ENG-A1009
Practical Work Training with 3D printers

Schedule

9:15 – 11:30 Lecture Brief background on 3D printing and different technologies

Digital steps: Cura demo

11:30 – 13:00 Lunch break

13:00 – 17:00 Practical session (Sign up required)

@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

+

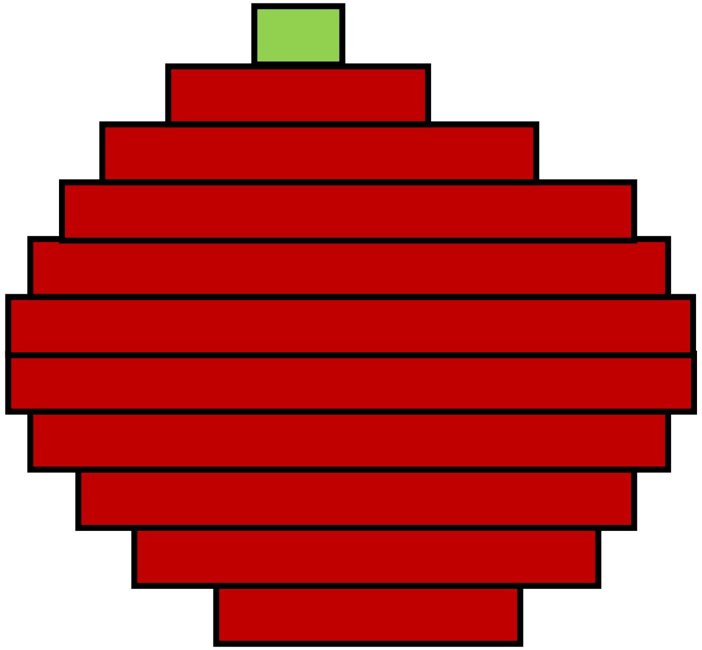
For 1 ECTS credit :

Small assignment given at the end of the lecture

NOTE: The access to an online calendar to schedule the ADDLAB 3D printers for personal projects **is ONLY given to those who have gained 1 ECTS**.

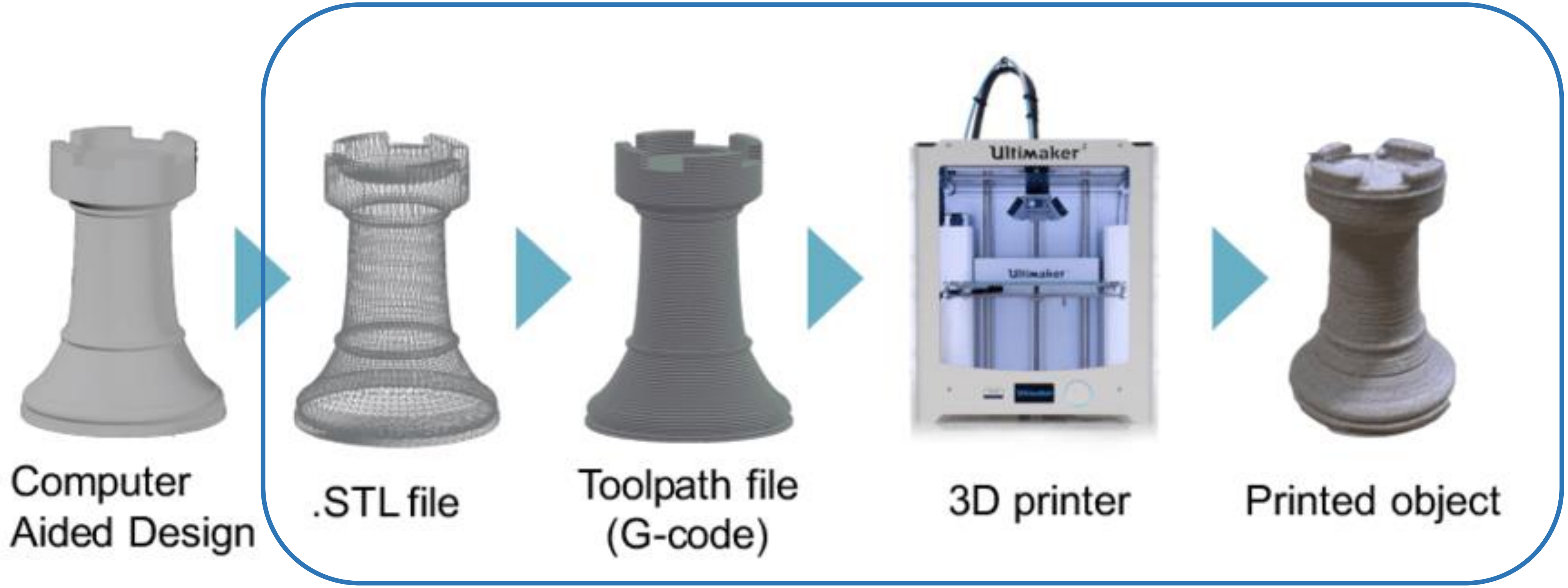
What is 3D printing and what to do with it?

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

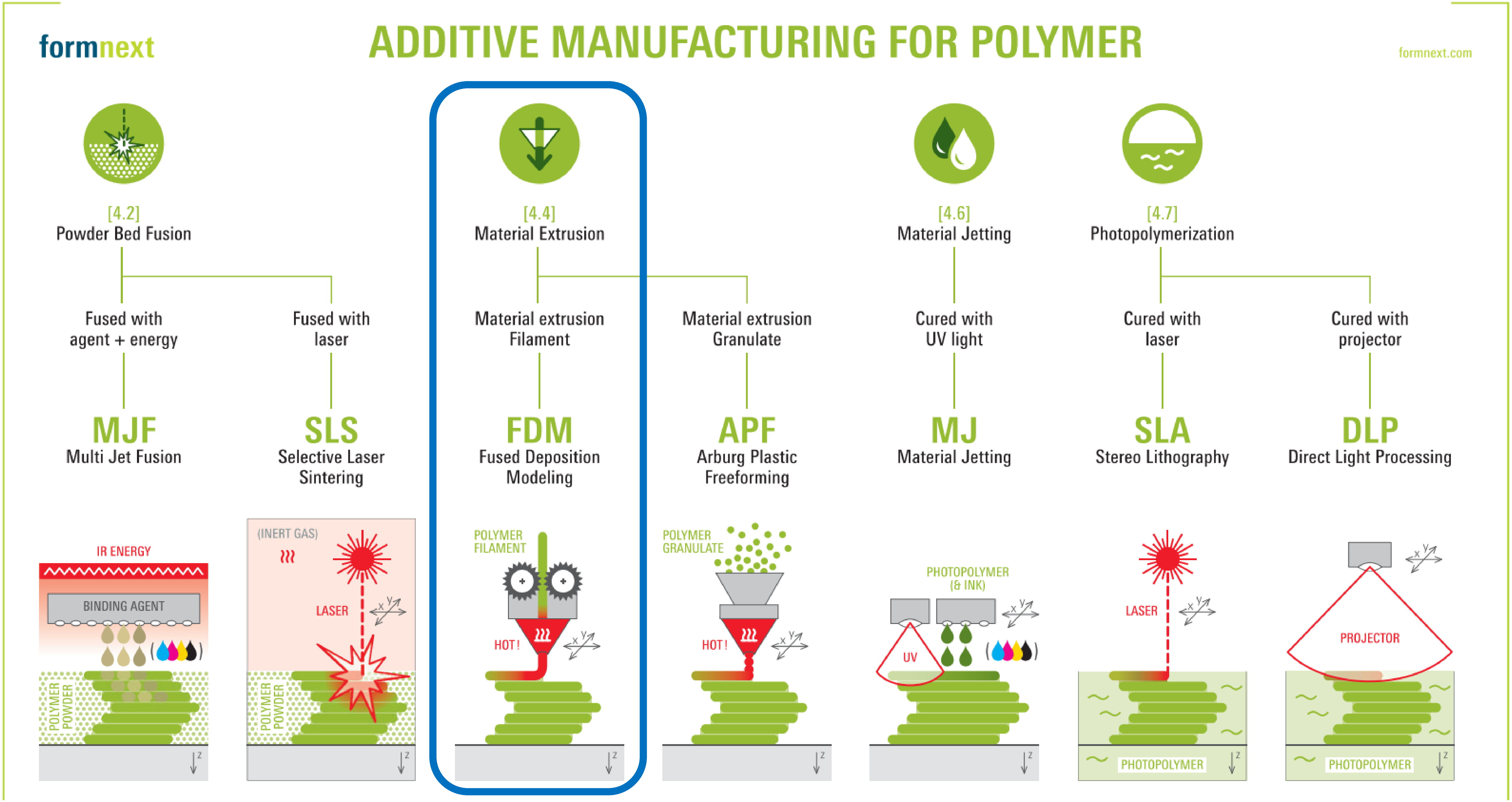
Cura slicing software, 2D slices out of 3D

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/



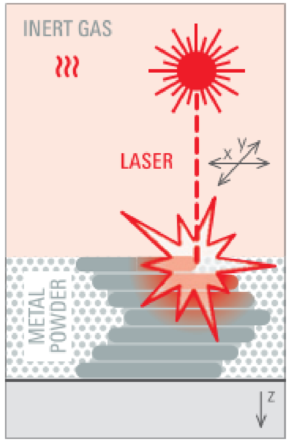
"Formnext 2019 – AM Field Guide Compact" formnext

ADDITIVE MANUFACTURING FOR METAL

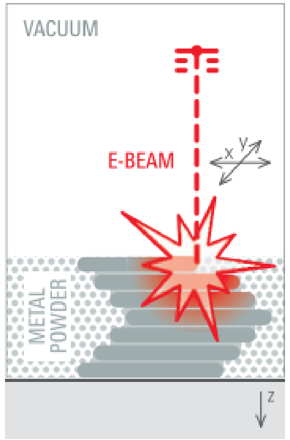
formnext.com

[4.2] Powder Bed Fusion

- Fused with laser → **SLM** – Selective Laser Melting

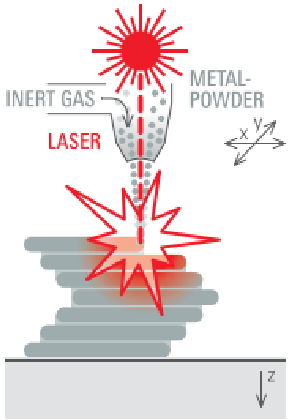


- Fused with electron beam → **EBM** – Electron Beam Melting

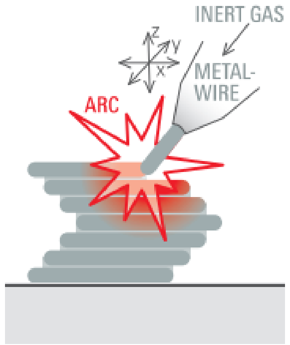


[4.3] Direct Energy Deposition

- Fused with laser → **LENS** – Laser Engineering Net Shape

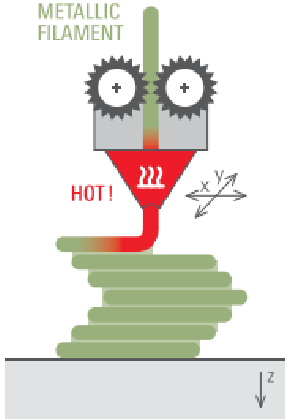


- Fused with electric arc → **WAAM** – Wire and Arc Additive Manufacturing



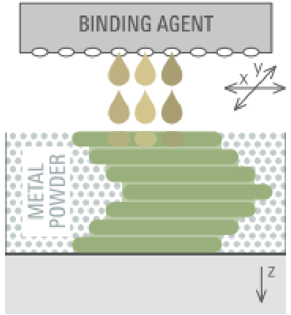
[4.4] Material Extrusion

- Green part is printed to be sintered afterwards → **FDM** – Fused Deposition Modeling



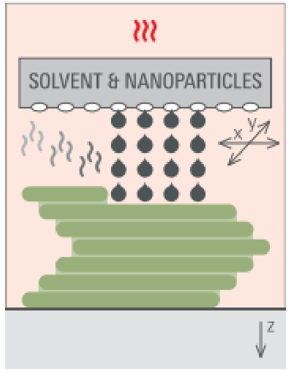
[4.5] Binder Jetting

- Joined with bonding agent to be sintered afterwards → **BJ** – Binder Jetting



[4.6] Material Jetting

- Cured with heat to be sintered afterwards → **NPJ** – Nano Particle Jetting



"Formnext 2019 – AM Field Guide Compact"

Photopolymerization

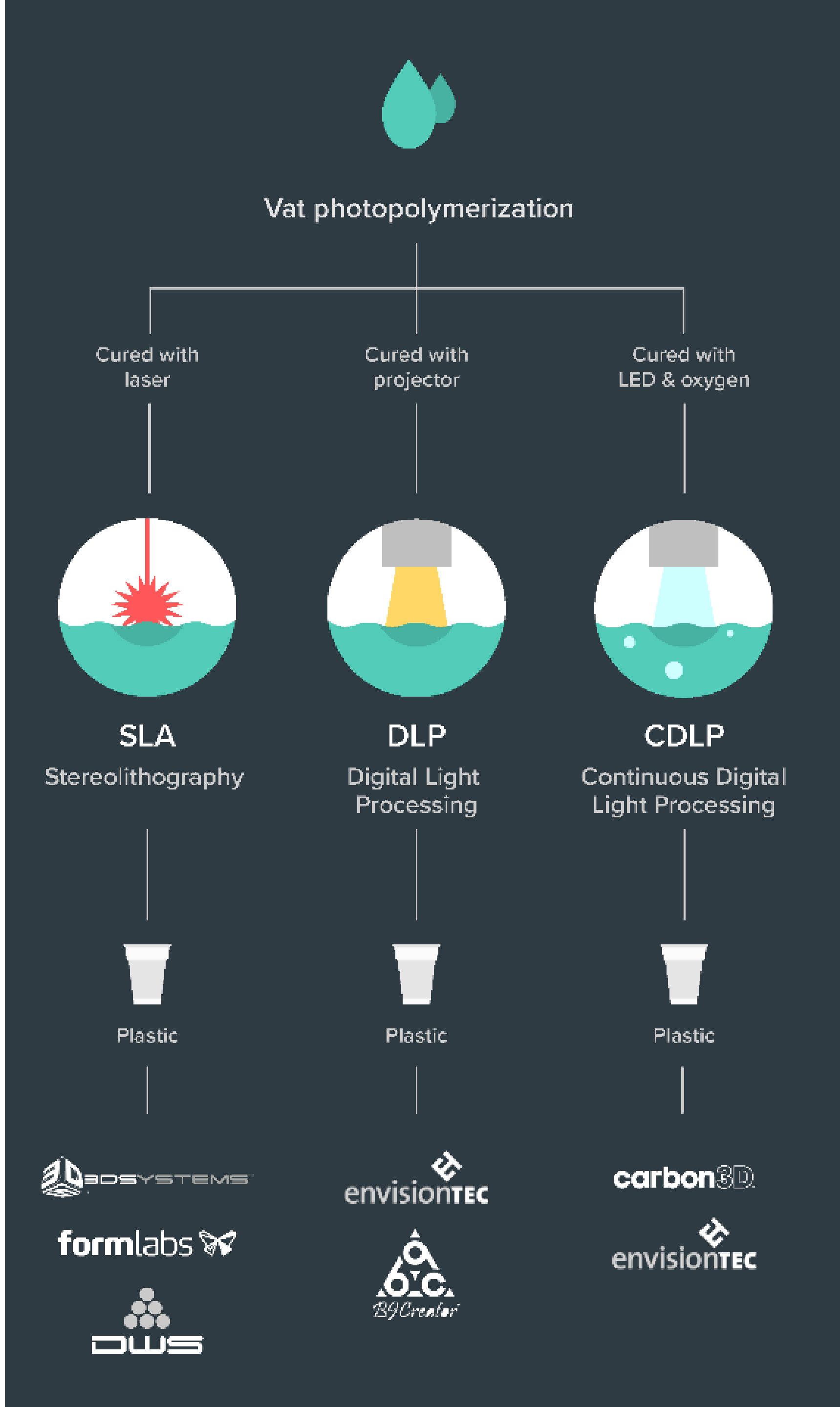
[Video 01]

Liquid photopolymers solidified with UV-light

The first 3D Printing technology (~1984)

Mostly used for prototyping and investment casting

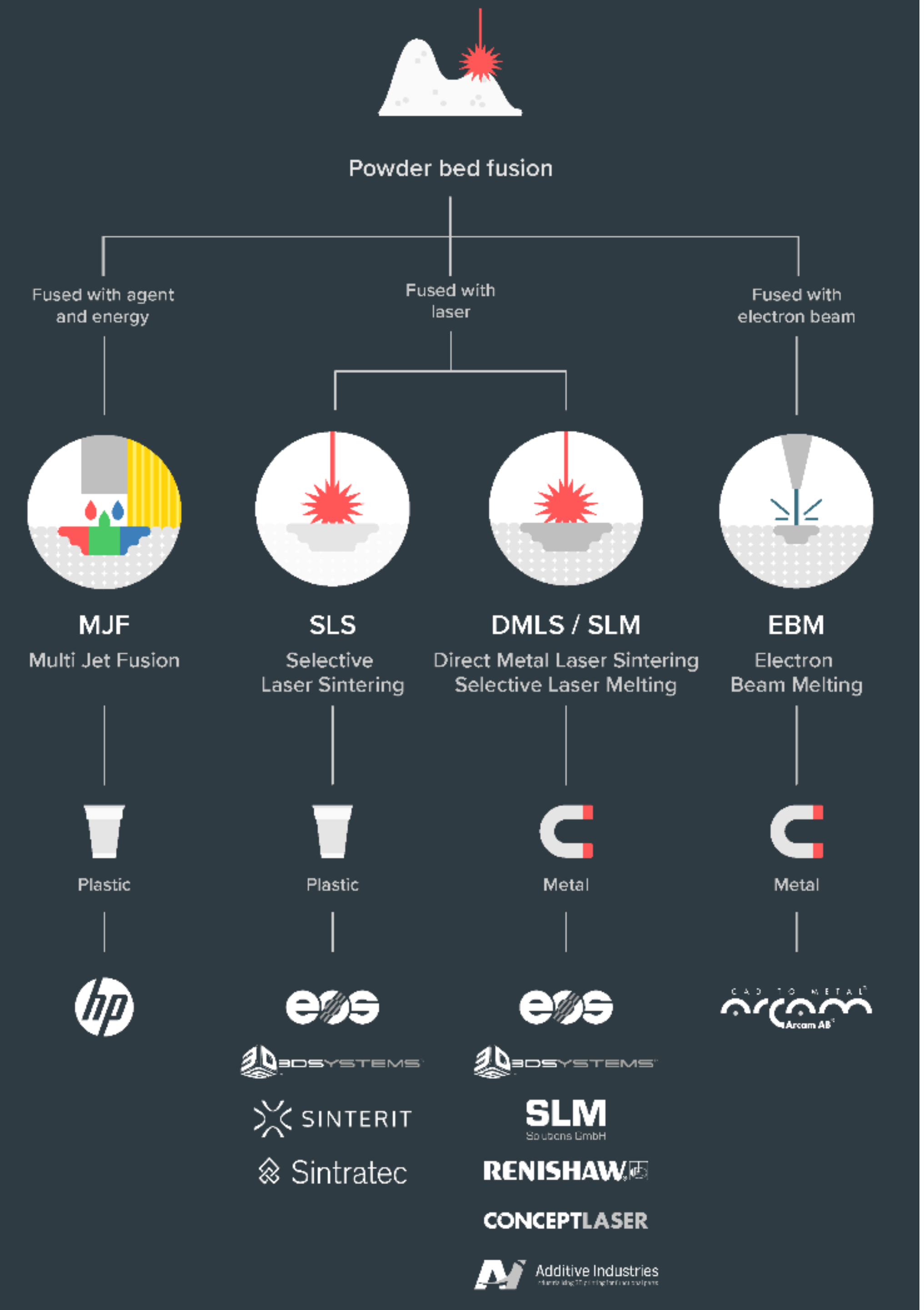
Often poor mechanical properties and parts will degrade in prolonged UV light



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]

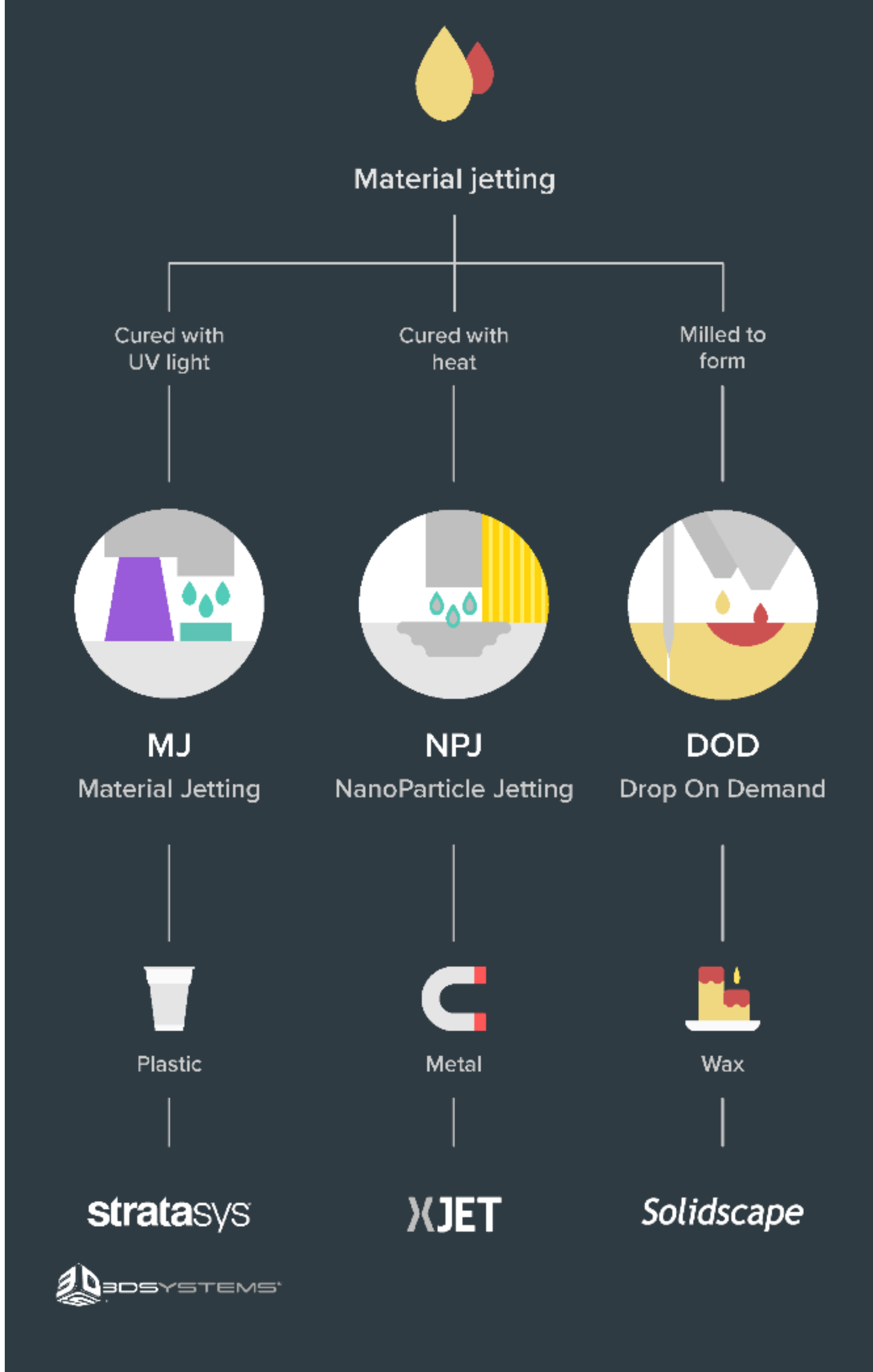
A cousin to photopolymerization : inkjet (2D printing tech) heads are used to drop small photopolymer droplets on the build platform which are then cured with a passing UV-light

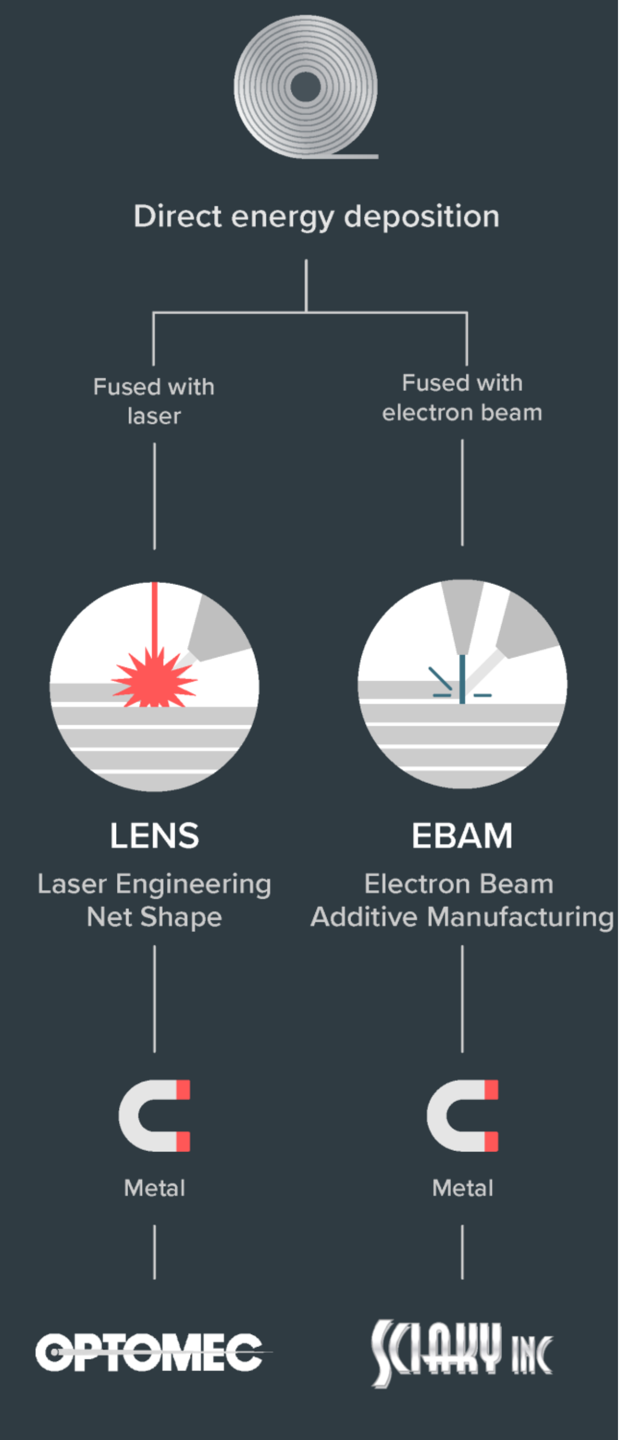
Multi-material possibilities

Very good resolution and fine features

Again poor mechanical properties and parts degrade with UV

Used for prototyping, medical models, and research





Direct 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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.

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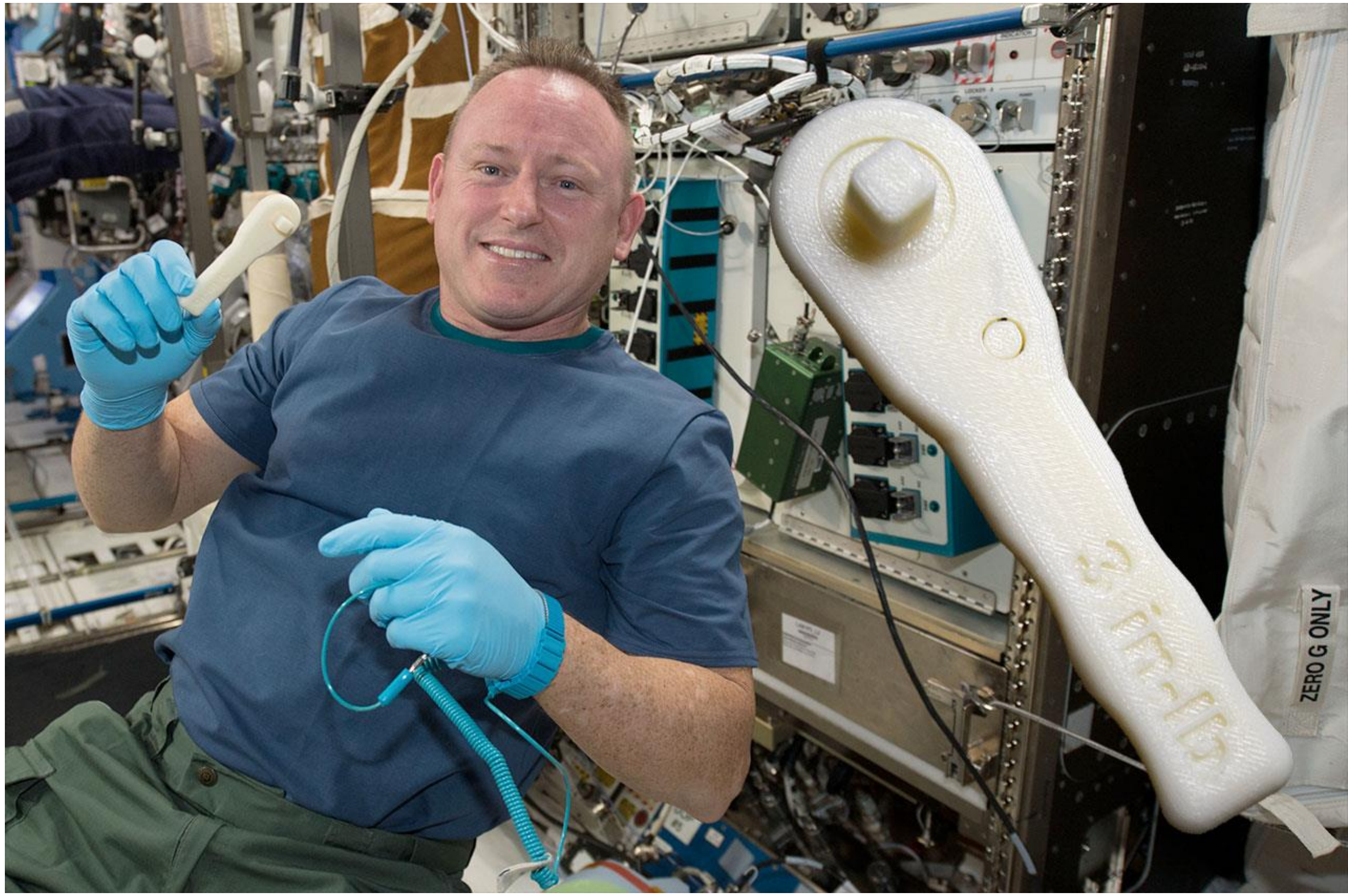
Let me fire up the *Refabricator.*

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

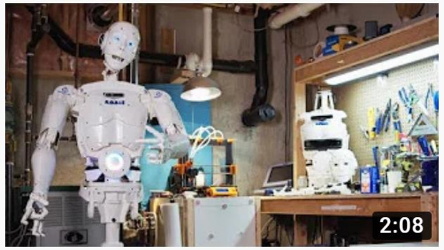
Decreasing Earth-dependance on manufacturing assets in space.



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

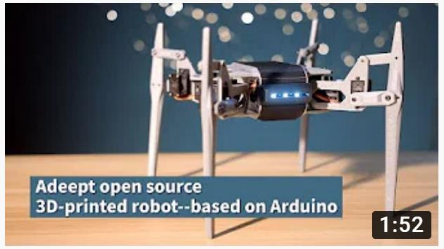


3D Printed Life-Size InMoov Robot

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

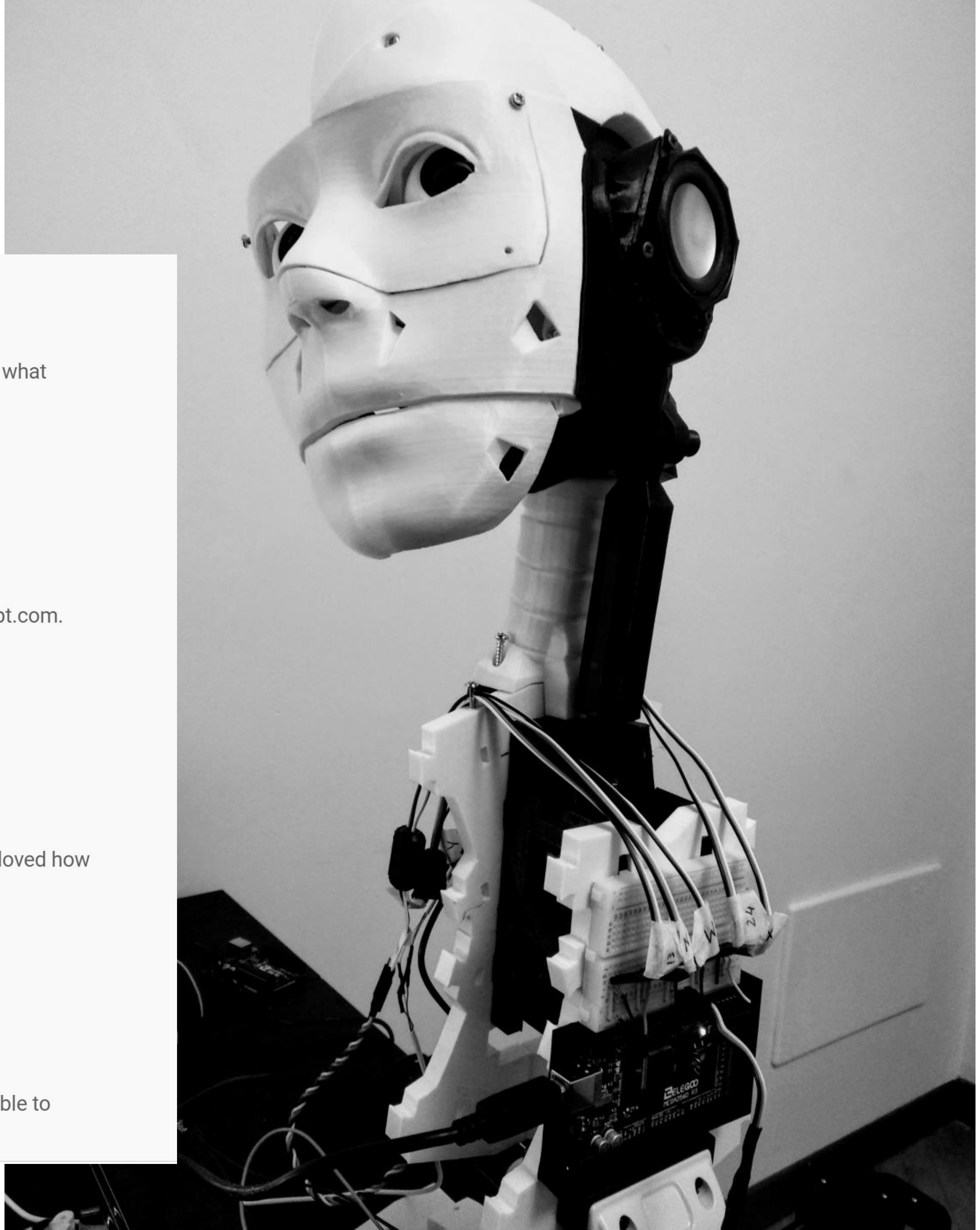
If you enjoyed the video please leave a like and consider subscribing for more. I have always loved how delta **robots** move and ...

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 ...

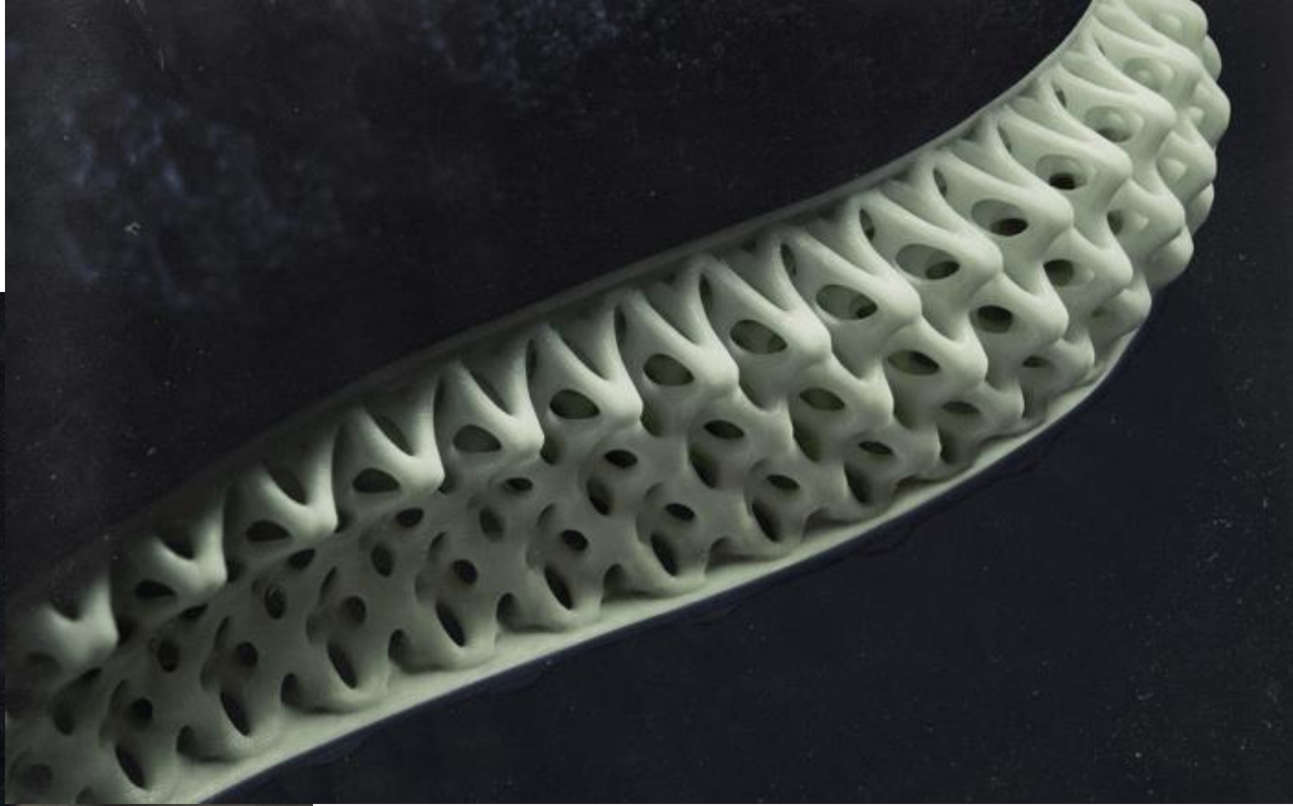
YouTube : some search results for “3d printed robot” published last year (2020)



Volkswagen : video_07
Jigs and fixtures to help assemble cars

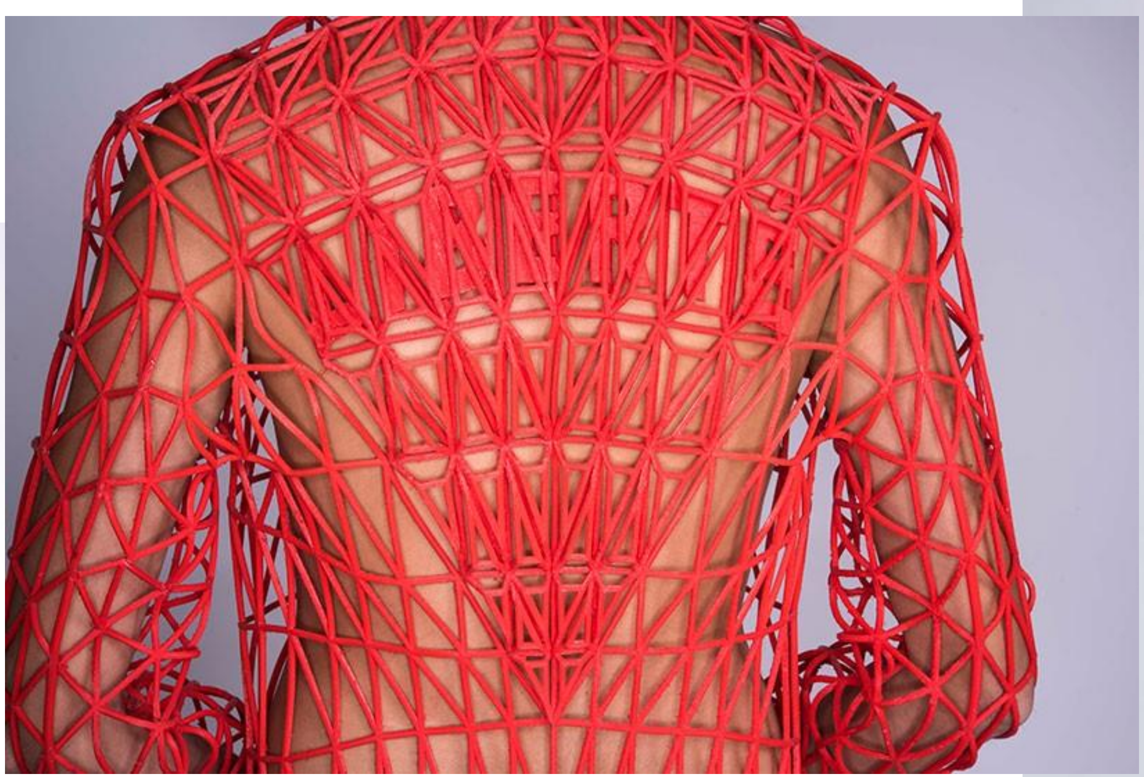
https://www.tctmagazine.com/can-you-jig-it-volkswagen-ultimaker-3d-printing/

Adidas



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

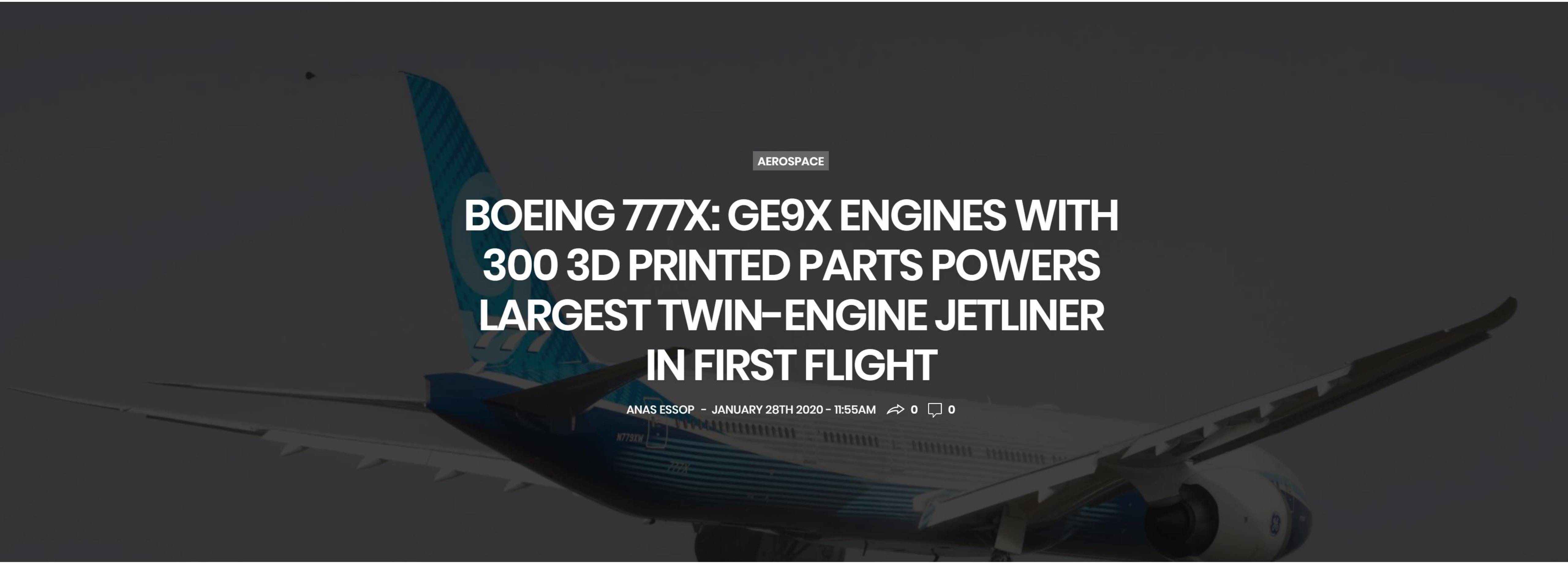
3D Printing in Fashion



Danit Pelege

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

Jet Engine Parts



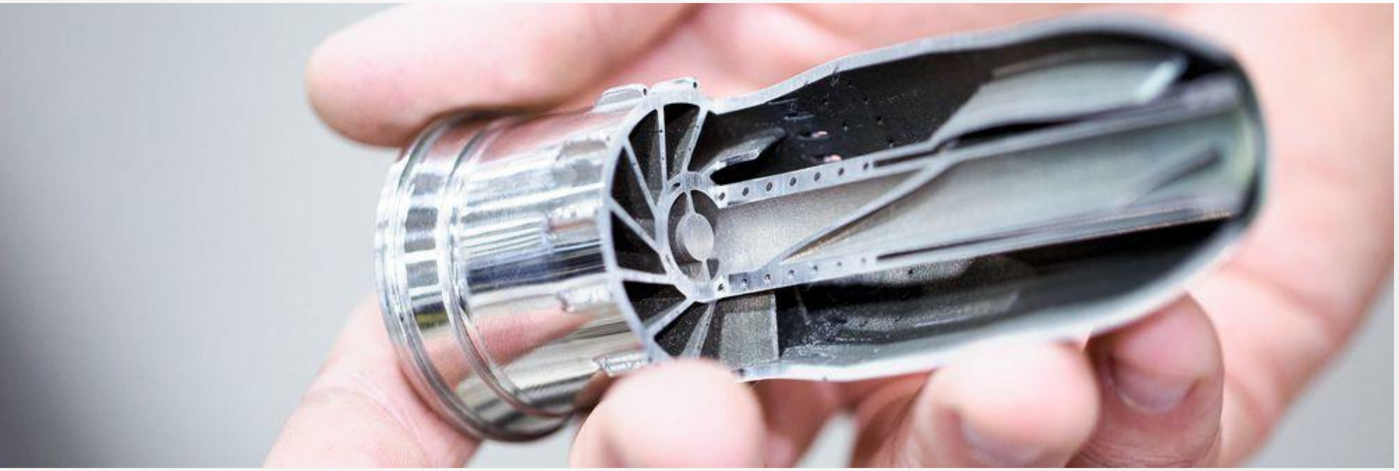
3D Printing Industry. Anas Essop. 2020. Boeing 777X: GE9X Engines with 300 3D Printed Parts Powers Largest Twin-Engine Jetliner in First Flight. Available at: https://3dprintingindustry.com/news/, Accessed 30.1.2020

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/

Glass / Ceramics / Concrete 3D printing

Neri Oxman

Ashish Mohite

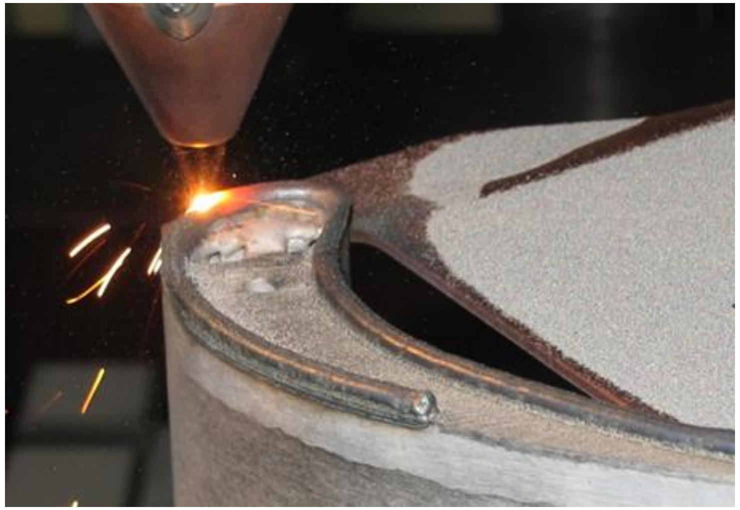
Company ‘Concreative’

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

3D printed house in Dubai

Eco-sustainable 3D printed house (local and recycled materials) - Tecla, 3D printed by WASP
https://www.youtube.com/watch?v=w9sXqxccRPM&t=12s

Repair of blades

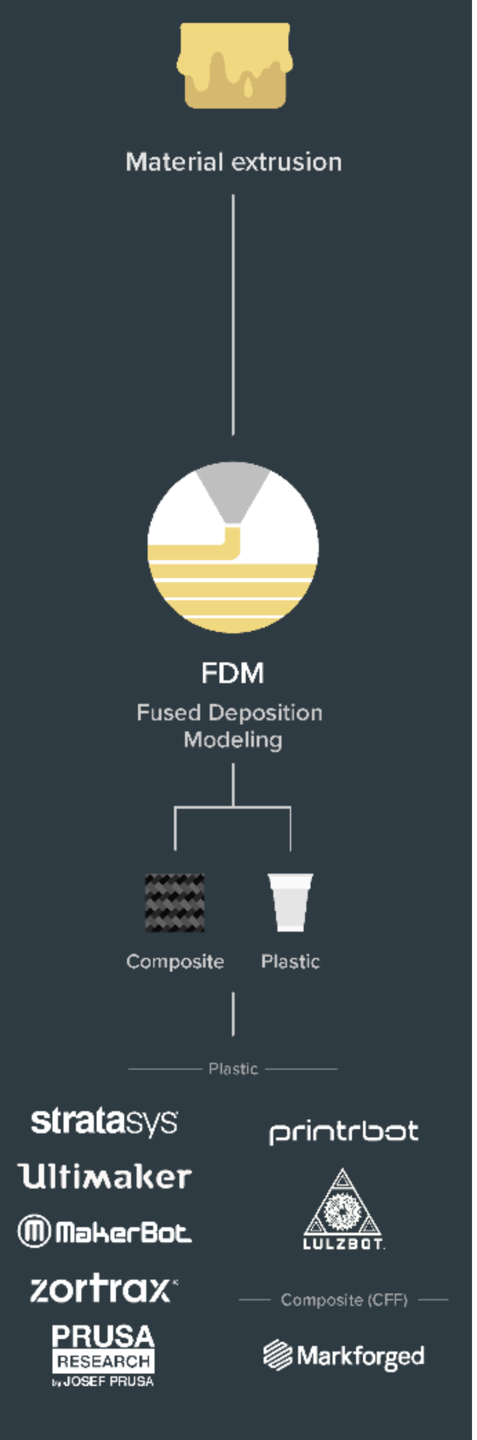


Repairing blades of different kinds is a common application of DED. The worn tips are regrown and machined to shape.

Sources: https://www.oerlikon.com/metco/en/products-services/coating-services/coating-services-laser-cladding/component-manufacturing-and-repair//

Material extrusion

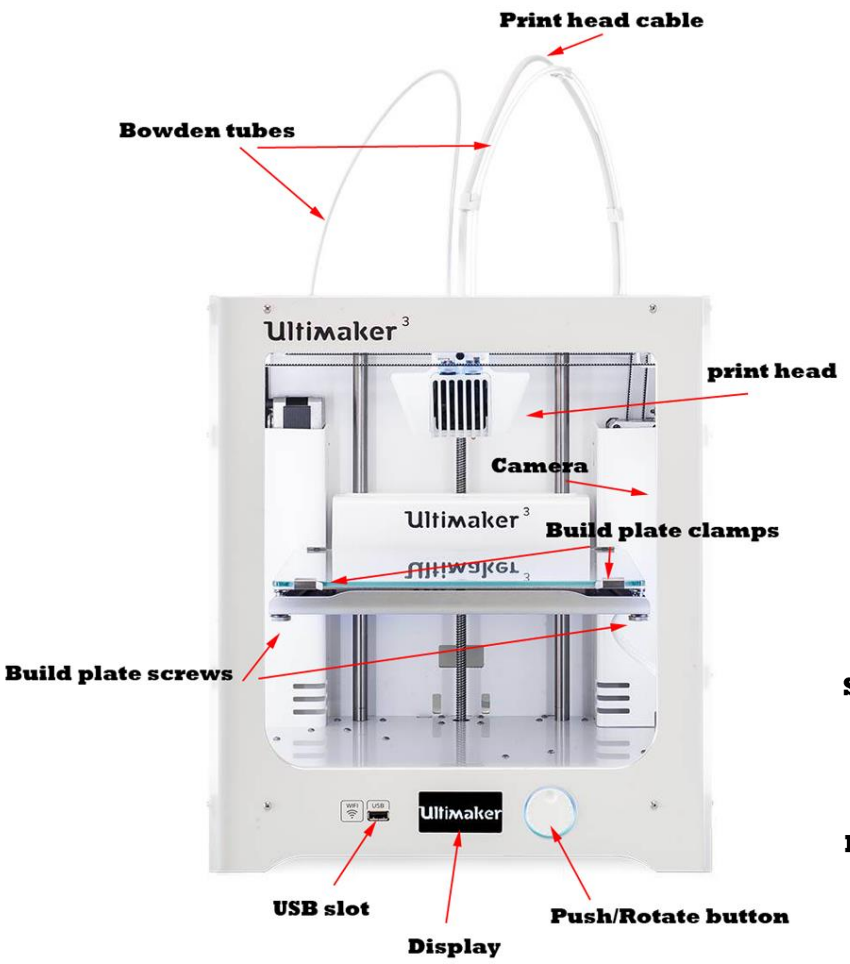
Material Extrusion (FDM)

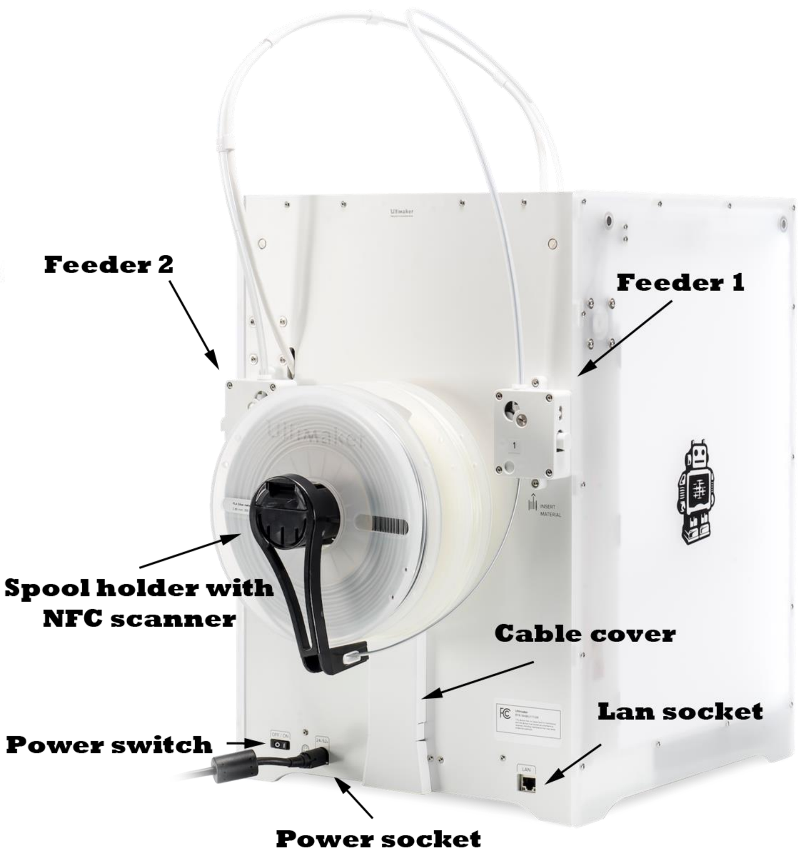


https://www.3dhubs.com/get/am-technologies/

Material Extrusion (FDM) – video_08

Ultimaker – what is what





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

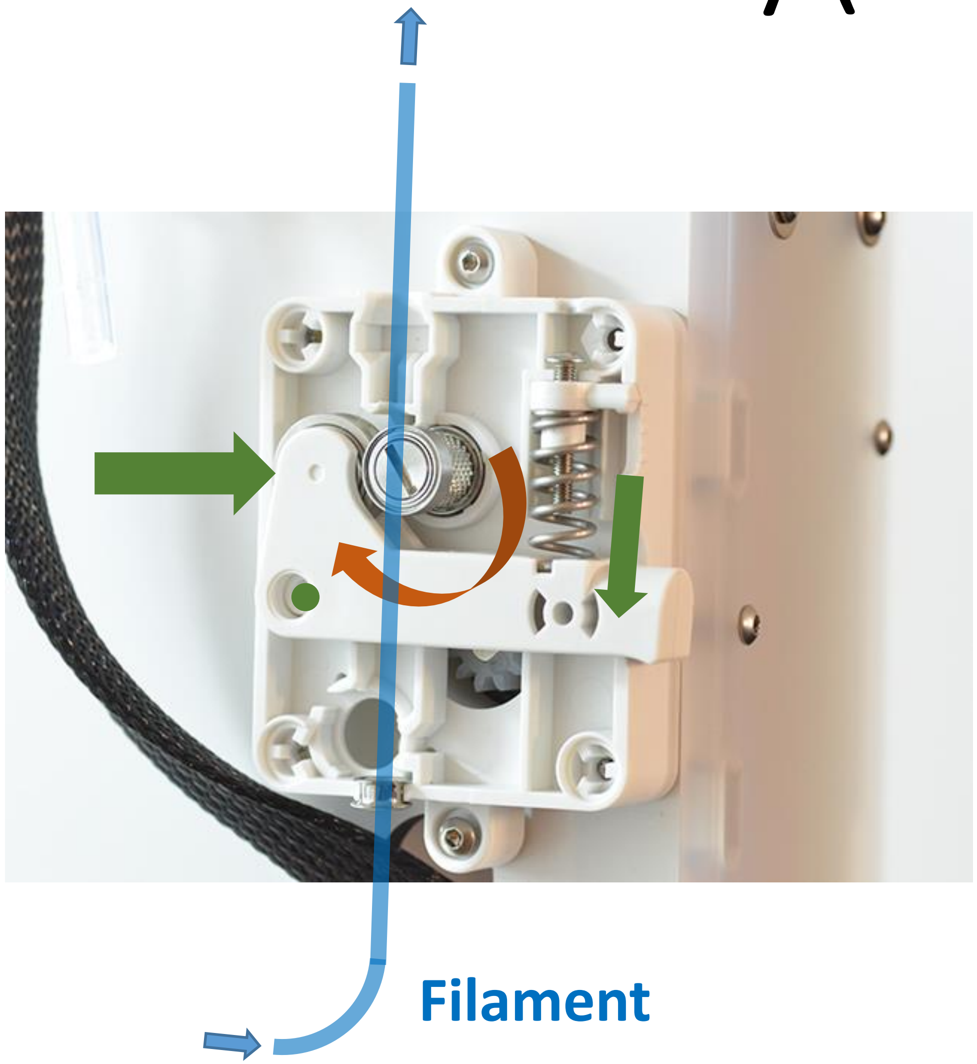
Ultimaker 2:
https://ultimaker.com/en/resources/22131-anatomy-of-an-ultimaker-2

Material Extrusion Systems

Main differences:

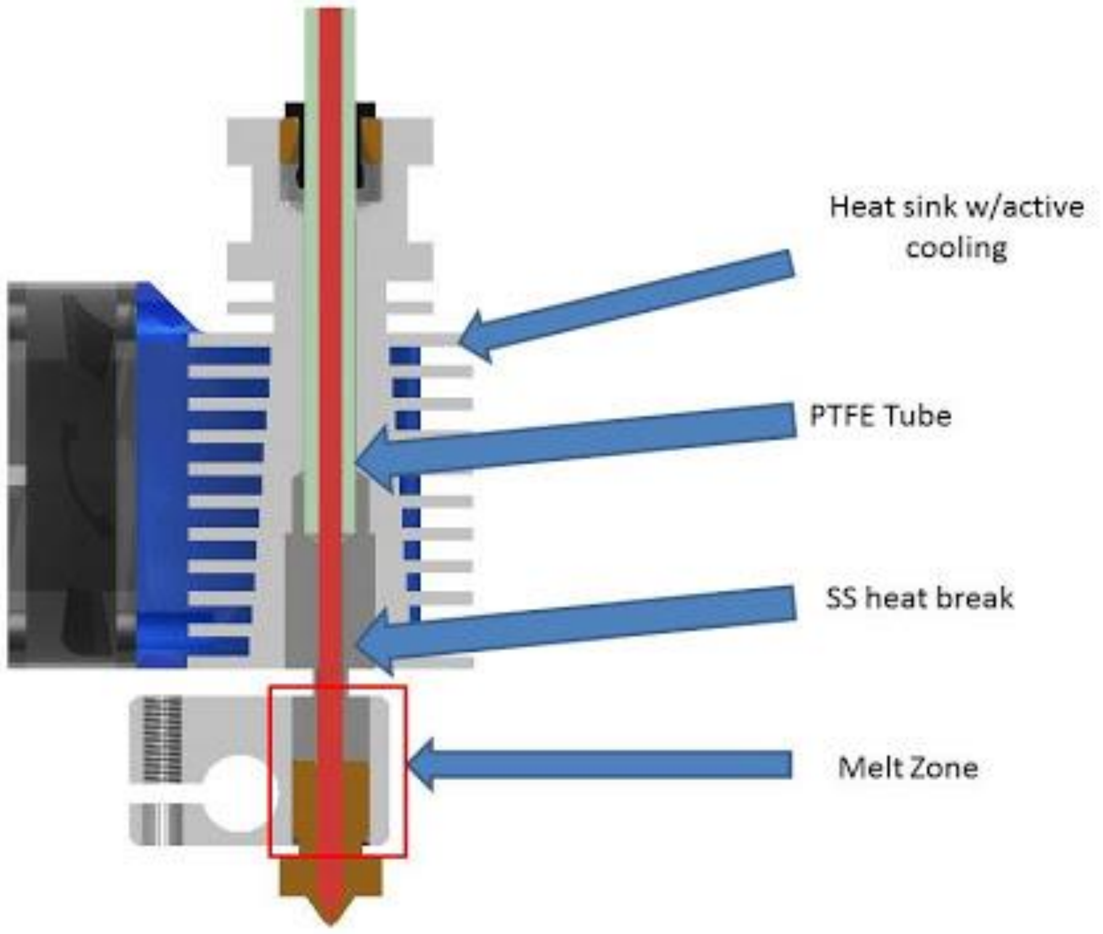
- Movement of the extruder, the build plate or both: *Cartesian or polar coordinates, delta arrangement or with an industrial robot*
- *Extruder type; filament-, plunger- and screw-based*
- *Bowden* or *Direct* extruder
- *Open* or *Closed* build volume
- No heating, Heated build plate and/or heated 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

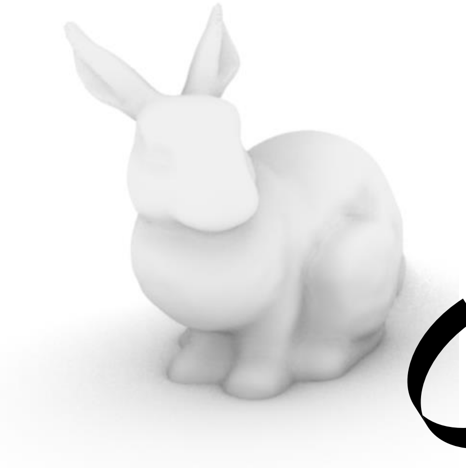
Extruder assembly (example)



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

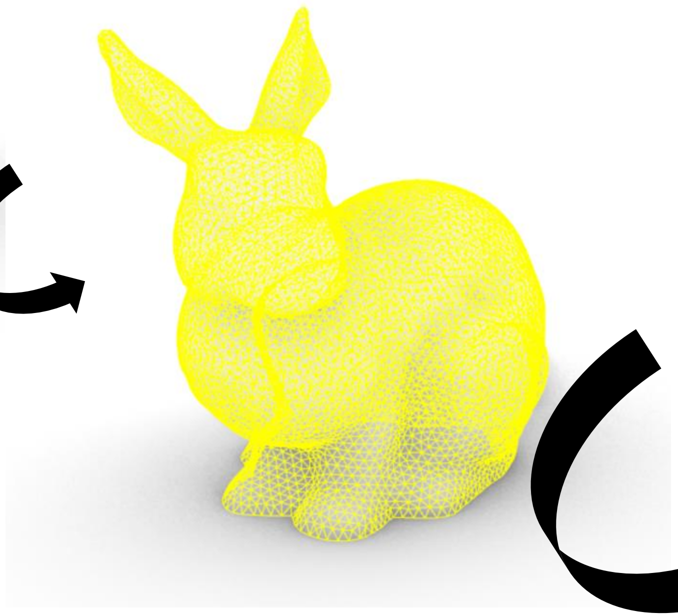
Digital workflow, software & design

From 3D model to printable file



1. **Original 3D model**

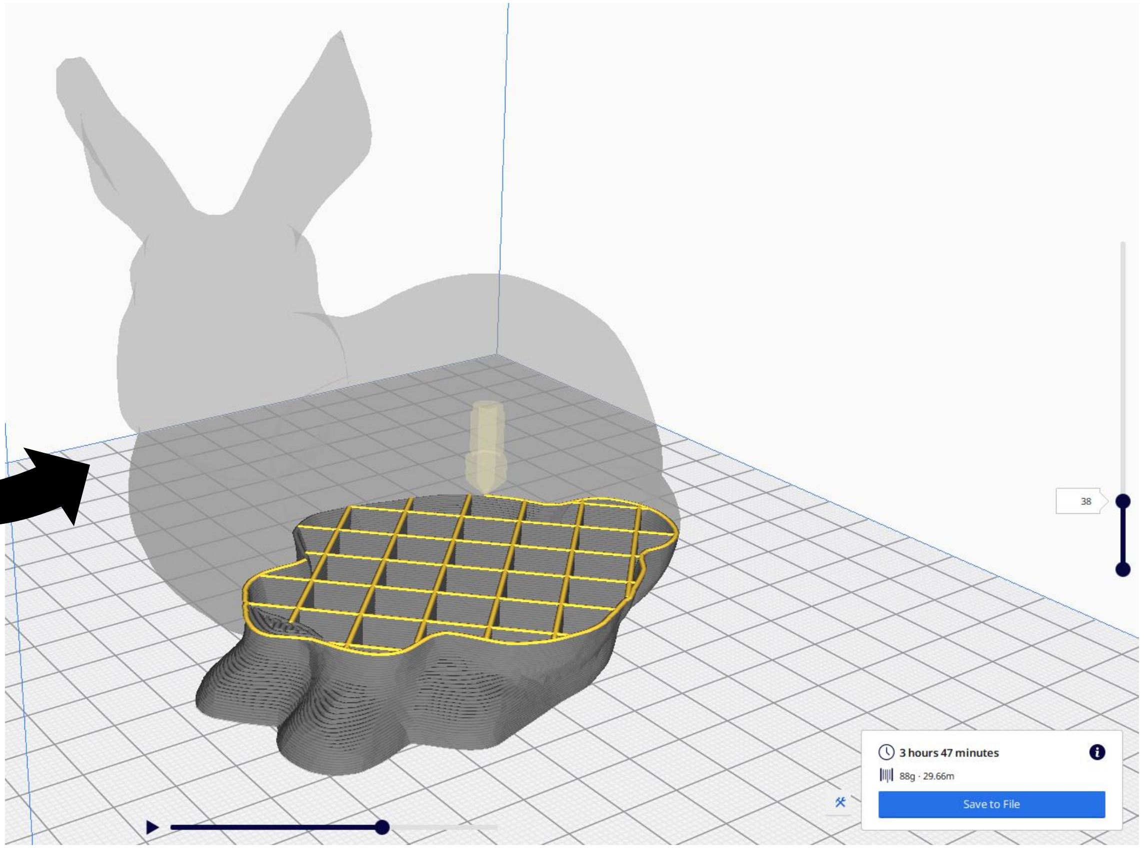
File format examples:
.OBJ, .STEP, .IGES, .PRT, .SLDPRT, …



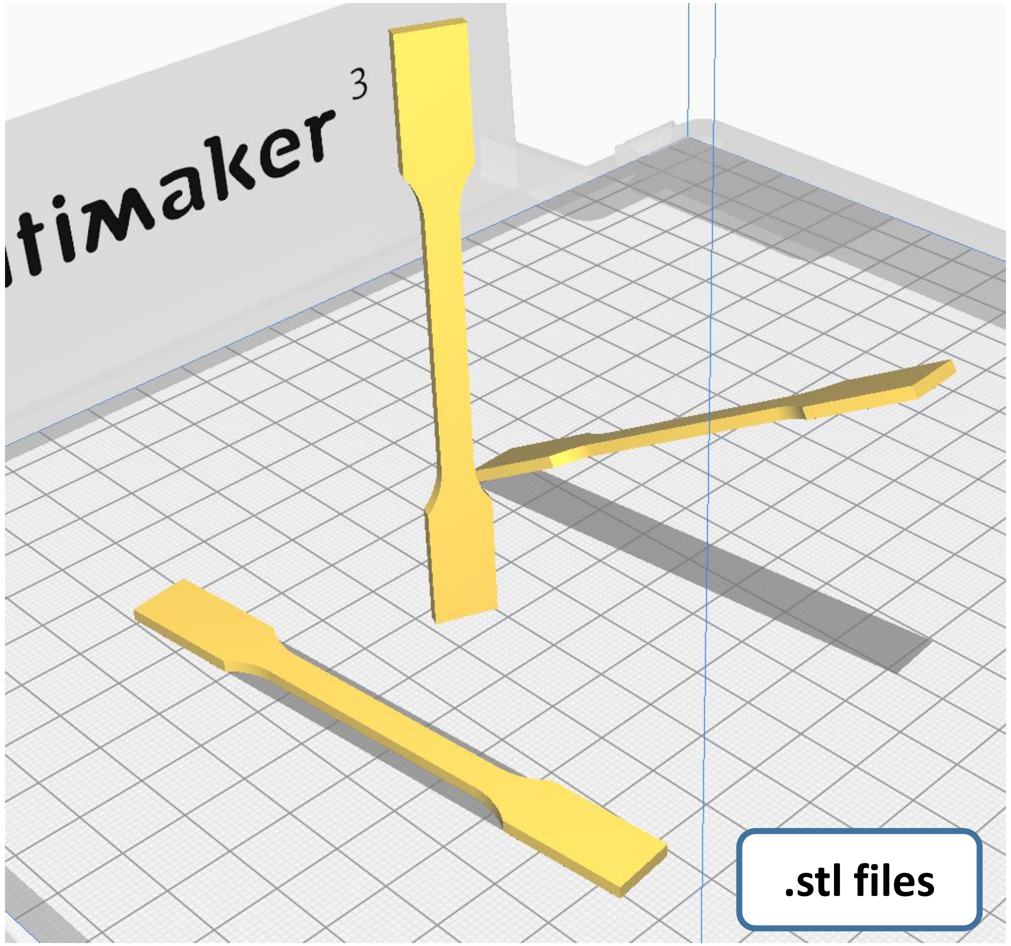
2. STL conversion
Standard **T**riangle/ **T**essellation **L**anguage

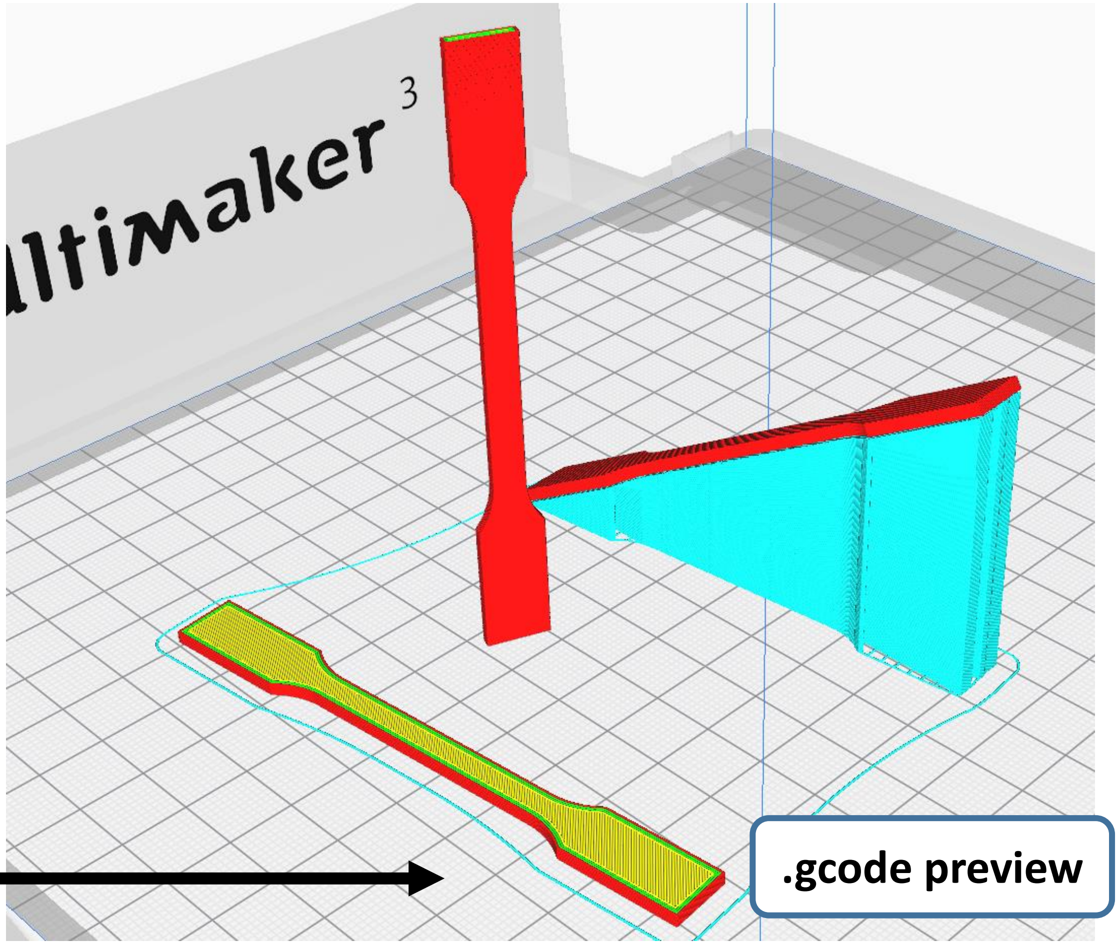
Current industry standard for 3D printing

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



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
```

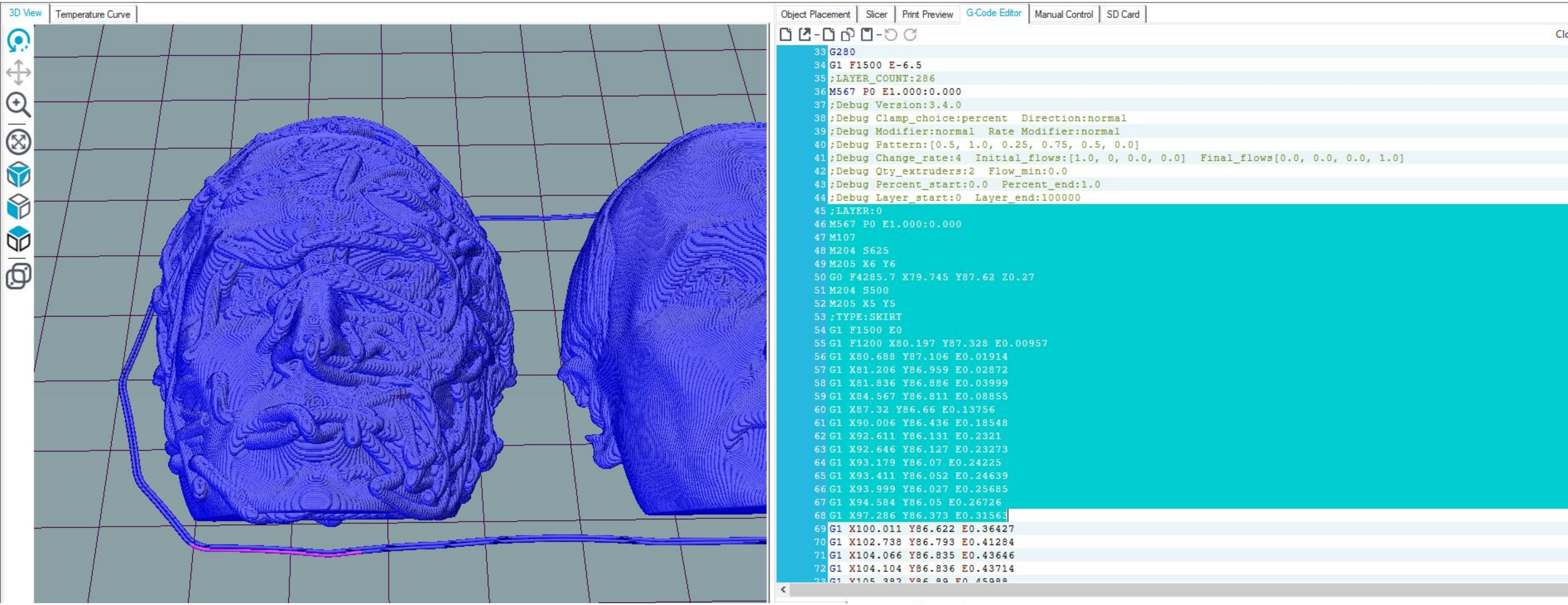
Some example G-code commands (RepRap):

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_09

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

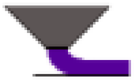
DESIGN RULES FOR 3D PRINTING

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 Sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm

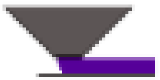
Nozzle Height & Build Plate Adhesion

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

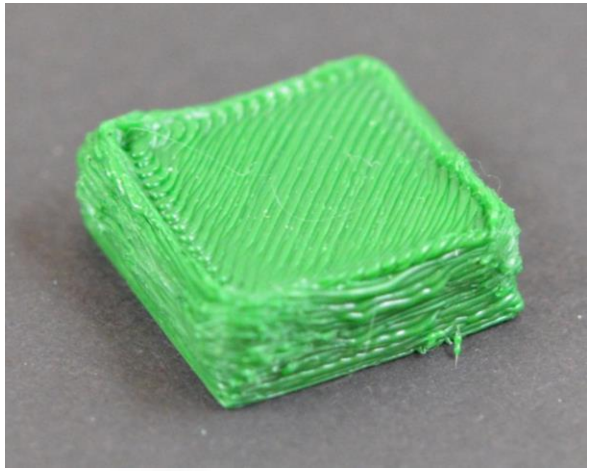
Not enough / too much material flow

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

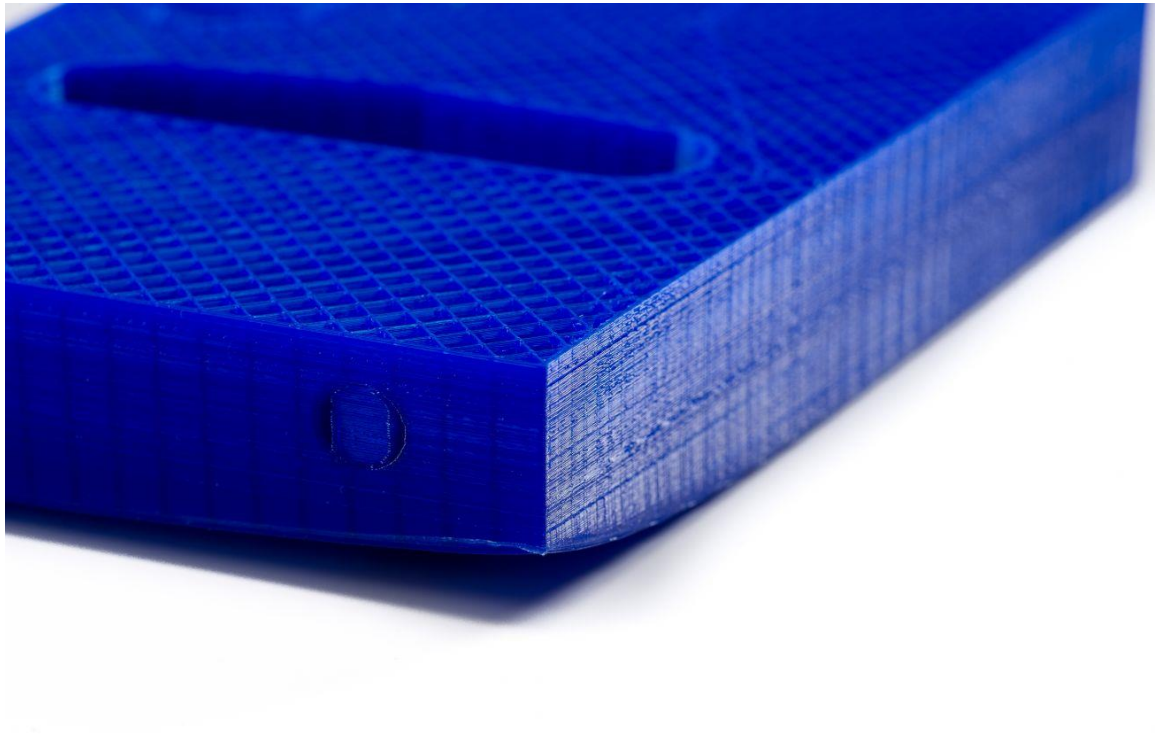
Warping

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

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 “ADD DMF Google Calendar” to check which printers are available and make reservations.

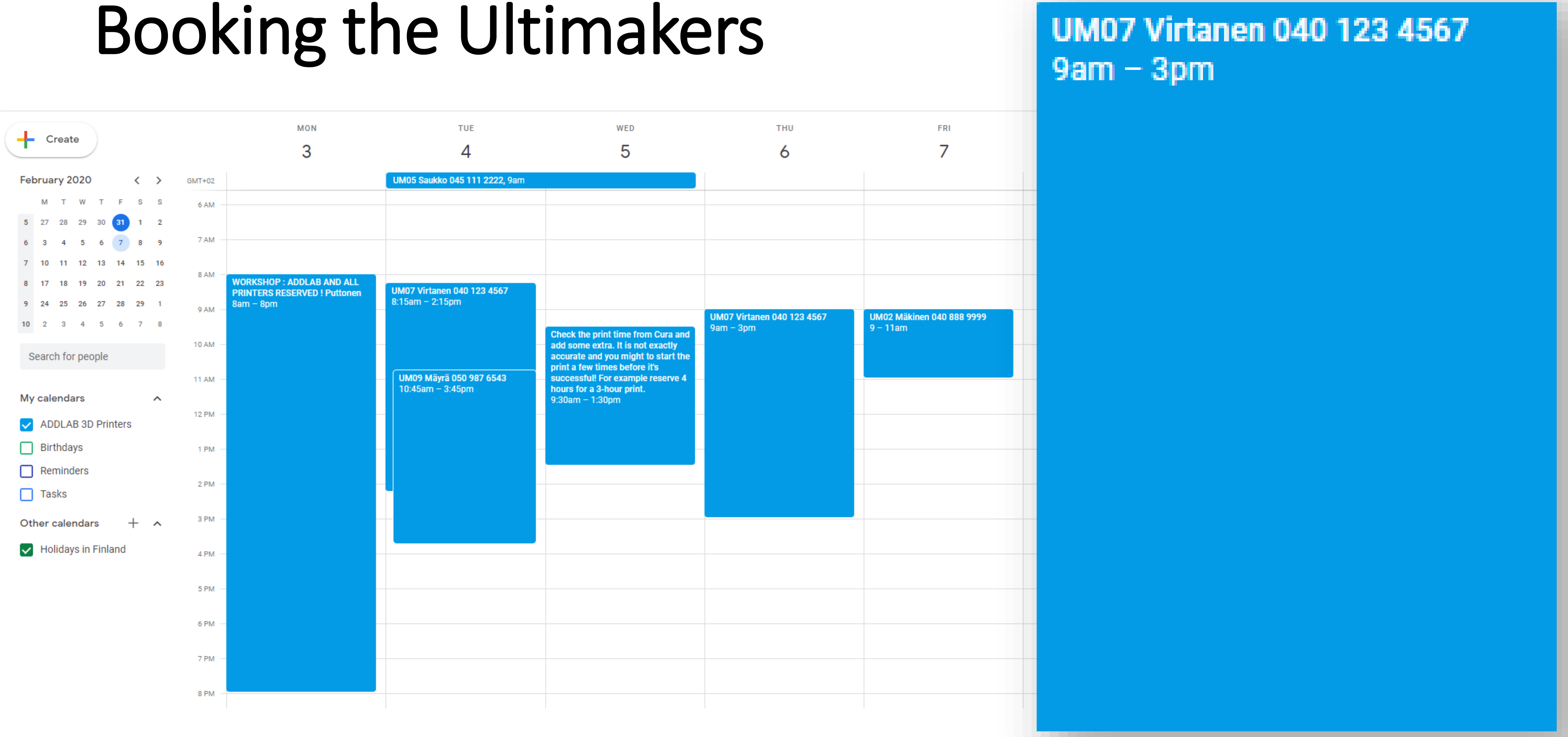
Write (clearly) your email in the participation list, I will send a link to join the calendar.

To reserve a printer for a time slot, simply add an entry in the “ADD DMF Google Calendar” *(not in your personal Google Calendar)* 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

- 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 "ADD DMF Google Calendar" *(this is not your personal 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 3D-printed part

1. Description of the part and its function?
2. Difficulties or problems faced during printing and an explanation of how you solved these?
3. A few examples of how you could reduce the printing time of the part (e.g., via adjusting Cura parameters or 3D design of the part)?

Submit the report on MyCourses before the deadline.

let's say the deadline is 25.02.2024 – 23.59

Dear second-year bachelor’s student and first-year master’s student – how are you?

Please answer the AllWell? student survey that we will send to you soon.

You will receive feedback based on your responses and help us do our work better.

Thank you!

AllWell?

The survey will be open 1.2-14.2.2024

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