ENG-A1009
Practical Work Training with 3D printers

Slide Ver: 15.10.2021

Schedule

9:15 – 12:00 Brief background on 3D printing and different technologies > closer look on material extrusion, digital and physical workflow, design guidelines & resources to help you achieve your printing needs and visions

Digital steps: Cura demo

12:00 – 13:15 Lunch break

13:15 – 15:15 Practical Part - Session 1

15:15 – 17:15 Practical Part - Session 2

@ADDLab: Ultimakers in practice, starting a print, filament change, bed leveling, troubleshooting problems

Learning goals & outcomes

Mostly a “surface-scrape” introduction to the world of 3D printing.

What is 3D printing – what could *you* do with it – the possibilities?

What are the digital and physical steps in 3D printing?

Hands-on use of the Cura slicing software and Ultimaker 3D printers

> Gain access to the **ADDLab** reservation calendar to book 3D printers

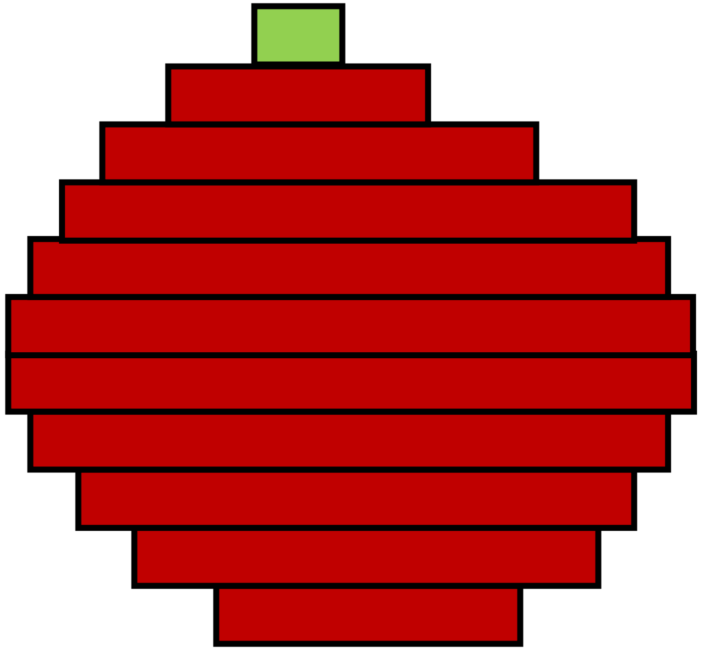
+

For 1 ECTS credit :

Small assignment given at the end of the practical part

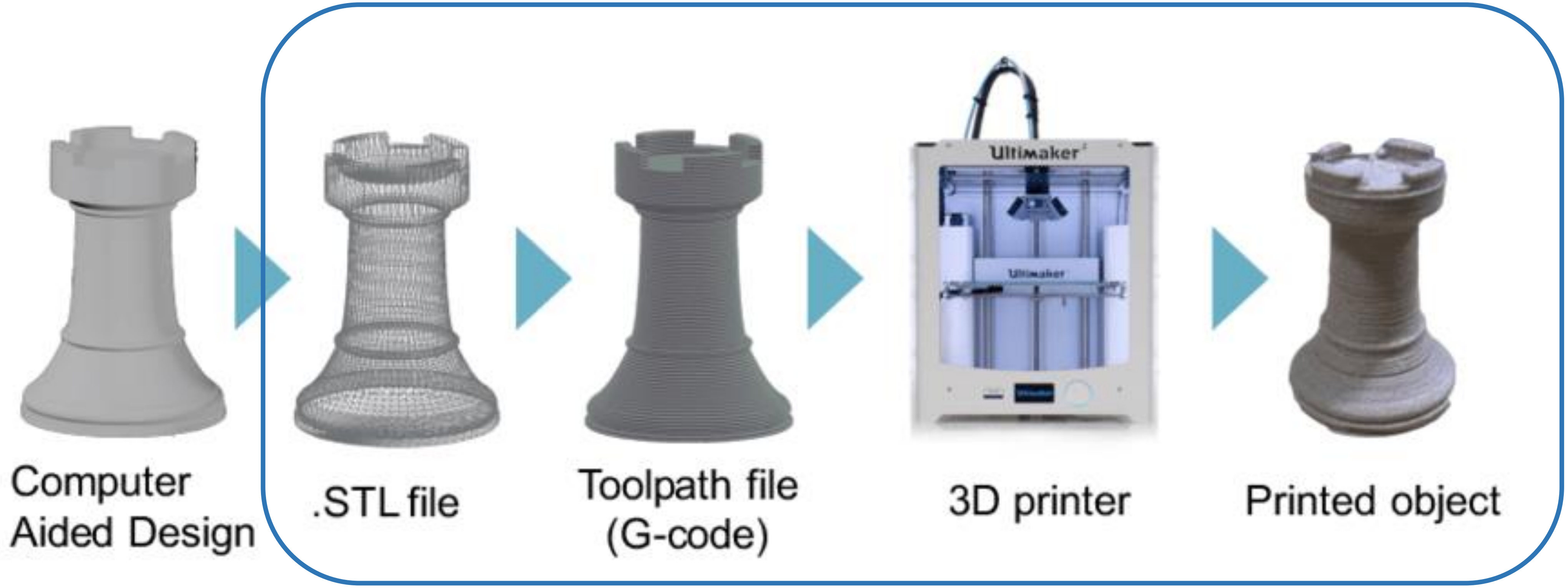
What is 3D printing and what to do with it?

3D printing ~ Additive Manufacturing (AM)



https://commons.wikimedia.org/wiki/File:Bright_red_tomato_and_cross_section02.jpg

3D printing – digital to physical



CAD model or scan, 3D

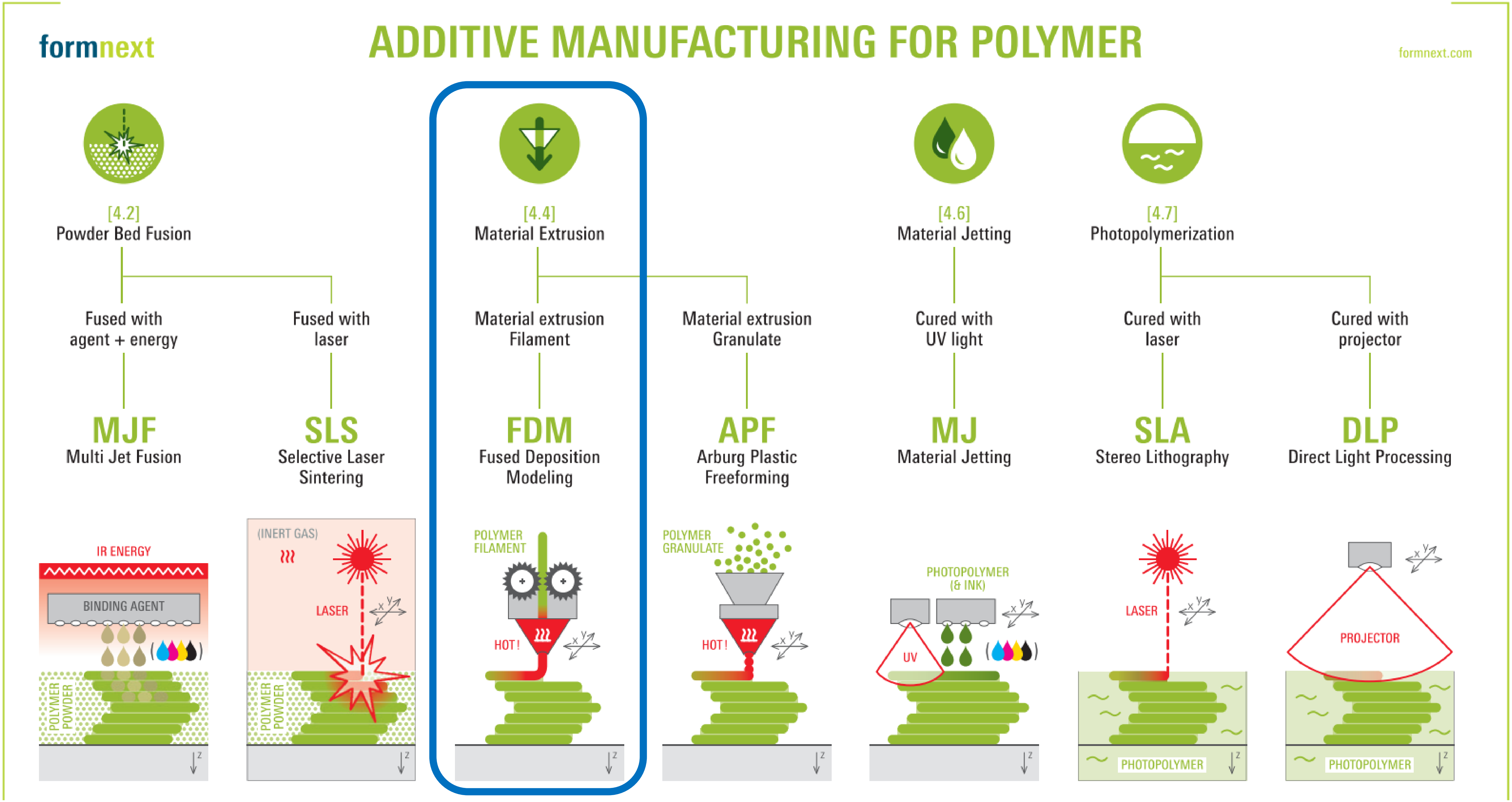
Cura slicing software, 2D slices out of 3D

Image source: Gao, Yang & Li, Borui & Wang, Wei & Xu, Wenyao & Zhou, Chi & Jin, Zhanpeng. (2018). Watching and Safeguarding Your 3D Printer: Online Process Monitoring Against Cyber-Physical Attacks. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies. 2. 1-27. 10.1145/3264918.

ADDITIVE MANUFACTURING TECHNOLOGIES

3D HUBS

https://www.3dhubs.com/get/am-technologies/



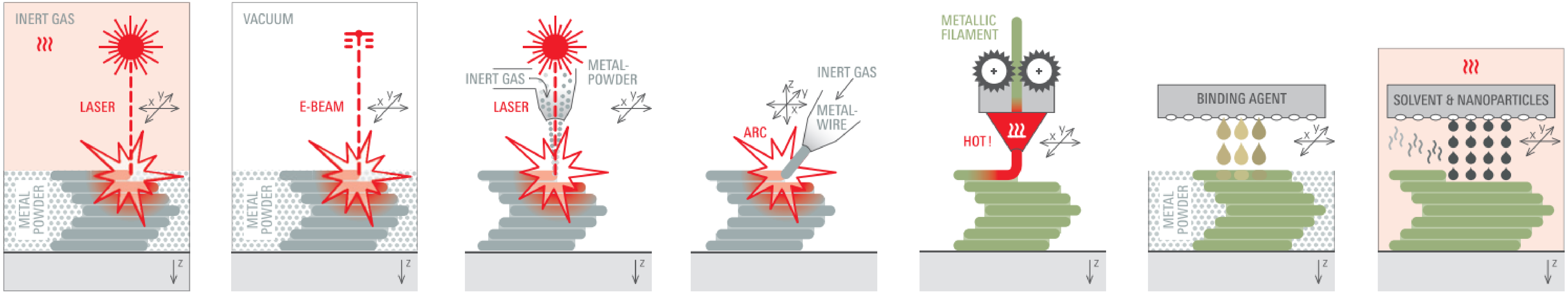
"Formnext 2019 – AM Field Guide Compact"

formnext

ADDITIVE MANUFACTURING FOR METAL

formnext.com

[4.2] Powder Bed Fusion		[4.3] Direct Energy Deposition		[4.4] Material Extrusion	[4.5] Binder Jetting	[4.6] Material Jetting
Fused with laser	Fused with electron beam	Fused with laser	Fused with electric arc	Green part is printed to be sintered afterwards	Joined with bonding agent to be sintered afterwards	Cured with heat to be sintered afterwards
SLM Selective Laser Melting	**EBM** Electron Beam Melting	**LENS** Laser Engineering Net Shape	**WAAM** Wire and Arc Additive Manufacturing	**FDM** Fused Deposition Modeling	**BJ** Binder Jetting	**NPJ** Nano Particle Jetting



"Formnext 2019 – AM Field Guide Compact"

Photopolymerization

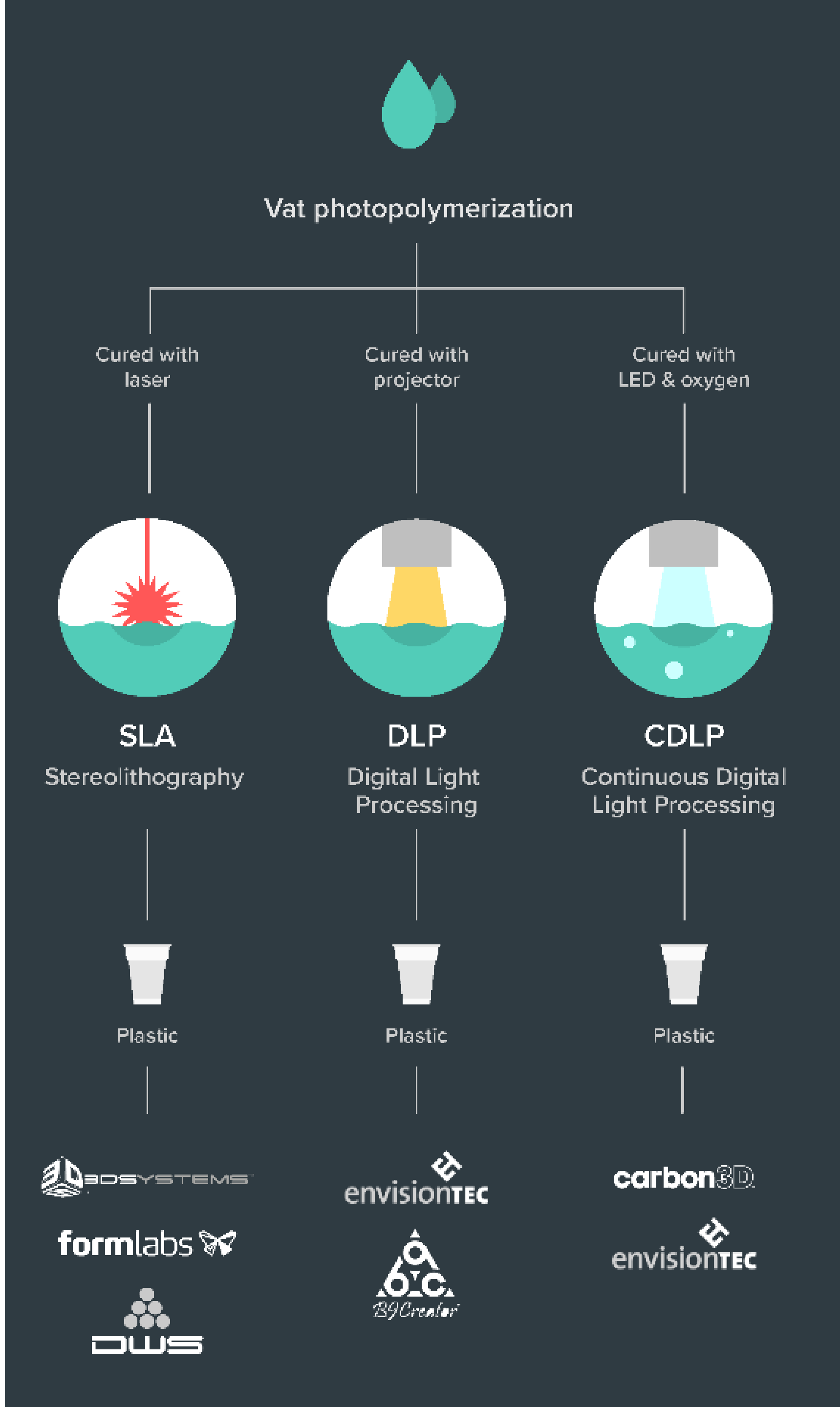
Video 01

Liquid photopolymers solidified with UV-light

The first 3D Printing technology (~1984)

Mostly used for prototyping and investment casting

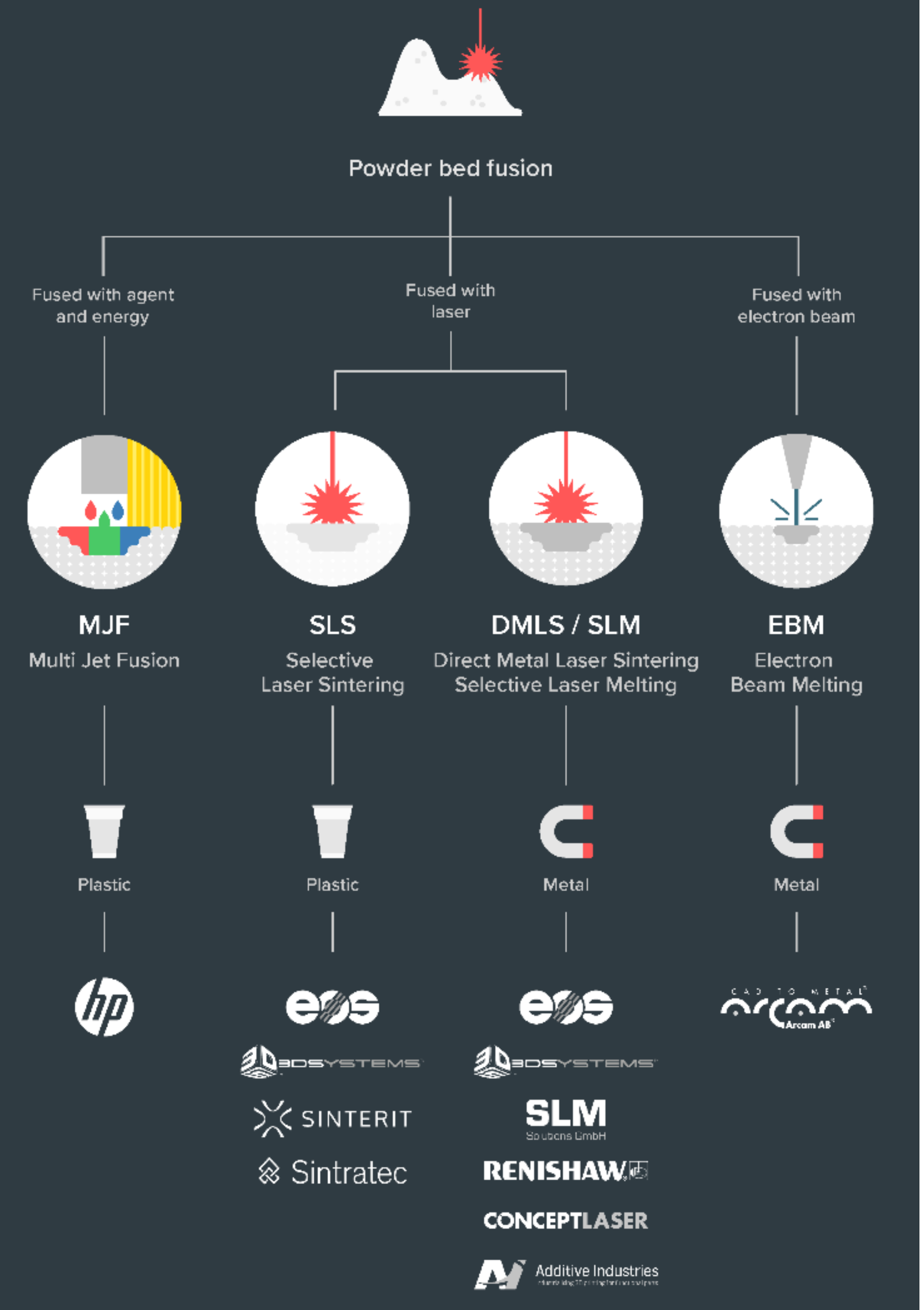
Often poor mechanical properties and parts will degrade in prolonged UV light



https://www.3dhubs.com/get/am-technologies/

First Commercially Successful Stereolithography Machine, Model SLA-1, 1987,
Chuck Hull – 3D Systems

https://www.thehenryford.org/collections-and-research/digital-collections/artifact/242212/#slide=gs-249773



Powder Bed Fusion

[Video_02]

For plastics (MJF / SLS) and metals (DMLS / SLM / EBM)

Material in powder format

High-power, focused laser melts material layer-by-layer

Industrialized technology, end-use products

Parts have good mechanical properties

EOS M290 – behold!

http://cam.usc.edu/references/Machines/EOS_M290_DMLS_3D_Printer.pdf

Material Jetting

Or Polyjet, video_03

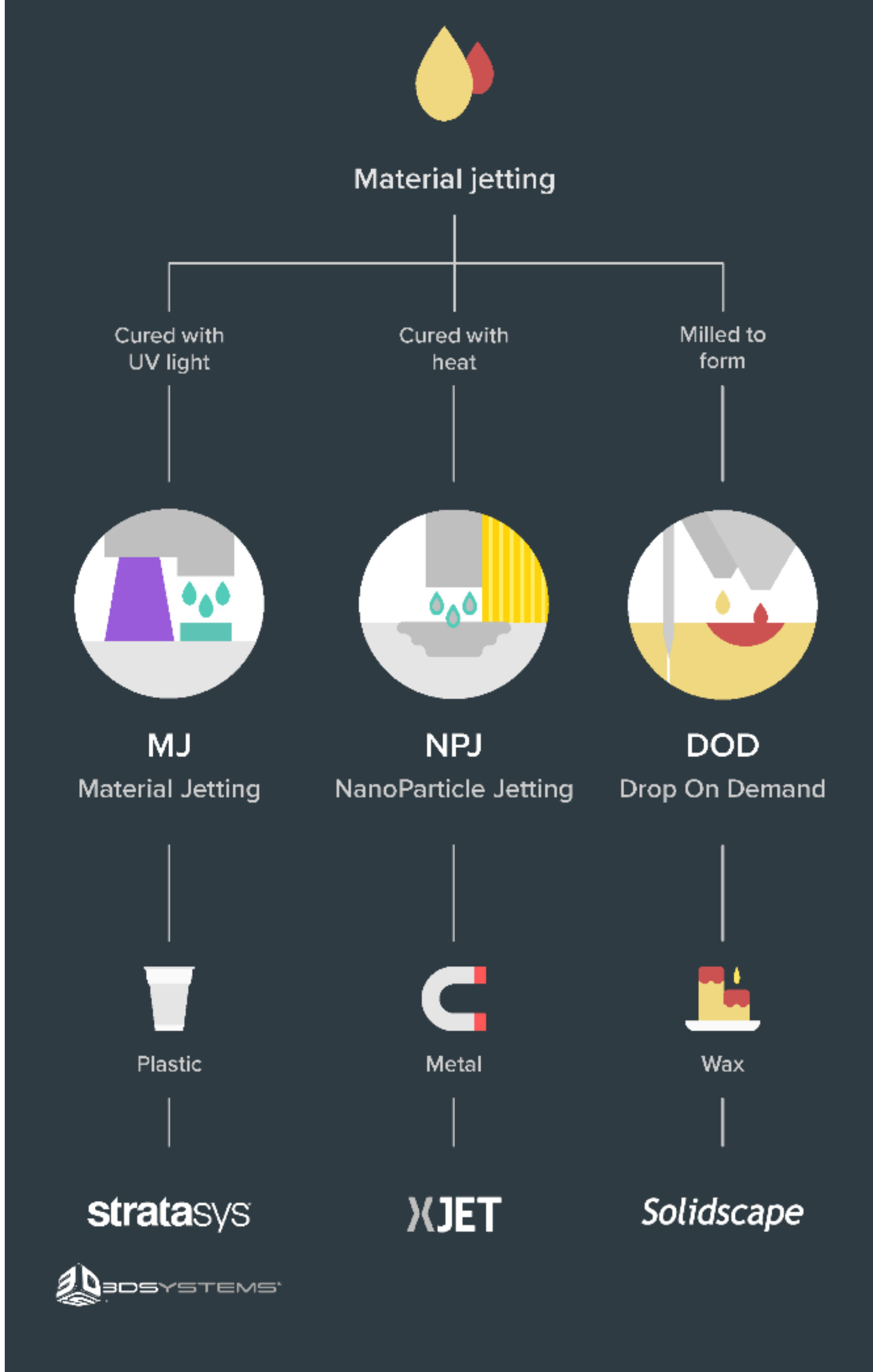
A cousin to photopolymerization : inkjet (2D printing tech) heads are used to drop small photopolymer droplets on the build platform which are then cured with a passing UV-light

Multi-material possibilities

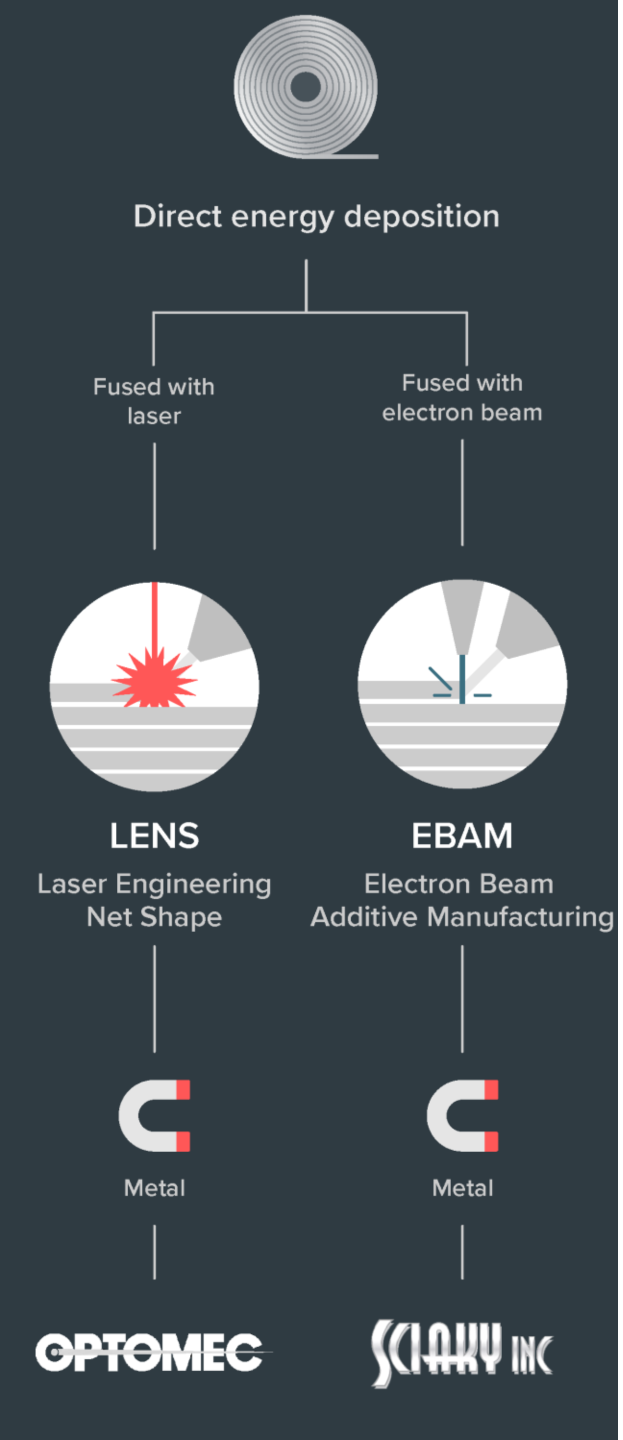
Very good resolution and fine features

Again poor mechanical properties and parts degrade with UV

Used for prototyping, medical models, and research



Directed Energy Deposition (DED)



video_04

Powder or wire fed and melted with a laser, electron beam or a plasma arc

Poor surface finish, machining often required

Large components

Repairs of broken parts

So.., what to do with all of this ? video_05

Simple, (sometimes) useful everyday objects

Shoe Support

Shoe Support (Source: Mickapouel, via Thingiverse)

Self-Watering Planter

Houseplants dying from neglect? NEVER AGAIN. Pr
plant waterer, and your conscience will remain clea
for kitchen herbs, where you can make them last up
re-potting in this natty device.

Who made it: Parallel Goods

Where to download it: Cults3D

Toothpaste Tube Squeezer

Squeeze every last drop of toothpaste from the tube with th
tube squeezer. It prints in three separate parts, and is wide e
accommodate most tubes on the market. Not only a cool th
but also something to keep your breath minty fresh.

Who made it: Justin Otten

Where to download it: Thingiverse

Bottle Opener and Cap Gun

Bottle Opener and Cap Gun (Source: 3Deddy, via Thingiverse)

https://all3dp.com/1/useful-cool-things-3d-print-ideas-3d-printer-projects-stuff/

Need a custom tool onboard the International Space Station?

Yes.

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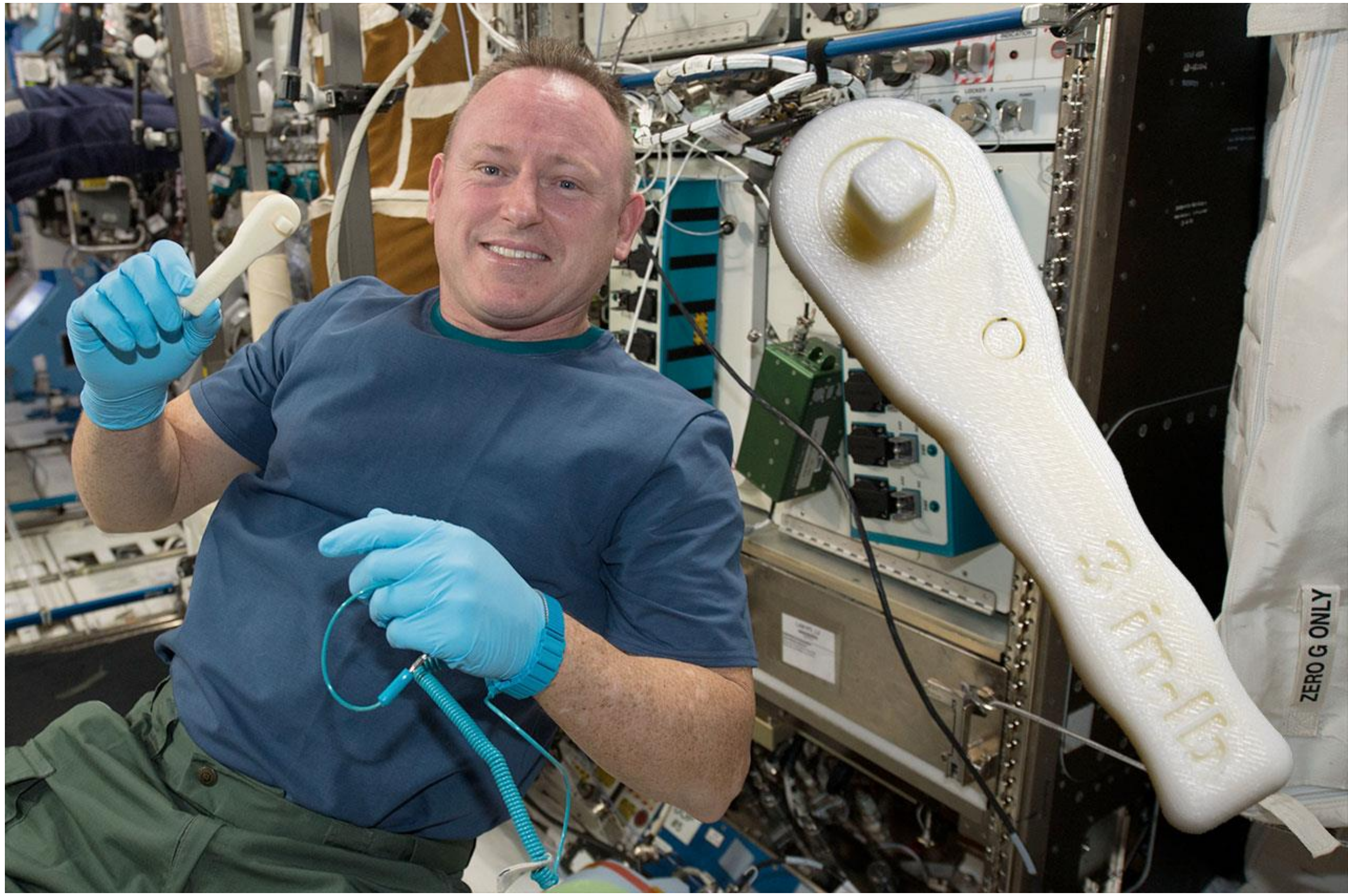
Let me fire up the *Refabricator.*

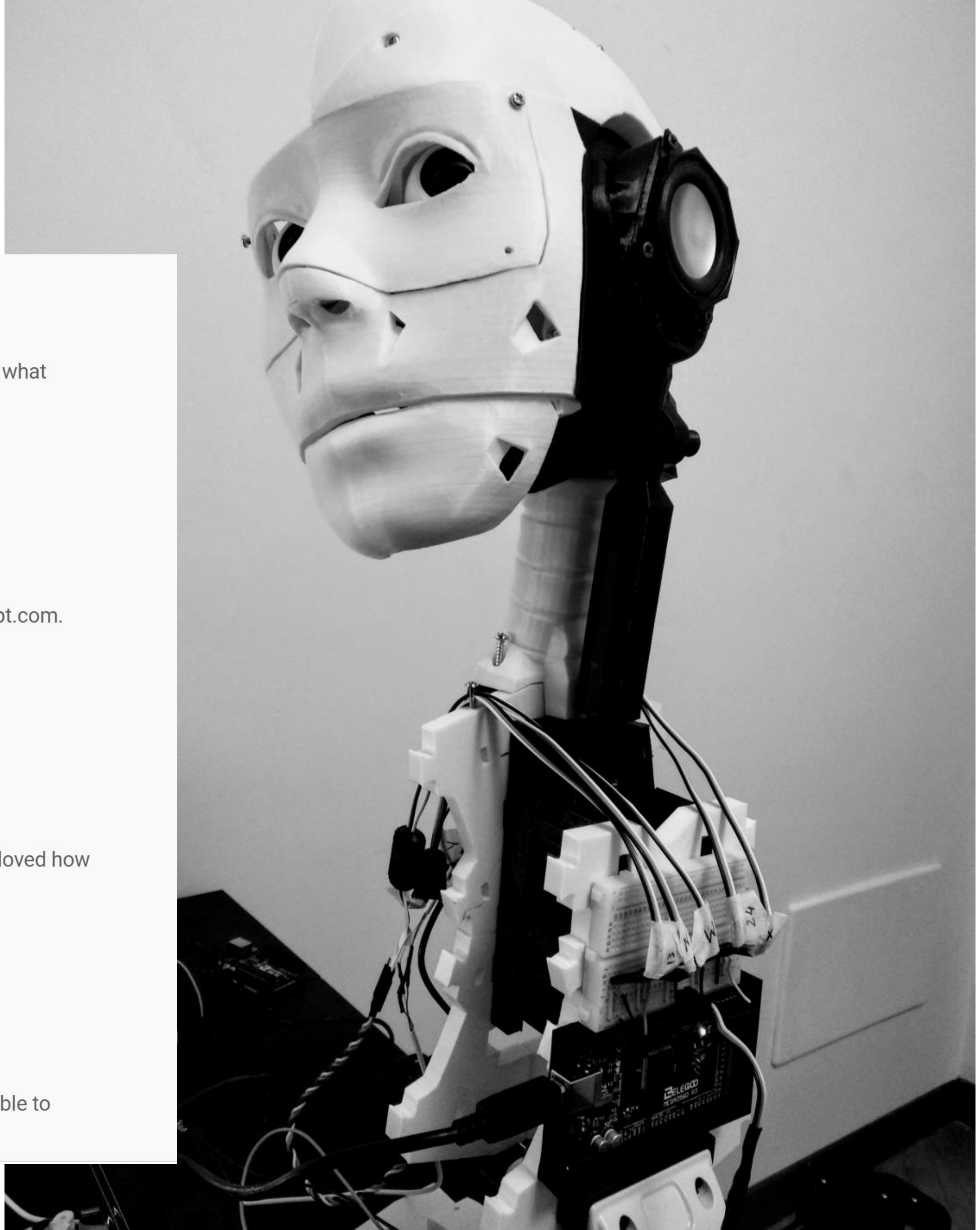
NASA Artemis program and building habitats on the Moon and later on Mars.

Decreasing Earth-dependance on manufacturing assets in space.

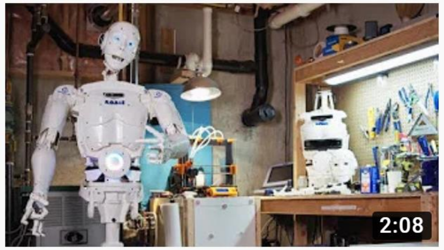


https://blog.grabcad.com/blog/2019/02/26/sending-3d-printed-parts-and-3d-printers-into-orbit/

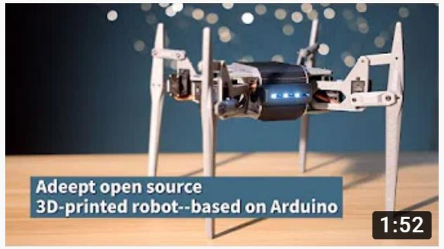
https://scognito.wordpress.com/category/inmoov/



DIY Robotics, video_06



3D Printed Life-Size InMoov Robot
Jukebooth • 2.4K views • 8 months ago
Matt Edminster and Billy Ramey, two New England guys, bought a **3D printer** 3 years ago and what started as a hobby became a ...
4K



Adeept open source 3D printed robot based on Arduino
Adeept Studio • 616 views • 4 months ago
Adeept open source **3D printed robot** based on Arduino. Welcome to the website: www.adeept.com.

3D Printed Delta Robot (Arduino Controlled) 2019
isaac879 • 57K views • 9 months ago
If you enjoyed the video please leave a like and consider subscribing for more. I have always loved how delta **robots** move and ...

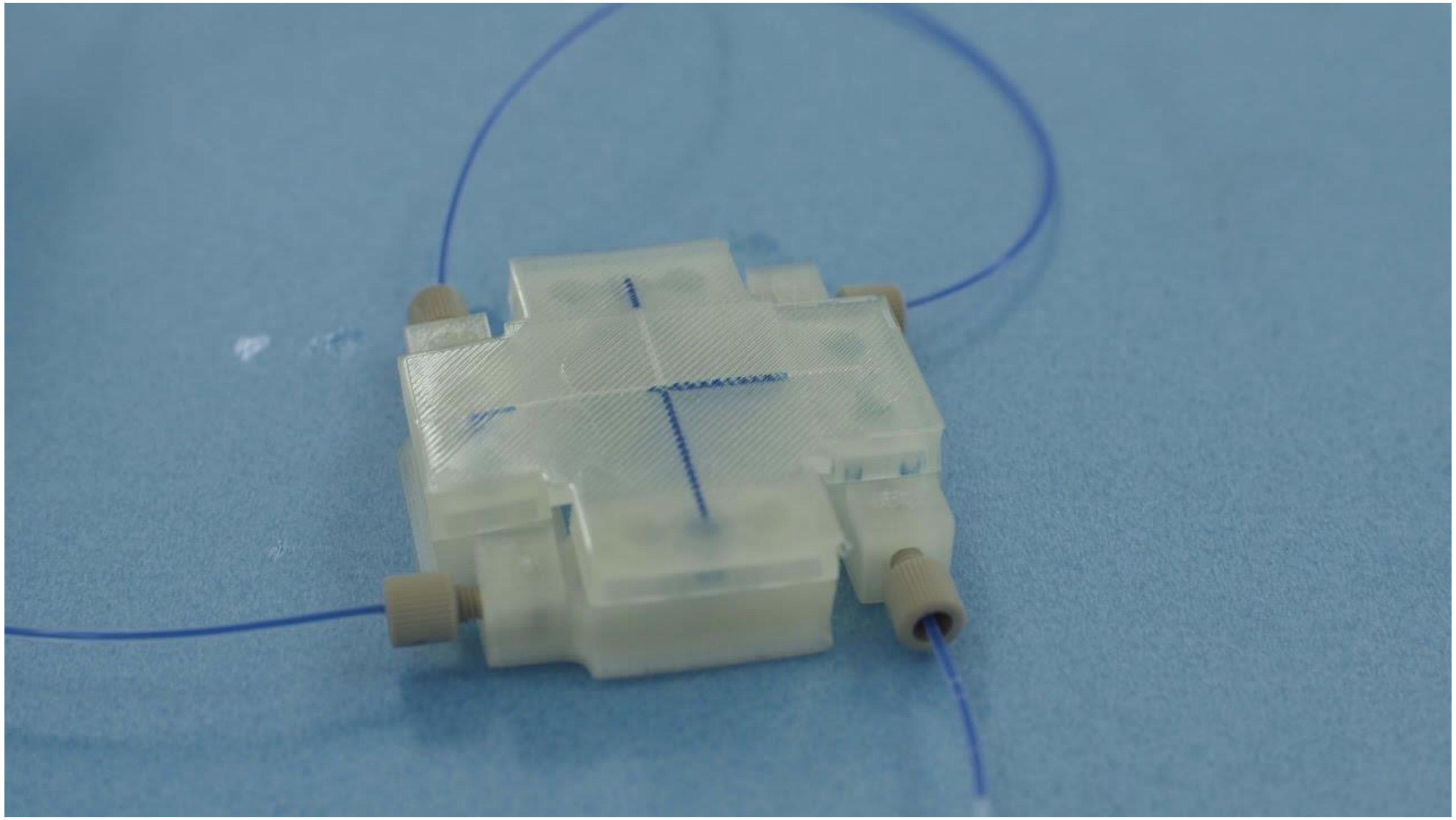
3D printed RC FPV tank rover
Brian Brocken • 12K views • 9 months ago
I designed the tank in a way that it can be almost completely **3D-printed**. It's of course inevitable to truely completely **3D print** the ...

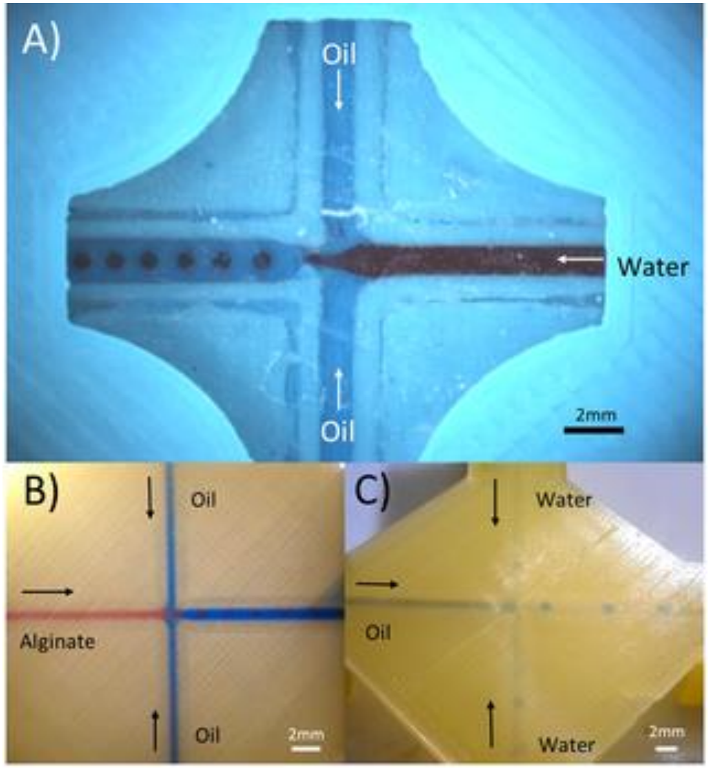
YouTube : some search results for “3d printed robot” published last year (2020)

Volkswagen : video_07
Jigs and fixtures to help assemble cars

https://www.tctmagazine.com/can-you-jig-it-volkswagen-ultimaker-3d-printing/

Microfluidic devices with an Ultimaker

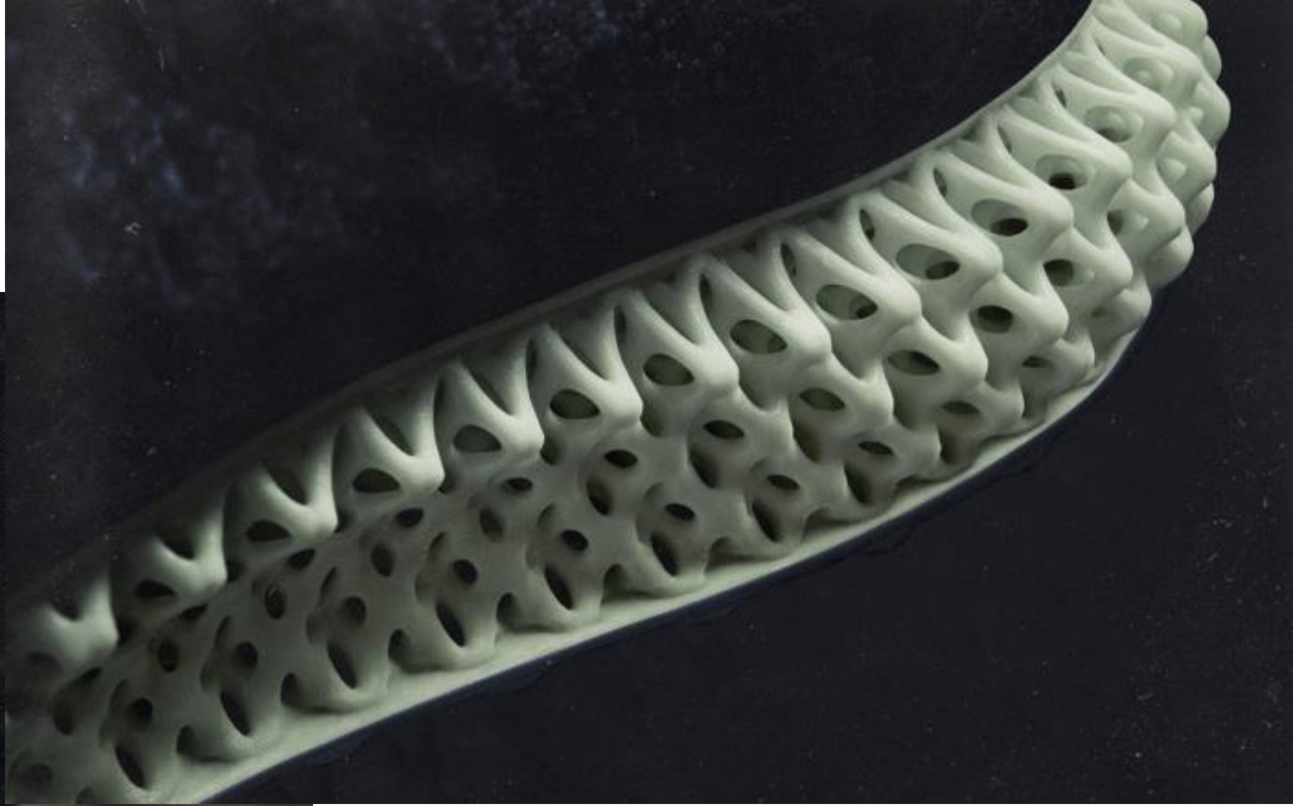




https://ultimaker.com/learn/cardiff-university-accessible-3d-printed-microfluidic-devices

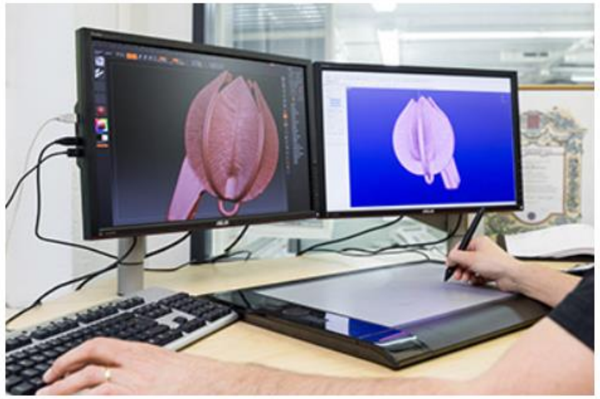
Morgan, A. J., San Jose, L. H., Jamieson, W. D., Wymant, J. M., Song, B., Stephens, P., ... & Castell, O. K. (2016). Simple and versatile 3D printed microfluidics using fused filament fabrication. *PloS one*, *11*(4).

Adidas



https://3dprintingindustry.com/news/adidas-to-release-a-new-version-of-3d-printed-shoe-alphaedge-4d-155578/

Kalevala Koru – jewellery with 3D Printing

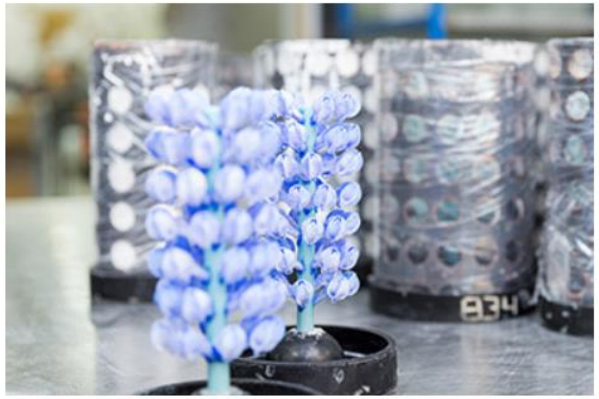


Also this can be a goldsmith's tool. The 3D model of the Snow Flower is being prepared using the drawing pad and the computer.

Snow Flowers printed in blue wax with a 3D printer.

Some of the wax models are still created traditionally by hand. Hot wax is injected inside a rubber mold and the solidified wax model is carefully removed from the mold.

The wax flowers are ready for the next stage.

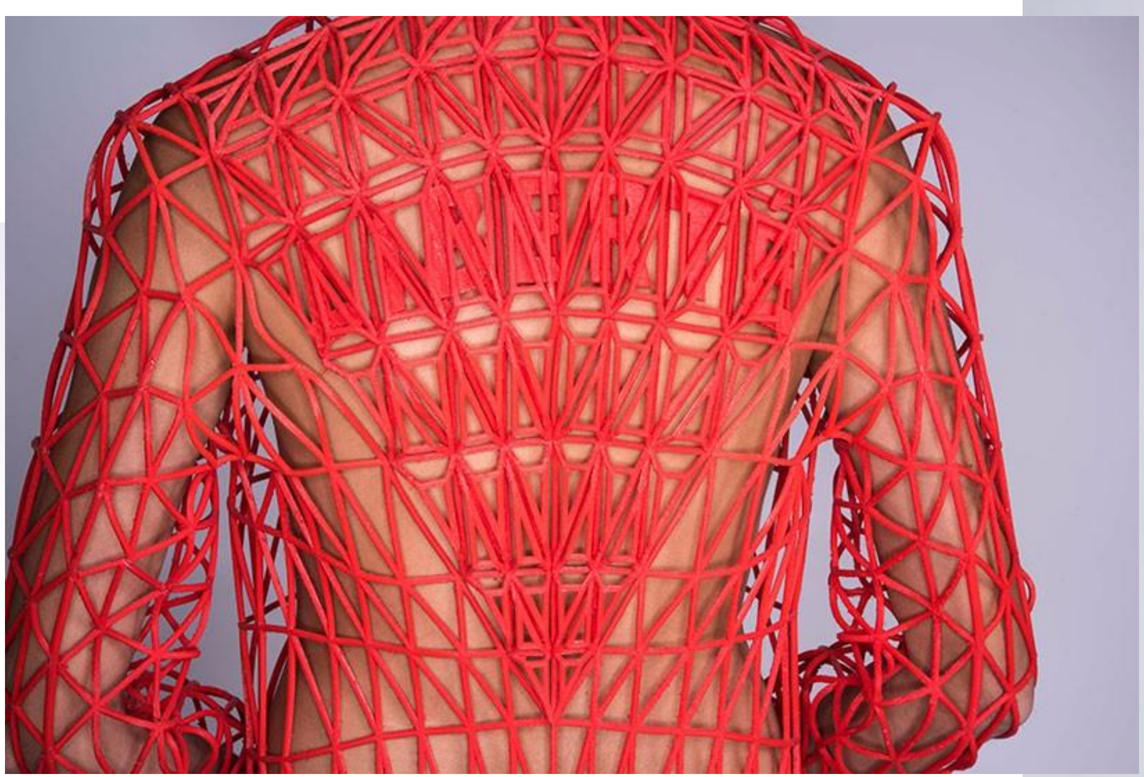


The wax models are attached to a wax pole forming tree-like structures. The trees are placed inside a cylinder which is then cast with plaster. Numbers on the cylinders mark the different treatments each cylinder receives depending on the jewelry model that is being produced.

The wax has been melted off from the cylinder and replaced with molten metal.

https://www.kalevalakoru.fi/en/story/handmade-in-finland

3D Printing in Fashion



Danit Pelege

https://3dprintingindustry.com/news/3d-printing-wins-big-at-the-oscars-with-black-panther-and-materialise-149884/

Glass / Ceramics / Concrete 3D printing

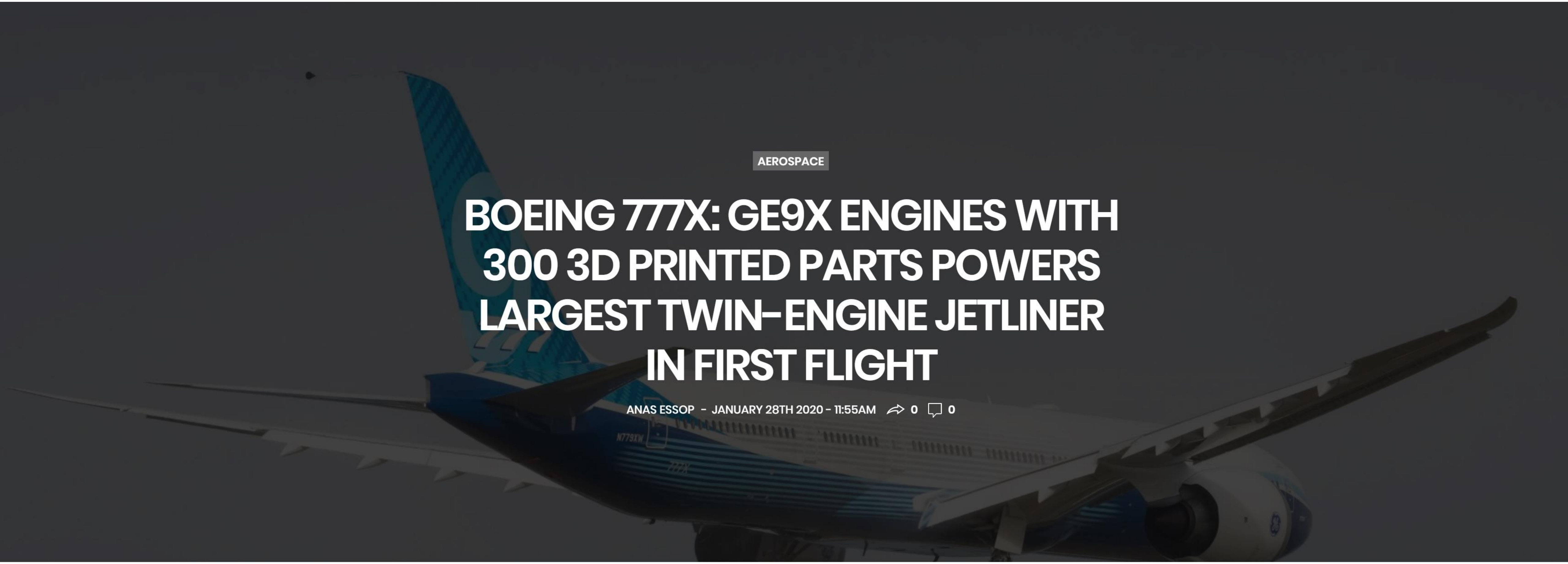
Neri Oxman

Ashish Mohite

Company ‘Concreative’

http://www.globalconstructionreview.com/markets/vinci-sets-factory-3d-printed-elements-dubai/

Jet Engine Parts



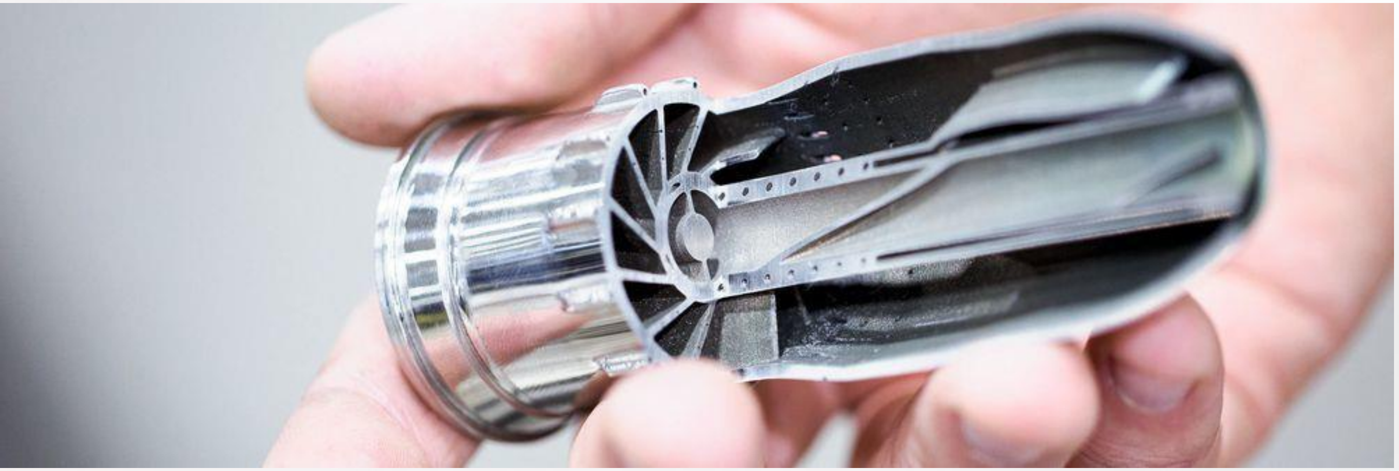
3D Printing Industry. Anas Essop. 2020. Boeing 777X: GE9X Engines with 300 3D Printed Parts Powers Largest Twin-Engine Jetliner in First Flight. Available at: https://3dprintingindustry.com/news/, Accessed 30.1.2020

LEAP fuel nozzle

Part Consolidation - previously almost 20 parts welded together, now 1 single part : 3D printed, machined, and heat treated. Already 30 000+ made.

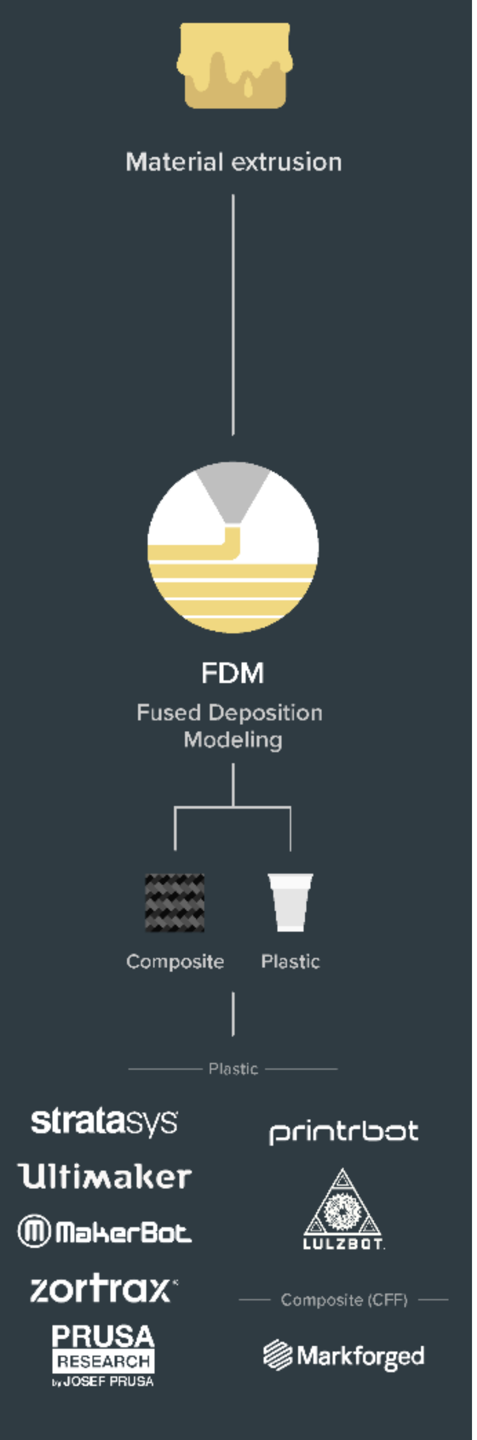
https://www.geaviation.com/commercial/engines/ge9x-commercial-aircraft-engine

https://www.ge.com/reports/heirs-gutenberg-ge-adding-next-chapter-3d-printing-push-germany/



https://www.ge.com/reports/all-the-print-thats-fit-to-pitt-new-additive-technology-center-opens-near-steel-town/

Material extrusion | The printers you will use today

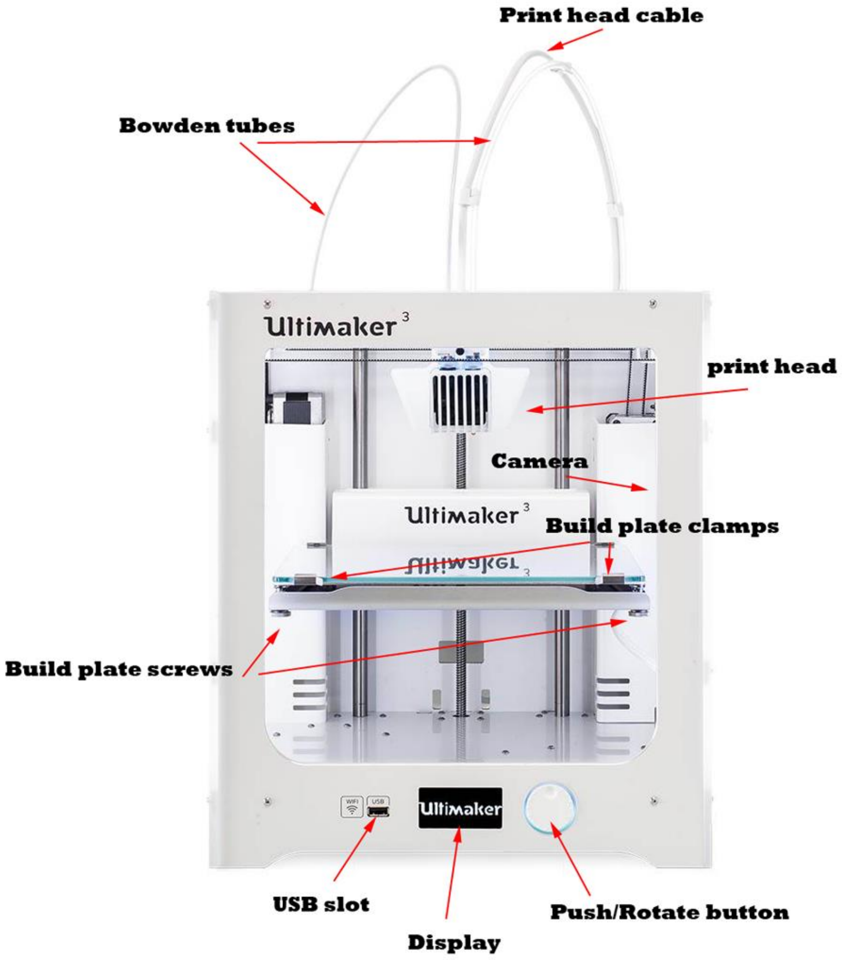


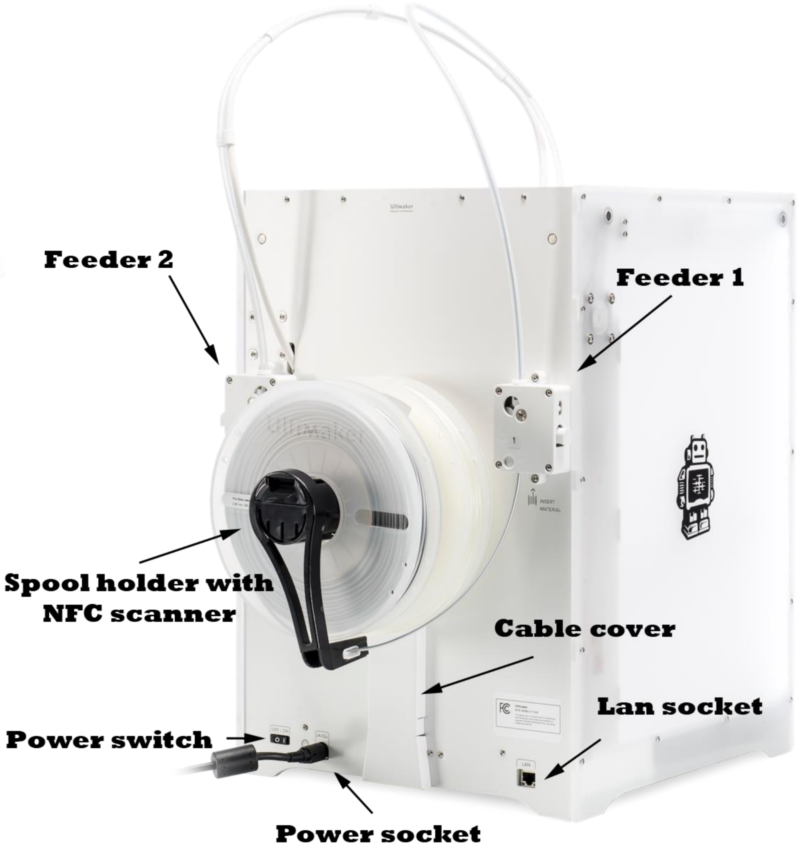
Material Extrusion (FDM)

https://www.3dhubs.com/get/am-technologies/

Material Extrusion (FDM) – video_09 1, video_09 2

Ultimaker – what is what

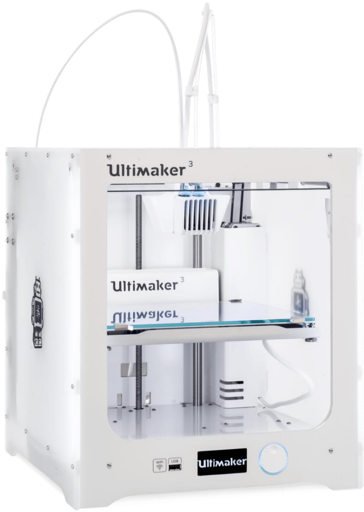




Ultimaker 3:
https://ultimaker.com/en/resources/45871-anatomy-of-an-ultimaker-3

Ultimaker 2:
https://ultimaker.com/en/resources/22131-anatomy-of-an-ultimaker-2

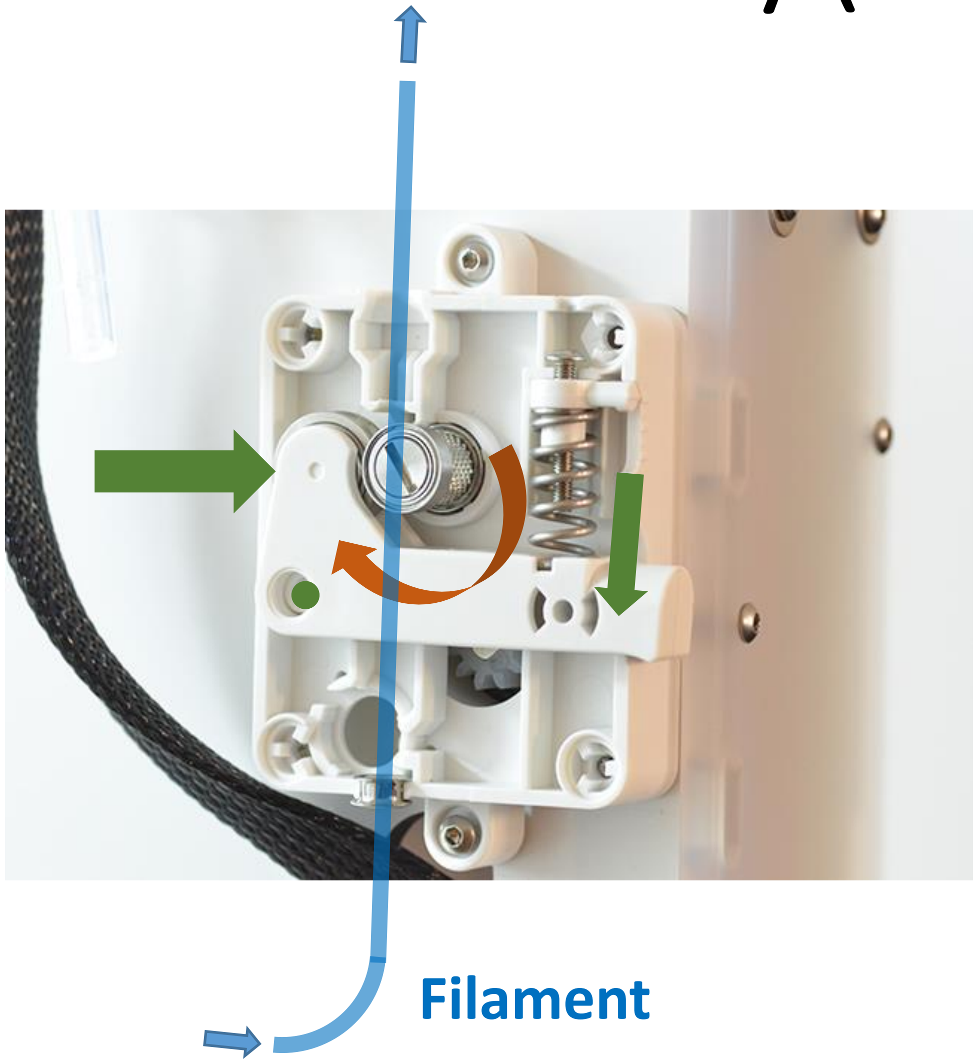
Material Extrusion Systems



Main differences:

- Movement of the extruder, the build plate or both: *Cartesian or polar coordinates, delta arrangement or with an industrial robot*
- *Extruder type; filament-, plunger- and screw-based*
- *Bowden* or *Direct* extruder
- *Open* or *Closed* build volume
- No heating, Heated build plate and/or heated build volume
- Higher temperature nozzles for more exotic materials (like PEEK, ULTEM, PPSU)

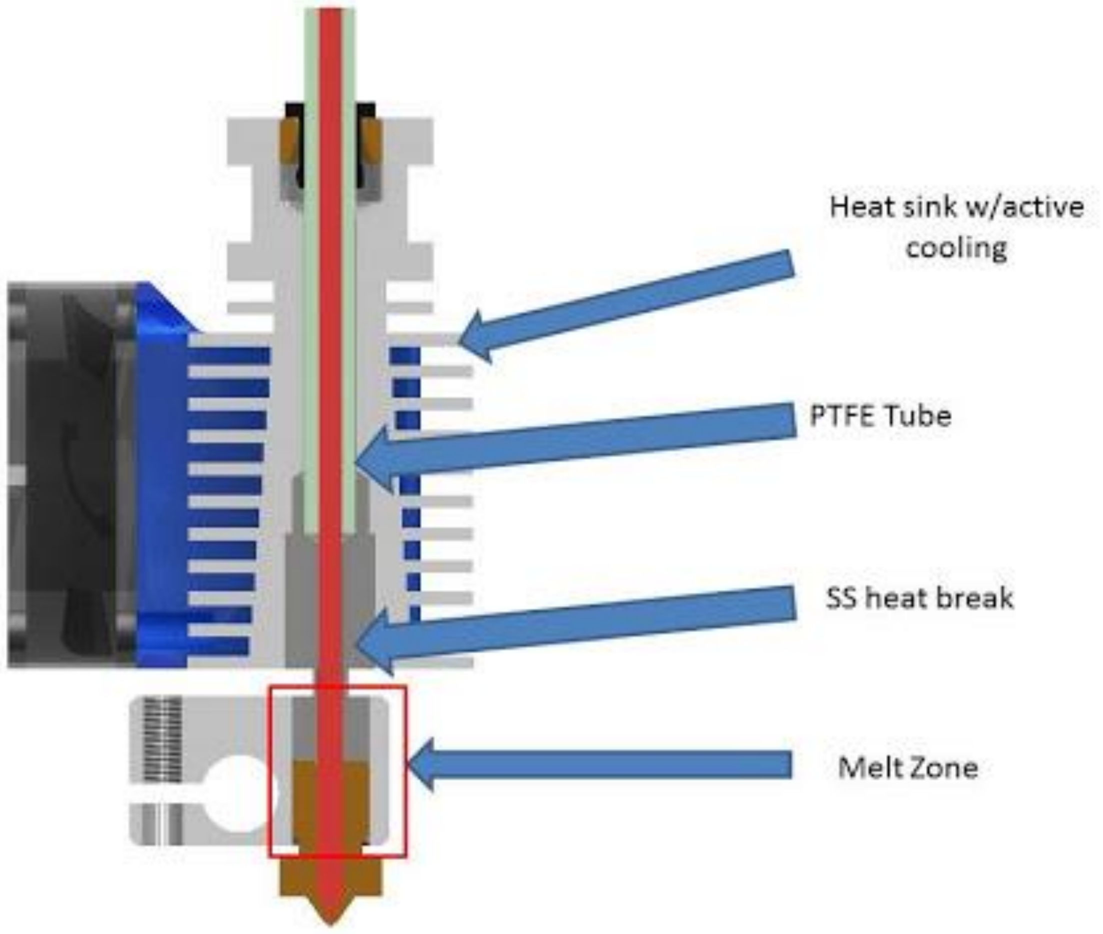
Feeder assembly (bowden)



Stepper motor (geared) rotates feeder screw
Spring loaded arm + bearing compresses filament against the feeder screw to move it towards the extruder

! Please do not adjust or open the Feeder boxes yourself. In case of a problem, ask the ADDLAB staff to do it !

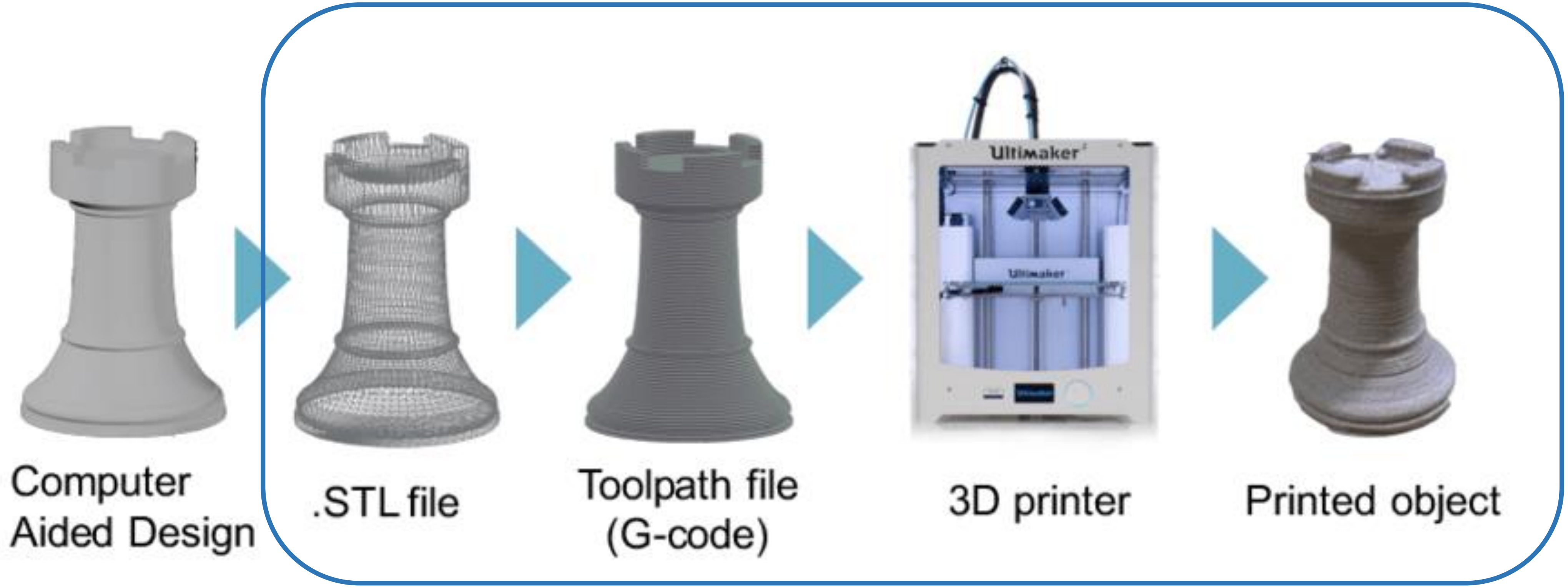
Extruder assembly (example)



https://www.matterhackers.com/articles/how-to-clear-and-prevent-jams

Digital workflow, software & design

3D printing – digital to physical

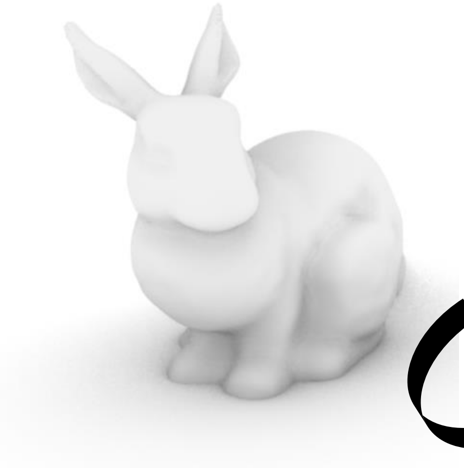


CAD model or scan, 3D

Cura slicing software, 2D slices out of 3D

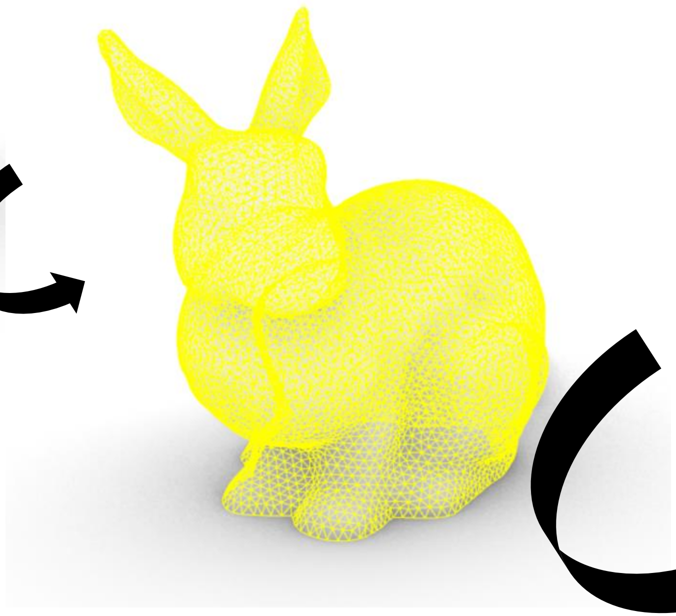
Image source: Gao, Yang & Li, Borui & Wang, Wei & Xu, Wenyao & Zhou, Chi & Jin, Zhanpeng. (2018). Watching and Safeguarding Your 3D Printer: Online Process Monitoring Against Cyber-Physical Attacks. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies. 2. 1-27. 10.1145/3264918.

From 3D model to printable file



1. Original 3D model

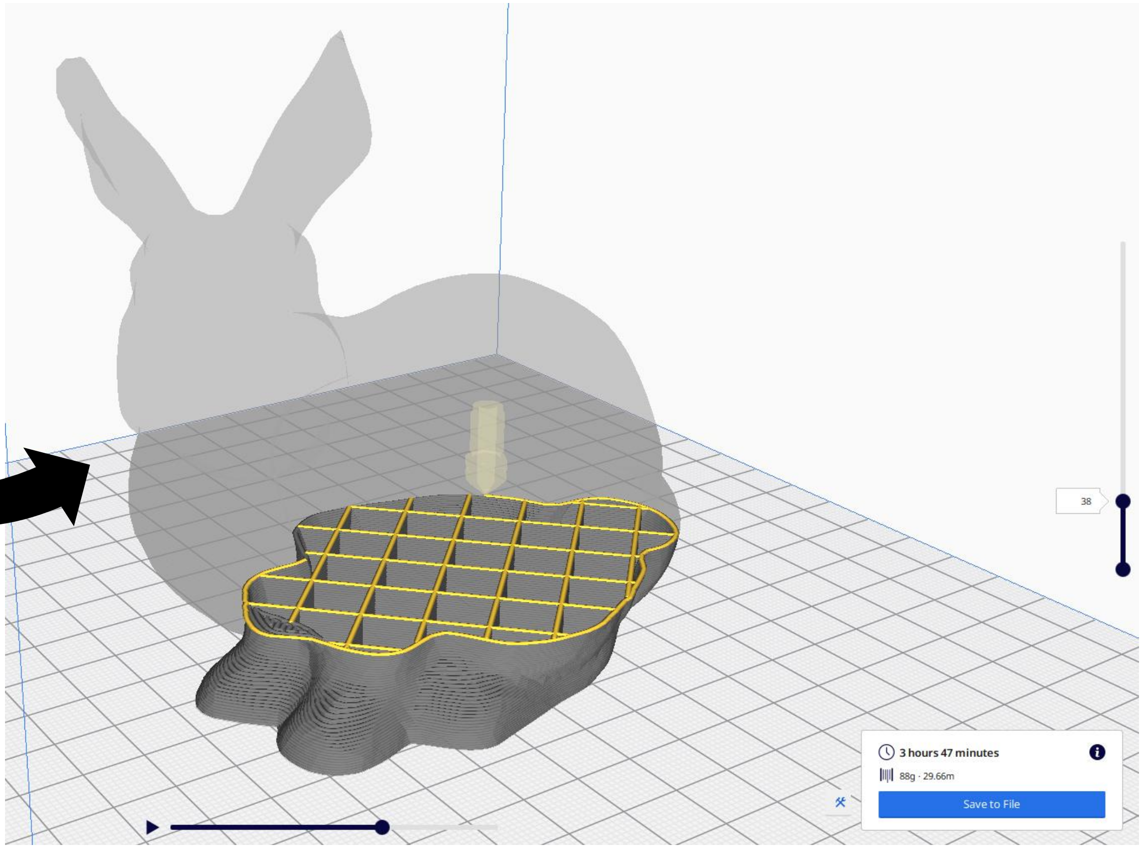
File format examples:
.OBJ, .STEP, .IGES, .PRT, .SLDPRT, …



2. STL conversion
Standard **T**riangle/ **T**essellation **L**anguage

Current industry standard for 3D printing

3. Sliced to 2D layers and G-code created
Layer thickness-, nozzle / bed temperature-, infill-, support-, etc. .. settings



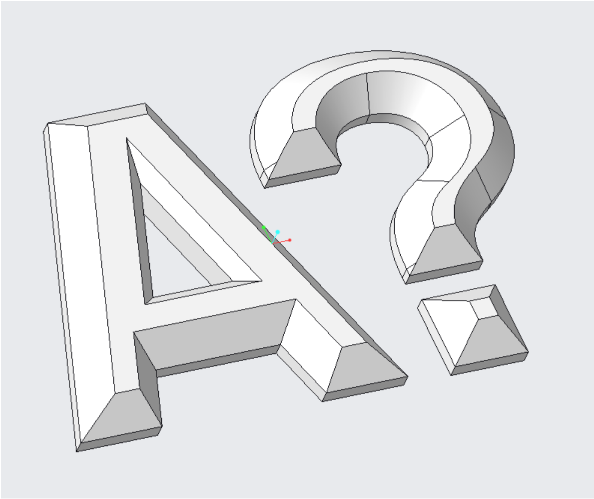
STL conversion (3D model to .stl)

STL (**S**tandard **T**essellation **L**anguage) https://en.wikipedia.org/wiki/STL_(file_format)

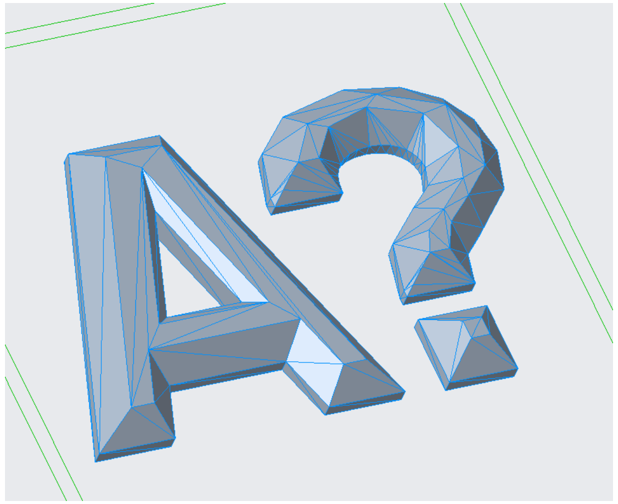
Approximates a surface of a solid 3D model by dividing it into triangles and normal vectors

Is the most common file format that the slicing software understand

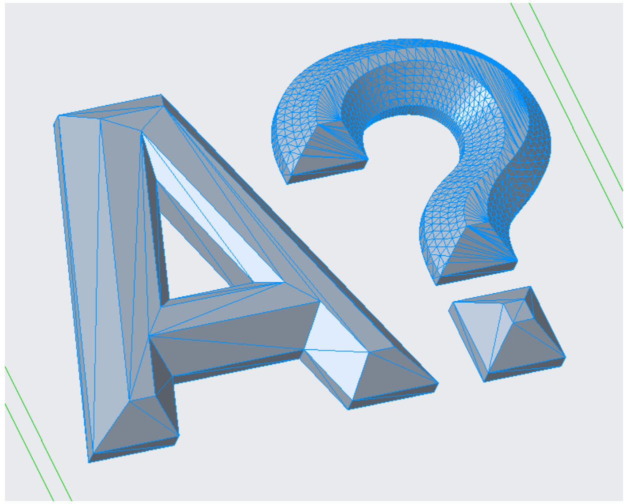
Supported by almost all 3D modeling software



3D model (Creo .prt), **143 KB**

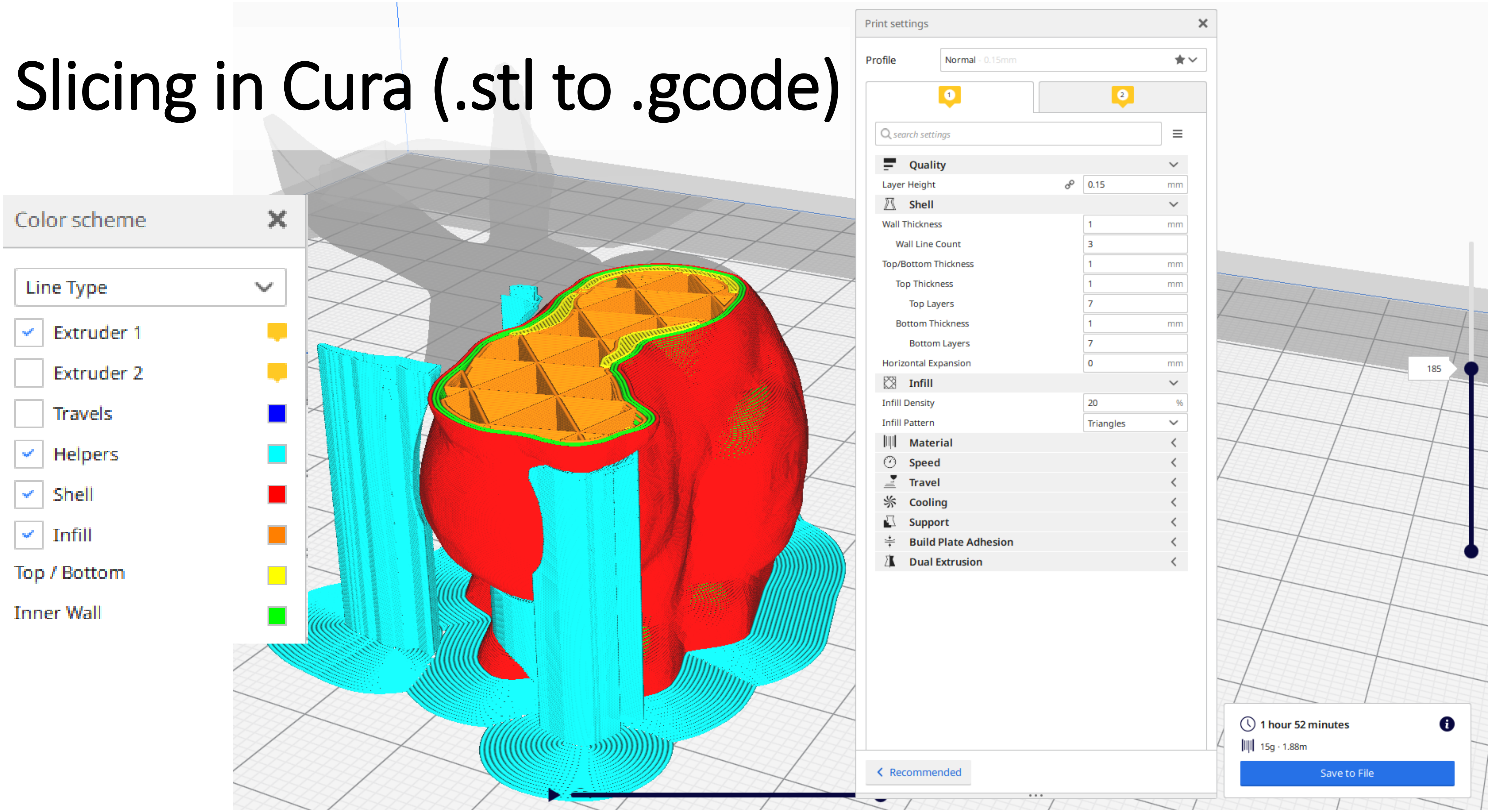


.stl coarse settings, **14 KB**

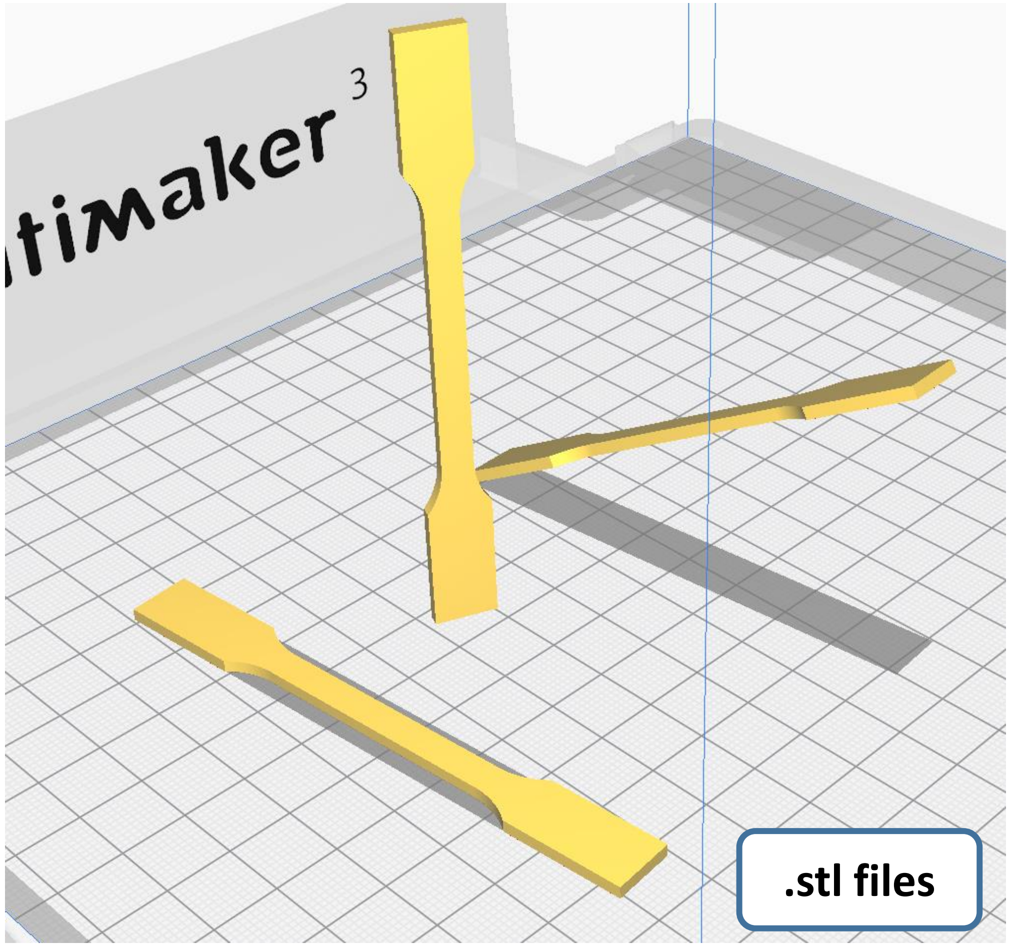


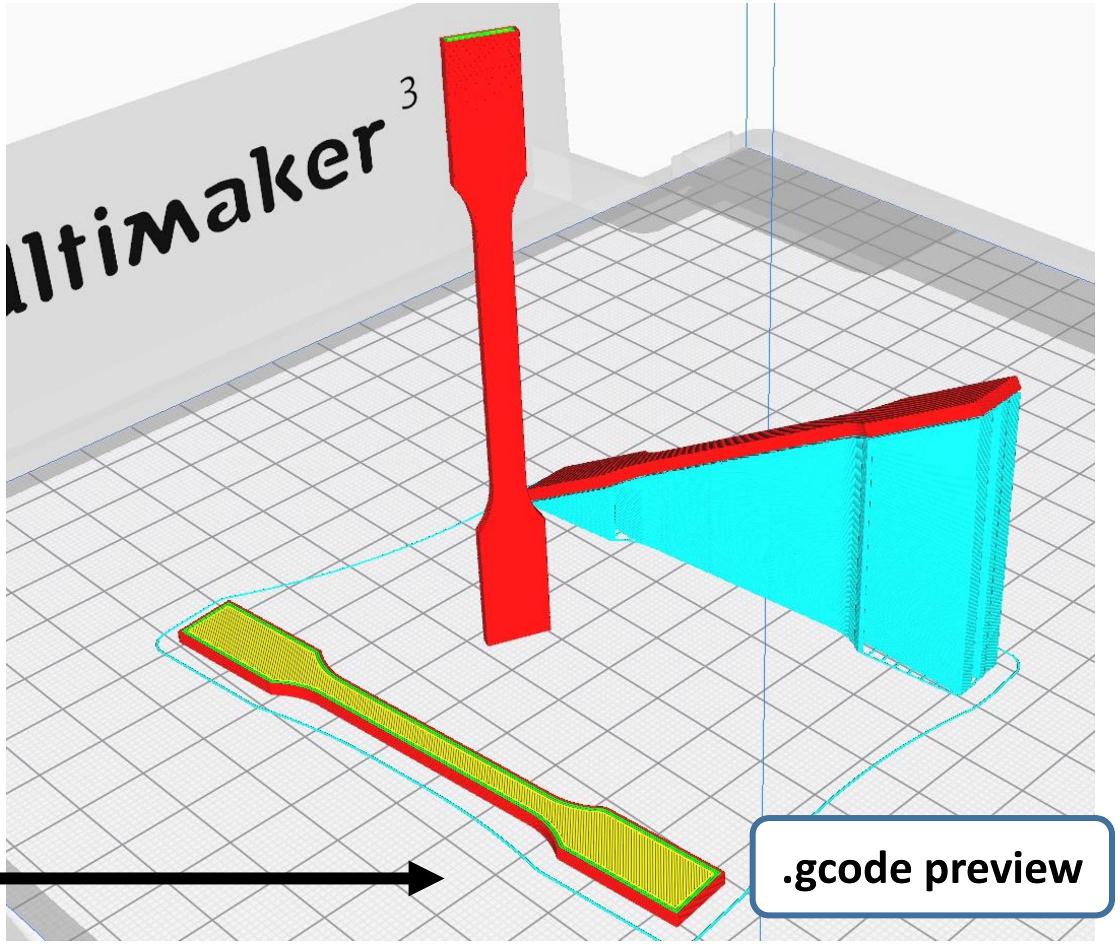
.stl fine settings, **96 KB**

Slicing in Cura (.stl to .gcode)



Build orientation, overhangs, support structure





.STL files brought into Cura, different build orientations

Slicing operation and support generation

G-code – commands for the printer

```
G0 X12               ; move to 12mm on the X axis
G0 F1500             ; Set the feedrate to 1500mm/minute
G1 X90.6 Y13.8 E22.4 ; Move to 90.6mm on the X axis and 13.8mm on the Y axis while extruding 22.4mm of material
```

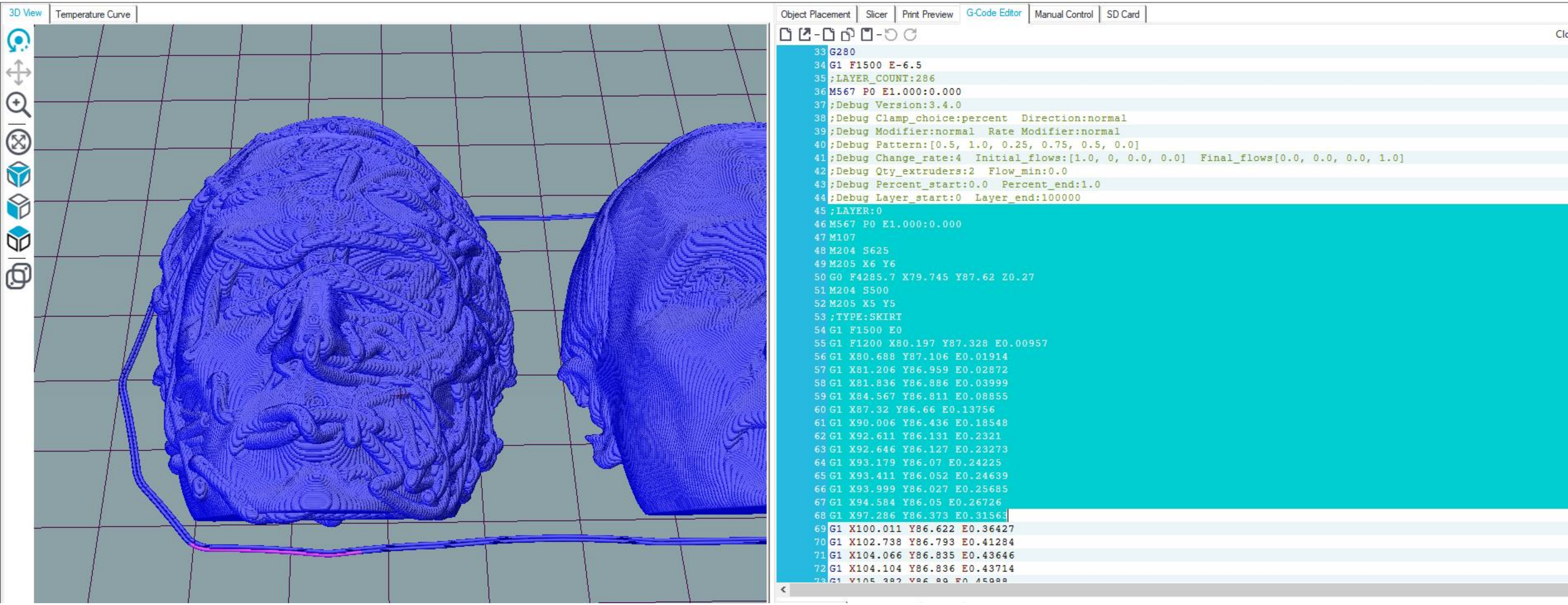
Some example G-code commands (RepRap):

G0 – rapid move
G1 – linear move
G28 – move to Origin (Home)

M109 – Set extruder temperature
M204 – Set default acceleration
… etc. refer to https://reprap.org/wiki/G-code

If you want to learn more about G-code and different ”flavours”: https://all3dp.com/g-code-tutorial-3d-printer-gcode-commands/, https://ultimaker.com/en/resources/20996-gcode-flavours-reprap-vs-ultigcode, https://reprap.org/wiki/G-code , https://marlinfw.org/meta/gcode/

G-code – commands for the printer



Those who are interested to better visualize, understand, and edit G-code, Repetier-Host: https://www.repetier.com/ (free)

Cura demo:

Software Overview &
preparing an .STL file for printing

Where to get 3D models?

The Internet is full of printable 3D files: maker communities, databases, 3D model shops: Google “3d models for printing” → **Thingiverse, Cults, Pinshape, GrabCAD, MyMiniFactory…**

- 3D scan an existing geometry for 3D printing

- 3D model your own parts
  - Ask a friend to 3D model for you
    - Pay a friend to 3D model ..
      - Pay a company to 3D model ..

3D Scanning for a printable model, video_10

https://formlabs.com/eu/blog/how-to-use-3d-scanning-and-3d-printing-for-reverse-engineering/

3D Modeling Software

BEGINNERS

TinkerCAD (free) - https://www.tinkercad.com/

Meshmixer (3D Sculpting and mesh modifications, free) - http://www.meshmixer.com/

FreeCAD - https://www.freecadweb.org/downloads.php

Autodesk Fusion 360 (free license for students and makers) - https://www.autodesk.com/campaigns/fusion-360-for-hobbyists

Onshape (cloud-based CAD) - https://www.onshape.com/education-plan

Solidworks, Creo, Siemens NX (Aalto student licence) - https://download.aalto.fi/student/

Blender (free, from mesh-based modeling to producing an animation movie) - https://www.blender.org/download/

Rhinoceros (Installed in some ARTS computer classes, Grasshopper included for algorithmic design)

ADVANCED

Autodesk Netfabb, **Altair Inspire** (Lattice design and topology optimization, student licenses available on request)

Options for programmatic 3D modeling: **OpenSCAD, ImplicitCAD, Matlab,** https://www.3dhubs.com/knowledge-base/key-design-considerations-3d-printing/#process-specific-guidelines

DESIGN RULES FOR 3D PRINTING

3D HUBS

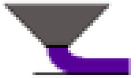
	Supported Walls	Unsupported Walls	Support & Overhangs	Embossed & Engraved Details	Horizontal Bridges	Holes	Connecting /Moving Parts	Escape Holes	Minimum Features	Pin Diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
Fused Deposition Modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective Laser Sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material Jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder Jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct Metal Laser			support	0.1 mm wide							

“Just press play and pick the finished part later”

3D Printing Troubleshooting :

Nozzle Height & Build Plate Adhesion

Too High



Too much distance will cause the filament to extrude into the air. This is wil not stick to the bed.

Perfect

The tip of the nozzle is adding slight pressure to the top of the filament, greatly increasing how much filament is securely sticking to the bed and subsequent layers.

Too Low

The filament is not flowing properly, which can cause retrograde extrusion. Layers are predominantly choppy and short. Continued printing in this manner will likely cause a jam.

https://www.matterhackers.com/articles/how-to-clear-and-prevent-jams

Under- / over extrusion

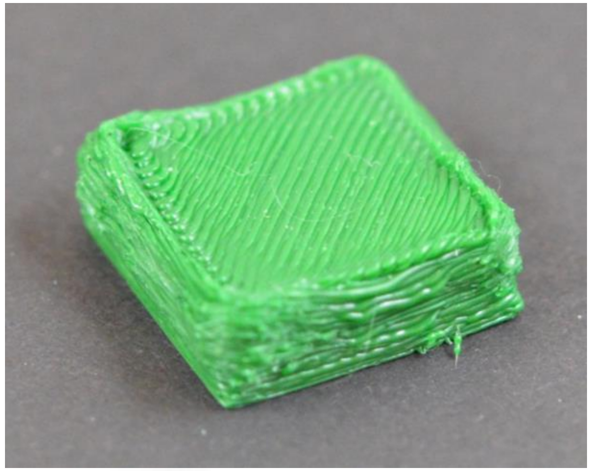
Not enough / too much material flow

Good material flow is a balance between nozzle diameter, print speed, temperature, and material flow rate

> double-check the Cura settings

Might be caused by feeder issues, or a clogged hot-end

> Use another Ultimaker and report a problem to the ADDLAB staff



https://ultimaker.com/en/resources/21477-how-to-fix-under-extrusion

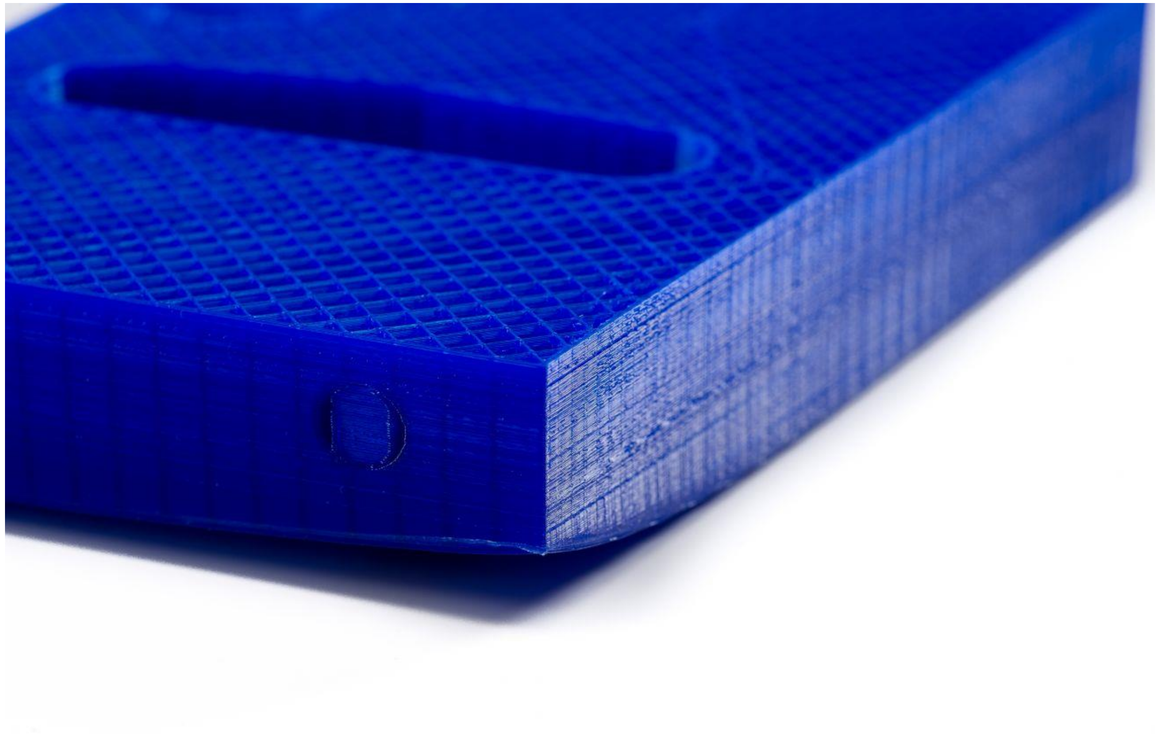
Warping

Caused by material shrinkage

Avoidable with good build plate leveling, adhesion to the plate (first layers), and proper but not excessive cooling.

A ‘brim’ or a ‘raft’ can help (See Cura settings)

Large, flat 3D designs will warp more likely !



Stringing

Caused by material leaking during print head travel moves.

Affected by printing temperature (higher strings more), print speed (+ travel speed) and 'retraction' settings

'Retraction' means a small recoil, or counter movement. The extruder will drive back filament to prevent leaking.

https://ultimaker.com/en/resources/19504-how-to-fix-stringing

Filament skipping or grinding

Feeder spring tension either too low or too high

Too many retraction moves (in a complex print) can cause grinding

Too low nozzle temperature : material is not properly melted and more pressure is required to push the filament => grinding

Online help

https://community.ultimaker.com/

https://rigid.ink/pages/ultimate-troubleshooting-guide

YouTube tutorials

ADDLAB and 3D Printers

Booking the Ultimakers

After the workshop you will be given access to a google calendar to check which printers are available and make reservations.

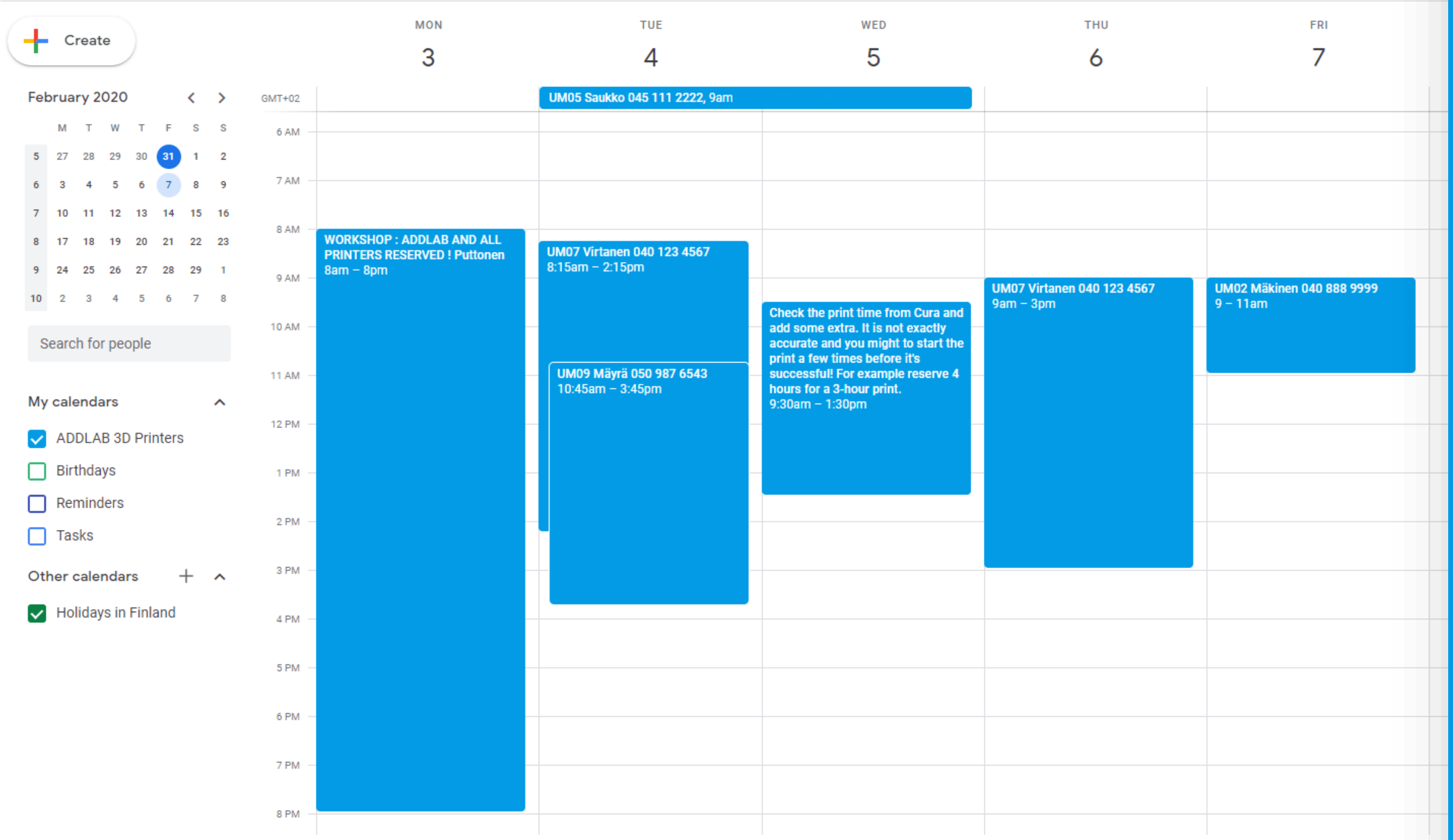
Write (clearly) your email in the participation list, I will send a link to join the calendar.

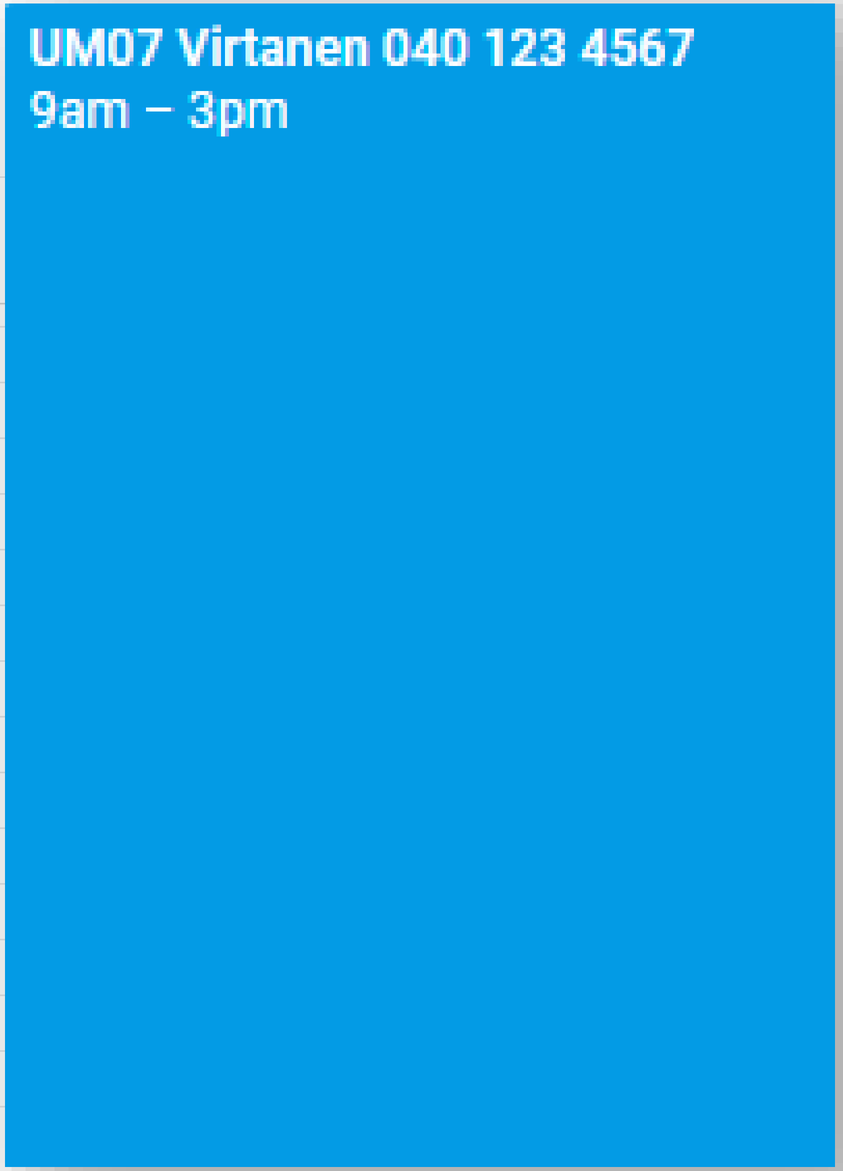
To reserve a printer for a time slot, simply add a calendar entry with:

The printer number, your name, your phone number :

UM22_Bond_James_040xxxxxxx

Booking the Ultimakers





ADDLAB - code of conduct

https://www.amazon.com/BEWARE-Guard-Dog-Duty-Sign/dp/B004QVRV2Y

Treat everyone and everything respectfully :)

Don’t make a mess

Return all tools to their own places

Report broken things

Ask and give help

Minimize the amount of new plastic waste to the world

Learn more about 3D Printing

- Go to **ADDLAB**, 3D print more, and learn by doing
- MEC-7006 Advanced Manufacturing course (5 credits), organized every Spring
- https://ultimaker.com/en/resources/education/getting-started-with-an-ultimaker
- https://www.youtube.com/user/Ultimaker3D/videos and numerous other info / tutorial videos on YouTube
- **Redwood, B., Schffer, F., & Garret, B. (2017).** *The 3D printing handbook: technologies, design and applications*. 3D Hubs.

Scientific sources:

- **Gibson, I., Rosen, D. W., & Stucker, B. (2014).** *Additive manufacturing technologies*. New York: Springer.
- **Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T., & Hui, D. (2018).** Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering*, *143*, 172-196.12-224.
- **DebRoy, T., Wei, H. L., Zuback, J. S., Mukherjee, T., Elmer, J. W., Milewski, J. O., ... & Zhang, W. (2018).** Additive manufacturing of metallic components–process, structure and properties. *Progress in Materials Science*, *92*, 1
- https://scholar.google.com/ and search ‘additive manufacturing’

Assignment

Assignment (1 credit)

Reserve an ADDLab 3D printer with the Google Calendar, 3D print a part and prepare a short report (max 1-2 pages) where you have:

- A screenshot of the part from the Cura slicer software (Preview mode) with the print orientation and main print parameters visible
- A picture of the finished part

1. What is the part and its function?

2. Were there any difficulties or problems during printing and how did you solve them?

3. Give a few examples how you could reduce the printing time of the part (via adjusting Cura parameters or part 3D design)?

Send to Kirsi.kukko@aalto.fi with the title *"ENG-A1009 Assignment_your name"* –deadline is 11.4.2022