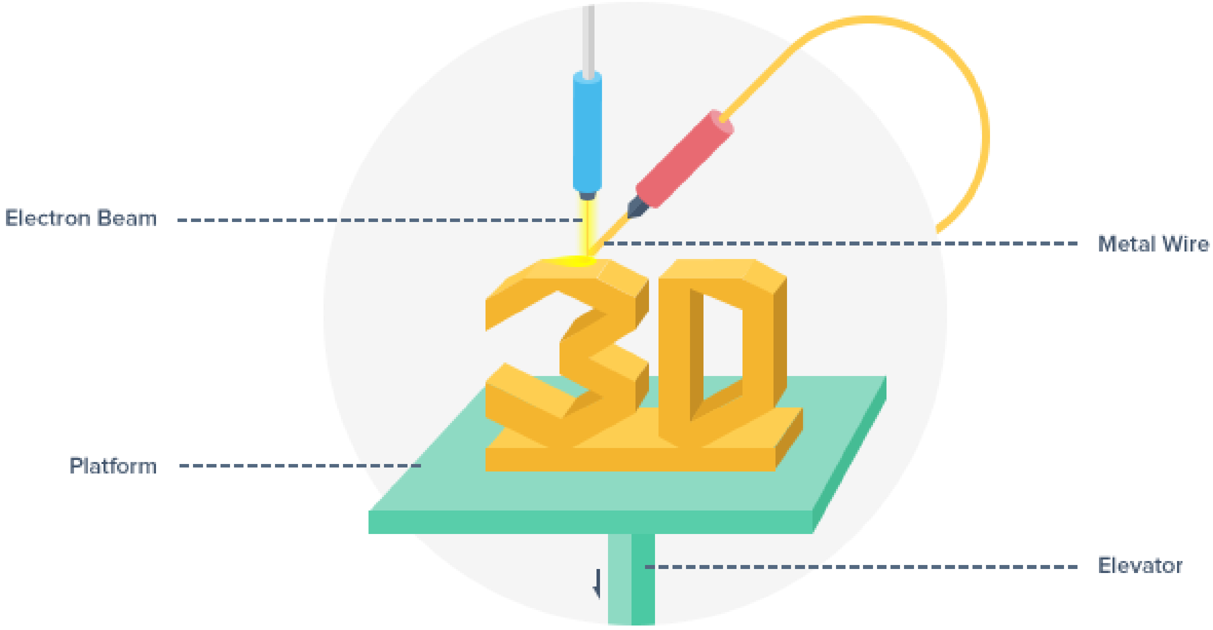
1. Electron Beam Direct Manufacturing (EBDM)

Direct manufacturing is a process used exclusively by Sciaky Inc. that melts metal wire as feedstock used to form an object within a vacuum chamber. With EBDM, material in wire form is fed into a molten pool created by an electron beam; the deposition mechanism creating the melt pool and feeding the wire is then guided by a computer to move about on an also non-stationary build platform. The deposition mechanism deposits the material just where it is needed to form a layer of the object. Repeating this process builds up the object one layer at a time. Finally, after the object is built, post processing usually requires machining to remove excess material. The process currently has one of the largest build capacities of any 3D printing process.

How it works?

With the EBDM process, an electron beam gun provides the energy source used for melting metallic material, typically wire. The electron beam is a highly efficient power source that can be both precisely focused and deflected using electromagnetic coils. A computer controls the electron beam head that guides the melting pool to build up the object on a movable build table. A major advantage of using metallic components with electron beams is that the process is conducted within a high vacuum environment. A contamination-free work zone is produced which does not require the use of additional inert gasses that are commonly used with laser and arc based processes, such as in laser engineered net systems or laser consolidation. EBDM can produce very large end-use objects quickly.

While the process can deposit material quickly that demonstrates excellent properties, EBDM is not as precise as other processes. Parts produced have a very coarse surface that requires extensive machining after building is complete.



Materials Used

Due to the characteristics of this process, a wide variety of materials are available for use. Materials include titanium, tantalum, stainless steel, inconel, aluminum alloys, nickel-based alloys, titanium aluminides, and metal matrix composites (including titanium matrix composites). There is now growing interest in strong steels such as Vascomax and 15-5 PH.

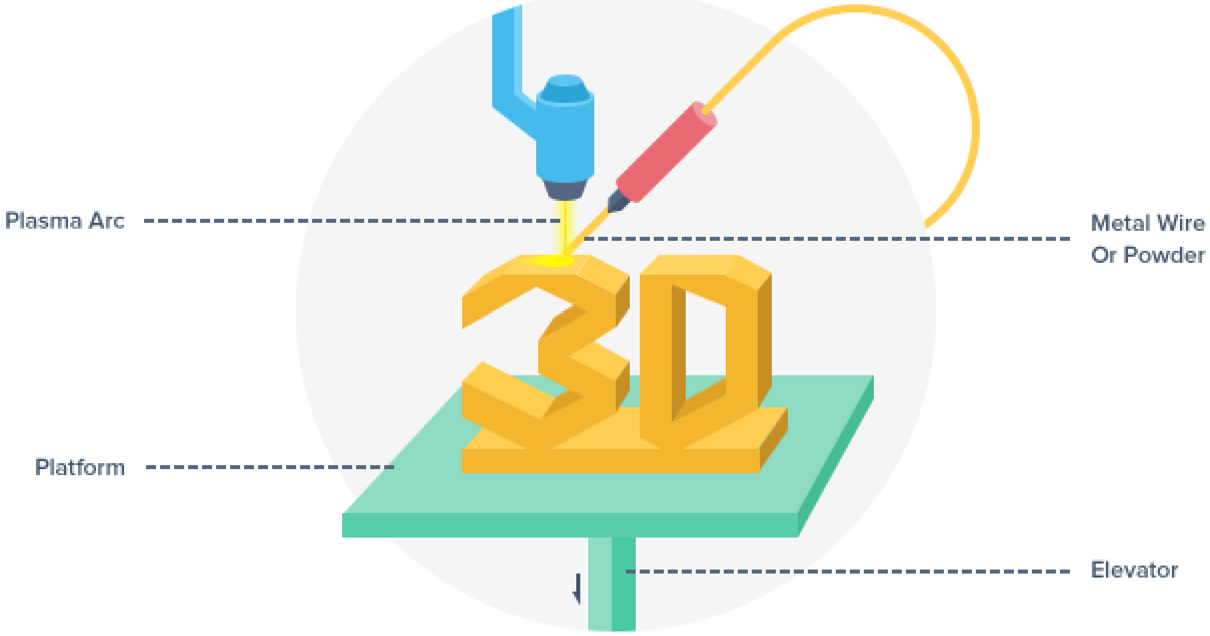
2. Ion Fusion Formation (IFF)

Ion Fusion Formation is a process used exclusively by Honeywell Aerospace that melts metal wire or powder with a plasma welding torch to form an object. A plasma of heated argon ions impell metal from a wire or powder feedstock onto the object. The deposition mechanism is then guided by a computer to move creating a melt pool while feeding the material into it. The deposition mechanism deposits the material just where it is needed to form a layer of the object. As the melt pool cools and hardens, it forms one layer, repeating this process builds up the object one layer at a time. The process is similar to other direct energy deposition processes, dering in the energy source it uses to melt the material. IFF is a relatively cheap but slow process compared with Laser Powder Forming (LPF) and Electron Beam Direct Manufacturing (EBDM).

How it works?

Super-heated argon gas is used as a plasma welding fuel to melt a concentration of metallic powder or wire feedstock to form a melt pool, which can then be manipulated to form lines and shapes. The process impels the metal material to the workpiece, and the metal material is delivered to the hot melt pool using a wire or a powder stream. In the case of metallic powder, a stream is focused onto the melt pool via a powder feeding system and nozzle, otherwise a wire feedstock system is used. Material can vary through the processing stage, creating a material gradient through the product. Each layer deposits more material to increase the volume of targeted areas of the original object.

The high cooling rate of the metallic structure means that there is minimal distortion and gives the deposits a very fine microstructure. The deposits, therefore, typically have improved mechanical and physical properties compared to milled objects from raw material.



Materials Used

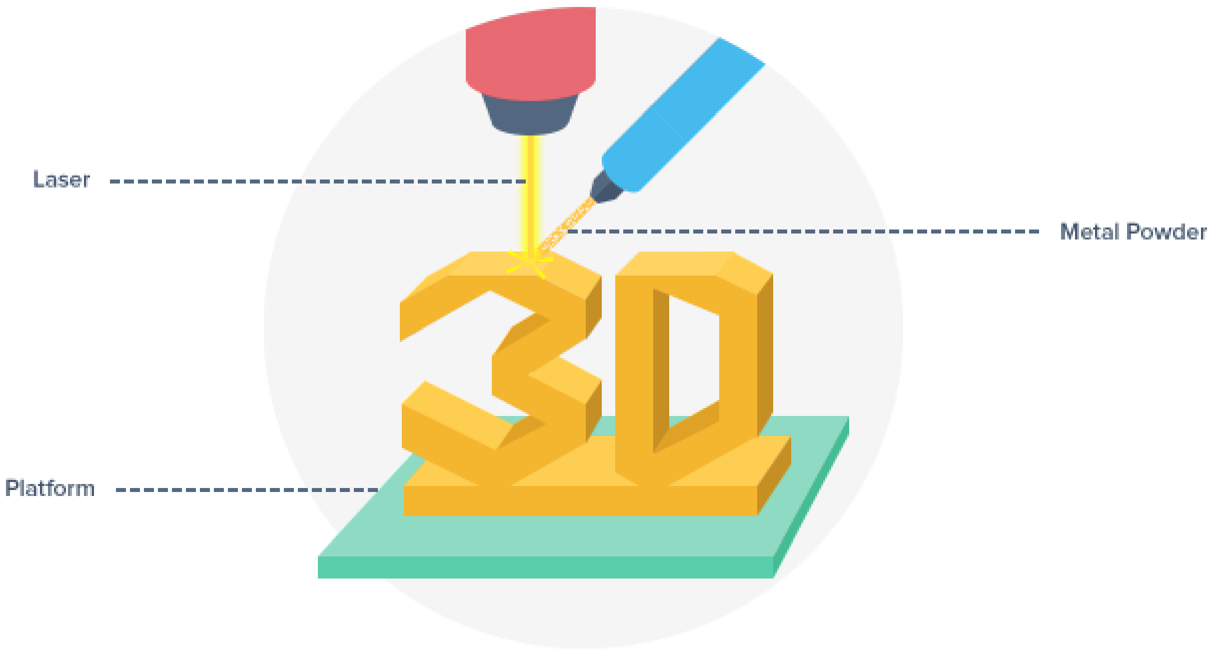
Materials for IFF typically include tool steel alloys, nickel superalloys, and other materials that come in either a wire or powdered form. Parts produced consistently have excellent mechanical characteristics, but those produced from wire material must be processed further because of the rough surface it leaves behind.

3. Laser Powder Forming (LPF)

Laser Powder Forming can be used to repair or add volume to pre-existing metal objects, as well as manufacture new objects. A laser is used to melt the surface of the target area while a stream of powdered metal is delivered onto the small targeted area creating a melt pool. The computer-controlled deposition mechanism guides the melt pool to deposit a strip of material, building the object. Repeating this process builds up the object one layer at a time. The atmosphere is tightly controlled for LPF, allowing for high-quality, fully-dense builds. The laser application head is manipulated by a multi axis joint and the object is built upon a rotary build platform, meaning that the material can be deposited in a variety of angles to produce complex geometries. LPF systems are marketed under the proprietary monikers Direct Metal Deposition (DMD), Laser-Engineered Net Shaping (LENS), and Laser consolidation (LC). Compared to processes that use powder beds, such as Selective Laser Melting (SLM), objects created with LPF can be substantially larger, even up to several feet long.

How it works?

A high power laser is used as an energy source to melt a concentration of metallic powder to form a melt pool, which can then be manipulated to form lines and shapes. A metallic powder stream is focused onto the melt pool via a powder feeding system and nozzle. In order to prevent oxidation, powder is fed into an inert gas stream, the process is contained within a hermetic chamber that controls oxygen levels, or both. The powder stream is precisely programmed for a consistent material flow and coverage. Material can vary through the processing stage, creating a material gradient through the product. Over time, layers form, giving more volume to targeted areas of the original object.
The high cooling rate of the metallic structure means that there is minimal distortion and gives the deposits a very fine microstructure. The deposits, therefore, typically have improved mechanical and physical properties compared to raw products. The inert gas promotes layer to layer adhesion by providing better surface wetting, and reduces surface problems that can lead to density issues. Even though objects with complex geometries can be made, support structures used to hold up overhanging areas can only be removed through significant machining. All products finished using LPF must be post processed to improve surface quality and prepare them for their end use application.



Materials

This process can use a wide variety of nickel, iron, cobalt, and titanium based alloys, as well as refractory metals and cermets (ceramic-metal composites). Composite materials may include a nickel/cobalt matrix filled with tungsten carbide or titanium carbide particles. Objects produced from LPF can demonstrate as good or better mechanical qualities than cast or wrought materials. Metals can also be aged, relieved and heat-treated to improve its ductility and strength according to application. Materials can also be combined in gradients during processing for increased performance.

Machines

a. MAGIC by BeAM

b. Lens450 by Optomec

c. MX-3 by InssTek

More machines can be found here- https://thre3d.com/category/printers

- Sheet Lamination Technology

1. Laminated Object Manufacturing (LOM)

Laminated Object Manufacturing works by layering sheets of material on top of one-another, binding them together using glue. The printer then slices an outline of the object into that cross section to be removed from the surrounding excess material later.

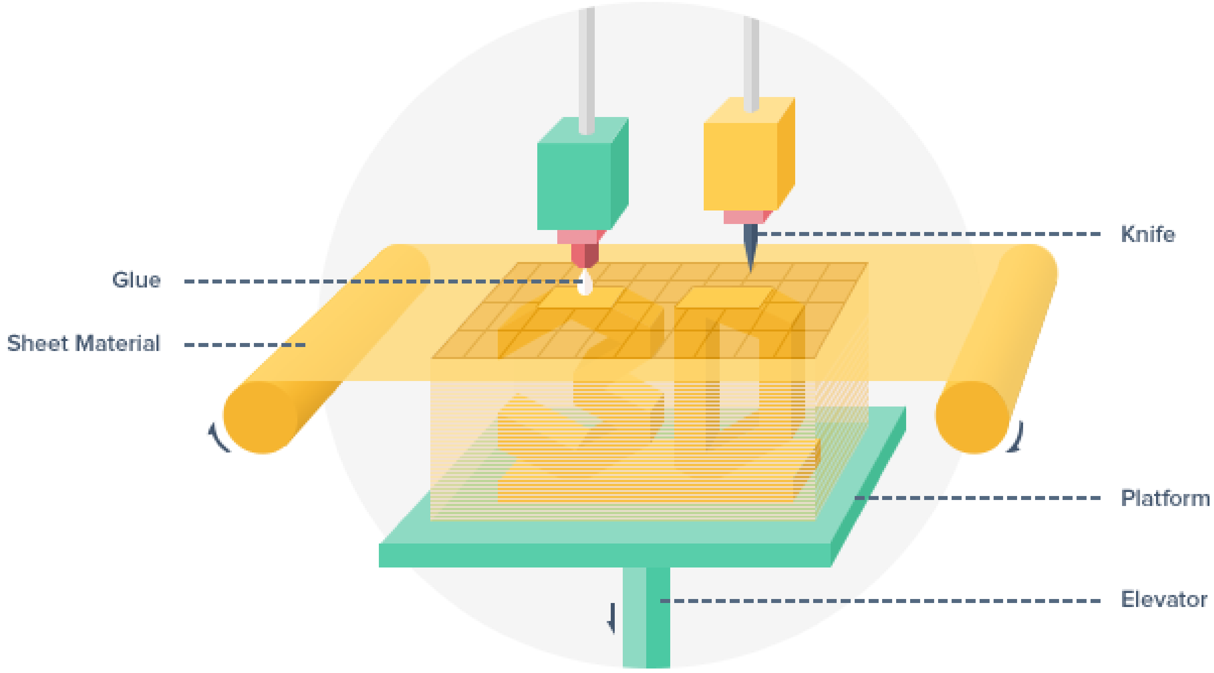
Repeating this process builds up the object one layer at a time. Objects printed using LOM are accurate, strong, and durable and generally show no distortion over time which makes them suitable for all stages of the design cycle. They can even be additionally modified by machining or drilling after printing. Typical layer resolution for this process is defined by the material feedstock and usually ranges in thickness from one to a few sheets of copy paper. Mcor's version of the technology makes LOM one of the few 3D printing processes that can produce prints in full colour. **This technology is also used in consumer level printing.**

How it works?

Sheets of material are positioned on top of one another after first applying an adhesive glue to bind the newly applied layer to the existing structure. The adhesive glue can be selectively applied, meaning that a higher amount is applied in the area that will become part of the object, and a lower amount is applied in the surrounding, supportive area. This uses the glue as efficiently as possible, since the scrap area does not need as strong a bond. After the new sheet is precisely layered on top of the existing model, bonded together with the adhesive, heat and pressure are applied, usually using a compressive plate. This ensures a tight fit between layers.

After bonding, a knife or laser cuts the newly bonded sheet of material, tracing a 2D outline of the model's cross section before the next layer of adhesive glue is applied and the next sheet added. The accuracy of LOM is slightly less than Stereolithography (SLA) and Selective Laser Sintering (SLS). There is no chemical reaction required, however, which means that relatively large parts can be produced reliably. LOM is also considered a comparatively inexpensive 3D printing method to operate, due to the widely available and low cost materials involved.

The only post processing step for LOM is the peeling and removal of excess material. However, this can often be tricky. The ease of removal depends on the design of the printed part; sometimes shaking the part is enough, whilst other times support structures must be chiselled out manually. The waste, or support, material is often diced by the printer to aid in its removal without damaging the 3D model.



Video showing the process- https://www.youtube.com/watch?v=Z1WNA6tdfWM

Materials Used

The most common materials used in LOM are metals, plastics and off-the-shelf copy paper. Paper models have wood-like characteristics and can be worked and finished accordingly. When using paper as a stock material, the sheets can first be printed using a traditional printer to colour the edges of the model, where the paper will be sliced for later removal. This allows the finished object to have accurate and well saturated colour. When using other materials as feedstock, they can be mixed and matched for various layers throughout the printing process giving more flexibility in determining the physical properties of the finished object.

Machines

a. ProJet 1500 by 3D Systems

b. ProJet 1000 by 3D Systems

c. Formiga P 110 by EOS

More machines can be found here- https://thre3d.com/category/printers

2. Ultrasonic Additive Manufacturing (UAM)

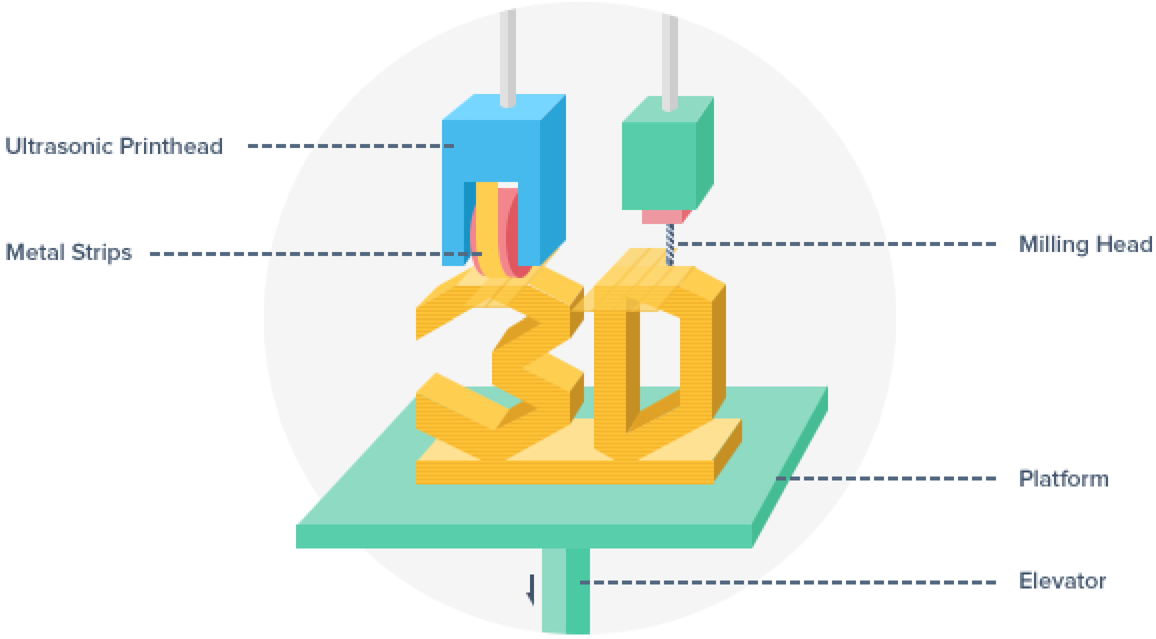
Ultrasonic Additive Manufacturing (also known as Ultrasonic Consolidation, UC) works by using a delicate welding process to secure strips of metal together, building up an object by one sheet of material. UAM adheres strips of metal using ultrasonic welding, a solid state welding process, meaning a bond is created without melting the material. The low temperatures used in UAM avoids brittleness found between layers of traditionally welded metals, and allows for metallic bonds between different metals. Next, the excess material is cut away using a CNC mill to complete the cross section. Repeating this process builds up the object one layer at a time. UAM's ability to create structures with multiple combinations of metals with tight bonds makes it ideal for special applications such as high-value end-use components. Typical layer resolution for this process is defined by the material feedstock and can be as thin as a sheet of copy paper.

How it works?

Thin layers of metal are welded together by a combination of ultrasonic energy delivered at a high-frequency and the compressive force generated by heavy machinery rolling on the foil. Vibration reaches a frequency of approximately 20,000 Hertz creating a solid state ultrasonic bond at a much lower temperature than traditional fusion welding. The process is repeated side to side to fully lay the strips of material for a single layer. Selectively applying the metallic foil where material is needed results in significant waste reduction.

While UAM employs CNC milling, it differs from that traditional process which starts with a solid block of material and builds an object through subtraction. By building the object up using thin layers of metal and milling each individually after it's laid, UAM is able to produce parts with much more internal complexity than is possible with traditional CNC milling, and is able to produce them with very little waste.

When printing is complete, the finished product can be removed immediately from the printer, reducing lengthy cool down times. Products can then be machined, drilled and finished in many different ways. The resulting objects have high resolution and mechanical properties comparable to objects made using traditional machining techniques starting from a solid block of material.



Materials Used

UAM uses a vast array of metallic materials, including nickel, titanium, copper, molybdenum, tantalum, silver, stainless steel and a variety of aluminium alloys. One of the most notable benefits of this process is its ability to interchange materials during the printing process. UAM also lends itself to creating “smart structures” where additional components become part of the finished object. It is possible, for example, to embed electronics into a sealed internal cavity during the printing process.

Machines

a. SonicLayer R200 by Fabrisonic
b. SonicLayer 4000 by Fabrisonic
c. SonicLayer 7200 by Fabrisonic
More machines can be found here- https://thre3d.com/category/printers

- Binder Jetting Technology

Binder Jetting (also known as Inkjet Powder Printing) works by spraying liquid binder onto a bed of powder, solidifying it into a cross-section. Each layer is printed in much the same way a traditional paper printer prints ink (in this case binder solution) onto a sheet of paper (in this case a layer of powder.) After each cross section is finished, an automated roller deposits additional powder to form the next layer of the object. Repeating this process builds up the object one layer at a time. Binder Jetting is one of the best options for 3D printing in full colour and has less noticeable layer definitions, making it an ideal choice for producing end-use products. This process is also unique in the fact that it been scaled up to print full architectural structures as big as a room.

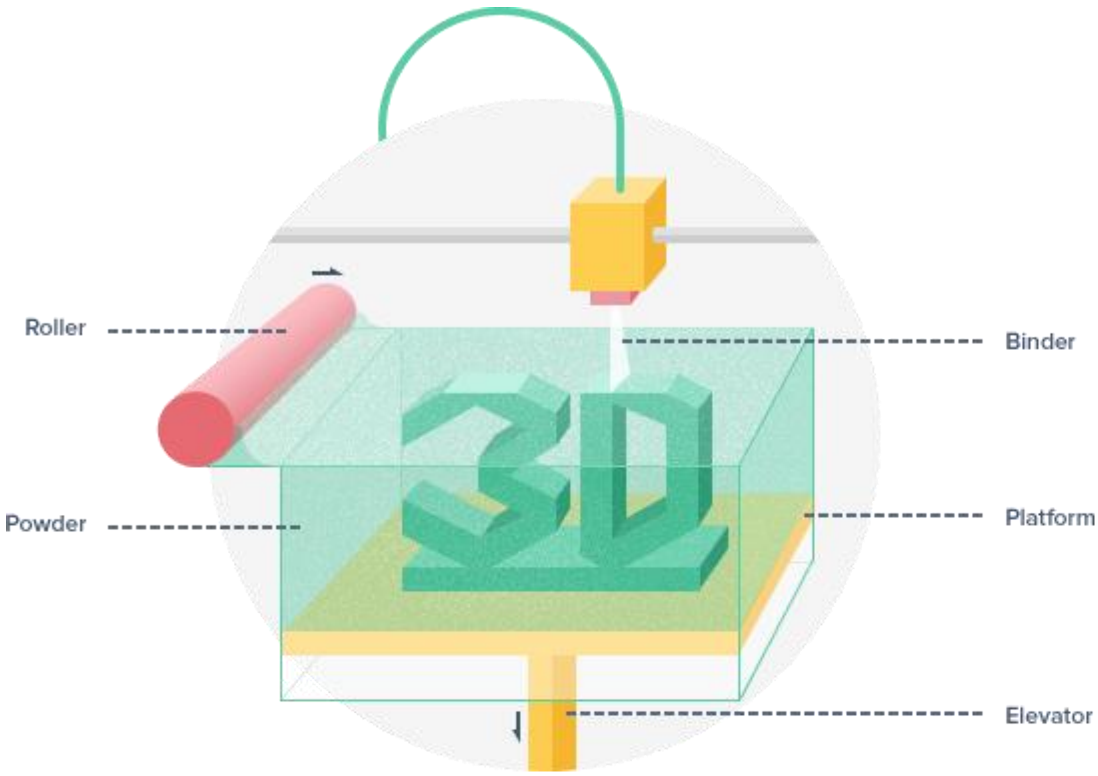
How it works?

One advantage of the Binder Jetting process is the ability to print in color, popularized by the successful Zprinters from 3D Systems. Before sending the object off to print, a model can be coloured in the printer's complimentary software suite. Models already containing colour can also be imported to take advantage of colour printing if they are saved as a supported file type.

The print starts by using an automated roller to spread the first layer of powder onto the build platform. Powder is fed from a piston to ensure that the layer is densely packed while excess powder is brushed to the sides. The print heads then apply the binder for that cross section of the object. The process then repeats itself, followed by the next layer of material being spread onto the build platform. Colouring can also be added by a normal colour inkjet print head that prints colours directly onto the cross-section after the binder is deposited, using the same process found in traditional paper printers.

Supports are rarely required with this type of 3D printing as each horizontal slice is supported by the excess powder material below. Objects created with the Binder Jetting process may not have the high quality mechanical properties of other additive manufacturing techniques because of the materials used and the lower level of adherence between particulates.

When the print is finished, the loose powder surrounds and supports the object in the build chamber. After initially removing the powder from the finished object, any excess is blown off using pressurized air. The leftover material can then be reused. Larger structures built using Binder Jetting must have the excess material removed using a fair amount of shovelling and manual labour. Post processing can then be used to infuse the object with additional material which mitigates disadvantages of poor mechanical properties. Techniques to infiltrate the object's porous cavities include infusing metal into the object which is then fired in a kiln or soaking it in a solution that solidifies inside.



Binder Jetting Video- https://www.youtube.com/watch?v=NVJifm2b6-c

Materials Used

Engineers have developed a wide range of materials for this flexible process. The different combinations available for pairing powder material with binder agents allows for a wide range of material properties. The composites used in Binder Jetting exhibit characteristics ranging from rigid to elastic and smooth to porus. Metals can be printed with this process, but while Binder Jetting cannot produce fully dense metal parts, the process is often used to create the structure for intricate metallic objects that are later fired to absorb metal into their porous structures.

Machines

a. ProJet 860Pro by 3D Systems

b. VX2000 by Voxeljet

c. S-Print Phenol by ExOne

More machines can be found here- https://thre3d.com/category/printers

- Material Jetting Technology

Material Jetting printers resemble traditional paper printers in more ways than many other 3D printing processes. In Material Jetting, the print head moves around the print area jetting photopolymer (light-reactive plastics) as opposed to ink. UV lights surrounding the print head pass over the material after it is jetted onto the build area and cures it, solidifying it in place. Repeating this process builds up the object one layer at a time. Printers utilizing this process are often able to print using multiple materials in a single job. The materials can be selectively positioned within the model and even be combined during the process to effectively multiply the material types available during one print. Material Jetting is common for prototyping due to its high resolution (down to 16 micron layer heights which are barely noticeable to the touch) and ability to match the look, feel and function of the desired finished product.

How it works?

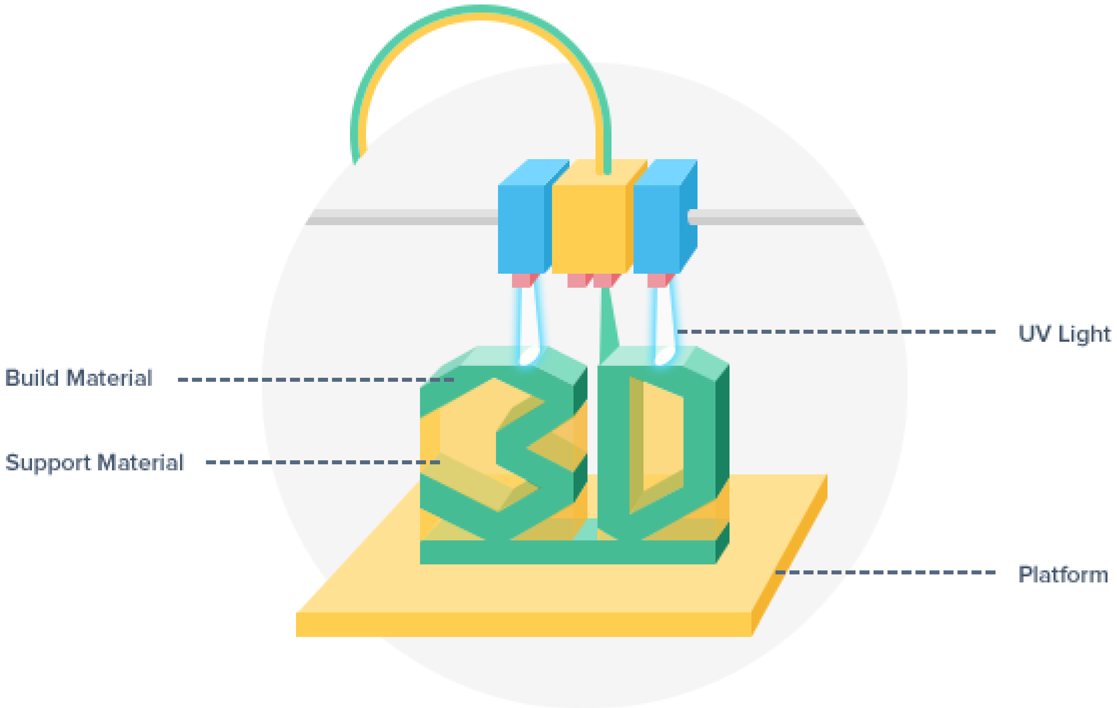
The multi-material aspect of Material Jetting is a distinct advantage of this process. When preparing a model for printing, software allows the user to select which components of the model will be printed with the available materials or material combinations. For example, a model can be configured to be printed with a soft and flexible handle on a hard and rigid functioning tool with moving parts, all printed in one piece.

The base materials are funnelled into a dedicated liquid stream which is then jetted onto the build tray to form the layers. Gel-like support material is used to support overhangs and complex geometries. A UV light follows the print path of the print head so that each successive layer is immediately cured and ready to be built upon. The curing process initiates a chemical polymerisation reaction which causes the plastic to dry and form a solid, fixing it in place. Material Jetting 3D printers are relatively large machines; often allowing for multiple objects to be printed in each run, resulting in a high productivity output, or capacity for large prints. The capacity to print using mixed materials eliminates the need to design and print each separate part in their respective materials and then assemble after printing, reducing production time.

When the print is finished, the gel-like support material is easily removed by dissolving with water, usually accelerated by using a pressurized sprayer. The finished product is ready shortly after removing it from the machine, unlike other rapid prototyping processes, which can require lengthy post processing treatments.

Materials Used

Material Jetting uses photopolymers which can be combined together in some printers to create new materials with distinct characteristics, ranging from rigid to rubber-like and opaque to transparent. For example, a rubbery material and a hard material can be combined at different rates to make materials with a range of different tensile, flexural and impact strengths. This is achieved when standard photopolymer liquid resins are combined in specific concentrations during the Material Jetting process to make new material. Material Jetting is also able to create various dental and medical materials which are biocompatible.



Machines

a. 3Z Pro by Solidscape

b. ProJet 5500X by 3D Systems

c. Object350 Connex by Stratasys

More machines can be found here- https://thre3d.com/category/printers

3D Printing Software

Free 3D Software

- Google SketchUp - This Google SketchUp is fun and free, and is known for being easy to use. To build models in SketchUp, you draw edges and faces using a few simple tools that you can learn in a short time. With with Push/Pull tool you can extrude any flat surface into a 3D form. Furthermore, it works together with Google Earth, that you can import a scaled aerial photograph directly from Google Earth, or use SketchUp to build models which can be seen in Google Earth.

- 3DCrafter - 3Dcrafter is a real-time 3D modeling and animation tool that incorporates an intuitive drag-and-drop approach to 3D modeling. The standard version of 3DCrafter is freeware. Paid versions (3DCrafter Plus and 3Dcrafter Pro) are available.

- 3Dtin - The simplest 3D software. You can draw directly from your browser.

- Anim8or - Anim8or is a 3D modeling and character animation program.

- Art of Illusion - Art of Illusion is a free, open source 3D modelling and rendering studio. Art of Illusion is more as a 3D design system for animated computer graphics than as an engineering CAD tool.

- Blender - Blender is the free open source 3D content creation suite, available for all major operating systems under the GNU General Public License. Blender was developed as an in-house application by the Dutch animation studio NeoGeo and Not a Number Technologies (NaN). It is a powerful program contains features that are characteristic of high-end 3D software.

- BRL-CAD - BRL-CAD is a powerful cross-platform open source solid modelling system that includes interactive geometry editing, high-performance ray-tracing for rendering and geometric analysis, image and signal-processing tools, a system performance analysis benchmark suite, libraries for robust geometric representation. BRL-CAD has been the primary tri-service solid modelling CAD system used by the U.S. military to model weapons systems for vulnerability and lethality analyses for more than 20 years. It became an open source project on 21 December 2004.

- Creo Elements/Direct - formerly CoCreate - is a complete design environment that offers direct 3D CAD modeller, along with 2D CAD, CAE and integrated product data management (PDM).

- DrawPlus Starter Edition - 100% free and simple, with Accurate vector drawing program, realistic brush, and pen, and pencil tools, text on a path, blend modes for advance artistic effects.

- FreeCAD - FreeCAD is a general purpose Open Source 3D CAD/MCAD/CAx/CAE/PLM modeller, aimed directly at mechanical engineering and product design but also fits in architecture or other engineering specialties.

- GLC Player - GLC player is a free application used to view 3d models (COLLADA 3DXML OBJ 3DS STL OFF COFF Format) and to navigate easily in these models. With the album management, capture and multi-capture capabilities, html export and navigation possibilities GLC Player is the accurate tool to review a lot of 3D models and to create illustrations. GLC Player is a cross-platform application (Mac, Linux and Windows). It is lighter than regular modelling software so very handy.

- LeoCAD - LeoCAD is a CAD program that can be used to create virtual LEGO models. It has an easy to use interface and currently features over 3000 different types of pieces created by the LDaw community.

- Netfabb Studio Basic - Netfabb Studio Basic provides mesh edit, repair and analysis capabilities. Its compact size of only a few megabytes allows a quick download, an easy installation and the handling of STL and slice files within seconds.

- K-3D - K-3D is free-as-in-freedom 3D modelling and animation software. It features a plugin-oriented procedural engine for all of its content, making K-3D a very versatile and powerful package. K-3D excels at polygonal modelling, and includes basic tools for NURBS, patches, curves and animation.

- OpenSCAD - OpenSCAD is a software for creating solid 3D CAD objects. It is free software and available for Linux/UNIX, MS Windows and Mac OS X. it does not focus on the artistic aspects of 3D modelling but instead on the CAD aspects.

- Tinkercad - Tinkercad is a new and faster way of creating designs for your 3D printer. With only three basic tools you can create a wide range of useful things. Once your project is ready simply download the STL file and start your 3D print.

- Wings 3D - Wings 3D is a subdivision modeller. It has been developed since 2001. Wings 3D offers a wide range of modelling tools, a customizable interface, support for lights and materials, and a built-in AutoUV mapping facility. There is no support in Wings for animation.

Commercial 3D Software

- **3DS Max**
- **Alibre**
- **AC3D**
- **AutoCAD**
- **AutoQ3D**
- **Cheetah3D**
- **Cloud9**
- **FormZ**
- **Maya**

- Magics
- NetFabb
- Rhino3D
- Solidworks
- ZBrush