BITS Pilani
Pilani Campus

M.Tech
Digital Manufacturing

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DMZG521- Design for Additive Manufacturing
Session 12 & Lecture 23-24

Design for Polymer AM

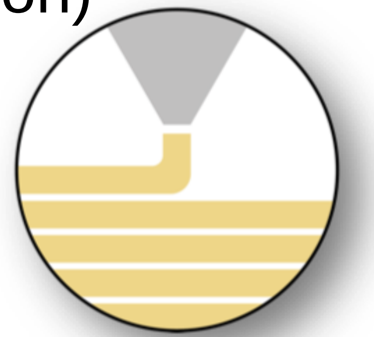
- Different polymer AM process
- Design aspects for polymer AM

Polymer AM processes

- Material Extrusion
- Powder Bed Fusion
- Vat Photopolymerization
- Binder Jetting
- Material Jetting
- Sheet Lamination

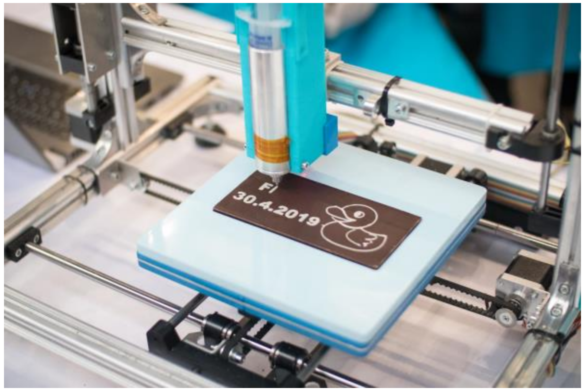
Material Extrusion

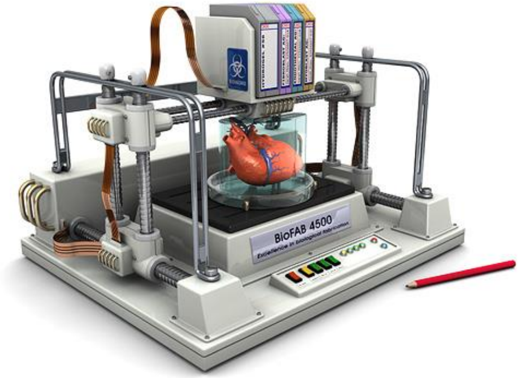
- ➢ Direct Ink Writing or DIW
- ➢ Extrusion Freeform Fabrication or EFF
- ➢ Fused Deposition Modelling or FDM® (Stratasys Inc.)
- ➢ Fused Filament Fabrication or FFF
- ➢ Glass 3D Printing or G3DP
- ➢ Liquid Deposition Modelling or LDM
- ➢ Micro pen Writing
- ➢ Plastic Jet Printing or PJP (3D Systems Corporation)
- ➢ Robocasting or Robotic Deposition



Materials in ME

- Polymers
- Cement
- Chocolate
- Ceramics
- Metal filled plastics
- Blended food
- Biocompatible cellular scaffolds

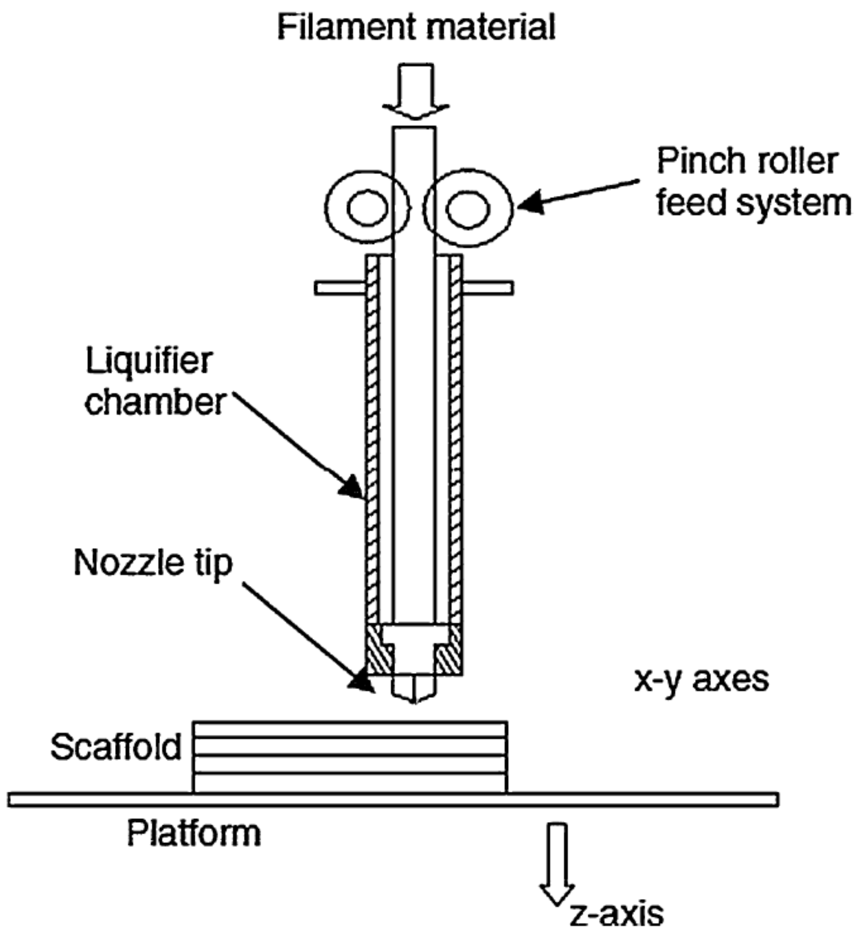




Key Features in ME

- Loading of material
- Liquification of the material
- Application of pressure to move the material through the nozzle
- Extrusion
- Plotting according to a predefined path and in a controlled manner
- Bonding of the material to itself or secondary build materials to form a coherent solid structure
- Inclusion of support structures to enable complex geometrical features

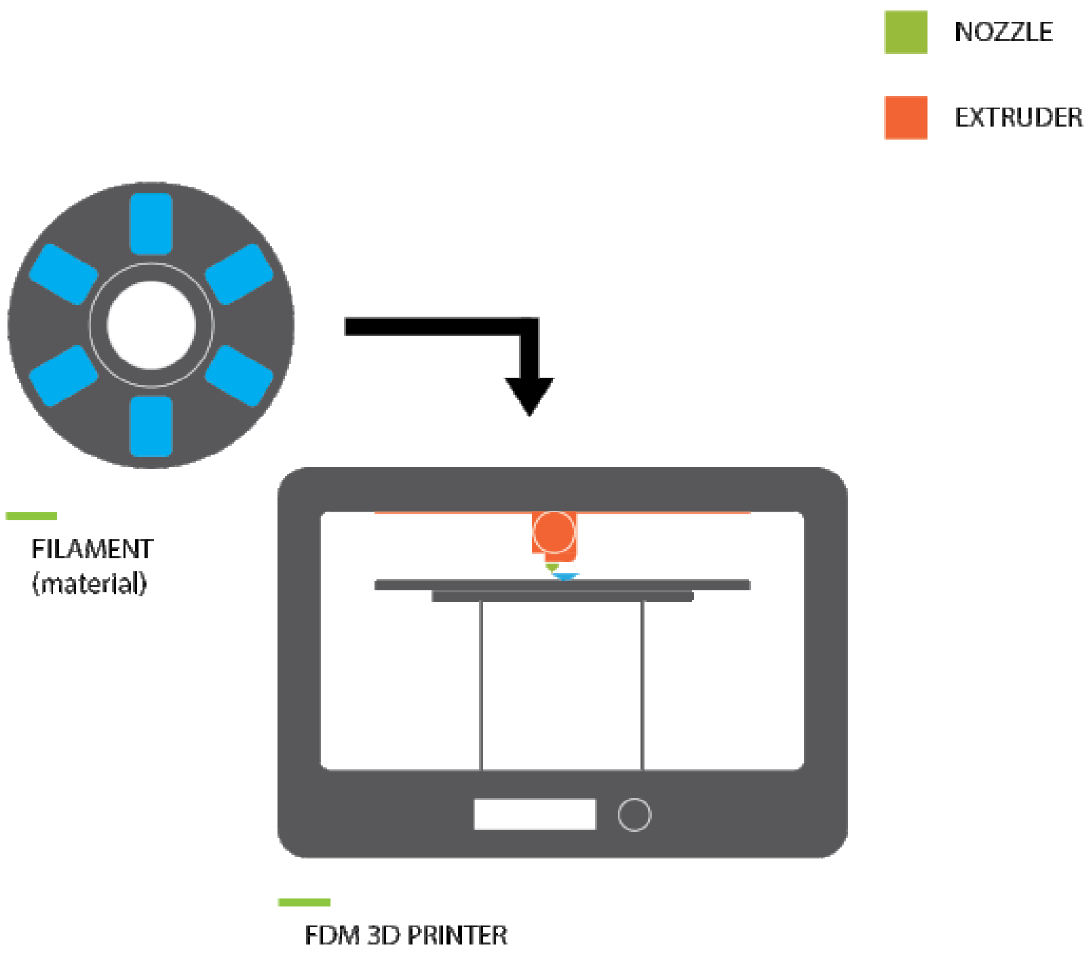
Schematic of extrusion based system



Support Generation

- Similar material supports
- Secondary material supports

Fused Deposition Modelling



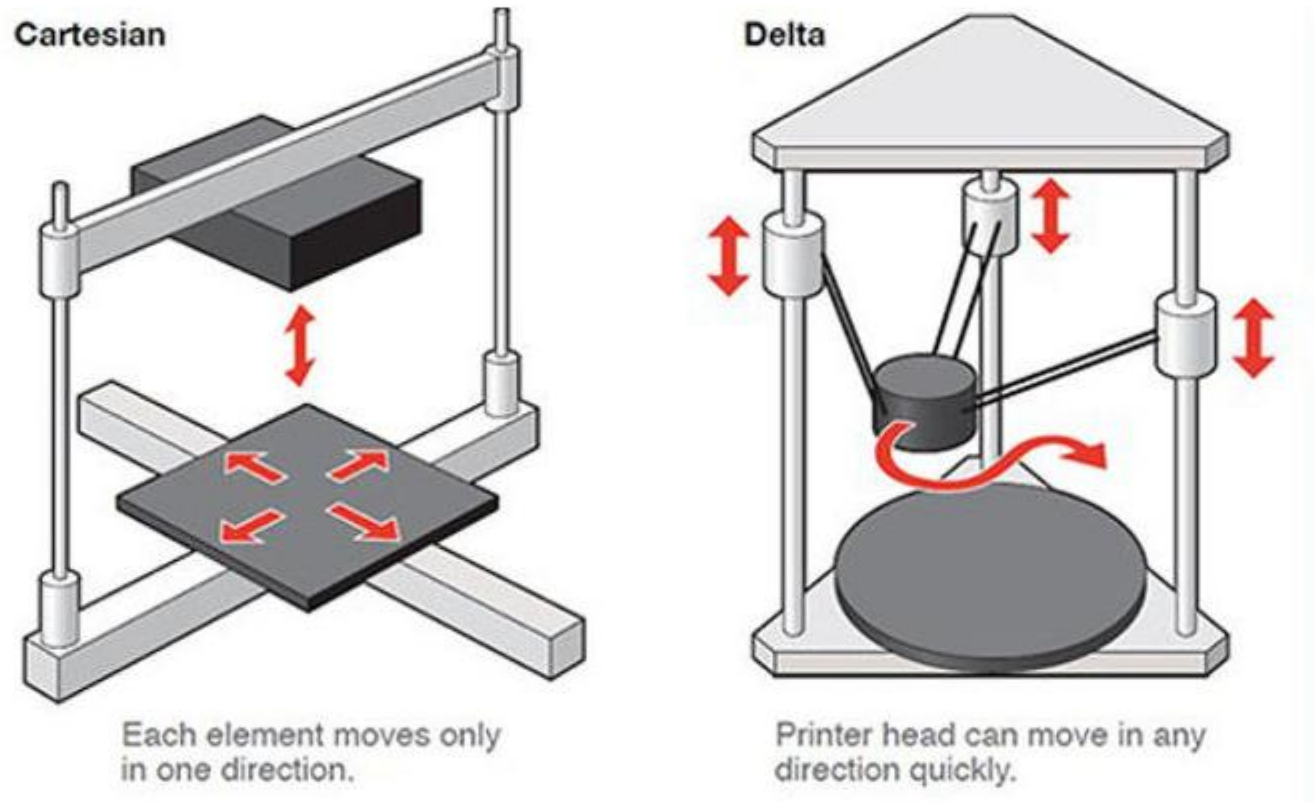
FDM

- Developed by Stratasys
- Clean, simple-to-use and office-friendly
- Supported production-grade thermoplastics are mechanically and environmentally stable

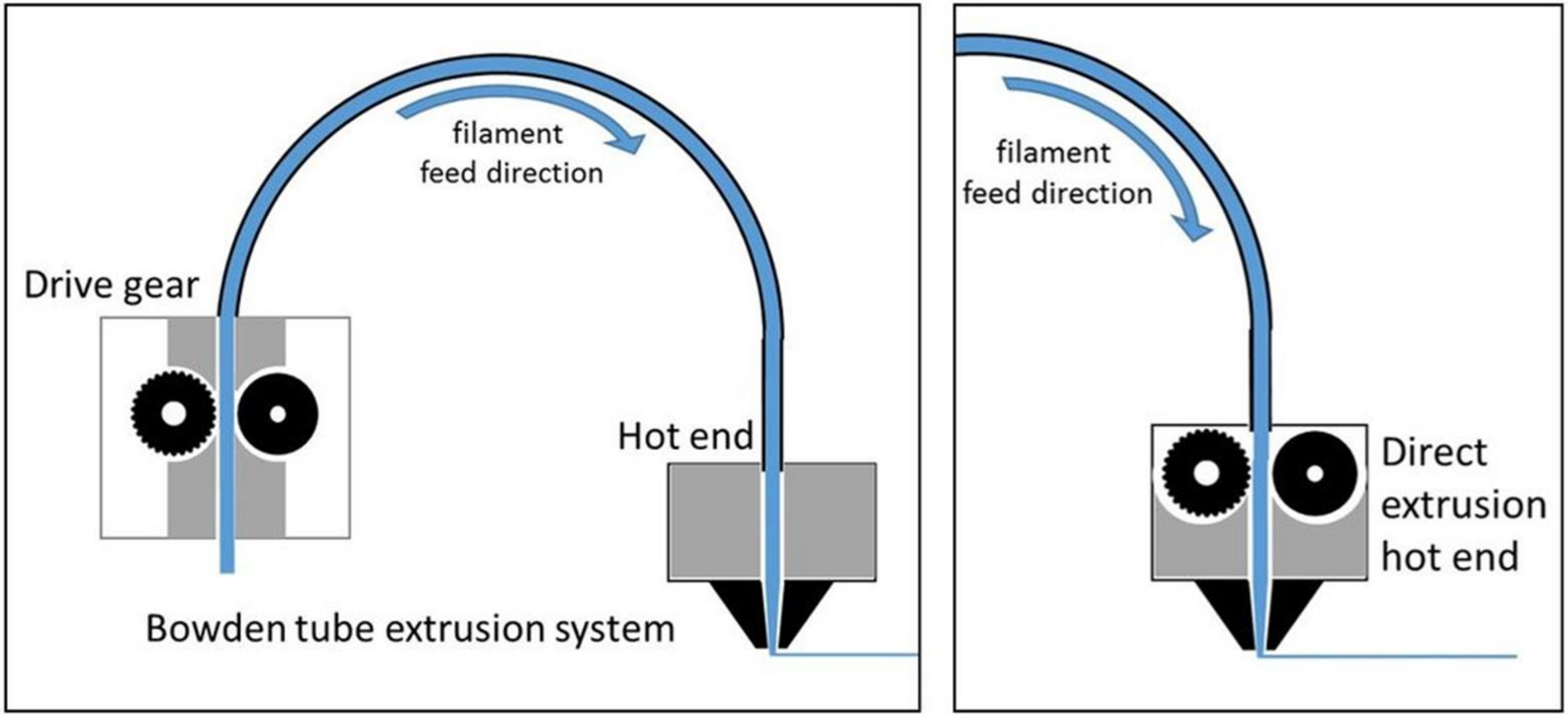
Types of FDM

- Types of FDM Printers
  - Cartesian
  - Polar
  - Delta
  - Arm

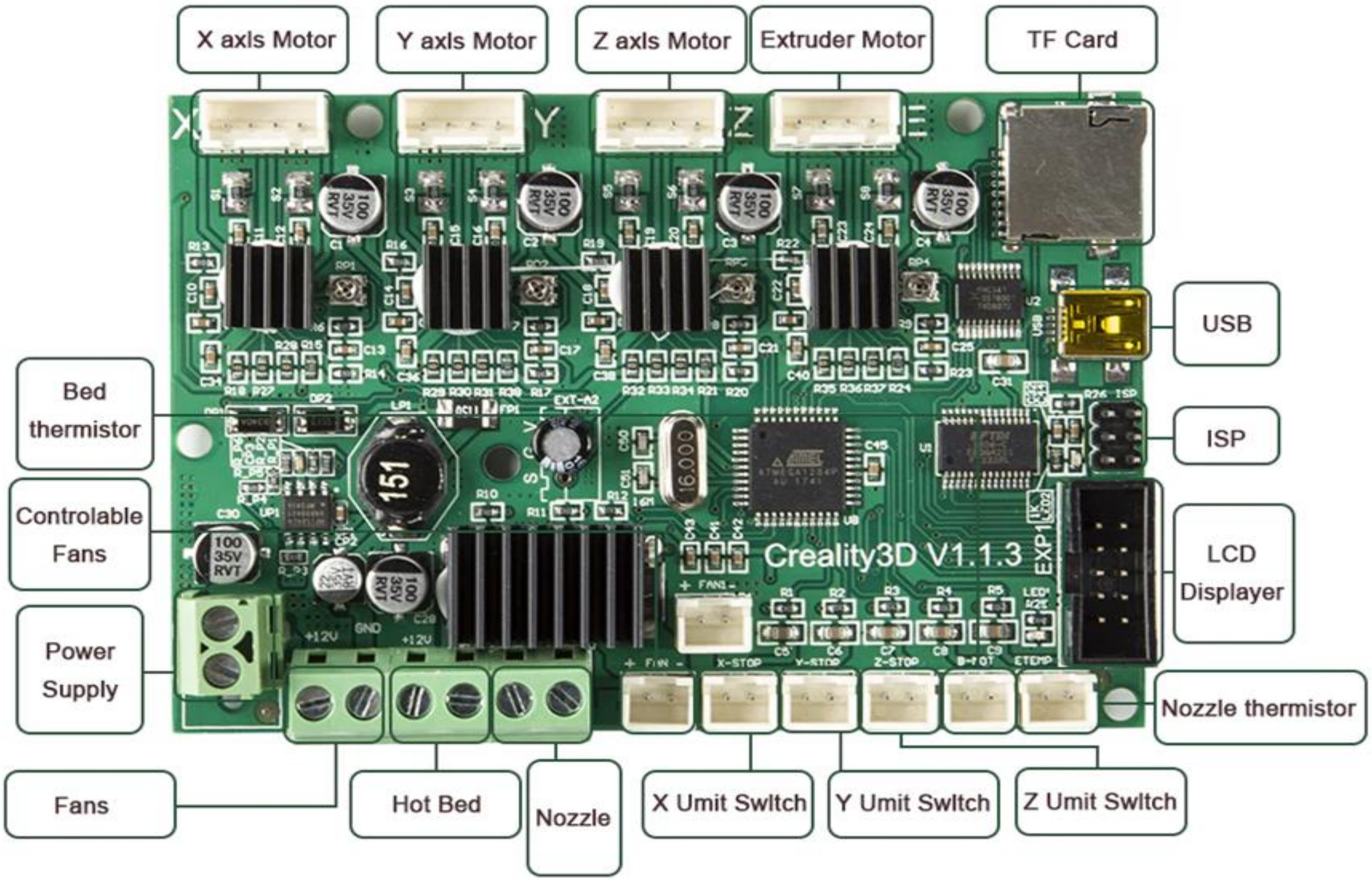
Cartesian and Delta Printers



Extruder and Hot end



FDM Motherboard



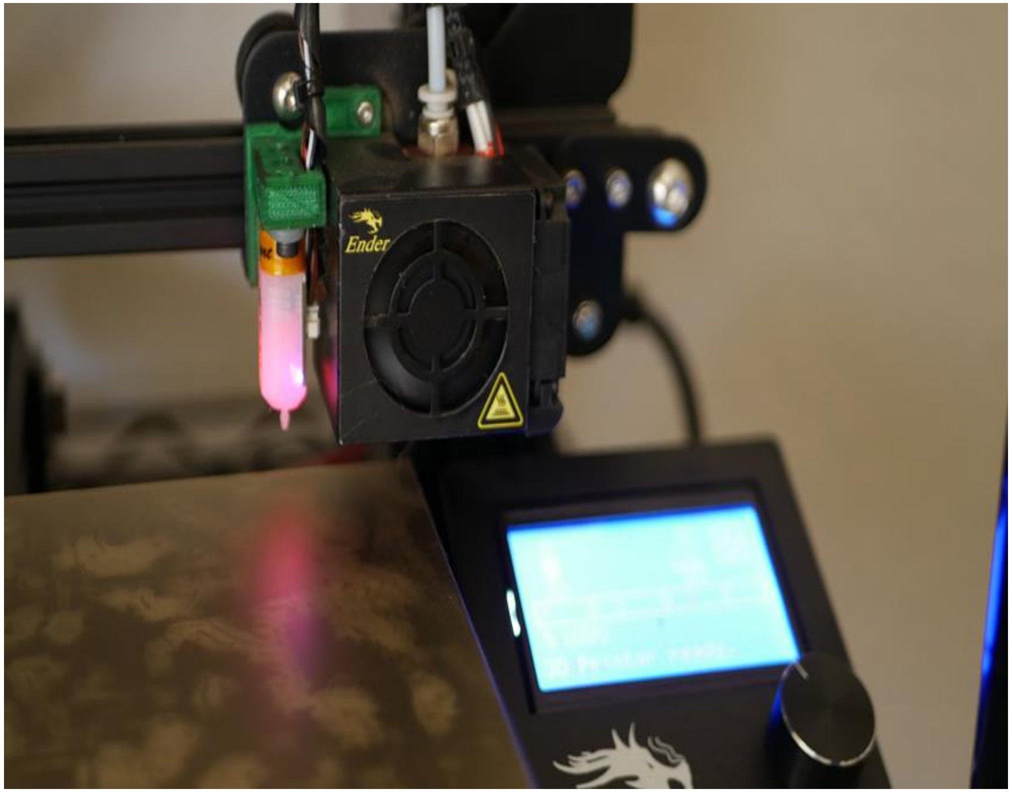
FDM Motherboard

Integrated Stepper Drivers	– StepStick A4988 Drivers (Quieter than stock)
Printer Axis Support	– E / Z / Y / X
Additional Ports	– X, Y and Z End Stops – Fan and Aux Fan – Extruder Temperature (ETEMP) – Heatbed Thermistor (B-MOT)
Voltage Input	– 12V / 24V DC (Optional)
Operating Voltage	– 12V / 24V DC

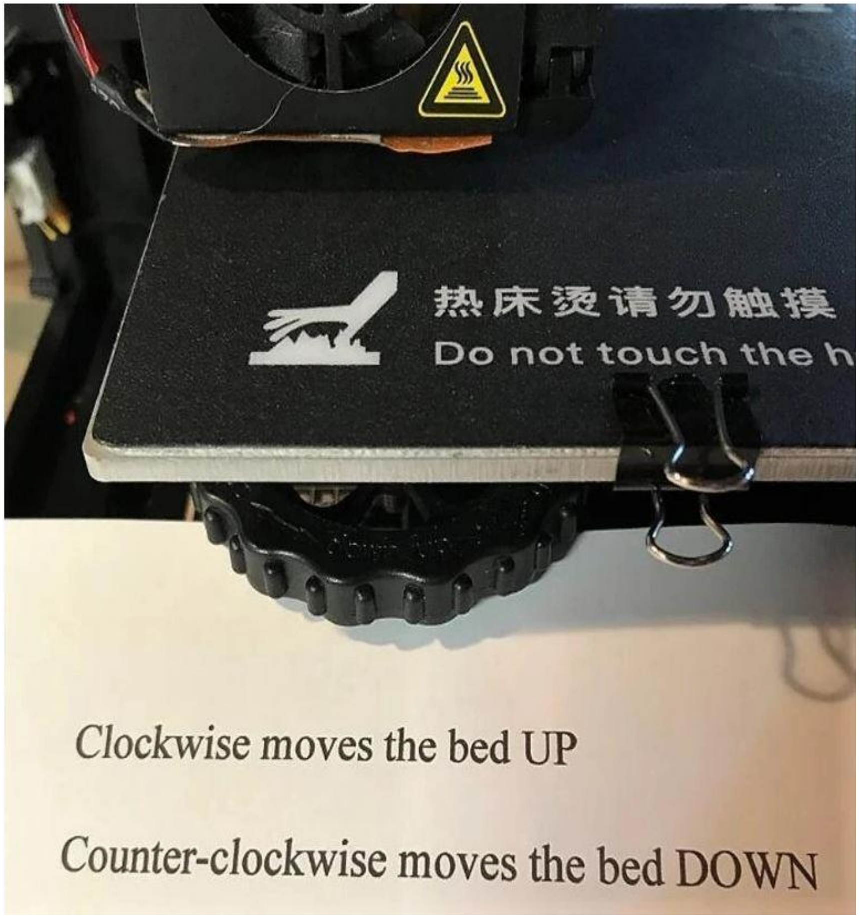
Issues with Printer

- Bed Levelling
- Non-sticky to platform

Bed levelling



Clean the Build Plate



FDM Overview

Materials

Thermoplastics (PLA, ABS, PETG, PC, PEI etc)

Dimensional accuracy

± 0.5% (lower limit ± 0.5 mm) - desktop± 0.15% (lower limit ± 0.2 mm) - industrial

Typical build size

200 x 200 x 200 mm - desktop1000 x 1000 x 1000 mm - industrial

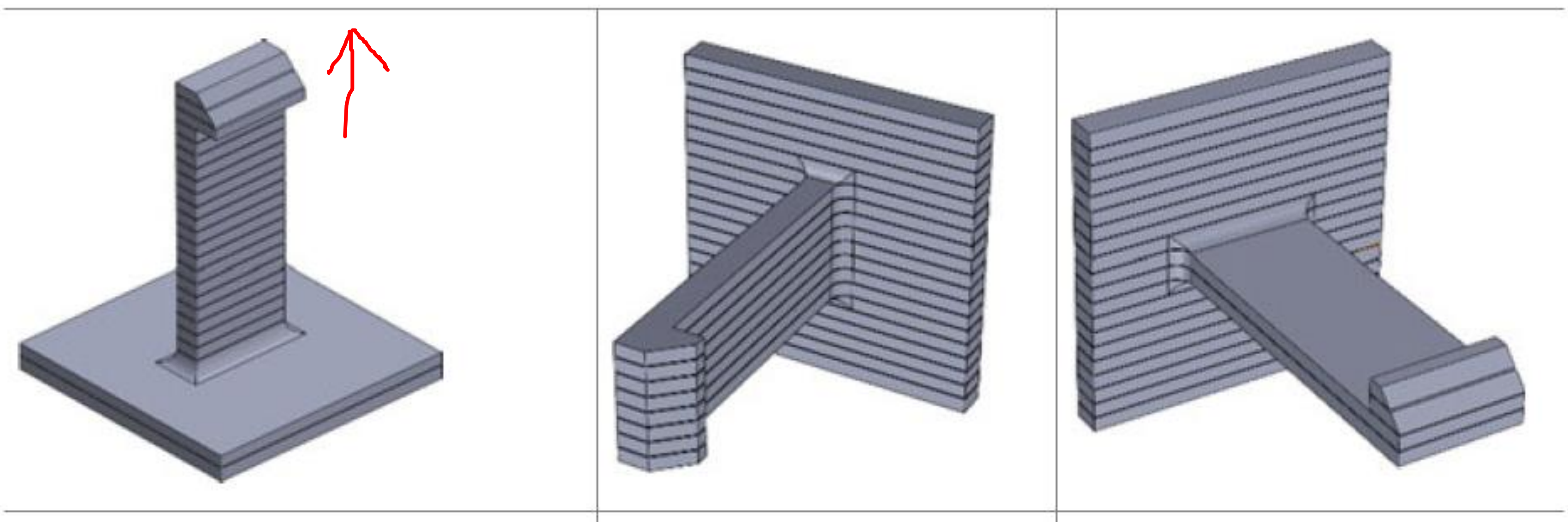
Common layer height

50 to 400 microns

Support

Not always required (dissolvable available)

Anisotropy in AM Parts



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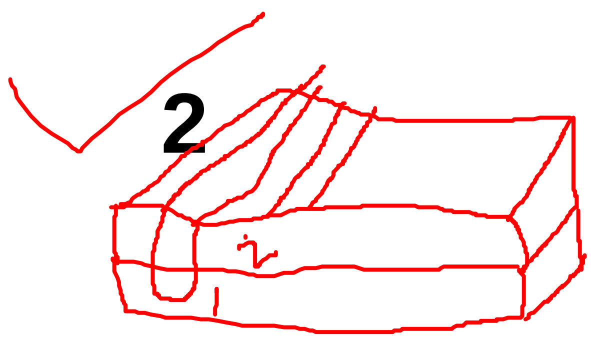
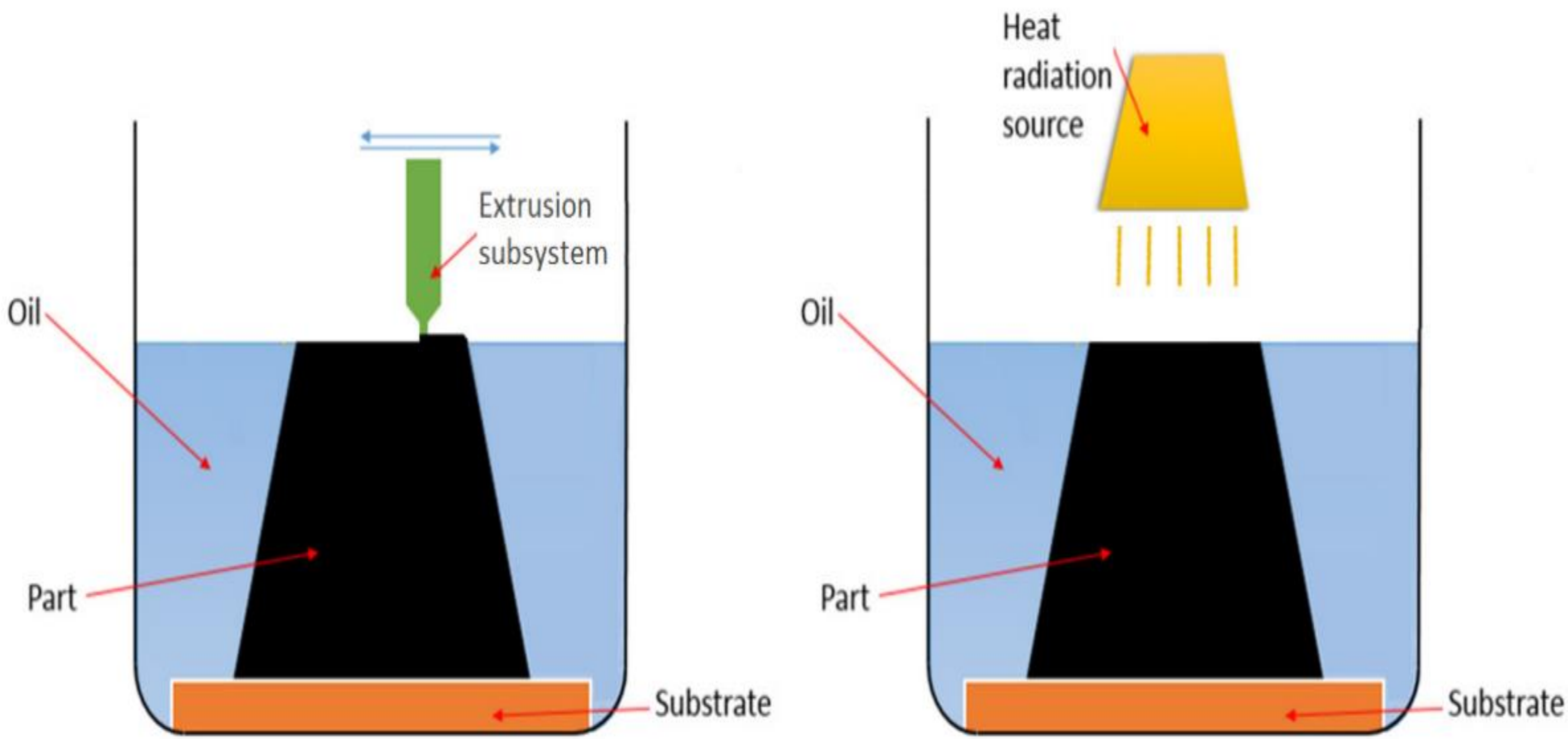


Ceramic On Demand Extrusion CODE



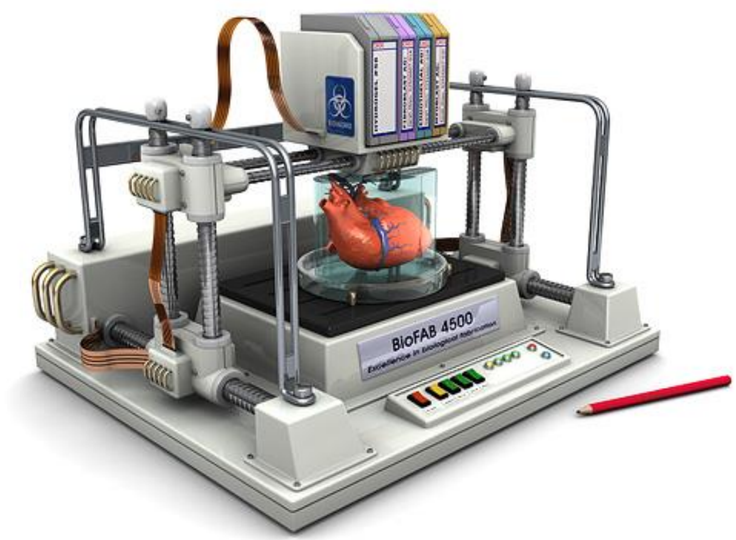
Schematic of the Ceramic On-Demand Extrusion process.

Slurry preparation

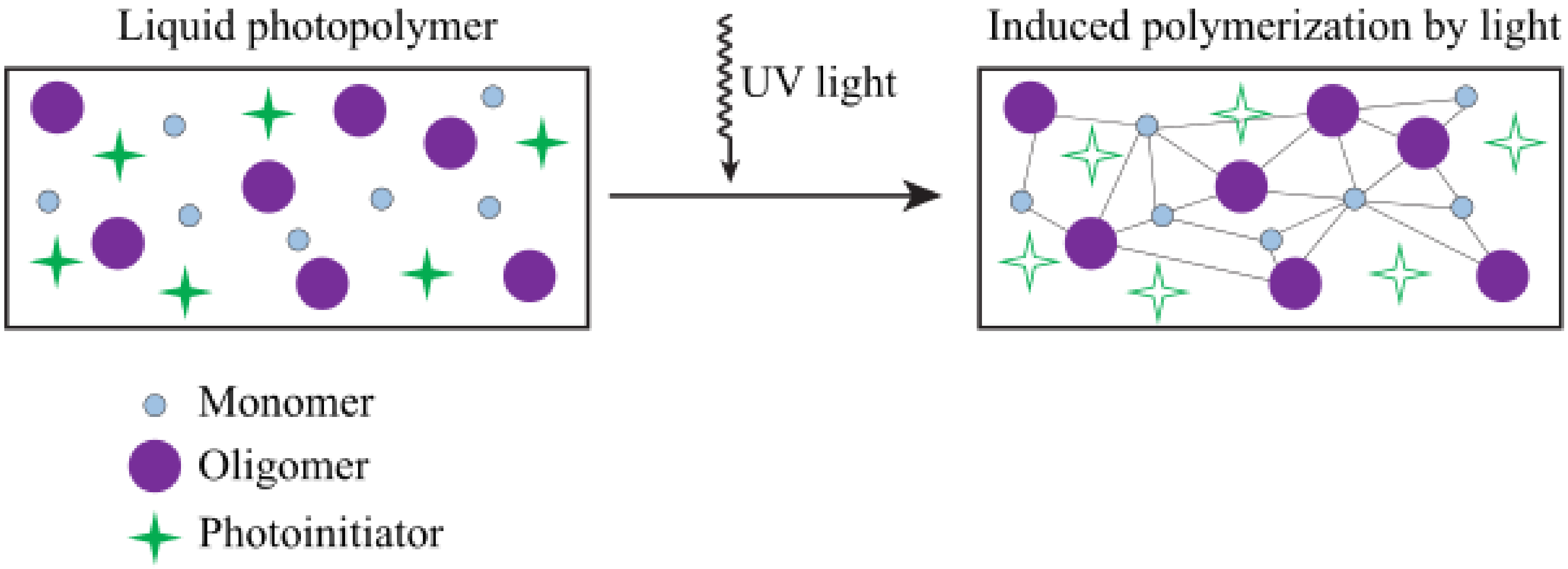
- Alumina paste 60 vol% solids loading alumina paste was prepared using a commercially available alumina powder
- Other materials including zirconia, silica, boron carbide, 13-93 bioactive glass, zirconium carbide, zirconium diboride, etc. could be potentially used in CODE

3D bioprinting

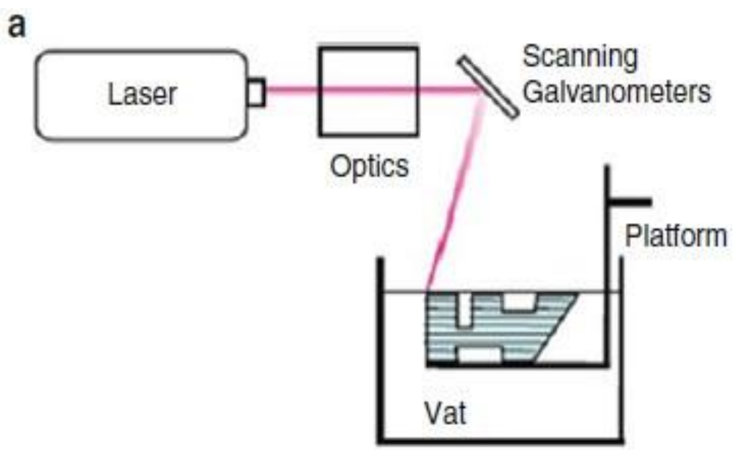
- Organ Printing
- Data from CT Scan and MRI
- 3D printing of drugs
- Soft tissues are used to print human organs



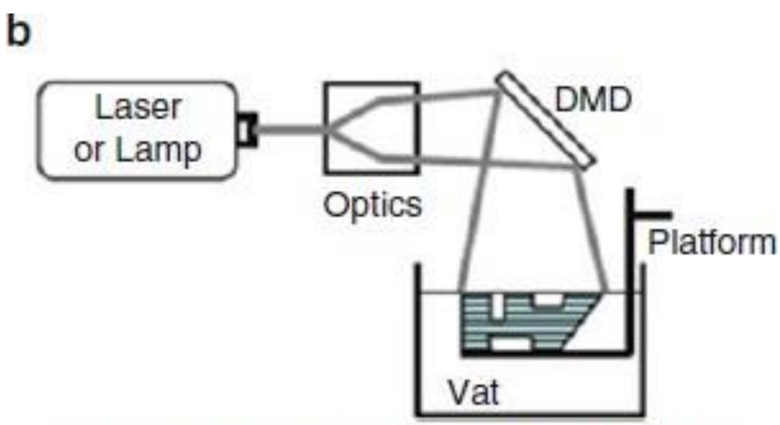
VAT Photopolymerization



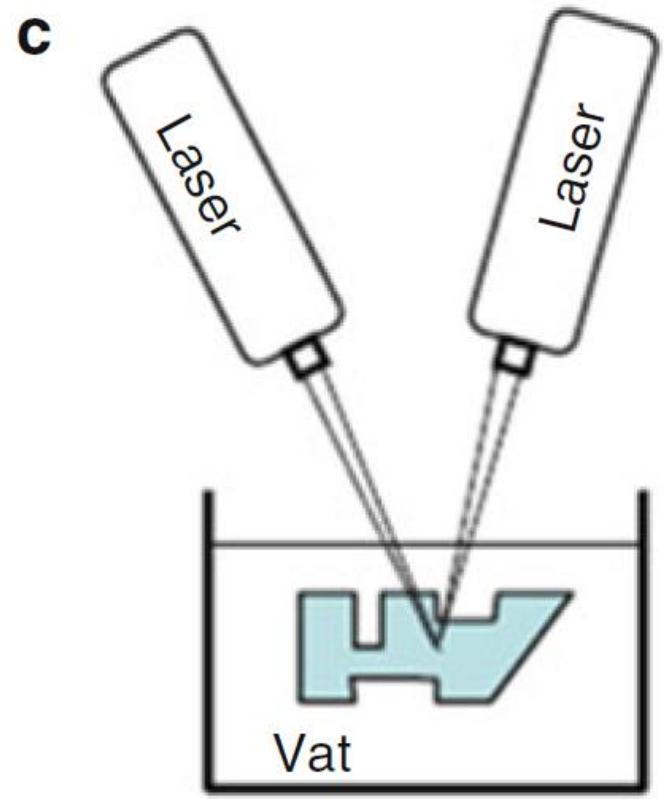
Scanning in VP



schematic of vector scan SL

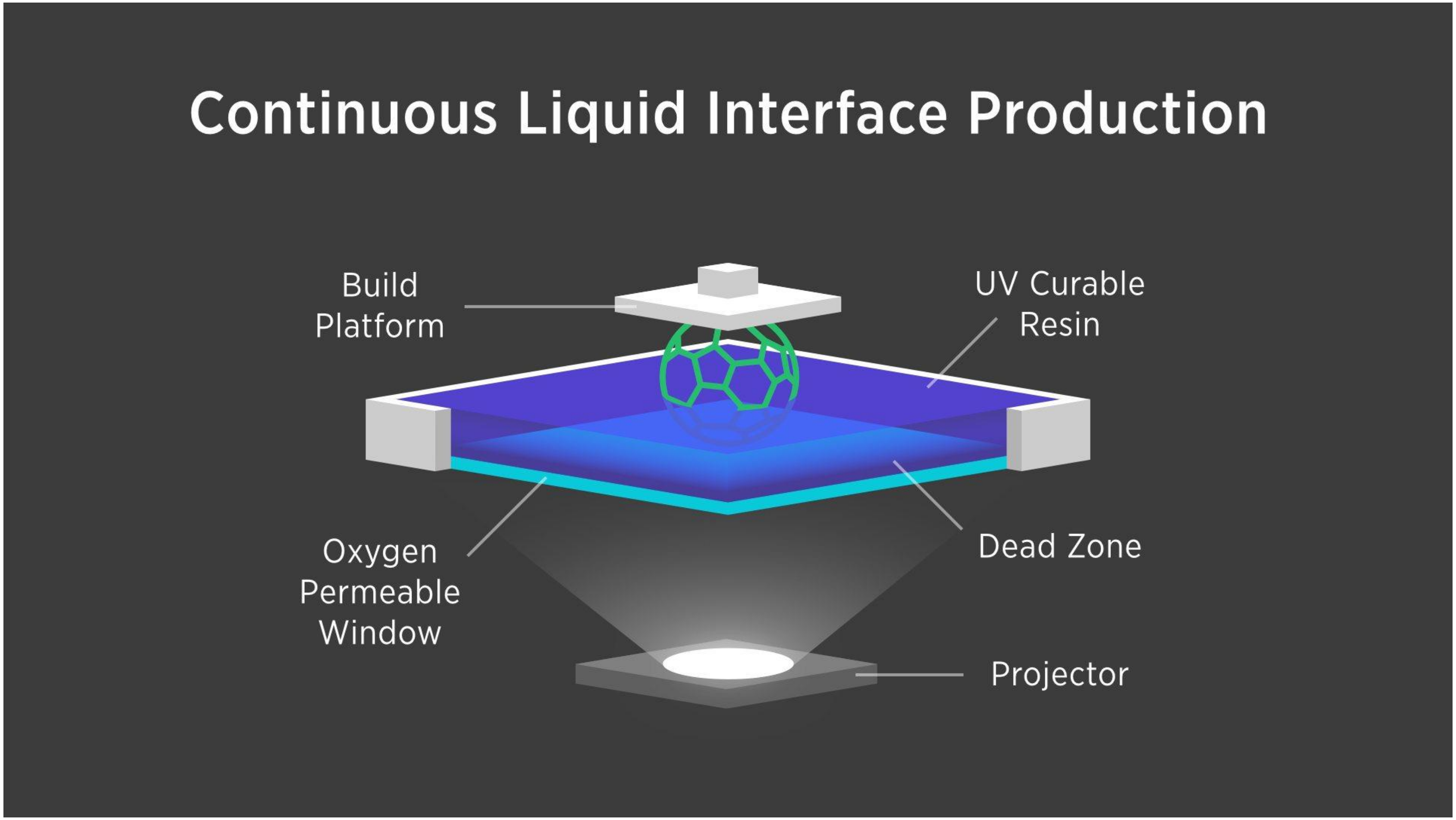


Schematic of mask projection approach to SL.



Two-photon approach

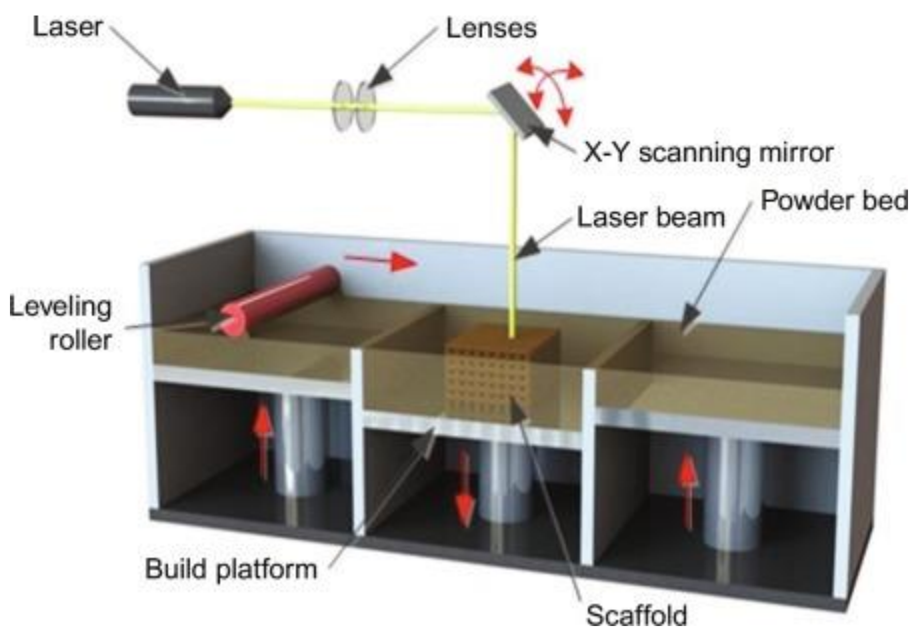
Continuous Liquid Interface Production (**CLIP**)



Source: https://www.tth.com/carbon-clip/

Powder bed fusion

- Selective laser sintering
- Materials
  - Polyamide (Nylon)
  - PCA
  - Polycarbonate
  - Polystyrene



Overview of polymer AM

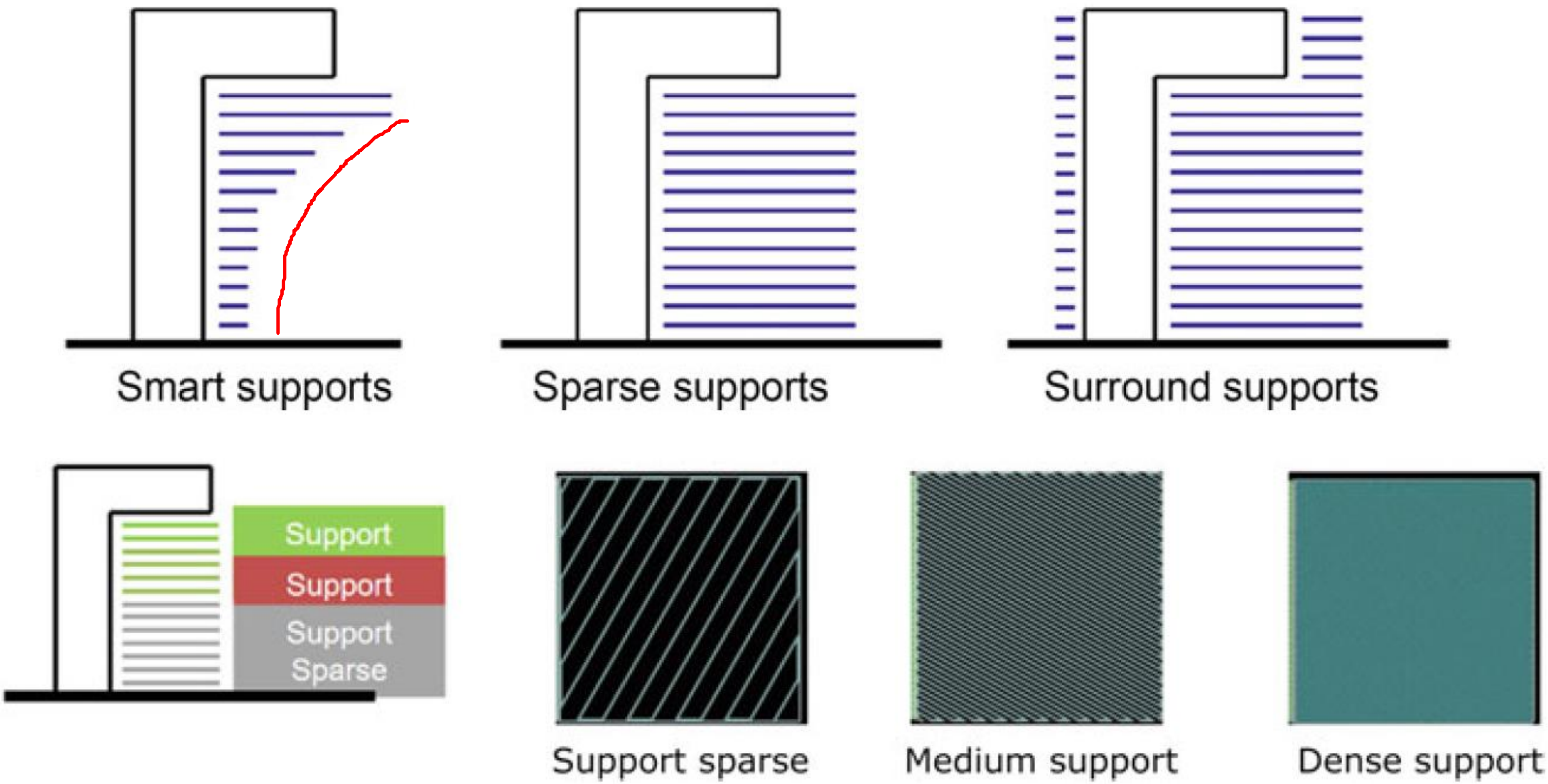
categorized techniques	typical and largest build volume	typical feature resolution	typical materials	advantages	disadvantages
Vat Photopolymerization					
exposure from top	$250 \times 250 \times 250$ mm^3 $800 \times 330 \times 400$ mm^3 (Prodways)	50–100 μm	acrylates/epoxides	excellent surface quality and precision	limited mechanical properties
CLIP	$150 \times 80 \times 300$ mm^3	75 μm	acrylates	high build speed	low-viscosity resins required
exposure from bottom	$100 \times 100 \times 100$ mm^3 $300 \times 300 \times 300$ mm^3 (DigitalWax 30X)	25–100 μm	acrylates/epoxides	low initial vat volume; better surface quality	limited mechanical properties
multiphoton lithography	$5 \times 5 \times 1$ mm^3 $100 \times 100 \times 3$ mm^3 (Nanoscribe)	0.1–5 μm	acrylates	very high resolution	low build speed; limited materials
Powder Bed Fusion					
polymer SLS	$250 \times 250 \times 250$ mm^3 $1400 \times 1400 \times 500$ mm^3 (Huake 3D HKS1400)	50–100 μm	PA12, PEEK	best mechanical properties; less anisotropy	rough surfaces; poor reusability of unsintered powder
Material and Binder Jetting					
polyjet	$300 \times 200 \times 150$ mm^3 $1000 \times 800 \times 500$ mm^3 (Objet 1000)	25 μm	acrylates	fast; allows multimaterial AM	low viscosity ink required
aerosol jet printing	$200 \times 300 \times 200$ mm^3 (Aerosol Jet 5X)	10 μm	conductive inks/dielectrics	high resolution; low temp process	low viscosity ink required
3D printing (binder jetting)	$200 \times 250 \times 200$ mm^3 $1000 \times 600 \times 500$ mm^3 (Voxeljet)	100 μm	starch, PLA, ceramics	fast; allows multimaterial AM; low temp	limited strength of parts; rough surfaces
Sheet Lamination					
laminated object manufacturing	$170 \times 220 \times 145$ mm^3 (Solidimension SD300)	200–300 μm	PVC, paper	compact desktop 3D printer	limited materials; low resolution; high anisotropy
Material Extrusion					
FDM	$200 \times 200 \times 200$ mm^3 $1005 \times 1005 \times 1005$ mm^3 (BigRep One)	100–150 μm	ABS, PLA, PC, HIPS	inexpensive machines and materials	rough surfaces; high temperature process
3D dispensing	$150 \times 150 \times 140$ mm^3 (3D Bioplotter)	100 μm to 1 cm	thermo-plastics, composites, photoresins, hydrogels, biomaterials	broad range of materials	rough surfaces; narrow viscosity process window

Material Extrusion Accuracy and Tolerances

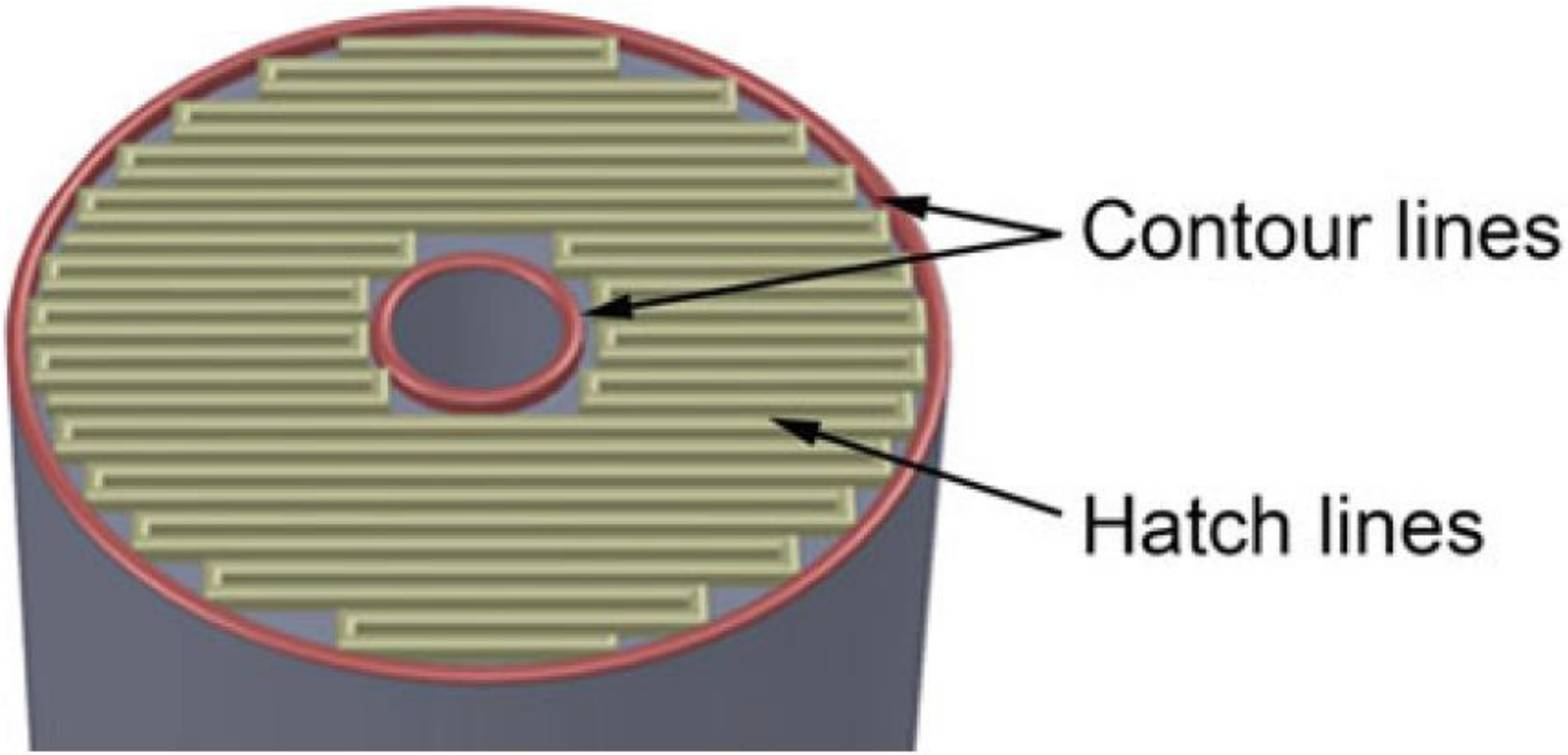
Layer thickness	0.1–0.3 mm (0.005–0.013 in.)
Accuracy	±0.1 or ±0.03 mm per 25 mm (±0.005 in. or ±0.0015 in. per inch), whichever is greater
Tolerance	Reality rule of thumb for Material Extrusion: typically 0.25 mm (0.01 in.)
Smallest feature size	Around 1 mm (0.04 in.)

FDM Design Guidelines

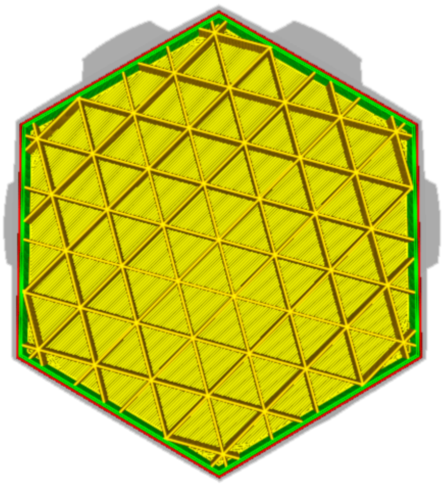
Support structure



Fill types



Fill types



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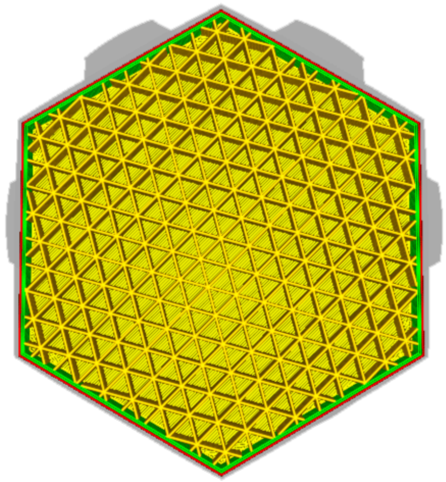
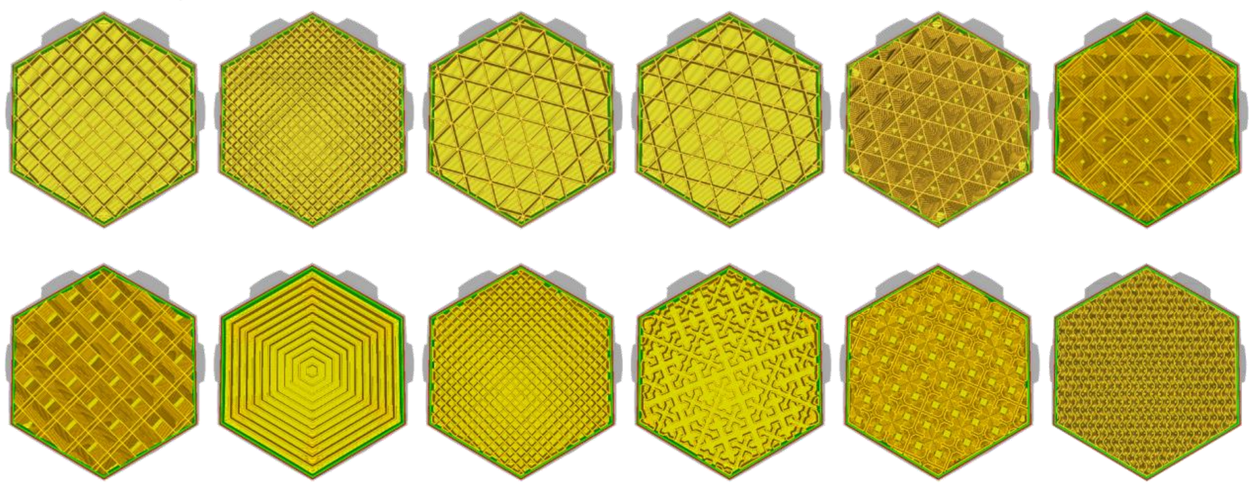
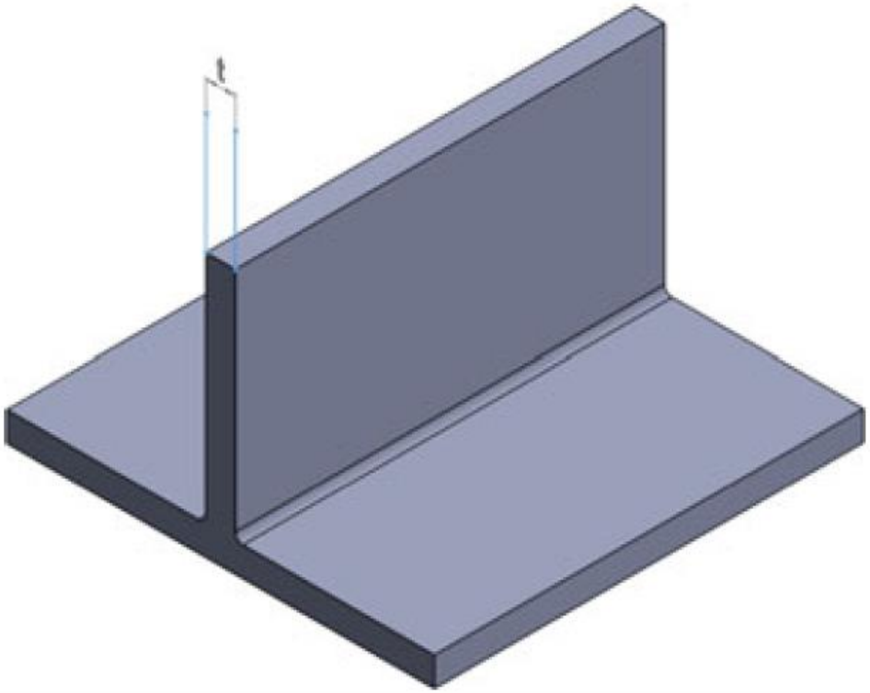


2



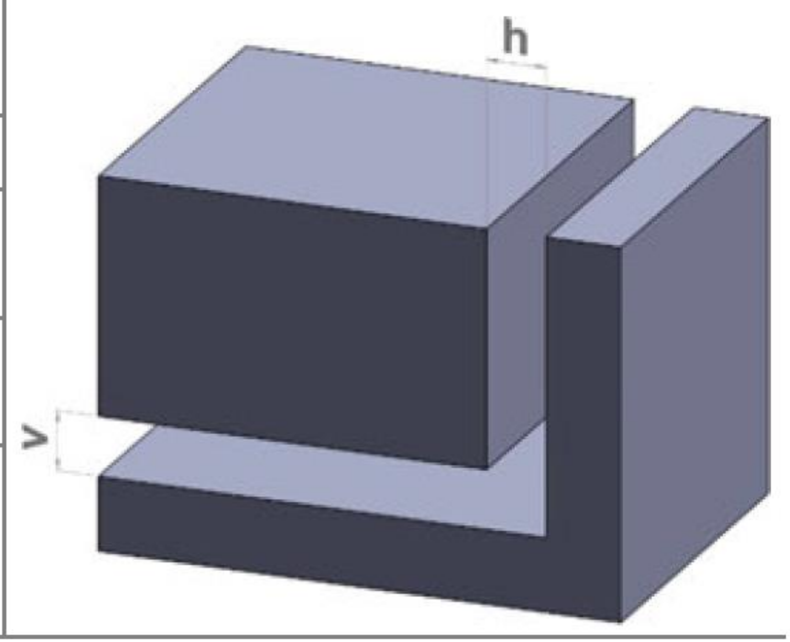
Features in the CAD model

Process variable	Wall thickness (t)	
Layer thickness	Minimum	Recommended minimum
0.18 mm (0.0071 in.)	0.36 mm (0.014 in.)	0.72 mm (0.028 in.)
0.25 mm (0.0098 in.)	**0.50 mm (0.02 in.)**	**1.00 mm (0.039 in.)**
0.33 mm (0.013 in.)	0.66 mm (0.026 in.)	1.32 mm (0.052 in.)



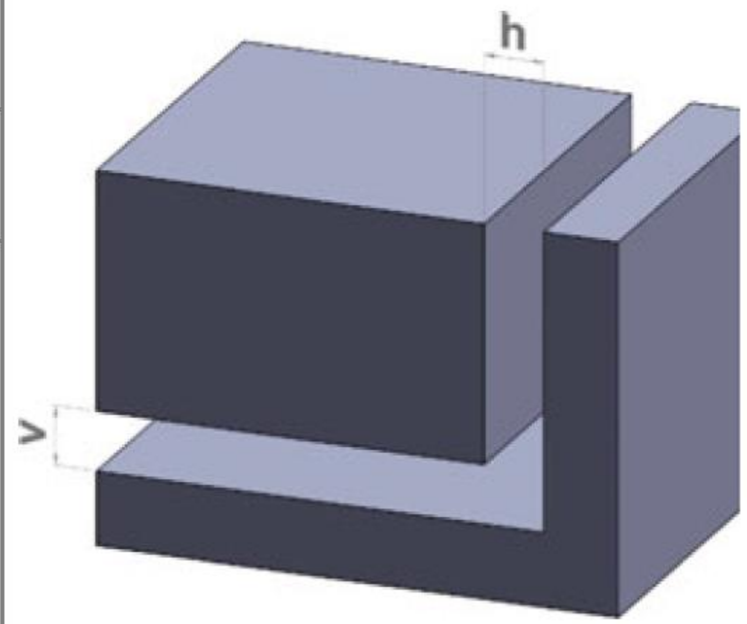
Clearances Between Moving Parts with Soluble Supports

Process variable	Minimum clearance	
Layer thickness	Horizontal (h)	Vertical (v)
0.18 mm (0.0071 in.)	0.36 mm (0.014 in.)	0.18 mm (0.0071 in.)
0.25 mm (0.0098 in.)	**0.50 mm (0.02 in.)**	**0.25 mm (0.0098 in.)**
0.33 mm (0.013 in.)	0.66 mm (0.026 in.)	0.33 mm (0.013 in.)



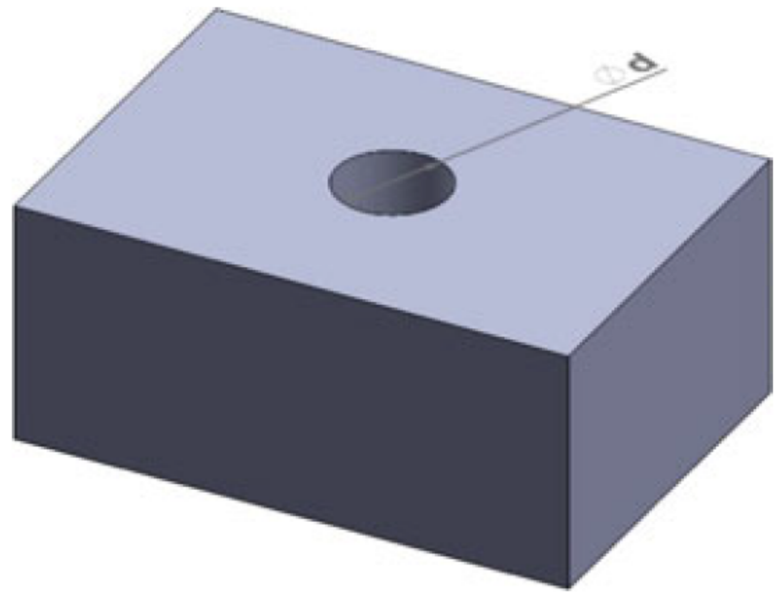
Clearance Between Moving Parts with Break-Away Support Material

Process variable	Minimum clearance	
Layer thickness	Horizontal (h)	Vertical (v)
0.18 mm (0.0071 in.)	0.36 mm (0.014 in.)	Adequate access to facilitate supports removal
0.25 mm (0.0098 in.)	**0.50 mm (0.02 in.)**	
0.33 mm (0.013 in.)	0.66 mm (0.026 in.)	

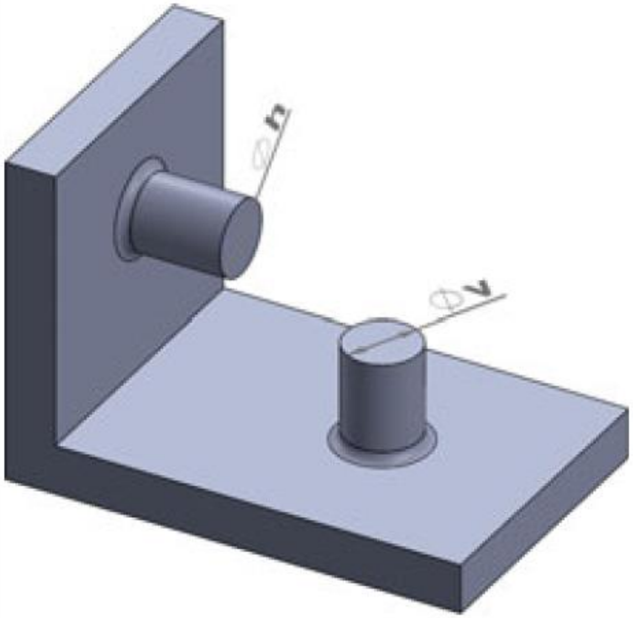


Vertical Circular Holes

Required diameter (d)	CAD model diameter
5.0 mm (0.197 in.)	5.2 mm (0.205 in.)
10.0 mm (0.394 in.)	10.2 mm (0.402 in.)
15.0 mm (0.591 in.)	15.2 mm (0.598 in.)
20.0 mm (0.787 in.)	20.2 mm (0.795 in.)

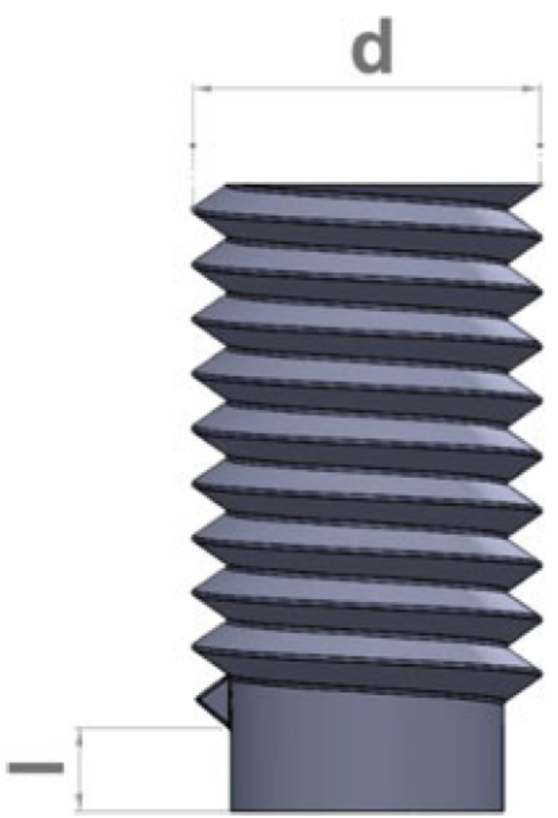


Circular Pins

Minimum diameter for vertical pins (v)	Minimum diameter for horizontal pins (h)	
2.0 mm (0.079 in.)	2.0 mm (0.079 in.)	

Screw Threads

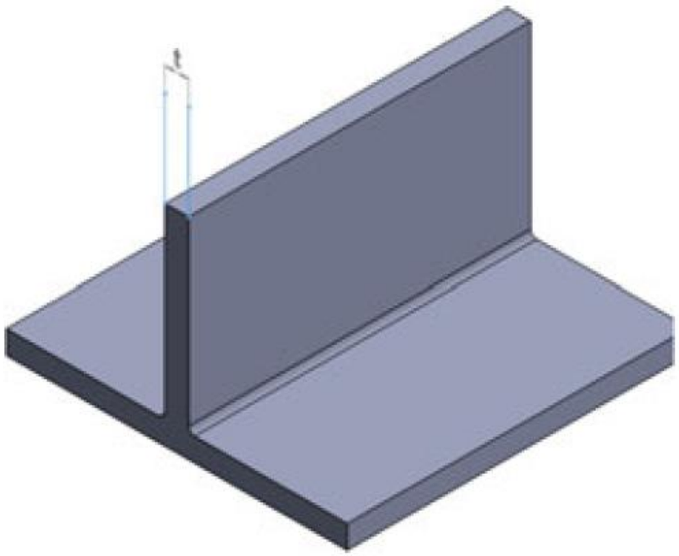
Minimum thread diameter (d)	Minimum "dog-point" lead in (l)
5.0 mm (0.197 in.)	1.0 mm (0.039 in.)



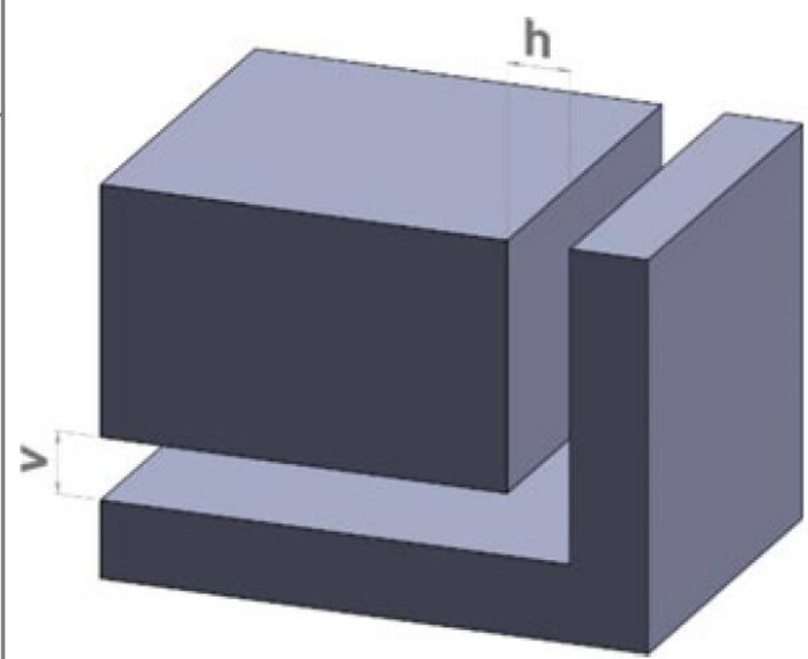
Powder Bed Fusion Accuracy and Tolerances

Layer thickness	0.1 mm (0.005 in.)
Accuracy	±0.3% lower limit of ±0.3 mm (0.010 in.)
Tolerance	±0.25 mm (0.010 in.) or ±0.0015 mm/mm (0.0015 in./in.)—whichever is greater
Smallest feature size	Around 0.5 mm (0.04 in.)

Wall Thickness

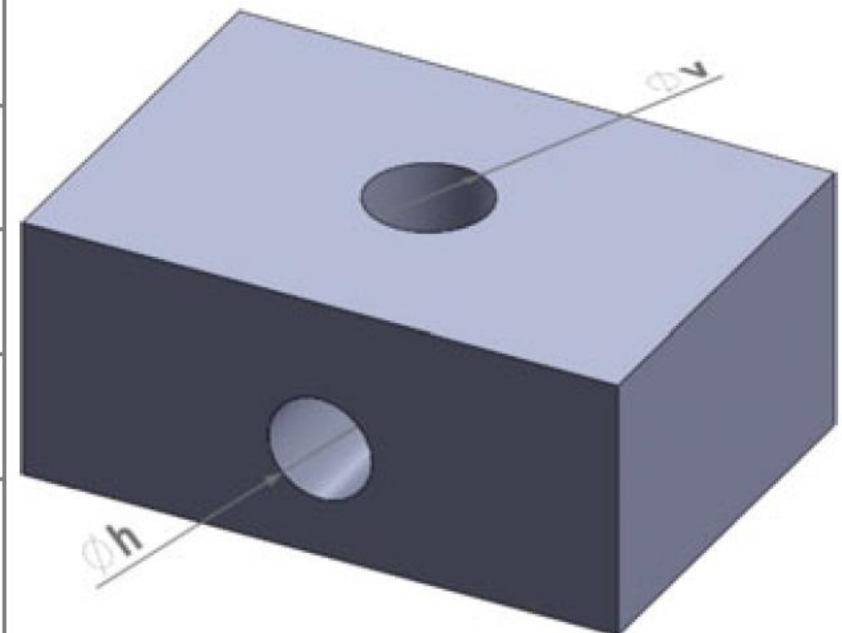
Minimum wall thickness (t)	Recommended minimum wall thickness (t)	
0.6–0.8 mm (0.031 in.)	1.0 mm (0.039 in.)	

Clearance Between Moving Parts

Minimum horizontal clearance (h)	Minimum vertical clearance (v)	
0.5 mm (0.02 in.)	0.5 mm (0.02 in.)	

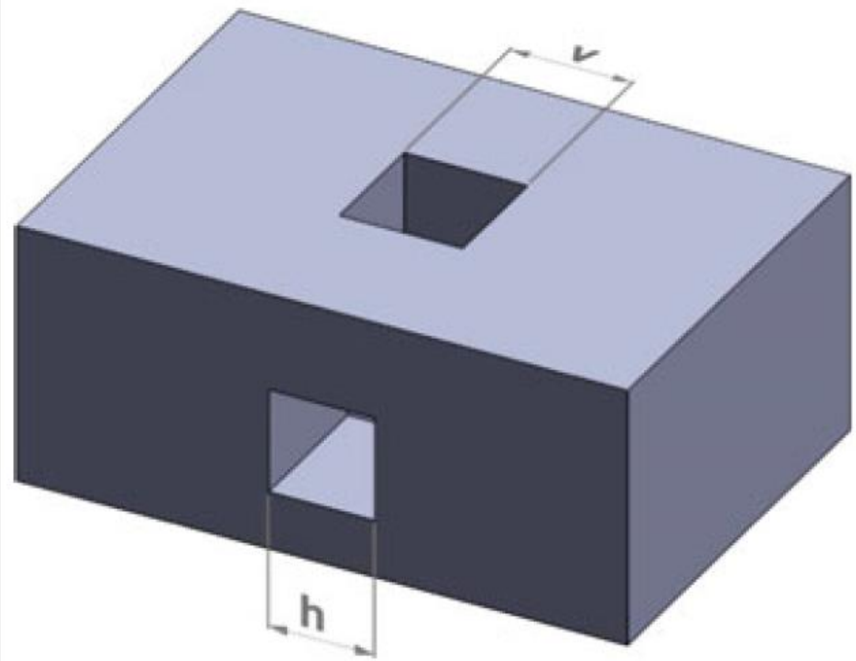
Circular Profile Through Holes

Process variable	Minimum diameter	
Wall thickness	Vertical hole (v)	Horizontal hole (h)
1 mm (0.039 in.)	0.5 mm (0.019 in.)	1.3 mm (0.051 in.)
4 mm (0.157 in.)	0.8 mm (0.031 in.)	1.75 mm (0.069 in.)
8 mm (0.314 in.)	1.5 mm (0.059 in.)	2.0 mm (0.079 in.)



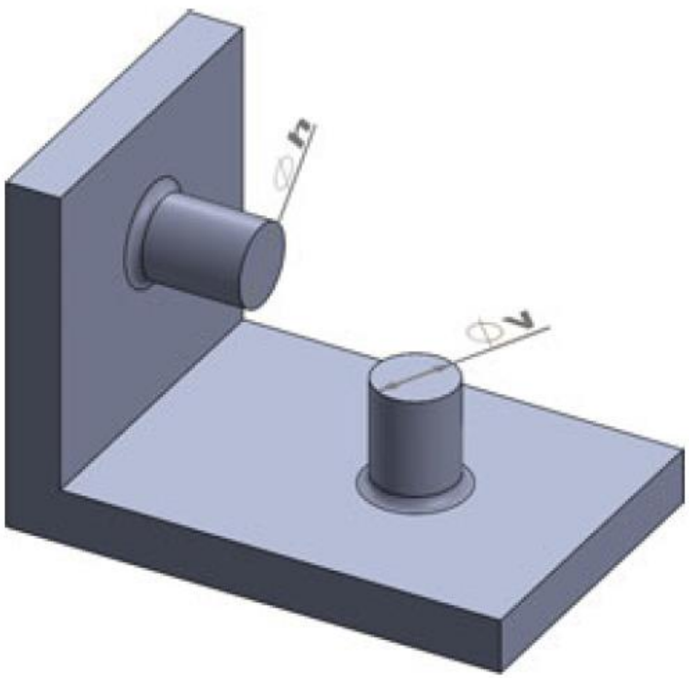
Square Profile Through Holes

Process variable	Minimum diameter	
Wall thickness	Vertical hole (v)	Horizontal hole (h)
1 mm (0.039 in.)	0.5 mm (0.019 in.)	0.8 mm (0.031 in.)
4 mm (0.157 in.)	0.8 mm (0.031 in.)	1.2 mm (0.047 in.)
8 mm (0.314 in.)	1.5 mm (0.059 in.)	1.3 mm (0.051 in.)



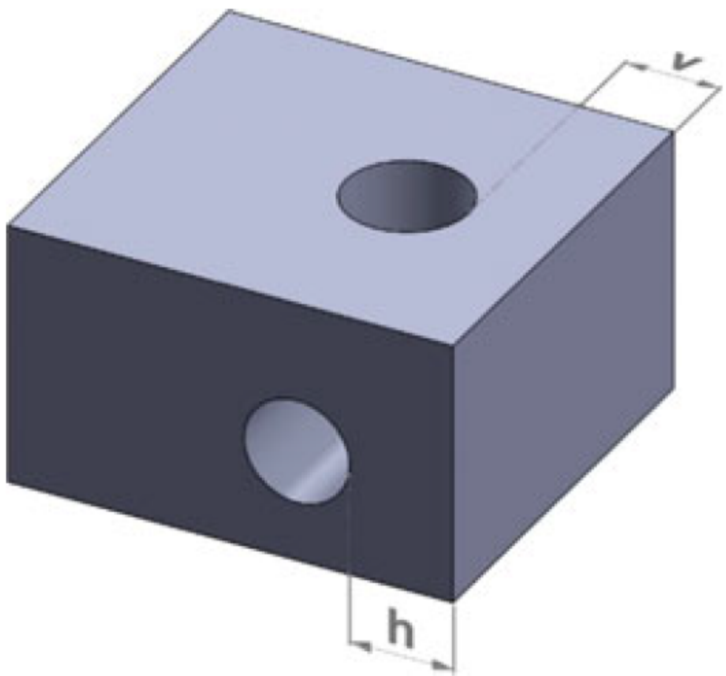
Circular Pins

Minimum diameter for vertical pins (v)	Minimum diameter for horizontal pins (h)
0.8 mm (0.031 in.)	0.8 mm (0.031 in.)



Hole Proximity to Wall Edge

Design variable	Minimum distance to edge	
Hole diameter	Vertical hole (v)	Horizontal hole (h)
2.5 mm (0.098 in.)	0.8 mm (0.031 in.)	0.8 mm (0.031 in.)
5.0 mm (0.197 in.)	0.9 mm (0.035 in.)	0.95 mm (0.037 in.)
10.0 mm (0.394 in.)	1.05 mm (0.041 in.)	1.0 mm (0.039 in.)

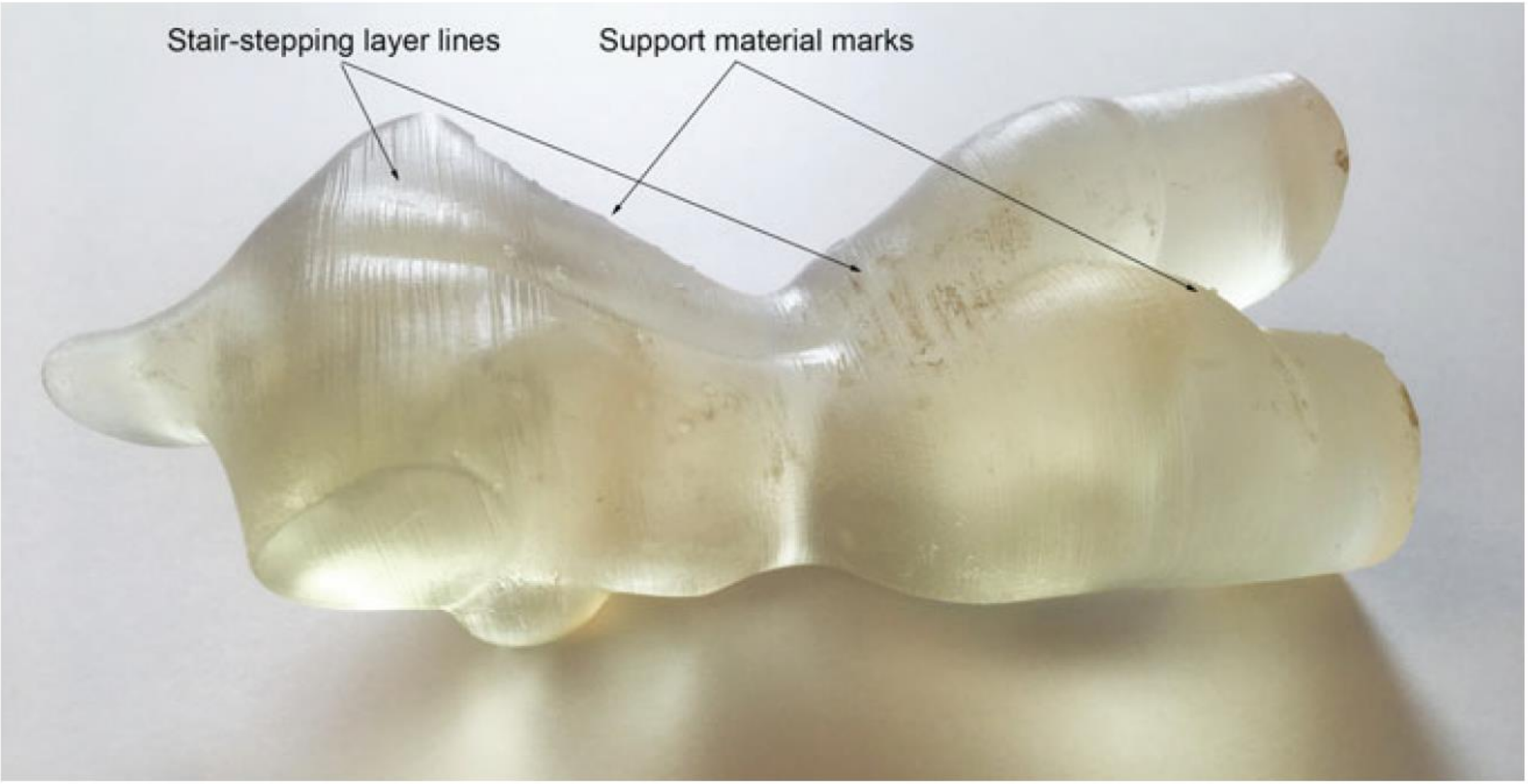


Designing for Vat Photopolymerisation

- SLA resolution in the XY-direction is dependent on the laser spot size and can range anywhere from 50 to 200 µm.
- The minimum feature size can therefore not be smaller than the laserspot size.
- Resolution in the Z-direction varies from 25 to 200 µm depending on the choices of layer thickness allowed by the machine

Part orientation

- Minimizing the cross-sectional area along the Z-axis is the best way to orient parts for SLA prints.



Details and features

- These must be at least 0.1 mm in height above the surface of the print to ensure the details will be visible
- Engraved details must be at least 0.4 mm wide and at least 0.4 mm deep.

SLS Vs FDM

FDM

SLS

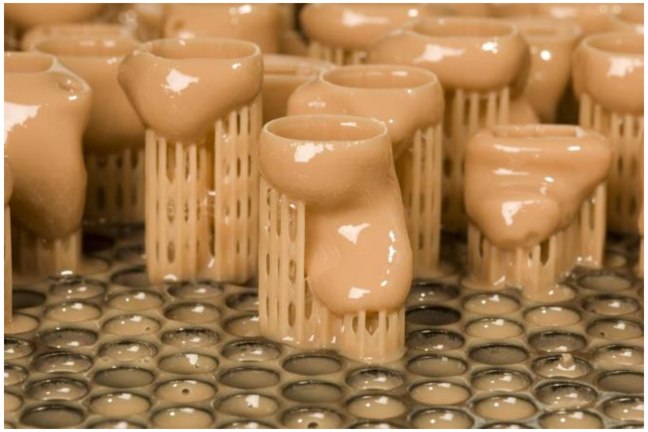
Polymer AM Application

Medical

Automotive industry

Architecture and design

Education



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End of session 12