ISDN2400 Physical Prototyping

Additive Manufacturing II

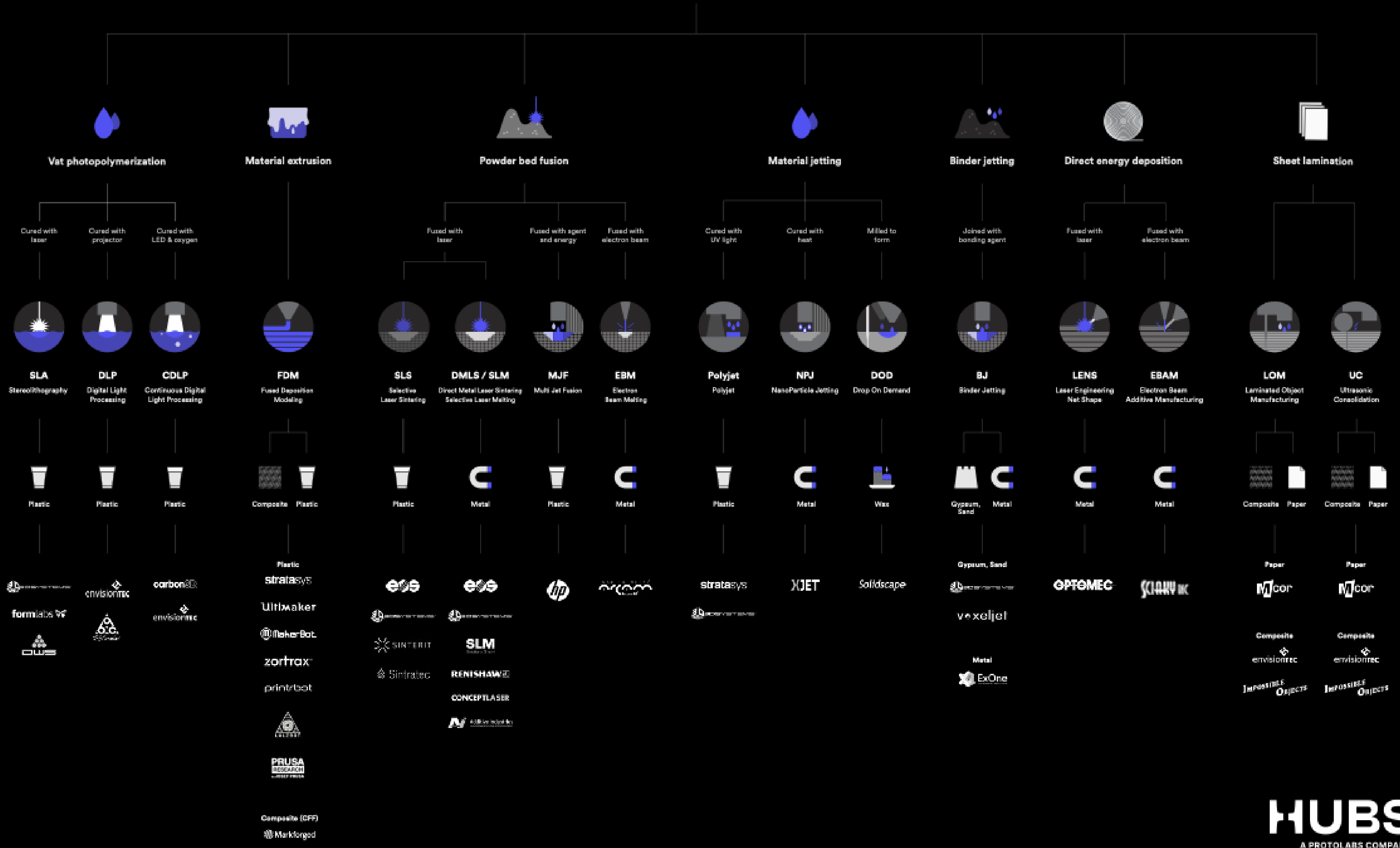
By Rob Scharff

March 2025

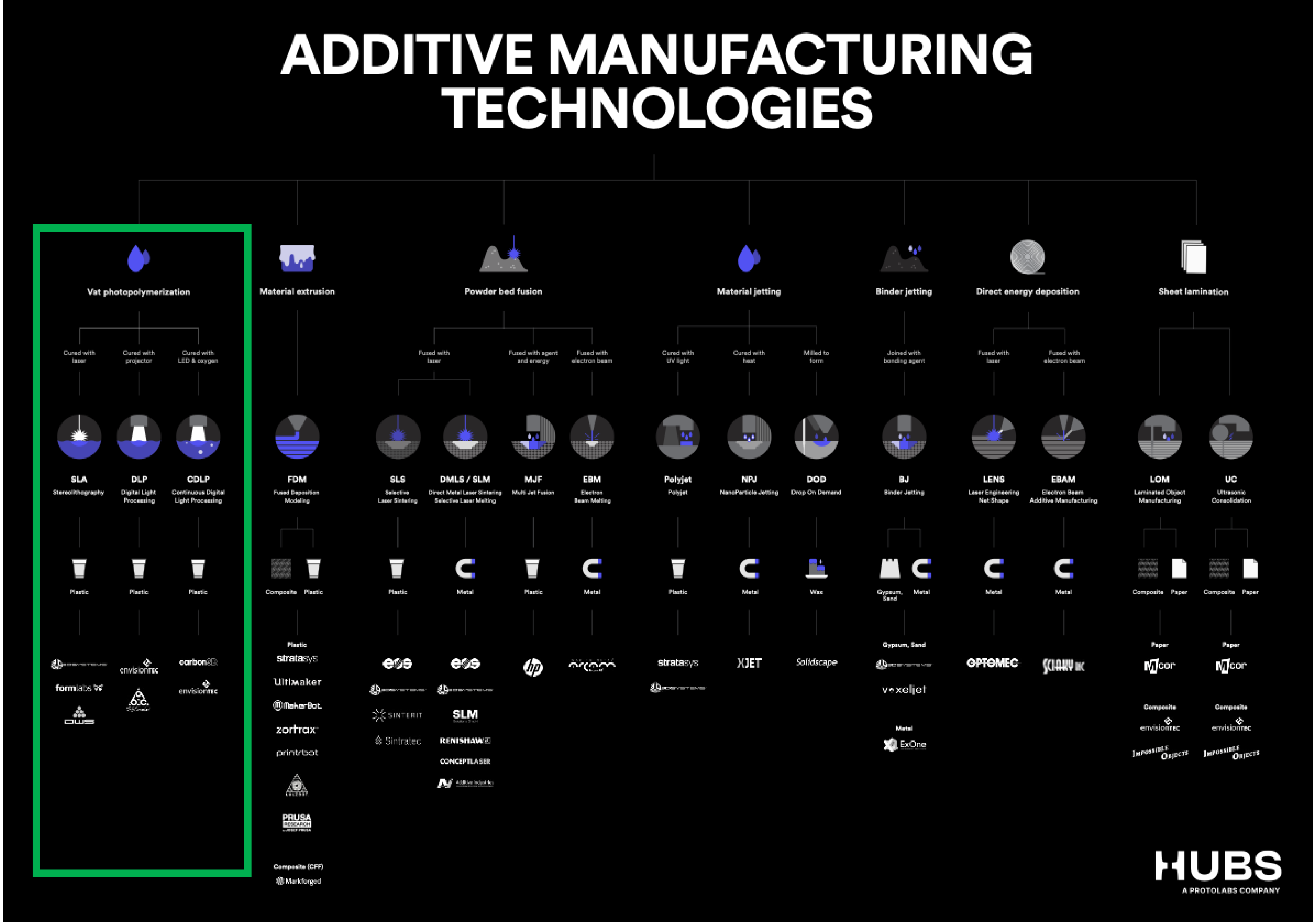
Today's lecture

- Overview of Additive Manufacturing methods
- Time for group work

ADDITIVE MANUFACTURING TECHNOLOGIES

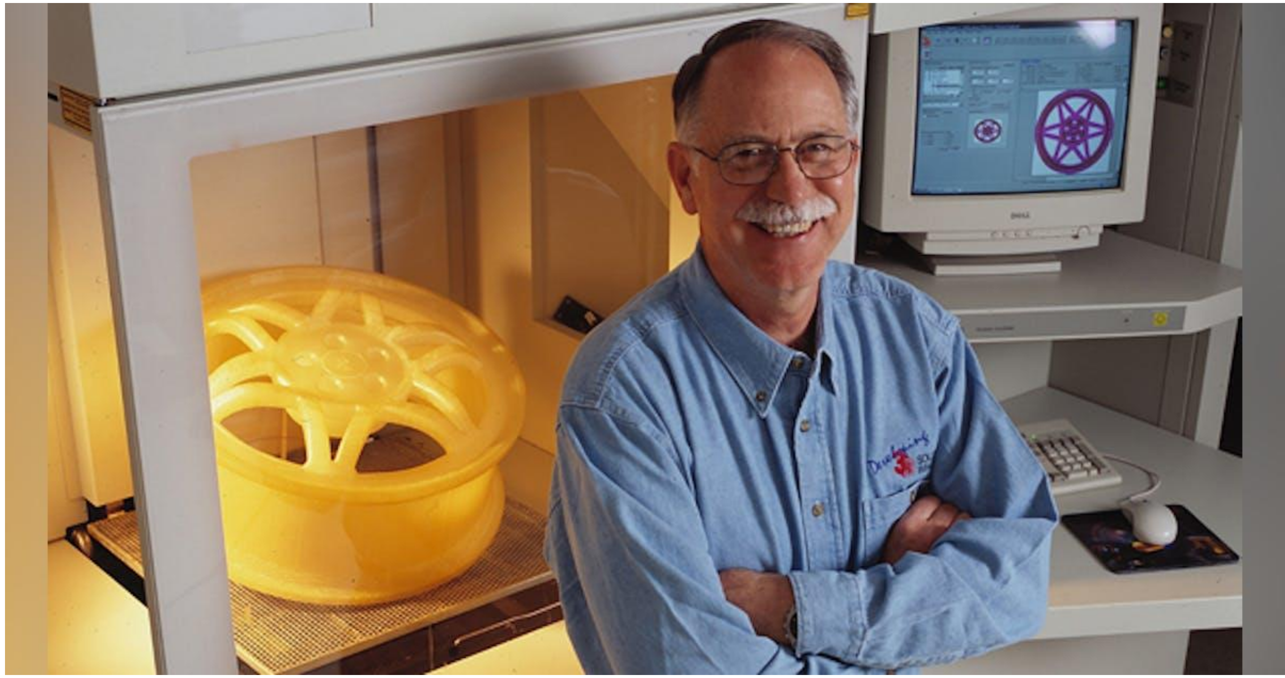


HUBS
A PROTOLABS COMPANY


ADDITIVE MANUFACTURING TECHNOLOGIES
Vat photopolymerization
Material extrusion
Powder bed fusion
Material jetting
Binder jetting
Direct energy deposition
Sheet lamination
SLA
Stereolithography
DLP
Digital Light Processing
CDLP
Continuous Digital Light Processing
FDM
Fused Deposition Modeling
SLS
Selective Laser Sintering
DMLS / SLM
Direct Metal Laser Sintering Selective Laser Melting
MJF
Multi Jet Fusion
EBM
Electron Beam Melting
Polyjet
NPJ
NanoParticle Jetting
DOD
Drop On Demand
BJ
Binder Jetting
LENS
Laser Engineering Net Shape
EBAM
Electron Beam Additive Manufacturing
LOM
Laminated Object Manufacturing
UC
Ultrasonic Consolidation
Plastic
Composite
Metal
Wax
Gypsum, Sand
Paper
Composite (CFF)
HUBS
A PROTOLABS COMPANY

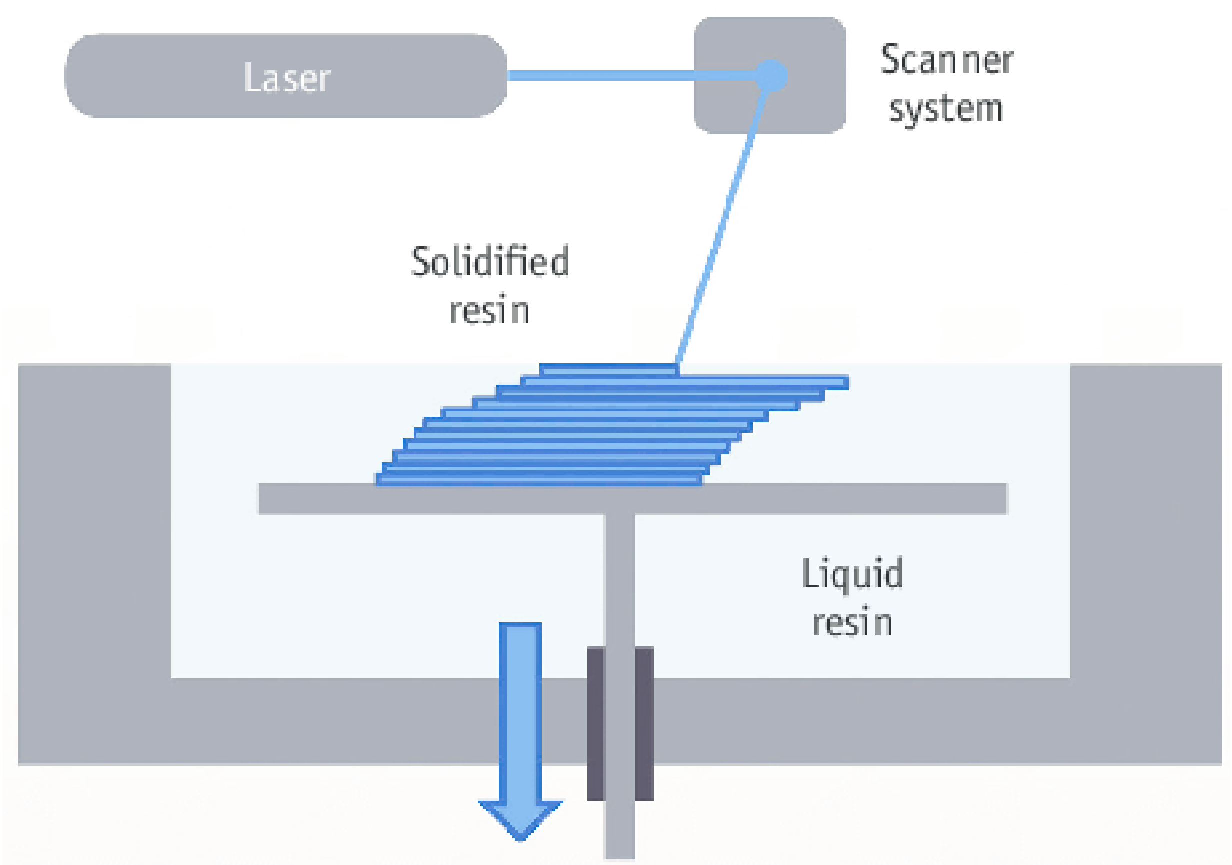
Stereolithography (SLA)

- Hideo Kodama invented the mechanism for using light to cure photosensitive polymers into solid shapes in the 1970s
- Term ‘stereolithography’ coined and patented by Chuck Hull in 1984
- Founded 3D Systems to commercialize the technology



Stereolithography (SLA)

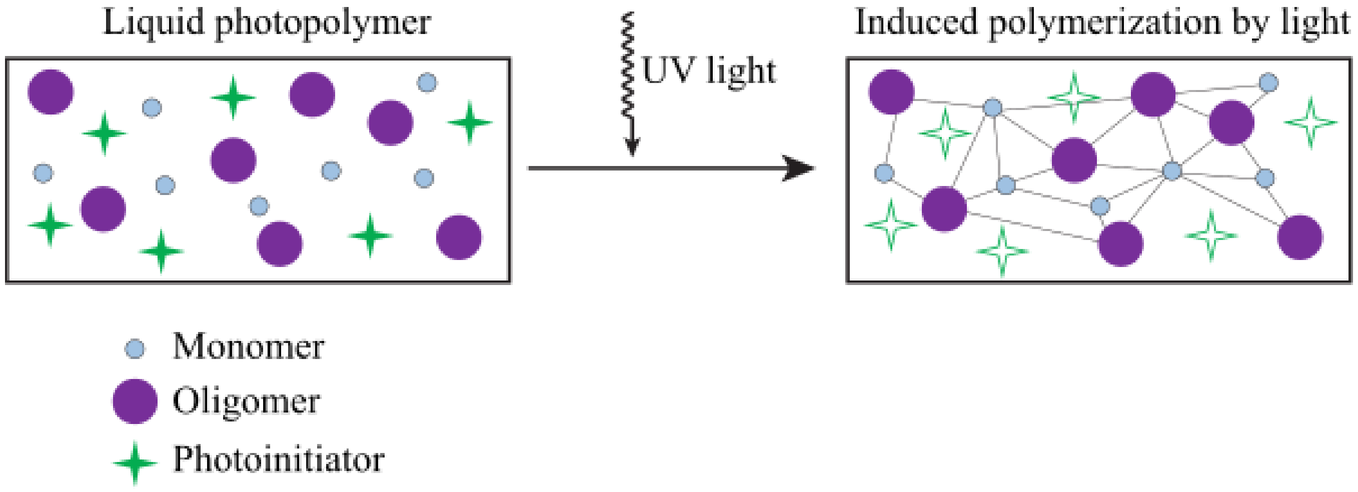
- UV laser to selectively cure photopolymer resin in a vat
- High resolution, accuracy, and good surface finish
- Post-processing required:
  - Cleaning of uncured resin attached to the part
  - Post-curing



Kim et al., "Three-Dimensional Printing: Basic Principles and Applications in Medicine and Radiology", 2016

Photopolymers

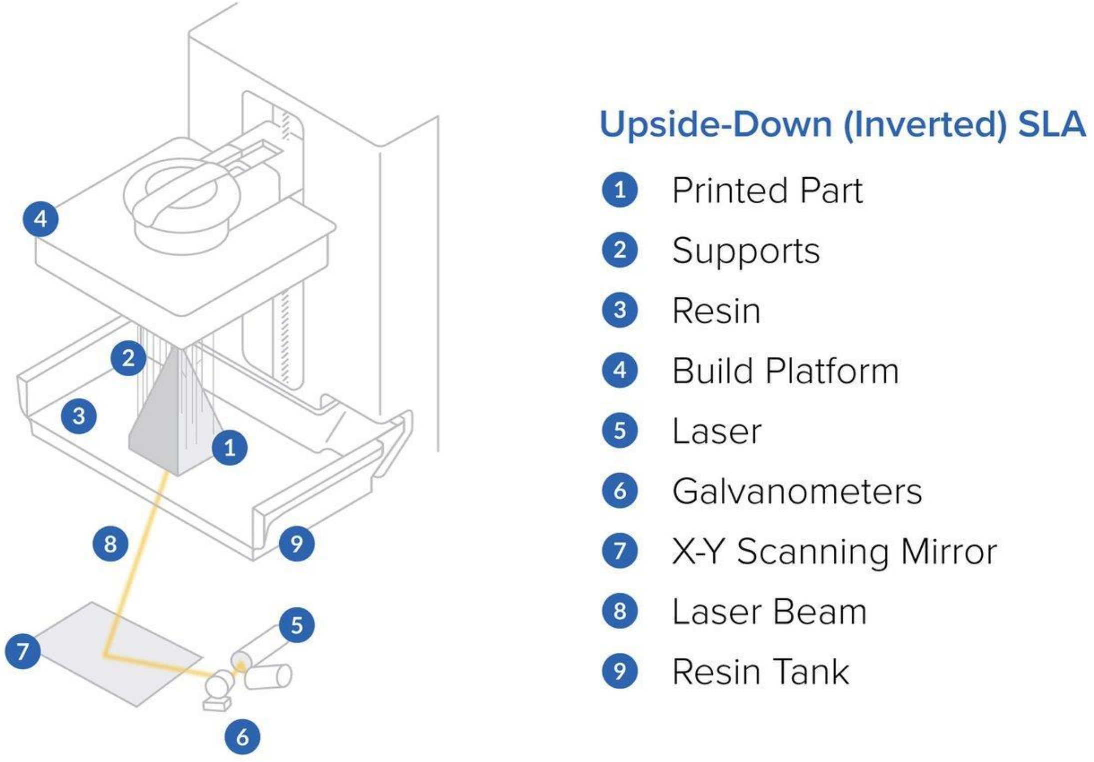
- Light-sensitive materials that change properties when exposed to light
- Combination of:
  - **Monomers:** small molecules
  - **Binders/oligomers:** long chain-like chemically reactive molecules
  - **Photoinitiators:** split into parts upon exposure to light. These parts react with the monomers and binders



www.en.wikipedia.org/wiki/Photopolymer

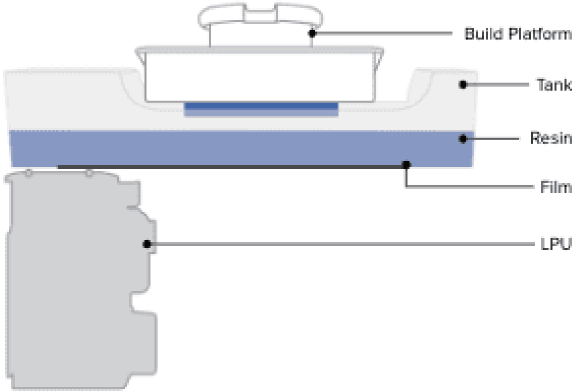
Inverted SLA

- More Compact (smaller vat)
- Risk of detachment from buildplate
    - Combat gravity (more support needed)
    - Force required to peel the print of the bottom surface at each layer

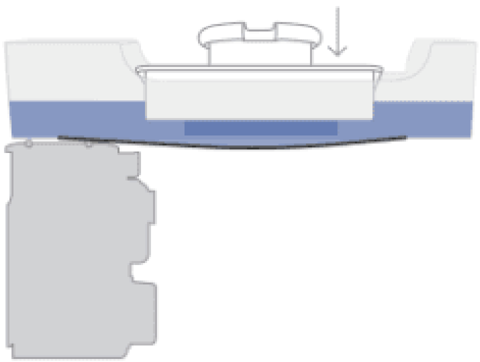


Formlabs

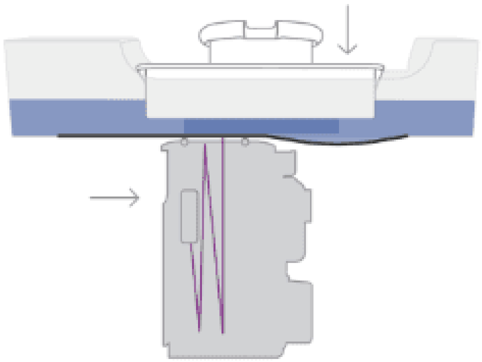
Reducing peeling forces



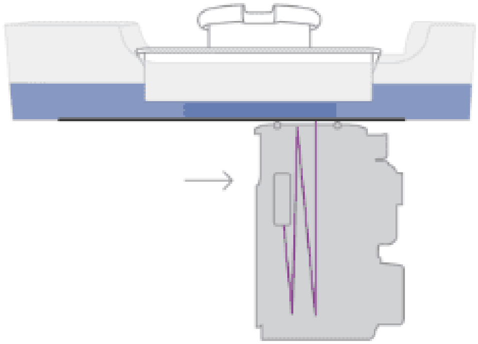
Build platform + part lowers into liquid resin



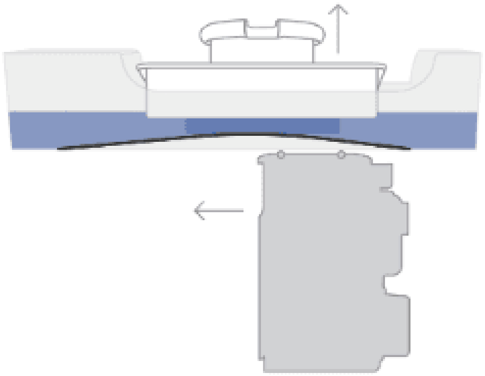
Rollers gently squeeze resin out from under the part to generate a thin, even layer of resin.



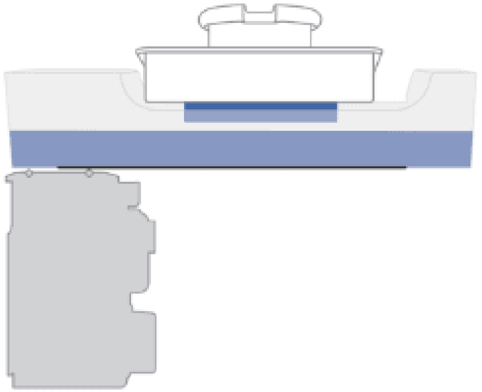
Layer is cured, film adheres to the cured material.



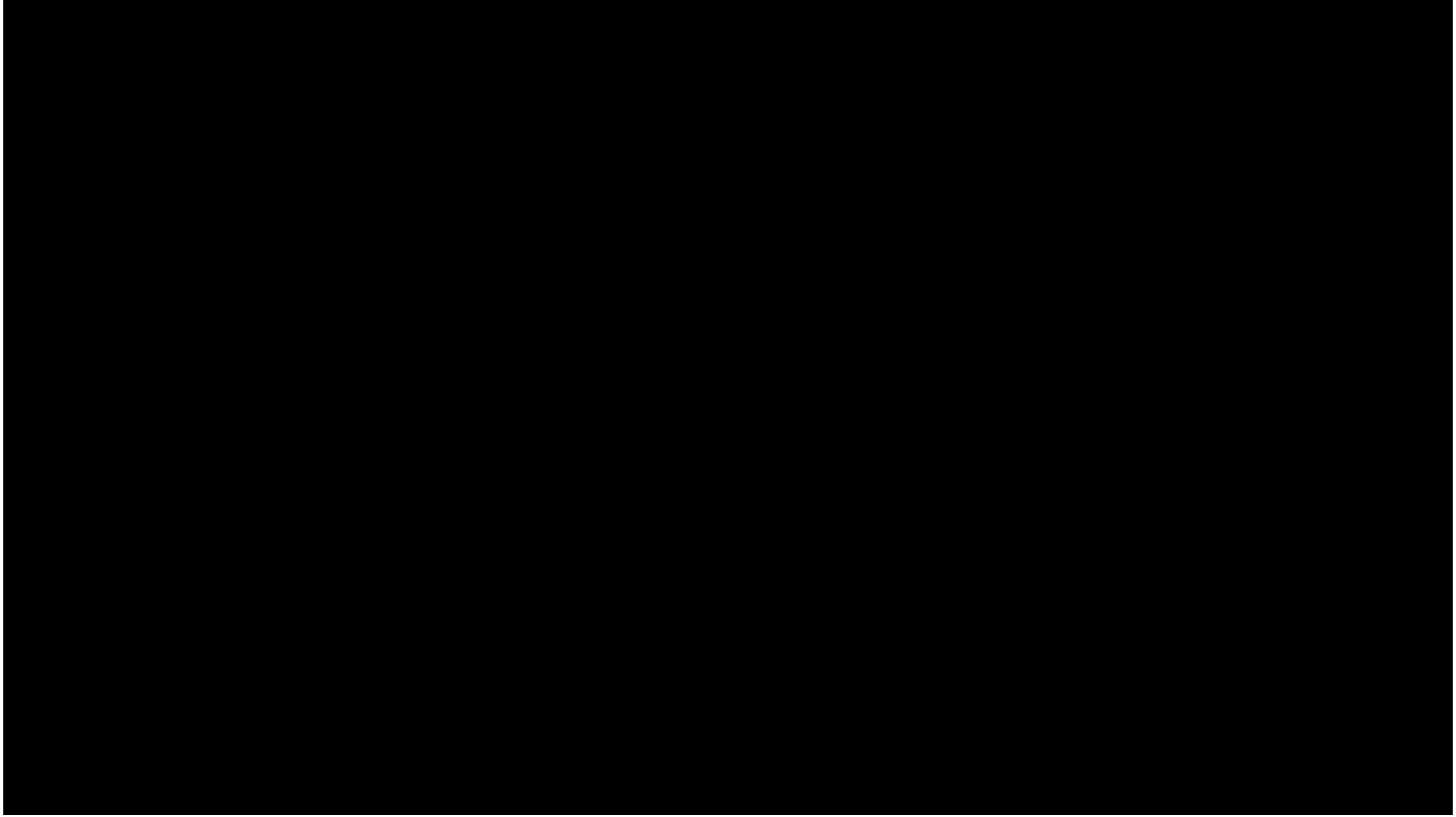
Build platform lifts out of liquid resin gently pulling part away from flexible film layer.



Film relaxes and is ready to print the next layer.



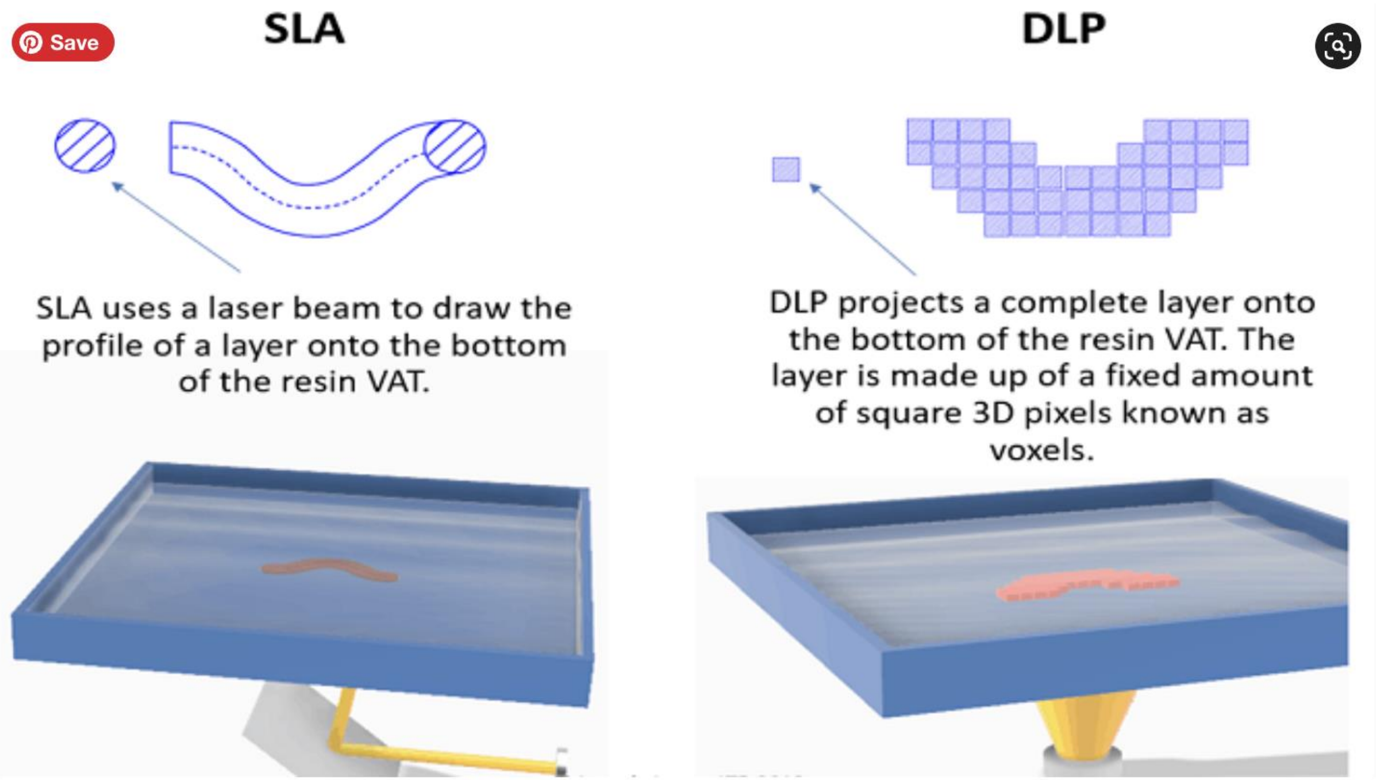
De Pascali et al., “3D-printed biomimetic artificial muscles using soft actuators that contract and elongate”, 2022



C. De Pascali, G. A. Naselli, S. Palagi, R. B. N. Scharff, and B. Mazzolai, “3D-printed biomimetic artificial muscles using soft actuators that contract and elongate,” Science Robotics, 2022.

Digital Light Processing (DLP)

- UV light from a projector instead of a laser
- Cures a complete layer at a time
- Faster
- Less expensive hardware
- Resolution dependent on projector resolution

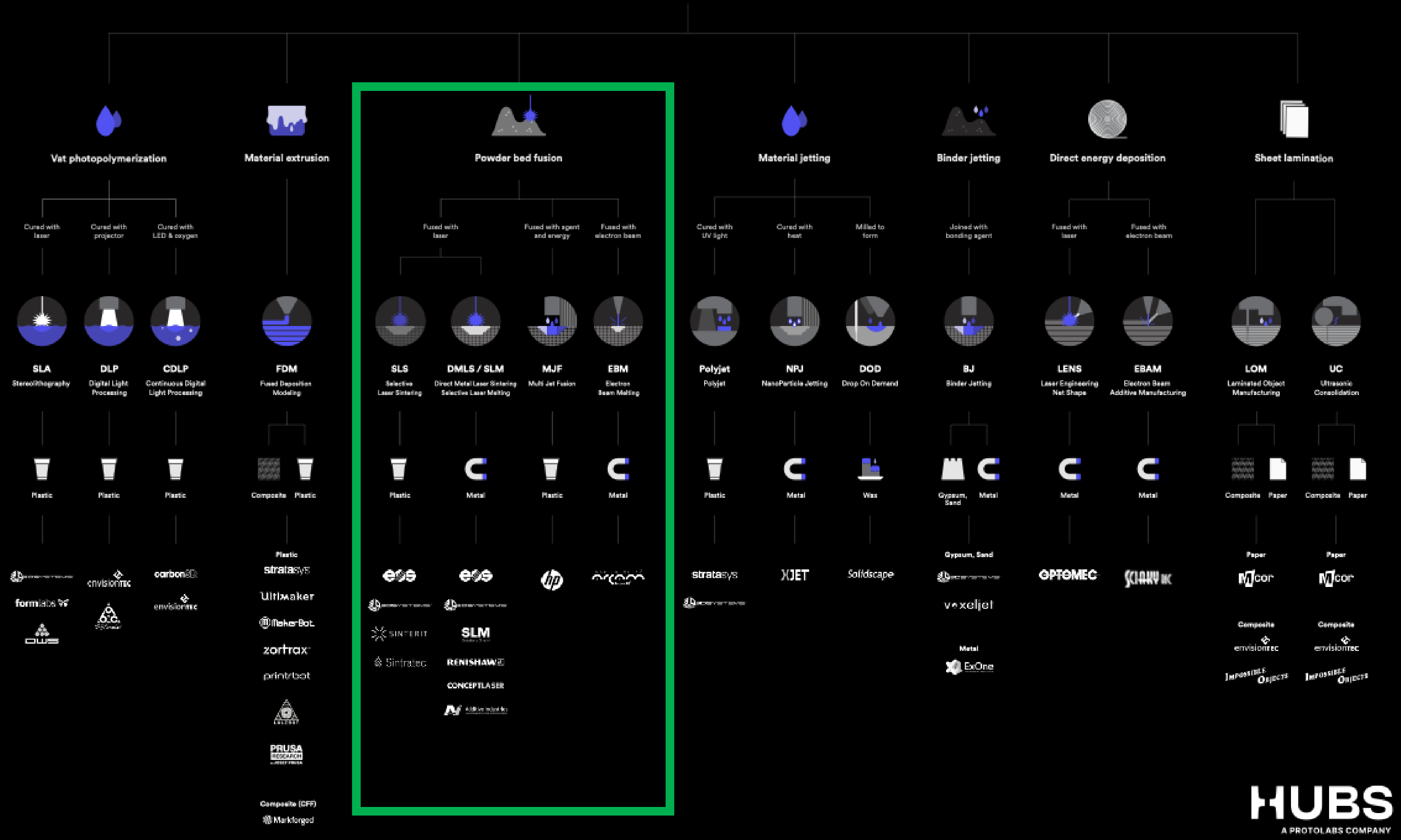


https://www.linkedin.com/pulse/difference-between-dlp-sla-gaurav-patel/

Anycubic

Photocentric

ADDITIVE MANUFACTURING TECHNOLOGIES

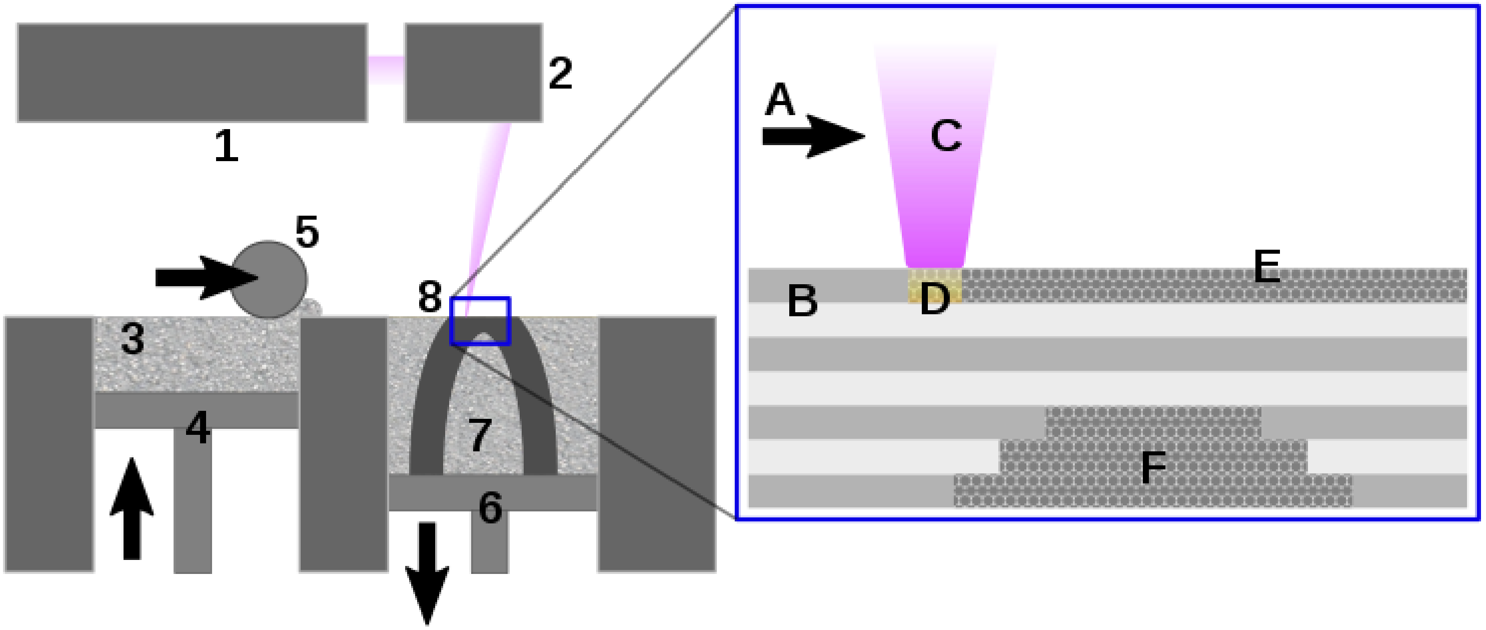


Selective Laser Sintering

- Developed and patented by Joe Beaman and Carl Deckard in the mid-1980s

Selective Laser Sintering (SLS)

- Fusing powdered material with a high-power laser
- Sintering temperatures around 85% of material melting point (no phase change)
- No support structures needed
- Wide range of materials – including metals and TPU
- Porous objects



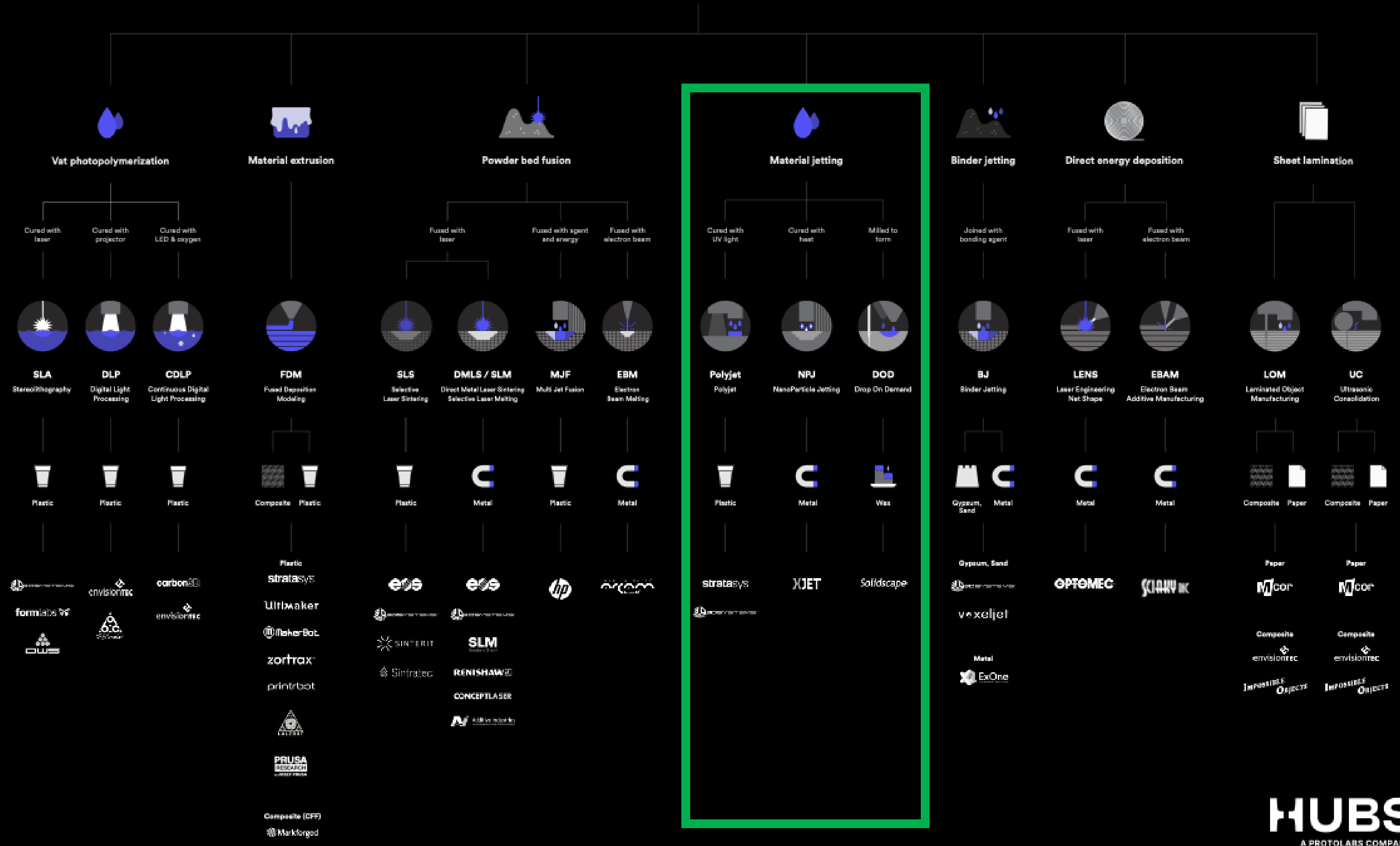
www.en.wikipedia.org/wiki/Selective_laser_sintering


SOLID CONCEPTS

Selective Laser Melting (SLM)

- Powder is heated until melting point
- Only used for metals
- No porosity

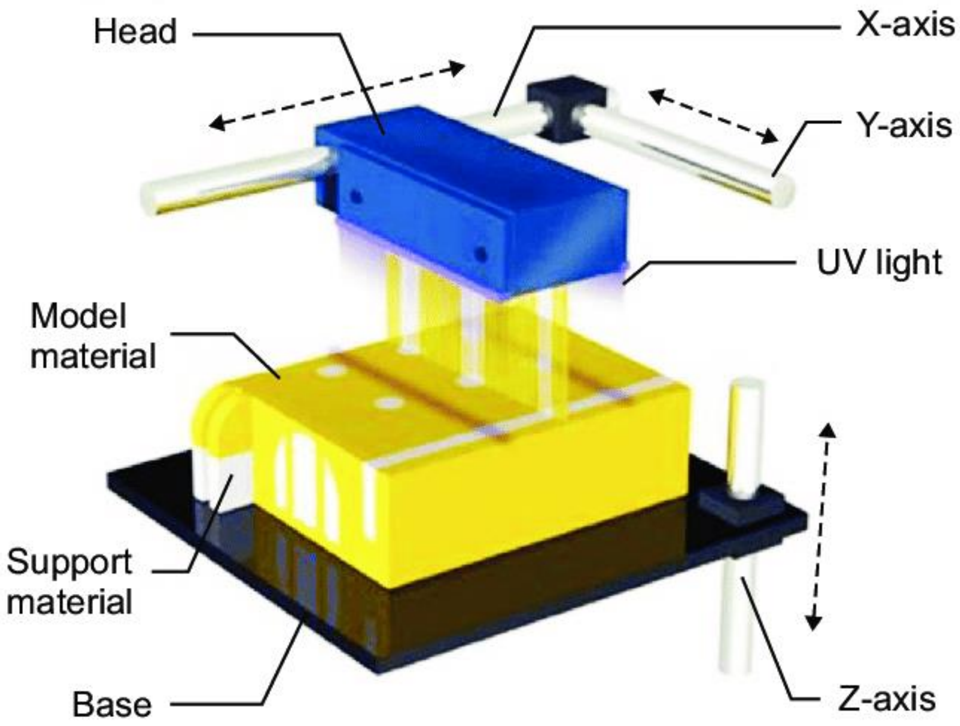
ADDITIVE MANUFACTURING TECHNOLOGIES

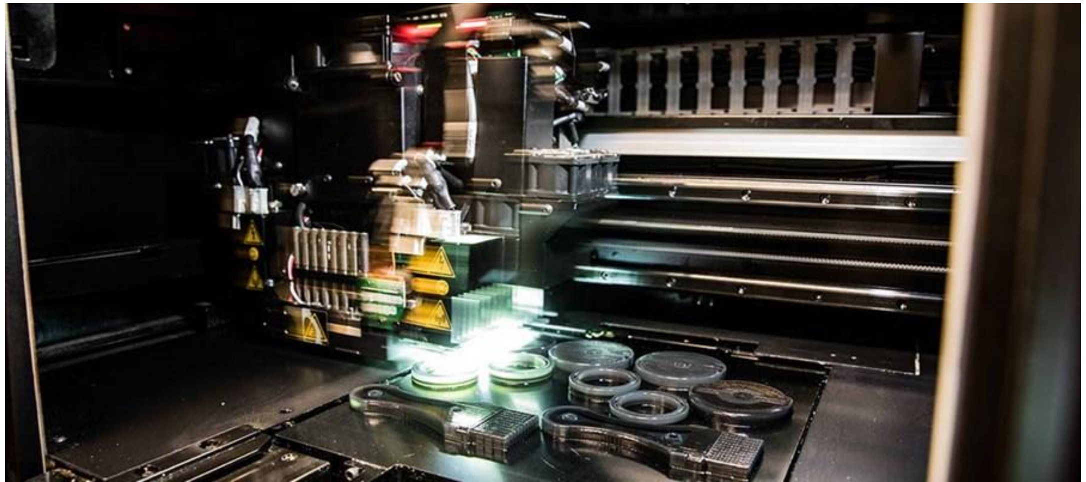


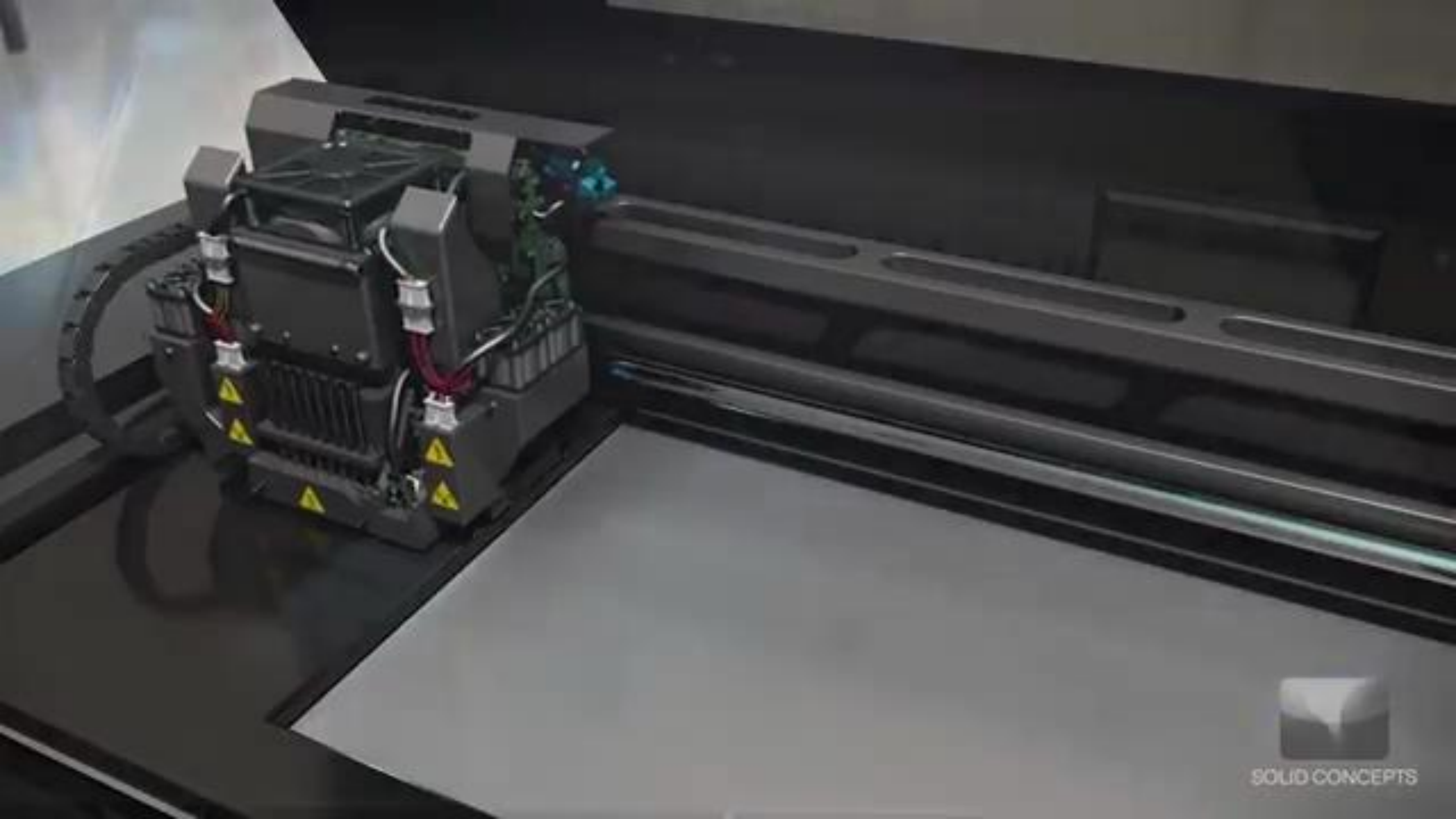
HUBS
A PROTOLABS COMPANY

Material Jetting

- Jetting liquid photopolymers on build tray
- Curing photopolymers with UV light
- Each printhead can jet a different photopolymer






SOLID CONCEPTS

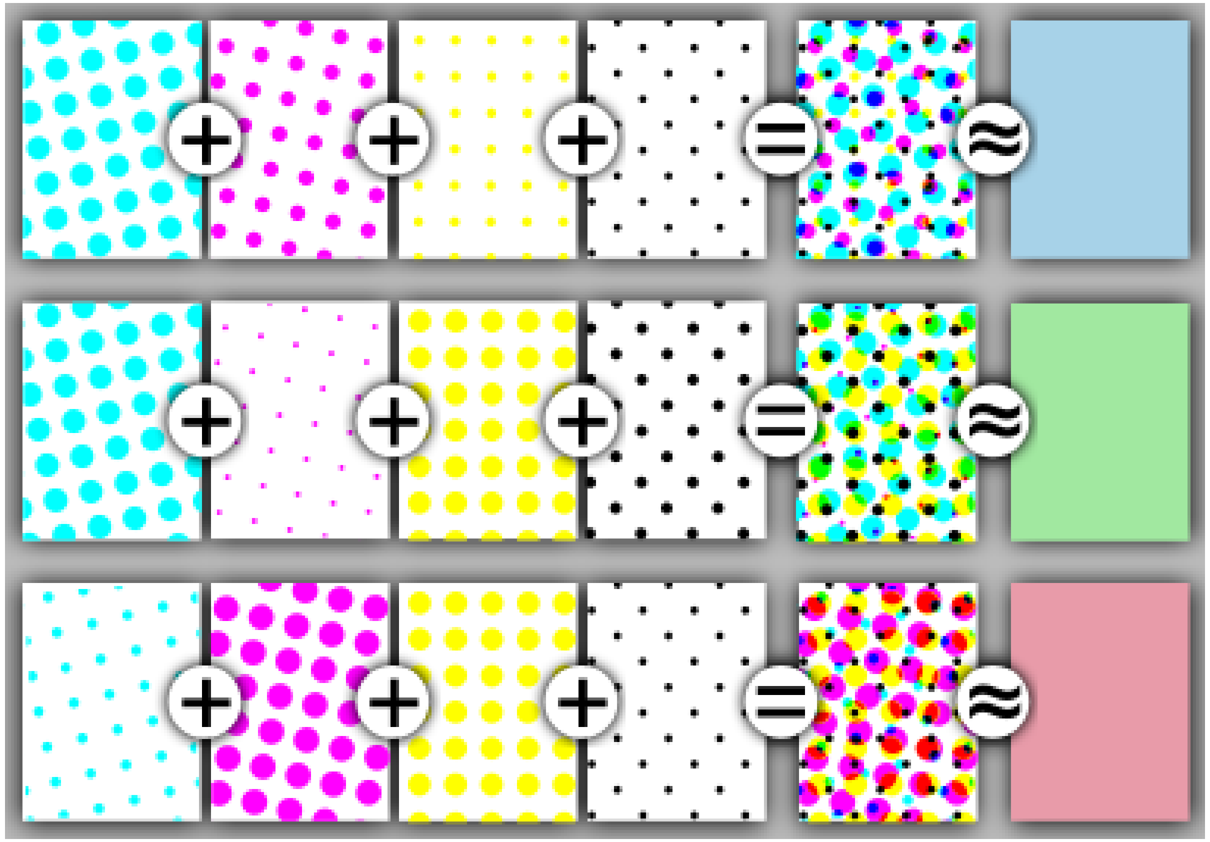
PolyJet J850

- 7 build materials and a support material
  - Full color
  - Transparent
  - Flexible material
- Now at ISD!

Stratasys

Full color printing: 2D

- CMYK: Cyan, Magenta, Yellow, and Black ('K' for Key)
- Halftoning: varying the size and placement of the dots to create gradients



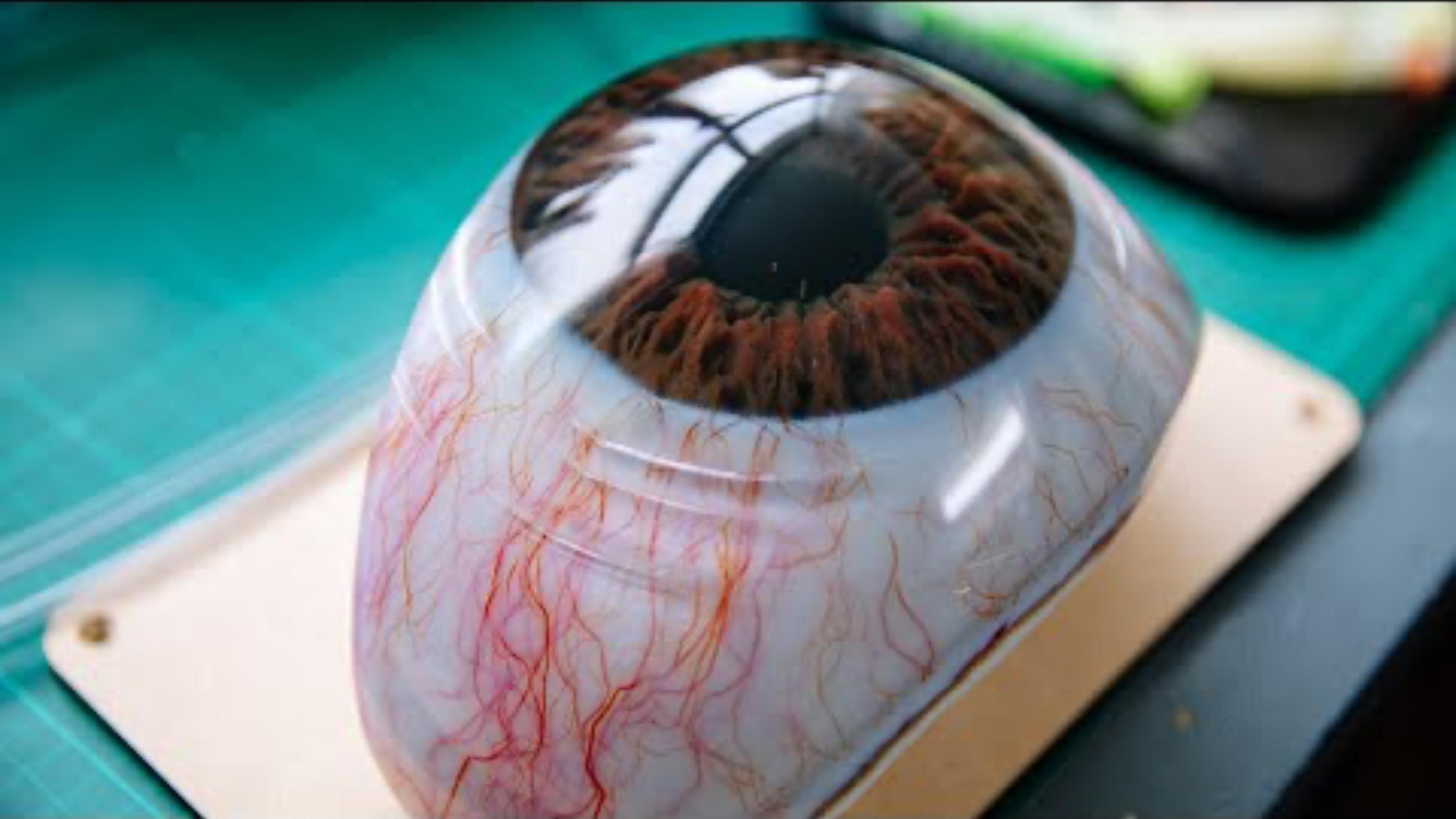
https://en.wikipedia.org/wiki/Halftone

Full color printing: 3D

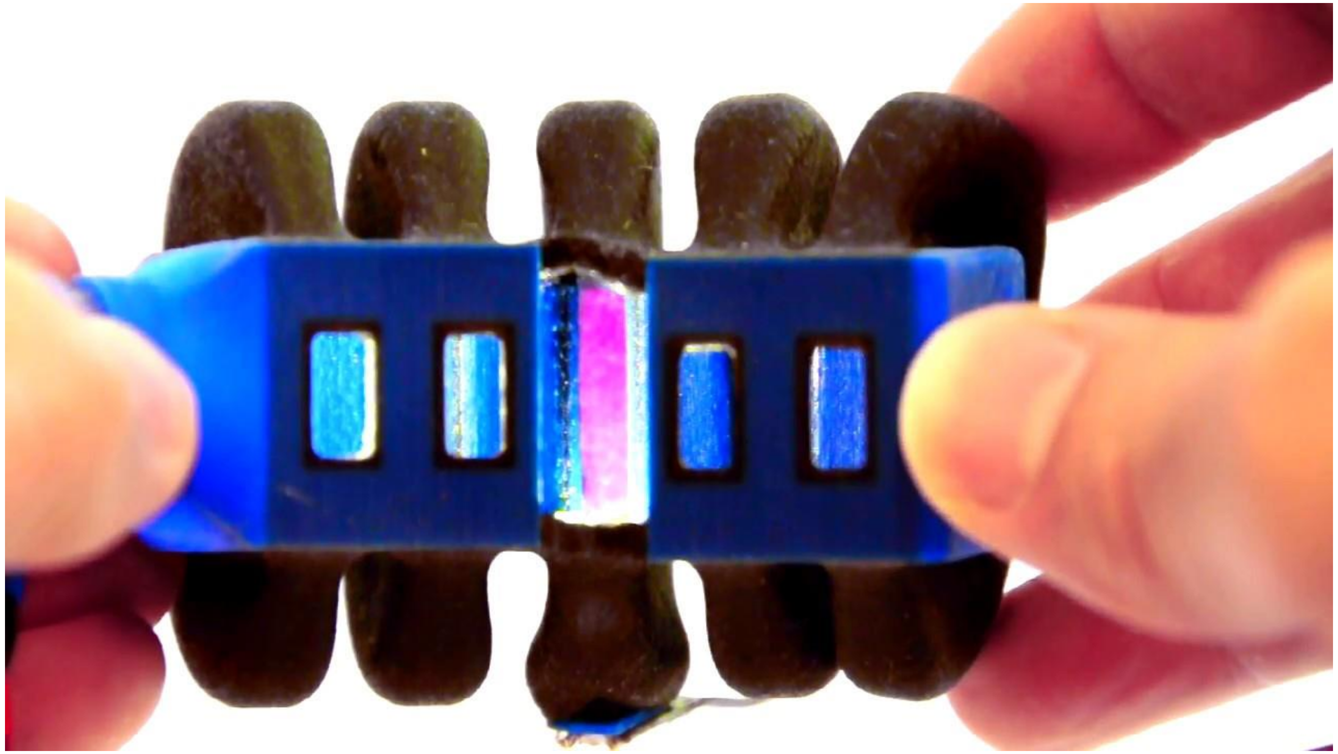
- How many materials do we need?
  - Cyan
  - Magenta
  - Yellow
  - Black
  - White
  - Support

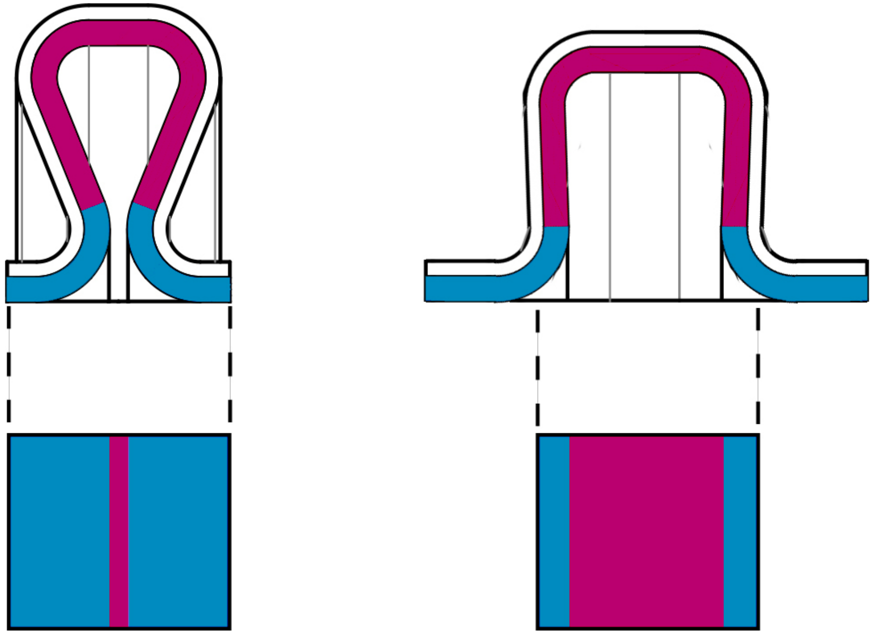
www.grabcad.com/library/fruit-for-polyjet-apple-banana-peach-1


- Having a physical prototype for the client to touch

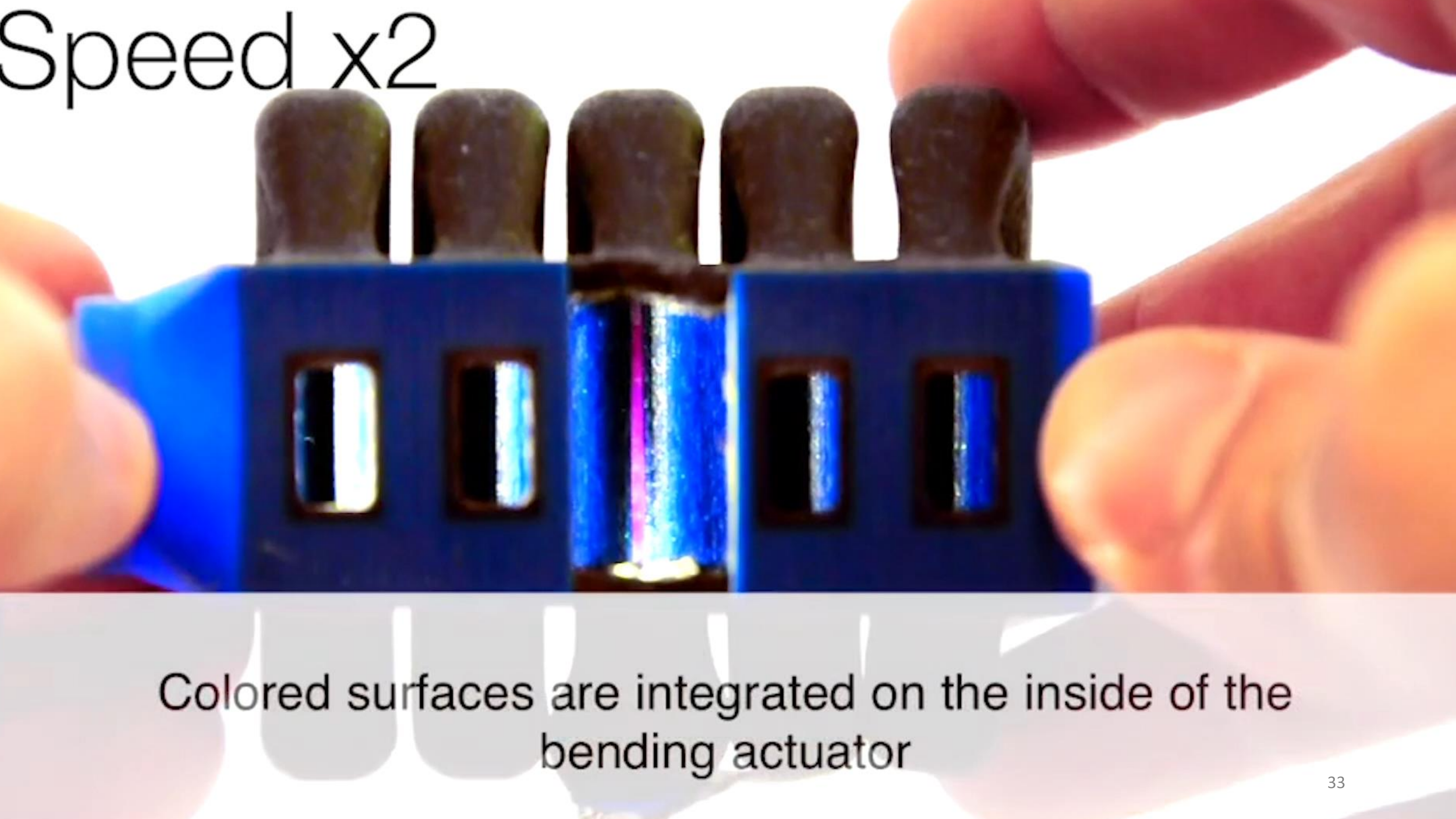


Proprioceptive sensors for soft robots

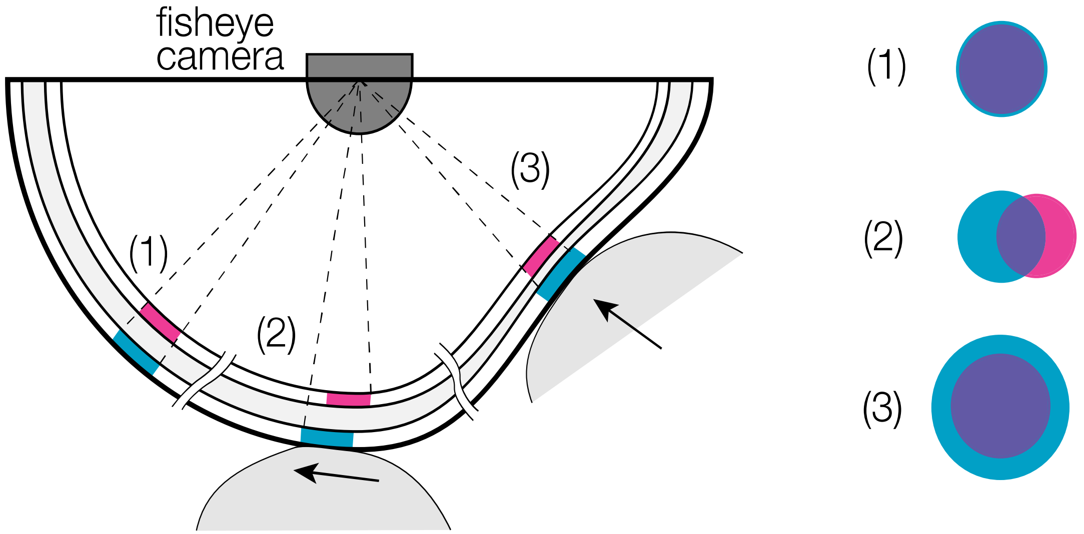


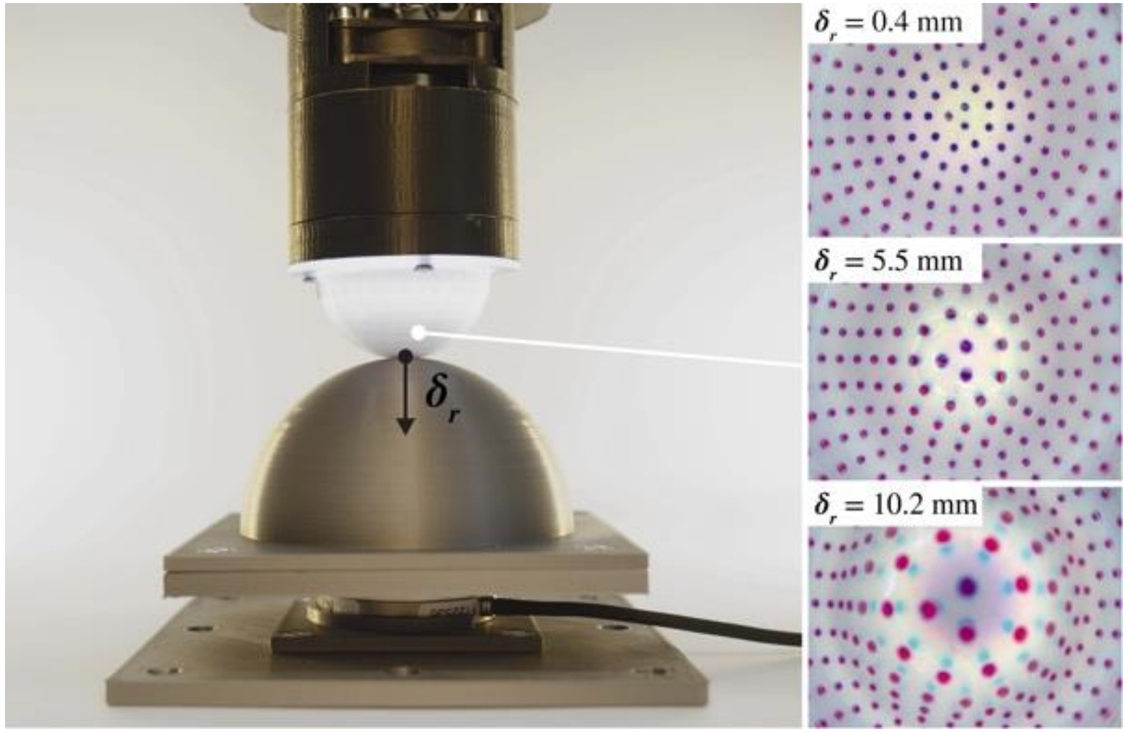


R. B. N. Scharff, R. M. Doornbusch, X. L. Klootwijk, et al., "Color-based sensing of bending deformation on soft robots," in 2018 IEEE International Conference on Robotics and Automation (ICRA), 2018.


Speed x2
Colored surfaces are integrated on the inside of the bending actuator

Tactile sensors





R. B. N. Scharff, D.-J. Boonstra, L. Willemet, X. Lin, and M. Wiertlewski, "Rapid manufacturing of color-based hemispherical soft tactile fingertips," 2022 IEEE International Conference on Soft Robotics (RoboSoft), 2022.

$N = 100$
$D_o = 42$ mm
$D_i = 32$ mm
$D_m = 2$ mm

$N = 400$
$D_o = 42$ mm
$D_i = 32$ mm
$D_m = 1$ mm

$N = 100$
$D_o = 26$ mm
$D_i = 16$ mm
$\mathrm{D}_m = 1$ mm

$N = 60$
$D_o = 22$ mm
$D_i = 12$ mm
$\mathrm{D}_m = 1$ mm

Rapid manufacturing of a color-based hemispherical soft tactile fingertips

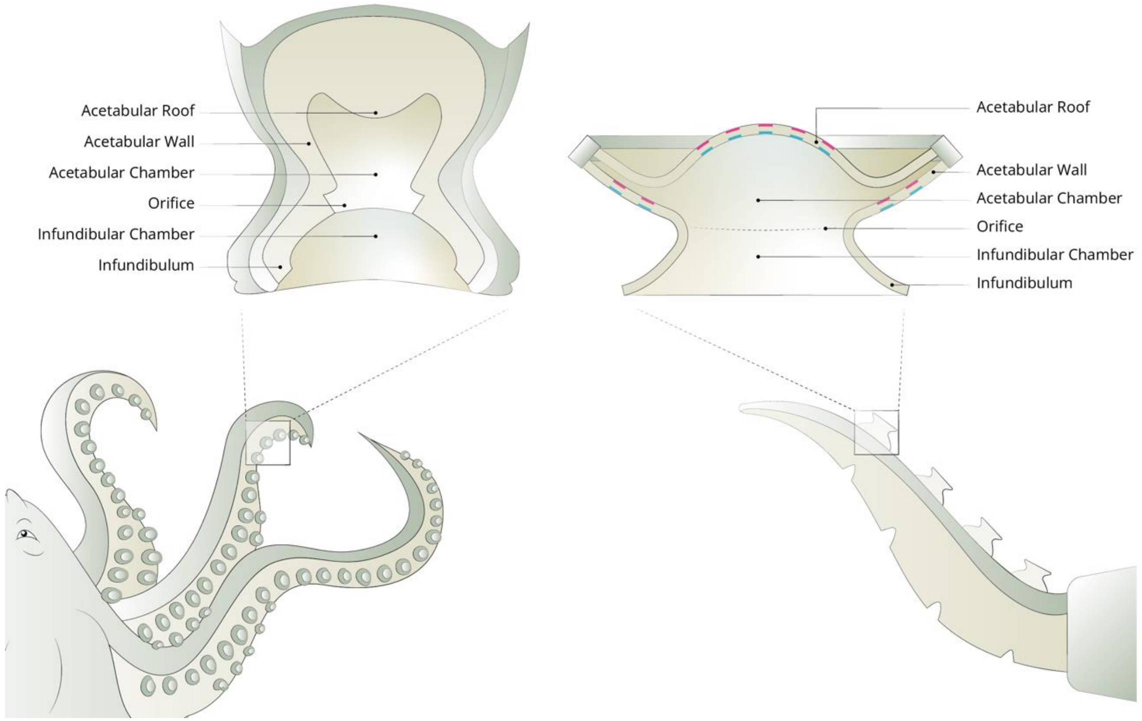
Rob B.N Scharff[a], Dirk-Jan Boonstra[b],
Laurence Willemet[b], Xi Lin[c], Michaël Wiertlewski[b]

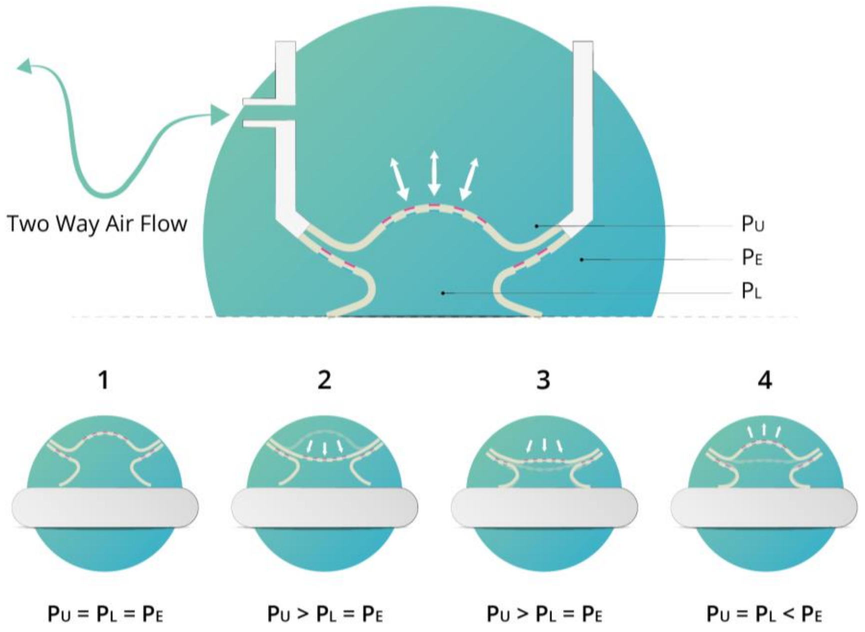
[a] Bioinspired Soft Robotics Lab, Istituto Italiano di Tecnologia (IIT)
[b] Cognitive Robotics Department, Delft University of Technology
[c] Carl Zeiss Meditec AG, China

ISTITUTO ITALIANO DI TECNOLOGIA

TU Delft

Suction cups with tactile sensors





Optoelectronically Innervated Suction Cup Inspired by the Octopus

Stein van Veggel, Michaël Wiertlewski *Member, IEEE*, Zjenja Doubrovski *Member, IEEE*,
Adrie Kooijman, Barbara Mazzolai *Member, IEEE*, Rob B.N. Scharff *Member, IEEE*

TU Delft

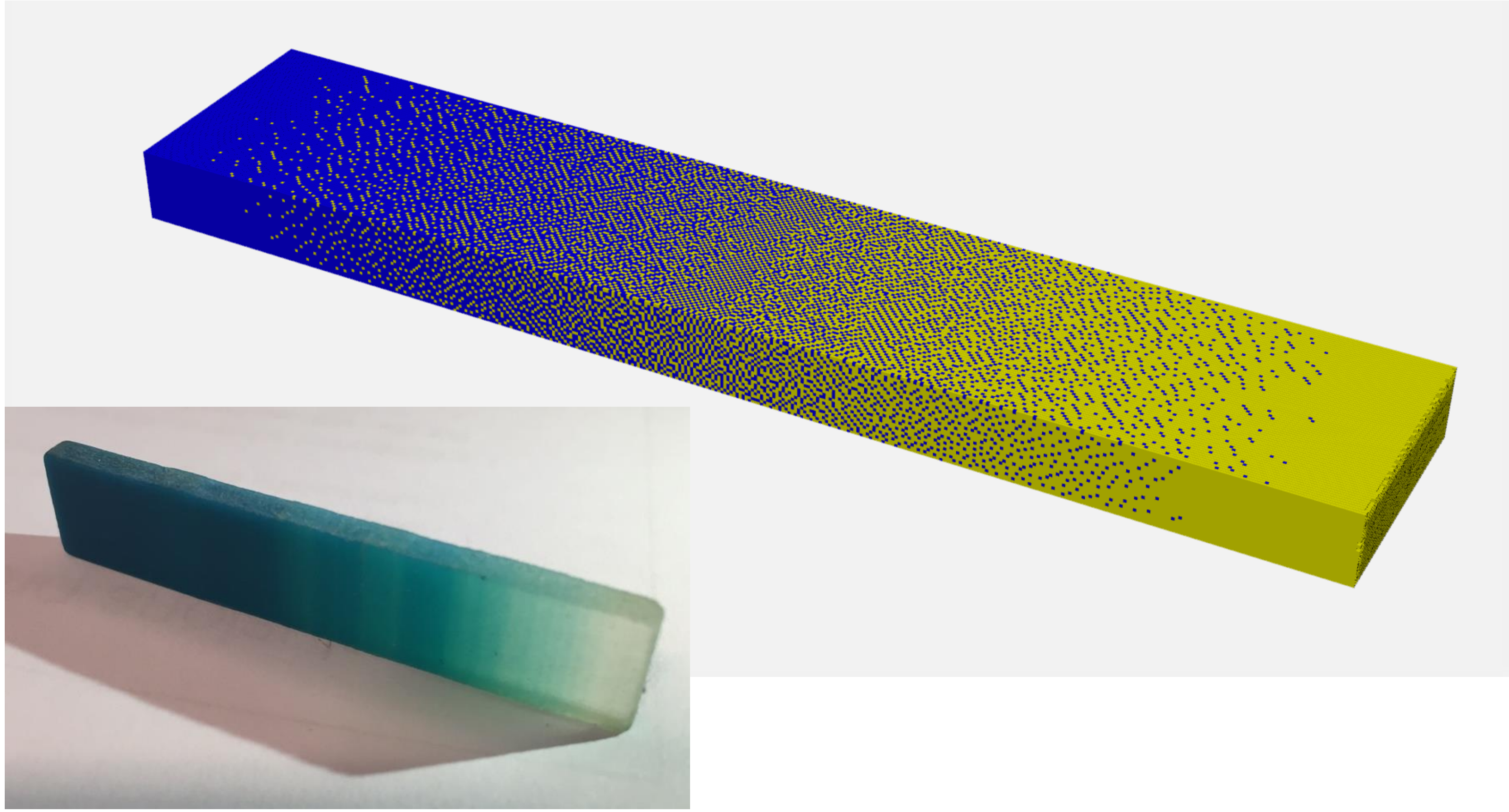
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

ISTITUTO ITALIANO DI TECNOLOGIA

Research package

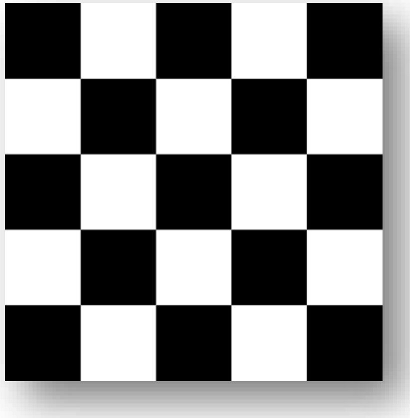
- Voxel printing
- Printing on textiles
- Air printing
- Liquid printing
- Pause & Resume

Voxel printing (Bitmap printing)

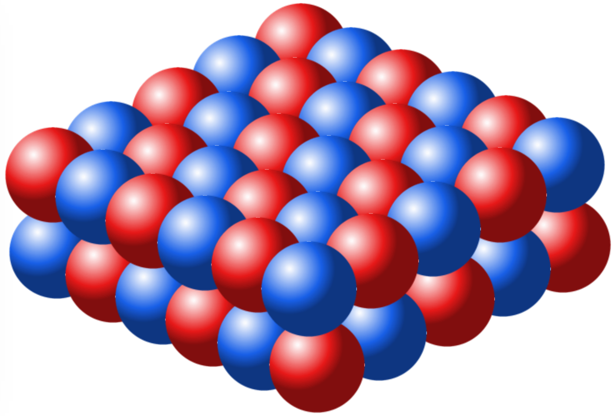


By Zjenja Doubrovski

Target density: 50%

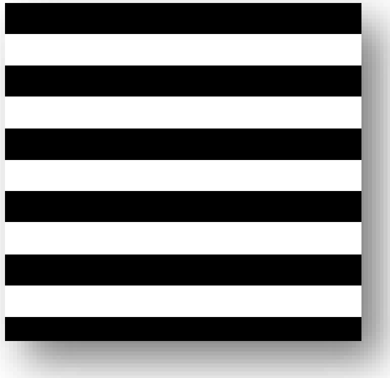


Checkerboard

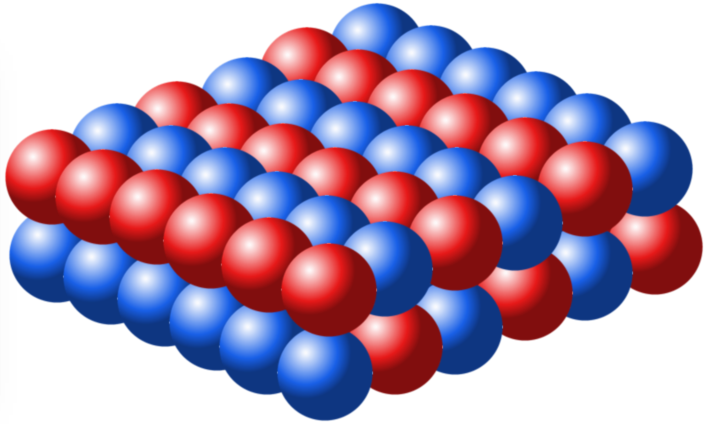


By Zjenja Doubrovski

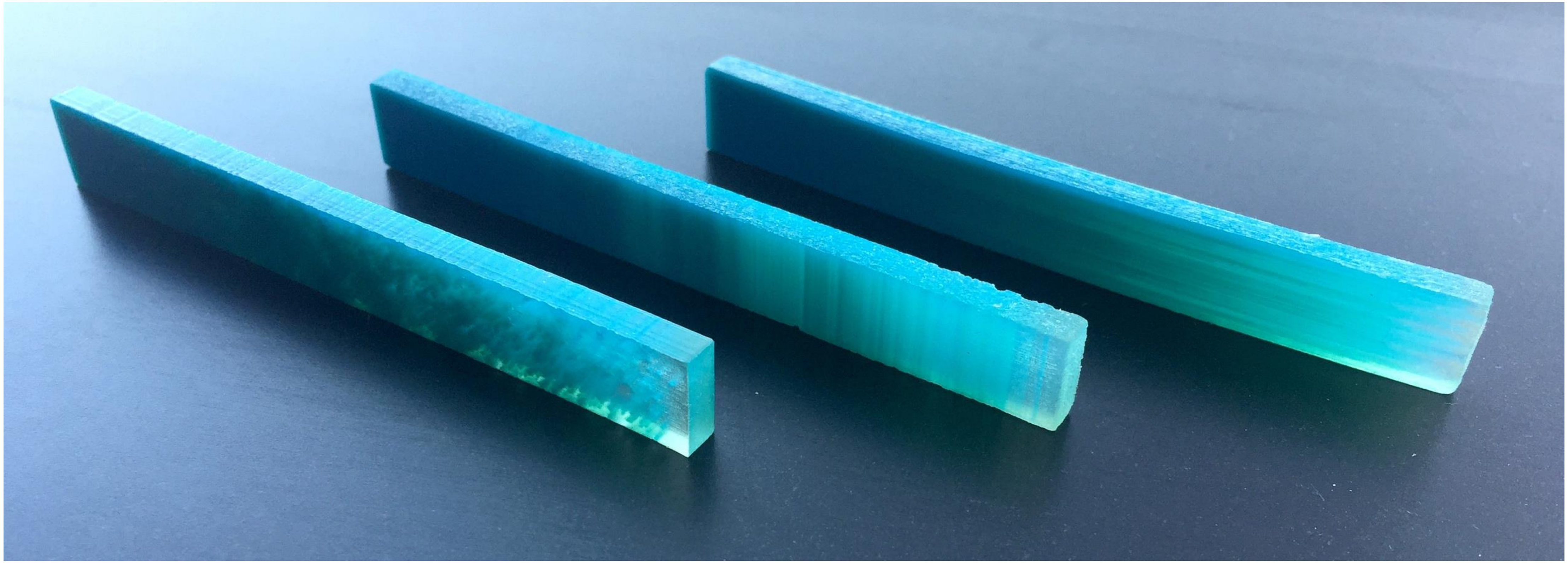
Target density: 50%

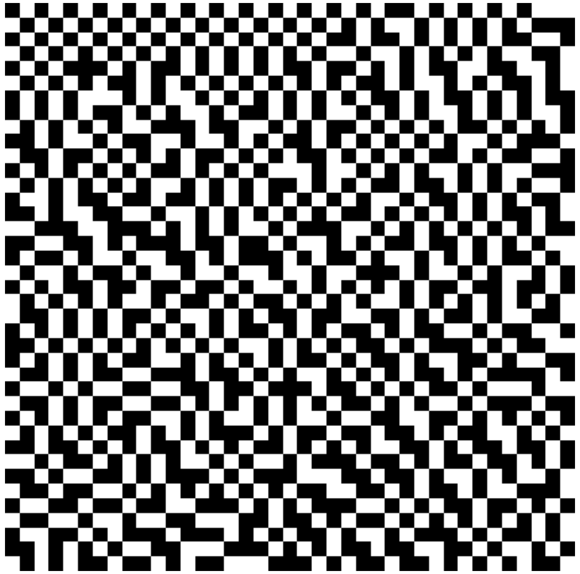


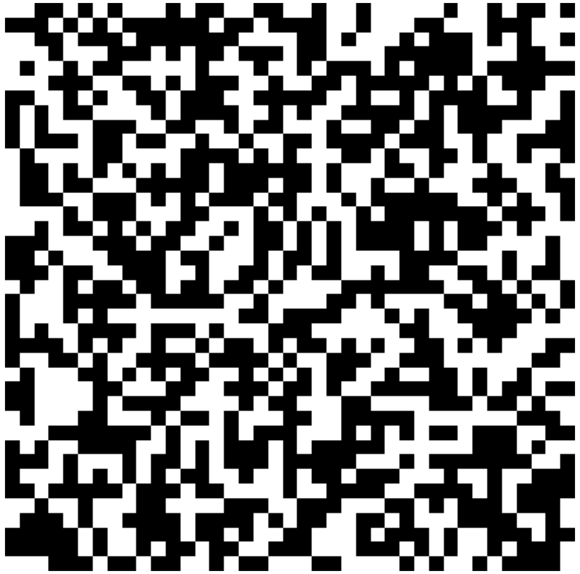
Lines

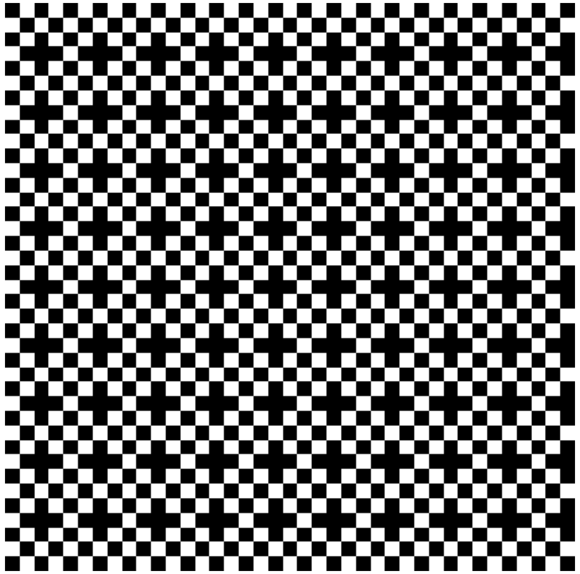


By Zjenja Doubrovski



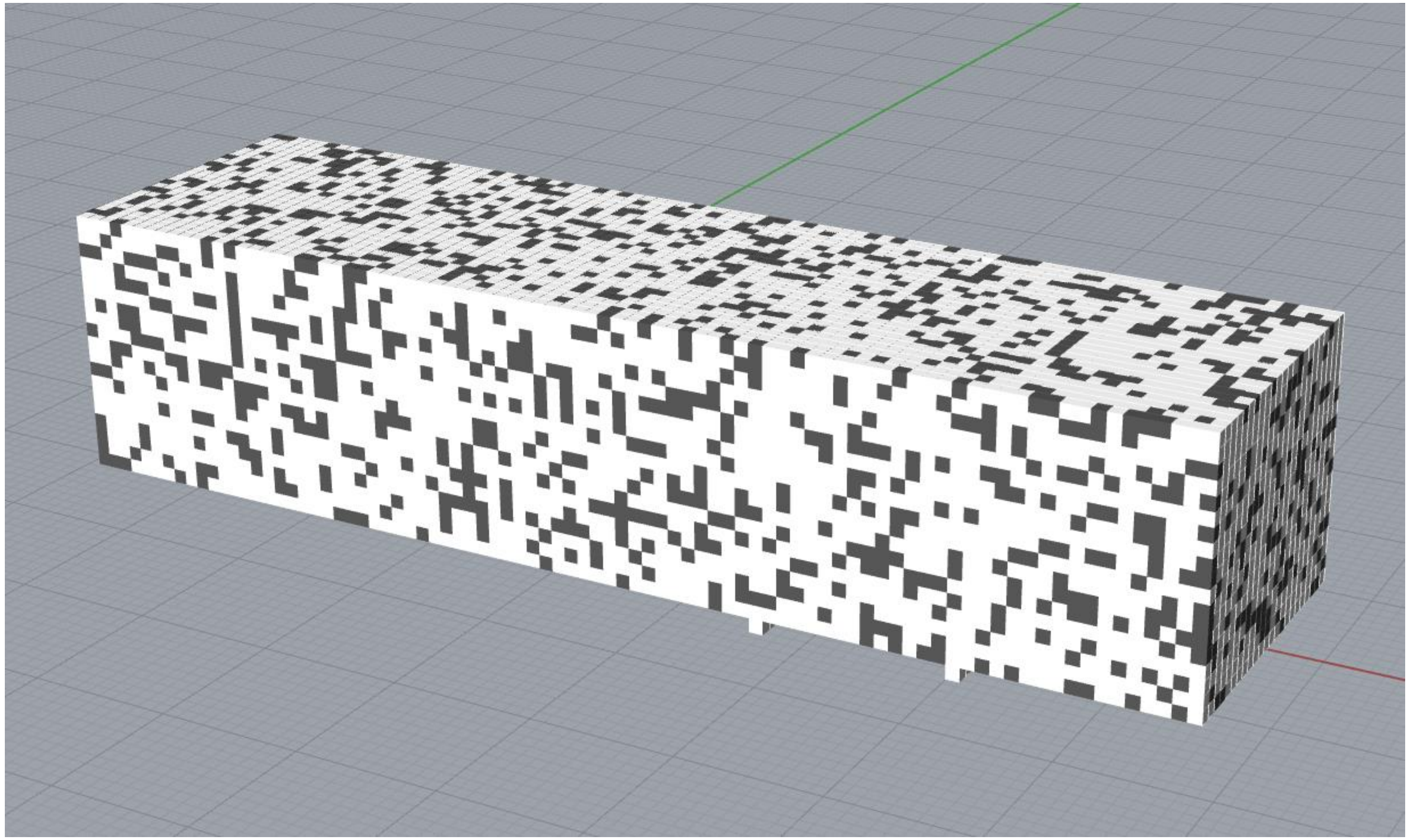






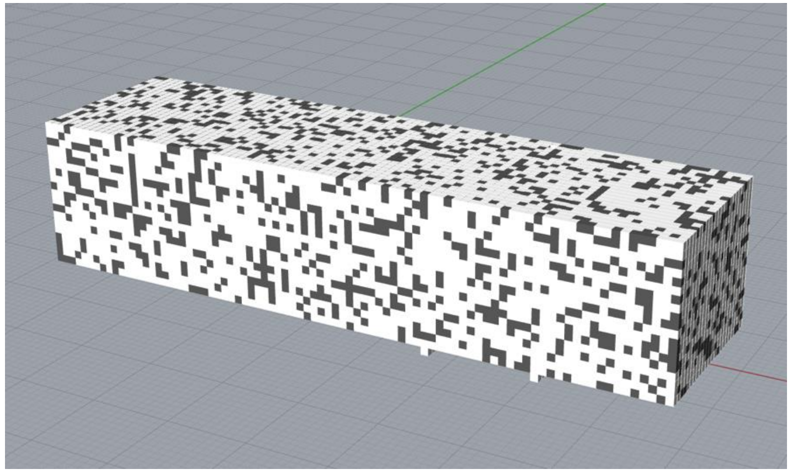
By Zienia Doubrovski

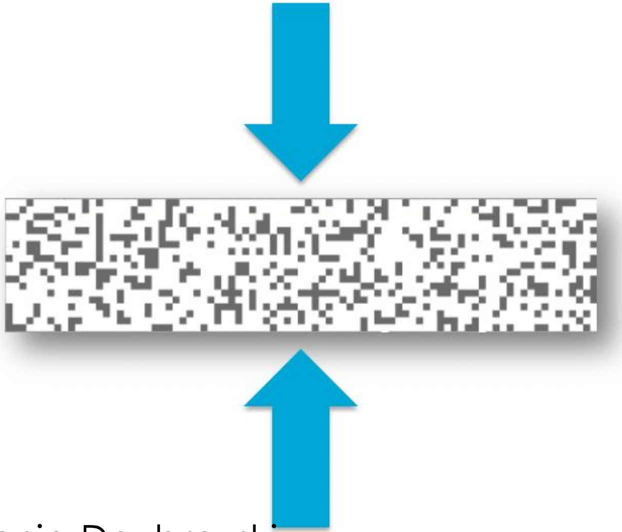
- 80% Flexible, 20% rigid
- Homogeneous distribution of material



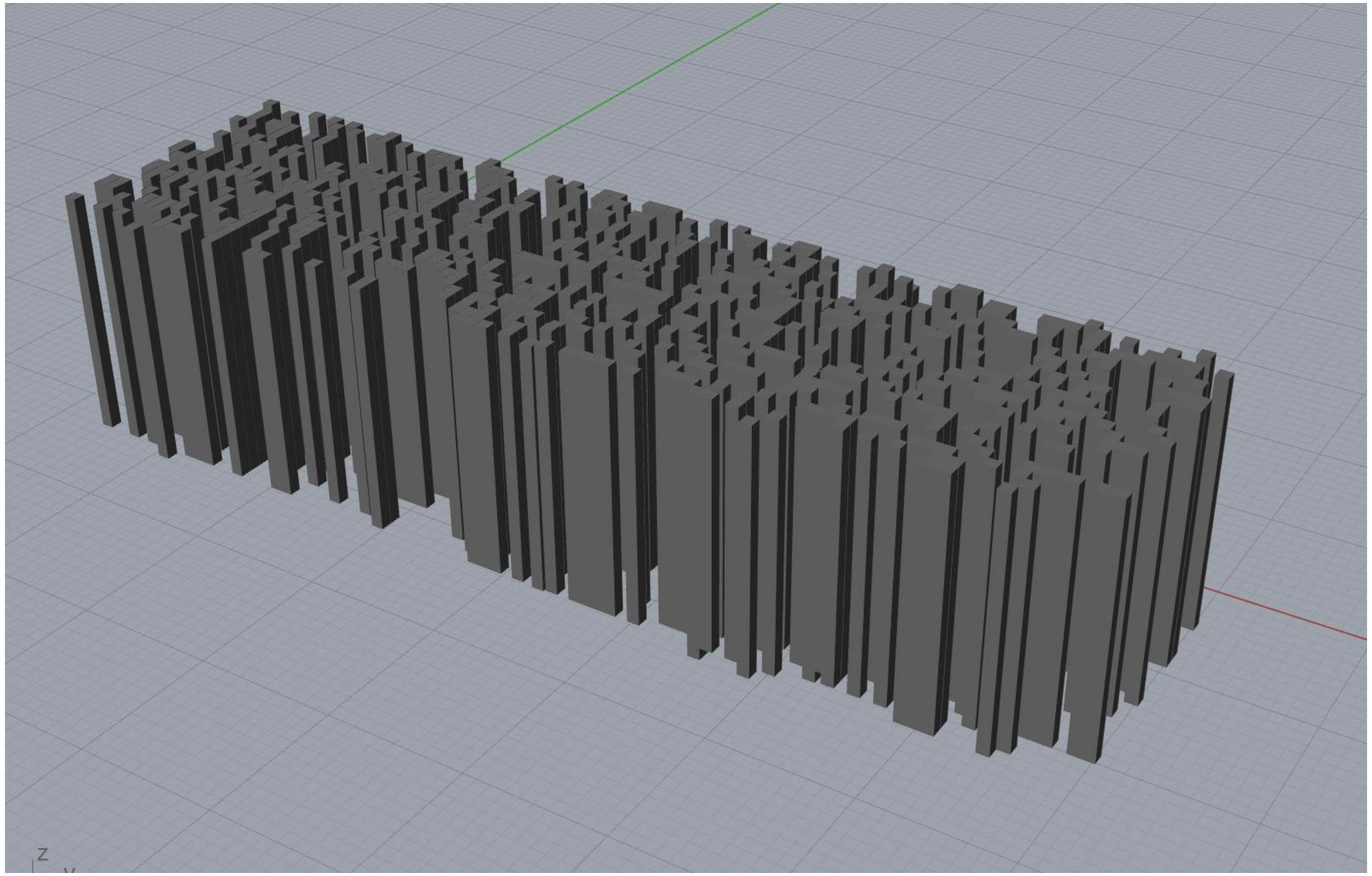
By Zjenja Doubrovski

- 80% Flexible, 20% rigid
- How to design…
  - Stiffness for compression

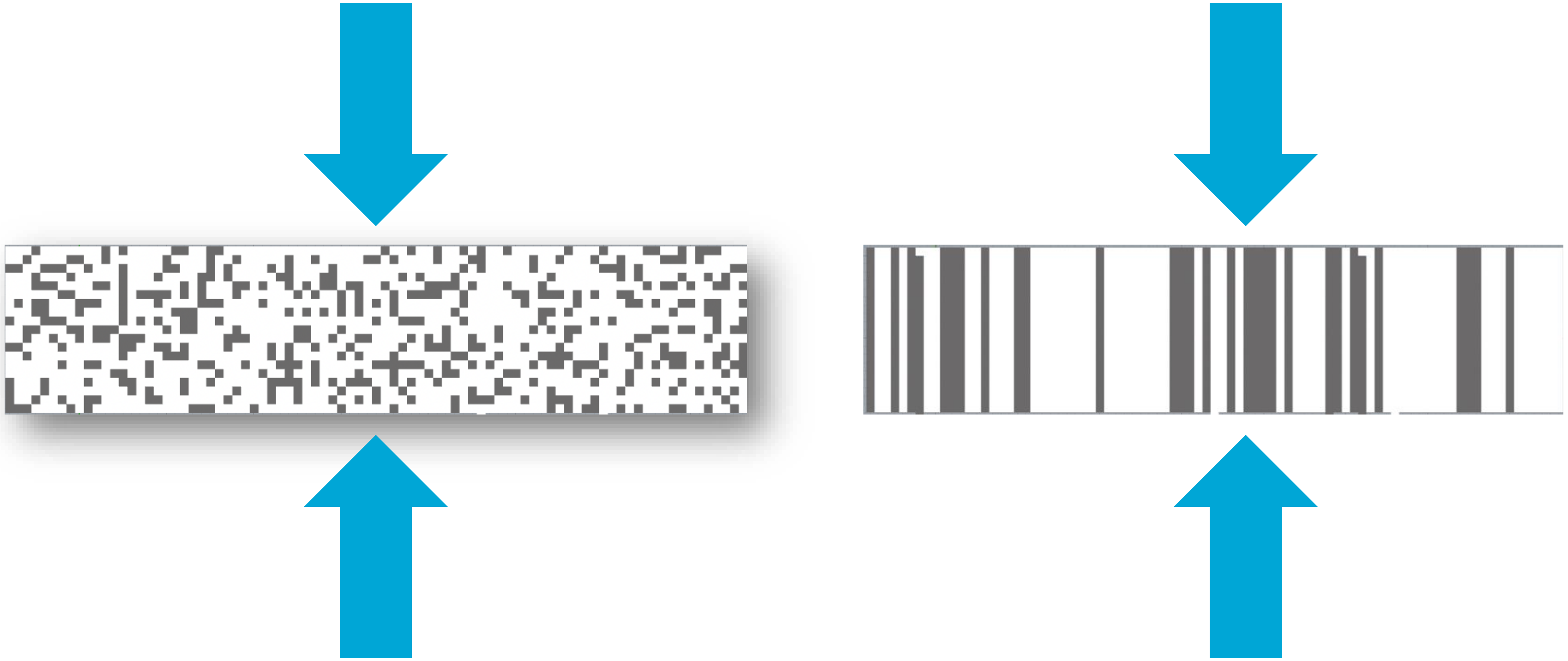




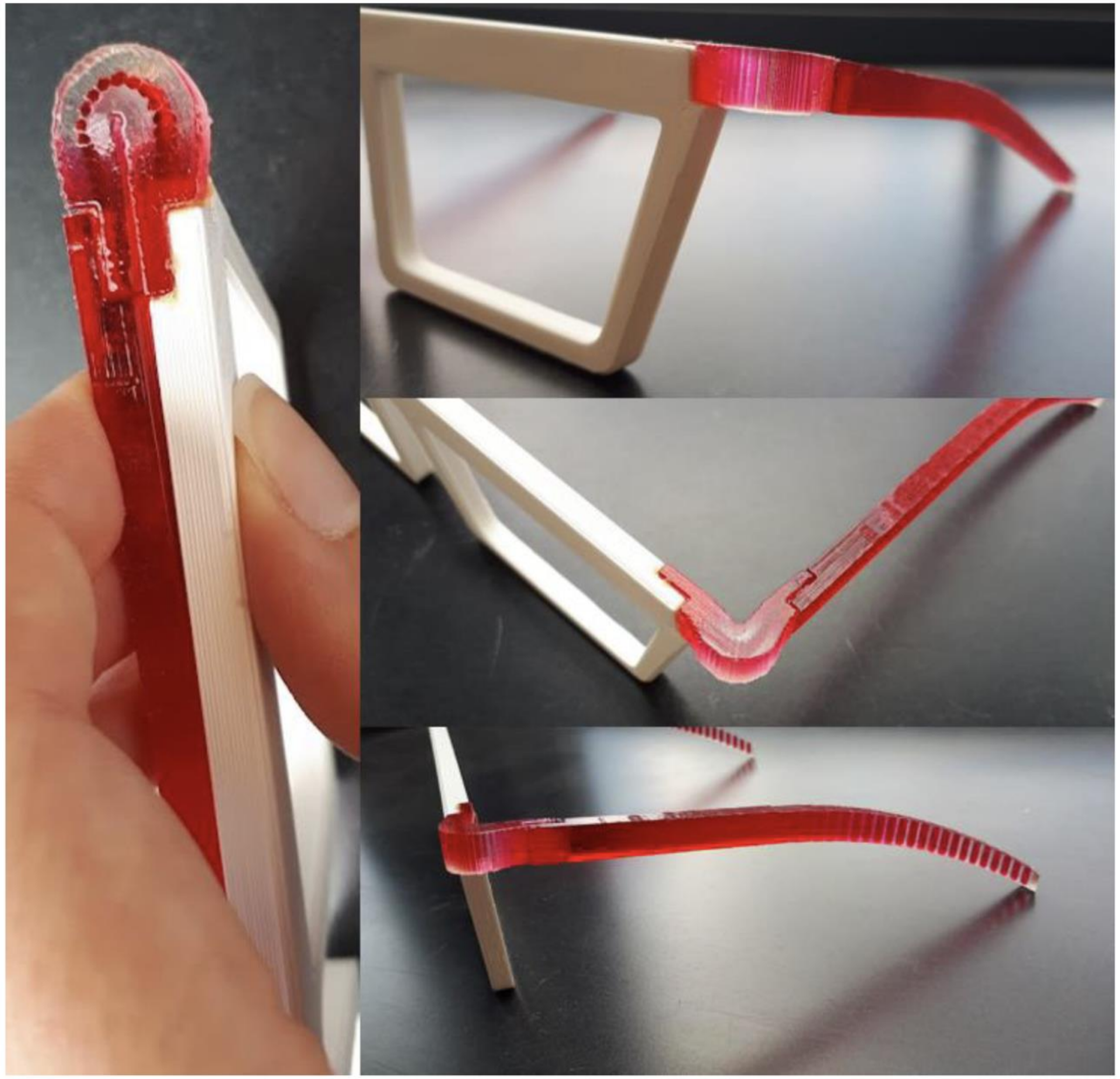
By Zjenja Doubrovski



By Zjenja Doubrovski



By Zjenja Doubrovski

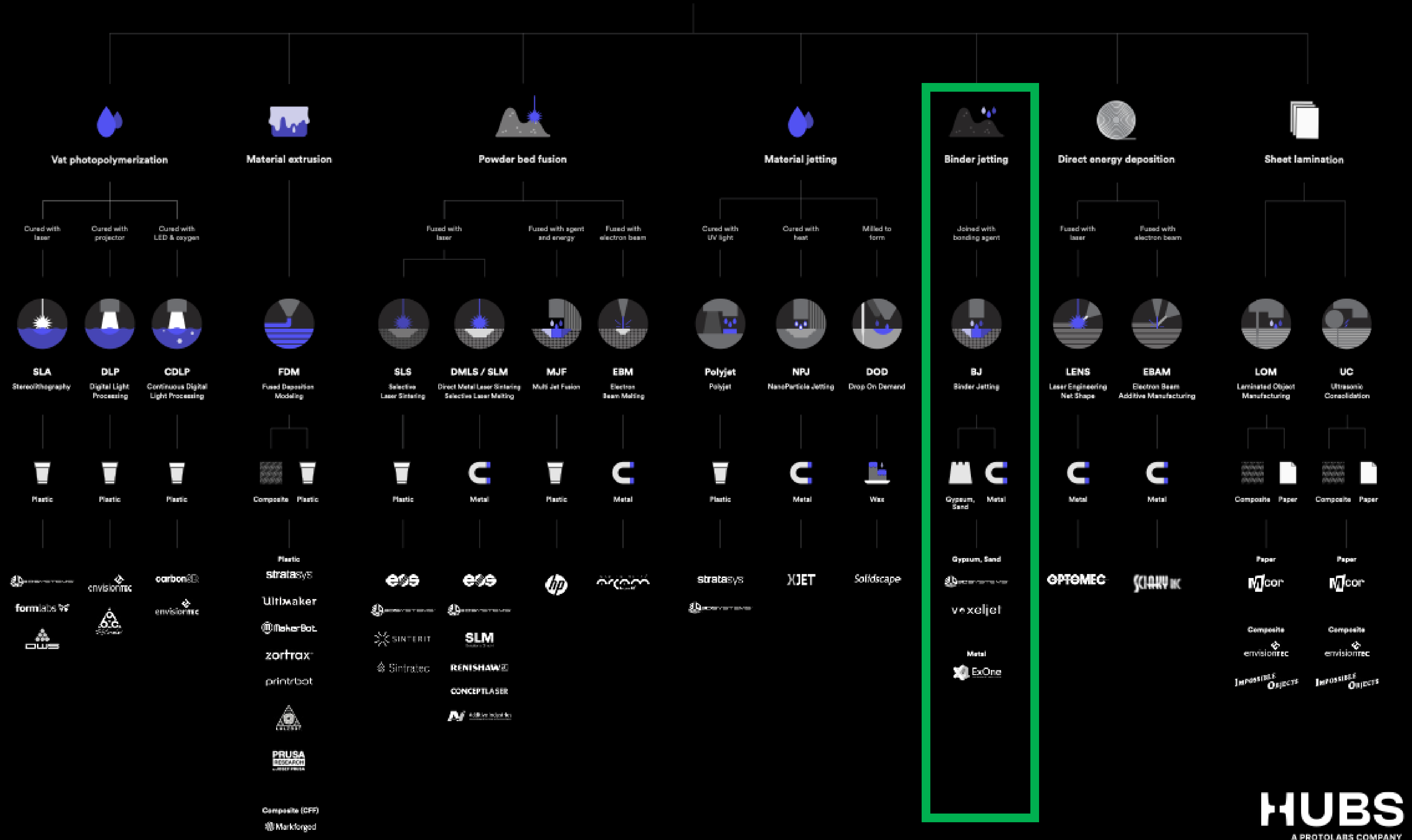


By Zjenja Doubrovski

Assignment: 3D Scanning & PolyJet Additive Manufacturing

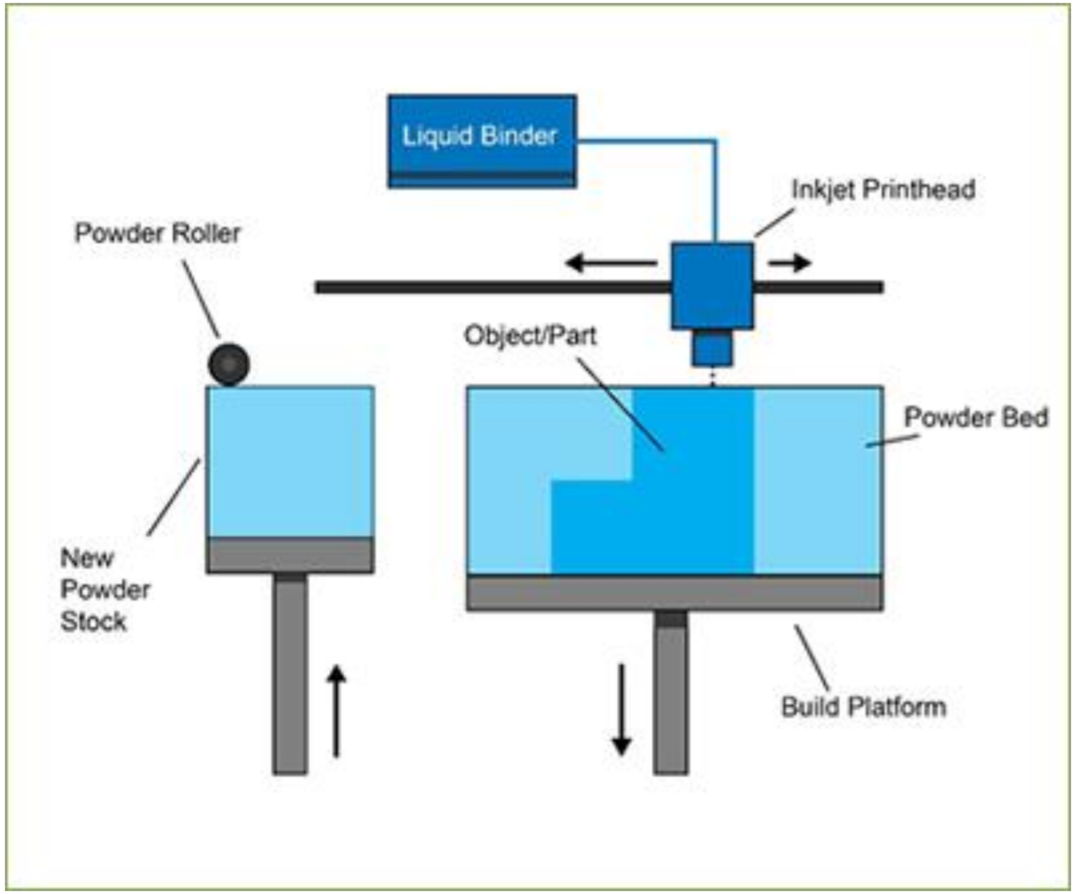
- Start thinking about what you want to 3D scan and print
- Printed object should fit in a bounding box of 30mm x 30mm x 30mm (keychain-size)
- Full color flexible materials

ADDITIVE MANUFACTURING TECHNOLOGIES

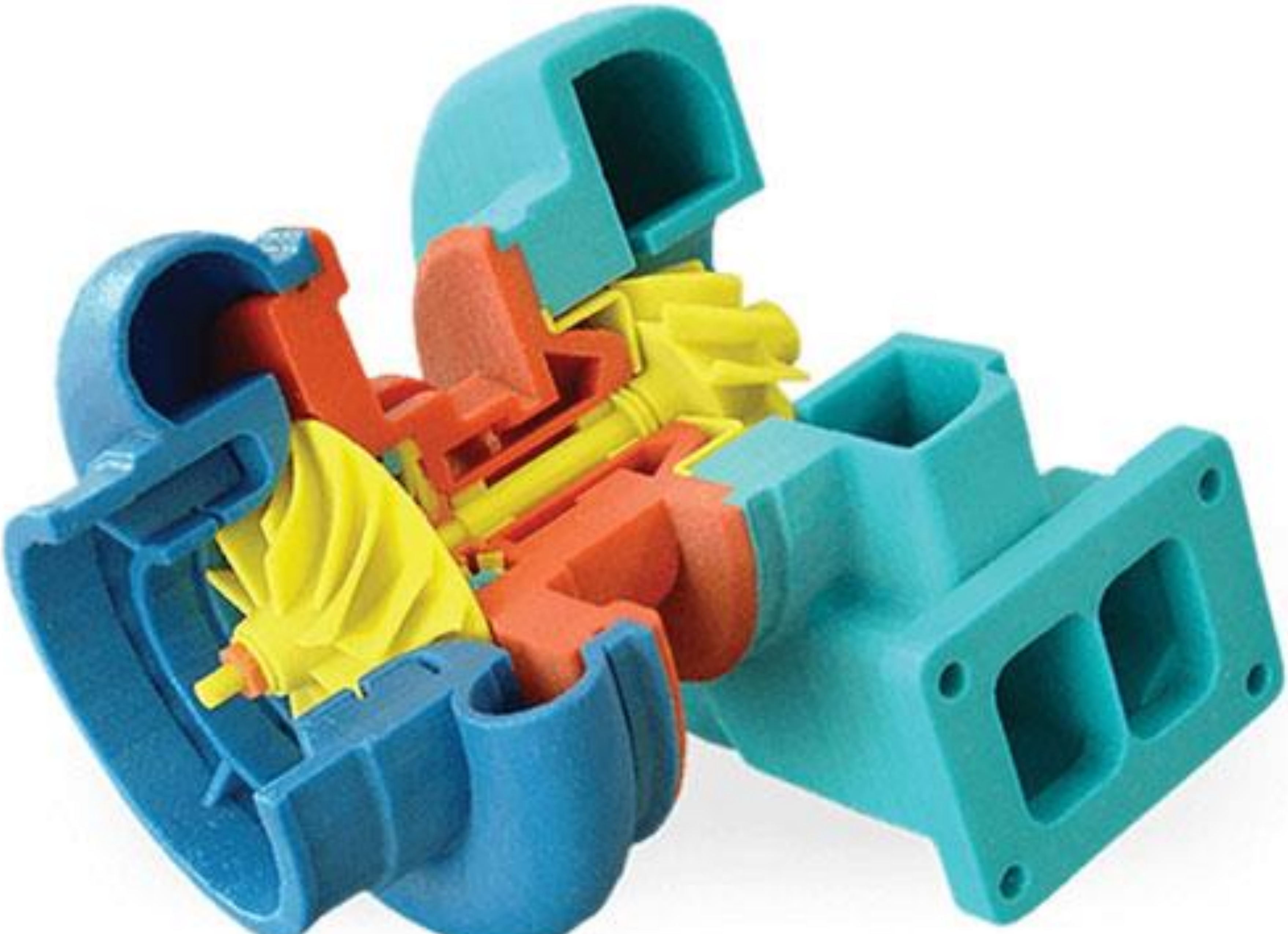


Binder Jetting

- Combination of a powder-based material and a binder
- Economic
- Metal printing possible
- Full color available for sandstone
- No warping/shrinking
- Inferior mechanical properties (brittle)

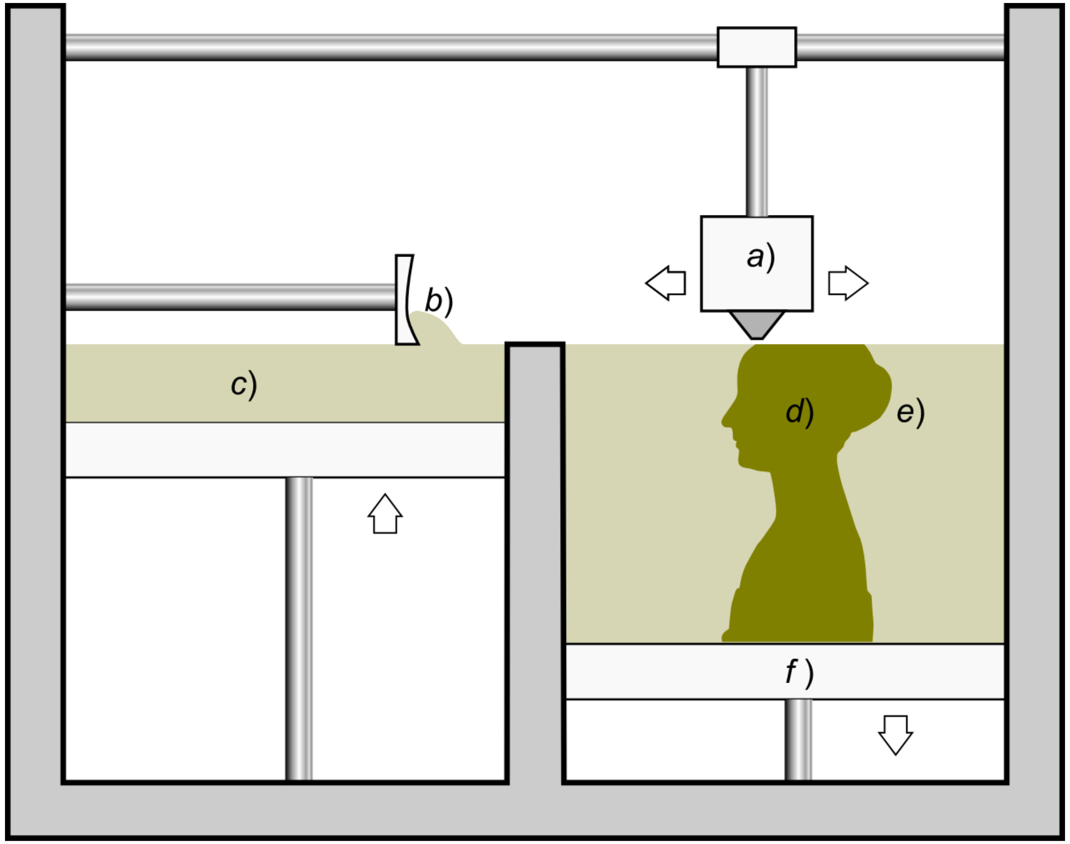


www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/binderjet



Multi-Jet Fusion (MJF)

- Combination of Binder Jetting and Powder Bed Fusion
- Infrared light as heat source
- Jetted ink as a fusing agent to promote the absorption of the infrared light
- Strong parts



www.weerg.com/guides/what-is-multi-jet-fusion-mjf-3d-printing

Next week's lab

- March 25: SLA and DLP lab
- Limited space in the lab
  - 2 project groups at a time
- Remaining time to assemble the robot fish

Questions?