RULES OF DESIGN

PRESENTED BY
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TRISTANT JEMELY, ELIAS PAJOT
17.11.2025

ME-413
ADDITIVE
MANUFACTURING

SUMMARY

EPFL

1. INTRODUCTION

- **HISTORY :** *Stereolithography, 1980s, additive manufacturing origins*
- **CONTEXT :** *Industrial expansion, new materials, design guidelines*
- **CHALLENGE :** *Printability rules, tolerances, support strategies, material-driven design limits*

: ***Made by ourselves***

Logos: https://www.flaticon.com/

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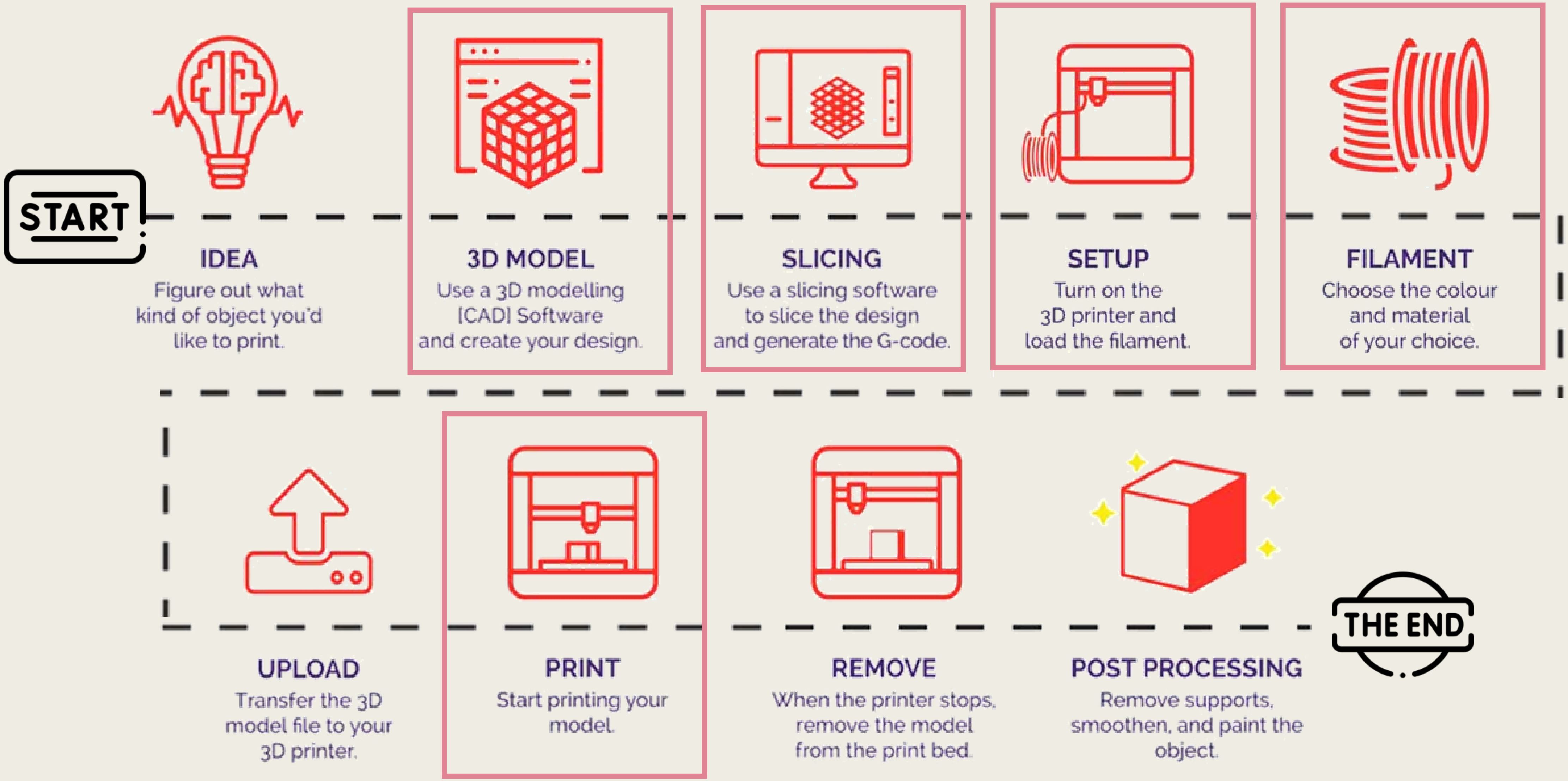
* QUICK RECALL*



https://ai.thestempedia.com/docs/3d-printing/getting-started-with-3d-printing/

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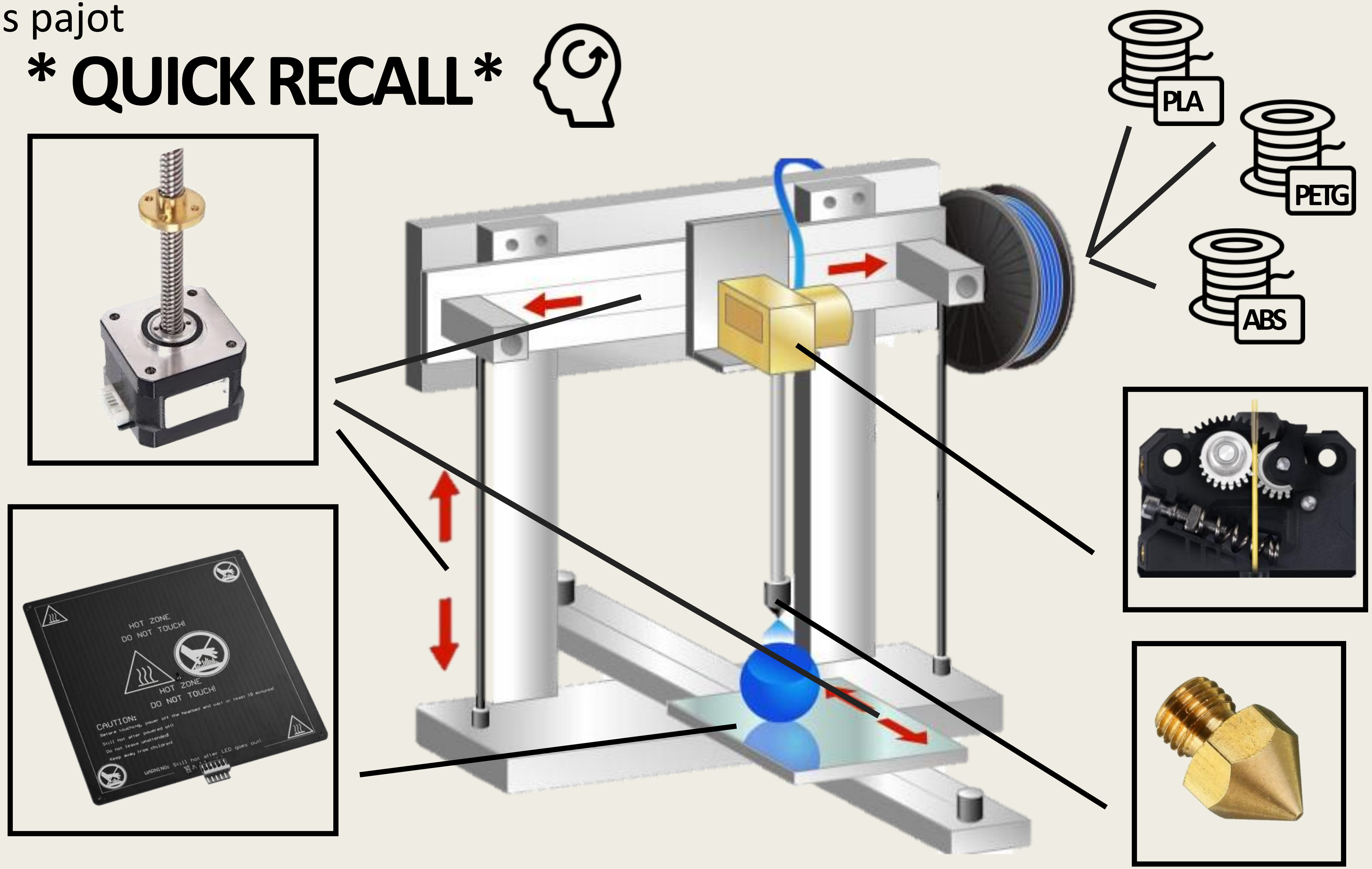
* QUICK RECALL*



https://storage.googleapis.com/medium-feed.appspot.com/images%2F9353691196%2F9745c3a1f1e2d-1718447437_863_O-que-e-impressao-3D-Parte-18.png
https://top3dshop.com/blog/3d-printer-nozzle-guide
https://www.amazon.de/-/en/Printer-Heated-HeatBed-Hotbed-Aluminium/dp/B0CH8XNPCY
https://www.amazon.fr/Moteur-engrenage-dimprimante-17HS3401S-motor%C3%A9ducteur/dp/B0CS6GX4XS
https://www.amazon.fr/Creality-dextrudeuse-directe-tension-r%C3%A9glable/dp/B0CZ8MF7CX

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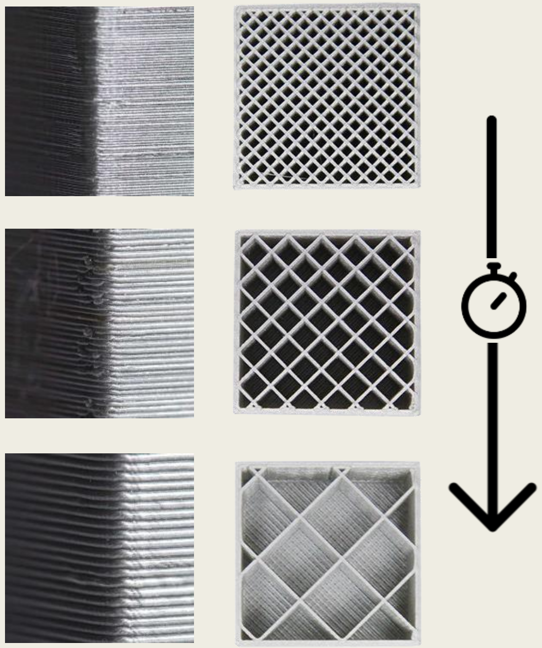
2.2 BEST PRACTICE GENERAL CASE

Parameter	PLA (Generic)	ABS (Generic)	PETG (Generic)
Filament-dependent settings			
Nozzle temperature (°C)	220-230	240–250	250–260
Bed temperature (°C)	50–60	100–110	85–90
Printing settings			
Layer height (mm)	0.1–0.3		
Infill density – rapid prototyping (%)	15-20		
Infill density – functional part (%)	60-80		
Support required	Depending on geometry		
Infill type	Grid / Adjust / Organic		
Perimeter speed (mm/s)	170		
Infill speed (mm/s)	200		



https://3dsolved.com/best-layer-height-for-3d-printing/

https://x3d.com.au/blogs/tips-and-tricks/3d-printing-infill-tips-tricks?srsltid=AfmBOopX9juI5w5aelj9WiPSUjsGpjJM_CLn7V297CwbsAuKgZBHTljh
https://prusaslicer.net/

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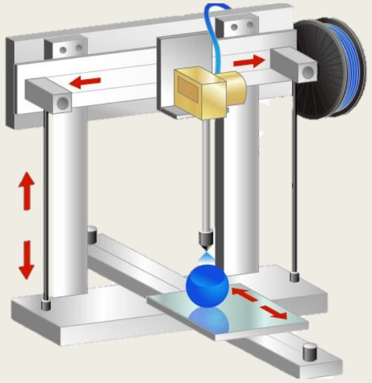
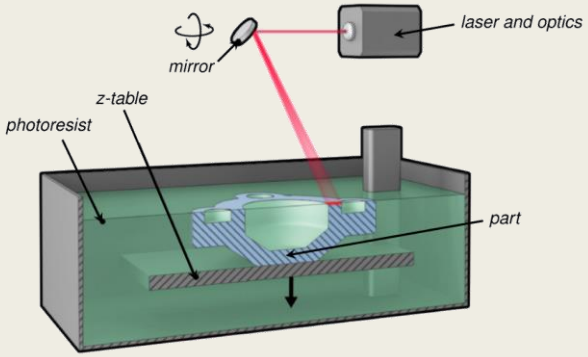
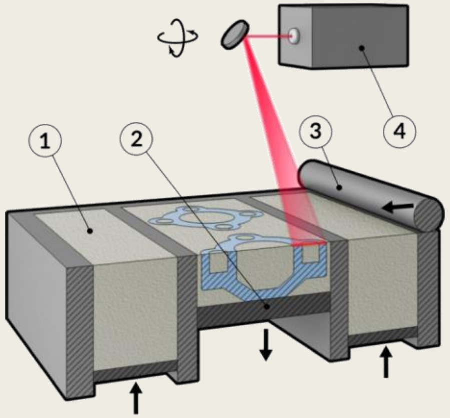
2.1 MATERIAL



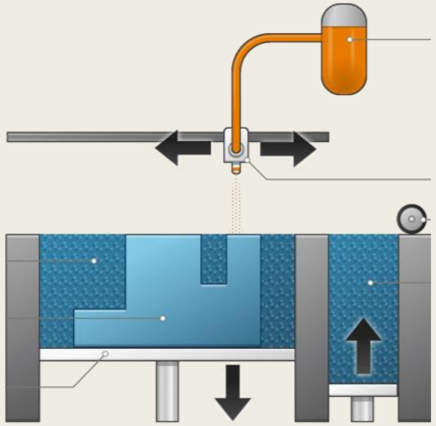
FUSED DEPOSITION MODELING



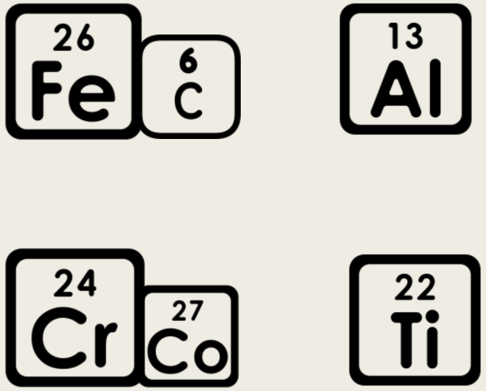
STEREOLITHOGRAPHY

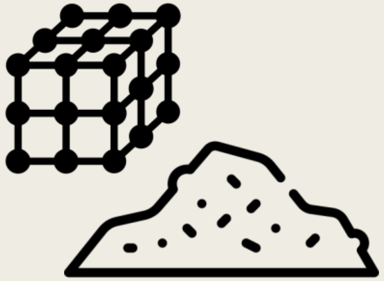


SELECTIVE LASER MELTING



BINDER JETTING





https://www.epfl.ch/about/campus/wp-content/uploads/2021/06/HIM21_Boillat-Eric_Additive-manufacturing-Application-to-Microengineering.pdf
https://www.3ds.com/make/guide/process/binder-jetting

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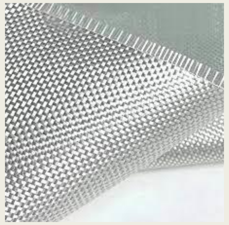
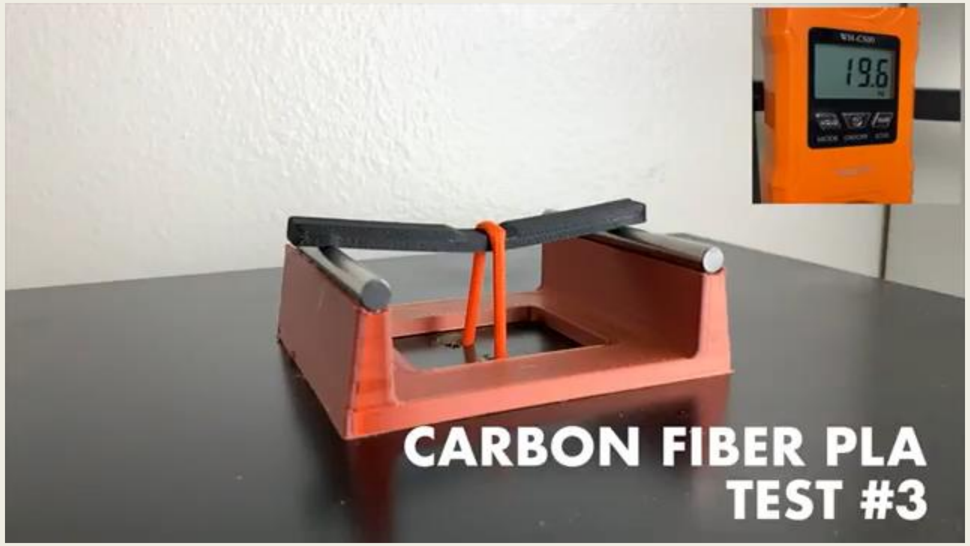
2.1 MATERIAL

REGULAR PLA: 13.7 KG
CARBON FIBER PLA: 24.2 KG





https://www.heaterk.com/info-detail/understanding-fiberglass
https://www.youtube.com/watch?v=cJIYHDDvIow
https://www.3djake.ch/fr-CH/the-filament/pla-silver-aluminium
https://arkcomposites.com/products/carbon-fiber-cloth-5-7-oz-x-16-3k-plain-weave?srsltid=AfmBOoradtur55k47eUwAwH81gtwaDTMNUDyEcwvmrMI_eS0yUa20f27

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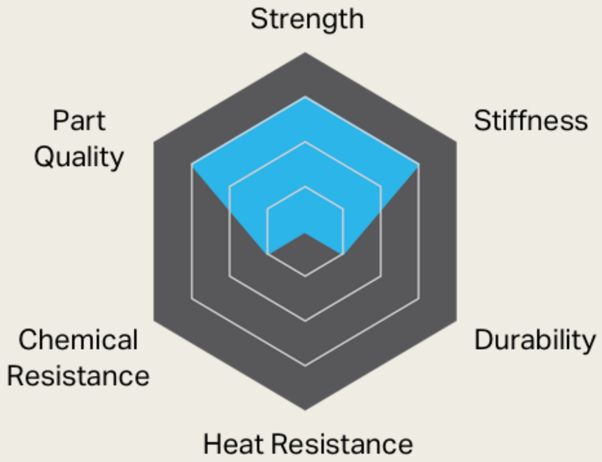
2.1 MATERIAL

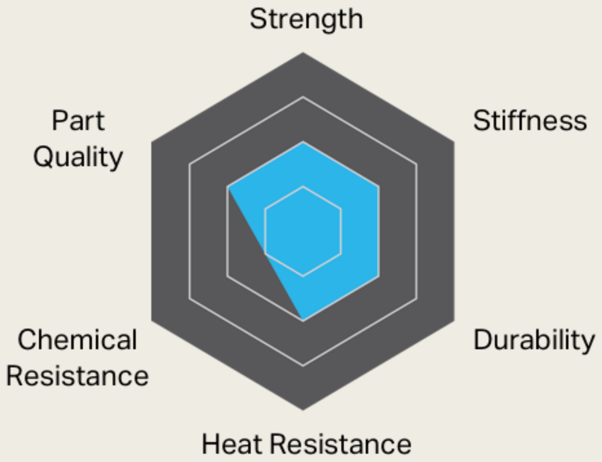
EPFL

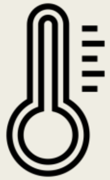
PLA



37-70 MPA

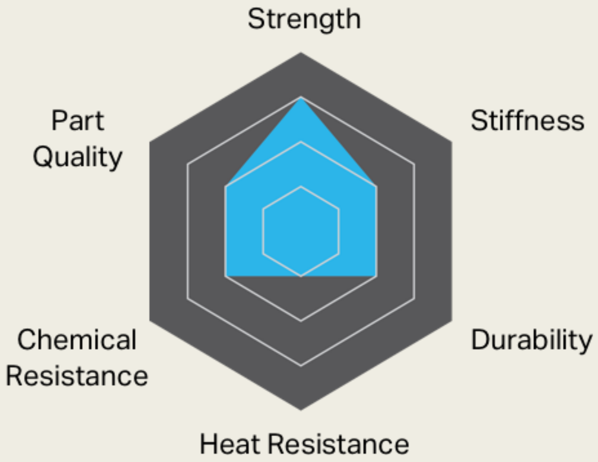
ABS





90-100 °C

PETG



50-75 MPA

https://markforged.com/fr/resources/learn/3d-printing-basics/how-do-3d-printers-work/3d-printing-materials

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	Strength	Yielding
PLA	1	3
ABS	2	2
PETG	3	1

https://www.youtube.com/watch?v=ycGDR752fT0&t=835s

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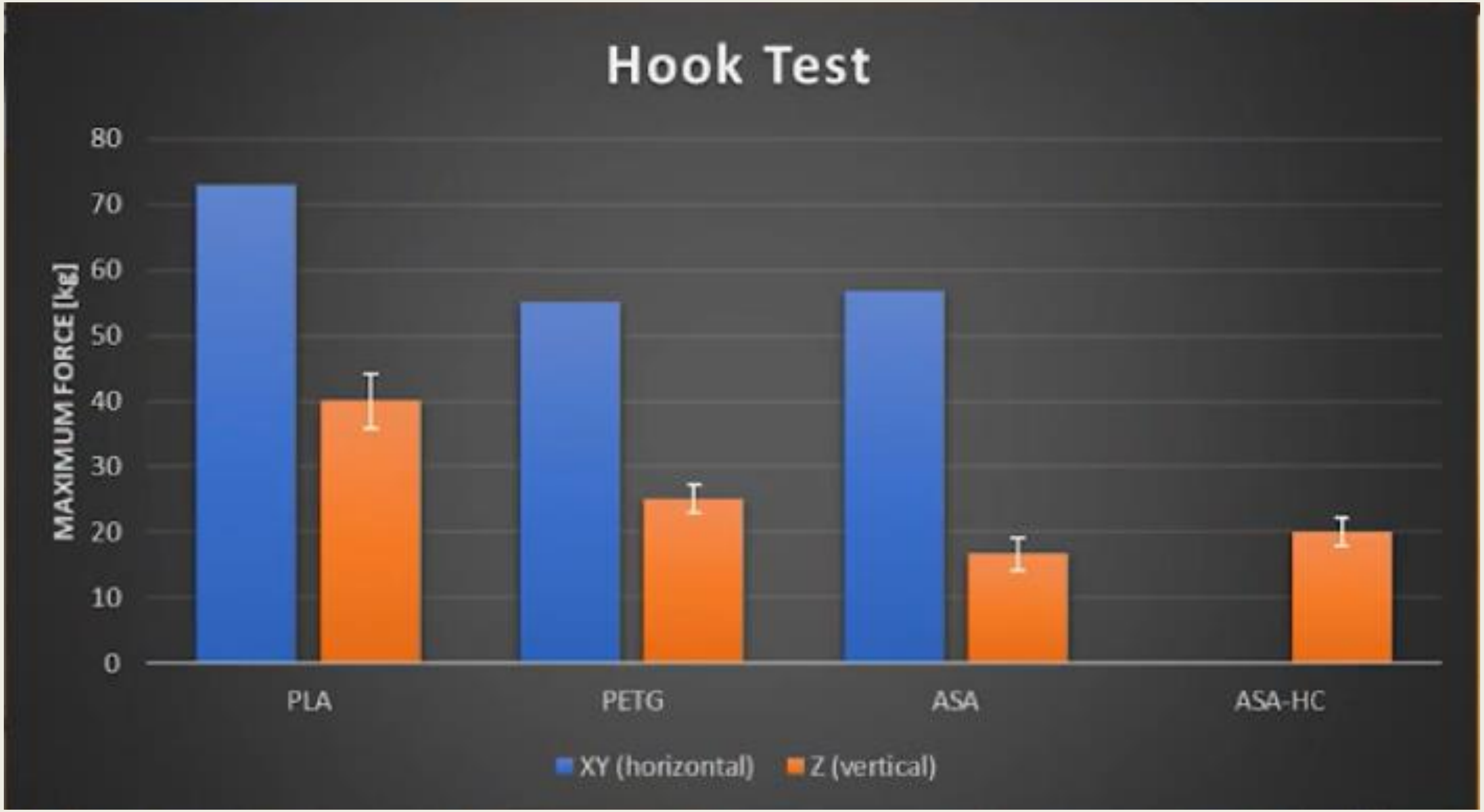
Hook Test
MAXIMUM FORCE [kg]
80
70
60
50
40
30
20
10
0
PLA
PETG
ASA
ASA-HC
XY (horizontal)
Z (vertical)

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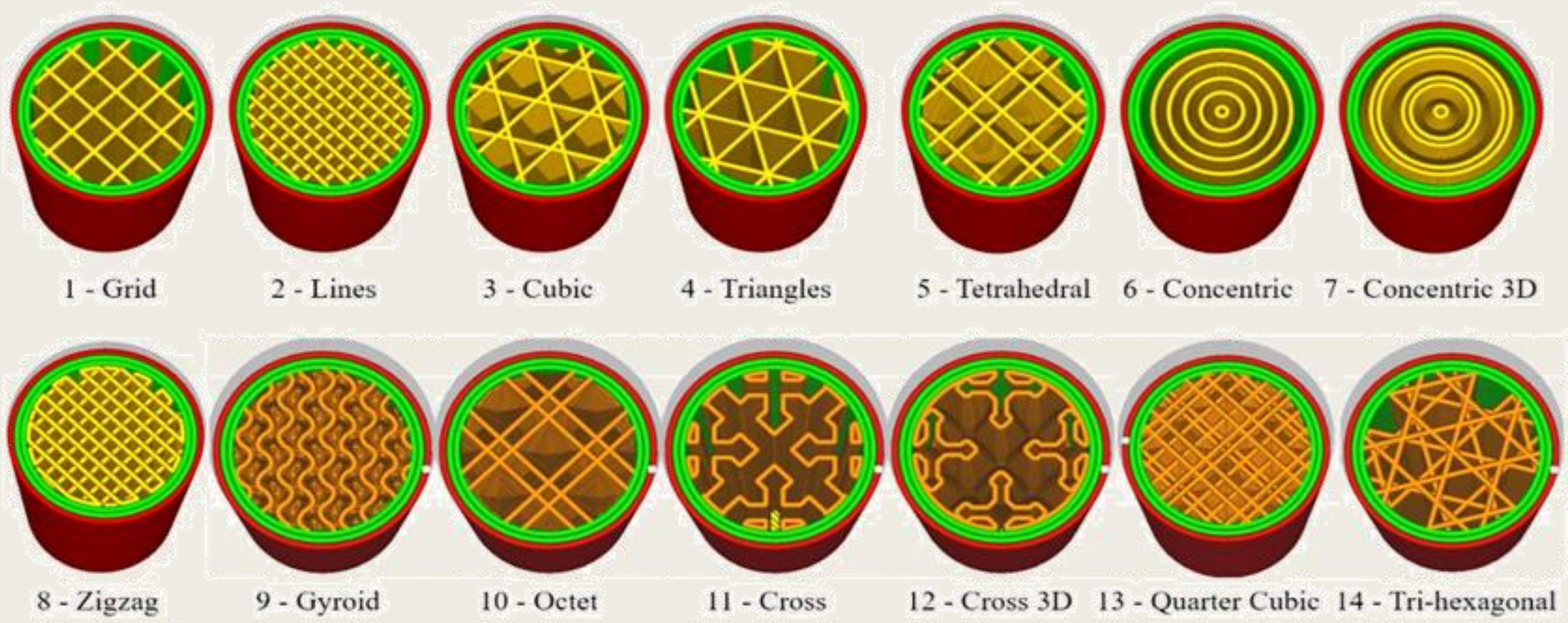
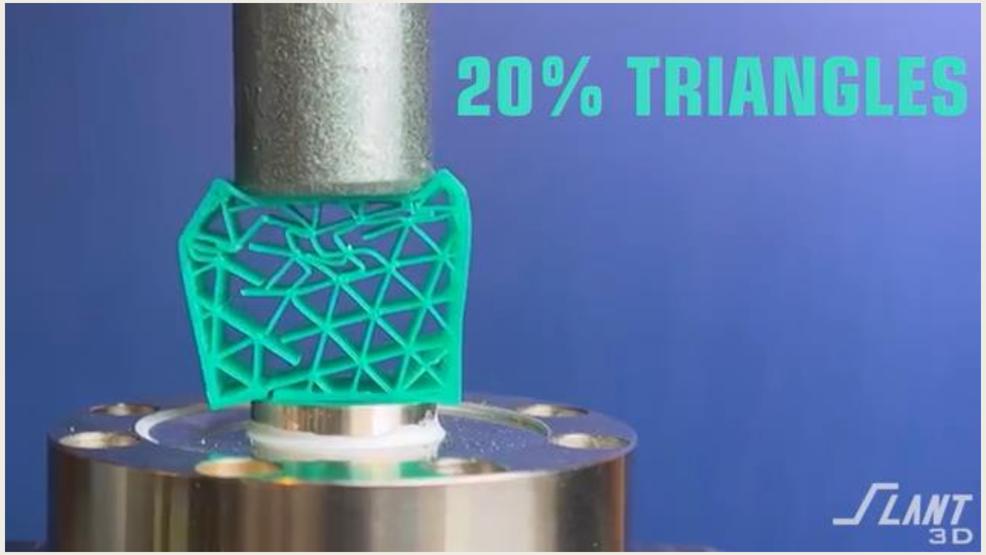
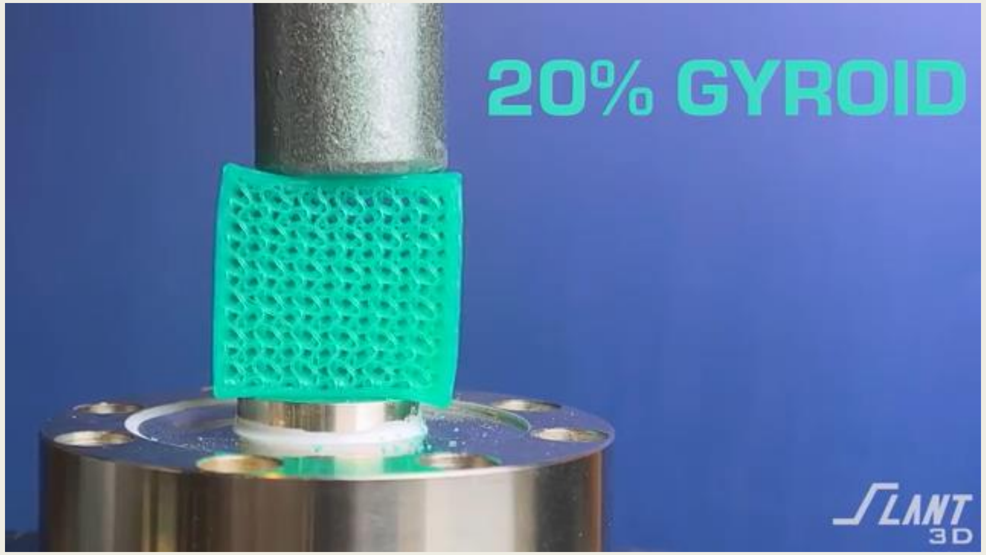
2.3 STRUCTURE



https://www.sciencedirect.com/science/article/pii/S2212827122001159?ref=pdf_download&fr=RR-2&rr=992f2d85eee33b51

2.3 STRUCTURE





https://www.youtube.com/watch?v=IIS9UagZaWI

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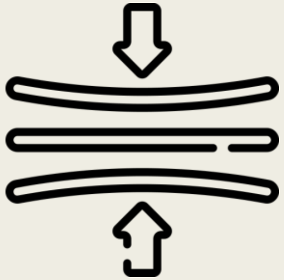
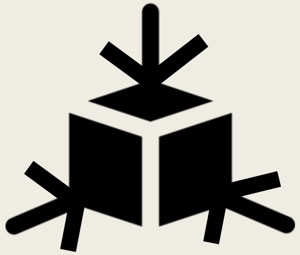
2.3 STRUCTURE

Parameters :

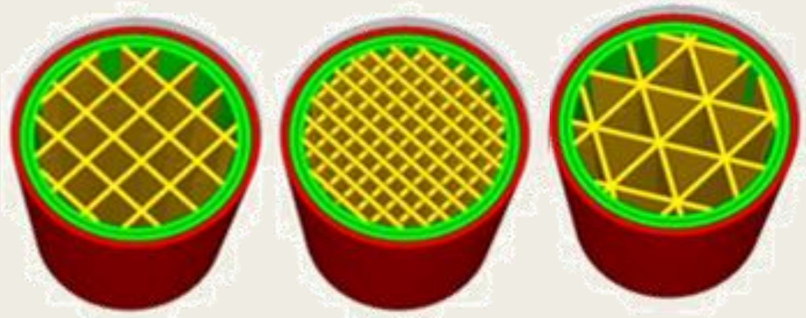




% INFILL

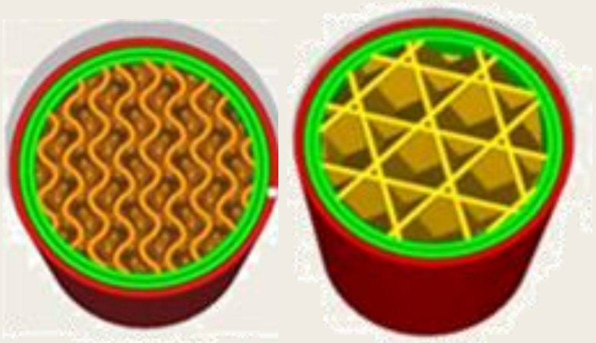
Good to remember:

Unidirectional constrain :



1 - Grid 2 - Lines 4 - Triangles

Multidimensional constrain :



9 - Gyroid 3 - Cubic

https://www.sciencedirect.com/science/article/pii/S2212827122001159?ref=pdf_download&fr=RR-2&rr=992f2d85eee33b51

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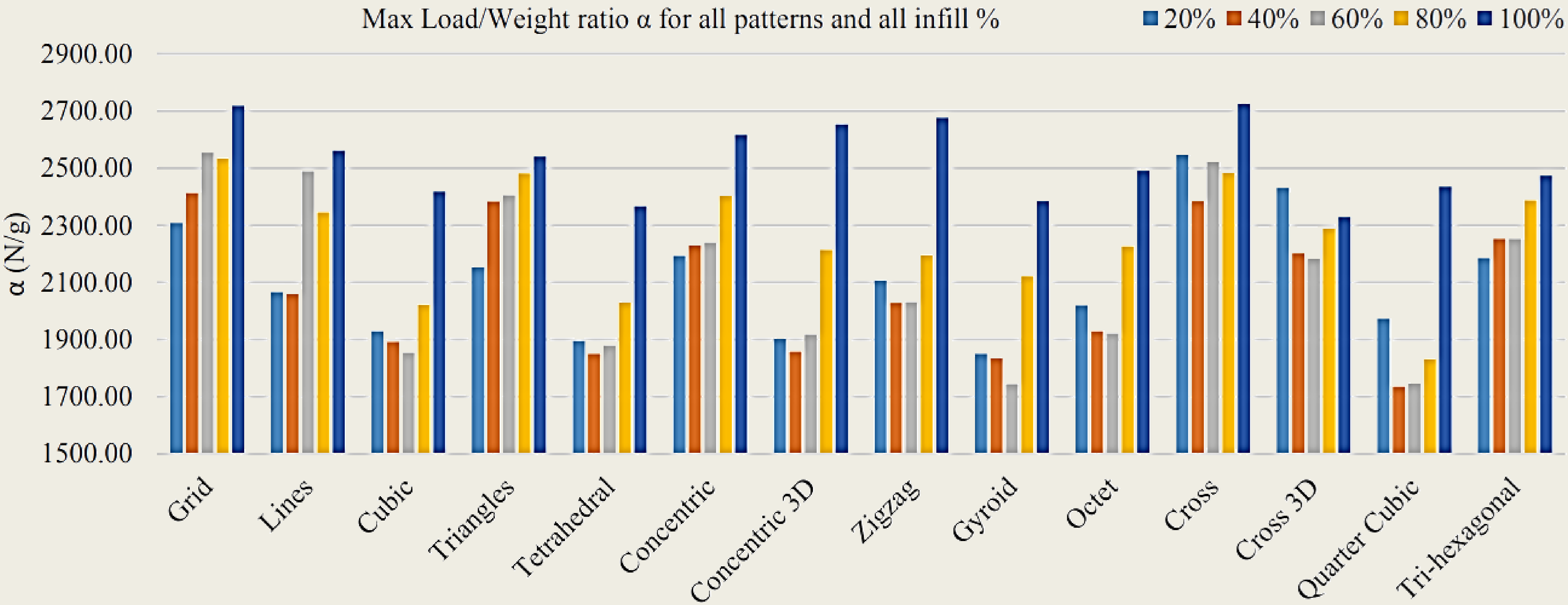
2.3 STRUCTURE

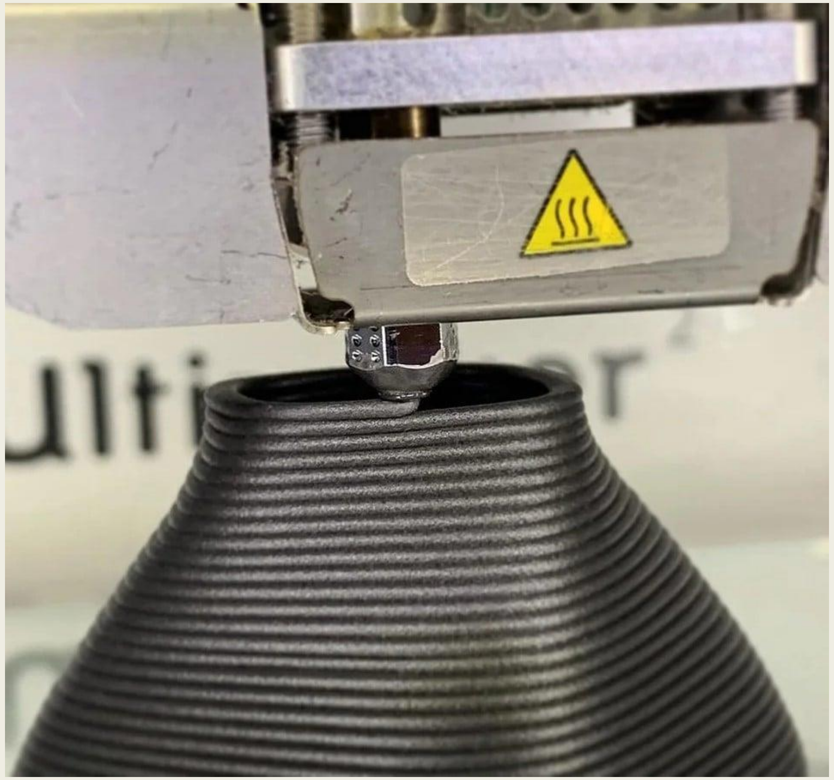
Parameters : % INFILL



https://www.sciencedirect.com/science/article/pii/S2212827122001159?ref=pdf_download&fr=RR-2&rr=992f2d85eee33b51

3.1 Geometrical challenges

- FDM works by depositing layers of molten filament.
- Each layer should go on top of the previous one.
- If not, underside surface quality may be worsened.



https://all3dp.com/fr/2/petg-vs-pla-filament-3d-impression/

3.1 Geometrical challenges

WE WILL NOT CONSIDER GEOMETRIES WITH SUPPORTS!

https://all3dp.com/1/3d-printing-support-structures/

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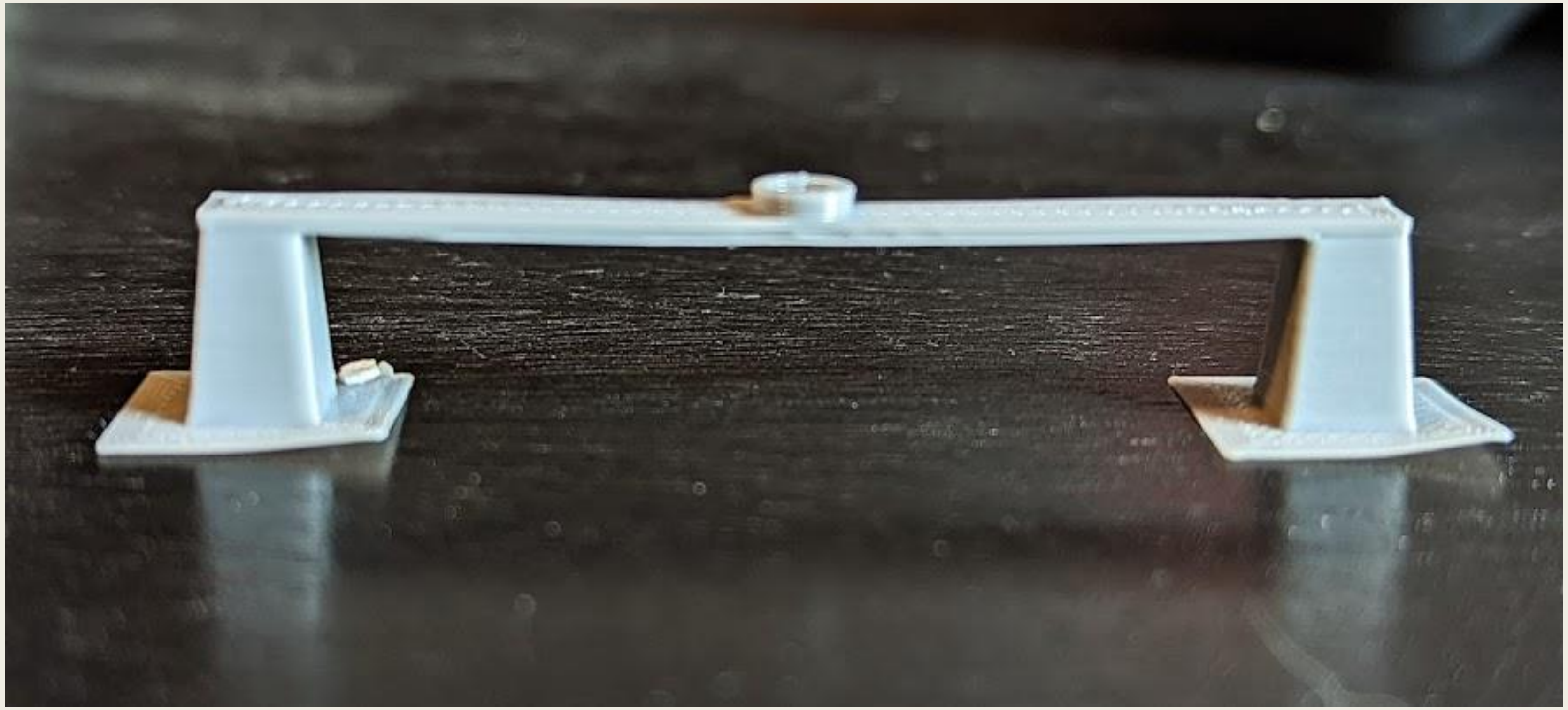
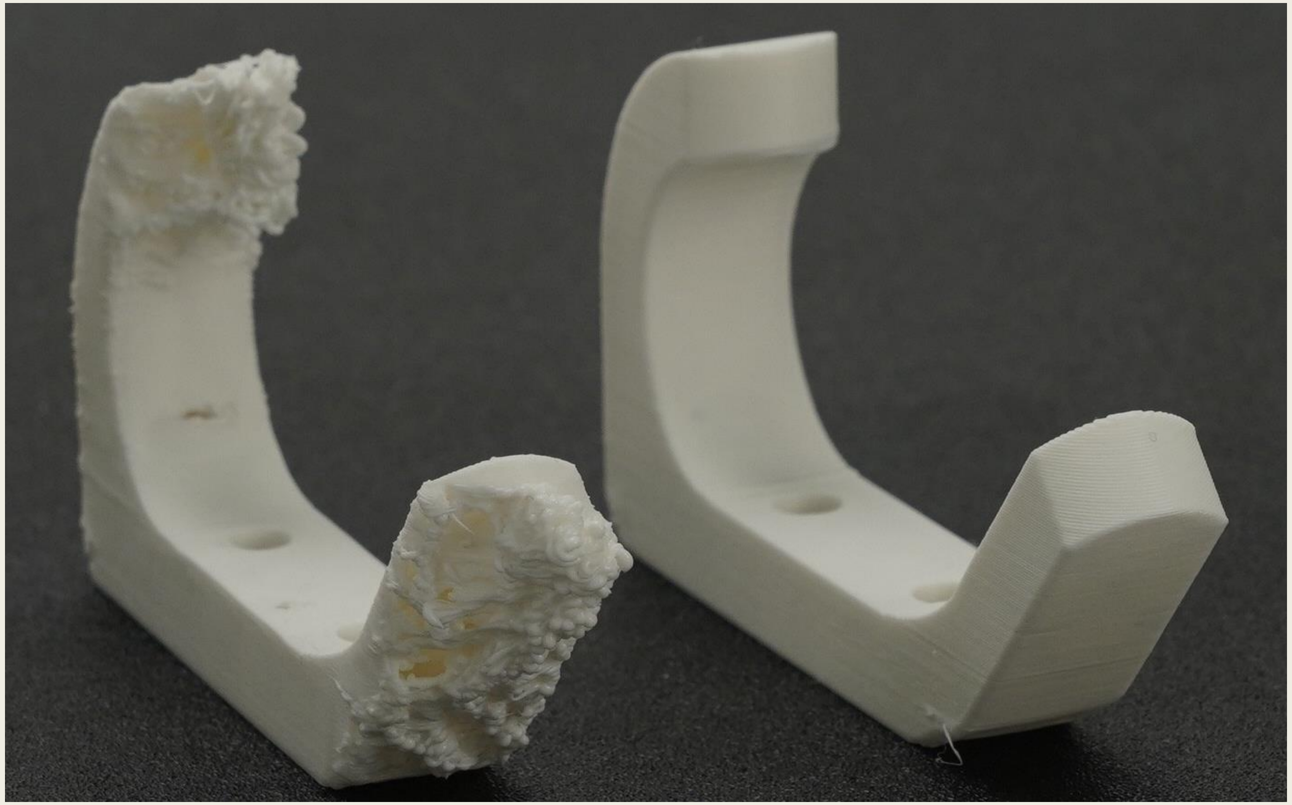
3.2 Suspended geometries



https://www.davidgunter.com/es-mx/2022/05/14/printing-with-petg-on-the-ender-3-v2/

We call it a suspended structure when the last layers are not deposited on top of the previous ones.

3.3 Overhangs



https://wiki.bambulab.com/en/filament-acc/filament/print-quality/overhang

- When the last layer is only partially deposited onto the previous ones, the sloped underside is called an overhang.
- 45° rule!!
- Overhangs can greatly reduce surface quality.

3.4 Good reflexes to improve overhangs surface quality

- Reduce nozzle temperature:

  PLA: 190-220°C

  PET-G: 220-240°C

  ABS: 230-250°C

- Increase cooling
- Reduce printing speed

https://all3dp.com/2/3d-printing-overhang-how-to-master-overhangs-exceeding-45/

3.5 Bridges

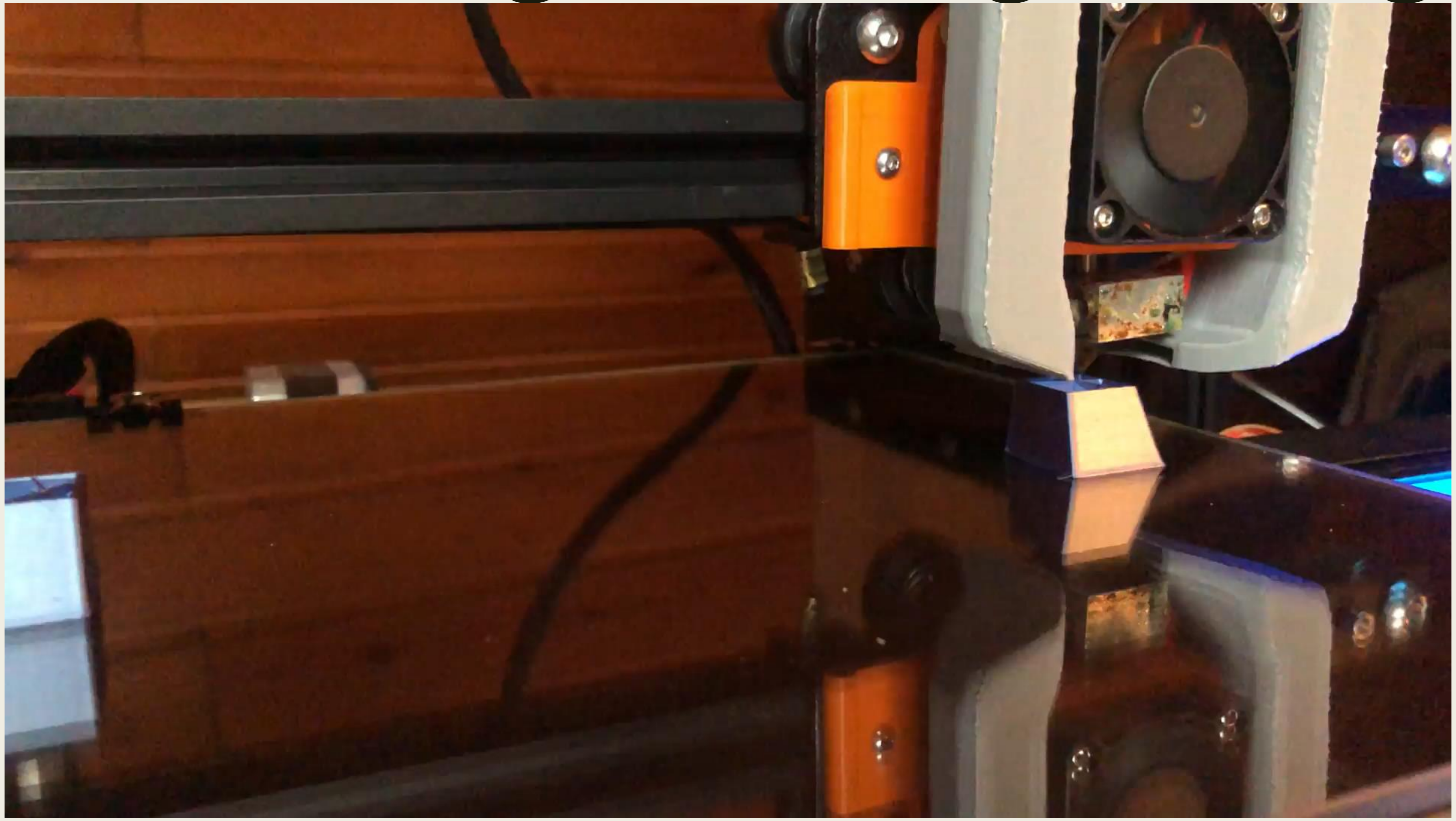
Bridges and cantilevers require the filament to be deposited onto nothing, and solidify quickly enough to resist gravity.

Usually, bridges should not exceed 100 mm length.

https://www.3dnatives.com/en/how-to-avoid-briding-in-3d-printing-2107234/#!

Andres Bettinger

3.5 Effect of good tuning on bridges

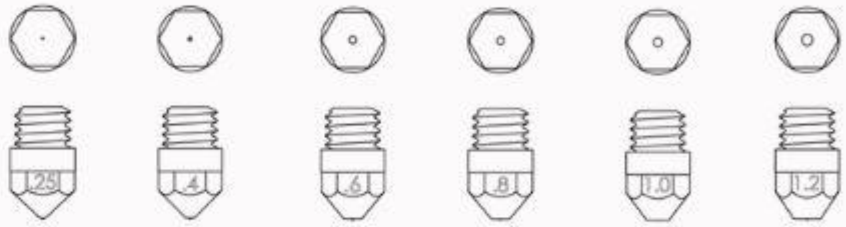


With excellent parameters, one can achieve bridge lengths up to 150 mm.

https://www.reddit.com/r/3Dprinting/comments/lkbmjb/150mm_bridge_took_me_a_lot_of_time_to_get_my/

3.6 Minimal wall thickness

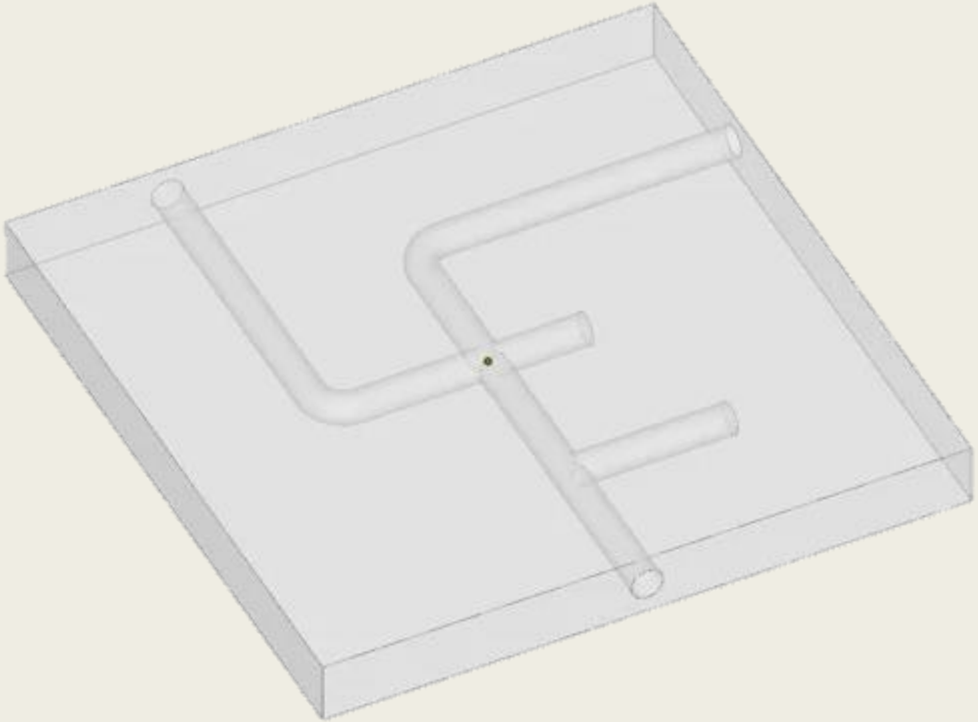
- Using a wall thickness too low can reduce the mechanical properties of a part.
- In general, the minimum recommended value for the wall thickness is around 1.5 millimeters.



1 wall	0.25	0.4	0.6	0.8	1.0	1.2	Weak
2 walls	0.50	0.8	1.2	1.6	2.0	2.4	Medium
3 walls	0.75	1.2	1.8	2.4	3.0	3.6	Minimum recommended
4 walls	1.0	1.6	2.4	3.2	4.0	4.8	Strong
5 walls	1.25	2.0	3.0	4.0	5.0	6.0	Strong

https://www.3dnatives.com/en/wall-thickness-in-3d-printing-all-you-need-to-know-281120234/#!

3.7 Holes, channels & gaps



- Internal structures can be hard to access, for example to remove supports
- They should then be designed with the same constraints as for the suspended geometries.

https://www.weerg.com/fr/faq/lignes-directrices-de-conception-pour-impression-3d

3.8 Embossing / engraving text & logos

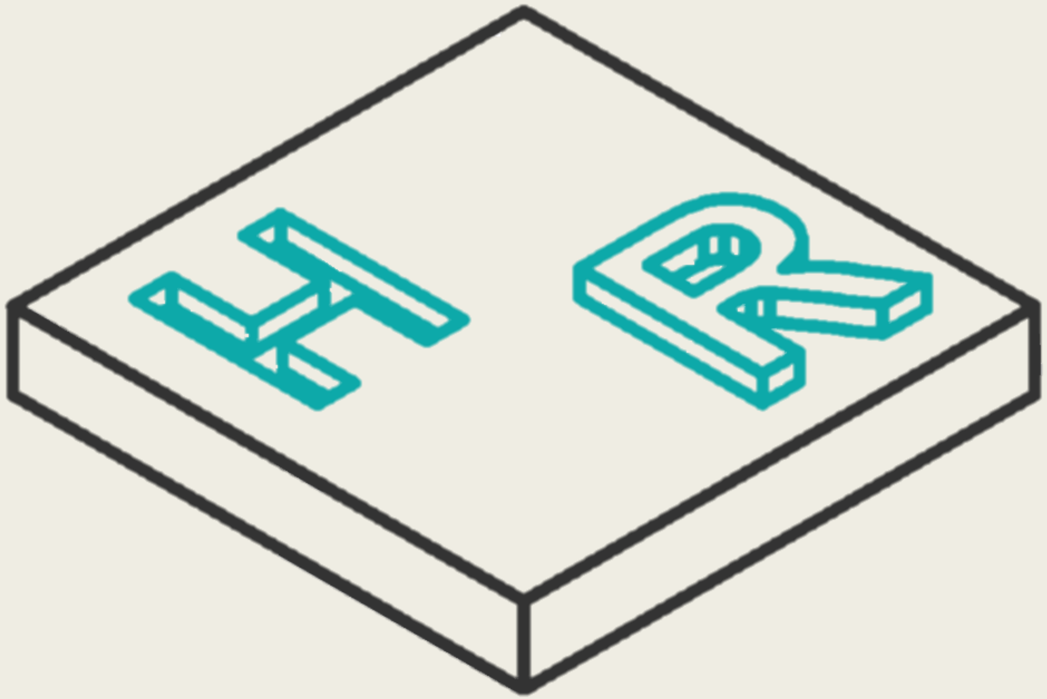
On vertical surfaces, the text and logos must become suspended structures and must therefore follow the same rules detailed previously.

https://www.hydraresearch3d.com/design-rules

3.9 Embossing / engraving text & logos

Horizontally, the design of such details should only be careful of the rules of minimal wall thickness.

One should also ensure that the heights and widths allows the details to be clearly visible.



https://www.hydraresearch3d.com/design-rules

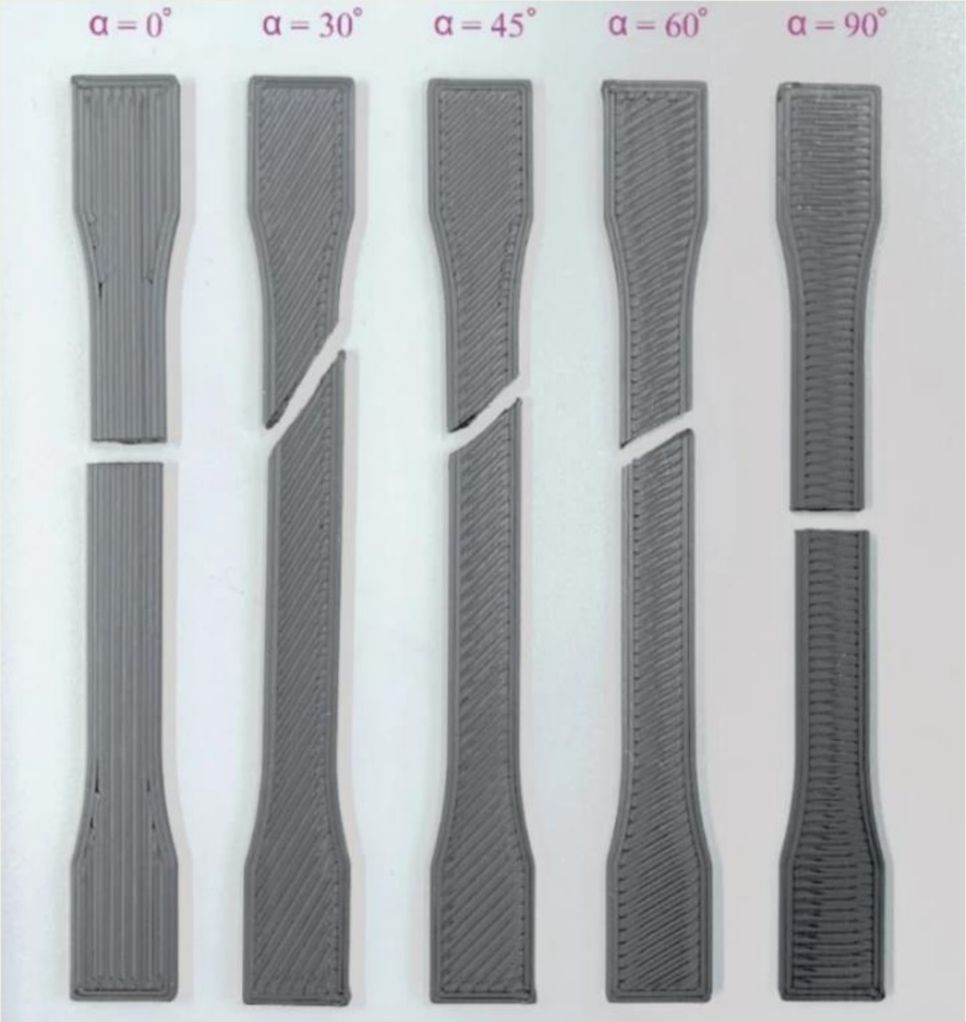
4. Considerations related to the FDM printing process

- Orientation
- Printing parameters
- Warping
- Dimensional accuracy
- Preparation of the filament

→ To achieve consistent, repeatable parts

4.1 Orientation – Raster Angle

- Strands are highly anisotropic
  - *Up to 50% loss at 90°*
  - *Can be compensated similarly to composite materials*
- "Welds" are the weakest points
  - *Due to the different bonding temperature : hot new layer over colder previous layer*

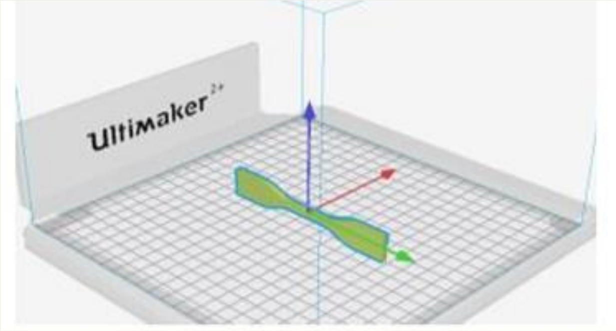


https://doi.org/10.1038/s41598-022-05005-4

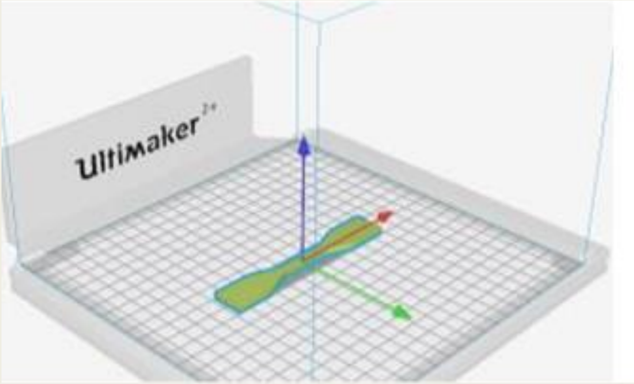
Paul Cheron

4.1 Orientation – Printing direction

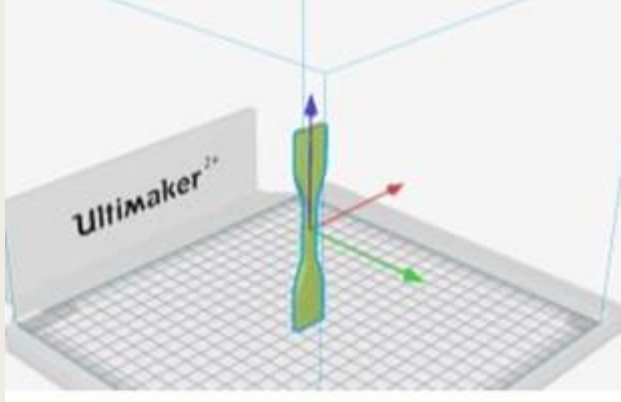
- YZ-direction:
  - *More layers in the axial direction, better properties*
- XY-direction:
  - *Slightly greater layer height, lowering performance*
- ZX-direction:
  - *Weakest, due to anisotropic behavior*



YZ-axis



XY-axis

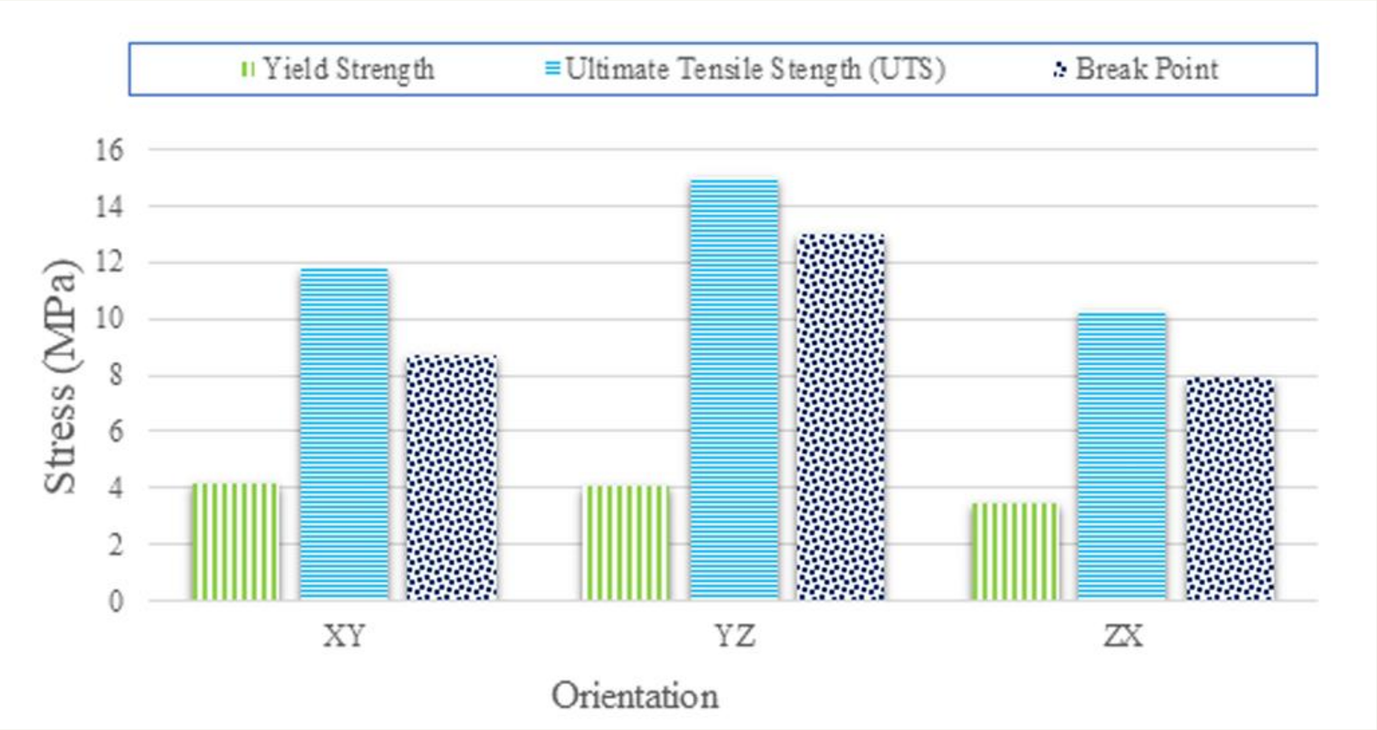


ZX-axis

https://www.researchgate.net/deref/https%3A%2F%2Flink.springer.com%2Fchapter%2F10.1007%2F978-981-19-2890-1_8?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19

4.1 Orientation – Printing direction

Resulting yield and ultimate tension strength



https://www.researchgate.net/deref/https%3A%2F%2Flink.springer.com%2Fchapter%2F10.1007%2F978-981-19-2890-1_8?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19

Paul Cheron

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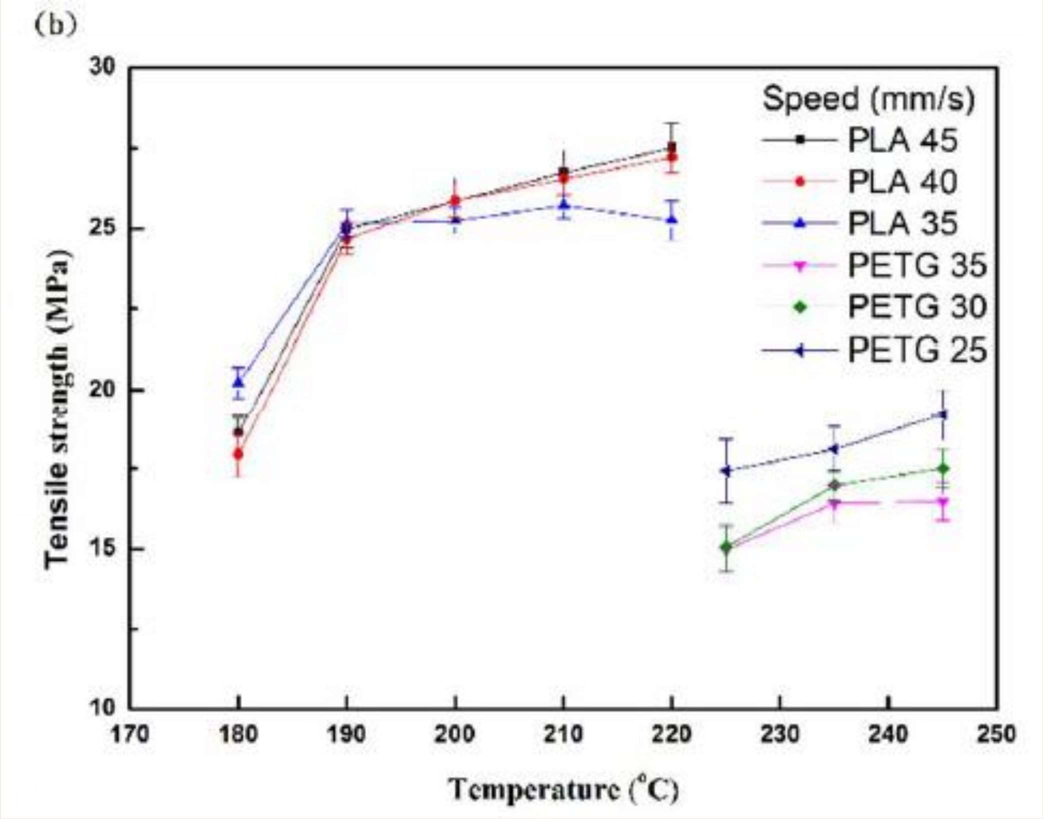
4.2 Printing parameters - Temperature

Effect of higher printing temperature:

- Increased fluidity
- Optimal point
- Usually improves mechanical properties:

In graph:

- Both PLA and PETG samples recorded improved properties



https://doi.org/10.3390/polym13111758

EPFL

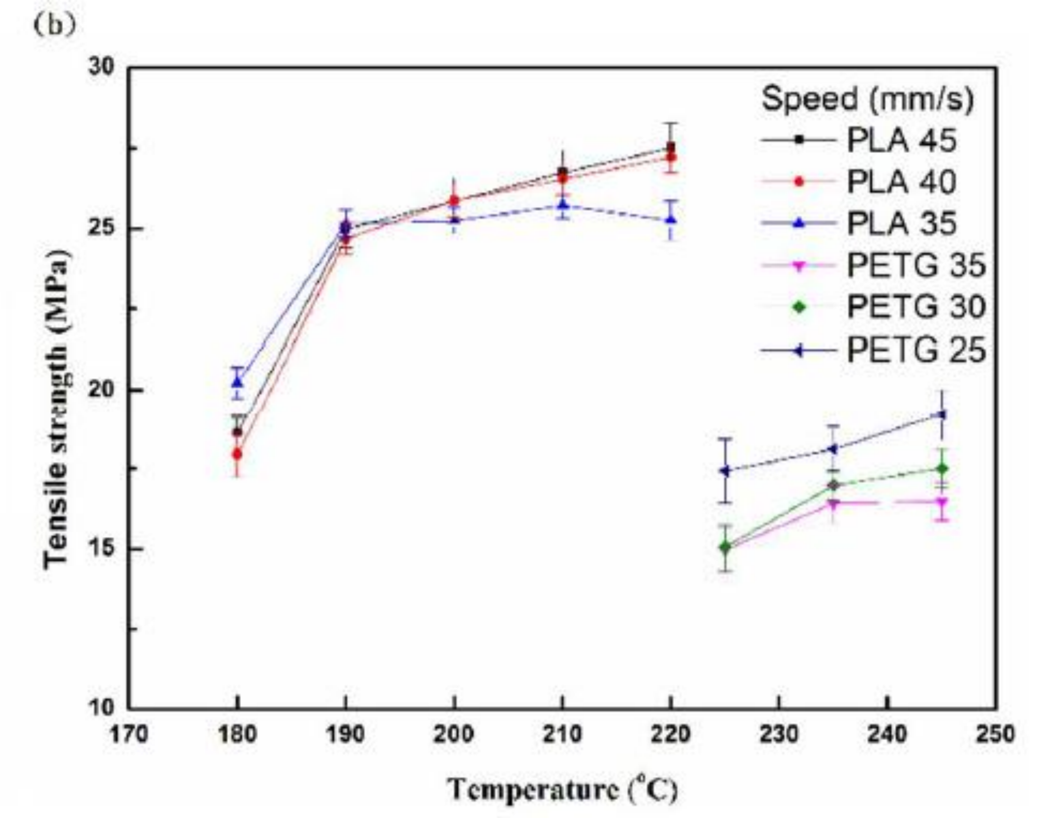
4.2 Printing parameters - Speed

Effect of a faster printing speed:

- Lower quality
  - *External blemishes*
  - *Internal defects*

Dependent on polymer chemistry:

- PLA –> Higher tensile strength
- PETG -> Lower tensile strength



https://doi.org/10.3390/polym13111758

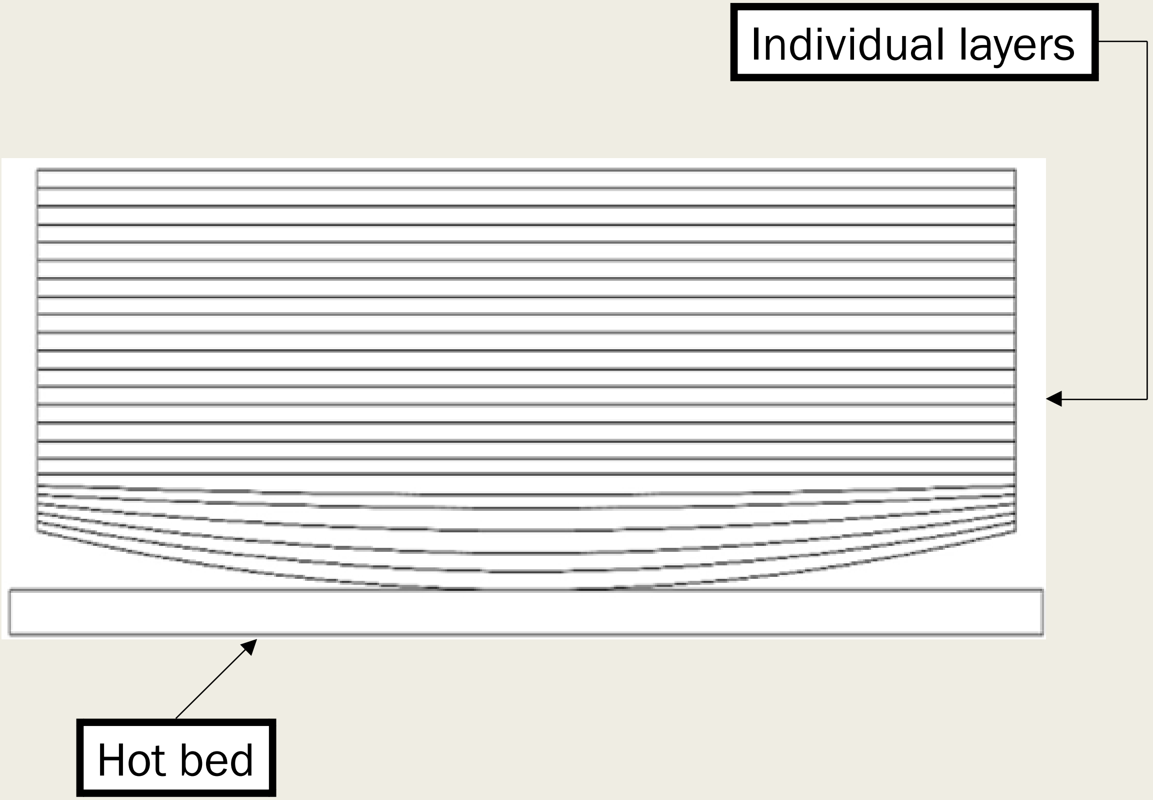
4.3 Warping

Caused by thermal contraction during cooling

- Uneven cooling/heating
- Low quality filament

Solutions:

- Large contact patch
- Fine-tuning of printing parameters



https://www.mdpi.com/1996-1944/14/22/7070

Paul Cheron

4.4 Dimensional accuracy

1. Machine accuracy
   - *Smallest practical nozzle is only 0.1mm*
   - *Stepper motor precision*
   - *Calibration*
2. Printing parameters
   - *Higher printing speed -> higher dimensional deviation*
   - *Smaller layer height -> more precision*

https://www.cnckitchen.com/blog/3d-printing-with-a-01-mm-nozzle

4.5 Preparation of the filament

Effect of moisture in the filament:

- Stringing
- Holes in the part
- Lower visual and strength

Causes:

- Expansion
- Fluidity
- Air holes

https://wiki.bambulab.com/en/filament-acc/filament/dry-filament

Paul Cheron

4.5 Preparation of the filament

Solutions:

- Forced air oven
- Storage and printing conditions

- For ABS: 8h at 75-85°C
- For PLA: 8h at 50°C
- Highly depends on the thermoplastic and on the manufacturer

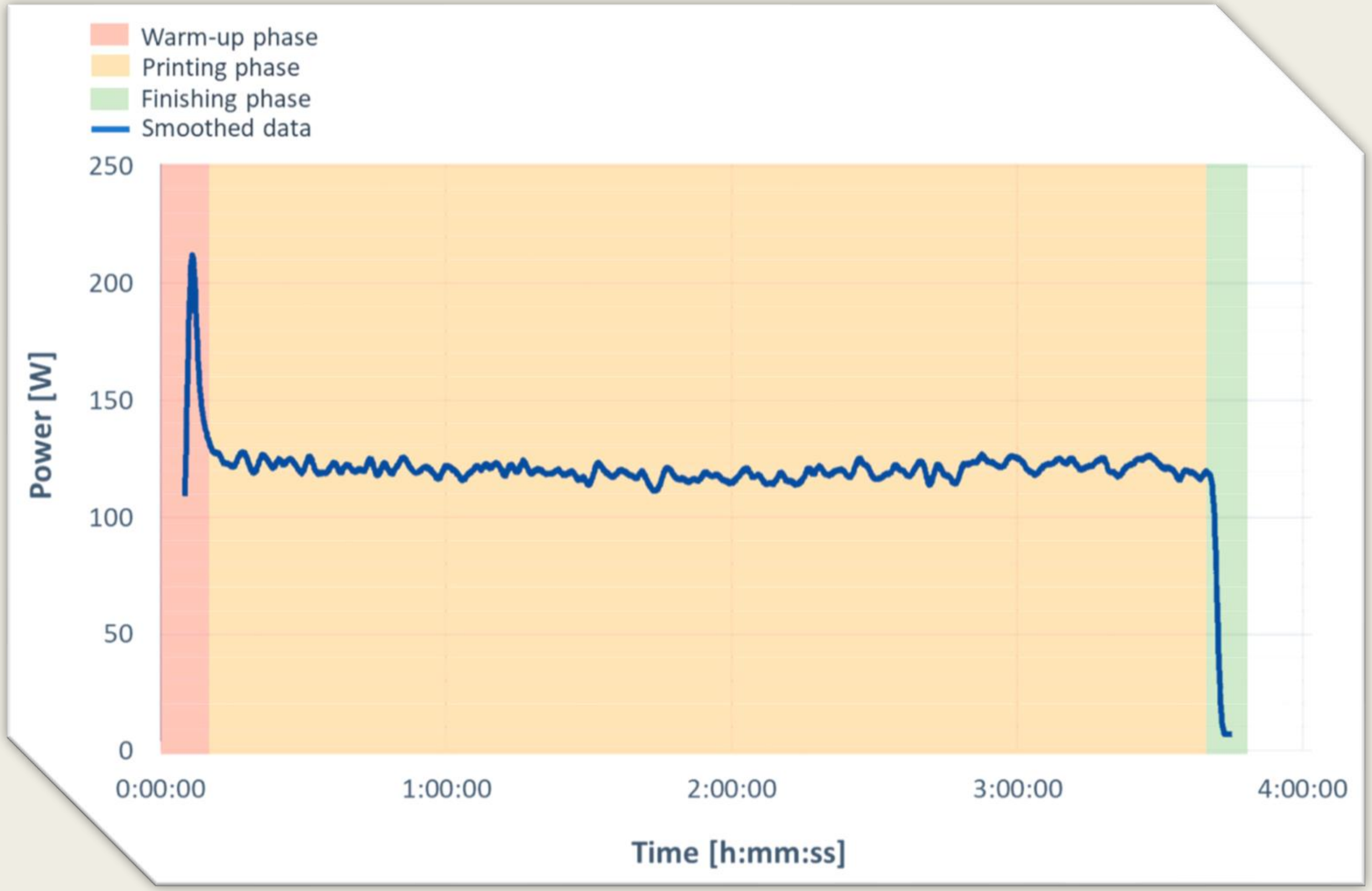
https://wiki.bambulab.com/en/filament-acc/filament/dry-filament

Tristan Jemmely

5.1 Sustainability and eco-design : energy

3 phases :

1. Heating
2. Printing
3. Finishing



https://www.mdpi.com/2071-1050/16/2/615

→ More energy-intensive : printing phase

5.1 Sustainability and eco-design : energy

Reduce 2nd phase :

- Hot-end insulation
- Printer enclosures
- Heated bed insulation

} Combining these three optimizations : 29-38% (average)

Reduce 1st % 3rd phase :

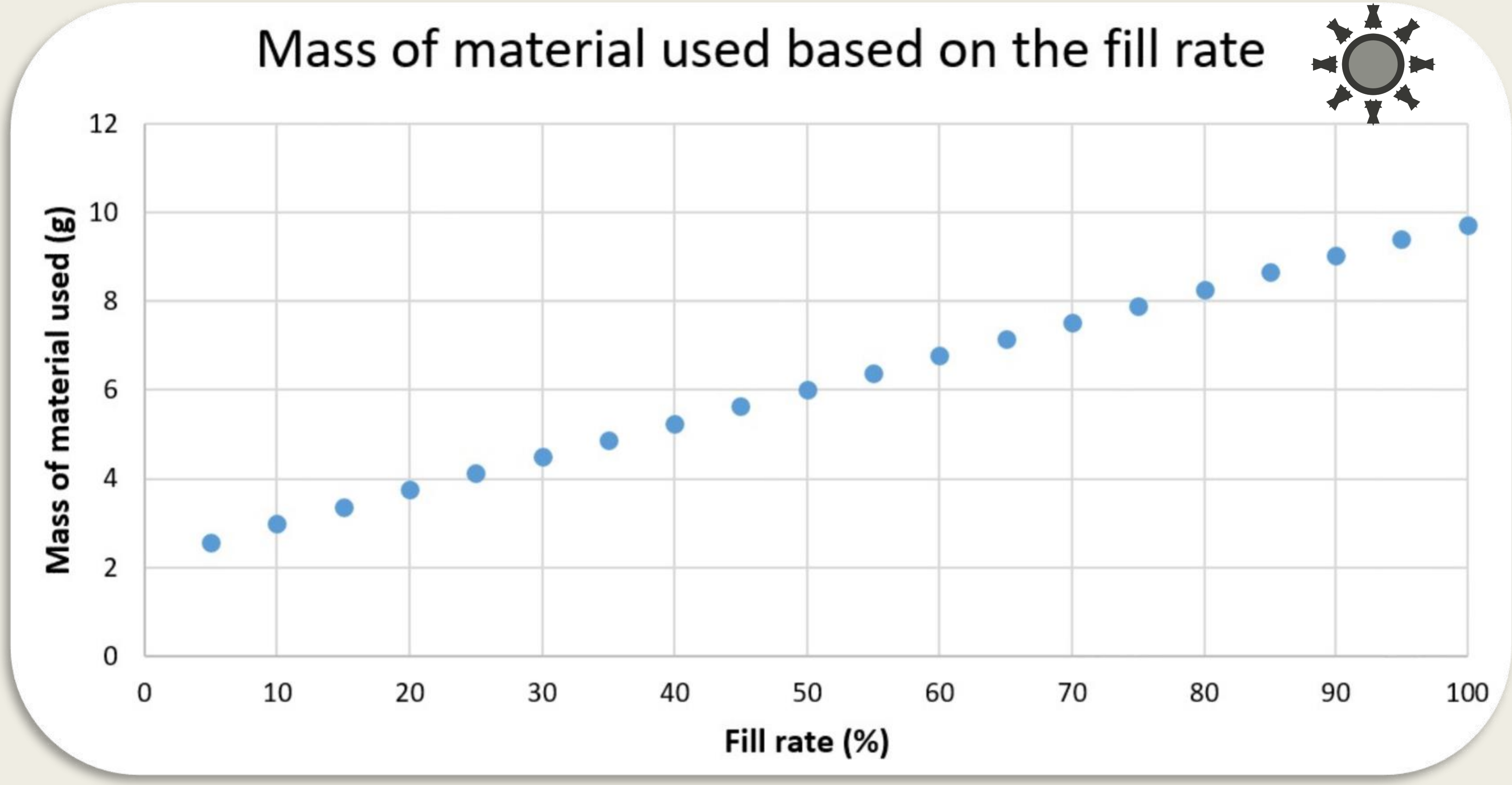
- Printing several parts

Energy consumption (fabrication)

- PLA : 50–55 kWh/kg
- ABS : 60–70kWh/kg
- PETG : 70–80 kWh/kg

→ Reduce matter quantity

5.1 Sustainability and eco-design : matter quantity : fill rate



Reducing the fill rate reduces the amount of material.

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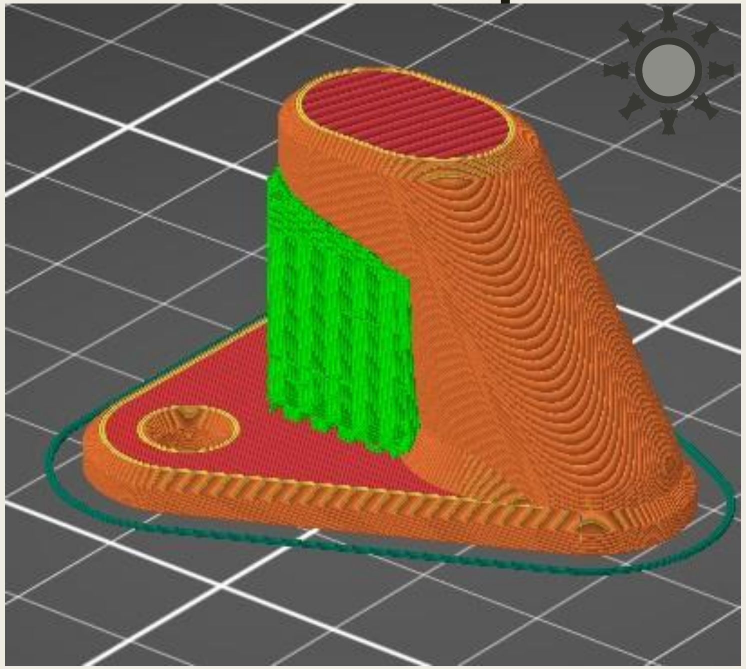
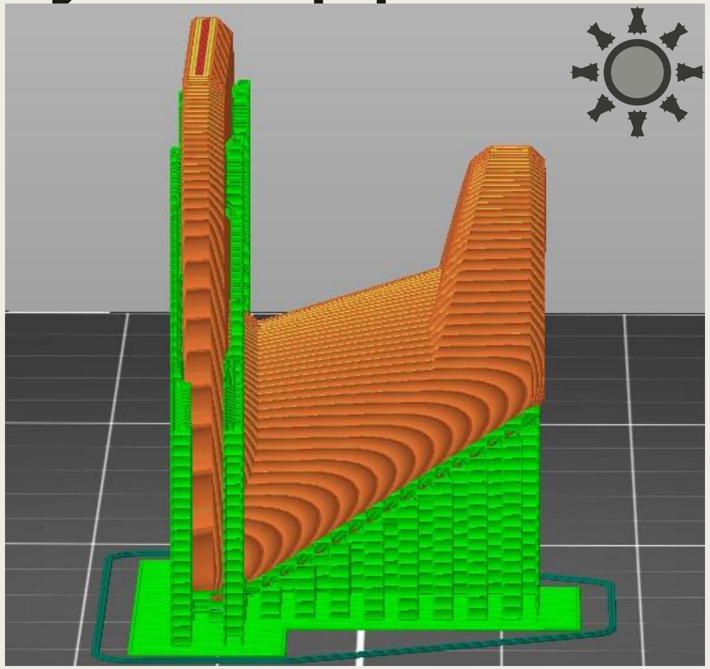
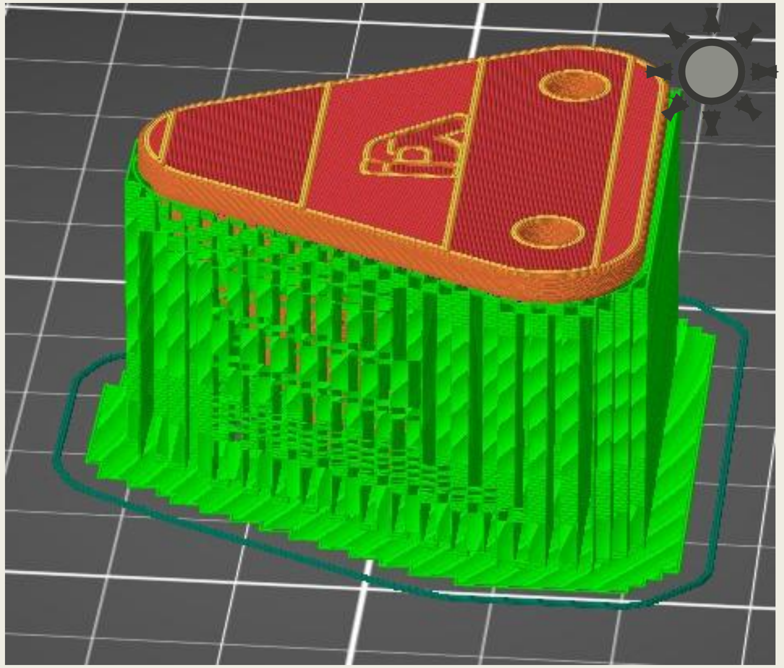
5.1 Sustainability and eco-design : matter quantity : support



Good orientation : 0.66 grams



Poorer orientation : 1.06 grams



Bad orientation : 5.96 grams

Decrease the support : choose the best orientation

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5.1 Sustainability and eco-design : Materials

Impact Categories	Unit	Raw Material Extraction			Manufacturing			Recycling		
		PLA	PETG	ABS	PLA	PETG	ABS	PLA	PETG	ABS
Climate Change	kg CO2-Eq	1.95E-01	2.05E-01	2.39E-01	6.61E-01	8.33E-01	8.33E-01	2.87E+00	2.43E+00	4.55E+00
Fossil Depletion	kg oil-Eq	5.27E-02	1.07E-01	1.12E-01	1.52E-01	1.92E-01	1.92E-01	6.60E-01	5.58E-01	1.05E+00
Fresh Water Ecotoxicity	kg 1,4-DCB-Eq	1.61E-03	1.44E-04	4.31E-04	1.81E-04	2.28E-04	2.28E-04	7.85E-04	6.64E-04	1.24E-03
Human Toxicity	kg 1,4-DCB-Eq	1.49E-02	1.61E-02	3.48E-03	1.73E-02	2.17E-02	2.17E-02	7.49E-02	6.34E-02	1.19E-01
Ozone depletion	kg CFC-11-Eq	1.39E-08	1.07E-08	2.65E-09	1.10E-08	1.38E-08	1.38E-08	4.77E-08	4.04E-08	7.56E-08
Particulate Matter Formulation	kg PM10-Eq	4.05E-04	3.31E-04	2.38E-04	1.98E-03	2.49E-03	2.49E-03	8.59E-03	7.26E-03	1.36E-02
Terrestrial Acidification	kg SO2-Eq	1.28E-03	9.16E-04	6.69E-04	4.11E-03	5.18E-03	5.18E-03	1.78E-02	1.51E-02	2.83E-02
Water Depletion	m3	2.41E-02	5.08E-04	2.15E-04	2.01E-03	2.53E-03	2.53E-03	8.71E-03	7.36E-03	1.38E-02

https://www.sciencedirect.com/science/article/pii/S2212827122002190

Best for environment :

1. PETG — 24-34 $/kg
2. PLA
3. ABS

PLA and ABS: 20-30 $/kg

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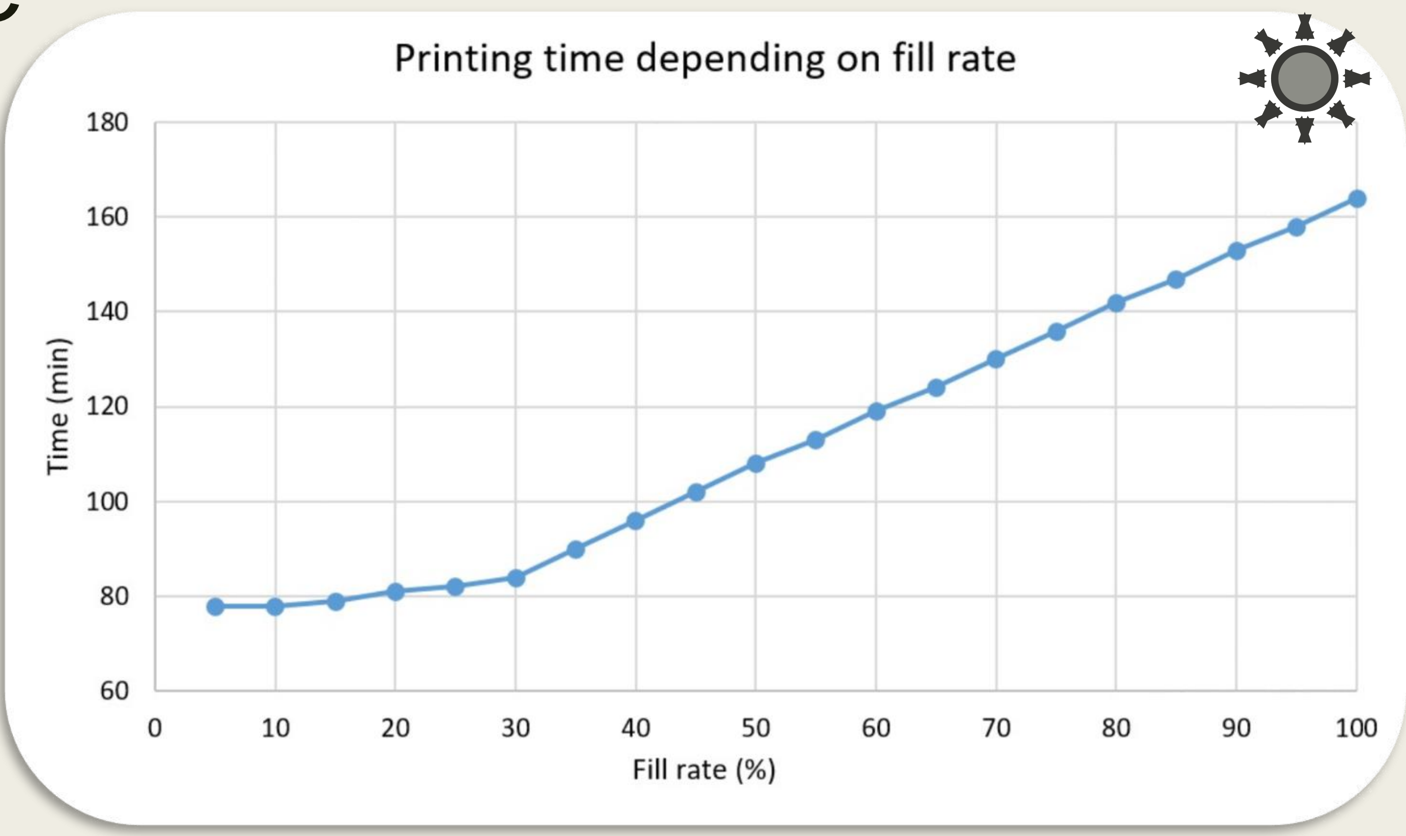
5.2 Optimization of manufacturing time : fill rate



↘ fill rate ↘ print time !

Careful to mechanical properties

5.2 Optimization of manufacturing time : nozzle diameter and layer thickness

$$Layer\ height < 0.75 \cdot diameter\ of\ the\ nozzle$$

Ideally

$$Layer\ height = 0.5 \cdot diameter\ of\ the\ nozzle$$

But

↗ nozzle diameter : ↘ resolution & ↘ surface finish

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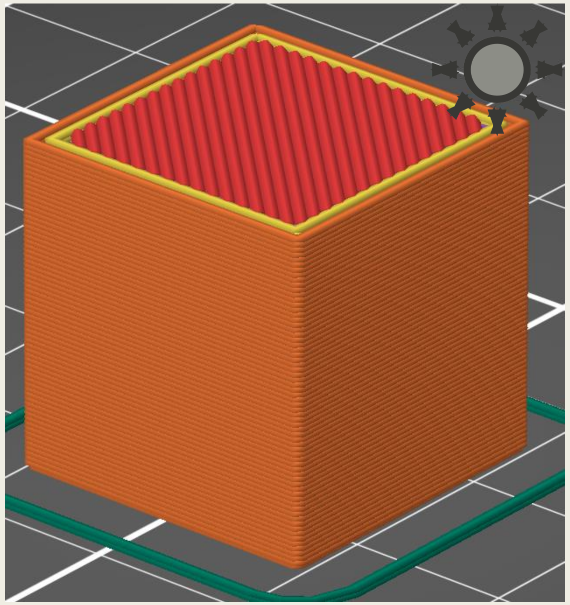
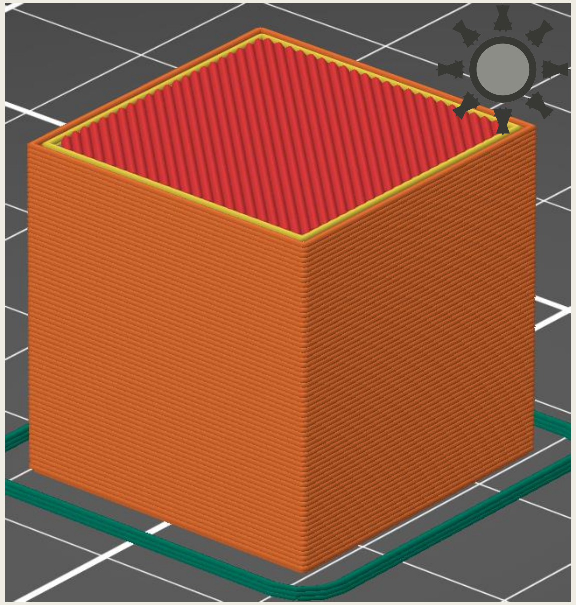
5.2 Optimization of manufacturing time : nozzle diameter and layer thickness



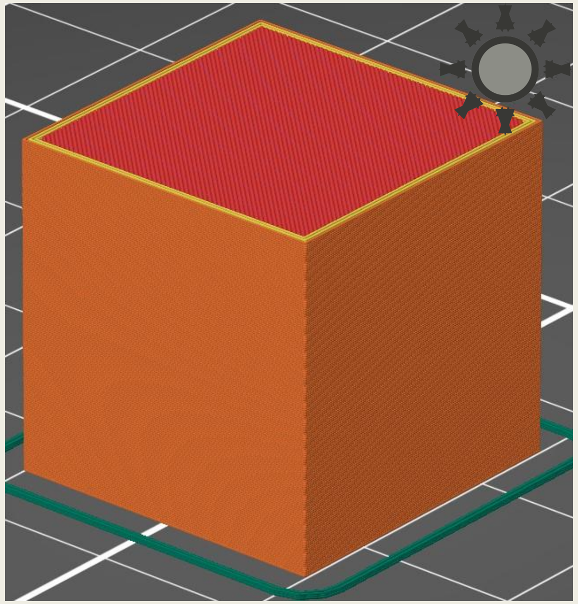
Nozzle diameter of 0.8 mm

Print time 18 minutes



Nozzle diameter of 0.6 mm

Print time 21 minutes



Nozzle diameter of 0.25 mm

Print time 1 hour 21 minutes

↗ nozzle diameter or layer thickness ↘ print time

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5.2 Optimization of manufacturing time : nozzle speed

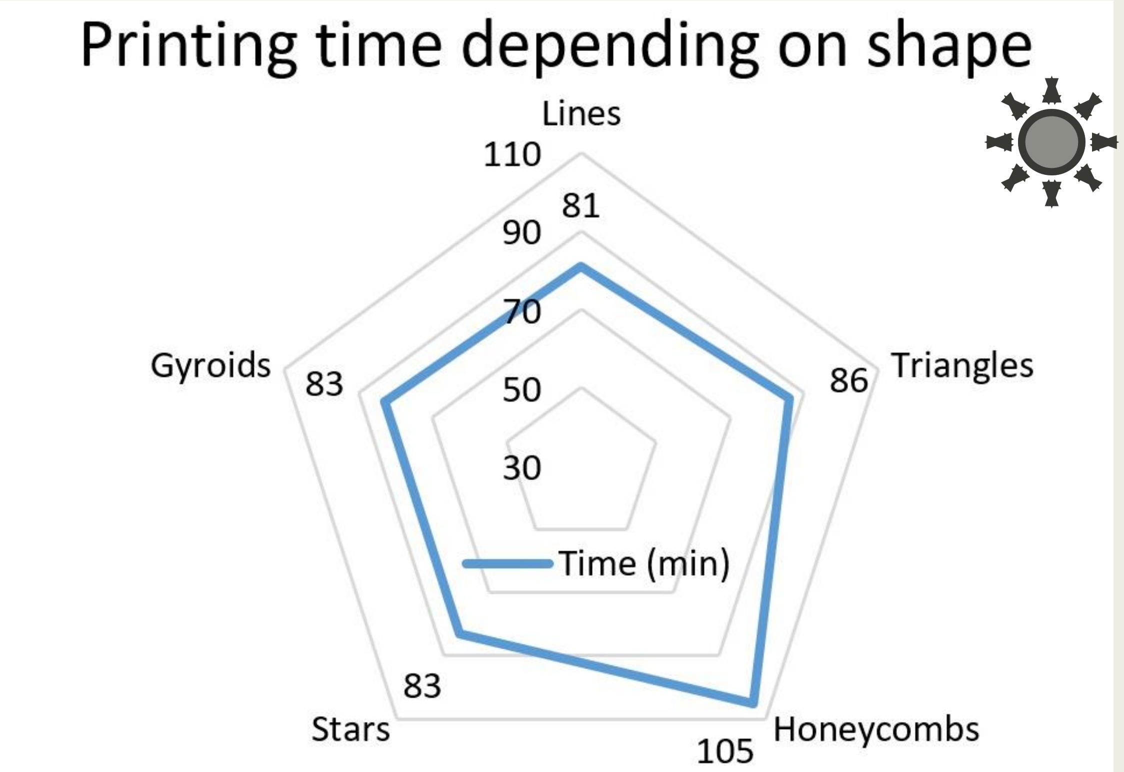
Nozzle speed : 50 to 1000 mm/s

↗ nozzle speed ↘ print time

But

↗ nozzle speed : ↗ temperature, ↘ precision, ↘ mechanical strength

5.2 Optimization of manufacturing time : filling form



Shape influence the printing time

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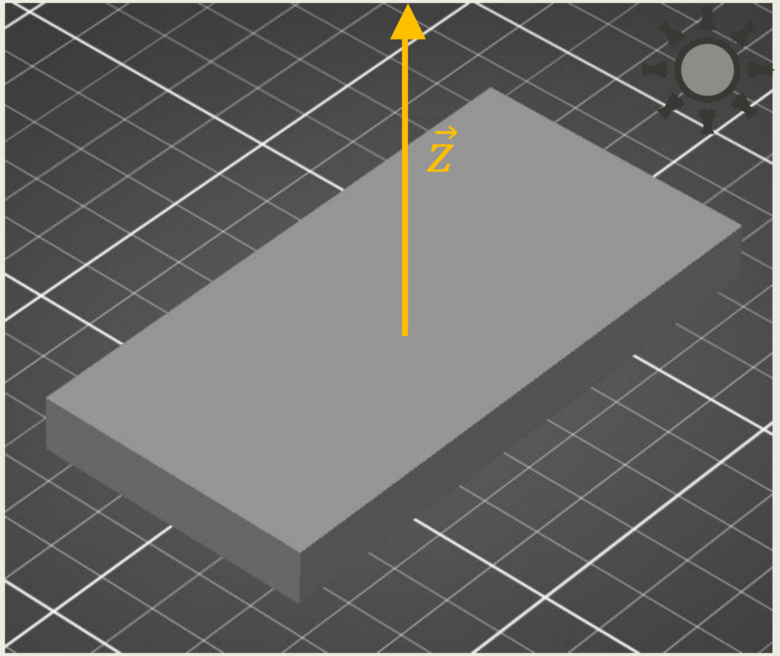
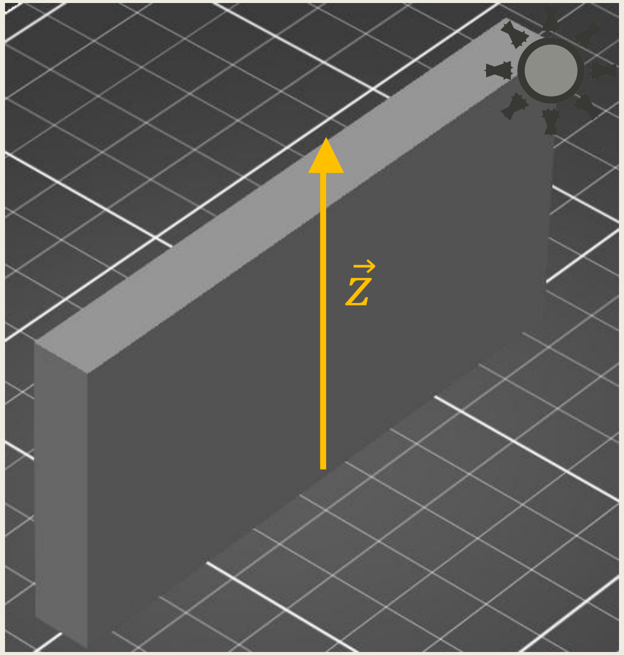
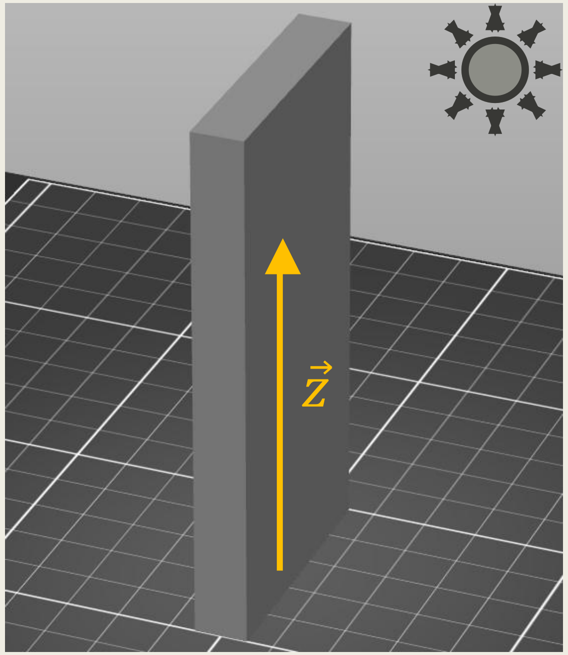
5.2 Optimization of manufacturing time : orientation



Best orientation :
printing time of 5h41



Poorer orientation :
printing time of 7h12



Worst orientation :
printing time of 7h28

Sometimes, orientation influence the printing time

→ rotate the part to its “flattest” position

EPFL

CONCLUSION

Parameter	PLA (Generic)	ABS (Generic)	PETG (Generic)
Filament-dependent settings			
Strength (MPa)	37–70	30–50	50–75
Stiffness (GPa)	3.5–4.0	2.0–2.7	2.0–2.5
Heat Resistance (°C)	50–60	90–100	70–85
Filament-dependent settings			
Nozzle temperature (°C)	220-230	240–250	250–260
Bed temperature (°C)	50–60	100–110	85–90
Printing settings			
Layer height (mm)	0.1–0.3		
Recommended wall thickness (mm)	1.5		
Infill density – rapid prototyping (%)	15-20		
Infill density – functional part (%)	60-80		
Infill pattern for compression	Grid, Cross, Triangle		
Infill pattern for other forces	Cubic, Concentric 3D, Cross 3D		

CONCLUSION

Energy consumption :

- hot-end insulation
- printer enclosures
- heated bed insulation

Amount of material :

- Orientation (for support)
- Fill rate

Parameter	Mechanical strength	Print time	Surface finish	Accuracy
Fill rate ↗	↗	↗	-	-
Nozzle speed ↗	↘	↘	↘	↘
Nozzle diameter ↘	↘	↗	↗	↗
Filling form change	It depends	It depends	-	-