Multidisciplinary Optimization and Machine Learning for Engineering Design

19 July 2021 – 5 August 2021

https://mdoml2021.ftmd.itb.ac.id/

Jointly organized by

香港科技大學 THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Design for Additive Manufacturing: Topology Optimization

Prof. Joseph Morlier

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Part 3

3D printing

(Thanks to MIT's prof. Markus J. Buehler and UW Madison's prof. Krishnan Suresh)

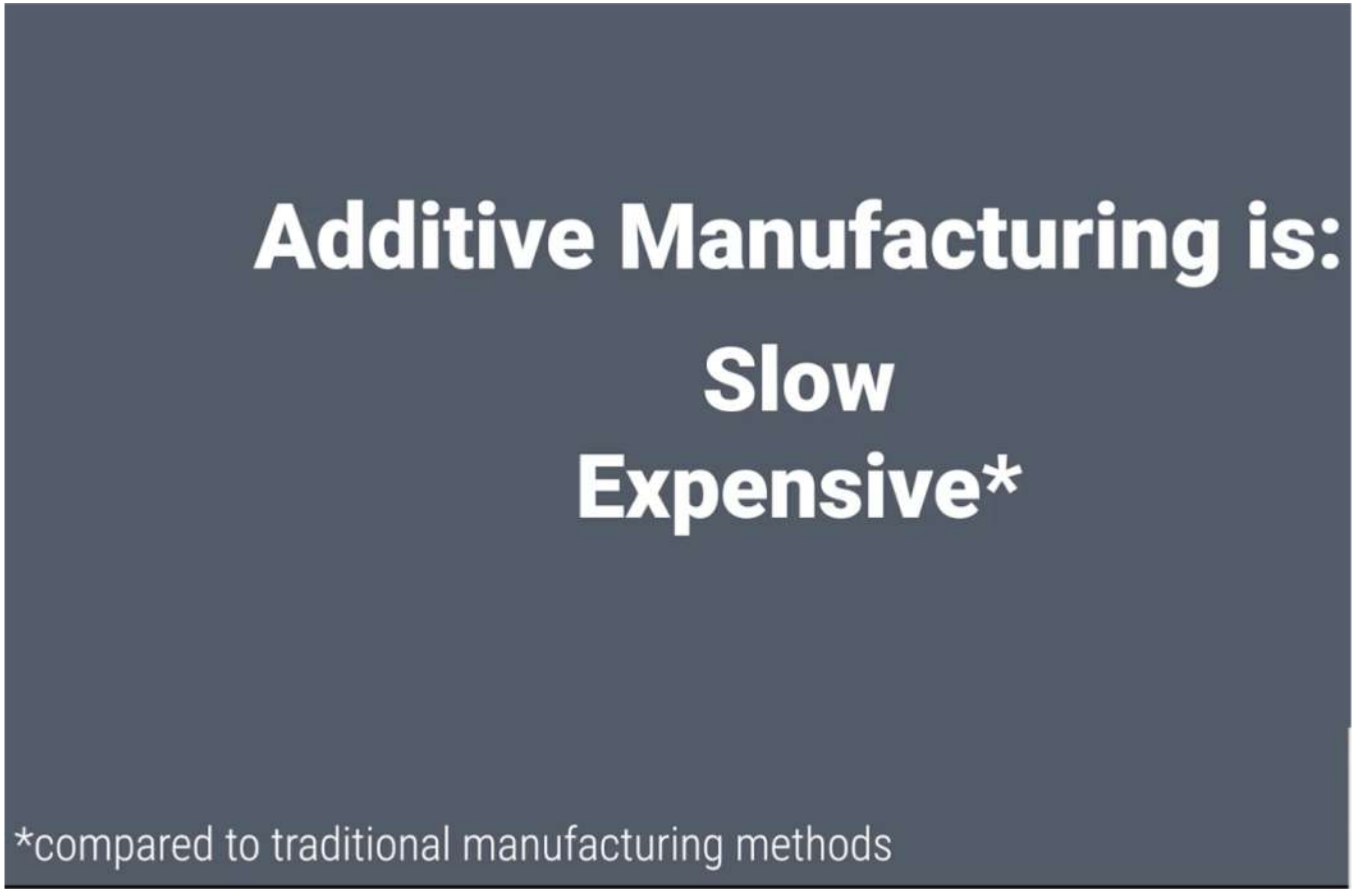
A brief history of 3D printing

- 1981: Hideo Kodama of Nagoya Municipal Industrial Research Institute invented fabricating methods of a three-dimensional plastic model with photo-hardening polymer
- First 3D printer: 1984 by Chuck Hull of 3D Systems Corp (https://en.wikipedia.org/wiki/Chuck_Hull) – e.g. STL format, others

http://www.cnn.com/2014/02/13/tech/innovation/the-night-i-invented-3d-printing-chuck-hall/index.html

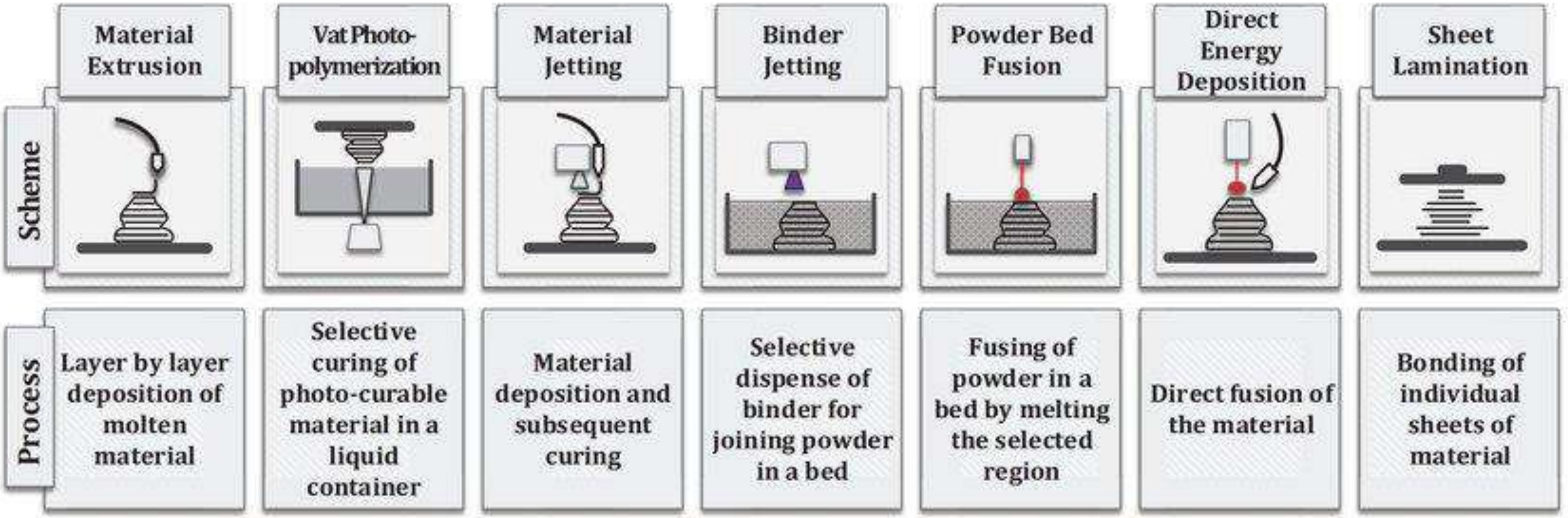
- Fab@Home 3D printer: 2005
- Multi-material printing with ultra-high resolution of tens of micrometers: 2010 and after
- **Processing techniques**: Selective laser sintering (SLS) and fused deposition modeling (FDM), cure liquid materials using different sophisticated technologies, such as stereolithography (SLA) or photopolymerization (PP) – ceramics, metals, high-precision polymers, biomaterials, living tissues
- General article: http://www.pcmag.com/article2/0,2817,2394720,00.asp

https://gen3d.com



- But you can definitely ReThink the way to design part

3D Printer's process



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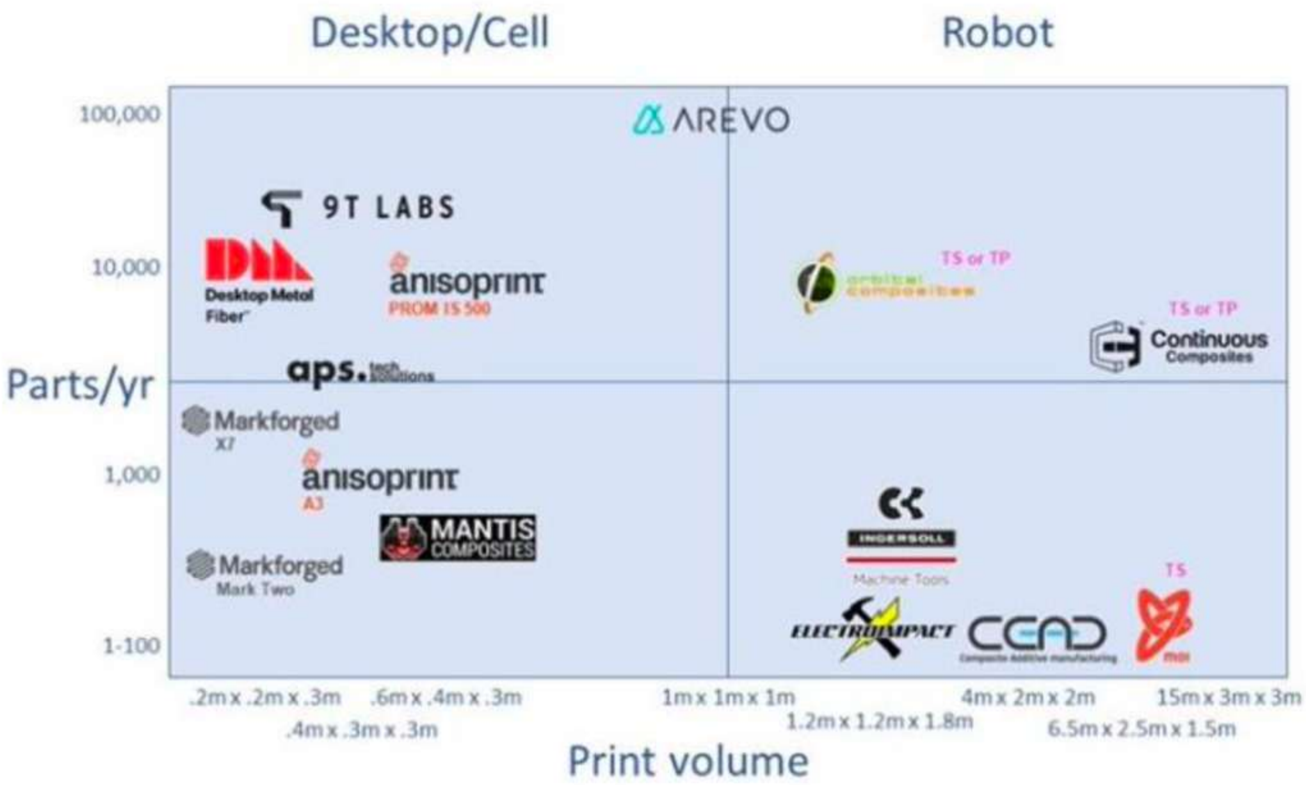
METAL AM Tech

composites tech



GE factory

https://www.ge.com/news/reports/3d-printed-age-futuristic-ohio-factory-proving-mark-twain-wrong

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Carbon filament

PETG CARBON 3D filament

- Tensile modulus: 4,541 MPa
- Tensile strength: 52.9 MPa

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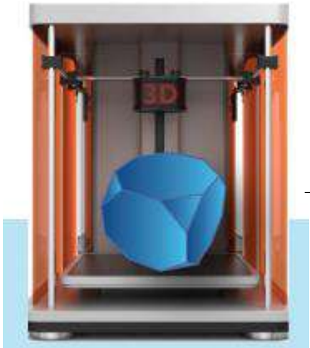
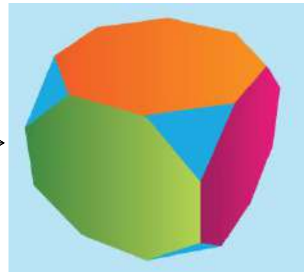
AM Process Flow. (see https://courses.gen3d.com)





3D CAD drawing
Generative design (code)
Software (ParaMatters, ntopology…)

Generate .stl/.gcode file

This is a very important step because .stl is the file that the printer understands!

AM machine

There are several different AM methods

Final product

Finished product could have support material which you remove

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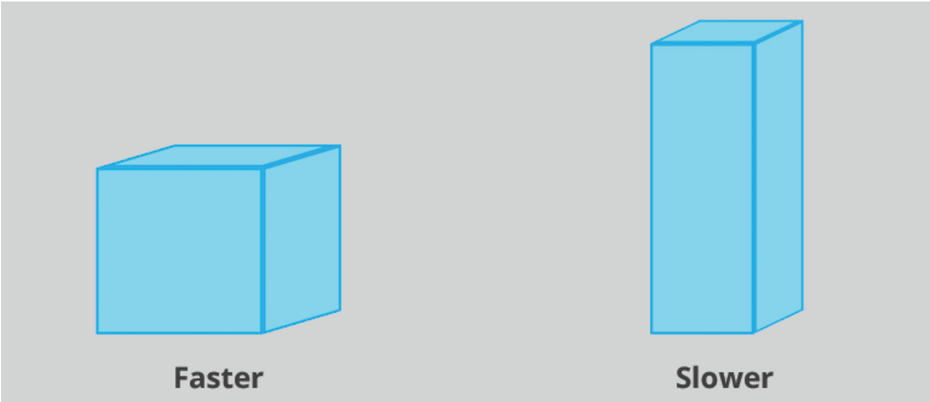
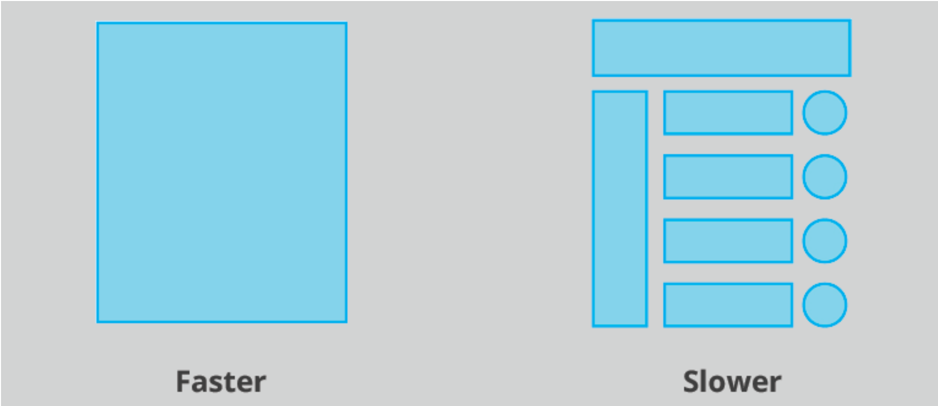
Time for 3D printing

https://3space.com/blog/how-long-does-3d-printing-take/

Part size & Geometry

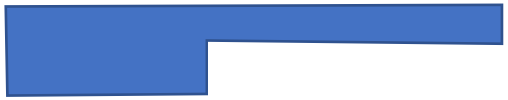


Taller parts will usually take longer to 3D print than shorter parts, even if their volume is the same.



3D printing is faster when parts have simple cross-sectional layers.

Print Direction

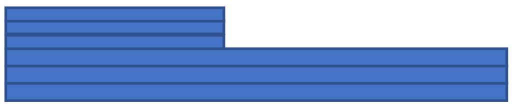


Layer by layer

Oops!

Dripping!

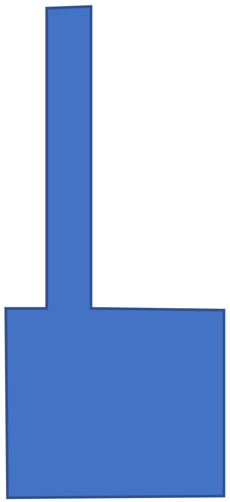
Solution?



No 'dripping'

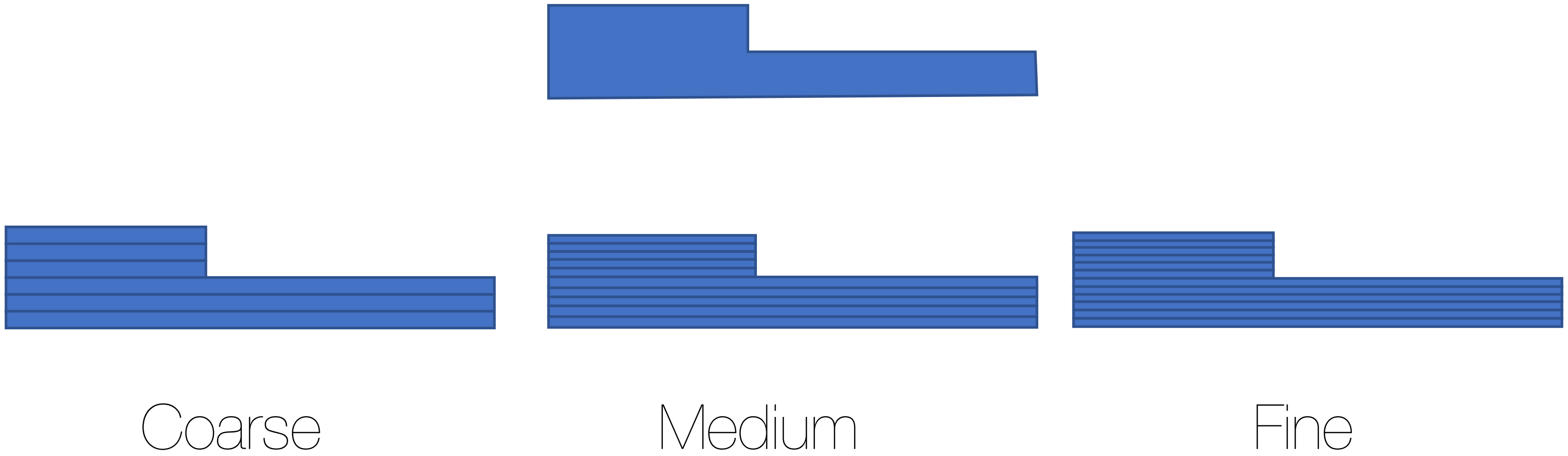
Print Direction

Solution?



Choose your print direction carefully!

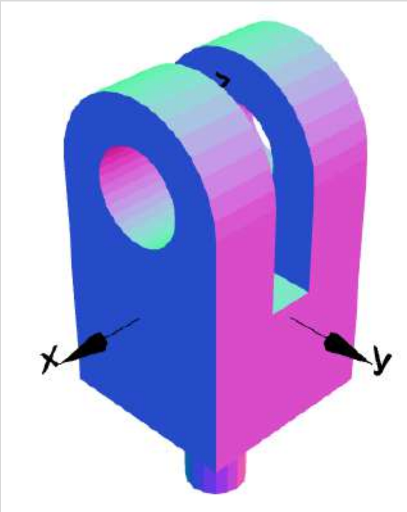
Printing Resolution

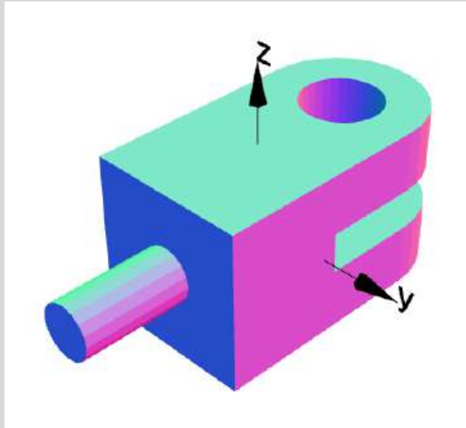


Printers can be set at different resolution

Finer resolutions take more time & cost more!

Print Direction



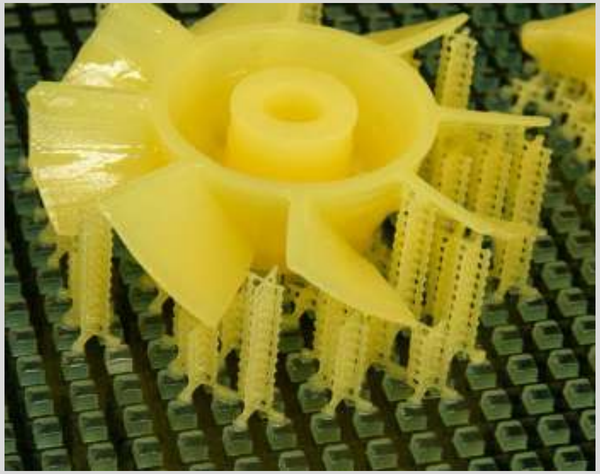


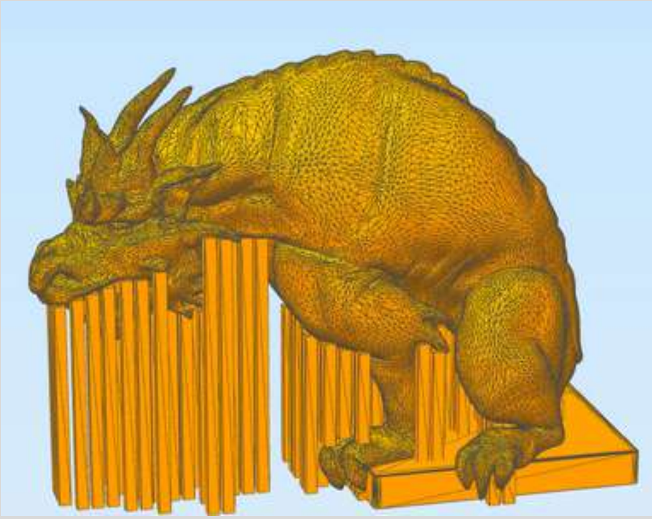
Pick the best orientation for Z axis!

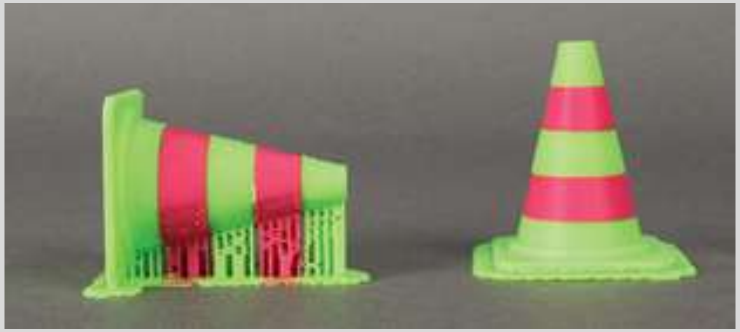
Drips in all direction!

Printer will add support structures

Support Structures



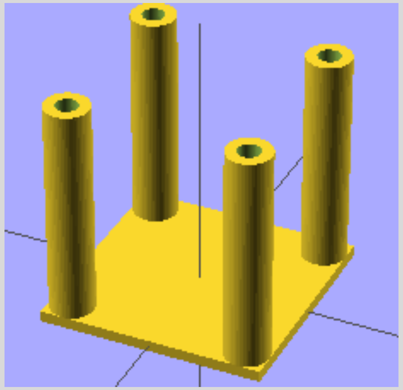




Cost of 3D Printing

Typical Lego Piece: $2.00 + Setup cost

What is the cost of printing?



Plastic

Low quality: $0.30 per cm^3

Medium quality: $2.00 per cm^3

High quality: $10.00 per cm^3

Metal

$10.00 ~ $200.00 per cm^3

Practical Aspects of 3D Printing

#1 Design part to avoid support structures

#2 Pick print direction with minimal support structures

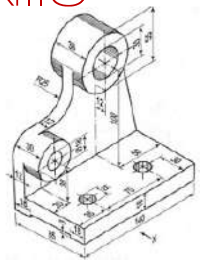
#3 Reduce material usage

#4 Avoid thin regions

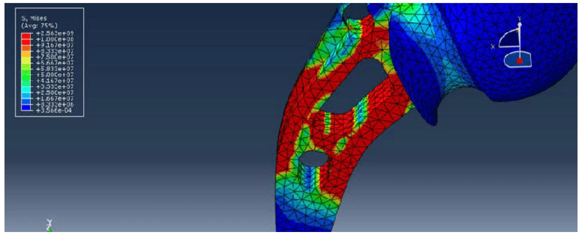
Practical Engineering Skills

CAD design

(engineering drawings)

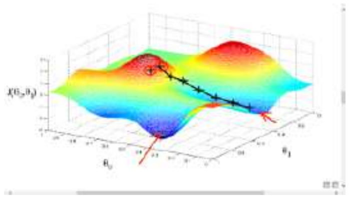


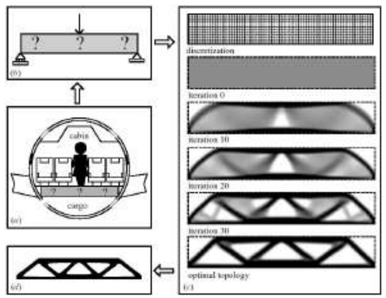
Finite Element Simulations



(stress analysis)

Gradient descent optimization
(TopOpt)





Additive Manufacturing
(future of industrial standards of manufacturing)

Mechanical Learning of Additive Manufacturing Parts

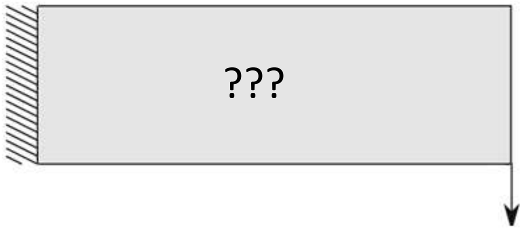
- Highlights of MATLS 2H04A (2018) – Structure Materials Design Project

Example of 3D printed parts
with different materials

Compression tests of students' designs
(video click to play: crushed samples will disappear)

Sessional Instructor: Dr. Bosco (Hiu Ming)
Yu, PhD
2018

What to print: Topology optimization



40% volume fraction
(=amount of material vs.
whole domain)

http://www.topopt.mek.dtu.dk/apps-and-software/topology-optimization-codes-written-in-python

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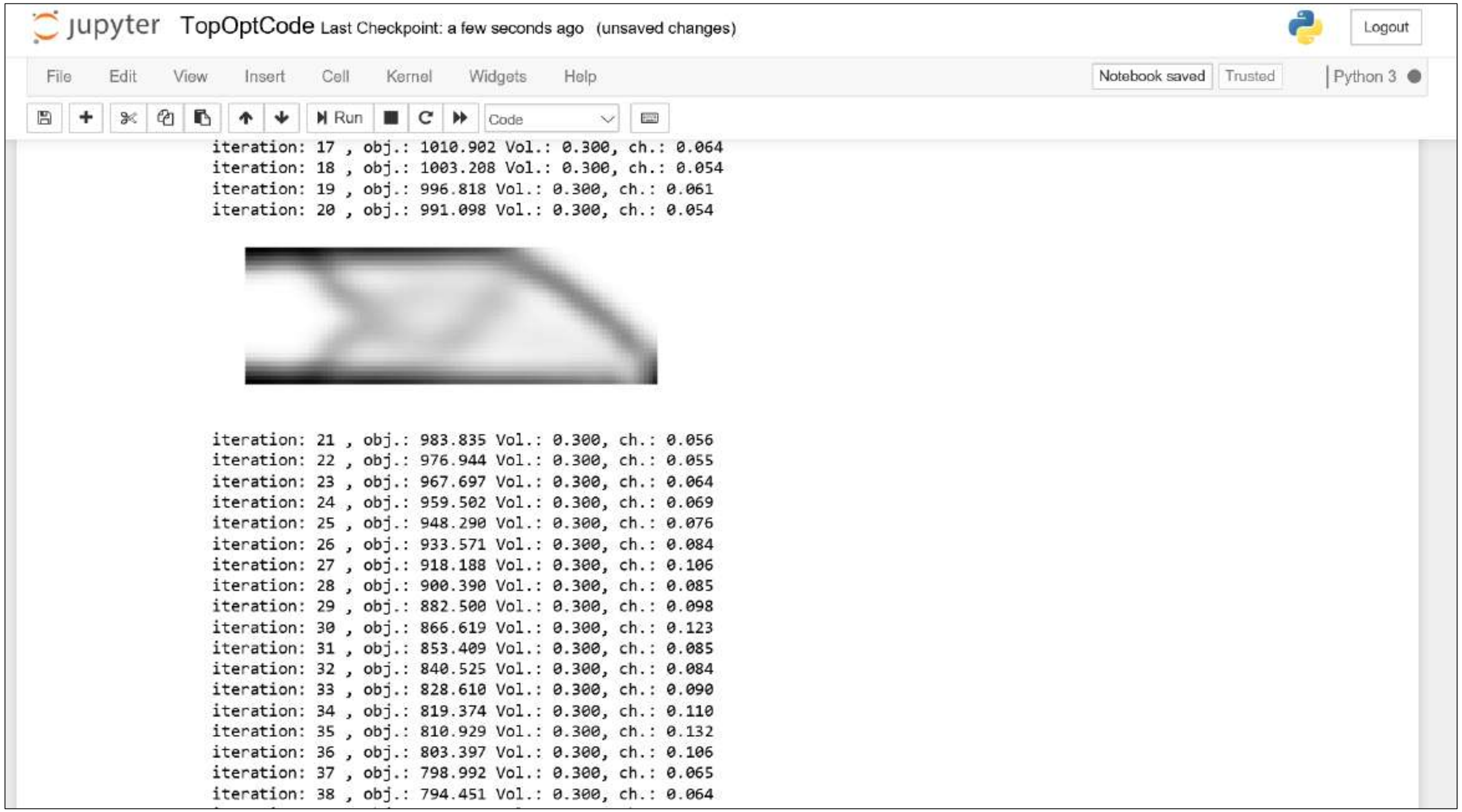
Jupyter notebook

Folder: Topology optimization - example



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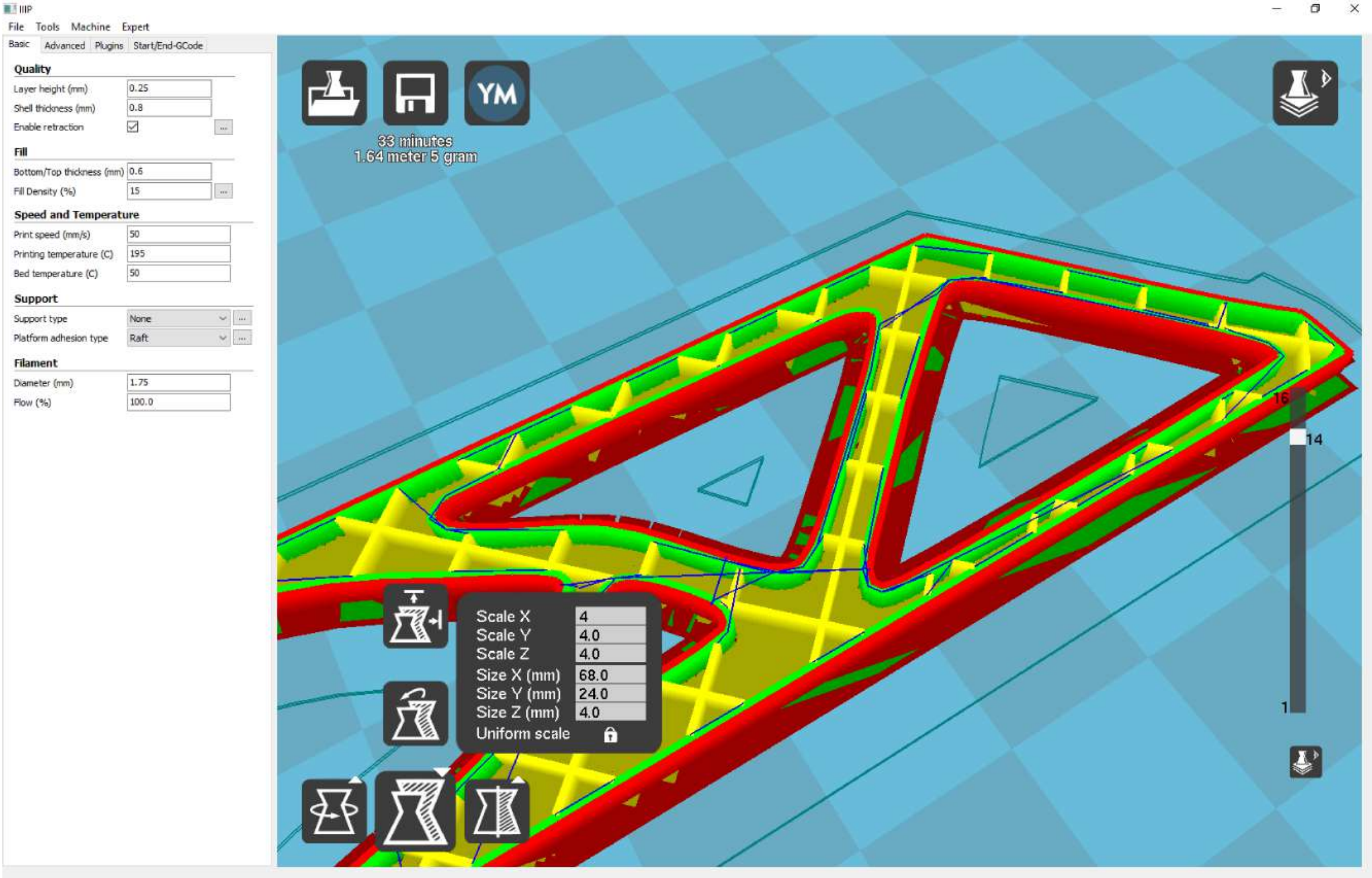

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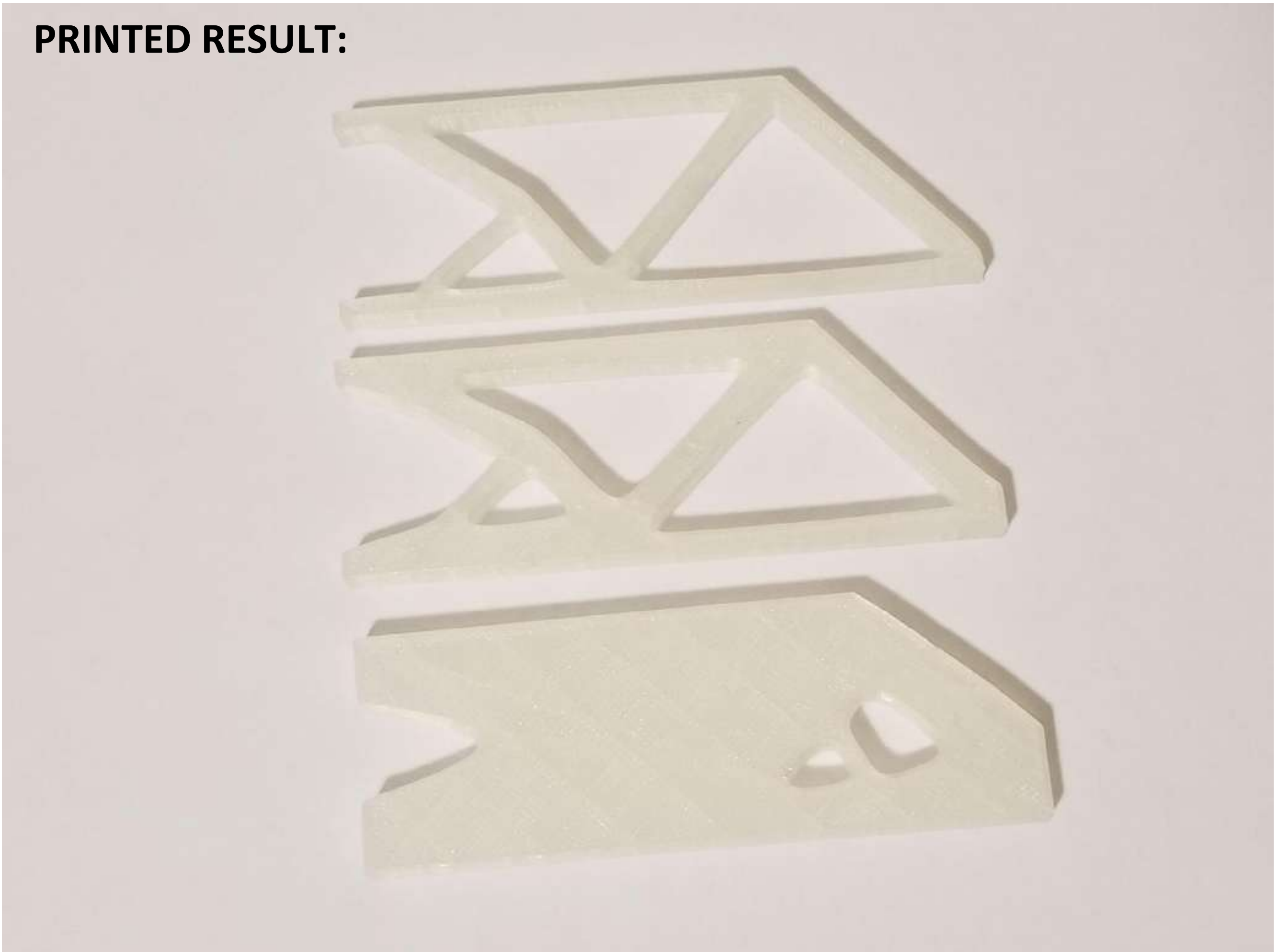

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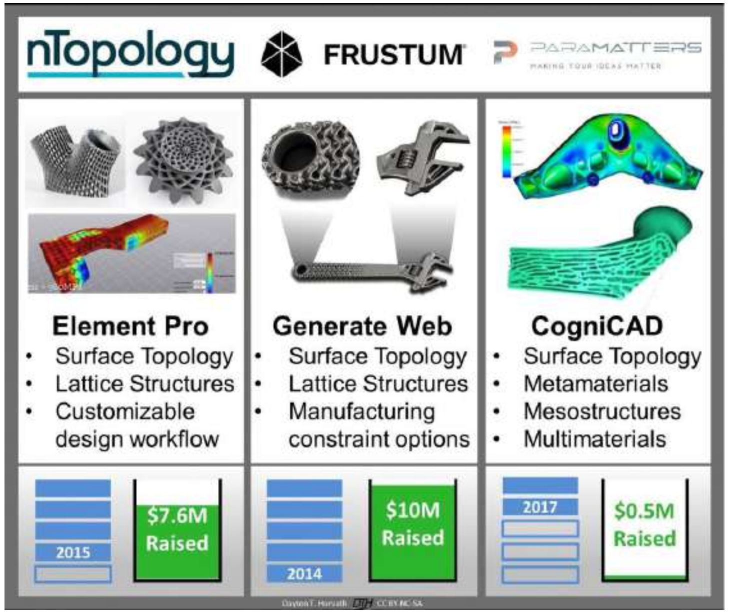
Software and algorithms for hierarchical design

Conventional CAD programs do not work well
New players are emerging

Examples:
- ntopology (see case studies): https://ntopology.com/
- additiveflow: https://www.additiveflow.com/
- Hyperganic
- ParaMatters: https://paramatters.com/
- Fusion 360 (Autodesk)



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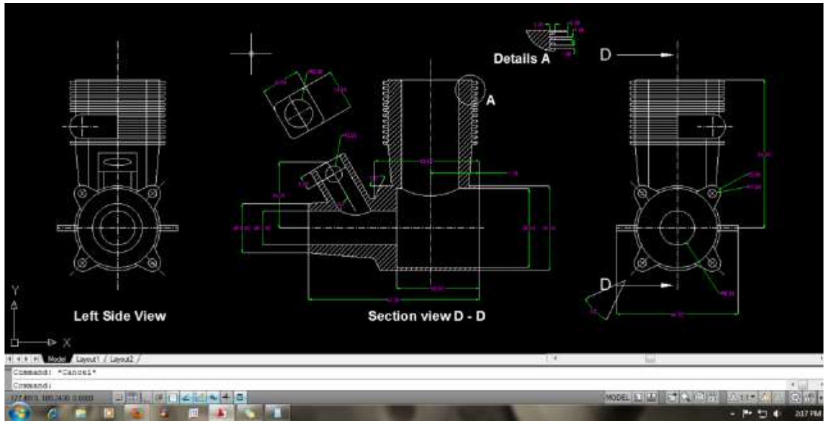
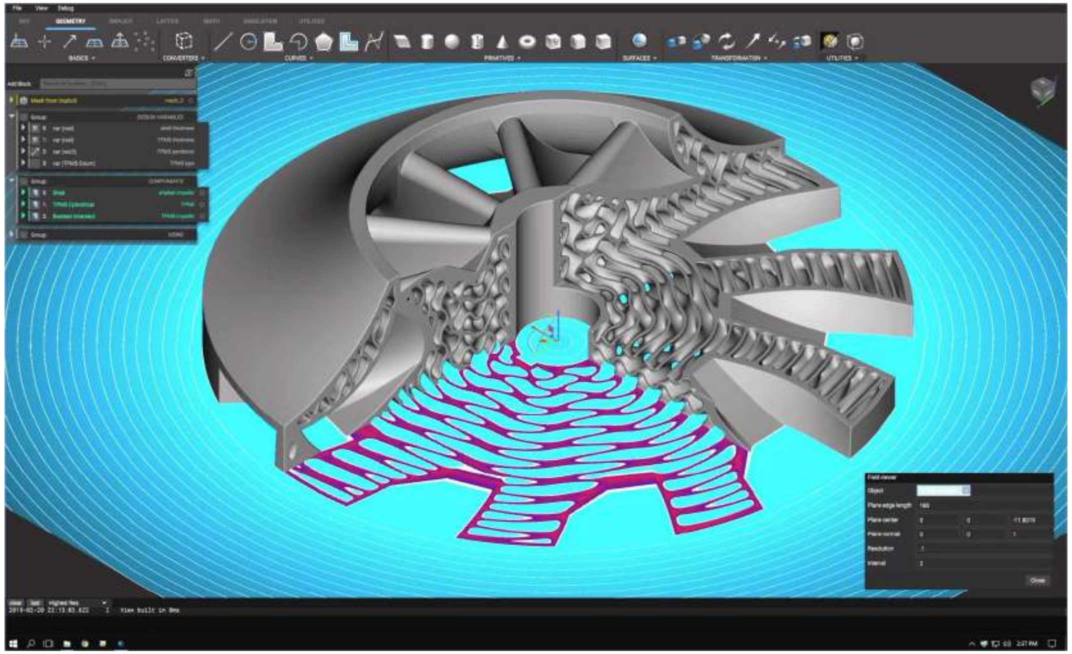
Conventional CAD vs novel tools





- Integrated shape, volume, meshing, simulation and modeling, optimization
- Can write 3D printing files

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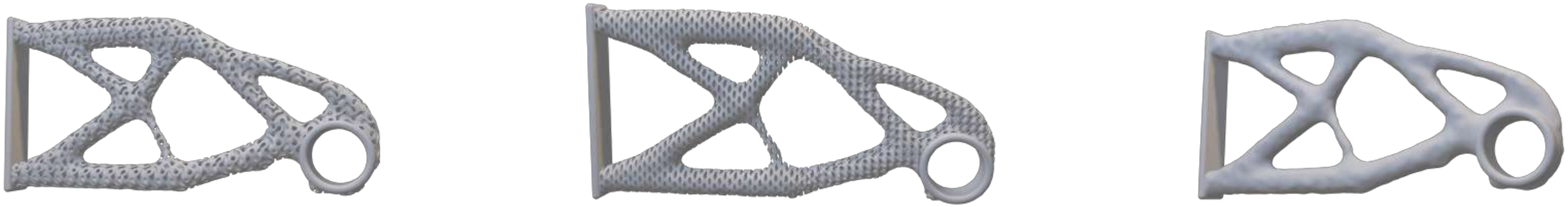

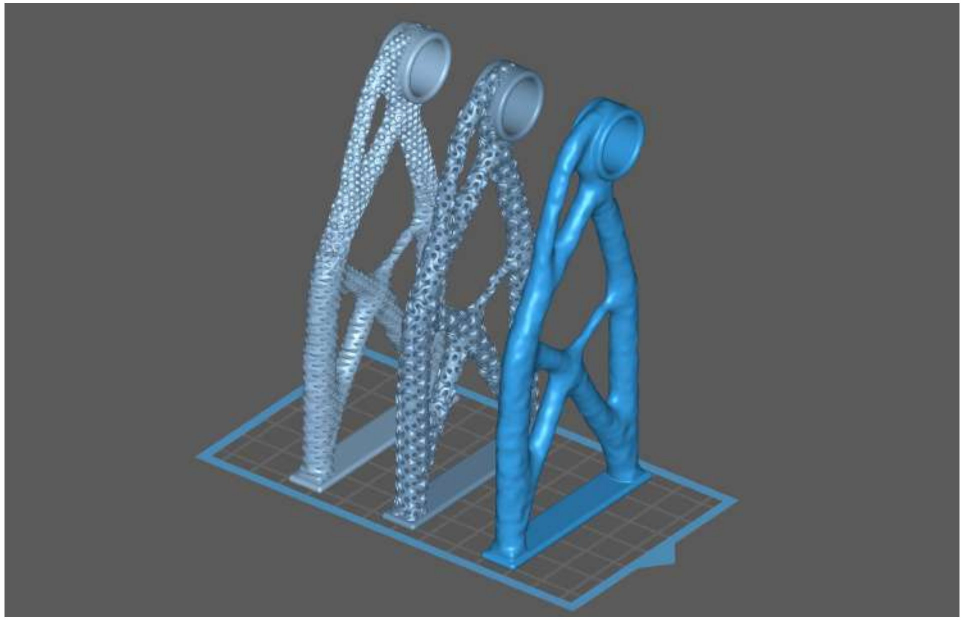

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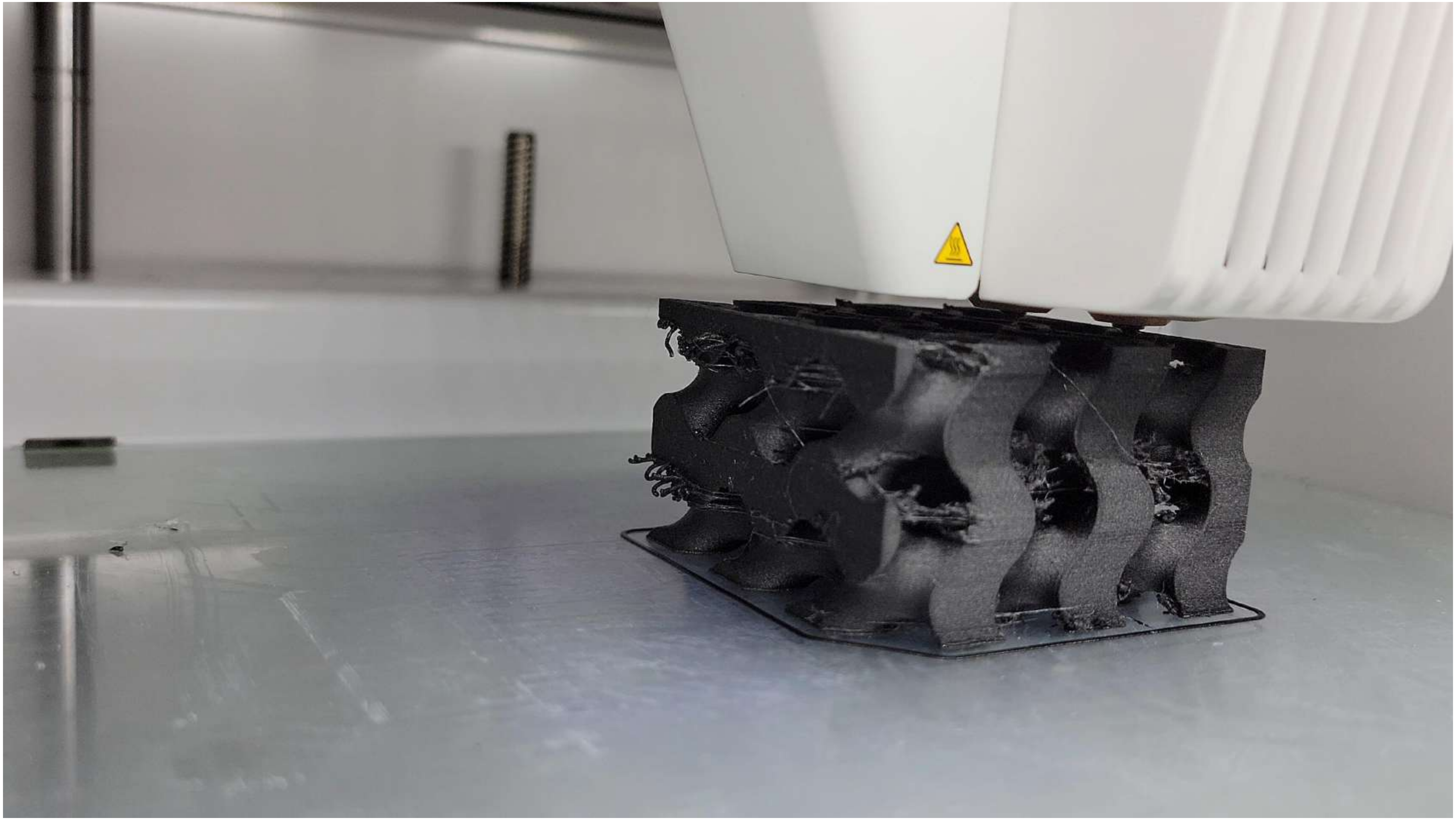

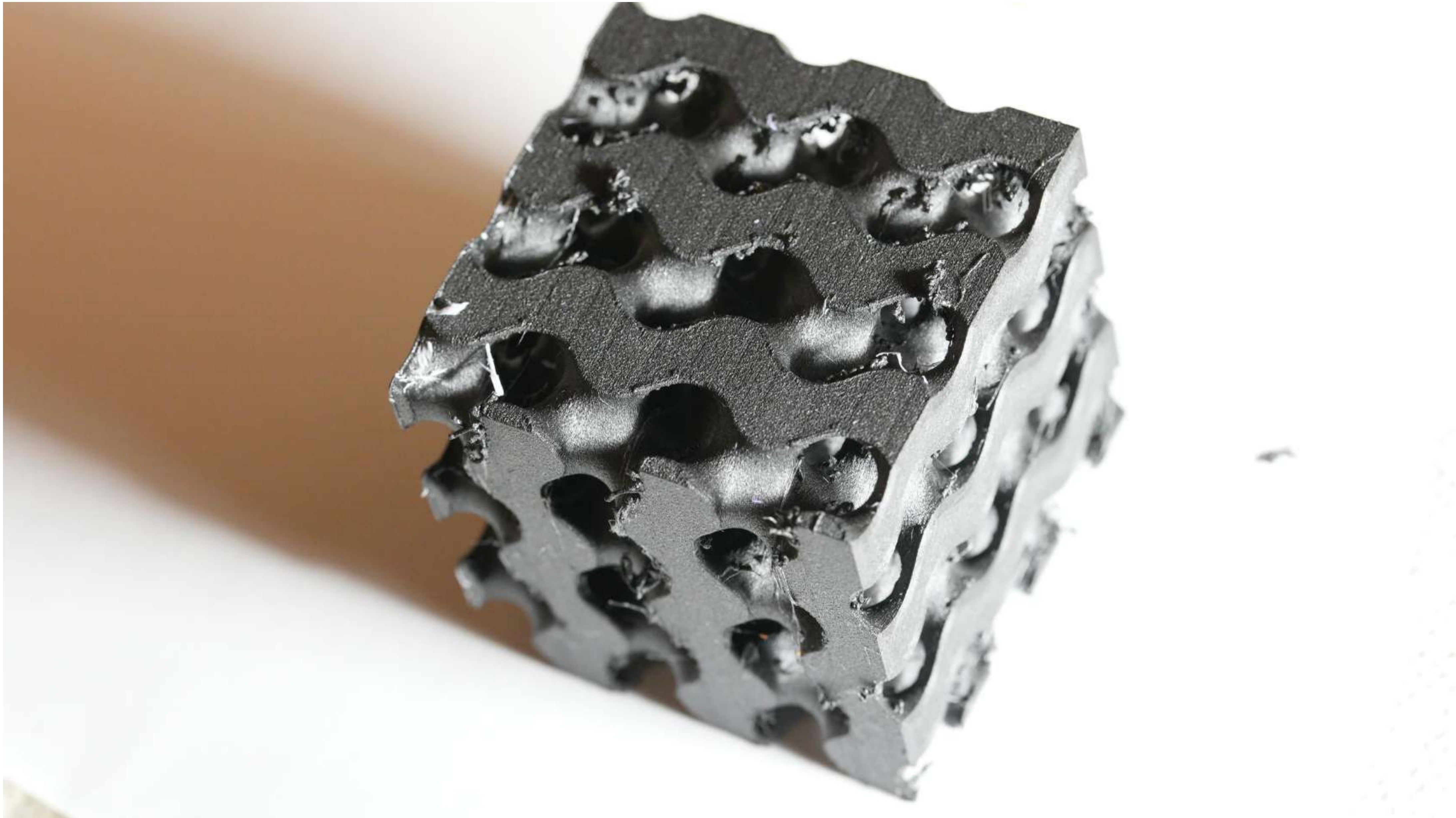

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TOHOKU

Break before Part 4

Prof. J. Morlier