

ADDITIVE MANUFACTURING

Additive Manufacturing (AM) definition

“Additive Manufacturing (AM) term refers to processes used to make three-dimensional objects, layer by layer, additively, in opposition to the subtractive method of chip removal”

- Da International Committee F42 for Additive Manufacturing Technologies, ASTM -



Additive Manufacturing process chain:



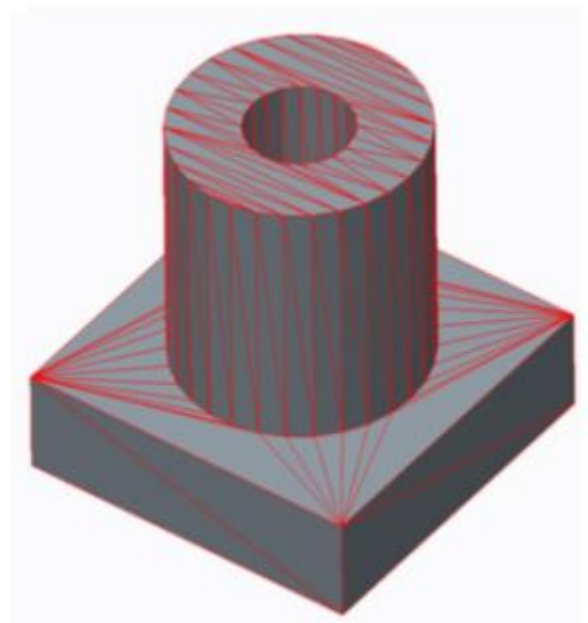
Additive Manufacturing process chain:

1. CAD

The generic AM process start with 3D CAD information

2. Conversion to STL

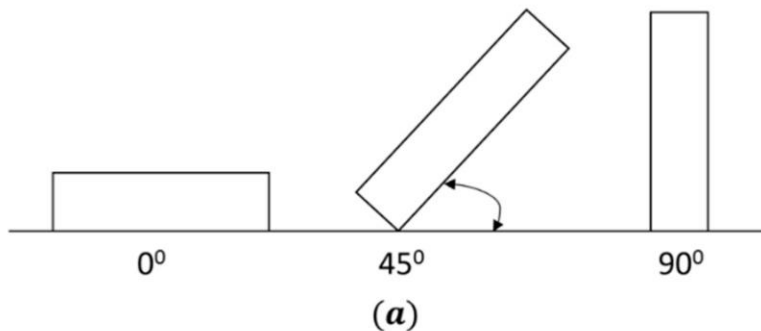
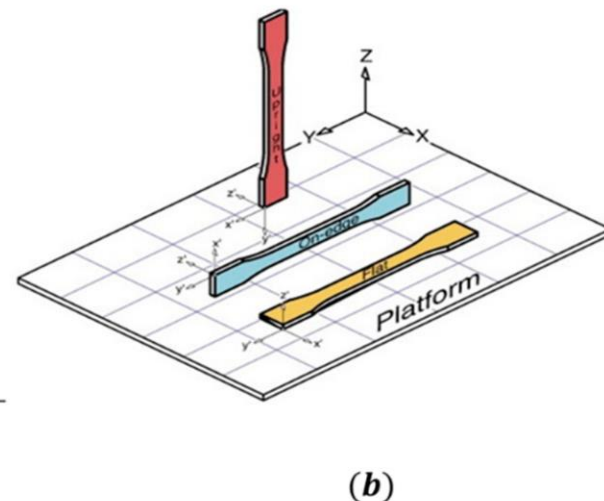
- The term STL derived from STereoLitography
- STL is a simple way of describing a CAD model in terms of its geometry alone
- It works by removing any construction data, modeling history and approximating the surfaces of the model with a series of triangular facets
- The minimum size of these triangles can be set within most CAD software and the objective is to ensure the model created do not show any obvious triangles on the surface



Additive Manufacturing process chain:

3. Transfer to AM machine and STL file manipulation

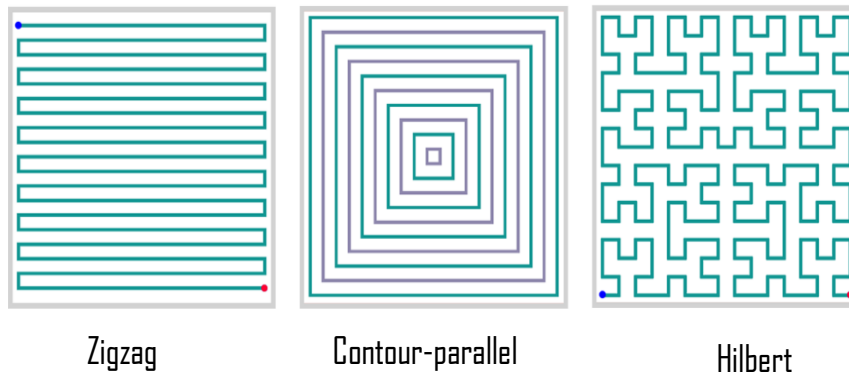
- AM system software has visualization tool that allows the user to view and manipulate the part
- The users may wish to reposition the part or even change the orientation to allow it to be built at a specific location within the machine
- It is quite common to build more than one part in an AM machine at time
- This may be multiple of the same part or completely different STL files



Additive Manufacturing process chain:

4. Machine setup

- All AM machines will have at least some setup parameters that are specific to that machining process
- Some machines are only designed to run perhaps one or two different materials and with no variation in layer thickness or other build parameters
- In the more complex cases to have default settings or save files from previously defined setups to help speed up the machined process setup process and to prevent mistakes



Additive Manufacturing process chain:

5. Build setup

- The few stages of the AM process are semi-automated tasks that may require considerable manual control, interaction and decision making
- Once these steps are completed , the process switches to the computer controlled building phase
- All AM machines will have a similar sequence of layer control, using a height adjustable platform, material deposition, and layer cross-section formation
- All machines will repeat the process until either the build is complete or there is no source material remaining

Additive Manufacturing process chain:

6. Removal and clean up

- The output of AM machines should be ready to use
- More often still require a significant amount of manual finishing before they are ready to use
- The part must be either separated from a build platform on which the part was produced or removed from excess build material surrounding the part
- Some AM process use additional material other than that used to make the part itself (secondary support material).

7. Post process

- Post processing refers to the stages of finishing the parts for application purposes
- This may involve abrasive finishing , like polishing or sandpapering or applications of coating

Additive Manufacturing process chain:

8. Application

- Following post processing, parts are ready to use
- Although parts may be made from similar materials to those available from other manufacturing process , parts may not behave according to **standard material specification**
- Some AM process creates parts with small voids or bubble trapped inside them , which **could be the source for part failure under mechanical loads**
- Some process may cause the material to degrade during build or for materials not to bond, link, or crystalize in an optimum way.

Complexity for free

Physical manufacturing principal allows almost any geometry when considering

- Material specifications
- Design rules for AM

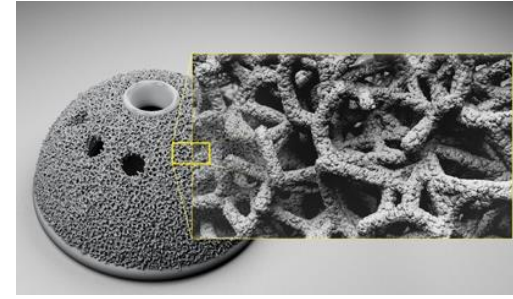
Possible applications:

- Lightweight parts (e.g. aerospace)
- Patient specific implants
- Load adapted parts

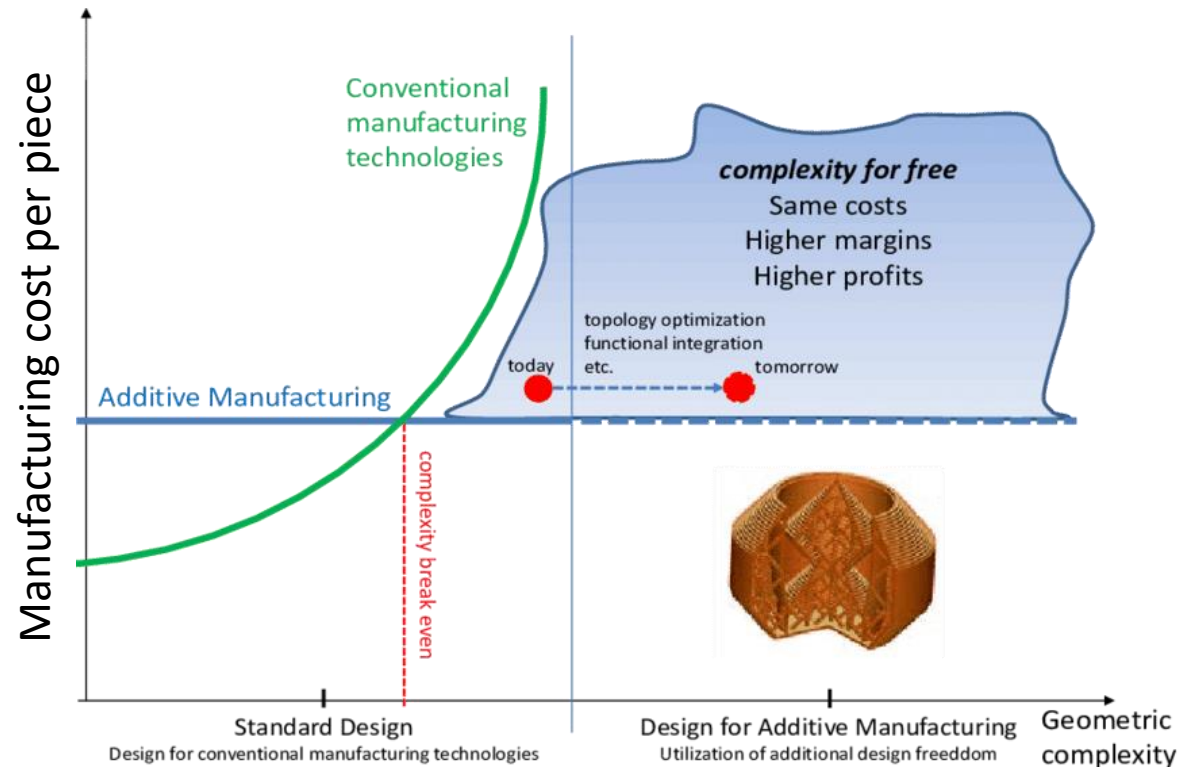
- Not possible with conventional manufacturing technologies
- Resource efficient at enhanced functionalities



Autodesk



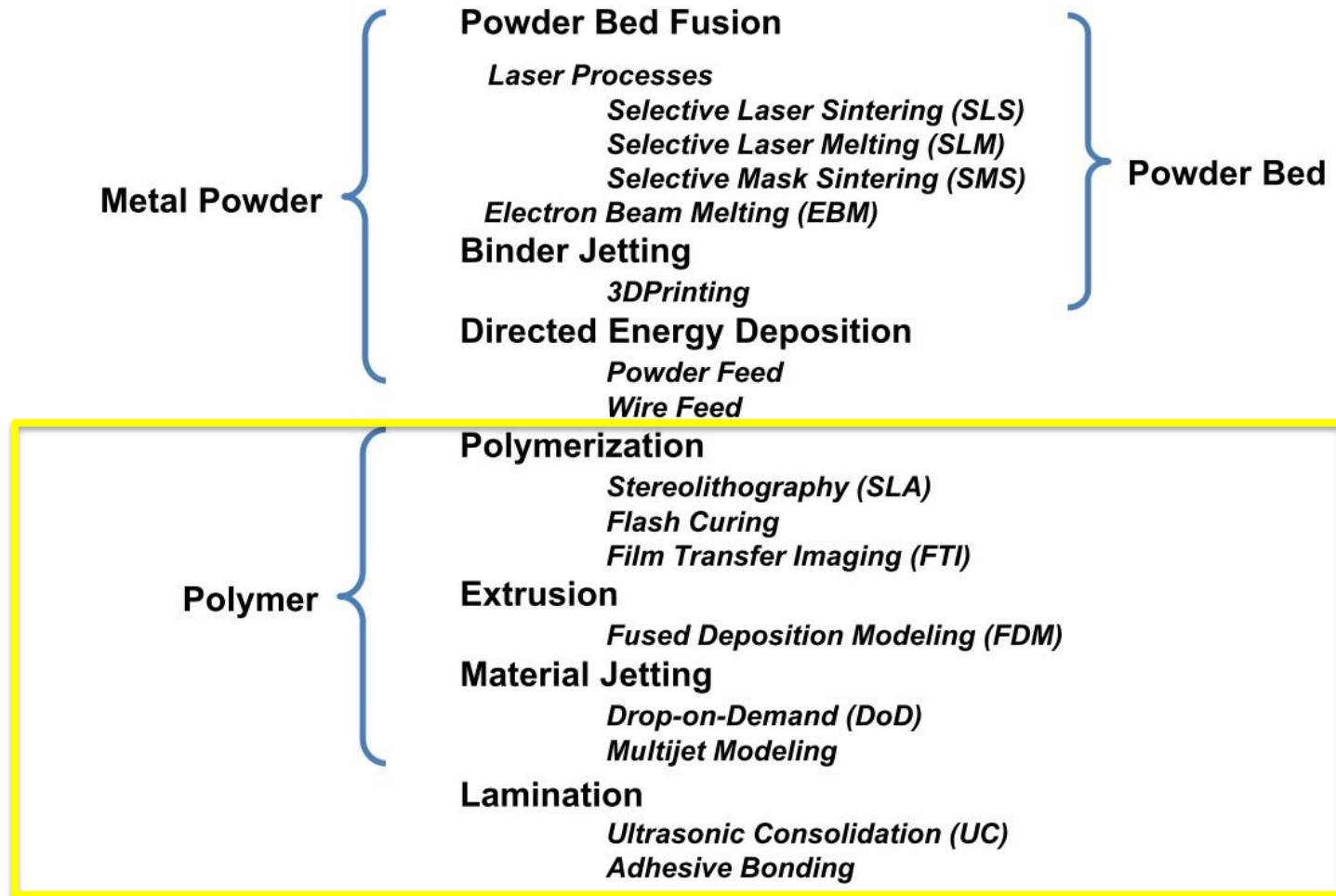
Within / EOS



Limitations of AM

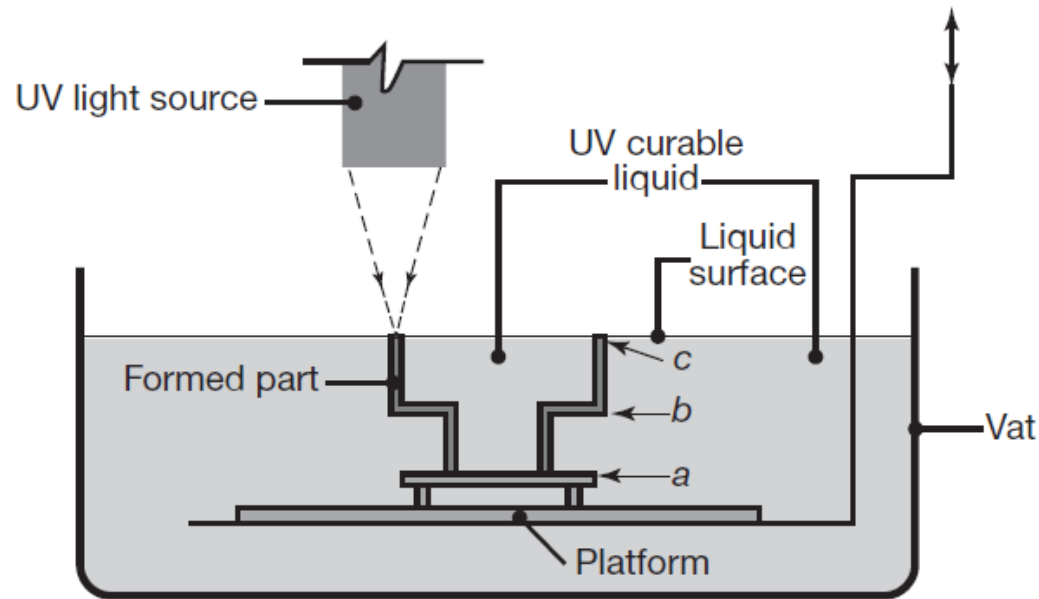
- **Parts size**
- **Production series:** generally suitable for unitary or small series and it is not relevant for mass production. For small sized parts, series up to 25000 parts/years are already possible
- **Material choice:** non weldable metals cannot be processed by AM and difficult to weld alloys require specific approaches
- **Material properties:** i) parts made by AM are anisotropy; ii) even if density of 99,99% can be reached some residual porosities can be leaved in the material; iii) mechanical properties are superior to cast but in general inferior to wrought parts

Classification of AM process



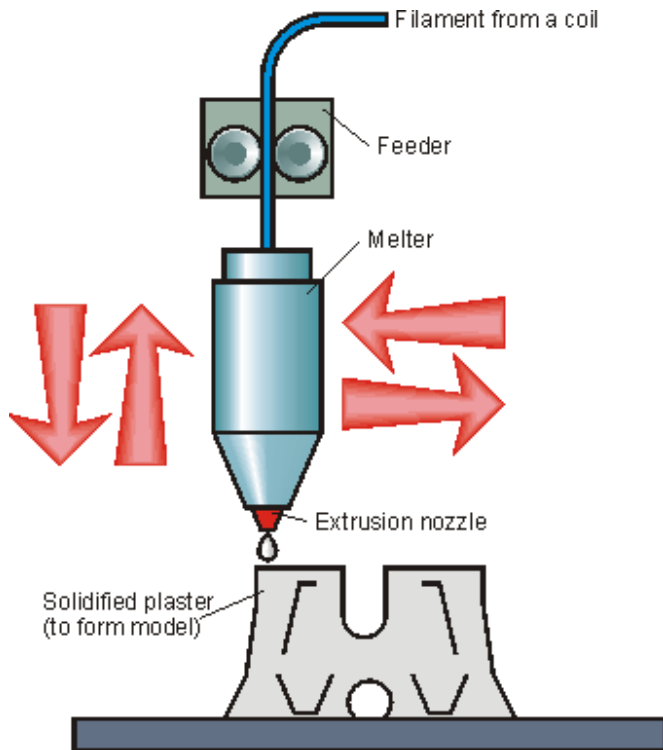
Stereolithography (SLA)

- Stereolithography uses a combination of photochemistry and laser technology on a photopolymer.
- A laser UV laser traces the 2D section on the photopolymer

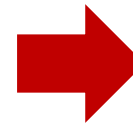


Stereolithographic process (3d system).

Fused Deposition Modelling (FDM)



- FDM uses a thermoplastic polymer filament to provide material to the extrusion nozzle
- The nozzle is heated to melt the material and its motion is driven by CAM software;
- The material harden immediately after being extruded



Fused Deposition Modelling (FDM)

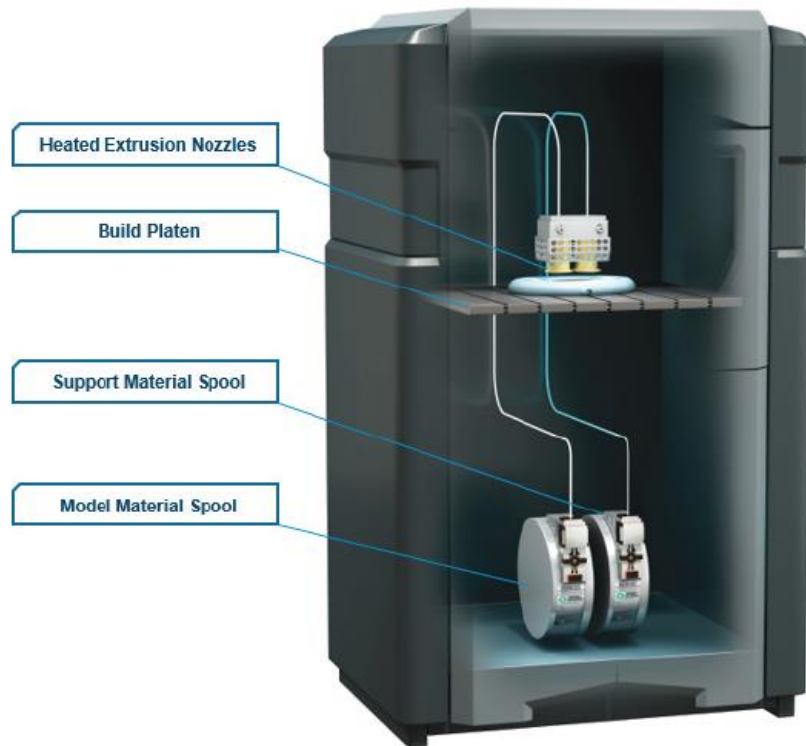


Figure 1: Fused Deposition Modeling (FDM) process.

- Z-axis resolution : 0.33-0.12 mm;
- X/Y-axis resolution: 0.025 mm;
- Bad surface finish: stepped surface -> finishing process
- Where support or buffering is needed, the 3D printer deposits a removable material that acts as scaffolding.
- Post-processing involves the removal of support material, either by manually breaking it away or dissolving it in detergent and water.

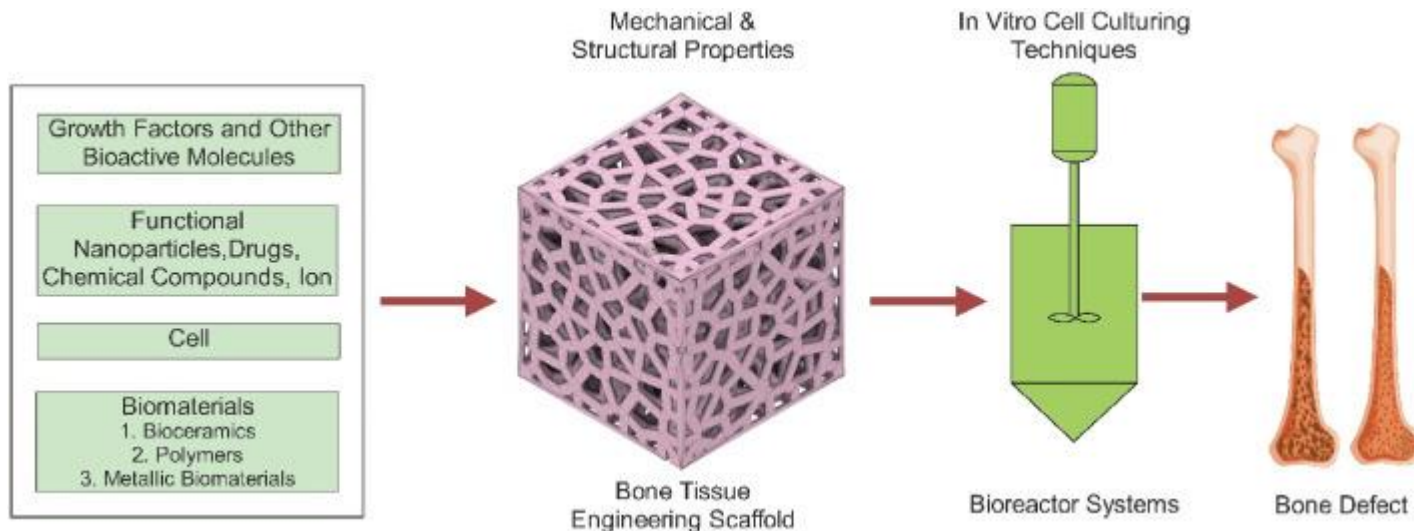
Applications of FDM

NASA Human-Supporting Rover has FDM Parts



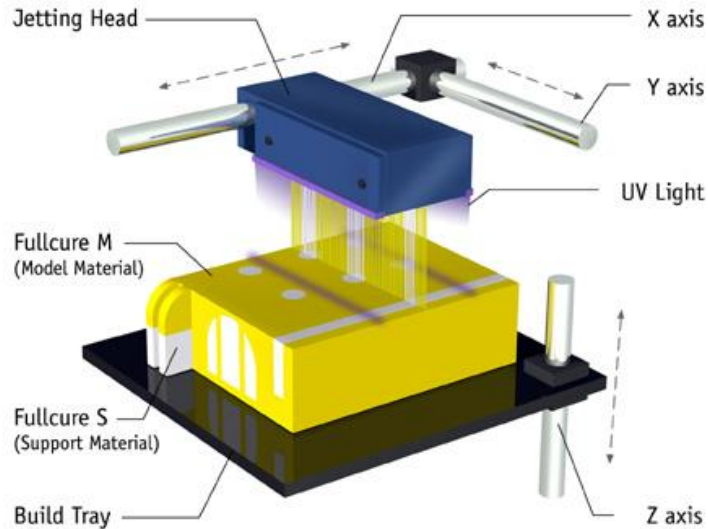
“...about 70 of the parts that make up the rover were built digitally, directly from computer designs, in the heated chamber of a production-grade Stratasys 3D Printer.”

-www.stratasys.com-



Bone tissue engineering strategy

Polyjet

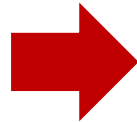
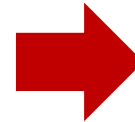


The Objet PolyJet Process

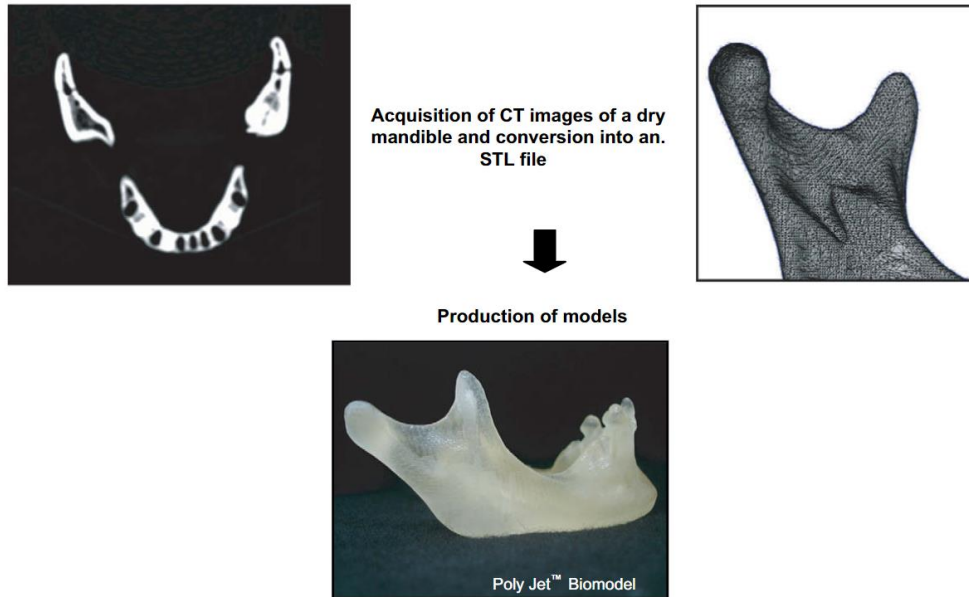
- PolyJet 3D is similar to an ink printer, but instead of injecting droplets of ink on the paper, PolyJet 3D Printers injects layers of heat-resistant photopolymer onto a support structure.

- Advantages:

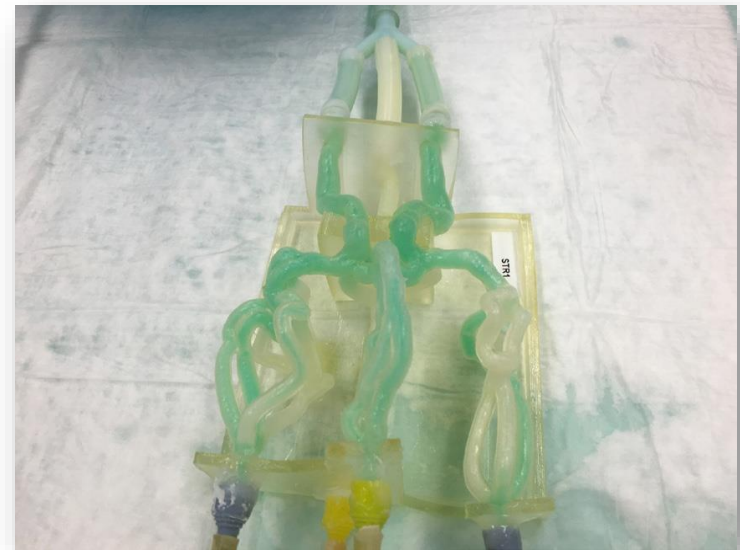
- ☐ Better resolution compared to SLA
- ☐ Elimination of post-processing operations



Applications of Polyjet

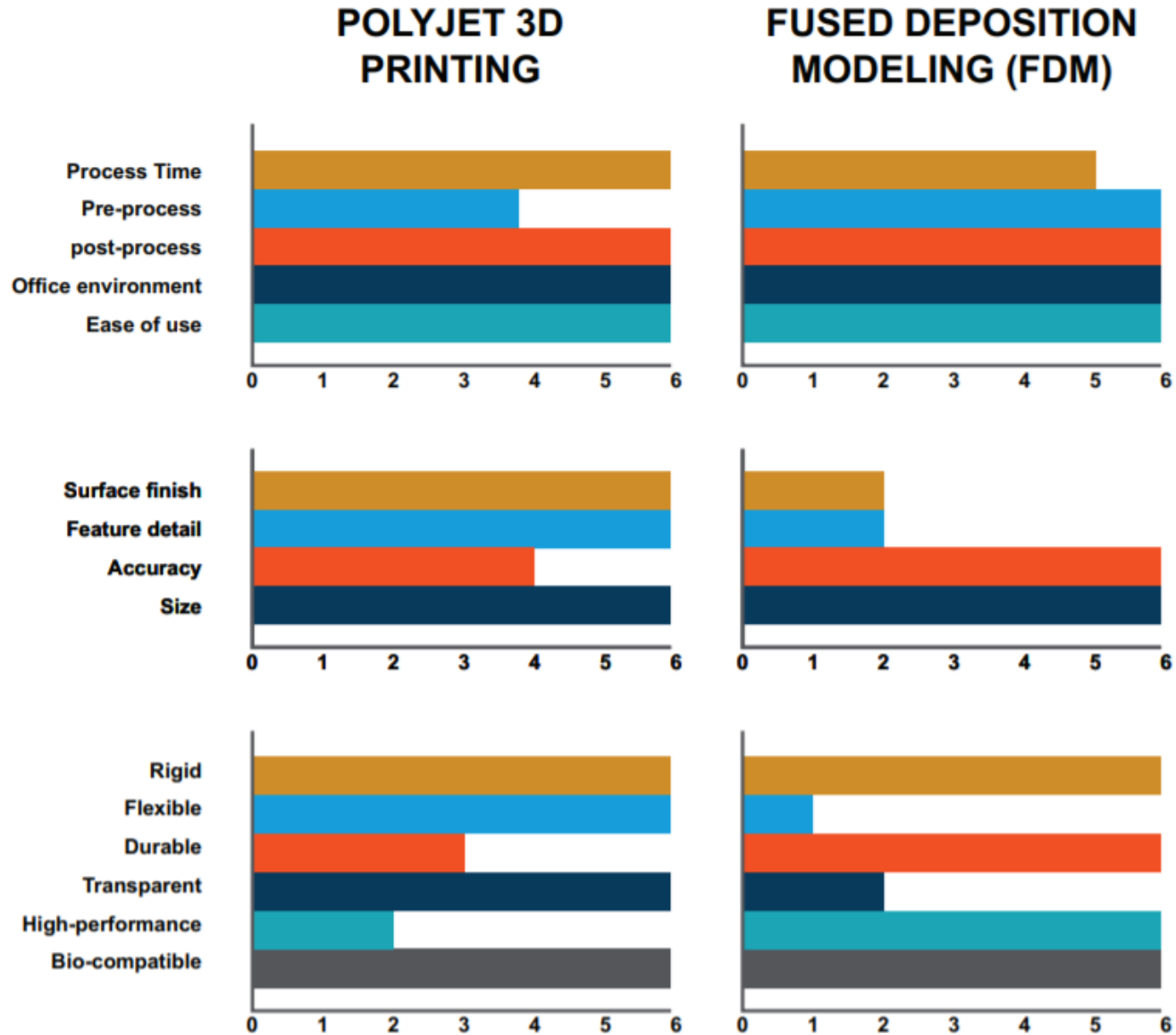


PolyJet models in the reproduction of mandibular anatomy

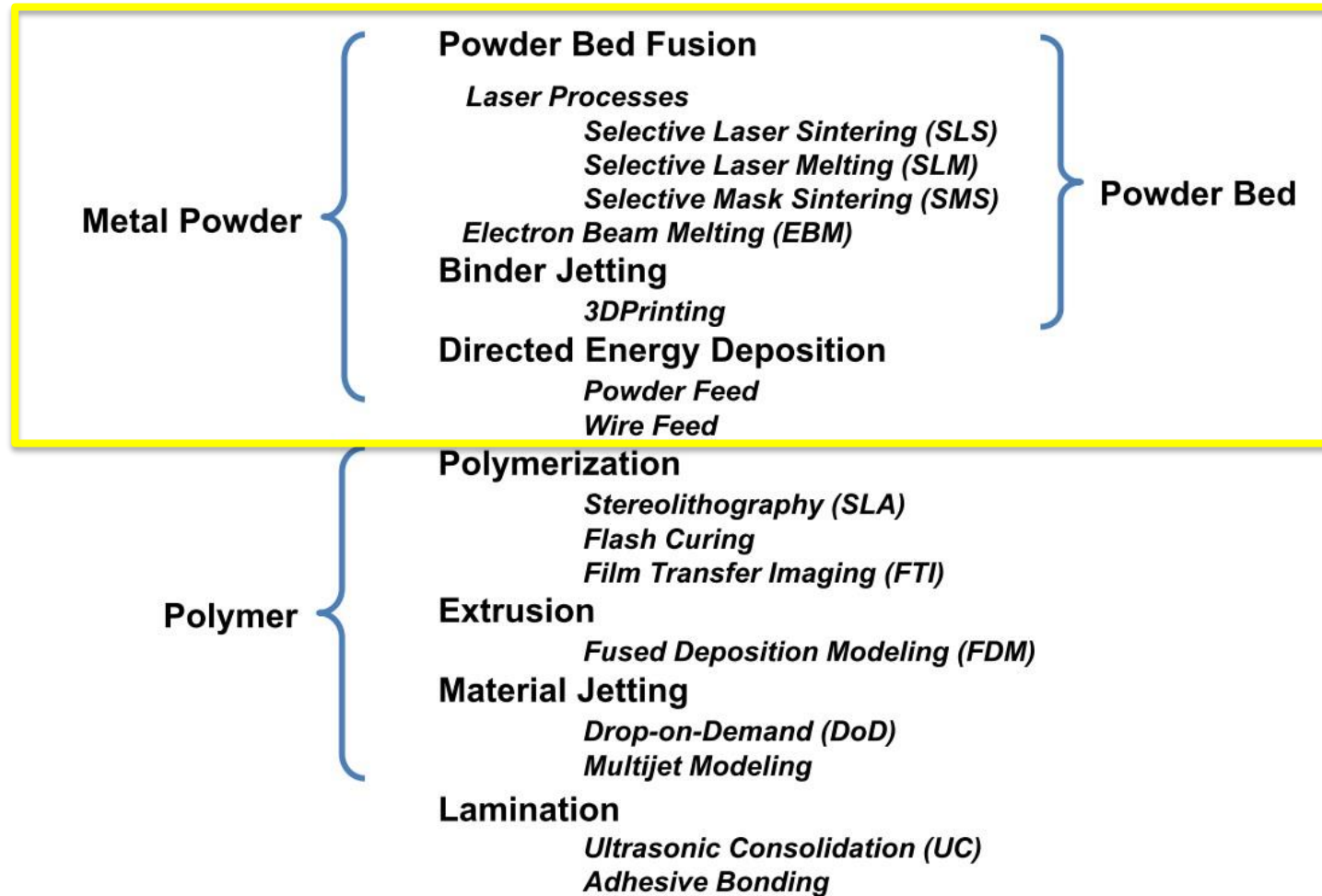


The Jacobs Institute 3D prints vascular models using Agilus30 material and PolyJet technology.

Polyjet vs FDM

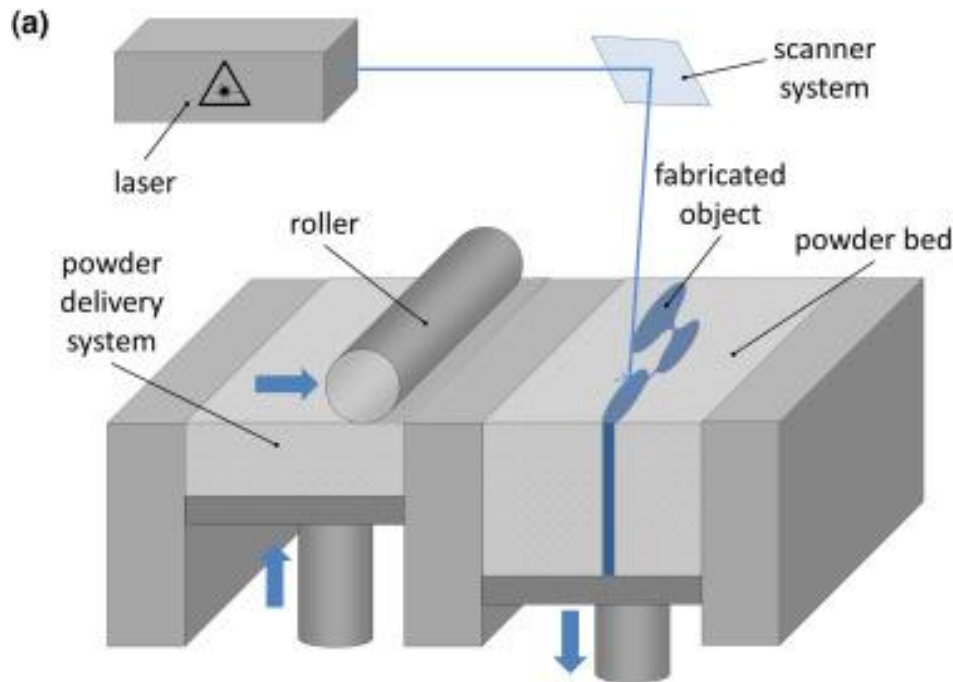


Classification of AM process



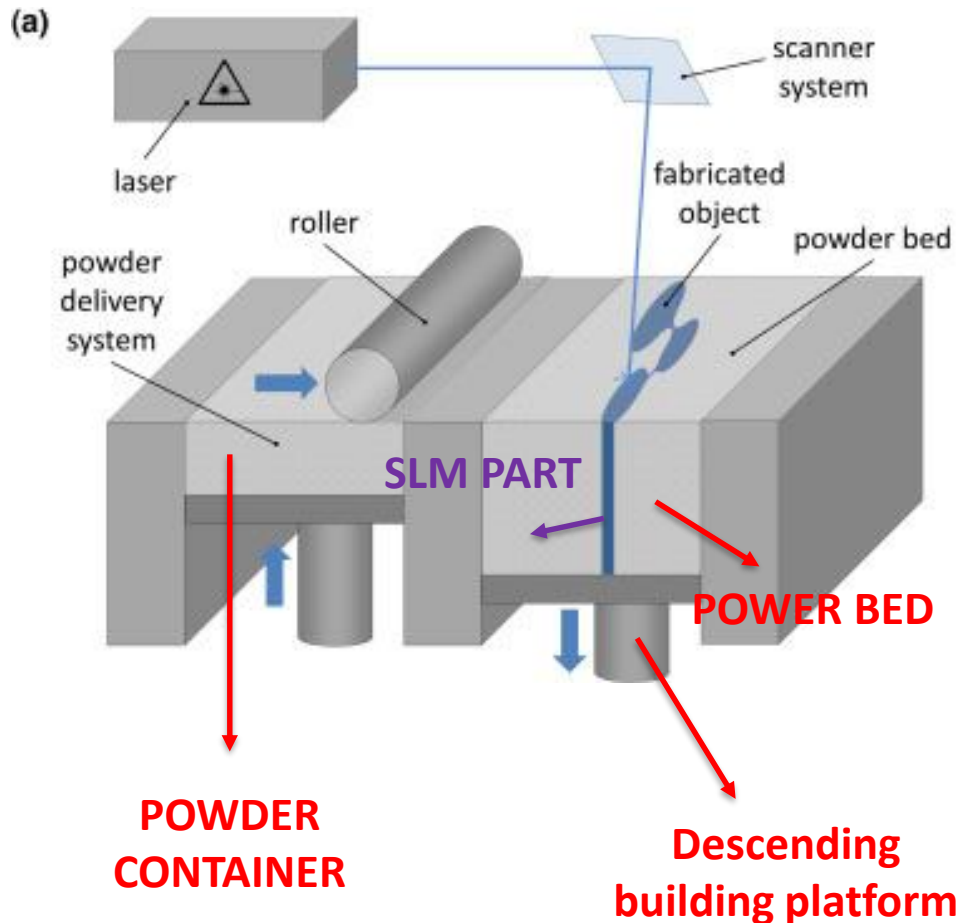
Power Bed Fusion (PBF)

- Alternative names are **Selective Laser Melting (SLM)** and **Direct Metal Laser Sintering (DMLS)**



- SLS uses a laser to melt powder metal into cross sections
- A new layer of powder is added to the previous one from each cross section
- Unfused powder acts as a support during the construction of the object

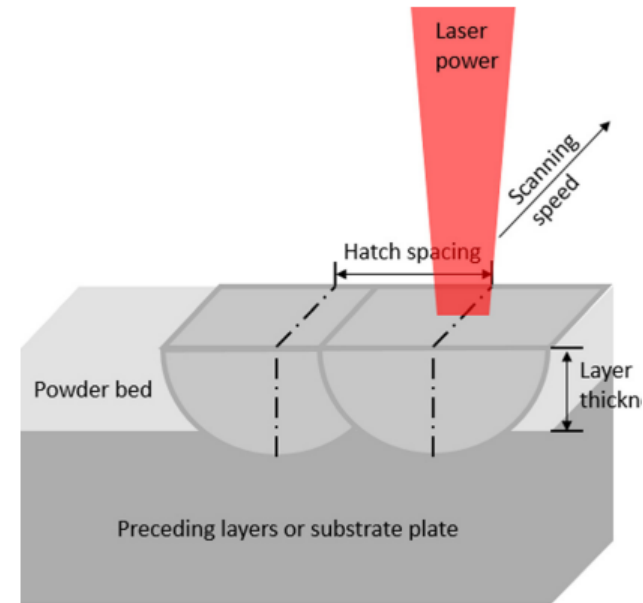
Power Bed Fusion (PBF)



- The process is carried out in inert atmosphere;
- The roller is used to lay down a layer of powders;
- The building platform gets up every layer;
- The powder container (in which the metallic powders are stored) gets up every layer;

Power Bed Fusion (PBF)

- Main process parameters:
Laser power (P) [W],
Scanning speed (S) [mm/s]
Hatch spacing (h) [mm]
Layer thickness (t) [mm]
- These parameters must be optimized for each material because they influence the mechanical properties, the microstructure, density and quality of the manufactured component.
- This energy density is the measure of the average applied energy from the laser per volume of material during the scanning of an individual layer



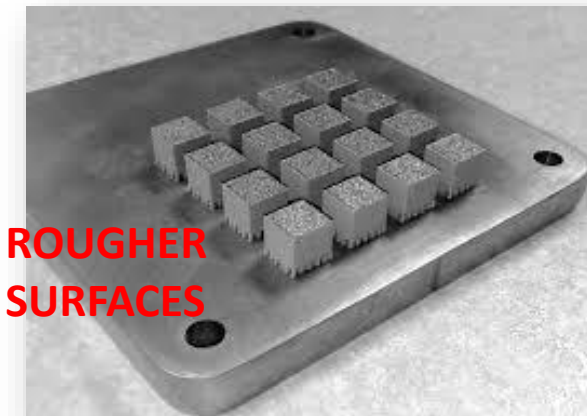
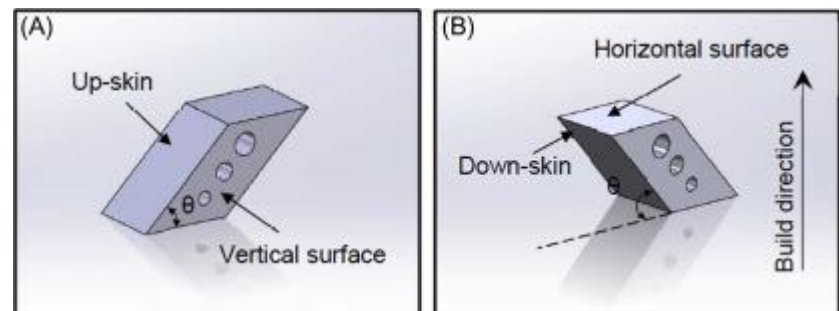
Energy density (FLUENZA) [J/mm³]:

$$E = \frac{P}{S * h * t}$$

Power Bed Fusion (PBF)

SURFACE FINISH

- AM components are characterized by poor surface finish; thus, they usually need finishing operations to improve surface finish;
- Up-skin and down-skin surfaces are critical (in down-skin surfaces the area scanned is supported by a powder bed instead of solidified metal of the previous deposition layers -> lower heat transfer -> lowest allowable inclination angle);
- It is possible to decrease surface roughness by optimizing process parameters in correspondence of the surface;
- Surface roughness depends on many factors (powder size, presence of supports, slant, scanning speed...)



Power Bed Fusion (PBF)

- Scanning strategy

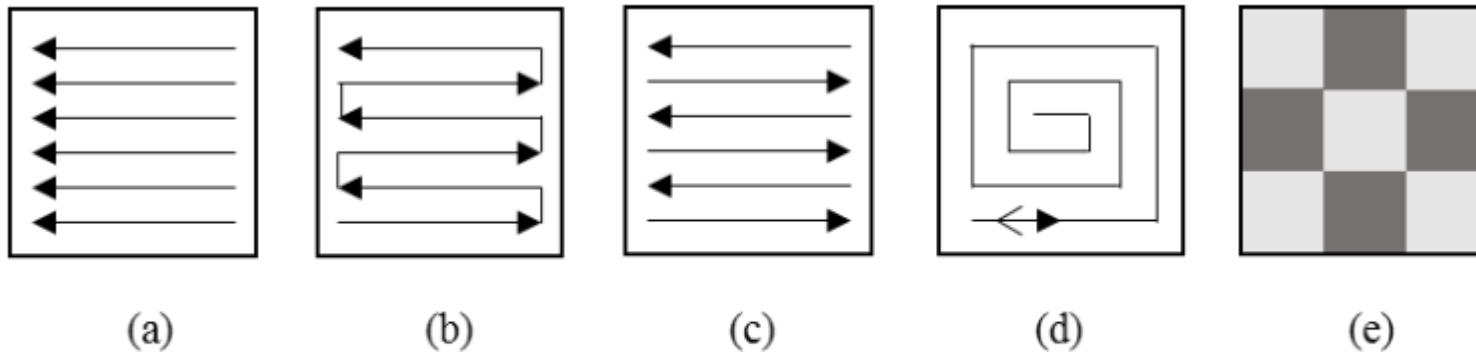


Figura 32: Alcune possibili strategie di scansione: (a) unidirezionale, (b) bidirezionale con percorso continuo, (c) bidirezionale, (d) a spirale e (e) a scacchiera.

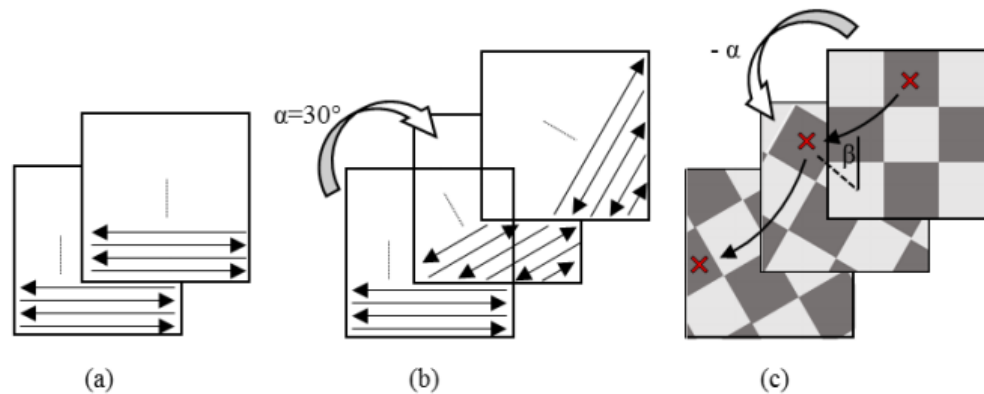


Figura 33: Relazione tra i percorsi laser di più layer successivi: (a) ripetitivo, (b) con rotazione della direzione e (c) con rotazione della direzione e spostamento del punto di partenza del laser.

Power Bed Fusion (PBF)

SUPPORTS DEFINITION:

MAIN FUNCTIONS:

- ensure that the component remains **anchored to the base** during the process;
- promote proper **heat dissipation** especially for cantilever zones

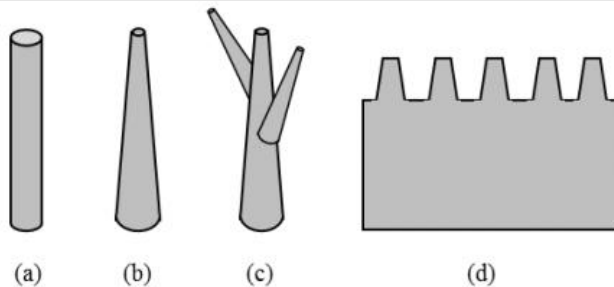


Figura 34: Geometrie utilizzate per supportare i componenti SLM: (a) cilindrica, (b) conica, (c) ad albero e (d) a muro.

For each of these geometries it is possible to define all the dimensions! It is important for setting up the best conditions for heat conduction!

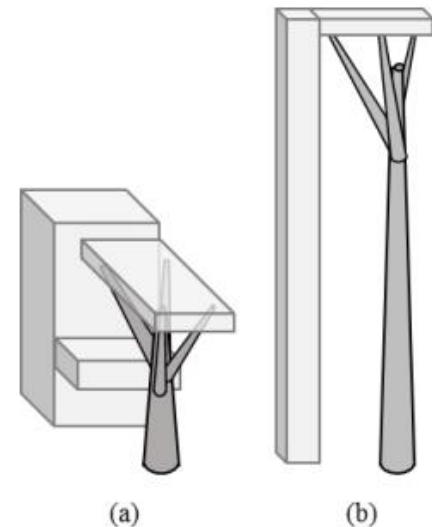
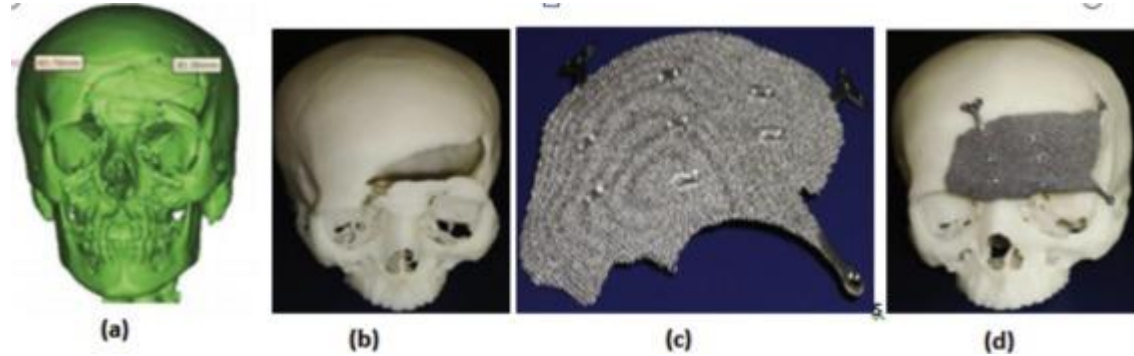


Figura 35: Principali utilizzi dei supporti ad albero.

Applicazioni PBF

Aerospace

- Lightweight supports
- High quality fuselage parts
- Functional prototypes (i.e. turbine parts)



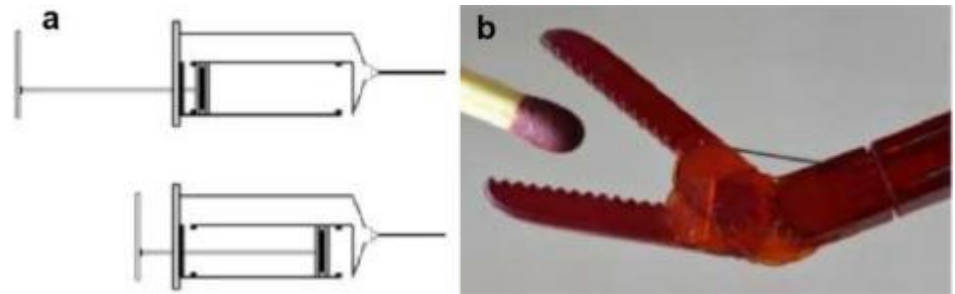
Representative images of applications of AM in medical sector: (a) 3D digital reconstruction of skull defect. (b) Skull model. (c) Porous Ti implant fabricated with EBM. (d) Ti implant fitted to the skull model

Automotive

- Wheel suspension
- Shaft
- Joints

Biomedical

- Dental prosthesis
- Surgical instruments
- Orthopedic applications



(a) AM printed double lumen syringe (b) Steerable laparoscopic grasper having 7 DOF