Design & Fabrication

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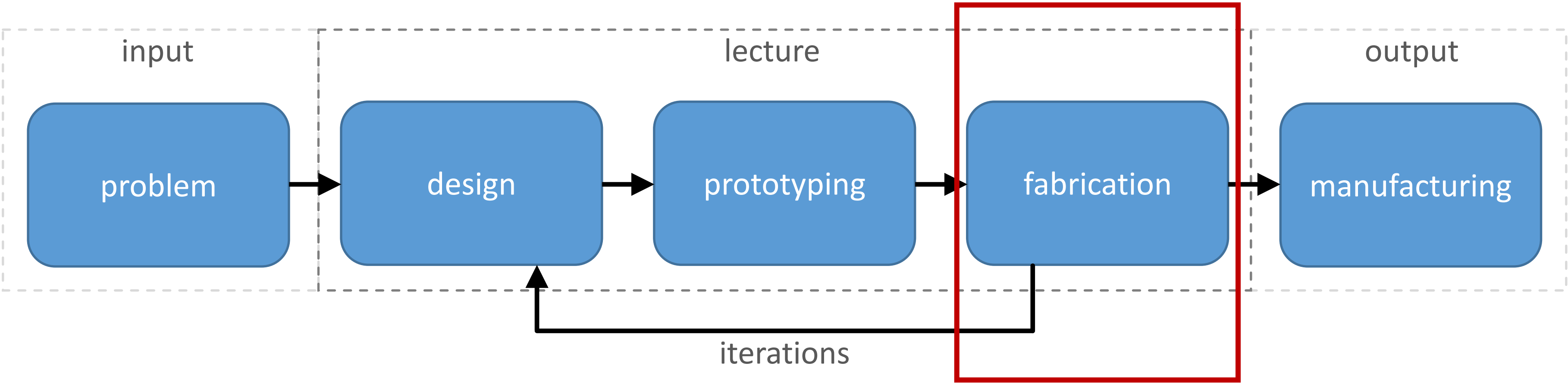
From Design to Fabrication
Recapitulation



From Design to Fabrication
Recapitulation: Subtractive Technologies

Key Advantages

- High surface accuracy
- High stability

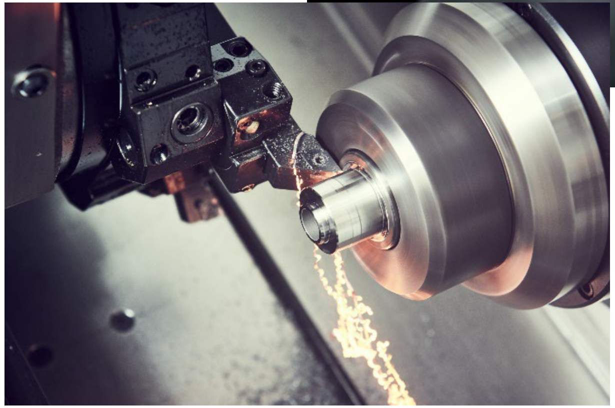
Key Disadvantages

- Large waste of material
- Local material defects, e.g. due to heating
- (Remaining surface roughness)

Lecture 7
Additive Fabrication Technologies

Subtractive Manufacturing

- Machining
- Start with a block of solid material
- Remove material to manufacture the given 3D model



Adobe Stock: 84086406, 149785005

Additive Fabrication Technologies
Fundamentals

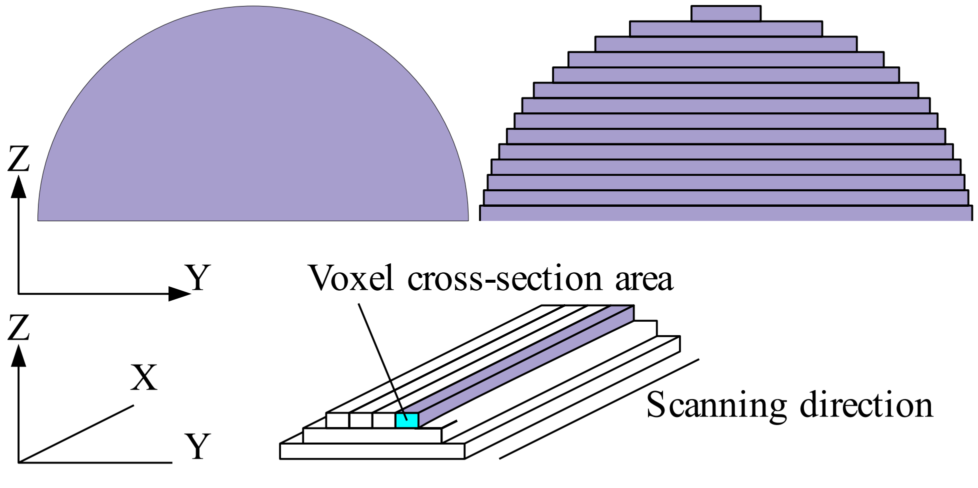
Additive Manufacturing

- Mostly 3D printing processes
  (plus additional manufacturing steps)
- Start with an empty printing bed
- Building layers of material one by one

Adobe Stock: 645259943

3D Model Slicing

- Slicing layers from a 3D model
- Vector file formats:
  - *.STL: stereolithography, unsorted "soup" list of triangular facets
  - *.GCO: G-Code, core instruction set, movement instructions for printers
  - *.OBJ: preferred for colored objects
  - *.3MF: format of the 3MF consortium



Wikipedia, File: Rapid_prototyping_slicing-en.svg (accessed on 2023-12-12)

Dream of Replication

- Star Trek: Food Replicator

https://www.youtube.com/watch?v=sXXWrW6DiJA (accessed on 2023-12-12)

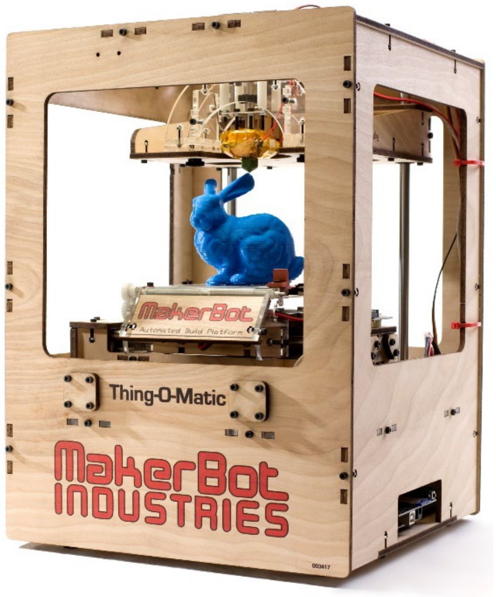
Additive Manufacturing Technologies

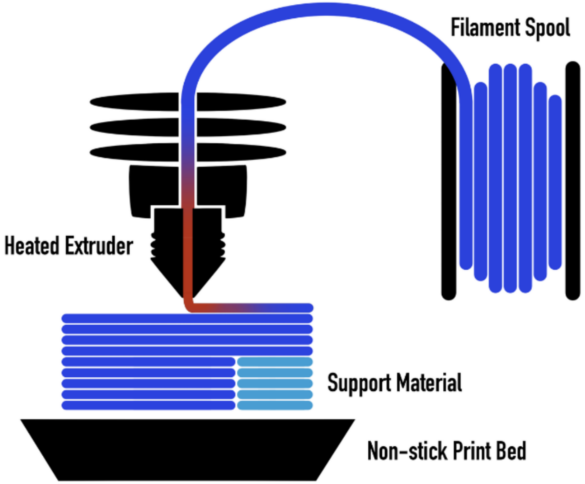
- Fused Deposition Modeling (FDM)
- Powder-Bed / Binder Jet
- Stereolithography (SLA)
- Digital Light Projector (DLP) Printing
- Selective Laser Sintering (SLS)
- Direct Metal Laser Sintering (DMLS)
- Plaster-based 3D Printing (PP)
- Laminated Object Manufacturing (LOM)

Additive Fabrication Technologies
Fundamentals

Fused Deposition Modeling (FDM)

- S. Scott Crump, Stratasys (1988)
- Thermoplastic extrusion
- Common materials:
  - ABS
  - PLA





Wikipedia, File: Makerbot_Thing-O-Matic_Assembled_Printing_Blue_Rabbit.jpg (accessed on 2023-12-12)

https://dozuki.umd.edu/Wiki/Introduction_to_Fused_Deposition_Modeling_%28FDM%29 (accessed on 2023-12-12)

Powder Bed / Binder Jet

- MIT (1993)
- Powder:
  - Plastics like PMMA, …
  - Or even metals (annealing req.)
- Binder:
  - Adhesive between powder layers
- No support structures required
- Hollow parts must allow evacuation
- Inkjet color prints possible

https://www.youtube.com/watch?v=VBK_4ruKC8s (accessed on 2023-12-12) https://www.youtube.com/watch?v=hjIoGPZPNjU (accessed on 2023-12-12)

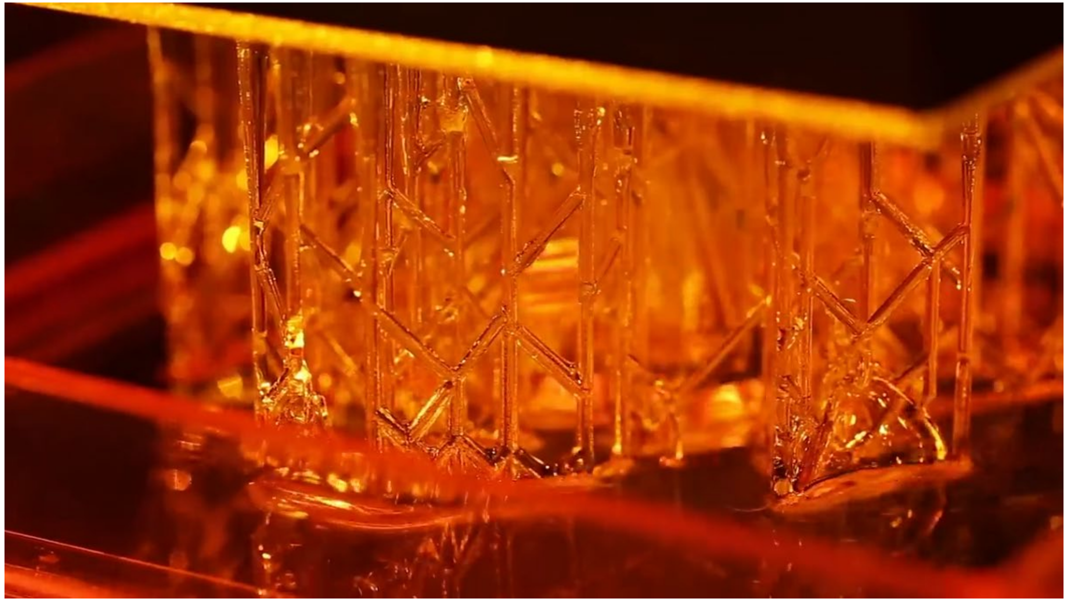
Additive Fabrication Technologies

Fundamentals

Stereolithography (SLA)

› UV laser beam

› Resin



https://www.youtube.com/watch?v=yW4EbCWaJHE (accessed on 2023-12-12)

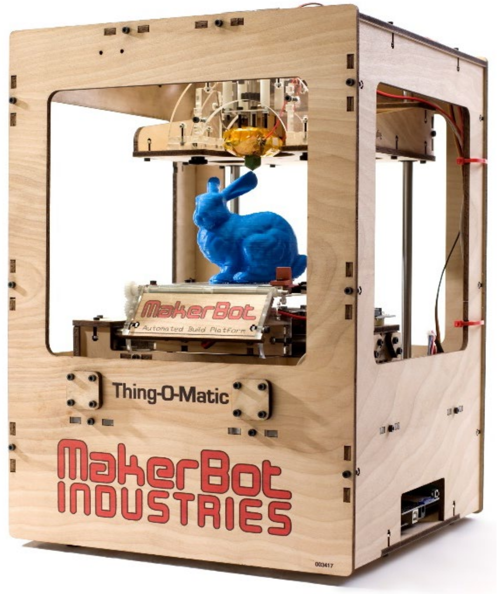
Materials

- Large diversity of materials available
- Characteristics:
  - High-temperature / ABS-like
  - Rigid / soft, rubber-like
  - Opaque / transparent
  - Bio-compatible

Kalweit et al. (2012), “Handbuch für Technisches Produktdesign”, Springer, ISBN 978-3-642-02641-6.

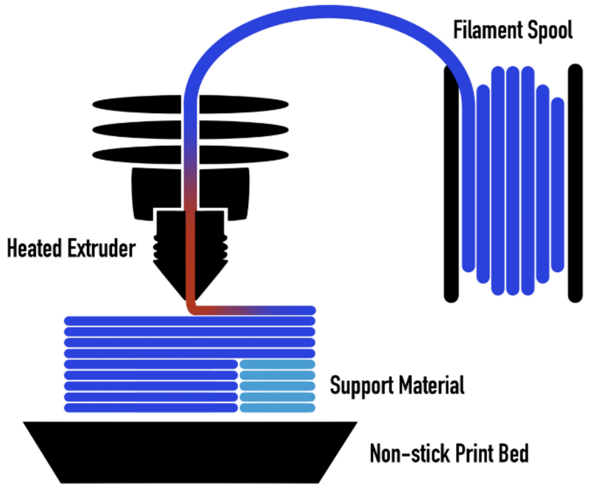
Fused Deposition Modeling (FDM)

Additive Fabrication Technologies
Fundamentals of 3D Printing



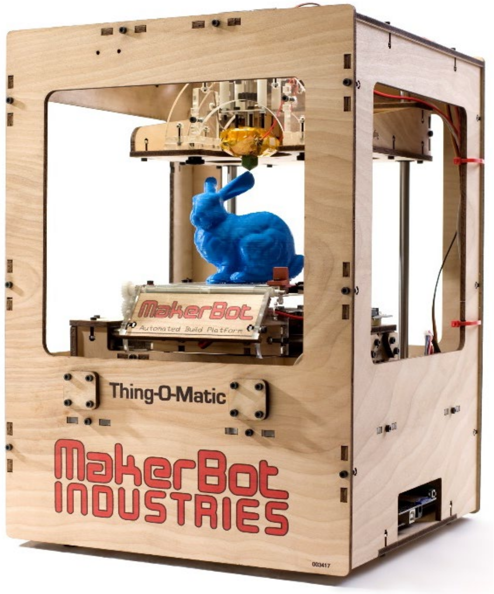
Printing Temperature

› Depends on material used
› Viscosity, allowed pressure for nozzle



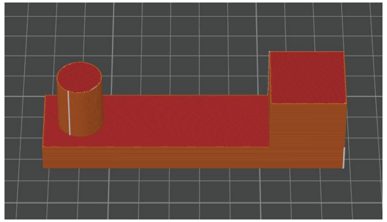
Wikipedia, File: Makerbot_Thing-O-Matic_Assembled_Printing_Blue_Rabbit.jpg (accessed on 2023-12-12)
https://dozuki.umd.edu/Wiki/Introduction_to_Fused_Deposition_Modeling_%28FDM%29 (accessed on 2023-12-12)

Additive Fabrication Technologies
Fundamentals of 3D Printing

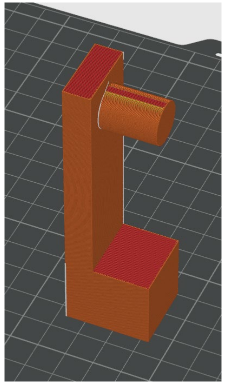


Print Speed and Travel Speed

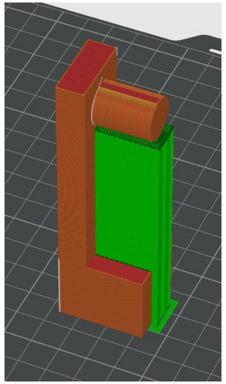
› Model orientation important
› Slower in z-direction
› Traveling between islands takes time



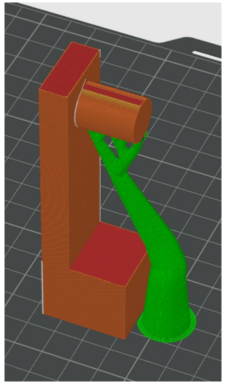
00:37 h
17.26 g / 5.79 m



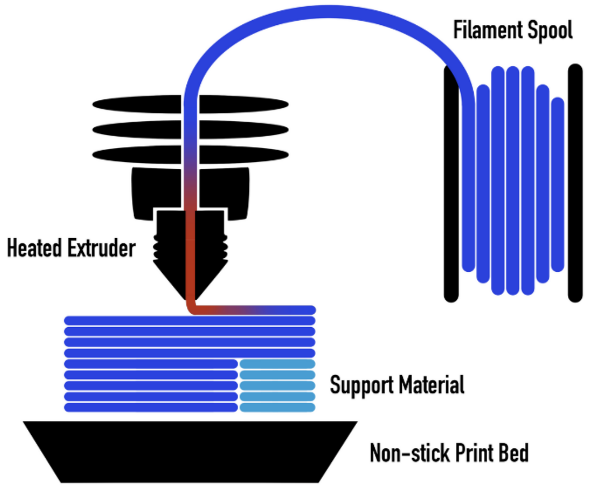
01:29 h
17.39 g / 5.83 m



01:30 h
20.64 g / 6.92 m



01:31 h
19.70 g / 6.60 m



Wikipedia, File: Makerbot_Thing-O-Matic_Assembled_Printing_Blue_Rabbit.jpg (accessed on 2023-12-12)

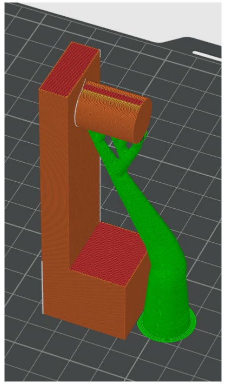
https://dozuki.umd.edu/Wiki/Introduction_to_Fused_Deposition_Modeling_%28FDM%29 (accessed on 2023-12-12)

Additive Fabrication Technologies

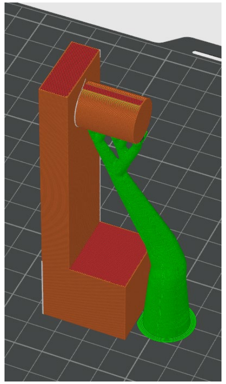
Fundamentals of 3D Printing

Layer Height vs. Print Speed

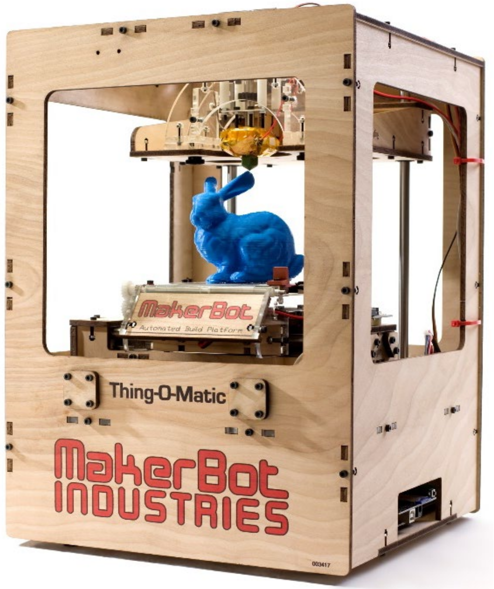
› Coarser layer resolution results in faster printing speed due to fewer steps in z-direction

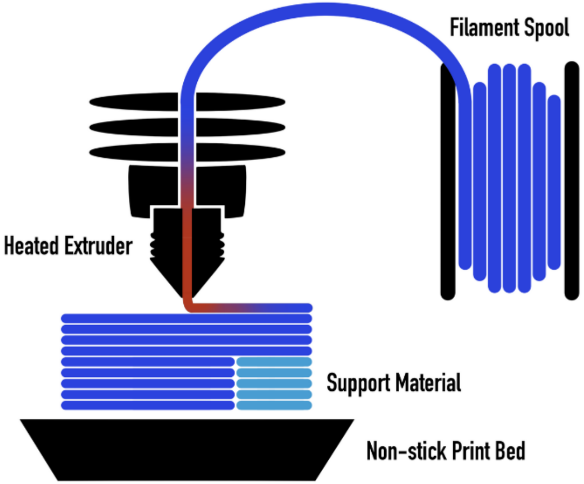


Layer height: 0.16 mm
01:31 h, 19.70 g / 6.60 m



Layer height: 0.25 mm
00:59 h, 19.28 g / 6.46 m

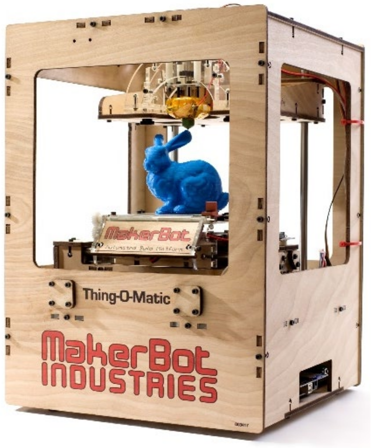


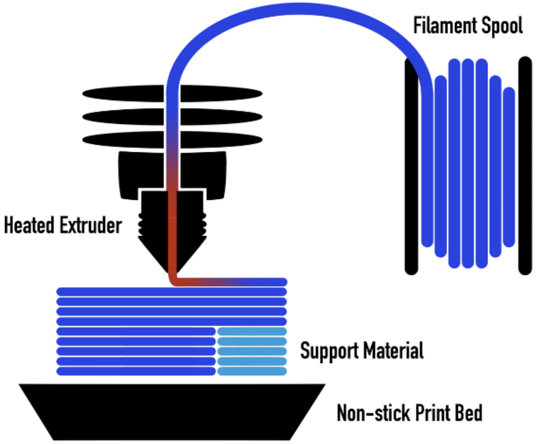


Wikipedia, File: Makerbot_Thing-O-Matic_Assembled_Printing_Blue_Rabbit.jpg (accessed on 2023-12-12)

https://dozuki.umd.edu/Wiki/Introduction_to_Fused_Deposition_Modeling_%28FDM%29 (accessed on 2023-12-12)

What is required to print faster?





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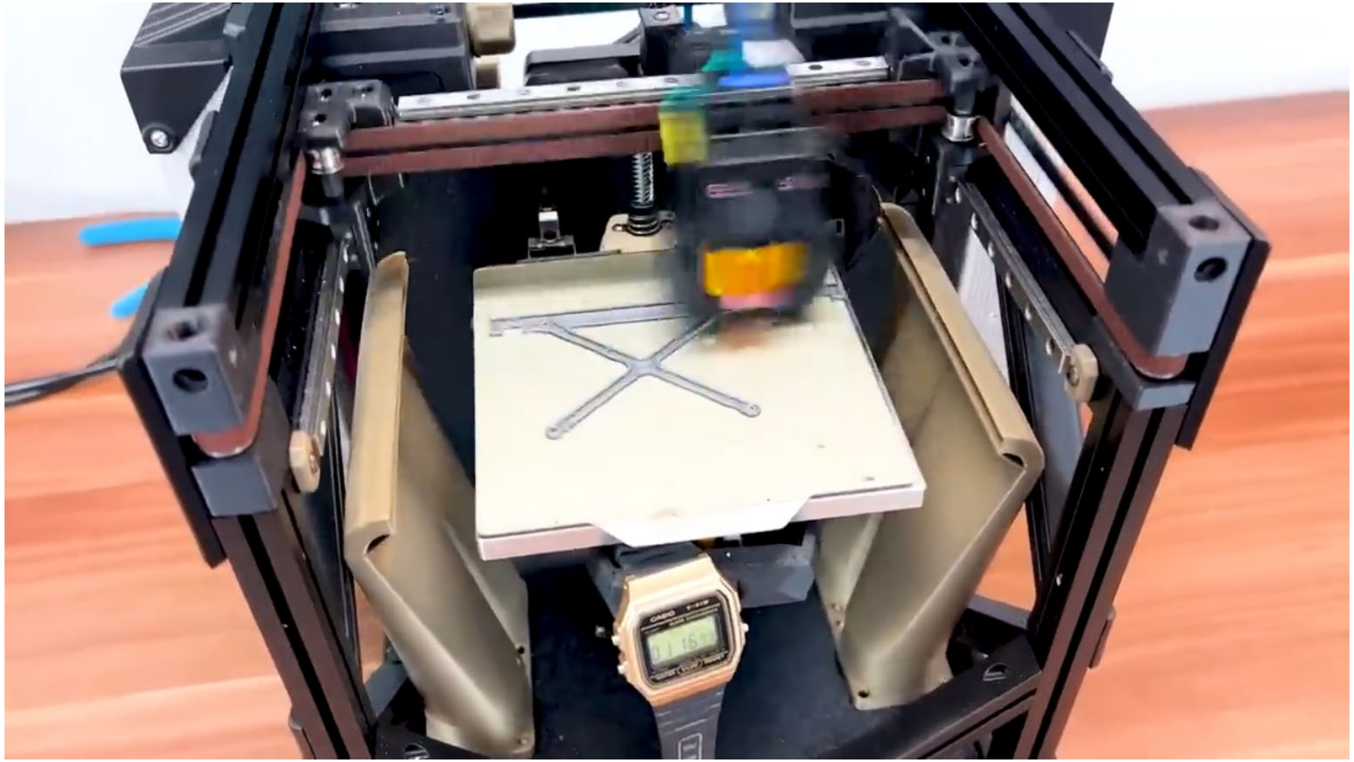
https://dozuki.umd.edu/Wiki/Introduction_to_Fused_Deposition_Modeling_%28FDM%29 (accessed on 2023-12-12)

Additive Fabrication Technologies

Print Speed and Technological Limits

2,500 mm/s



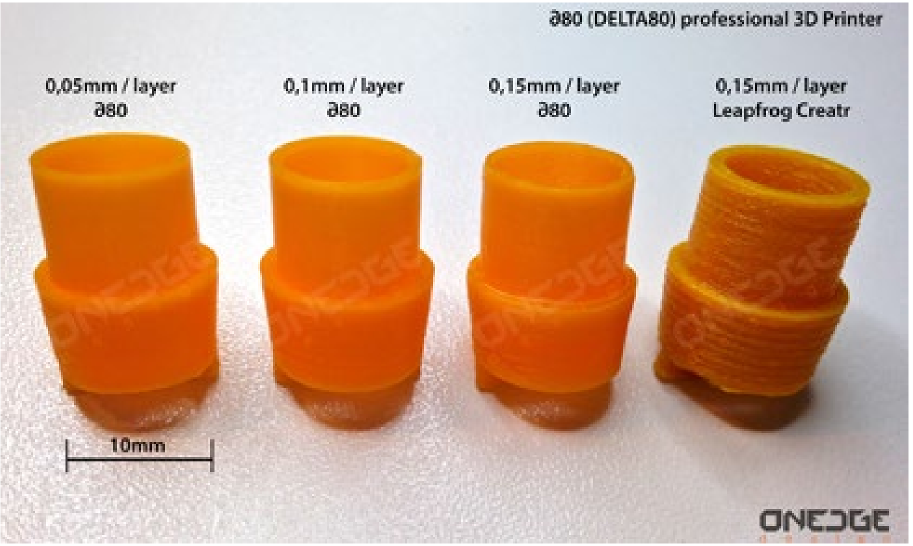
https://www.youtube.com/watch?v=UQuhLFF-7w8 (accessed on 2023-12-12)

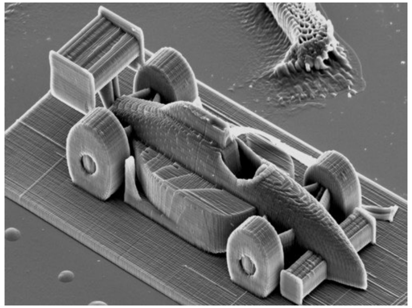
Additive Fabrication Technologies

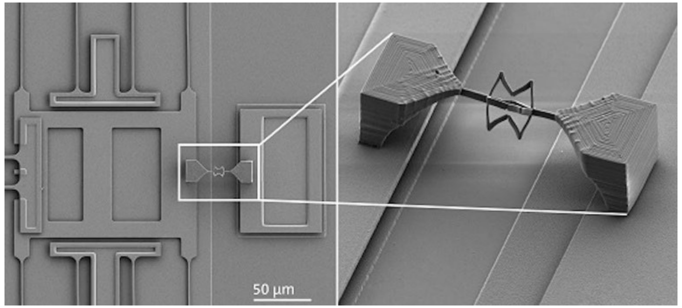
Fundamentals of 3D Printing

Print Quality

- Resolution
  - Layer Height
  - Building- vs. nano-scale
- Surface Accuracy



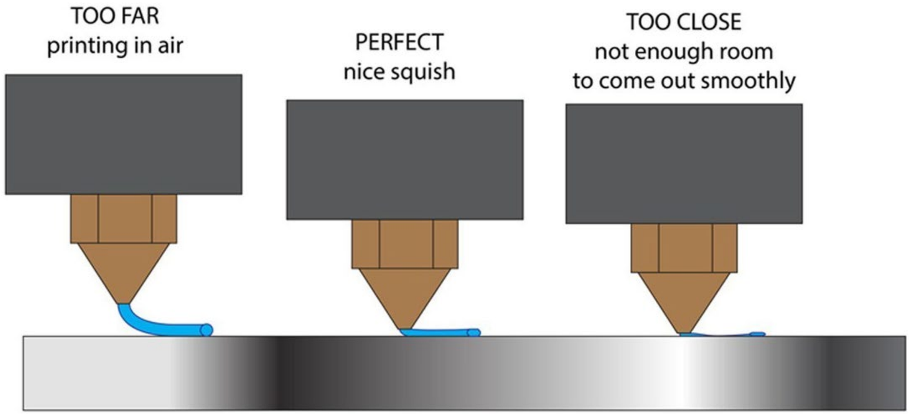


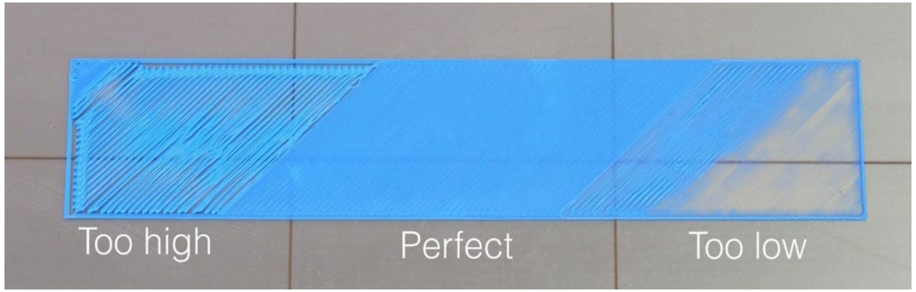


https://www.makepartsfast.com/resolution-defined-3d-printing/, https://www.peri.com/en/business-segments/3d-construction-printing.html, and https://cobod.com/how-long-does-it-take-to-3d-print-a-house/ (accessed on 2023-12-12)
https://phys.org/news/2012-03-3d-printer-nano-precision.html and https://www.laserfocusworld.com/lasers-sources/article/16571636/nanoscribe-prints-3d-mems-and-microscopic-components-on-integrated-circuits (accessed on 2023-12-12)

Print Bed Leveling

› Well-leveled print surface

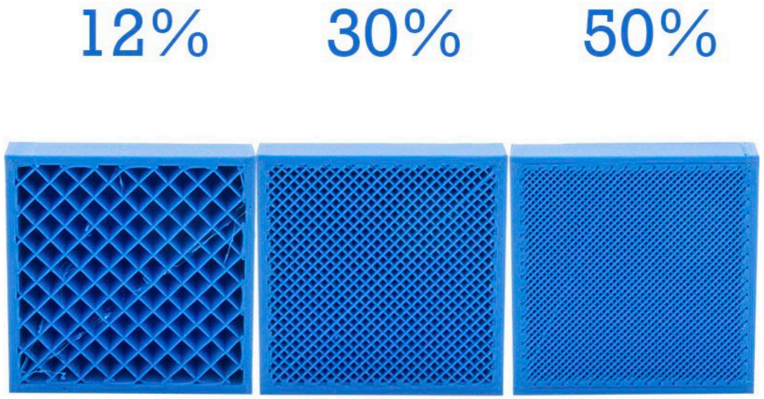


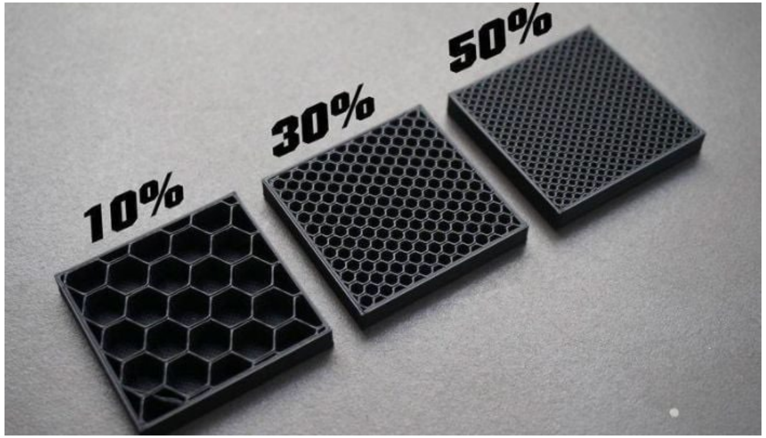


https://cults3d.com/en/blog/articles/6-main-factors-for-perfect-first-layer-3d-printing (accessed on 2024-11-12)

Shell and Infill

- Shelling (contour only)
- Infill of specific density
  - Fill pattern
  - Linear, honeycomb, Hilbert …
  - 100% = solid body



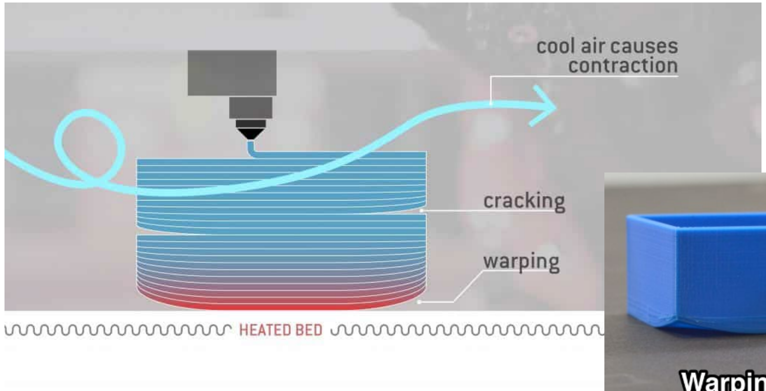


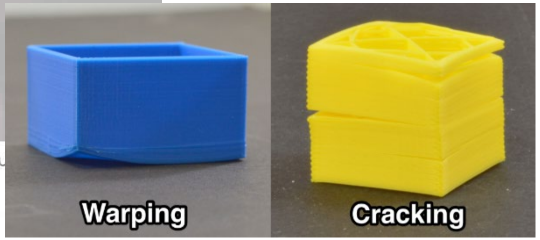
https://filament2print.com/gb/blog/71_importance-infill-3d-printing.html and https://www.3dnatives.com/en/the-infill-puzzle-cracking-the-code-for-perfectly-balanced-3d-prints-1007234/ (accessed on 2023-12-12)

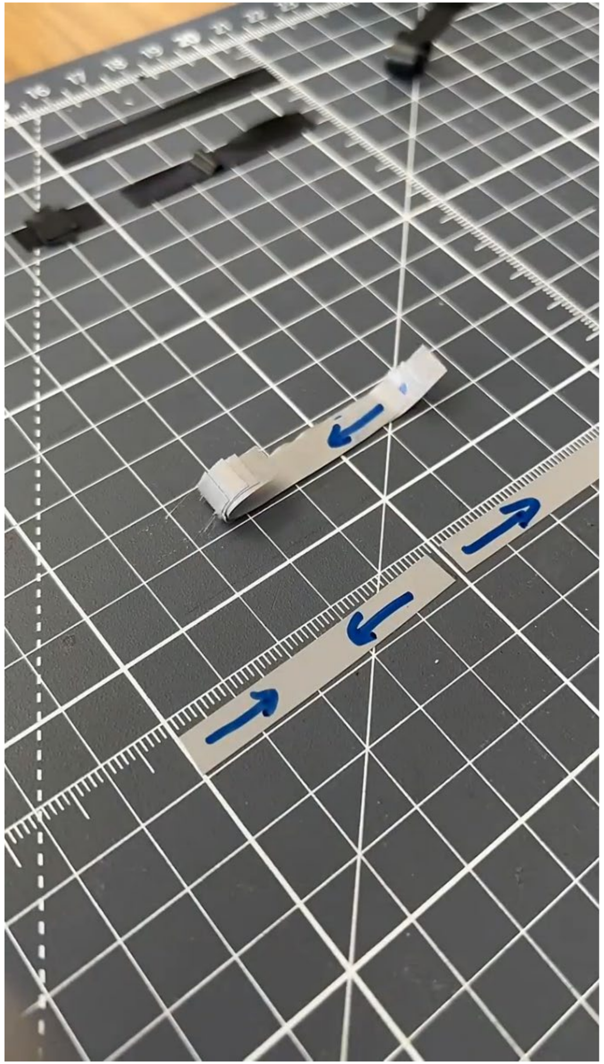
Additive Fabrication Technologies
Fundamentals of 3D Printing

Typical Defects

- Build plate suitable for material
- Sufficient build plate adhesion
- Avoidance of warping and cracking, e.g., due to shrinkage







https://www.box3d.eu/warping-cracking-closed-environment-3d-printers/ (accessed on 2024-11-12)
https://3d4create.com/blogs/3d-filaments/abs-filament-how-to-print-safely (accessed on 2024-11-12)
https://www.youtube.com/watch?v=8bF8jxYwUM4 (accessed on 2024-11-12)

Mechanical Properties

- Model orientation important
- Printing direction: strong/weak

Overhang, Bridging, and Support

- Model orientation important
- Build time
- Support volume
- Support contact area
- FDM can print some overhang
- Water-soluble support

Future of Additive Technologies

Additive Fabrication Technologies
Fabrication Technologies

Finishing

- Post-processing:
  - Binder removal (baking)
  - Annealing: Internal layer bonding and recrystallization to improve stability
- Coloration (e.g. binder jet)
- Subtractive technologies:
  - Improve surface accuracy, smoothing through chemical vaporing with solvents, e.g. acetone



https://formlabs.com/asia/blog/guide-color-3d-printers/ (accessed on 2023-12-12)

https://all3dp.com/2/abs-acetone-smoothing-3d-print-vapor-smoothing/ (accessed on 2023-12-12)

Additive Fabrication Technologies

Fabrication Technologies

3D Sketching

› Manual 3D sketching

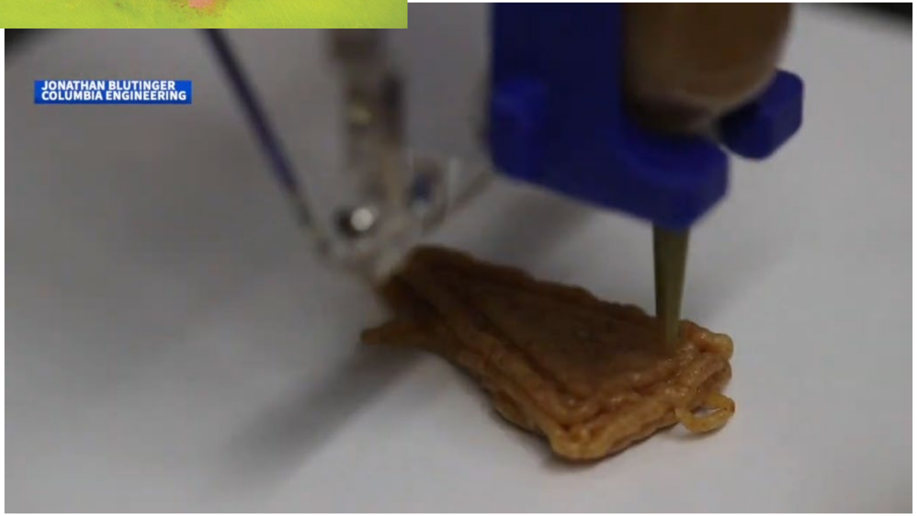
› 3Doodler, LIX, …

LIX: https://www.kickstarter.com/projects/lix3d/lix-the-smallest-3d-printing-pen-in-the-world (accessed on 2023-12-12)
https://dkc87.wordpress.com/2014/05/02/worlds-smallest-3d-printing-pen/ (accessed on 2023-12-12)

3Doodler: https://the3doodler.com (accessed on 2023-12-12)
https://trybestsm.live/product_details/106237183.html (accessed on 2023-12-12)

3D Food Printing

- **Customization** of shape, color, texture, flavor, or nutrition
- **Healthcare**: people with dysphagia
- Used materials:
  - Chocolate
  - Cake doughs and creams
  - Mashes of different nutritive substances, e.g. vegetables, proteins



Wikipedia, File:3D_Printed_Chocolate.jpg (accessed on 2023-12-12)
https://cen.acs.org/food/food-science/3D-printed-foods-enter-kitchen/100/i5 (acc. on 2023-12-12)
https://www.youtube.com/watch?v=EVW2nj5rySE (accessed on 2023-12-12)
https://www.foodnavigator.com/Article/2014/10/21/3D-printed-food-for-the-elderly-may-hit-shelves-in-2016 (acc. on 2023-12-12)

What are the main dis-/advantages of additive technologies?

www.pngwing.com, 2023.

Additive Fabrication Technologies
Additive Technologies

Key Advantages
- Freedom in design and complexity
- Cheaper and faster prototyping
- Customized products
- No (or little) waste of material

Key Disadvantages
- Slow
- Expensive
- Limited volume
- Remaining surface roughness
- Stability
- Local material defects

Additive Fabrication Technologies

Questions?

What are your questions?

www.pngwing.com, 2023.

Project
Honorable Mentions

Celebrating Creativity: Impressive Paper Prototypes

Group 7 - InSight Bag

Group 9 - Smart Trash Can

Design & Fabrication

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