ATME College of Engineering

Additive Manufacturing 18ME741

Module-1
Introduction, Development, Basics, Process in AM

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AM EVOLUTION

- Initially, AM was used specifically to create visualization models for products as they being developed.
- Later, Models were employed to supply information on **“3 Fs”**
- **Form:** Models appreciated the shape and general purpose of design fully.
- **Fit:** With improved accuracy, components were built to the tolerances required for assembly purposes.
- **Function:** With improved material properties, parts were assessed according to how they would eventually work.

RAPID PROTOTYPING

- Rapid Prototyping (RP) is a process used for rapidly creating a part, usually a prototype or basis model from which the further models and eventually the final product will be derived.
- The term Rapid Prototyping is inadequate and does not effectively describe more recent applications of the technology.
- Many parts are now directly manufactured from RP machines. Hence it is not possible to label them as just “prototypes”
- The term also overlooks the basic principle from which the parts are fabricated. i.e., additive approach.
- Because of these reasons the terminology has essentially evolved from Rapid Prototyping to **Additive Manufacturing**.

ADDITIVE MANUFACTURING (AM)

- The basic principle of this technology is that a model, initially generated using a 3-D CAD system, can be directly fabricated without the need for process planning.
- In AM, parts are made by adding materials in layers; each layer is a thin cross-section of the part derived from the original CAD data.
- The thinner each layer is, the closer the final part will be to original.

Distinction between AM & CNC Machining

- AM shares some of its DNA with CNC Machining technology.
- Just like AM, CNC is also a computer based technology.
- CNC primarily works on principle of subtractive process to manufacture products rather than additive one.
- The knowledge of the differences between the two processes is important, to understand how each of them may be implemented for different stages in product development process or for different types of product.

Distinction between AM and CNC Machining

Sl. No	Particulars	AM	CNC Machining
1	Material	It is originally developed around polymeric materials, waxes and paper laminates.	It works particularly well for hard, relatively brittle materials like steels and other metal alloys.
		AM parts may have voids or anisotropy based on how the design was input to the machine.	CNC parts will normally be more homogeneous and predictable in quality.
2	Speed	To make a part in an AM machine, it may only take a few hours	Using CNC machining, this same process may take weeks
		AM technology can be used to produce a part in a single stage.	CNC is likely to be a multistage manufacturing process, which requires considerable setup and process planning.
3	Complexity	Complexity in geometry of a part like undercuts and internal features can be easily built.	Some geometrical features cannot be fabricated, as there may be certain accessibility constraints which prevents tool from being located on part surface.
4	Accuracy	Accuracy in build plane is determined by the positioning of build mechanism, which will normally involves gearboxes and motors of some kind.	The accuracy in CNC machines is mainly determined by similar positioning resolution along the axes and by the diameter of the rotary cutting tools.
5	Geometry	AM machines break a complex 3D problem into a series of simple 2D cross-sections with normal thickness.	In CNC, machining of surfaces is normally generated in 3D space.
		Continuity in complex parts can be created by creating close proximity of one cross- section with adjacent one.	Complex geometries like undercuts, enclosures, sharp internal corners becomes extremely difficult to produce if these features are beyond certain limit.
6	Programming	Part will not be built very well if the programming is not done properly.	Incorrect programming could result in severe damage to the machine.

Reasons Why You Need to Consider Design for Additive Manufacturing

1. Create parts with greater complexity

Additive manufacturing can overcome the limitations of traditional manufacturing methods to create highly complex parts with improved functionality.

One example is the traditional manufacture of injection moulds: here, cooling channels are typically straight, leading to a slower and less consistent cooling of a moulded part. In contrast, with 3D printing the cooling channels can be re-designed to create more complex or curved shapes, providing more homogeneous heat transfer. This results in improved cooling characteristics, helping to produce higher quality parts whilst prolonging the service life of a mould.

Reasons Why You Need to Consider Design for Additive Manufacturing

2. Minimal material waste

With the new design possibilities afforded by 3D printing, engineers can produce lightweight parts in part by optimising the distribution of material, leading to substantial material savings.

This can be achieved in part thanks to advanced software liketopology optimisation, and tools like generative design and lattice structures. Based on mathematical calculations, topology optimisation can help to analyse the best shape for a part and remove unnecessary material without compromising the structural integrity of the part. Using traditional (subtractive) methods, this material would simply be cut away

Coupled with 3D printing, generative design and topology optimisation software are already used by industrial giants likeSiemensandGeneral Motors. While Siemens used generative design software to develop its 3D printed gas turbine blades, General Motors aims to reduce the weight of a vehicle by exploring various options for material distribution within a component.

Reasons Why You Need to Consider Design for Additive Manufacturing

3. Simplified assembly

Part consolidation is another game-changing design benefit of additive manufacturing. With traditional manufacturing, multiple components must be produced and then subsequently assembled to create the final part.

However, with 3D printing, several smaller components can be integrated into a single custom part during the design stage, allowing you to print the entire part at once. This significantly simplifies the assembly process, and can even eliminate the need for assembly at times. In addition to this, a consolidated part eliminates the need for procuring and storing any additional subcomponents or spare parts, ultimately reducing inventory and maintenance costs.

Reasons Why You Need to Consider Design for Additive Manufacturing

4. Material innovation

Advancements in materials research have led to the exciting development of new materials. Consequently, unique 3D printing materials have been developed that would be difficult to machine or mould, such as TPU filaments and metal superalloys powders). Or take for example3D printing with high-performance thermoplastics, developed specifically for engineering applications. In some cases, these high-performance materials can even substitute metal parts, providing a lightweight, cost-saving alternative.

Therefore, when designing a part for 3D printing, engineers can explore new options that offer better material properties, such as thermal conductivity or malleability. In addition to this, 3D printing gives an opportunity to design parts withmulti-material properties(e.g. rigidity and flexibility) or integrated insulating and conductive properties.

Reasons Why You Need to Consider Design for Additive Manufacturing

5. Cost-effective customization

3D printing enables quick and multiple design iterations at no extra cost, taking customisation possibilities to new heights. And as additive manufacturing creates parts directly from digital files, the manufacturing process is significantly accelerated. This means that companies can produce customised products much faster and cost-effectively.

Customised designs will enable mass customisation across industries, from consumer goods to medical and automotive. For example, in the medical industry, mass customisation is already revealing itself in the 3D printed devices, tailored to the needs of the patient. Such devices range from individualised braces and prosthetics to surgical guides and hearing aids, designed to perfectly match patient's anatomy.

Reasons Why You Need to Consider Design for Additive Manufacturing

6. Minimum support structures

Part orientation is one of the key benefits when designing for additive manufacturing. Choosing the correct part orientation during the design stage can reduce the printing and post-processing time whilst minimising the need for supports. In spite of the fact that support structures are virtually a necessity for many complex 3D printed parts, it is ideal to design parts with as few supports as possible, as this will make post-processing easier, saving you time and material.

While there is no a one-size-fits-all solution when it comes to minimising the number of supports used, with careful design a part can often be orientated and optimised to carry itself whilst using a minimum amount of support structures, saving post-processing time.

Looking ahead, as automation trends take hold in the AM industry, part orientation, as well as supports, could be automatically generated with a new generation of AM software.

Advantages of Additive Manufacturing:

Speed: The rapid character of the technology is not only about the time it takes to build parts but also it enhances the whole product development process.

Ease of Data Conversion: Since 3D CAD is being used as the starting point and the transfer to AM is relatively seamless, there is much less concern over data interpretation.

Reduction of Process Steps: Regardless of the complexity of parts to be built, building within an AM machine is generally performed in a single step.

Reduction in Process Time: Irrespective of the complexity of the product, added features the time required for manufacturing is less compared to CNC Manufacturing.

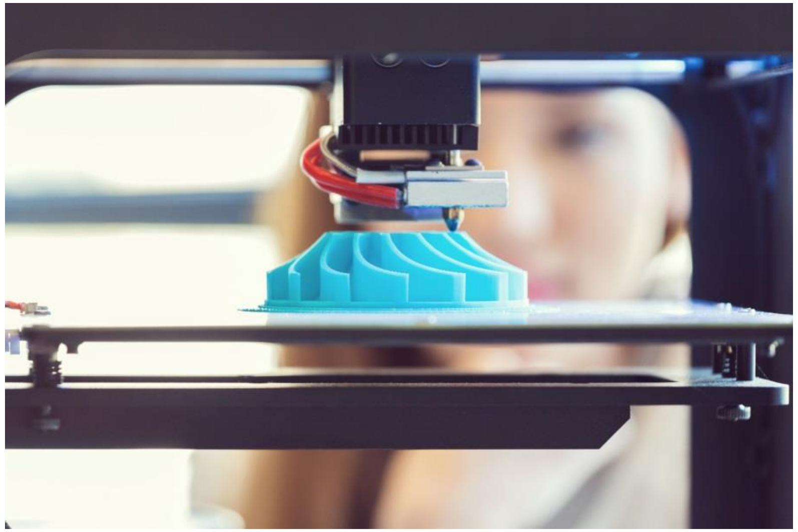
Reduction in Cost: Since the process is carried out in a single step, the process brings down manufacturing cost to minimum compared to conventional manufacturing processes.

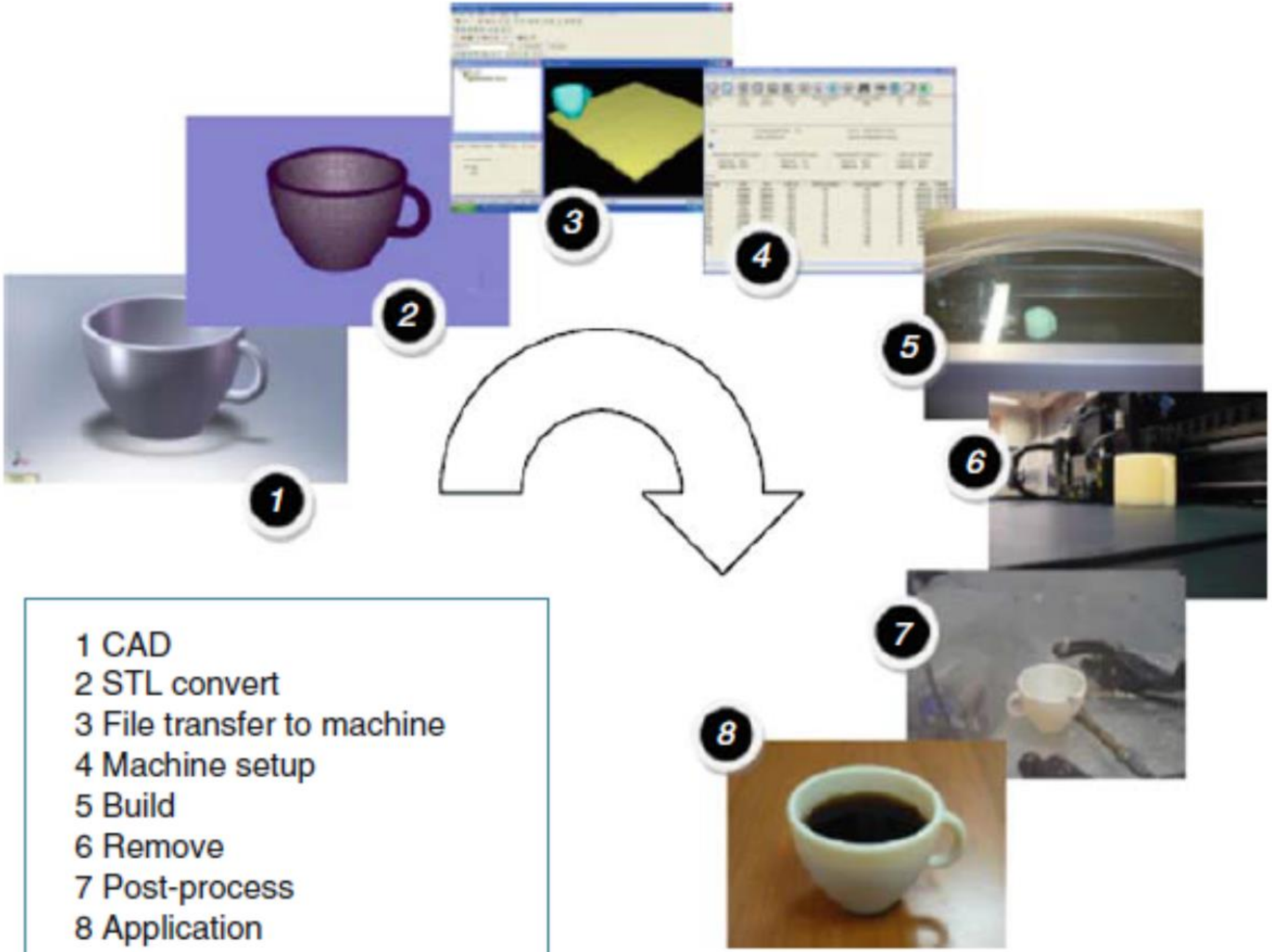
Wide Range of Application: With some supporting technologies it can be possible to manufacture a vast range of parts with different characteristics.

Generic AM Process Chain:

AM involves a number of steps that move from the virtual CAD description to the physical resultant part.

- Step 1: Conceptualization and CAD
- Step 2: Conversion to STL
- Step 3: Transfer to AM Machine and STL File Manipulation
- Step 4: Machine Setup
- Step 5: Build
- Step 6: Removal
- Step 7: Postprocessing
- Step 8: Application





1 CAD
2 STL convert
3 File transfer to machine
4 Machine setup
5 Build
6 Remove
7 Post-process
8 Application

Generic AM Process Chain:

Step 1: Conceptualization and CAD

- The first step in product development process is to come up with a idea of how the product will look and perform.
- Conceptualization takes many forms from textual and narrative descriptions to sketches and representative models.
- In AM, product description will be in the form that allows a physical model to be made.
- The AM process therefore start with 3D CAD information.
- The 3D source data can be created by computer user, using user-interface or via **reverse engineering technologies.**

Generic AM Process Chain:

Step 2: Conversion to STL

- Every AM machine accepts the STL file format, and every CAD system can output such a file format.
- The term STL is derived from StereoLithography, which is the first commercial AM technology from 3D systems.
- The file describes the external closed surfaces of the original CAD model and forms the basis for calculation of slices.

Generic AM Process Chain:

Step 3: Transfer to AM Machine and STL file Manipulation

- The STL file describing the part is then transferred to the AM machine.
- Here some general manipulation to the file is done in order to correct size, position and orientation for building.
- AM system software normally has a visualization tool that allows the user to view and manipulate the part.
- It is quite common to build more than one part in an AM machine. This may be multiples of same part or completely different STL files.

Generic AM Process Chain:

Step 4: Machine Setup

- The AM machine will be properly setup prior to the build process.
- The settings includes the build parameters like material constraints, energy source, layer thickness, timings etc.
- The setup parameters will be specific to a machine or process being used.
- Some machines will have very few setup changes while others provide a variety of parameters to choose and optimize the process.

Generic AM Process Chain:

Step 5: Build

- Building the part is mainly an automated process and machine can carry out the process without supervision.
- Only superficial monitoring is done to ensure no errors have taken place like running out of material, power or software glitches.

Generic AM Process Chain:

Step 6: Removal and Cleanup

- Once the AM machine has completed the build, the parts are separated from the build platform
- At this time it is necessary to ensure that the operating temperatures are sufficiently low and there are no actively moving parts.
- Sometimes the parts produced still requires significant amount of manual finishing before they are ready to use.
- This cleanup stage is also considered as the initial part of post-processing stage.

Generic AM Process Chain:

Step 7: Postprocessing

- Once removed from the machine, the parts may be weak at this stage or may have supporting structures to be removed for application purposes.
- This may involve abrasive finishing like polishing, sandpapering or application of coatings.
- This stage in the process is application specific. Some requires minimum of post-processing while other applications need careful handling to maintain good precision and finish.
- This stage is primarily a manual task due to the complexity of AM parts.

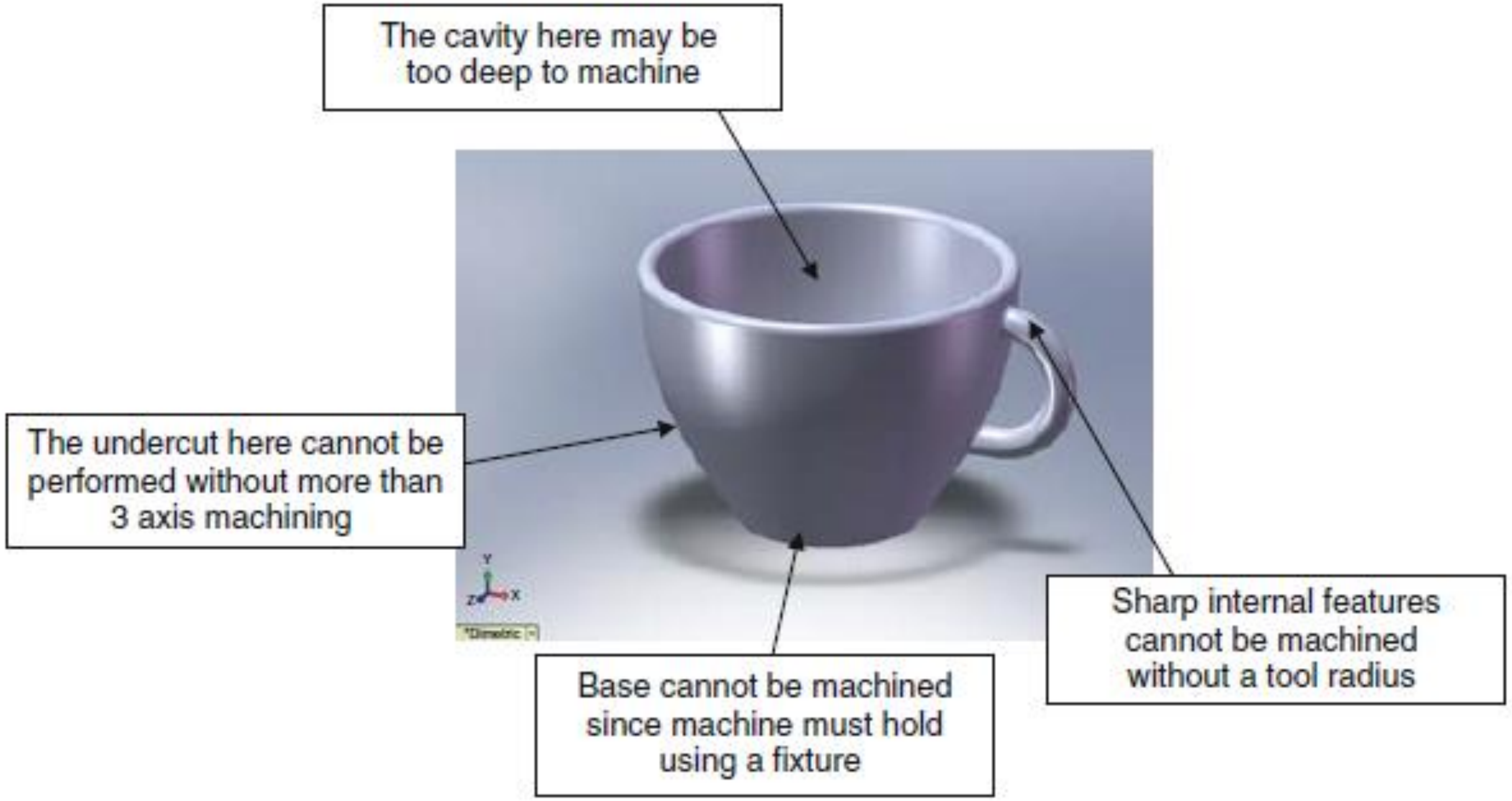
Generic AM Process Chain:

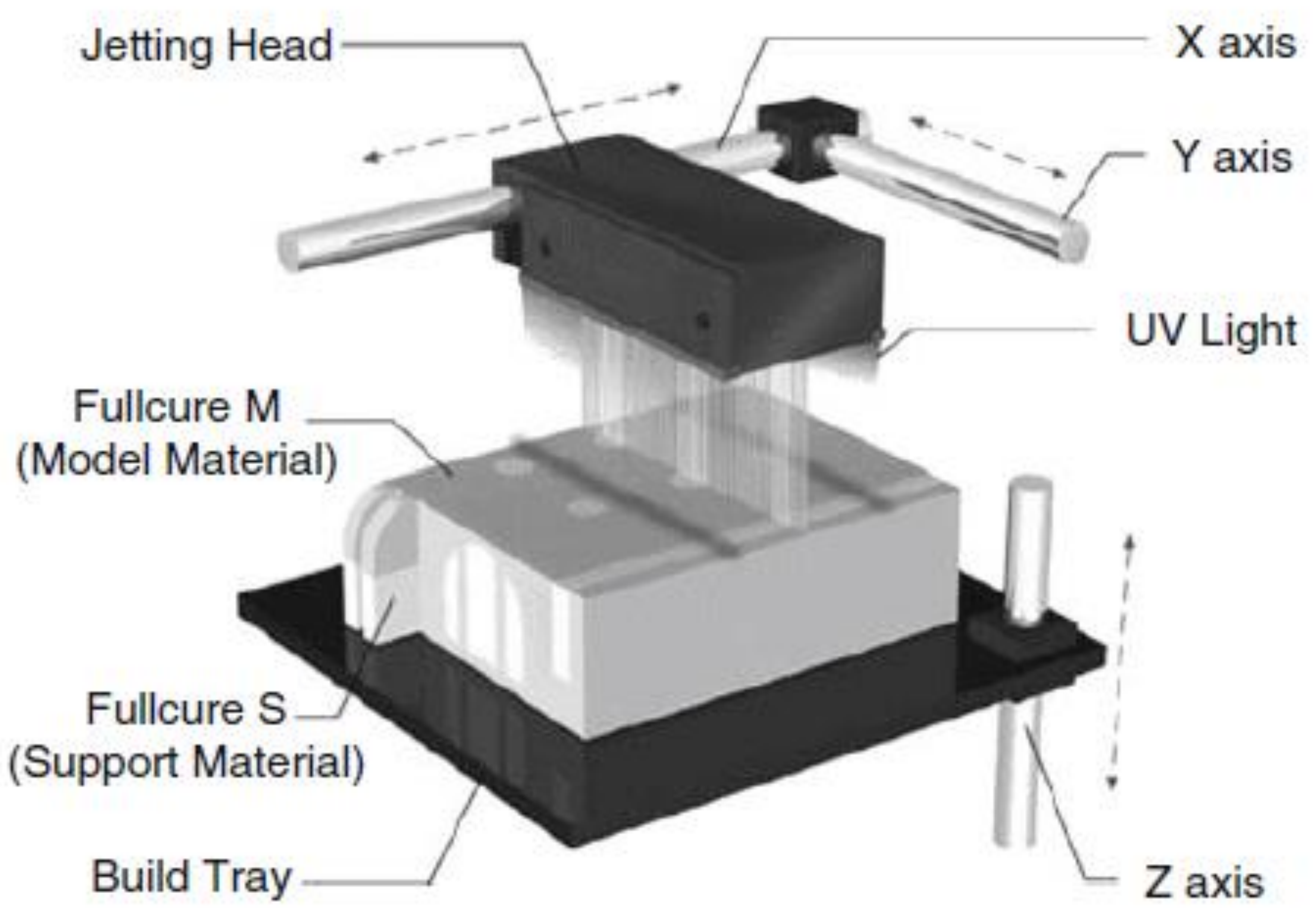
Step 8: Application

- Parts at this stage will be ready to use, with some prior additional treatment like painting to give an acceptable surface texture and finish.
- More the finishing requirements, more are the laborious and lengthy will be the treatments.
- They may also be required to be assembled together with other mechanical or electronic components to form a final model or product.
- Although parts may be made from similar materials to those available from other manufacturing processes, parts may not behave according to standard material specifications.

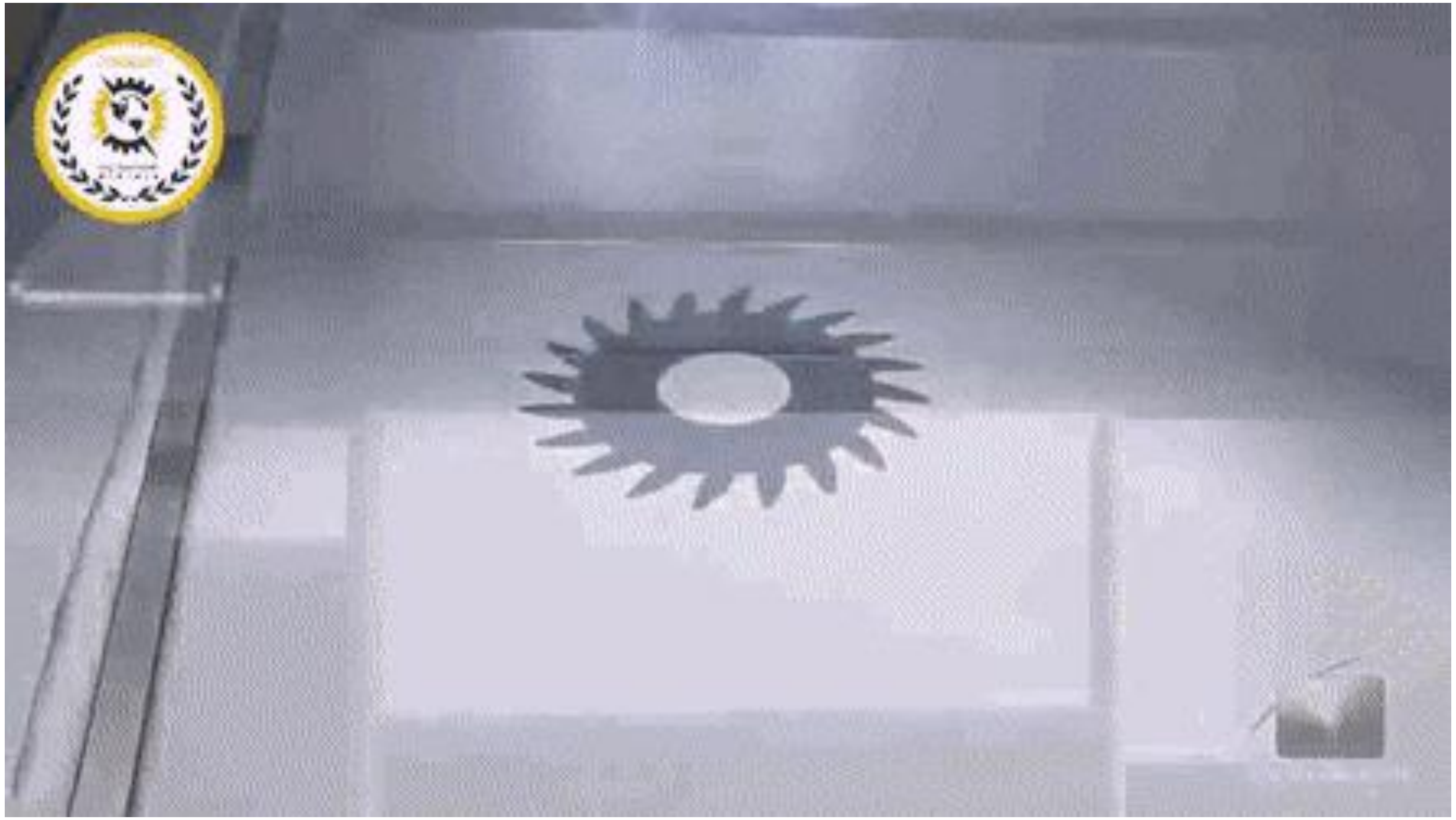
Computer-Aided Design Technology

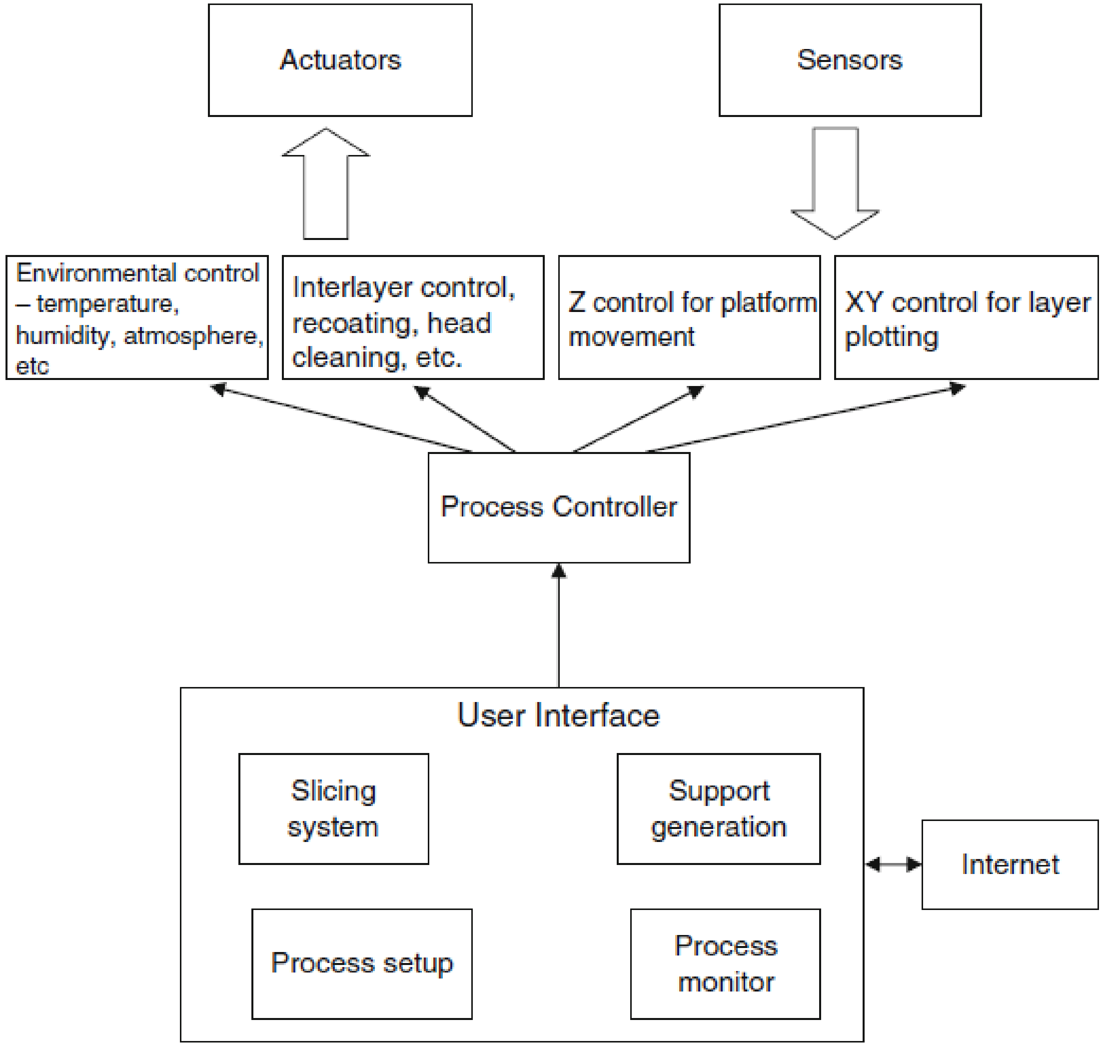
A CAD model on the left converted into STL format on the right


The cavity here may be too deep to machine
The undercut here cannot be performed without more than 3 axis machining
Base cannot be machined since machine must hold using a fixture
Sharp internal features cannot be machined without a tool radius



Printer technology used on an AM machine (photo courtesy of Objet)

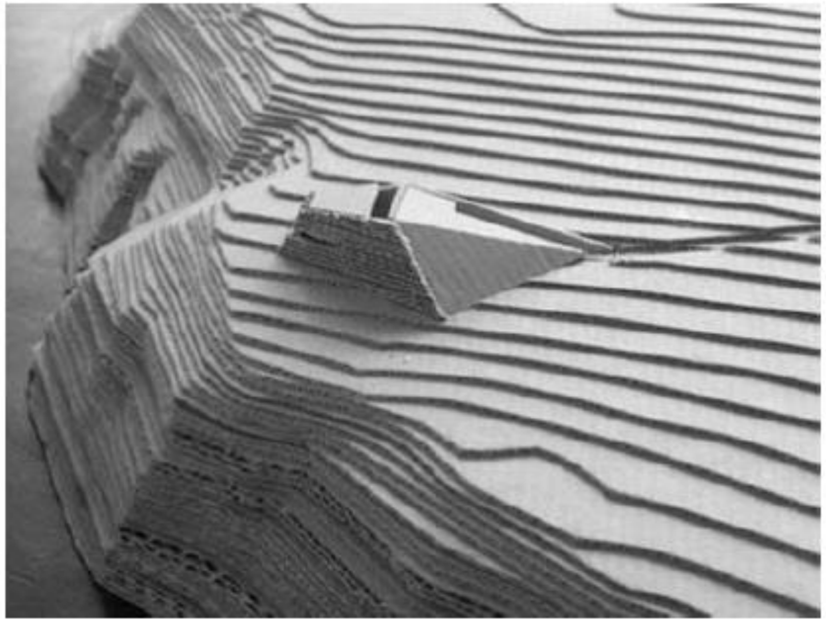




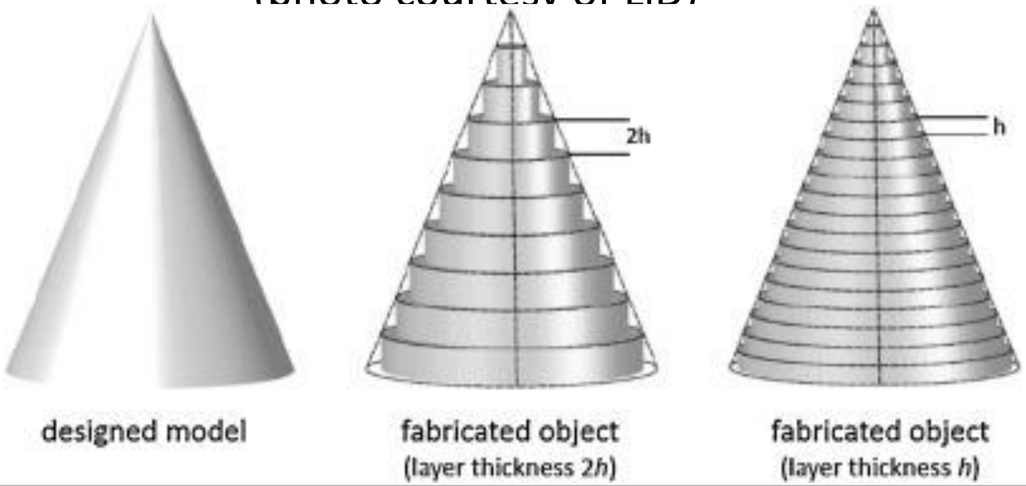
General integration of an AM machine

The Use of Layers

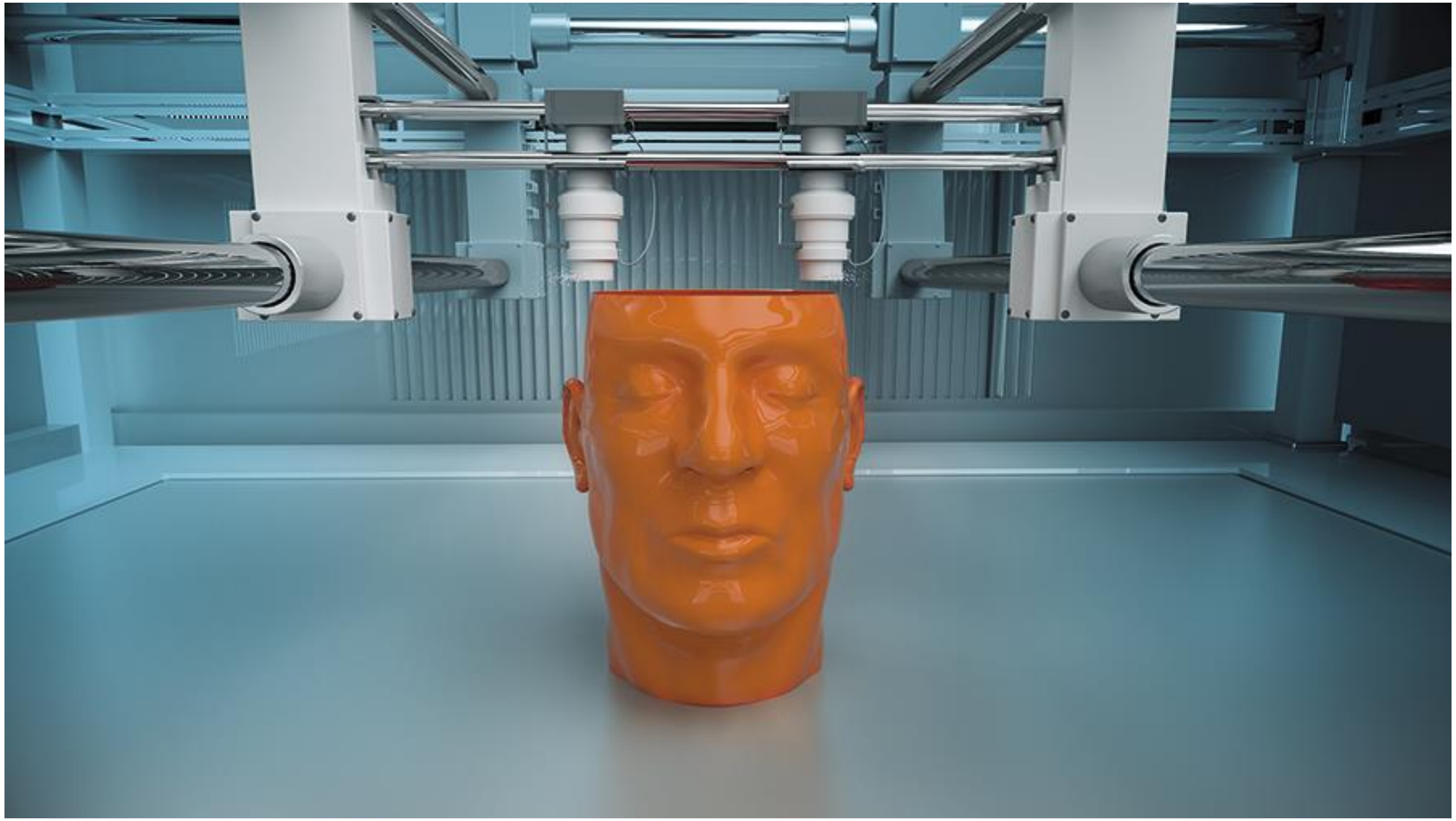
- A key enabling principle of AM part manufacture is the use of layers as finite 2D cross-sections of the 3D model.
- Almost every AM technology builds parts using layers of material added together; and certainly all commercial systems work that way, primarily due to the simplification of building 3D objects.
- Using 2D representations to represent cross-sections of a more complex 3D feature has been used in many applications outside AM.
- The most obvious example of this is how cartographers use a line of constant height to represent hills and other geographical reliefs.



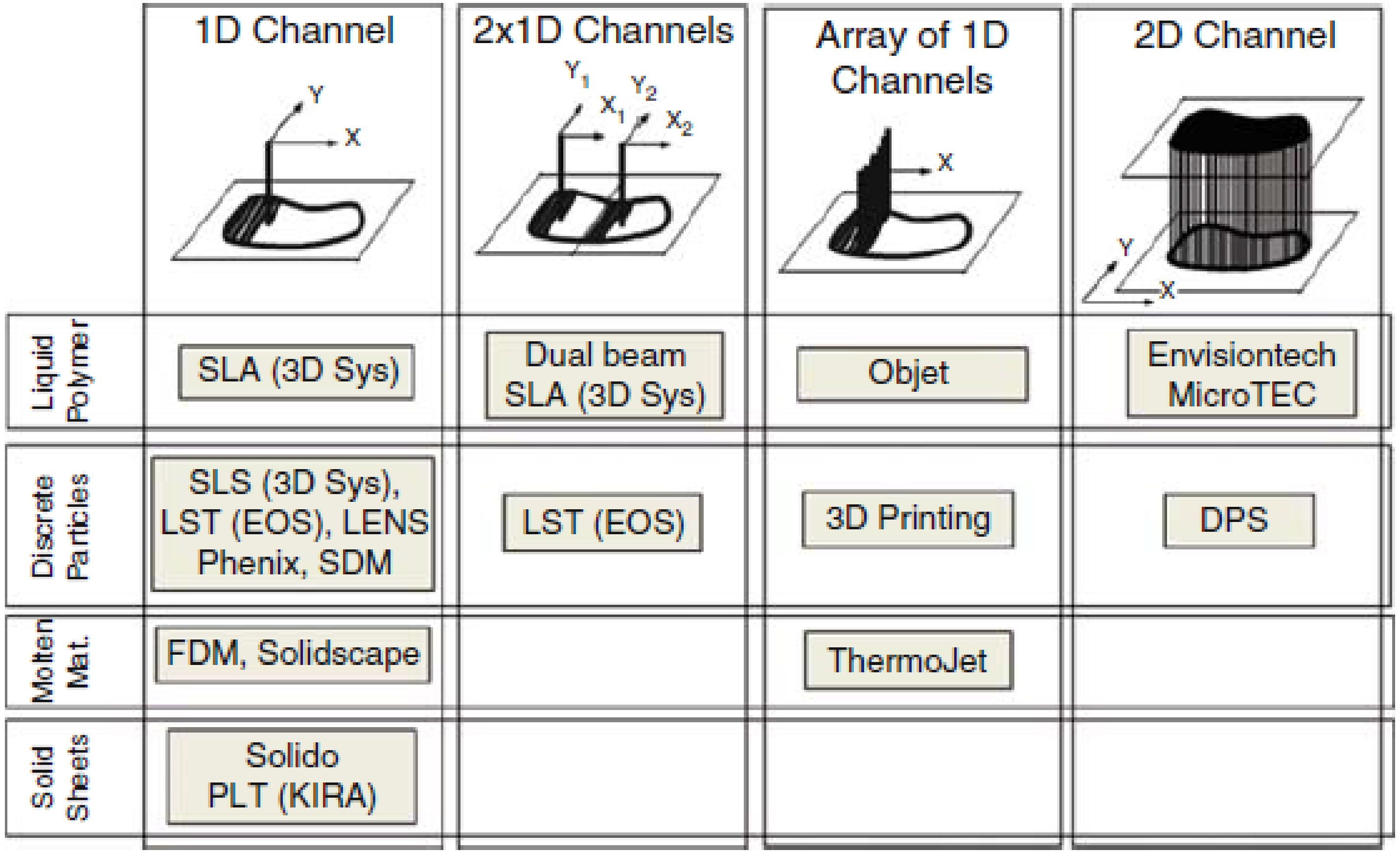
An architectural landscape model, illustrating the use of layers (photo courtesy of LiD)



The Use of Layers



Classification of AM Processes

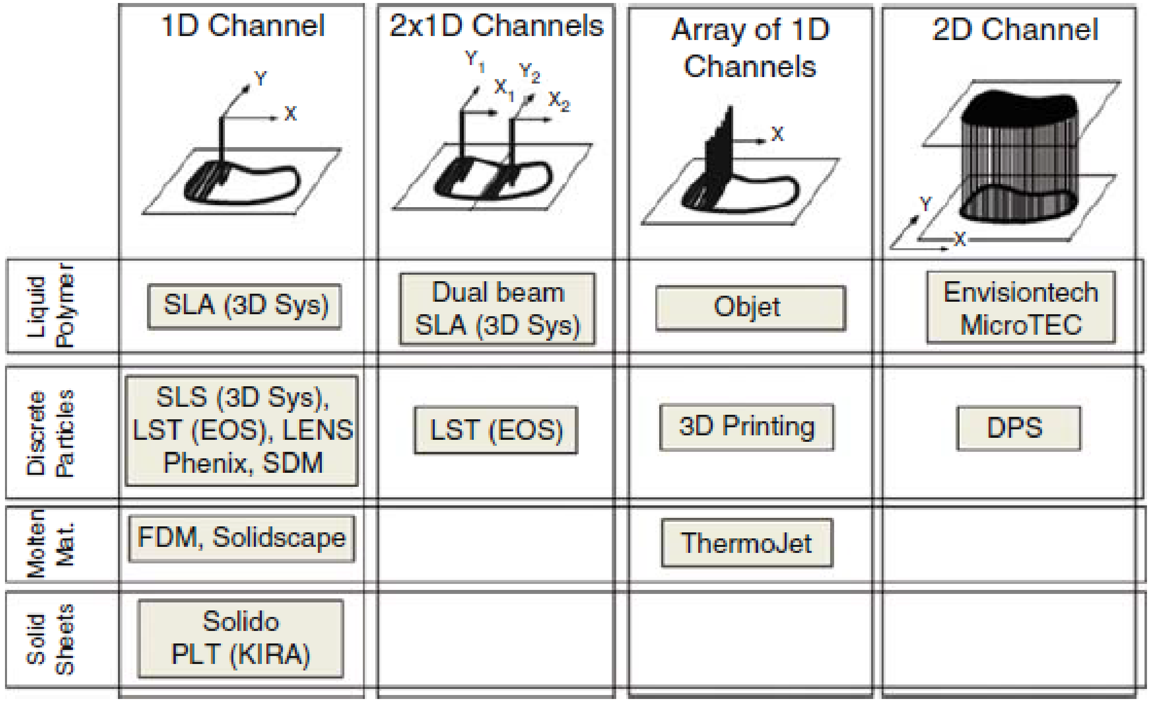


	1D Channel	2x1D Channels	Array of 1D Channels	2D Channel
Liquid Polymer	SLA (3D Sys)	Dual beam SLA (3D Sys)	Objet	Envisiontech MicroTEC
Discrete Particles	SLS (3D Sys), LST (EOS), LENS Phenix, SDM	LST (EOS)	3D Printing	DPS
Molten Mat.	FDM, Solidscape		ThermoJet	
Solid Sheets	Solido PLT (KIRA)			

Layered Manufacturing (LM) processes as classified by Pham (note that this diagram has been amended to include some recent AM technologies)

Classification of AM Processes........

- The first dimension relates to the method by which the layers are constructed.
- Earlier technologies used a single point source to draw across the surface of the base material. Later systems increased the number of sources to increase the throughput, which was made possible with the use of droplet deposition technology
- For example, which can be constructed into a one dimensional array of deposition heads. Further throughput improvements are possible with the use of 2D array technology using the likes of **Digital Micro-mirror Devices (DMDs)** and high resolution display technology, capable of exposing an entire surface in a single pass.



Layered Manufacturing (LM) processes as classified by Pham (note that this diagram has been amended to include some recent AM technologies)

Classification of AM Processes:

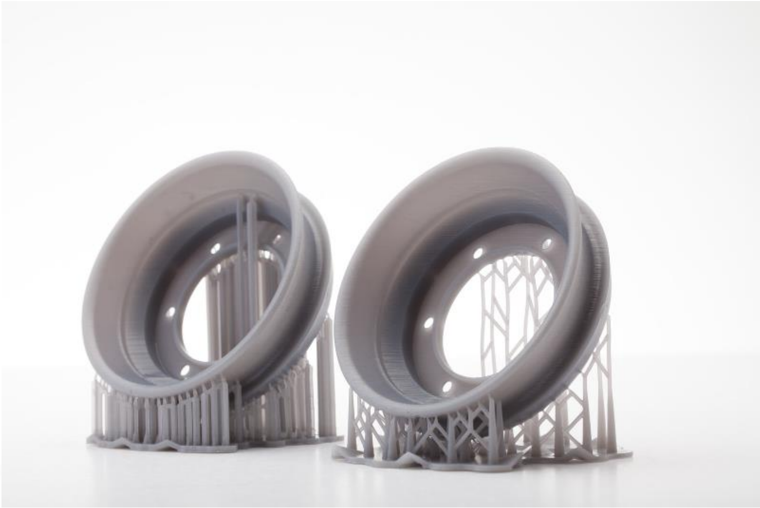
AM Technologies can be classified in numerous ways:

1. According to Baseline technology, like whether process uses lasers, printer technology, extrusion technology etc.
2. According to type of raw material input

- Liquid polymer
- Discrete particles
- Molten material
- Laminated sheets

Removal of Supports

- Wherever the supports meet the part there will be small marks and reducing the amount of supports would make the part more accurate and reduce the amount of part cleanup and post-process finishing.
- Parts that require supports may also require planning for their removal. Supports may be located in difficult to reach regions within the part. For example, a hollow cylinder with end caps built vertically will require supports for the top surface



Metal Systems

1. The Use of Substrates:

- Most metal systems make use of a base platform or substrate onto which parts are built and from which they must be removed using machining, wire cutting, or a similar method.
- The need to attach the parts to a base platform is mainly because of the high temperature gradients between the temporarily molten material and its surroundings.
- If the material did not adhere to a solid platform then there would be a tendency for the part to warp as it cools, which means further layers of powder cannot be spread evenly.
- Therefore, even though these are mainly powder-based systems, there is still a need for supports.

2. Energy Density

- The energy requirements for melting metals to over $1{,}000^{0}$C is obviously much higher than heating polymers to around 200^{0}C.
- Heat shielding, insulation, temperature control, and atmospheric control are much more stringent than in the lower cost polymer systems.

3. Weight

- Metal powder systems may process lightweight titanium powders but they also process high-density tool steels.
- The powder handling technology must be capable of withstanding the mass of these materials.
- This means that power requirements for positioning and handling equipment must be quite substantial or gear ratios must be high (and corresponding travel speeds lower) to deal with these tasks.

4. Accuracy

- Metal powder systems are generally at least as accurate as corresponding polymer powder systems.
- Surface finish is characteristically grainy but part density and part accuracy are very good.
- Surface roughness is in the order of a few tens to a few hundreds of microns depending on the process and can be likened in general appearance to precision casting technology.
- For metal parts, this is often not satisfactory and at least some shot-peening is required to smooth the surface.
- Key mating features on metal parts often require surface machining or grinding. The part density will be high (generally over 99%), although some voids may still be seen.

5. Speed

- Since there are heavy requirements on the amount of energy to melt the powder particles and to handle the powders within the machine, the build speed is generally slower than a comparable sized polymer system.
- Laser powers are not excessively high, usually just a few hundred watts (polymer systems start at around 50 watts of laser power).
- This means that the laser scanning speed is quite low to ensure enough energy is delivered to the powder.

Hybrid Systems

- Some of the machines described above are, in fact, hybrid additive/subtractive processes rather than purely additive.
- Including a subtractive component can assist in making the process more precise.
- This stage makes for a smooth planar surface onto which the next layer can be added, negating cumulative effects from errors in droplet deposition height.
- It should be noted that when subtractive methods are used, waste will be generated.
- Machining processes require removal of material that in general cannot easily be recycled.
- Similarly, many additive processes require the use of support structures and these too must be removed or “subtracted.”

Milestones in AM Development

- We can look at the historical development of AM in a variety of different ways. The origins may be difficult to properly define and there was certainly quite a lot of activity in the 1950s and 1960s, but development of the associated technology (computers, lasers, controllers, etc.) caught up with the concept in the early 1980s.
- Interestingly, parallel patents were filed in 1984 in Japan (Murutani), France (Andre et al.) and in the US (Masters in July and Hull in August).
- All of these patents described a similar concept of fabricating a 3D object by selectively adding material layer by layer.
- While earlier work in Japan is quite well-documented, proving that this concept could be realized, it was the patent by Charles Hull that is generally recognized as the most influential since it gave rise to 3D Systems.
- This was the first company to commercialize AM technology with the Stereolithography apparatus

Milestones in AM Development…….

- Further patents came along in 1986, resulting in three more companies, Helisys (Laminated Object Manufacture or LOM), Cubital (with Solid Ground Curing, SGC), and DTM with their Selective Laser Sintering (SLS) process.
- It's interesting to note neither Helisys or Cubital exist anymore, and only SLS remains as a commercial process with DTM merging with 3D Systems in 2001.
- In 1989, Scott Crump patented the Fused Deposition Modeling (FDM) process, forming the Stratasys Company. Also in 1989 a group from MIT patented the 3D Printing (3DP) process.
- These processes from 1989 are heavily used today, with FDM variants currently being the most successful.
- Rather than forming a company, the MIT group licensed the 3DP technology to a number of different companies, who applied it in different ways to form the basis for different applications of their AM technology.
- The most successful of these is ZCorp, which focuses mainly on low-cost technology.

The first AM technology from Hull, who founded 3D systems (photo courtesy of 3D Systems)

Maintenance of Equipment

- It is important to realize that many machines require careful maintenance.
- Some machines use fragile laser or printer technology that must be carefully monitored and that should preferably not be used in a dirty or noisy environment.
- Similarly, many of the feed materials require careful handling and should be used in low humidity conditions.
- While machines are designed to operate unattended, it is important to include regular checks in the maintenance schedule.
- Laser-based systems are generally expensive because of the cost of the laser itself. Furthermore, maintenance of a laser can be very expensive since the expected lifetime can be as low as 4,000 operating hours for tube lasers and up to more than 15,000 h for solid state lasers.
- Printheads are also components that have finite lifetimes for the printer-based systems.
- The fine nozzle dimensions and the use of relatively high viscosity fluids mean they are quite prone to clogging and contamination effects. Replacement costs are, however, generally quite low.

Materials Handling Issues

- In addition to the machinery, AM materials often require careful handling. The raw materials used in some AM processes have **limited shelf-life** and must also be kept in conditions that prevent them from chemical reaction or **degradation**.
- **Exposure to moisture** and to excess light should be avoided.
- Most processes use materials that can be used for more than one build. However, it may be that this could degrade the material if used many times over and therefore a procedure for maintaining **consistent material quality** through recycling should also be observed.
- While there are some **health concerns** with extended exposure to some photopolymer resins, most AM polymer raw materials are safe to handle.
- SLS powders may have **additives** that prevent degradation due to oxidation since they are kept at elevated temperatures for long periods of time.

Design for AM

Number of build-related factors when considering the setup of an AM machine

Part Orientation:

- If a cylinder was built on its end, then it would consist of a series of circular layers built on top of each other.. Additionally, as the layering process for most AM machines takes additional time, a long cylinder built vertically will take more time to build than if it is laid horizontally.
- Orientation of the part within the machine can affect part accuracy. Since many parts will have complex features along multiple axes, there may not be an ideal orientation for a particular part. Furthermore, it may be more important to maintain the geometry of some features when compared with others, so correct orientation may be a judgment call.
- In general upward-facing features in AM have the best quality. The reason for this depends upon the process. For instance, upward-facing features are not in contact with the supports required for many processes. For powder beds, the upward-facing features are smooth since they solidify against air, whereas downward-facing and sideways-facing features solidify against powder and thus have a powdery texture. For extrusion processes, upward-facing surfaces are smoothed by the extrusion tip. Thus, this upward-facing feature quality rule is one of the few rules-of-thumb that are generically applicable to every AM process.

Design for AM

Removal of Supports:

- It is a good idea to try and minimize the amount. Wherever the supports meet the part there will be small marks and reducing the amount of supports would reduce the amount of part cleanup and post-process finishing.
- Parts that require supports may also require planning for their removal. Supports may be located in difficult-to-reach regions within the part.

Hollowing Out Parts:

- A honeycomb- or truss-like internal structure can assist in providing support and strength within a part, while reducing its overall mass and volume.
- All of these approaches must be balanced against the additional time that it would take to design such a part. However, there are software systems that would allow this to be done automatically for certain types of parts.

Inclusion of Undercuts and Other Manufacturing Constraining Features:

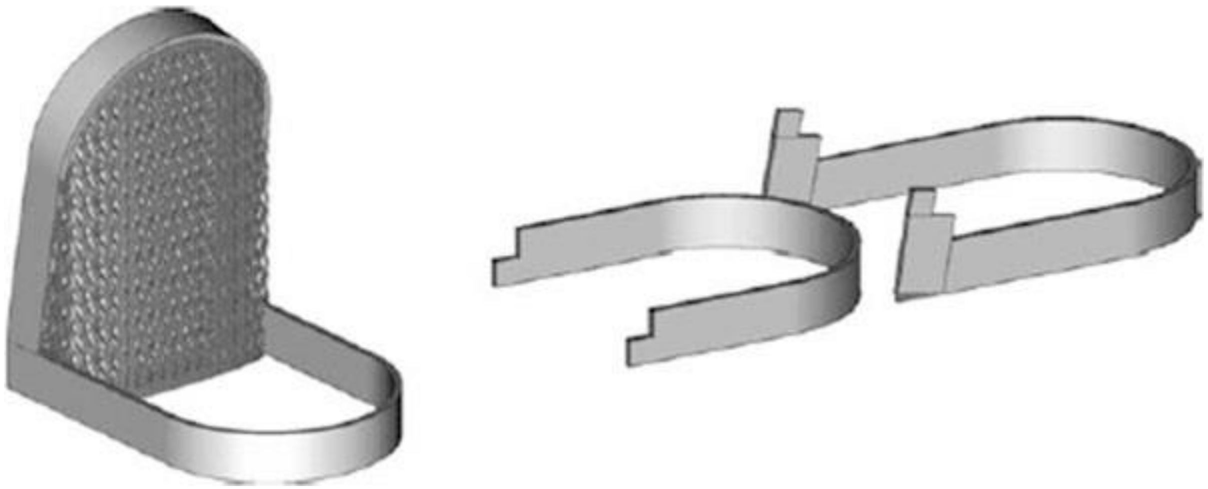
- Undercuts, draft angles, holes, pockets, etc. must be created in a specific order when using multiple-stage conventional processes. While this can be ignored when designing the part for AM, it is important not to forget them if AM is being used just as a prototype process.
- AM can be used in the design process to help determine where and what type of rib, boss, and other strengthening approaches should be used on the final part. If the final part is to be injection molded, the AM part can be used to determine the best location for the parting lines in the mold.

Design for AM

Interlocking Features:

A solution may be to break the design up into segments that can fit into the machine and manually assemble them together later.

Techniques can include incorporation of interlocking features and maximizing surface area so that adhesives can be most effective. Such regions should also be in easy-to-reach but difficult-to-observe locations.



Design for AM

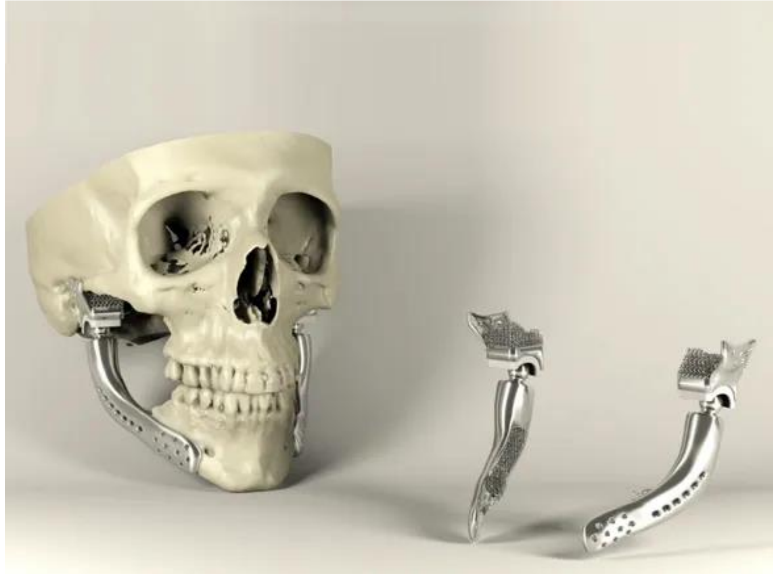
Reduction of Part Count in an Assembly:

The AM process is therefore toward the end of the product development process and the design does not need to consider alternative manufacturing processes. This in turn means that if part assembly can be simplified using AM, then this should be done. For example, it is possible to build fully assembled hinge structures by providing clearance around the moving features. In addition, complex assemblies made up of multiple injection molded parts, for instance, could be built as a single component. Thus, when producing components with AM, designers should always look for ways to consolidate multiple parts into a single part and to include additional part complexity where it can improve system performance.

Design for AM

Identification Markings/Numbers

- Although AM parts are often unique, it may be difficult for a company to keep track of them when they are possibly building hundreds of parts per week.
- It is a straightforward process to include identifying features on the parts. This can be done when designing the CAD model but that may not be possible since the models may come from a third party.
- There are a number of software systems that provide tools for labeling parts by embossing alphanumeric characters onto them as 3D models.
- In addition, some service providers build all the parts ordered by a particular customer (or small parts which might otherwise get lost) within a mesh box so that they are easy to find and identify during part cleanup.



Applications

- Product development
- Data visualization
- Rapid prototyping
- Specialized manufacturing

Additive Manufacturing Applications

Aerospace

AM excels at producing parts with weight-saving, complex geometric designs. Therefore, it is often the perfect solution for creating right, strong aerospace parts.

In August 2013, NASA successfully tested an SLM-printed rocket injector during a hot fire test that generated 20,000 pounds of thrust. In 2015, the FAA cleared the first 3D-printed part for use in a commercial jet engine. CFM's LEAP engine features 19 3D-printed fuel nozzles. At the 2017 Paris Air Show, FAA-certified, Boeing 787 structural parts fabricated from titanium wire were displayed, according to Aviation Week.

Automotive

CNN reported that the McLaren racing team is using 3D-printed parts in its Formula 1 race cars. A rear wing replacement took about 10 days to produce instead of five weeks. The team has already produced more than 50 different parts using additive manufacturing. In the auto industry, AM's rapid prototyping potential garners serious interest as production parts are appearing. For example, aluminum alloys are used to produce exhaust pipes and pump parts, and polymers are used to produce bumpers.

Additive Manufacturing Applications

Healthcare

At the New York University School of Medicine, a clinical study of 300 patients will evaluate the efficacy of patient-specific, multi-colored kidney cancer models using additive manufacturing. The study will examine whether such models effectively assist surgeons with pre-operative assessments and guidance during operations.

Global medical device manufacturing company Stryker are funding a research project in Australia that will use additive manufacturing technology to create custom, on-demand 3D printed surgical implants for patients suffering from bone cancer.

In general, healthcare applications for additive manufacturing are expanding, particularly as the safety and efficacy of AM-built medical devices is established. The fabrication of one-of-a-kind synthetic organs also shows promise.

Product Development

As the potential for AM's design flexibility is realized, once impossible design concepts are now being successfully re-imagined. Additive manufacturing unleashes the creative potential of designers who can now operate free of the constraints under which they once labored.

Additive Manufacturing Materials

It is possible to use many different materials to create 3D-printed objects. AM technology fabricates jet engine parts from advanced metal alloys, and it also creates chocolate treats and other food items.

Thermoplastics

Thermoplastic polymers remain the most popular class of additive manufacturing materials. Acrylonitrile butadiene styrene (ABS), polylactic acid (PLA) and polycarbonate (PC) each offer distinct advantages in different applications. Water-soluble polyvinyl alcohol (PVA) is typically used to create temporary support structures, which are later dissolved away.

Metals

Many different metals and metal alloys are used in additive manufacturing, from precious metals like gold and silver to strategic metals like stainless steel and titanium.

Ceramics

A variety of ceramics have also been used in additive manufacturing, including zirconia, alumina and tricalcium phosphate. Also, alternate layers of powdered glass and adhesive are baked together to create entirely new classes of glass products.

Biochemicals

Biochemical healthcare applications include the use of hardened material from silicon, calcium phosphate and zinc to support bone structures as new bone growth occurs. Researchers are also exploring the use of bio-inks fabricated from stem cells to form everything from blood vessels to bladders and beyond.

Additive Manufacturing Processes

There are a variety of different additive manufacturing processes:

Powder Bed Fusion

Powder Bed Fusion (PBF) technology is used in a variety of AM processes, including direct metal laser sintering (DMLS), selective laser sintering (SLS), selective heat sintering (SHS), electron beam melting (EBM) and direct metal laser melting (DMLM). These systems use lasers, electron beams or thermal print heads to melt or partially melt ultra-fine layers of material in a three-dimensional space. As the process concludes, excess powder is blasted away from the object.

Binder Jetting

The binder jetting process is similar to material jetting, except that the print head lays down alternate layers of powdered material and a liquid binder.

Directed Energy Deposition

The process of directed energy deposition (DED) is similar to material extrusion, although it can be used with a wider variety of materials, including polymers, ceramics and metals. An electron beam gun or laser mounted on a four- or five-axis arm melts either wire or filament feedstock or powder.

Additive Manufacturing Processes

Material Extrusion

Material extrusion is one of the most well-known additive manufacturing processes. Spooled polymers are extruded, or drawn through a heated nozzle mounted on a movable arm. The nozzle moves horizontally while the bed moves vertically, allowing the melted material to be built layer after layer. Proper adhesion between layers occurs through precise temperature control or the use of chemical bonding agents.

Material Jetting

With material jetting, a print head moves back and forth, much like the head on a 2D inkjet printer. However, it typically moves on x-, y- and z-axes to create 3D objects. Layers harden as they cool or are cured by ultraviolet light.

Sheet Lamination

Laminated object manufacturing (LOM) and ultrasonic additive manufacturing (UAM) are two sheet lamination methods. LOM uses alternate layers of paper and adhesive, while UAM employs thin metal sheets conjoined through ultrasonic welding. LOM excels at creating objects ideal for visual or aesthetic modeling. UAM is a relatively low-temperature, low-energy process used with various metals, including titanium, stainless steel and aluminum.

Vat Polymerization

With vat photopolymerization, an object is created in a vat of a liquid resin photopolymer. A process called photopolymerization cures each microfine resin layer using ultraviolet (UV) light precisely directed by mirrors.