Introduction to 3D printing

(With hints for a new approach to creative design in the era of ubiquitous 3D printers)

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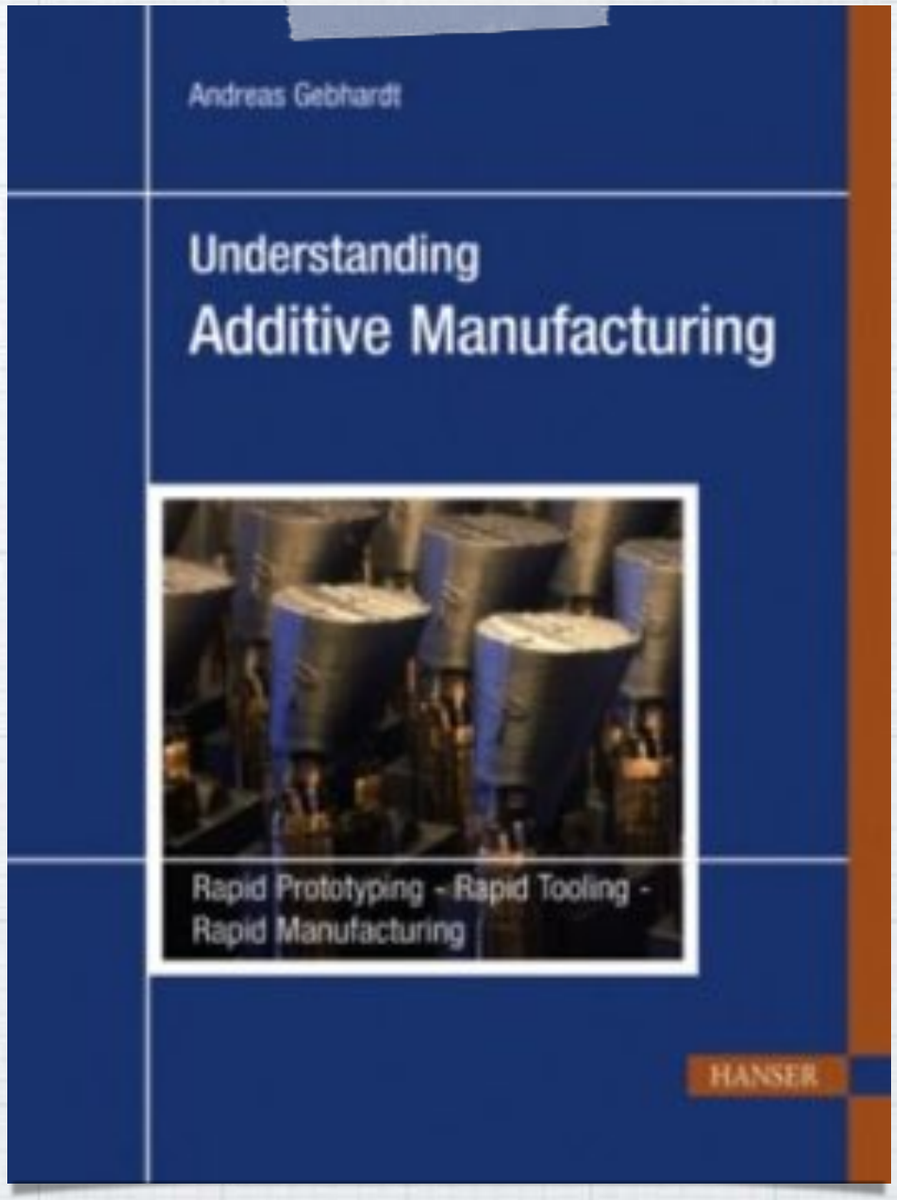
3DP in 2 hour

- 3D printing *short* intro (FDM)
- Mesh & mesh issues
- Slicing (science or art?)
- Common problems & solutions
- Beyond the usual models: design objects meant to be 3D printed

3DP is addi(c)tive!

- 3D printing is an ***additive manufacturing*** technology, opposed to the more common ***subtractive manufacturing*** machining systems like milling machines/CNC, etc.



3D printing: limits

- any 3D printed object is an approximation, because of the digital-to-analog conversion (sampling problem) *–true for all 3DP technologies*:
  - limited precision and resolution
- physical limits *(related to the material/technology)*:
  - non-isotropy of characteristics due to layering (e.g.: lower mechanical resistance along Z axis)

Many 3DP technologies

A possible categorization by (raw) material:

- **powder** (self-supported, metal sintering, fast, cavities need holes, very expensive) (*inkjet+powder*)
- **liquid** (optical –high precision, light-controlled polymerization –special resins, expensive) (*inkjet*)
- **solid** (FDM, support is needed, pointed tips/cuspids are hard, wide choice of polymers, inexpensive)

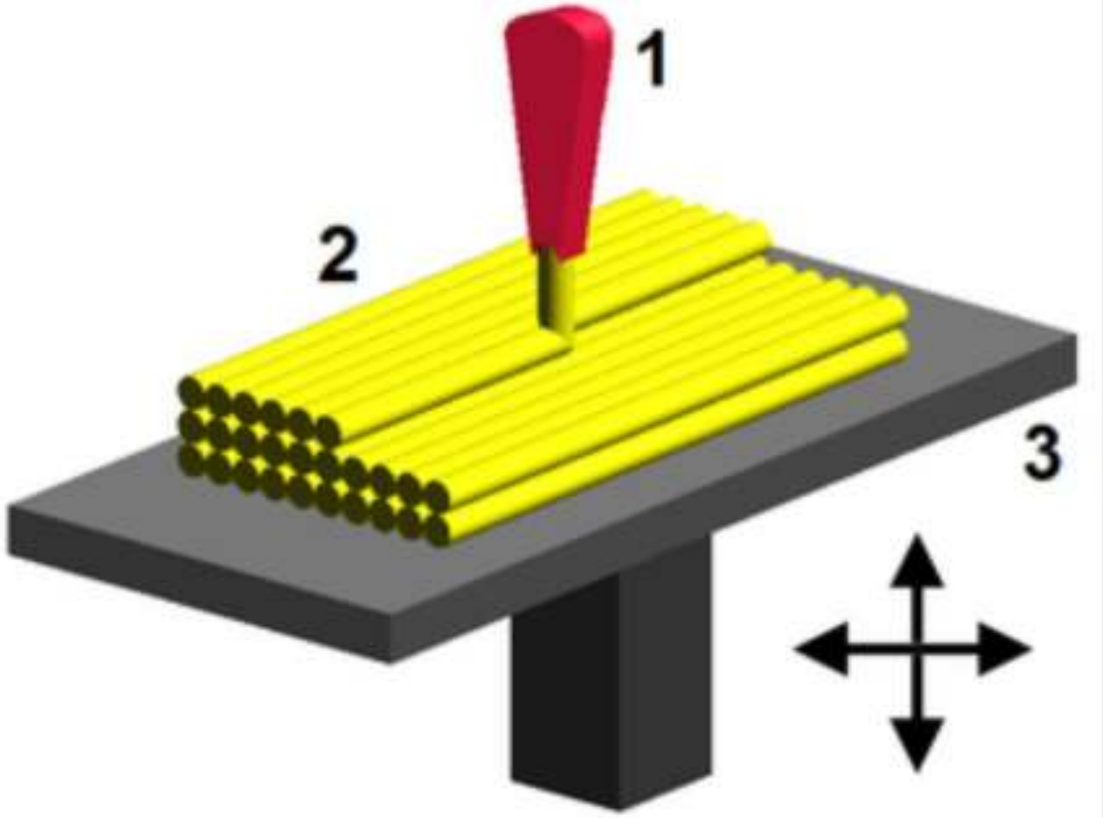
Professional 3D printers (10.000$+)

- Pro 3D-printers can print objects
  - in plastic, starting from a filament (with FDM), or
  - in other material (like metals, ceramics, etc.) provided as powder and “assembled” by sintering (SLS)
    - and some are even able to print in full RGB color
- Up to a (very) big size
- Very expensive (“*pro*” market)
- Beautiful results ;-)

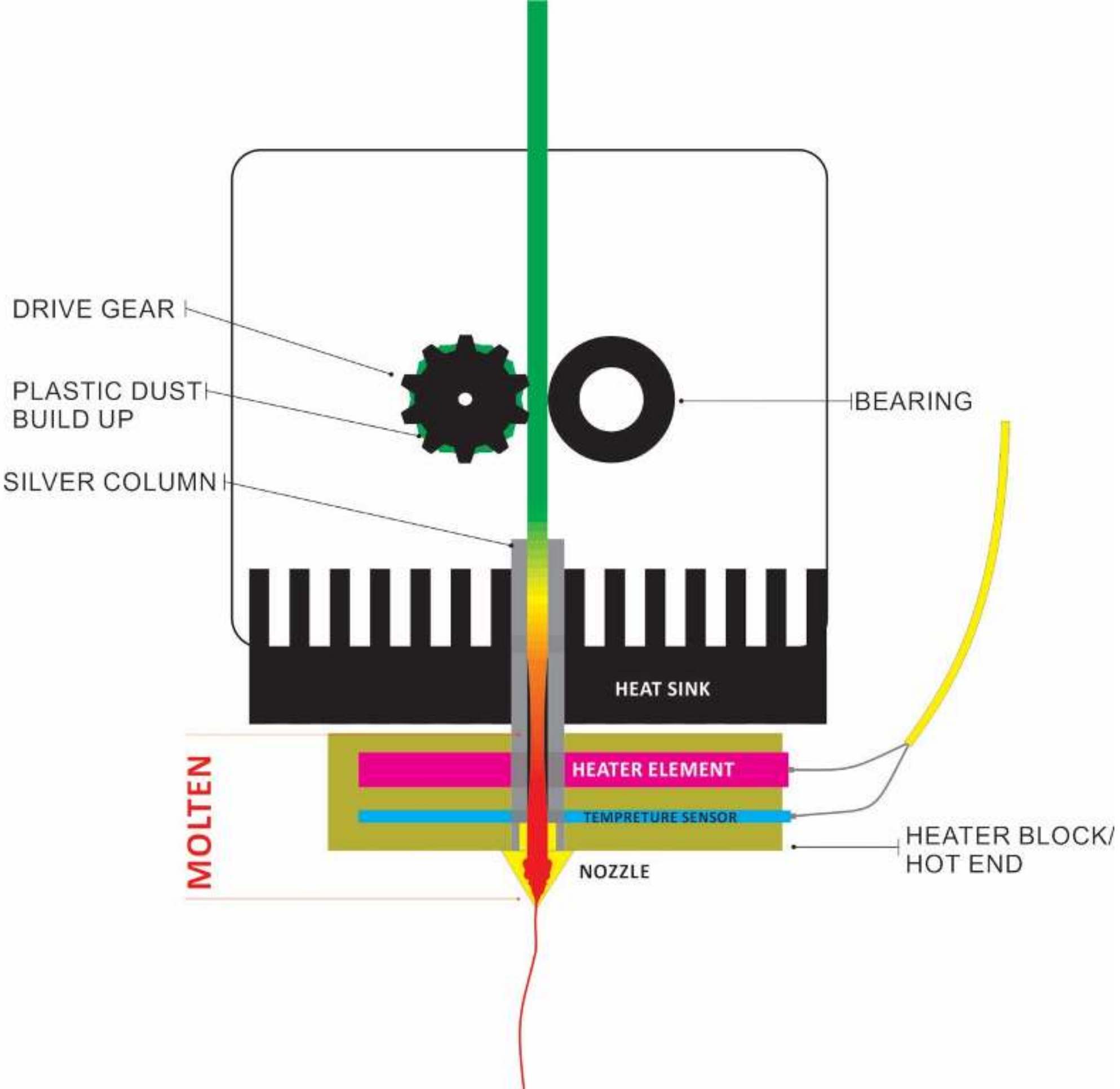
Fused Deposition Modeling (FDM)

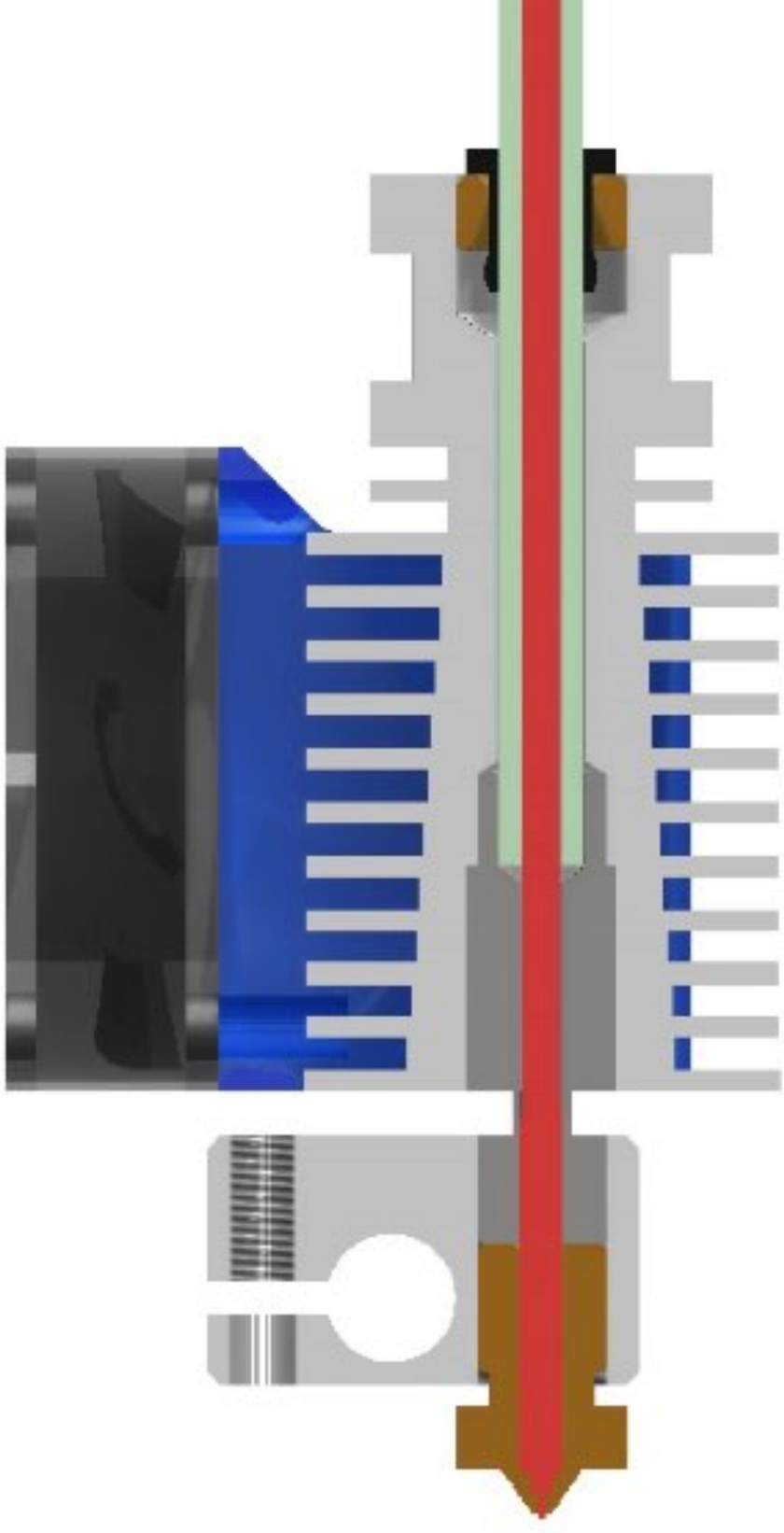
- The most affordable 3D printing technology is FDM: it uses molten plastic extruded through a nozzle. The nozzle or the object (or more often both) are moved along the three axes X, Y, Z.

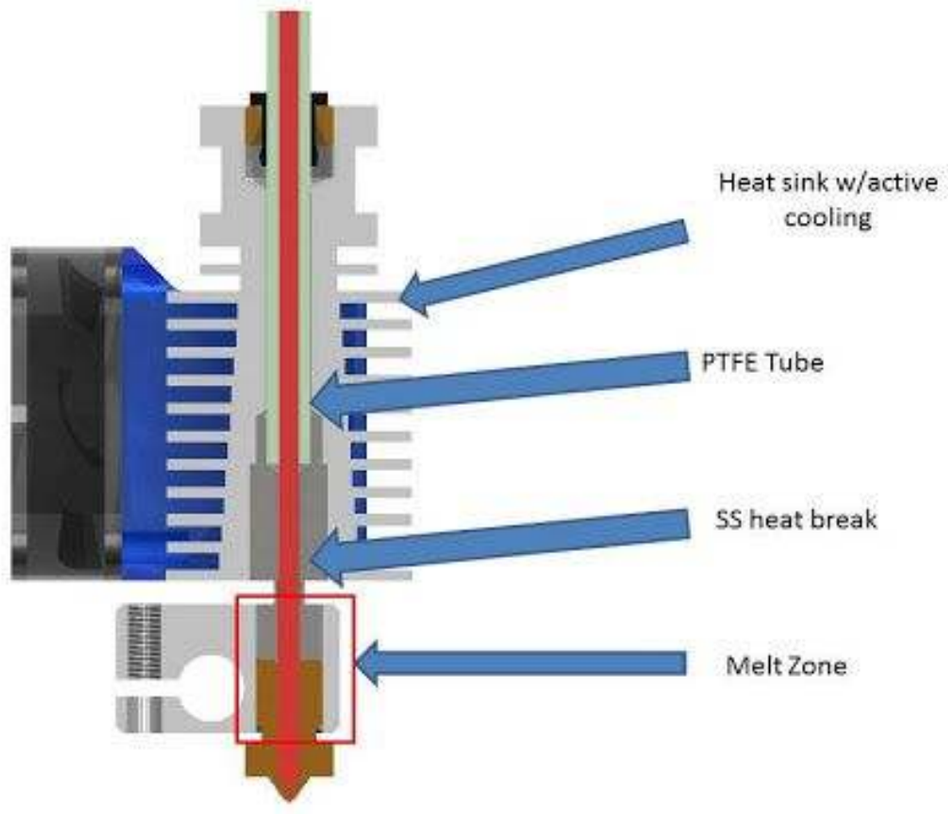
- Also called FFF (fused filament fabrication).



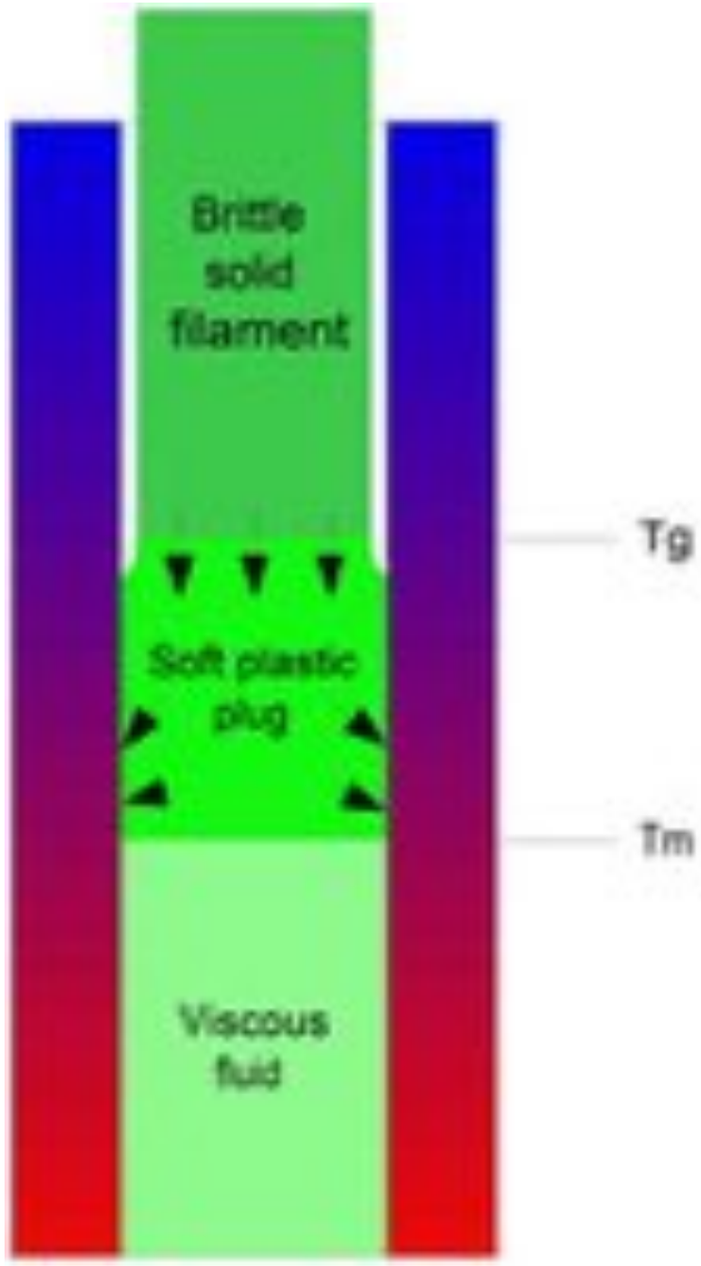
Fused deposition modeling: 1 - nozzle ejecting molten plastic, 2 - deposited material (modeled part), 3 - controlled movable table


DRIVE GEAR
PLASTIC DUST
BUILD UP
SILVER COLUMN
BEARING
HEAT SINK
HEATER ELEMENT
TEMPRETURE SENSOR
MOLTEN
NOZZLE
HEATER BLOCK/
HOT END

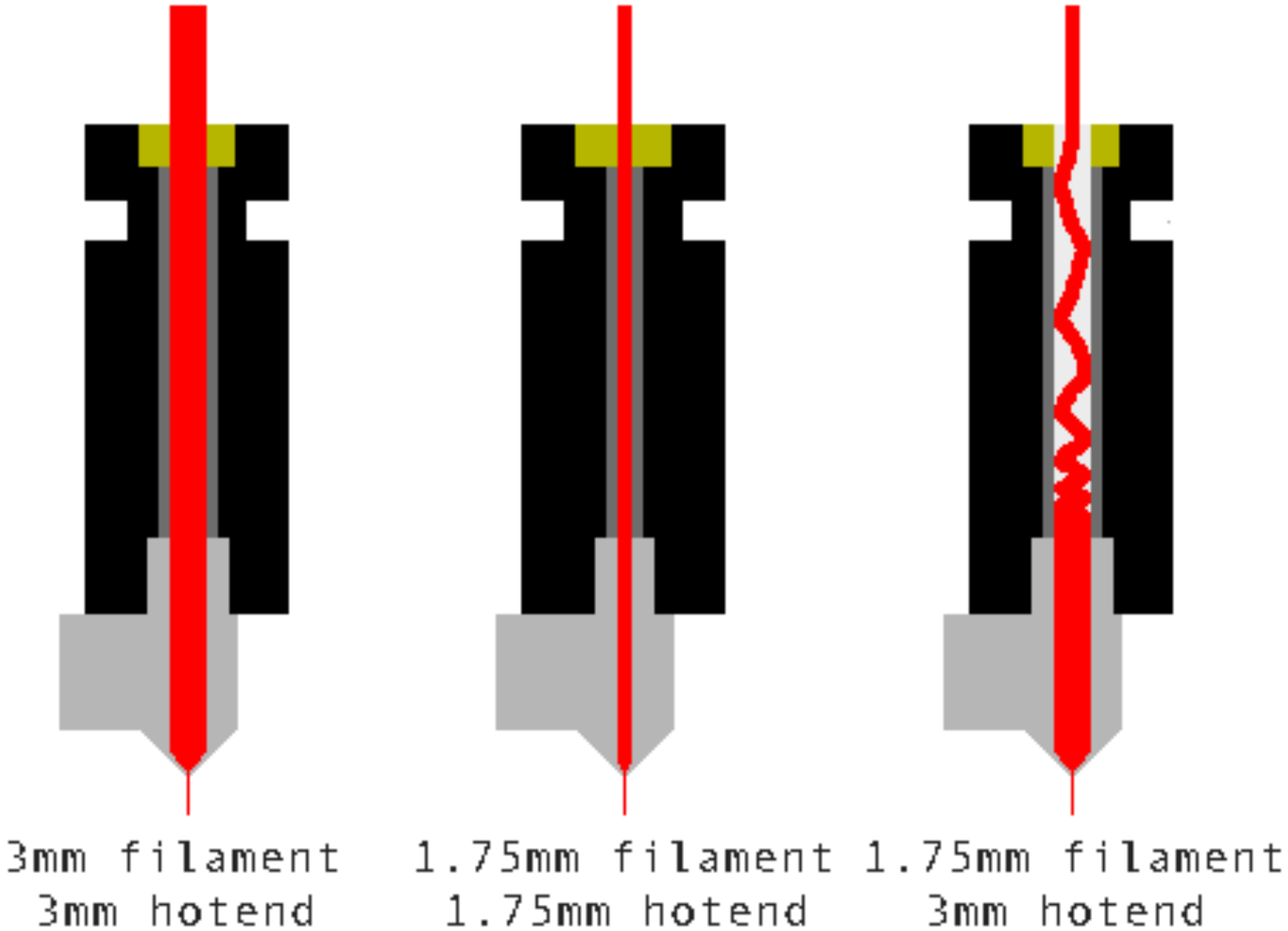




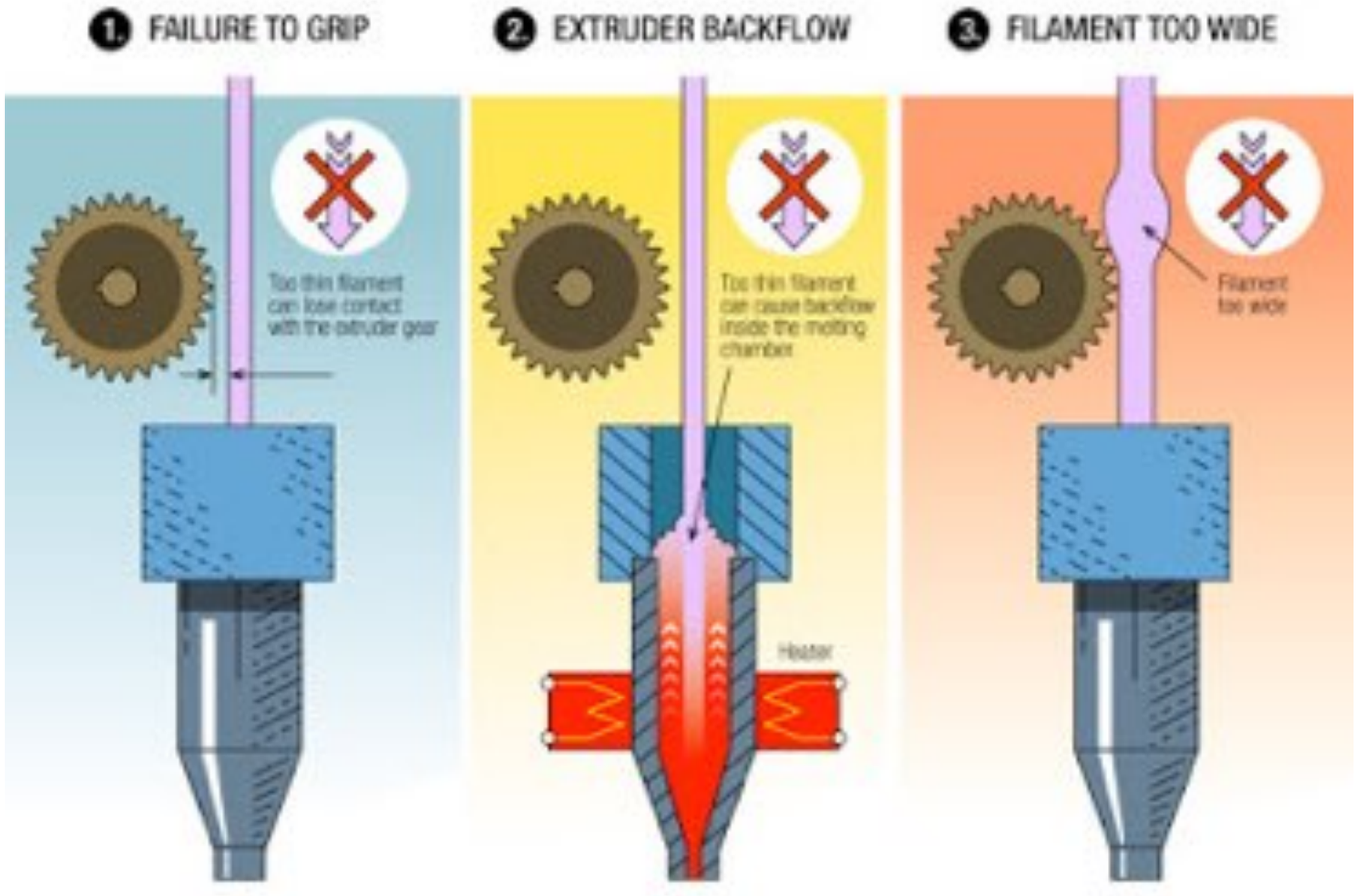
https://www.matterhackers.com/articles/how-to-clear-and-prevent-jams



https://reprap.org/wiki/Print_Troubleshooting_Pictorial_Guide



http://forums.reprap.org/read.php?1,449405,page=2



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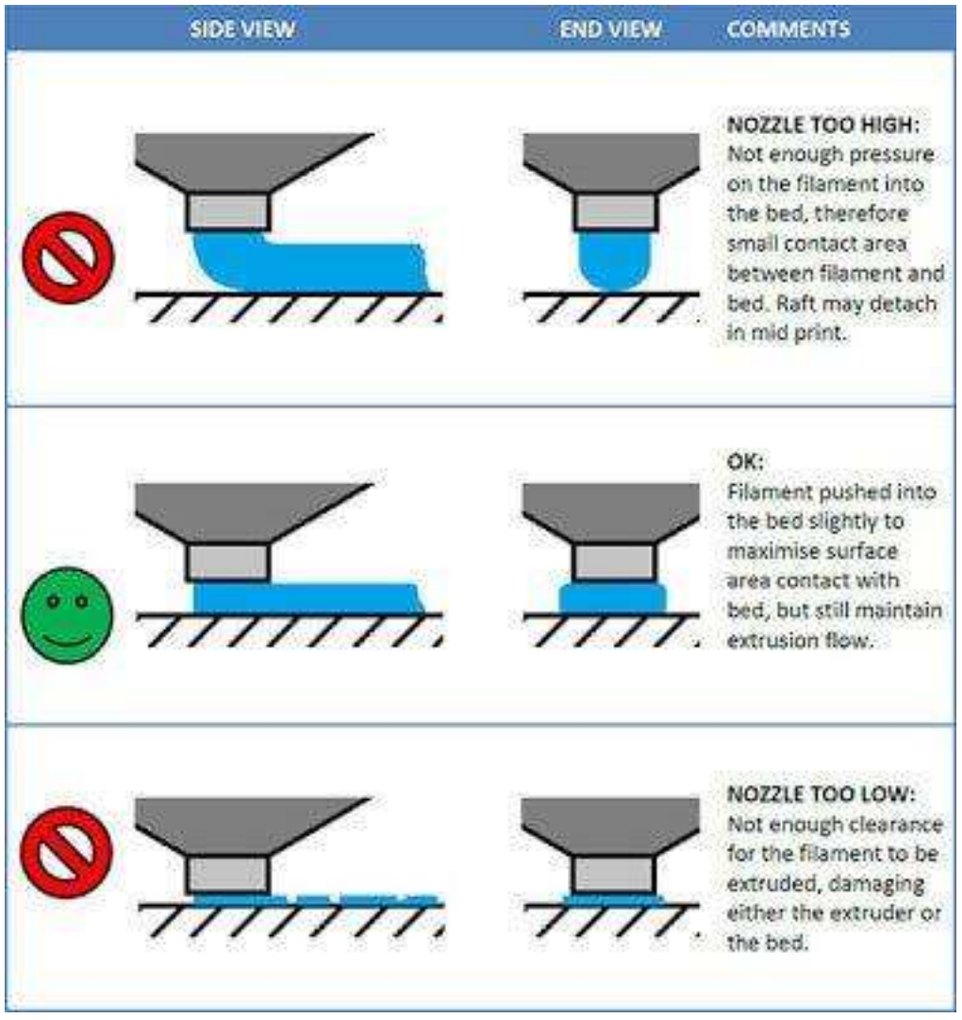


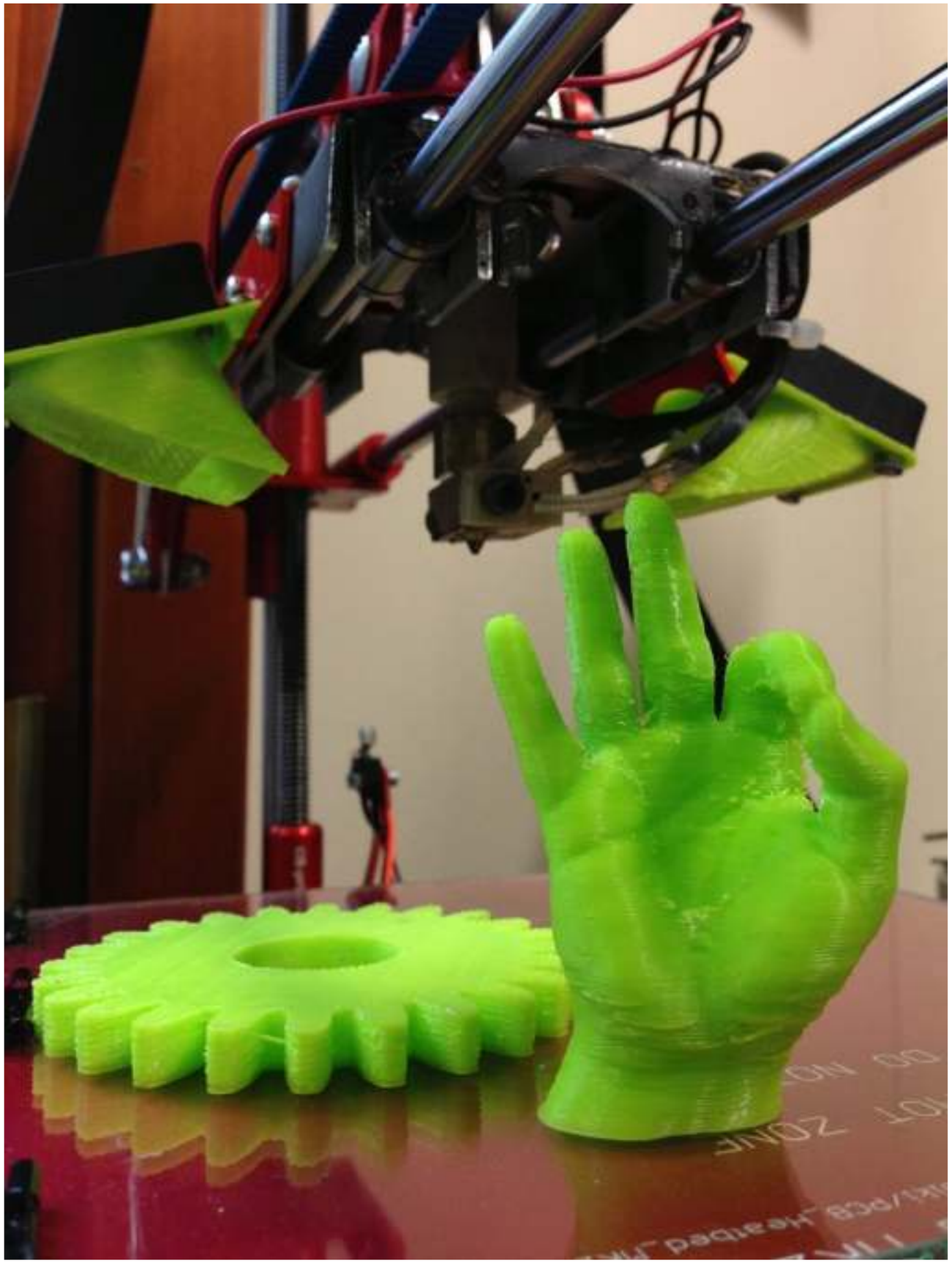
https://www.reddit.com/r/3Dprinting/comments/620tr8/this_is_by_far_the_most_universally_helpful/

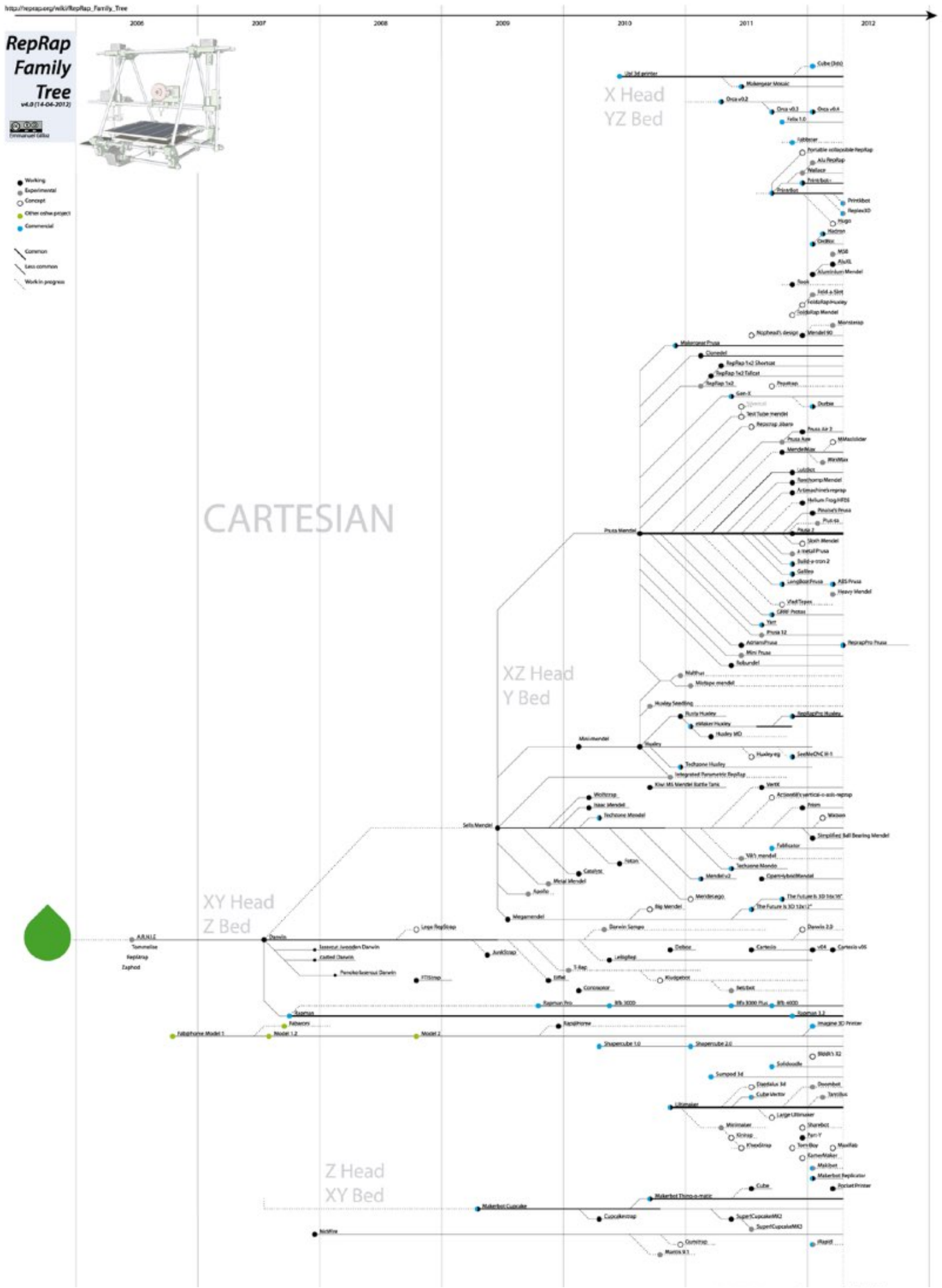
Low-cost *personal*
3D printers

cost: from 300 to 3000 USD

Open source + Open Hardware

- Low-cost printers use a plastic filament (ABS or PLA, 1.75 or 3mm thickness)
- Often hand-build, with plywood or acrylic frame and parts
- the software is free and mostly **open source**: 3D design apps, *slicers*, printer control apps, etc
- extensive use of **open hardware** (Arduino, RAMPS, etc. ...small cheap computer boards), blueprints are open and downloadable
- some printers can (partially) *replicate* themselves, because are made with printed parts
- **RepRap** project, started by Adrian Bowyer (Univ. of Bath, UK)





DIY 3D Printing Mechanics

- Building things with a hot-melt glue gun
  - A very small glue gun: nozzle 0.2 to 0.6 mm dia
  - A very hot glue gun: 190 to 230 °C = 350 to 450 °F

http://www.thingiverse.com/thing:2084

Cartesian Coordinates

- Z Axis
  - +Up -Down
- X Axis
  - +Right -Left
- Y Axis
  - +Back -Front
- A Axis
  - Filament drive!

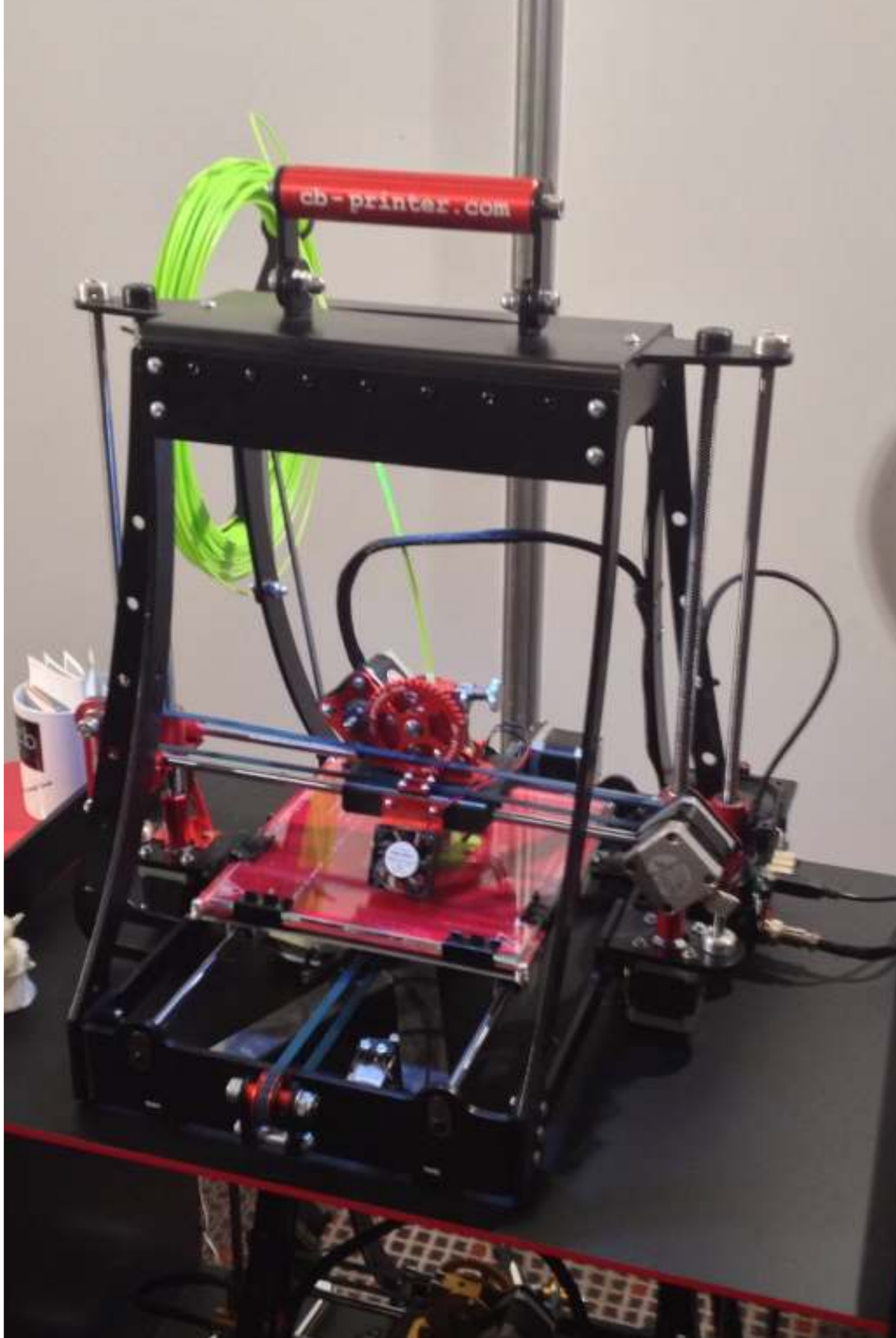
http://www.thingiverse.com/thing:2084

3D Printing Mechanics

- Z Axis stage
  - Filament drive = A Axis
  - Extruder "Hot End"
  - Nozzle
- X and Y Axis Stages
  - Heated build plate(s)
  - Automated belt (?)
- Build Chamber
  - LED strip lighting!

RepRap: Prusa/ Mendel/Darwin/etc...

- Many variations on the theme
- Mostly designed (and marketed) by members of the hacker community in US and Europe
- Everything is open, you can buy or build/modify them

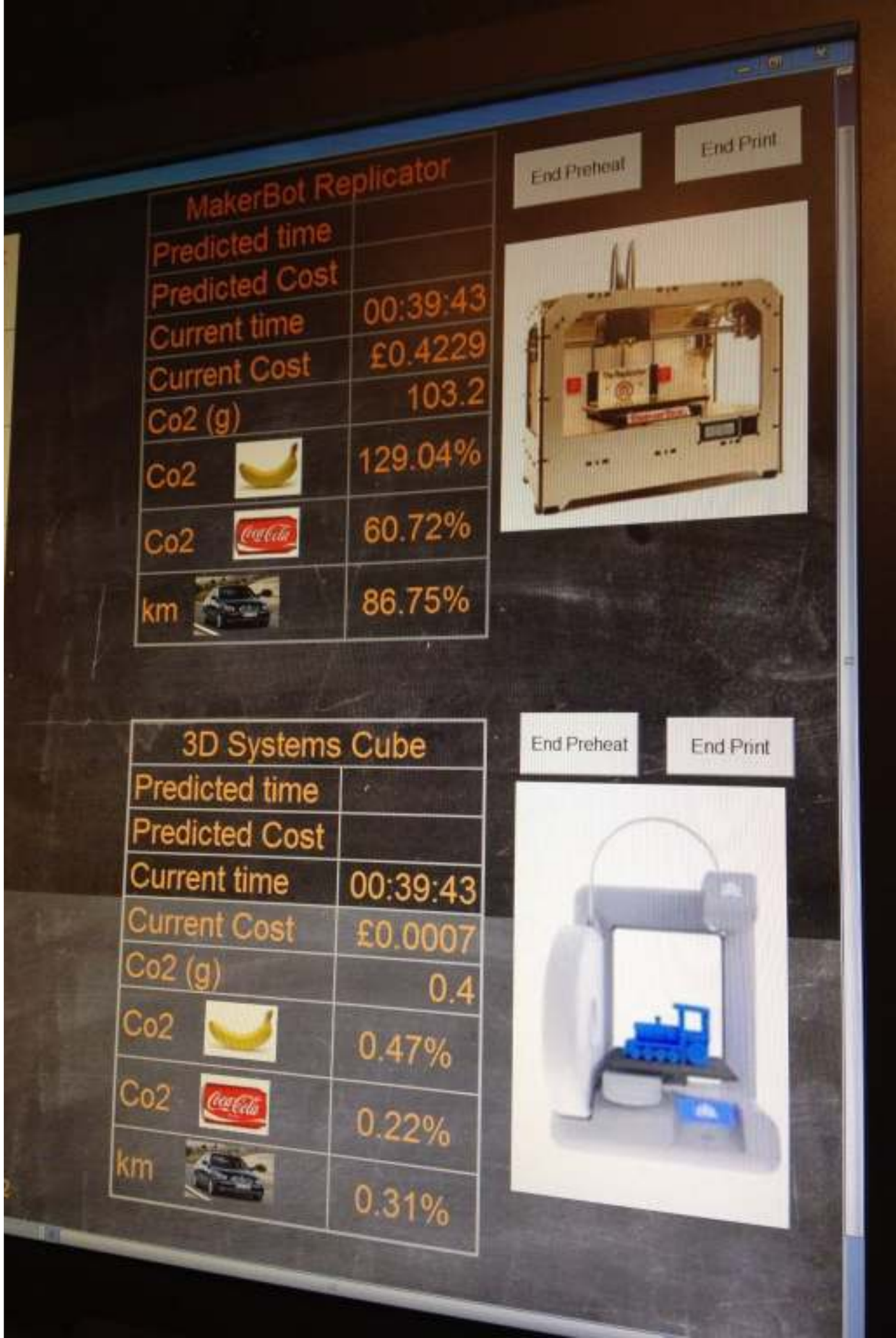


Not only from U.S.: the Ultimaker

- Developed in the *Netherlands* by a student (as a byproduct of his MSc thesis)
- Cost: €1000 as kit, fully open source

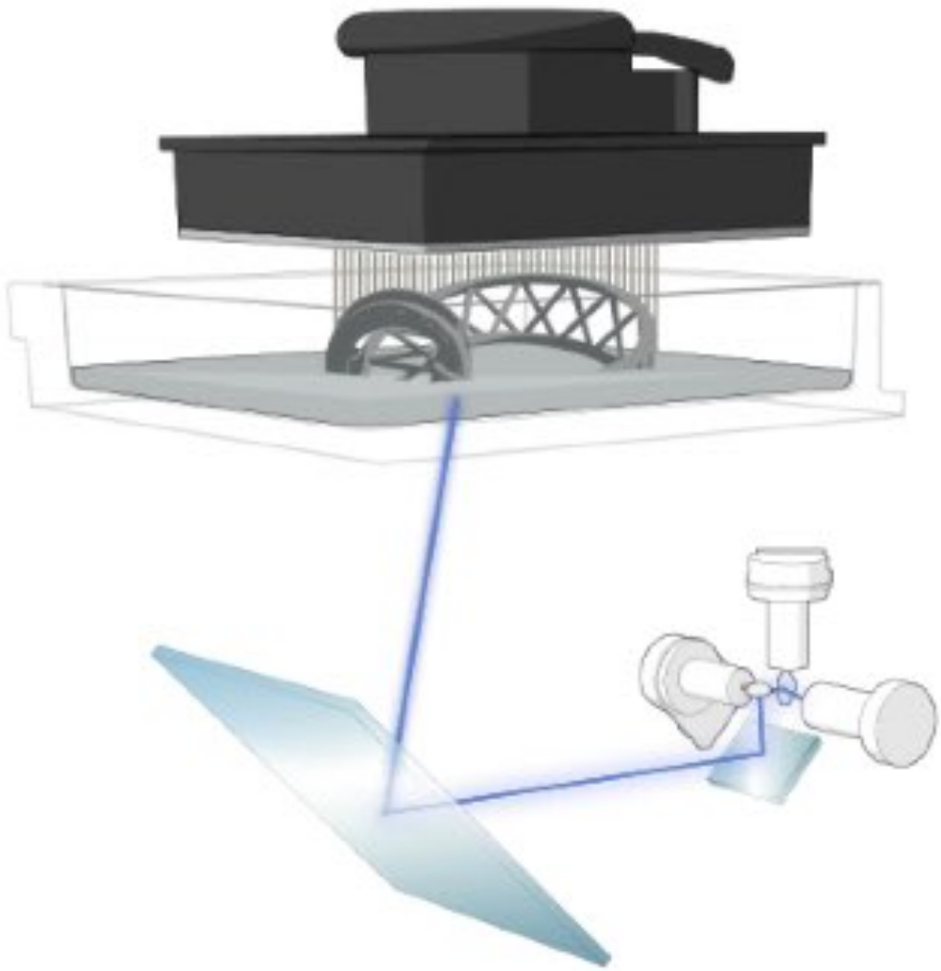
And many more...

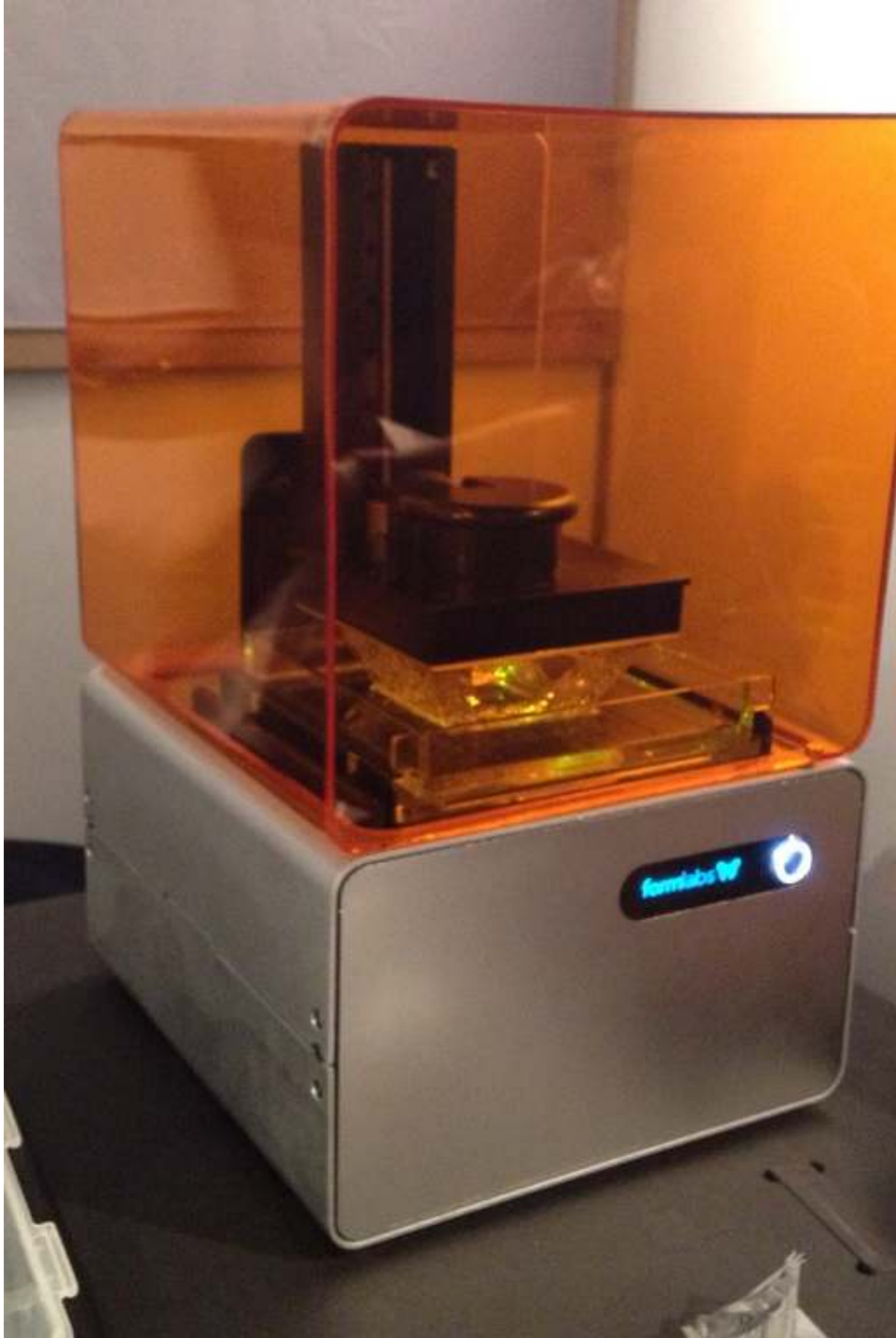
- Different solutions
- Different level of skills required to operate
- Different prices
- Different philosophies
- The market is still growing quickly and searching an equilibrium...



Laser + liquid resin

- another promising technology from low-cost 3D printers: it uses a special liquid resin that costs 3x more than plastic, has better resolution and precision.

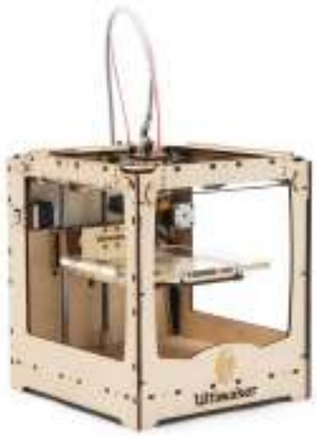




History of the Personal Computer
(is it repeating all again?)

Pro only

first personal
(for hackers)

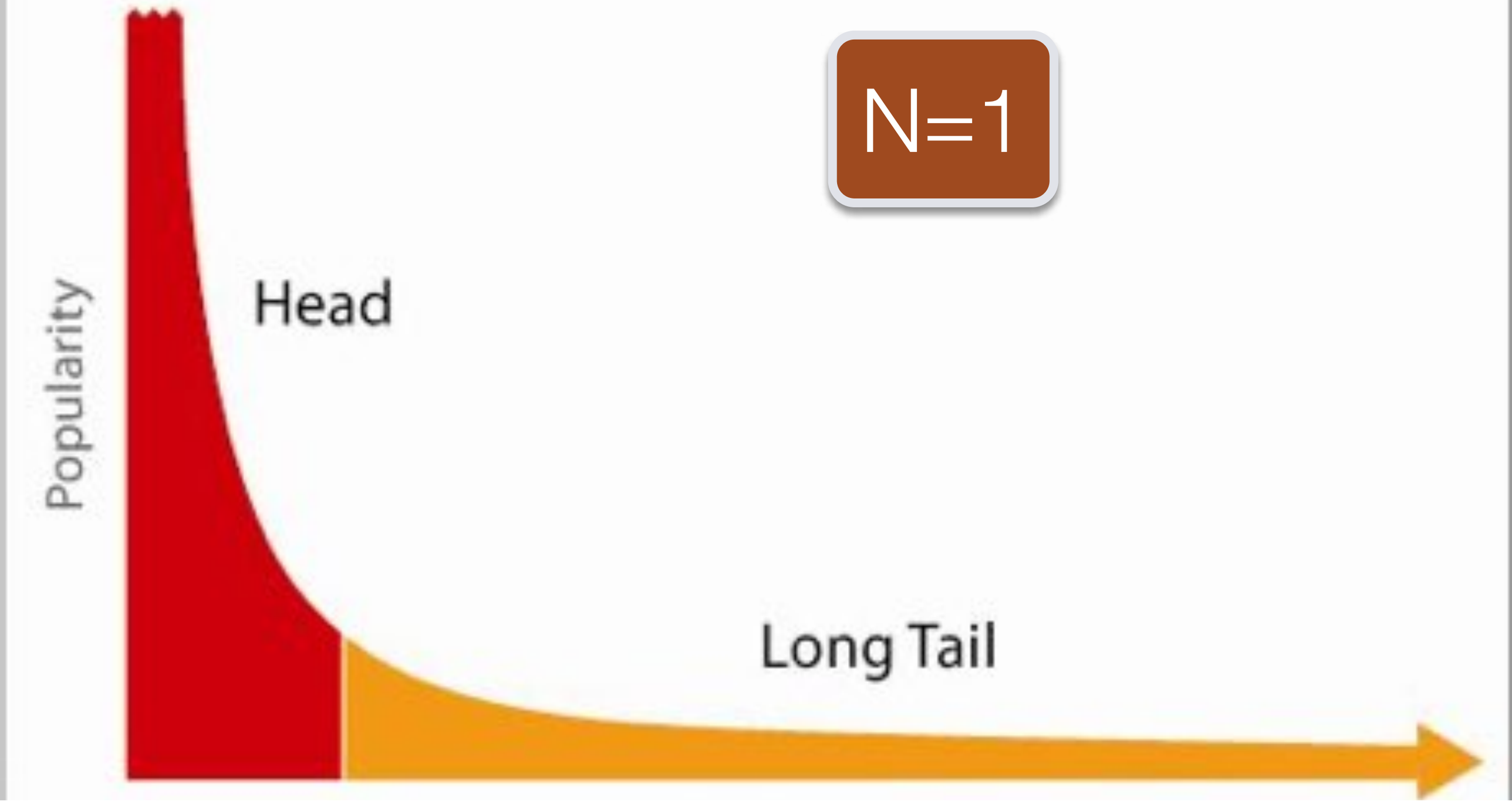


really personal
(mass produced)

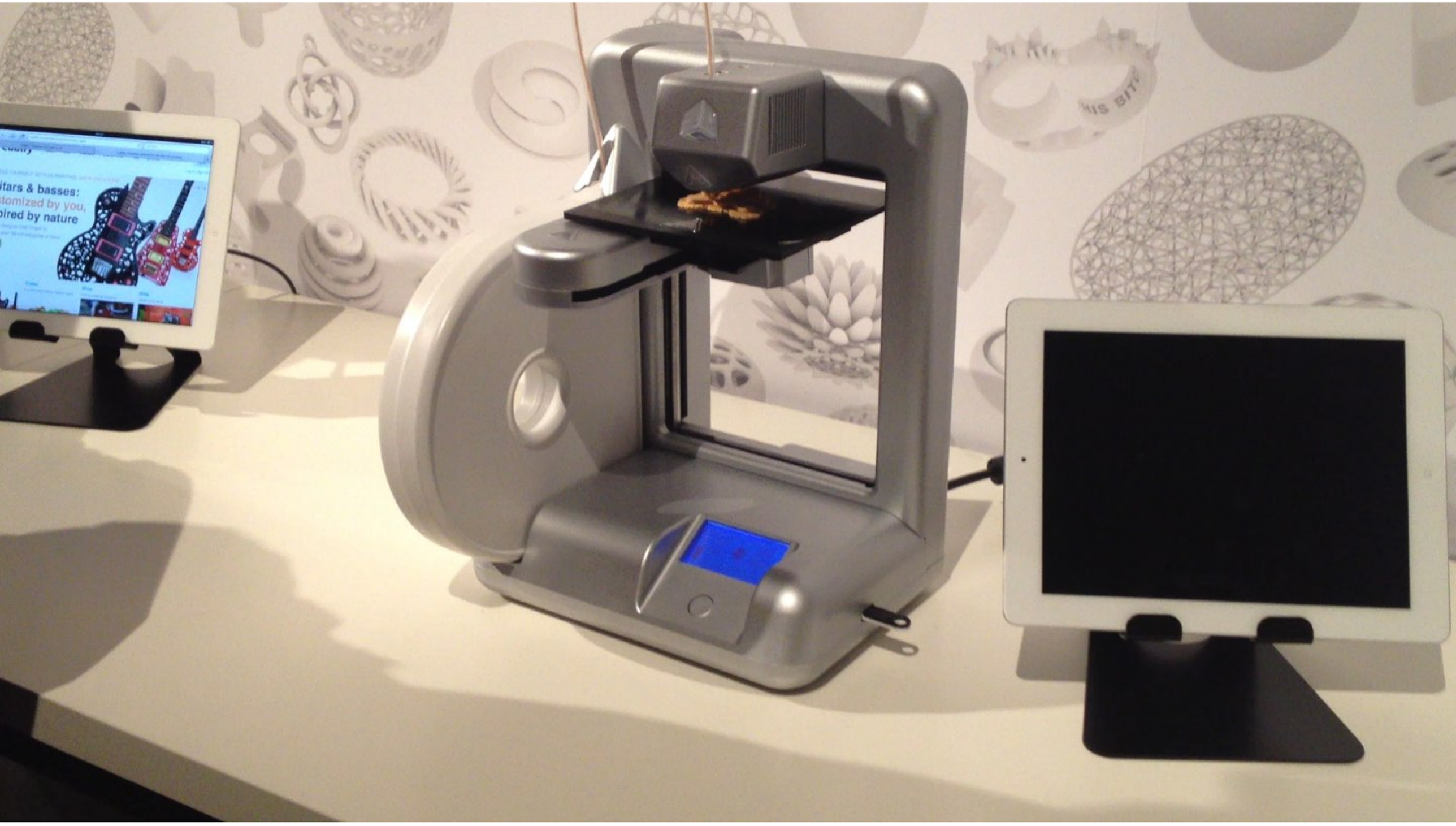
?

???

N=1



The *long tail* | by Chris Anderson



HOW TO print an object?

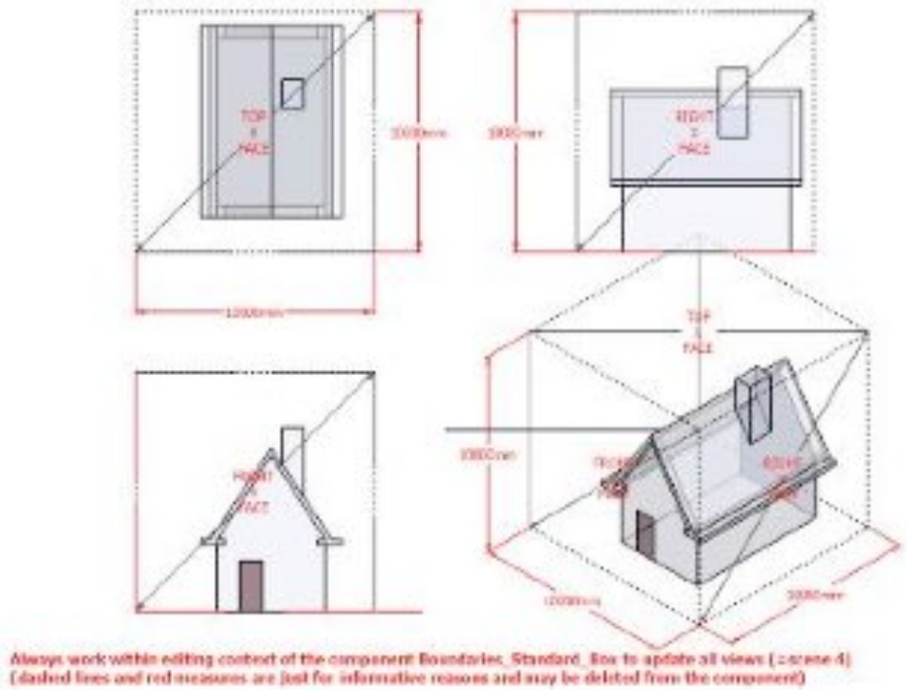
...practical 3D-printing for beginners

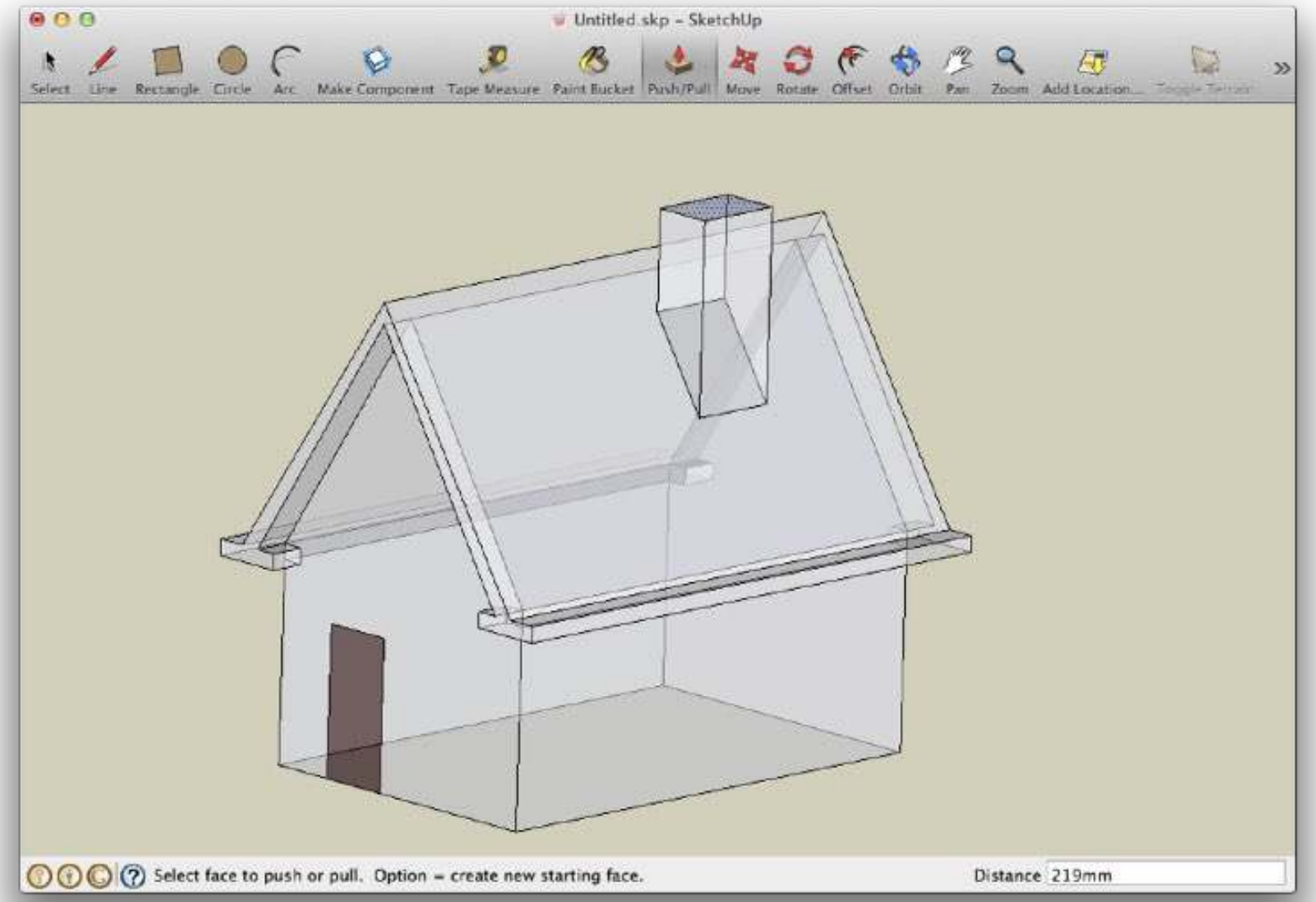
#1 - Design a model

- The first step for creating a 3D-printed object is to make a digital model of it.

- There are many CAD programs (Computer-aided Design software), some are even free and open source.

- To learn how to use well a CAD program is not easy, it may require some days (or months) and a lot of patience and practice...





Examples: *free* software for *technical* 3D modeling

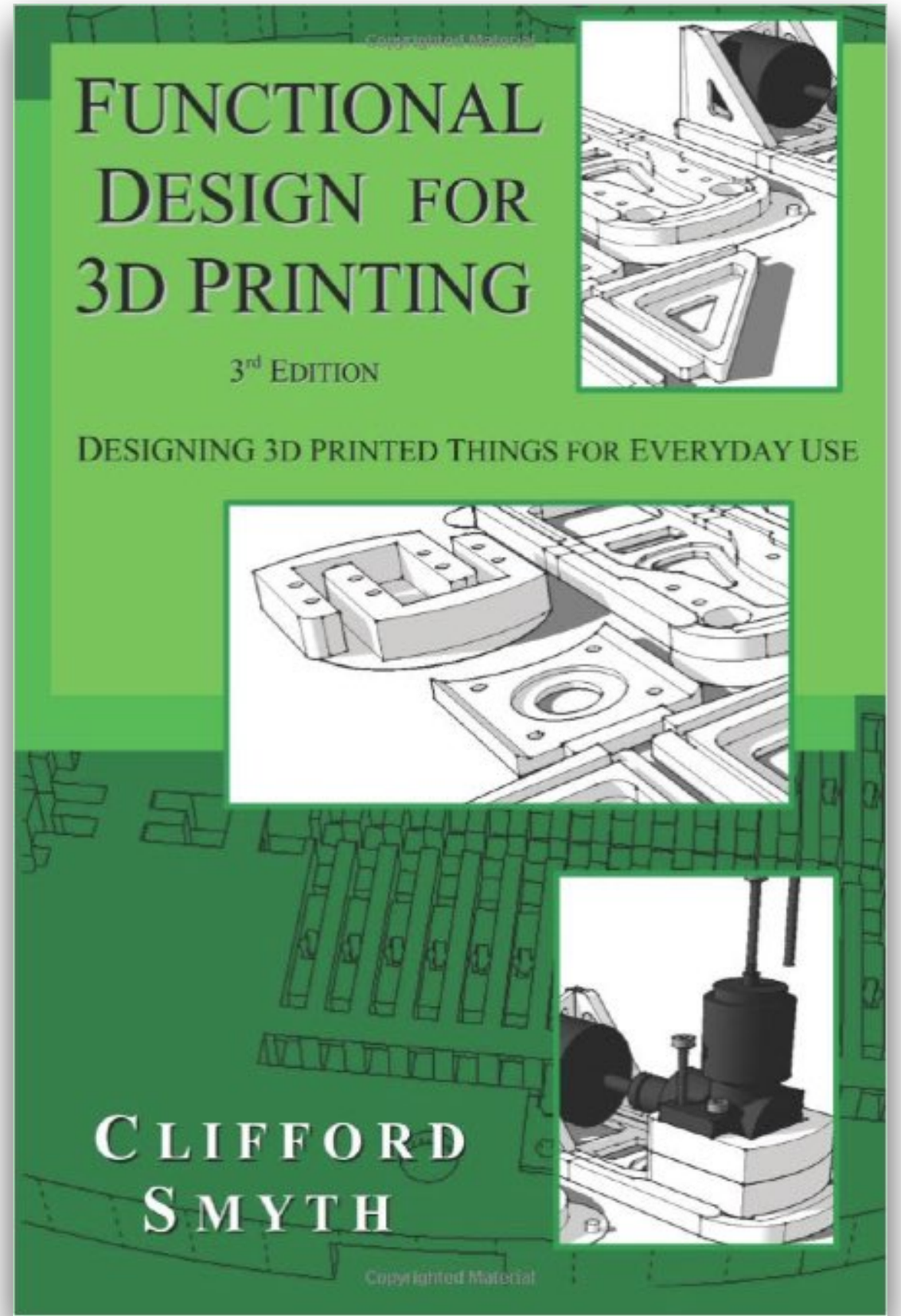
- SketchUp (by Trimble, *was:* by Google)

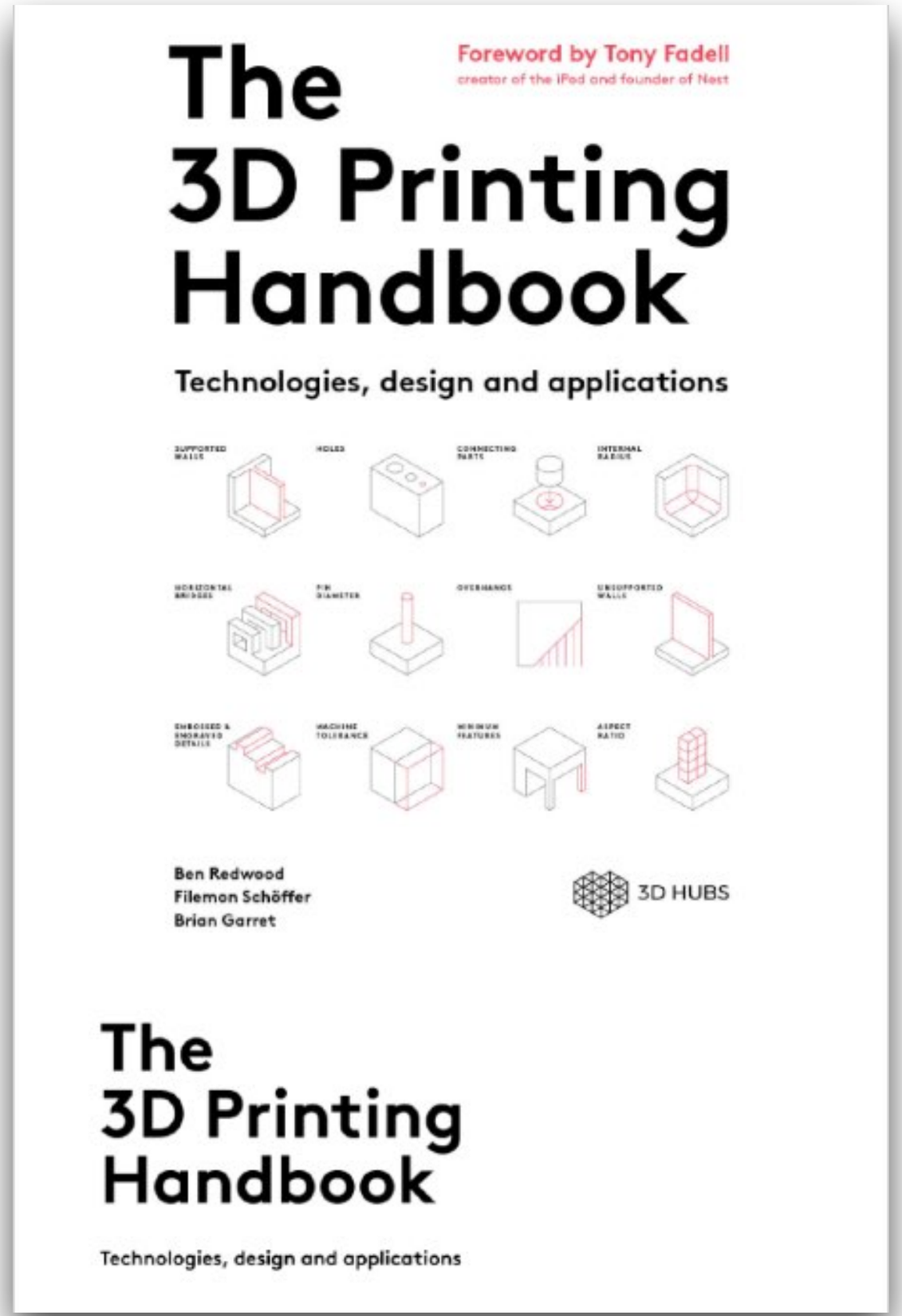
- FreeCAD (open source, Win/Mac/Linux)

- Blender (open source, Win/Mac/Linux)

- **OpenSCAD** (programming language)

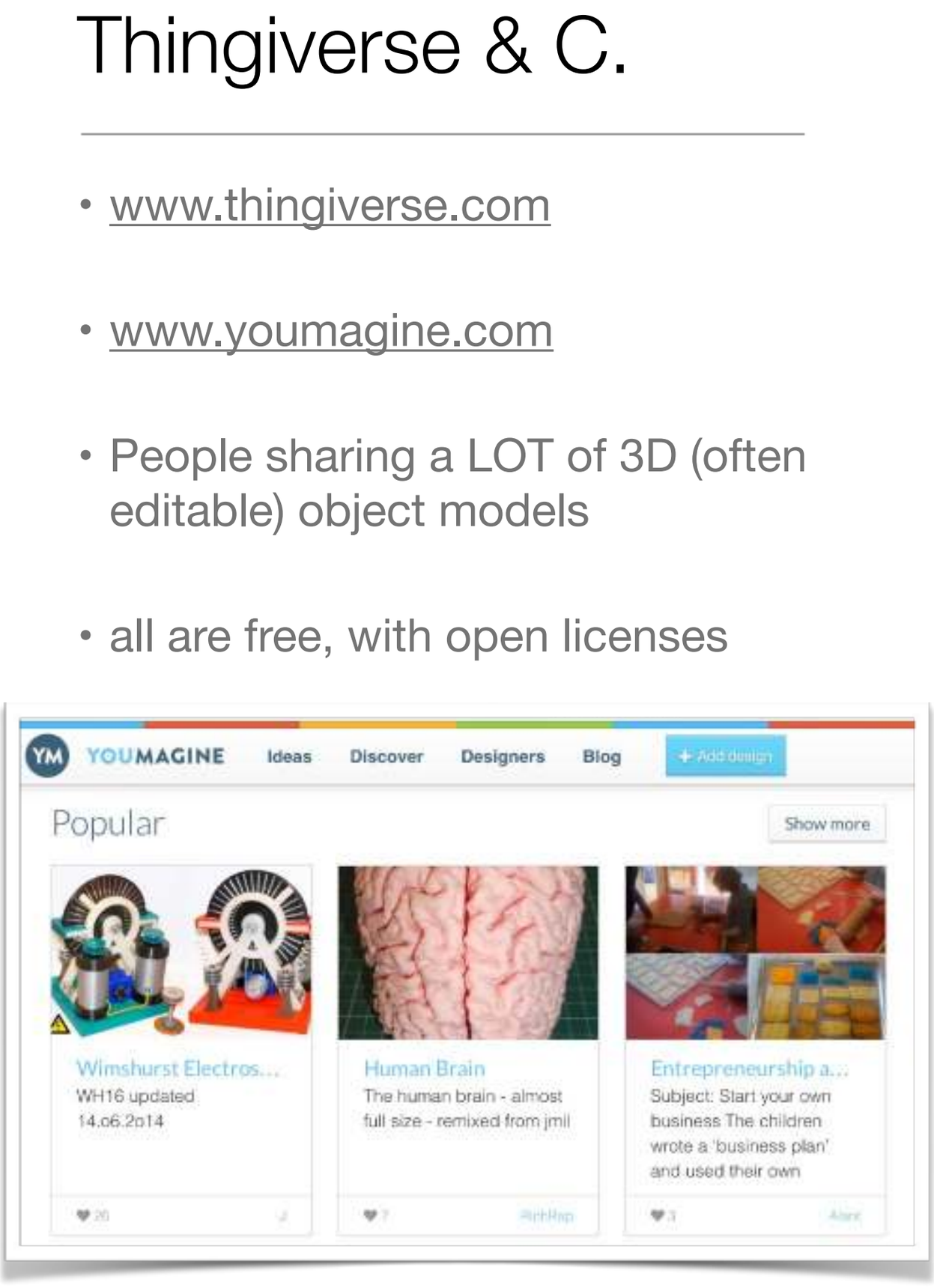
- and many others...

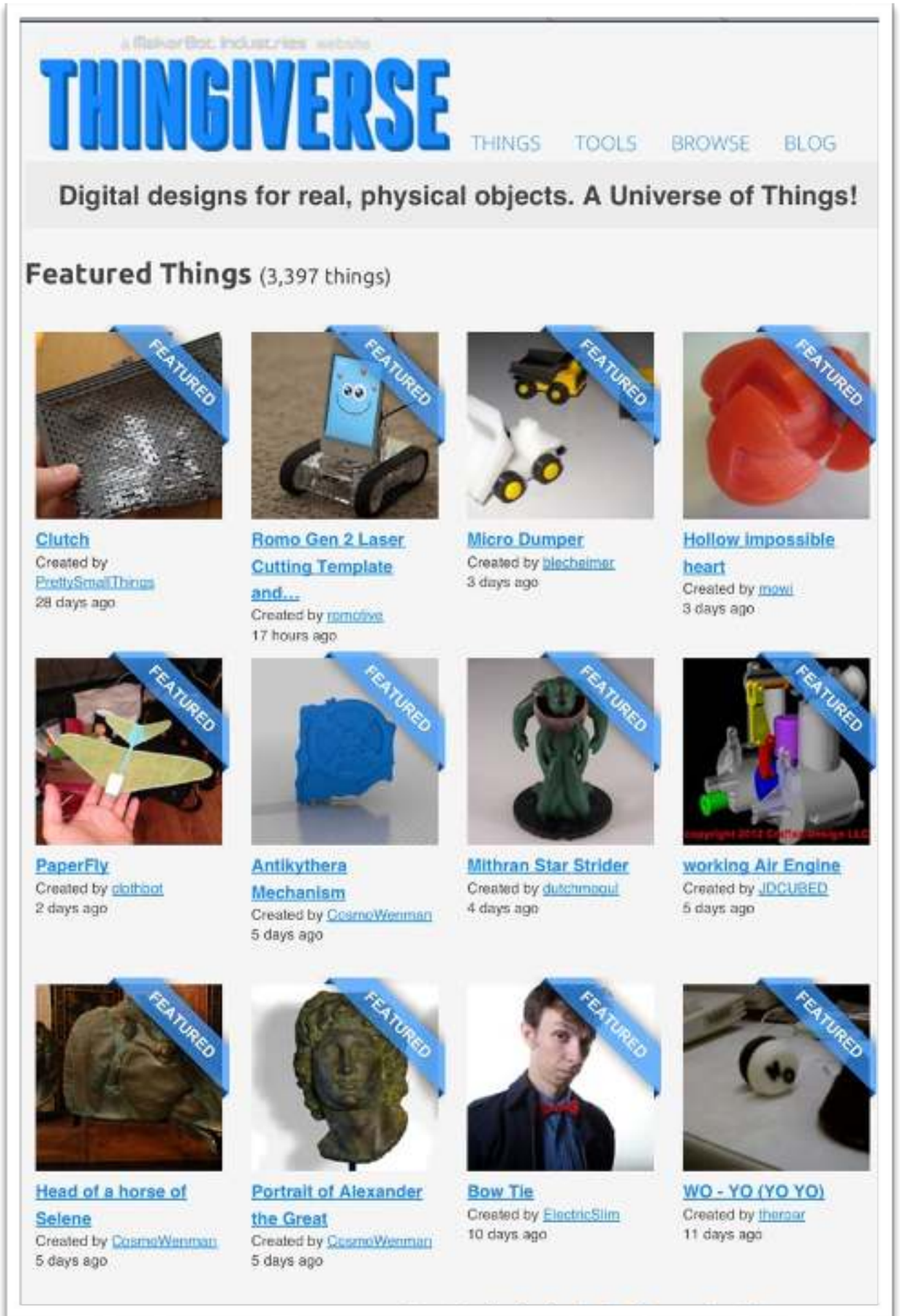

FUNCTIONAL
DESIGN FOR
3D PRINTING
3rd EDITION
DESIGNING 3D PRINTED THINGS FOR EVERYDAY USE
CLIFFORD
SMYTH
Copyrighted Material


Foreword by Tony Fadell
creator of the iPod and founder of Nest
The
3D Printing
Handbook
Technologies, design and applications
Ben Redwood
Fileman Schöffer
Brian Garret
3D HUBS
The
3D Printing
Handbook
Technologies, design and applications

Thingiverse & C.

- www.thingiverse.com
- www.youmagine.com
- People sharing a LOT of 3D (often editable) object models
- all are free, with open licenses





#2 - Check & repair

- The STL files that have been created by the modeling software may not be yet ready for printing, they should be checked for problems.

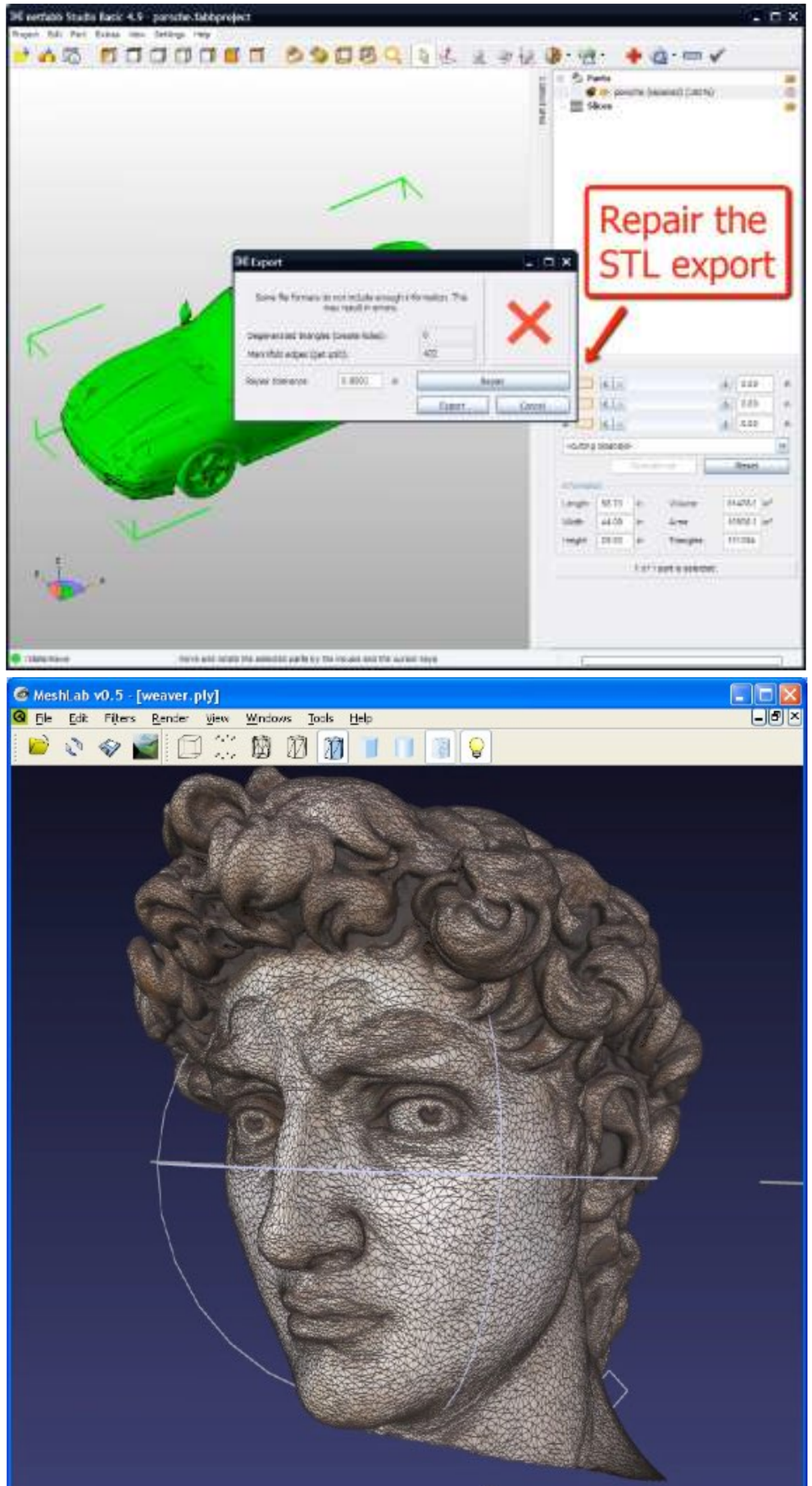
- Software for control and repair:

  - **netfabb** Studio Basic

  - **MeshLab** (conversion too)

  - **Meshmixer** from Autodesk (great for STL mashups)

  - also Cura and Slic3r can repair meshes in their latest version



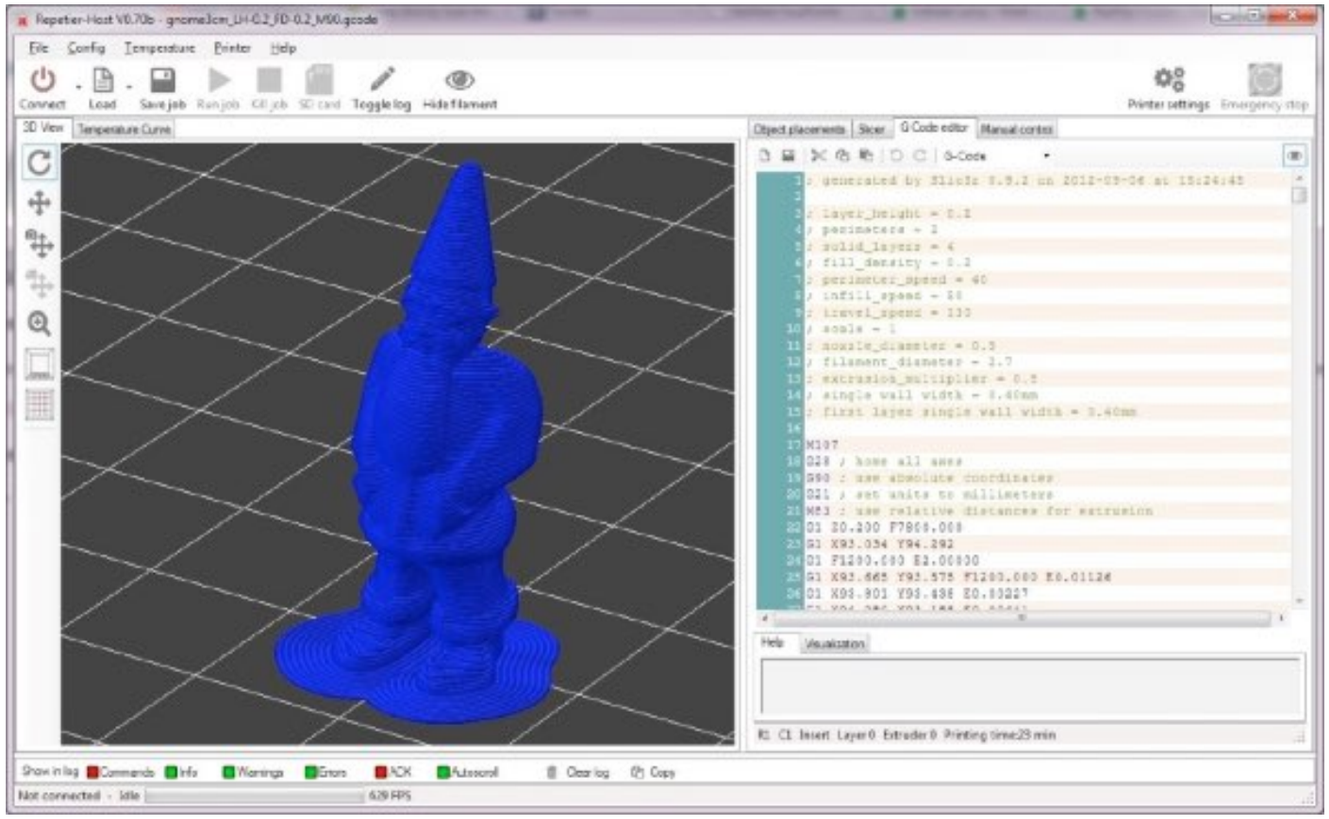
#3 - Slice

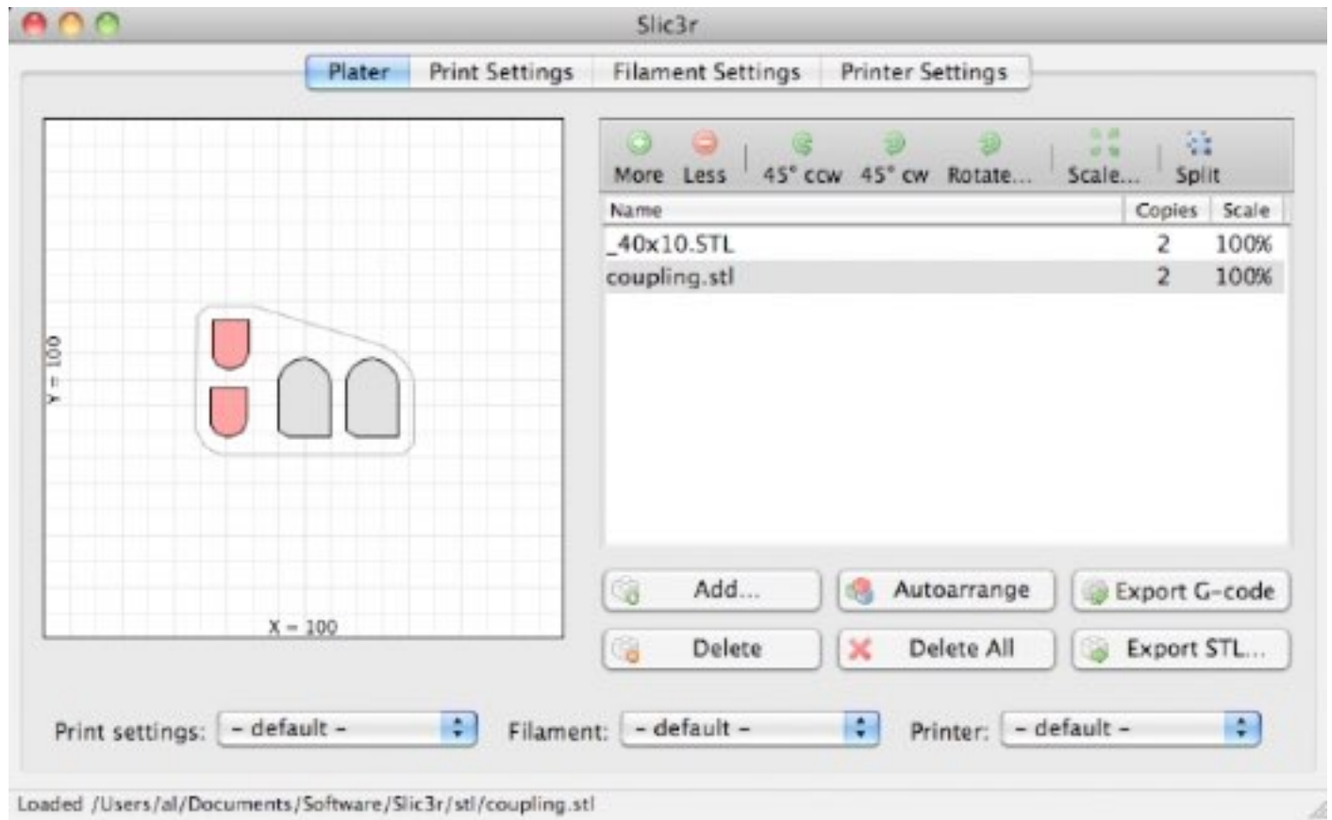
- *Here comes the fun...*

- In order to print, the model (STL file) should be first converted into a set of instructions (a common one is called *G-code*) that tell to the printer how to move the printing head, when and how much plastic to extrude, etc.

- This is called **slicing**, and your model is now a *pile of layers*.

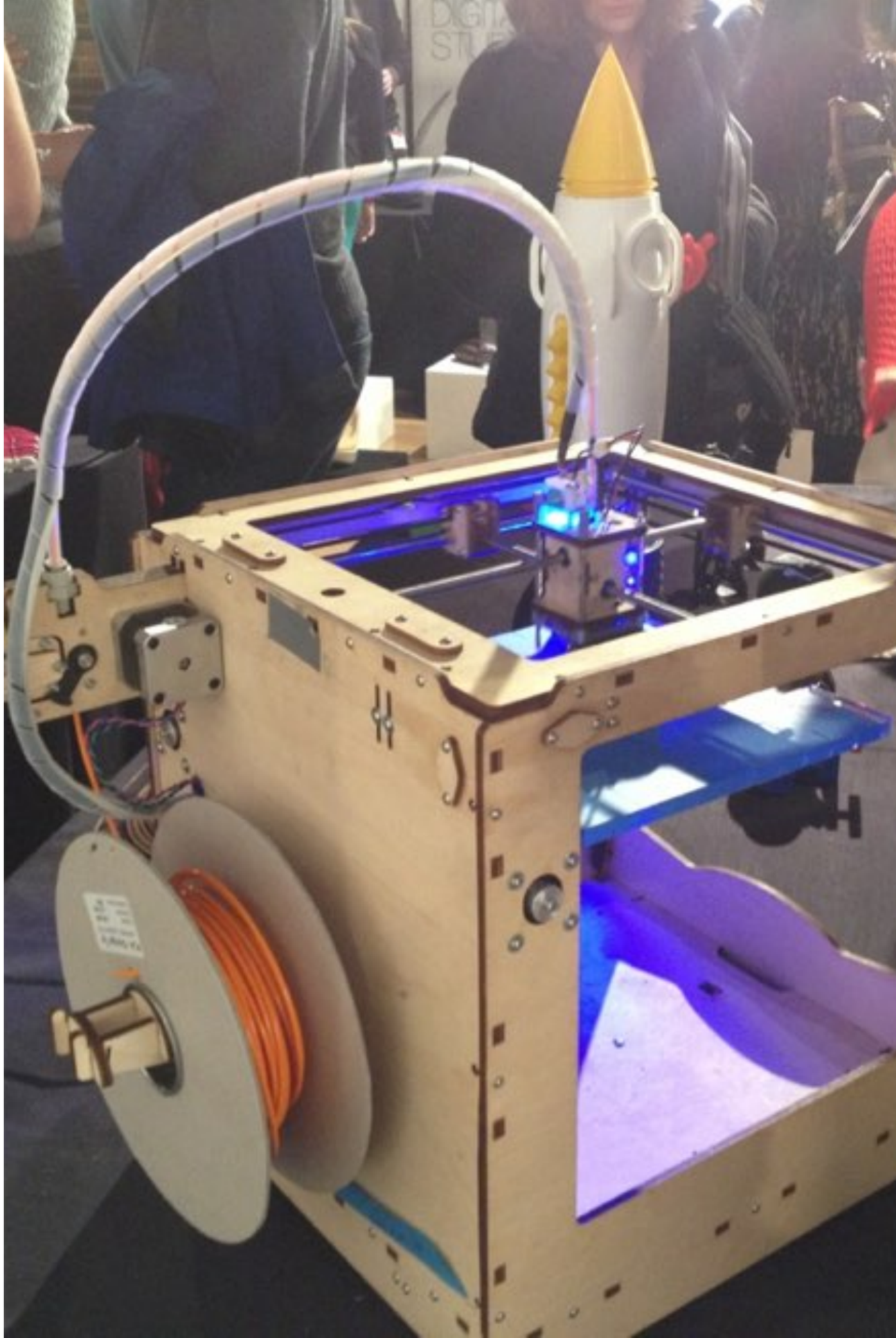
- This is the MOST CRITICAL part of the whole process, the final quality of the printed object is determined almost entirely by a correct choice of values for the many different *slicing parameters*.





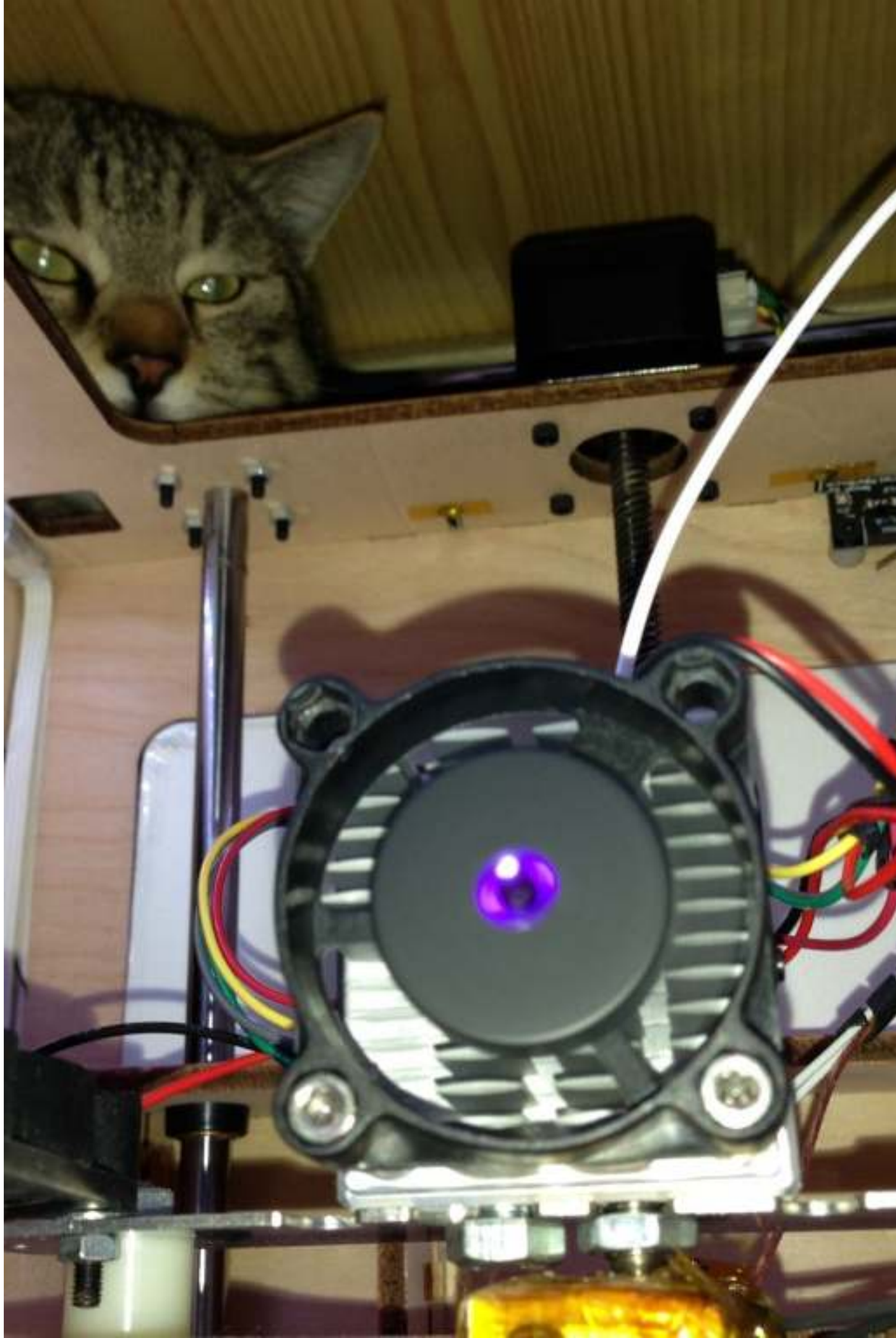
#4 - Prepare the printer

- calibrate (level) the platform (printing bed) and clean it
- pre-heat the printing head
- load the plastic filament into the extruder
- extrude some plastic, in order to fill the nozzle
- start the print ;-)



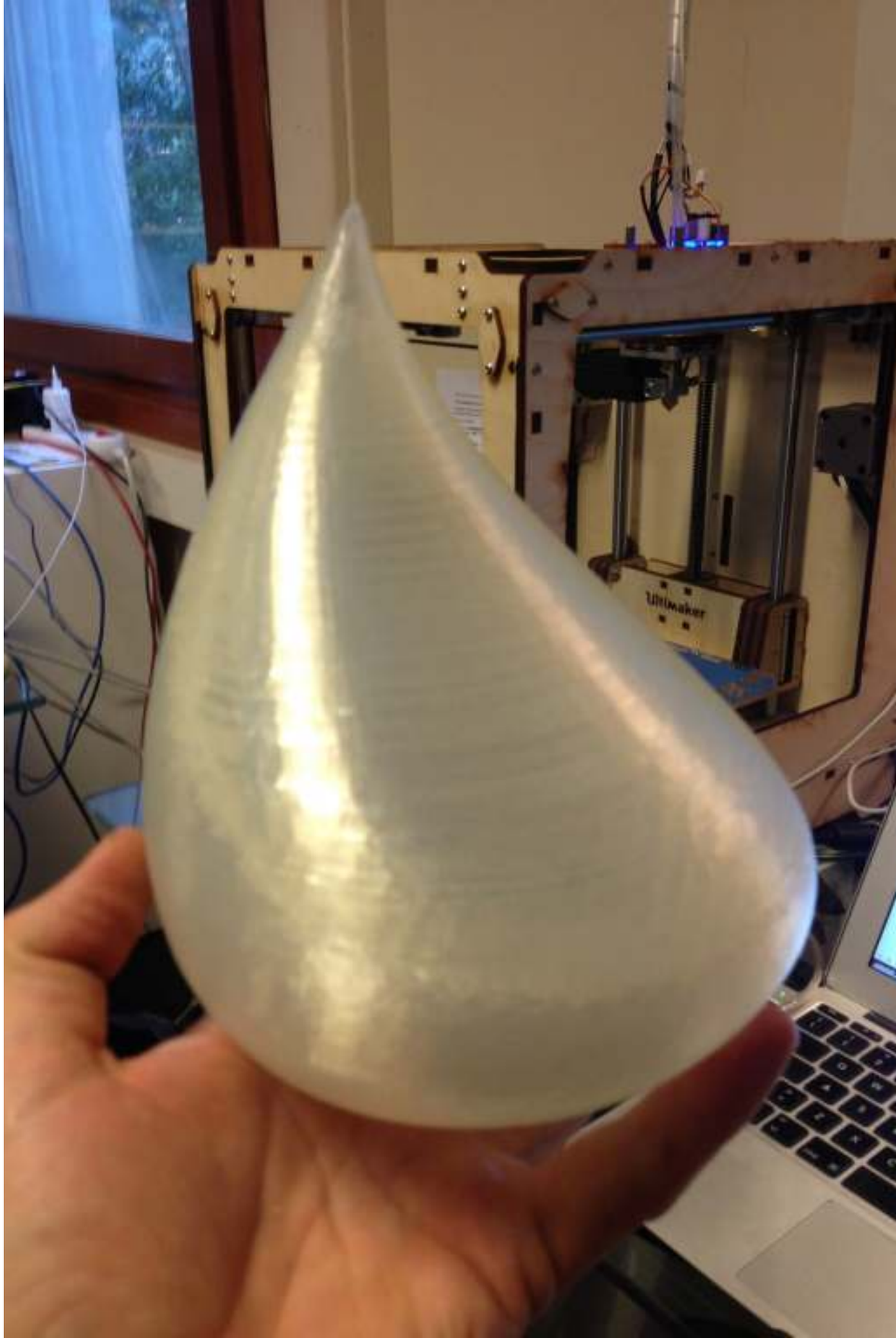
#5 - Wait until finished

- Printing time for a small object can be 10-20 minutes.
- For an object the size of an apple, can be up to 1 hour and more (it depends on resolution, infill, and printer speed).
- Bigger objects can take 10+ hours, complex ones even 20+ hours...
- May be dangerous to leave a 3D printer unattended when printing (temp > 200ºC, melted plastic, electricity, moving parts, wooden frame...).



#6 - Finishing

- After the print, you may want to give a few minutes for the object to cool down (it will be easier to detach it from the bed).
- You may have to remove raft/ support structures.
- If needed, the object surface can be smoothed by using sandpaper (it may ruin the finishing), a chemical solvent (i.e. Acetone for ABS), heat (hot air blower) or a coating paint.



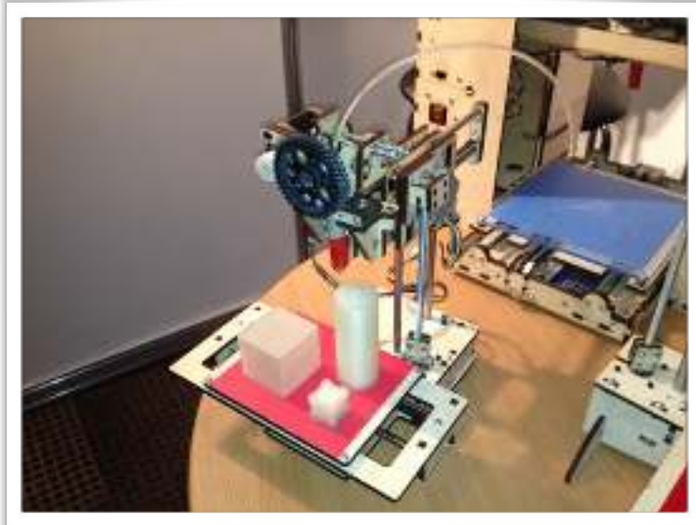
Small is beautiful

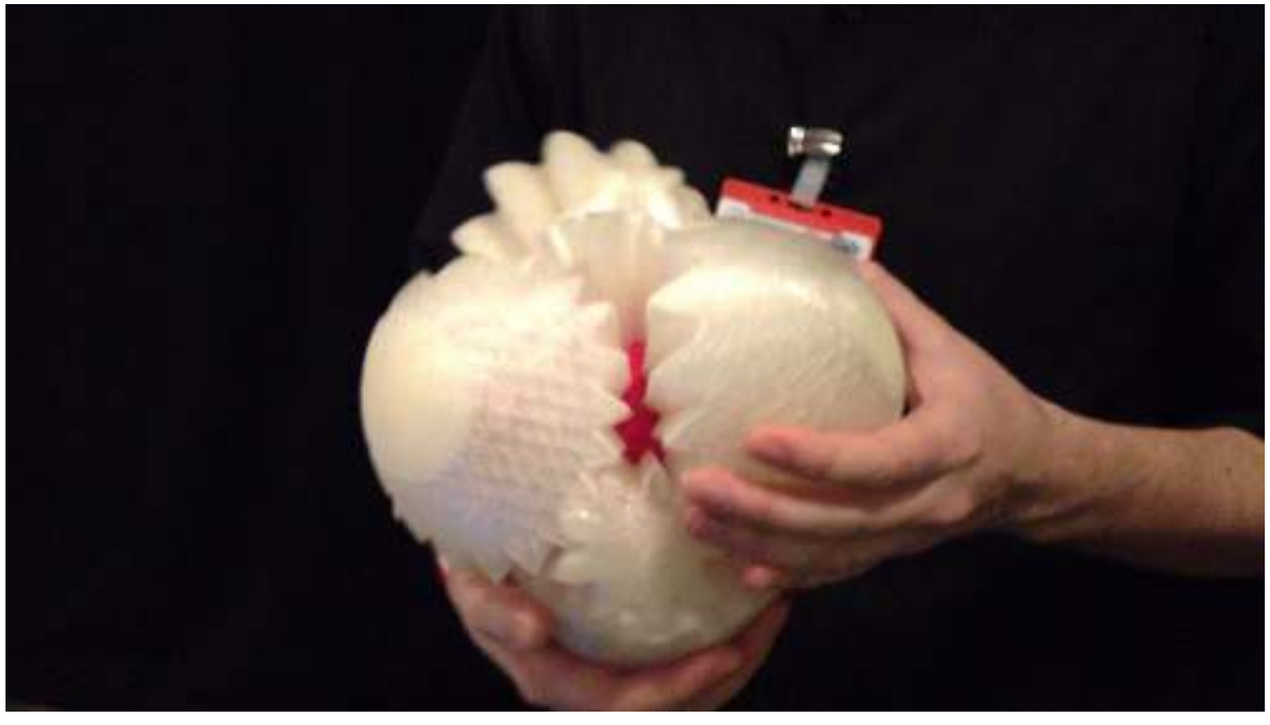
- Common low-cost 3D-printers can print objects with dimensions of **less than 20x20x20cm (approx.)**

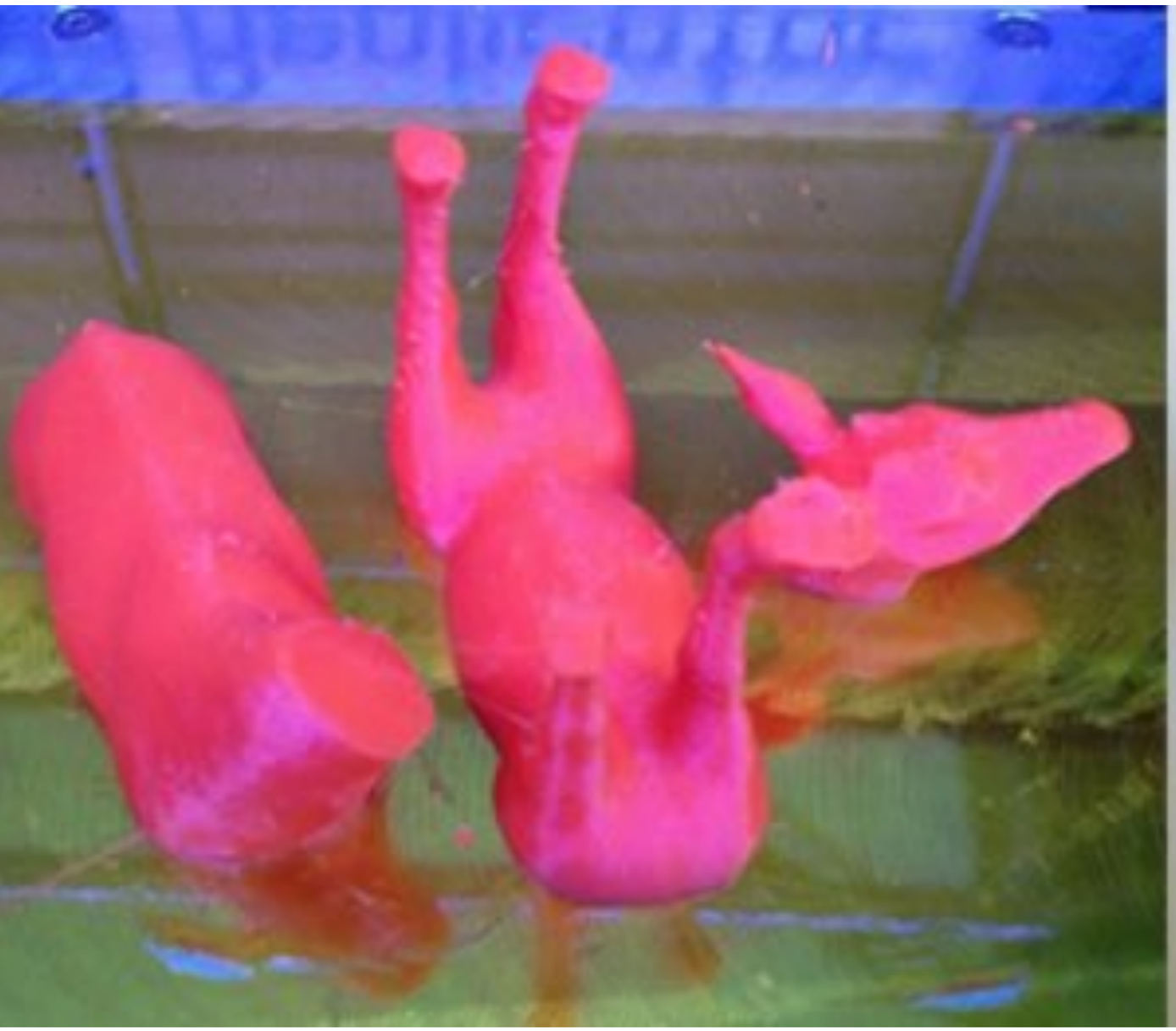
- In some models isn't very difficult to increase the vertical size. Horizontal limits are harder to break.

- It is still possible to build larger object by combining together multiple parts (with glue, screws or joints).

- Final object size may be incorrect because of thermal contraction/ dilation, always check (measure and and compensate)







Combining multiple prints can be a solution…

World's First 3D Printed Kayak

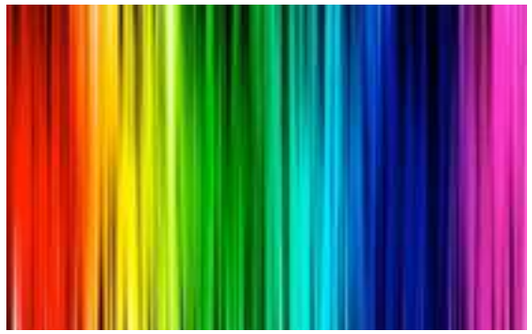
A world of plastic

don’t pollute,
3D-print!

Many types of plastics

- **ABS** (Acrylonitrile Butadiene Styrene), petroleum based plastic (used for the Lego™ bricks)
- **PLA** (Polylactic Acid or Polylactide), a *biodegradable* plastic made out of plant starch
- **Nylon** (®Taulman 618/645 or *“grass cutter”* filament –available at lower cost)
- **PVA** (Polyvinyl Alcohol), *water-soluble*
- **PS** (Polystyrene), used for plastic cups/dishes
- **HIPS** (High Impact Polystyrene, *soluble in Limonene*)
- **PET** (Polyethylene terephthalate), used in most water bottles
- **others**: soft/flexible, temperature-sensitive, wood-based, stone-like, conductive, etc...

Filament



- Filament comes in two standard diameters, **1.75 mm** and **3.0 mm**. The 3.0 mm filament is somehow an older standard and is slowly being upstaged by the 1.75 mm because it can be pushed slightly more easily, controlled a little better and sometimes leaves fewer tails hanging off the sides of your object.

- Cost: around 30$ (25€) per kg.

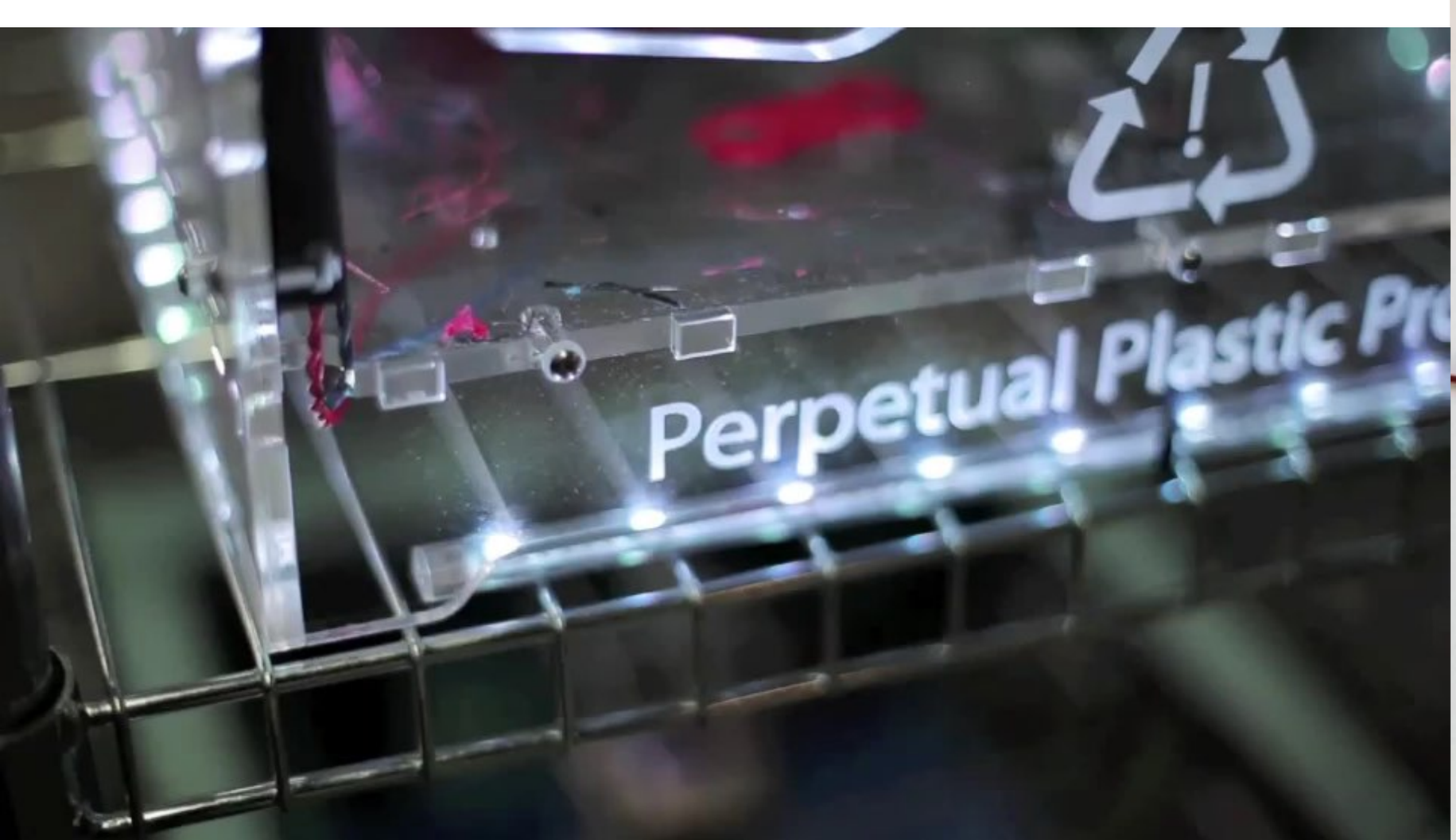
- 1g of printed object ~ 0.03 cents

- active development of systems for **low-cost filament production "at home"**, starting from plastic pellets or –even better– from recycling of plastic waste.

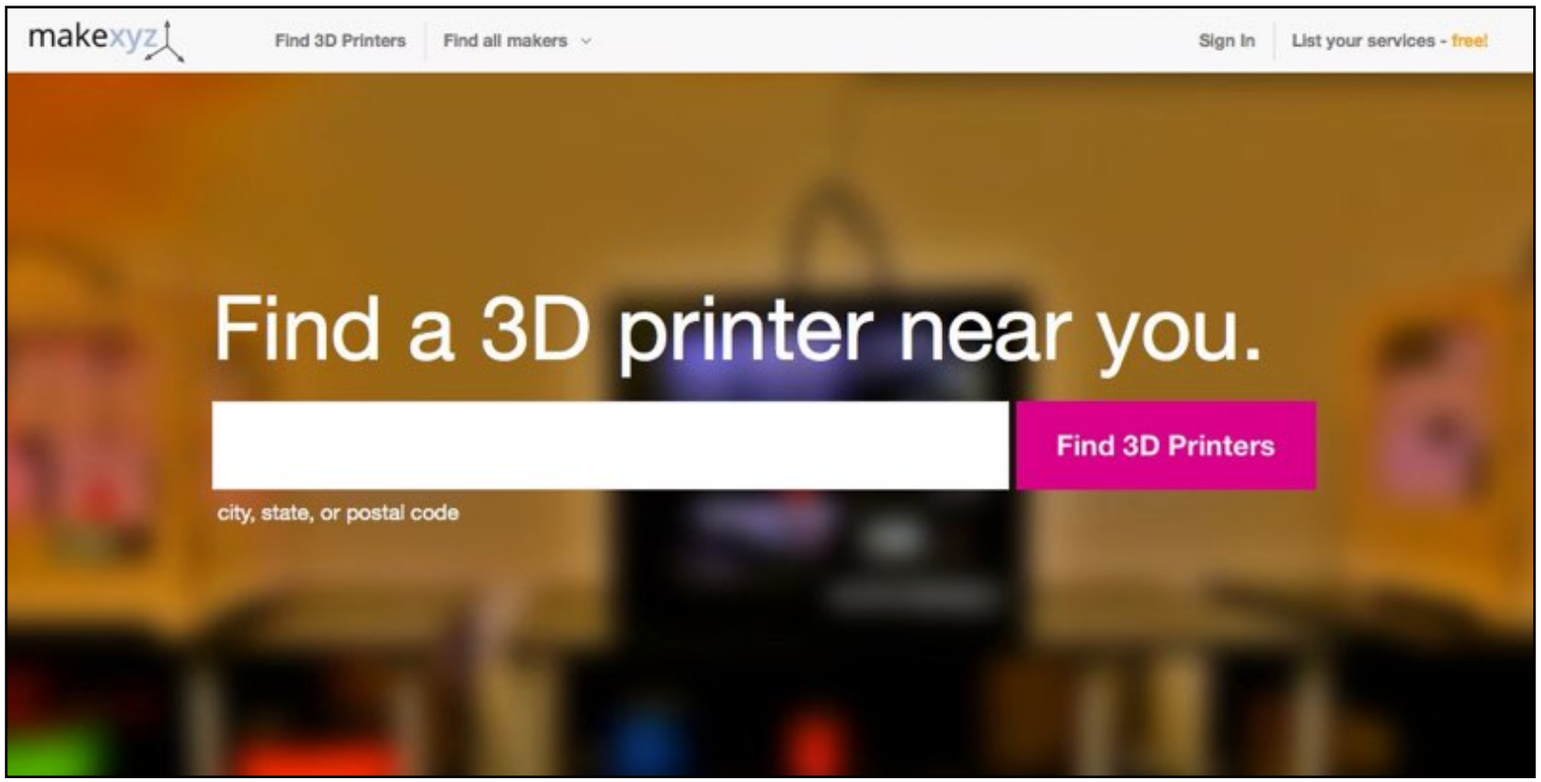
Recycling plastic

www.perpetualplasticproject.com

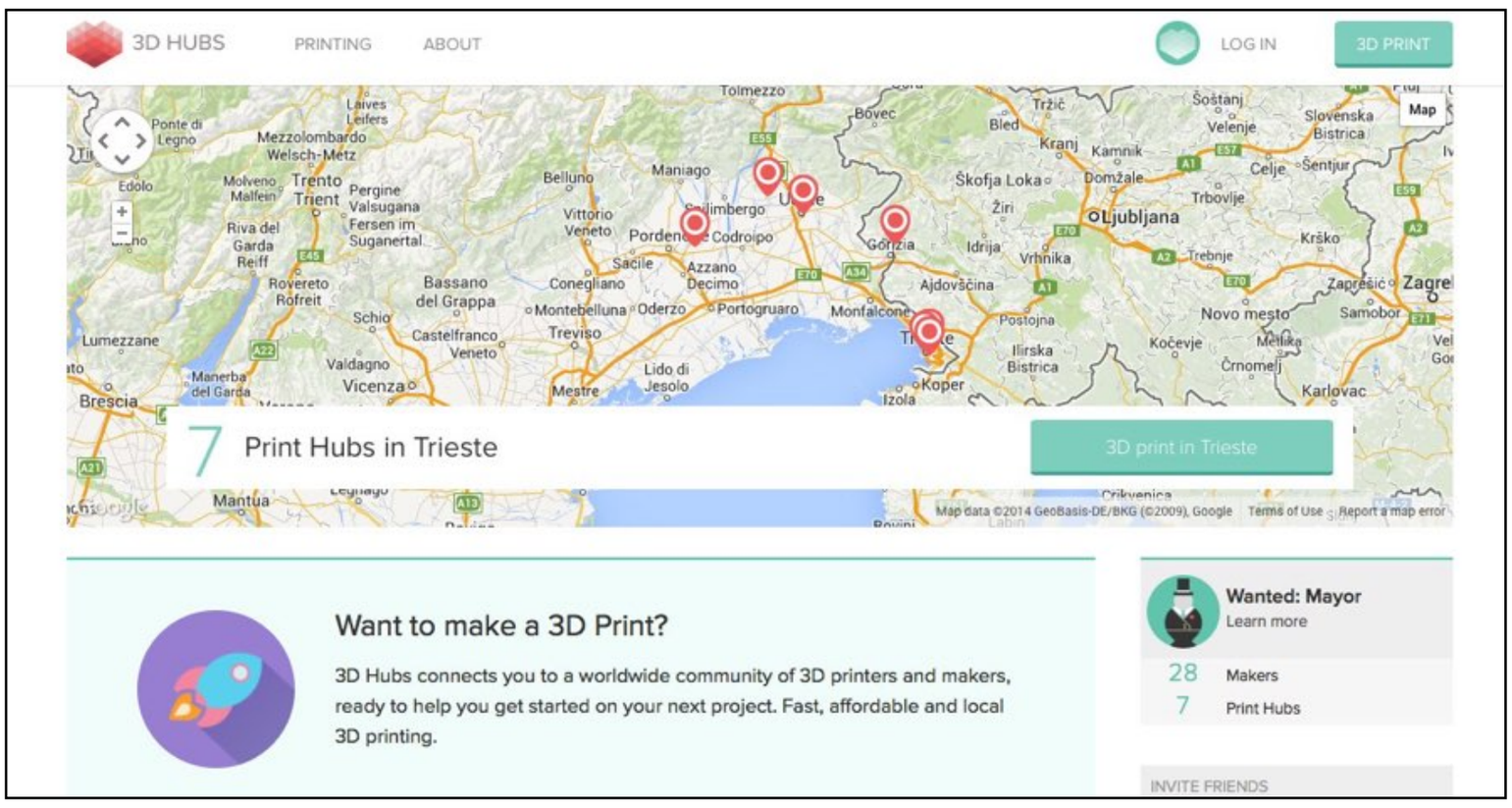
- make 3D-printed objects from recycled plastic



3DP as Service



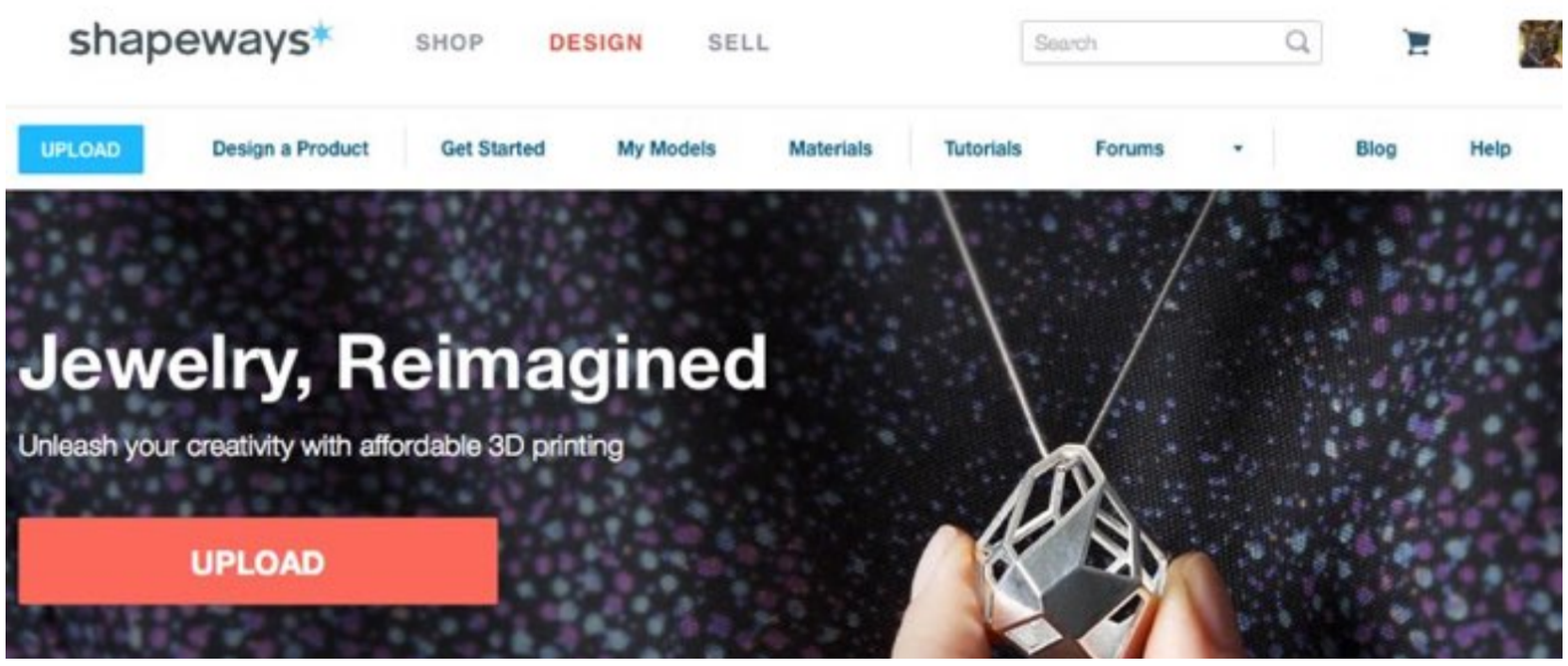
www.makexyz.com



www.3dhubs.com

3DP as Service

www.3ditaly.it



www.shapeways.com

polyamide

alumide

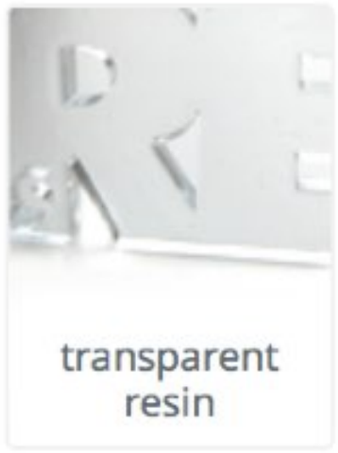
multicolor

The Periodic Table of Materials

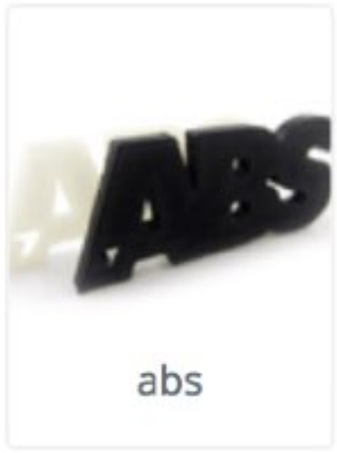
Display material icons

high detail resin

paintable resin



transparent resin



abs

titanium

Rank

Symbol

material

stainless steel

gold

silver

prime gray

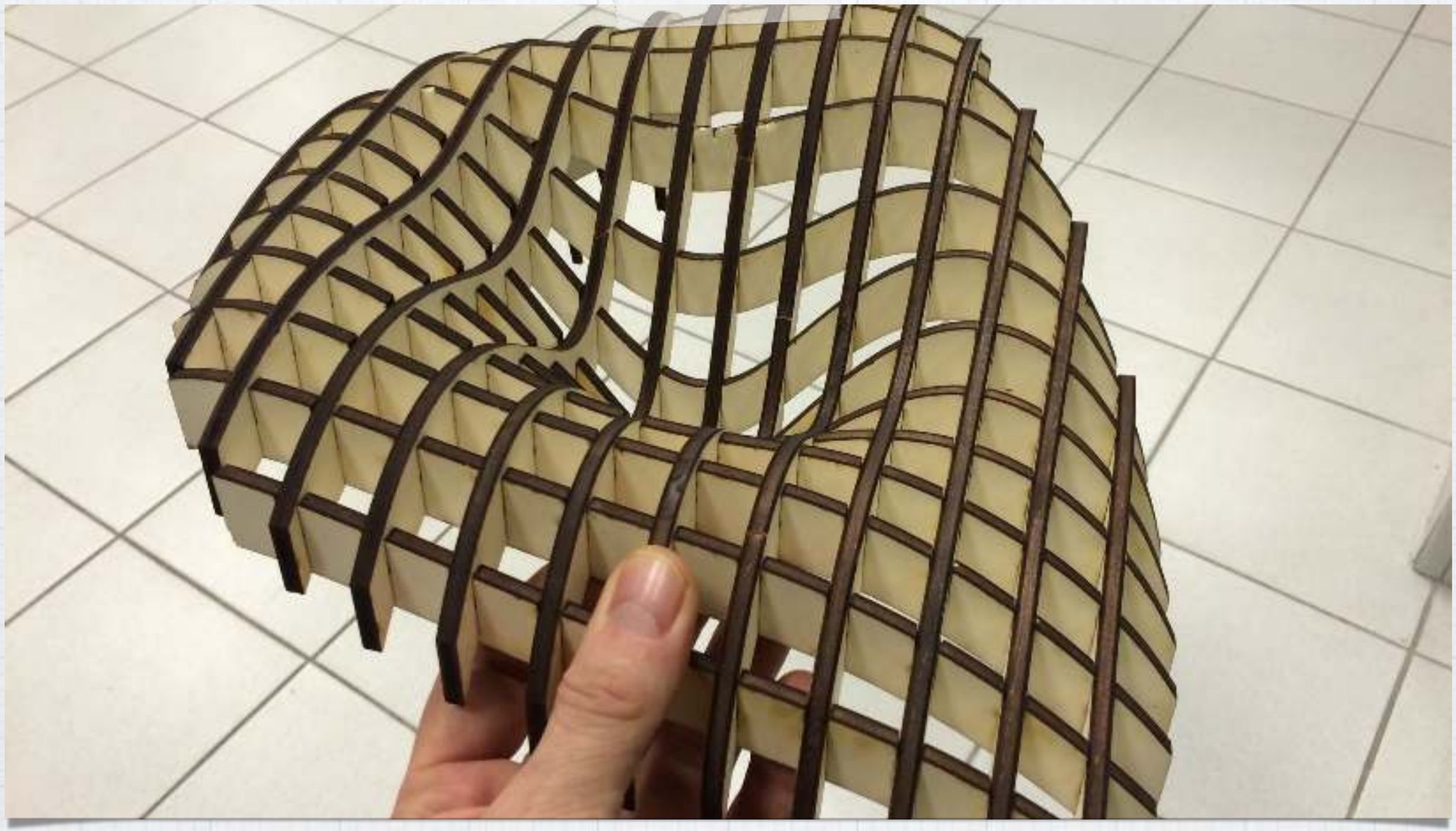
brass

bronze

ceramics

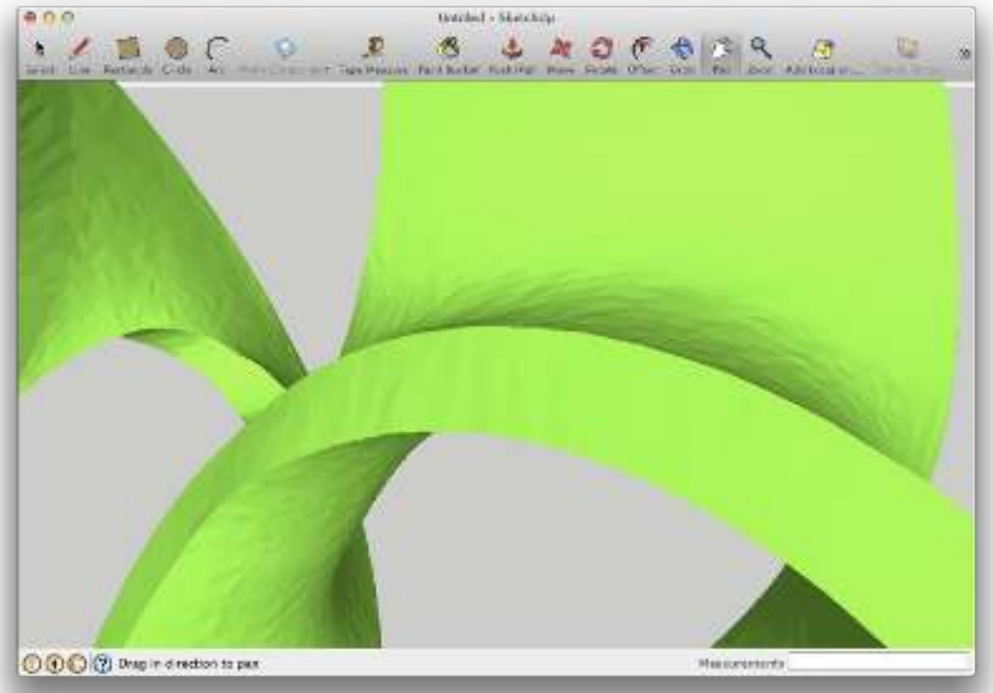
high detailed stainless steel

http://i.materialise.com/

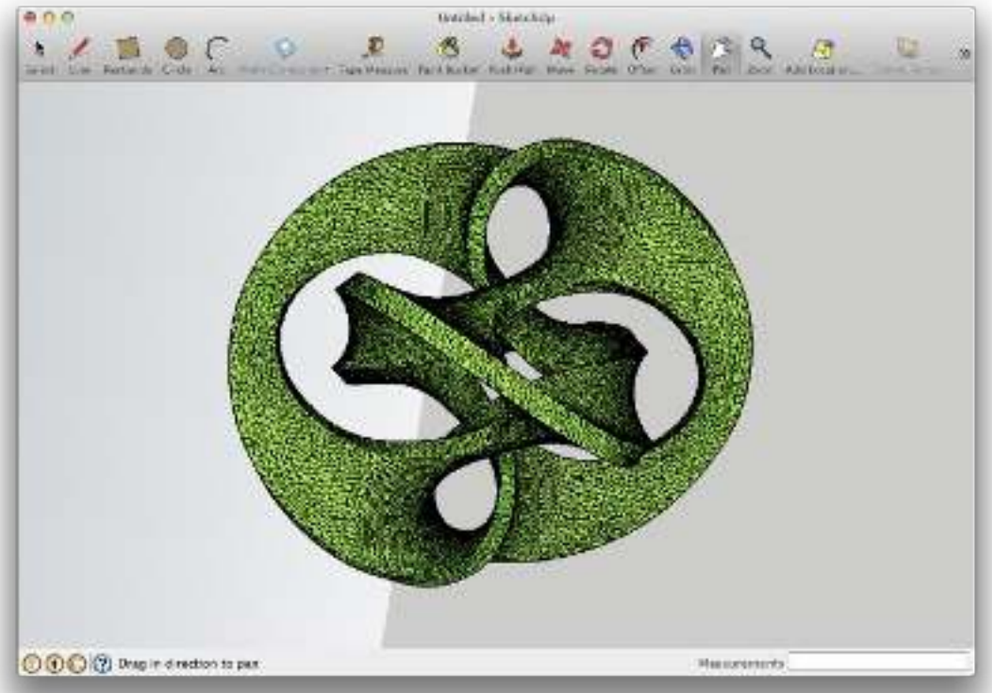


Mesh

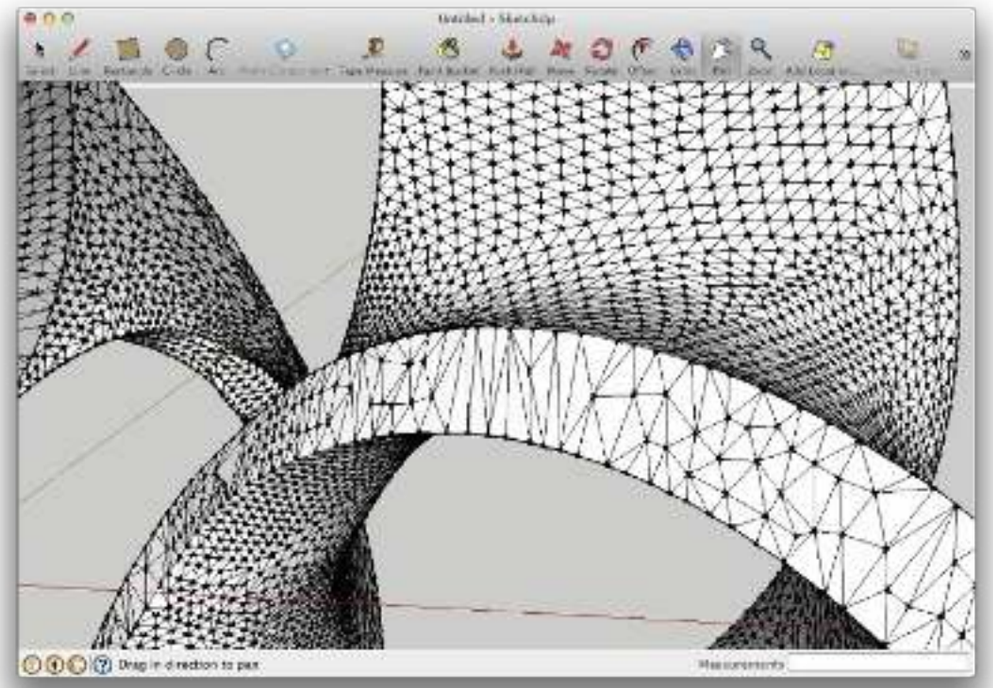
3D model (detail):



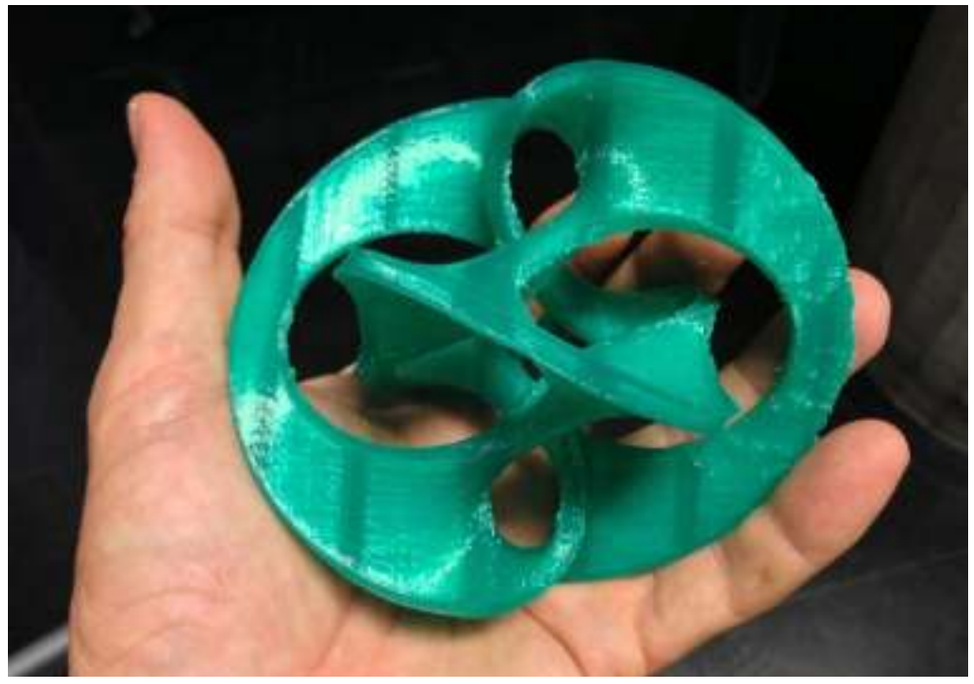
3D model, mesh:



mesh (detail):



printed object:



File format: STL (StereoLithography)

An ASCII STL file begins with the line:

`solid` *name*

where *name* is an optional string. The file continues with any number of triangles, each represented as follows:

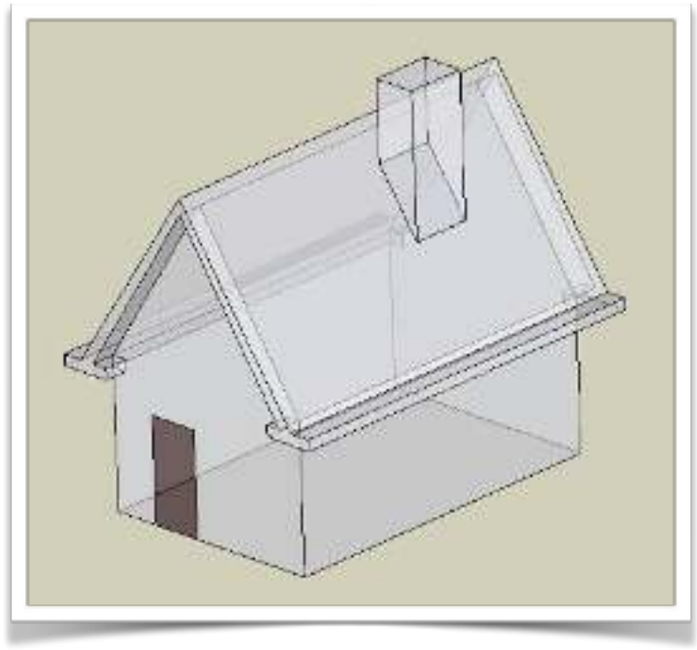
```
facet normal ni nj nk
outer loop
vertex v1x v1y v1z
vertex v2x v2y v2z
vertex v3x v3y v3z
endloop
endfacet
```

where each *n* or *v* is a floating point number in sign-mantissa 'e'-sign-exponent format, e.g., "-2.648000e-002". The file concludes with:

`endsolid` *name*

The structure of the format suggests that other possibilities exist (e.g., facets with more than one 'loop', or loops with more than three vertices) but in practice, all facets are simple triangles.

[source: Wikipedia]

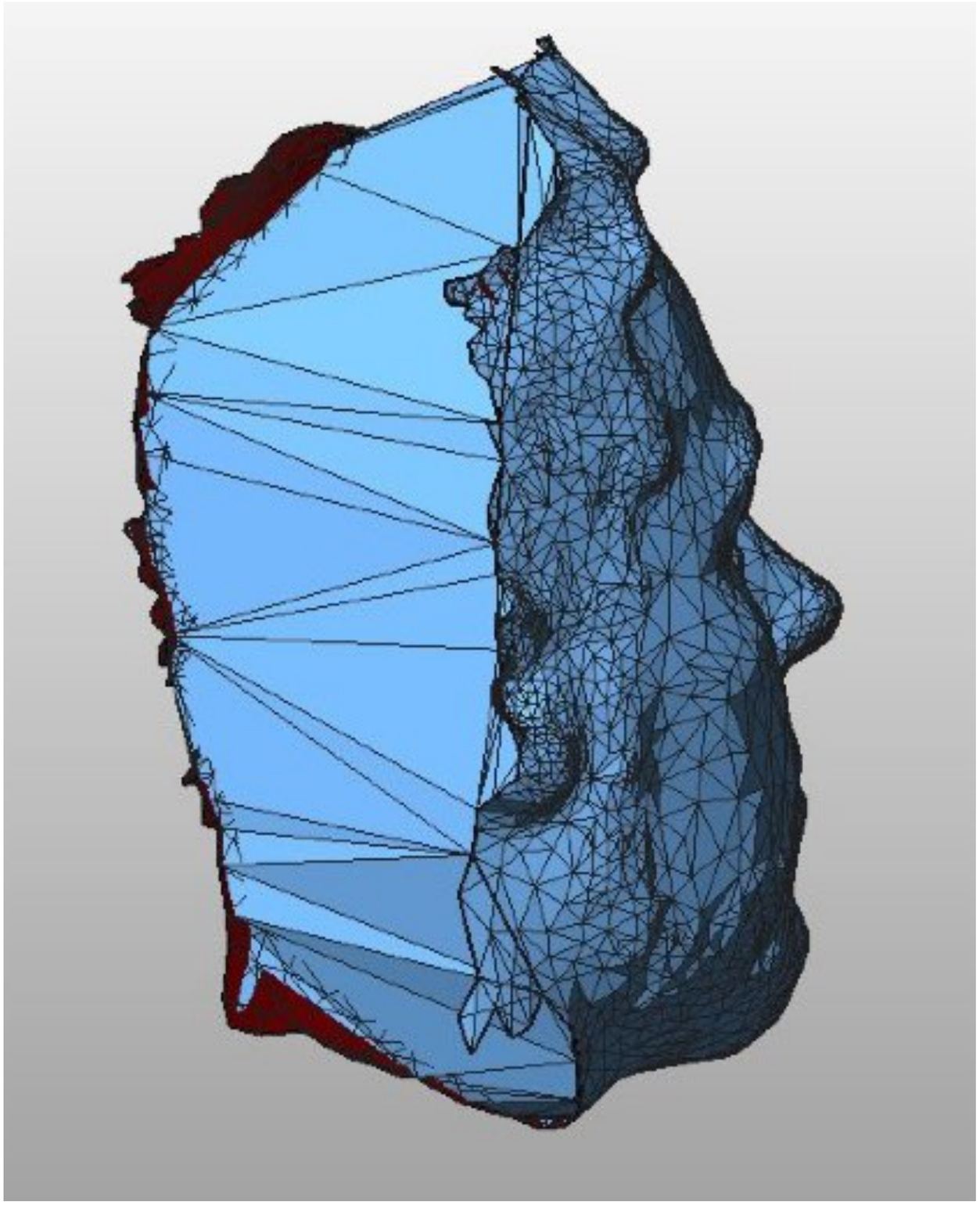


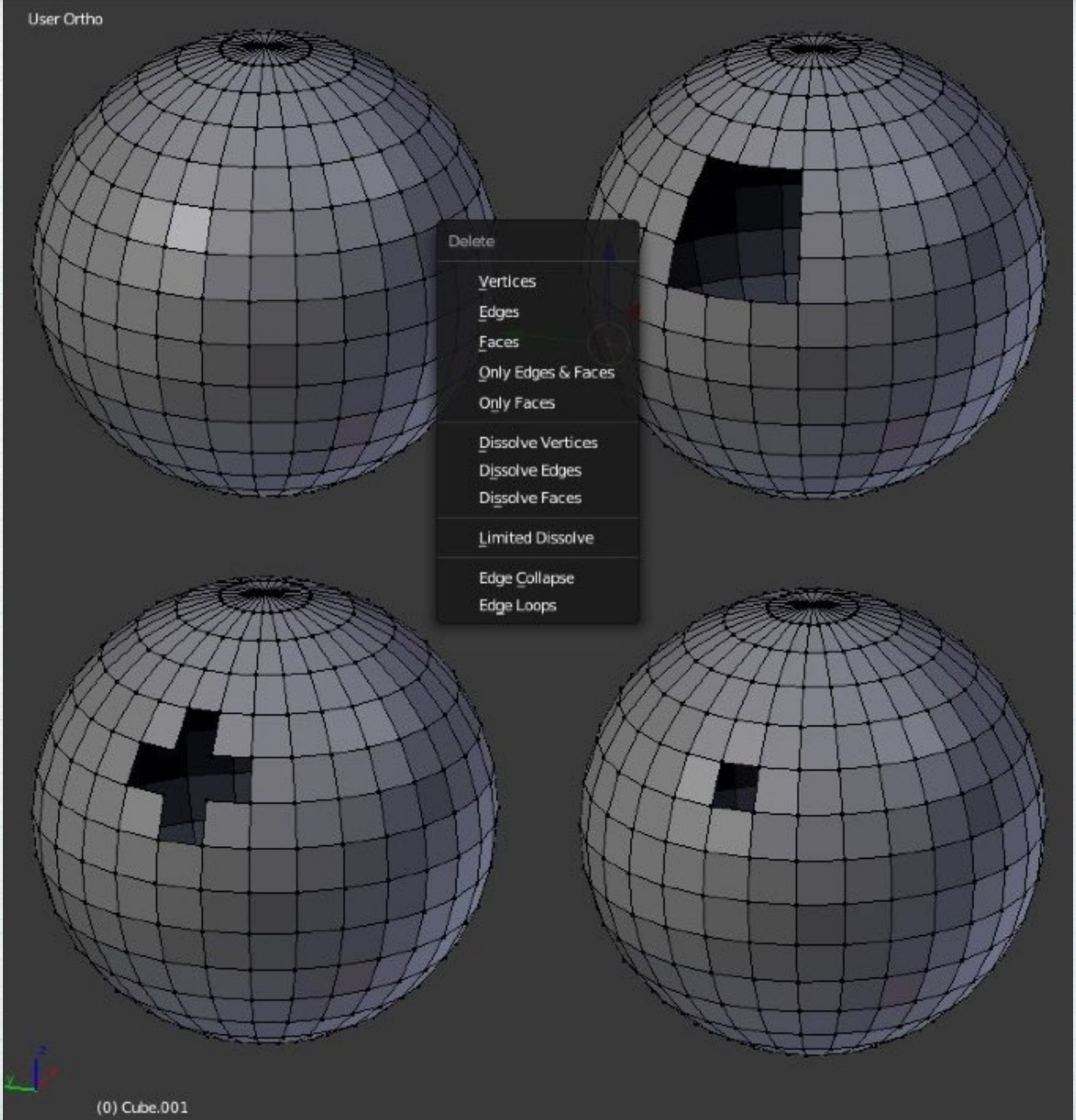
```
solid House
facet normal 6.82119751824952e-17 -0.816496580927727 -0.577350269189624
outer loop
vertex 93660.6382456757 40.3376838970568 -161.045352763136
vertex 92599.4905807017 244.743283455853 -450.118523884189
vertex 92953.043971295 448.86742868779 -738.793658479011
endloop
endfacet
facet normal 6.82119751824952e-17 -0.816496580927727 -0.577350269189624
outer loop
vertex 92599.4905807017 244.743283455853 -450.118523884189
vertex 93660.6382456757 40.3376838970568 -161.045352763136
vertex 92811.6226150577 122.268796316693 -276.913443127299
endloop
endfacet
facet normal 6.82119751824952e-17 -0.816496580927727 -0.577350269189624
outer loop
vertex 92811.6226150577 122.268796316693 -276.913443127299
vertex 93660.6382456757 40.3376838970568 -161.045352763136
vertex 87861.8751467518 -2735.46923693036 3764.53844120011
endloop
endfacet
facet normal 6.82119751824952e-17 -0.816496580927727 -0.577350269189624
```

Mesh requirements: watertightness

Float, don't sink!

- It is very important to generate a **“watertight” surface** for your model, so that the 3D printer can always clearly separate the inner volume (internal part, the one that has to be filled with plastic) from the outer one (external space). Simply, “watertight” means that **, there aren't holes, splits or missing parts in the mesh surface**.



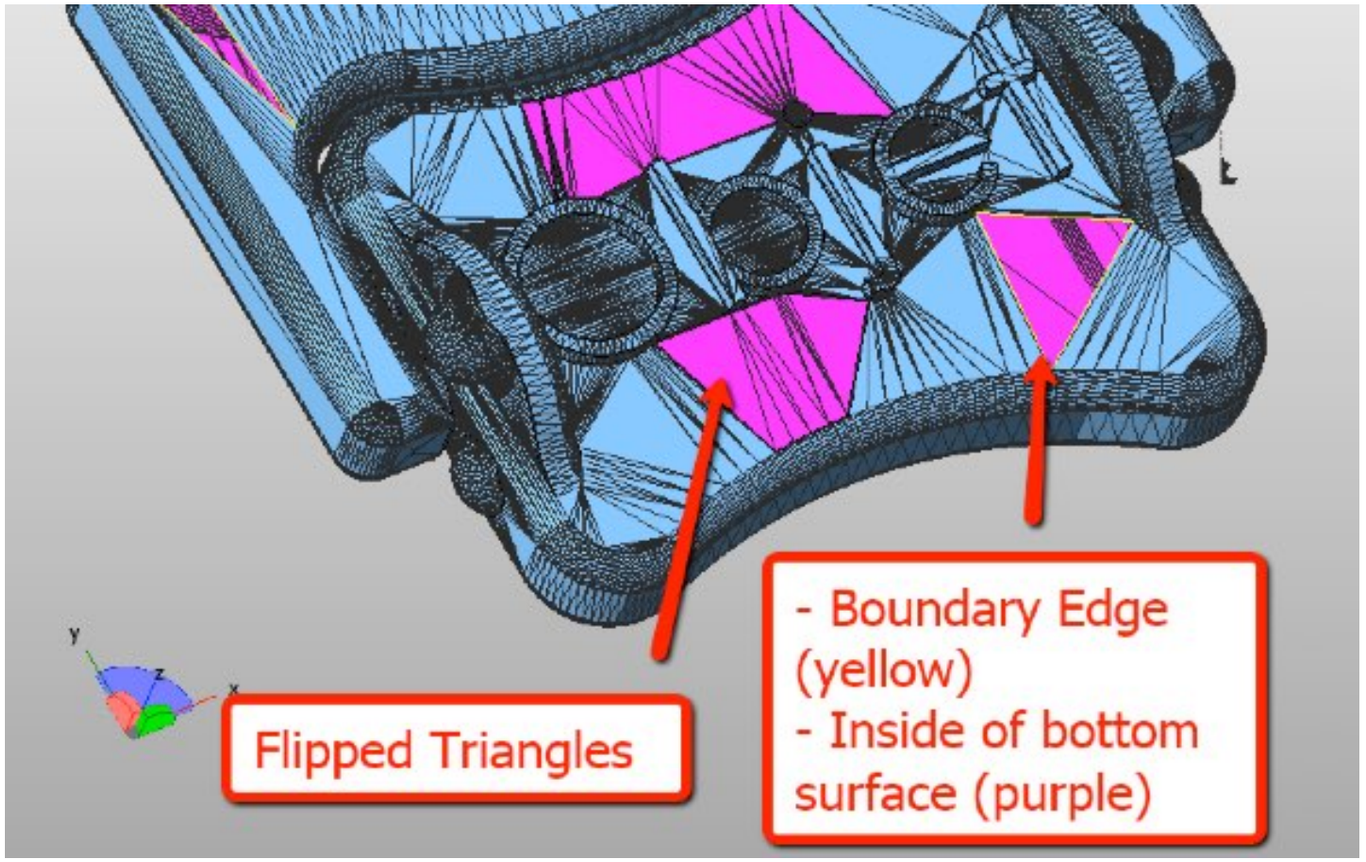

User Ortho
Delete
Vertices
Edges
Faces
Only Edges & Faces
Only Faces
Dissolve Vertices
Dissolve Edges
Dissolve Faces
Limited Dissolve
Edge Collapse
Edge Loops
(0) Cube.001

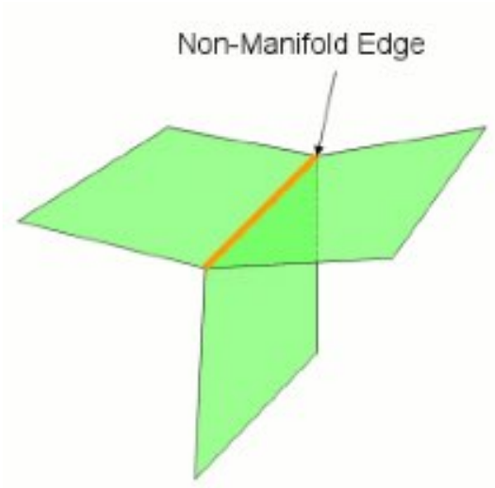
Mesh requirements: flipped triangles

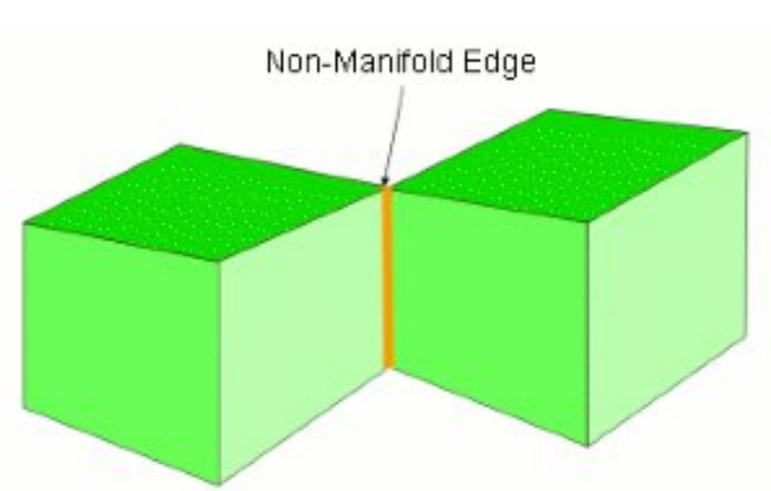
- Another issue is a mesh surface containing **triangles with inverted faces**. These have to be reversed (flipped) in order to get the correct orientation before slicing the mesh.

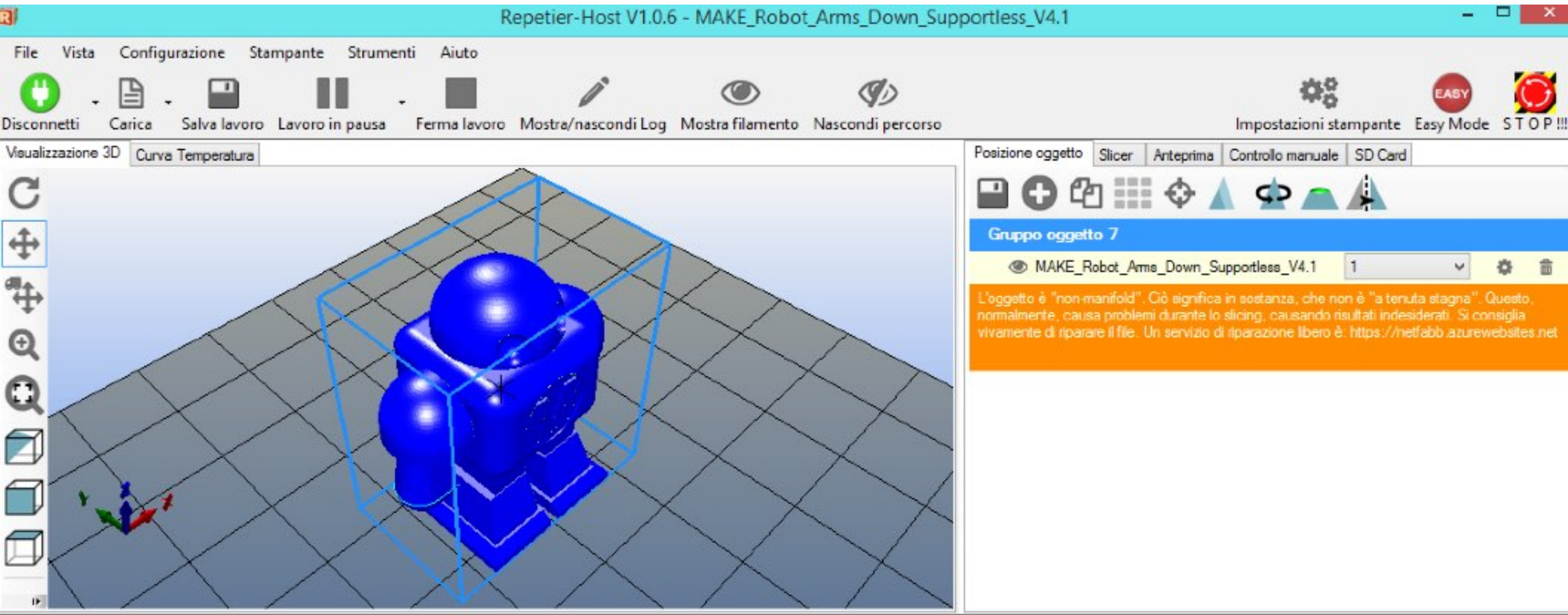
- Also the **“non-manifold” edges** have to be removed or corrected: these are the edges common to 3 or more multiple faces (an edge should only connect two faces).

- If these issues aren't corrected, the slicing software is not able to understand with side of the mesh is the *inside* and which is the *outside* in a unambiguous way.

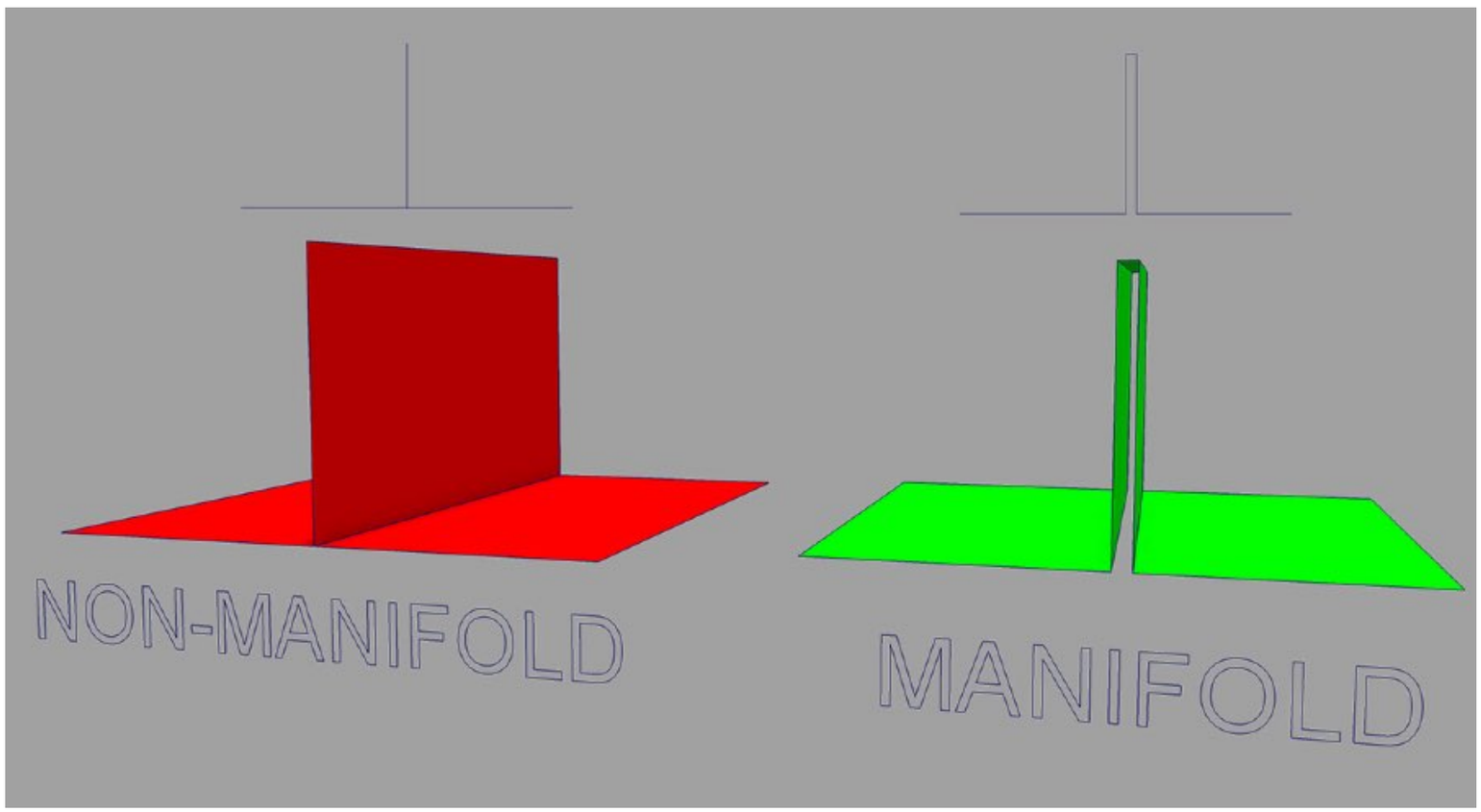




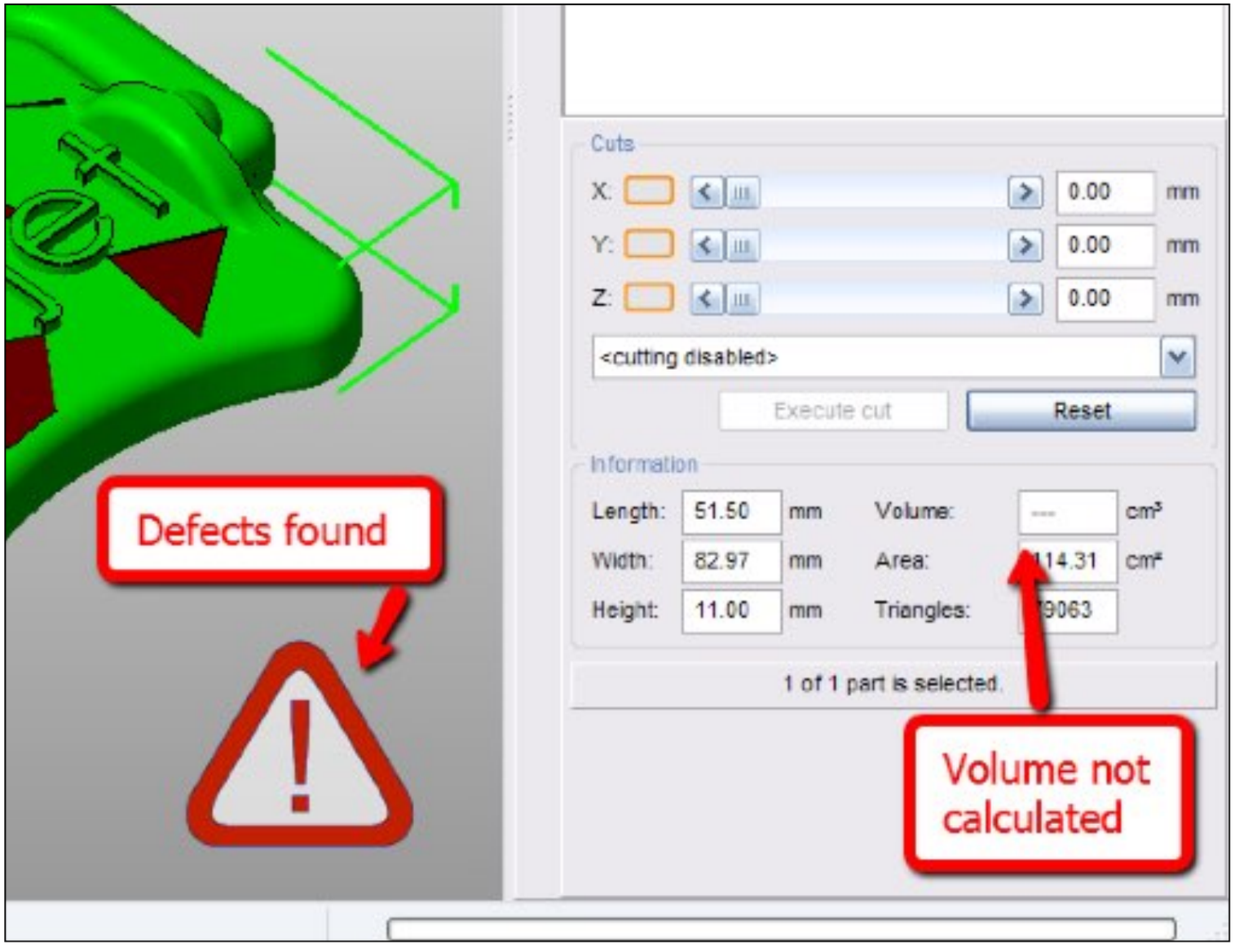


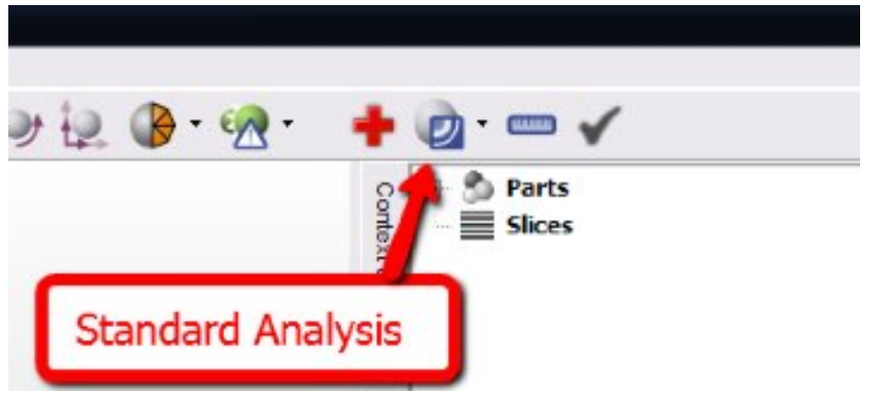

Repetier-Host V1.0.6 - MAKE_Robot_Arms_Down_Supportless_V4.1
File
Vista
Configurazione
Stampante
Strumenti
Aiuto
Disconnetti
Carica
Salva lavoro
Lavoro in pausa
Ferma lavoro
Mostra/nascondi Log
Mostra filamento
Nascondi percorso
Impostazioni stampante
Easy Mode
S T O P !!!
Visualizzazione 3D
Curva Temperatura
Posizione oggetto
Slicer
Anteprima
Controllo manuale
SD Card
Gruppo oggetto 7
MAKE_Robot_Arms_Down_Supportless_V4.1
1
L'oggetto è "non-manifold". Ciò significa in sostanza, che non è "a tenuta stagna". Questo, normalmente, causa problemi durante lo slicing, causando risultati indesiderati. Si consiglia vivamente di riparare il file. Un servizio di riparazione libero è: https://netfabb.azurewebsites.net

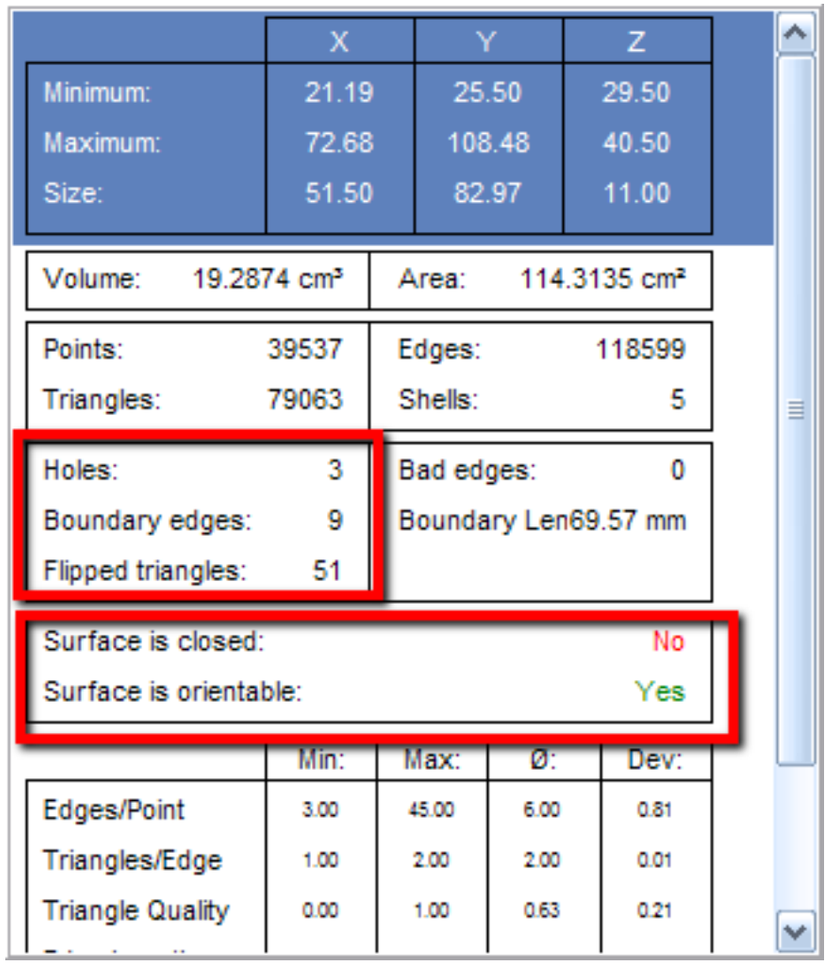
Warning!


NON-MANIFOLD
MANIFOLD

Netfabb





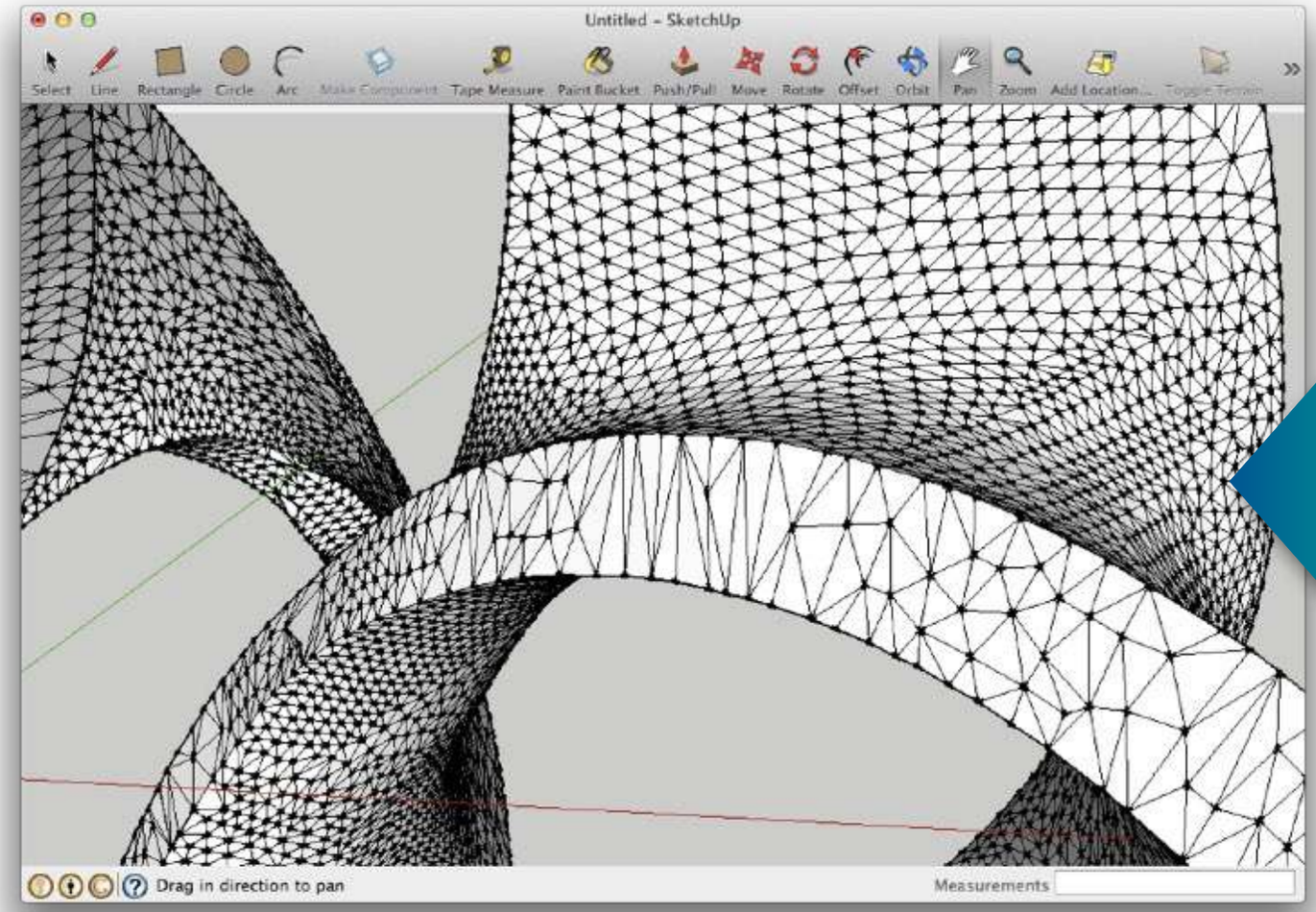


	X	Y	Z
Minimum:	21.19	25.50	29.50
Maximum:	72.68	108.48	40.50
Size:	51.50	82.97	11.00

Volume:	19.2874 cm³	Area:	114.3135 cm²
Points:	39537	Edges:	118599
Triangles:	79063	Shells:	5
Holes:	3	Bad edges:	0
Boundary edges:	9	Boundary Len	69.57 mm
Flipped triangles:	51		
Surface is closed:			No
Surface is orientable:			Yes

	Min:	Max:	Ø:	Dev:
Edges/Point	3.00	45.00	6.00	0.81
Triangles/Edge	1.00	2.00	2.00	0.01
Triangle Quality	0.00	1.00	0.63	0.21

Slicing




```
M109 S200 ; wait for temperature to be reached
M90 ; use absolute coordinates
M21 ; set units to millimeters
G92 E0
M82 ; use absolute distances for extrusion
G1 F1800.000 E-1.00000
G1 Z0.630
G92 E0
G1 X111.025 Y108.686 F7200.000
G1 Z0.330
G1 F1800.000 E1.00000
G1 X110.405 Y108.956 F900.000 E1.02268
G1 X109.765 Y109.196 E1.04559
G1 X108.785 Y109.476 E1.07977
G1 X107.785 Y109.666 E1.11390
G1 X106.775 Y109.766 E1.14793
G1 X106.095 Y109.776 E1.17074
G1 X105.075 Y109.726 E1.20498
G1 X101.345 Y109.356 E1.33066
G1 X100.665 Y109.266 E1.35366
G1 X99.995 Y109.136 E1.37655
G1 X99.335 Y108.966 E1.39940
G1 X98.685 Y108.756 E1.42231
G1 X97.745 Y108.376 E1.45630
G1 X96.835 Y107.906 E1.49065
G1 X96.255 Y107.546 E1.51354
G1 X95.425 Y106.936 E1.54808
G1 X94.655 Y106.266 E1.58230
G1 X93.955 Y105.526 E1.61646
G1 X93.315 Y104.726 E1.65081
```

The conversion from **mesh** (3D model, STL/OBJ format) to **gcode** (instructions for the 3D printer) is called "**slicing**" (*Ilke when you are slicing bread or meat, this explains the cover photo... ;-)*

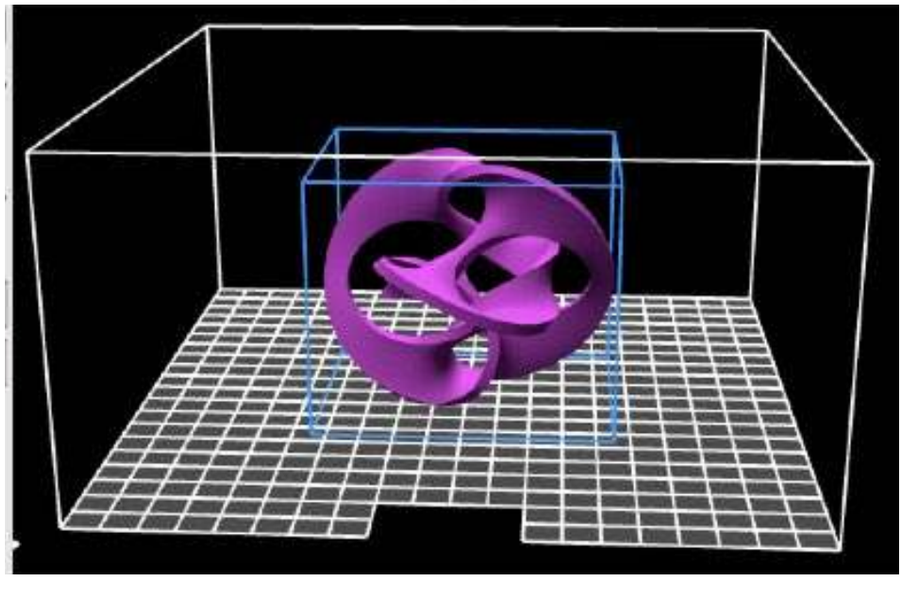
```
solid vcg
  facet normal  1.644528e-01  9.728446e-01 -1.628764e-01
    outer loop
      vertex  -2.251450e+01 -1.116070e+01  1.606290e+01
      vertex  -2.335270e+01 -1.109470e+01  1.561080e+01
      vertex  -2.328920e+01 -1.096510e+01  1.644900e+01
    endloop
  endfacet
  facet normal -1.989384e-01  2.022959e-01 -9.589056e-01
    outer loop
      vertex  -1.090160e+01  5.158700e+00  2.825740e+01
      vertex  -1.032000e+01  5.417800e+00  2.819140e+01
      vertex  -9.804300e+00  4.709100e+00  2.793490e+01
    endloop
  endfacet
  facet normal -8.213068e-01 -5.629737e-01  9.228100e-02
    outer loop
      vertex  -9.804300e+00 -2.974080e+01
```

slicing

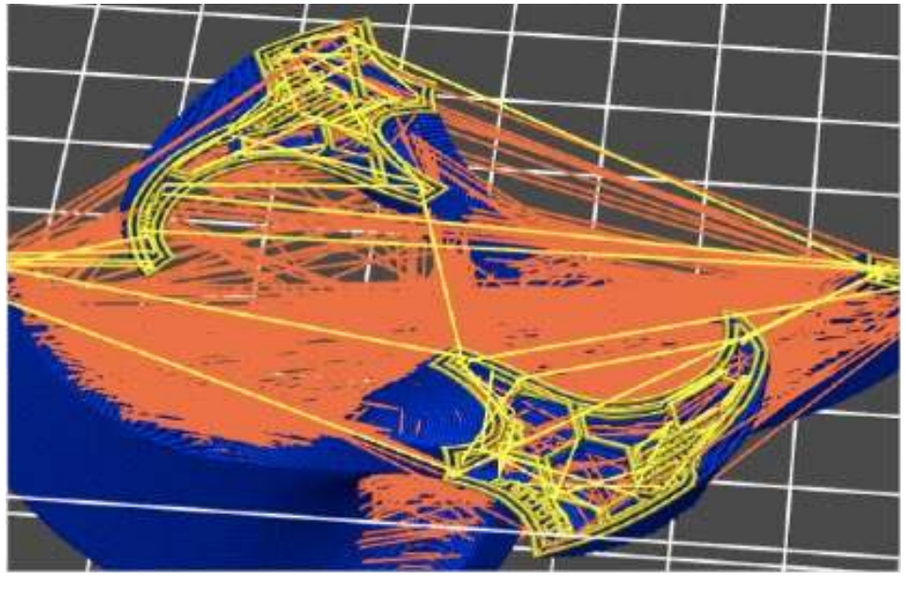
```
M109 S200 ; wait for temperature to be reached
G90 ; use absolute coordinates
G21 ; set units to millimeters
G92 E0
M82 ; use absolute distances for extrusion
G1 F1800.000 E-1.00000
G1 Z0.630
G92 E0
G1 X111.025 Y108.686 F7200.000
G1 Z0.330
G1 F1800.000 E1.00000
G1 X110.405 Y108.956 F900.000 E1.02268
G1 X109.765 Y109.196 E1.04559
G1 X108.785 Y109.476 E1.07977
G1 X107.785 Y109.666 E1.11390
G1 X106.775 Y109.766 E1.14793
G1 X106.095 Y109.776 E1.17074
G1 X105.075 Y109.726 E1.20498
G1 X101.345 Y109.356 E1.33066
```

STL (vertexes)

g-code (printing instructions)



slicing



3D model

path of the printing head

netfabb Pro

Slic3r

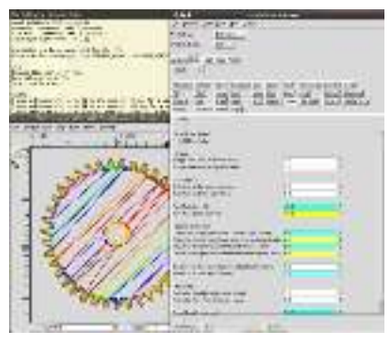
Cura

MakerWare

Craftware

Simplify3D

IceSL

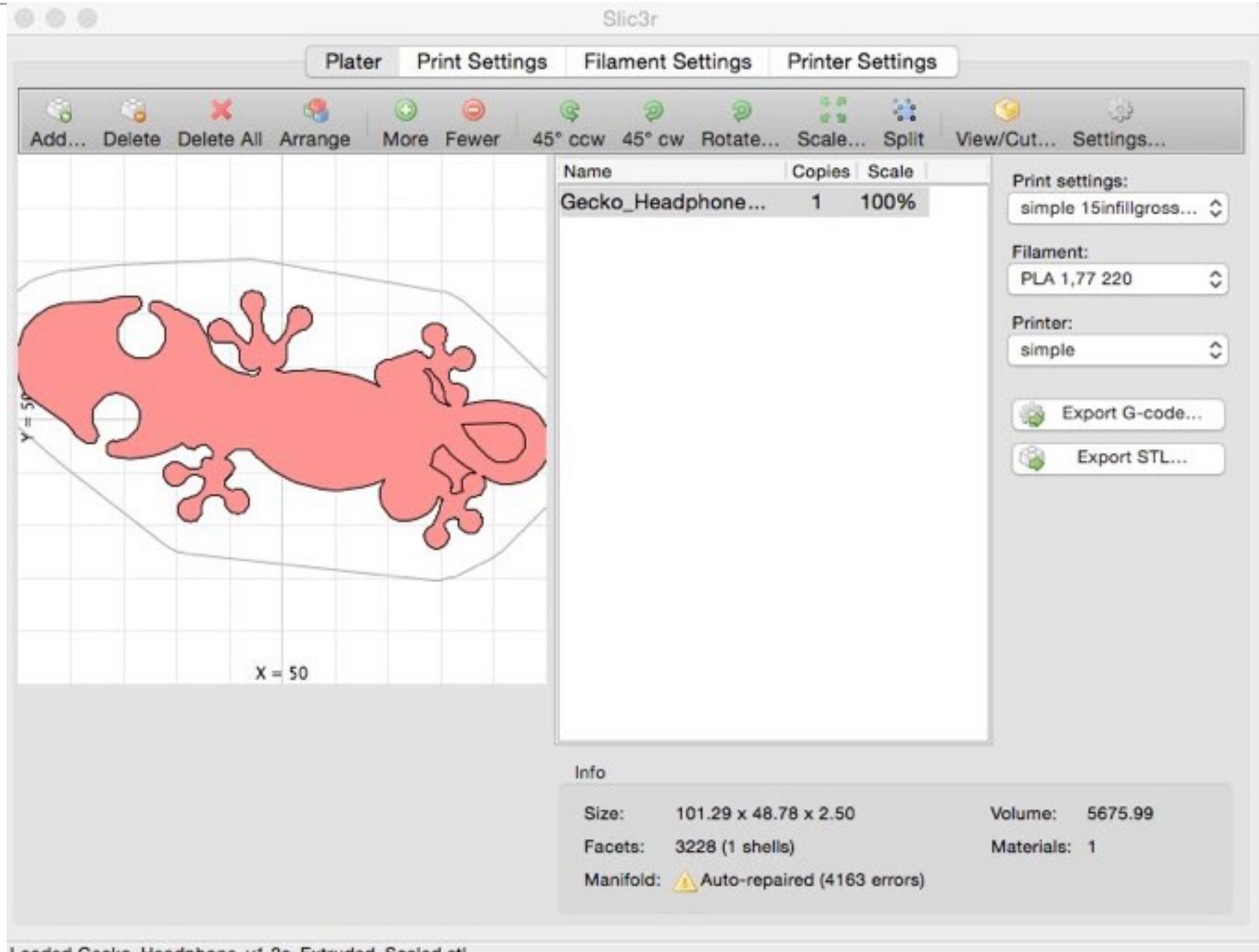


Skeinforge

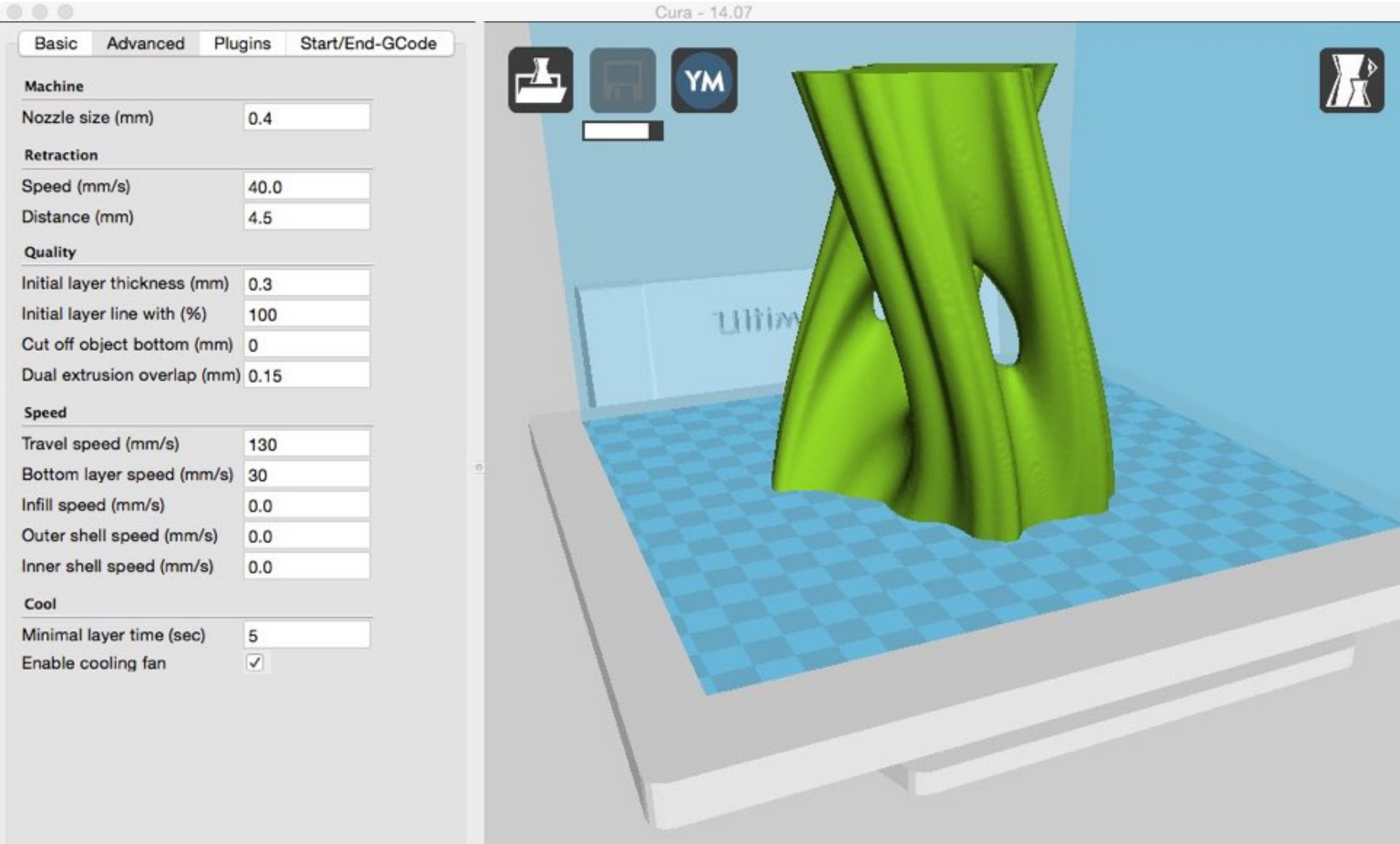
KISSlicer

Software	User	Price	OS
3DPrinterOS	Beginners, Advanced Users	Freemium	Browser, Windows, Mac
Astroprint	Beginners, Advanced Users	Freemium	Browser, Raspberry Pi, pcDuino
CraftWare	Beginners, Advanced Users	Free	Windows, Mac, Linux
Cura	Beginners, Advanced Users	Free	Windows, Mac, Linux
IceSL	Advanced Users	Free	Windows, Linux
ideaMaker	Beginners, Advanced Users	Free	Windows, Mac, Linux
KISSlicer	Beginners, Advanced Users	Free/$35	Windows, Mac, Linux, Raspberry Pie
MakerBot Print	Beginners	Free	Windows, Mac
MatterControl	Beginners, Advanced Users	Free	Windows, Mac, Linux
Netfabb Standard	Intermediate Users, Advanced Users	$1,000 to $4,300 (annual subscription)	Windows
OctoPrint	Intermediate Users, Advanced Users	Free	Raspberry Pi, Windows, Mac Linux
Repetier	Intermediate Users, Advanced Users	Free	Windows, Mac, Linux
SelfCAD	Beginner, Advanced Users	Free trial, $9.99/month	Browser
Simplify3D	Beginners, Advanced Users	$150	Windows, Mac
Slic3r	Advanced Users, Professional Users	Free	Windows, Mac, Linux
SliceCrafter	Advanced Users	Free	Browser
Tinkerine Suite	Beginners	Free	Windows, Mac
Z-Suite	Beginners	Free	Windows, Mac

Slic3r

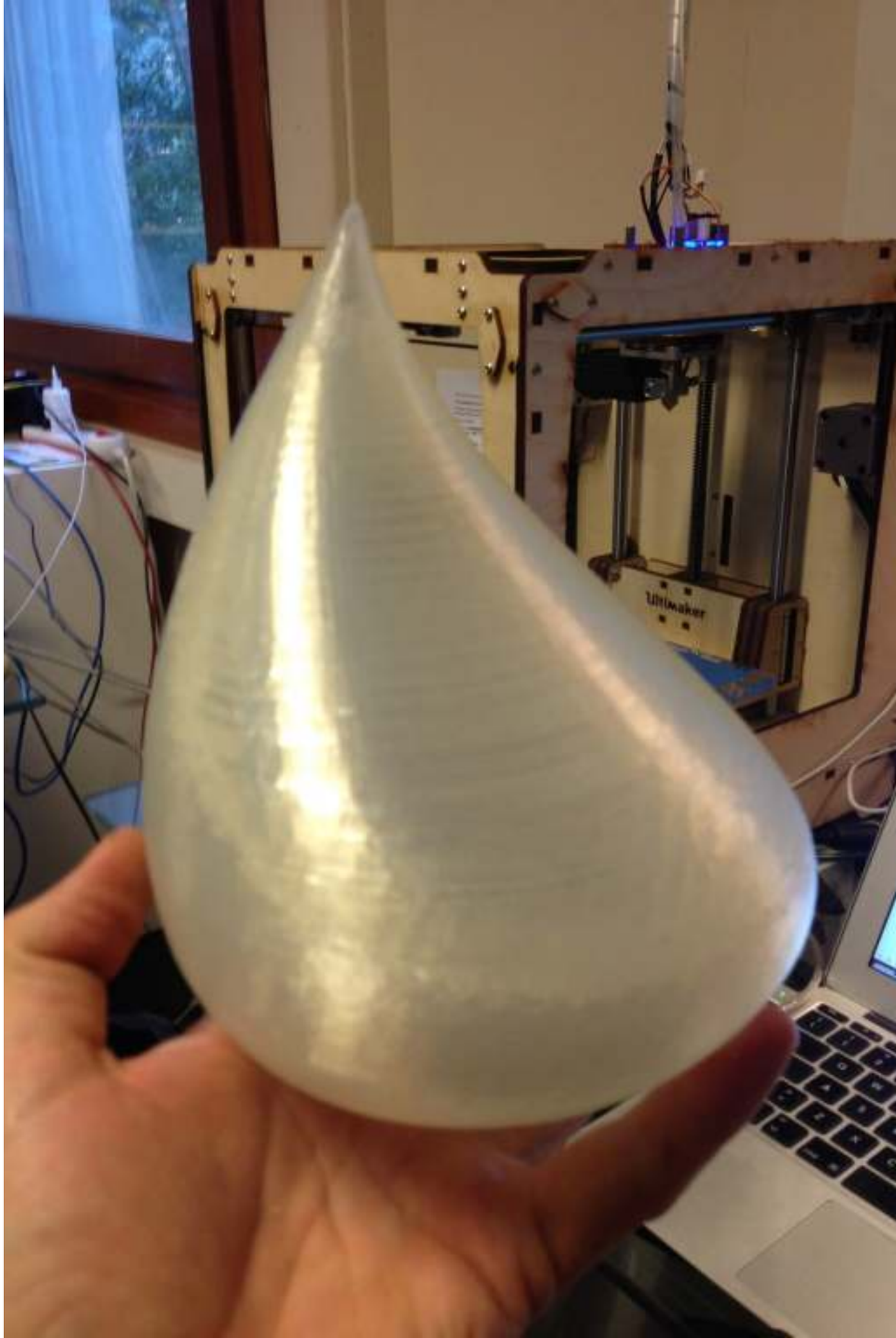

Slic3r
Plater
Print Settings
Filament Settings
Printer Settings
Add...
Delete
Delete All
Arrange
More
Fewer
45° ccw
45° cw
Rotate...
Scale...
Split
View/Cut...
Settings...
Name
Copies
Scale
Gecko_Headphone...
1
100%
Print settings:
simple 15infillgross...
Filament:
PLA 1,77 220
Printer:
simple
Export G-code...
Export STL...
X = 50
Info
Size:
101.29 x 48.78 x 2.50
Volume:
5675.99
Facets:
3228 (1 shells)
Materials:
1
Manifold:
Auto-repaired (4163 errors)
Loaded Gecko_Headphone_v1.2a_Extruded_Scaled.stl

Cura


Cura - 14.07
Basic
Advanced
Plugins
Start/End-GCode
Machine
Nozzle size (mm) 0.4
Retraction
Speed (mm/s) 40.0
Distance (mm) 4.5
Quality
Initial layer thickness (mm) 0.3
Initial layer line with (%) 100
Cut off object bottom (mm) 0
Dual extrusion overlap (mm) 0.15
Speed
Travel speed (mm/s) 130
Bottom layer speed (mm/s) 30
Infill speed (mm/s) 0.0
Outer shell speed (mm/s) 0.0
Inner shell speed (mm/s) 0.0
Cool
Minimal layer time (sec) 5
Enable cooling fan
YM

Post-processing and finishing

- After the printing process has finished, leave the object on the heatbed for a few minutes to allow to cool down (this will make it easier to remove the object from the platform).



Join multiple prints

Sand paper

Polish


Before


BEFORE
AFTER
TREATMENT: REACTING POLYMER
AIRWOLF3D.COM

epoxy glue (two components)

XTC-3D®

Aceton vapours

Ethyl acetate vapours

http://www.printedsolid.com/smoothpla/

http://artforcestudios.com/wp/design-services/

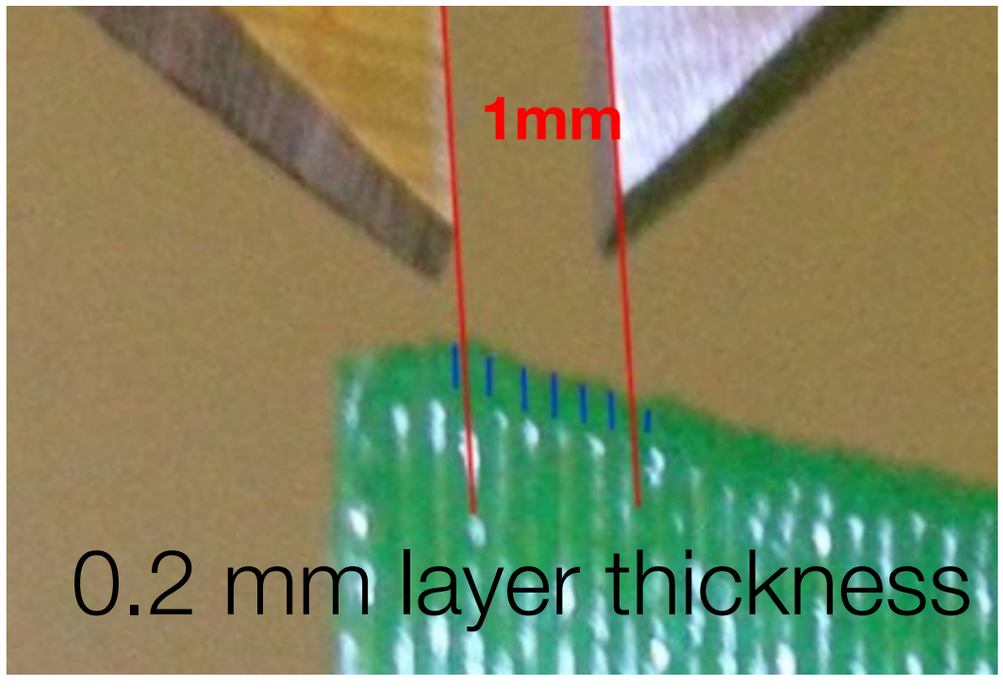
Advanced: slicing parameters

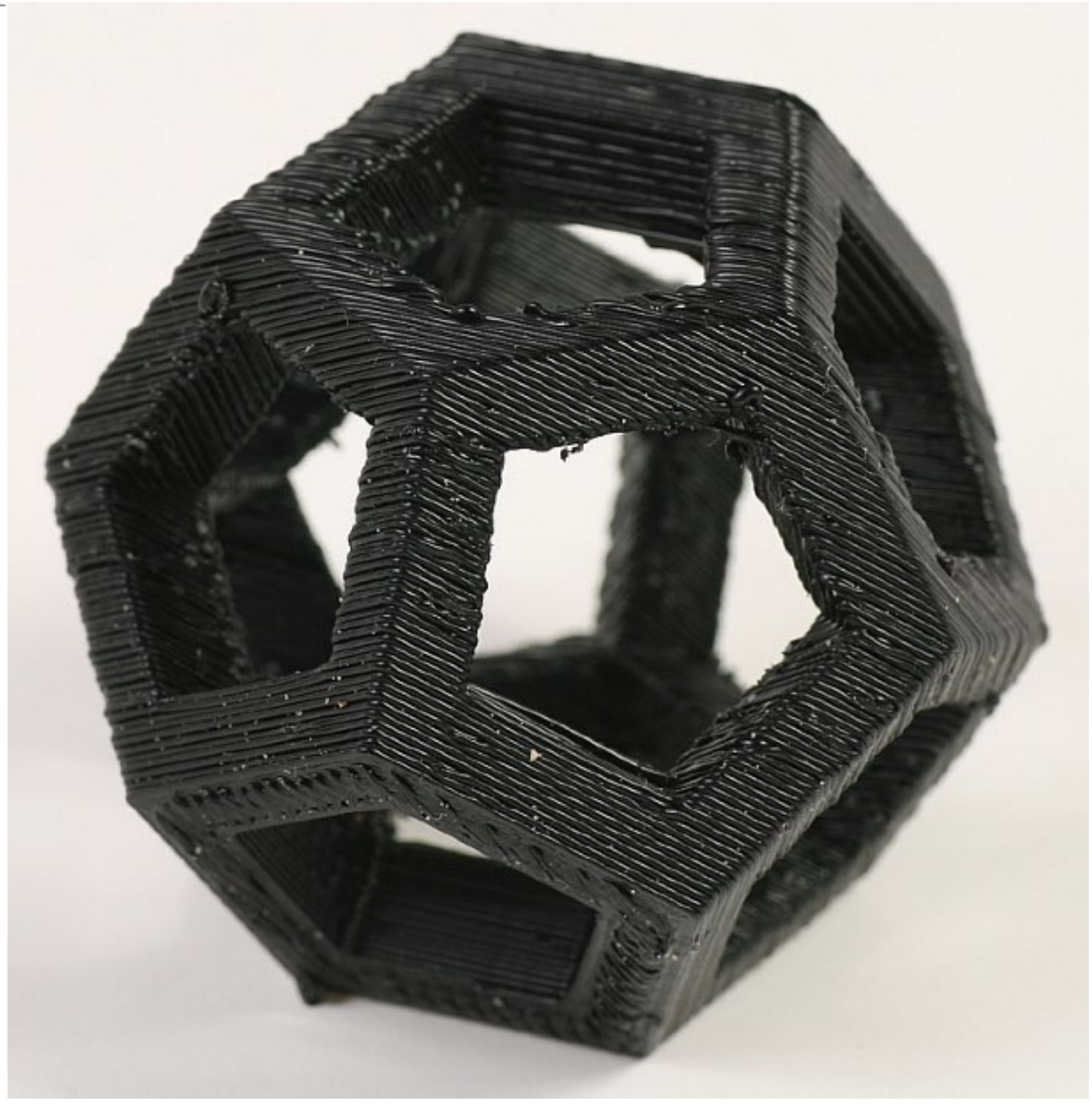
(Science or Art?)

Details that make the difference...

- Small details are difficult to print: the diameter of the nozzle is usually in the range 0.3–0.5 mm, the head/platform movement resolution is ~0.1 mm.

- A typical value for layer thickness is 0.2 mm (range: 0.05–0.5 mm).





Layer height

0.1mm 0.2mm 0.3mm 0.4mm

Filling the empty

- 3D printing is an additive process. That means you aren't paying for a machine to take material away, but to build material up. So the less material your design needs (e.g. the less volume), the lower the cost.

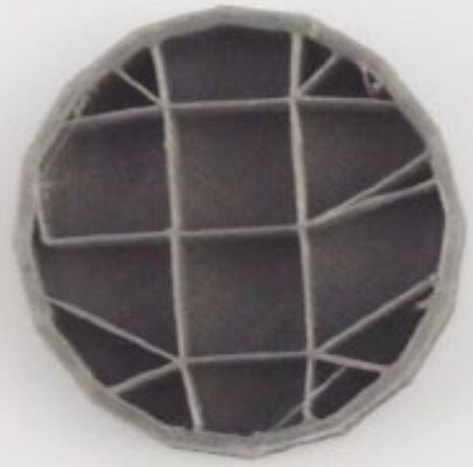
- For this reason, most of the objects are printed with the ***infill*** parameter set to a value in the range: 10% to 50%

- Robustness is obtained with the proper number of ***perimeters*** (shells), and ***bottom/top layers***.

INFILL PERCENTAGE

The variable that defines the density of the internal support structure of FFF printed objects
Rule-of-thumb: the higher the percentage of infill, the denser the object

0%



5%

10%

15%

100%

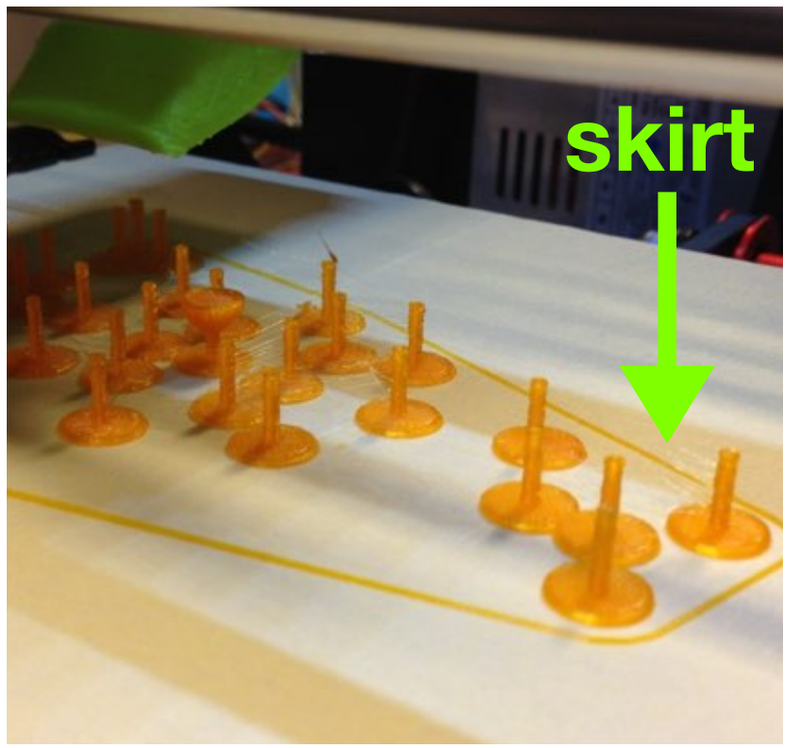
75%

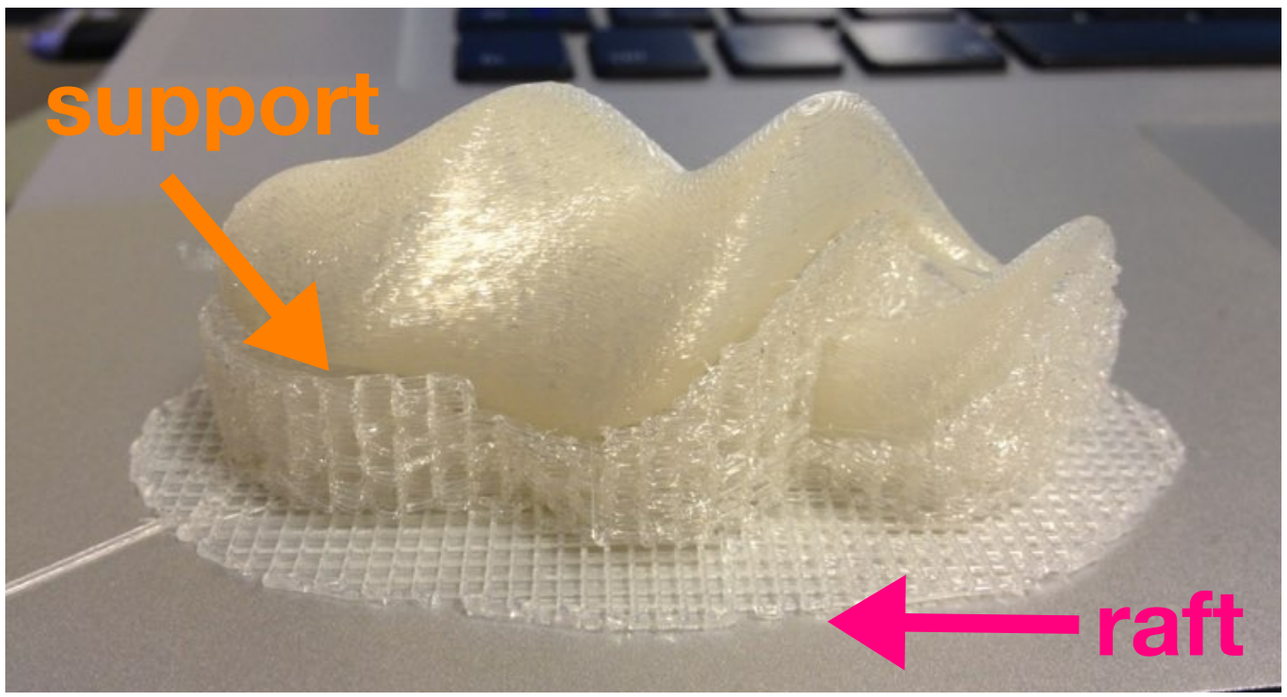
50%

25%

Raft and Skirt

- Objects can be built on top of a "**raft**" of disposable material (i.e. the same plastic of the print and the support) instead of directly on the build surface. The raft is larger than the part and so has *more adhesion*. It can also prevent *warping*.

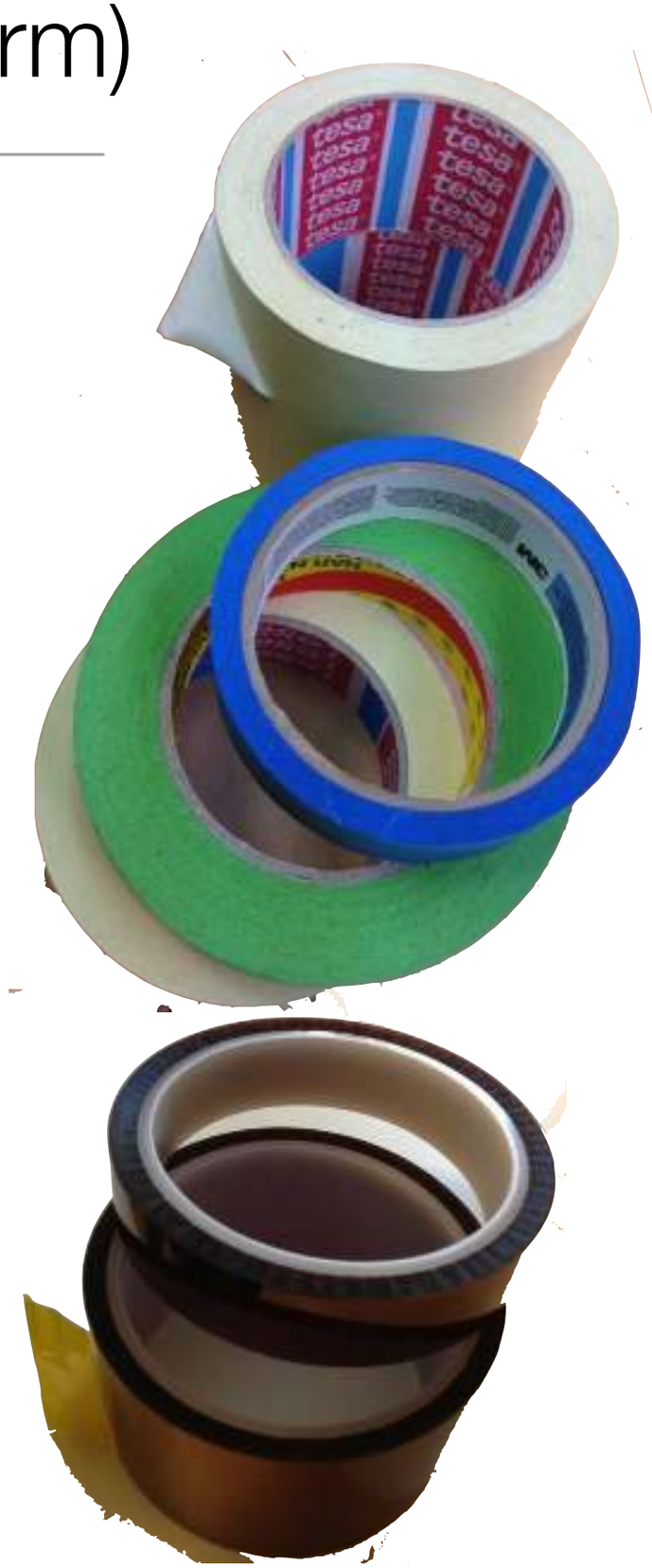


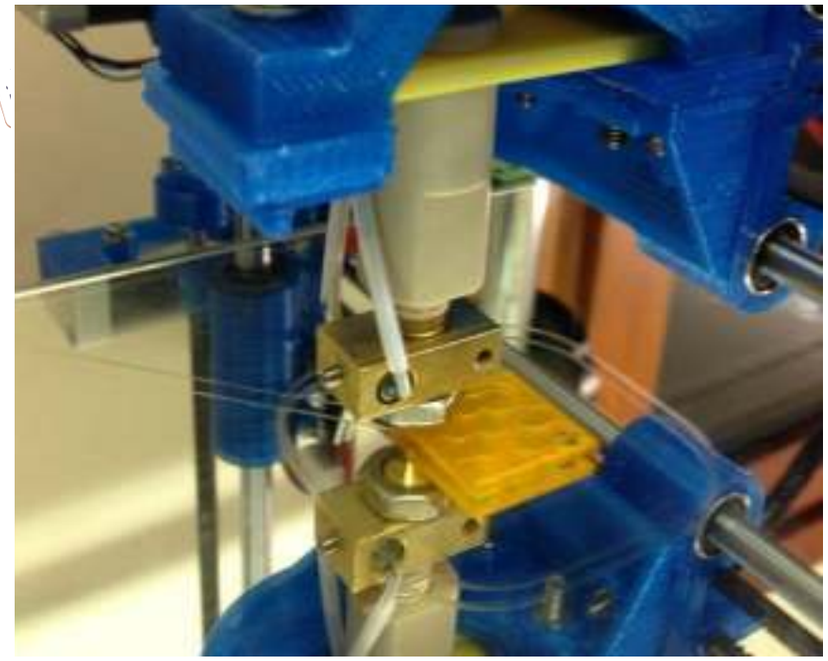


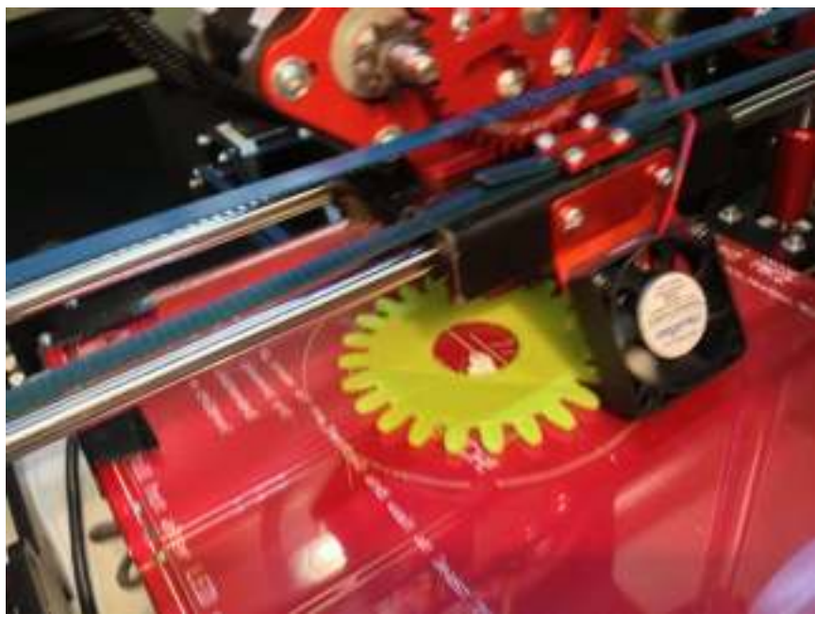
- Sometime, when the print starts the filament is barely dribbling out of the empty nozzle. To solve this problem, a little bit of extra plastic can be extruded *around the object* before starting the actual print. This is called **skirt**.

Printing bed (platform)

- The goal is to **stick the object** onto the platform. A few solutions are:
- bare glass (or mirror)
- bare plywood or aluminum
- PLA: glass/plywood/ aluminum covered by a layer of **blue tape**
- ABS: same, covered by **Kapton** tape and **heated** (~100+ ºC)
- or use some (spray) glue...



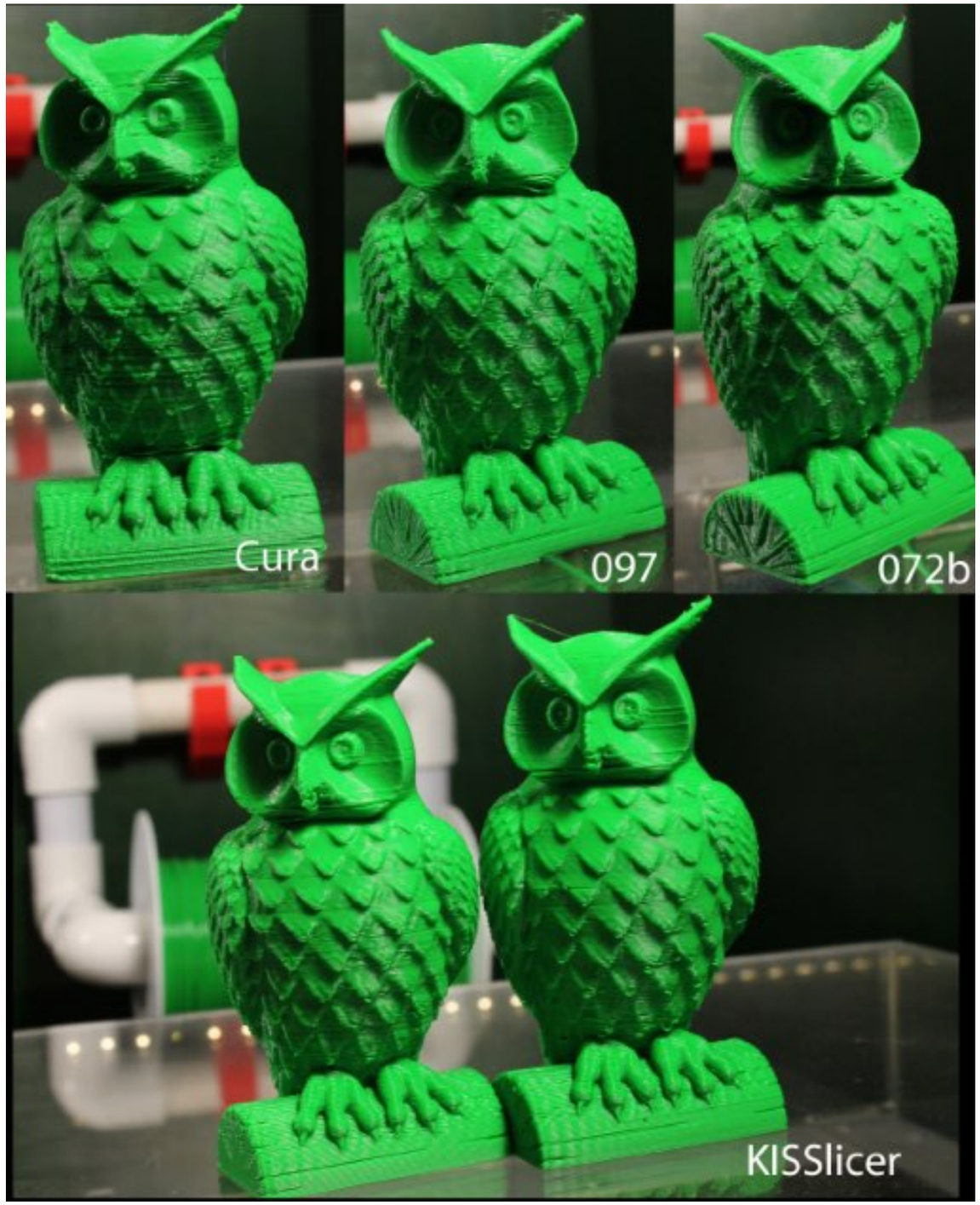


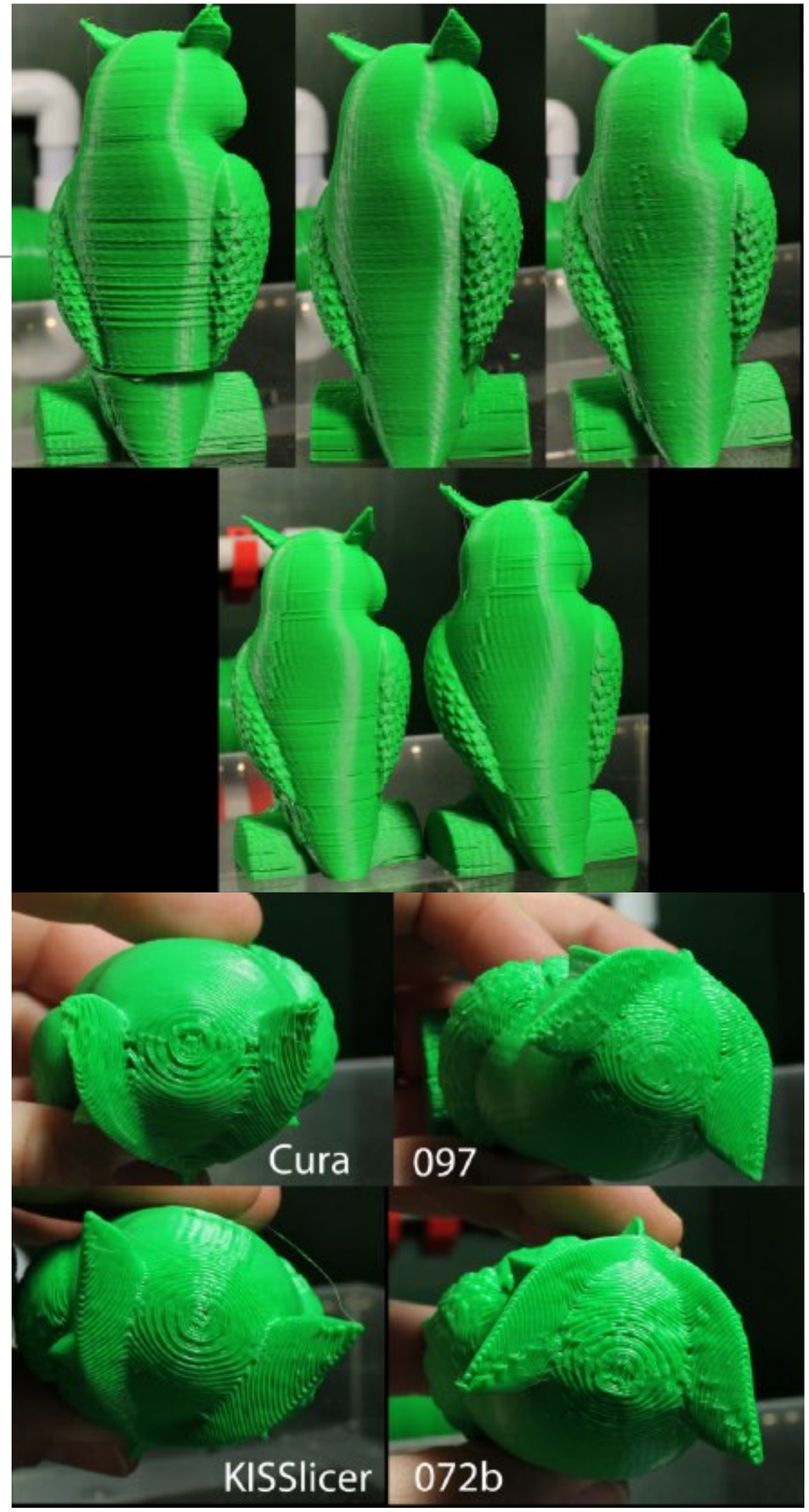


Note: a *non-heated* bed cannot be used for ABS without glue

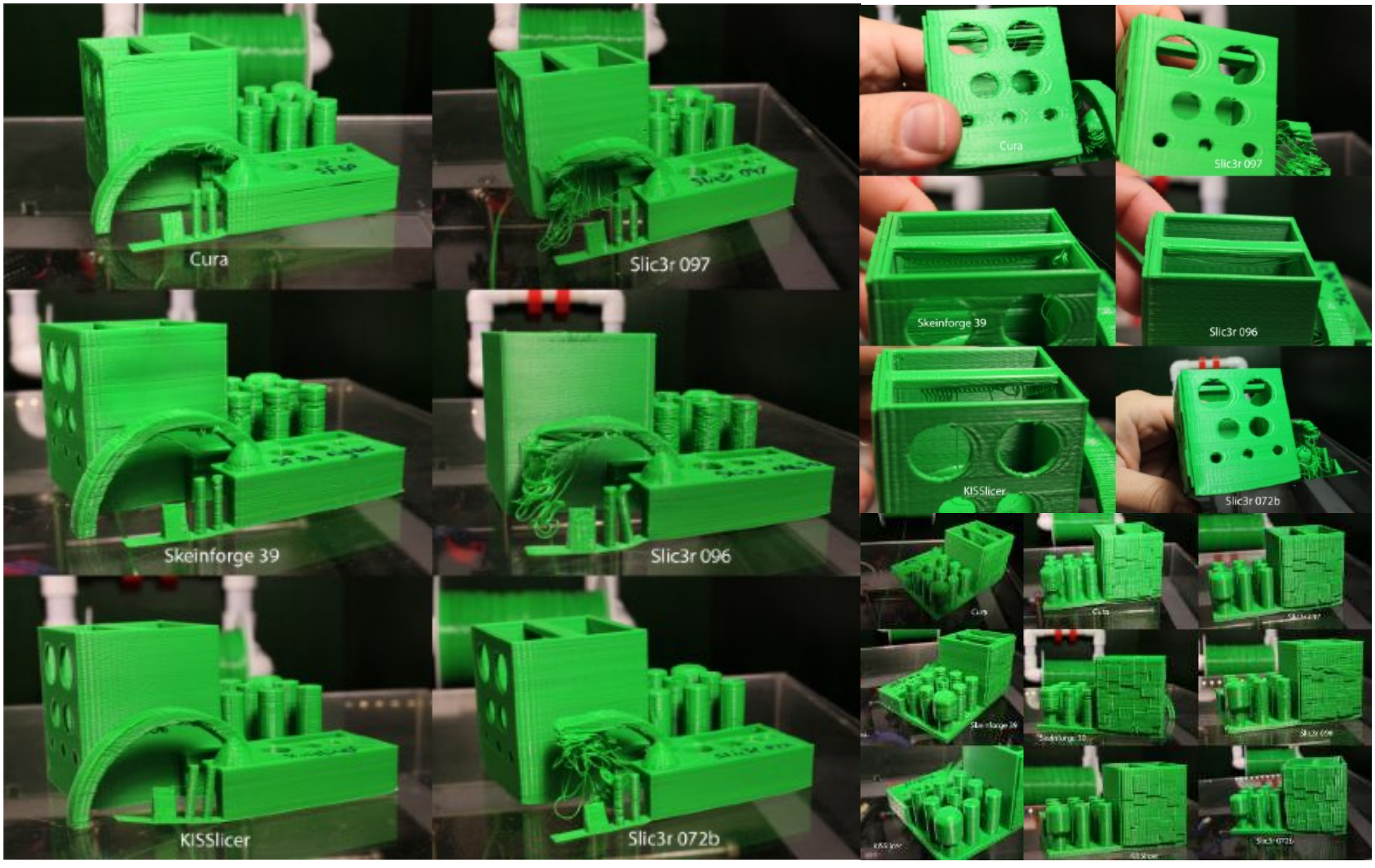
Good 3D-printing is difficult...

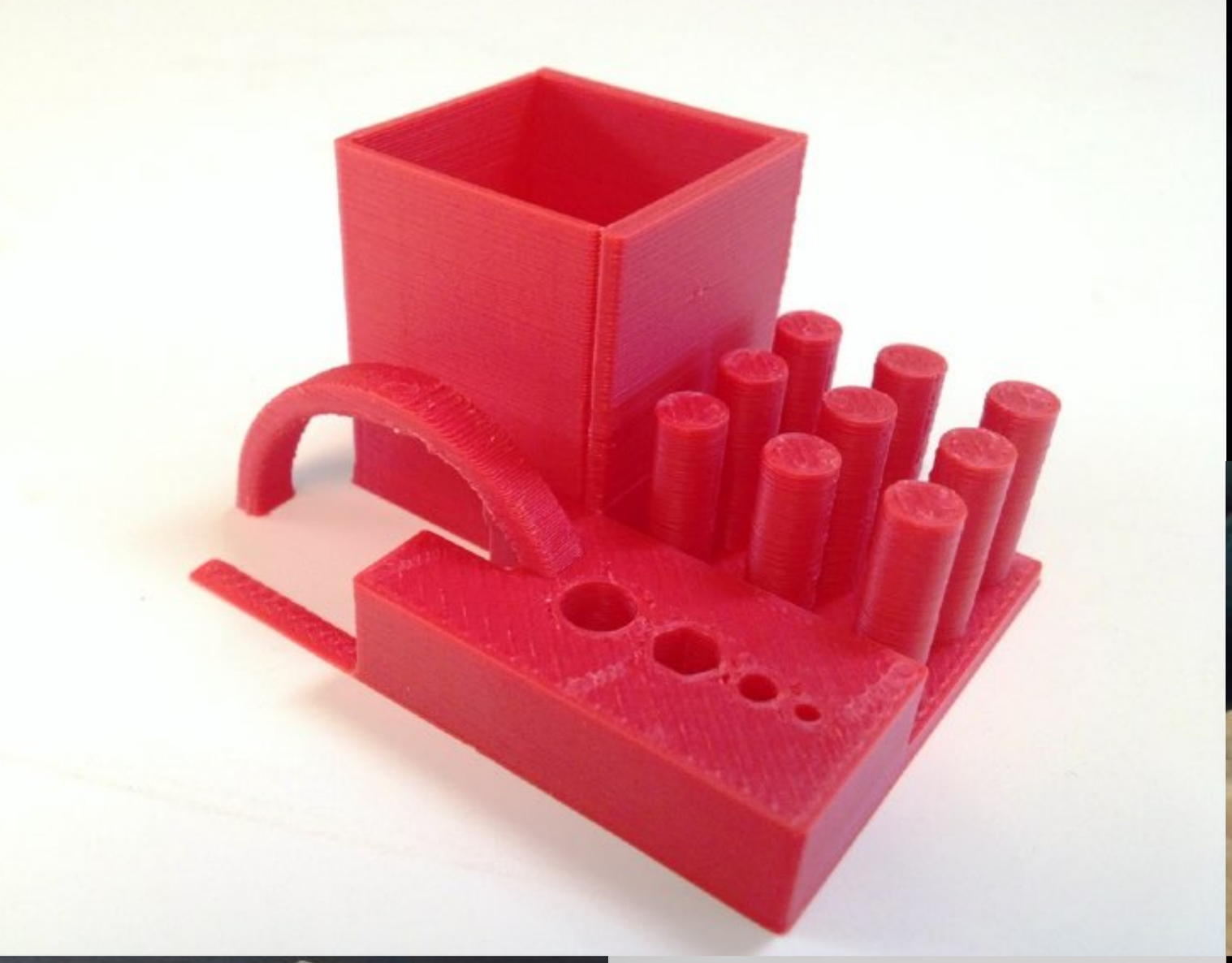
Slicing software: art, science, and pain in the neck ;-)

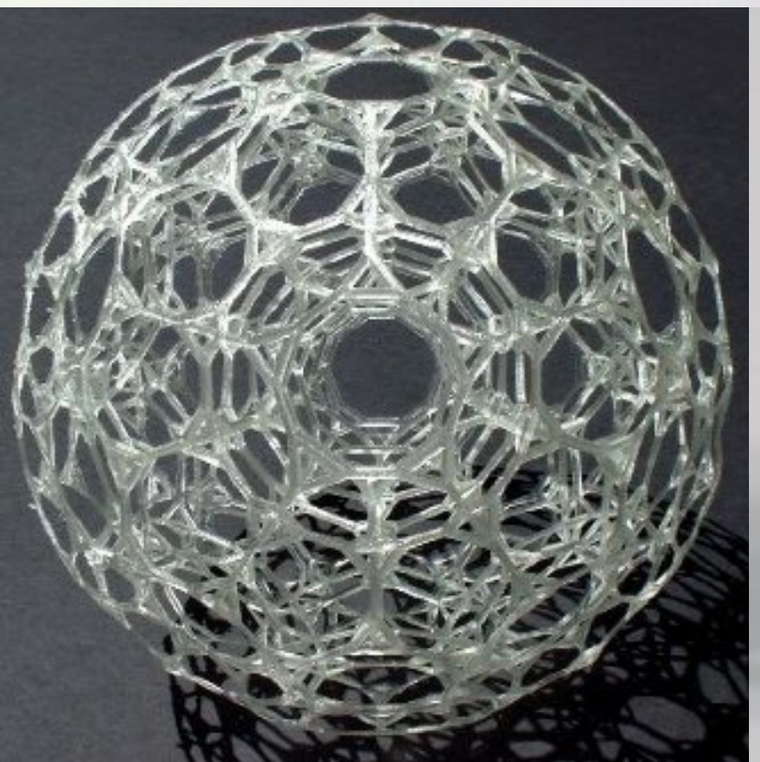


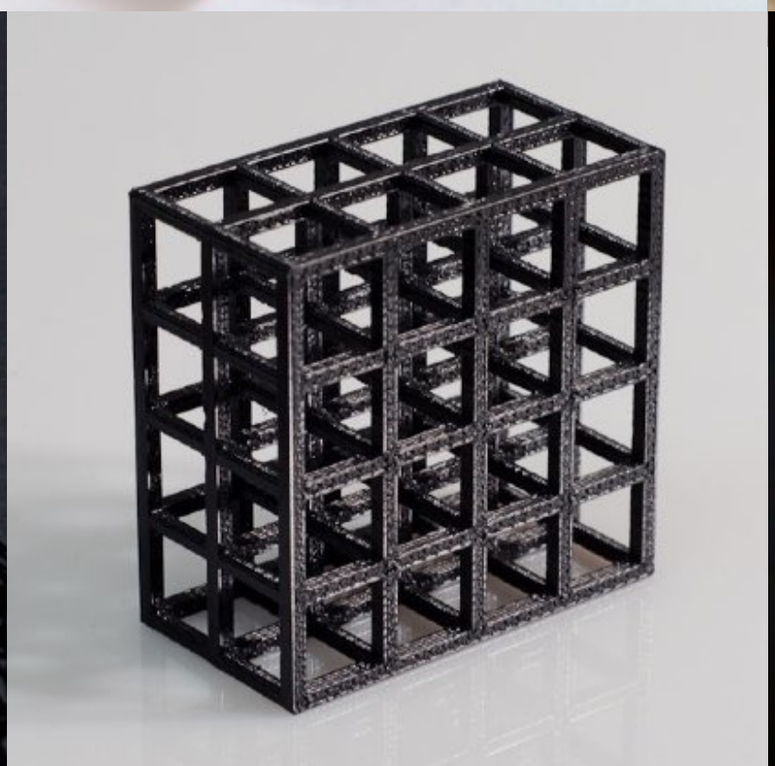


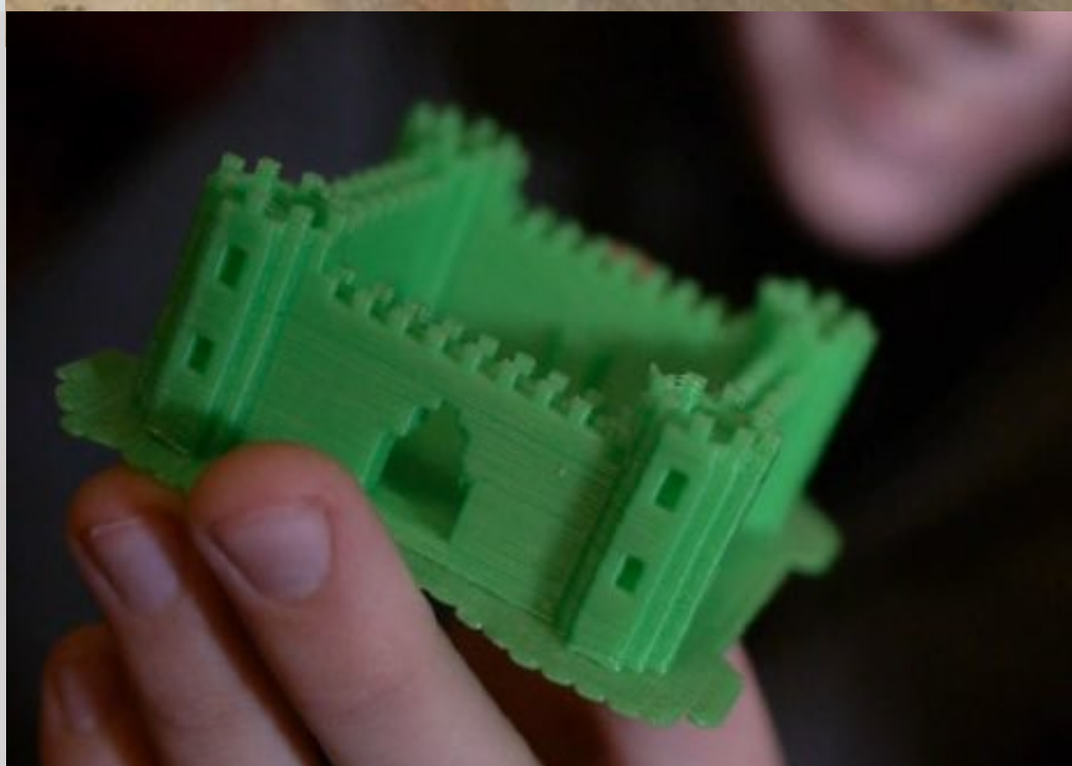
Solution: do many tests, and compare the results...

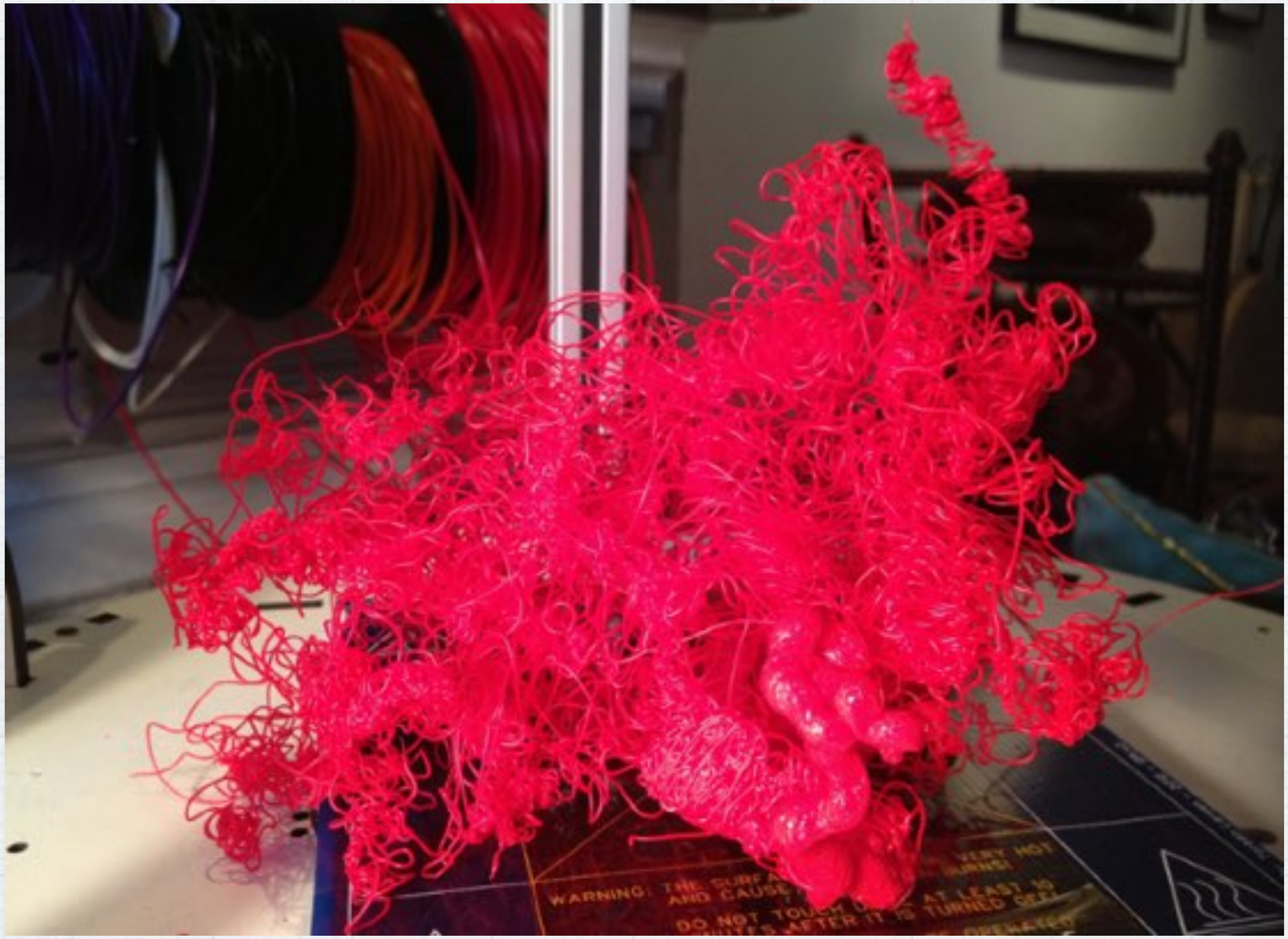












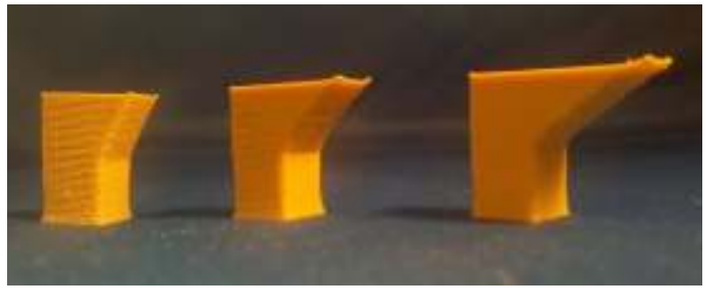
Common issues

Photo from: “The art of 3D print failure” https://www.flickr.com/groups/3d-print-failures/

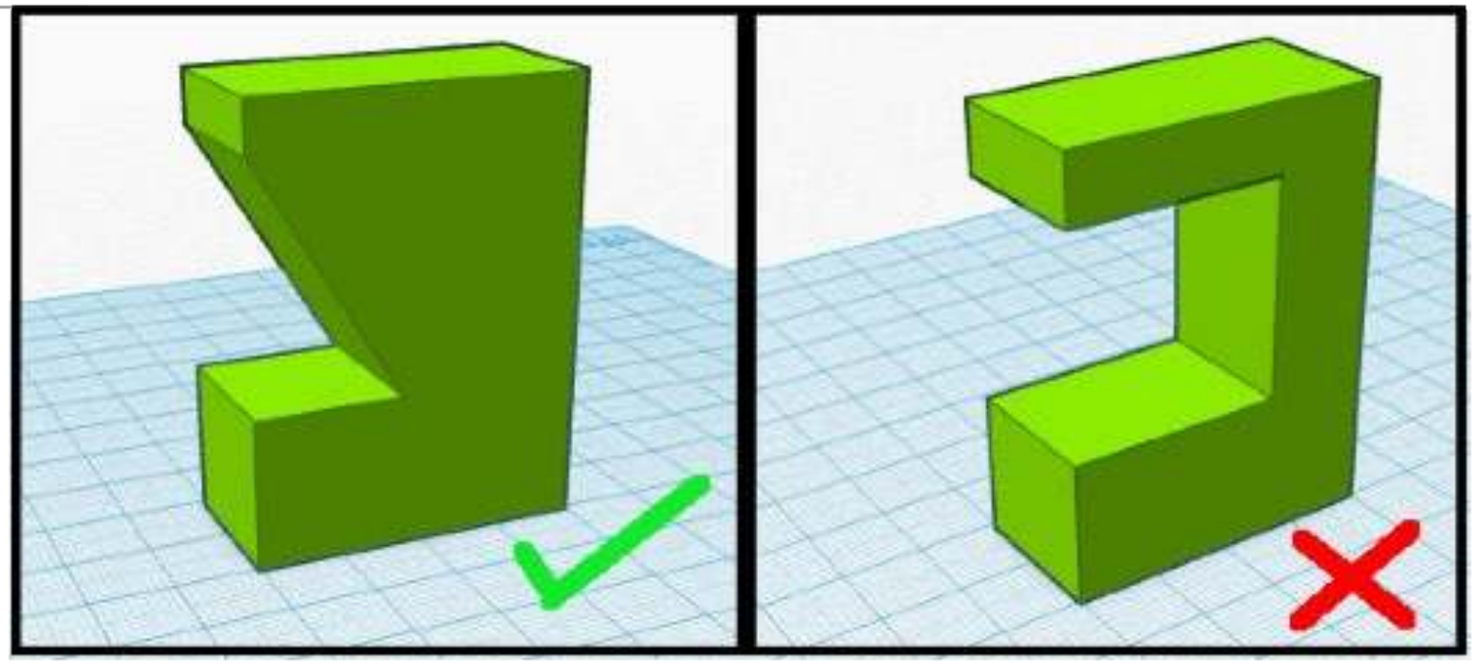
Model issues

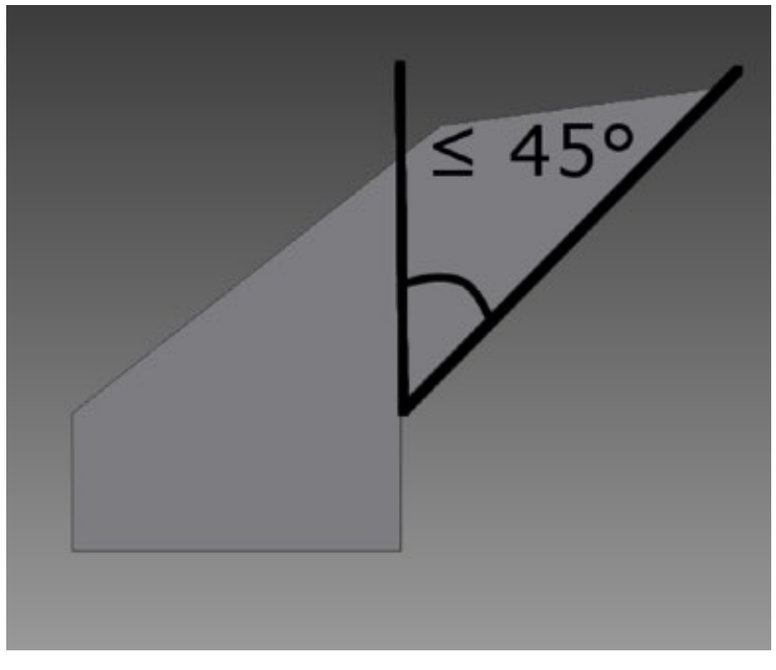
Problems you can solve by modifying the original 3D model (or simply its orientation) or by correcting the mesh

Watch out overhangs!



- 3D printers generally handles overhangs up to 45 degrees well without special tricks.
- If possible, rotate the 3D model in order to minimize the parts with an overhang (before slicing).
- Point a fan at the part during the print, to cool the filament as soon as it comes out of the nozzle (before it has a chance to droop and ruin the print).
- Turn on support material in the slicing software. This is a hassle because the process uses more plastic, takes longer to print, and you have to clean off the support material with a knife afterwards.

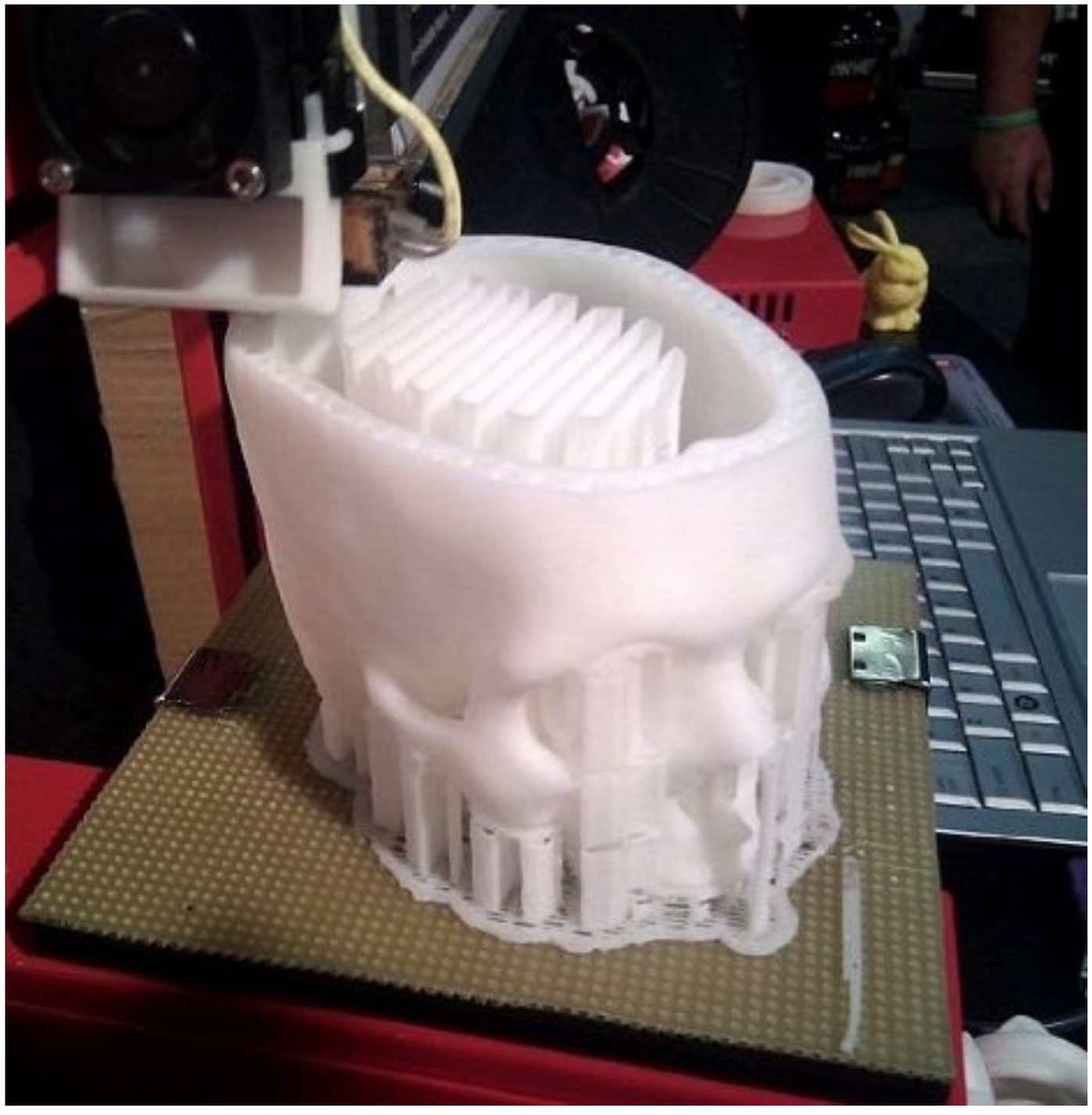


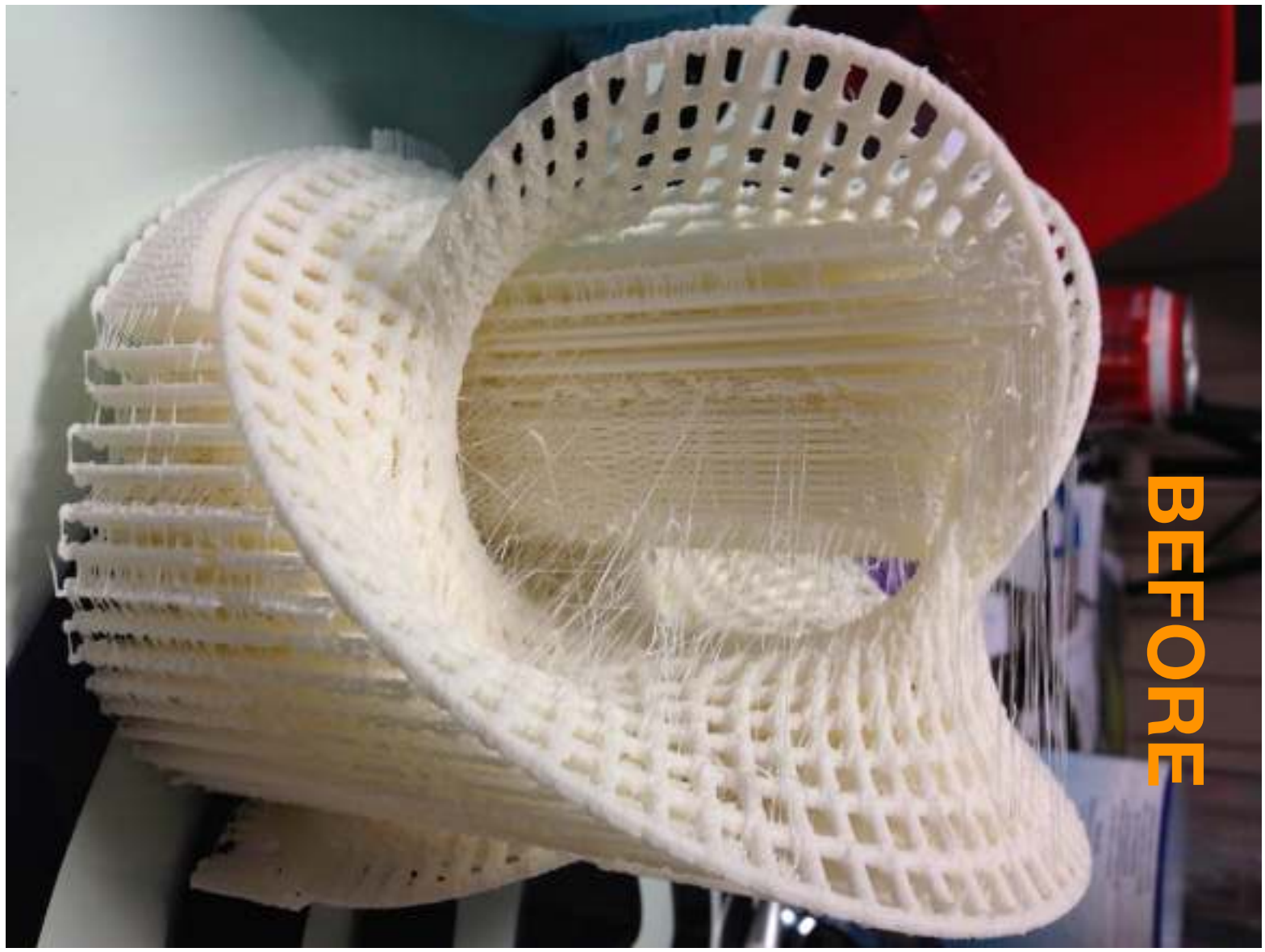


Support me, please!

- FDM-based printers usually cannot produce stalactite-like structures as well as extreme overhangs, since they would be unsupported during the build. If these cannot be avoided, an extra thin **support** structure may be added into the object, which can be broken or cut away after the print process.

- Most slicing software can create automatically such support structures or you can add them by yourself when modeling the object.





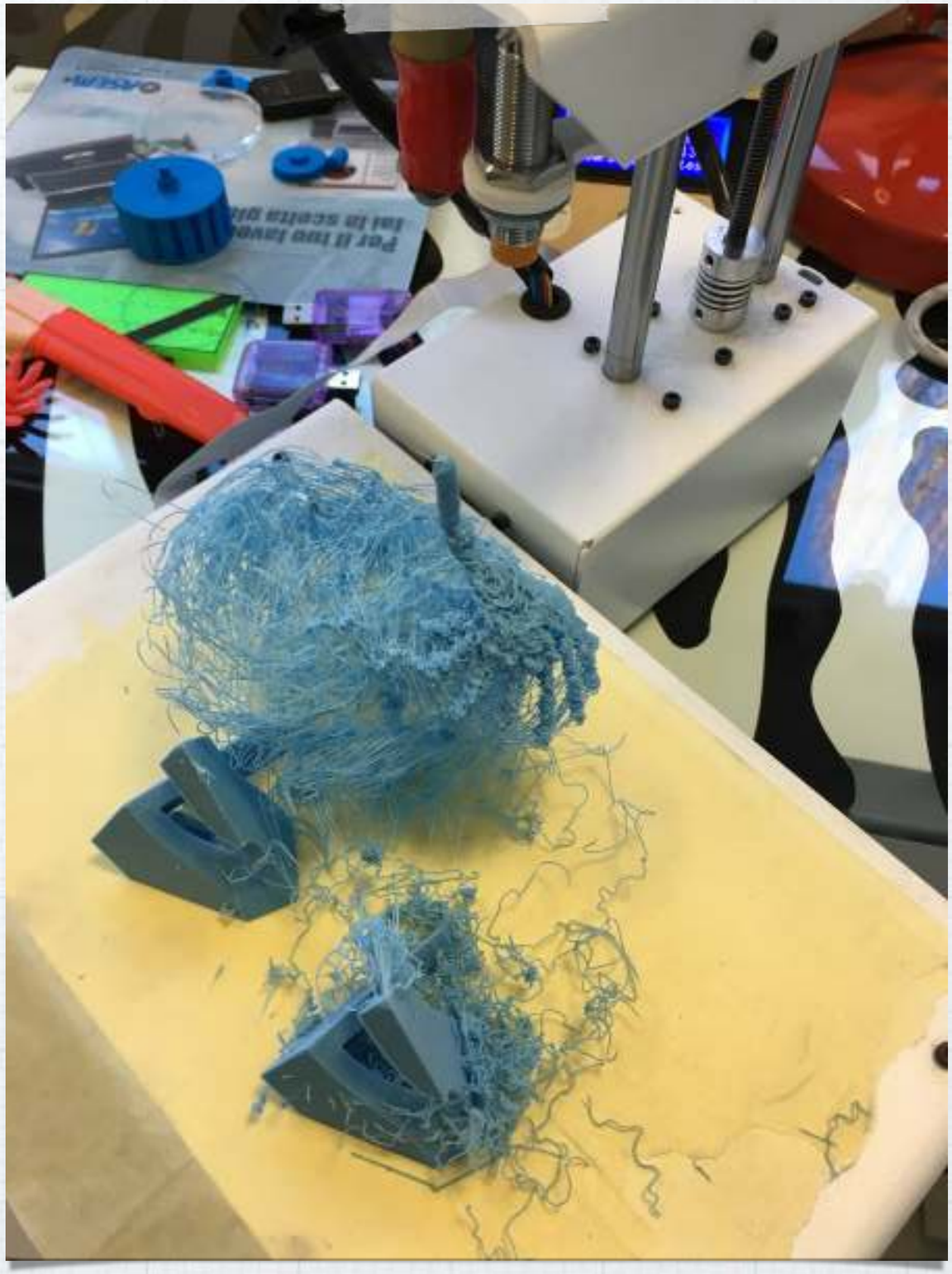
CLEANING PROCESS

PROCESS

CLEANING

Technical issues

Problems you can solve with a better printer and/or by tuning the slicing parameters



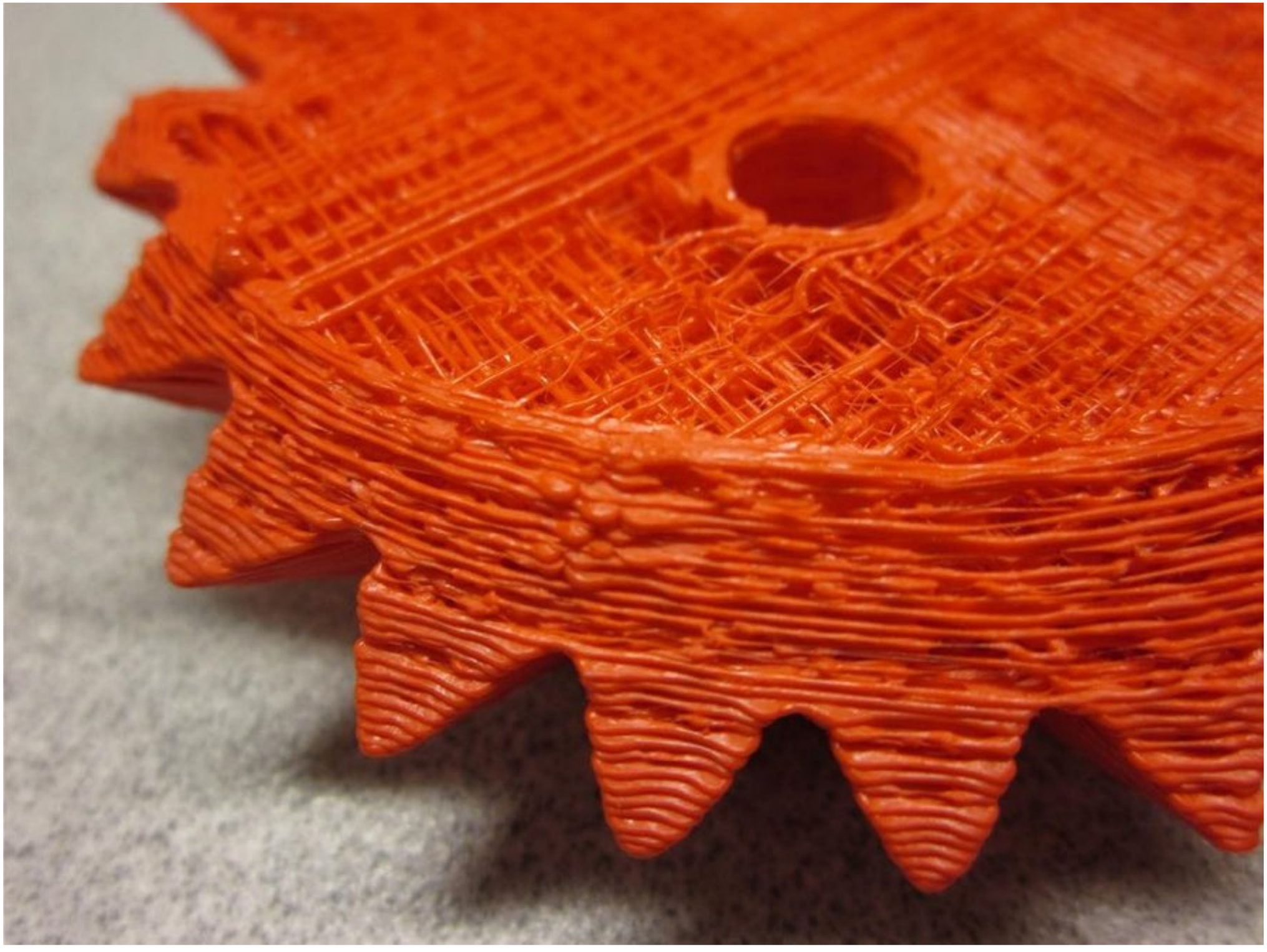
Delamination

ABS and Nylon printed in a cold environment

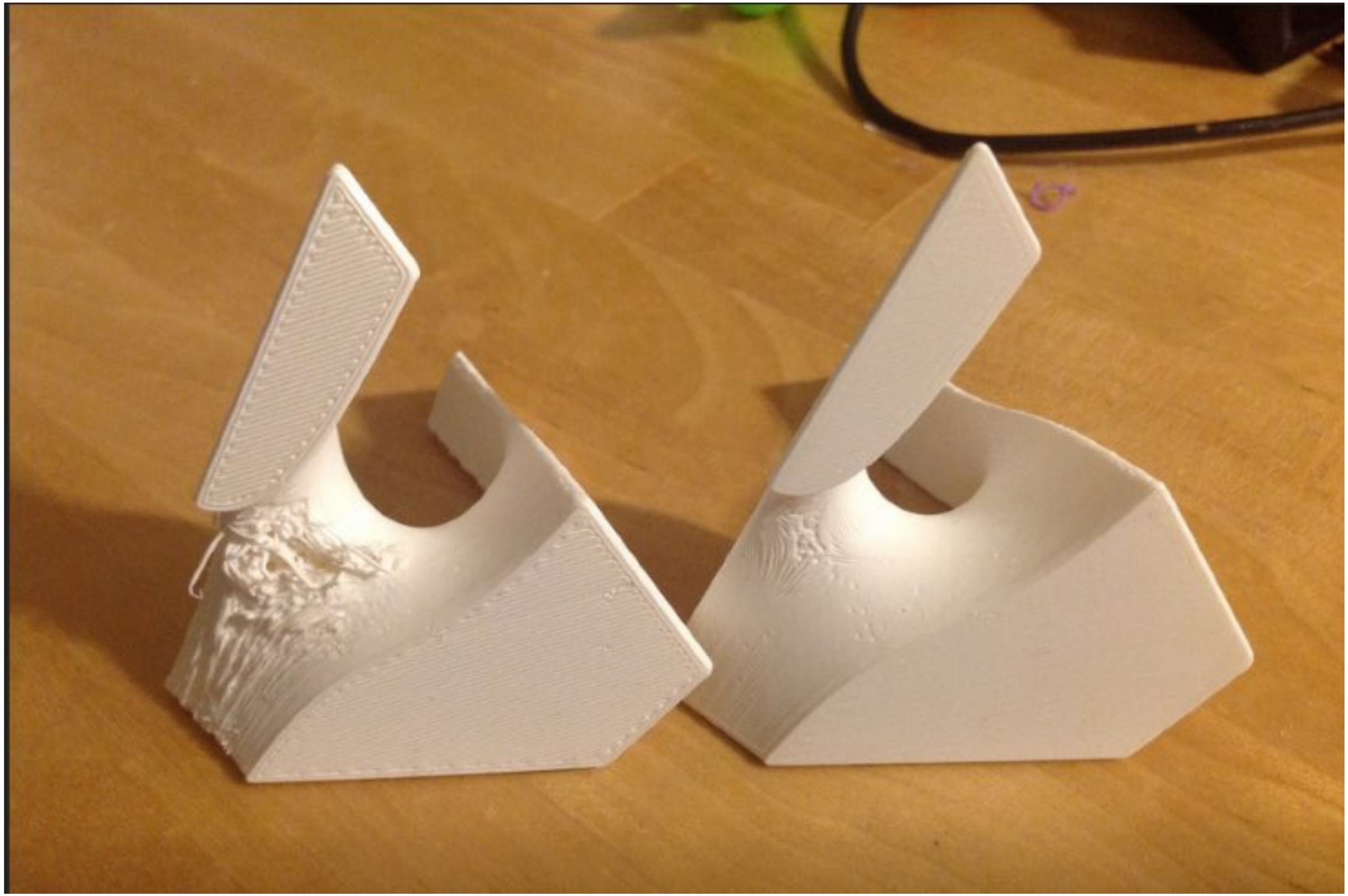
Strings

Not enough retraction,
or too high temperature

Irregular plastic flow



Wrong temperature or dirty extruded pulley



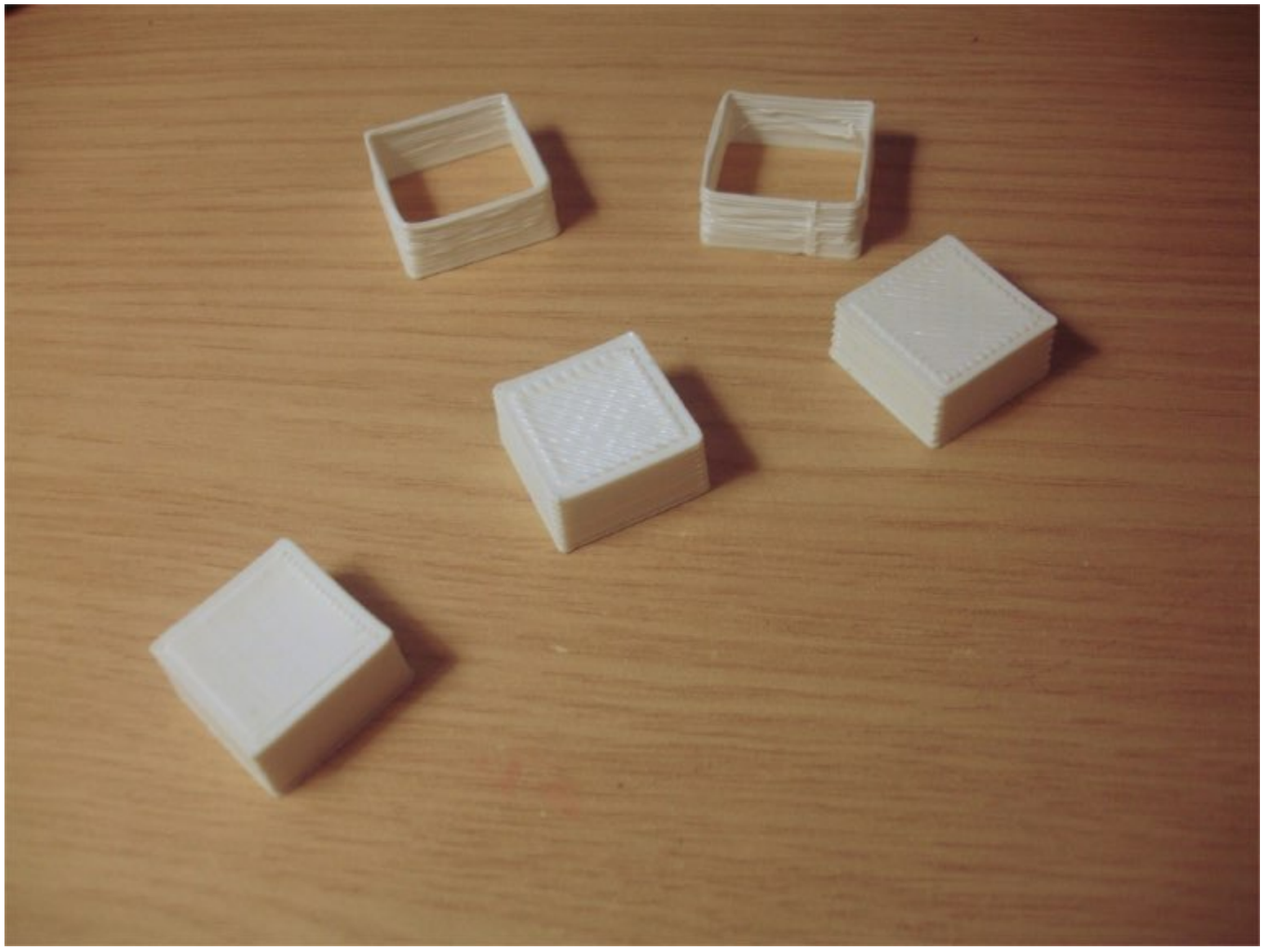
200°

220°

Distorted parts

Calibration problems

warping

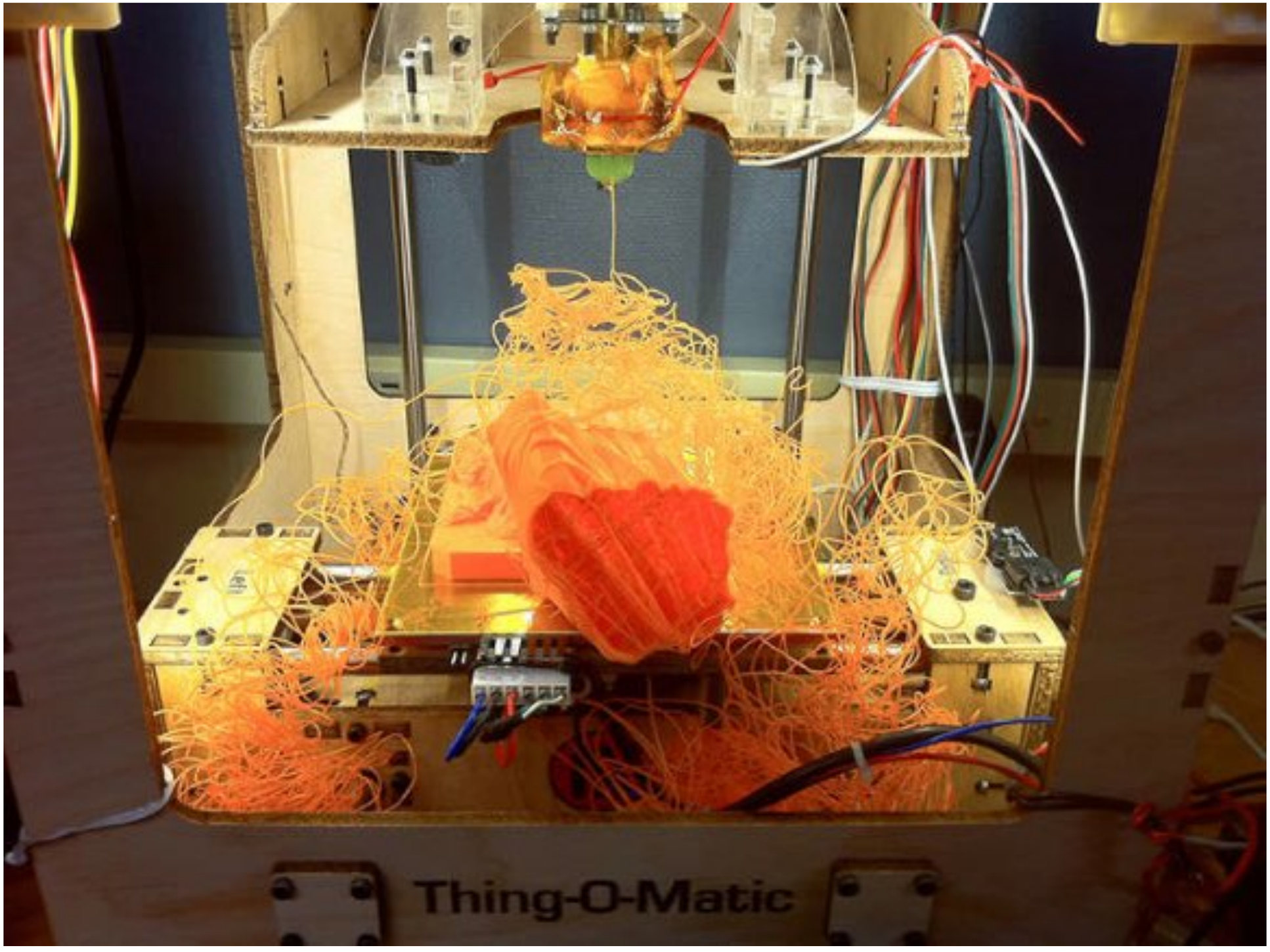


Belt issues!

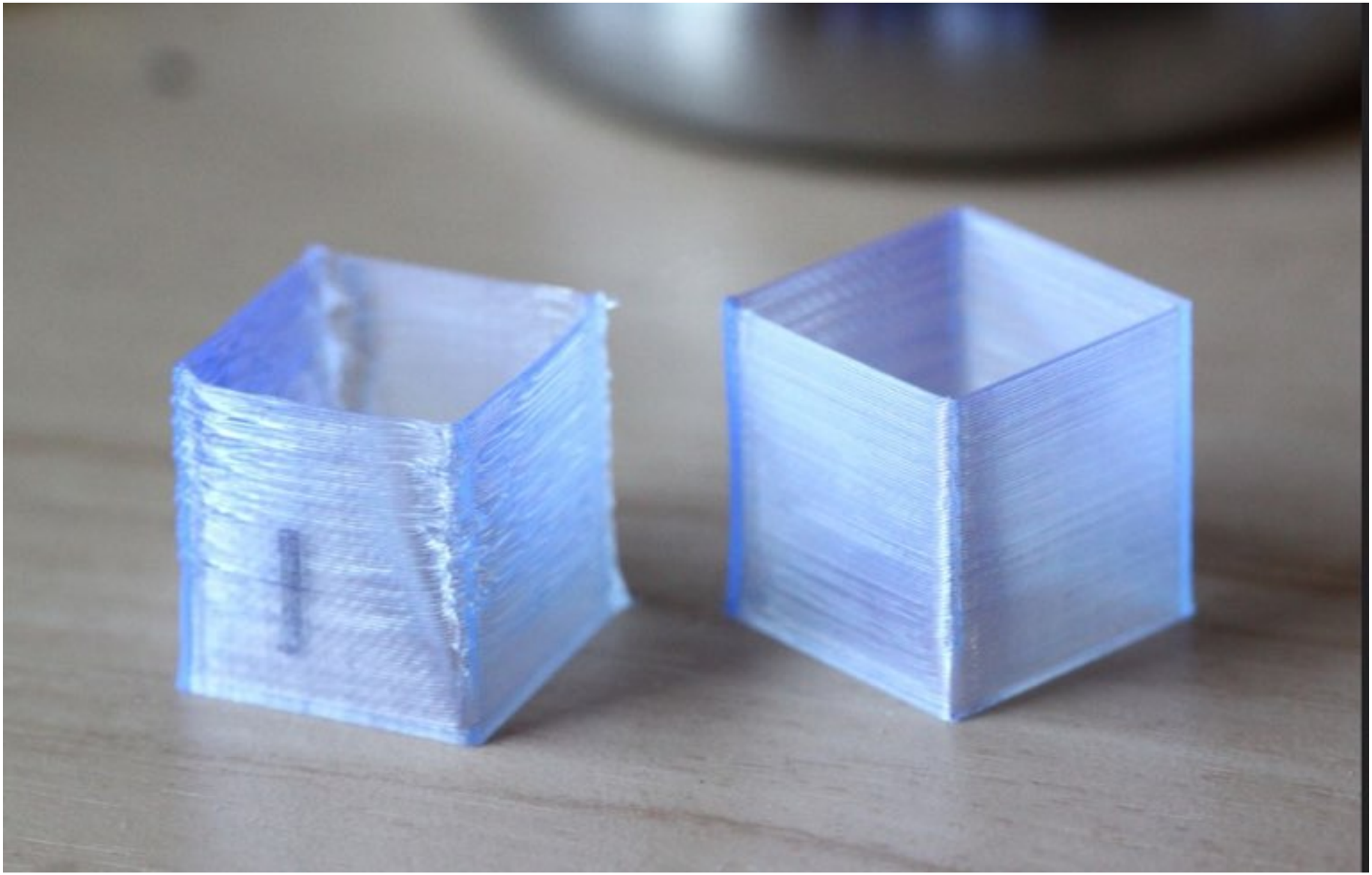
not enough tightening?

Details are
too small/fragile

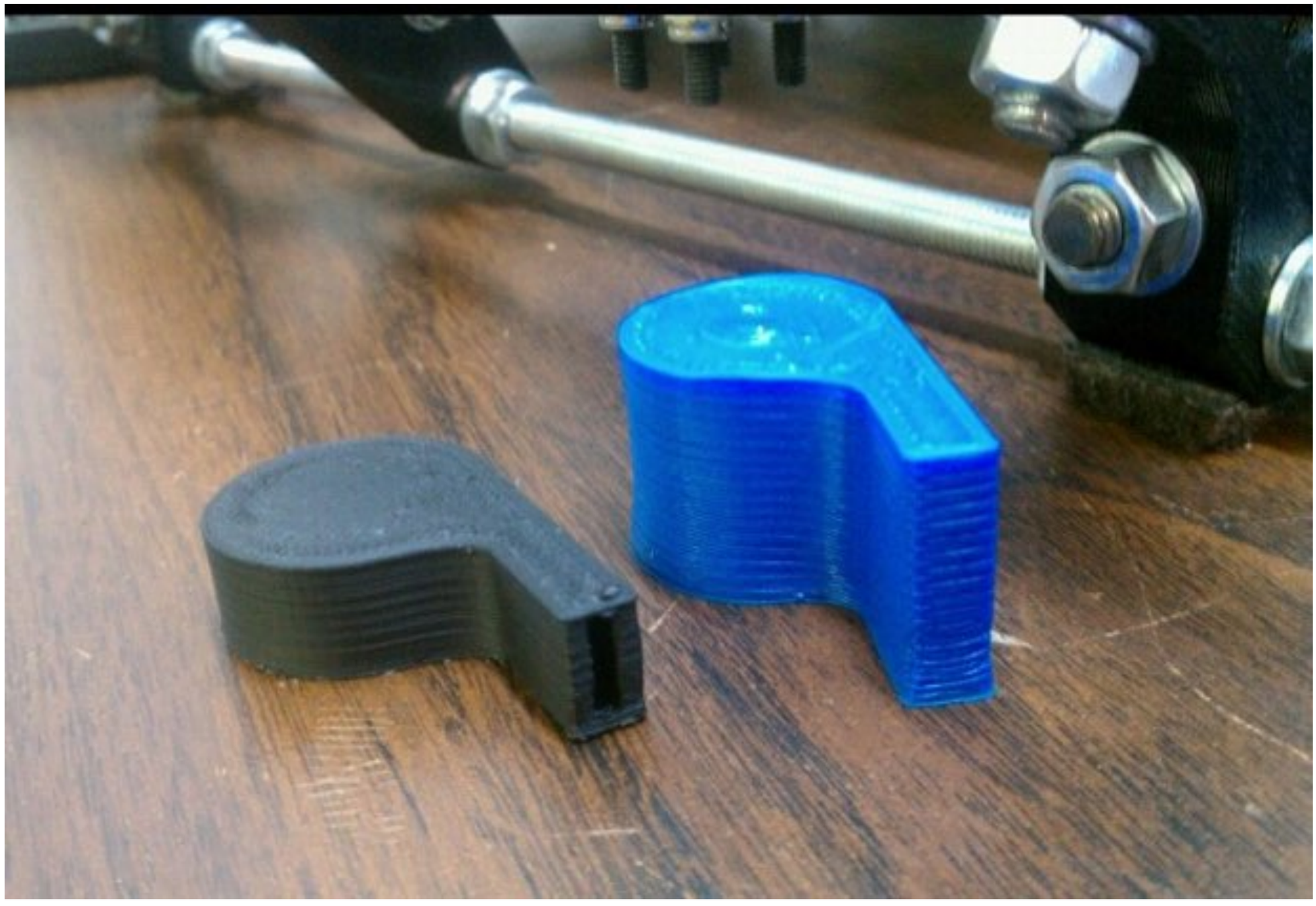
Object detaching from printing bed

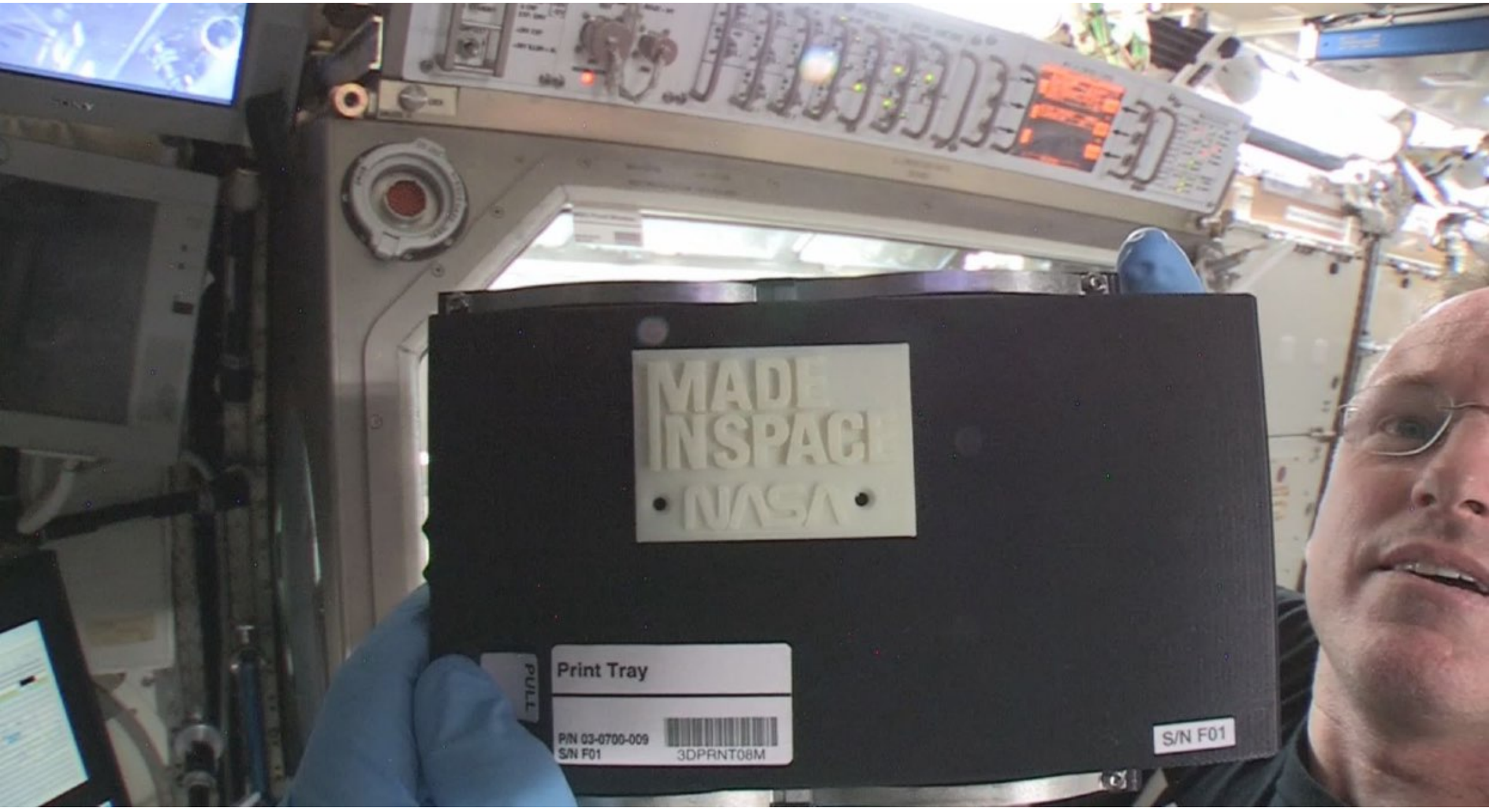


not enough cooling

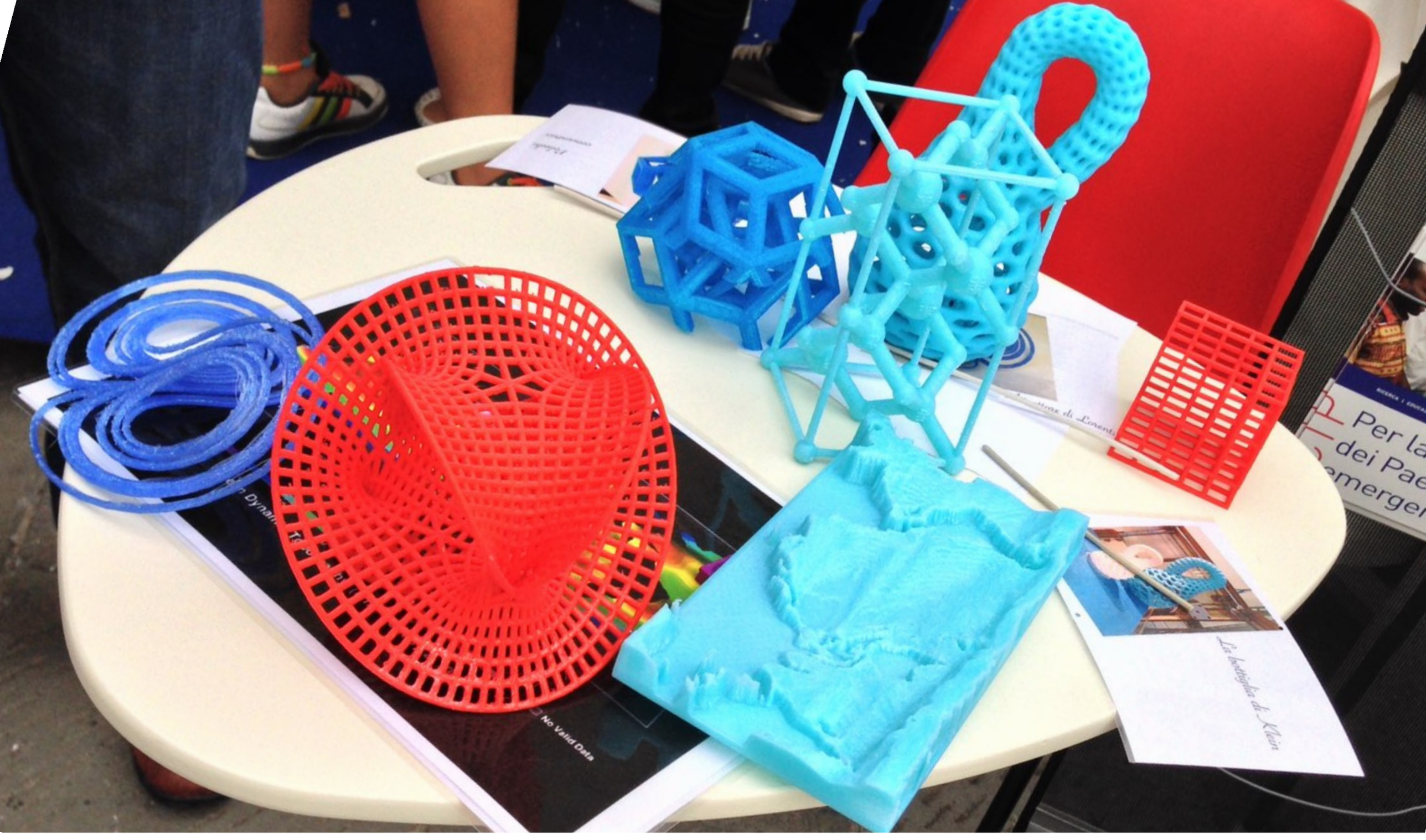


slicing errors (mesh issues):
hollow parts are filled




MADE IN SPACE
NASA
Print Tray
PULL
P/N 03-0700-009
S/N F01
3DPRNT08M
S/N F01

Credit: NASA



3DP: what is it for?

... still looking for an answer!

3DP for....

everyday life!

3DP for....

Art!

Testa del cavallo di Selene
Acropoli, Atene, 438-432 BC
Fregio est del Partenone, presso il British museum di Londra

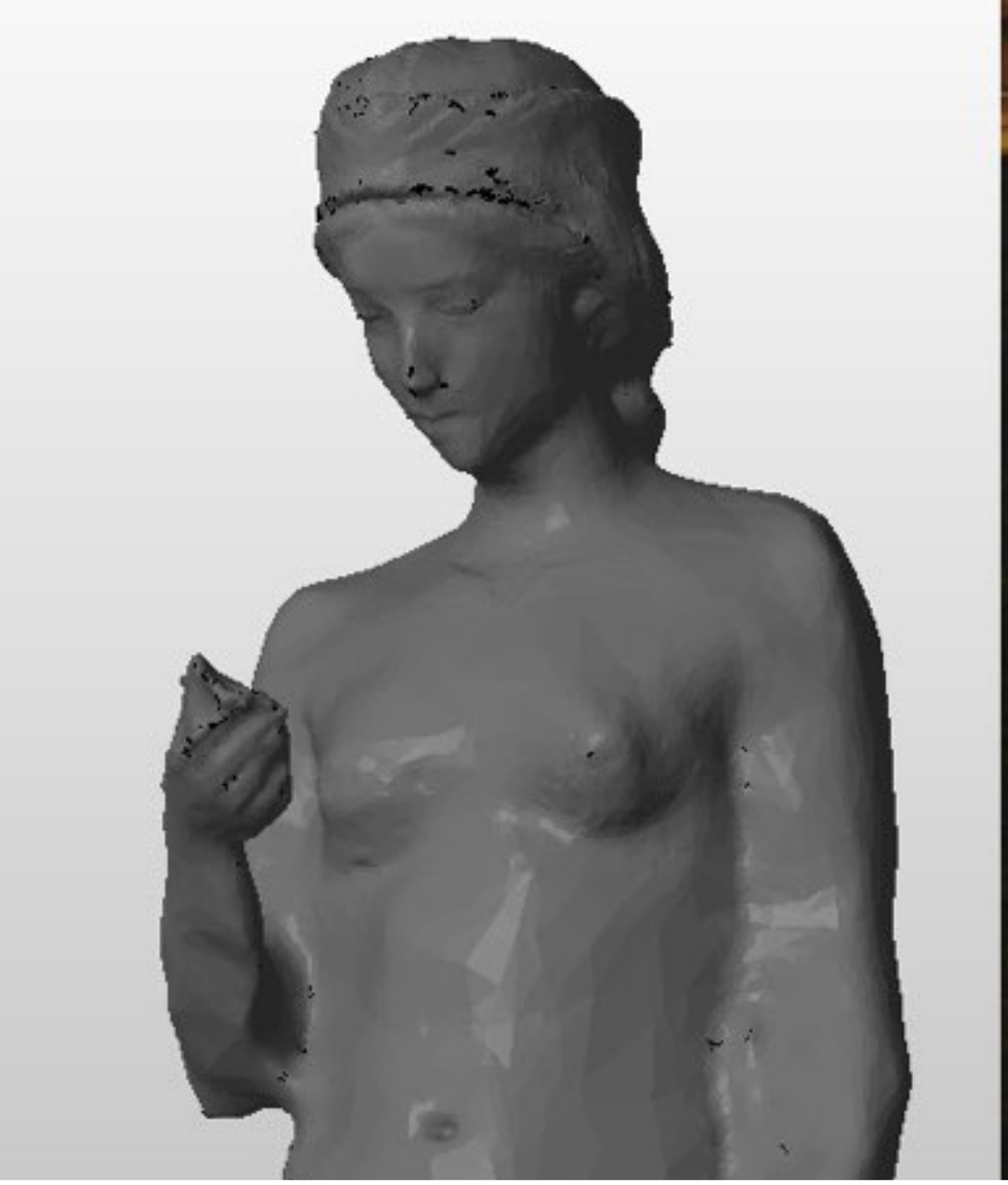
KNMER 406
Paranthropus boisei
Age: 1.7 million years
Element: Cranium
Locality: Ileret, East Turkana, Kenya
Date of Discovery: 1969

Cosmo Wenman

Cloning objects

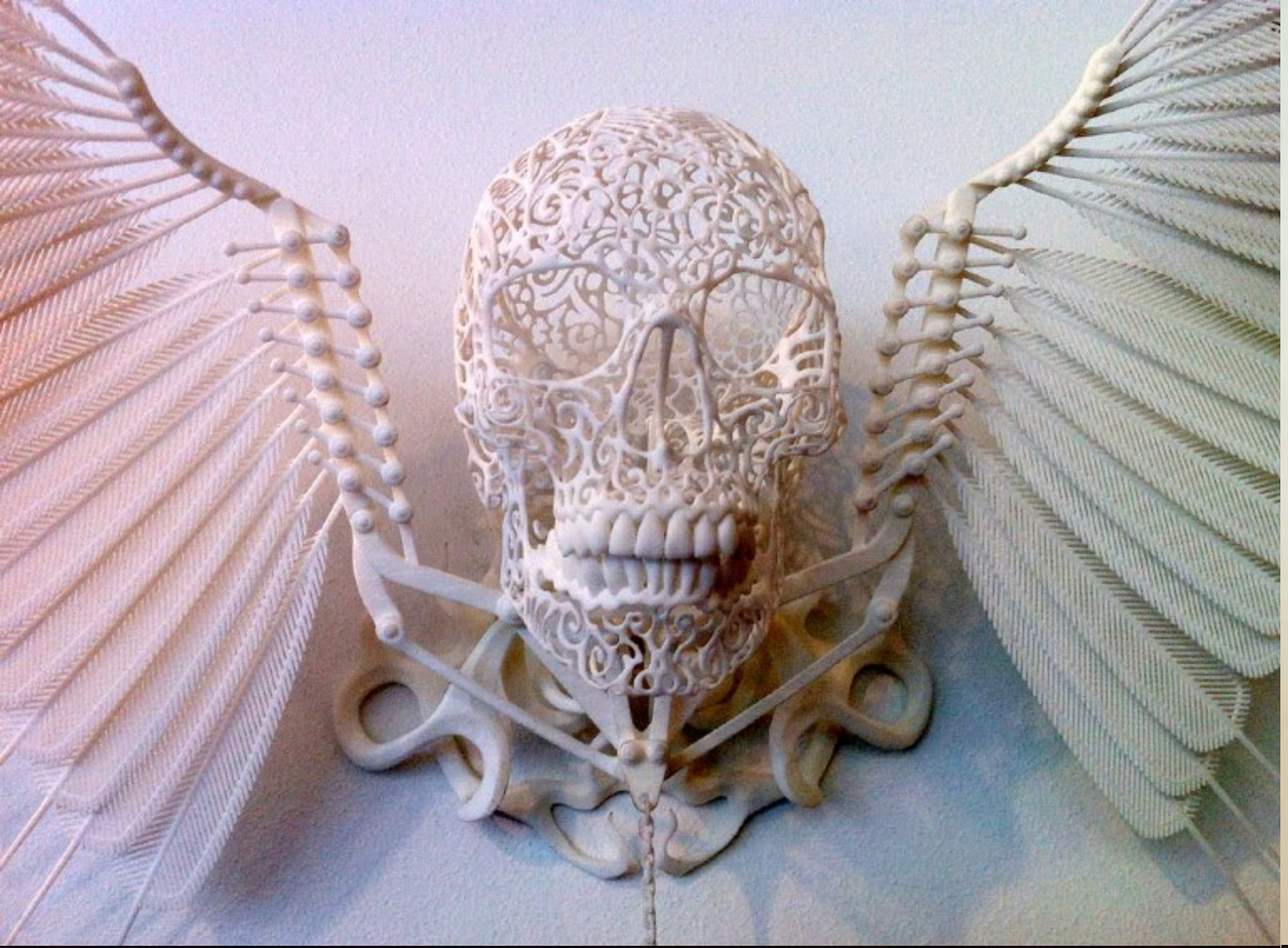
- Combining 3D scanners with 3D printers, it becomes possible (and affordable) to make copies (1:1 or scaled) of objects (even at a distance!)

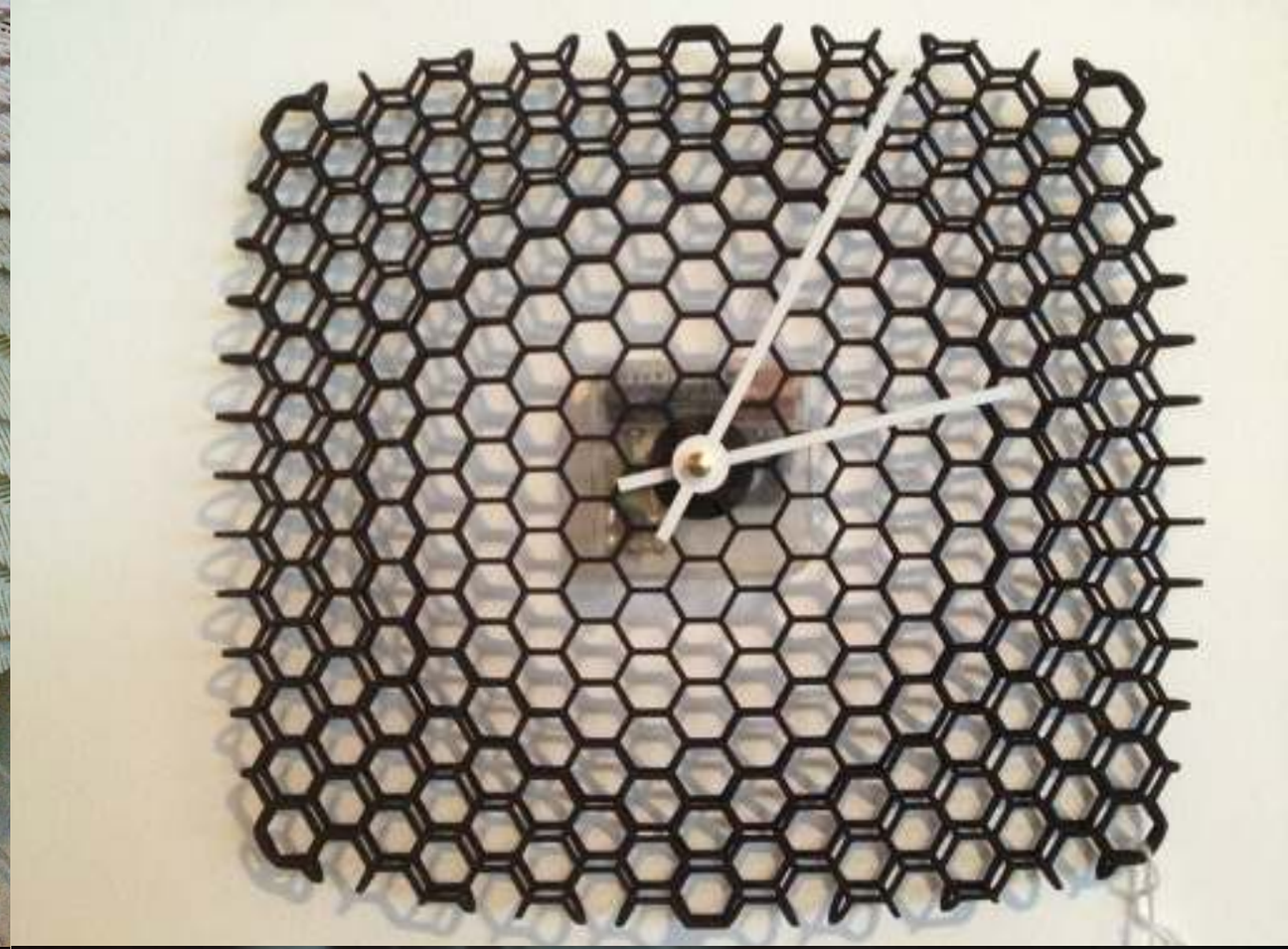
A model (left) was digitally acquired by using a 3D scanner, the scanned data processed using MeshLab, and the resulting 3D model used by a rapid prototyping machine to create a resin replica (right)



During the summer of 2012, the Metropolitan Museum of Art held an event to make 3D scans and prints of works from throughout the museum. Participants used digital cameras and Autodesk's 123D Catch to generate the 3D models, and then printed them using MakerBot Replicators.

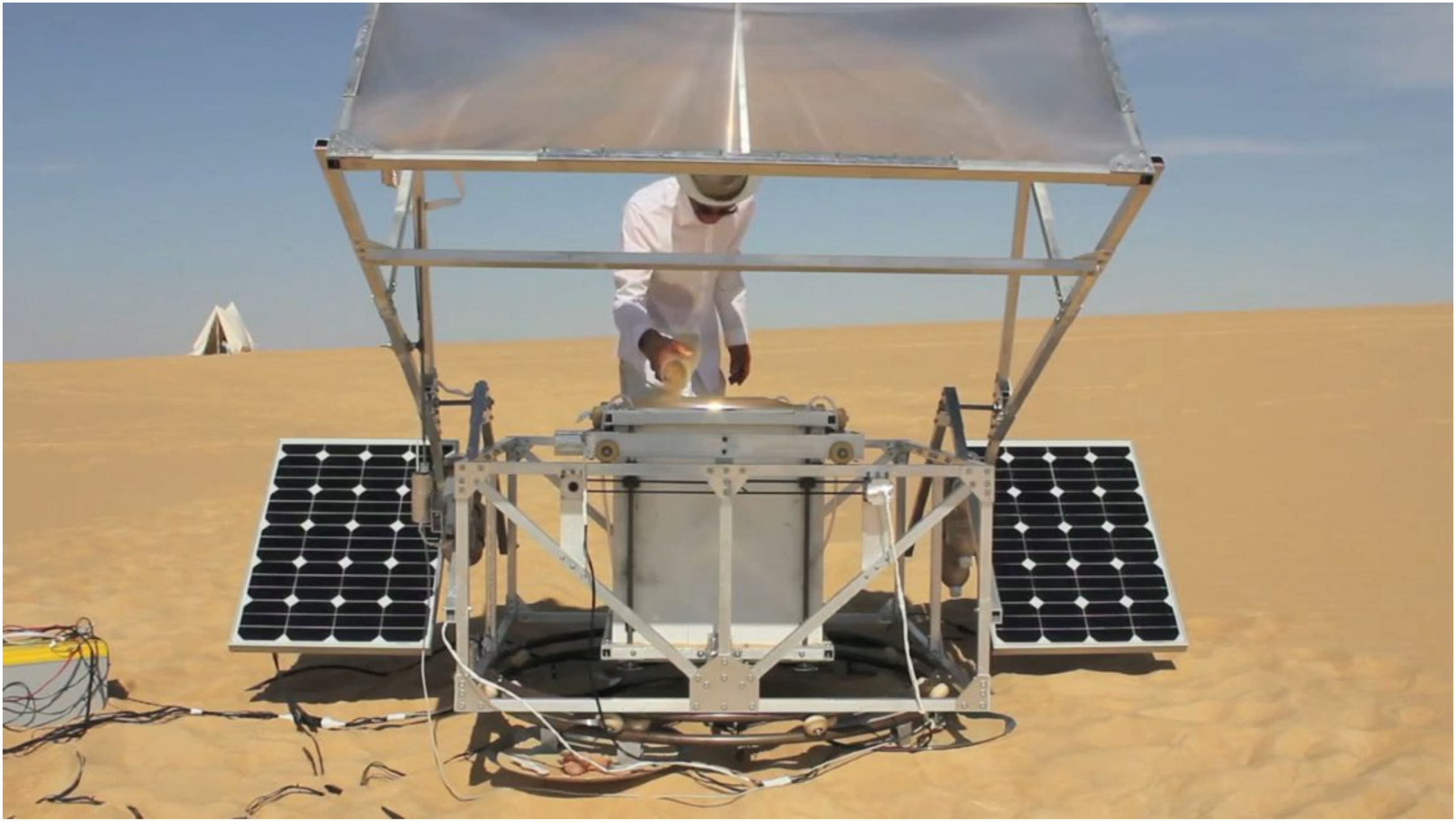
Met3D





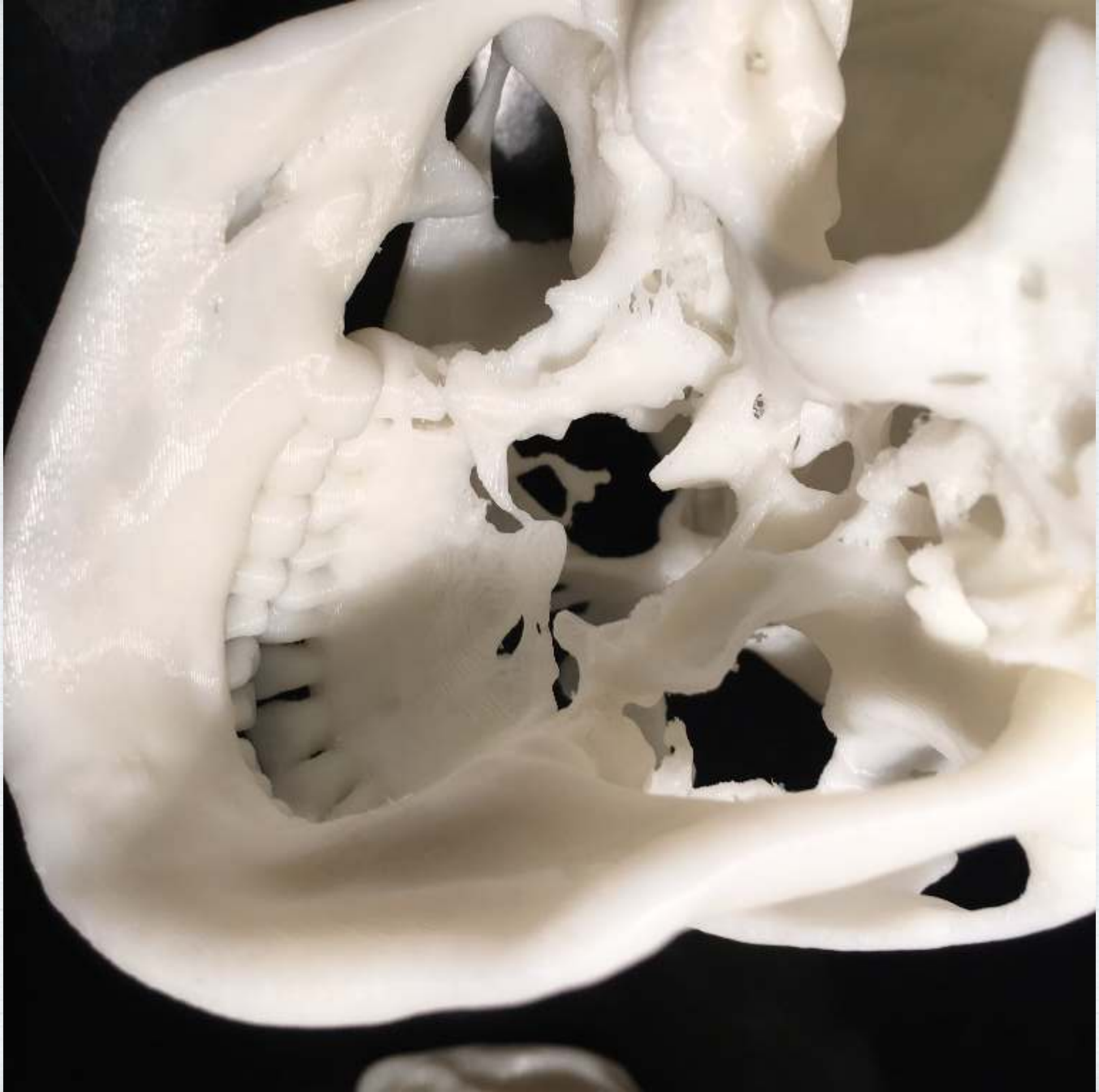

3Dizingof.com

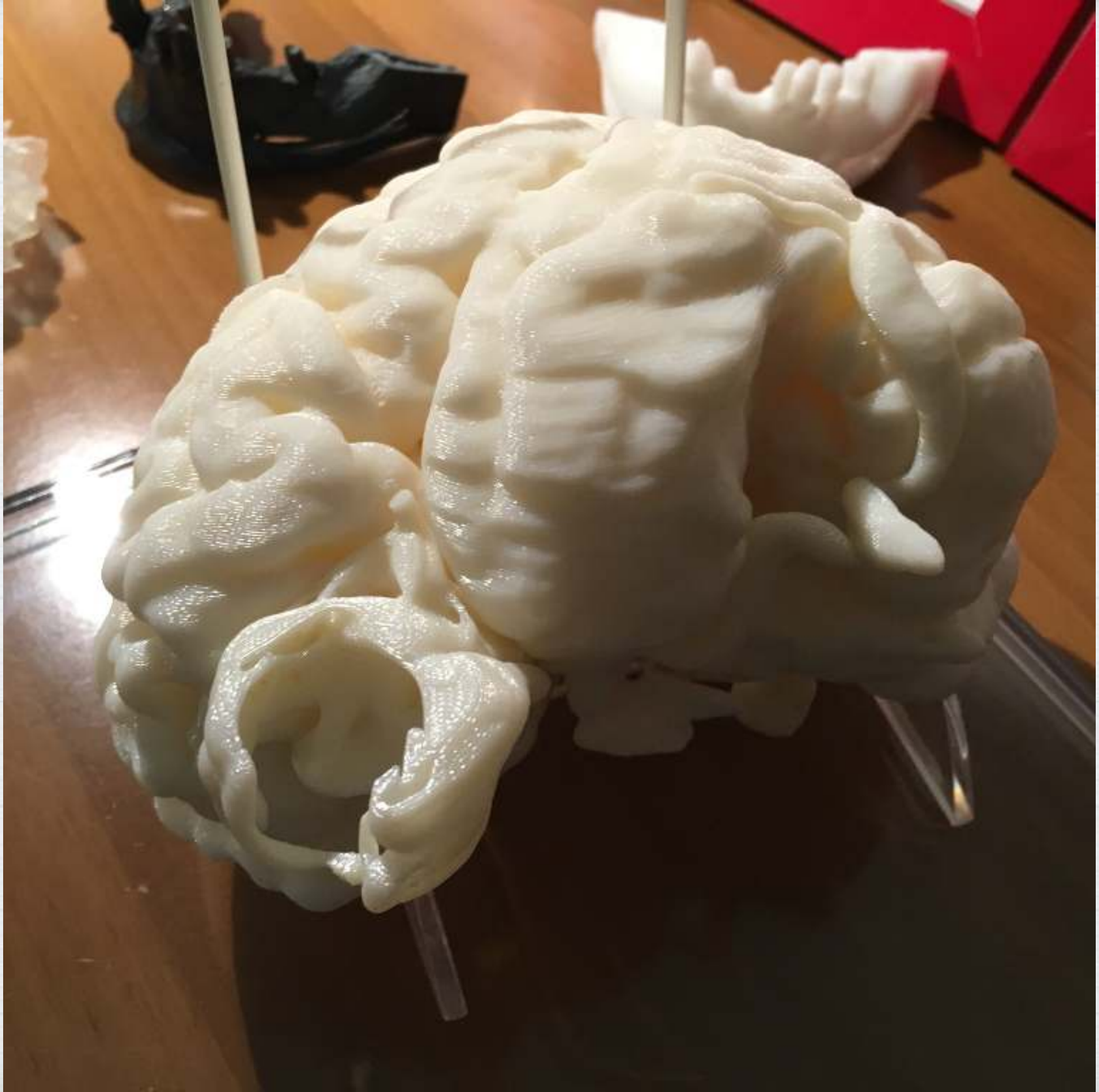

nervous system

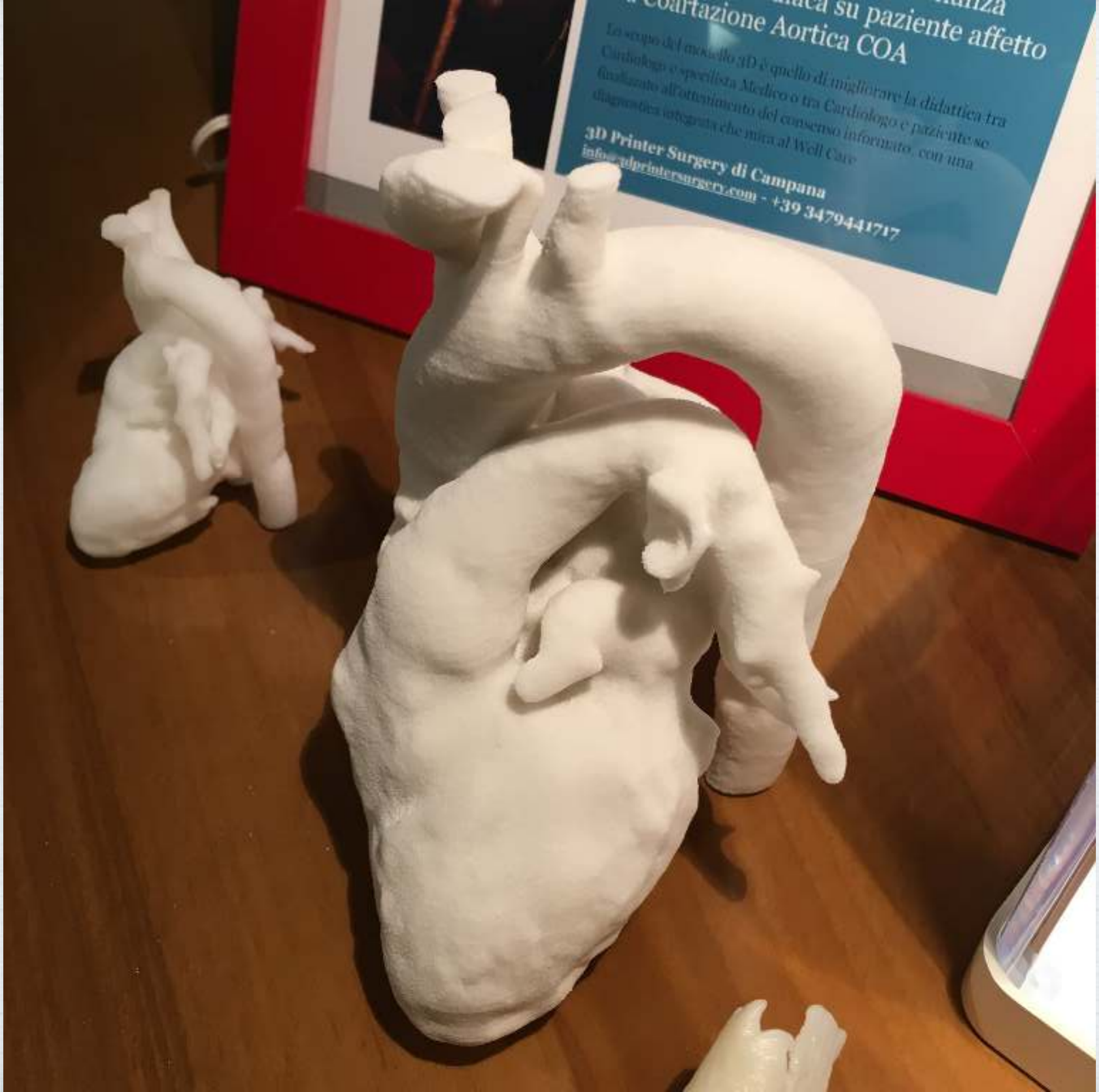


Markus Kayser

3DP for... Medicine!





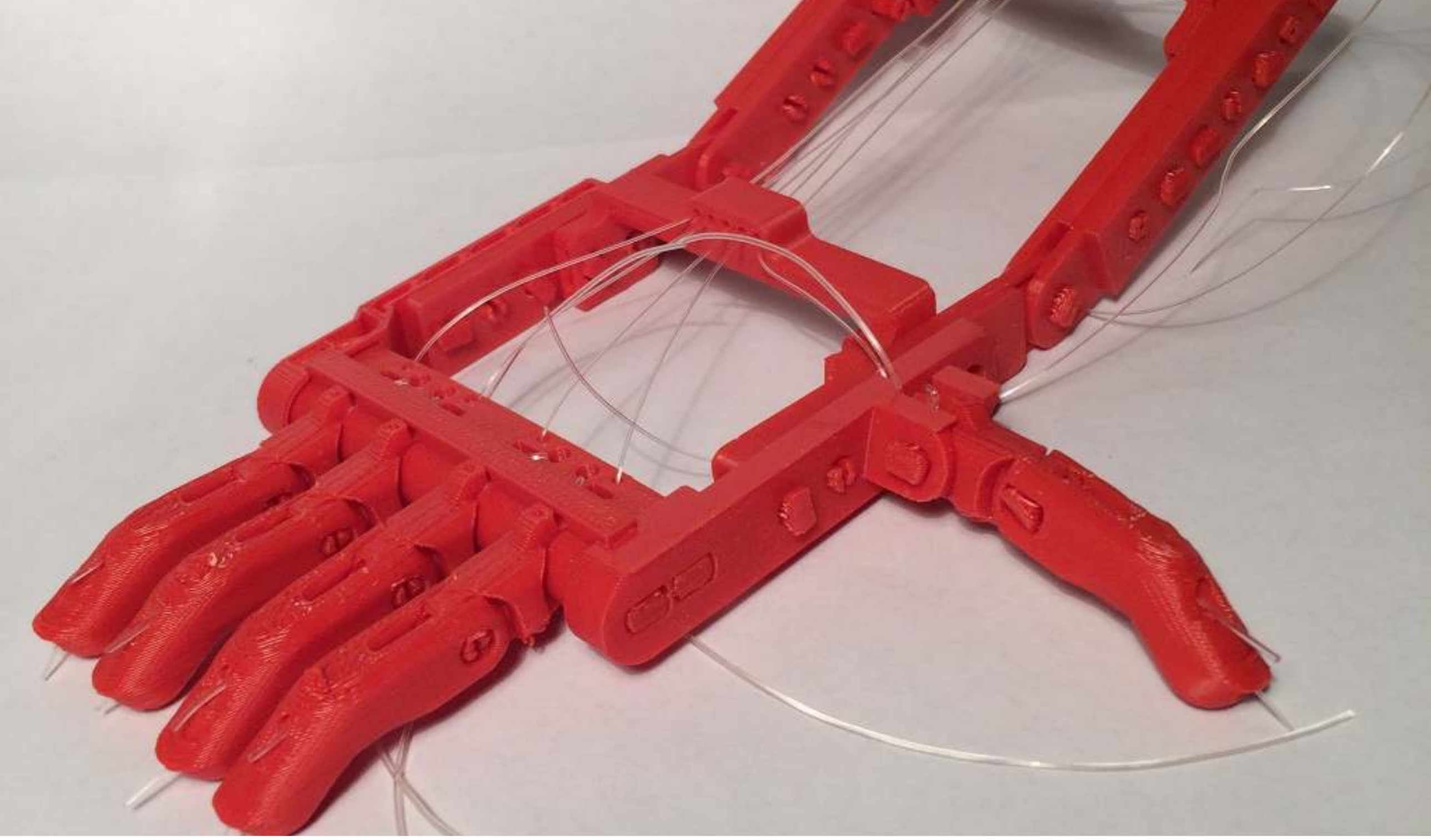

Coartazione Aortica COA
3D Printer Surgery di Campana
+39 3479441717

Giorgio Faganello, Carlo C
Manuel Belgrano, Giulia Ru
Pozzi, Giovanni Cioffi & An
Lenarda

The International Journal of Cardiovascular Imaging

CARDIOVASC
IMAGING

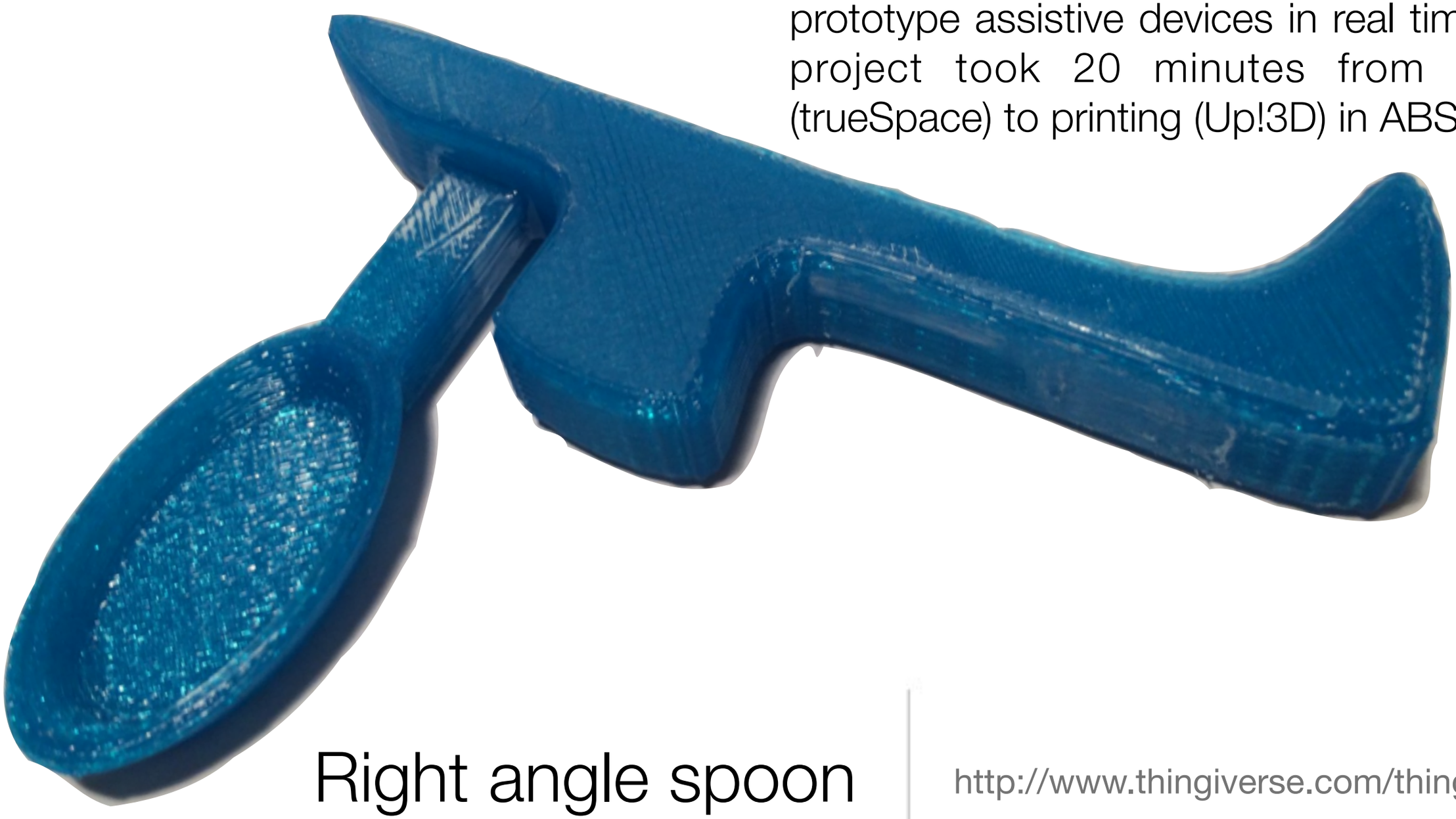
Springer



Possible applications for physical disabilities

... maybe the most ethical use!

Right angle, 90 degree, assistive device (spoon) for someone with, for example, limited grip strength or control. Quick design and prototype of assistive device. This demonstrtes that anyone with beginner skills and freeware 3D design software can prototype assistive devices in real time. This project took 20 minutes from design (trueSpace) to printing (Up!3D) in ABS.



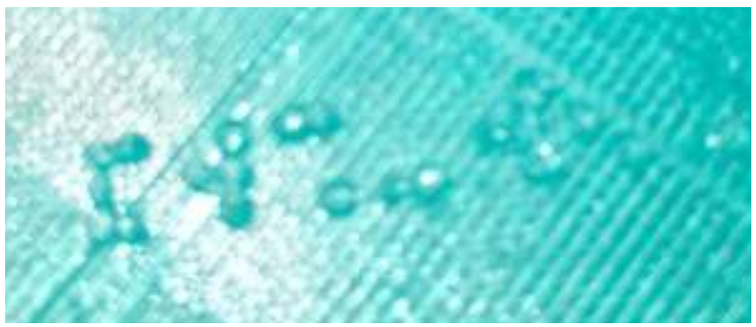
Right angle spoon

http://www.thingiverse.com/thing:23729

The planets of our solar system mounted on 3mm thick boards.

All the planets are represented in correct size. The size reference is the sun (1 meter in diameter, could be represented by for example a beach ball)

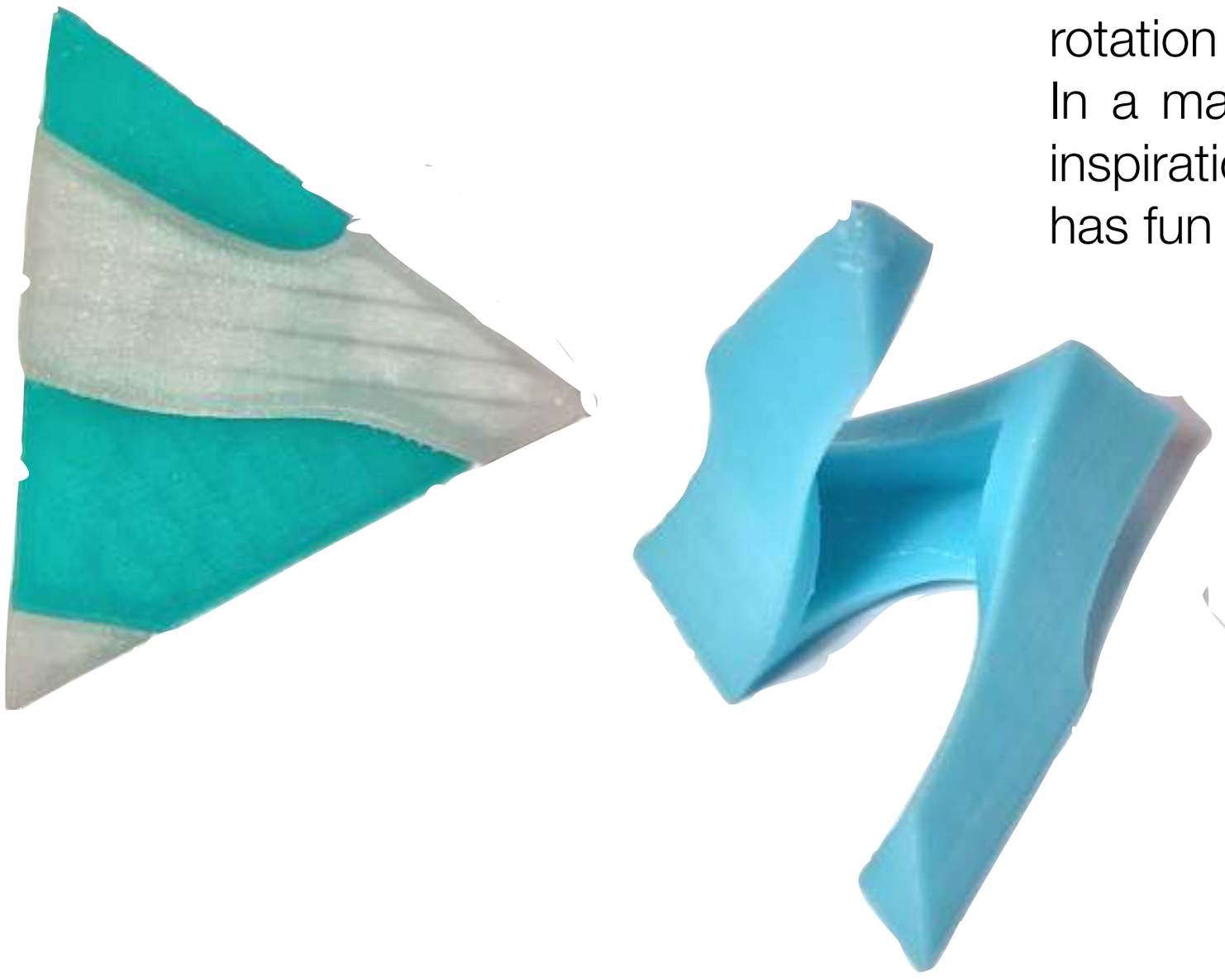
The planet name is printed in Braille above the planet and the order from the sun is printed below the planet.



Our solar system for the blind

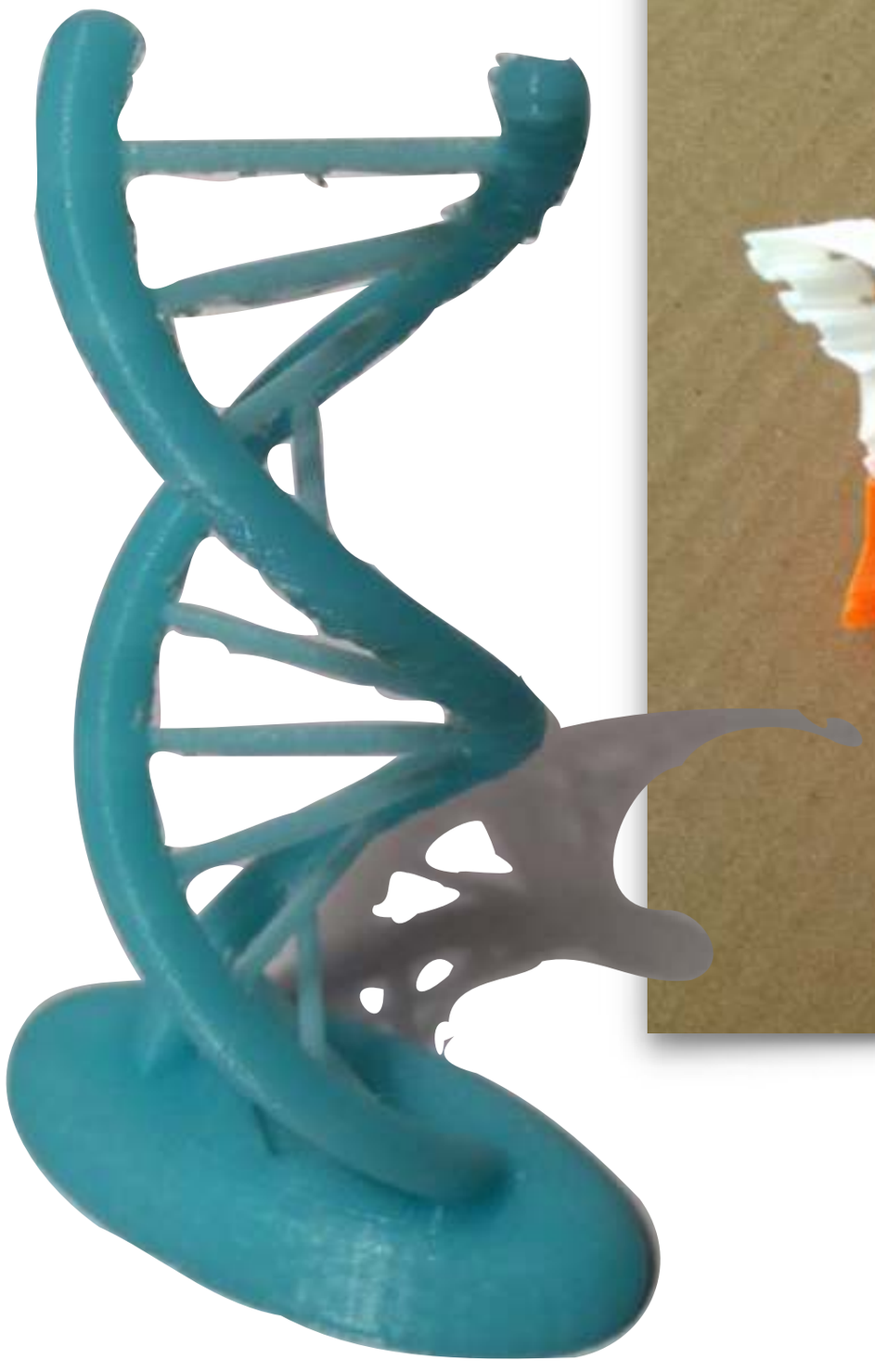
http://www.thingiverse.com/thing:65916

These puzzles challenge anyone who plays with them to think about combining the geometric transformations of translation and rotation in new ways.
In a math class, they also provide inspiration to see that mathematics has fun and creative applications.



Screw-puzzle
by George Hart

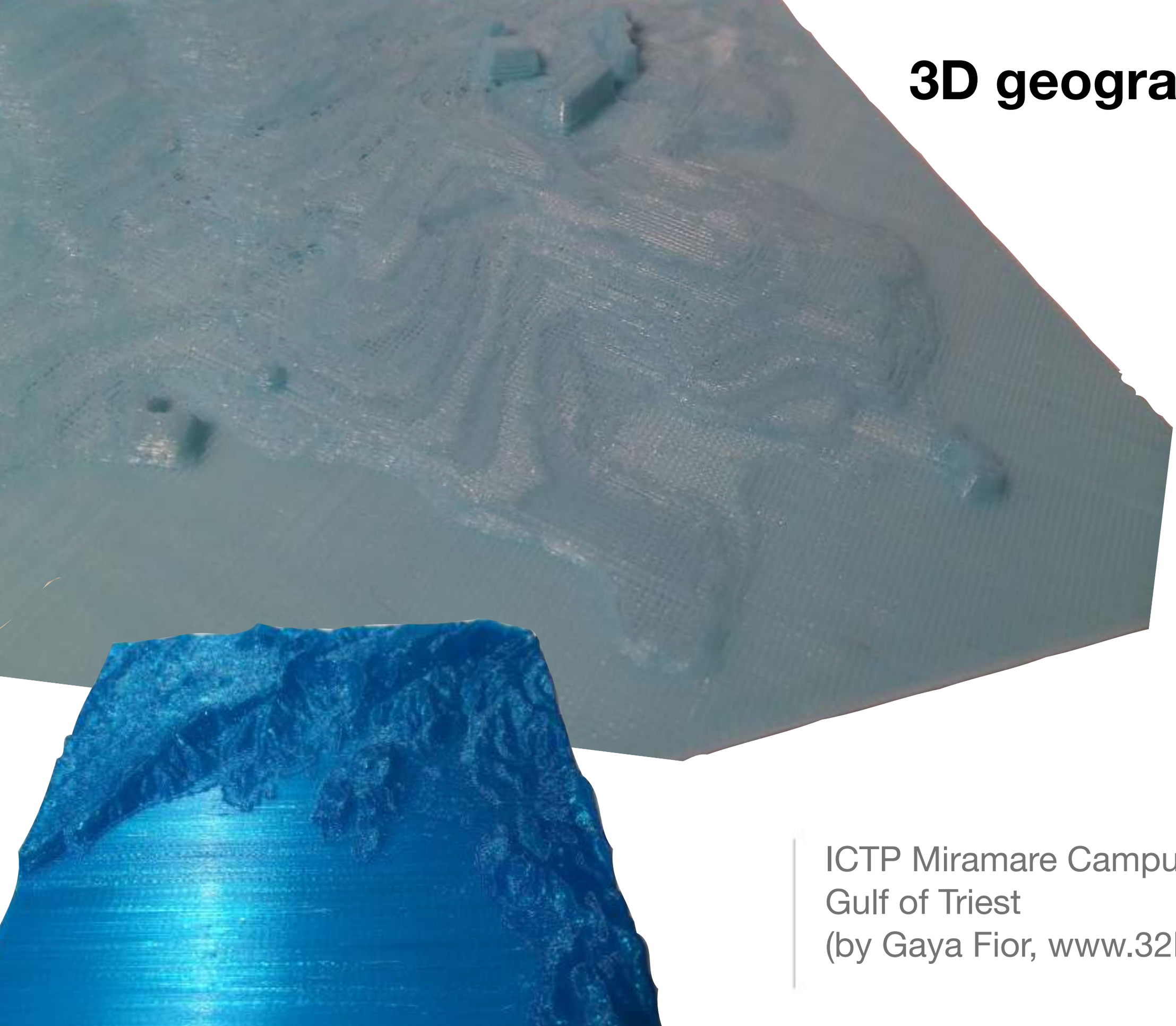
http://www.thingiverse.com/thing:186372



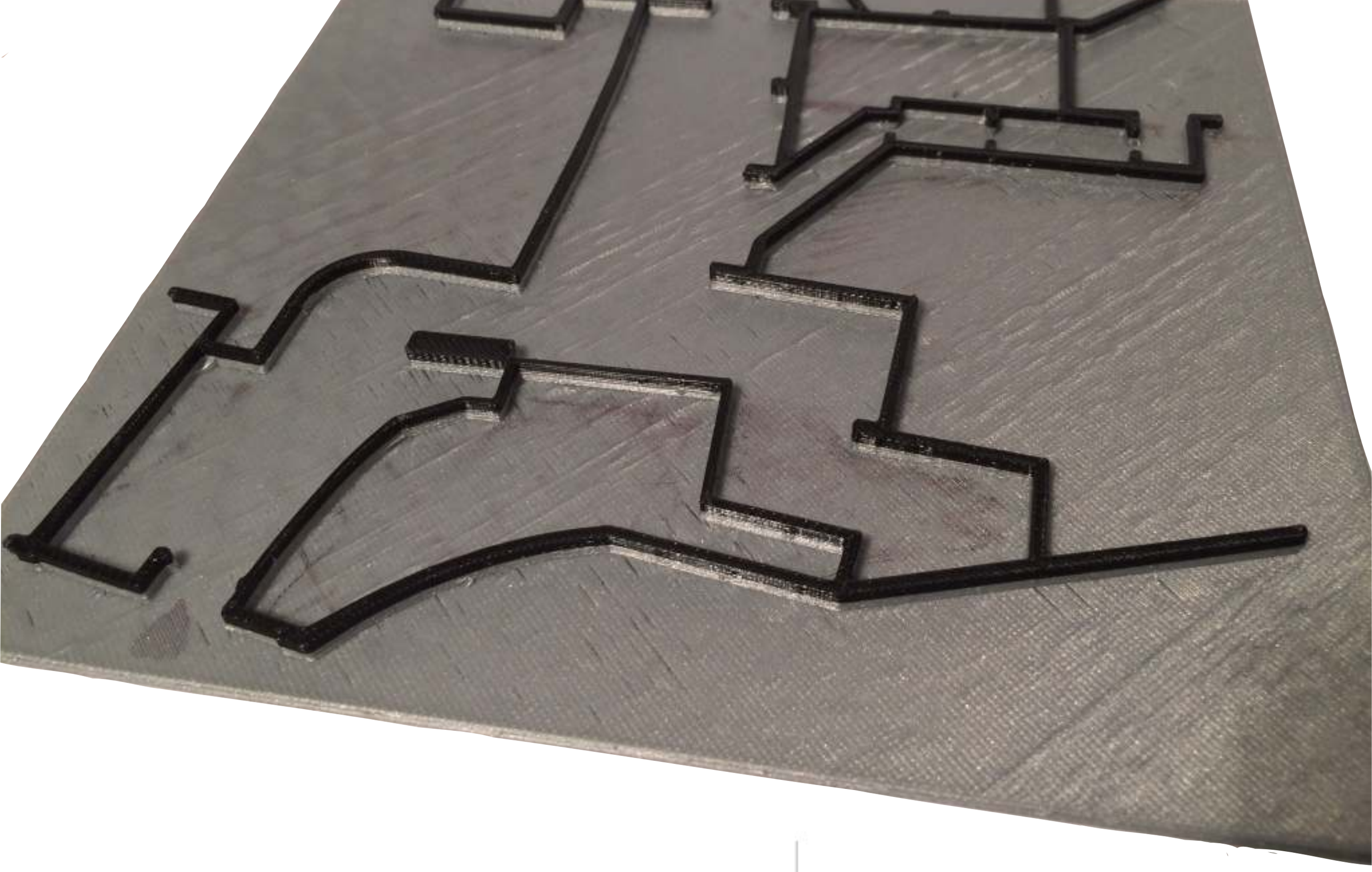
Double Helix of DNA

http://www.thingiverse.com/thing:10398
http://www.thingiverse.com/thing:17343

3D geographical maps

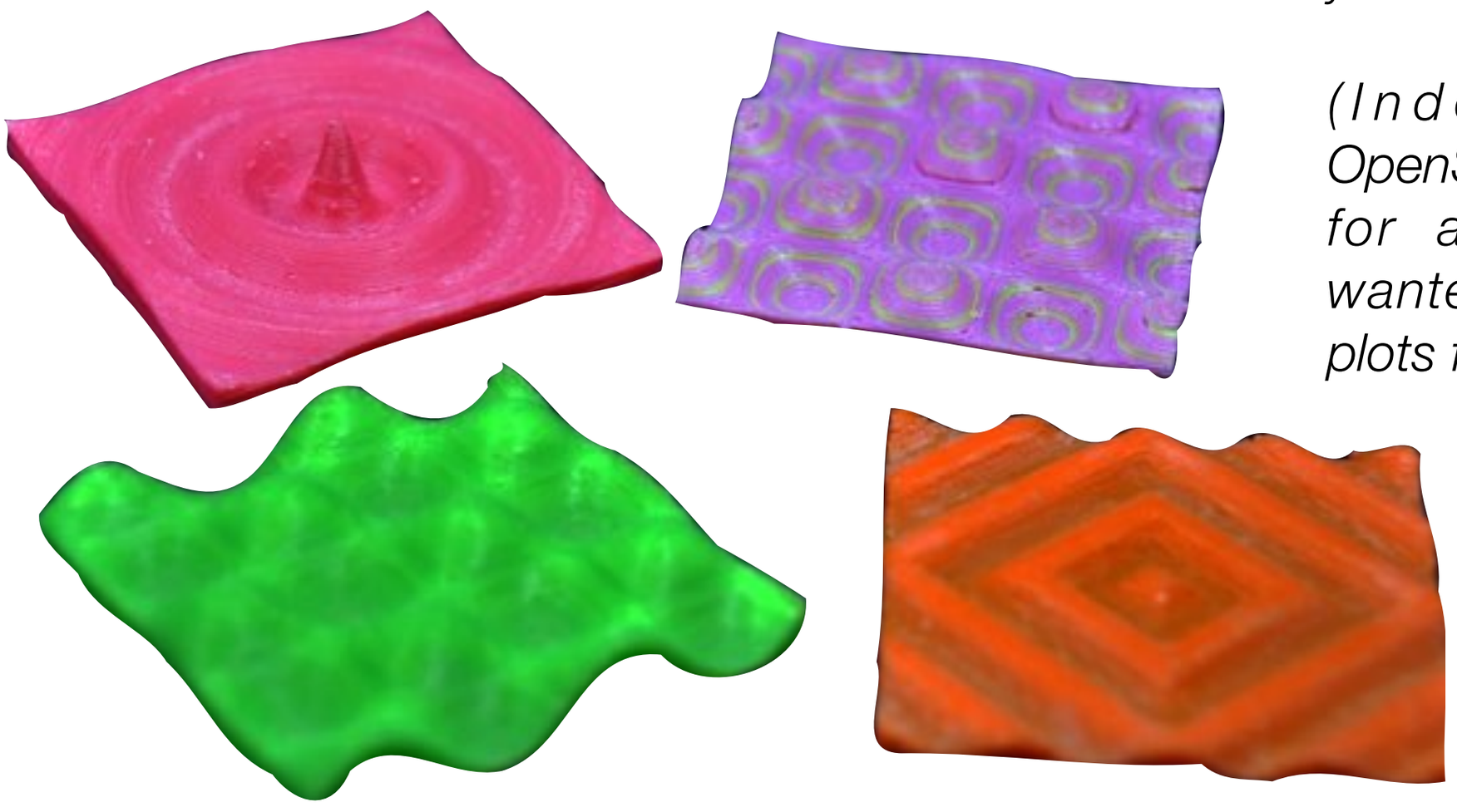


ICTP Miramare Campus
Gulf of Triest
(by Gaya Fior, www.32b.it)



Tactile map of a building

Immaginario Scientifico
(by C. Fonda, F. Deganis)

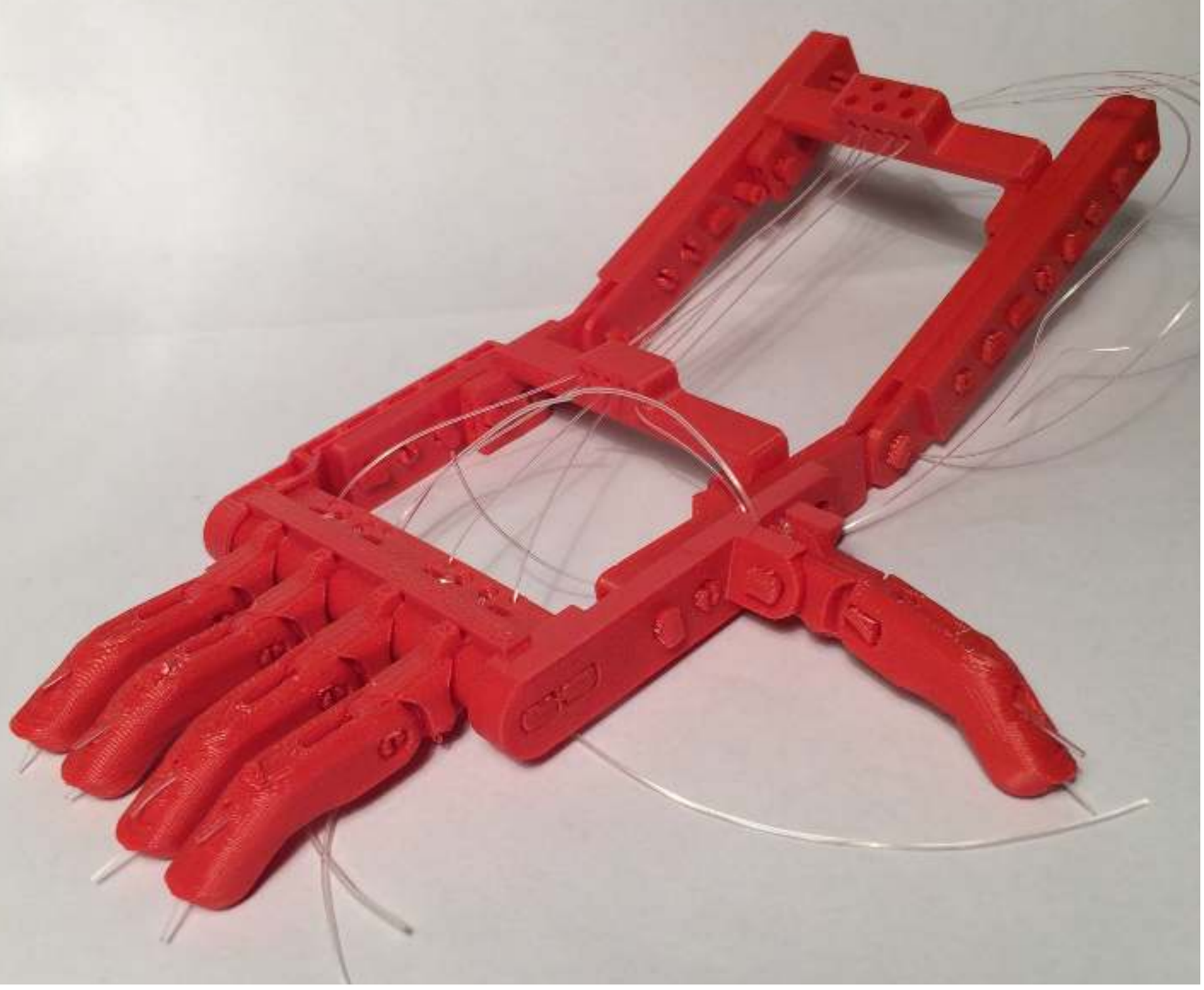


“Could there be anything more fun than drawing 3D surface plots?
Yes, you can 3D print 3D surface plots and hold them in your own hands!

(Indeed, I wrote this OpenSCAD program in 2011 for a math teacher who wanted some tangible 3D plots for a blind student.)”

OpenSCAD 3D Surface Plotter

http://www.thingiverse.com/thing:24897



Not everyone is fortunate enough to have two hands.
Robohand is an open source tool created to help restore the superpowers of humans who are missing the fingers from their hand. The original version was created by Richard Van As and Ivan Owen.

Robohand

Complete set of mechanical anatomically driven fingers

http://www.thingiverse.com/thing:44150
http://www.thingiverse.com/thing:92937

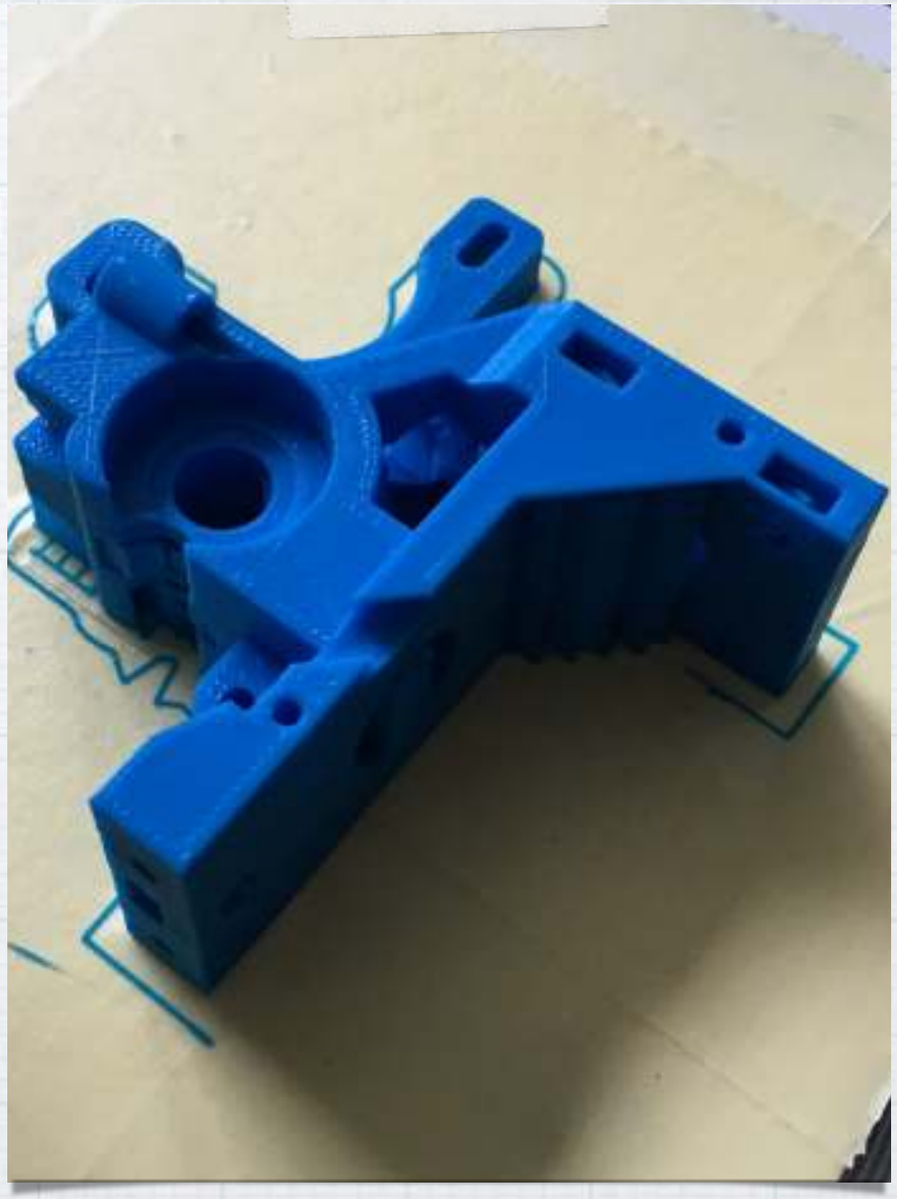
Movie from: http://www.thingiverse.com/thing:44150

Issues with 3DP: printing weapons (a non-issue)

Something old

3DP-oriented modeling

- traditional objects
- optimized for FDM (or other 3DP technologies)
- to avoid/minimize supporting, bridging, ...



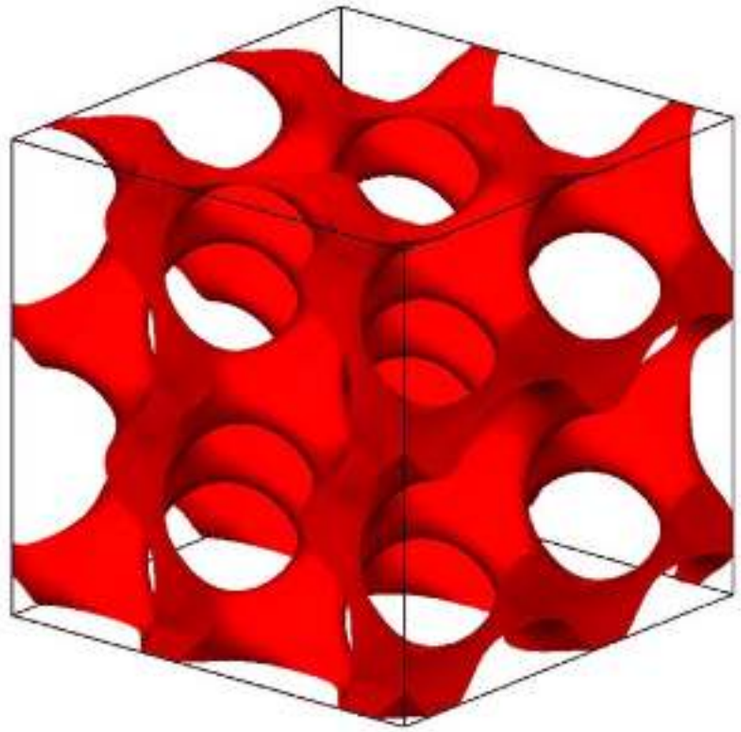
Something new...

"impossible" objects

- they can be modelled but *not manufactured* with traditional means

- 3D printers open a whole new world of possibilities

The gyroid is a complex cubic structure based on a surface that divides space into two separate volumes that are interpenetrating and contain various spirals. Pores and the superconducting material have structural dimensions of only around 10 nanometers, which could lead to entirely novel property profiles of superconductors.



"Now it's up to you to creating something new."

cfonda@ictp.it
Carlo Fonda, ICTP Scientific Fablab