Additive Manufacturing (10 h)

UPenAUTO : 2017-1-ES01-KA203-03858

Erasmus+

UPenAUTO: UPSKILLED ENGINEERING PROFILES FOR THE AUTOMOTIVE SECTOR AND UPTAKE OF ALTERNATE SCHEME IN EUROPE´S HIGHER EDUCATION.

Gestamp

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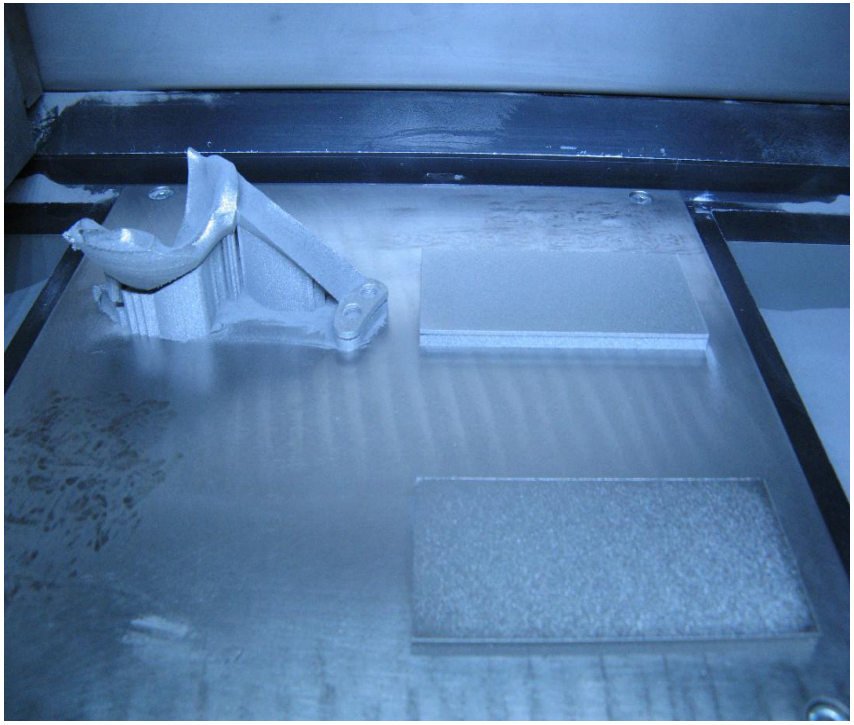
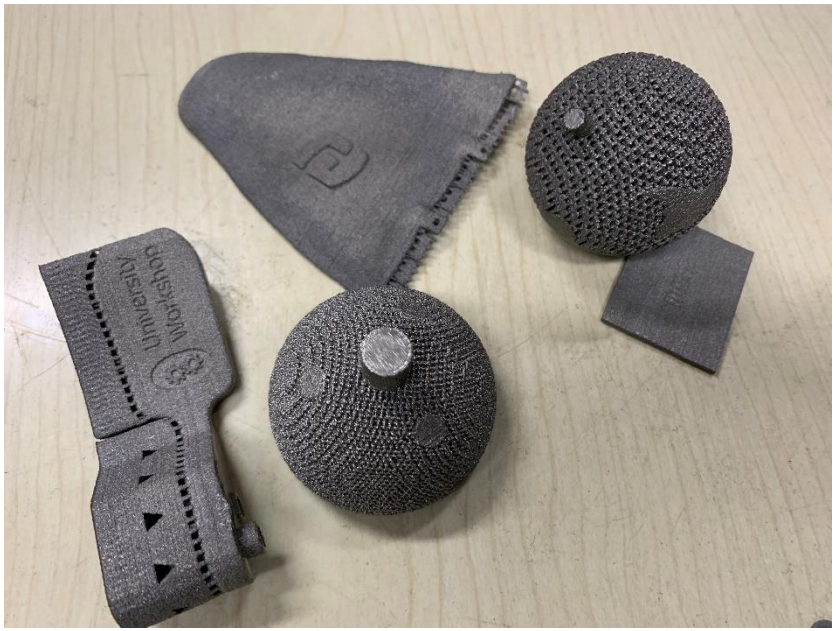


1. Introduction to additive manufacturing

- History of additive manufacturing
- Additive manufacturing workflow
- Introduction to AM technologies



Introduction to AM technologies

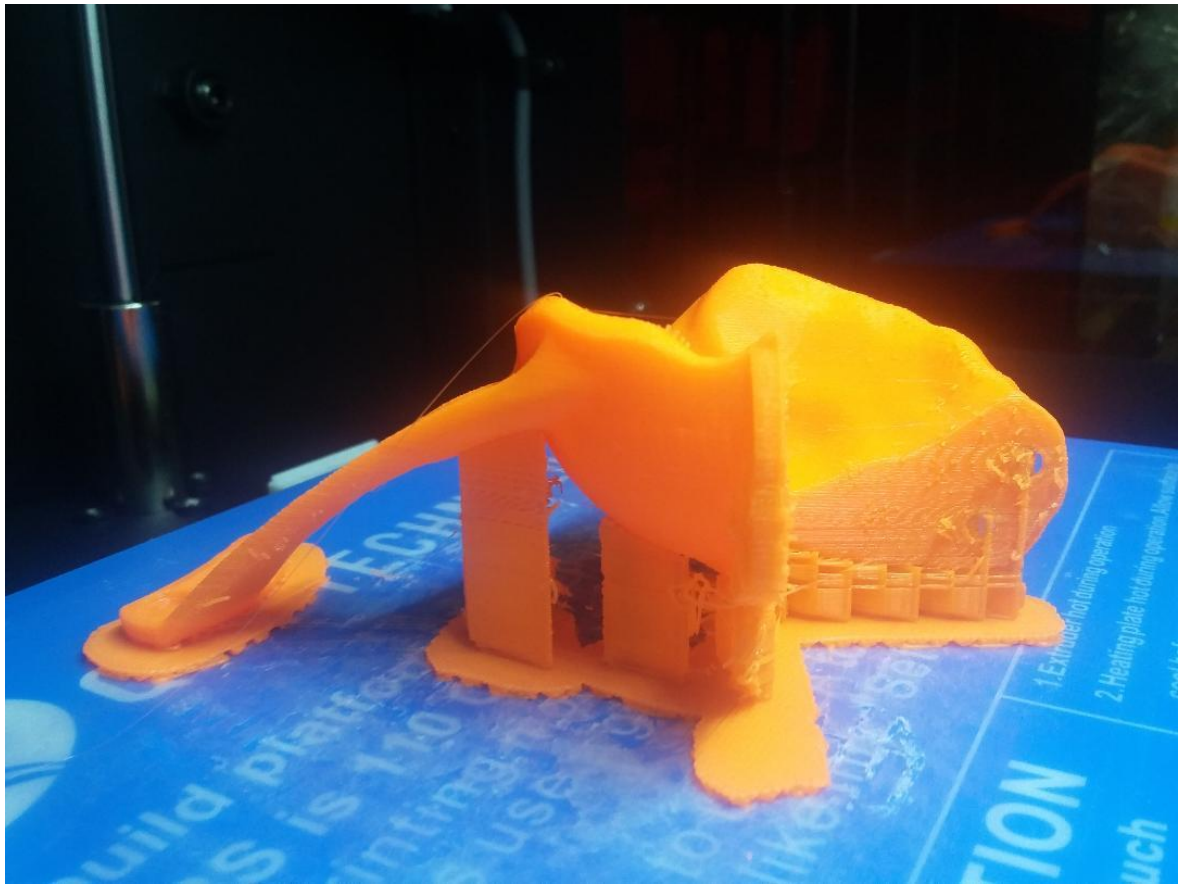
The term Additive Manufacturing is also called 3D printing.

These technologies can be used with a wide range of different materials, such as metal, plastic, ceramic and wax to produce ready made products based on a CAD file.

The products are built up layer by layer in the AM machine by melting, welding or gluing thin layers of powder together, hardening liquid using UV light, or melting thin plastic wires together [1].

Additive manufacturing technologies

Additive manufacturing technologies are used to build parts by depositing the material in successive layers based on the 3D drawing of the parts.



History of additive manufacturing

1980: Selective laser sintering
by Carl Deckard

1984: Stereolithography
by Chuck Hull

1987: Digital Light Processing
by Larry Hornbeck

1988: Fused Deposition Modeling
by S. Scott Crump

1989: Fused Deposition Modeling
By Scott Crump

Additive manufacturing workflow

Create the model

- method for producing a digital model: computer-aided design (CAD) or reverse engineering via 3D scanning

Identification and select AM technology

- depending on the characteristics of the part, quality and delivery time

Pre Processing

- convert a 3D CAD file into instructions, AM guidelines, process limitations

Sample Parts

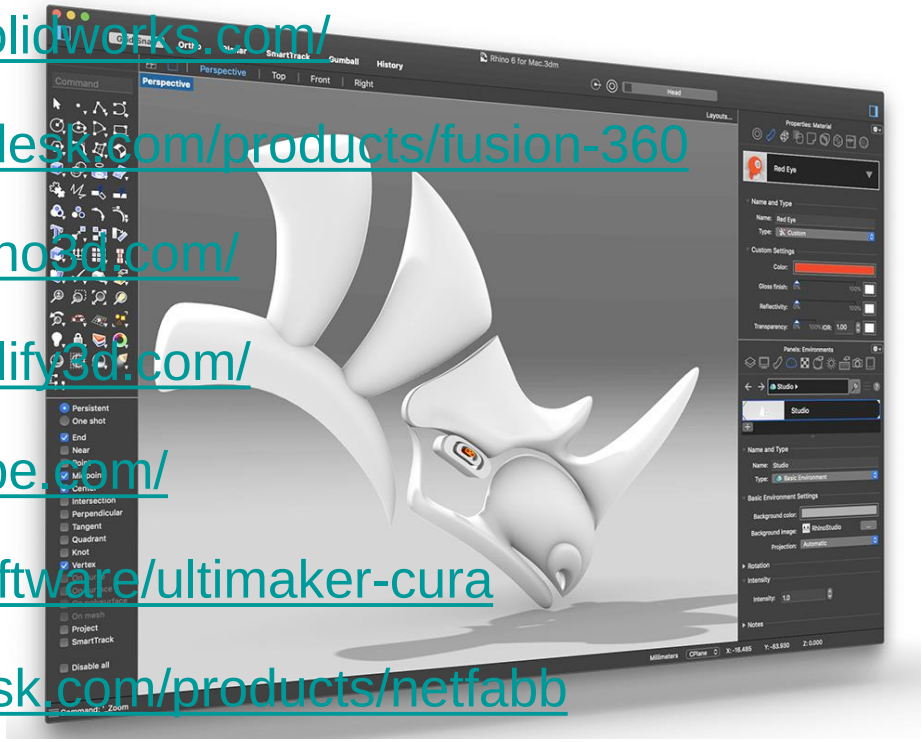
- characteristics part can be checked , the design or the manufacturing settings can change according to desired properties, optimization of the design feature

Manufacturing process

Producing a digital model

CAD design software for designing parts:

- **SOLIDWORKS** https://www.solidworks.com/
- **FUSION 360** https://www.autodesk.com/products/fusion-360
- **RHINOCEROS** https://www.rhino3d.com/
- **SIMPLIFY3D** https://www.simplify3d.com/
- **ONSHAPE** https://www.onshape.com/
- **CURA** https://ultimaker.com/software/ultimaker-cura
- **NETFABB** https://www.autodesk.com/products/netfabb



Additive Manufacturing

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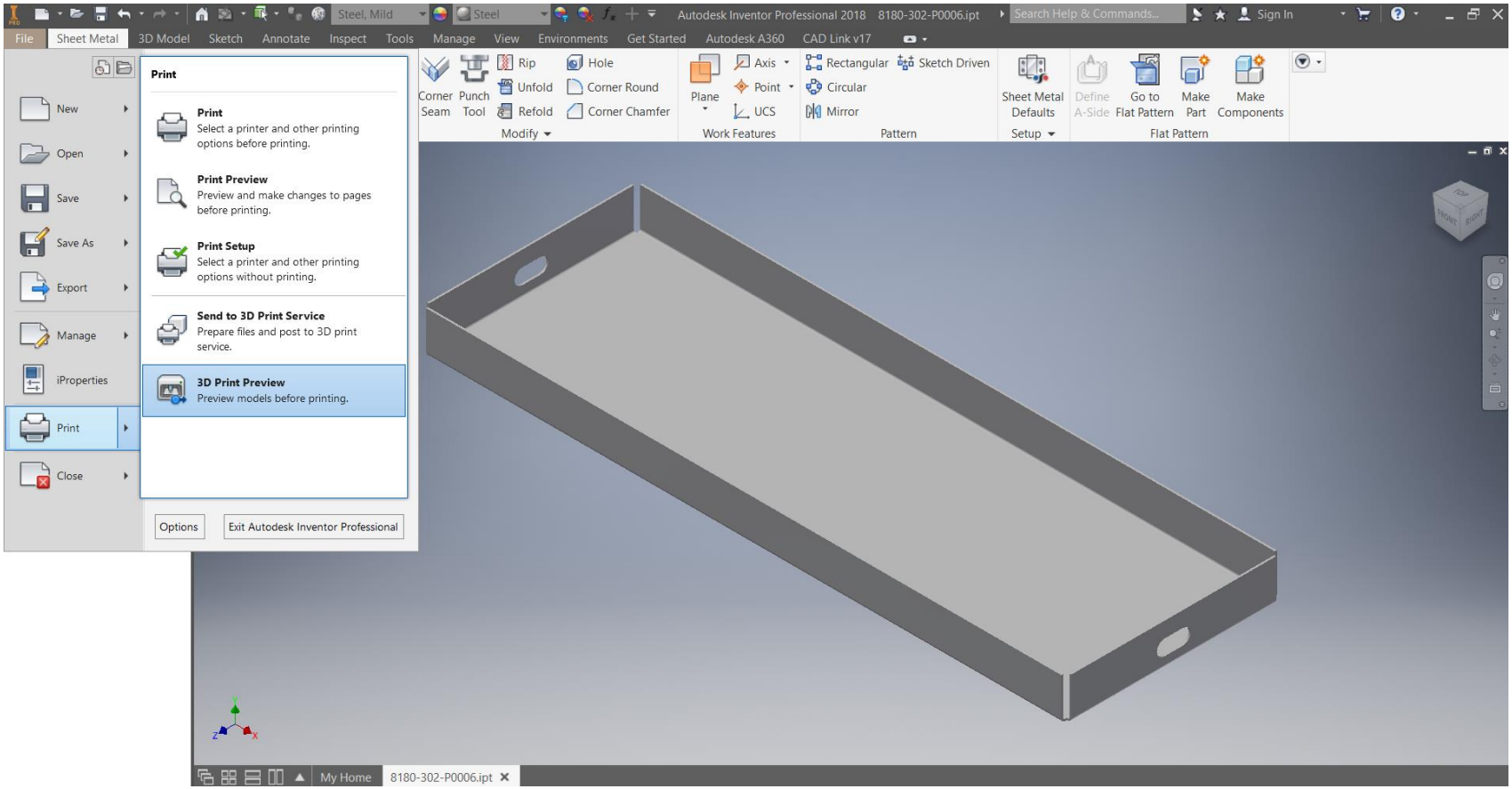
PTC Cre[illegible]	File > Save As... > Save a Copy Change Type to Stereolithography (*.stl). Click OK > a new Export STL dialog will open. Under Deviation Control, change export settings.
Rhino	File > Save As… In the Save As... box, select Stereolithography [*.stl].
Sketchup	Download Sketchup to DXF or STL plugin. Start Sketchup. Tools > Export to DXF or STL
Solid Edge	File > Save As... Set Save As... file type to STL. Options > Select export options
ZBrush	Use Decimation Master to appropriately reduce the polygon count. Zplugin > 3D Print Hub > Export as STL.

Convert a CAD model to an STL file in Inventor



Printing

The machine will follow an automatic process and generally problems will occur only when the machine runs out of material or there is a software error.

Post processing

SLA requires a component to cure under UV before handling.

Metal parts often need to be stress relieved in an oven .

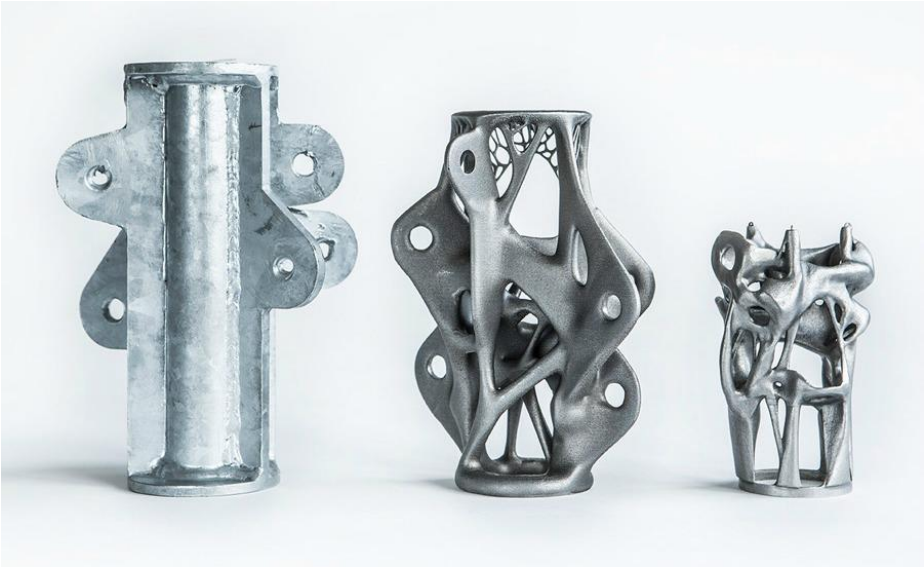
FDM parts can be handled right away.

For technologies that utilize support, this is also removed at the post-processing stage.

Most 3D printing materials are able to be sanded and other post-processing techniques including tumbling, high-pressure air cleaning, polishing, and coloring are implemented to prepare a print for end use [2].

Additive Manufacturing benefits

- ✓ AM technologies are fast, precise and flexible form of production.
- ✓ There are not geometric limitations.
- ✓ Single step manufacture
- ✓ Complexity and design freedom
- ✓ Reduce waste production
- ✓ Save on energy costs
- ✓ Reduce the time-to-market

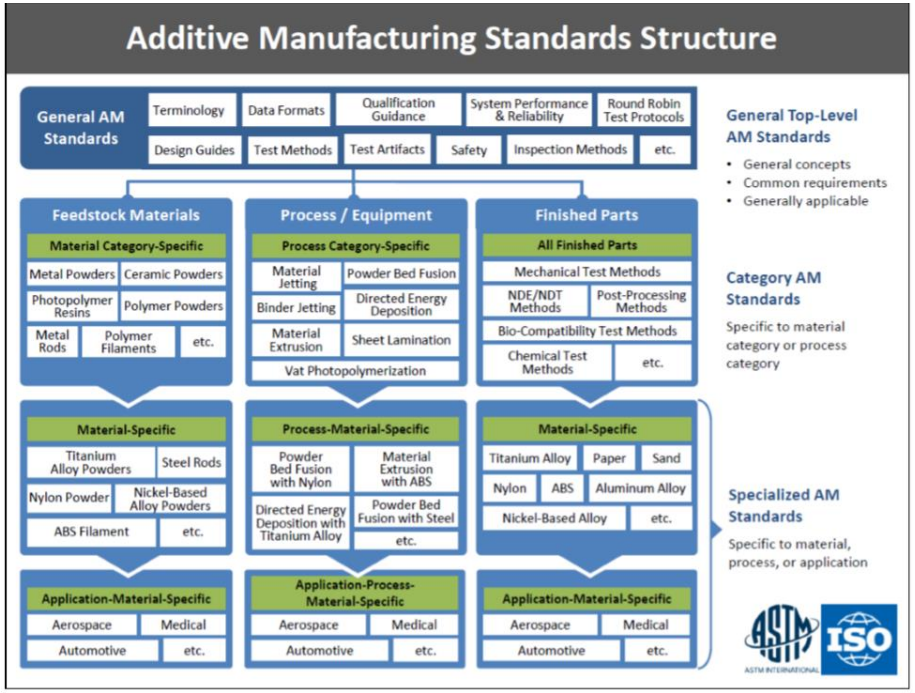


Posted on 13 May 2015 by Jonny Williamson

2. Additive Manufacturing (AM) processes

Type of Additive Manufacturing (AM) processes according to ISO/ASTM52900-15 :

- vat photopolymerization
- material extrusion
- powder bed fusion
- material jetting
- binder jetting
- sheet lamination
- directed energy deposition.



Additive manufacturing technologies

Photopolymerization

Additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light activated polymerization

- **Stereolithography (SLA)**
- **Direct Light Processing (DLP)**
- **Continuous DLP (CDLP)**

Powder Bed Fusion

Process in which thermal energy selectively fuses regions of a powder bed

- **Selective Laser Sintering (SLS)**
- **Selective Laser Melting (SLM)**
- **Direct Metal Laser Sintering (DMLS)**
- **Electron Beam Melting (EBM)**
- **Multi Jet Fusion (MJF)**

Material Extrusion

Process in which material is selectively dispensed through a nozzle.

- **Fused Deposition Modeling (FDM)**

Material Jetting

Process in which material droplets o build material are selectively deposited.

- **Material Jetting**
- **Nano particle jetting**
- **Drop-On-Demand**

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• Additive manufacturing technologies

Binder Jetting

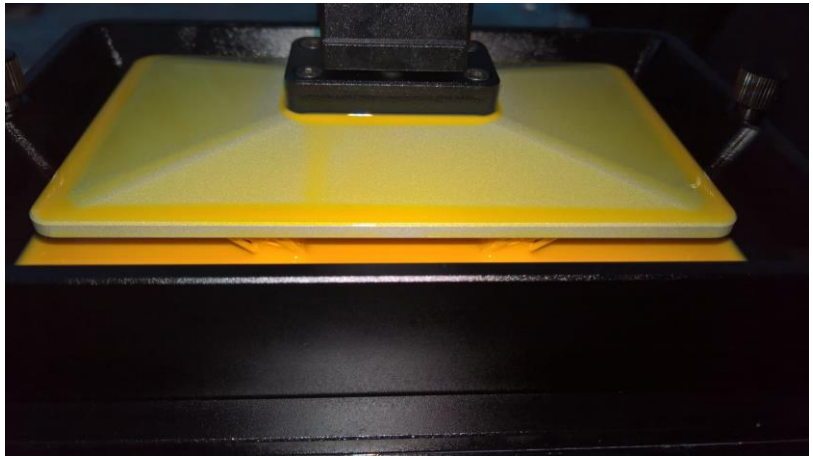
Process in which a liquid bonding agent is selectively deposited to join powder materials.

- **Binder Jetting**

Direct Energy Deposition

Process in which focused thermal energy is used to fuser material by melting as they are being deposited.

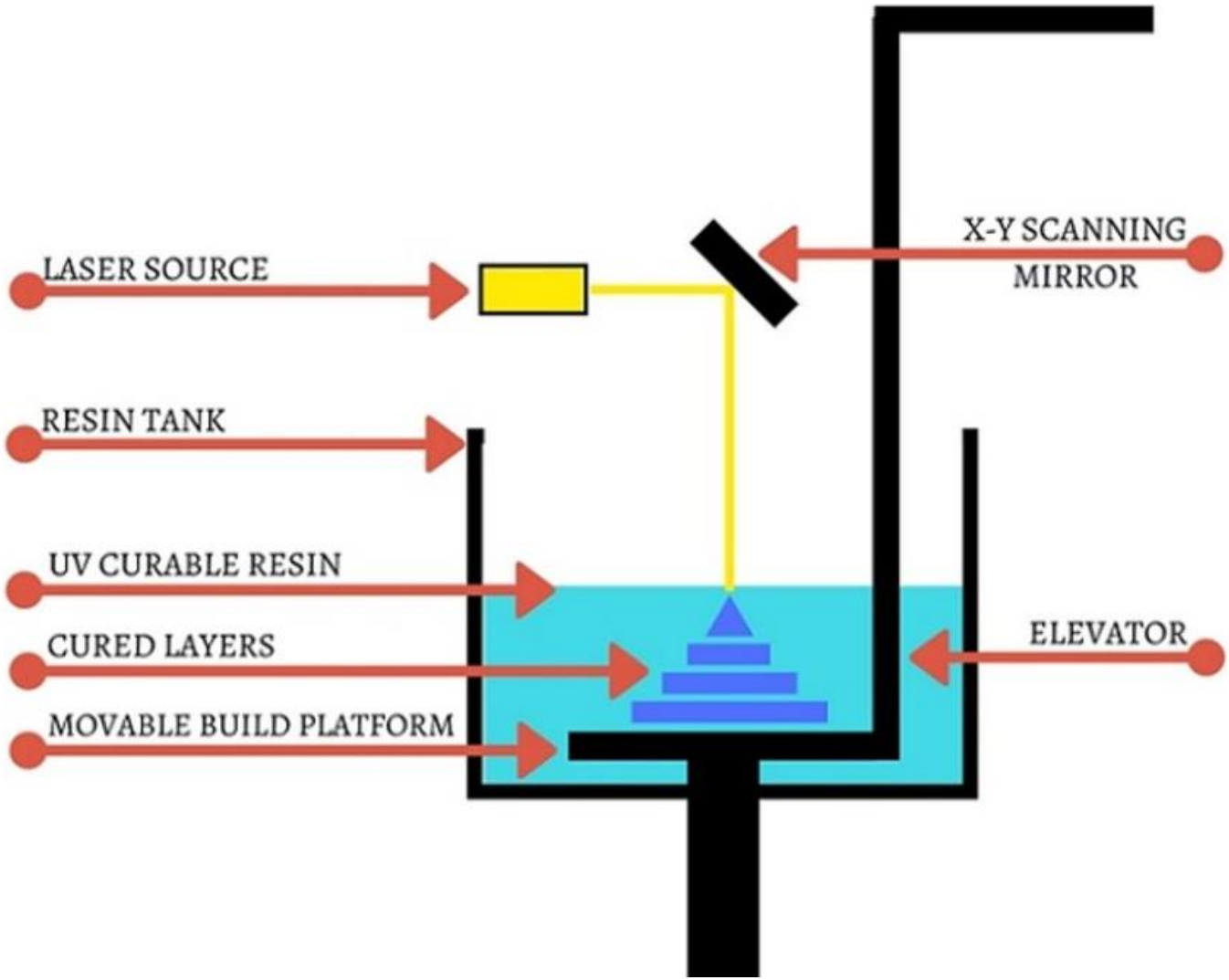
- **Laser Engineered Net Shape**
- **Electron Beam Additive Manufacture**



Stereolithography (SLA)

The part is created by selectively curing a polymer resin layer-by-layer using an ultraviolet (UV) laser beam.

Components of the stereolithography

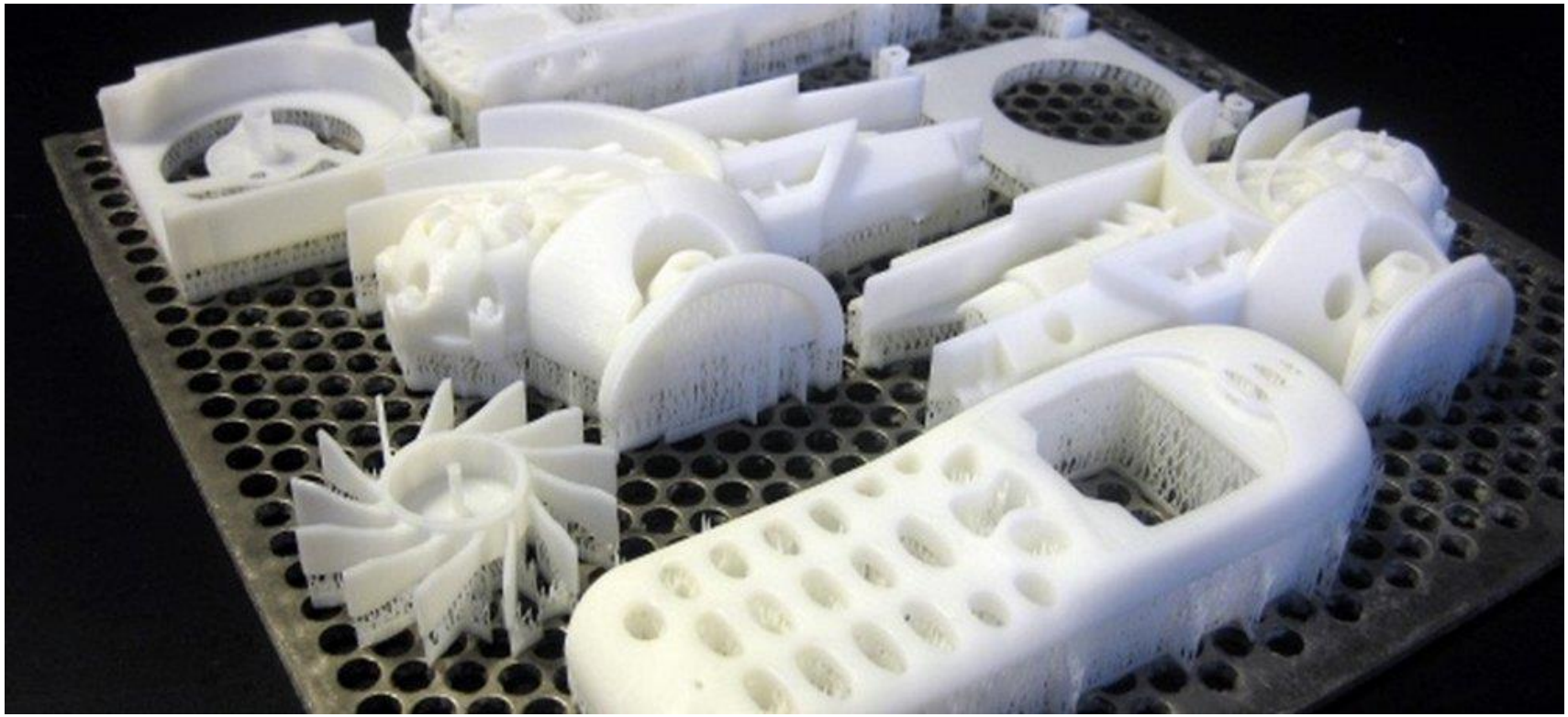


Source: Manufactur3DMag.com

SLA fabrication process steps [2]

- The build platform is first positioned in the tank of liquid photopolymer, at a distance of one-layer height for the surface of the liquid.
- Then a UV laser creates the next layer by selectively curing and solidifying the photopolymer resin. The laser beam is focused in the predetermined path using a set of mirrors. The whole cross-sectional area of the model is scanned, so the produced part is fully solid.
- When a layer is finished, the platform moves at a safe distance and the sweeper blade re-coats the surface. The process then repeats until the part is complete.
- After printing, the part is in a green, no-fully-cured state and requires further post processing under UV light if very high mechanical and thermal properties are required.

Objects printed through stereolithography



Source: Engitype.com

Stereolithography: Pros and Cons [3]

Pros	Cons
• SLA is one of the most precise 3D printing techniques on the market.	• Printing tends to take a long time.
• Prototypes can be created with extremely high quality, with finely detailed features (thin walls, sharp corners, etc…) and complex geometrical shapes. Layer thicknesses can be made as low as 25 µm, with minimum feature sizes between 50 and 250 µm.	• Steep slopes and overhangs require support structures during the building process. Such parts may potentially collapse during printing or curing phases.
• SLA provides the tightest dimensional tolerances of any rapid prototyping or additive manufacturing technology: +/- 0.005″ (0.127 mm) for the first inch, and an additional 0.002″ for each additional inch.	• Resins are comparatively fragile and therefore not suitable for functional prototypes or mechanical testing.
• Print surfaces are smooth.	• SLA offers limited material and color choice, usually offering black, white, grey and clear material. Resins are oftentimes proprietary and therefore cannot be easily exchanged between printers from different brands.
• Build volumes can be as high as 50 x 50 x 60 cm^3 without sacrificing precision.	• SLA printing costs are comparatively high (e.g. machine, materials)

Direct Light Processing (DLP)

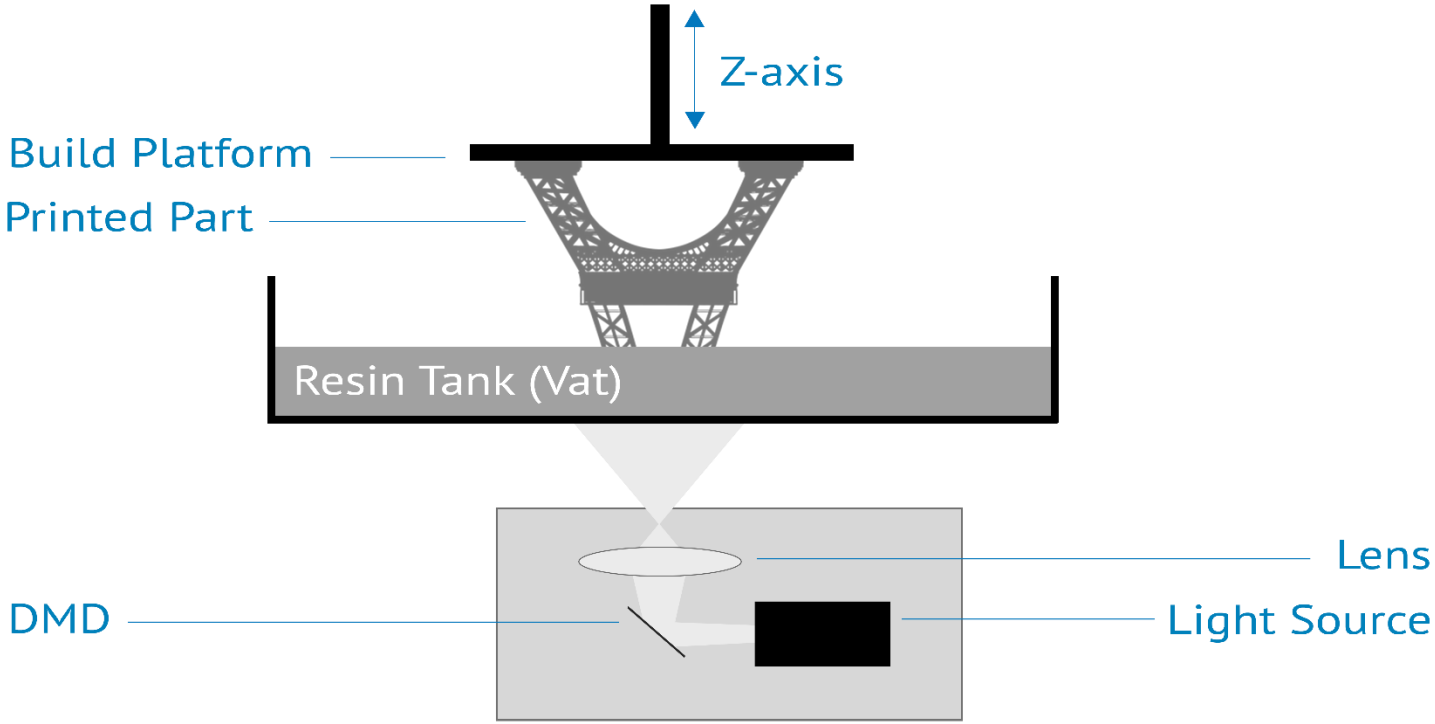
Direct Light Processing (DLP) uses a digital light projector screen to flash a single image of each layer all at once.

It was originally developed in 1987 by Larry Hornbeck of Texas Instruments

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.

Components of the Direct Light Processing

The main components of a DLP 3D printer are the following: digital light projector screen, DMD, vat (resin tank), the build plate and the elevator for the build plate



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Digital Light Processing process steps [4]

- Objects are built in a shallow container with a transparent bottom filled with liquid photopolymer, which is a plastic that responds to light. An adjustable building platform is initially placed in its lowest position closest to the bottom of the container. A projector projects the cross section of the detail through the transparent base of the container, which solidifies a single layer of the photopolymer.
- The platform with the solidified is then lifted so that a new thin layer of fhotopolymer is filled against the bottom of the vessel. The projection is repeated with a new cross section which builds on the previous cross section.
- Support structures can be created if the fluid can not support the weight of the component's overhanging parts.
- The cycle is repeated until the entire 3D object is created after which it is cleared of any support structures and cured in a UV oven.

Object printed through Direct Light Processing

source: 3D Hubs

Digital Light Processing: Pros and Cons [5]

Pros

- Smooth (at 1080p resolution), jitter-free images.
- Perfect geometry and excellent grayscale linearity achievable.
- Usually excellent ANSI contrast.
- The light source is more-easily replaceable than the backlights used with LCDs, and on DLPs is often user-replaceable.
- The light from the projected image is not inherently polarized.
- New LED and laser DLP display systems more or less eliminate the need for lamp replacement.
- DLP offers affordable 3D projection display from a single unit and can be used with both active and passive 3D solutions.
- Lighter weight than LCD and plasma televisions.
- are not limited in size by their inherent mirror mechanisms,
- DLP projectors can process up to seven separate colors, giving them a wider color gamut.

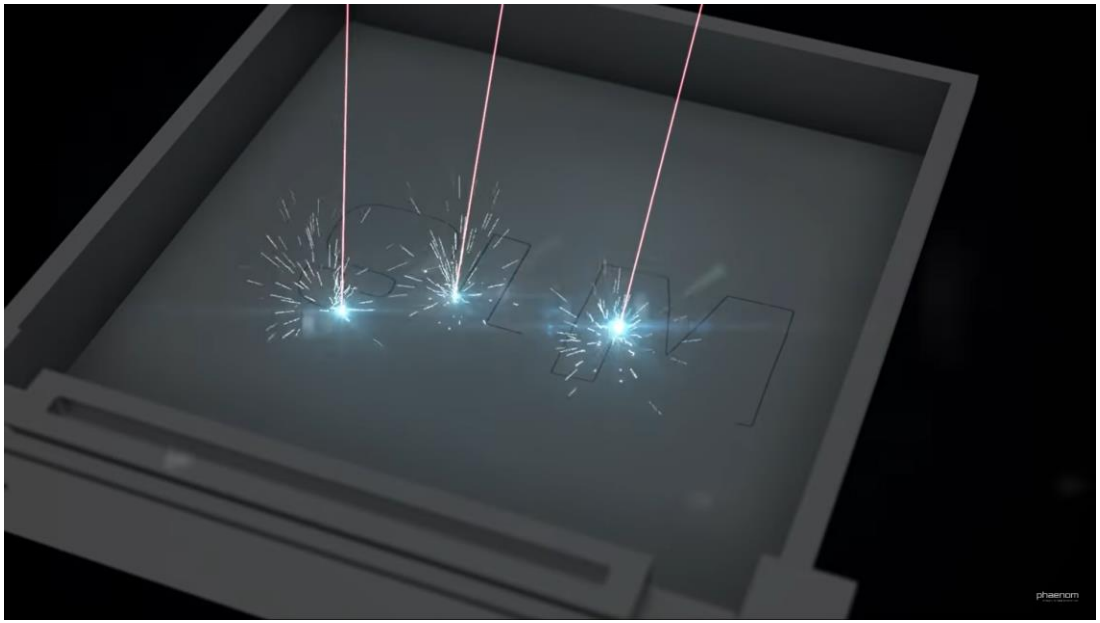
Cons

- Some viewers are bothered by the "rainbow effect" present in colour-wheel models - particularly in older models (explained above).
- Rear projection DLP TVs are not as thin as LCD or plasma flat-panel displays
- Replacement of the lamp / light bulb in lamp-based units.
- Dithering noise may be noticeable, especially in dark image areas.
- Error-diffusion artifacts caused by averaging a shade over different pixels, since one pixel cannot render the shade exactly
- Response time in video games may be affected by upscaling lag
- Reduced viewing angle as compared to direct-view technologies such as CRT, plasma, and LCD
- May use more electricity, and generate more heat, than competing technologies.

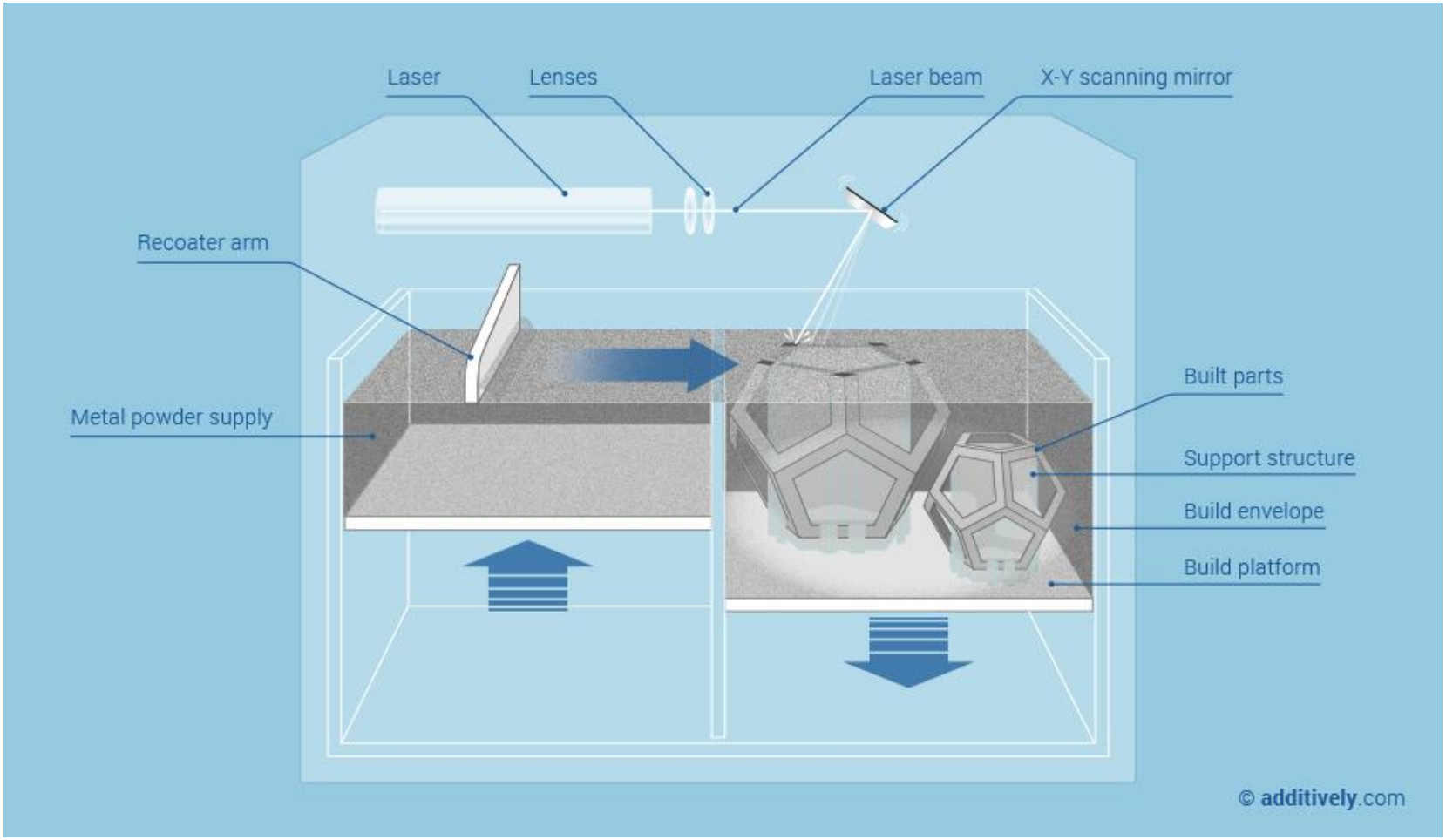
Selective Laser Melting (SLM)

Selective Laser Melting use a laser beam to fuse metal powder layer by layer.

SLM works on the principle of melting. Melting actually creates a pool where the materials can consolidate before reforming and hardening to create new solid structure.

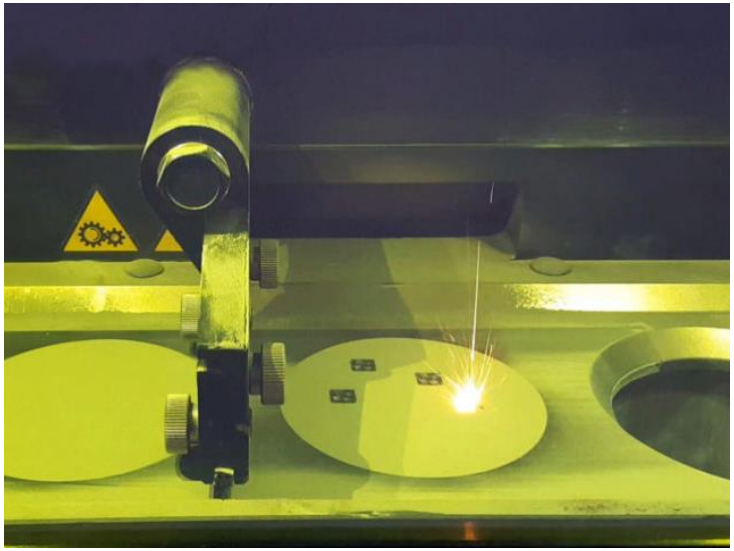


Components of SLM

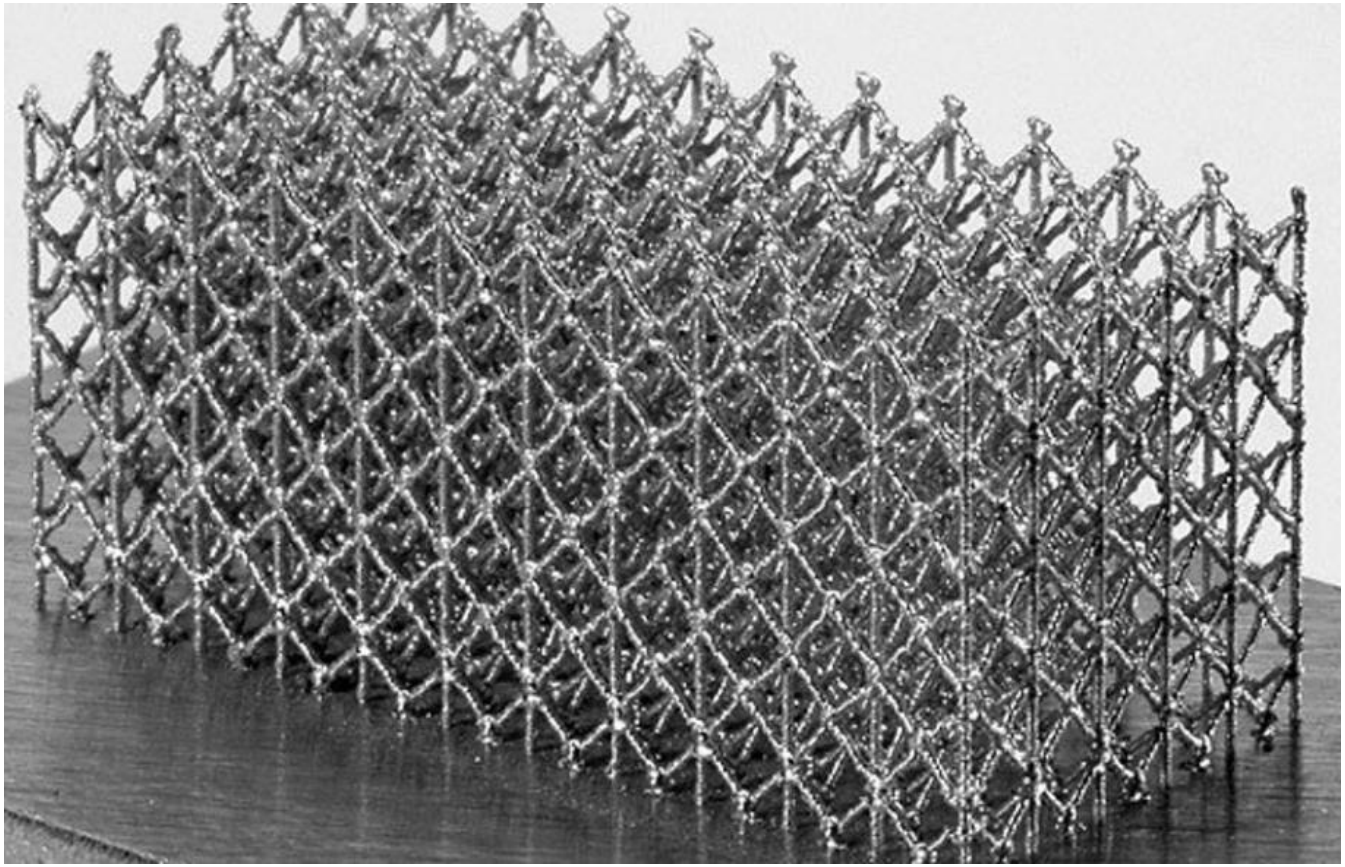


SLM process steps

- Selective laser melting uses a laser to melt successive layers of metallic powder.
- The laser will heat particles in specified places on a bed of metallic powder until completely melted. The CAD 3D file dictates where melting will occur.
- Then, the machine will successively add another bed of powder above the melted layer, until the object is completely finished.



- Objects printed through SLM



Source: Appliancedesig

SLM Pros and Cons

Pros

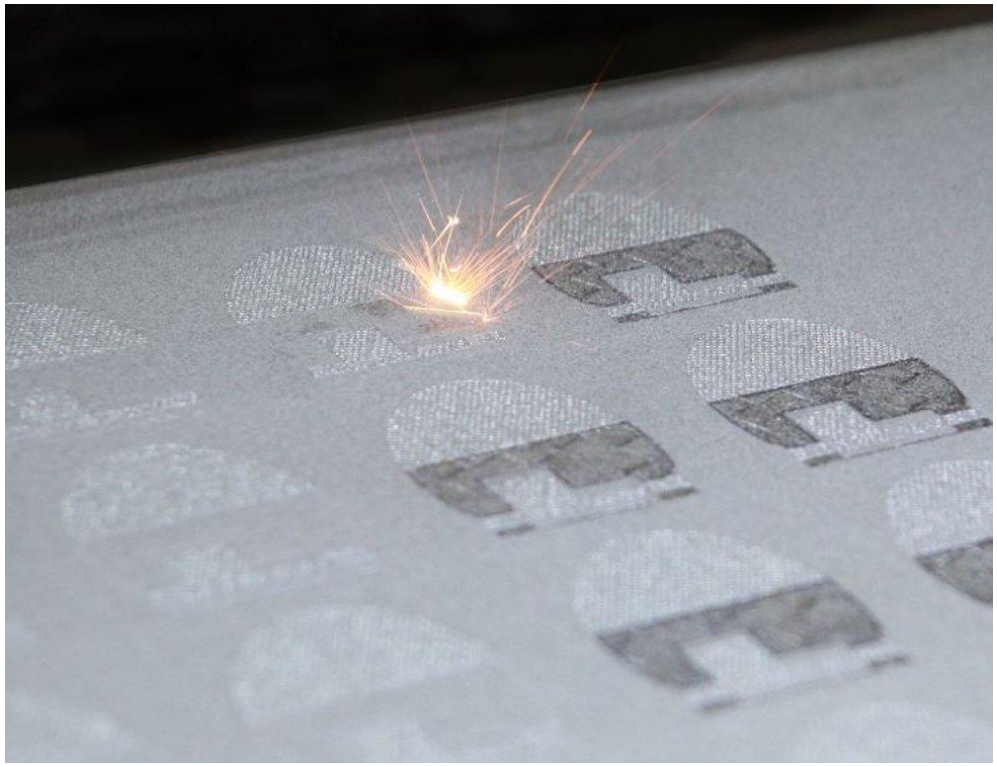
- Possibility of making several parts at the same time
- Possibility of making different designs in the same batch
- Automatic process
- Manufacturing of parts that cannot be machined
- High resolution

Cons

- Expensive, especially if parts aren't optimized or designed for the process
- Specialized design and manufacturing skills and knowledge needed
- Limited currently to relatively small parts
- Rough surface finish
- Lots of post-processing required

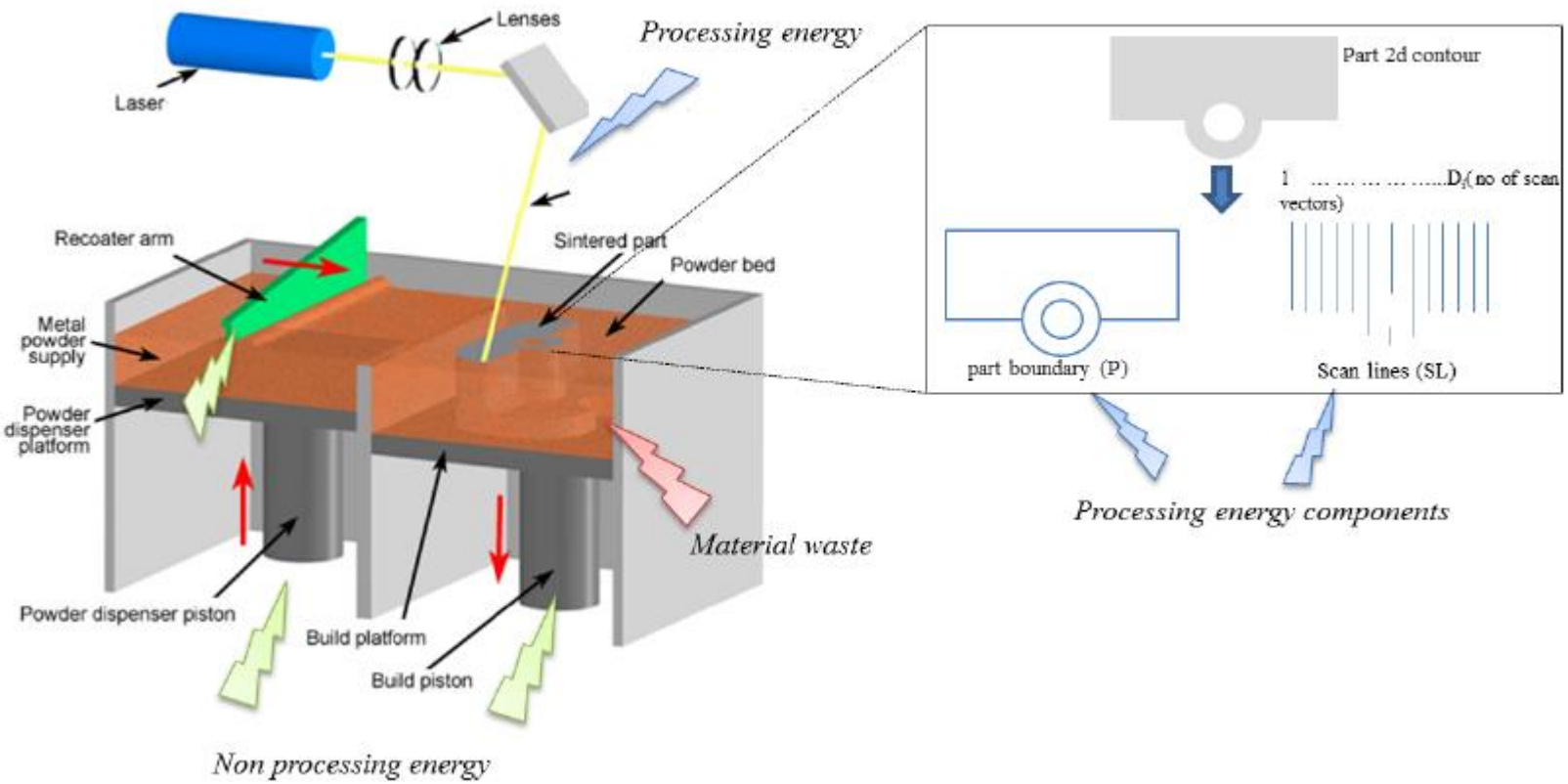
Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) produces solid plastic parts using a laser to sinter thin layers of powdered material one layer at a time.



Source: EOS

Components of the Selective Laser Sintering



Selective Laser Sintering process steps

Steps in SLS [2]

- I. The powder bin and the build area are first heated just below the melting temperature of the polymer and a recoating blade spreads a thin layer of powder over the build platform.
- II. A CO2 laser then scans the contour of the next layer and selectively sinters (fuses together) the particles of the polymer powder. The entire cross section of the component is scanned, so the part is built solid.
- III. When the layer is complete, the build platform moves downwards and the blade re-coats the surface. The process then repeats until the whole part is complete.

Objects printed through SLS

www.bigstock.com · 211289524

SLS Pros and Cons [2]

Pros	Cons
• SLS parts have good, isotropic mechanical properties, making them ideal for functional parts and prototypes. • SLS requires no support, so designs with complex geometries can be easily produced. • The manufacturing capabilities of SLS is excellent for small to medium batch production	• Only industrial SLS systems are currently widely available, so lead times are longer than other 3D printing technologies, such as FDM and SLA. • SLS parts have a grainy surface finish and internal porosity that may require post processing, if a smooth surface or watertightness are required. • Large flat surfaces and small holes cannot be printed accurately with SLS, as they are susceptible to warping and oversitnering.

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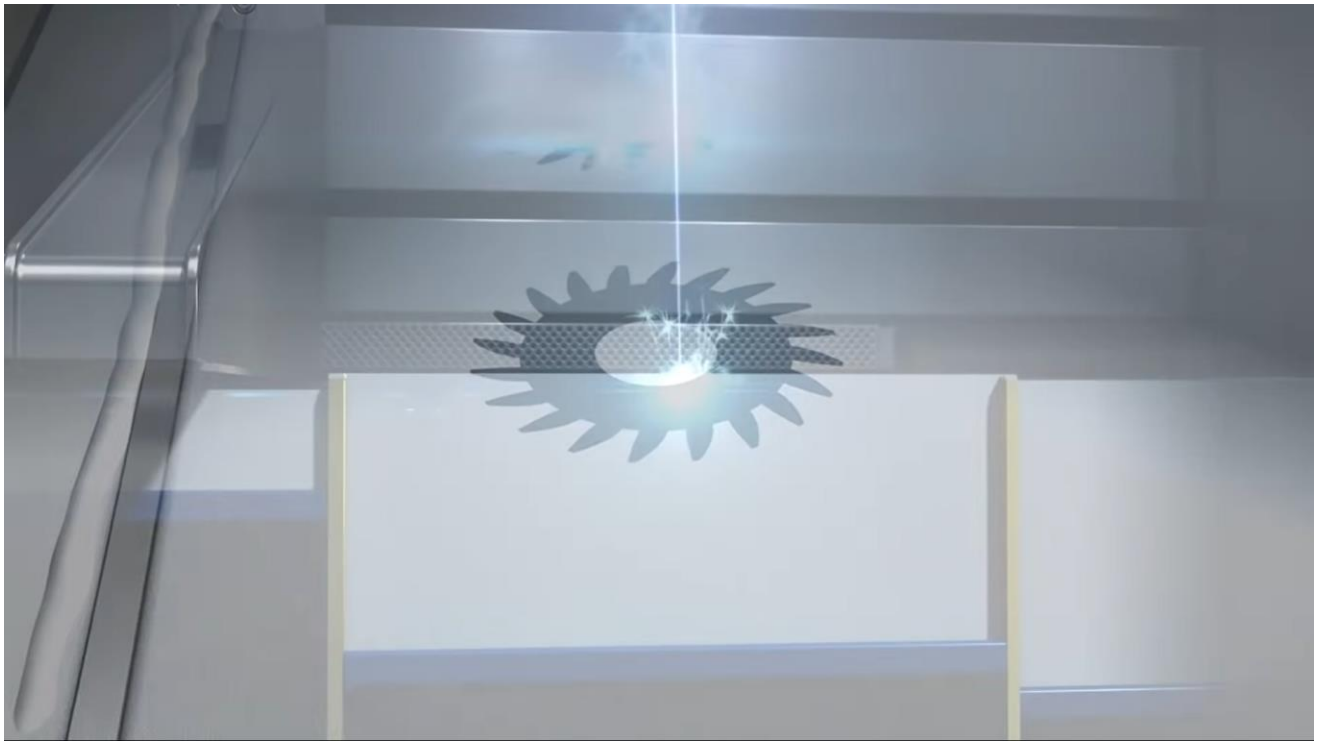
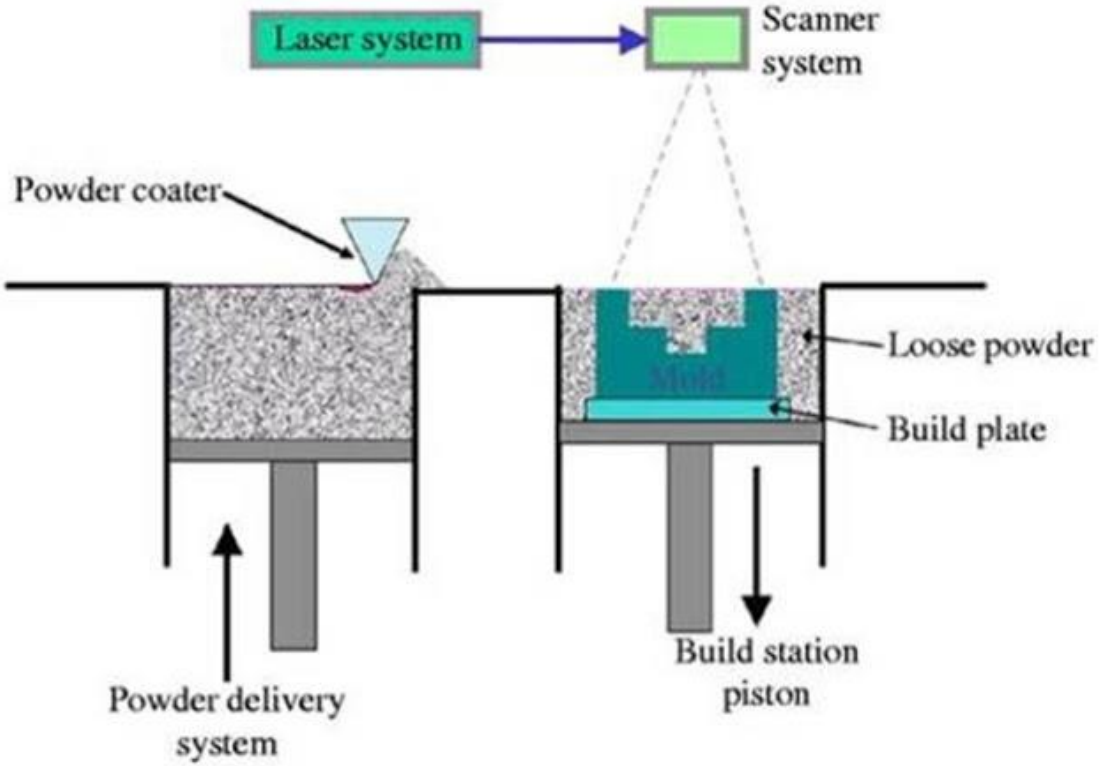
Direct Metal Laser Sintering (DMLS)

Direct Metal Laser Sintering use the laser what shape to ‘print’, moving across the powder to trace a cross-section of the product.



Components of the DLMS



DMLS process steps

DMLS is used exclusively with metal and metal alloys.

DMLS melts down thin layers of metal powder with an electronically driven laser beam.

The metal sintering or melting process fuses the powder together and creates a solid form. Once this first layer has been established, the printer platform drops, typically by no more than 0.1mm to expose a new layer of powder and the whole process of first tracing, then heating begins again.

- Objects printed through DMLS

• DMLS Pros and Cons

Pros

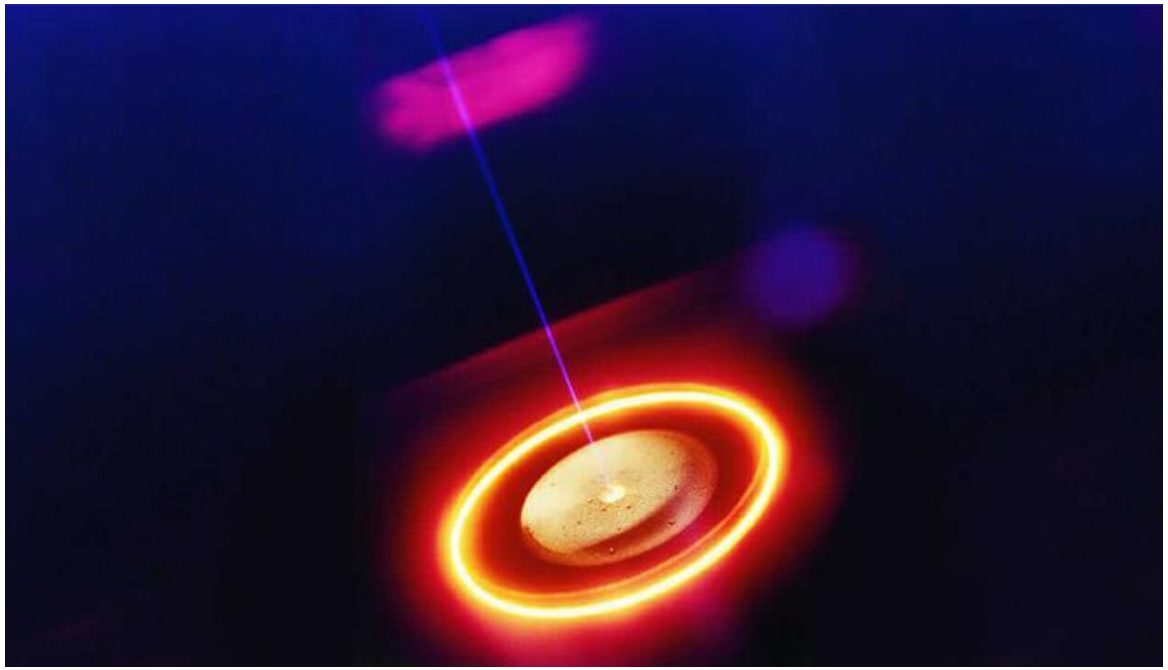
- objects are created by an easy and completely automatic procedure
- The technology allows the creation of very complex geometries that cannot be produced by machining
- Parts can be finished with conventional polishing techniques,

Cons

- Costs of a DMLS Machine are very high.
- Not suitable for large production runs.
- Not cost effective for 'simple' engineered products.
- The density of the final metal component, is likely to be lower than one manufactured through conventional engineering processes.
- Laser manufacture requires high levels of energy consumption.
- The finished component may have a level of porosity, allowing liquids and gases to be absorbed.

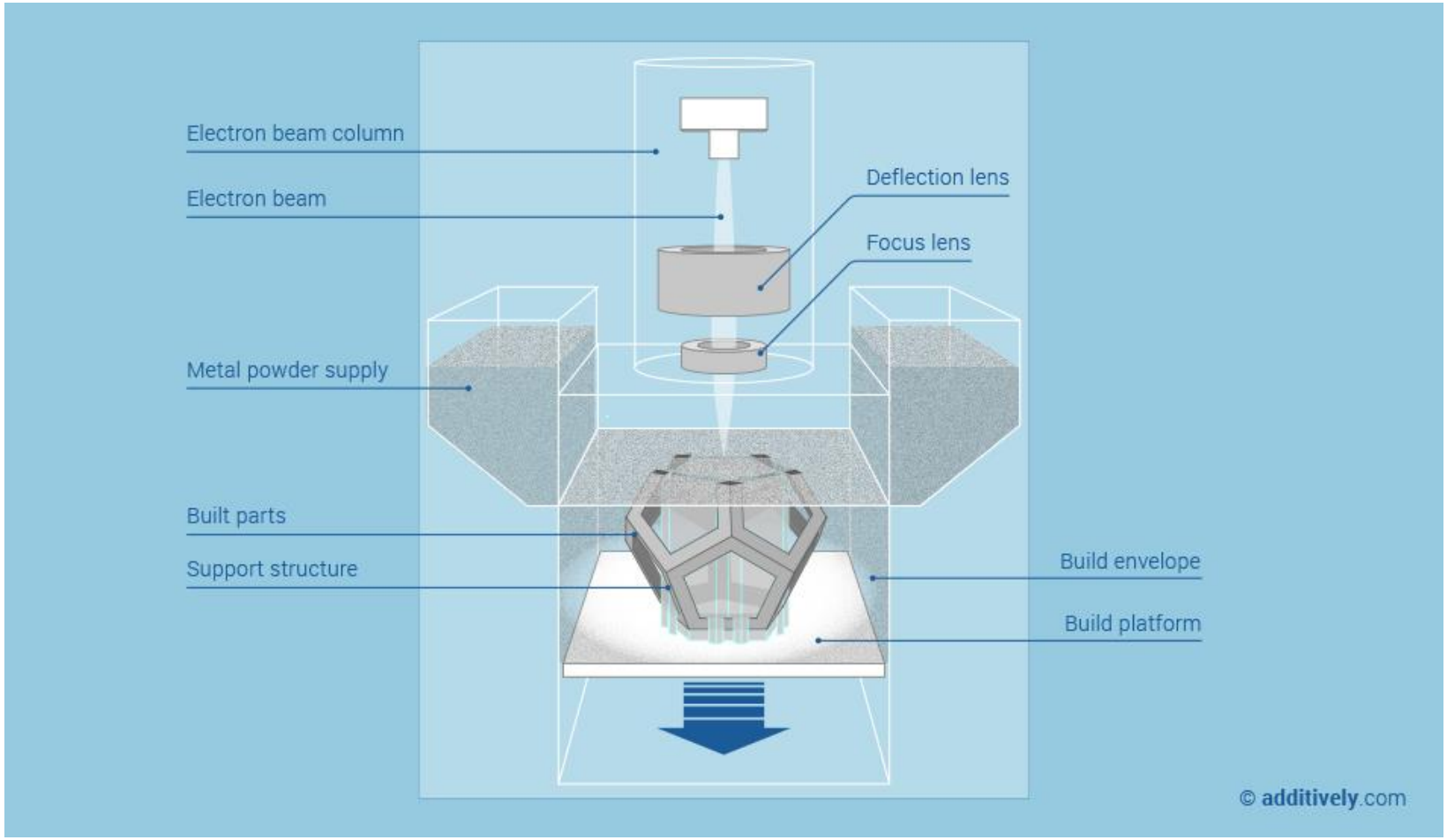
Electron Beam Melting (EBM)

EBM technology uses an electron beam produced by an electron gun to fuse metal particles and create, layer by layer, the desired part.



Source: Arcam

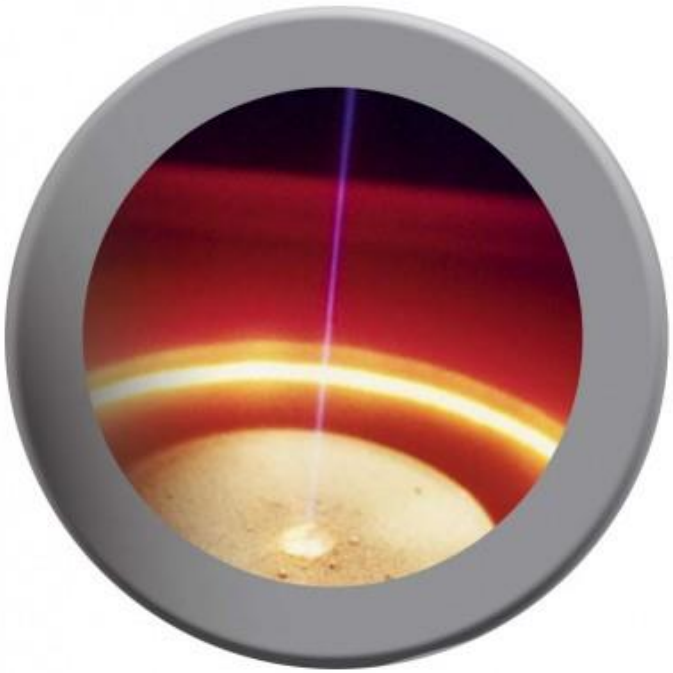
Components of the EBM



EBM process

EBM 3D printers consist of an energy source capable of emitting the electron beam, a powder container, a powder feeder, a powder re-coater, and a heated build platform.

The printing process must take place in a vacuum. That's because electrons of the electron beam would otherwise collide with gas molecules, which would "kill" the electron beam.



- Objects printed through EBM

Source: Arcam

EBM Pros and Cons

Pros

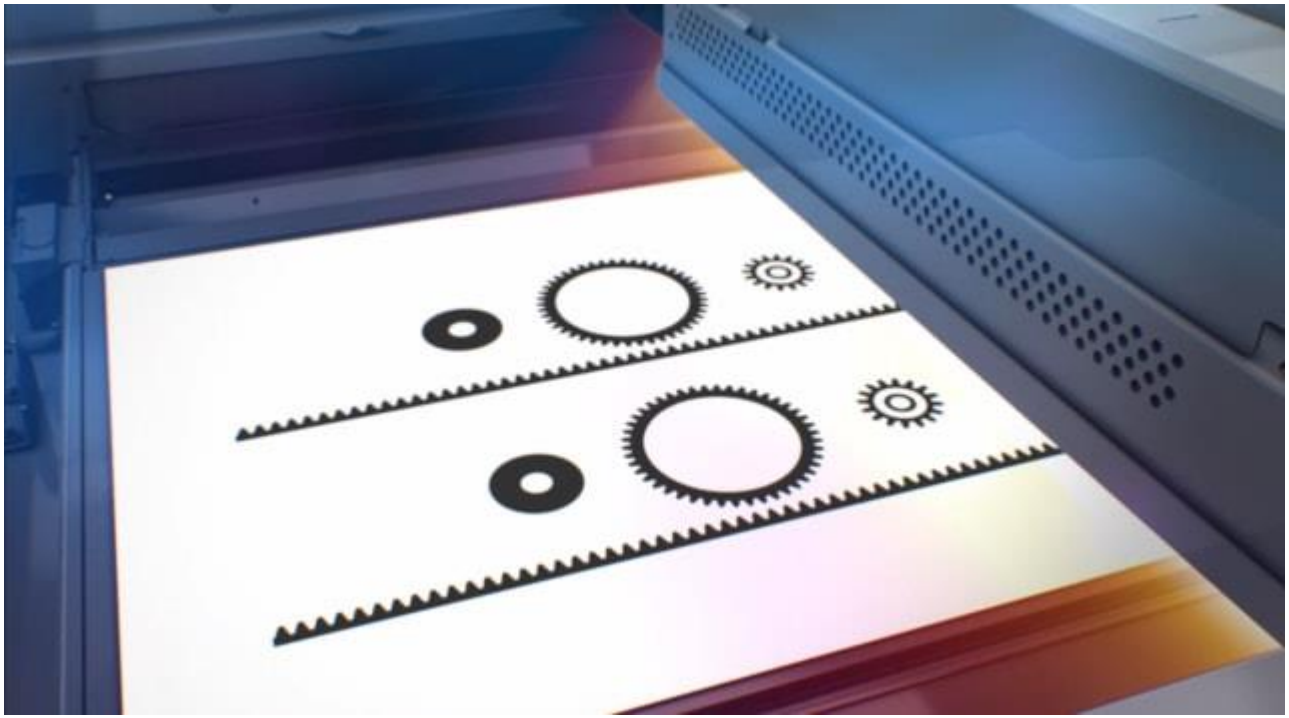
- Geometric freedom for engineering product designers
- Minimum material waste
- Less tooling and set up costs
- Residual stress reduction due to increased process temperature
- Oxidation reduction due to vacuum environment

Cons

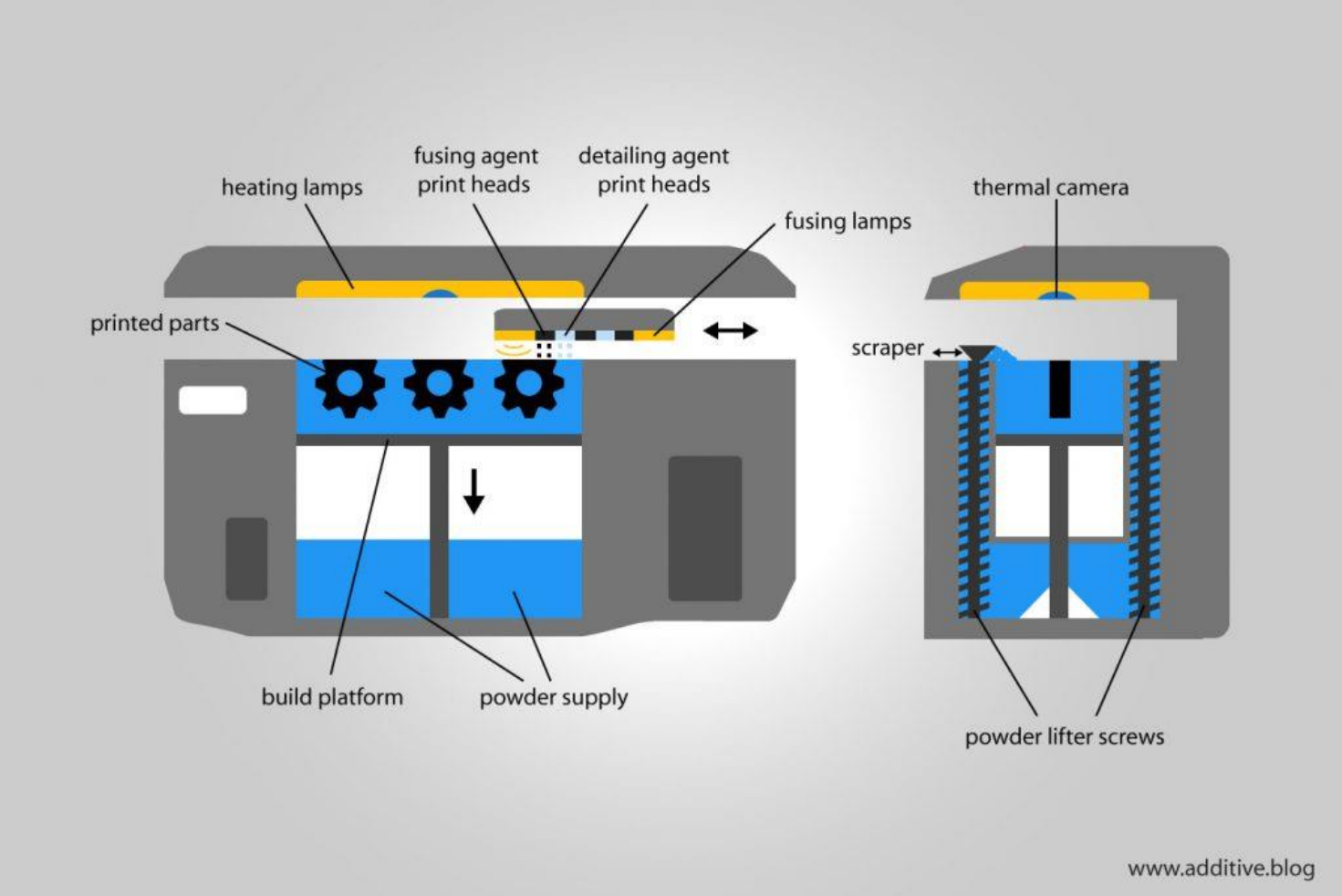
- Commercially available material are limited
- Surface finish similar to sand casting
- Needs full understanding to get the full benefit of the process

Multi Jet Fusion (MJF)

MJF is a powder-based 3d printing process that uses inkjet to deposit fusing and detailing agents to control voxels that are then fused into a solid layer then repeated until the build is complete [7].



Components of MJF



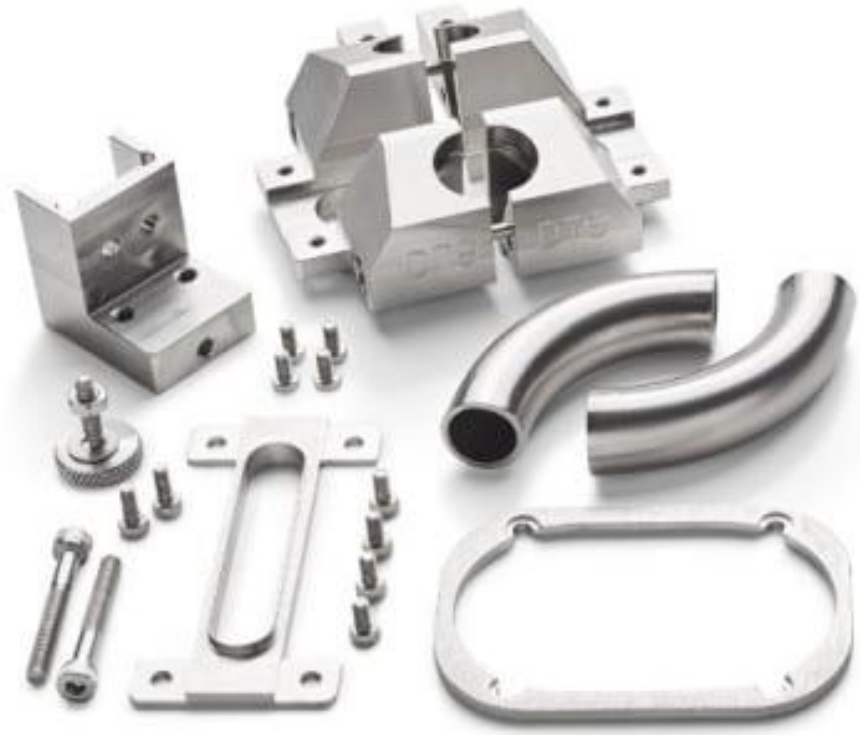
MJF process

The fabrication process begins by laying down a thin layer of material in the build space.

A carriage containing the thermal inkjet array passes from right-to-left, depositing chemical agents across the full working area. These chemical agents are actually two; one is a fusing agent, to create a solid layer from the material, and the other is a detailing agent, to determine the physical outline of the layer being created.

Energy is applied to catalyze the fusing agent, and the powder imbued with the detailing agent remains inert [8].

- Objects printed through MJF



Source: HP

• MJF: Pros and Cons

Pros

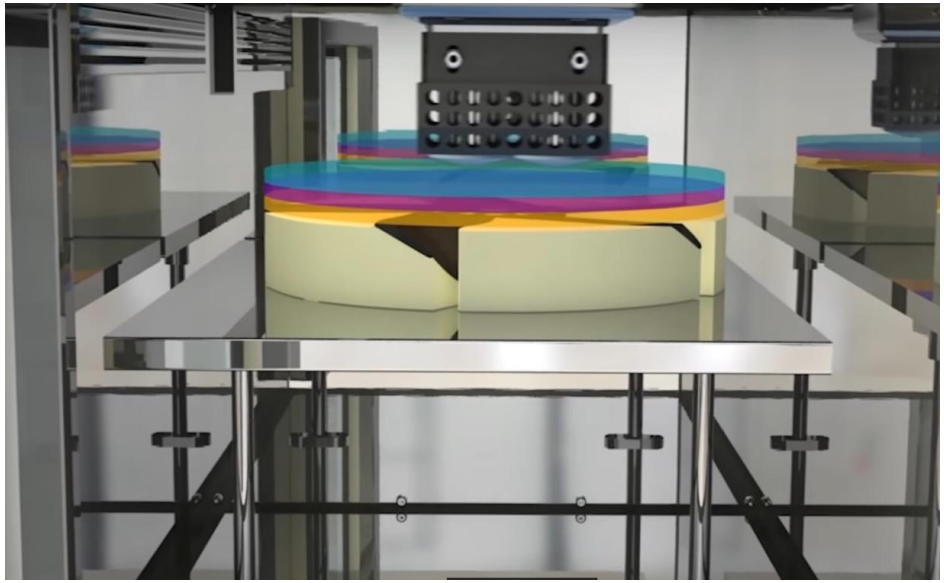
- Very high accuracy and resolution
- Parts exceptionally strong and virtually isotropic
- Extremely fast and cost efficient

Cons

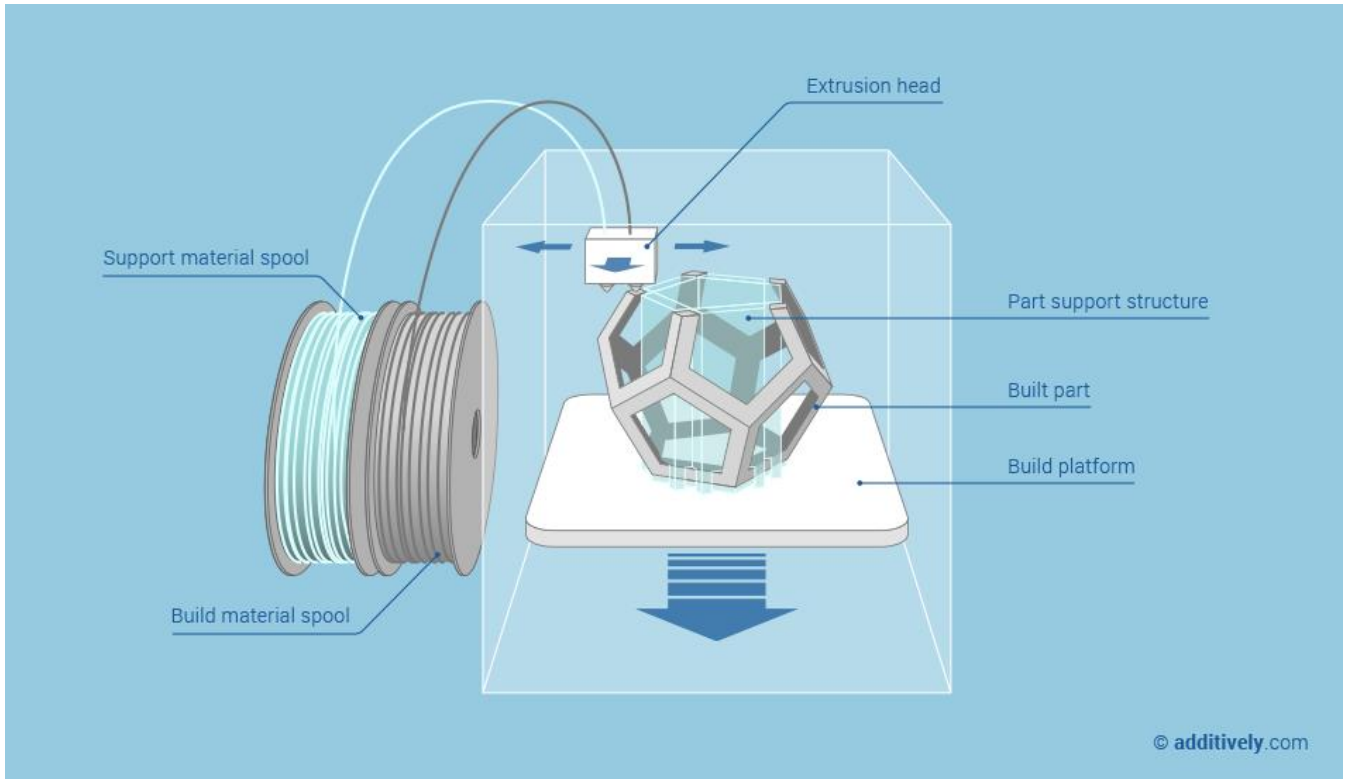
- Surface quality is good, but rougher than that produced by photopolymer-based technologies (Stereolithography, Polyjet).
- The raw parts are grey; these parts can easily be dyed black, but other colors require coating (at extra cost).
- Only some materials are available

• Fused Deposition Modeling (FDM)

FDM process constructs three-dimensional objects directly from 3D CAD data. A temperature-controlled head extrudes thermoplastic material layer by layer.



Components of FDM



FDM process

FDM begins with a software process, developed byStratasys, which processes an STL file (stereolithography file format) in minutes, mathematically slicing and orienting the model for the build process. If required, support structures are automatically generated. The machine dispenses two materials – one for the model and one for a disposable support structure [9].

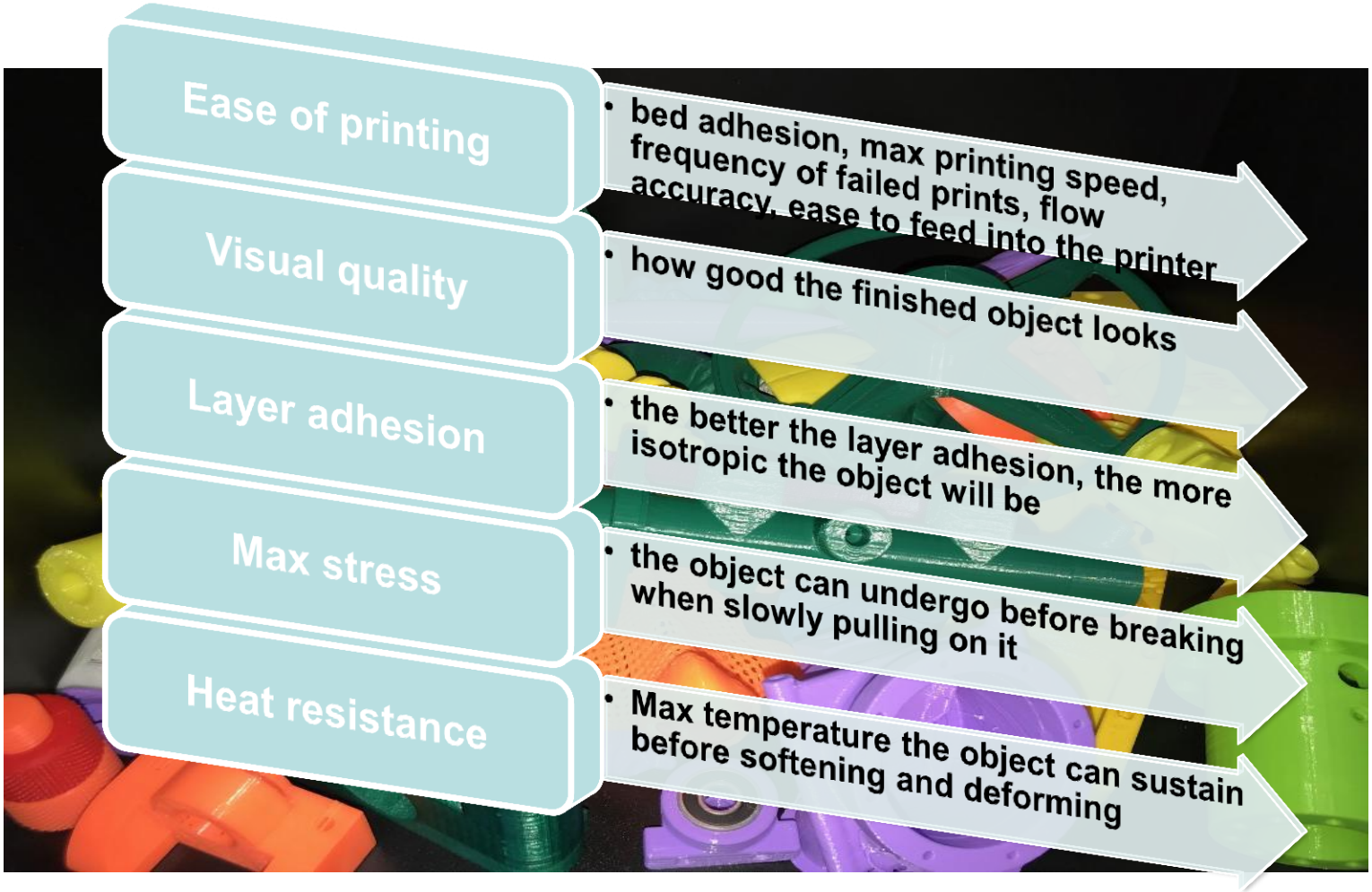
The thermoplastics are liquefied and deposited by an extrusion head, which follows a tool-path defined by the CAD file [9].

A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing(CAM) software package [9].

- Objects printed through FDM

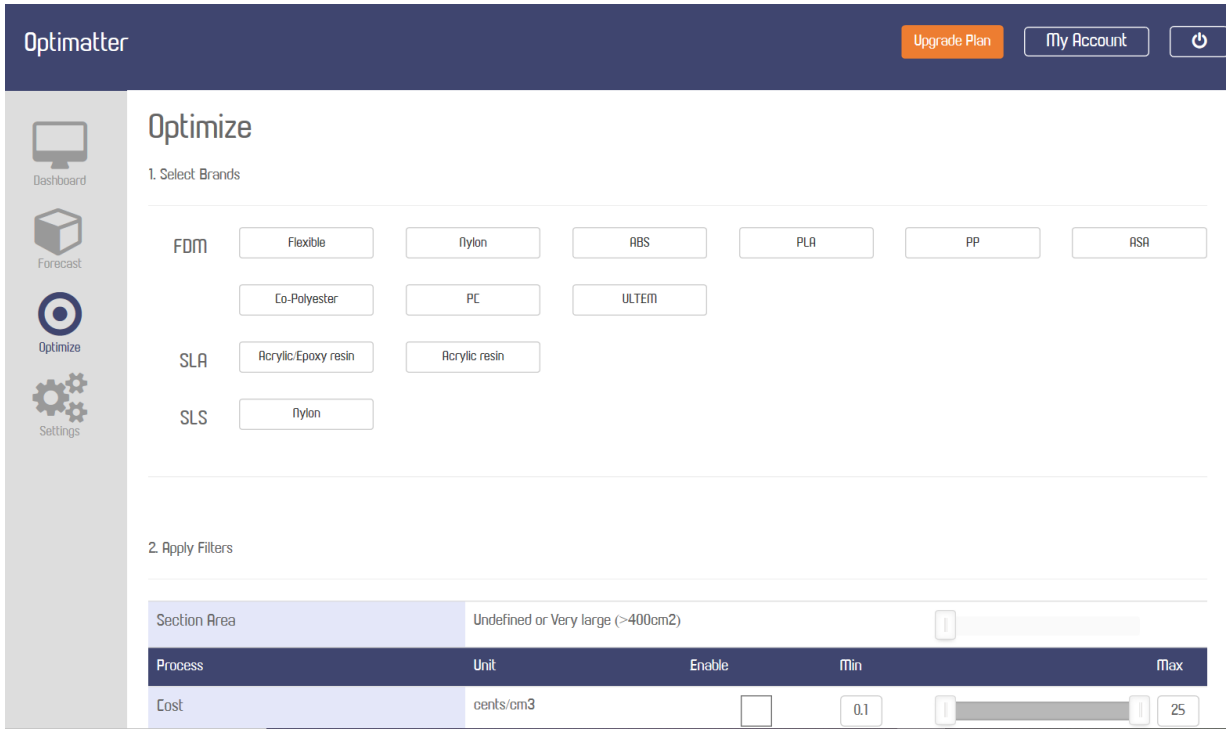
3. Materials

Criteria to choose a materials for AM



Find the right material

OptiMatter provides a wide range of data on materials, technologies and parameters and calculates the best printing configuration based on the user's requirements. https://www.optimatter.com



The main materials used in SLA [2]

Resin	Description
Standard resin	High-detail resin that produces parts with a smooth, injection mold-like surface finish. It is brittle and used for non-functional parts.
Clear resin	Has a semi-transparent appearance
Tough resin (ABS-like)	Has properties of ABS and produces parts with improved mechanical properties compared to standard resin. Can be used for functional parts.
Durable resin (PP-like)	Semi-flexible, ideal for snap fit assemblies and high-detail durable prototypes.
Rubber-like resin	Rubber-like feel and shore hardness < 70A that can be compressed and bent. Lacks the performance of true rubber.
Heat-resistant resin	Has high stiffness and excellent temperature resistance.
Castable resin	High-detail resin used to produces patterns for investment casting. They burn out cleanly with no ash or residue.

The main materials used in SLS [2]

Material	Description
Nylon 12 (PA 12)	SLS nylon is a robust thermoplastic with all-around excellent physical properties, ideal for functional prototypes and end-use applications.
Glass-filled Nylon (PA 12 GF)	Glass-filled SLS nylon is reinforced with glass beads creating parts with higher stiffness and thermal stability than standard nylon.
TPU / TPE / TPA *	Thermoplastic elastomers combine high elasticity and strength with good chemical resistance, making them ideal for functional, flexible parts.

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DMLS MATERIALS [6]

Materials	Alloy Designation	Layers	Hardness	Advantages	Applications
Stainless Steel (PH1)	15-5 PH, DIN 1.4540 and UNS S15500	20 or 40 Micron Layers	30-35 HRC Built, Post Hardened to 40 HRC	High Hardness & Strength	Prototype / Production Parts
Stainless Steel (GP1)	17-4, European 1.4542, German X5CrNiCuNb16-4	20 or 40 Micron Layers	230 ± 20 HV1 Built, Ground & Polished to 250-400 HV1	High Toughness & Ductility	Engineering Applications
Cobalt Chrome (MP1) (Cobalt Chromium)	ISO 5832-4 and ASTM F75	20, 40 or 50 Micron Layers	35-45 HRC Built	High Temperature Resistance	Turbines & Engine Parts
Maraging Steel (MS1)	18% Ni Maraging 300, European 1.2709, German X3NiCoMoTi 18-9-5	20 or 40 Micron Layers	33-37 HRC Built, Post Hardened to 50-56 HRC	Easily Machinable & Excellent Polishability	Injection Molding Tooling, Conformal Cooling
Aluminium AlSi10Mg	Typical Casting Alloy	30 Micron Layers	Approx 119 ± 5 HBW	Low Weight, Good Thermal Properties	Automotive, Racing
NickelAlloy IN718 (Inconel 718)	UNS N07718, AMS 5662, AMS 5664, W.Nr 2.4668, DIN NiCr19Fe19NbMo3	40 Micron Layers	30 HRC Built, Post Hardened 47 HRC	Heat & Corrosion Resistant	Turbines, Rockets, Aerospace
Stainless Steel (316L)	ASTM F138	20 Micron Layers	85 HRB	Corrosion & Pitting Resitant	Surgical Tools, Food & Chemical Plants
Titanium Ti-64 *	ASTM F2924	30 or 60 Micron Layers	320 ± 15 HV5	Light Weight, High Strength, Corrosion resistance	Aerospace, Motorsport Racing
Titanium Ti-64 ELI *	ASTM F136 Properties	30 or 60 Micron Layers	320 ± 15 HV5	Corrosion Resistance, Biocompatibility	Medical, Biomedical, Implants

- FDM materials [10]

MATERIALS	DESCRIPTION
TPU (thermoplastic polyurethane elastomer)	• Accurate elastomer parts with high elongation • Superior toughness and abrasion resistance • Wide variety of applications including flexible hoses, tubes, air ducts and vibration dampeners
Antero™ 800NA (polyetherketoneketone)	• High heat and chemical resistance • Low outgassing and high dimensional stability • Excellent strength, toughness and wear-resistant properties
ULTEM™ 1010 resin (polyetherimide)	• Food safety and bio-compatibility certification • Highest heat resistance, chemical resistance and tensile strength • Outstanding strength and thermal stability
ULTEM 9085 resin (polyetherimide)	• FST (flame, smoke, toxicity)-certified thermoplastic • High heat and chemical resistance; highest flexural strength • Ideal for commercial transportation applications such as airplanes, buses, trains and boats
FDM Nylon 12™ (polyamide 12)	• The toughest nylon in additive manufacturing • Excellent for repetitive snap fits, press fit inserts and fatigue-resistance applications • Simple, clean process – free of powders
FDM Nylon 12CF™ (polyamide 12CF)	• Carbon-filled thermoplastic with excellent structural characteristics • Highest flexural strength • Highest stiffness-to-weight ratio
PC (polycarbonate)	• Most widely used industrial thermoplastic with superior mechanical properties and heat resistance • Accurate, durable and stable for strong parts, patterns for metal bending and composite work • Great for demanding prototyping needs, tooling and fixtures

4. AM Application

More information about AM application can be found on the following videos.

AM process	Source
DMLS	https://www.youtube.com/watch?time_continue=3&v=PHaXX2OoOs4&feature=emb_logo
EDM	https://www.youtube.com/watch?time_continue=89&v=M_qSnjKN7f8&feature=emb_logo
MJF	https://www.youtube.com/watch?v=DdAocUqrFts&list=PLoMwRIIUViGQsA-49cKLGZ62iX4MmWrXb&index=88&app=desktop
FDM	https://www.youtube.com/watch?v=WHO6G67GJbM
SLA	https://www.youtube.com/watch?v=yW4EbCWaJHE
DPL	https://www.youtube.com/watch?v=9nb8mM3uEIc
SLM	https://www.youtube.com/watch?v=R5WCyafMPLs
SLS	https://www.youtube.com/watch?v=9E5MfBAV_tA

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