Waste reduction by alternative technologies: additive manufacturing.

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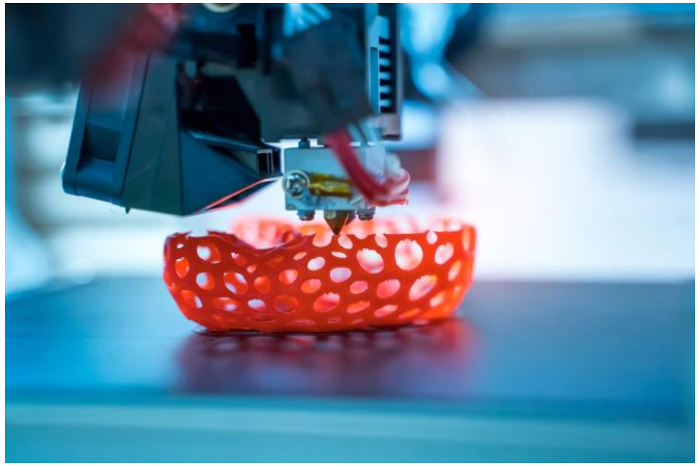
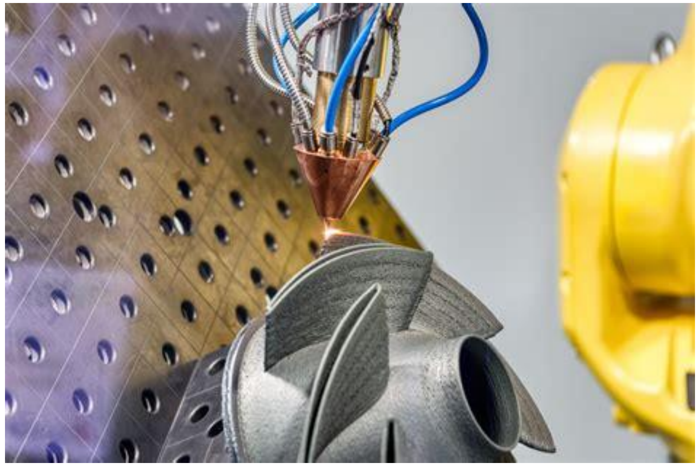
General presentation of Additive Manufacturing

Additive manufacturing (AM), also known as 3D printing, is a process of **creating physical objects from digital designs by adding layer upon layer of material** until the final shape is achieved. Unlike traditional manufacturing methods, which involve subtracting or shaping material to create the final product, additive manufacturing builds up the object layer by layer, using materials such as plastics, metals, ceramics, and even living cells. Additive manufacturing allows for **greater flexibility and customization in design, faster prototyping, and reduced waste** compared to traditional manufacturing techniques.

The process is seen as a **true revolution**. It allows to go beyond the limits of traditional manufacturing (injection molding, machining, forming, assembly) and offers the possibility to manufacture parts of great complexity, unattainable by other techniques, thus widening the potential for innovation. Additive manufacturing has continued to develop and thanks to the development of equipment, prototyping activities have migrated in some areas to those of direct manufacturing of functional parts. The maturity of the processes and the current equipment allow the mass production of metallic manufactured parts. The automotive, aeronautical and medical industries are strongly interested in the potential that AM can offer them.

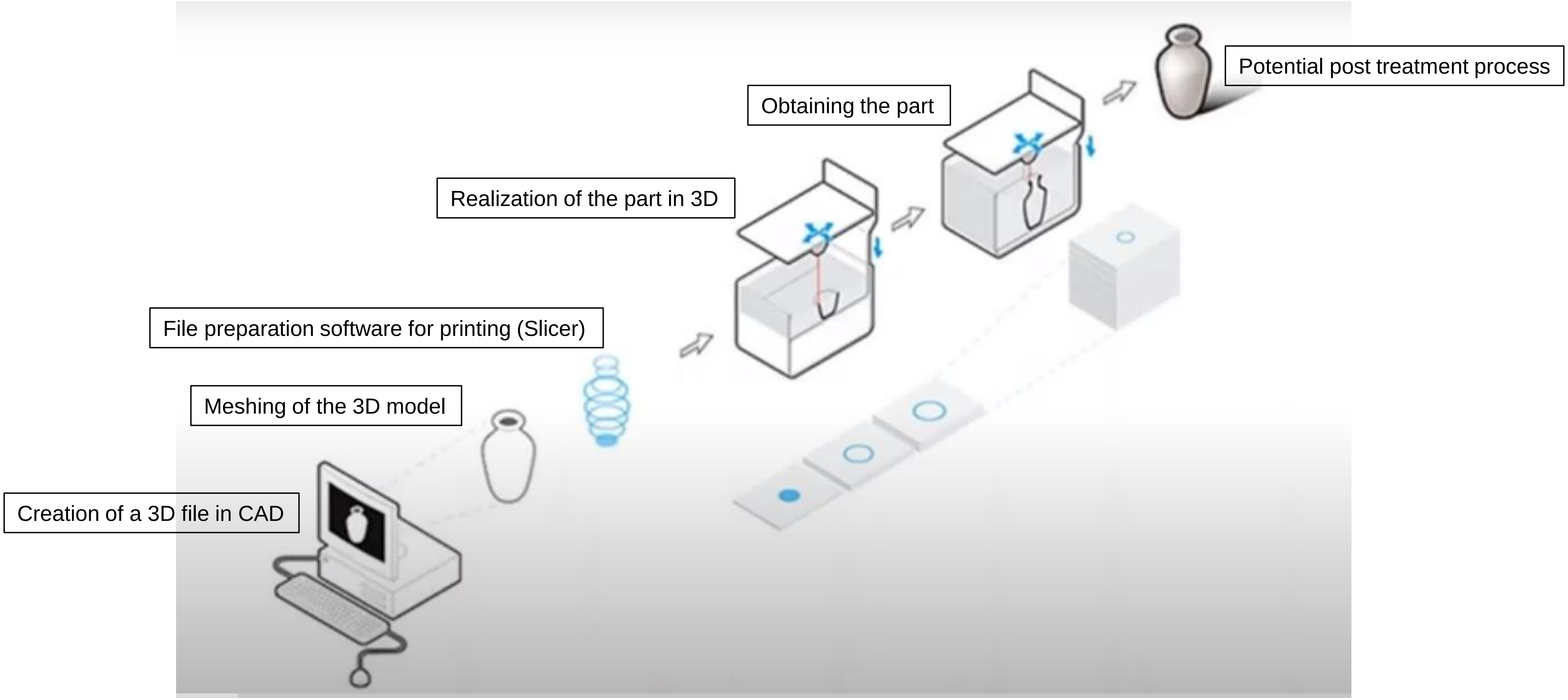




Manufacturing process of a 3D printed part

1. **Design:** A digital model of the part is created using computer-aided design (CAD) software. The design can be created from scratch or using a pre-existing template.
2. **Preparation:** The digital model is prepared for printing using slicing software, which breaks down the 3D model into individual layers. This process generates instructions for the printer to follow, including the positioning and movement of the print head and the temperature and speed of the material being used.
3. **Printing:** The 3D printer adds material layer by layer until the final part is created. The printer head moves back and forth along the x and y axes, while the build platform moves up and down along the z-axis. The material used can vary depending on the printer, but common materials include plastics, metals, ceramics, and even living cells.
4. **Post-processing:** Once the part is printed, it may require post-processing to achieve the desired finish. This can include removing support structures, cleaning the part, and curing or sintering the material to strengthen the part.
5. **Quality control:** The final step is to ensure that the part meets the desired specifications. This can include dimensional accuracy checks, testing for strength and durability, and other quality control measures

Manufacturing process of a 3D printed part



Benefits and opportunities of additive manufacturing.

PRODUCE

Benefits	Opportunities
Greater design freedom and customization	Rapid prototyping and iteration
Reduced material waste	On-demand production and supply chain flexibility
Energy efficiency	Design optimization and product innovation
Reduced transportation emissions	Distributed manufacturing and localized production
Customization for several applications	Personalization and mass customization
Reduced tooling costs	Complex geometries and integrated assemblies
Reduced lead times	Sustainable material usage and circular economy
Reduced inventory costs	Supply chain resilience and risk mitigation
Lower barriers to entry for small and medium-sized enterprises	New business models and revenue streams

Overall, additive manufacturing offers a range of benefits and opportunities, including greater design freedom and customization, reduced material waste, energy efficiency, and reduced transportation emissions. It also presents opportunities for rapid prototyping and iteration, on-demand production, personalized and mass-customized products, and sustainable material usage. These benefits can lead to cost savings, increased flexibility and efficiency, and new revenue streams for businesses.

Environmental impact

Additive manufacturing printing, has several potential environmental benefits compared to traditional manufacturing methods. Here are some of the environmental benefits of additive manufacturing:

- **Reduced material waste:** Additive manufacturing builds up objects layer by layer, meaning that only the necessary amount of material is used to create the object, which reduces material waste.
- **Energy efficiency:** Additive manufacturing can be more energy-efficient than traditional manufacturing because it uses less energy to produce objects. Traditional manufacturing often involves heating, shaping, and cutting raw materials, which can require a significant amount of energy.
- **Reduced transportation emissions:** Additive manufacturing can reduce transportation emissions because it allows objects to be produced on-site, eliminating the need to transport finished goods from a manufacturing facility to the end-user.
- **Circular economy:** Additive manufacturing can play a role in creating a more circular economy, where products are designed to be reused, recycled, or repurposed at the end of their life. By enabling the production of complex geometries and customized parts, additive manufacturing can facilitate the design of products that are easier to disassemble and recycle. This can reduce waste and promote more sustainable resource use.
- **Reduced water usage:** Traditional manufacturing methods, such as machining and injection molding, often require the use of coolants and lubricants that can contaminate water sources. Additive manufacturing eliminates the need for these fluids, reducing water usage and potential contamination.
- **Use of sustainable materials:** Additive manufacturing allows for the use of sustainable materials, such as bioplastics, recycled plastics, and natural materials, that can reduce the environmental impact of manufacturing.
- **Reduced air pollution:** Traditional manufacturing processes can release harmful pollutants into the air, such as volatile organic compounds (VOCs) and particulate matter. Additive manufacturing produces fewer emissions, reducing the impact on air quality and potentially improving workplace safety.

The Role of Software in Additive Manufacturing

Software plays a **critical role in the additive manufacturing process,** from the design stage to the final production of the object. Here are some examples of the role of software in additive manufacturing:

1. **Design:** Software is used to create the digital model of the object that will be printed. This can be done using Computer-Aided Design (CAD) software, which allows the designer to create a 3D model of the object with precision and accuracy.
2. **Slicing:** Once the 3D model is created, it needs to be sliced into multiple layers, each of which will be printed one at a time. Slicing software takes the 3D model and breaks it down into the individual layers, each of which can be printed as a 2D image.
3. **Printing:** During the printing process, software is used to control the printer and ensure that each layer is printed accurately and precisely. The software controls the movement of the printer head, the speed of the print, and the temperature of the material being printed.
4. **Quality control:** After the object is printed, software can be used to perform quality control checks to ensure that the object meets the design specifications. This can include checking for defects, measuring dimensions, and performing other tests to ensure that the object is of high quality.

Overall, **software is an essential part of the additive manufacturing process**, allowing for precise control over the design and production of objects, as well as faster and more efficient prototyping and manufacturing.are plays a critical role in the additive manufacturing process, from the design stage to the final production of the object. **You will find examples of software that you can use for each of these process in the following slide.**

Examples of software that can be used in the 3D creation process

CAD Softwares :

Free softwares for **beginner** (non-industrial use) : TinkerCAD, FreeCAD

https://www.tinkercad.com/

https://www.freecadweb.org/

Intermediate level softwares : CREO, Fusion 360°

https://www.ptc.com/en/products/creo

https://www.autodesk.fr/products/fusion-360/overview?term=1-YEAR

Professional level softwares : Solidworks, CATIA, Rhino3D

https://www.solidworks.com/

https://www.3ds.com/products-services/catia/

Rhinoceros

https://www.rhino3d.com/

Examples of software that can be used in the 3D creation process

Slicers 3D :

The slicer, also called slicing software, acts as an intermediary between the 3D model and the printer. The slicer divides the object into a stack of layers (slices the object) and tells the printer what movements the extruder or laser should make.

Main softwares :

Cura is probably the most widely used 3D slicer on the market. It is a free open-source software, compatible with most desktop 3D printers. It is suitable for beginners and professionals alike. Among its features are the display of a route, estimation of printing time and material usage. Experienced users can use third-party plugins.

https://ultimaker.com/fr/software/ultimaker-cura

3DPrinterOS™
Cloud 3D Printer Management

3DPrinterOS is a cloud platform that integrates a slicing application but also other essential features for 3D printing, such as a repair function. This makes it an easy way to manage the various machine files within an enterprise. The range of printers compatible with this platform is very wide

https://www.3dprinteros.com/

Examples of software that can be used in the 3D creation process

Main softwares :

An acronym for "Keep it Simple Slicer", this 3D slicer is a fast cross-platform application that can be quite sophisticated depending on the version chosen. There is a free one suitable for beginners but also a professional version that you can buy, allowing double extrusion 3D printing

https://www.kisslicer.com/

Presentation/Objective of the guideline

The objective of this presentation is to introduce the different methods of additive manufacturing and their advantages and disadvantages and their applications.

We hope that this presentation will help you to choose the right method for your needs.

Additive Manufacturing Methods

1. Powder Bed Fusion
2. Material Extrusion
3. Shett Lamination
4. Vat Photopolymerization
5. Material Jetting
6. Binder Jetting
7. Direct Energy Deposition

Powder Bed Fusion

Definition

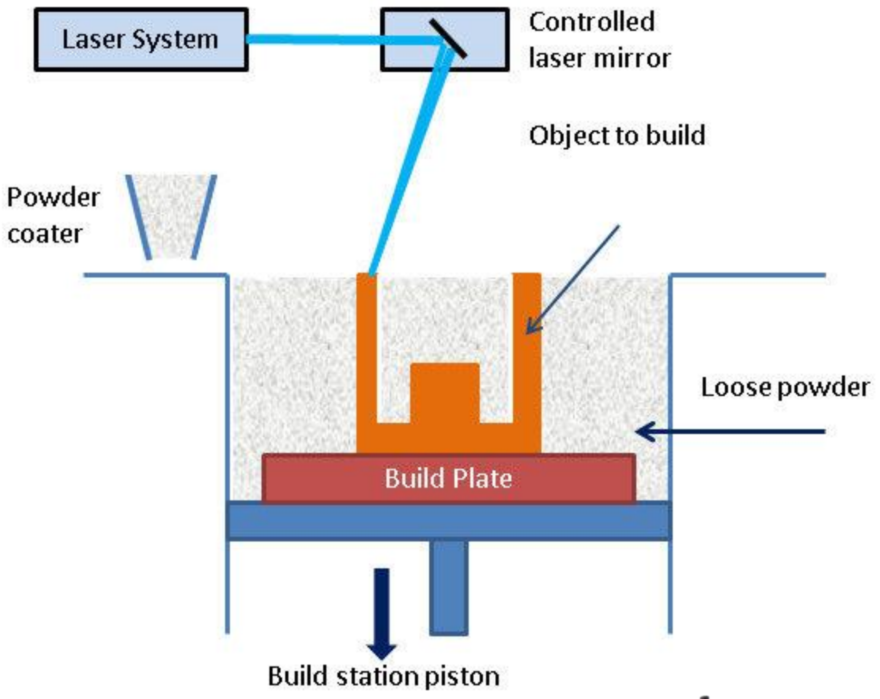
The Powder bed fusion (PBF) process begins with the creation of a 3D CAD model, which is numerically 'sliced' into several discrete layers.

For each layer, a heat source scan path is calculated. The heat source is typically an energy beam (e.g. a laser).

Each layer is then sequentially bonded on top of each other.

PBF processes spread powdered material over the previously joined layer. A hopper supplies the powdered material which is then spread uniformly over the powder bed build platform area via a roller or blade. *

The optimal thickness of each layer of spread powder is dependent on the processing conditions and material used, but values of 25 to 100µm are common.



Processes

Selective laser sintering (SLS) is an additive manufacturing process that uses a high-powered laser to sinter small particles of polymer powder into a solid structure, based on a 3D model. Low cost per part, high productivity and well-honed materials are the characteristics that make it ideal for a number of applications, including rapid prototyping and the manufacture of small, complementary or customized series.
Recent advances in equipment, materials and software have made SLS printing accessible to a wider range of activities, allowing more and more companies to use tools that were previously reserved for a few high-tech industries.

Selective Laser Melting (SLM) comparable to SLS in that a laser is used to provide heat, however the laser fully melts the powder rather than sintering it. An inert atmosphere (typically argon) is included in the build chamber to prevent oxidation of the consolidated material. SLM is often faster than SLS but has higher energy costs and typically has a poor energy efficiency of 10 to 20%.

Selective Heat Sintering (SHS) uses a heated thermal printhead to fuse powder material together. The process is used in creating concept prototypes and less so structural components. The use of a thermal print head and not a laser benefits the process by reducing significantly the heat and power levels required. Thermoplastics powders are used.

Processes

Direct Metal Laser Sintering (DMLS) uses the same process as SLS, but with the use of metals and not plastic powders. Despite the term 'sintering' being used, full melting is achieved. The DMLS additive manufacturing process allows for high printing precision. It is therefore suitable for the manufacture of parts with complex geometries and structures, with thin walls and hidden voids or channels, but also for the design of very small objects. Today, this manufacturing technique still has a high cost and seems to be uneconomical for mass production.

Electron Beam Melting (EBM) is a comparable process to SLM, replacing the laser with an electron gun. Owing to the use of an electron beam, the build chamber uses a vacuum instead of an inert atmosphere, though a small amount of inert gas (typically helium) is used to allow better process control. EBM provides models with very good strength properties due to an even temperature distribution during fusion. The high quality and finish that the process allows for makes it suited to the manufacture of high standard parts used in aeroplanes and medical applications.

Multi jet fusion (MJF) allows for rapid manufacturing of functional parts at a low cost per part. The MJF process works by depositing a binder on a powder. The object is printed layer by layer in the powder tray: the binder is deposited on the material layer where the particles are to be fused; then a second liquid binder is deposited to fuse and create the part; and finally, each material layer is heated to react the binders and material to create the part. This technology is considered the ideal 3D printing technology for prototyping, mechanical testing or rapid manufacturing.

Material

Materials	Recommended Process
Nylon	SHS
Stainless Steel, Titanium, Aluminum, Cobalt Chrome, Steel	DMLS, SLS, SLM
Titanium, Cobalt, Chrome, Stainless steel, Aluminum, Copper	EBM
Thermoplastics (mainly Polyamide 11 or 12 and Polyurethane)	MJF

Application of PBF

In the medical sector for making customized orthopedic components, such as titanium alloy cranial or acetabular implants.

From an aerospace perspective, PBF processes are finding much interest and use for military and commercial aircraft. Examples of this include the PBF manufactured fuel nozzle on General Electric's GE9X engine, which is used on Boeing 777 aircraft. This version is five times more durable than previous versions

Swedish automotive manufacturer Koenigsegg has implemented PBF techniques throughout the manufacturing process of its latest hypercar, the "One:1".
Additive manufacturing processes enabled a reduction in material waste and costs for Koenigsegg. For lower production runs (as is common with high-end cars), building complex parts by additive manufacturing is cheaper, quicker and more efficient than building the necessary tooling for production of certain complex parts, which is common in the automotive industry

Cranial implant

Fuel nozzle

Koenigsegg One:1

Pros and Cons of PBD

Pros	Cons
Fully customized parts	Relatively slow speed
Efficient recycling of un-melted powder	Lack of structural properties in materials
Ability to use many materials	Size limitations
Reduced material wastage	High power usage
Powder recycling	Finish is dependent on powder grain size
No or minimum support	Thermal distortion (mainly for polymer)
	Post processes

Powder Bed Fusion

Summary

Preferential sectors: Automobile, Aerospace and Health

Price: Starting around 10 000 € for the machine and 50€/kg for Powders

Environmental impact: 50% of the powders are recycling

Main Pros: Fully customized parts

Main Cons: Size limitations

To go further

SLS Video: https://www.youtube.com/watch?v=oO77VKDB89I

Complete Guide to PBF in 3D Printing:

https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/powderbedfusion/

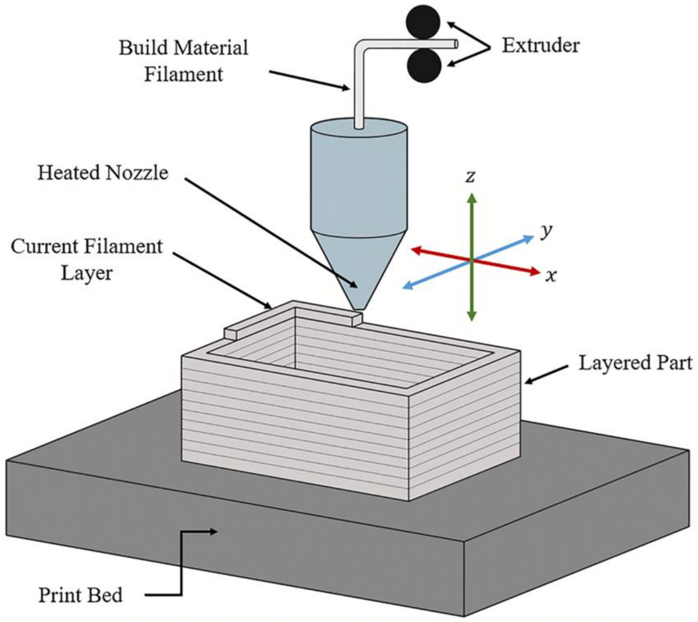
https://www.3dnatives.com/en/direct-metal-laser-sintering100420174-2/

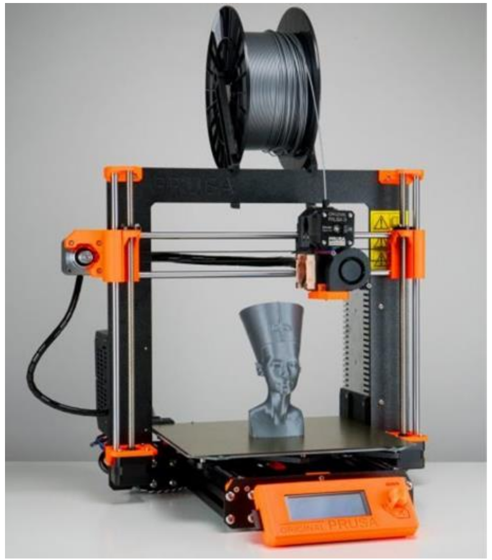
Material Extrusion

Definition

Material extrusion is an additive manufacturing technique which uses continuous filament of thermoplastic or composite material to construct 3D parts. The material in the form of plastic filament fed through an extruding nozzle, where it is heated and then deposited onto the build platform layer by layer.

Material extrusion is now the most popular additive manufacturing process in terms of availability for general consumer demand and quality.





Process

Fused Deposition Modeling (FDM) or FFF (Fused Filament Fabrication) is used by most printers, mainly those of private individuals. FDM systems use two rolls of different materials: the first for the building material of which the final part will be made, and the second for the support material needed during manufacturing to support the bottom surfaces and hold the overhanging ones.

The 3D printing process starts with the heating of the machine (around 200°C), necessary for the fusion of the material

Once the machine is heated, a 1.75mm or 2.85mm diameter filament material is extruded onto the platform through a nozzle moving on 3 axes, x, y and z. The platform moves down one level with each new layer applied, until the object is printed.

During the printing process, supports can be used like a scaffold. They support the cantilevered parts of the 3D model that are most likely to collapse. These supports can be made of the same material as the printed object or of a water-soluble material such as limonene. Although more complicated to operate, some 3D printers are equipped with multiple extruders to combine different colors or materials.

Material

Materials	Recommended Process
Acrylonitrile Butadiene Styrene (ABS)	FDM
PolyLactic Acid (PLA)	
High-Impact Polystyrene (HIPS)	
Thermoplastic PolyUrethane (TPU)	
aliphatic PolyAmides (PA, also known as Nylon)	
PolyEther Ether Ketone (PEEK)	
PolyEtherimide (PEI)	

Note that it is possible to fuse PA with materials such as wood, metal or carbon to give other properties to the product. The sole condition is that the base material (a thermoplastic) is present in sufficient quantities to guarantee a fusion between layers

Application of Material Extrusion

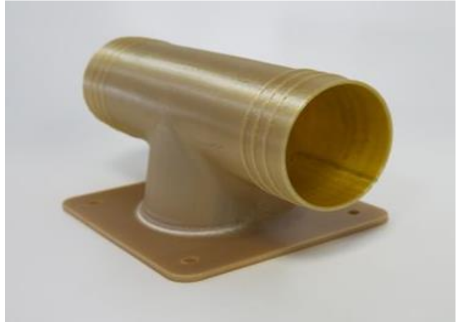
One of the most popular applications of the FDM technology still remains prototyping FDM offers a very easy, affordable and quick alternative to manufacturing prototypes. FDM 3D printing technology has been instrumental in helping numerous doctors all across the globe to plan surgeries better by providing them organs which are an exact replica of the specific patient in question. They are accurate in structure, are made hollow or solid according to the requirement, and printed rapidly in a few hours.

One of the most rapidly growing application of FDM 3D printing is the field of prosthetics. Since traditional prosthetics are heavy, costly and take a long time to be manufactured, 3D printed prosthetics are largely seen as the disrupters, especially FDM 3D printed prosthetic arms.

Industrial 3D printers are capable of producing end-use application parts which can be used in aerospace, automotive, manufacturing and medical applications.

3D printed heart

3D printed hand prosthesis



3D printed ducting for air conditioners

Pros and Cons of PBD

Pros	Cons
Widespread and inexpensive process	Visible layer lines
Easily understandable printing technique	Susceptible to warping and other temperature fluctuation issues such as delamination
No supervision required	Accuracy and speed are low when compared to other processes
Wide selection of print material	Supports may be required
Small equipment size compared to other AM	Inefficient with mass production
Low-temperature process	

Material Extrusion

Summary

Preferential sectors: Automotive, Aerospace, Medical, Maritime and Railway

Price: 40€/kg for the filament and for the machine 300€ for small 2500€ for middle and 10 000 € for professional

Environmental impact: Possibility to create filaments with recycled materials or used filament pieces

Main Pros: Easily understandable printing technique perfect for newbie

Main Cons: Accuracy and speed are low when compared to other processes

To go further

FDM Video : https://www.youtube.com/watch?v=J4OQQ9bA6g0&t=10s&ab_channel=AMVideos

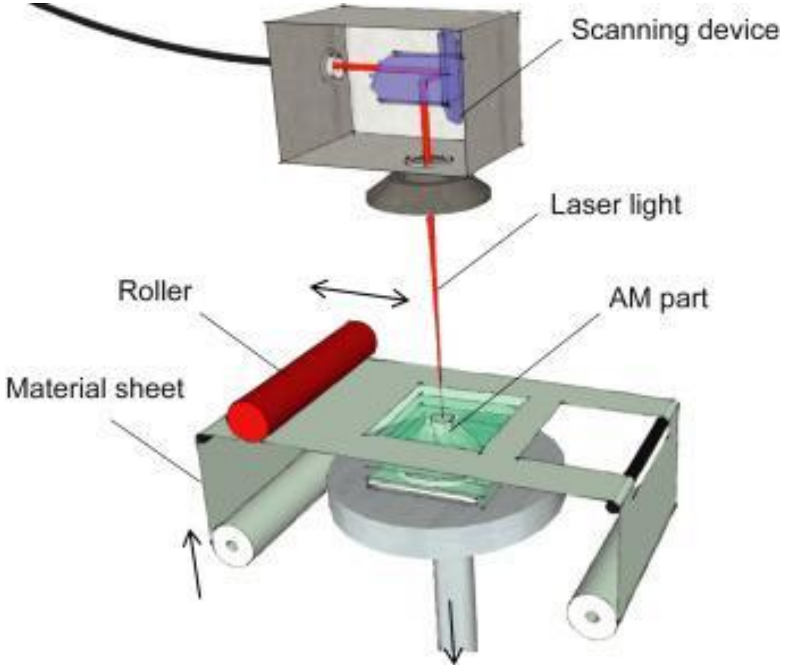
Complete Guide to Material Extrusion in 3D Printing:

https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/materialextrusion/

Definition

The Sheet Lamination (SL) 3D printing manufacturing technique, consists of superpositioning several layers of material composed of foil in order to manufacture an object. Each foil is cut to shape with a knife or laser in order to fit to the object’s cross-section.

To achieve the desired shape, this technique can be combined with a computer-controlled cutting device to delineate the boundaries of each layer. Objects printed with this technique may be additionally modified by machining or drilling after printing



PRODUCE

Processes

Laminated Object Manufacturing (LOM) uses a continuous sheet of material — plastic, paper or (less commonly) metal — which is drawn across a build platform by a system of feed rollers. Plastic and paper build materials are often coated with an adhesive. To form an object, a heated roller is passed over the sheet of material on the build platform, melting its adhesive and pressing it onto the platform. A computer-controlled laser or blade then cuts the material into the desired pattern.

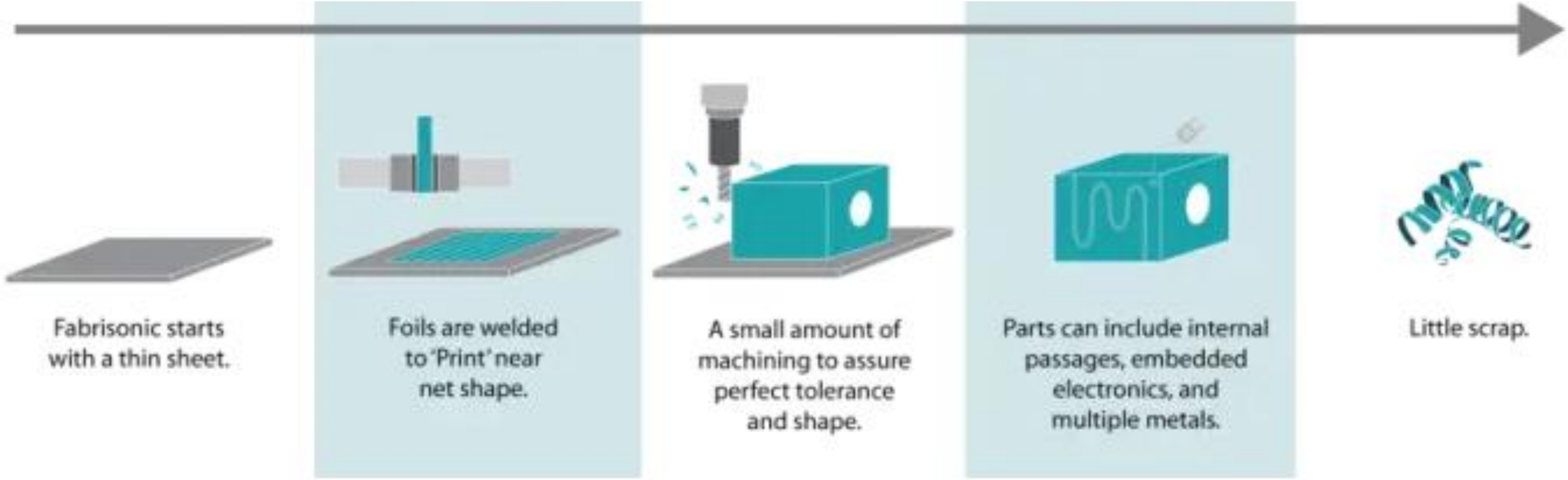
After one layer of the object is formed, the build platform is lowered. New material is then pulled across the platform and the heated roller again passes over the material, binding the new layer to the one beneath it. This process is repeated until the entire object has been formed.

Objects printed in paper take on wood-like properties, and can be sanded or finished accordingly. Paper objects are usually sealed with a paint or lacquer to keep out moisture.

In addition, Laminated Object Manufacturing does not allow for the creation of parts with the same level of detail as technologies such as Selective Laser Sintering (SLS) or Stereolithography (SLA)

Processes

Ultrasonic additive manufacturing (UAM) combines a unique room-temperature metal deposition process with the ease of traditional CNC milling. The patented ultrasonic 'print head' is integrated into 3-axis mills to create a hybrid additive-subtractive process. Swapping from additive to subtractive is as easy as doing a tool change. UAM is ultrasonic welding on a semi-continuous basis where solid metal objects are built up to a net three-dimensional shape through a succession of welded metal tapes. Through periodic machining operations, detailed features are milled into the object until a final geometry is created by removing excess material. Since UAM operates at relatively low processing temperatures, many types of optical fibers can be deposited without damage.



Sheet Lamination

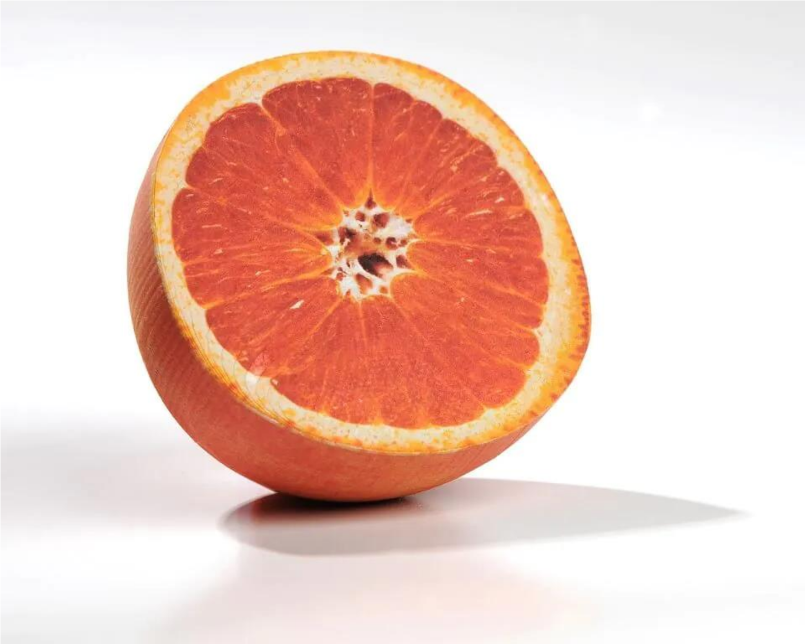
Materials

Materials	Recommended Process
Stainless steel	UAM
Aluminum	UAM
Titanium	UAM
Copper	UAM
Plastic sheets	LOM
A4 size papers	LOM

Applications of Sheet Lamination

The main field of LOM-printers is prototyping techniques and creating of architectural models. Technology is also used in education and design, as it allows you to create products with a minimum cost.

Yet it is more popular in the production of customized objects than for personal or industrial use. The reason is the fact that at low cost of raw materials LOM-devices are much more expensive than FDM-printers, for example. In addition, Laminated Object Manufacturing does not allow for the creation of parts with the same level of detail as technologies such as Selective Laser Sintering (SLS) or Stereolithography (SLA)



PRODUCE

Pros and Cons of Sheet Lamination

Pros	Cons
Fast print time	Post-processing will be required
Relatively low cost as it uses standard material	The strength and integrity of models is reliant on the adhesive used
Multi-material layers possible (UAM)	Hollow parts (internal voids and cavities) are difficult to produce (LOM)
Cut material can be easily recycled	Finishes can vary depending on paper or plastic material
No support structures necessary	
Larger working area than most of the current AM technology equipment	

Summary

Preferential sectors: Prototyping

Price: Between 10 000 € and 50 000€

Environmental impact: Cut material can be easily recycled

Main Pros: Pretty fast print time

Main Cons: The strength and integrity of models is reliant on the adhesive used

To go further

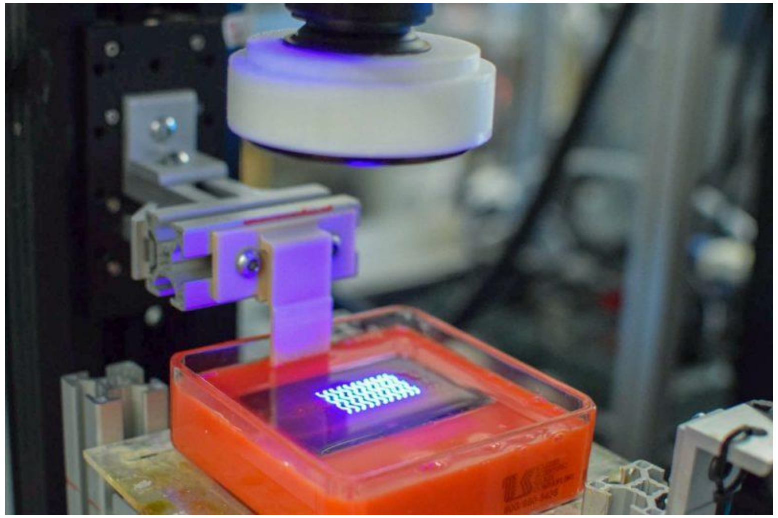
Sheet Lamination video : https://www.youtube.com/watch?v=XTmL_2BA4dc&ab_channel=MaterialCharact

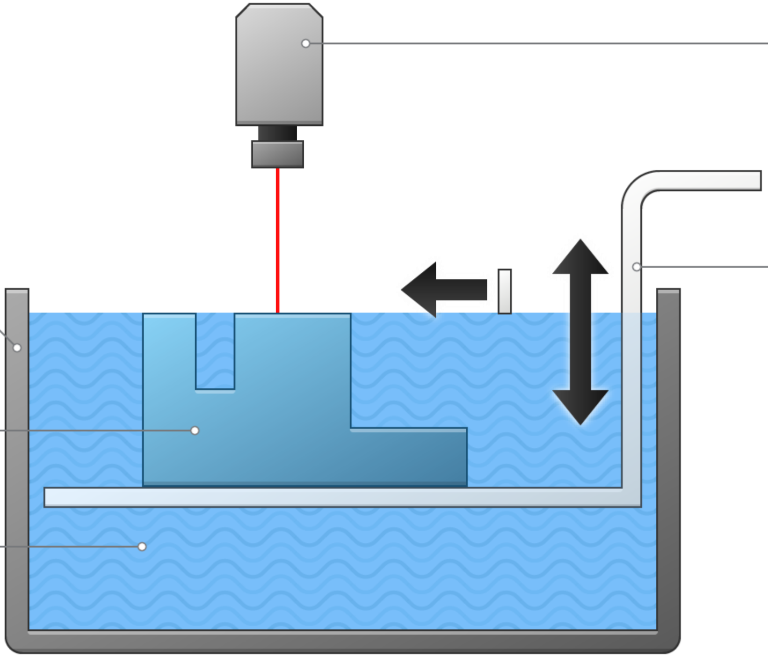
Complete Guide to Sheet Lamination in 3D Printing:

https://engineeringproductdesign.com/knowledge-base/sheet-lamination/
https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/sheetlamination/
https://www.sciencedirect.com/topics/engineering/sheet-lamination

Definition

Vat Photopolymerization 3D printing technology encompasses several different process that rely on the same basic strategy: a liquid photopolymer contained in a vat (or tank) is selectively cured by a heat source. Layer by layer, a 3D physical object is built until completion.





Processes

StereoLithogrAphy (SLA) also known as SL, optical fabrication, photo-solidification, or resin printing. During the SL manufacturing process, a concentrated beam of ultraviolet light or a laser is focused onto the surface of a vat filled with a liquid photopolymer. The beam or laser is focused, creating each layer of the desired 3D object by means of cross-linking or degrading a polymer.

Digital Light Processing (DLP), a digital projector screen is used to flash a single image of each layer across the entire platform at once. Because the projector is a digital screen, the image of each layer is composed of square pixels, resulting in a layer formed from small rectangular bricks called voxels. DLP can achieve faster print times for some parts, as each entire layer is exposed all at once, rather than drawn out with a laser.

Vat Photopolymerization

Materials

Materials	Recommended Processes
UV-curable Photopolymer resin	SLA, DLP

The materials used for Vat Photopolymerization are commonly called "resins" and are thermosetting polymers. A wide variety of resins are commercially available and it is also possible to use "homemade" resins to test different compositions for example.

Applications of Vat Photopolymerization

Photopolymerization is successfully applied to medical modeling, which enables the creation of accurate 3D models of various anatomical regions of a patient, based on data from computer scans. The high resolution of this technique also makes it ideal for all types of prototyping, as well as mass production. Vat polymerization processes are excellent at producing parts with fine details and a smooth surface finish. This makes them ideal for jewelry, investment casting and many dental and medical applications. Material developments have also allowed the printing of low-run injection molds.

Photopolymerization in jewelry

Dental prosthesis with Photopolymerization

Pros and Cons of Vat Photopolymerization

Pros	Cons
High level of accuracy and good finish	Relatively expensive
Relatively quick process	Limited material use of photo-resins
Less waste (reusable resin)	Very long post-processing time and resin approval.
Smooth surface finish	Large volume productions are inadvisable (costly and time-consuming)
	Needs additional curing in post-processing for increased stiffness

Vat Photopolymerization

Summary

Preferential sectors: Medical (especially dental)

Price: from 3 000€ to 500 000€

Environmental impact: Less waste because of reusable resin

Main Pros: High level of accuracy and good finish

Main Cons: Relatively Expensive

To go further

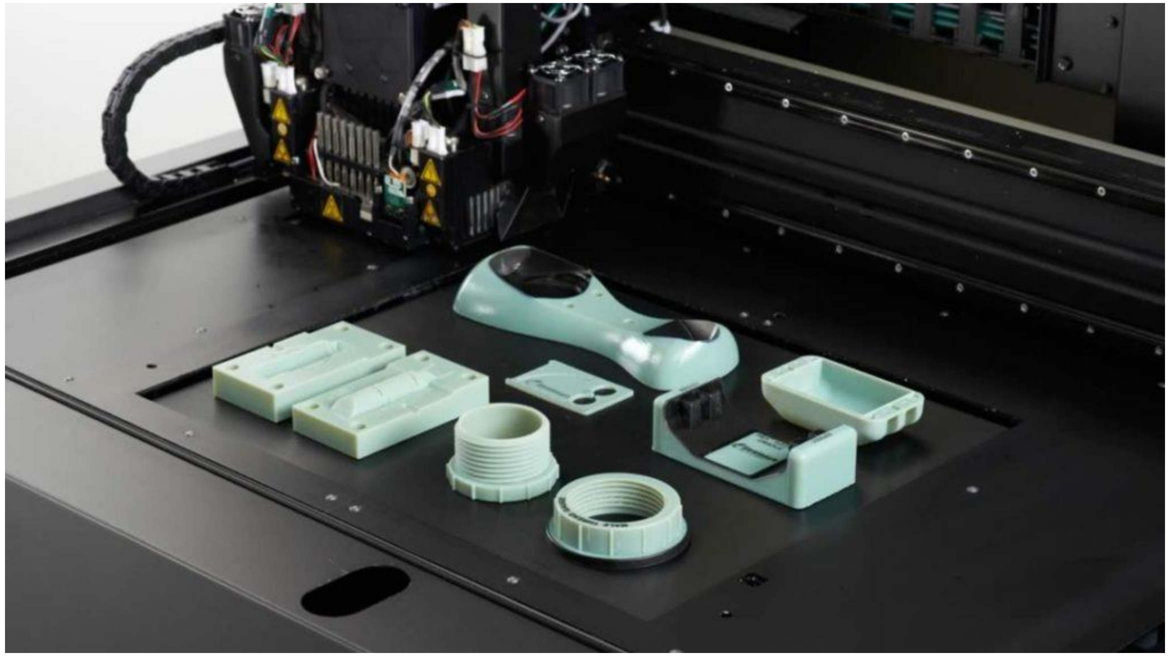
SLA Video : https://www.youtube.com/watch?v=oNpAnBhgIIs&ab_channel=AMVideos

Complete Guide to Vat Photopolymerization in 3D Printing:

https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/vatphotopolymerisation/

Definition

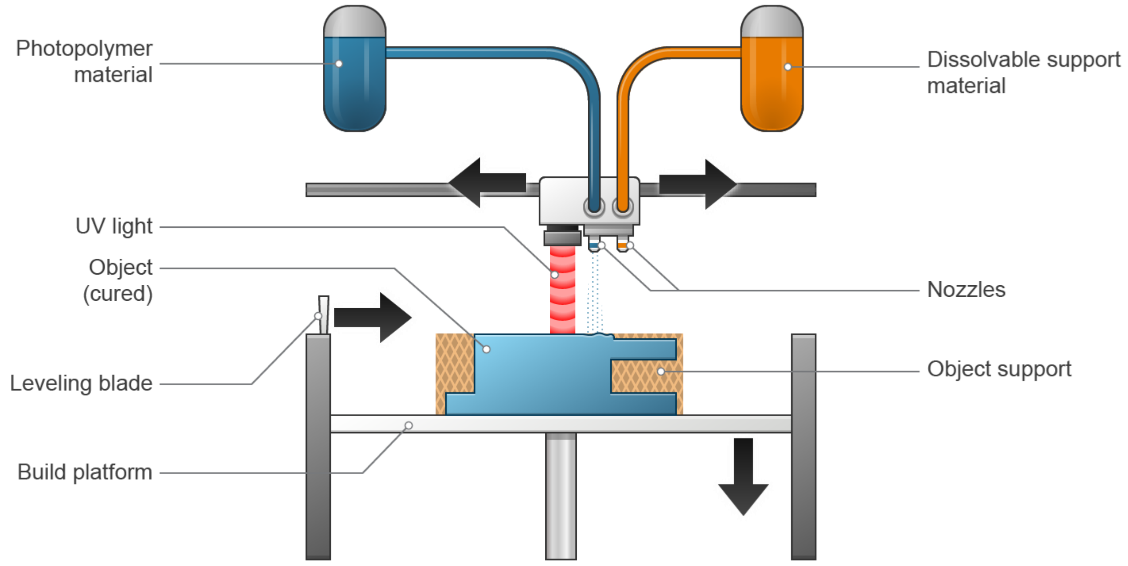
The Material Jetting 3D printing manufacturing technique is often compared to the standard 2D ink jetting process. Utilizing photopolymers, metals, or wax that solidify when exposed to light or heat (in a similar fashion to stereolithography) ensures that physical objects are built up one layer at a time. The material jetting manufacturing process allows for different materials to be 3D printed within the same part. Droplets which are not used are recycled back into the printing system.



Materia Jetting 3D Printer

Processes

Drop On Demand (DOD) material jetting printers have two print jets: one to deposit the build material and another for dissolvable support material. Like all additive manufacturing machines, DOD 3D printers follow a pre-determined path and deposit material in a point-wise fashion to build the cross sectional area of a component. These machines also employ a fly-cutter that skims the build area after each layer to ensure a perfectly flat surface before printing the next layer. DOD technology is typically used to produce wax-like patterns for lost-wax casting/investment casting and mold making applications, making it an indirect 3D printing technique.



Materials

Materials	Recommended Process
Polypropylene	DOD
HDPE	
PMMA	
PC	
ABS	
ED	

Applications of Material Jetting

Material jetting 3D printing technology is a great choice for realistic prototypes, providing an excellent level of details, high accuracy and smooth surface finish. Material jetting allows a designer to print a design in multiple colors and with a number of materials in a single print. This method is of particular interest to the medical sector because it allows the creation of anatomical models to scale, in different colors, faithful to the human body. In this way, the doctor can explain a disease to a patient in a concrete way and surgeons can train for surgery in advance. This 3D printing technology is also used in artistic or jewelry fields.

Heart in colors realized with Material Jetting

Human Reproduction realized with Material Jetting

Pros and Cons of Material Jetting

Pros	Cons
High accuracy of deposition of droplets and therefore low waste	Material jetted parts are mainly suitable for non-functional prototypes, as they have poor mechanical properties
Multiple material parts and colors under one process	Compared to some other AM technologies, MJ machines are still expensive making it not feasible for some applications (like production)
Low wastage due to accurate jetting and material on-demand dropping technology	Materials are limited and only polymers and waxes can be used

Material Jetting

Summary

Preferential sectors: Prototyping

Price: From 10 000€ to 250 000€

Environmental impact: Low wastage due to accurate jetting and material on-demand dropping technology

Main Pros: High accuracy

Main Cons: Materials are limited and only polymers and waxes can be used

Material Jetting

To go further

Complete Guide to MJ in 3D Printing:

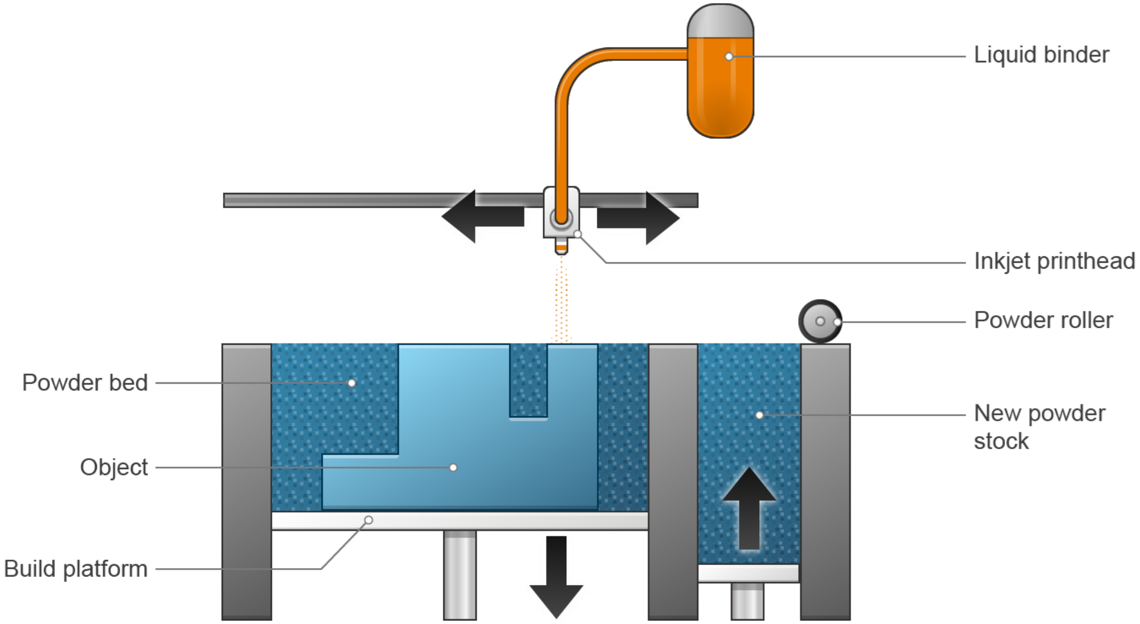
https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/materialjetting/

https://all3dp.com/2/what-is-material-jetting-3d-printing-simply-explained/

MJ video : https://www.youtube.com/watch?v=uhAigUKJ0ok&ab_channel=MaterialCharactMaterialCharact

Definition

The **Binder Jetting** process uses two materials; a powder based material and a binder. The binder acts as an adhesive between powder layers. The binder is usually in liquid form and the build material in powder form. A print head moves horizontally along the x and y axes of the machine and deposits alternating layers of the build material and the binding material. After each layer, the object being printed is lowered on its build platform. The powdered materials are either ceramic-based (for example glass or gypsum) or metal (for example stainless steel).



Processes

There is one **Binder Jetting** process and it will be explain step by step :

First, a coating blade spreads a thin layer of powder over the build platform.

Next, a carriage equipped with inkjet nozzles (similar to those used in desktop 2D printers) passes over the bed, selectively depositing droplets of a binder (adhesive) that binds the powder particles together. For color binder jetting technology, colored ink is also deposited during this step. The size of each droplet is about 80 μm in diameter, which allows for good resolution.

When the layer is complete, the build platform moves down and the slide covers the surface again. The process then repeats until the entire part is finished.

After printing, the part is encapsulated in powder and allowed to cure and gain strength. Then the part is removed and the excess unbound powder is cleaned off with compressed air.

Binder Jetting

Materials

Materials	Recommended Process
Ceramics	DOD
Sands	
Stainless Steel	
PC	
ABS	
PA	
Glass	

Applications of Binder Jetting

Binder jetting is great for applications that require good aesthetics and form, such as architectural models, packaging, toys and figurines. It is generally not suited for functional applications due to the brittle nature of the parts.

Architectural model by Binder Jetting

Figurine realized with Binder Jetting

Binder Jetting

Pros and Cons of Binder Jetting

Pros	Cons
Parts can be made with a range of different colours	Additional post processing can add significant time to the overall process
The process is generally fast	High cost of systems
Ability to process a wide range of materials	Low part strength
100% of unused powder can be reused in future prints	Less accurate than Material Jetting
Doesn’t require supports	
Not limited by any thermal effects	

Binder Jetting

Summary

Preferential sectors: Packaging and Model

Price: From 25 000 € to 250 000 € and more

Environmental impact: 100% of unused powder can be reused in future prints

Main Pros: High accuracy

Main Cons: Low part strength

To go further

BJ Video https://www.youtube.com/watch?v=ONMYx1yhJuo&ab_channel=AMVideos

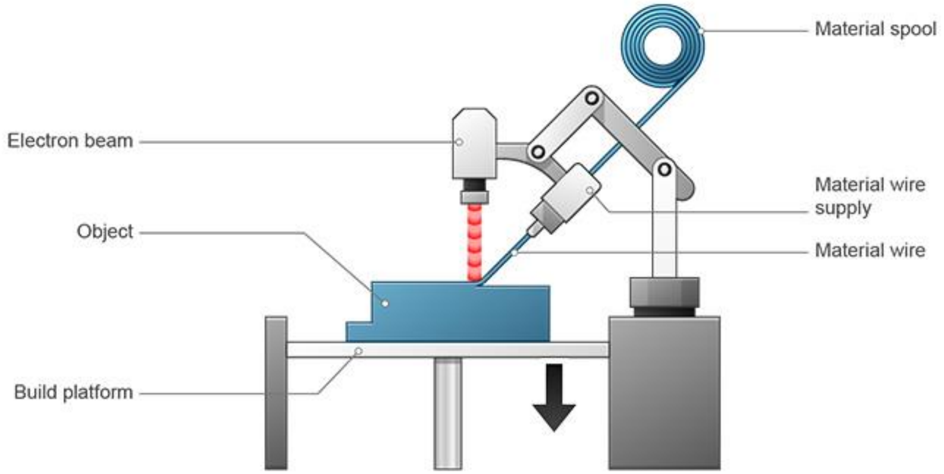
Complete Guide to Binder Jetting in 3D Printing:

https://www.3dnatives.com/en/powder-binding100420174/
https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/binderjetting/

Definition

The Directed Energy Deposition (DED) 3D printing technology, creates parts by directly melting materials and deposing them on the workpiece, layer by layer. This additive manufacturing technique is mostly used with metal powders or wire source materials. Other popular terms for DED include laser engineered net shaping, directed light fabrication, direct metal deposition, Laser Deposition Welding (LDW) and 3D laser cladding. In addition to the capability to build parts from scratch (often with the hybridation of a mill/turn CNC tool), DED is also capable of fixing complex damaged parts, such as turbine blades or propellers.

Most DED 3D printers are industrial machines with very large footprints that require a closed and controlled environment to operate. Therefore, typical Directed Energy Deposition consists of a nozzle mounted on a multi-axis arm inside a closed frame, which deposits melted material onto the workpiece surface, where it solidifies. The process is similar in principle to the material extrusion 3D printing technique, but with DED, a nozzle can move in multiple directions, with up to five different axes compared to only three for most FFF machines.



Directed Energy Deposition

Processes

Laser Engineered Lens Shaping (LENS) use lasers to build objects layer by layer directly from powdered metals, alloys, ceramics or composites. The LENS process must take place in a hermetically-sealed chamber which is filled with argon so that the oxygen and moisture levels stay very low. This keeps the part clean and prevents oxidation. The metal powder material is directly delivered to the material deposition head. Once a single layer has been deposited, the material deposition head moves on to the next layer. By building up successive layers, the whole part is constructed. When complete, the component is removed and can be heat-treated, hot isostatic pressed, machined, or finished in any required fashion.

Electron Beam Additive Manufacturing (EBAM) is an additive manufacturing technology that produces large scale metal structures. The Electron Beam (EB) gun deposits metal via a wire feedstock, layer by layer, until the part reaches near-net shape and is ready for finish machining. Material deposition rates range from 3 to 9 kg of metal per hour. Compatible metals include titanium, tantalum, and nickel. This DED technique can also be used to repair damaged parts

Directed Energy Deposition

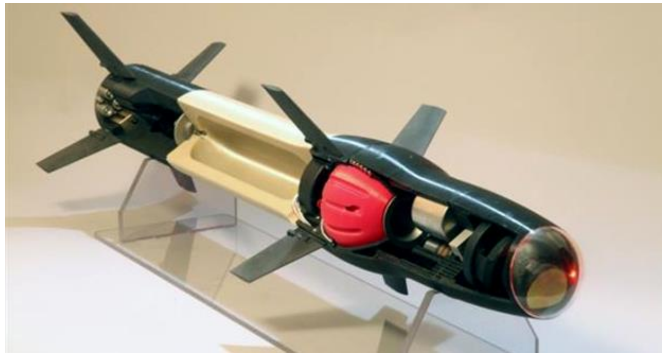
Materials

Materials	Recommended Process
Ceramics	LENS
Composites	LENS
Cobalt	LENS
Copper	LENS
Chrome	LENS
Titanium	EBAM
Tantalum	EBAM
Nickel	EBAM

Applications of Directed Energy Deposition

The aviation industry is one of the biggest industries researching new additive manufacturing methods, and Directed Energy Deposition specifically. Aircraft companies recognize the benefit of reduced waste material and reducing weight of plane parts, potentially saving millions of dollars in fuel costs per year.
DED can be used to manufacture everything from small brackets and fixtures, to the skeleton and exterior panels of the aircraft. DED's versatility allows it to print a range of different materials used in aircraft production.

Additive manufacturing is being explored in the production of firearms, body armor, armored vehicles, missiles and helmets. DED is able to produce large components for these items in one piece, making them less likely to break and less susceptible to wear and tear. Additionally, DED is useful for metal repairs, meaning any damaged items could be fixed in the field.
While we are yet to reach mass production capacity, the US military has already begun dabbling in investment into additive manufacturing, with DED being among the most useful technologies available in this field.



American Missile created by BED

Pros and Cons of Directed Energy Deposition

Pros	Cons
High build rates	Comparably very expensive to the other types of metal additive manufacturing systems
Dense and strong parts	Low build resolution with a poor surface finish
Ability to control the grain structure to a high degree, which lends the process to repair work of high quality, functional parts	
Reduced material waste – DED only deposits the material it needs during the process meaning less wastage	

Summary

Preferential sectors: Aviation and Army

Price: From 85 000€ to 2 000 000 € and more

Environmental impact: Reduced material waste – DED only deposits the material it needs during the process meaning less wastage

Main Pros: Can be used for repairing

Main Cons: Very dependent on the material used

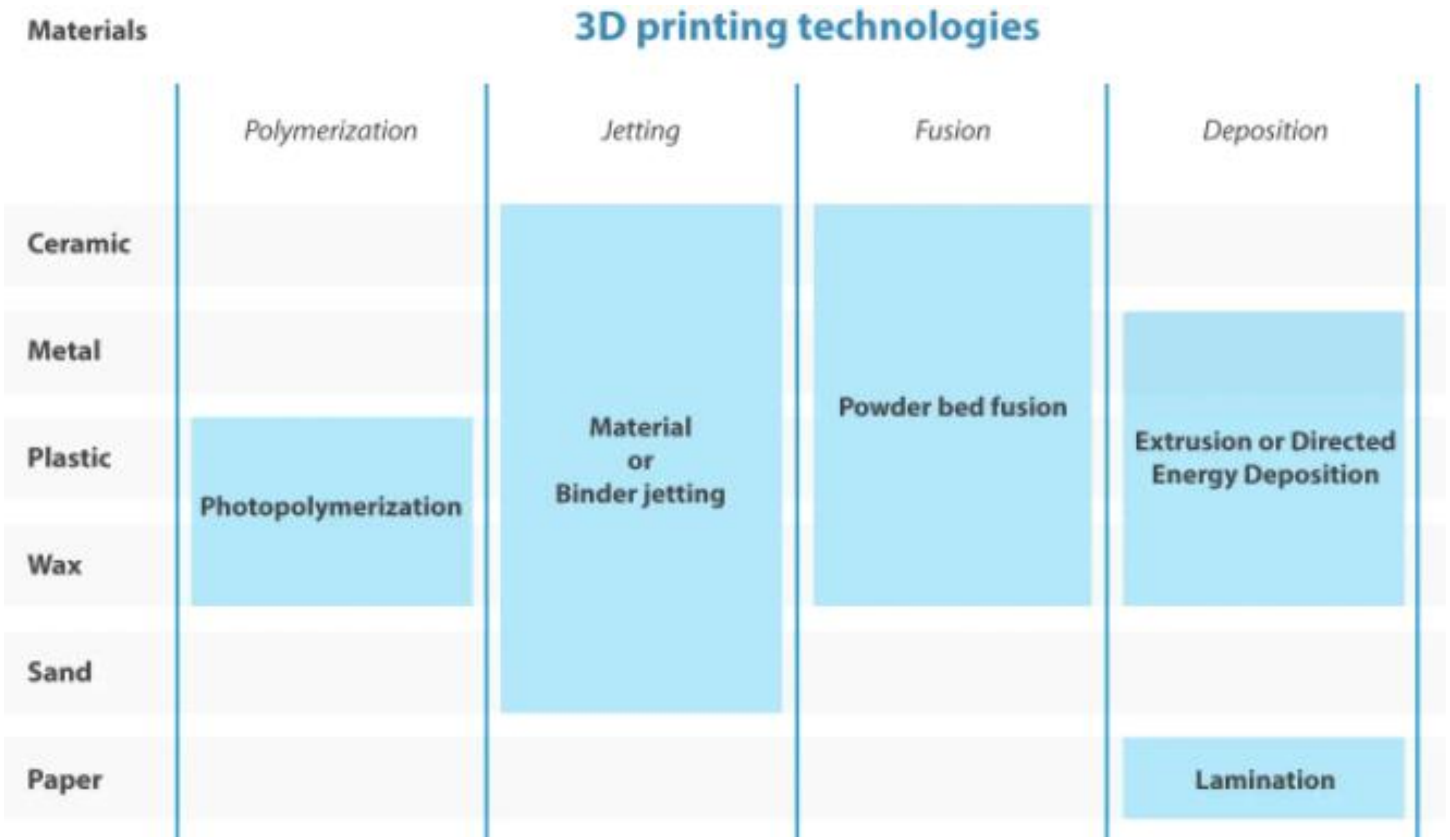
To go further

Complete Guide to DED in 3D Printing:

https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/directedenergydeposition/
https://www.sciencedirect.com/topics/materials-science/directed-energy-deposition

DED Video : https://www.youtube.com/watch?v=oL7bMhPTtDI&ab_channel=BeAMMachines

Global Overview



Infographic of materials for 3D printing and different technologies

Global Overview

Methods	Caracteristics			
Powder Bed Fusion	Spare part creation	Light and strong prototype	Post process required	Slow Speed
Material Extrusion	Good for small and medium series	Very good for beginner		
Sheet Lamination	Creation of lightweight functional technical components	Fast print time		
Vat Photopolymerization	High print resolution	Good for small and medium series	Quick process	
Material Jetting	High accuracy better than Binder Jetting	Not suited for functional applications	Low parts strength	
Binder Jetting	High level of detail	Use of colors	Low parts strength	Not suited for functional applications
Direct Energy Deposition	Spare part creation	Addition of material on existing components	Able to produce large components	

3D printers comparison

This web site is good if you want to buy a 3D printer, thanks to filters it is easy to find what is good for you;

https://www.aniwaa.fr/comparatif/imprimantes-3d/

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