Mass personalization of medical devices
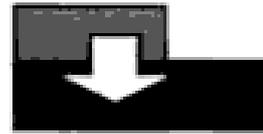
Carmelo De Maria – Andrés Díaz Lantada

Building 3D objects
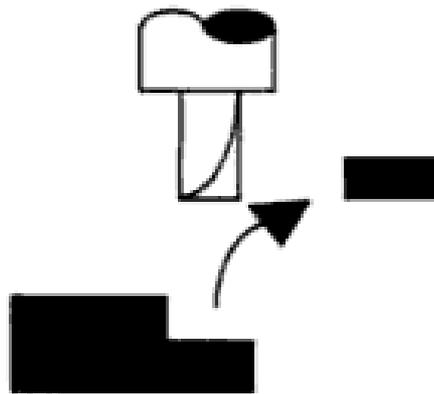
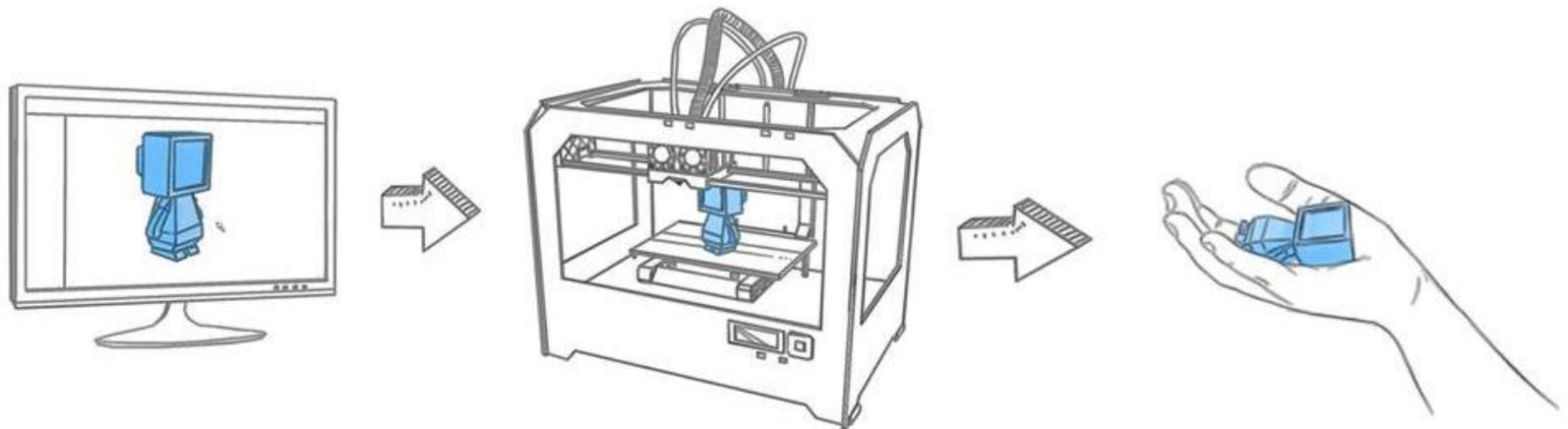

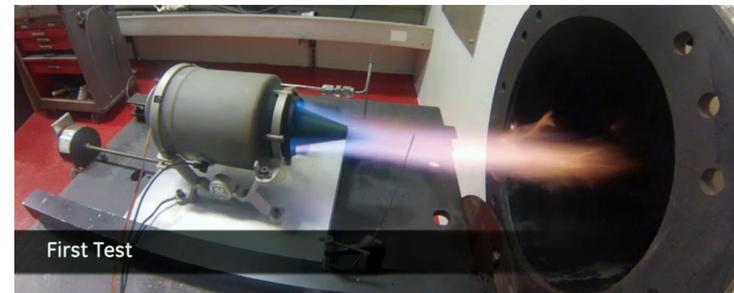**Subtractive**   **Additive**   **Formative**
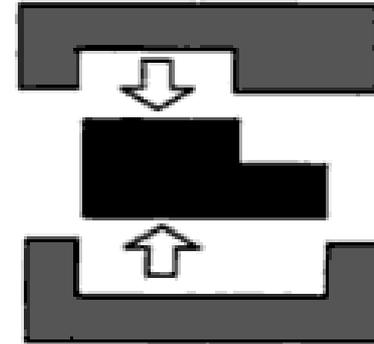
Additive manufacturing

- Additive manufacturing is a process of making a 3D solid object of virtually any shape **from a digital model**.

- It is achieved using an additive process, where successive layers of material are laid down in different shapes

Hype cycle 2017

3D printing what?
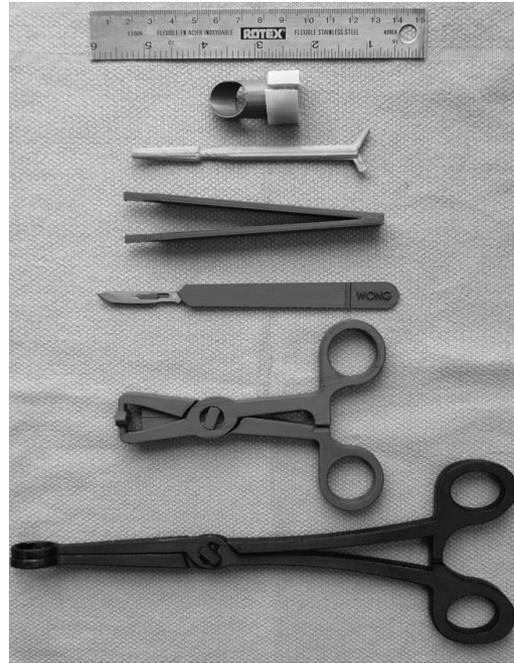
Invisalign Orthodontic Aligners

- An aligner for orthodontic use manufactured using a combination of rapid tooling and thermoforming.

Additive manufacturing technologies

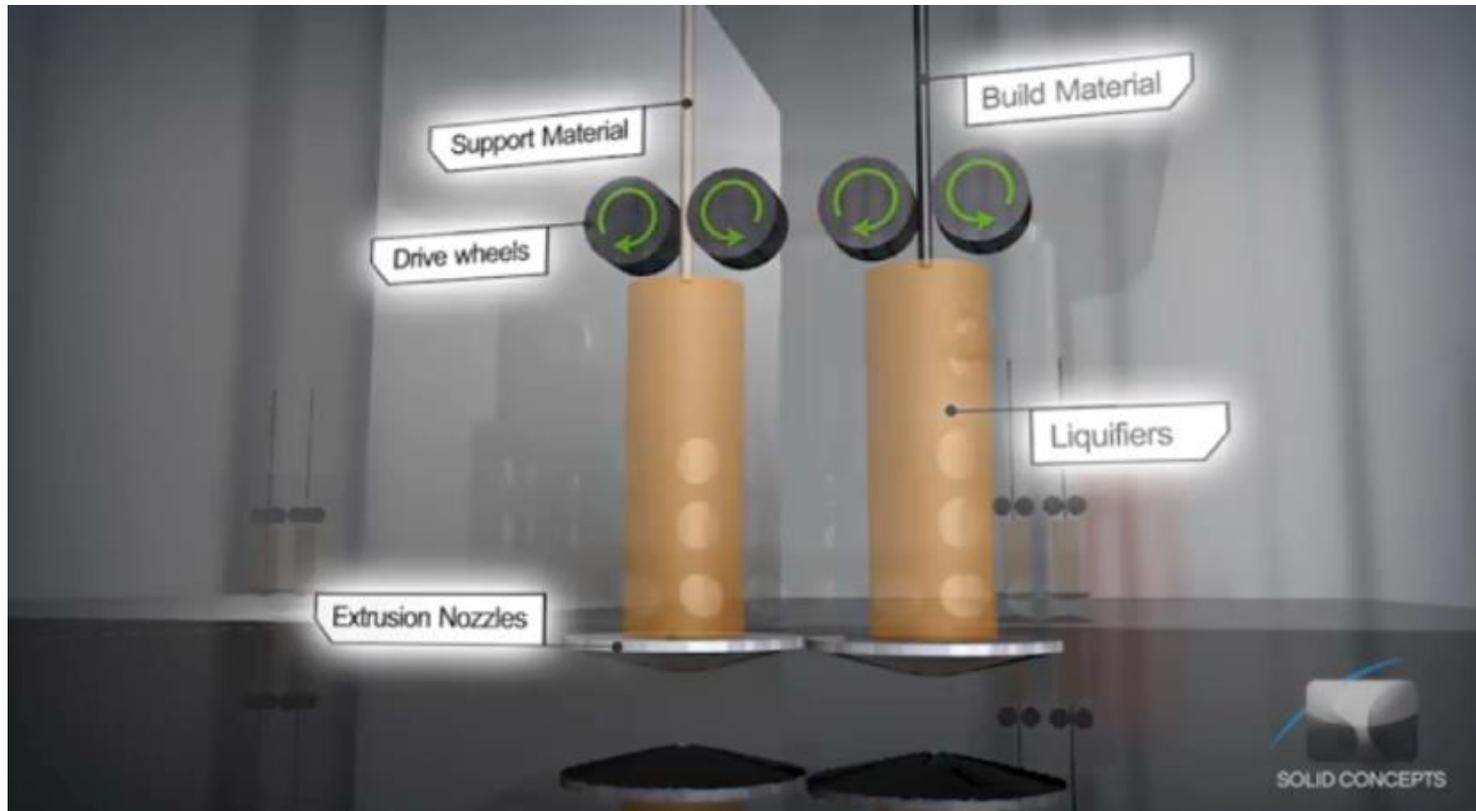# ASTM/ISO 52900 classification

- **Binder jetting**: AM process in which a liquid bonding agent is selectively deposited to join powder materials;

- **Directed energy deposition:** AM process in which focused thermal energy is used to fuse materials by melting as they are being deposited;
  - Note: "Focused thermal energy" means that an energy source (e.g. laser, electron beam, or plasma arc) is focused to melt the materials being deposited.

- **Material extrusion:** AM process in which material is selectively dispensed through a nozzle or orifice;

- **Material jetting:** AM process in which droplets of build material are selectively deposited
  - Note: Example materials include photopolymer and wax.

- **Powder bed fusion:** AM process in which thermal energy selectively fuses regions of a powder bed;

- **Sheet lamination:** AM process in which sheets of material are bonded to form a part;

- **Vat photopolymerisation:** AM process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.
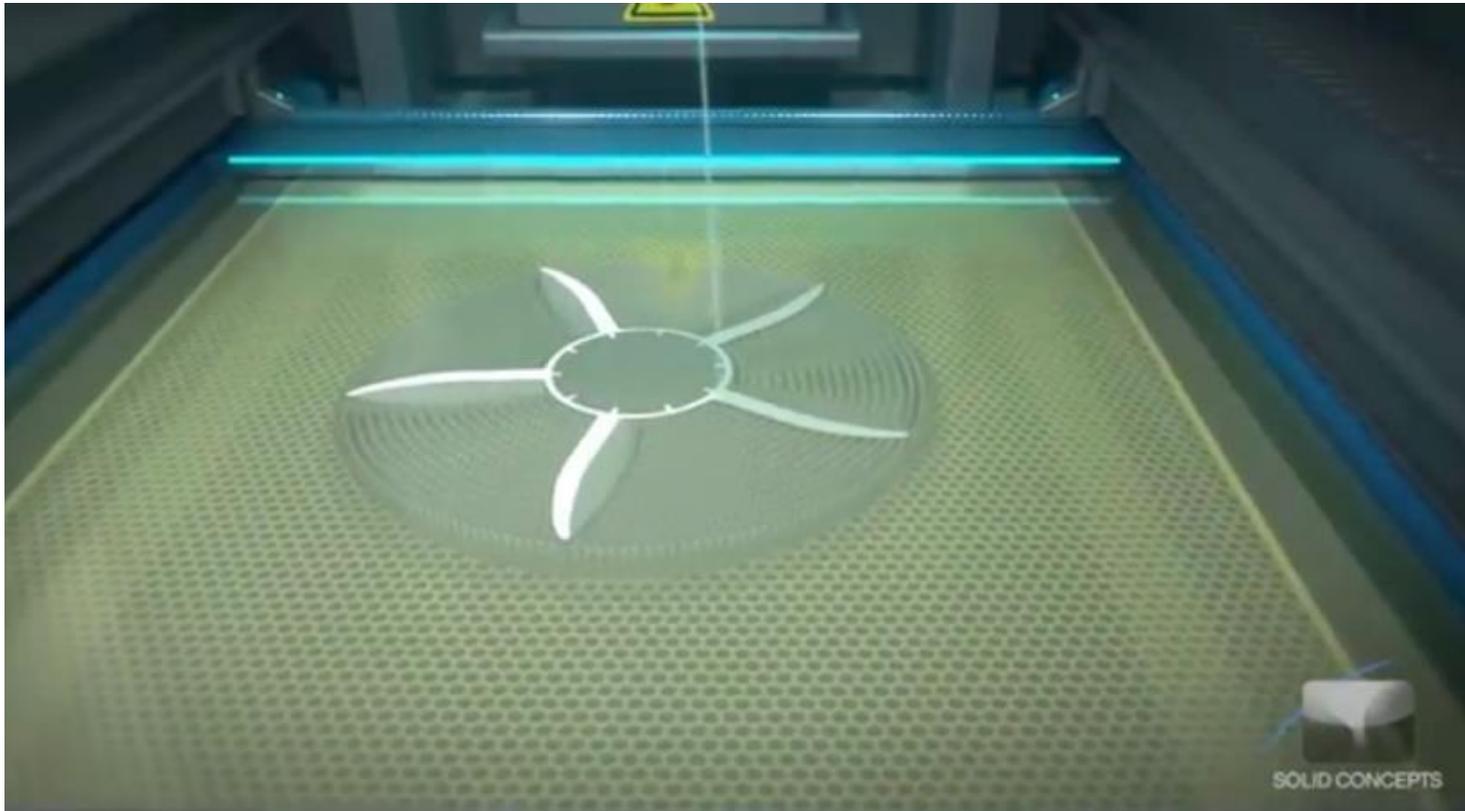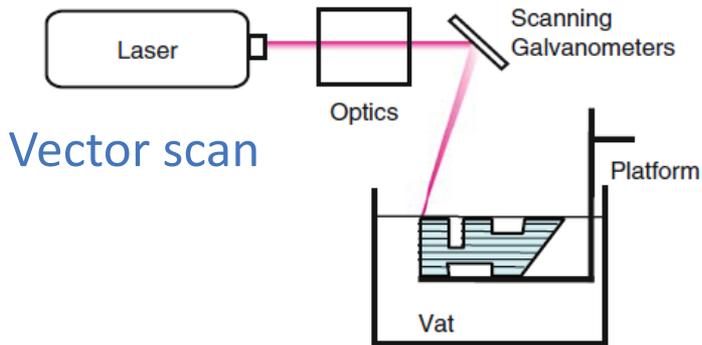
Fused deposition modelling

- https://www.youtube.com/watch?v=WHO6G67GJbM

Fused deposition modelling

- "Standard" materials:
  - Poly-Lactic-Acid (PLA) (soft and hard)
  - Acrylonitril-Butadiene-Stiren (ABS)
  - Polycarbonate (PC)

- "Experimental" materials:
  - Nylon
  - Poly vinyl alcohol (PVA)
  - Conductive (carbon and graphen loaded materials)
  - Metallic loaded plastics

Support material filament
Build material filament
Extrusion head
Drive wheels
Liquifiers
Extrusion nozzles
Part
Foam base
Build platform
Part supports
Support material spool
Build material spool

Copyright © 2008 CustomPartNet

Photopolimerization processes

- https://www.youtube.com/watch?v=NM55ct5KwiI
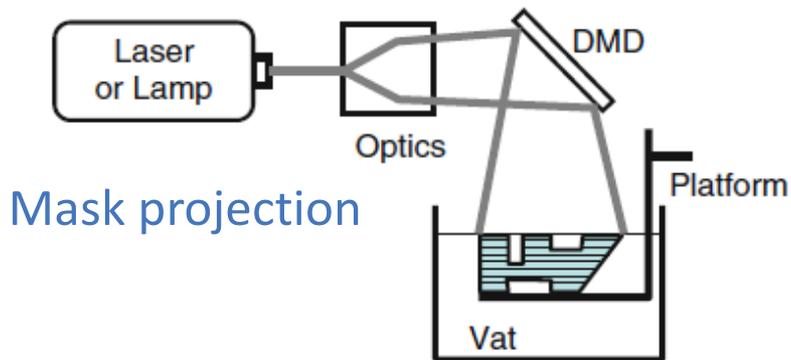
Stereolithography

Vector scan

Mask projection

Materials:
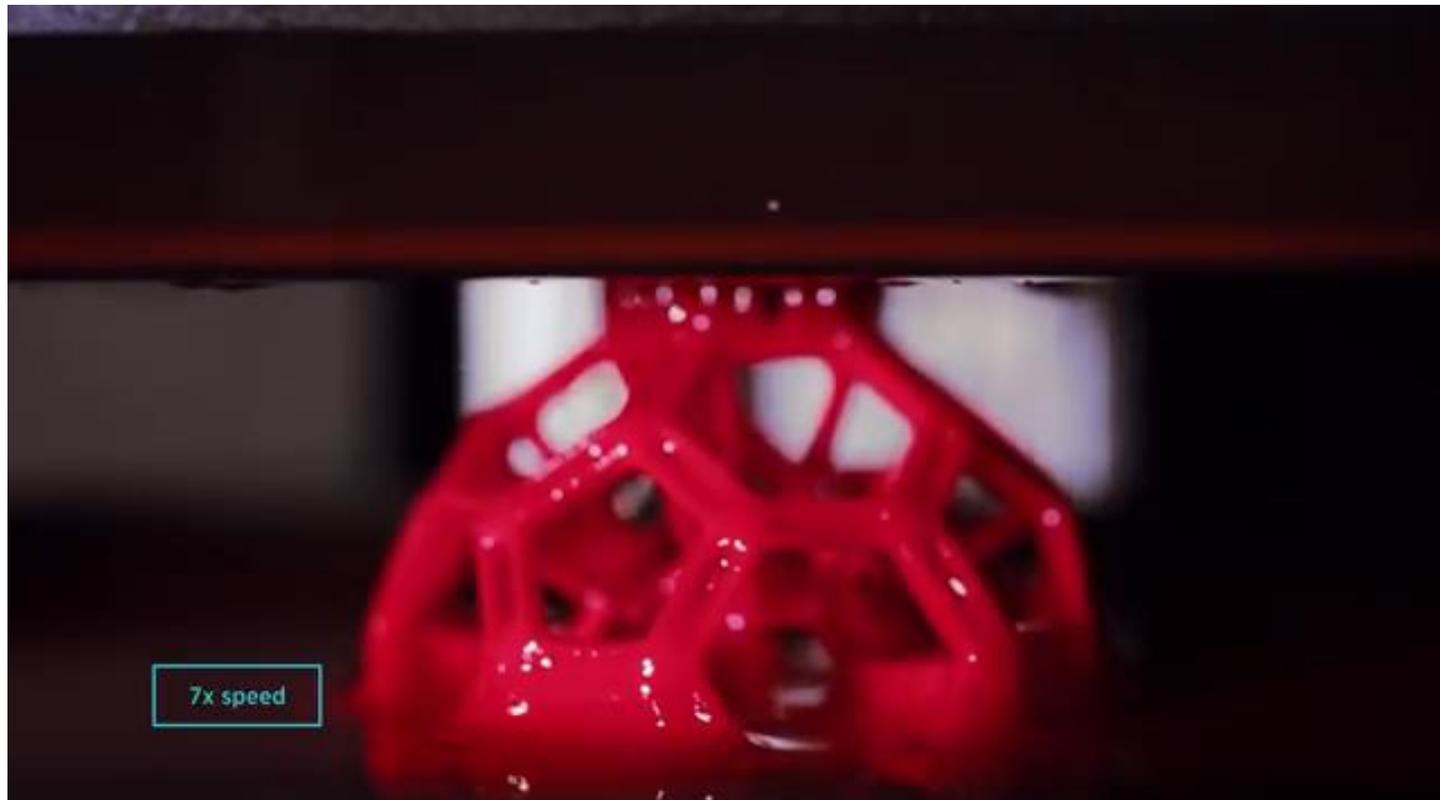
- Different types of resins (hard-soft, transparent)

- Hydrogels
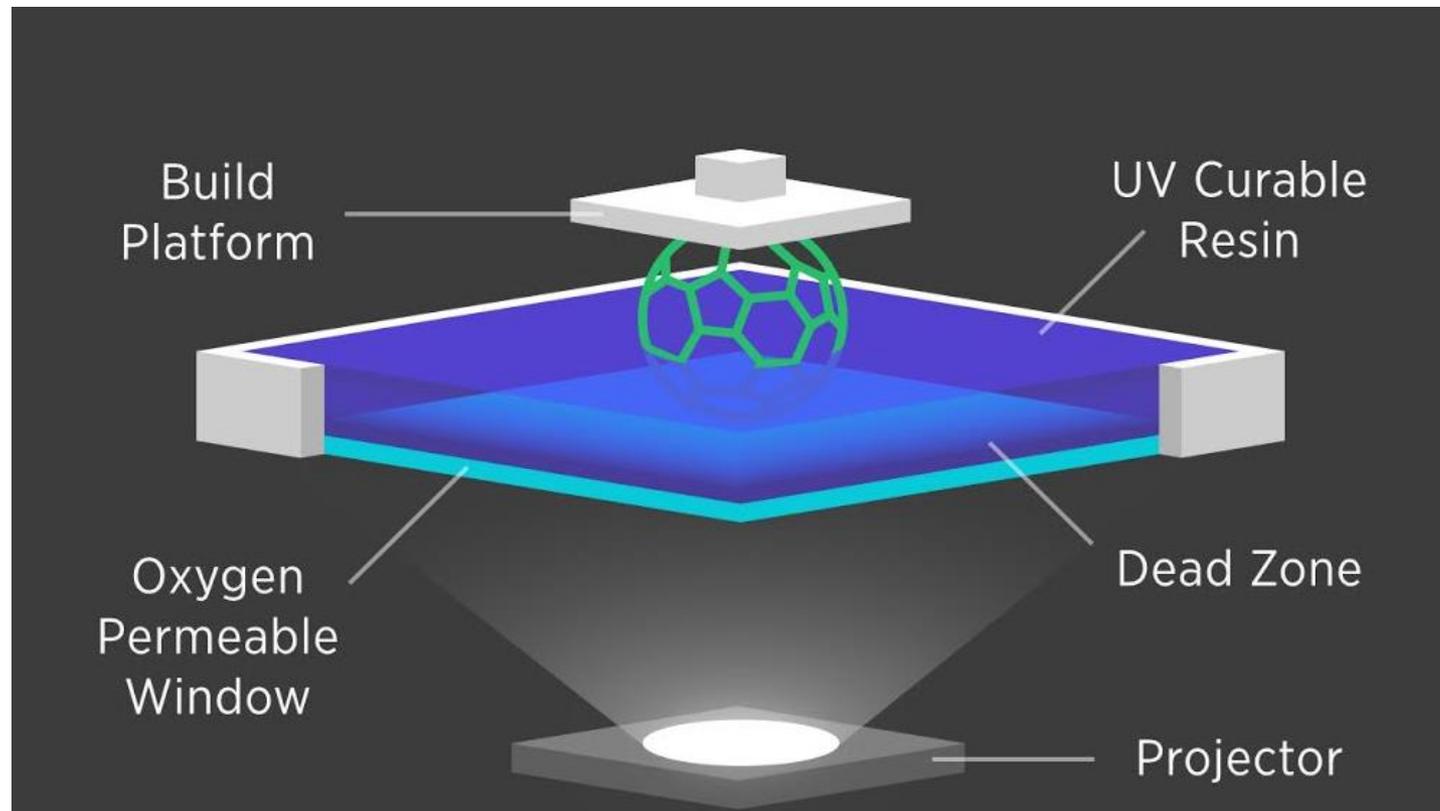
Continuous liquid interface sterolitography (Carbon 3D)

https://www.youtube.com/watch?v=UpH1zhUQY0c

Continuous liquid interface sterolitography (Carbon 3D)
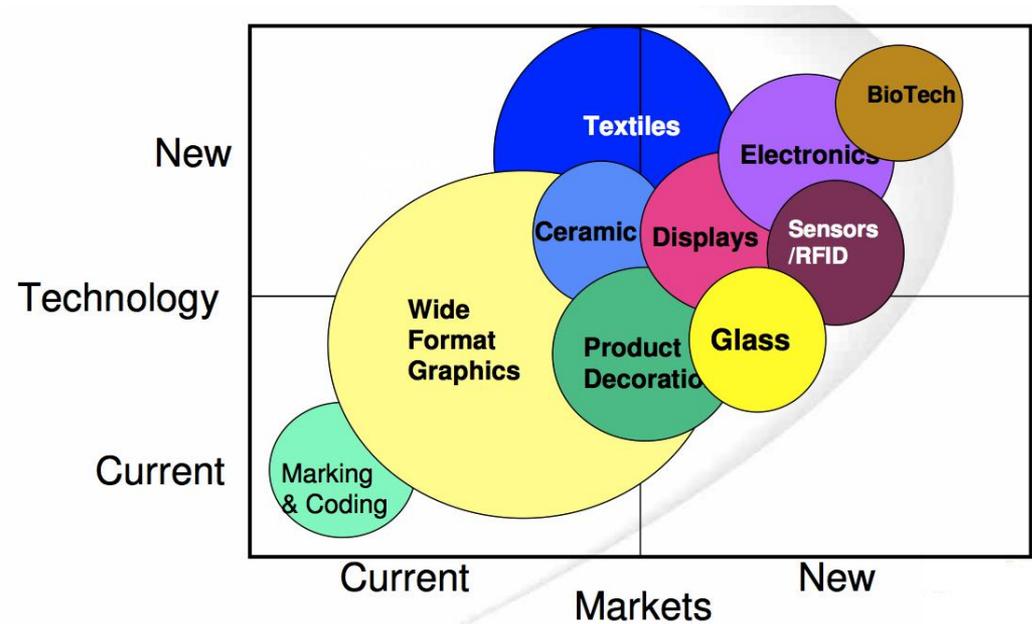
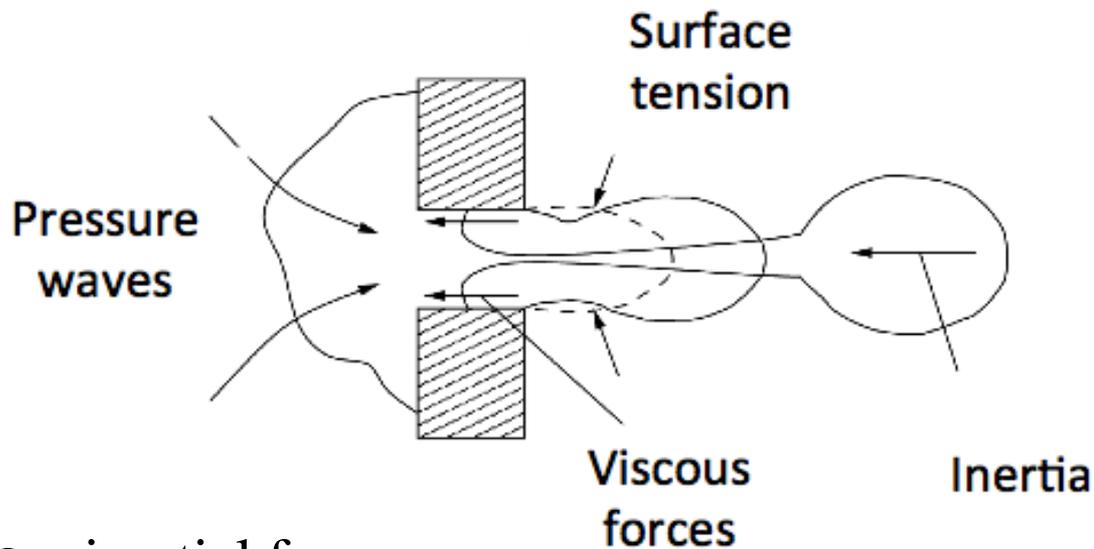https://www.youtube.com/watch?v=UpH1zhUQY0c

Inkjet based technologies

- The ink-jet technology is a contact free dot matrix printing procedure. Ink is issued from a small aperture directly onto a specific position on a medium
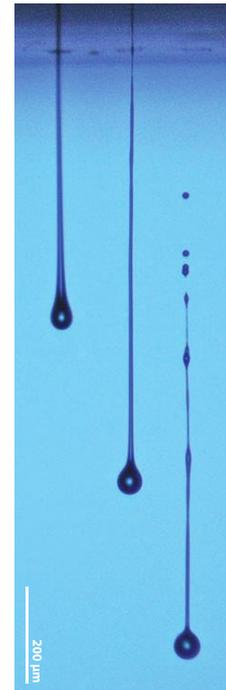
Printability of inks

Pressure waves

Viscous forces

Inertia

$$We = \frac{v^2 r a}{g} = \frac{\text{inertial forces}}{\text{surface forces}}$$

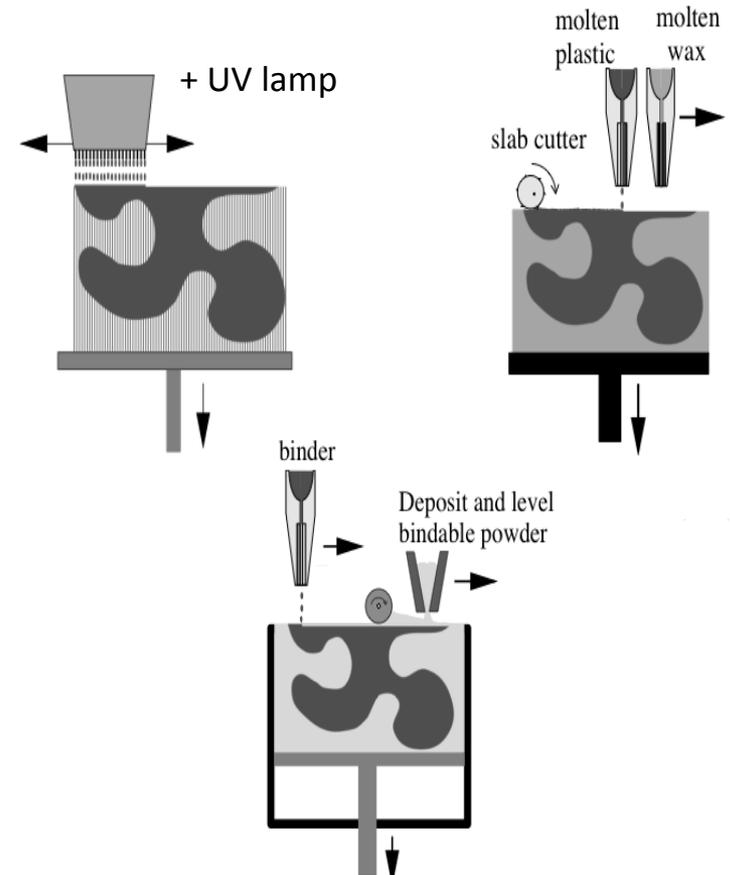$$Re = \frac{v r a}{h} = \frac{\text{inertial forces}}{\text{viscous forces}}$$

$$Oh = \frac{\sqrt{We}}{Re} = \frac{\text{viscous forces}}{\text{surface forces}}$$

200 μm

Additive manufacturing processes with inkjet technology

- **Stereolithography – Polyjet**
  - Liquid photopolymer

- **Multijet Modeling**
  - Wax like ink

- **Three dimensional printing (3DP)**
  - Printing a binding agent onto a powder
  - Conglutination of granules and binders

+ UV lamp

molten plastic   molten wax

slab cutter

binder

Deposit and level bindable powder

Polyjet

https://www.youtube.com/watch?v=Som3CddHfZE

Laser sintering

https://www.youtube.com/watch?v=bgQvqVq-SQU

Laser sintering

- Polymers
  - nylon, ABS, PVC, and polystyrene,
  - nylon/polycarbonate powders are health hazards (dangerous to breathe).
  - glass-filled or with other fillers
  - metals encapsulated in plastic.

- Metals
  - low melting metal alloys of nickel bronze, steel, titanium, alloy mixtures, and composites
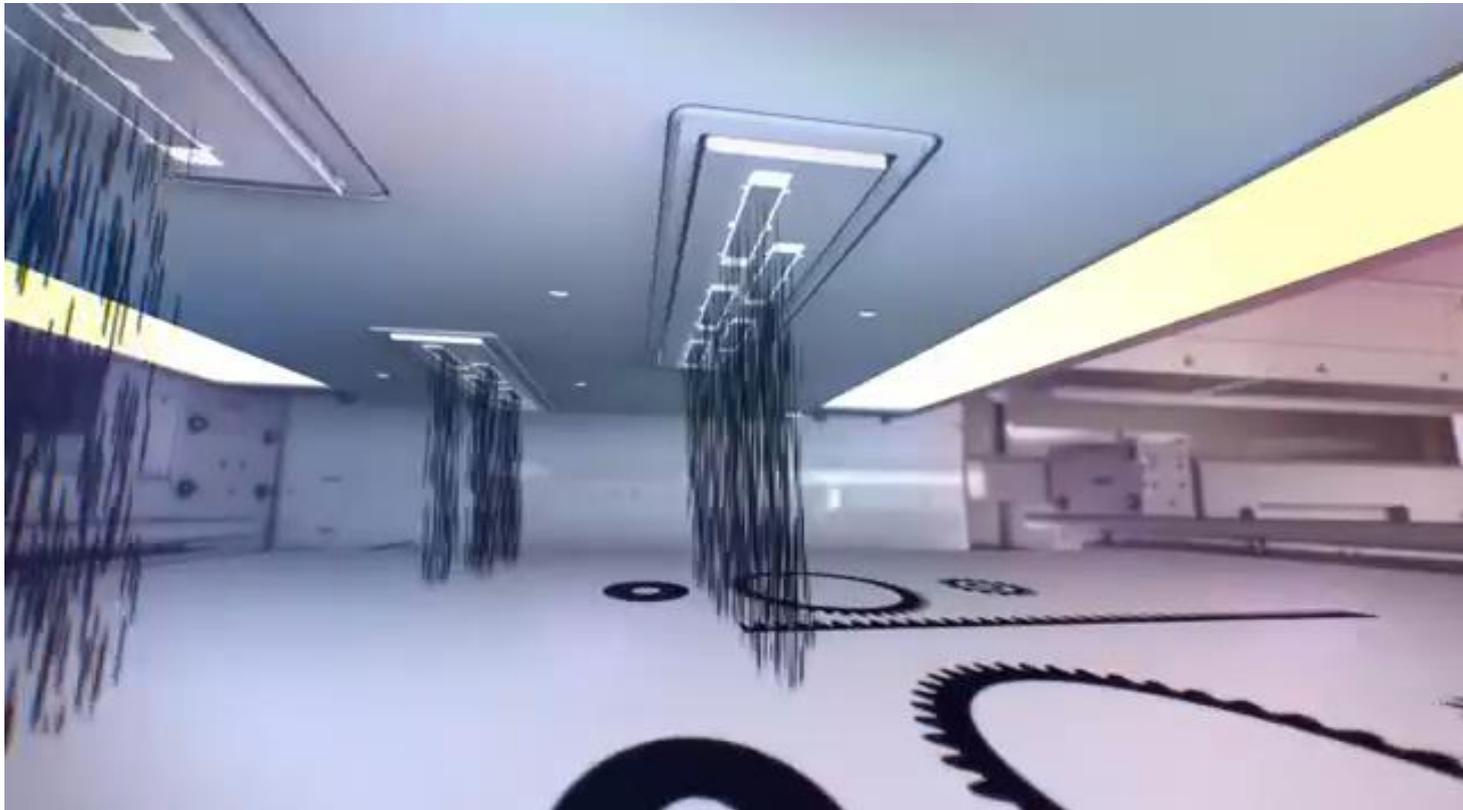
- Green sand (for sand casting).

Directed energy deposition
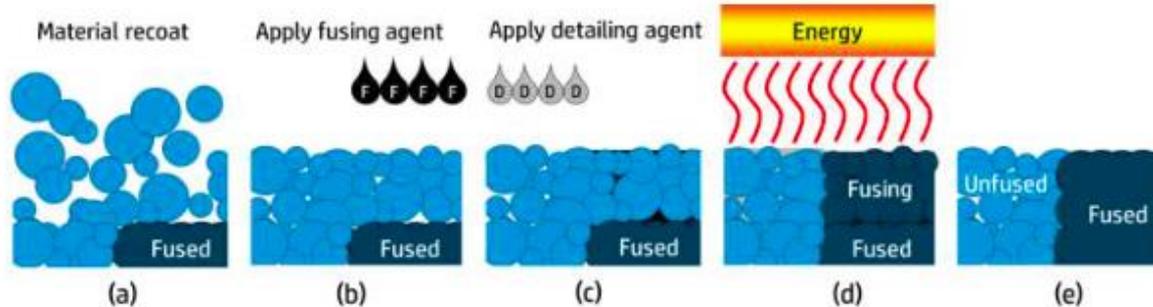
- Laser engineering net shaping (LENS)
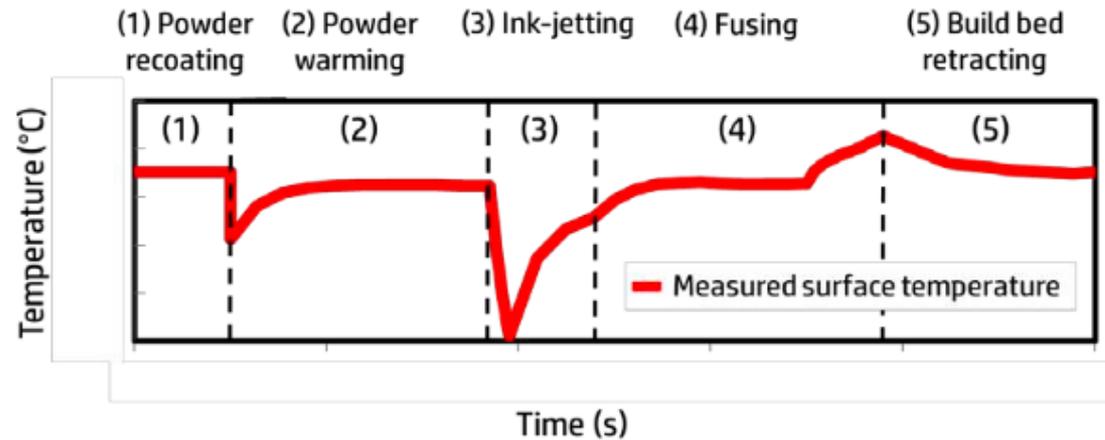- https://www.youtube.com/watch?v=d2foaRi4nxM

Multiject fusion

https://www.youtube.com/watch?time_continue=1&v=VXntl3ff5tc

Multijet fusion

- binder jetting + thermal energy

General considerations on Additive Manufacturing technologies

Materials

- Polymers
  - Thermoplastics
  - Resins
  - Wax
- Slurries and gels
- Metals
- Ceramics
- Biological materials

Materials

Materials	Example materials	Process categories						
		Vat photo-polymer-ization	Material jetting	Binder jetting	Powder bed fusion	Material extrusion	Directed energy deposition	Sheet lamination
Thermoset Polymers	Epoxies and acrylates	X	X					
Thermo-plastic polymers	Polyamide, ABS, PPSF		X	X	X	X		X
Wood	paper							X
Metals	Steel, Titanium alloys, Cobalt chromium			X	X		X	X
Industrial ceramic materials	Alumina, Zirconia, Silicone nitride	X		X	X			X
Structural ceramic materials	Cement, Foundry sand			X	X	X		
Note: Combinations of the above material classes, e.g. a composite, are possible								

Accuracy-repeatability-resolution

NOT ACCURATE NOT REPEATABLE

VERY REPEATABLE NOT ACCURATE

VERY ACCURATE VERY REPEATABLE
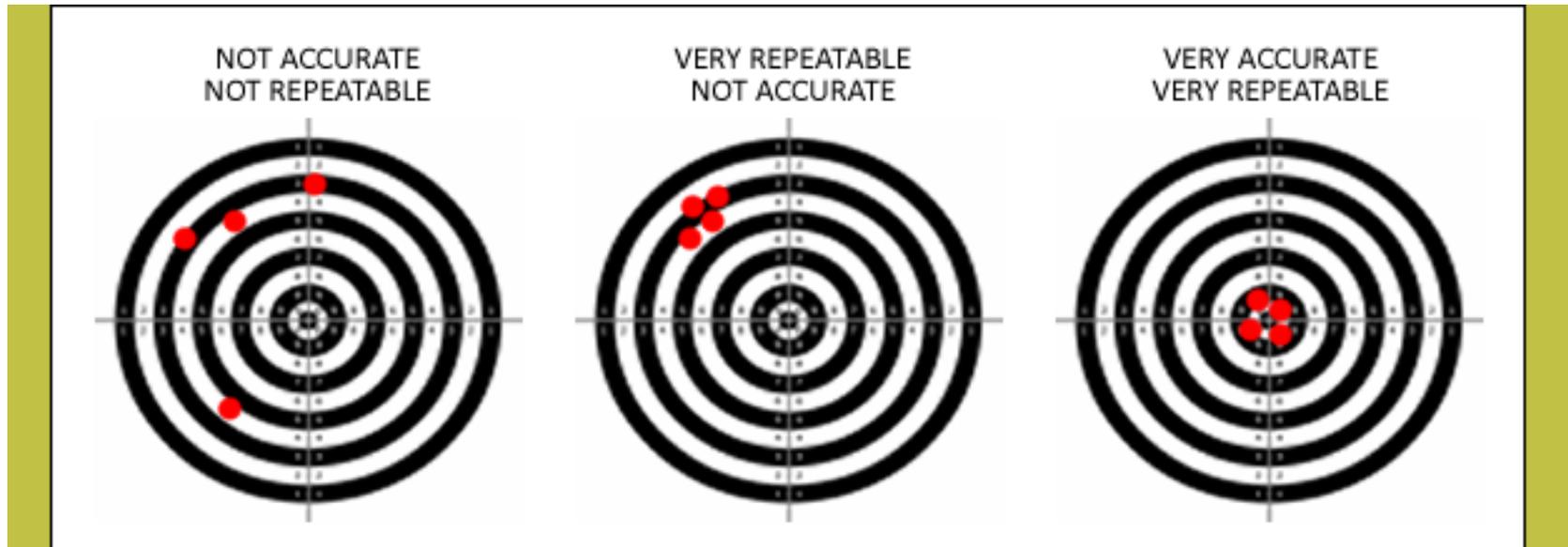
ACCURACY
Degree of comformity of a measurement to a standard or known value

REPEATABILITY
The closeness of aggreement among a number of consecutive measurements

RESOLUTION
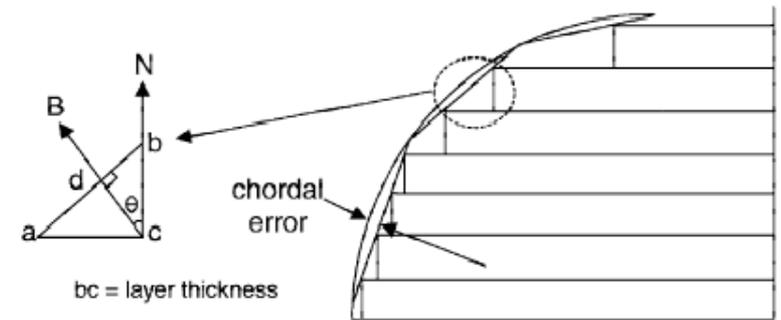The smallest degree of movement that a scale can detect

Accuracy

	Layer thickness(mm)	Accuracy (mm)
Stereolithography	0.05 - 0.3	0.01 - 0.2
Layered Object Manufacturing	0.1 - 1	0.1 - 0.2
Fused Deposition Modelling	≈0.05	0.130 - 0.260
Selective laser sintering	≈0.08	0.03 - 0.4

Accuracy

- Stair stepping

Accuracy and resolution

- Tolerances are still not quite at the level of CNC,

- Because of intervening energy exchanges and/or complex chemistry one cannot say with any certainty that one method of RP is always more accurate than another, or that a particular method always produces a certain tolerance.

'Spikes' Print

Objet30 Pro

Dimension SST 1200
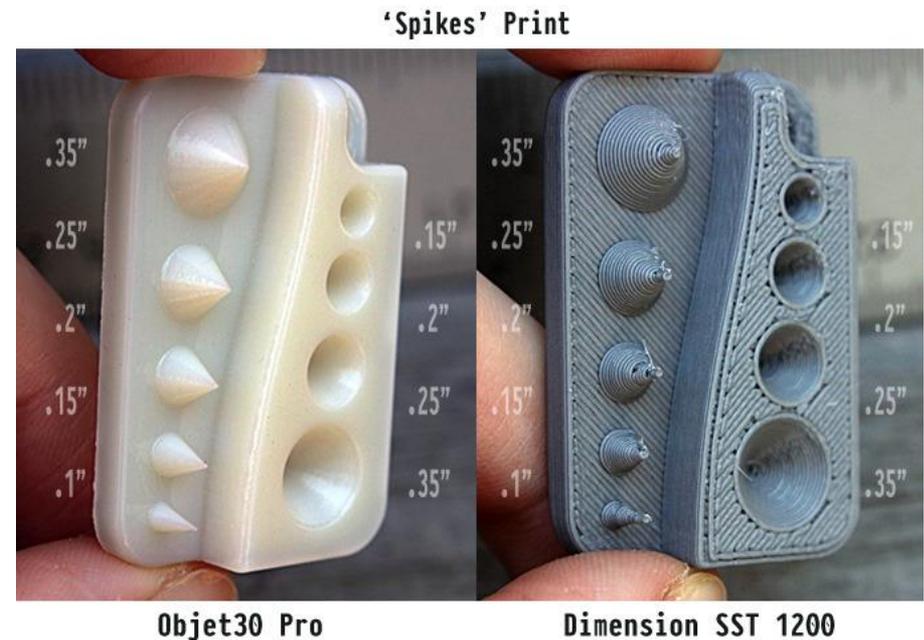
Surface finish

- The finish and appearance of a part are related to accuracy, but also depend on the method of RP employed.

- Technologies based on powders have a sandy or diffuse appearance, sheet-based methods might be considered poorer in finish because the stairstepping is more pronounced.

0.35 mm Layer Height with Vapor Bath Treatement   0.1 mm Layer Height   0.35 mm Layer Height
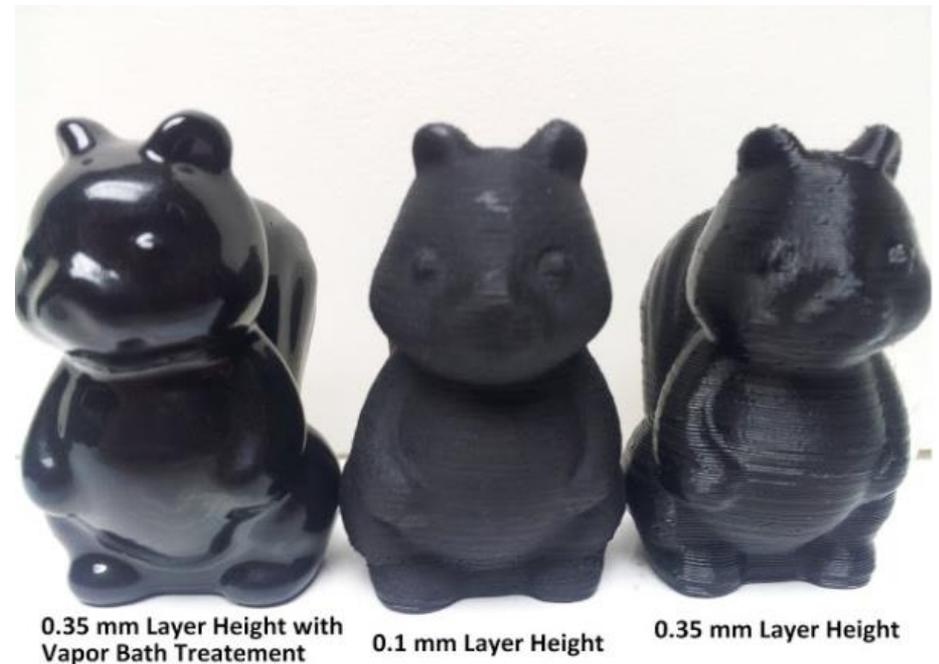
Costs

- ## System costs
  - from $30,000 to $800,000
  - training, housing and maintenance (a laser for a stereolithography system costs more than $20,000)

- ## Material
  - High cost
  - Available choices are limited.

- ## Costs and time due to secondary operations
  - Post Curing (Stereolithography)
  - Infiltration, for fragile parts (3DP, SLS)
  - Final machining of metal parts
  - Removing of the support structures

Not soluble support structure (SLA)

Soluble support structure (white material, FDM)
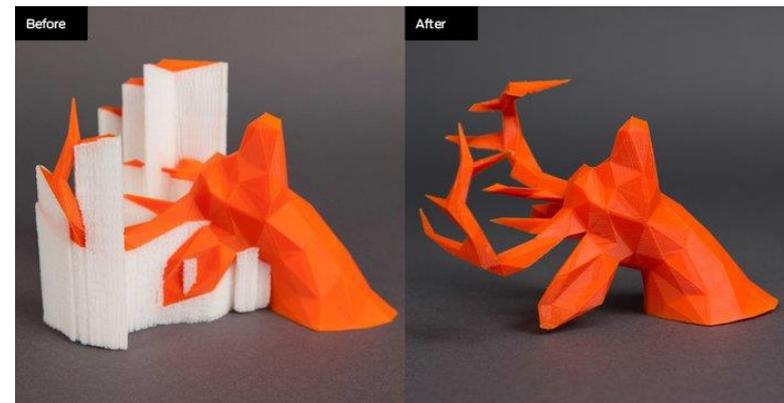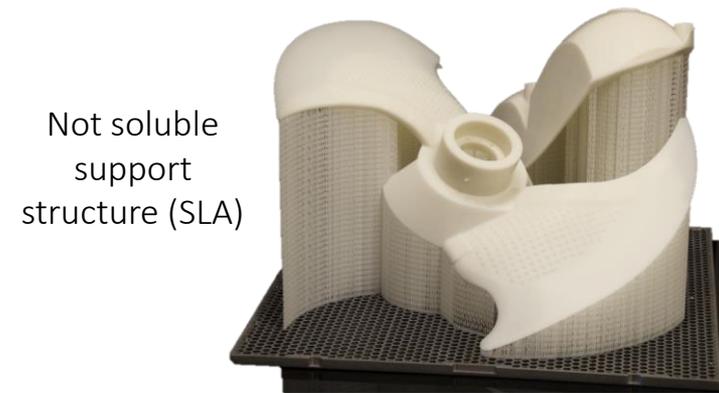
Additive vs subtractive

- AM can not become complete replacement for the SM (Milling, Turning, EDM etc.)

- AM technologies are instead complementary for:
  - complex or intricate geometric forms,
  - simultaneous fabrication of multiple parts into a single assembly,
  - multiple materials or composite materials in the same part.

- Thus, AM is the enabling technology for controlled material composition as well as for geometric control.

Additive manufacturing process flow

Additive manufacturing process flow

- Solid 3D modeling
- Export (Tessellation/Voxelization)
- Support Generation
- "Slicing" of the Model
- Model Physical Buildup
- Cleanup and Post Curing
- Surface Finishing

Solid 3D modeling

- ## Representation of a volume
  - ### CAD model
    - Your specific design
    - Web repository (http://www.thingiverse.com, https://www.youmagine.com, https//3dprint.nih.gov, http://www.appropedia.org, http://opensourceecology.org, http://reprap.org)
  - ### Instruments output
    - Segmentation of medical Images (Tomographic Data: CT scan, RM scan)
    - Surface scanning (Laser)
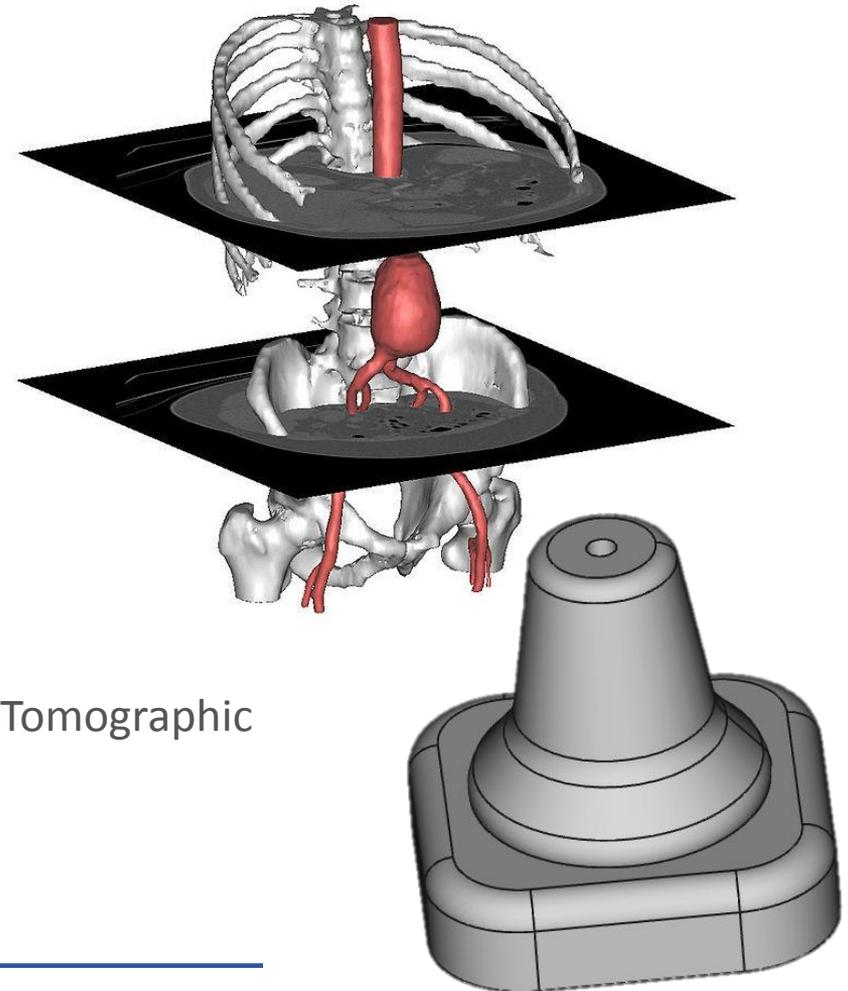
Tessellation / voxelization

- Exchange formats for exporting 3D model
  - Polygon-based representation (STL, AMF, 3MF, OBJ, PLY)
  - Voxel based models
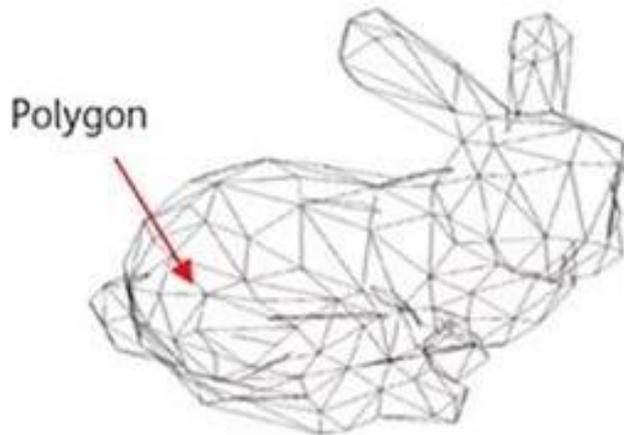
(a) Polygon-based representation
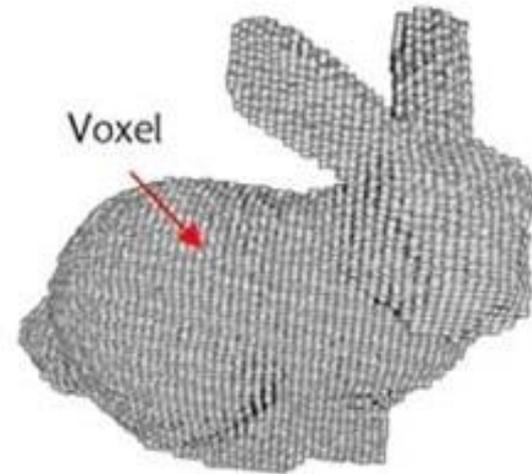
(b) Voxel-based representation

Support generation
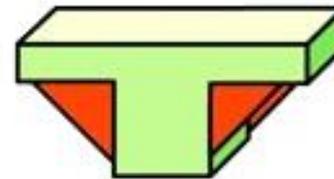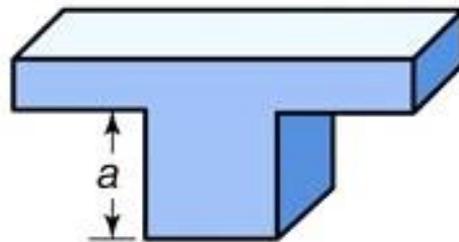
Gussets
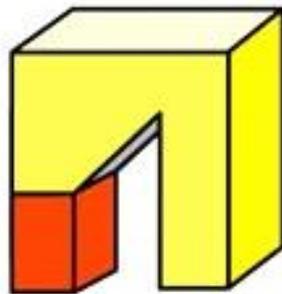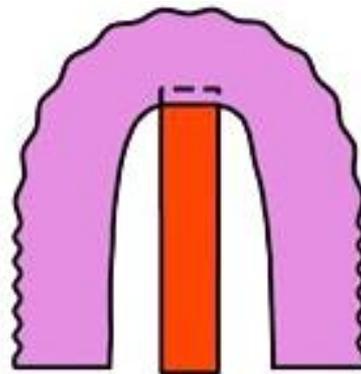
Island   Ceiling within an arch   Ceiling
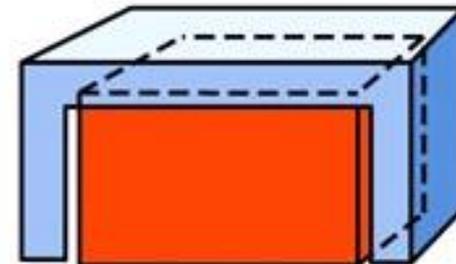
Support generation

- **Support generation may depend on**
  - objects orientation,
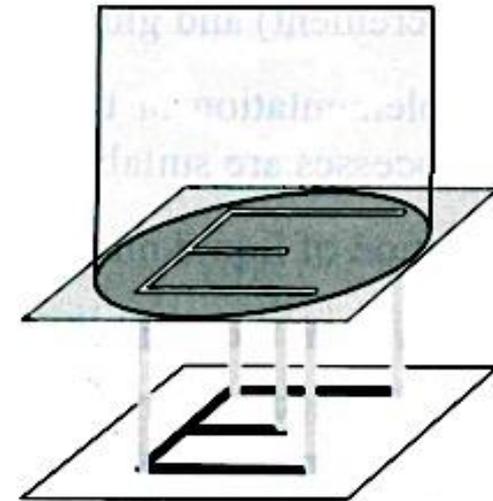 - on the specific additive manufacturing technology
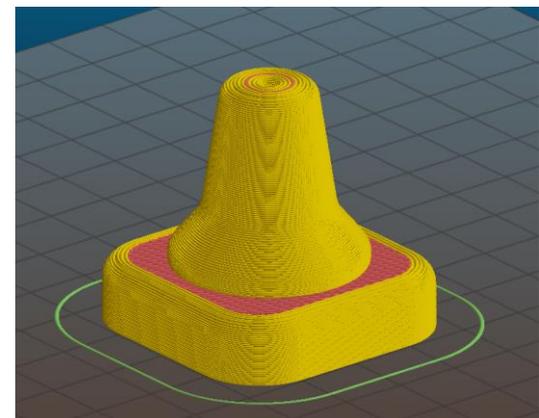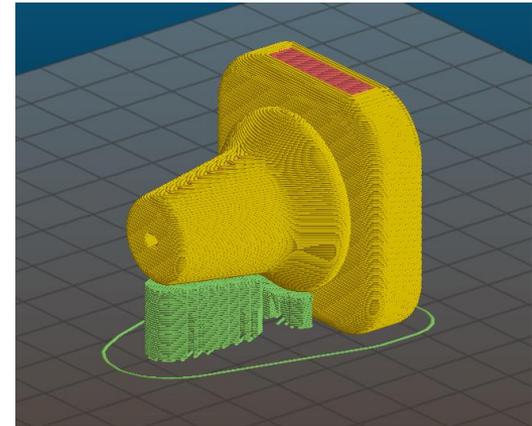
Fused deposition modelling

Support generation

- Support generation may depend on
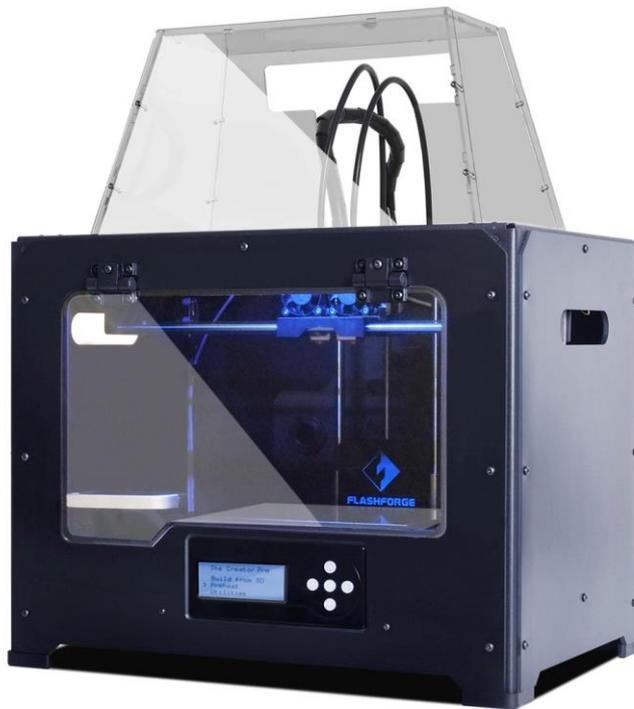 - objects orientation,
  - on the specific additive manufacturing technology
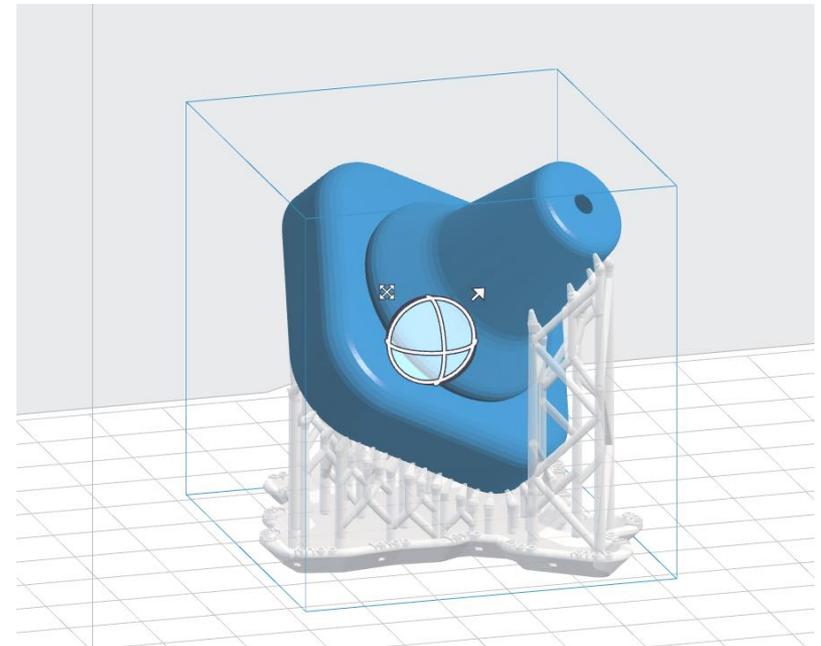
Stereolithography

Slicing the model

- Patterning
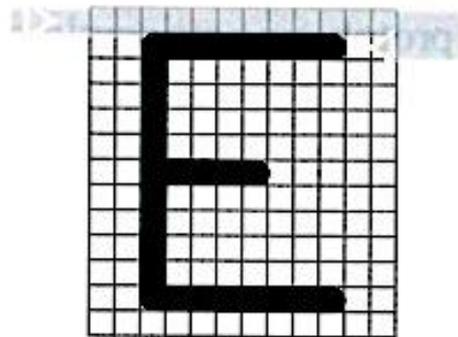
Vector   Raster   Projection

Slicing the model

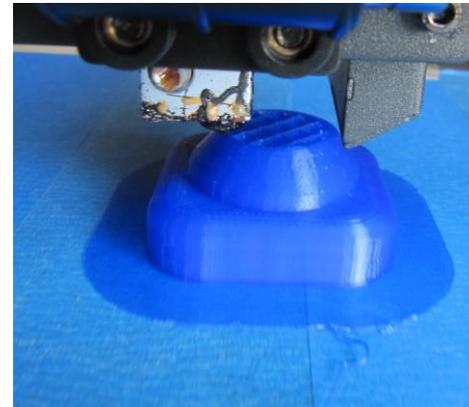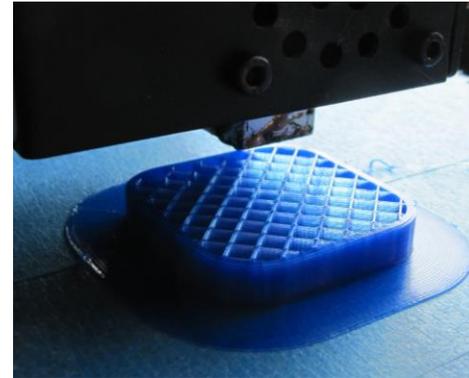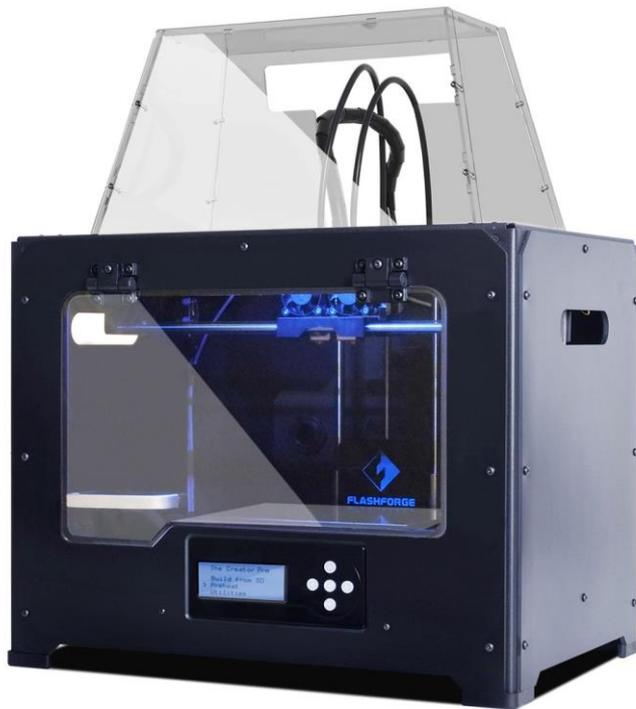- Patterning and printing parameters
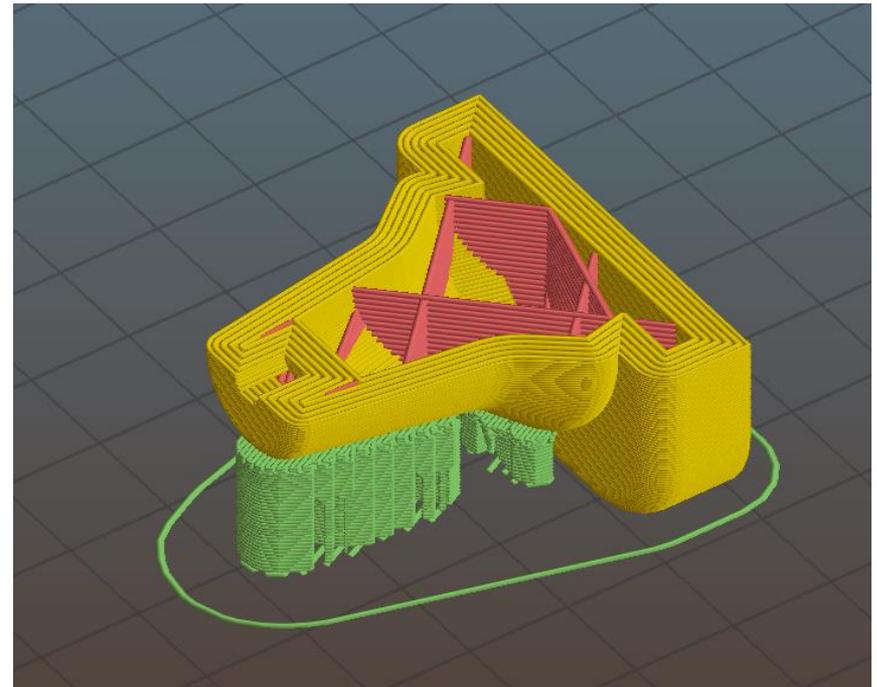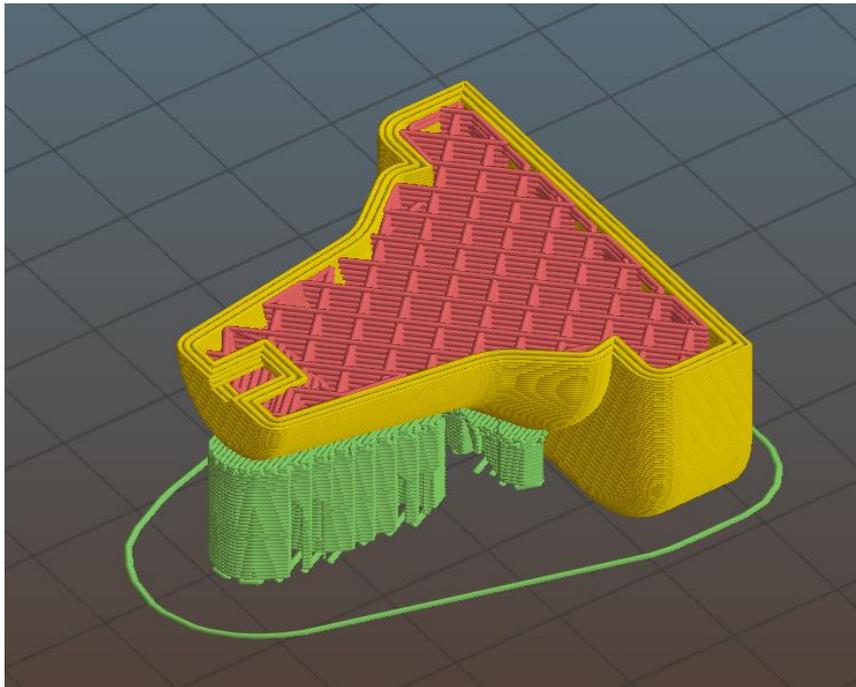
Slicing the model

- Patterning and printing parameters
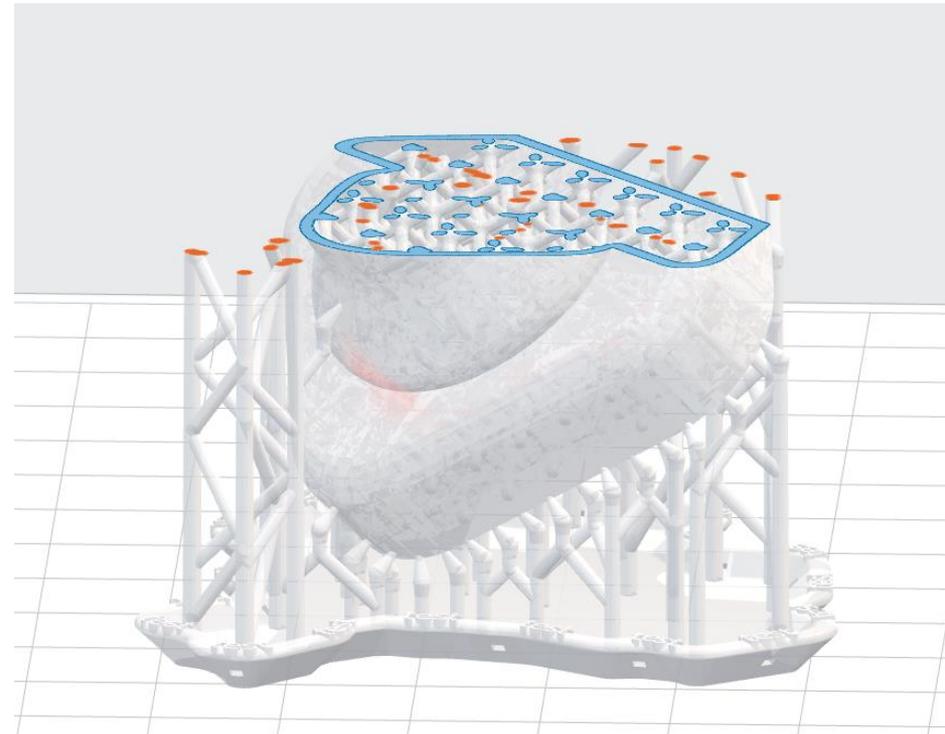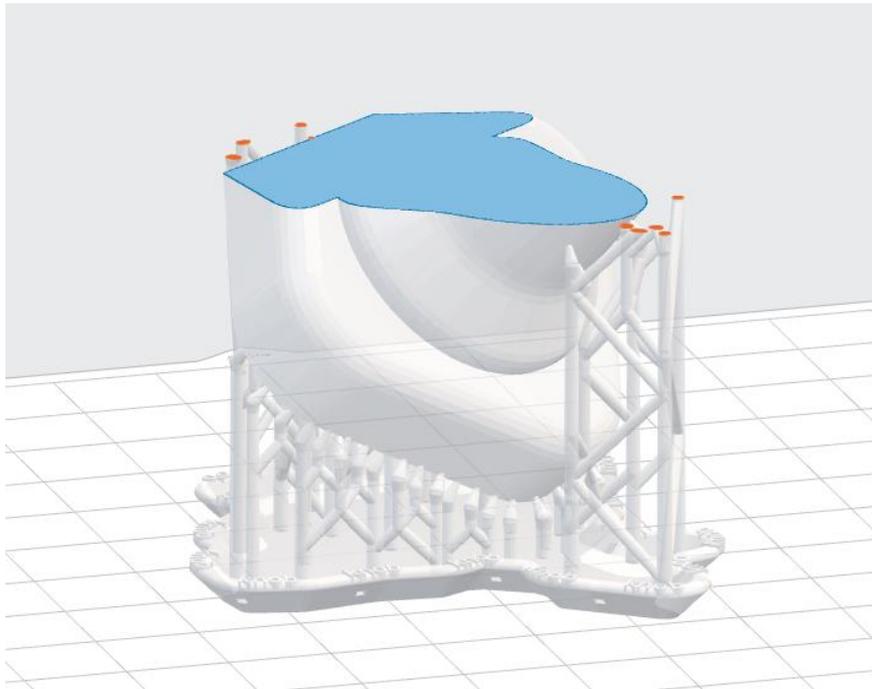
Model physical buildup
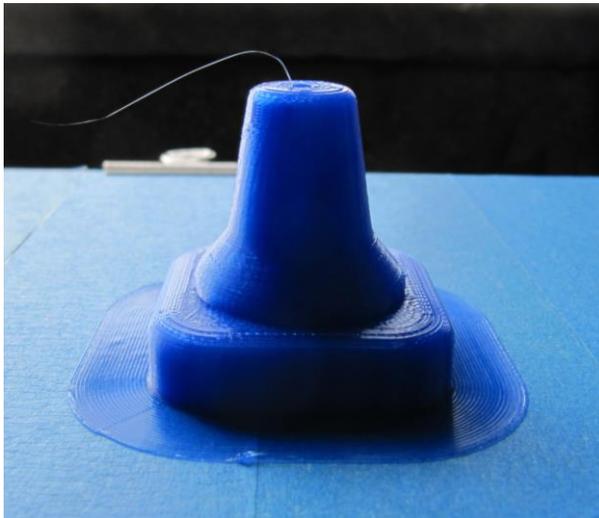
Model physical buildup
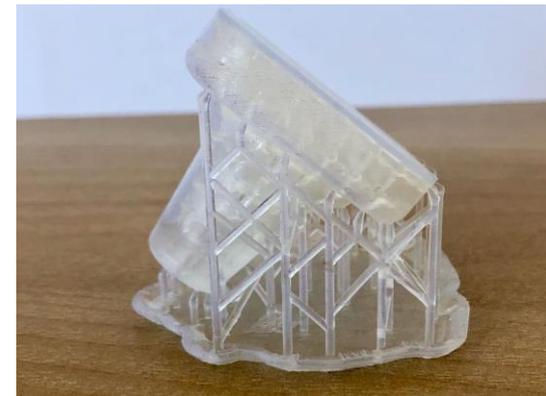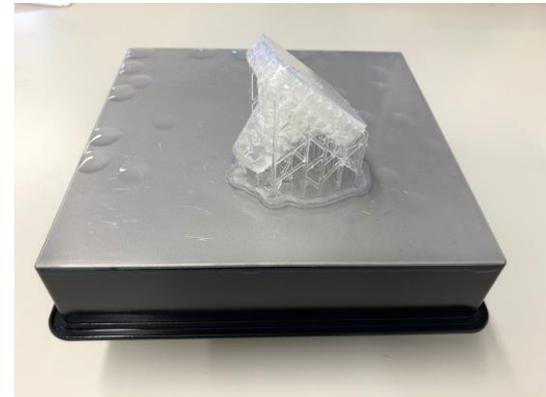
Cleanup and post curing Surface finishing

- Fused Deposition modelling

- Stereolithography

UBORA: Euro-African Open Biomedical Engineering e-Platform for Innovation through Education

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731053