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TAFI 3
Unidad de Fabricación Aditiva e Impresión 3D

ADDITIVE MANUFACTURING AS A MEAN FOR SUPPORTING RAPID DEVELOPMENT OF INNOVATIVE PRODUCTS

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- ❑ ADDITIVE MANUFACTURING METHODS
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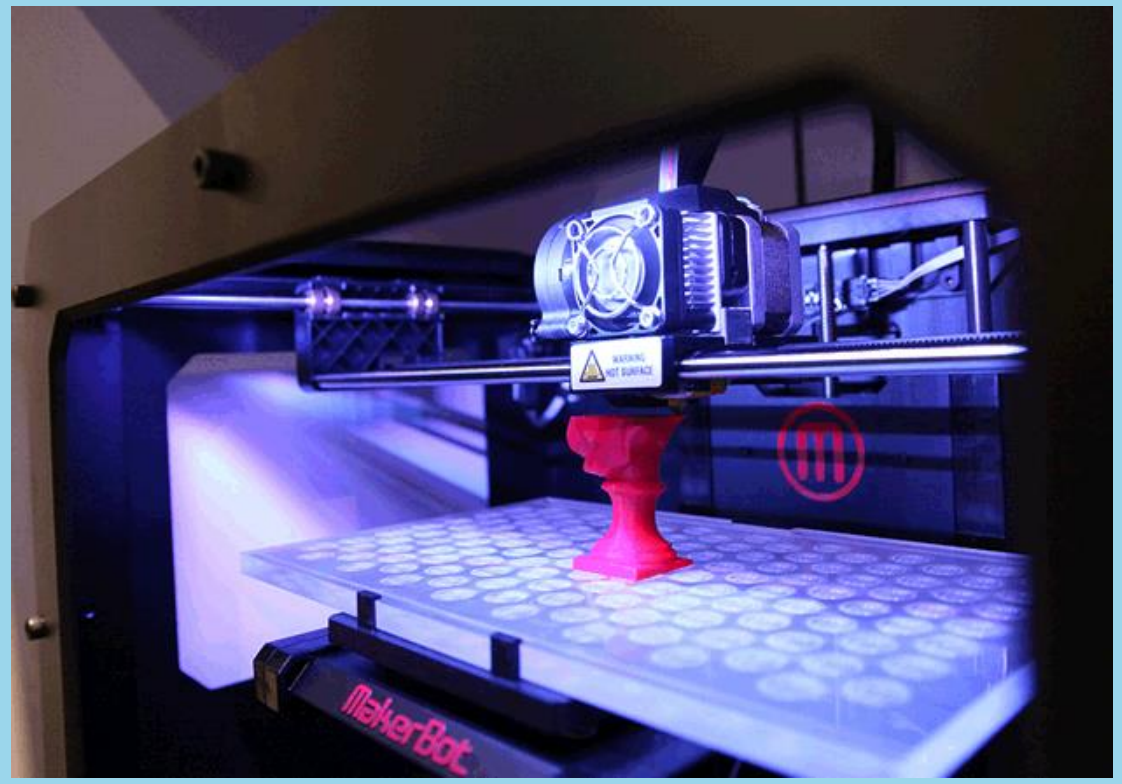
- ❑ LIMITS AND CHALLENGES OF ADDITIVE MANUFACTURING
- ❑ GENERAL ADDITIVE MANUFACTURING APPLICATIONS



WHAT IS **ADDITIVE MANUFACTURING**?

Also known as **3D printing**

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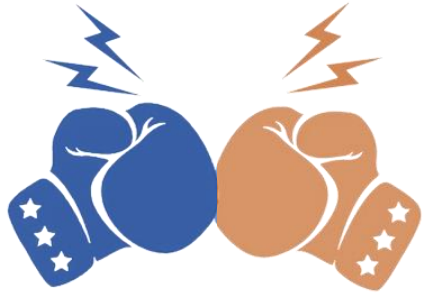
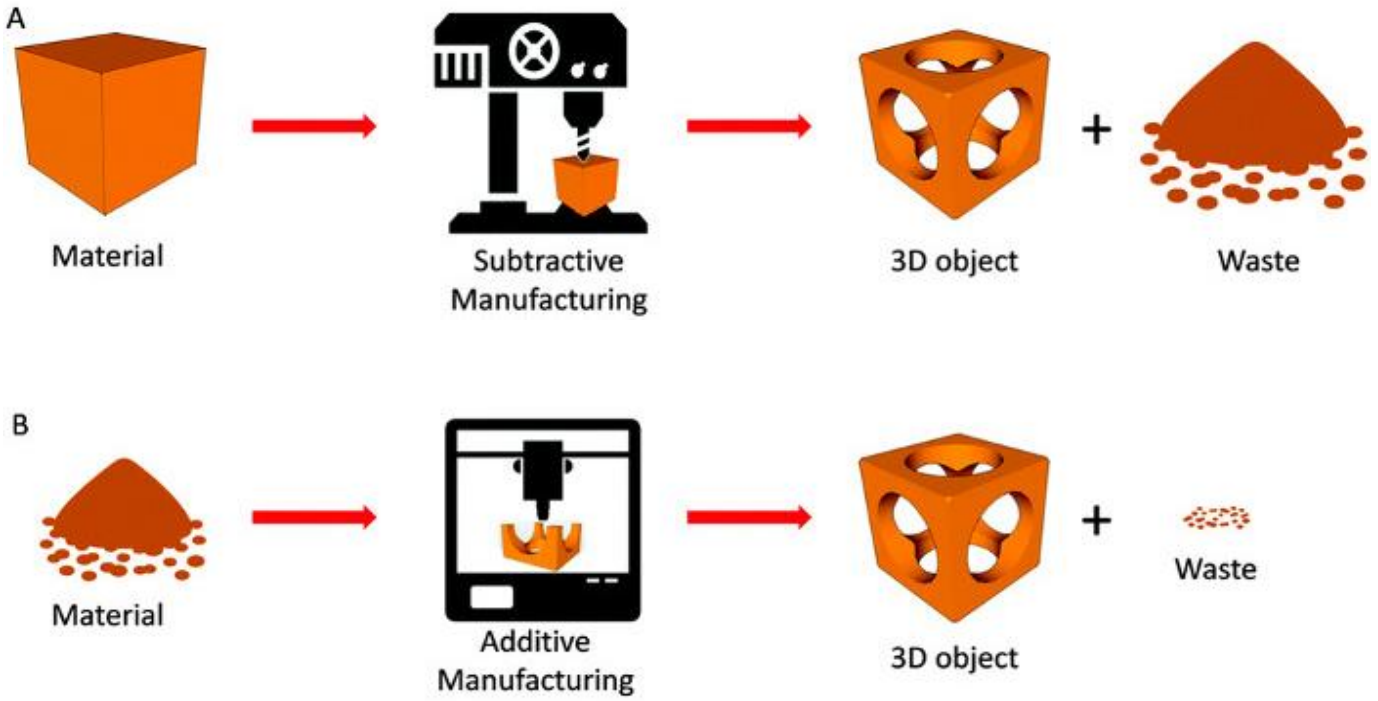
The process of **joining materials** to produce parts or objects from 3D model data, typically **layer by layer**, as opposed to subtractive and forming manufacturing methods [1].

[1] ISO/ASTM 52900:2021 Additive manufacturing. General principles. Fundamentals and vocabulary



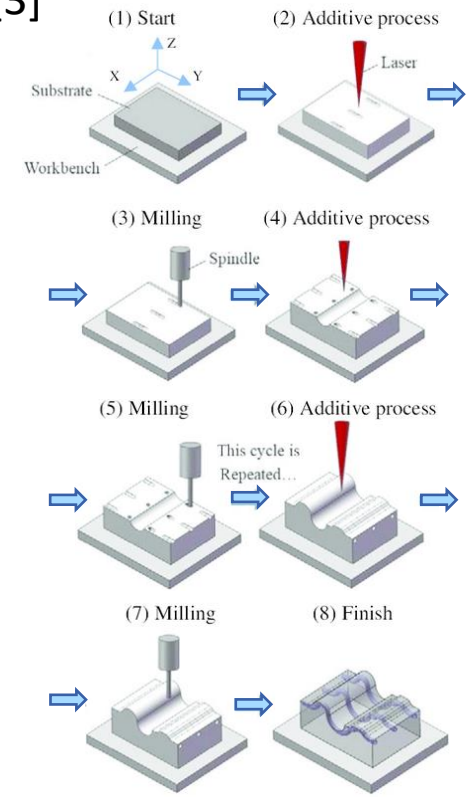
ADDITIVE VS SUBTRACTIVE MANUFACTURING

[2]



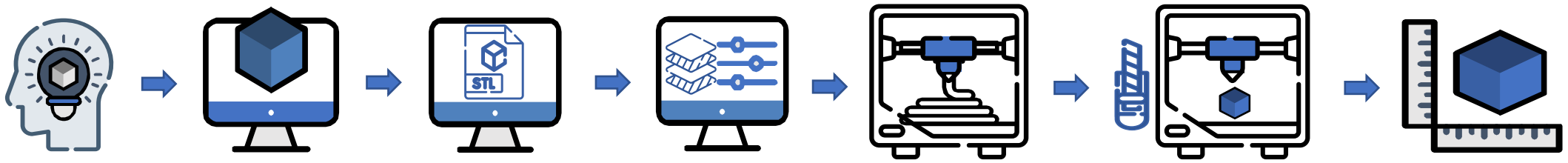
But… they are not mutually exclusive!!

[3]



[2] Comparing Additive Manufacturing Vs Subtractive Manufacturing: What Are the Differences, 2012, https://www.rapiddirect.com/blog/additive-vs-subtractive-manufacturing/,
[3] Du, Wei & Bai, Qian & Zhang, Bi. (2016). A Novel Method for Additive/Subtractive Hybrid Manufacturing of Metallic Parts. Procedia Manufacturing. 5. 1018-1030. 10.1016/j.promfg.2016.08.067.

BASIC STEPS OF ANY ADDITIVE MANUFACTURING PROCESS



IDEA

STEP 1
3D Model Generation

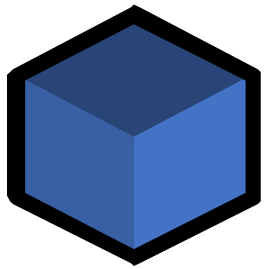
STEP 2
3D Model Simplification into printing format

STEP 3
Slicing

STEP 4
Manufacturing

STEP 5
Extraction

STEP 6
Post-processing & Surface finish



FINAL PART

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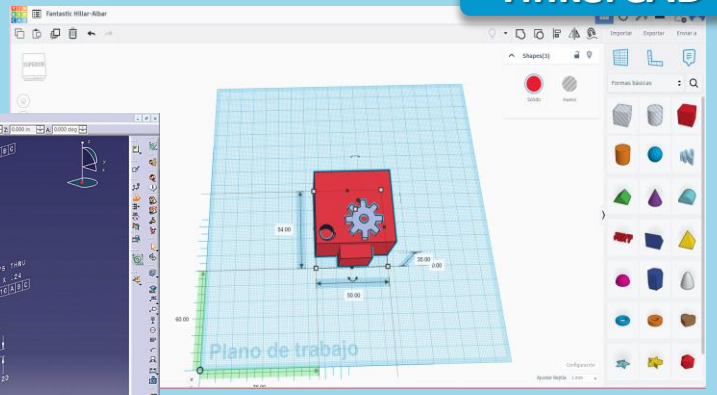
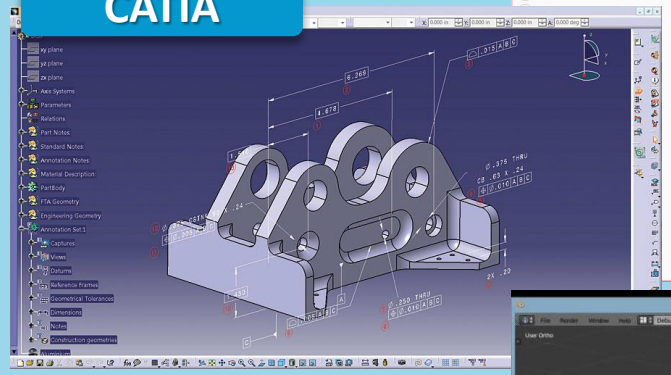
STEP 1: 3D MODEL GENERATION

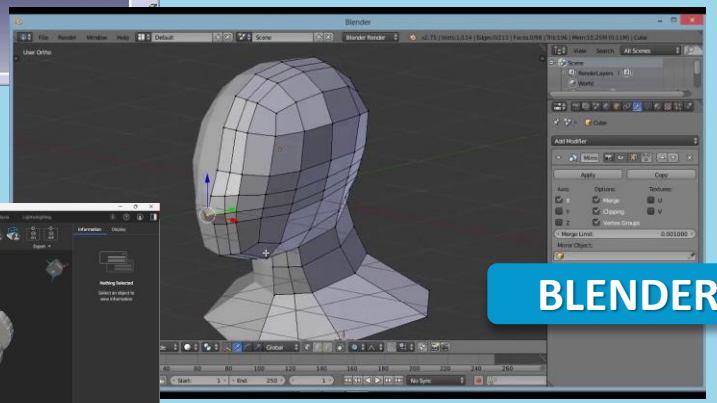
1 CAD

TinkerCAD



CATIA



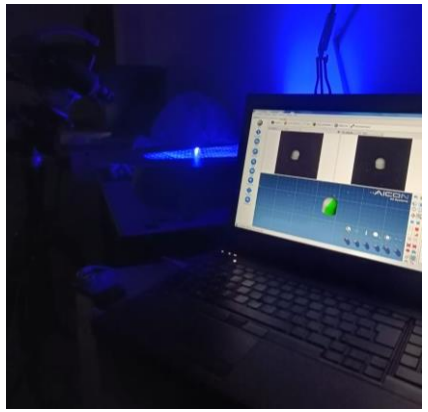


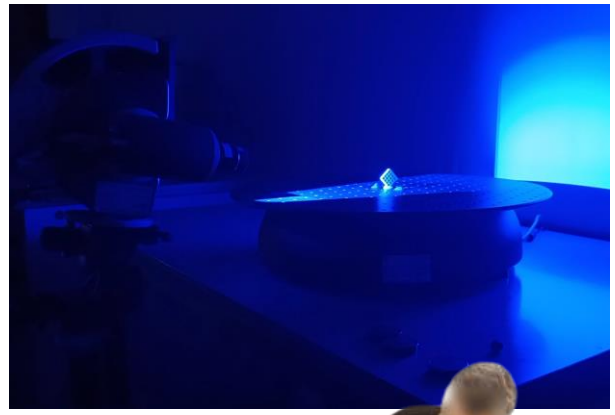
BLENDER

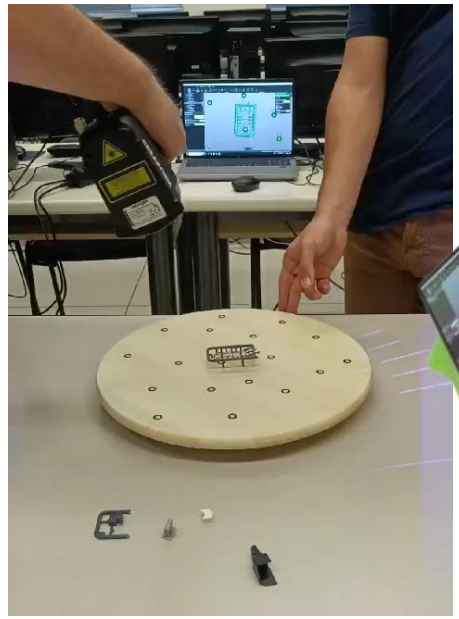
NTOP

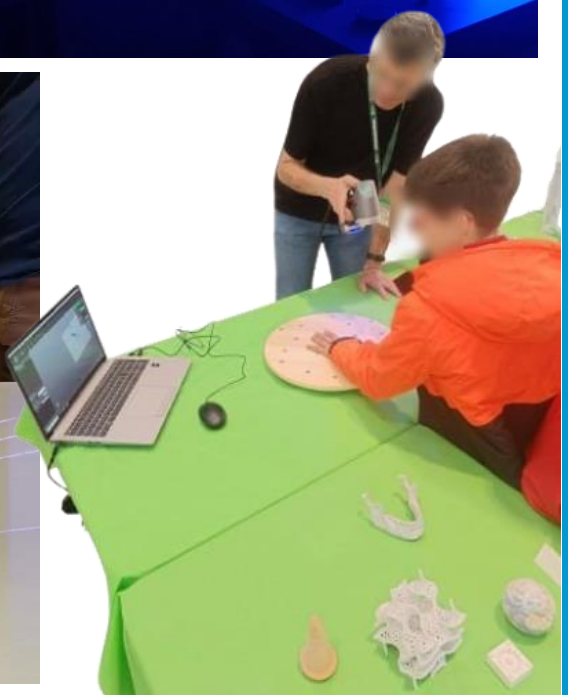
Among others...

2 3D SCAN + REVERSE ENGINEERING









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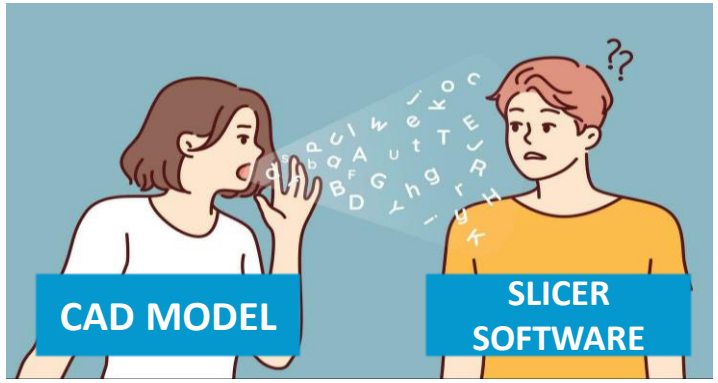
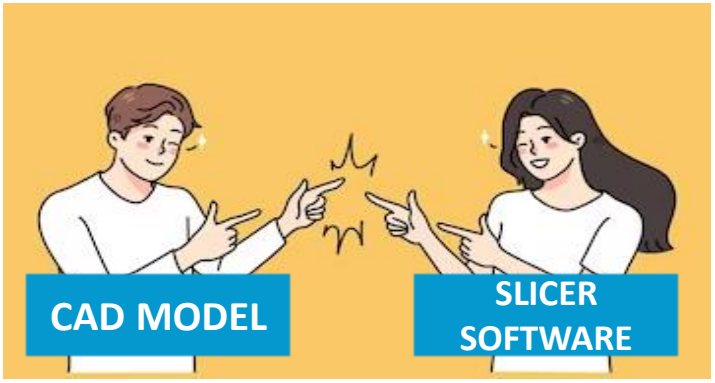
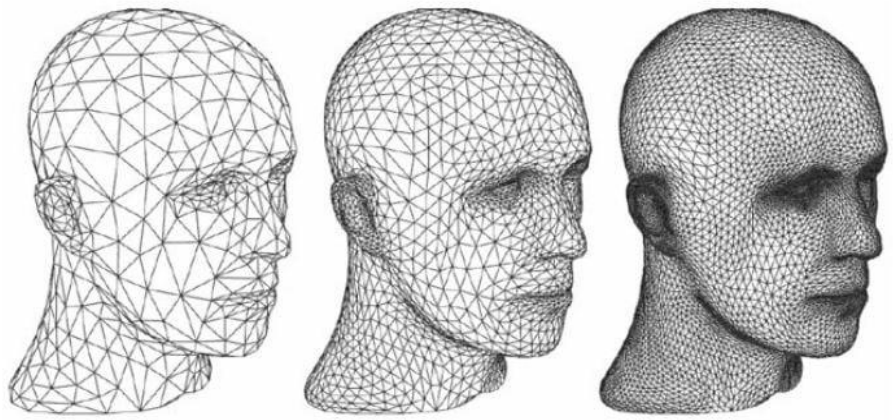
STEP 2: 3D MODEL SIMPLIFICATION INTO PRINTING FORMAT



CAD DESIGN → MESH





ACCURACY

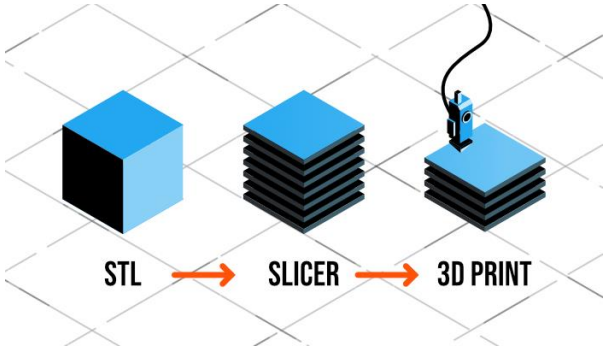
FILE SIZE

- ❑ STL
- ❑ PLY
- ❑ OBJ
- ❑ 3MF

DATA STORAGE

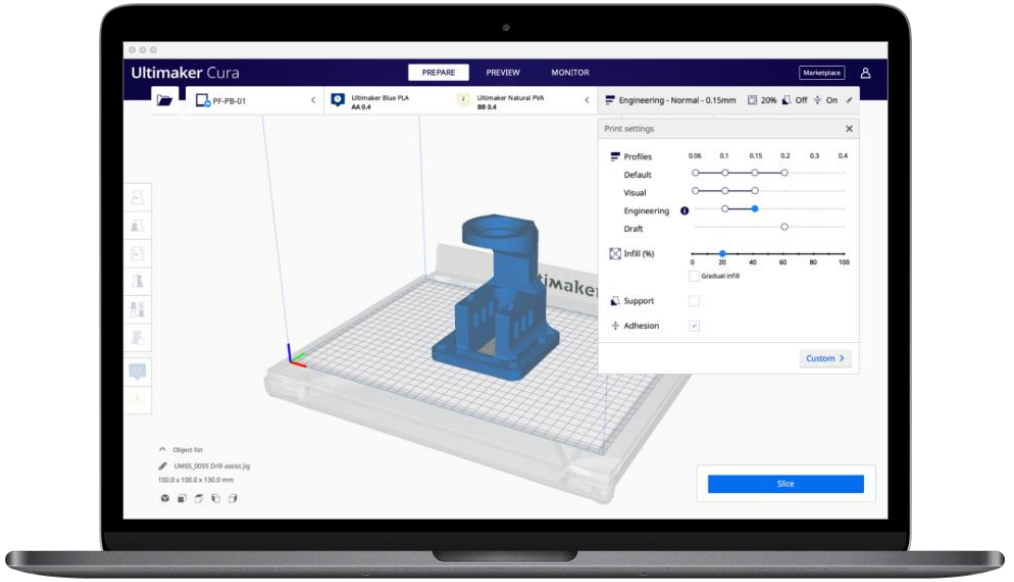
- Geometry (Mesh)
- Geometry, texture & colour
- Geometry, texture, colour & material
- Geometry, texture, colour, material, manufacturing method,…

STEP 3: SLICING



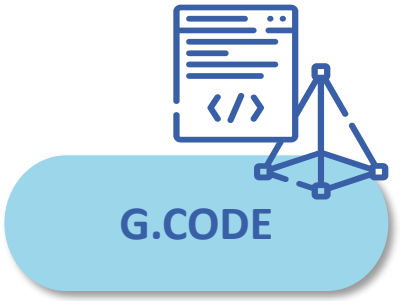
PARAMETERS DEPENDING THE METHOD OF MANUFACTURING

- LAYER HEIGHT
- INFILL
- WALL THICKNESS
- STRATEGY PATH
- SUPPORTS
- MATERIAL
- SPEED
- …



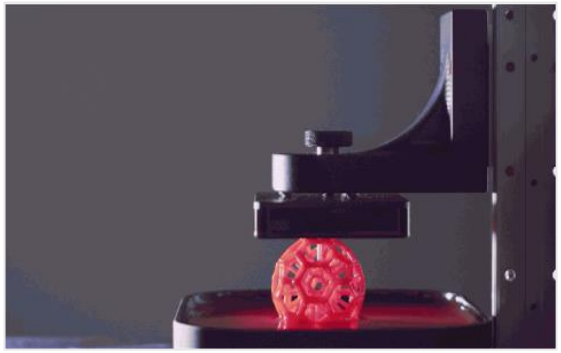
MECHANICAL PROPERTIES
SURFACE FINISH (STAIRCASE EFFECT)
TIME OF PRINTING
MATERIAL CONSUMPTION

STEP 4: MANUFACTURING



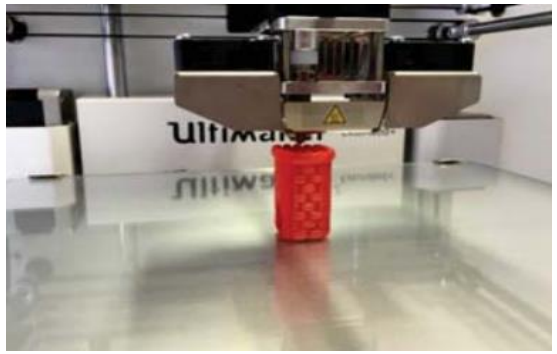
DIRECT ENERGY DEPOSITION (DED)

VAT PHOTOPOLYMERISATION (VPP)

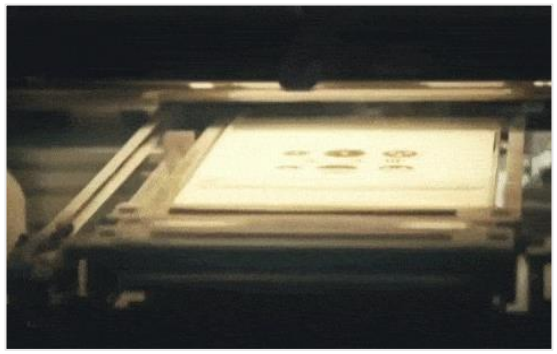


BINDER JETTING (BJT)

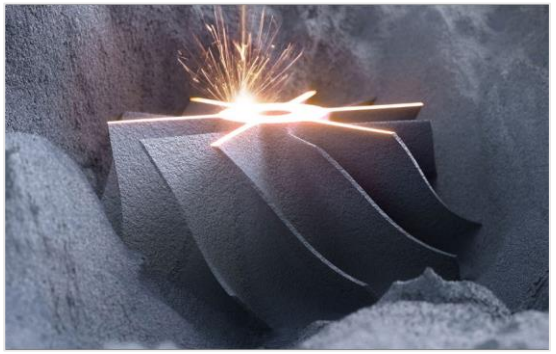
MATERIAL EXTRUSION (MEX)



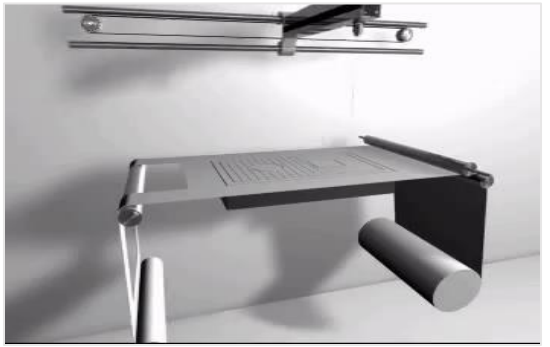
MATERIAL JETTING (MJT)



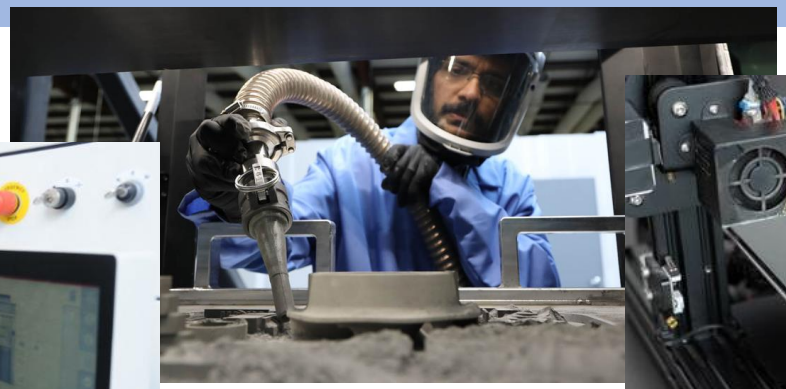
POWDER BED FUSION (PBF)

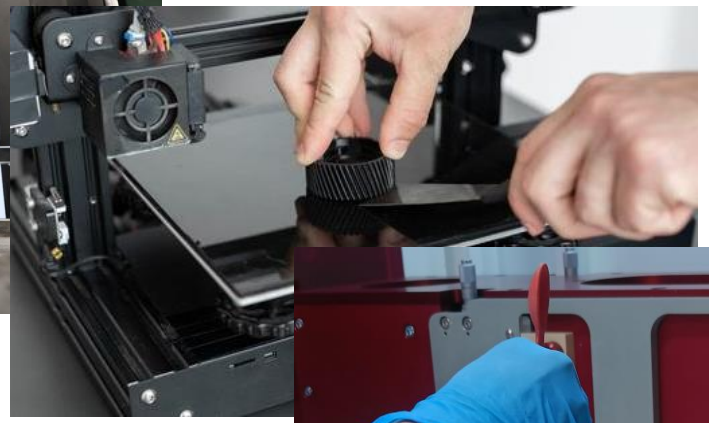


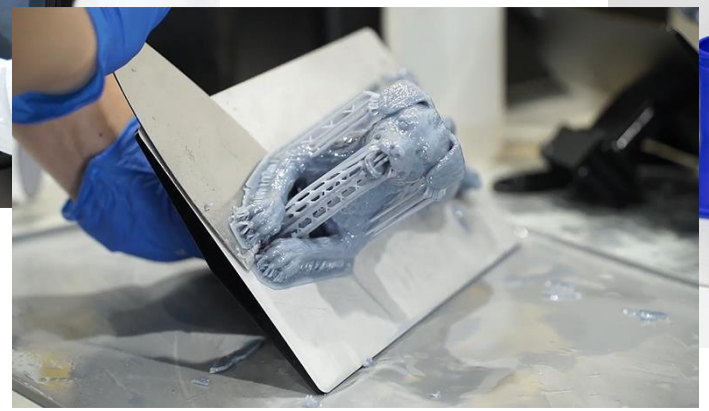
SHEET LAMINATION (SHL)



STEP 5: EXTRACTION







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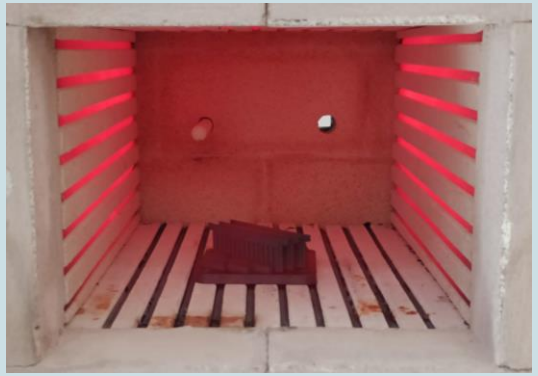
STEP 6: POST-PROCESSING & SURFACE FINISH

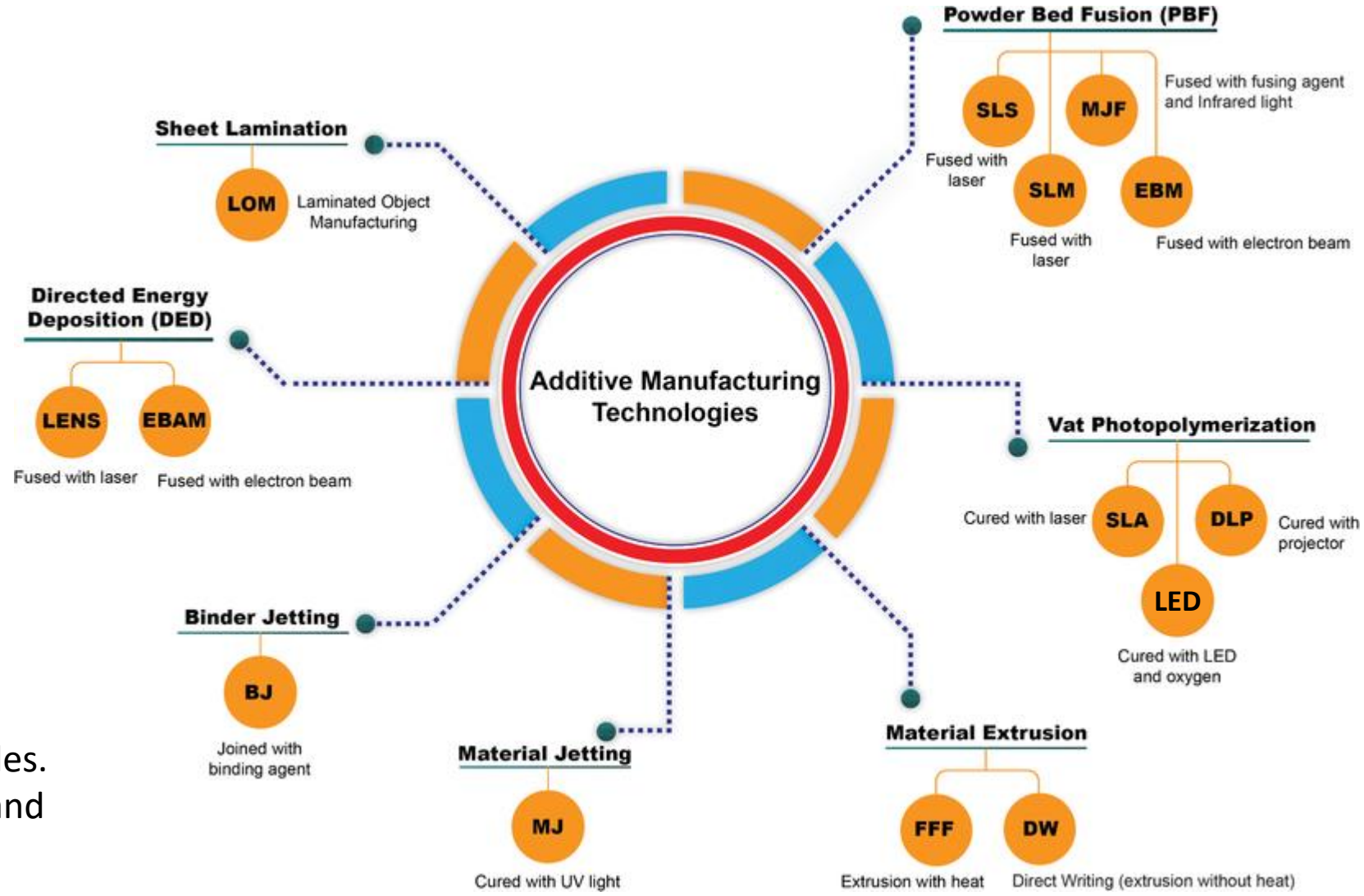
THERMAL



CHEMICAL

SURFACE FINISH

CLASSIFICATION OF AM TECHNOLOGIES: THE 7 CATHEGORIES



ISO/ASTM 52900:2021
"Additive manufacturing. General principles. Fundamentals and vocabulary."

CATEGORIES	TECHNOLOGIES	PRINTED "INK"	POWER SOURCE	STRENGTHS / DOWNSIDES
Material Extrusion	Fused Deposition Modeling (FDM)	Thermoplastics, Ceramic slurries, Metal pastes	Thermal Energy	• Inexpensive extrusion machine • Multi-material printing • Limited part resolution • Poor surface finish
	Contour Crafting			
Powder Bed Fusion	Selective Laser Sintering (SLS)	Polyamides /Polymer	High-powered Laser Beam	• High Accuracy and Details • Fully dense parts • High specific strength & stiffness • Powder handling & recycling • Support and anchor structure • Fully dense parts • High specific strength and stiffness
	Direct Metal Laser Sintering (DMLS)	Atomized metal powder (17-4 PH stainless steel, cobalt chromium, titanium Ti6Al-4V), ceramic powder		
	Selective Laser Melting (SLM)			
	Electron Beam Melting (EBM)		Electron Beam	
Vat Photopolymerization	Stereolithography (SLA)	Photopolymer, Ceramics (alumina, zirconia, PZT)	Ultraviolet Laser	• High building speed • Good part resolution • Overcuring, scanned line shape • High cost for supplies and materials
Material Jetting	Polyjet / Inkjet Printing	Photopolymer, Wax	Thermal Energy / Photocuring	• Multi-material printing • High surface finish • Low-strength material
Binder Jetting	Indirect Inkjet Printing (Binder 3DP)	Polymer Powder (Plaster, Resin), Ceramic powder, Metal powder	Thermal Energy	• Full-color objects printing • Require infiltration during post-processing • Wide material selection • High porosites on finished parts
Sheet Lamination	Laminated Object Manufacturing (LOM)	Plastic Film, Metallic Sheet, Ceramic Tape	Laser Beam	• High surface finish • Low material, machine, process cost • Decubing issues
Directed Energy Deposition	Laser Engineered Net Shaping (LENS) Electronic Beam Welding (EBW)	Molten metal powder	Laser Beam	• Repair of damaged / worn parts • Functionally graded material printing • Require post-processing machine

MATERIAL EXTRUSION (MEX)

Material extrusion is an AM process where the material is **selectively deposited** through an **extruder or an orifice**.

MOST KNOWN
90% market of "Desktop Printers"
30% professional market

Identification according to ISO/ASTM 52900:2021

MEX-CRB

Bounded by chemical reaction

MEX-TRB

Bounded by thermal reaction

MATERIAL EXTRUSION (MEX)

MEX-TRB

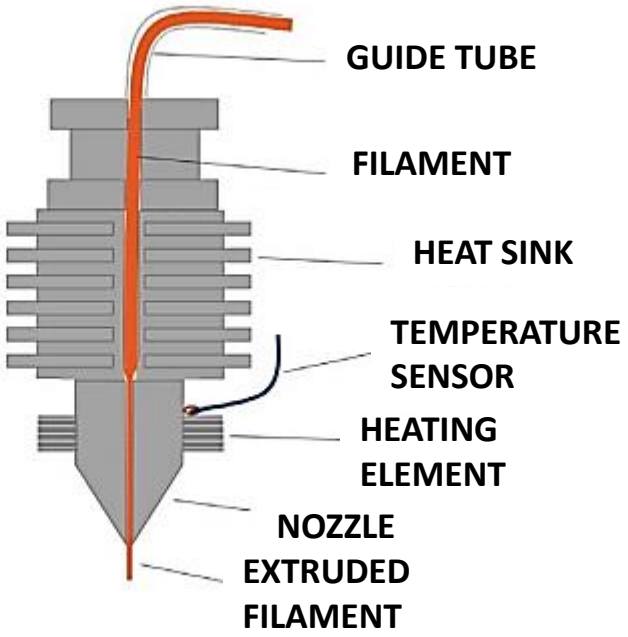
FDM/FFF
Fused Deposition Modeling / Fused Filament Fabrication

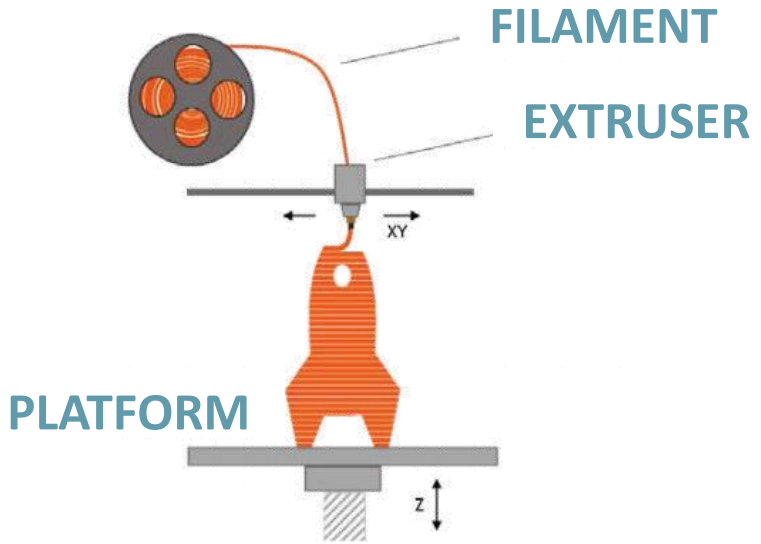
CFF
Continuos Fibre Fabrication

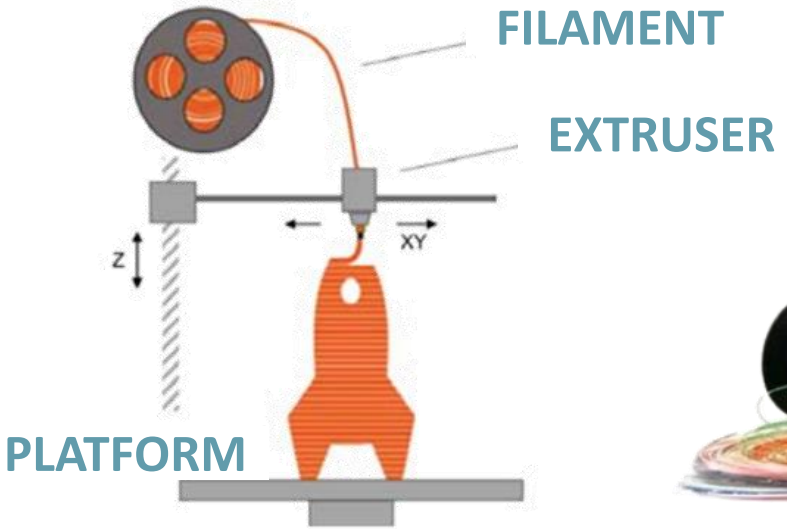
DIW
Direct Ink Write

HEAT DISSIPATION ZONE

HEATING ZONE







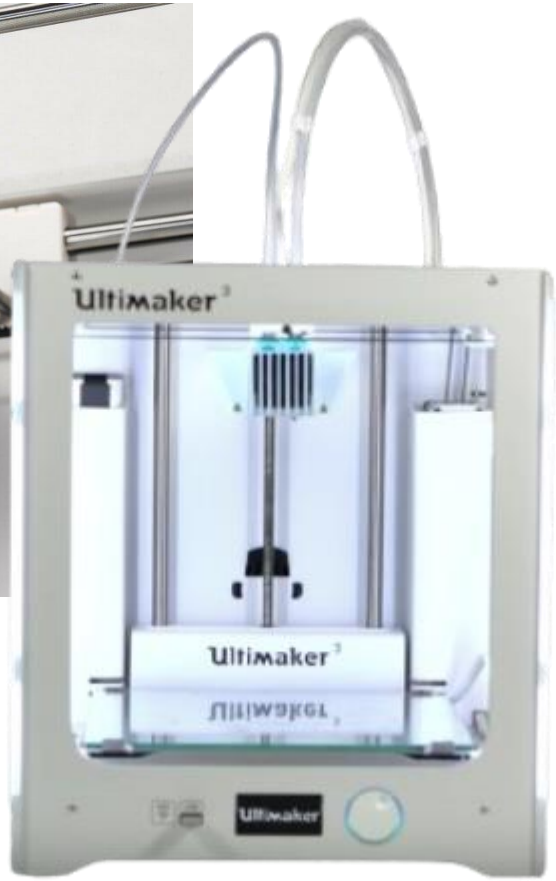
MATERIAL EXTRUSION (MEX)

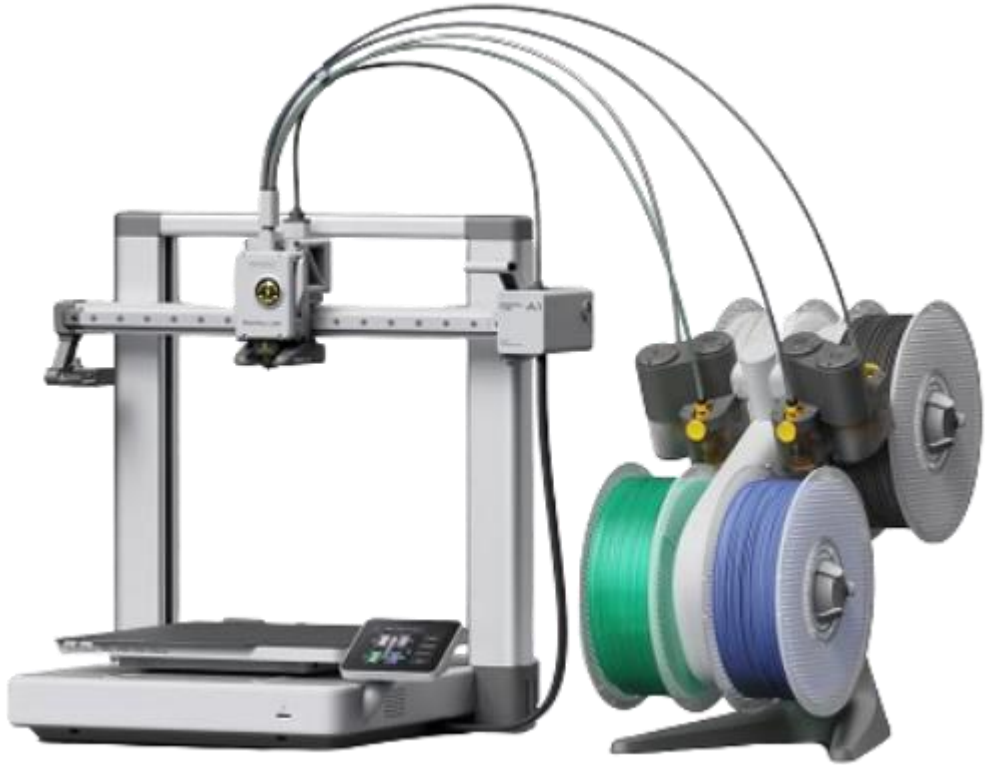
MEX-TRB

FDM/FFF
Fused Deposition Modeling / Fused Filament Fabrication

CFF
Continuos Fibre Fabrication

DIW
Direct Ink Write





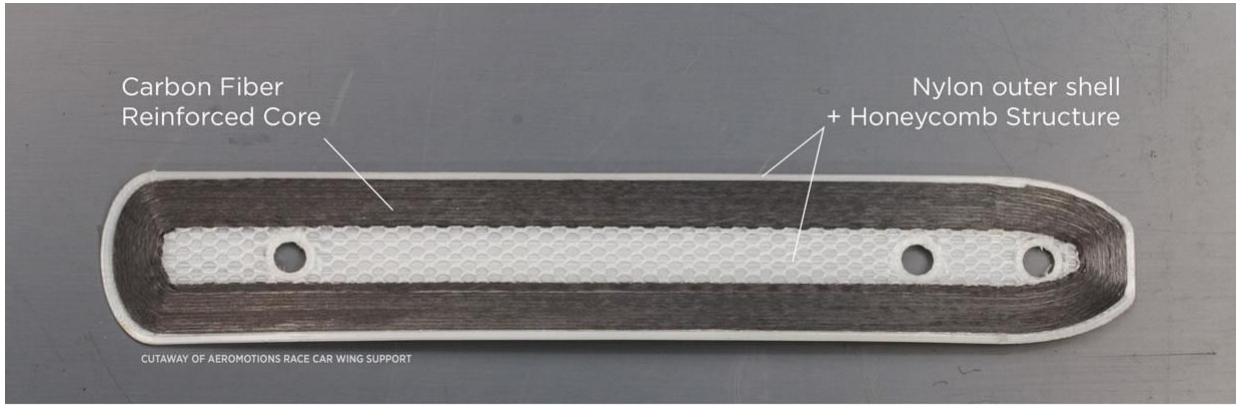
MATERIAL EXTRUSION (MEX)

MEX-TRB

FDM/FFF
Fused Deposition Modeling / Fused Filament Fabrication

CFF
Continuos Fibre Fabrication

DIW
Direct Ink Write



MATERIAL EXTRUSION (MEX)

MEX-TRB

FDM/FFF

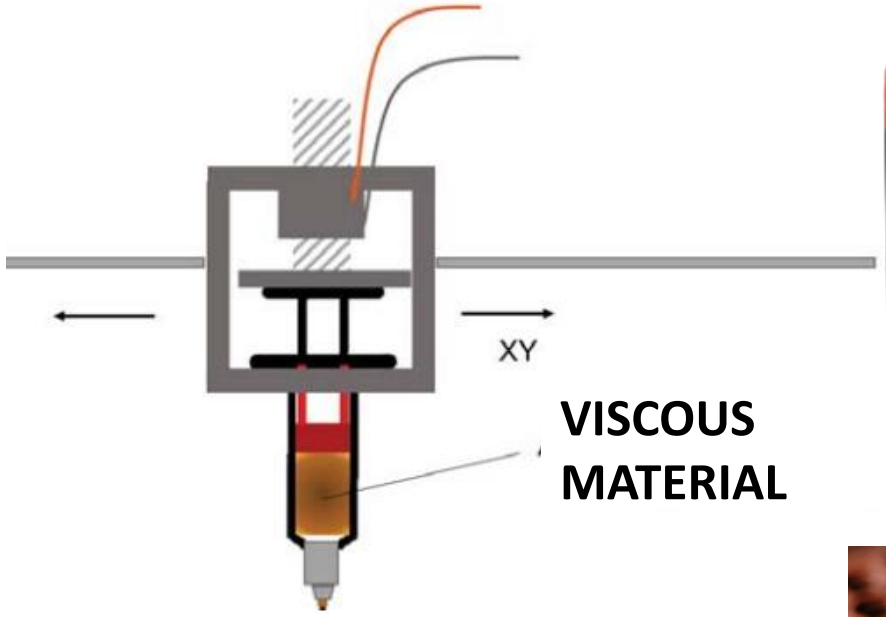
Fused Deposition Modeling / Fused Filament Fabrication

CFF

Continuos Fibre Fabrication

DIW

Direct Ink Write



VISCOUS MATERIAL

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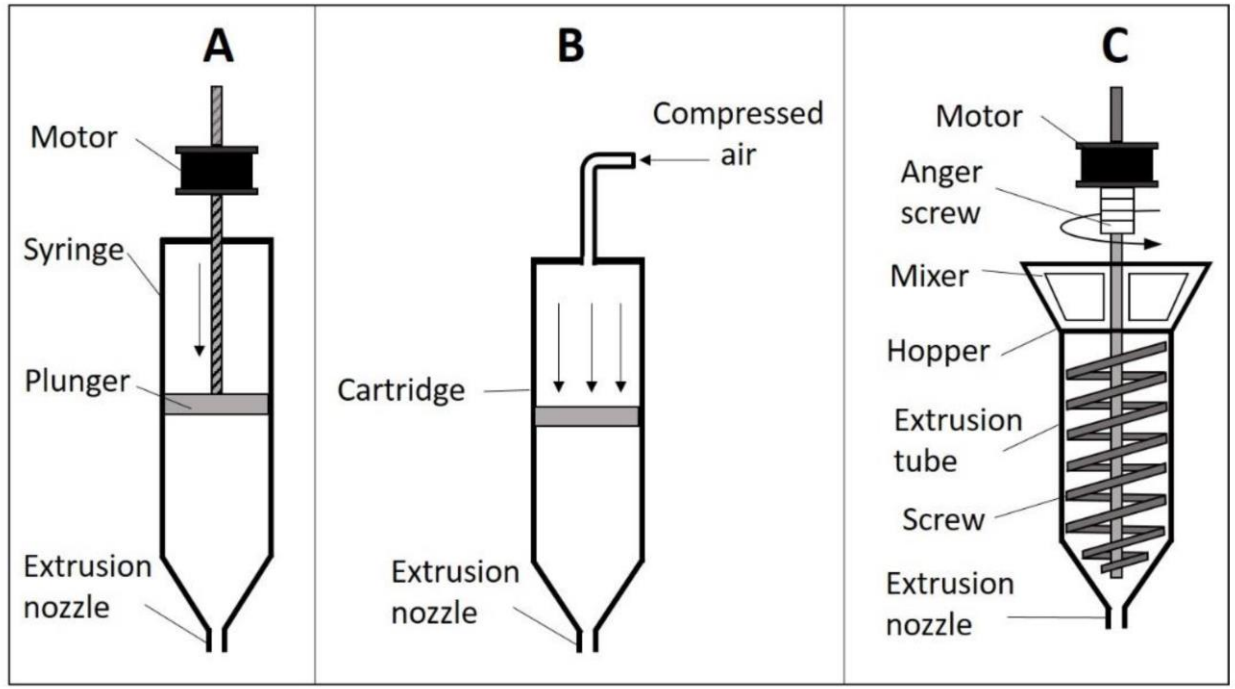
MATERIAL EXTRUSION (MEX)

MEX-CRB

Bounded by
Chemical Reaction

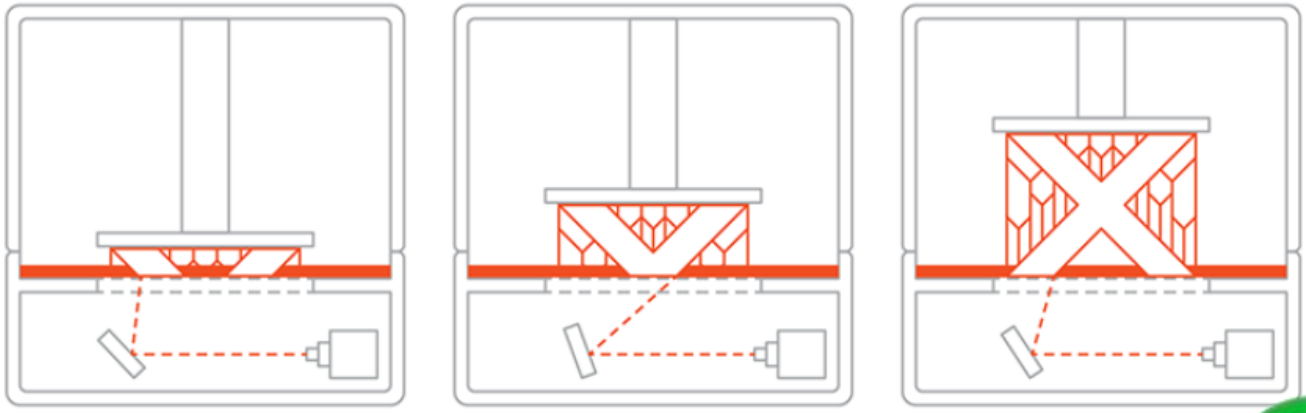


VAT PHOTOPOLIMERIZATION (VPP)

ALSO KNOWN AS STEREOLITHOGRAPHY (SLA)

First AM process to be successfully commercialized. (**Chuck Hull** – **1980s**)

Vat photopolymerization uses a **light source** to activate a **photopolymer that hardens** when hit by the right wavelength and intensity of light.



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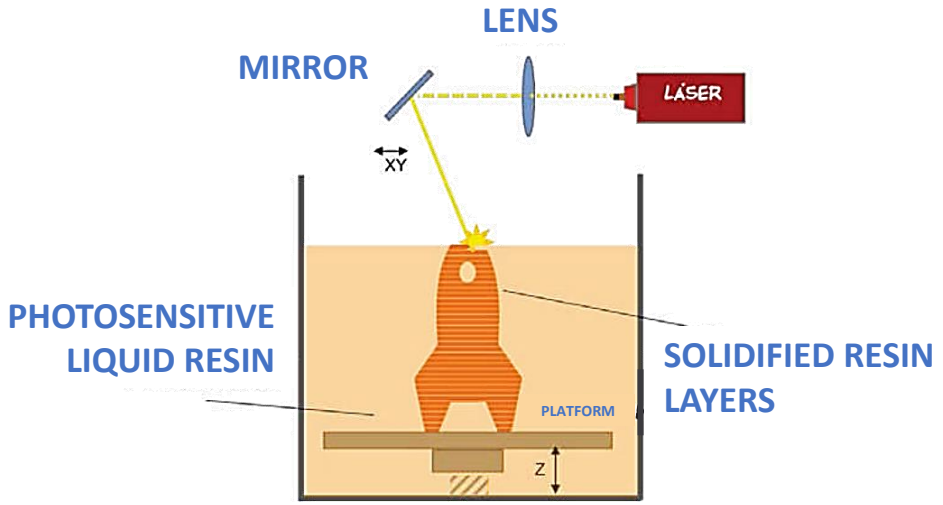
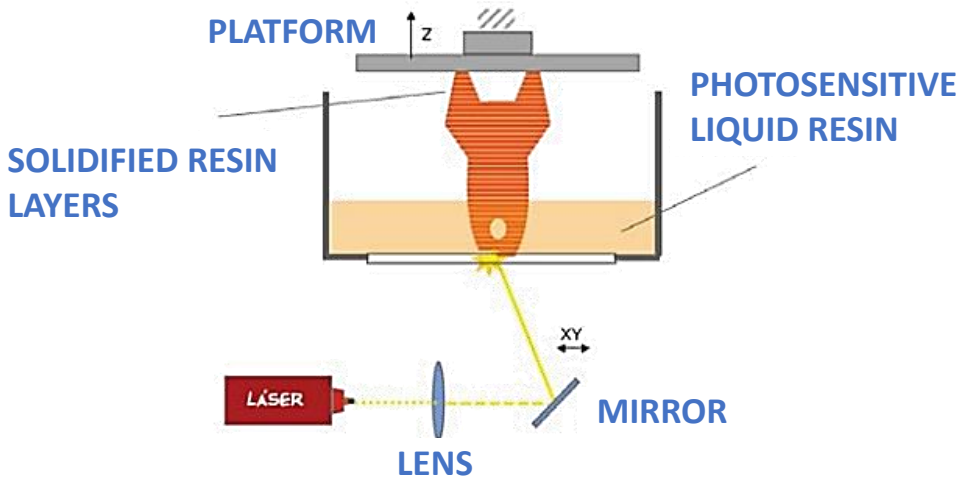
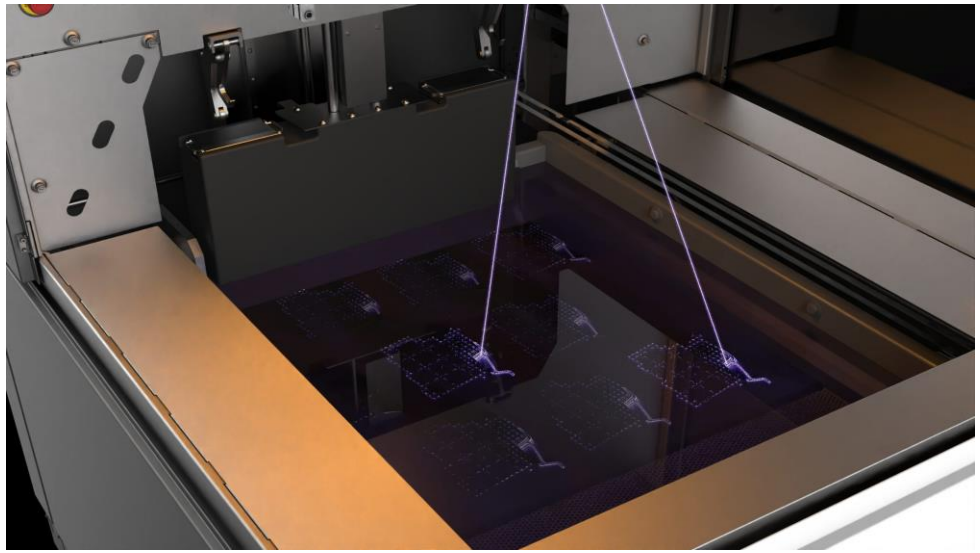
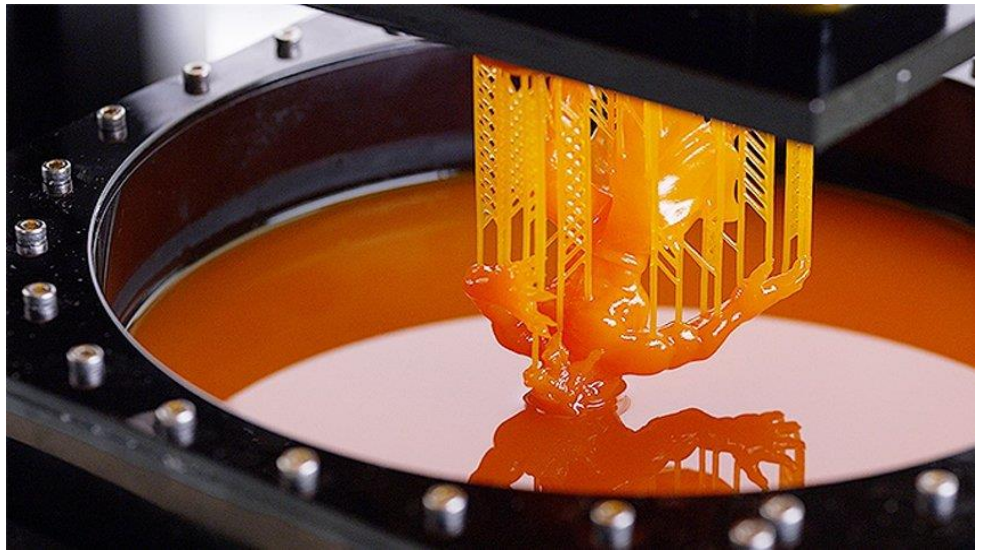
VAT PHOTOPOLIMERIZATION (VPP)

ALSO KNOWN AS STEREOLITHOGRAPHY (SLA)



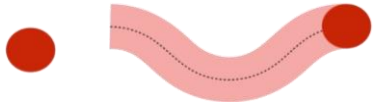
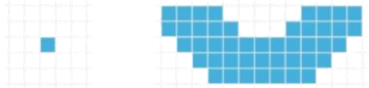
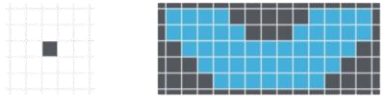


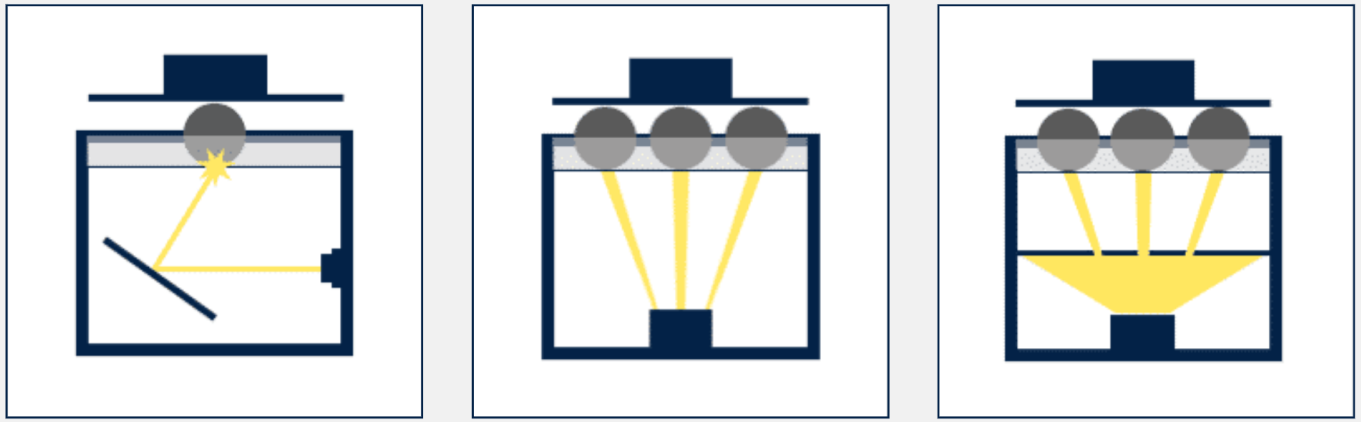




VAT PHOTOPOLIMERIZATION (VPP)

ALSO KNOWN AS STEREOLITHOGRAPHY (SLA)

Identification according to ISO/ASTM 52900:2021	**VPP-UVL** ULTRAVIOLET LIGHT	VS	**VPP-UVM** ULTRAVIOLET MASK	VS	**VPP-LED**
Commercial names	**SLA** Stereolithography		**DLP** Digital Light Processing		**LCD** Liquid Cristal Display
Projection mode					

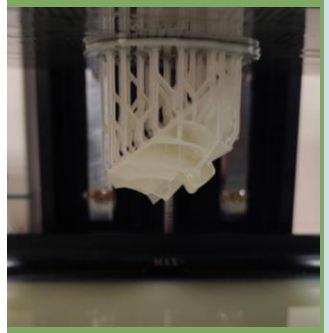


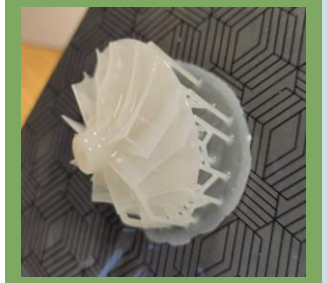
VAT PHOTOPOLIMERIZATION (VPP)

ALSO KNOWN AS STEREOLITHOGRAPHY (SLA)

POSTPROCESSING

EXTRACTION

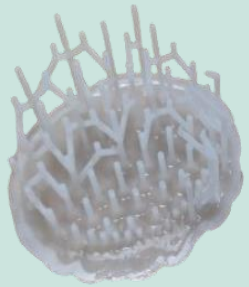




CLEANING

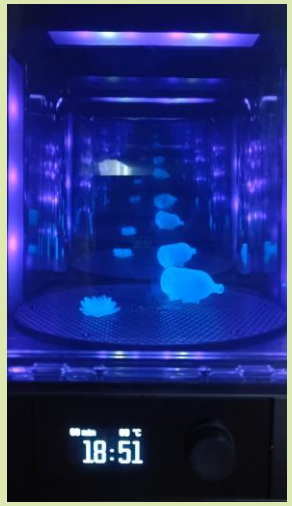
- ISOPROPYL ALCOHOL
- ULTRASONIC (5-10 MIN)
- AIR DRYING (30 MIN) OR PRESSURISED AIR (2 MIN)

REMOVAL OF SUPPORTS



POST-CURING (UV)

- PARAMETERS:
  - Tª
  - TIME



OPTIONAL POSTPROCESSING

- SANDING
- POLISHING
- PRIMING
- PAINTING
- CHROME PLATING
- ETC

HUBS

Artcraft plating

FINAL PART

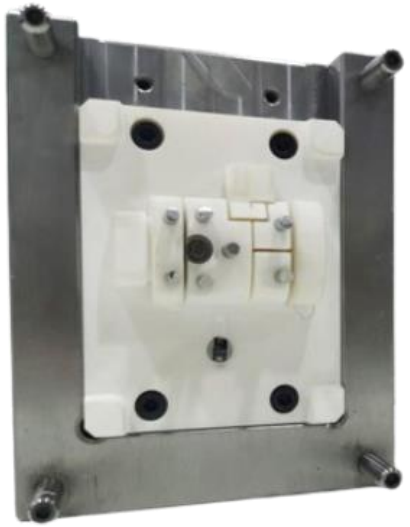
VAT PHOTOPOLIMERIZATION (VPP)

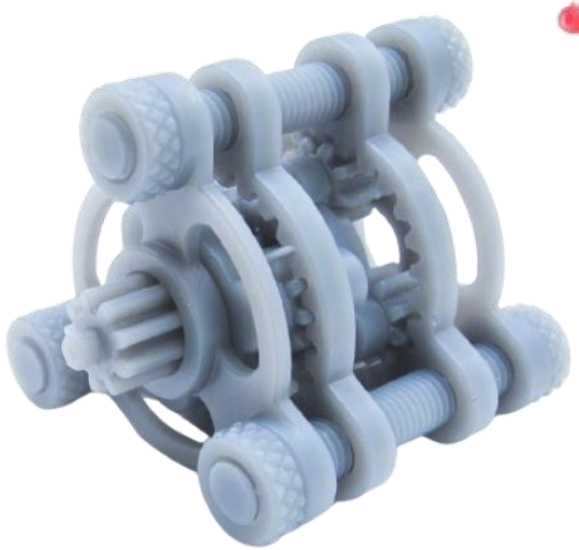
ALSO KNOWN AS STEREOLITHOGRAPHY (SLA)

Photo Credits: HUBS; Formlabs; ELEGOO;

MAIN APPLICATIONS

- PRODUCT DESIGN AND ENGINEERING
- MANUFACTURING
- DENTISTRY
- EDUCATION
- HEALTHCARE
- ENTERTAINMENT
- JEWELLERY





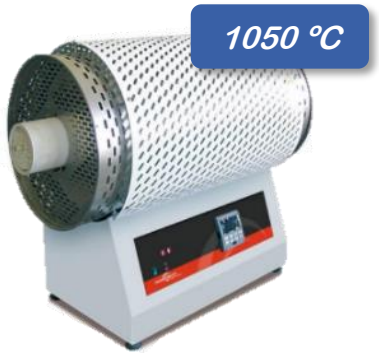
VAT PHOTOPOLIMERIZATION WITH CERAMICS (VPP-UVL/C)

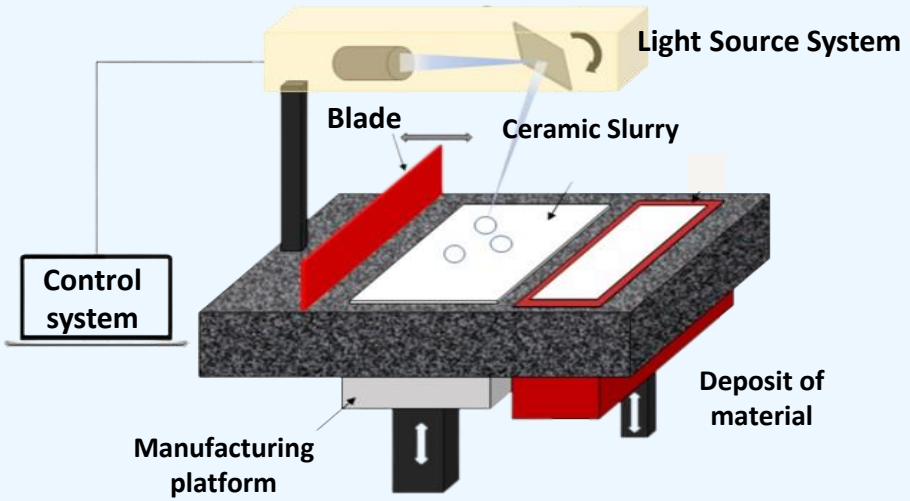
PRINTING → CLEANING → DEBINDING → SINTERING → FINAL PART

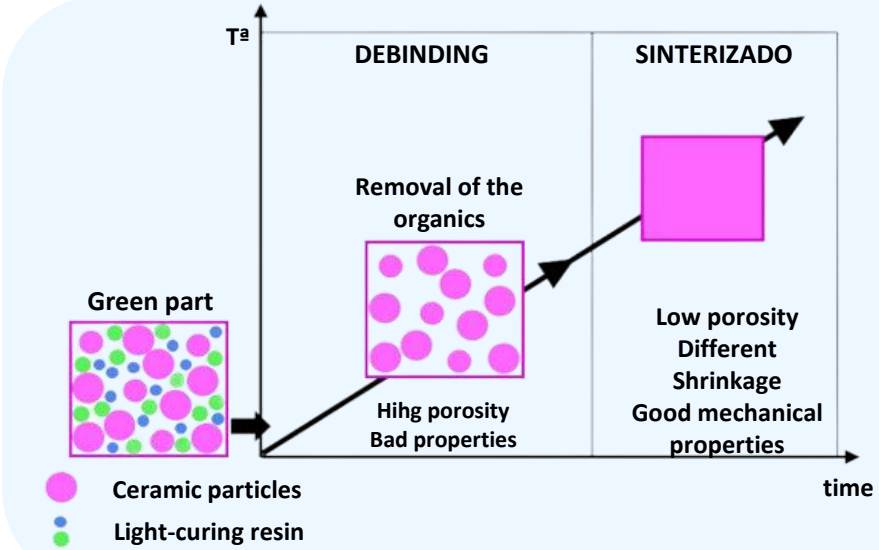
MATERIAL: ALUMINA SUSPENSION MIXED WITH PHOTOPOLYMERS

C900-Flex

Green part

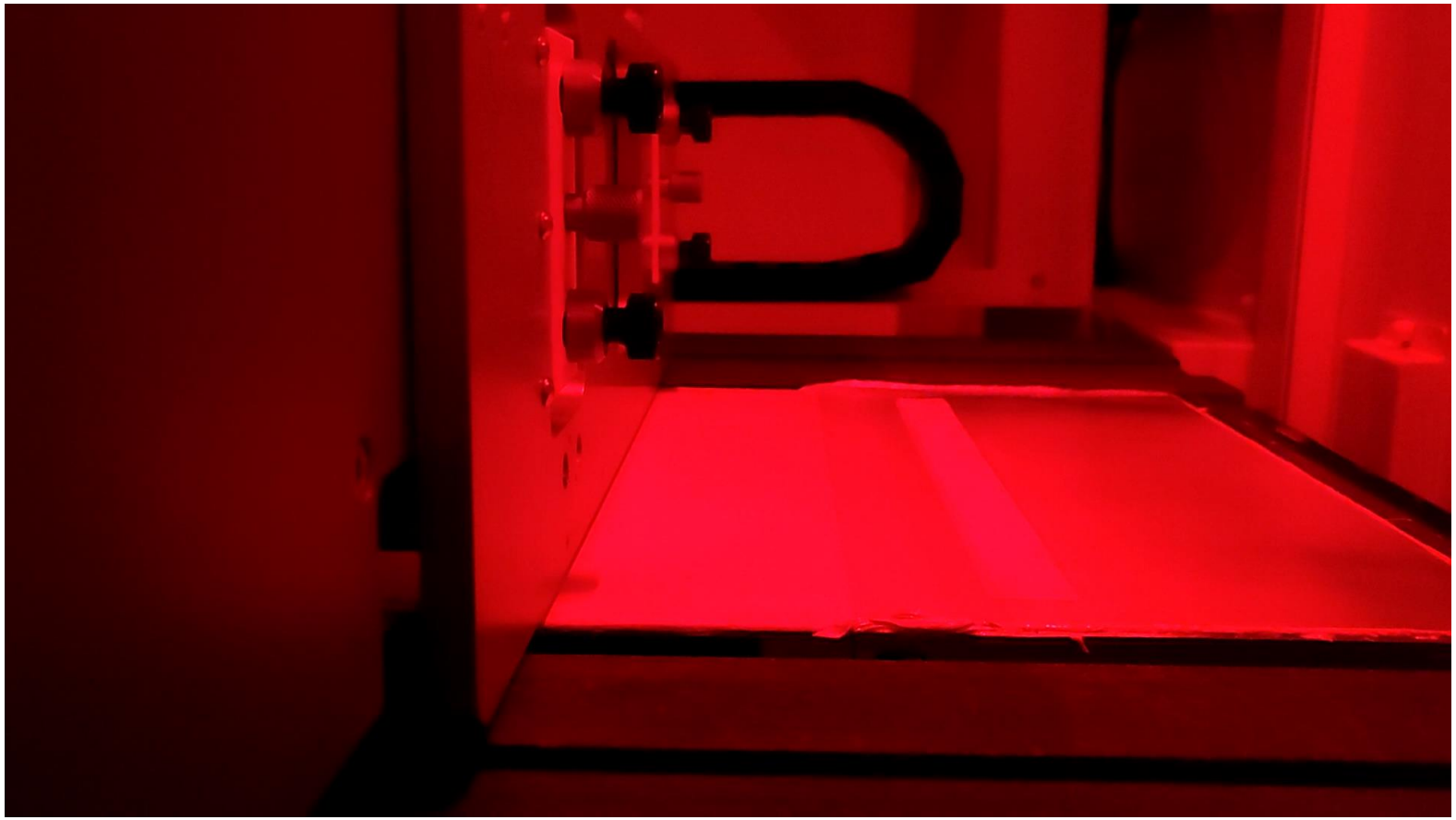






VAT PHOTOPOLIMERIZATION WITH CERAMICS (VPP-UVL/C)

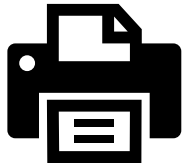
PRINTING PROCESS



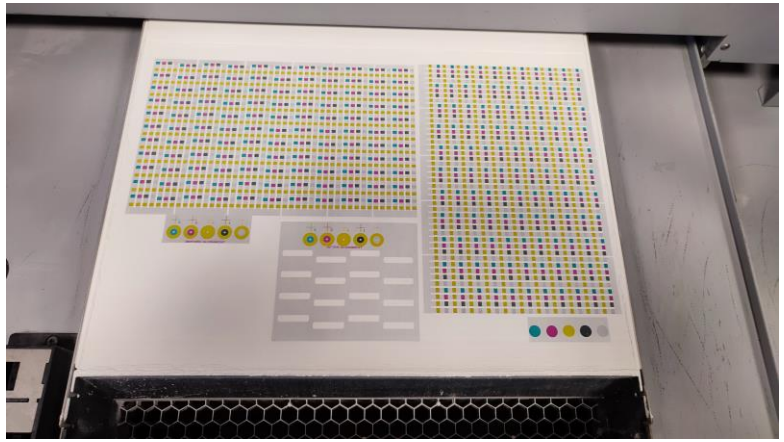
ADVANTAGES

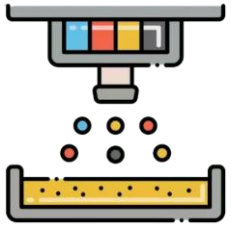
- High density sintered parts (guaranty of good mechanical properties)
- High dimensional accuracy
- Smooth surface finish

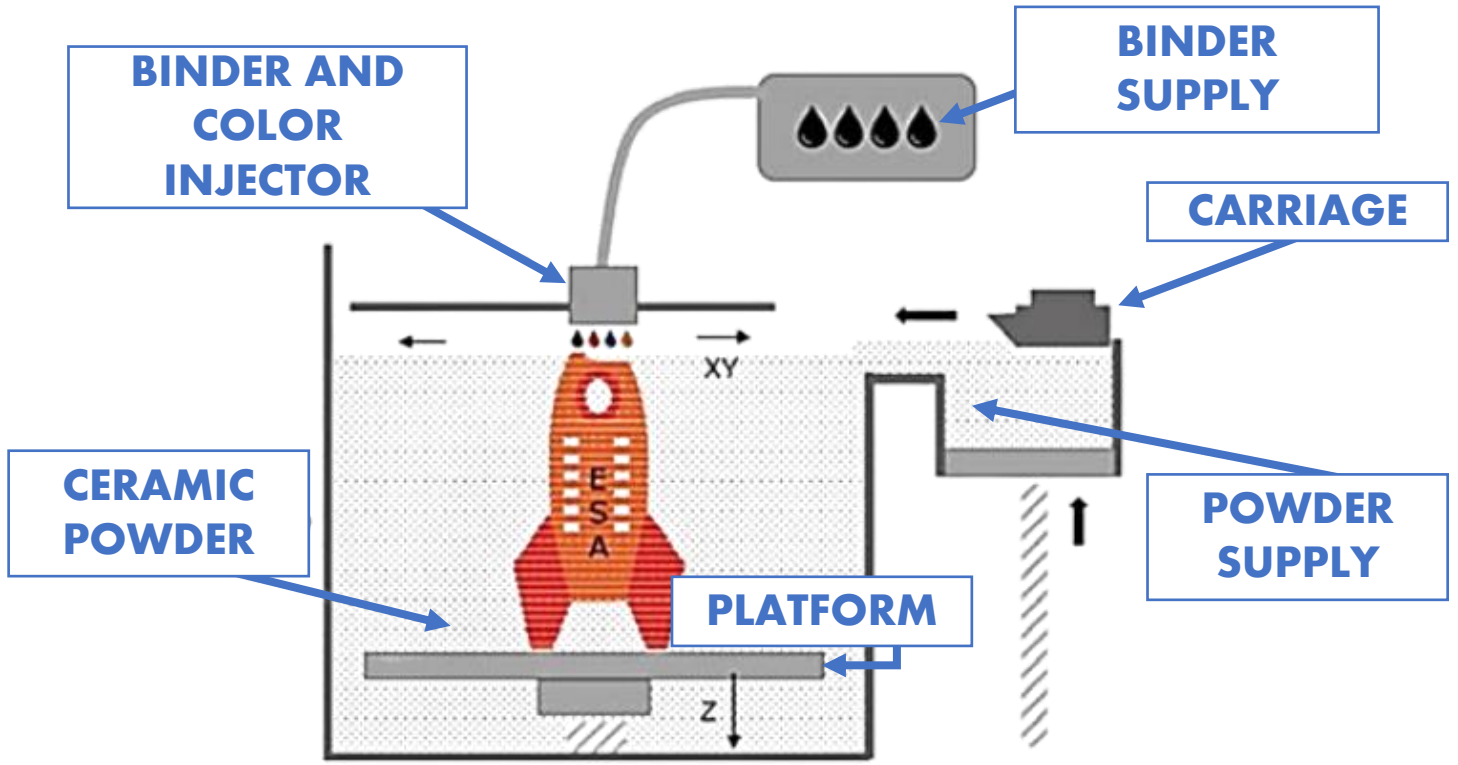
BINDER JETTING (BJT)



This process of AM is the one that gave the **3D printing** name due to its similarity with the **paper printers**

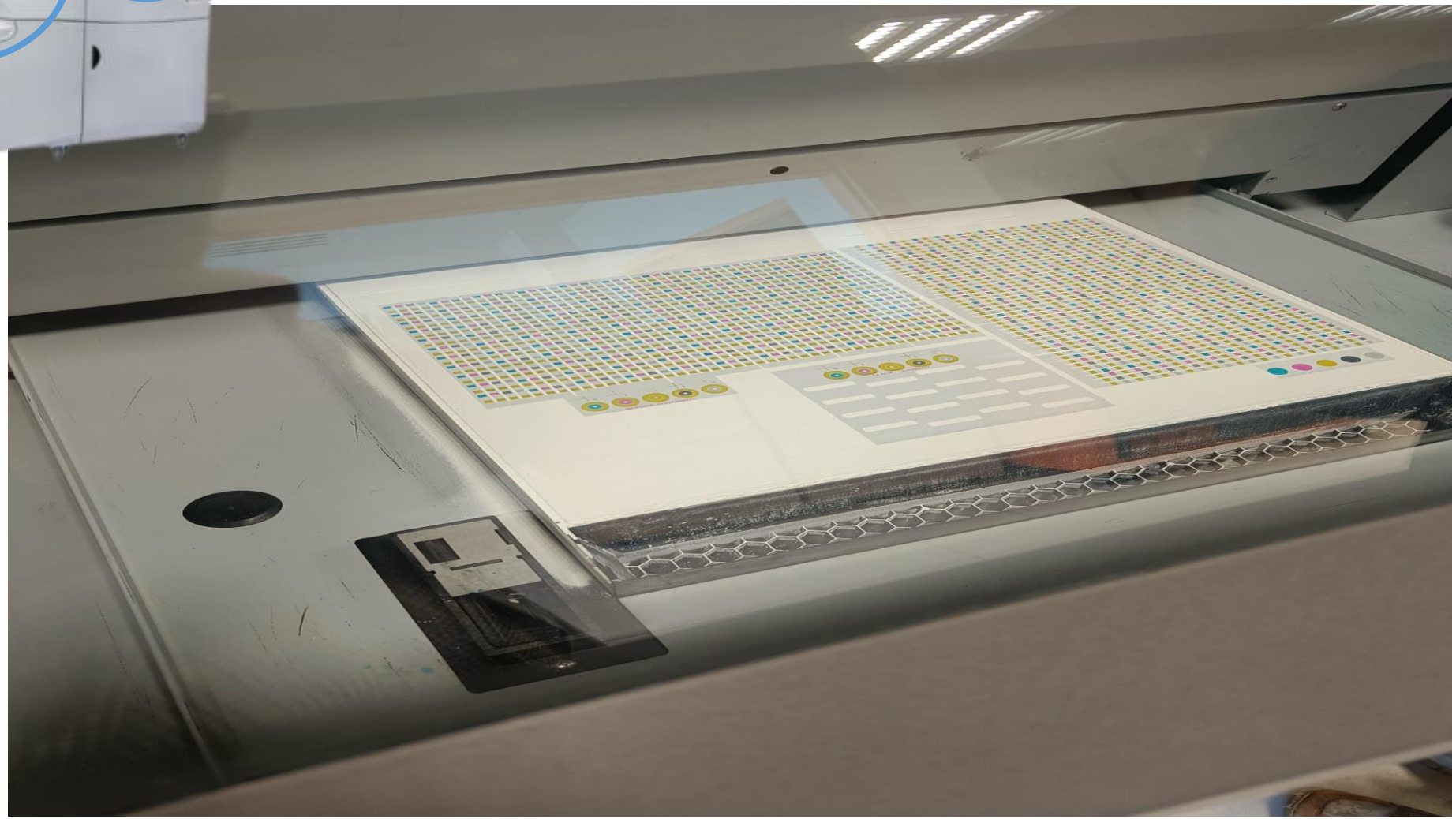






Binder Jetting consists in a liquid binding agent (**binder**) is **selectively deposited** to join **powdered materials**.

BINDER JETTING (BJT)



Video from SiDe Design

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BINDER JETTING (BJT)

POSTPROCESSING

- CERAMIC MATERIALS
  - INFILTRATION
- METAL MATERIALS
  - INFILTRATION
  - SINTERING
  - FINISHING

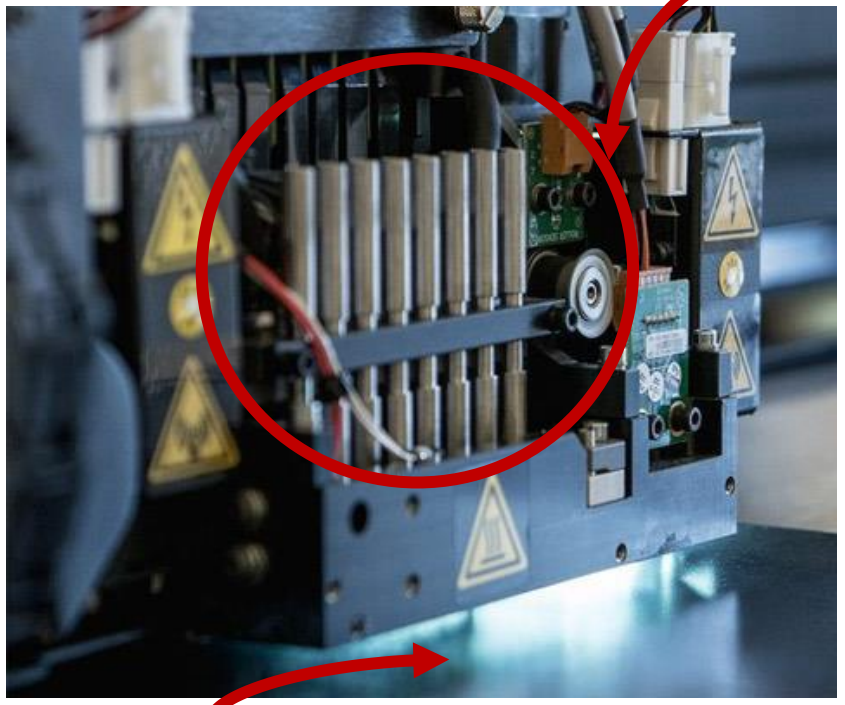
APPLICATIONS

Photo Credits:
- 3DSystems
- ExOne
- UFI3D Unileon

MATERIAL JETTING (MJT)

Material Jetting process consists in **droplets** of feedstock material are selectively deposited.

MANUFACTURING PRINCIPLE:https://share.vidyard.com/watch/tutFoLzyXgqbUU8itzpFKf



MATERIAL JETTING (MJT)

Photo Credits: Stratasys; Additive 3D;

ADVANTAGES

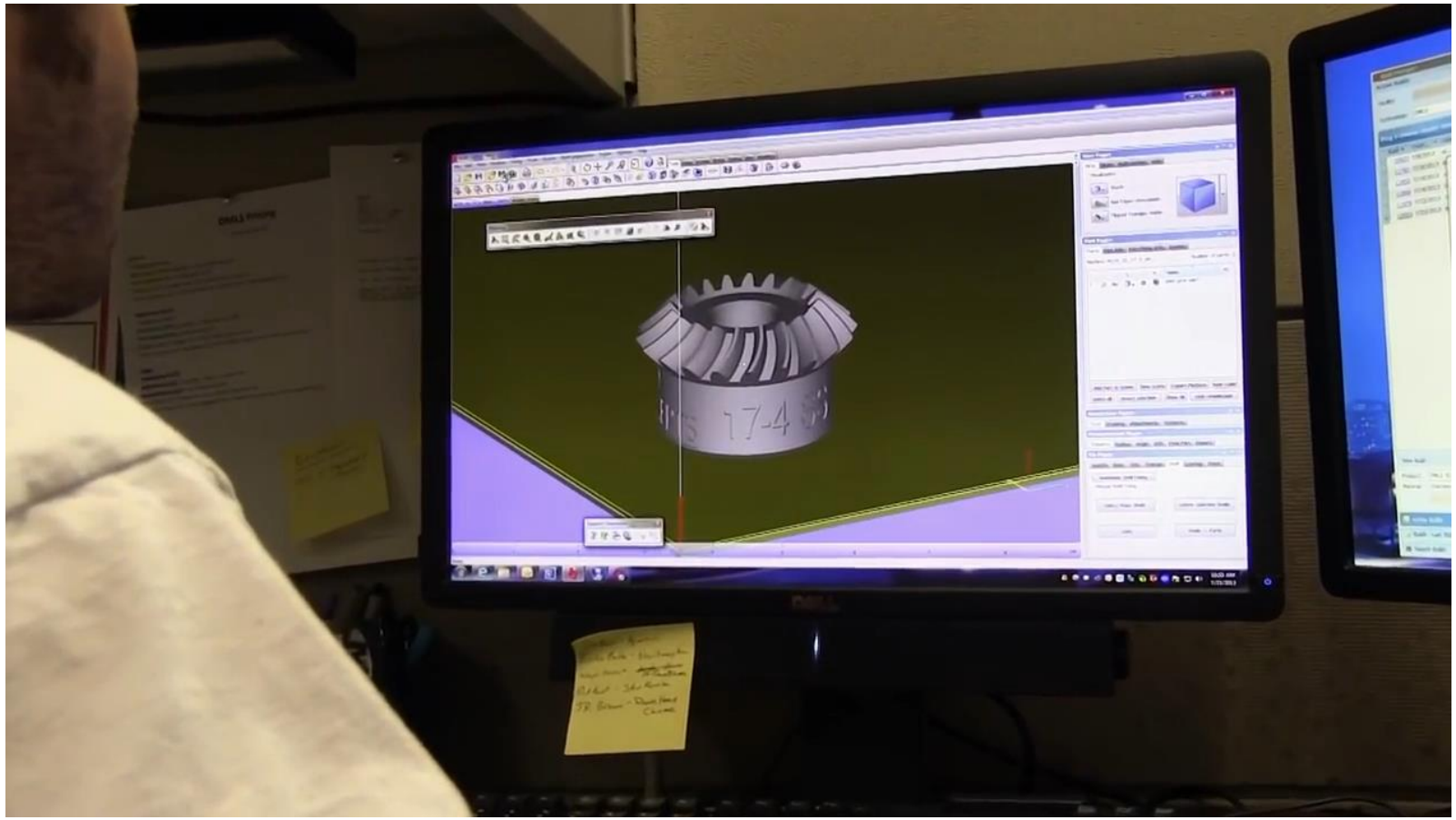
- Accuracy
- Full-colour and multi-material parts
- Support structures

LIMITATIONS

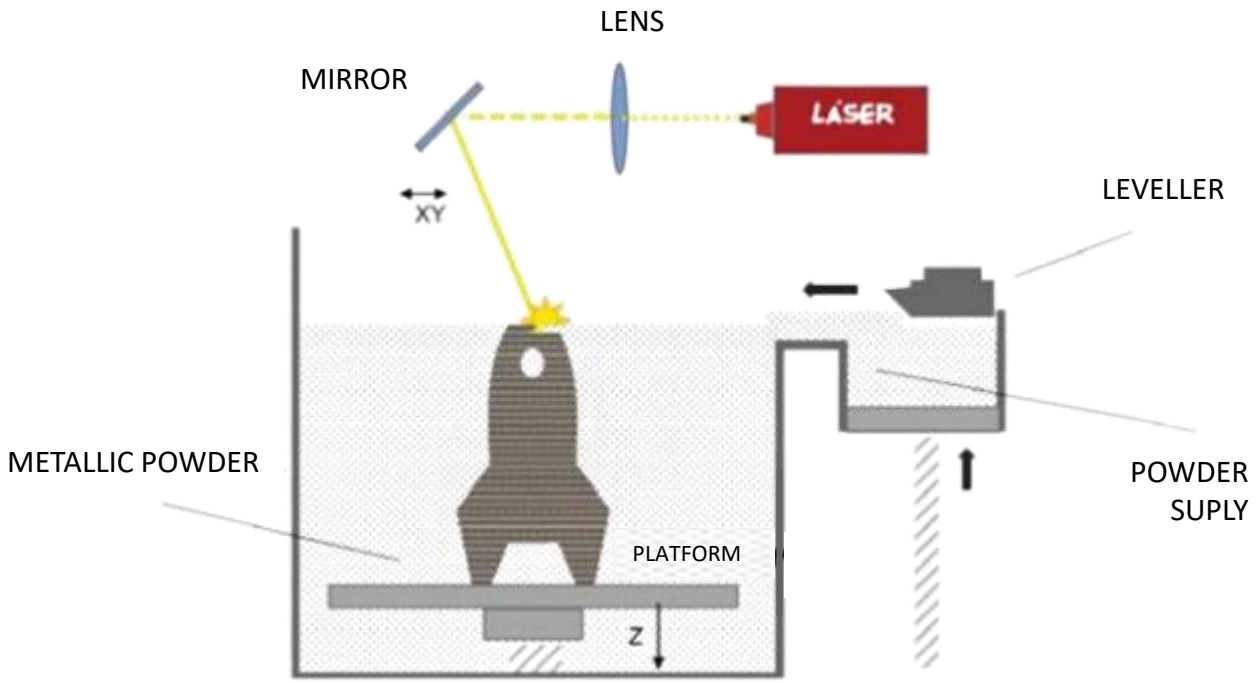
- Poor mechanical properties
- Slow printing process
- Material limitations

POWDER BED FUSION (PBF)

Powder Bed Fusion achieve 3D manufacturing by **melting selectively** a **powdered material** through a **thermal energy** source.



POWDER BED FUSION (PBF)



Selective Laser Melting (SLM)

- Fused with laser. Homogeneous metallic powder of the same metal

Direct Metal Laser Sintering (DMLS)

- Fused with laser. Metallic Alloys powder.

Selective Laser Sintering (SLS)

- Fused with laser.Non-metallic materials powder

Electro Beam Melting (EBM)

- Fused with Electro Beam. Metallic powder

Multi-Jet Fusion (MJF)

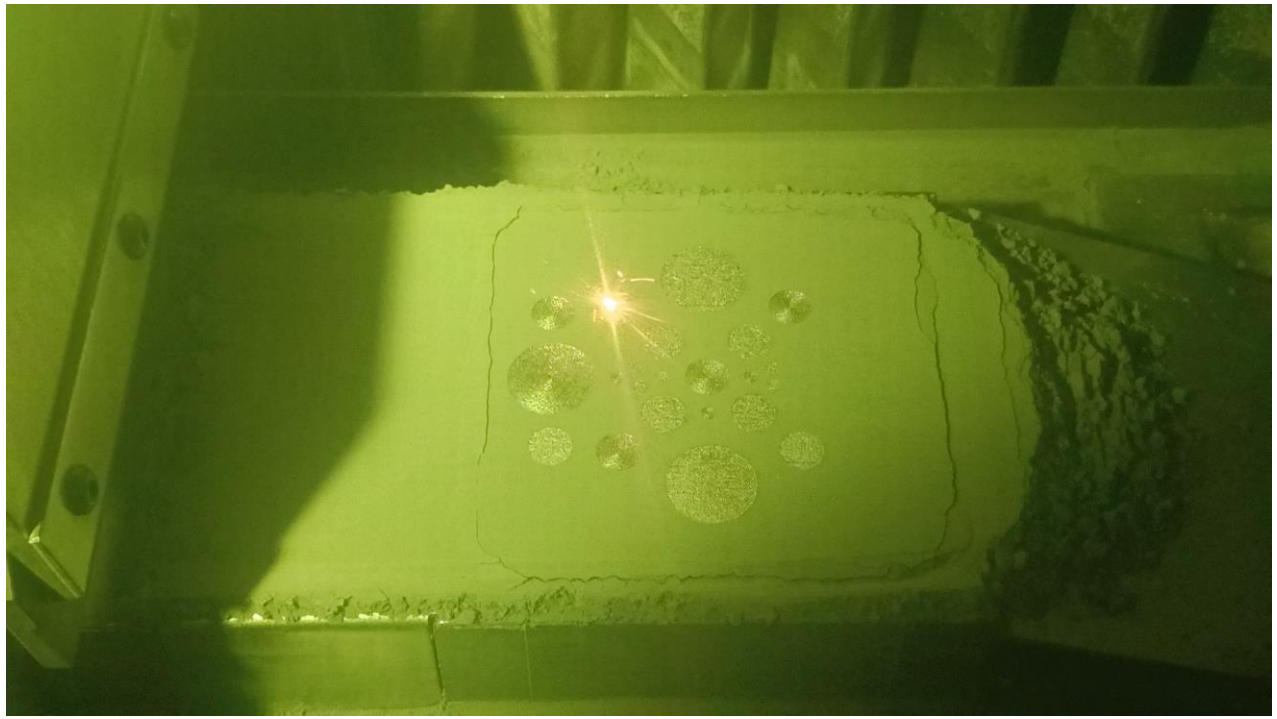
- Fused with fusing agent and infrared light.

POWDER BED FUSION (PBF)

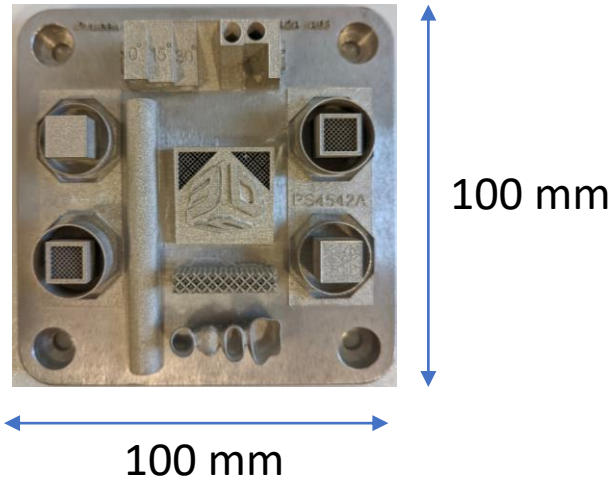
Direct Metal Laser Sintering (DMLS)

https://youtu.be/MtOvlzyoS4s

Printing with different path strategies



Phenix ProX DMP 100



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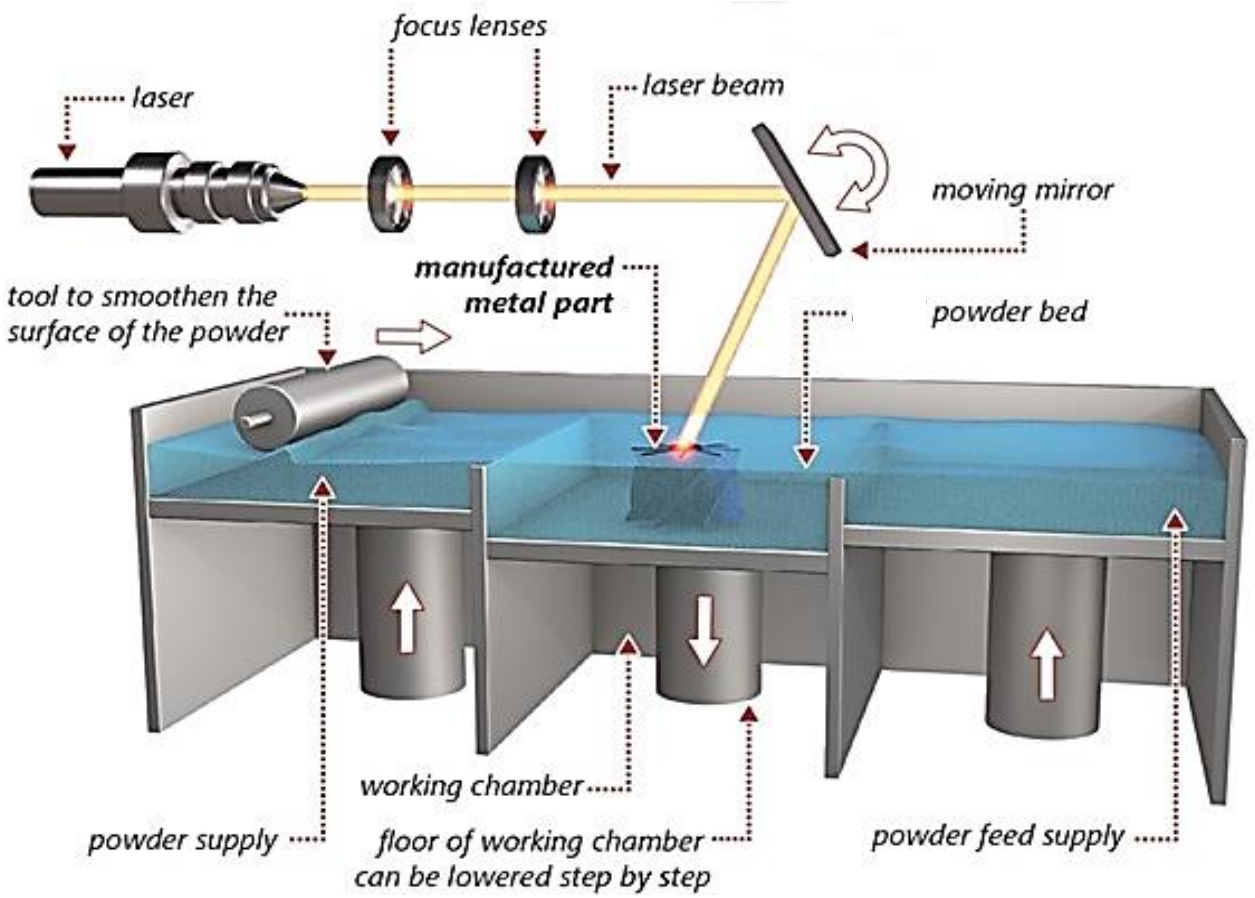
POWDER BED FUSION (PBF)

Selective Laser Sintering (SLS)

[How Does Selective Laser Sintering (SLS) 3D Printing Work? (youtube.com)]



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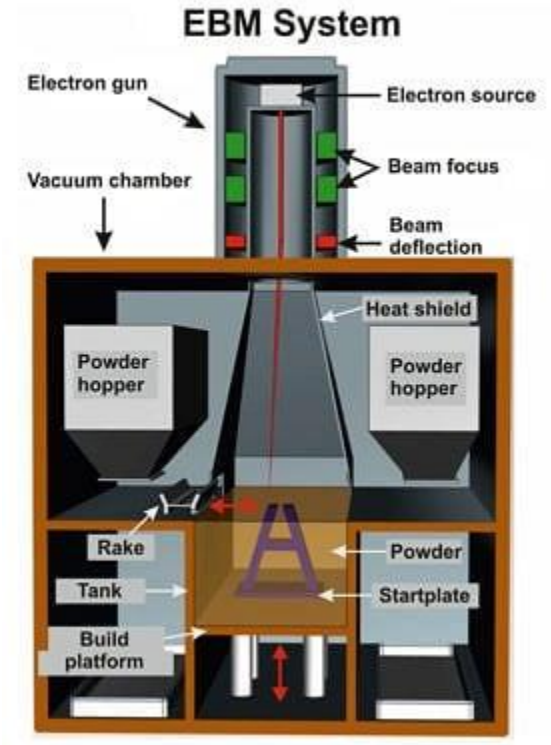
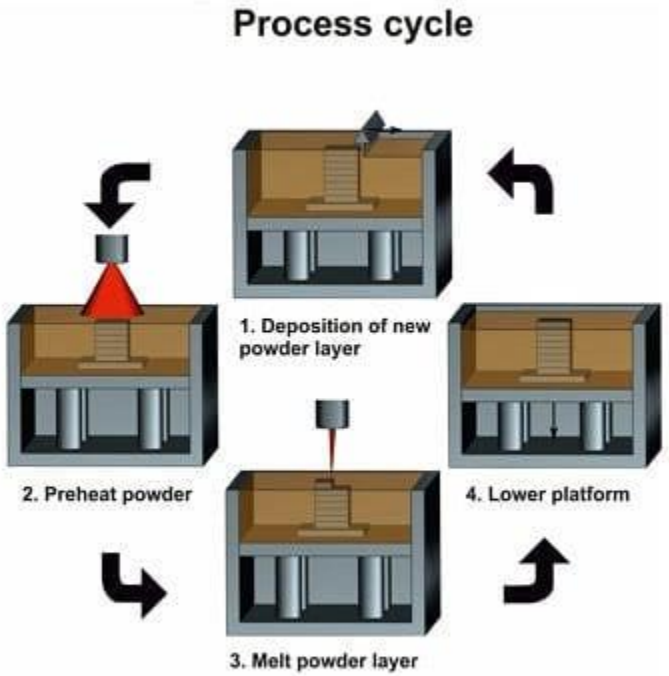
POWDER BED FUSION (PBF)

Electro Beam Melting (EBM)

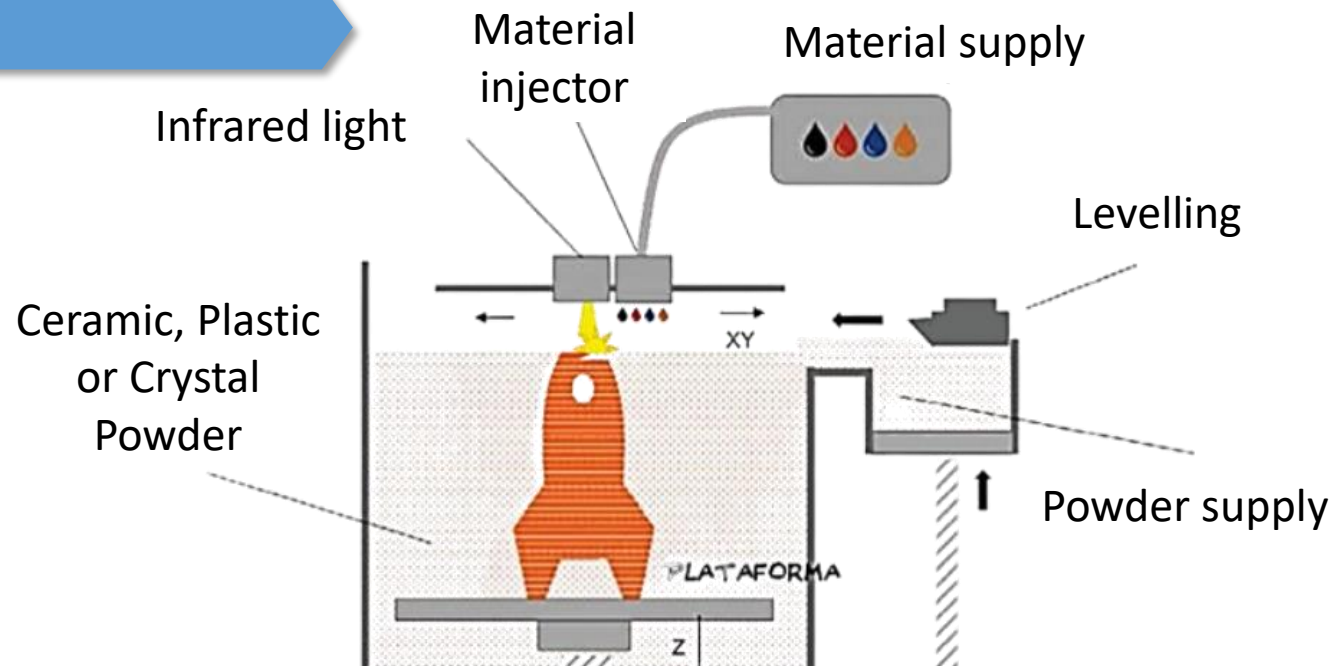


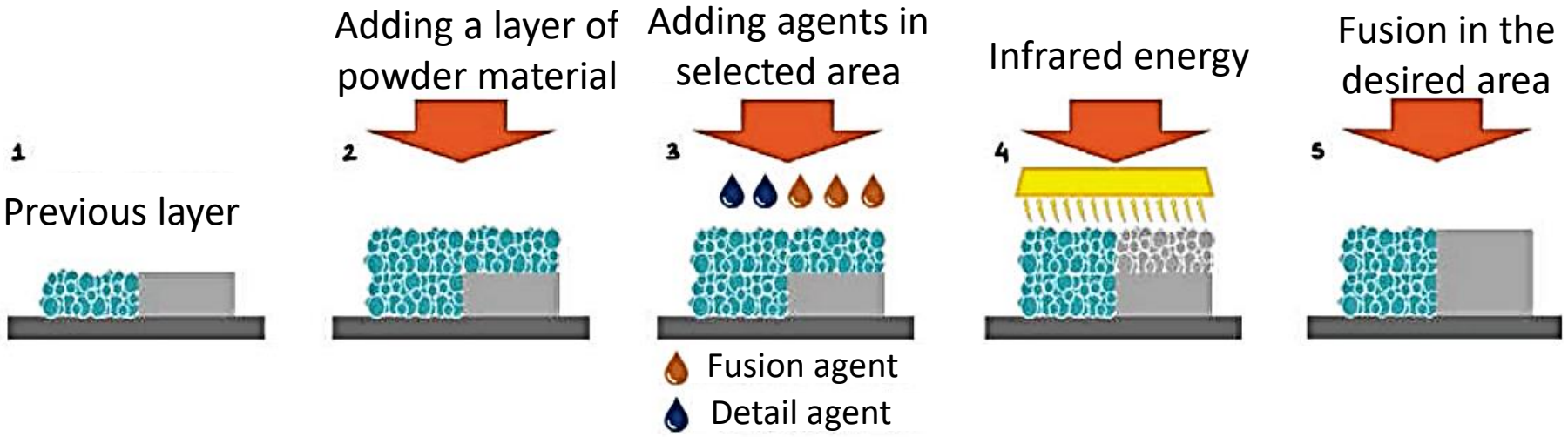


POWDER BED FUSION (PBF)

"MJ + SLS"

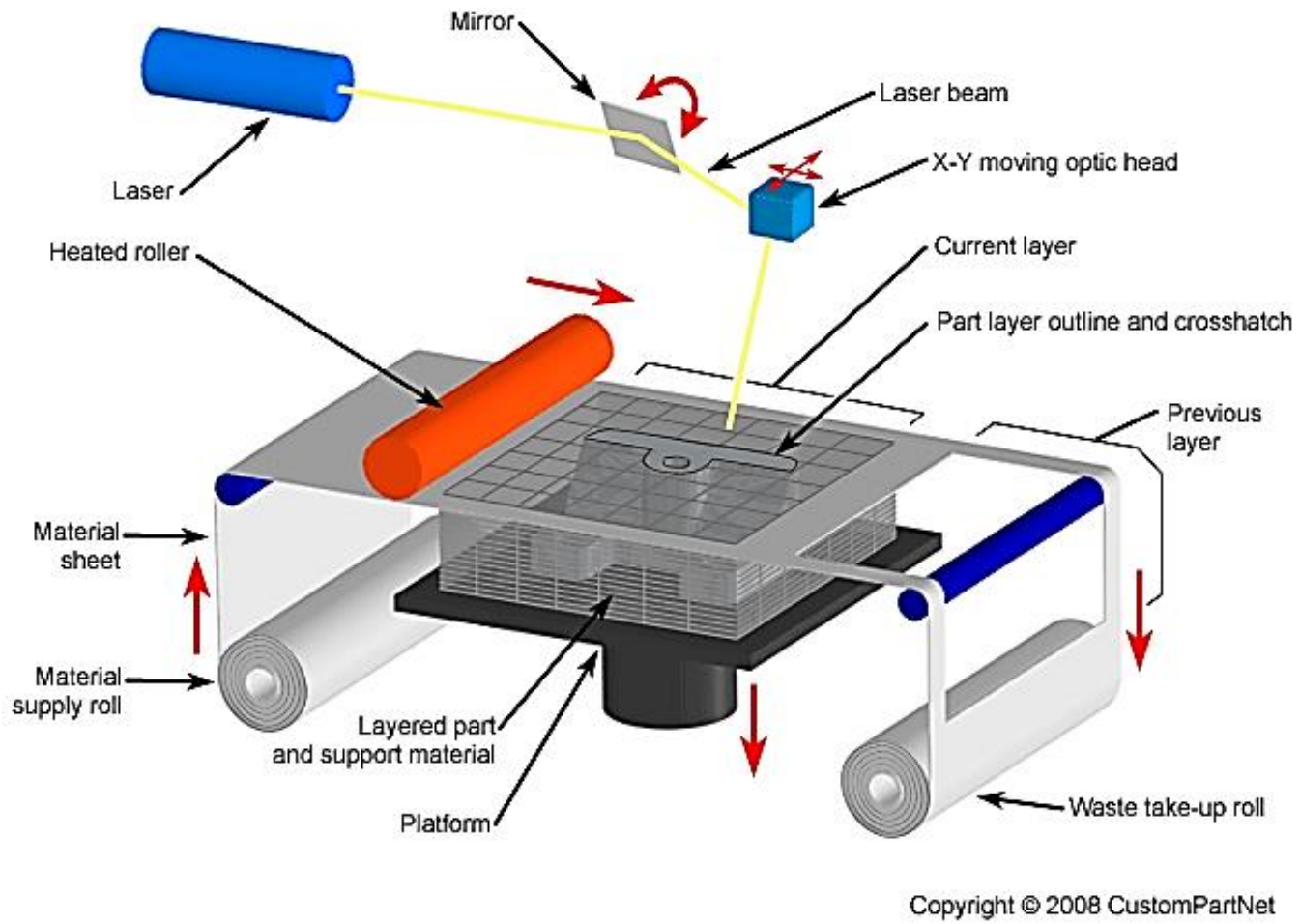
Multi-Jet Fusion (MJF)





SHEET LAMINATION (SHL)

ALSO KNOWN AS LAMINATED OBJECT MANUFACTURING (LOM)



In this process, the material, in form of **sheets**, is **bonded** together to form an object. For that, each sheet is cut to shape with a **knife or laser**.

HOW TO BOND?

Identification according to ISO/ASTM 52900:2021

SHL-AJ

ADHESIVE JOINING

PAPER

PLASTIC

SHL-UC

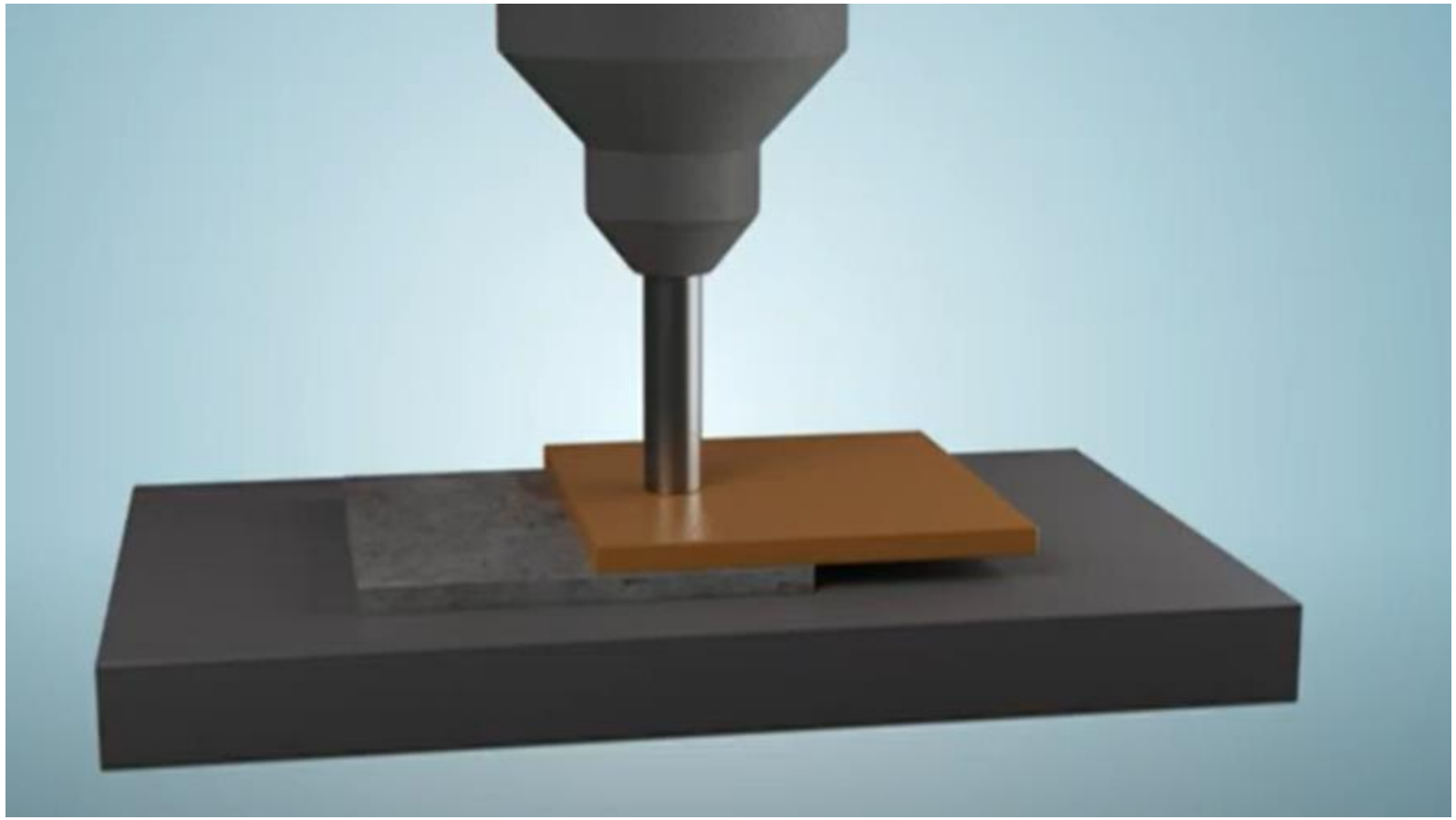
ULTRASONIC CONSOLIDATION

METAL

This one need additional CNC

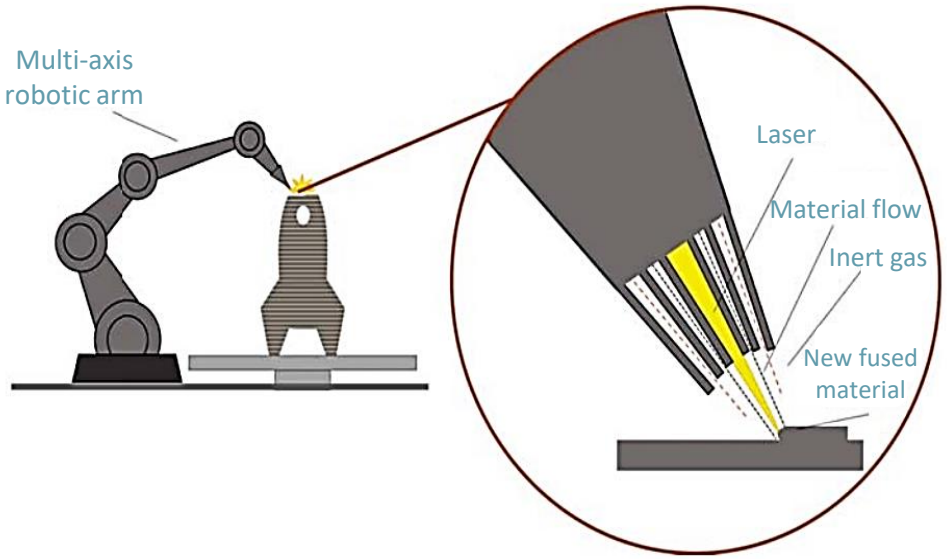
SHEET LAMINATION (SHL)

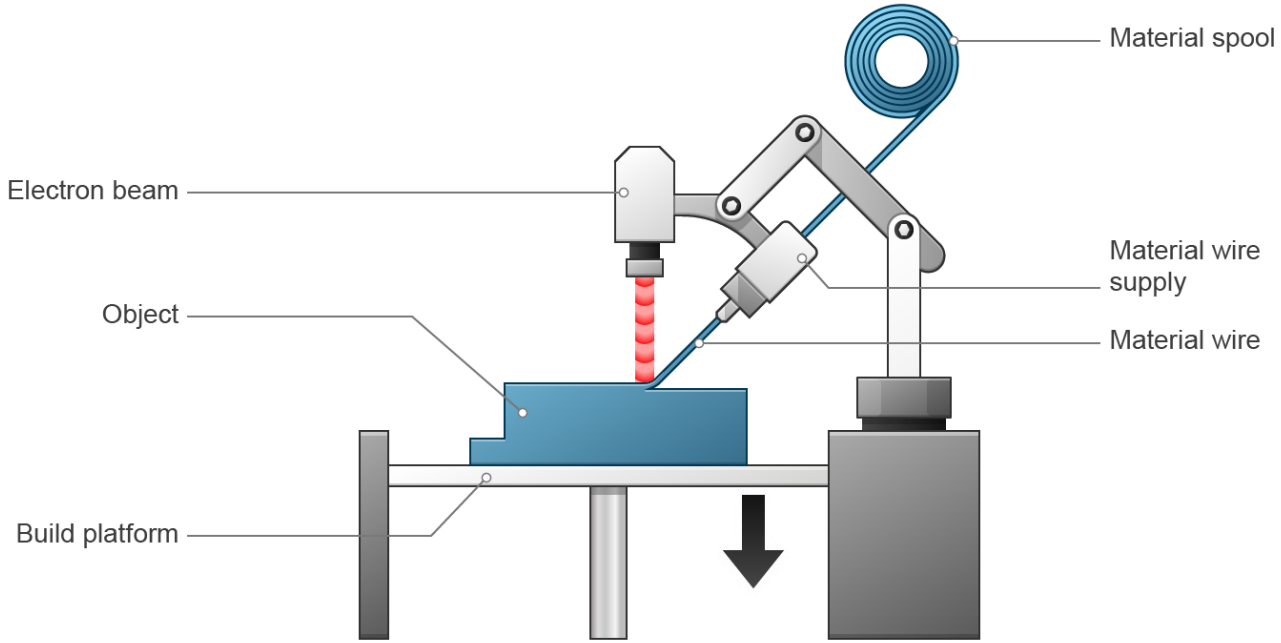
ALSO KNOWN AS LAMINATED OBJECT MANUFACTURING (LOM)



DIRECT ENERGY DEPOSITION (DED)

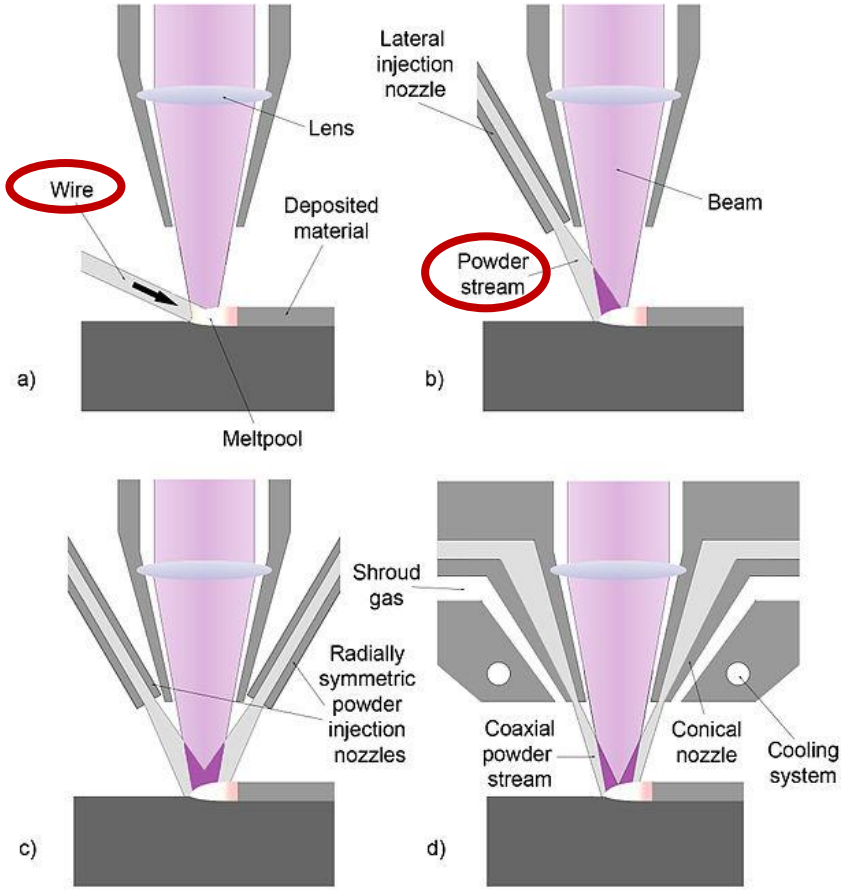
Direct Energy Deposition is an AM process in which **focused thermal energy** is used to fuse materials by melting **as they are being deposited**.



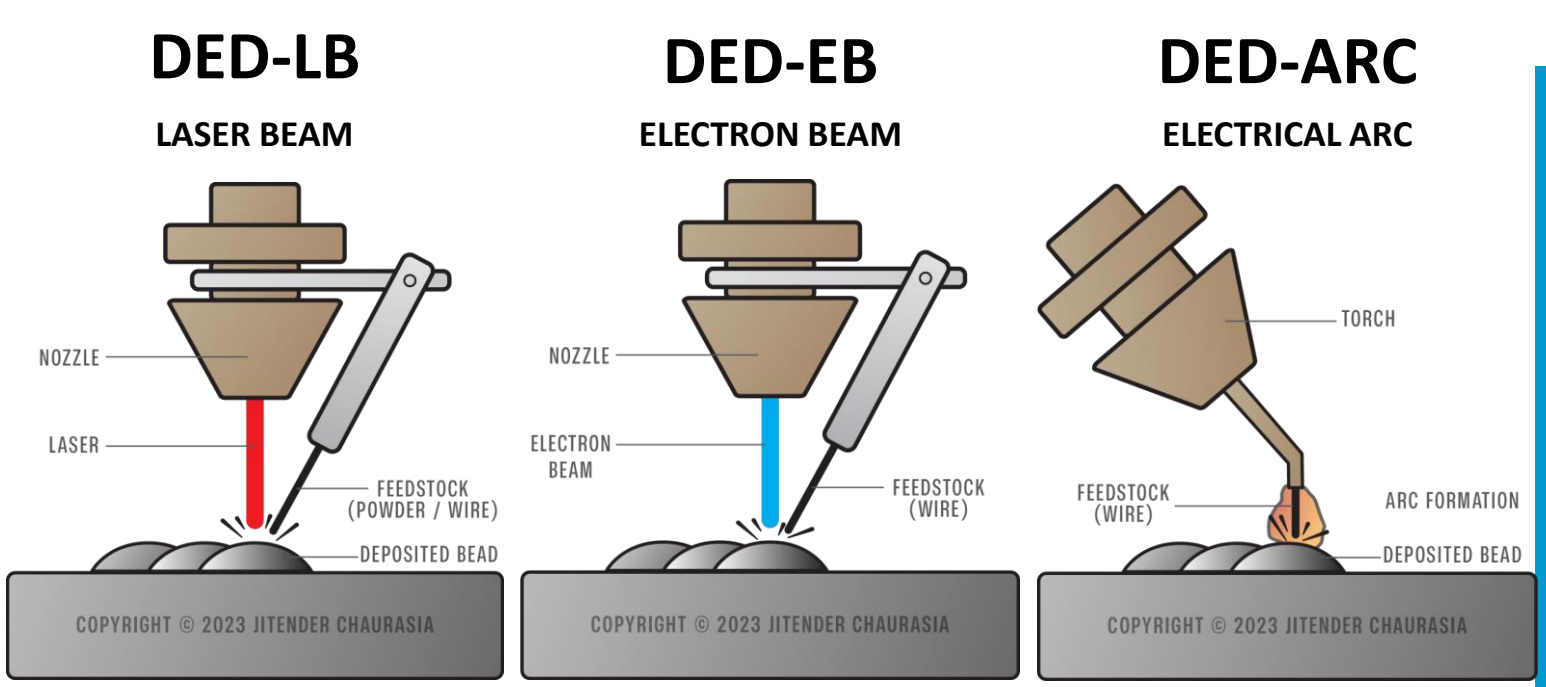


2018 © Dassault Systèmes

DIRECT ENERGY DEPOSITION (DED)



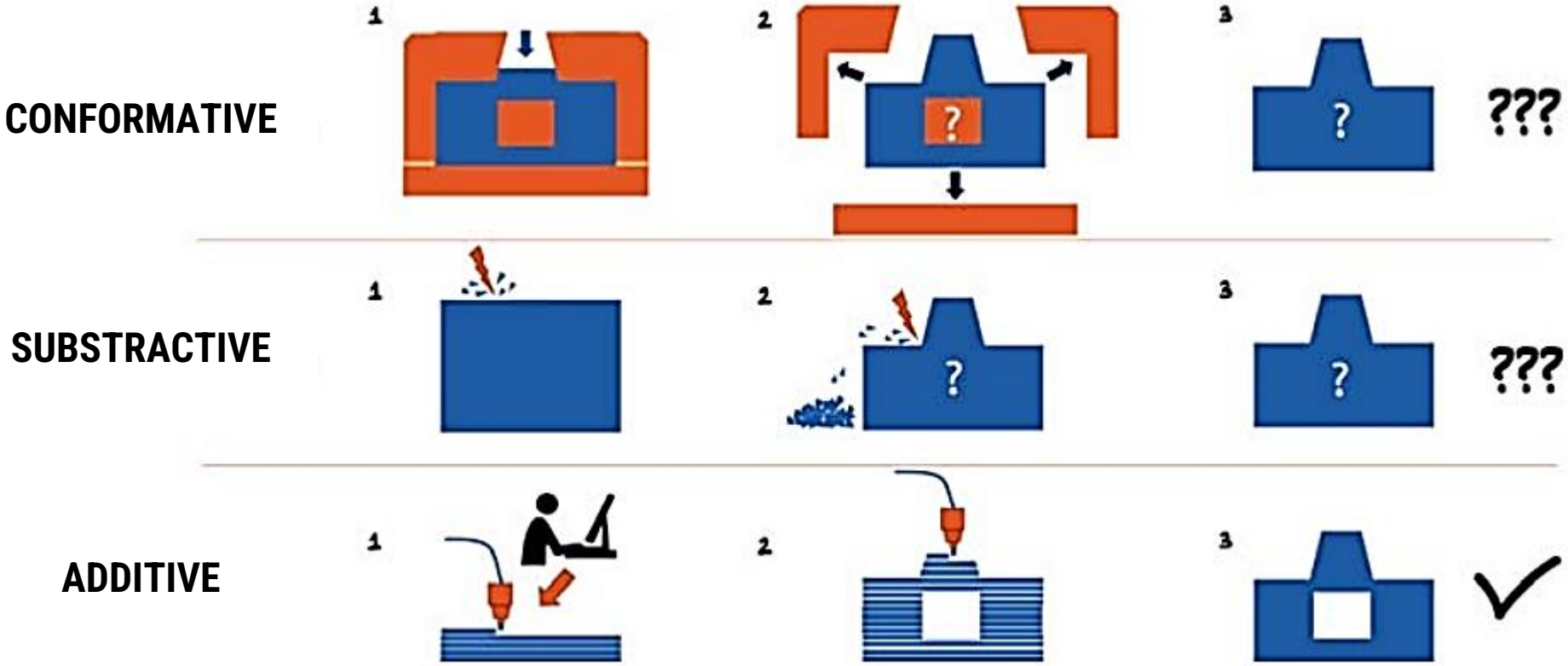
Identification according to ISO/ASTM 52900:2021



DIRECT ENERGY DEPOSITION (DED)

FEATURES AND BENEFITS OF ADDITIVE MANUFACTURING

VERSATILITY



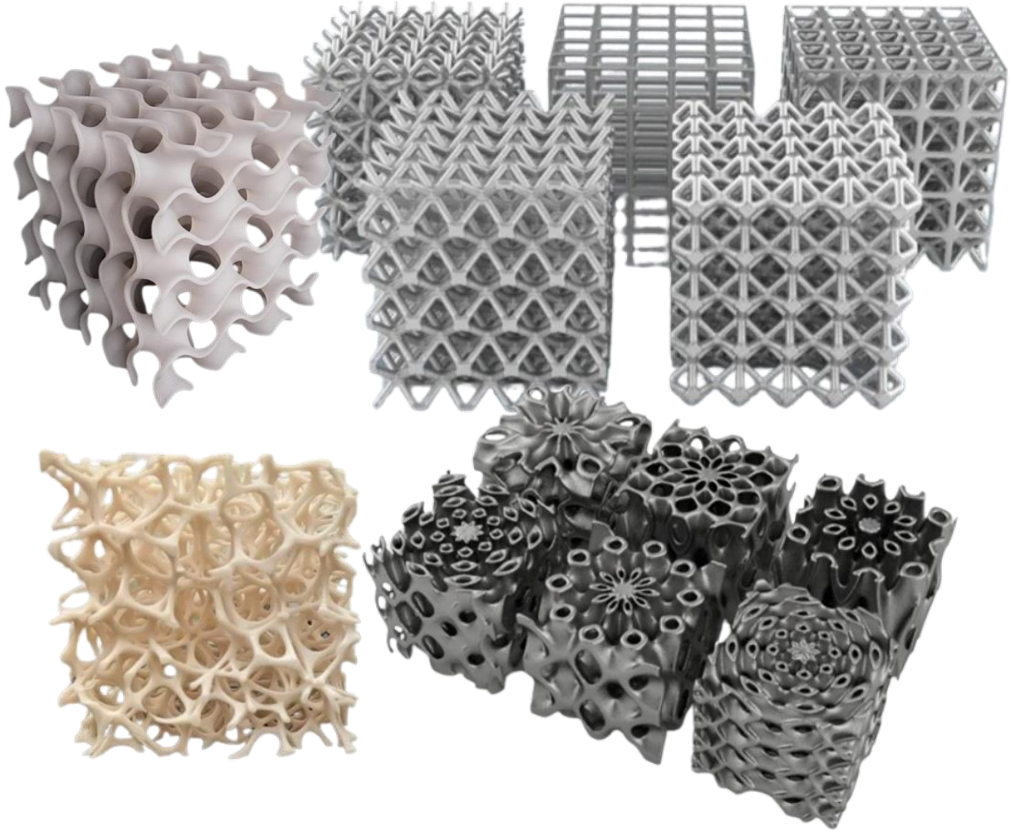
FEATURES AND BENEFITS OF ADDITIVE MANUFACTURING

IMPOSSIBLE PARTS AND CUSTOMISED PARTS

IMPOSSIBLE GEOMETRIES

CUSTOMISED PARTS

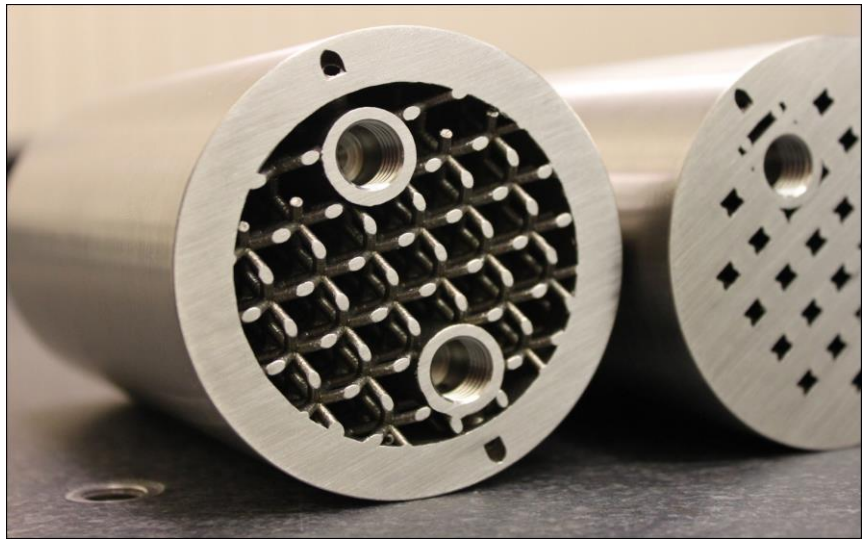
LATTICE STRUCTURES

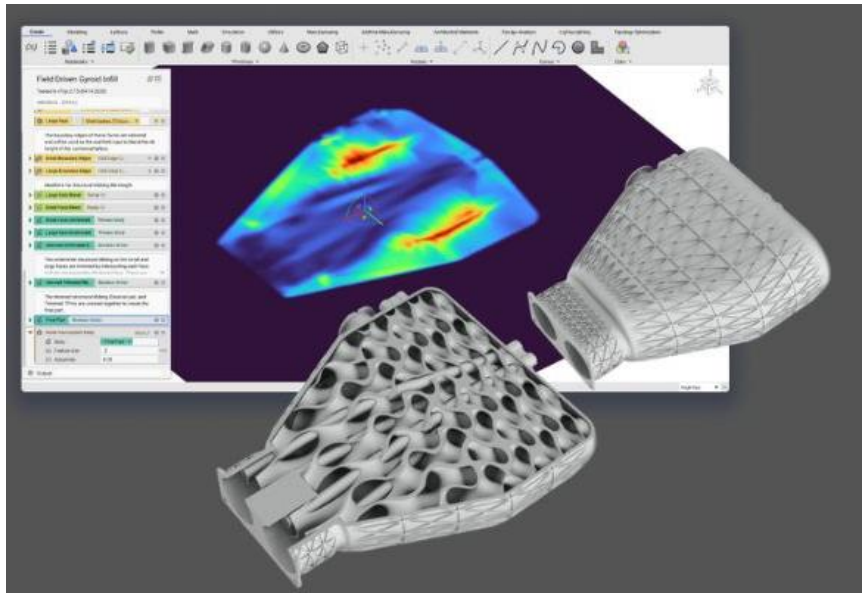


FEATURES AND BENEFITS OF ADDITIVE MANUFACTURING

TOPOLOGICAL OPTIMISATION & LIGHTWEIGHTING

Topology optimization flow (source:3DPrint.com)





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FEATURES AND BENEFITS OF ADDITIVE MANUFACTURING

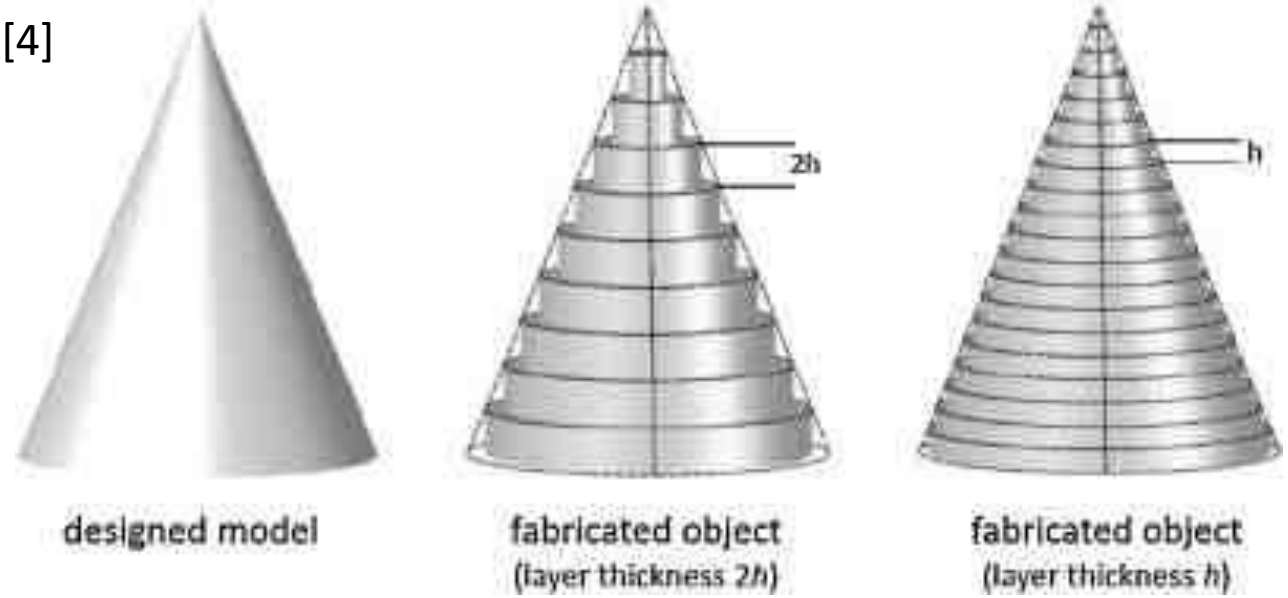
- RAPID MANUFACTURING
- COST SAVINGS
- MUCH LESS WASTE THAN SUBTRACTIVE MANUFACTURING
- ACCELERATION OF R&D PERFORMANCE

LIMITS AND CHALLENGES OF ADDITIVE MANUFACTURING

SURFACE FINISH AND ACCURACY

Staircase effect

[4]



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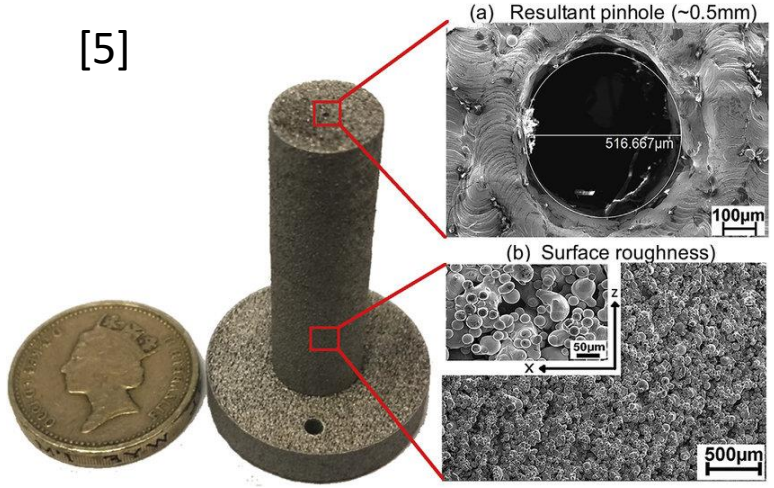


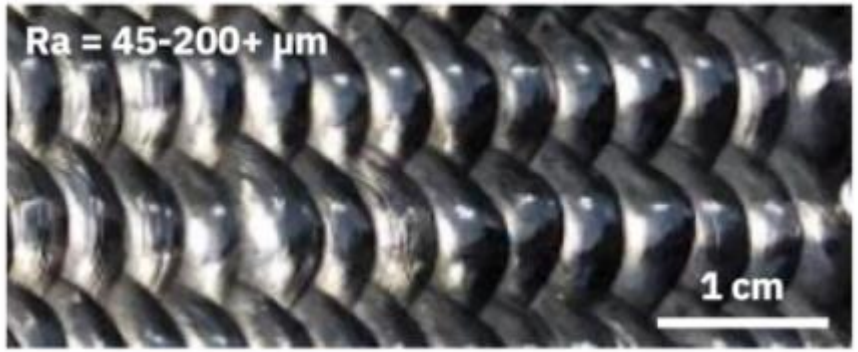
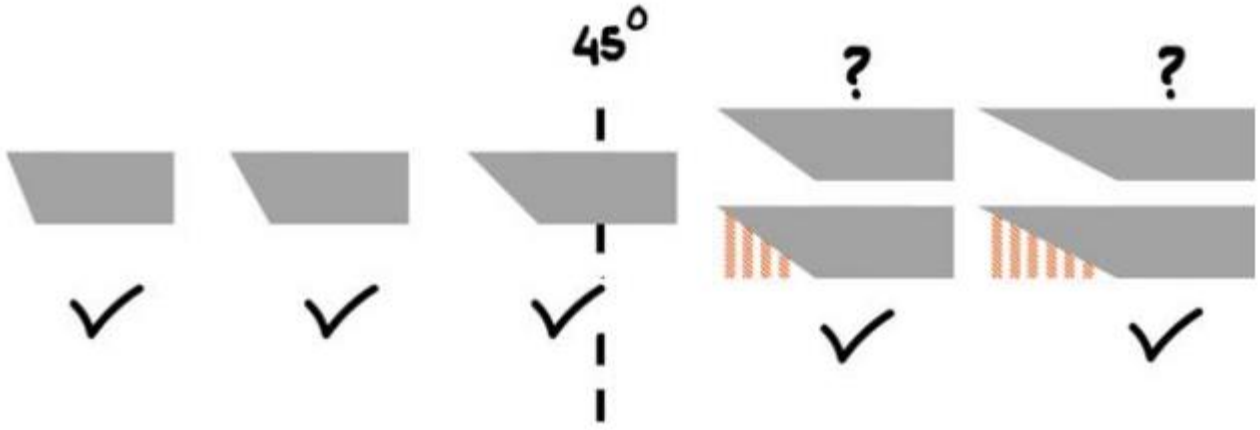


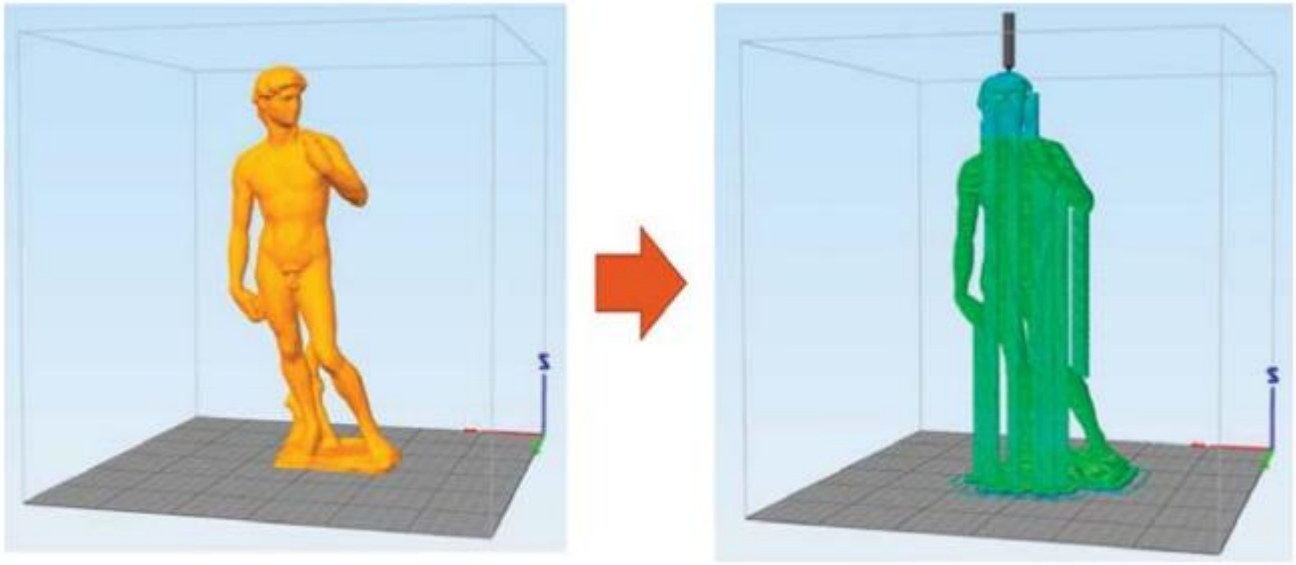
Photo Credits: Digital Alloys;

[4] Quan, Zhenzhen & Wu, Amanda & Keefe, Michael & Qin, Xiaohong & Yu, Jianyong & Suhr, Jonghwan & Byun, Joon-Hyung & Kim, Byung & Chou, Tsu-Wei. (2015). Additive manufacturing of multi-directional preforms for composites: Opportunities and challenges. Materials Today. 255. 10.1016/j.mattod.2015.05.001.
[5] Sidambe, Alfred & Judson, D.S. & Colosimo, Samantha & Fox, Peter. (2019). Laser powder bed fusion of a pure tungsten ultra-fine single pinhole collimator for use in gamma ray detector characterisation. International Journal of Refractory Metals and Hard Materials. 84. 104998. 10.1016/j.ijrmhm.2019.104998.

LIMITS AND CHALLENGES OF ADDITIVE MANUFACTURING

SUPPORTS REMOVAL





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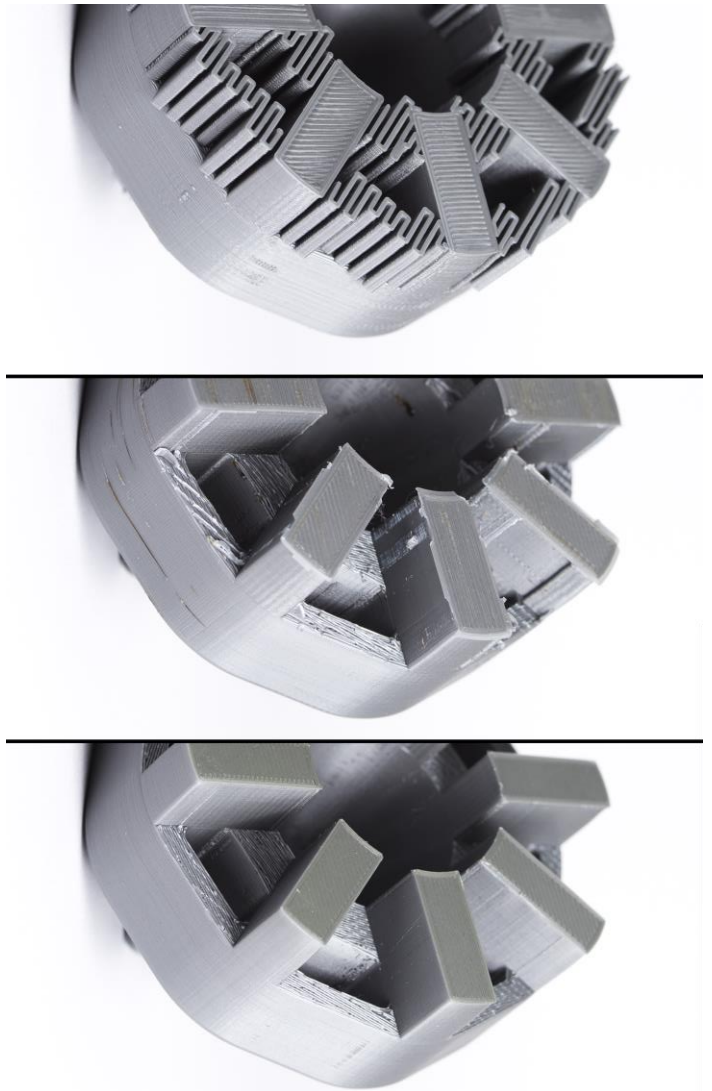
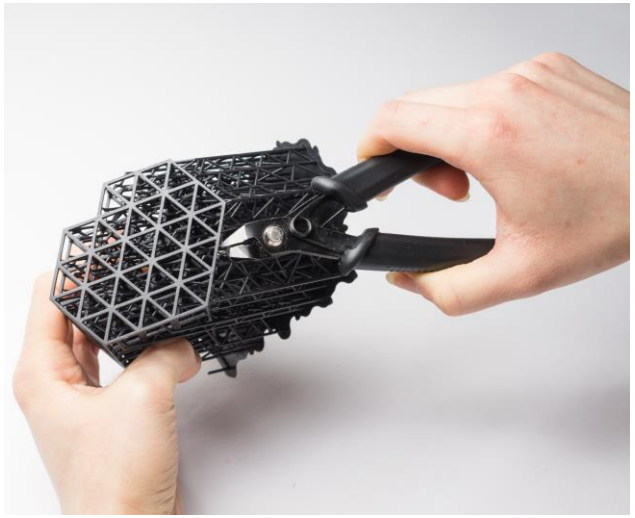


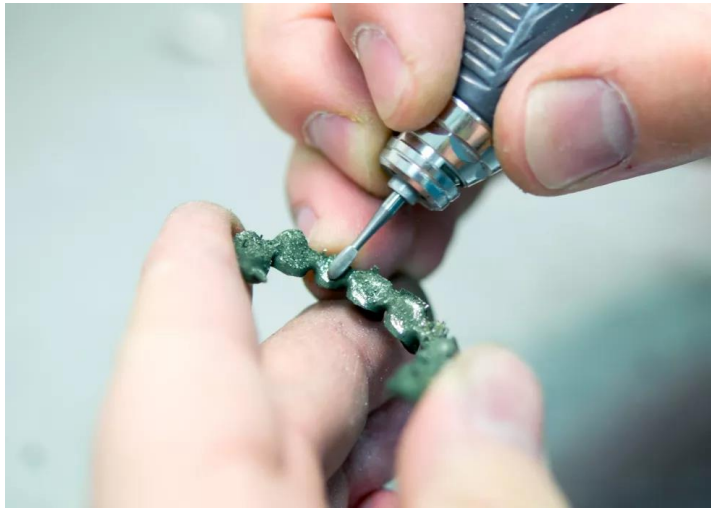
LIMITS AND CHALLENGES OF ADDITIVE MANUFACTURING

MANUAL POST-PROCESSING

ACCURACY ?

Photo Credits: Getty Images; Impresiontresde





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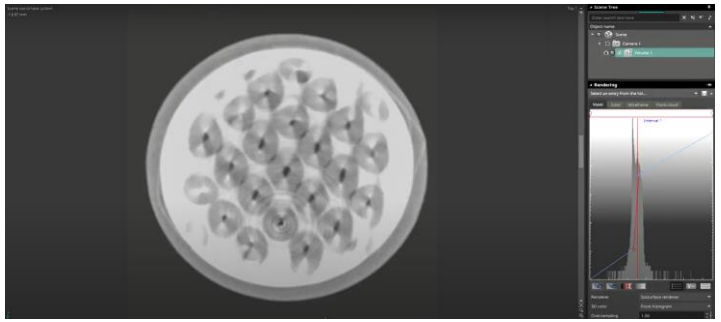
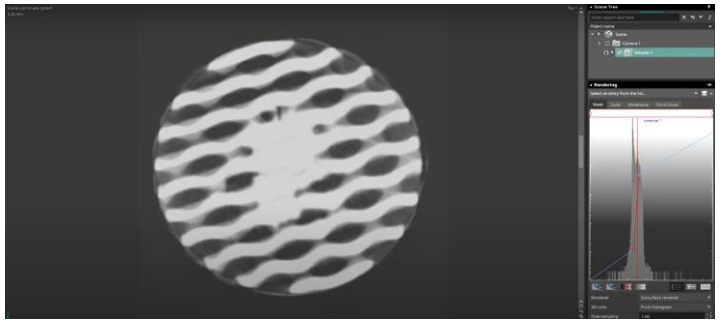
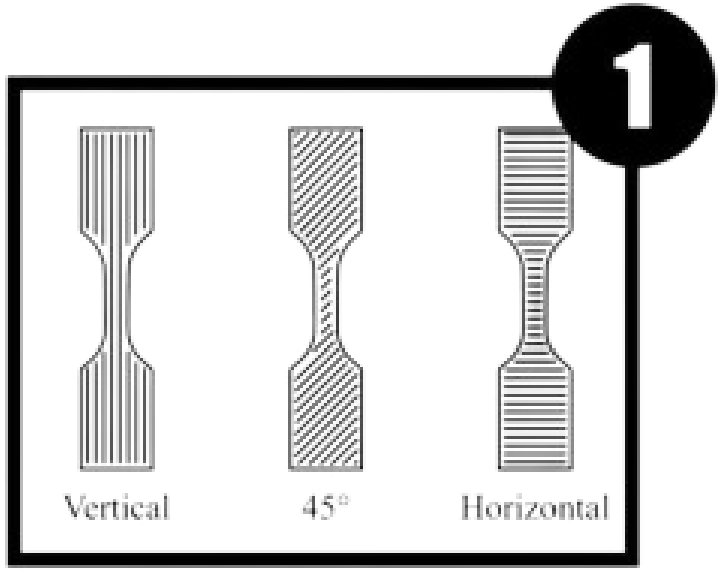


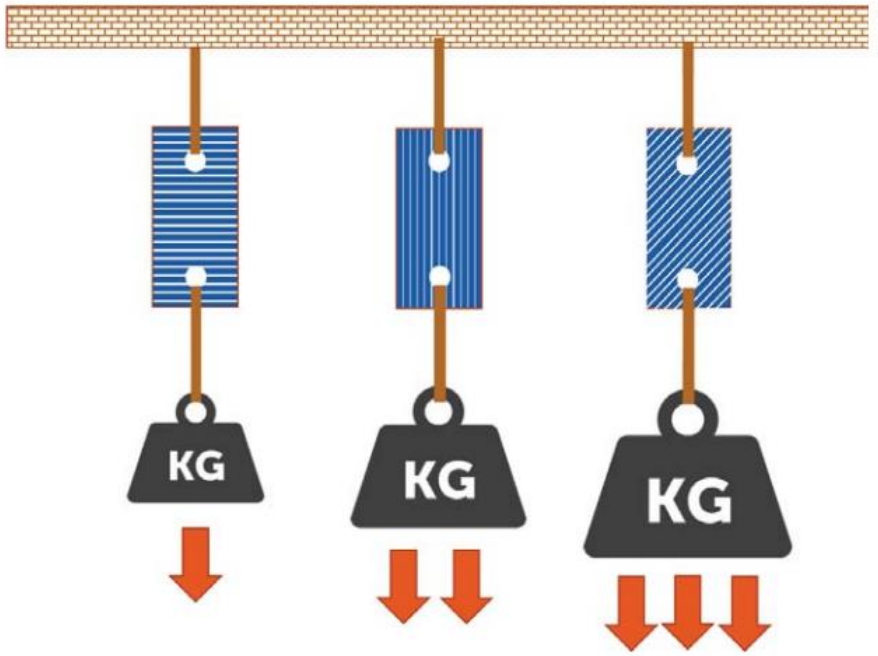


LIMITS AND CHALLENGES OF ADDITIVE MANUFACTURING

ANISOTROPY



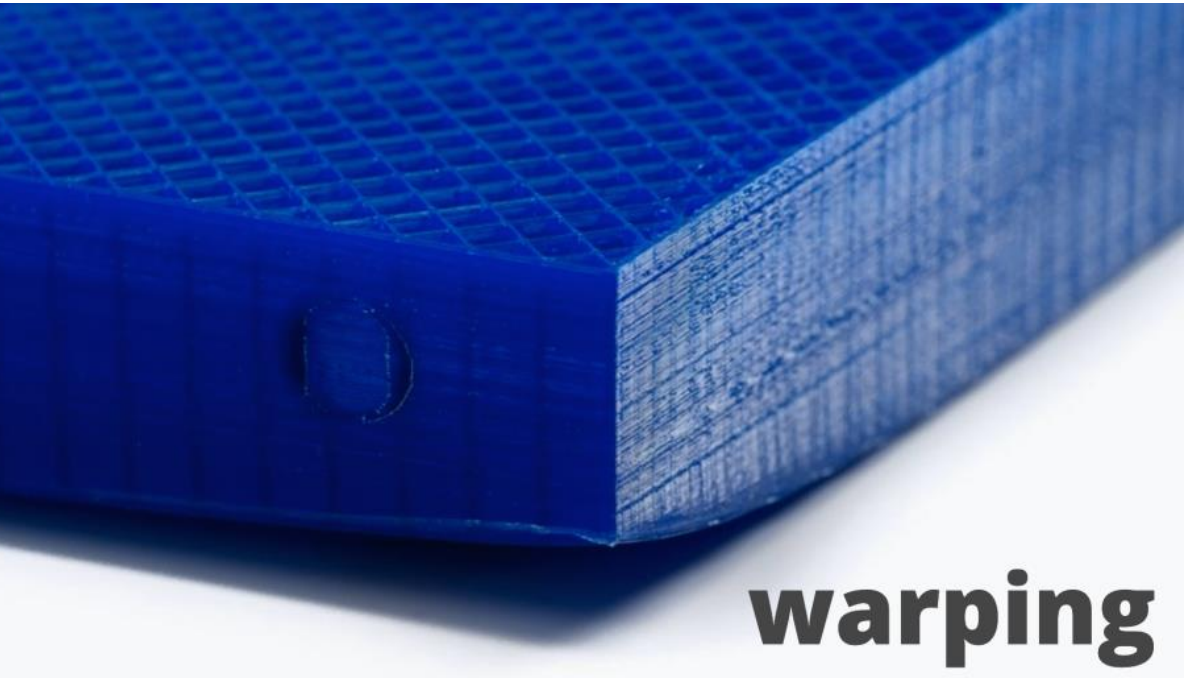
3-D printing
(Fused Depostion Modeling)

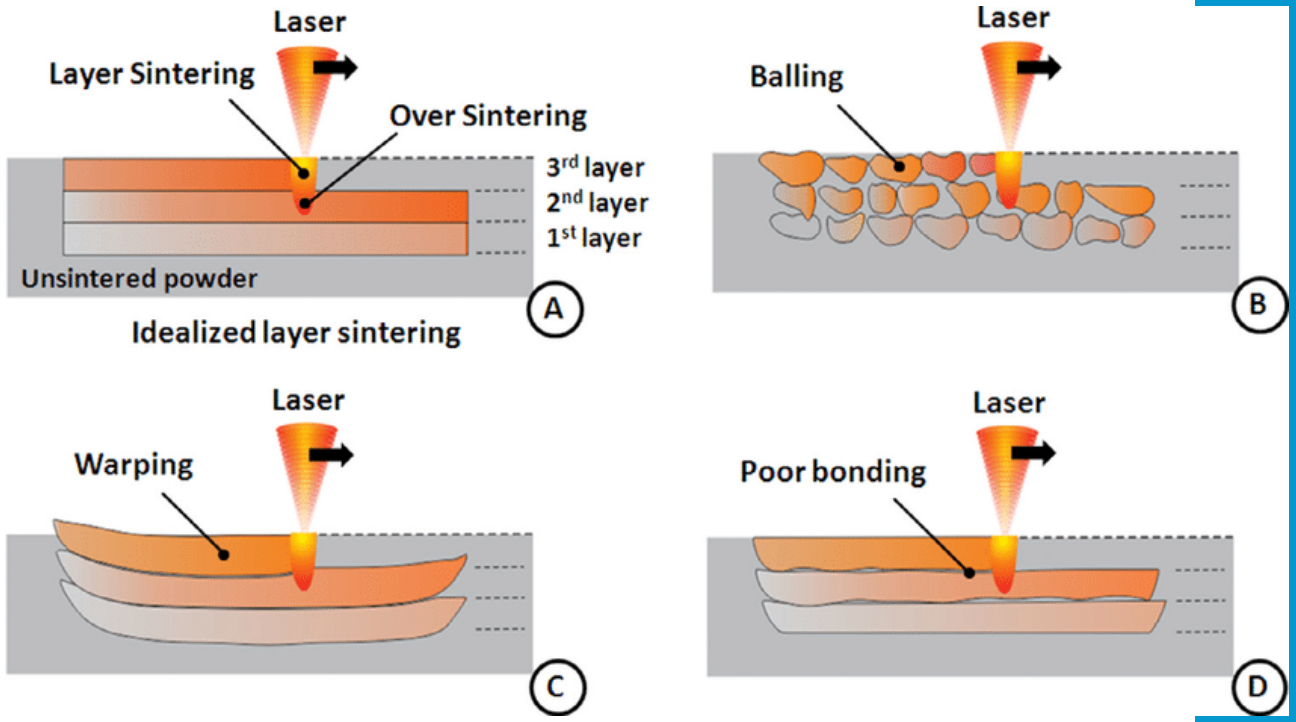


LIMITS AND CHALLENGES OF ADDITIVE MANUFACTURING

DEFORMATIONS IN PRINTING

Photo Credits: BitFab





[X] Nouri, Alireza & Rohani, Anahita & Li, Yuncang & Wen, Cuie. (2021). Additive manufacturing of metallic and polymeric load-bearing biomaterials using laser powder bed fusion: A review. Journal of Materials Science & Technology. 94. 10.1016/j.jmst.2021.03.058.

CHALLENGES OF ADDITIVE MANUFACTURING

- LOW VOLUME VS MASS MANUFACTURING
- HIGH INITIAL INVEST COST, MATERIALS AND MAINTENANCE
- RANGE OF MATERIALS AND SIZE LIMITED
- MATERIAL HETEROGENEITY AND STRUCTURAL RELIABILITY
- LACK OF STANDARDS

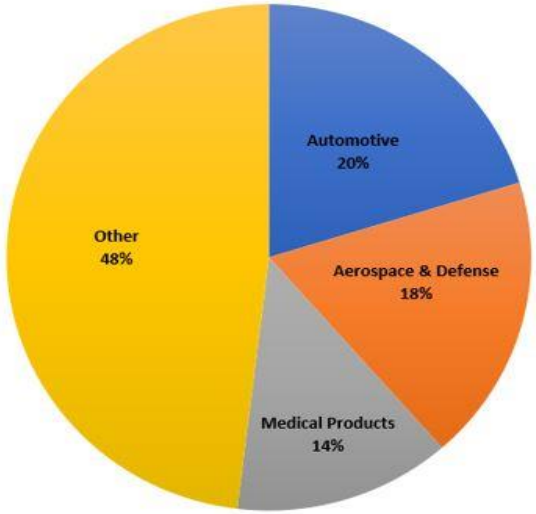
GENERAL ADDITIVE MANUFACTURING APPLICATIONS

Conceptual models

Functional prototypes

Final parts

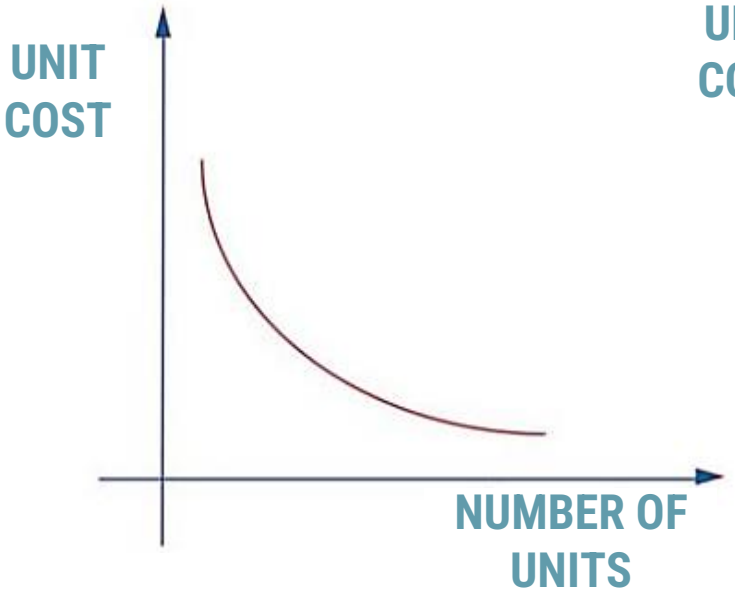
Research



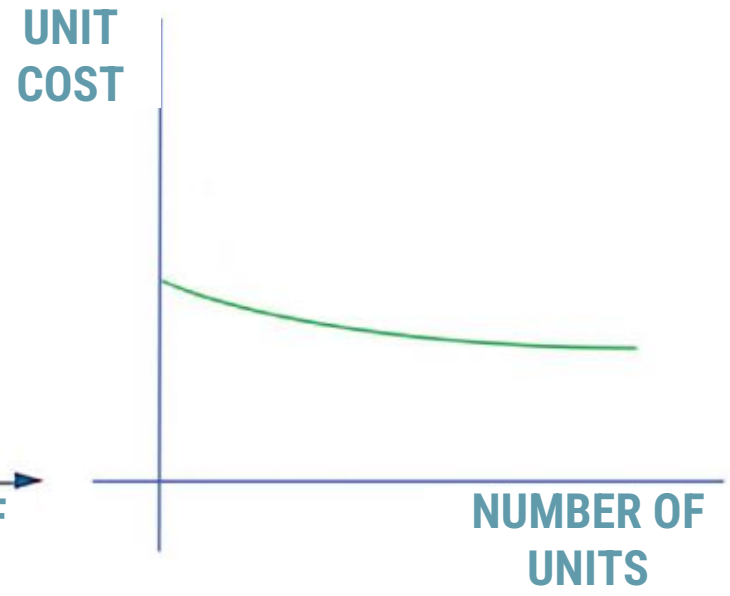
Additive Manufacturing Market:
Top Three Industries
(Source: ARC Advisory Group's Market Research)

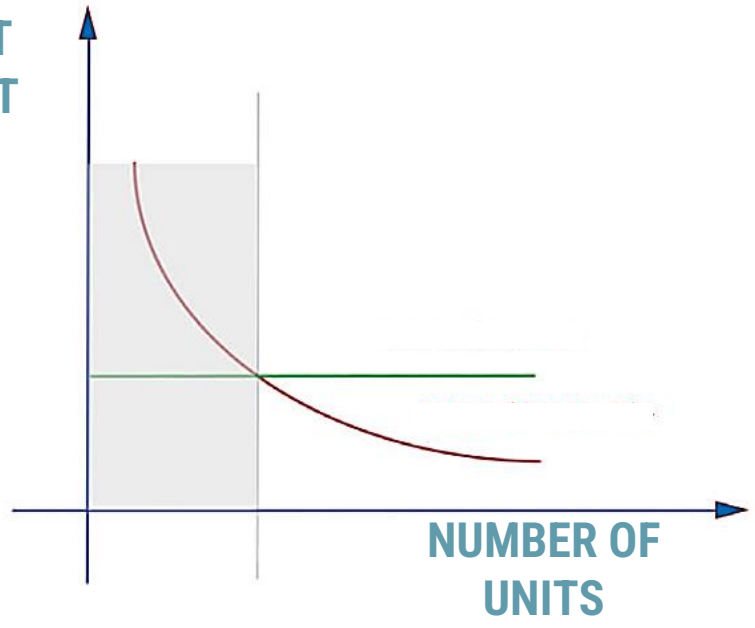
COST CURVES

TRADITIONAL PROCESS



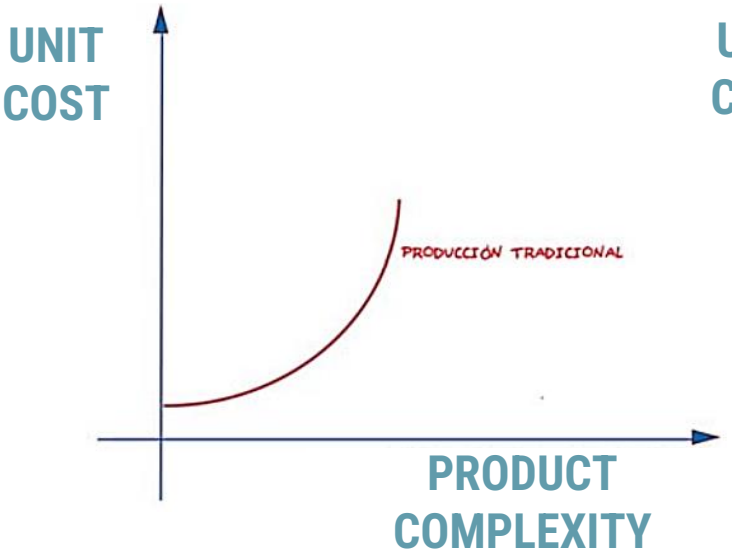
ADDITIVE MANUFACTURING



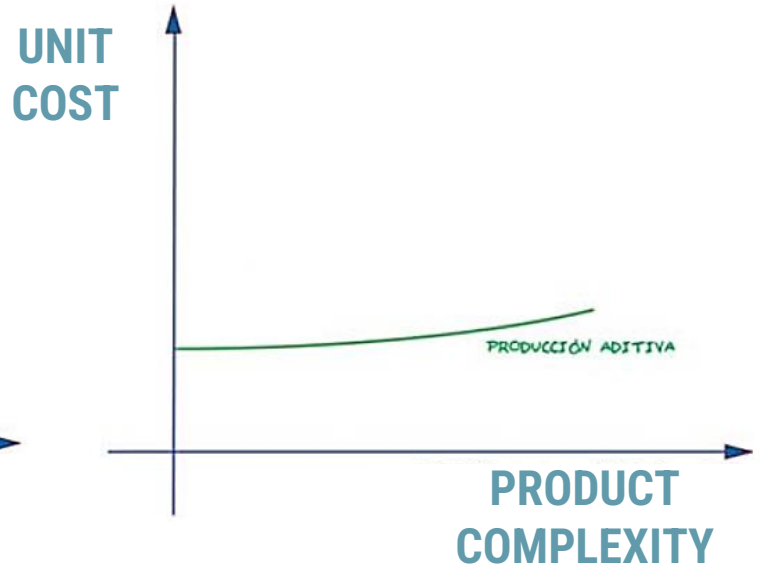


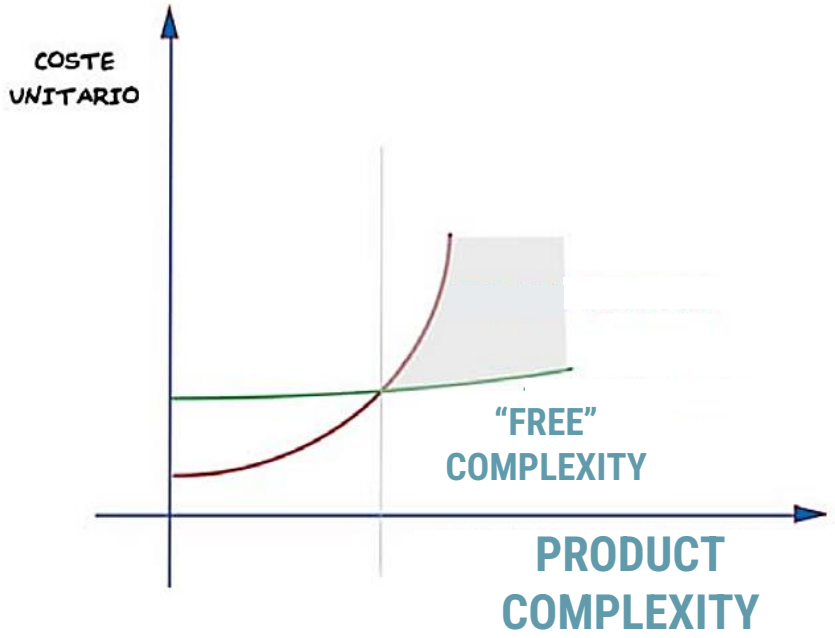
COST CURVES

TRADITIONAL PROCESS

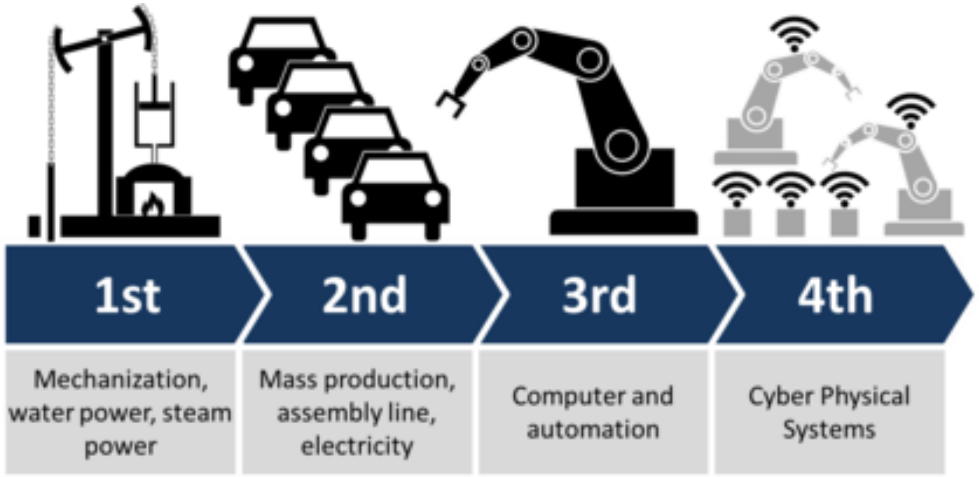


ADDITIVE MANUFACTURING

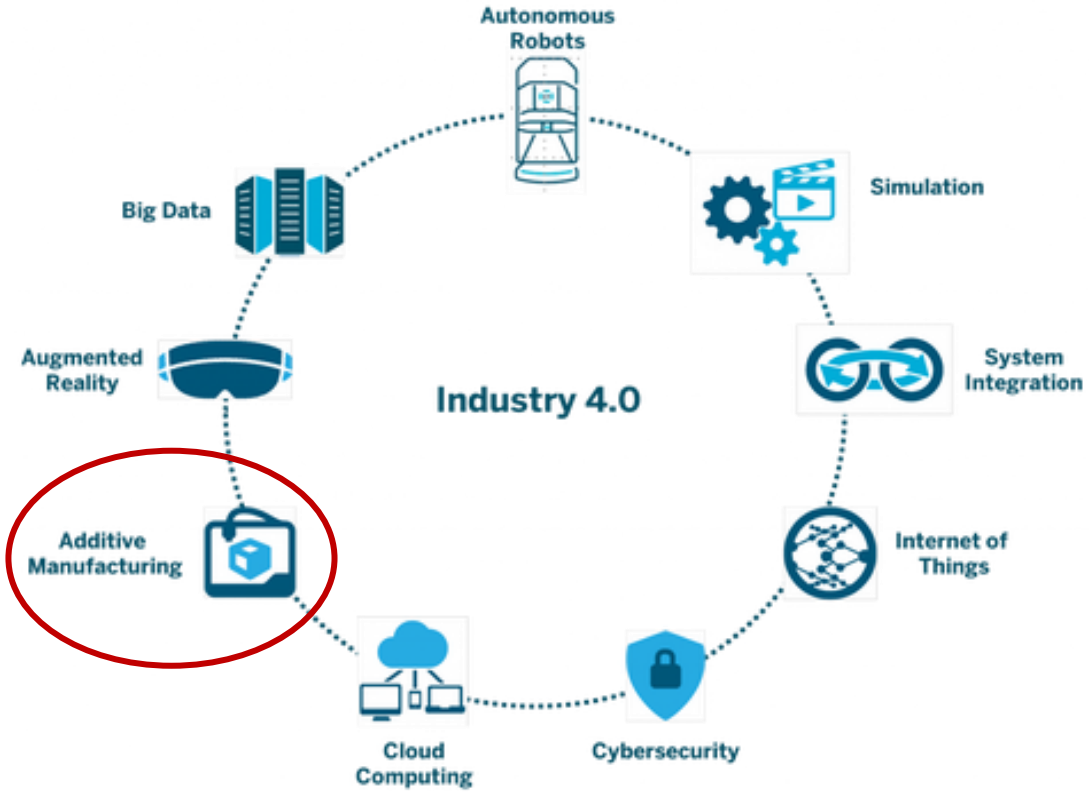




INDUSTRY 4.0



"A new phase in the industrial revolution that focuses on interconnectivity, automation, machine learning and real-time data. "



REGINNA 4.0

SOFÍA PELÁEZ PELÁEZ

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spelp@unileon.es

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