ECE 478-578
Intelligent Robotics I

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3D Printing

Cura

Powered by Ultimaker

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Overview

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Today's Agenda

- Additive Manufacturing
- History of 3D Printing
- 3D Printing File Formats
- 3D Printing Process
- Where are they used?
- 3D Printing Hubs and Centers
- Different types of 3D Printing Materials
- 3D Printing Terms
- Different Types of 3D Printing Technologies
- 3D Designing for 3D Printing
- Free 3D Design for 3D Printing
- How to use Cura?

What is 3D Printing?

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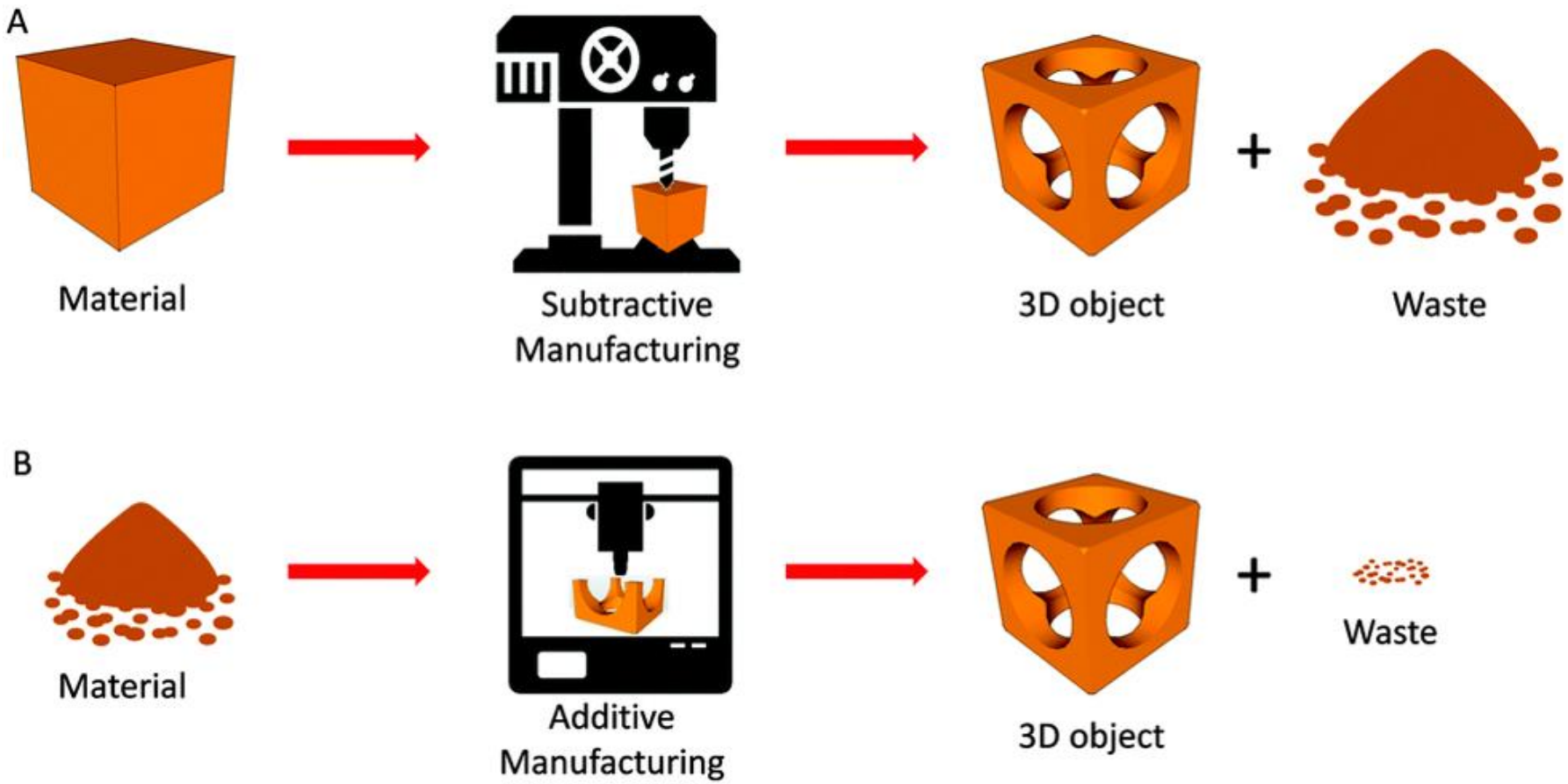
What is 3D Printing?

- It is an additive manufacturing method
- Simply it is using a computer controlled tool to build a physical object
- CAD (Computer Aided Design) software is used to create a digital design and CAM (Computer Aided Manufacturing) device such as 3D printer is used to print the design in 3D
- It is an over 30 year old technology

Subtractive vs Additive Manufacturing



Source

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History of 3D Printing

- First started in 1980's
- Charles Hull invented first stereolithography machine
- It used laser to cure resin
- It was very high cost
- Adrian Bowyer started the RepRap Project – Low Cost Printers
- Open Source drove innovation
- It required so much technical knowledge
- New companies tried to make it more user friendly
  - ex: Makerbot, Ultimaker
- Today there are so many faster, bigger, more reliable options

3D Printing Process

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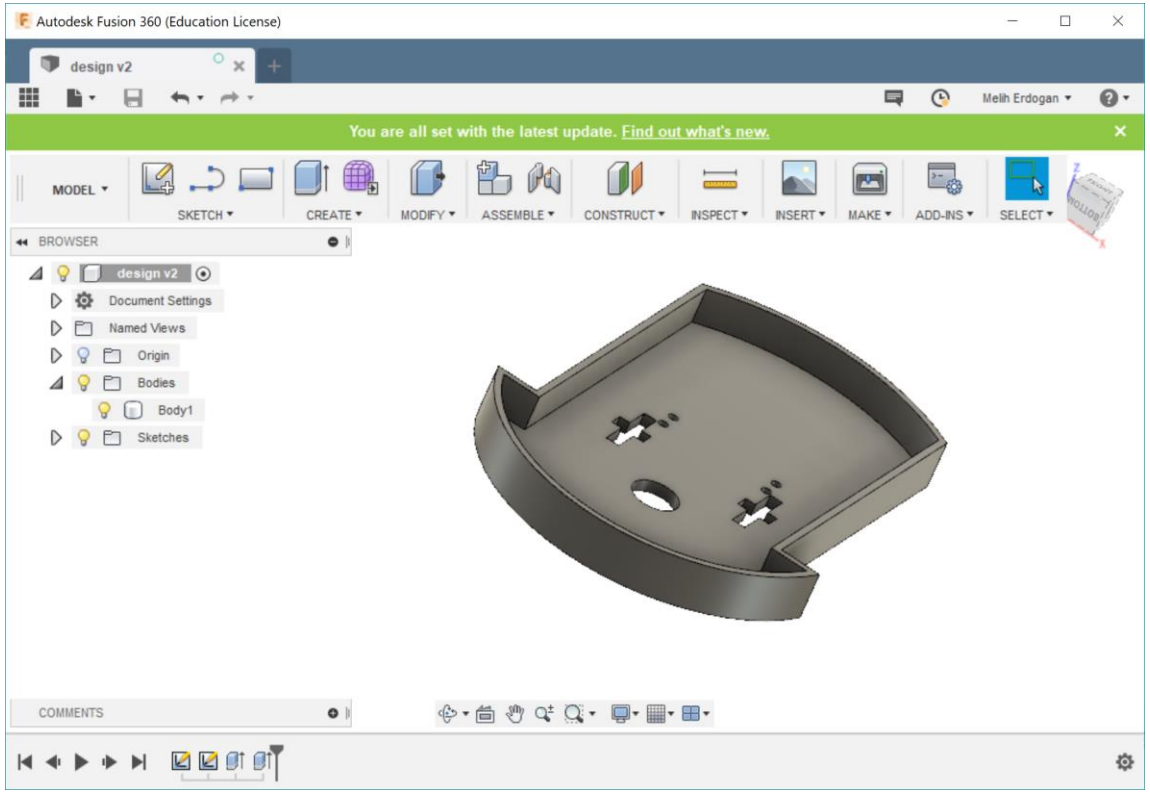
CAD (Computer Aided Design)

- It is used to create a 3D content
- In this course we will use Fusion 360.



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STL

- STL is the most common 3D printing format
- It stands for STereoLithography
- It is consist of mash data
- It is collection of faces that forms a surface
- It has no color information

Other 3D Printing File Formats

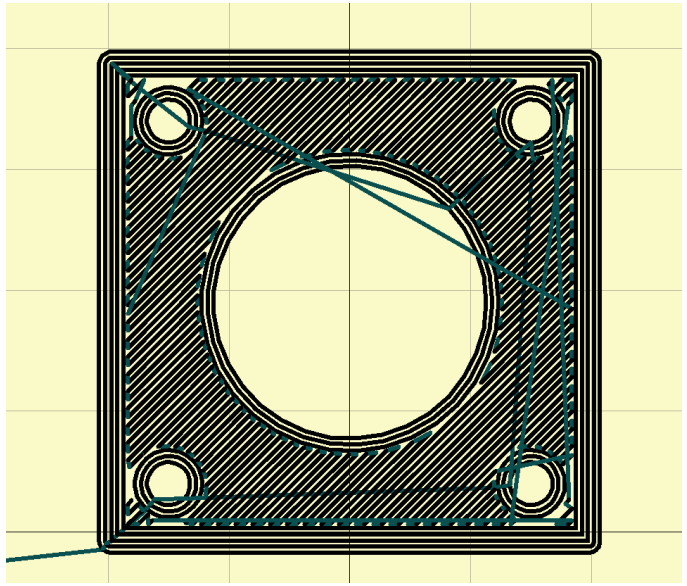
- If you want full color in your prints you should prefer X3D, WRL, VRML, PLY
- OBJ and DAE are some other 3D printing file formats.
- They are easy to convert to STL

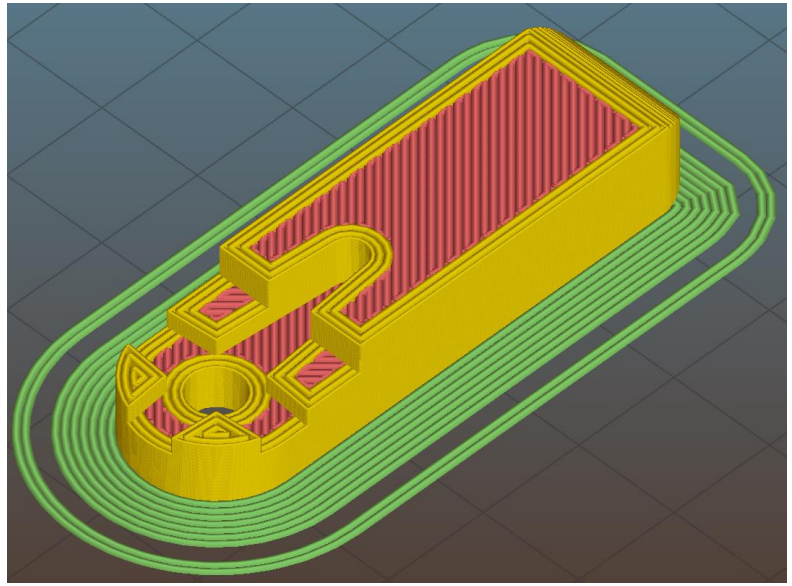
CAM (Computer Aided Manufacturing)

- Any types of machine that takes geometric design data and generates instruction for the machine to follow.
- Computer program called slicer is used in this process
- It converts 3D data in 2D slices.

Slicer

- Lines show the path that the 3D printer will follow.
- STL file is saved as G Code file
- G Code is a long list of instructions telling machine what to do
- You may not notice this step with some 3D printing software





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G Code - Example

```
M107
M104 S200 ; set temperature
G28 ; home all axes
G1 Z5 F5000 ; lift nozzle
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
G92 E0
G1 Z0.400 F7800.000
G1 X107.600 Y107.600
G1 F1800.000 E1.00000
G1 X88.400 Y107.600 F600.000 E1.79925
G1 X88.400 Y88.400 E2.59850
G1 X107.600 Y88.400 E3.39775
G1 X107.600 Y107.490 E4.19240
G1 X107.600 Y107.600 E4.19700
M106 S255
G1 F1800.000 E3.19700
G92 E0
```

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G Code - Parameters

Letter	Meaning
A	A axis of machine
B	B axis of machine
C	C axis of machine
D	Tool radius compensation number
F	Feed rate
G	General function (See table Modal Groups)
H	Tool length offset index
I	X offset for arcs and G87 canned cycles
J	Y offset for arcs and G87 canned cycles
K	Z offset for arcs and G87 canned cycles.
	Spindle-Motion Ratio for G33 synchronized movements.
L	generic parameter word for G10, M66 and others
M	Miscellaneous function (See table Modal Groups)
N	Line number
P	Dwell time in canned cycles and with G4.
	Key used with G10.
Q	Feed increment in G73, G83 canned cycles
R	Arc radius or canned cycle plane
S	Spindle speed
T	Tool selection
U	U axis of machine
V	V axis of machine
W	W axis of machine
X	X axis of machine
Y	Y axis of machine
Z	Z axis of machine

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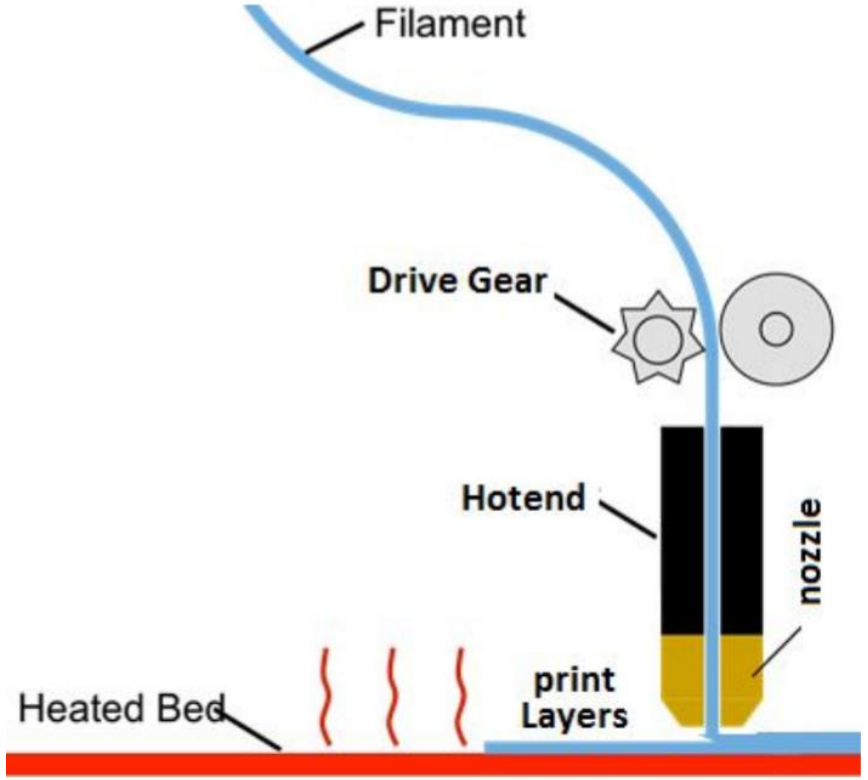
FDM – Fused Deposition Modeling

- In other words, it is a hot glue gun attached to a 3D robot.
- It pushes the filament through a hot nozzle and prints one layer at a time.



Advantages of 3D Printing

- It is originated as a rapid prototyping technology
- It can be used for finished products as well
- It is cheap comparing the injection molding method
- Molding is good if you need 1000s of parts
- 3D printing could be a better choice if we only need a few parts
- More complex designs can be printed with 3D printers
- If you can design it you can print it

Where is it used?

Jet Engines and Space Station

GE fired up world's largest commercial jet engine using 3D-printed metal parts

By Michael J. Coren · April 25, 2016

Stronger, sleeker, and partly 3D-printed.

General Electric this month started testing the largest jet engine ever built, at its wooded test site near Peebles, Ohio. The new engine, the GE9X, is more efficient, more powerful, and more heat resistant than its predecessors. It's also made with 3D-printed parts.

3-D Printing

Dec. 22, 2014

Space Station 3-D Printer Builds Ratchet Wrench To Complete First Phase Of Operations

The International Space Station's 3-D printer completed the first phase of a NASA technology demonstration by printing a tool with a design file transmitted from the ground to the printer. The tool was a ratchet wrench.

"For the printer's final test in this phase of operations, NASA wanted to validate the process for printing on demand, which will be critical on longer journeys to Mars," explained Niki Werkheiser, the space station 3-D printer program manager at NASA's Marshall Space Flight Center in Huntsville, Alabama. "In less than a week, the ratchet was designed, approved by safety and other NASA reviewers, and the file was sent to space where the printer made the wrench in four hours."

This ratchet wrench will be returned to the ground for analysis and testing, along with the other parts printed in space. The 4.48-inch-long by 1.29-inch-wide wrench was designed by Noah Paul-Gin, an engineer at Made In Space Inc., a northern California company that NASA contracted to design, build and operate the printer. The 3-D printer built the wrench by additive manufacturing, depositing 104 layers of plastic.

The ratchet wrench was designed by Noah Paul-Gin, an engineer at Made In Space Inc., a northern California company that NASA contracted to design, build and operate the printer. Paul-Gin created a 3-D model of the ratchet and made several wrenches, such as the one shown here on an identical printer.
Credits: Made In Space

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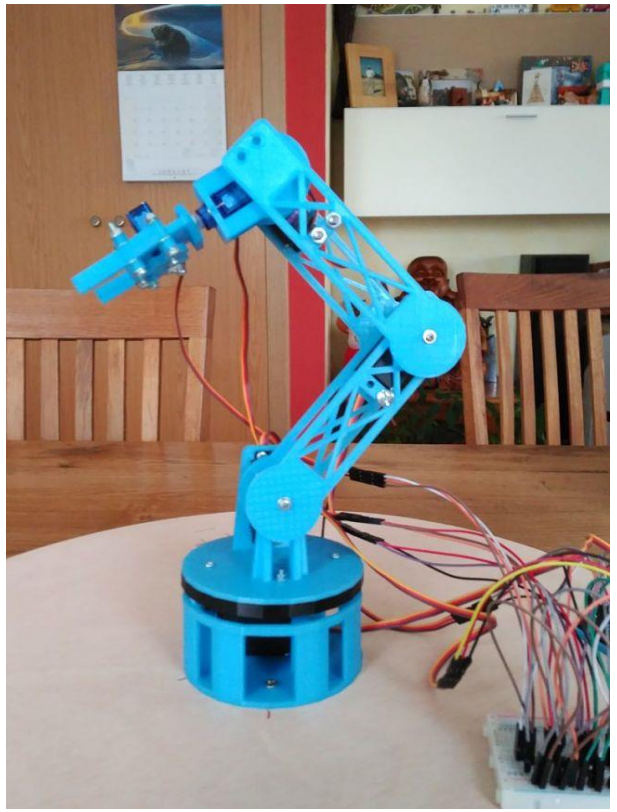
Robots



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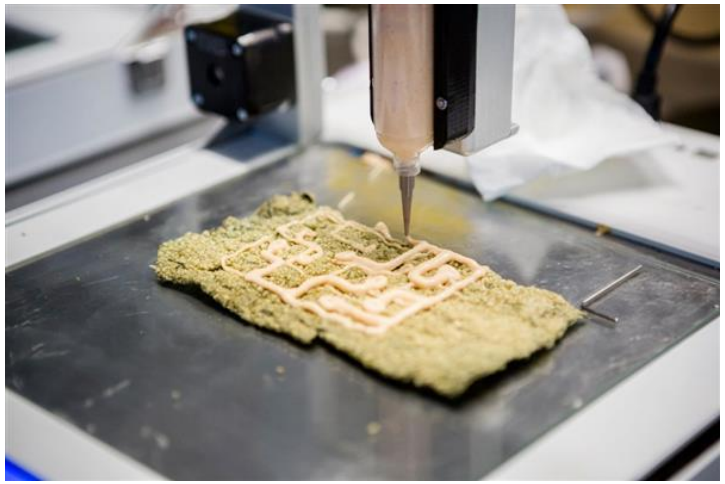
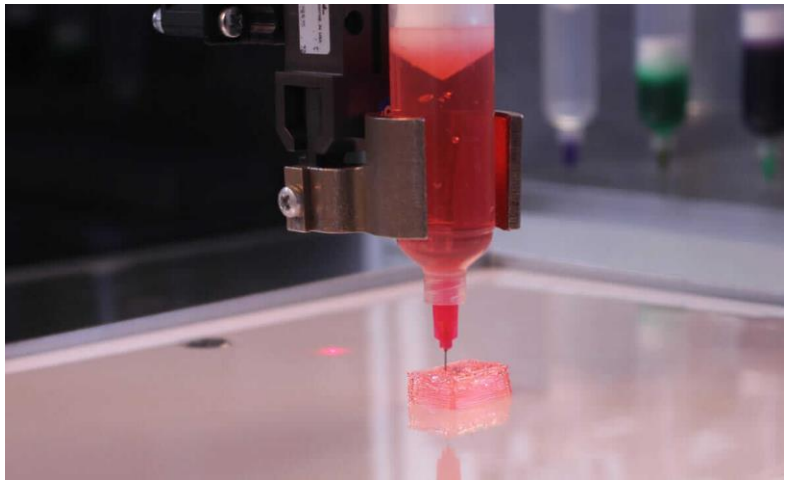
Other



Food



Tissue

Construction

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3D Printers

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Desktop 3D Printers

- Good for hobbyists, schools, and individuals
- Can be useful for some businesses
- Usually good quality and detail
- $150 - $4,000

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Commercial 3D Printers

- Very High Quality
- Fine-Details
- Smooth Surface Finishes
- Reliable
- Consistent
- Professional Service and Help
- High end products start from $200,000
- It can cost over $800,000

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PJP – Plastic Jet Printing

- Plastic Jet Printing is a 3D printing technology that uses only plastic to create 3D printed parts.
- It’s similar to Fused Deposition Modeling (FDM), but the printers are made for consumers rather than industrial use.
- Usually small size
- Low quality prints
- Cheap 3D Printers

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3D Printing Centers

- If you don’t have a 3D printer or need to print so many parts in a very short time, you can use the 3D printing hubs and centers.
- 3Dhubs.com
- makexyz.com
- Staples
- UPS etc.

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3D Printing Materials

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3D Printing Materials

- PLA – Bio-plastic
- ABS - Plastic
- Nylon -
- Rubber - Elastic
- Polystyrene – High Impact
- Copper - Conductive

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3D Printing Terms

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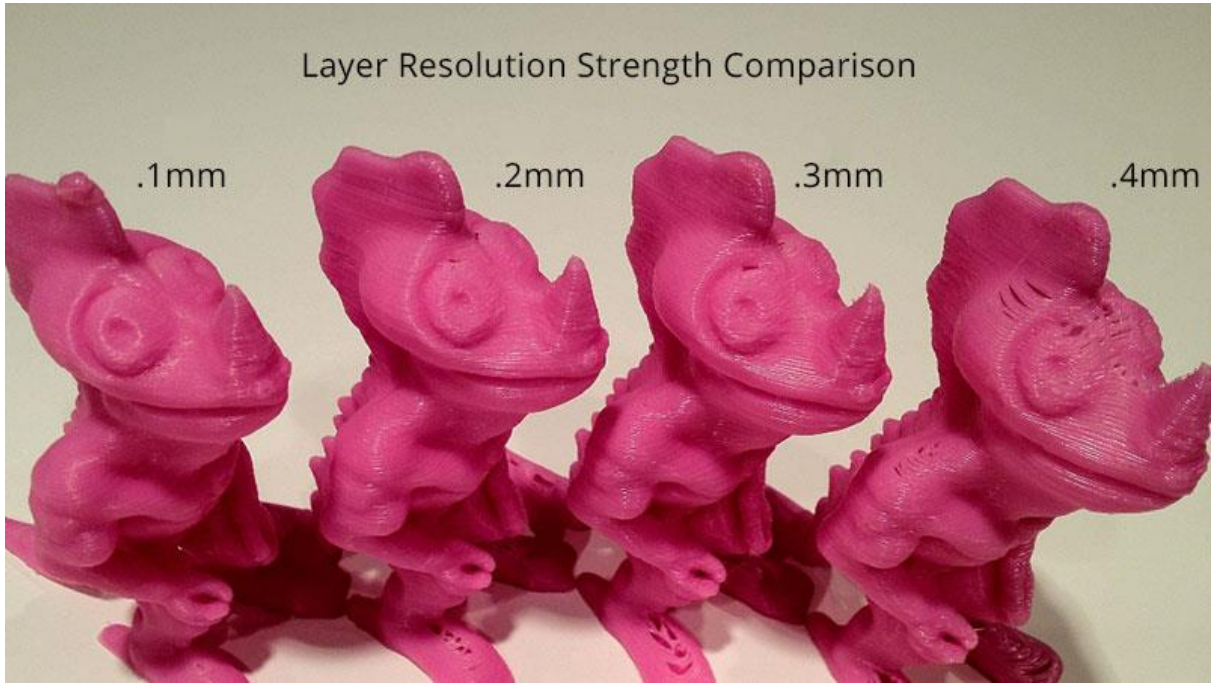
3D Printing Terms

- Layer Resolution
- Wall Thickness
- Infill Density and Patterns
- Travel Speed and Retraction
- Printing Speed
- Filament Thickness
- Extruder
- Extruder Temperature
- Bed Temperature
- Home Position
- Bed Leveling and Z-axis Hight
- Support Material
- Raft, Brim, Skirt

Layer Resolution - Quality

- Measured in Microns or Millimeters
- Describes the thickness of one layer of the 3D print.



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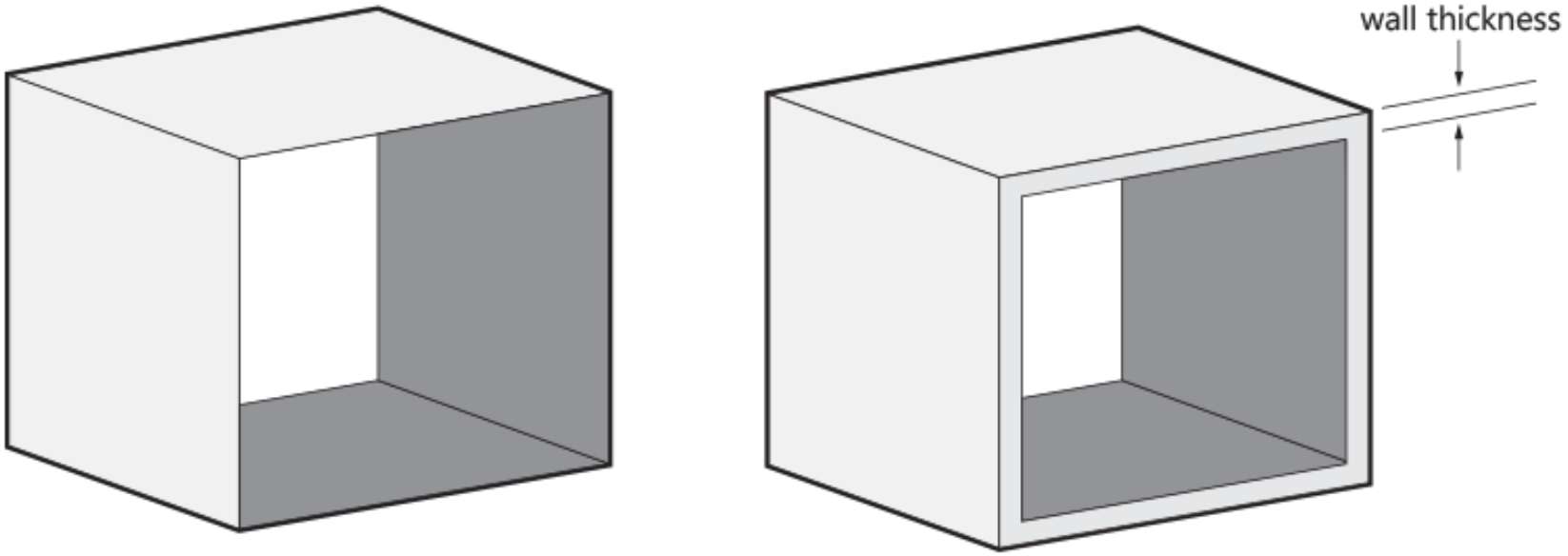
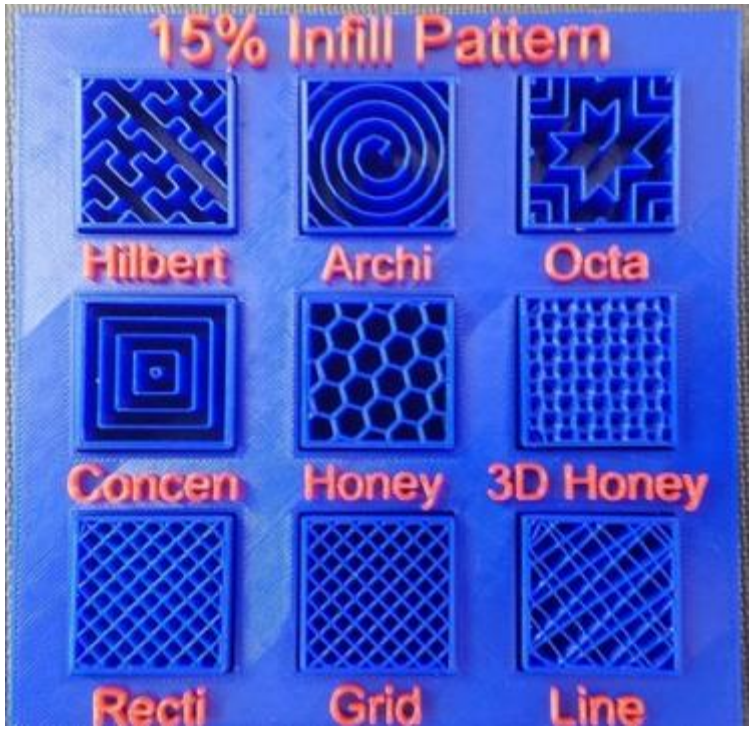
Wall Thickness

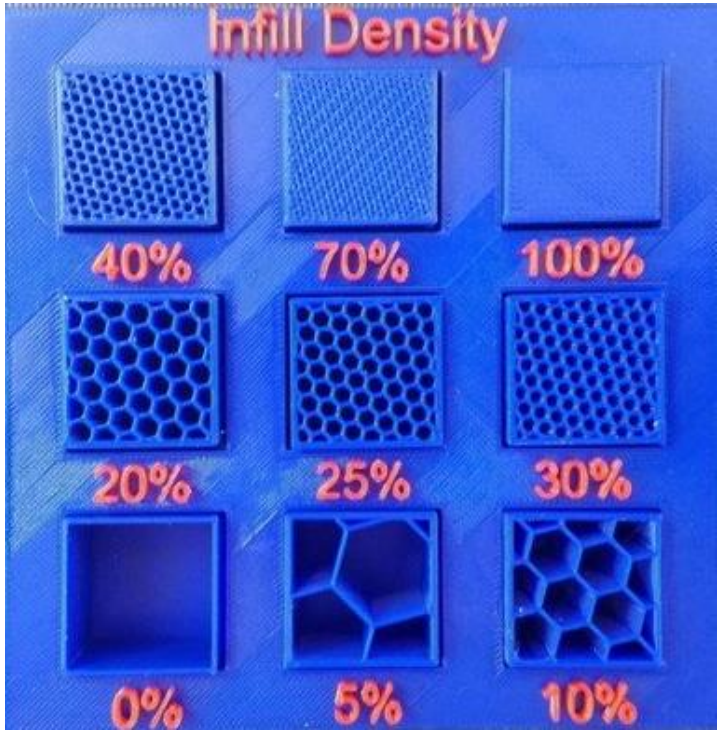
- The distance between two surfaces of a wall in a design.



Infill Density and Patterns

- Infill is a structure used to take up space inside a 3D print.
- Common infill density is 20%-25%.
- There are many different patterns you can use.
- They all have different advantages and disadvantages.
- In most cases, it doesn't matter which pattern you choose.





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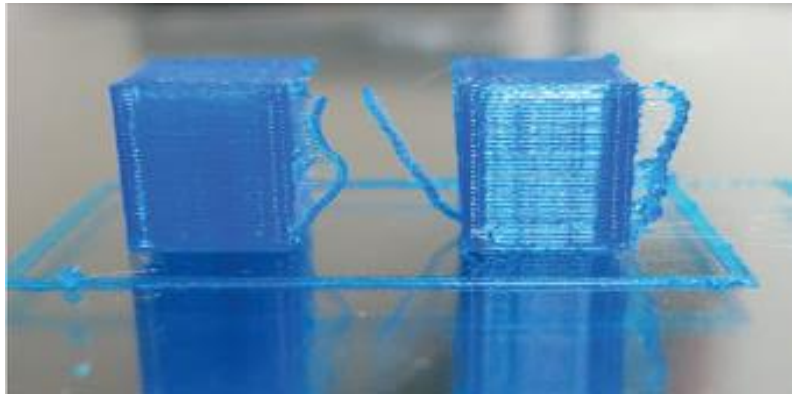
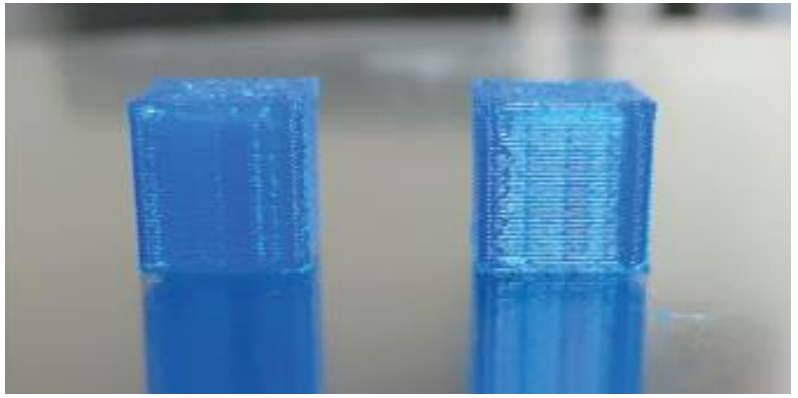
Travel Speed and Retraction

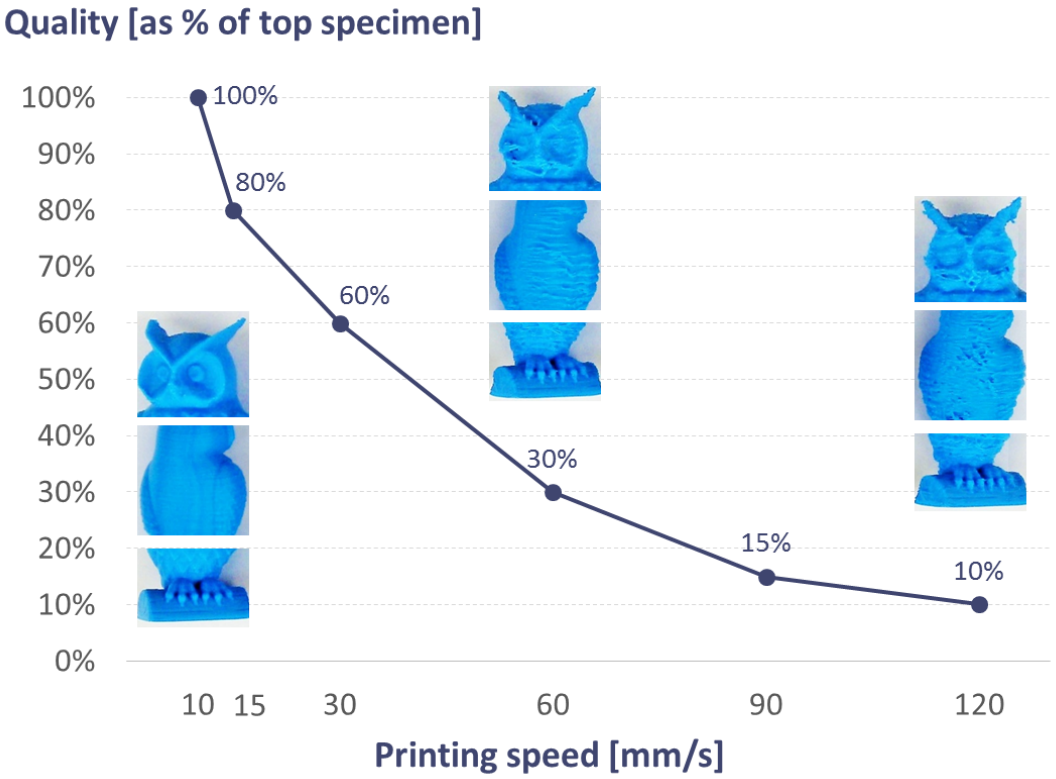
- Travel speed is the speed of the 3d printing head while it is not printing.
- The purpose of retraction is simply to relieve pressure from the melt zone so that filament isn’t being forced through the nozzle during non-print moves.
- It can be different for each 3d printer. You should use the default value and then experiment different values if the print quality is not good..





Printing Speed

- The speed of the 3D printing head while it is printing.
- It will affect the print quality



Link

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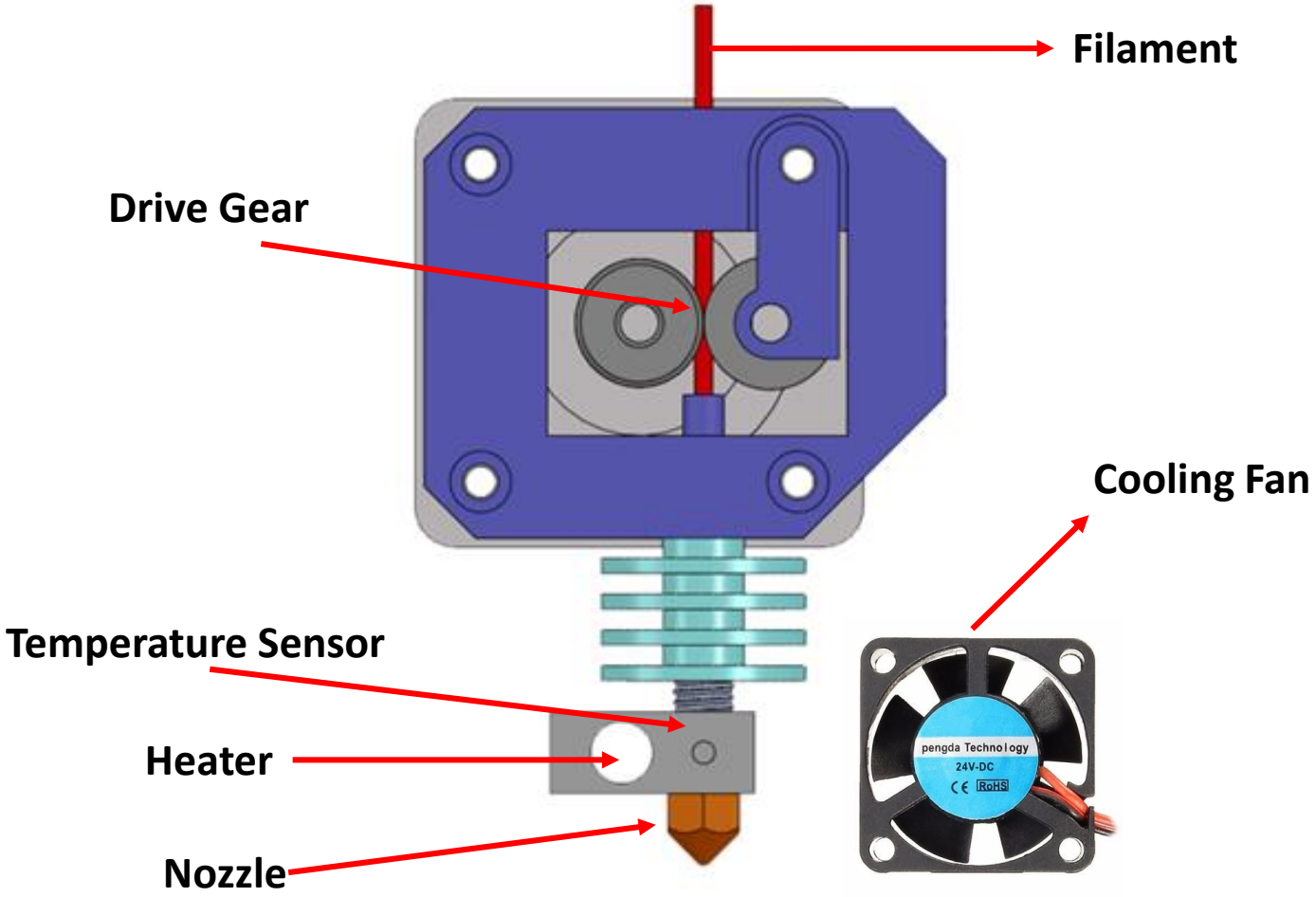
Filament Thickness

- When 3D printers started getting popular, plastic welding filament (3mm) was the commonly available
- Filaments are usually find in two different thicknesses.
  - 3.00 mm
  - 1.75 mm
- Hard to tell which is a better option
- You need to make sure what filament thickness your printer uses

Extruder – How does it work?



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Extruder and Bed Temperature

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Extruder Temperature

- Temperature of the 3D printing head.
- Extruder temperature for different type of 3d printing filaments
  - PLA 210 C – 240C
  - ABS 230C – 240C
  - PVA 190C – 220C
  - Nylon 240C – 280C

https://filaments.ca/pages/temperature-guide

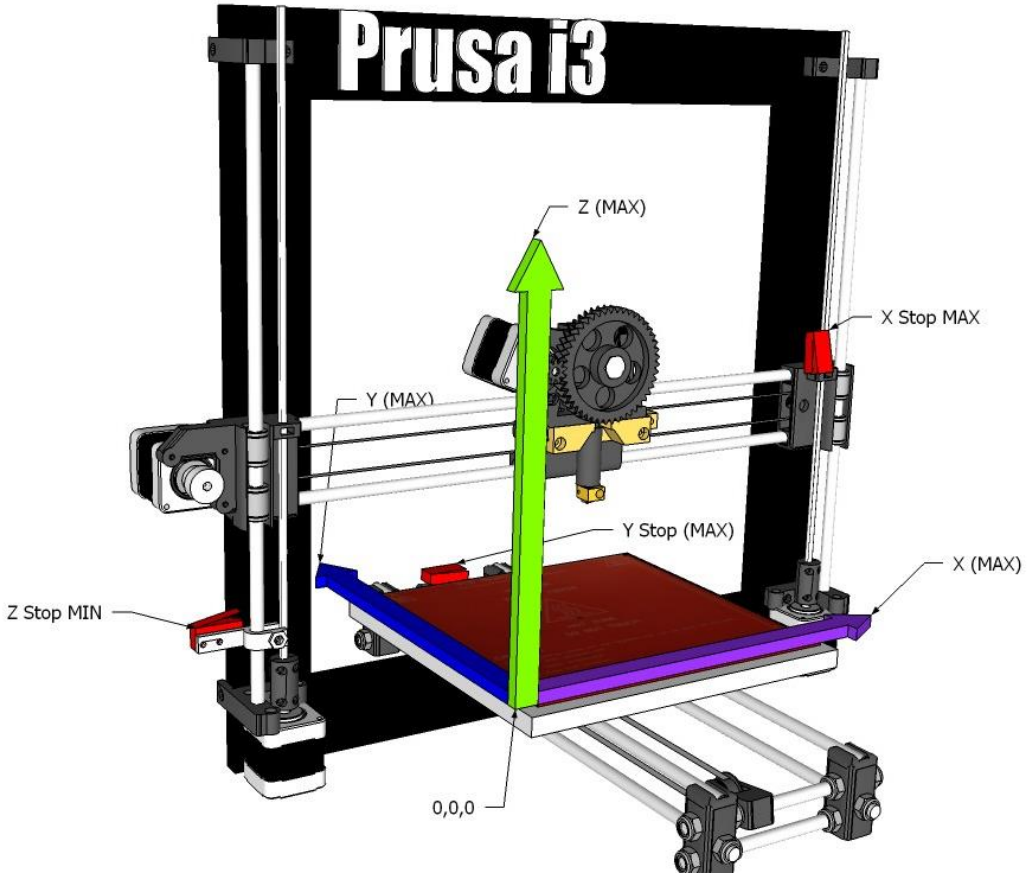
Bed Temperature

In order to make 3D prints stick on a surface while it is printing, 3D printing bed needs to be heated.

- 70C is recommended for PLA
- 110C is recommended for ABS

Home Position

- For 3D printers to understand where its print head is, it needs a reference point, called the home position.
- To find the home position a sensor or switch located at the ends of each axis is used.
- The switch is triggered when the printer's head has reached home position for that axis.



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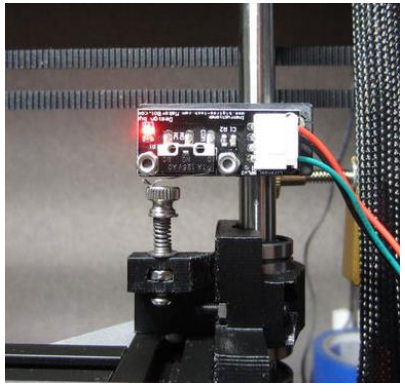
Bed Leveling and Z Axis Hight

- 3D Printing bed need to be perfectly leveled for a successful print.
- Some printers come with auto bed leveling and z axis feature.
- Most printers have screws under their 3D printing bed to adjust the bed level and also the Z axis.



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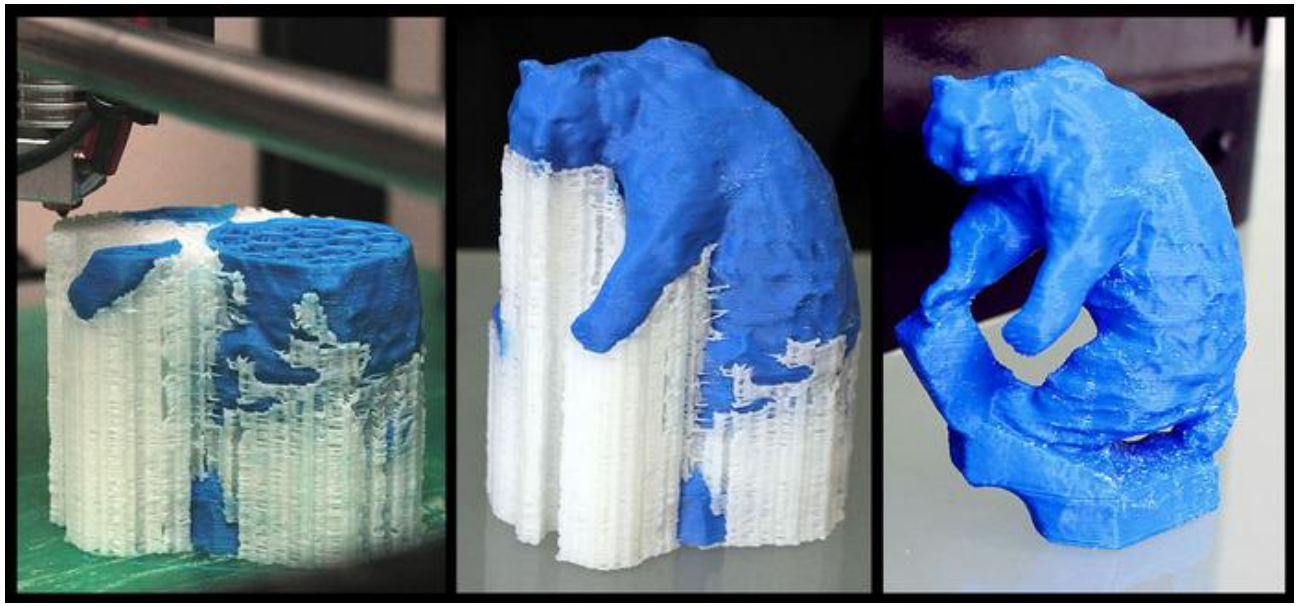
Support Material

- 3D printers can not print in mid-air
- Objects with overhangs over 45 degrees require support material



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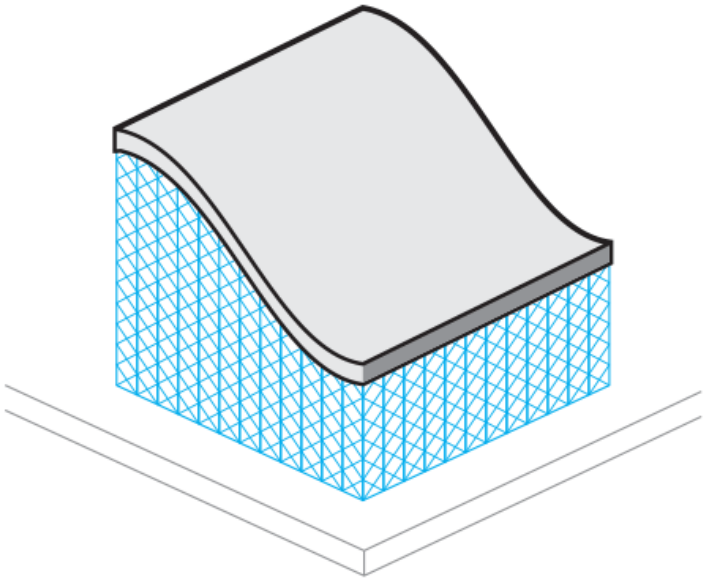
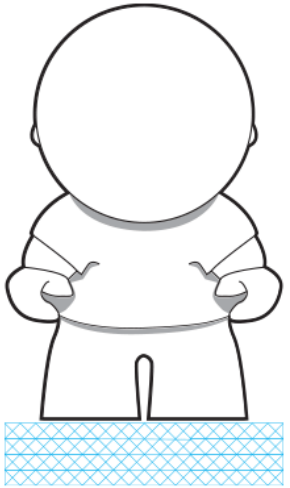
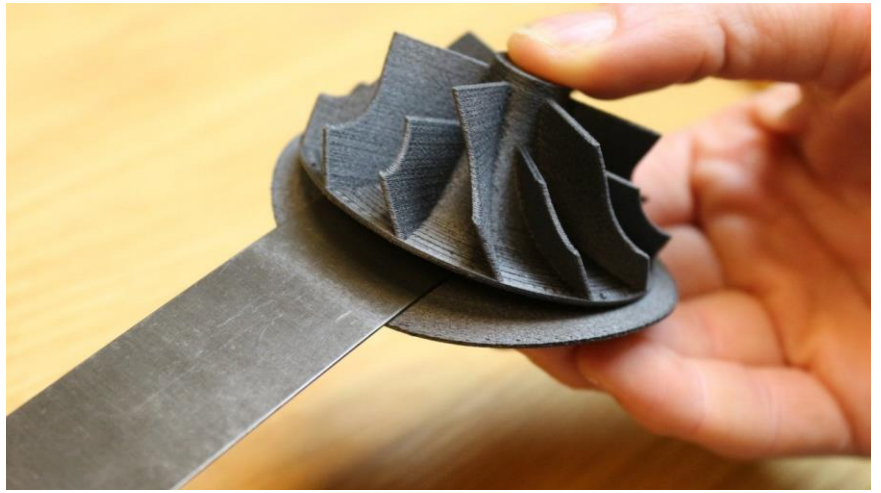


Raft

- Raft is located underneath of the part.
- The design will be 3D printed on top of this raft instead of directly on the printing bed.
- Better adhesion (preferred for ABS)
- Sometimes difficult to remove and makes the bottom bed surface finish





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Brim

- A skirt that is attached of the edges of the design.
- Number of outlines can be increased.
- It will help with bed adhesion and hold down the edges of the part on the bed.

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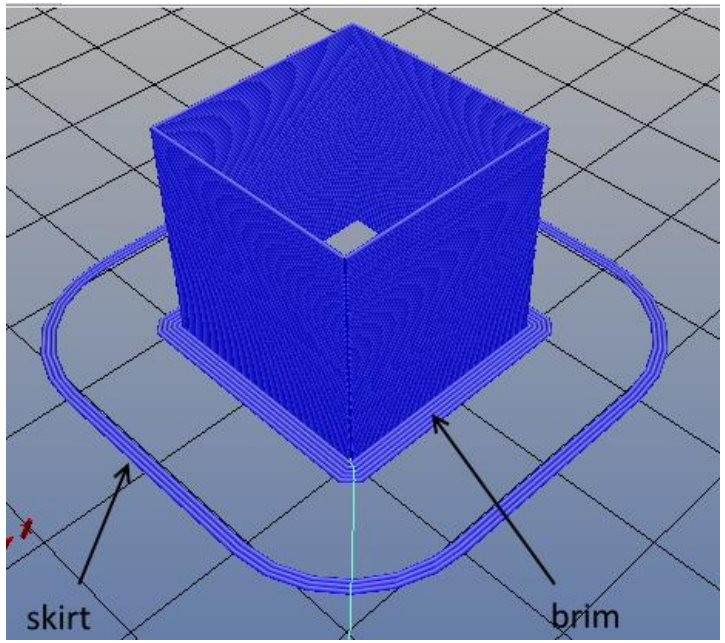
Skirts

- It is an outline that surrounds the part.
- It helps with getting the extruder ready for the print and smoothing the flow of filament.
- Number of outlines can be increased.



3D Printing Troubleshooting

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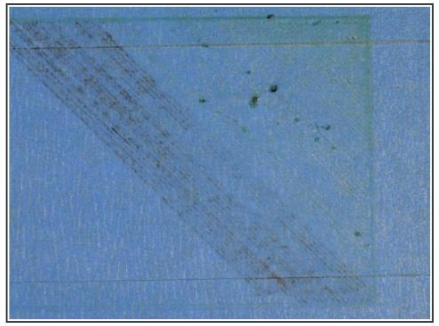
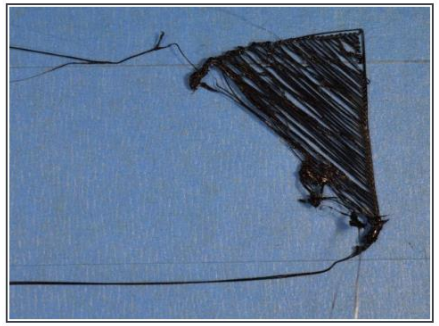
3D Printing Troubleshooting

https://www.simplify3d.com/support/print-quality-troubleshooting/



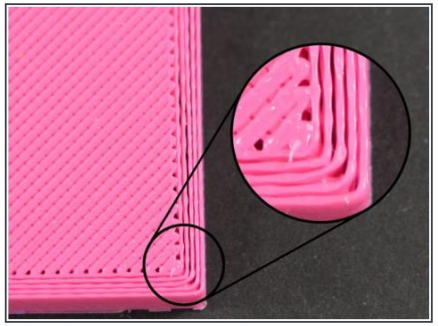
Not Extruding At Start

Printer does not extrude plastic at the beginning of the print



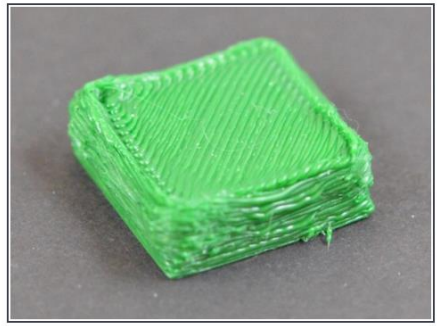
Not Sticking To Bed

The first layer does not stick to the bed and the print quickly fails



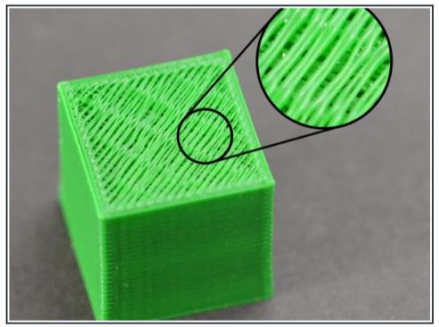
Under-Extrusion

Printer does not extrude enough plastic, gaps between perimeters and infill



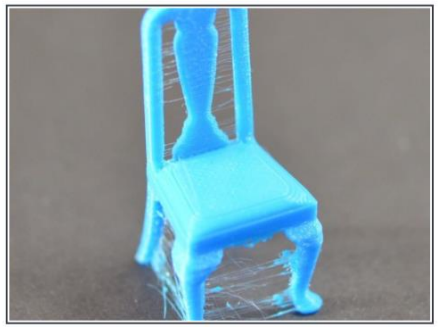
Over-Extrusion

Printer extrudes too much plastic, prints looks very messy



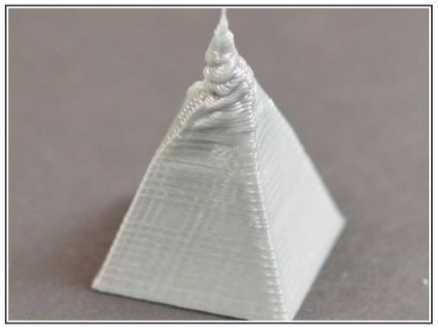
Gaps in Top Layers

Holes or gaps in the top layers of the print



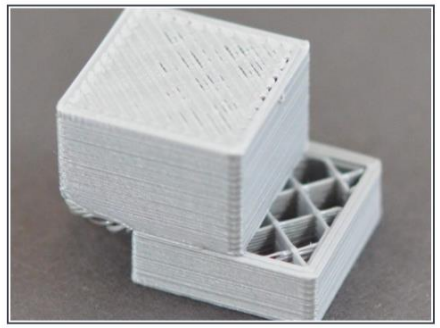
Stringing or Oozing

Lots of strings and hairs left behind when moving between different sections of the print



Overheating

Small features become overheated and deformed



Layer Shifting

Layers are misaligned and shift relative to one another

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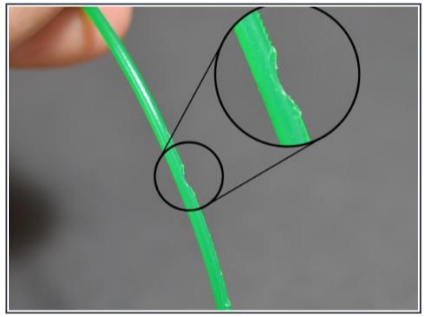
3D Printing Troubleshooting

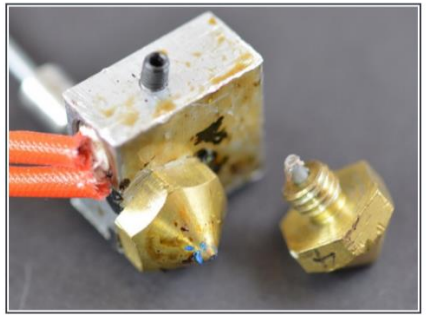
Layer Separation and Splitting

Layers are separating and splitting apart while printing



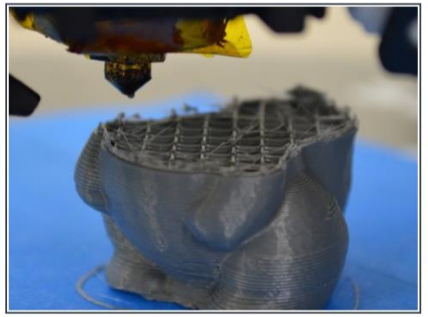
Grinding Filament

Plastic is being ground away until the filament no longer moves, otherwise known as "stripped" filament



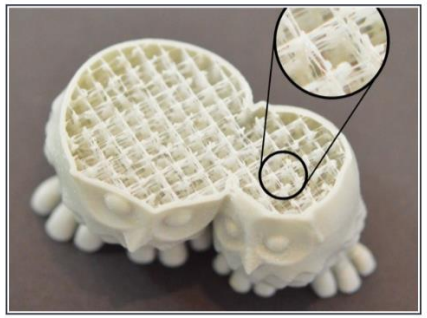
Clogged Extruder

Extruder is clogged or jammed and will no longer extrude plastic from the nozzle tip



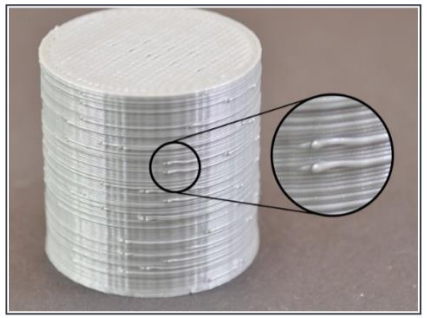
Stops Extruding Mid Print

Printer stops extruding plastic randomly in the middle of a print



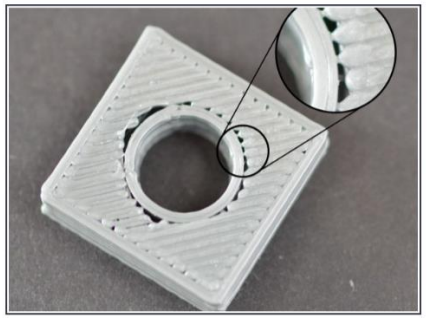
Weak Infill

Very thin, stringy infill that creates a weak interior and does not bond together well



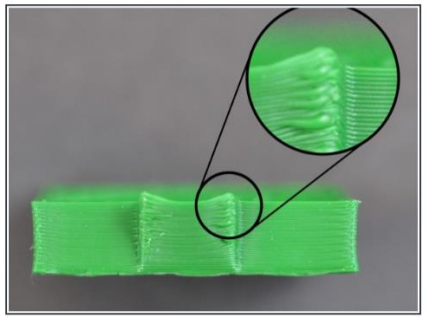
Blobs and Zits

Small blobs on the surface of print, otherwise known as zits



Gaps Between Infill and Outline

Gaps between the outline of the part and the outer solid infill layers



Curling or Rough Corners

Corners of the print tend to curl and deform after they are printed

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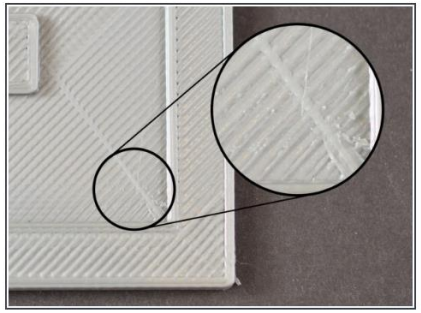
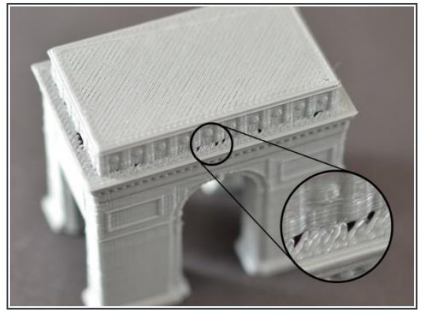
3D Printing Troubleshooting



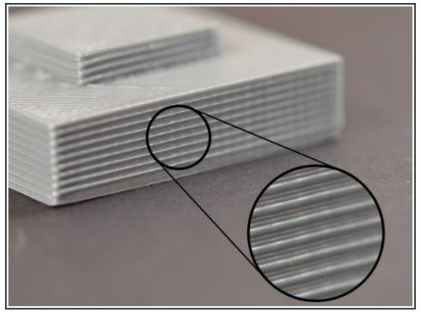
Scars on Top Surface

The nozzle drags across the top of the print and creates a scar on the surface



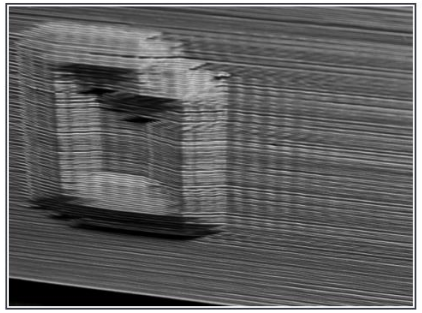
Gaps in Floor Corners

Gaps in the corners of the print, where the top layer does not join to the outline of the next layer



Lines on the Side of Print

Side walls are not smooth, lines are visible on the side of the print



Vibrations and Ringing

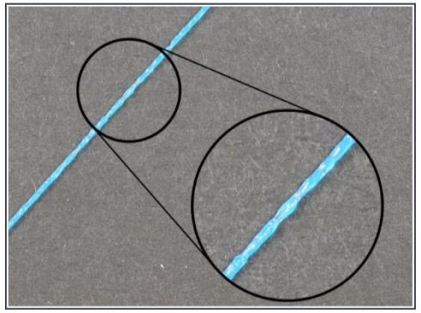
Vibrations that cause oscillations on the surface of the print, otherwise known as "ringing"

Gaps in Thin Walls

Gaps between thin walls of the print where the perimeters do not touch

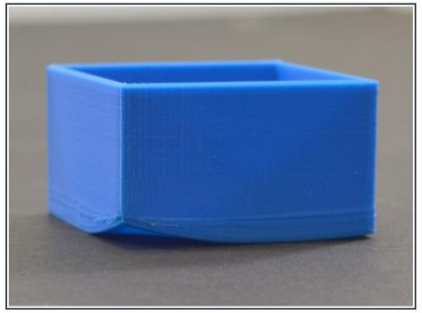
Small Features Not Printed

Very small features are not printed or are missing from the software preview



Inconsistent Extrusion

Extrusion amount tends to vary and is not consistent enough to produce an accurate shape



Warping

Warping of large parts, particularly with high temperature materials such as ABS

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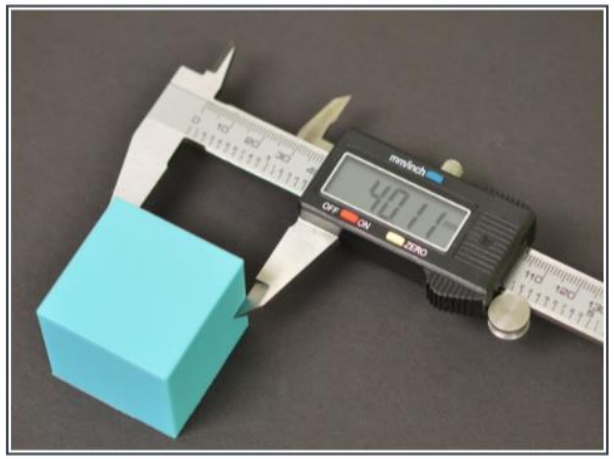
3D Printing Troubleshooting

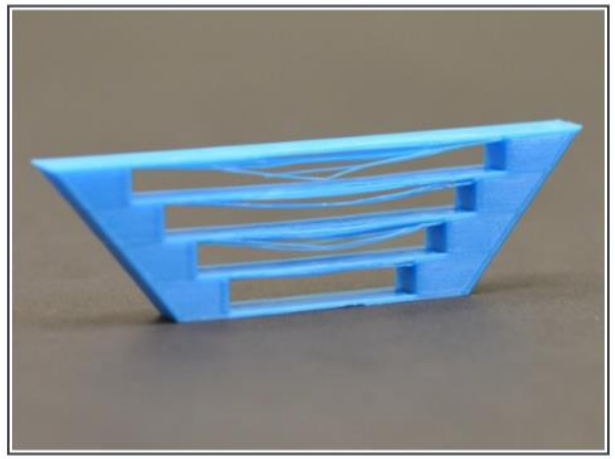
Poor Surface Above Supports

Poor surface quality on the underside of the part where it touches the support structures



Dimensional Accuracy

Dimensional issues where the measured dimensions do not match the original design intent



Poor Bridging

Sagging, drooping, or gaps between the extruded segments of your bridging regions

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3D Printing Technologies

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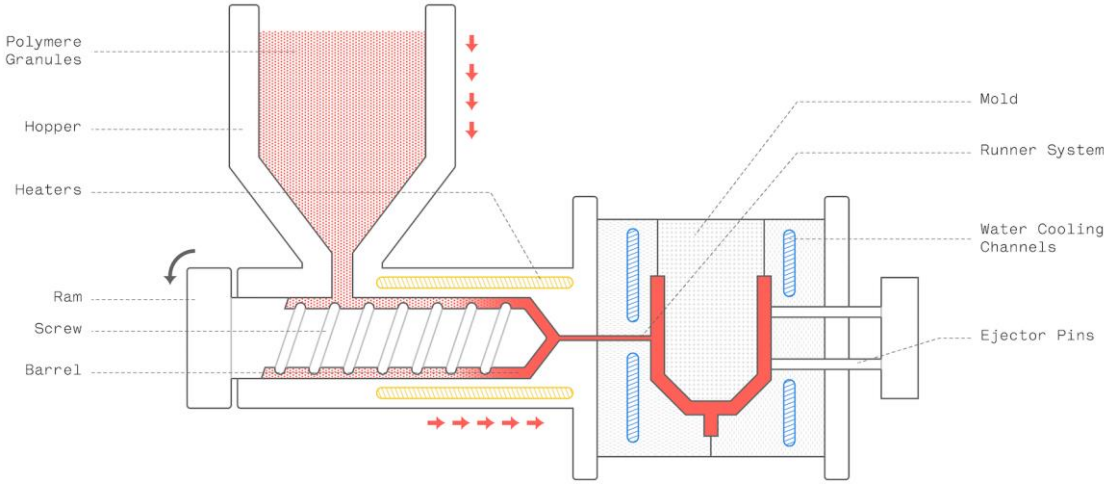
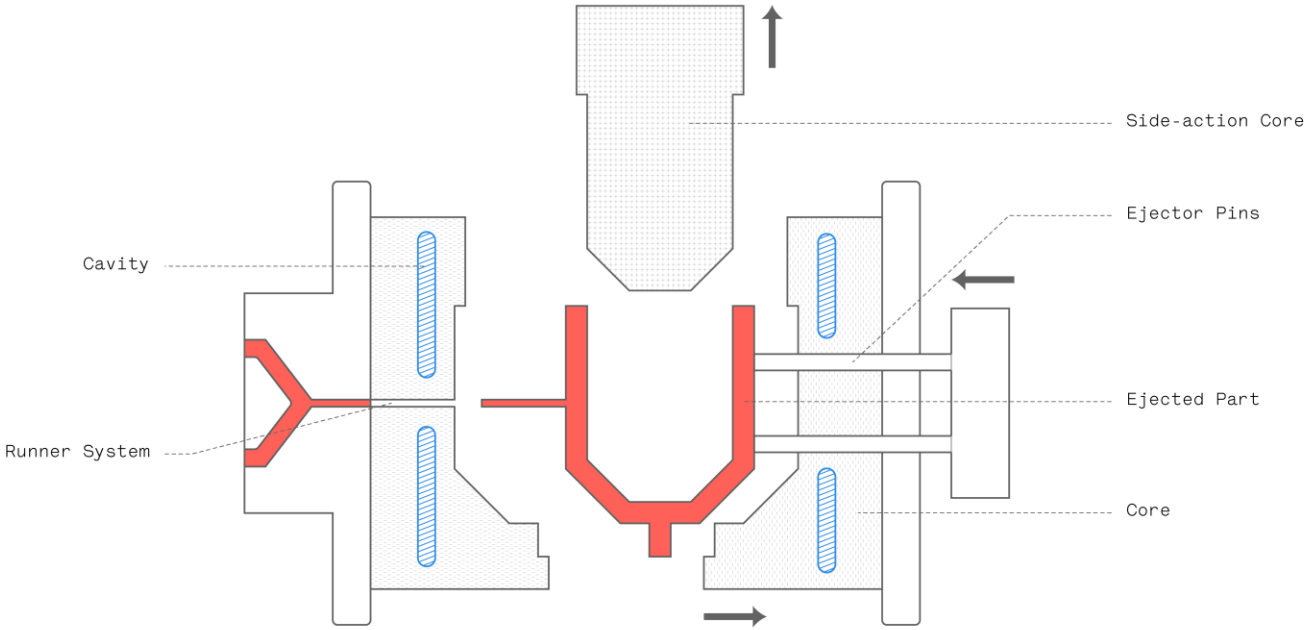
Injection Molding - Traditional Method

- High quality accurate results
- Fast manufacturing. Mold is ready to be used in 30 to 90 seconds.
- CNC is used to create molds
- Usually aluminum is used to create molds
- Simple mold design can cost $2000 - $5000
- Molds for full scale production (100.000 units or more) can go up to $100,000

Injection Molding – Traditional Method





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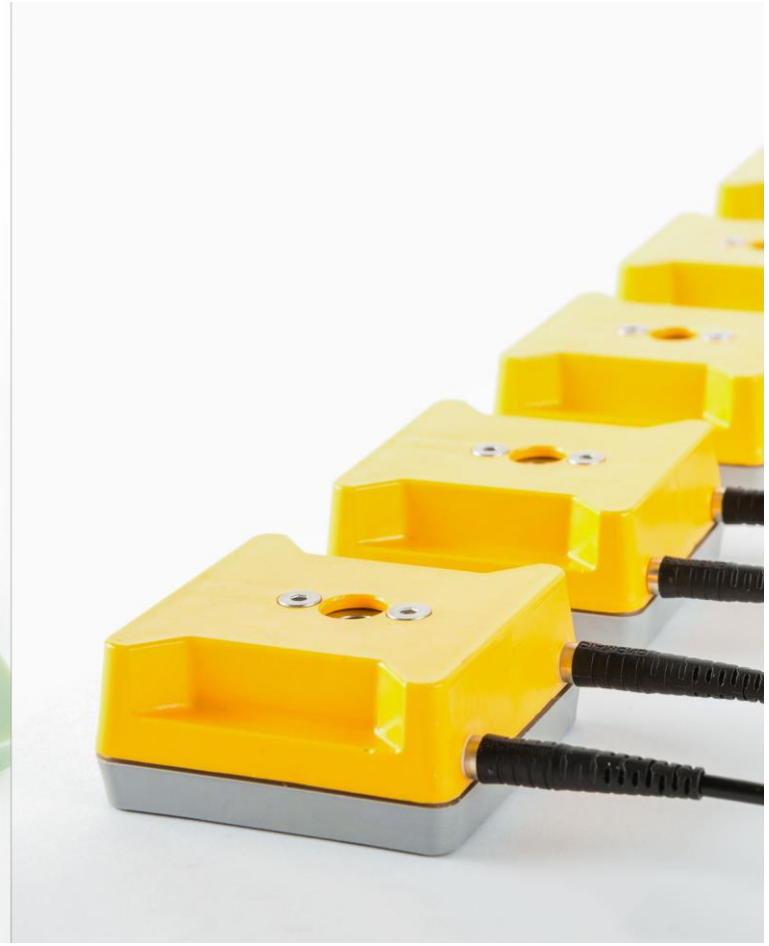
3D Printing + Injection Molding

- Mold is 3D printed to lower the cost of the mold
- Fast turnaround times (1-2 week)
- Quantities are low (50 - 100 parts).
- Mold designs where changes or iterations are probable.
- Parts that are relatively small (less than 150 mm).

3D Printing + Injection Molding



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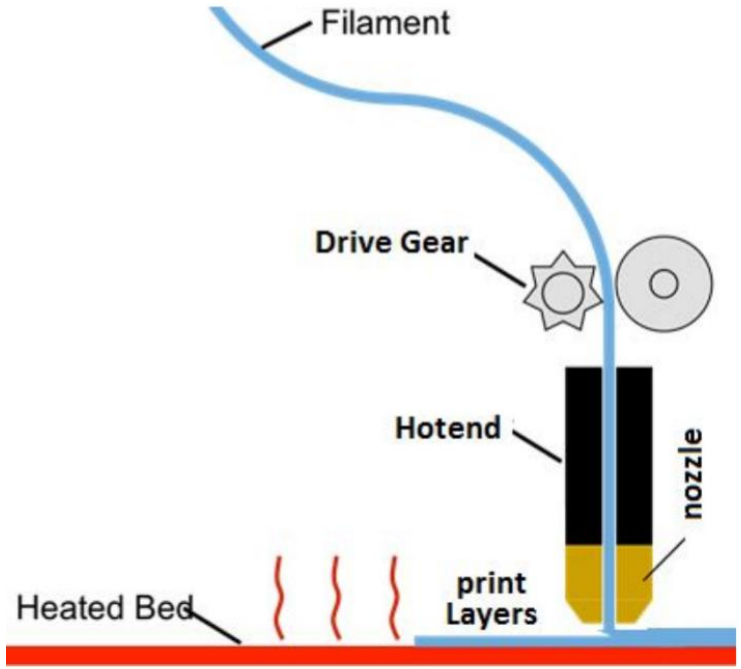
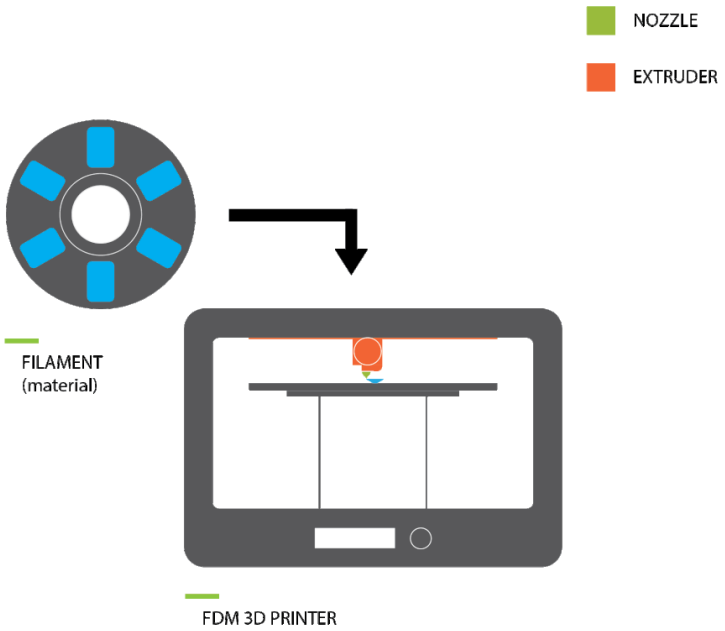
FDM – Fused Deposition Modeling

- In other words, it is a hot glue gun attached to a 3D robot.
- Print one layer at a time.
- Print layer by layer from the bottom up.
- It is the most popular method.
- “Easy to use” and clean

FDM – Fused Deposition Modeling





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FDM – Fused Deposition Modeling

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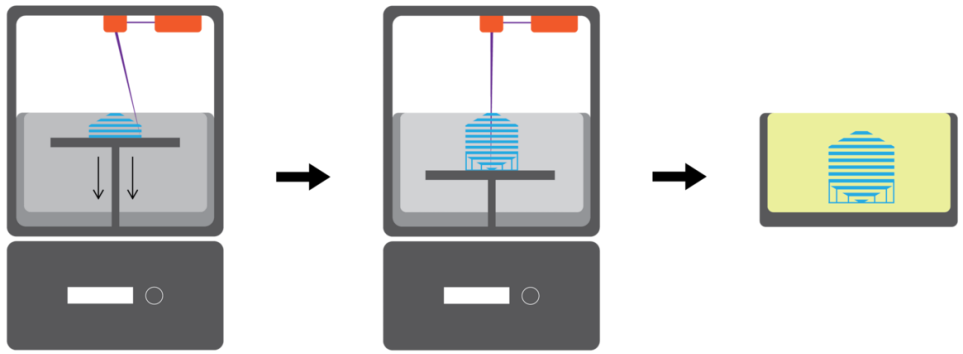
FFF - Fused Filament Fabrication

- Same as FDM.
- FDM is trademarked by a company, so RepRap project called it FFF instead.

SLA - Stereolithography

- Liquid resin
- UV laser is used to cure layer after layer
- Objects are oriented 45 degrees during the 3D printing process
- Support is added during the printing process
- A lot more layers = Very high resolution = Highly detailed prints
- Longer time to print

SLA - Stereolithography



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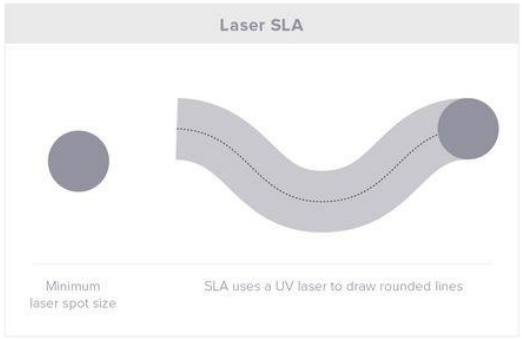

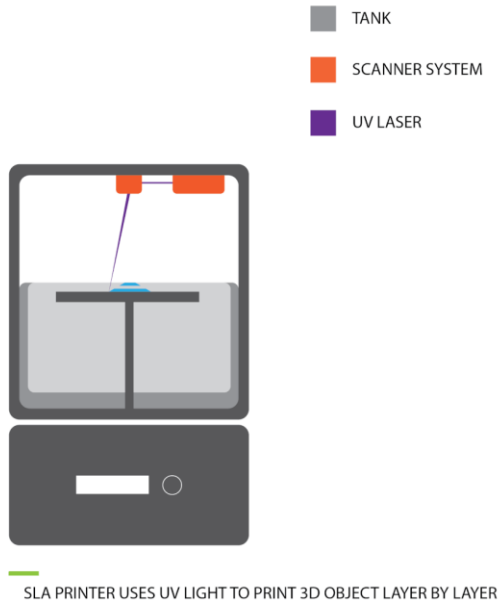

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SLA - Stereolithography

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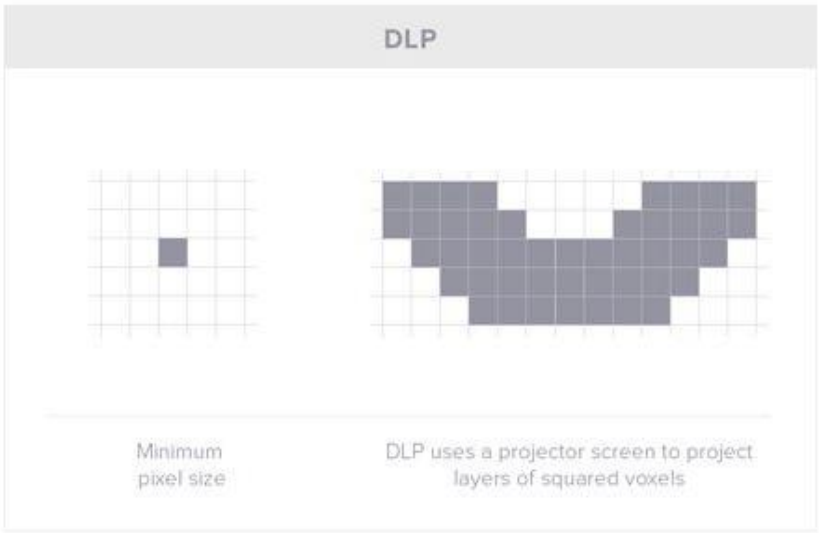
DLP - Digital Light Processing

- Instead of laser projected light is used to cure resin
- DLP uses a digital projector screen to flash a single image of each layer across the entire platform at once.
- Because the projector is a digital screen, the image of each layer is composed of square pixels, resulting in a layer formed from small rectangular bricks called voxels.
- Good for quickly printing large parts without much detail

DLP - Digital Light Processing



DLP - Digital Light Processing

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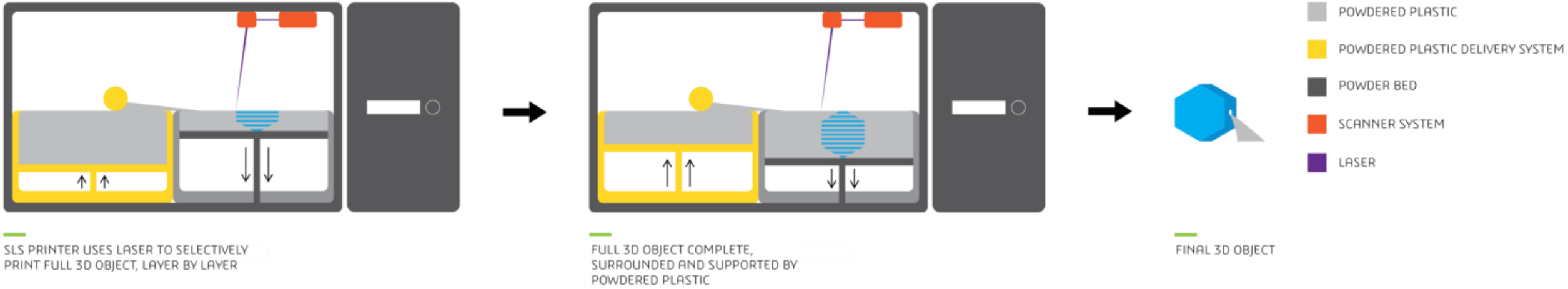
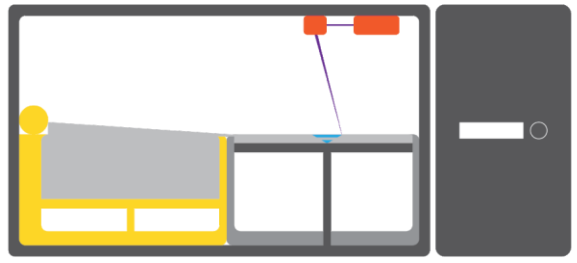
SLS – Selective Laser Sintering

- A layer of powders is cured by laser
- Usually white
- Slightly rough, porous surface finish
- Thin features are flexible and thick walls are durable
- No supports to cut or melt
- Good for low cost projects
- Can be died in different colors
- Other options stainless steel powder, ceramic powder, flexible polymer
- The initial patents have expired so we will see more of them soon!

SLS – Selective Laser Sintering





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SLS – Selective Laser Sintering

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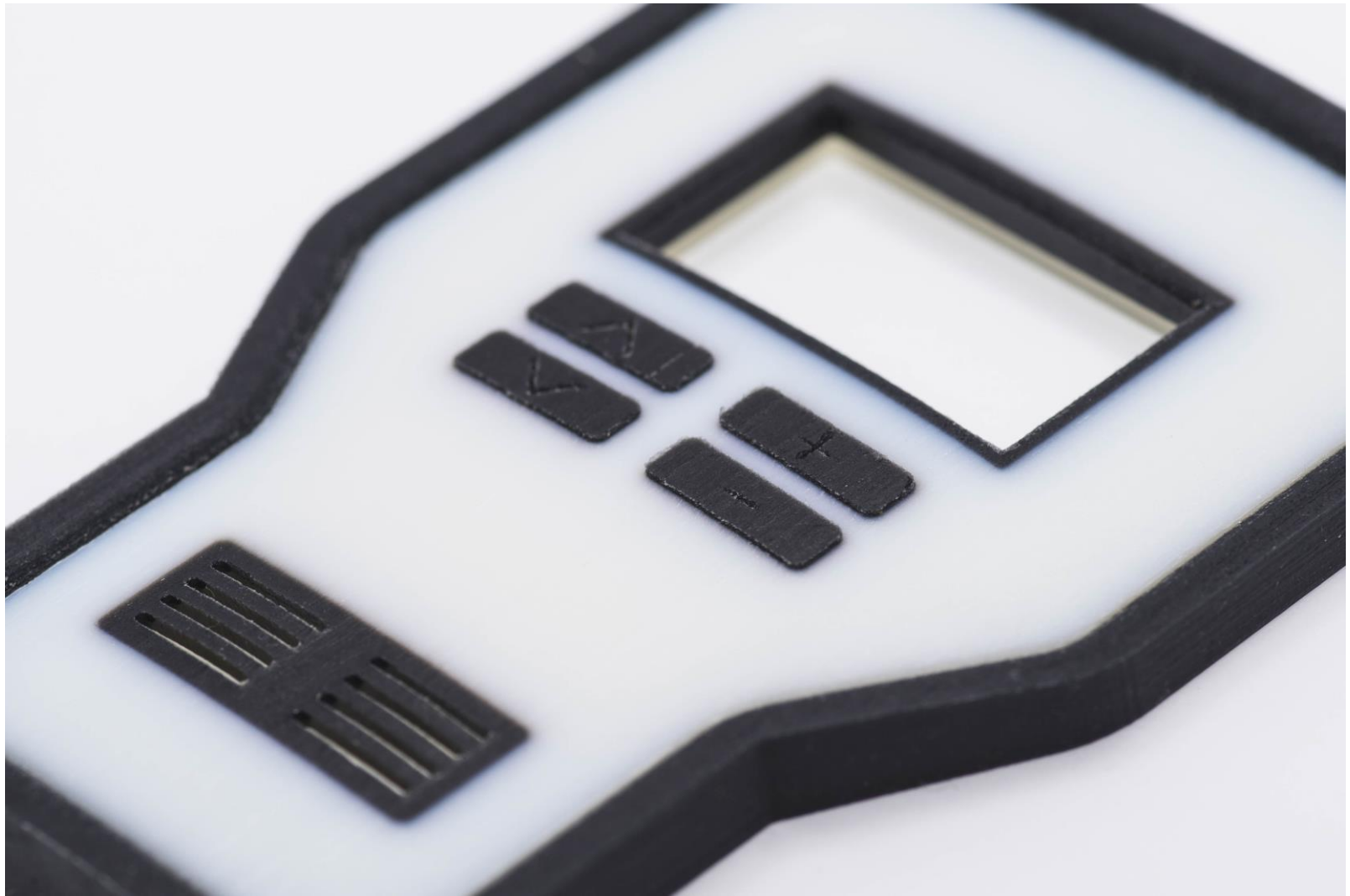
Material Jetting

- Material jetting is similar to inkjet document printing
- Instead of jetting drops of ink onto paper, 3D printer's jet drops of **liquid photopolymer** onto the build tray.
- Multiple print heads jet material simultaneously to create each layer, and **UV light is then used to cure the layers**.
- Usually printer parameters are pre-set.
- Multi material and multi color prints.
- This technology is under active patents

Material Jetting



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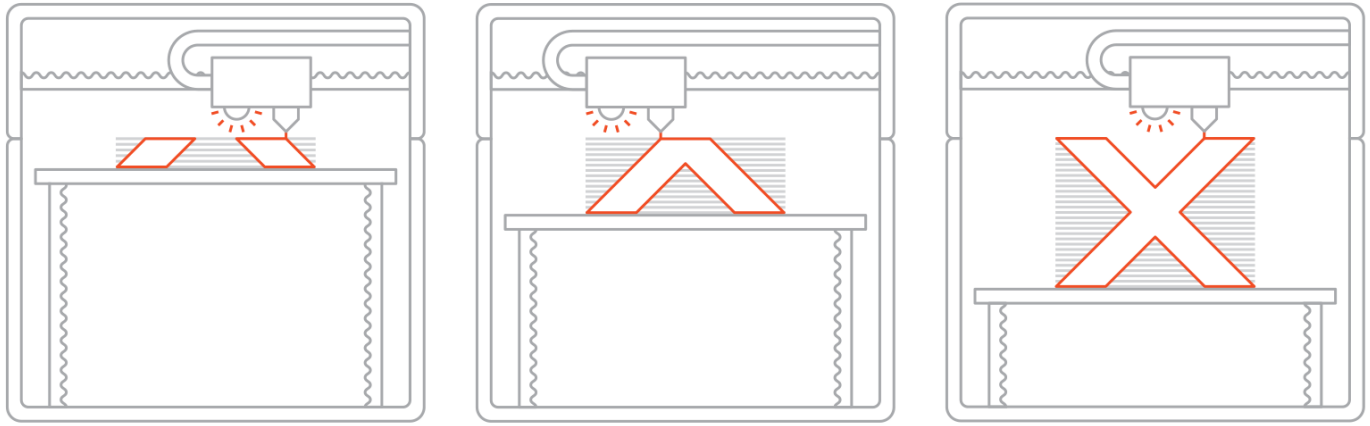
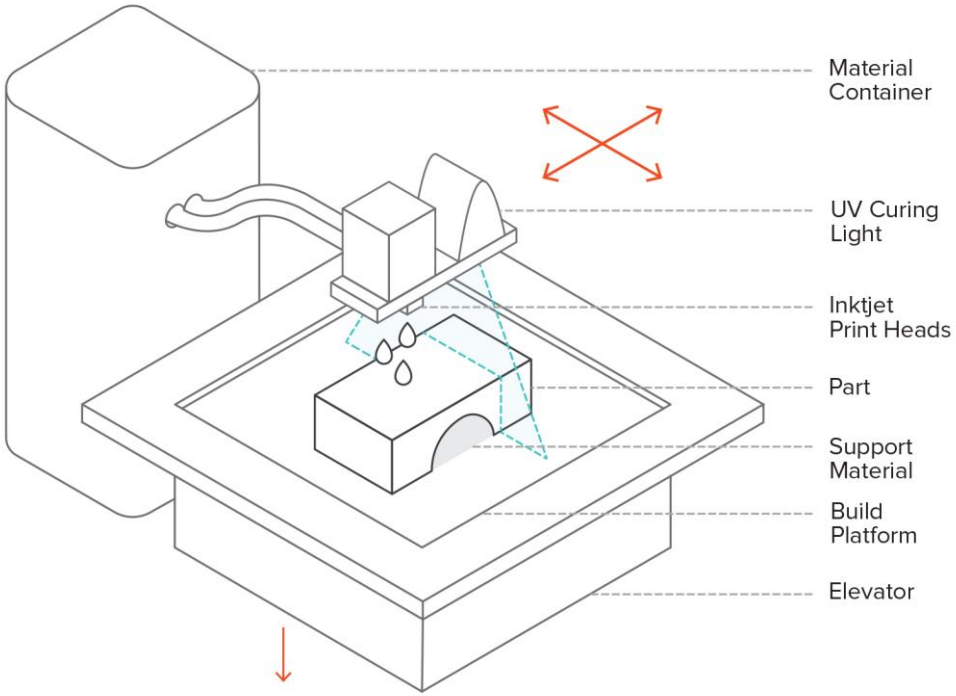
Material Jetting

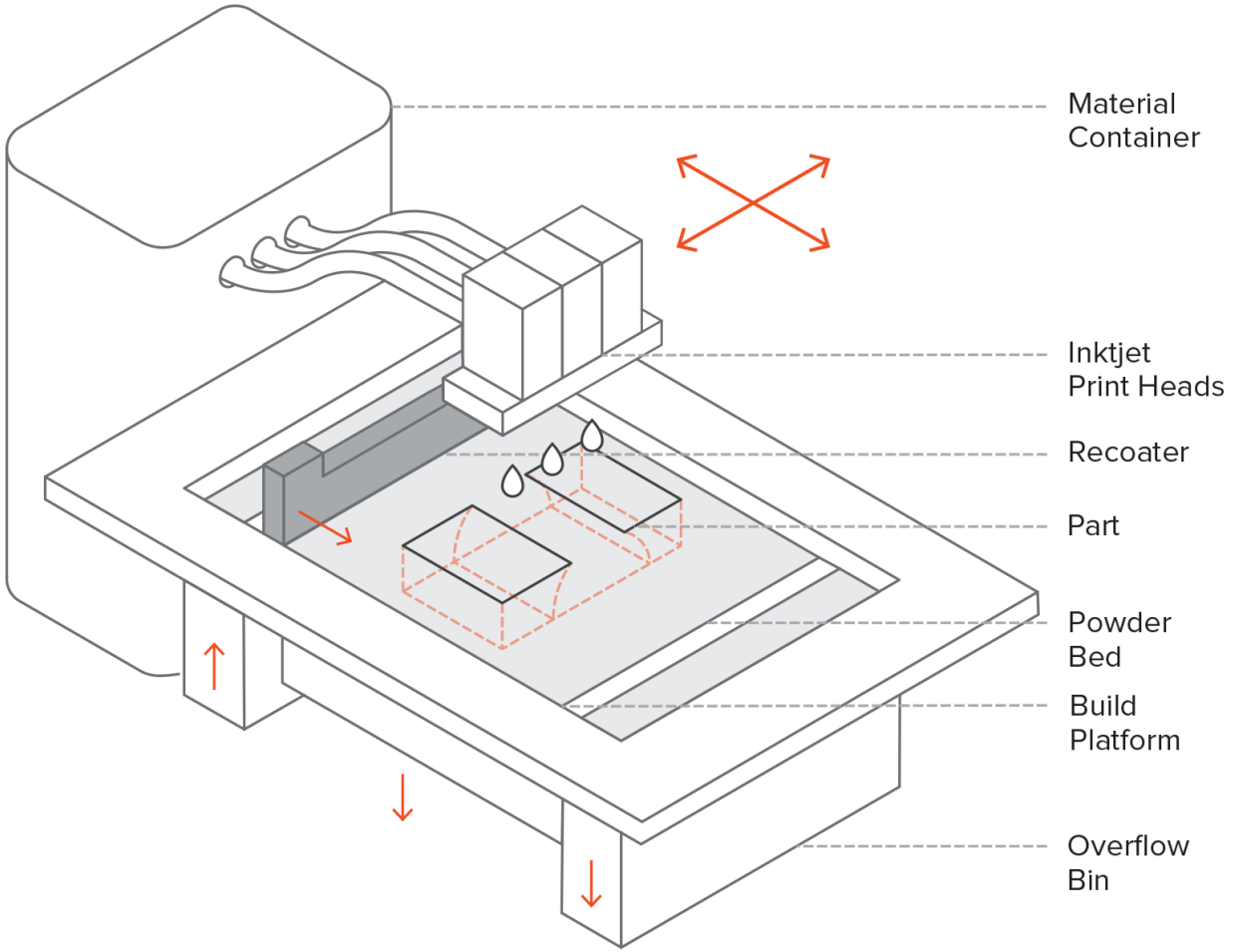




Binder Jetting – Full Color Printing

- A moving head selectively binds the surface of a powder bed by dropping glue or by laser sintering.
- In full-color Binder Jetting, the colored ink is also deposited with binder.
- New powder is continuously added to the bed from a powder container.
- Detailed full color prints

Binder Jetting – Full Color Printing



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Binder Jetting – Full Color Printing

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Compering Different 3D Printing Technologies

	FDM	SLS	SLA
Material	ABS, PLA, Nylon	Polyamide (Nylon), Polystyrenes, Thermoplastic Polyurethane (TPU),Metal	Photosensitive Resins
Achievable quality	Low to Medium	High	High
Layer thickness	0.5 to 0.127 mm	0.05 to 0.01 mm	0.05 to 0.015 mm
Minimum wall thickness	1 mm	0.8 mm	5 mm
Surface texture	Rough ("staircase" effect) but can be polished	Slightly rough but can be polished	Smooth, Often shiny
Colors (without post-process)	Opaque and translucent all colors	Opaque White, Gray and Black	Opaque and translucent all colors
Support (complex designs)	Required	Not required	Required
Mechanically	Variable (can be strong or flexible)	Strong and flexible	Strong and brittle, New flexible compounds
Mechanical failure	Gradual deformation until fracture	Gradual deformation until fracture	Almost no deformation until sudden fracture
Abrasion resistance	Variable	Superior	Variable
Post-process	Polishing, Painting, Sealing, Smoothing (with acetone vapor)	Polishing, Smoothing Beautifier, Varnishing, Dyeing, Painting	Polishing (rarely needed),Painting
Food compatibility	Leakage due to micro-gaps	Yes	Only with special resins (can be expensive)
Chemicals compatibility	Leakage due to micro-gaps	Highly resistant (Nylon)	Not defined
Cost	Printers inexpensive,Material inexpensive	Printers very expensive,Material inexpensive	Printer medium priced,Resins can be expensive

Link

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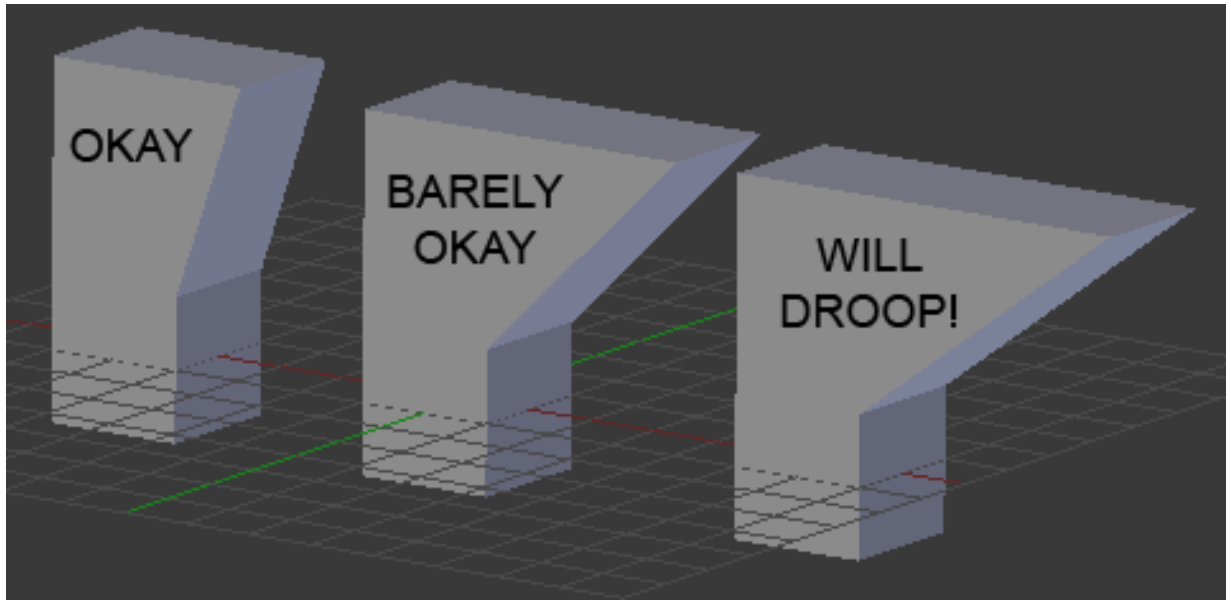
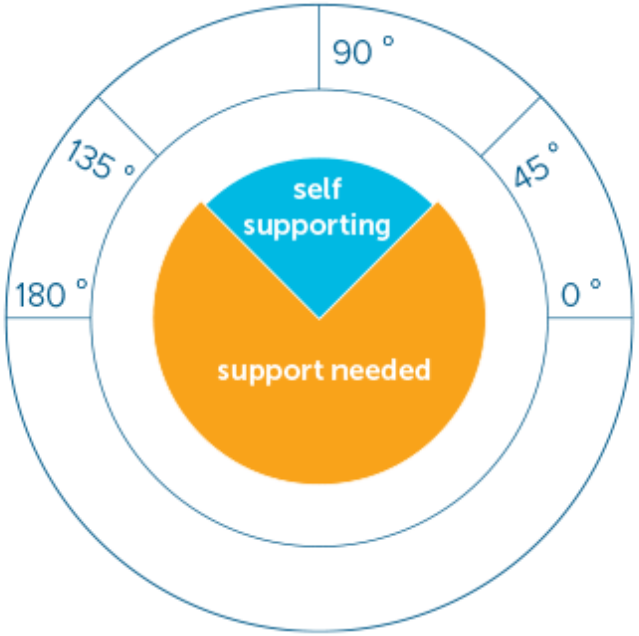
3D Designing for 3D Printing

- Manifold – Watertight Geometry
- Balanced Designs
- Avoid
  - Loose faces and holes
  - Overlapping faces
  - Unconnected edges
  - Overhang more than 45 degrees

3D Designing for 3D Printing





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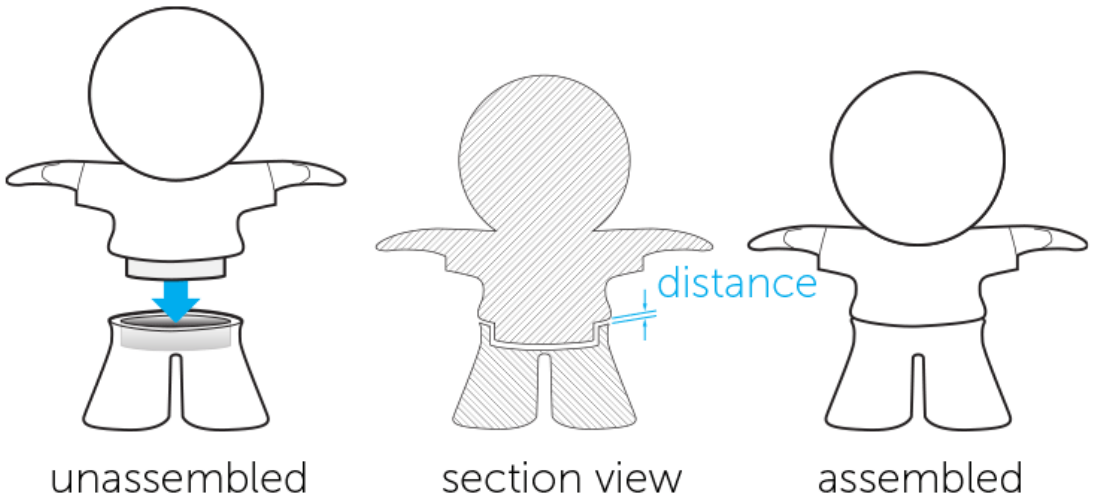
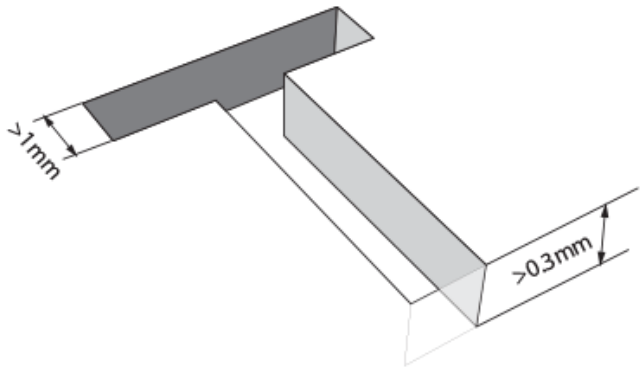
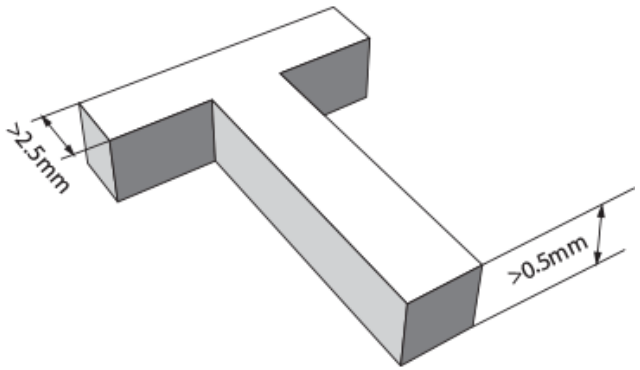
3D Designing for 3D Printing







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3D Designs for 3D Printing

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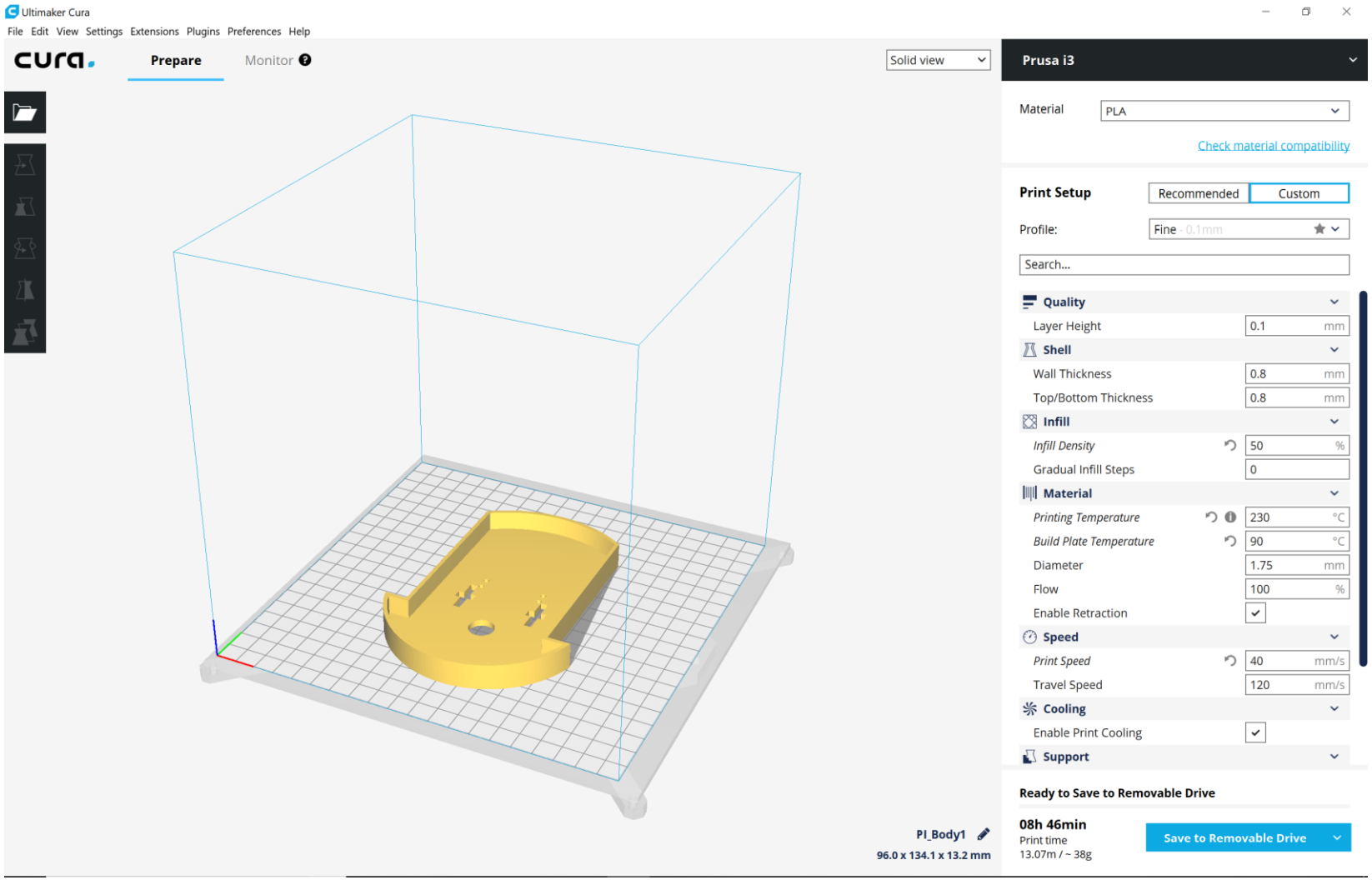
3D Design Websites

- There are so many websites to download free STL files of all kinds of 3D designs for 3D Printing.

- https://www.thingiverse.com/
- https://www.tinkercad.com/
- https://all3dp.com/
- https://pinshape.com/

CURA



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