

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>

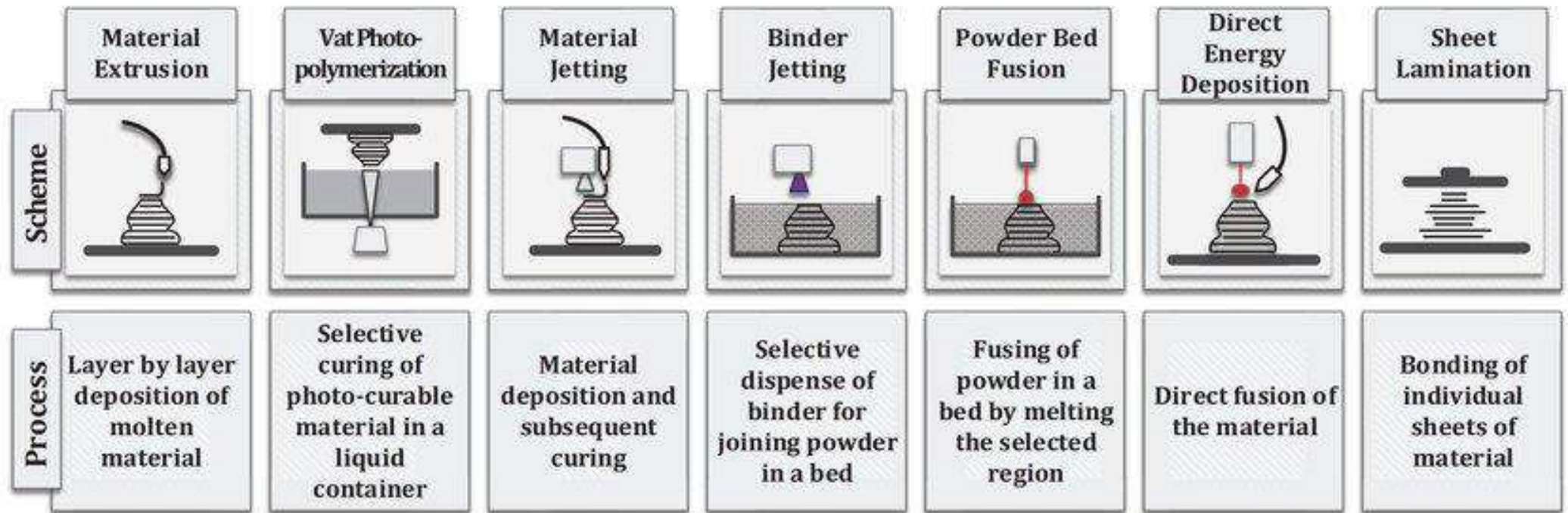
<https://gen3d.com>

**Additive Manufacturing is:
Slow
Expensive***

*compared to traditional manufacturing methods

- But you can definitely ReThink the way to design part

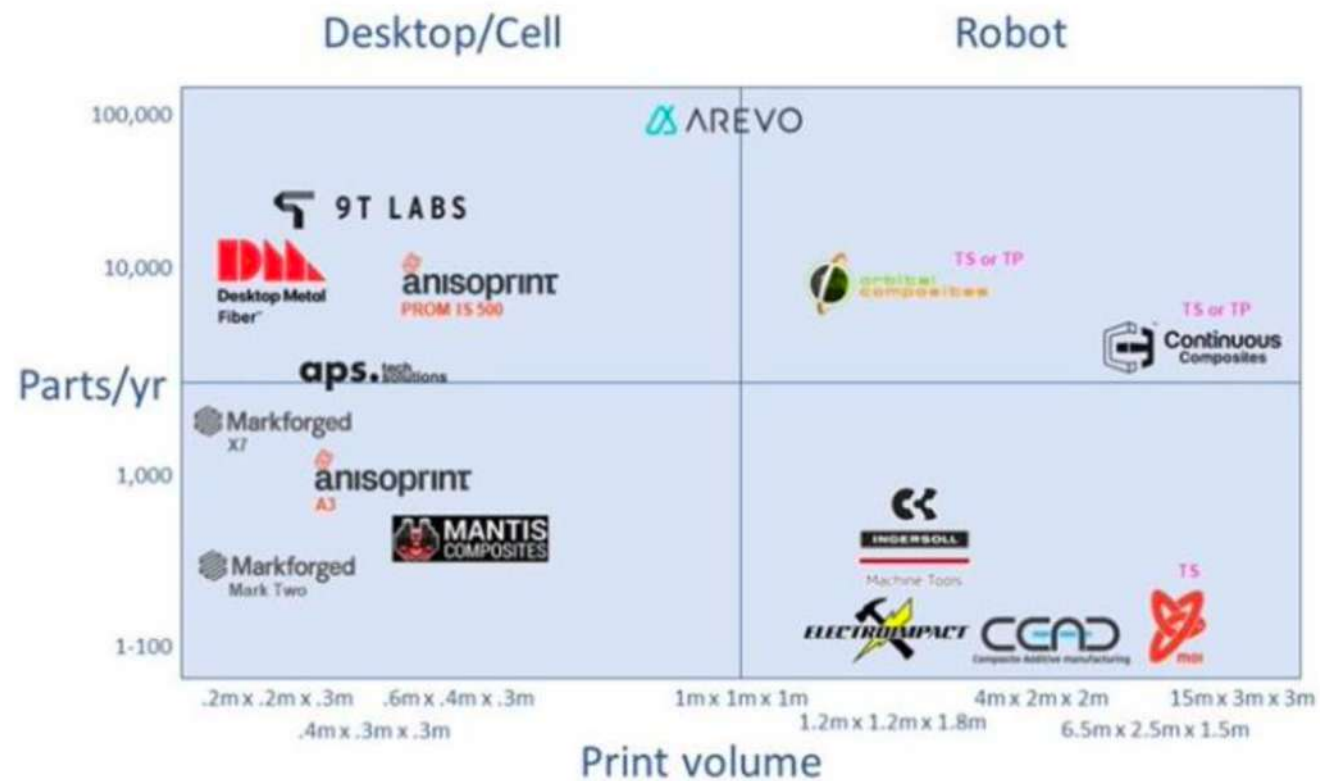
3D Printer's process



METAL AM Tech



composites tech



GE factory



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

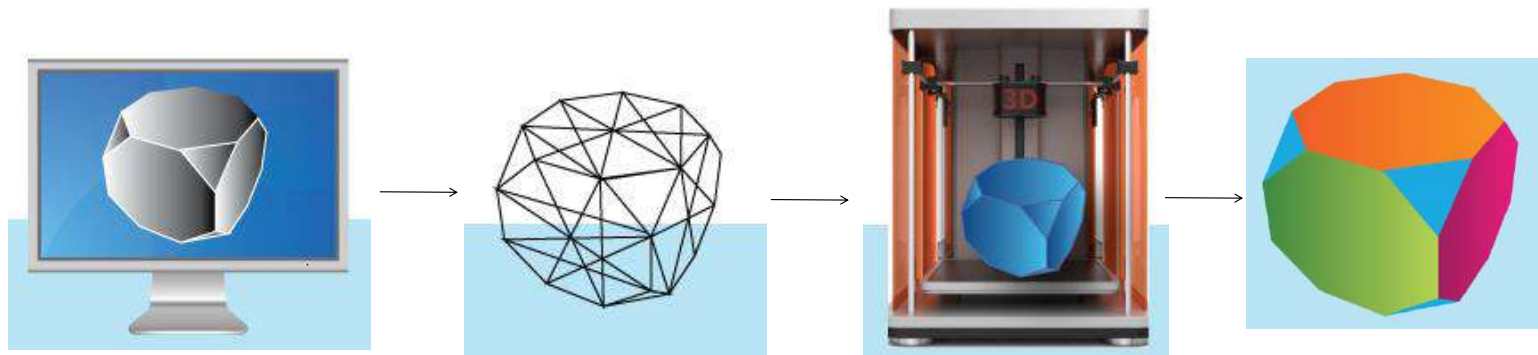
Carbon filament



PETG CARBON 3D filament

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

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

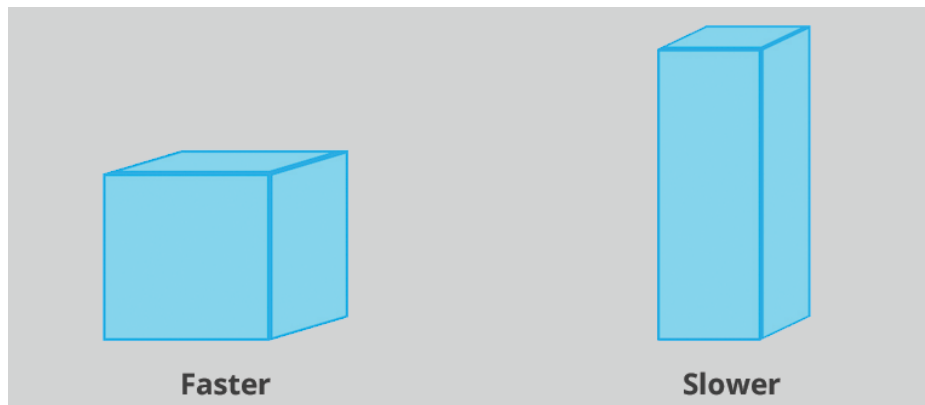
Finished
product could
have support
material which
you remove

Time for 3D printing

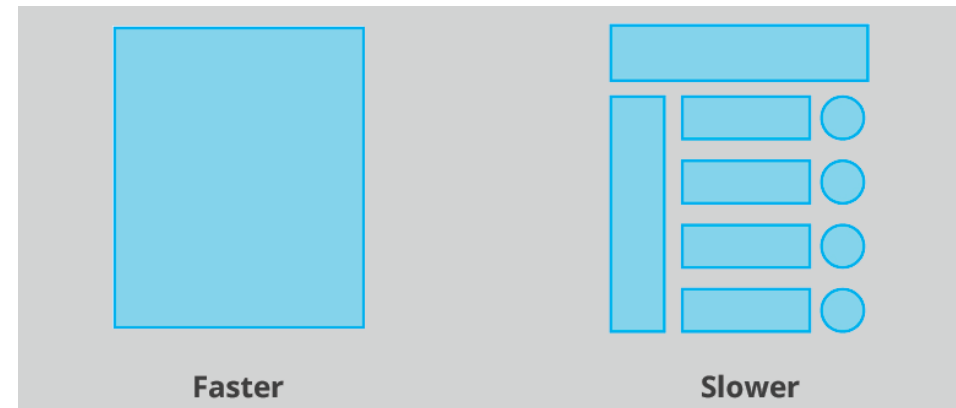
<https://3space.com/blog/how-long-does-3d-printing-take/>

		
Electronics Case	Turbo Housing	Transmission Case
Size: 4x3x2"	Size: about 8" diameter	Size: 15x10x5"
Time: 4 hours	Time: about a day	Time: several days

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?

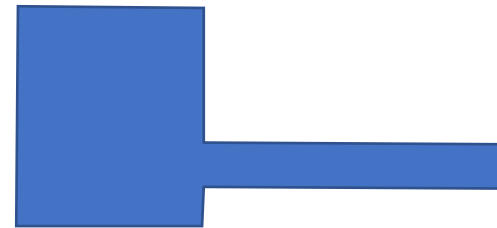


No 'dripping'

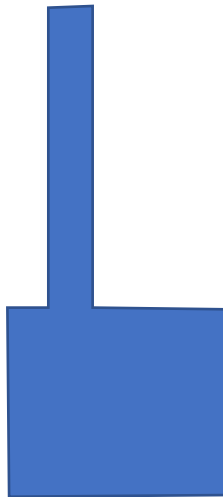
Print Direction



Drip?

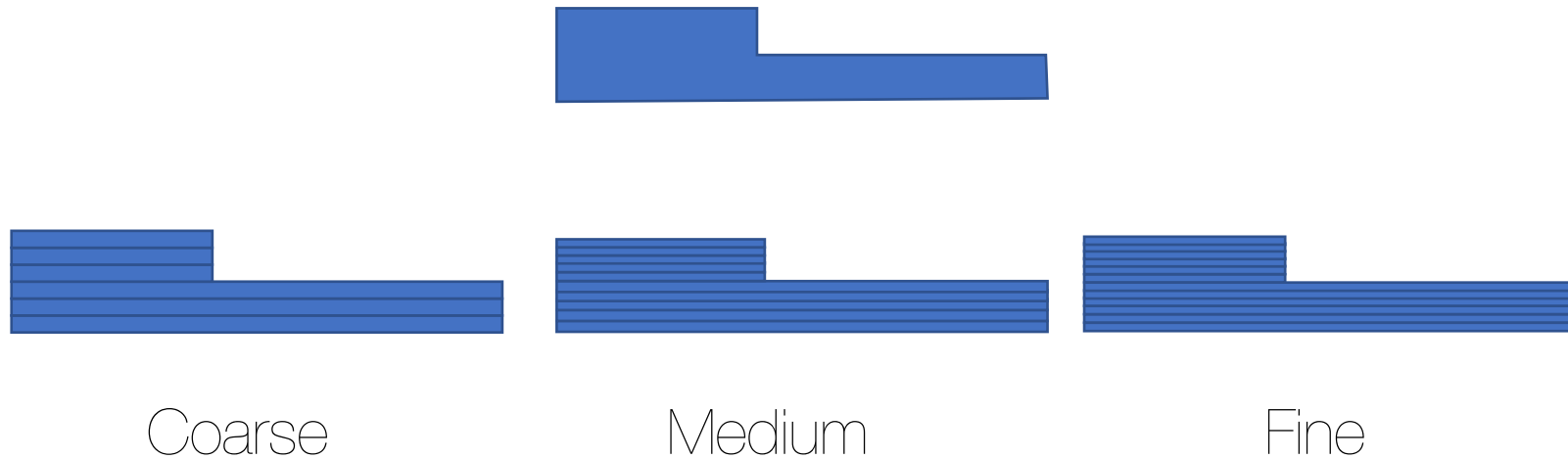


Solution?



Choose your print direction carefully!

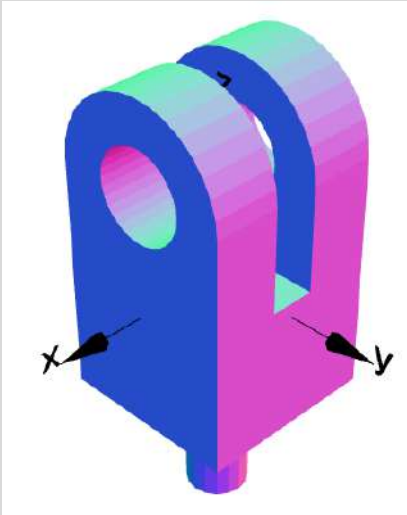
Printing Resolution



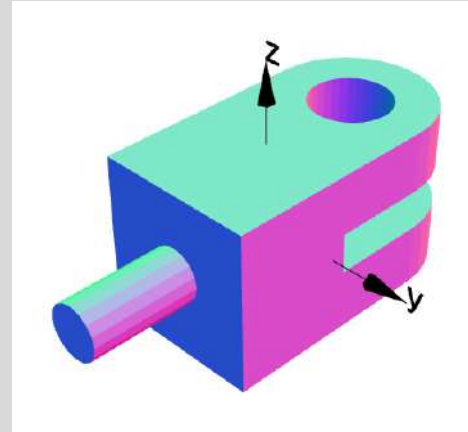
Printers can be set at different resolution

Finer resolutions take more time & cost more!

Print Direction



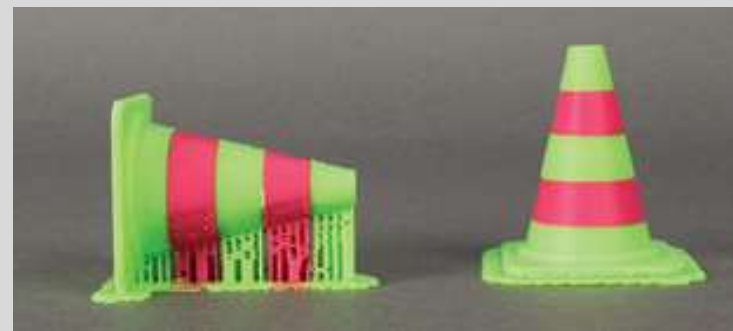
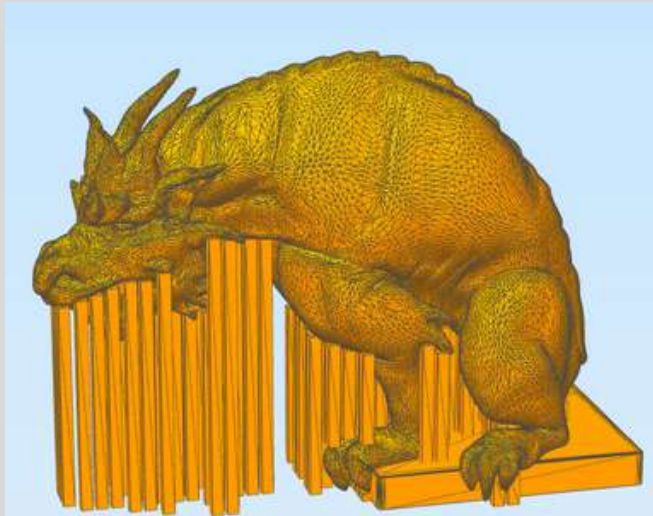
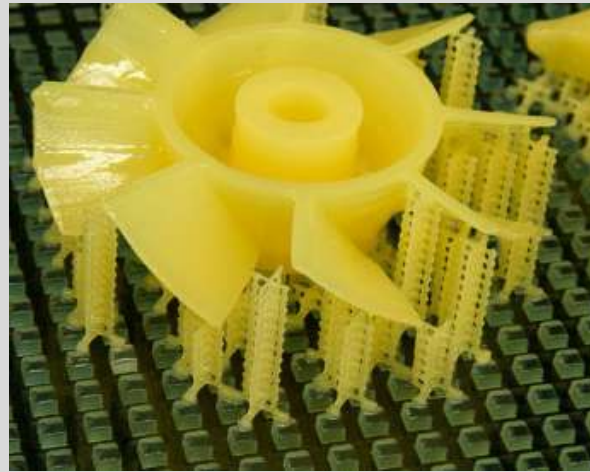
Drips in all direction!



Pick the best orientation for Z axis!

Printer will add support structures

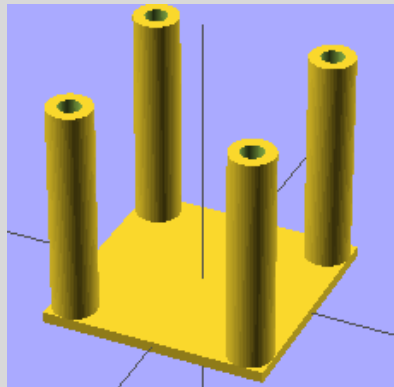
Support Structures



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

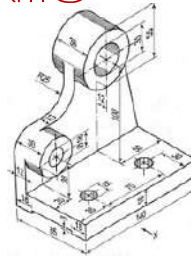
#3 Reduce material usage

#4 Avoid thin regions

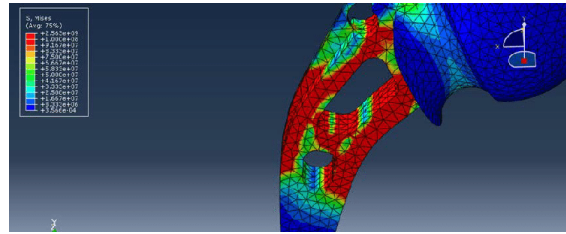
Practical Engineering Skills

CAD design

(engineering drawings)

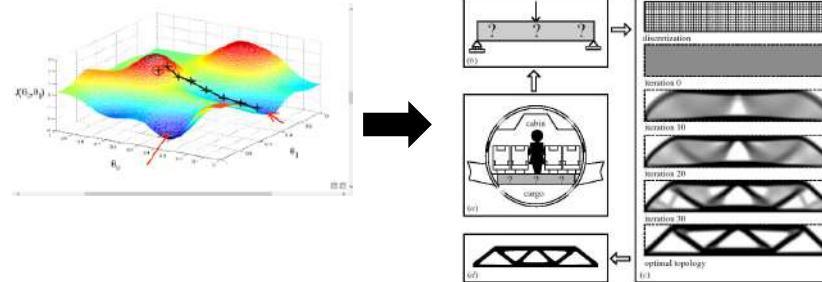


Finite Element Simulations



(stress analysis)

Gradient descent optimization
(TopOpt)



Additive Manufacturing
(future of industrial standards of manufacturing)



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Mechanical Learning of Additive Manufacturing Parts

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



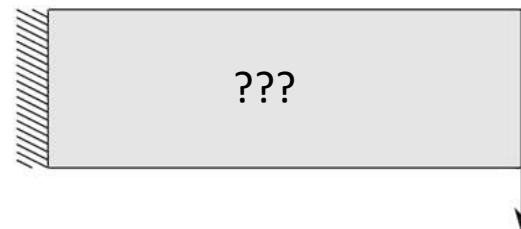
Example of 3D printed parts
with different materials

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



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

What to print: Topology optimization

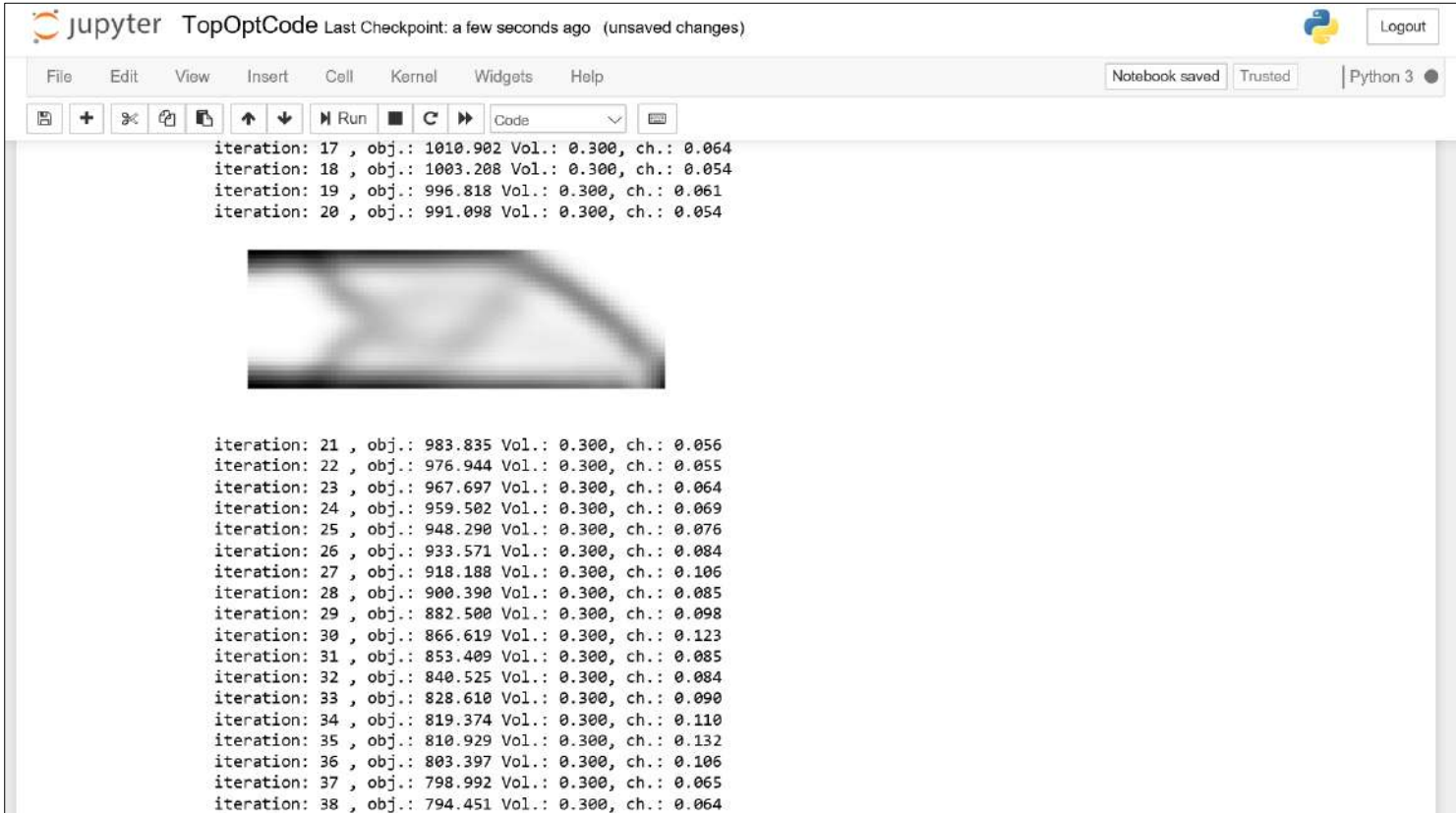


40% volume fraction
(=amount of material vs.
whole domain)

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


Jupyter notebook

Folder: Topology optimization - example

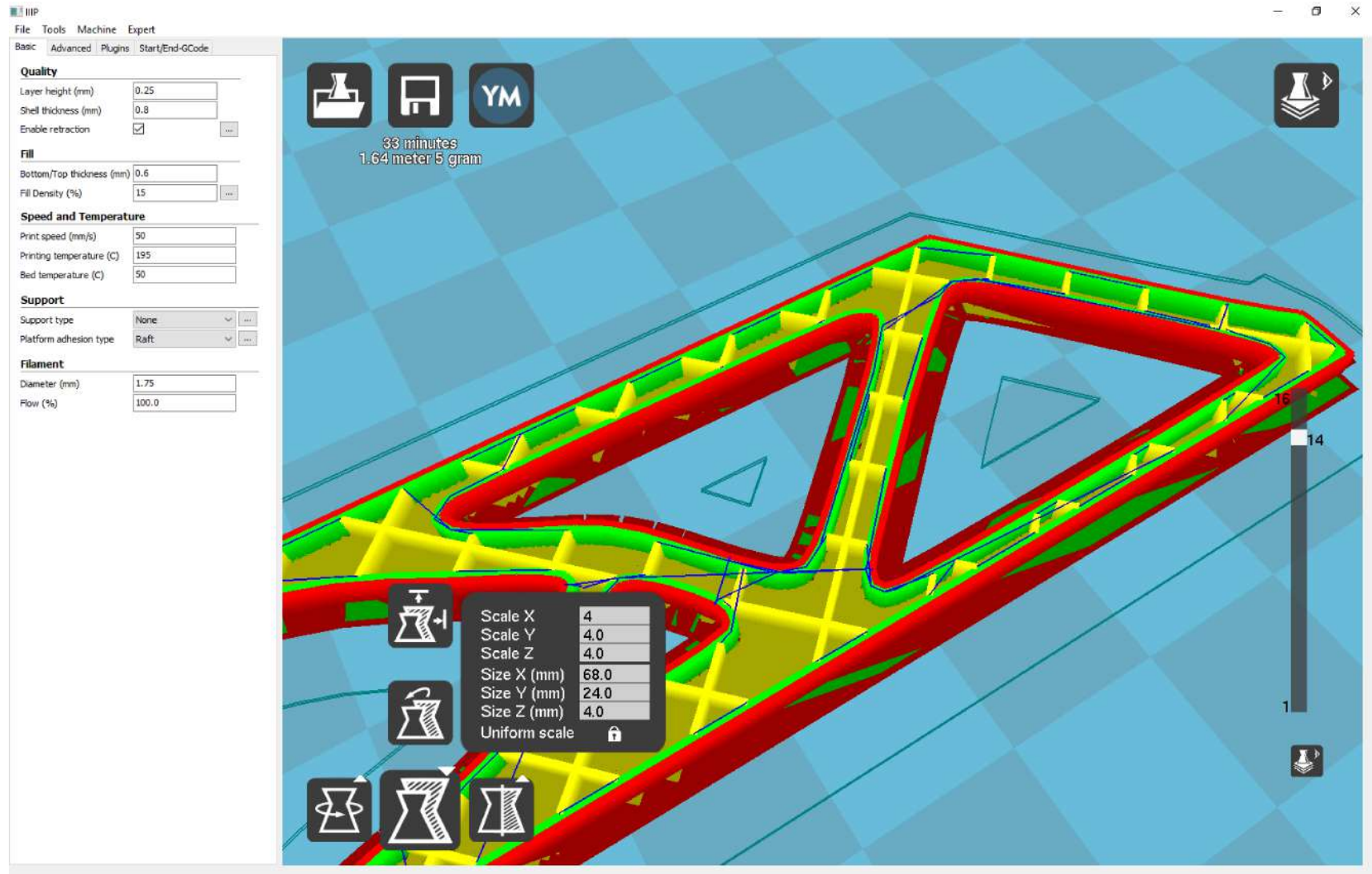


The screenshot shows a Jupyter notebook titled "TopOptCode" with a "Last Checkpoint: a few seconds ago (unsaved changes)" status. The interface includes a menu bar (File, Edit, View, Insert, Cell, Kernel, Widgets, Help) and a toolbar with icons for file operations, running, and code execution. The notebook content displays a series of iteration results for a topology optimization process, followed by a grayscale visualization of the optimized structure.

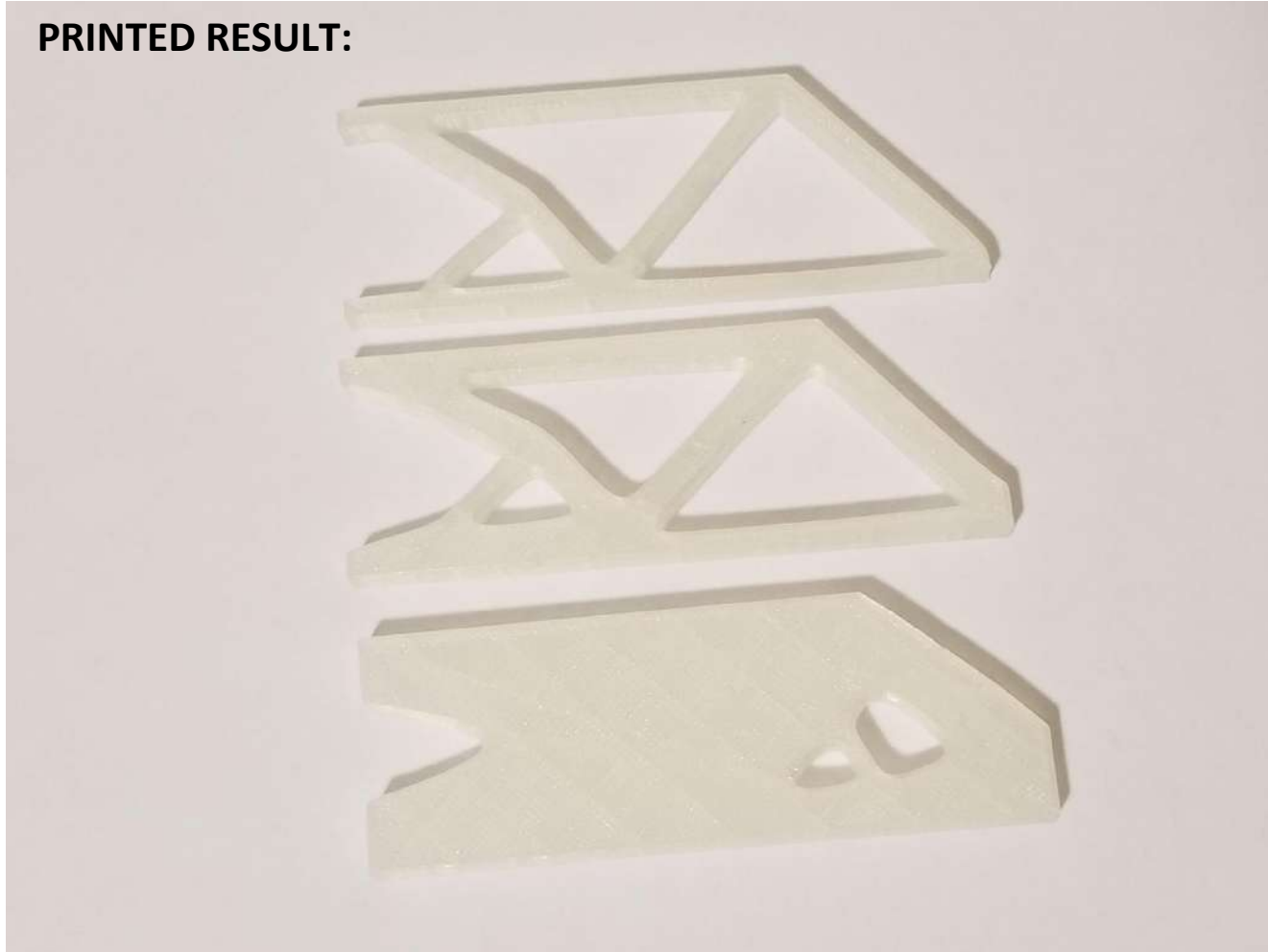
```
iteration: 17 , obj.: 1010.902 Vol.: 0.300, ch.: 0.064
iteration: 18 , obj.: 1003.208 Vol.: 0.300, ch.: 0.054
iteration: 19 , obj.: 996.818 Vol.: 0.300, ch.: 0.061
iteration: 20 , obj.: 991.098 Vol.: 0.300, ch.: 0.054
```



```
iteration: 21 , obj.: 983.835 Vol.: 0.300, ch.: 0.056
iteration: 22 , obj.: 976.944 Vol.: 0.300, ch.: 0.055
iteration: 23 , obj.: 967.697 Vol.: 0.300, ch.: 0.064
iteration: 24 , obj.: 959.502 Vol.: 0.300, ch.: 0.069
iteration: 25 , obj.: 948.290 Vol.: 0.300, ch.: 0.076
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iteration: 27 , obj.: 918.188 Vol.: 0.300, ch.: 0.106
iteration: 28 , obj.: 900.390 Vol.: 0.300, ch.: 0.085
iteration: 29 , obj.: 882.500 Vol.: 0.300, ch.: 0.098
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iteration: 31 , obj.: 853.409 Vol.: 0.300, ch.: 0.085
iteration: 32 , obj.: 840.525 Vol.: 0.300, ch.: 0.084
iteration: 33 , obj.: 828.610 Vol.: 0.300, ch.: 0.090
iteration: 34 , obj.: 819.374 Vol.: 0.300, ch.: 0.110
iteration: 35 , obj.: 810.929 Vol.: 0.300, ch.: 0.132
iteration: 36 , obj.: 803.397 Vol.: 0.300, ch.: 0.106
iteration: 37 , obj.: 798.992 Vol.: 0.300, ch.: 0.065
iteration: 38 , obj.: 794.451 Vol.: 0.300, ch.: 0.064
```



PRINTED RESULT:



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110

Software and algorithms for hierarchical design

Conventional CAD programs do not work well
New players are emerging

Examples:

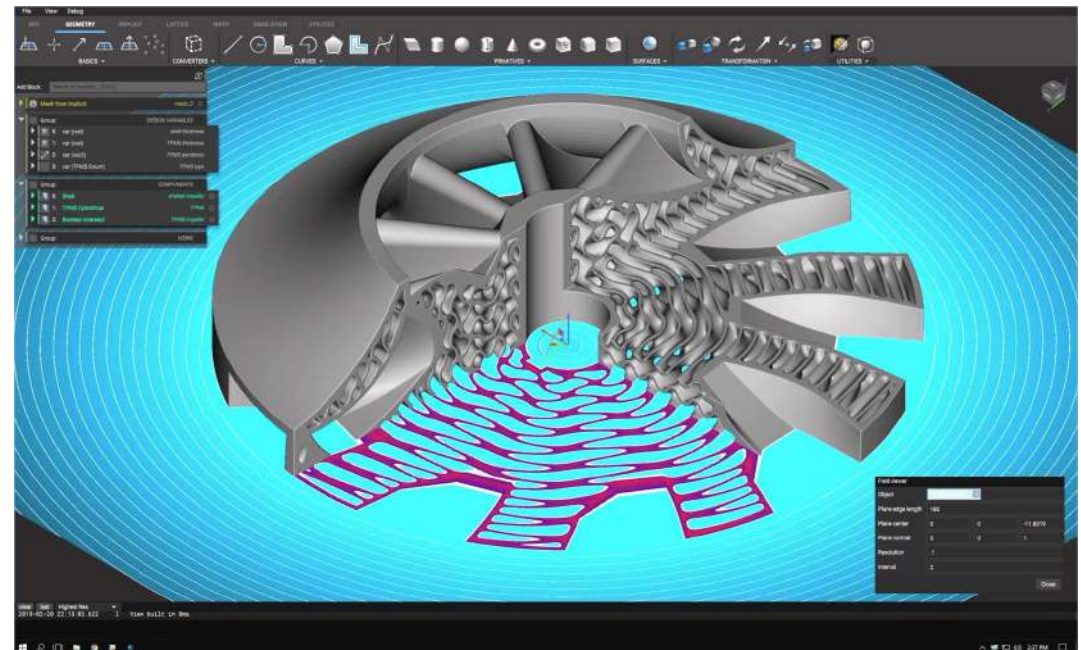
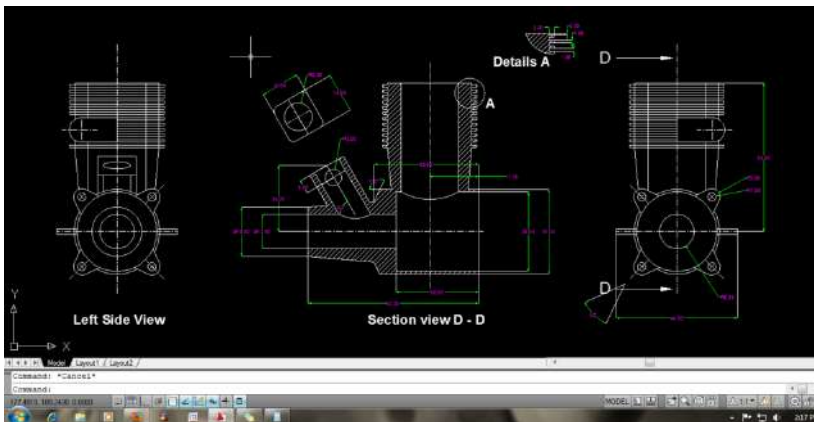
- ntopology (see case studies): <https://ntopology.com/>
- additiveflow: <https://www.additiveflow.com/>
- Hyperganic
- ParaMatters: <https://paramatters.com/>
- Fusion 360 (Autodesk)

The image is a comparison chart for three generative design software packages: nTopology, FRUSTUM, and PARAMATTERS. Each package is shown in a column with its logo, representative images of generated parts, a list of features, and a funding record.

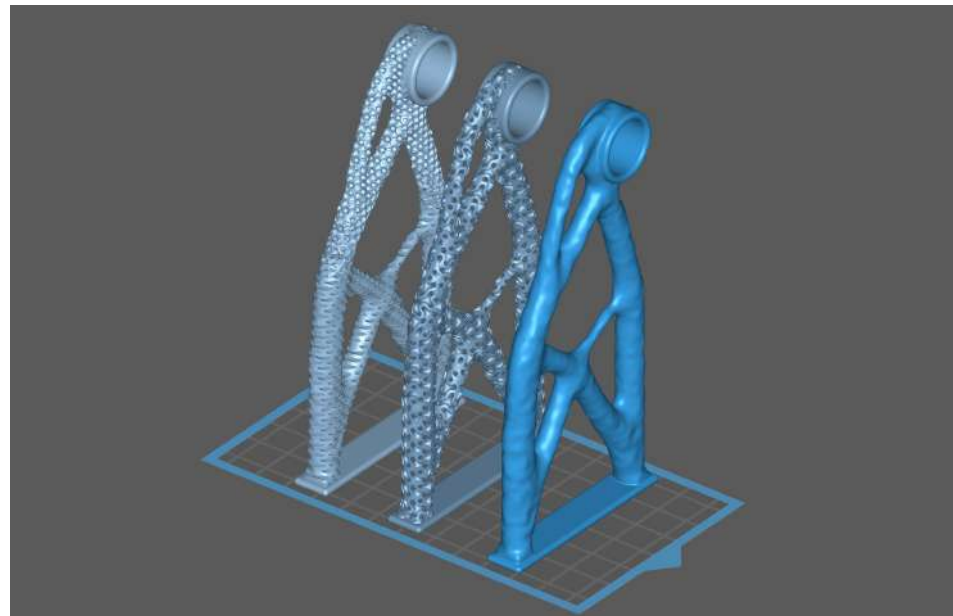
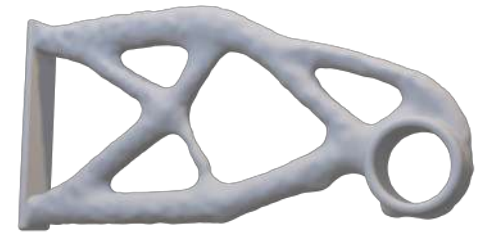
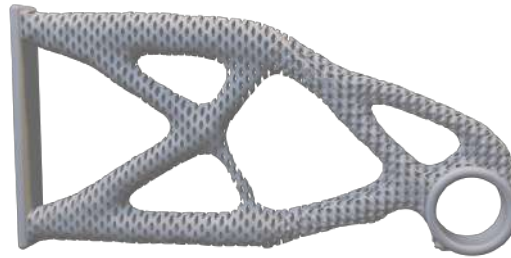
nTopology	FRUSTUM	PARAMATTERS
Element Pro <ul style="list-style-type: none">• Surface Topology• Lattice Structures• Customizable design workflow	Generate Web <ul style="list-style-type: none">• Surface Topology• Lattice Structures• Manufacturing constraint options	CogniCAD <ul style="list-style-type: none">• Surface Topology• Metamaterials• Mesostructures• Multimaterials
2015 \$7.6M Raised	2014 \$10M Raised	2017 \$0.5M Raised

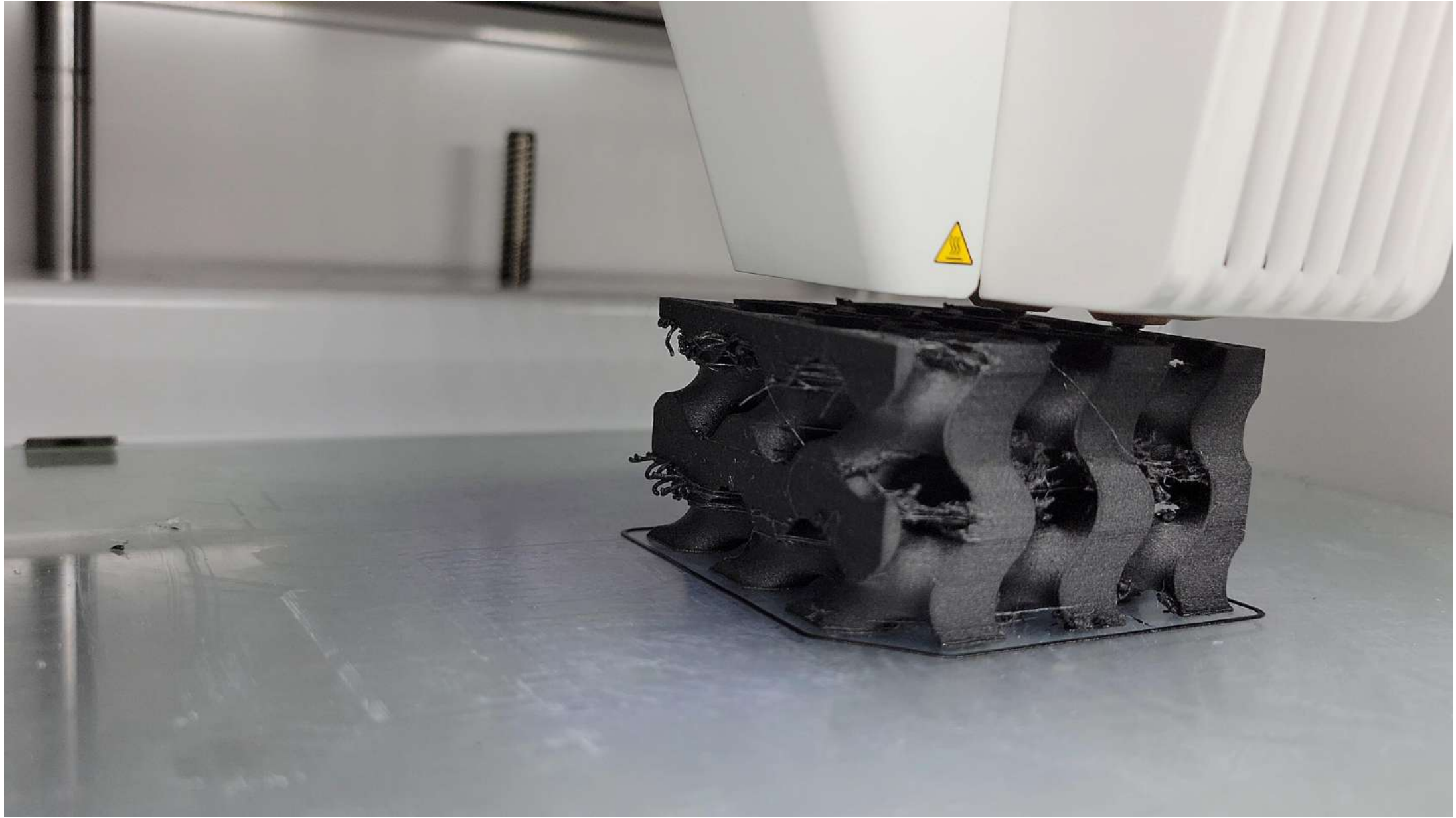
Images: T. Horvath, MIT; CC BY-NC-SA

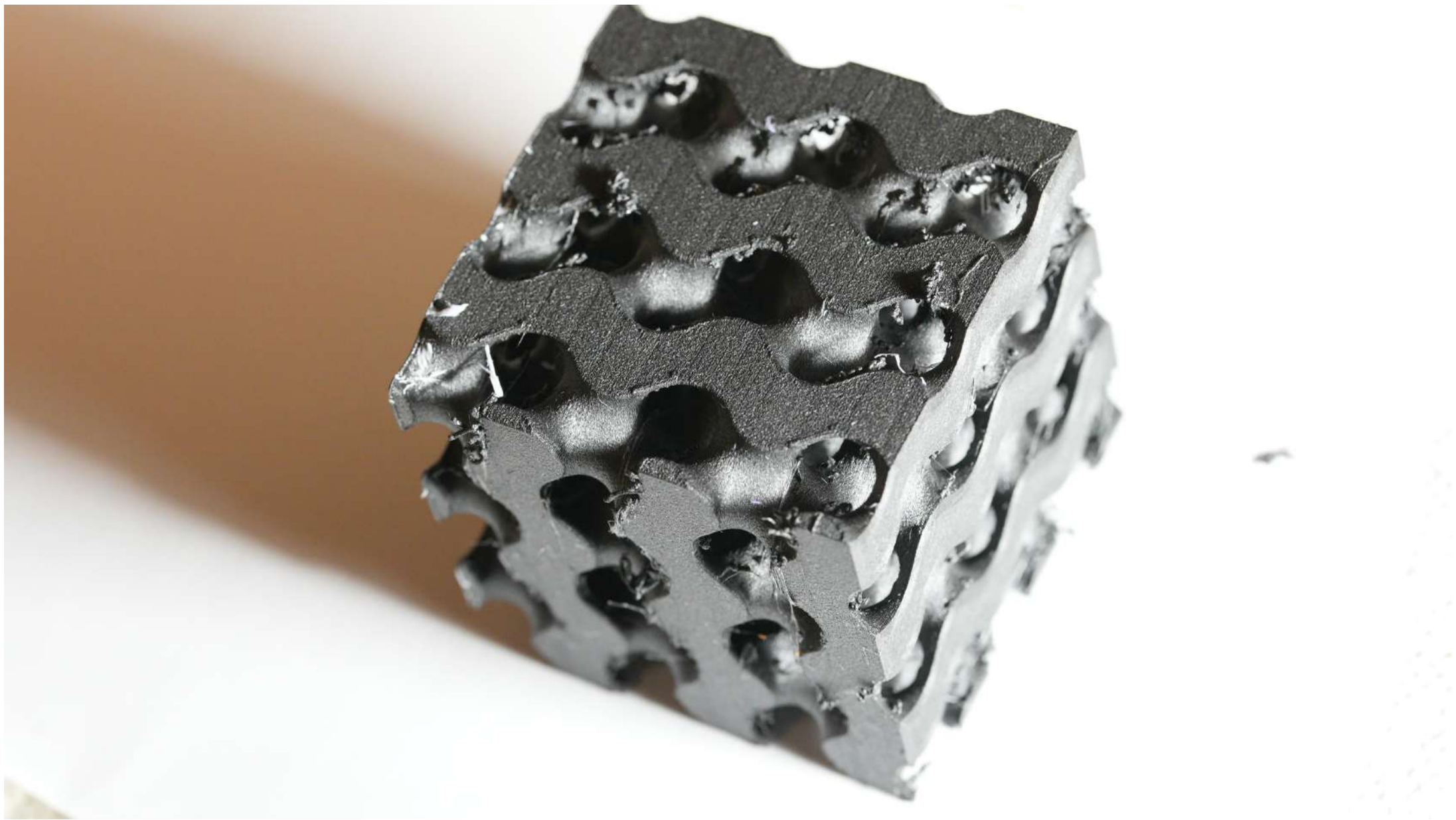
Conventional CAD vs novel tools



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







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Break before Part 4

Prof. J. Morlier