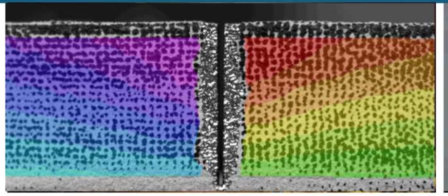
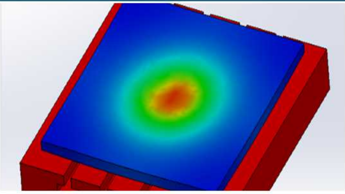
SAND2018-7894PE

Overview of and Design for Additive Manufacturing





PRESENTED BY

Shaun Whetten

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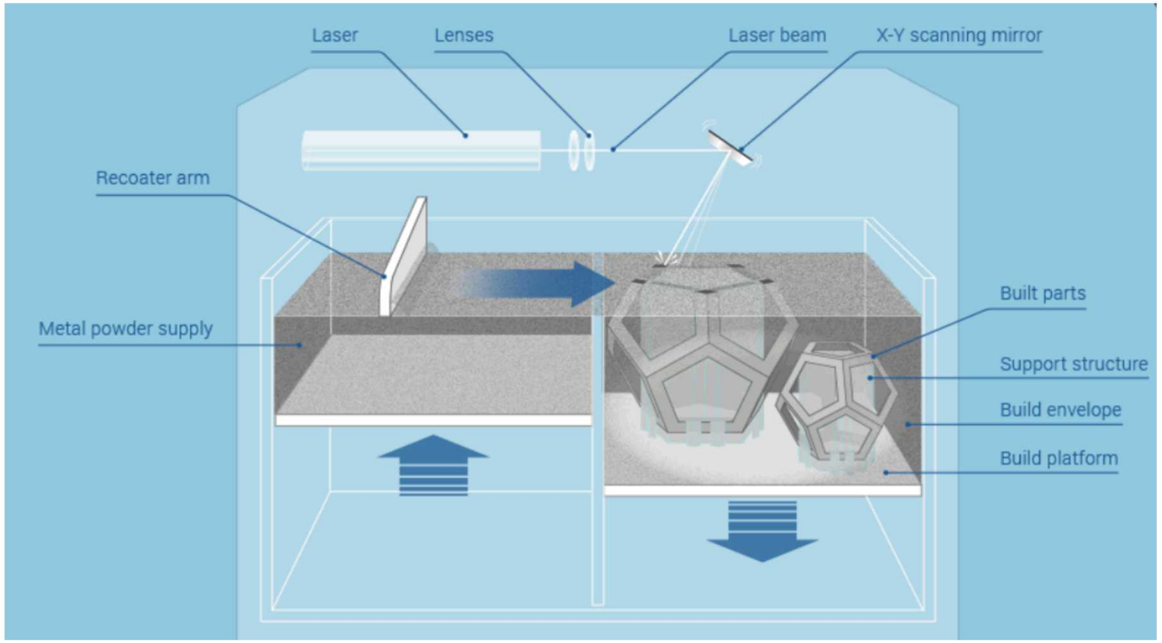
Outline

- Overview of Additive Manufacturing Technologies
- Other Additive Manufacturing Techniques
- Design Considerations
- Go Over Example Part Design

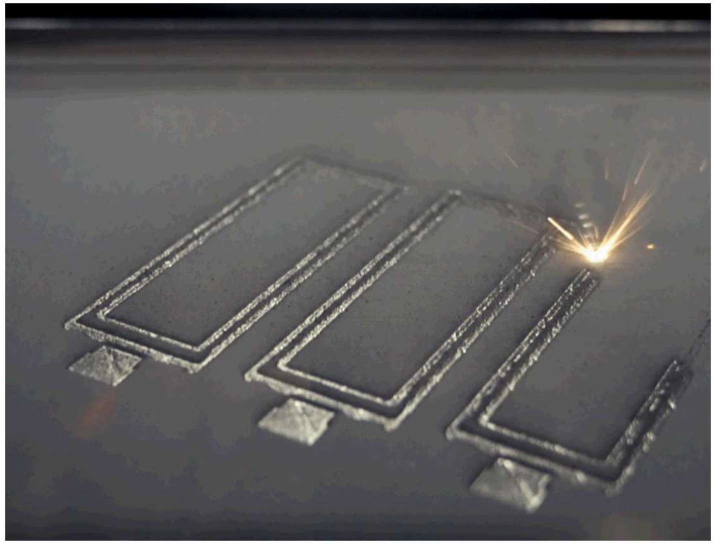
Overview and Design for Additive Manufacturing

Powder Bed

- Uses laser or electron beam to selectively melt particles
- Parts can be applied to engineering applications
- High residual stress in Selective Laser Sintering (SLS) but not so much in Electron Beam Powder Bed (EBPB).
- Can be used to print most materials that are in powder form
- Most common use is for metals
- Excellent feature resolution and surface finish



https://www.additively.com/en/learn-about/laser-melting

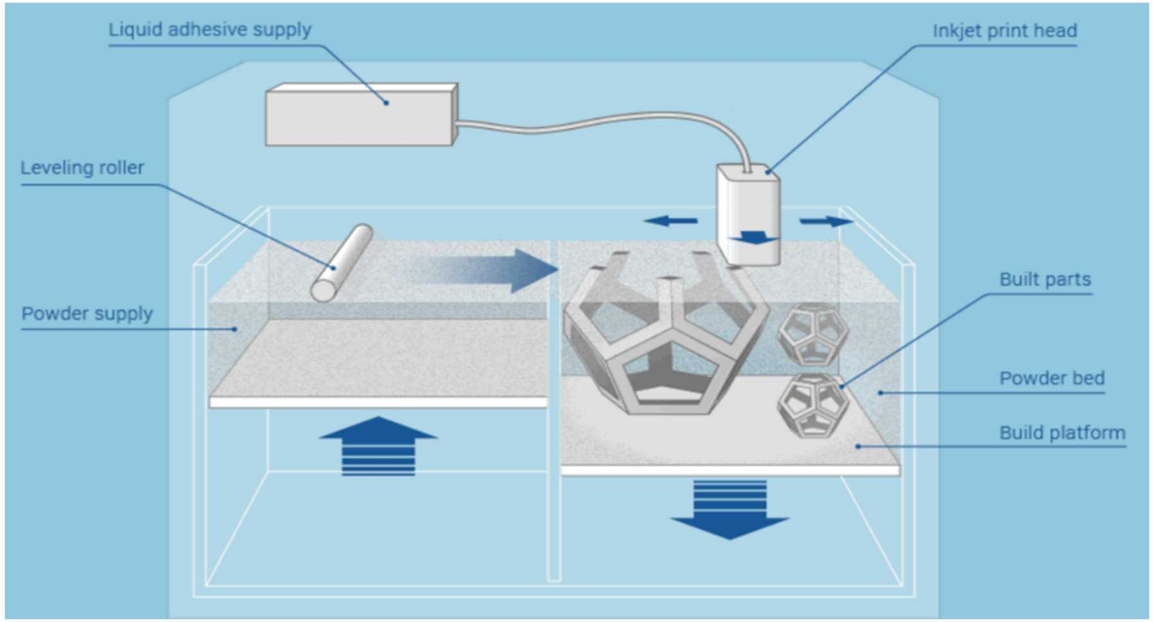


http://www.harbec.com/capabilities/rapid-prototyping/

Image of 3D systems Pro-X 200

Binder Jet

- Uses binder adhesive to hold powder particles together
- Binder is then burnt out and particles are sintered
- Low densities require post processing (post processing required for engineering applications)
- Low residual stress
- Relatively inexpensive
- Can do large overhangs and bridges without support



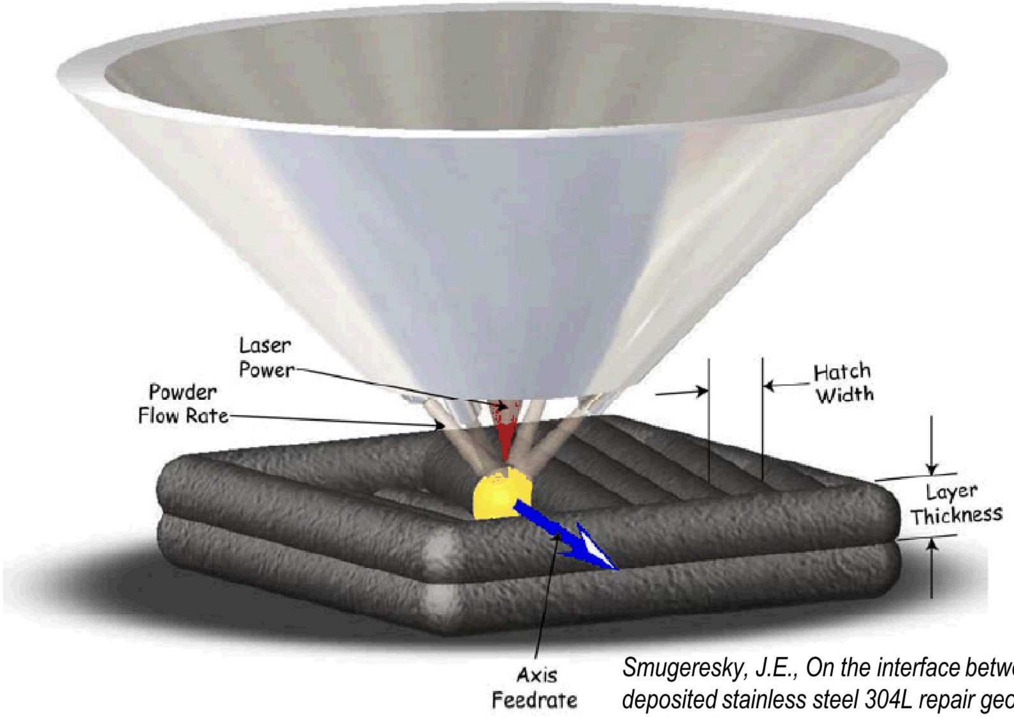
https://www.additively.com/en/learn-about/binder-jetting

https://www.sculpteo.com/blog/2016/09/28/top-10-future-3d-printing-materials-that-exist-in-the-present/

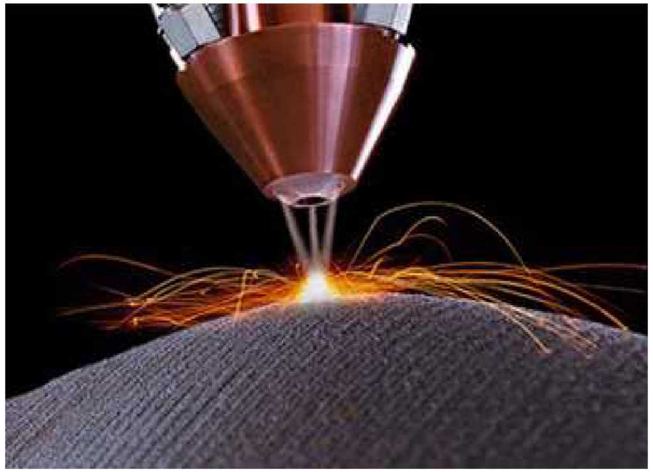
Digital Metal Binder Jet http://www.metal-am.com/digital-metal-begins-commercial-production-binder-jet-metal-systems/

LENS (Laser Engineered Net Shaping)

- Invented at Sandia National Labs
- Powder injection moves with laser and nozzle
- Can be used in Multi Material and Functionally Graded applications
- Can by used in hybrid additive subtractive applications
- High density of parts
- Poor surface finish
- Does not handle overhangs and bridges well



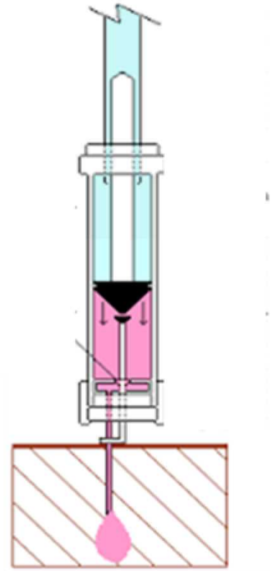
Smugeresky, J.E., On the interface between LENS deposited stainless steel 304L repair geometry and cast or machined components.



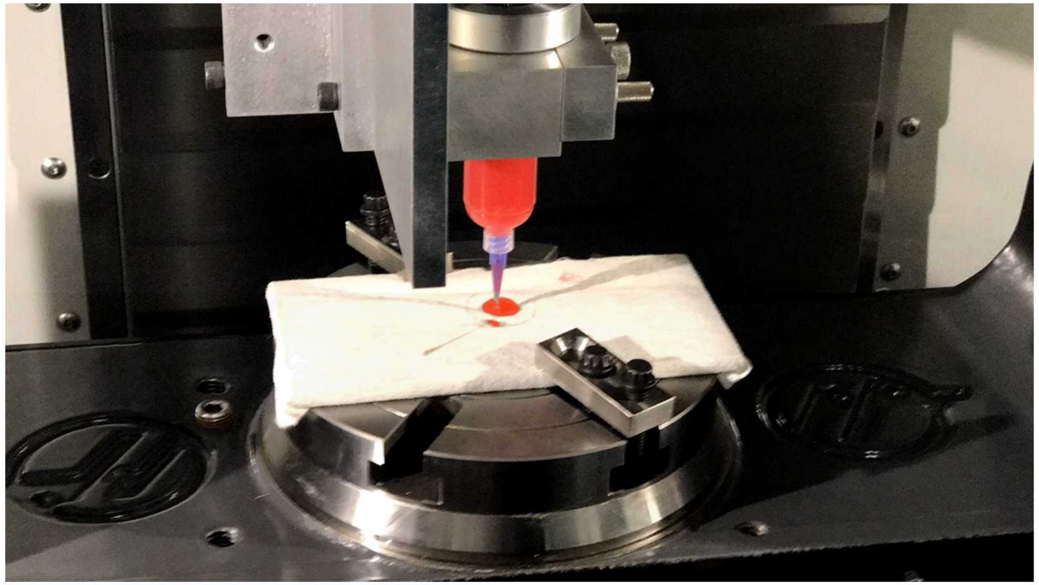
https://inside3dprinting.com/news/optomec-and-tec-partner-to-bring-3d-metal-printing-systems-to-classrooms/17112/

Extrusion Printing

- Material loaded in syringes
- Syringe pump dispenses material through a nozzle
- Small overhangs, but in general bridges cannot be achieved
- Commonly used to dispense materials that are loaded with ceramics or metals
- High deposition rates are commonly achieved
- Is often difficult to "shutter" the deposition making starts and stops messy

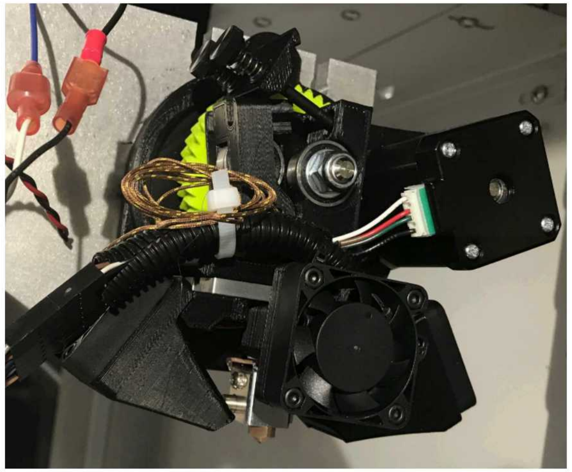


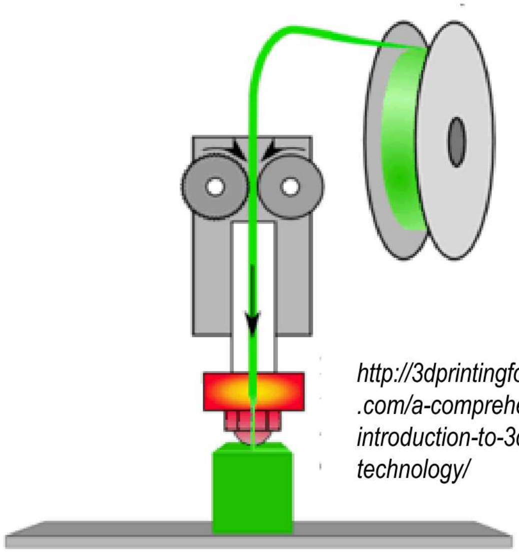
https://www.researchgate.net/figure/Simplified-schematic-of-an-electrohydrodynamic-jet-system-used-for-cell-printing-adapted_fig10_265804290



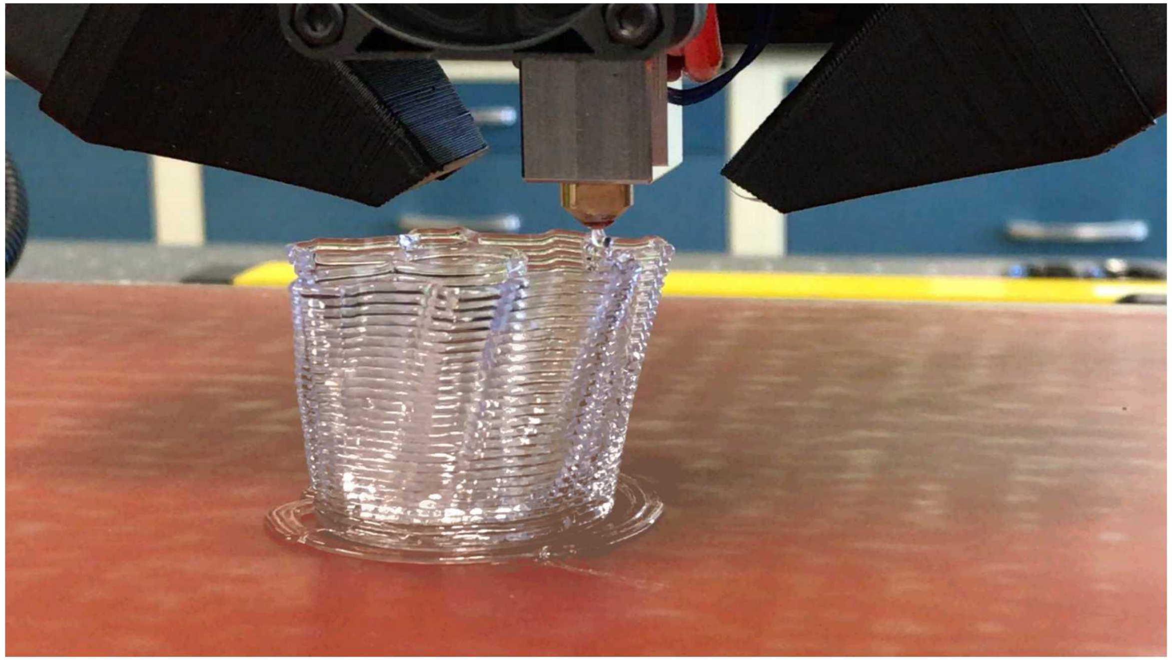
FDM (Fused Deposition Modeling)

- Most common type of 3D printing especially for the hobbyist
- Filament is fed into hot tip and extruded as a bead of material
- Overhangs more than ≈40° and most bridges need support material
- Working temperature 90°C- 290°C
- Bed temperature 25°C- 110°C
- Most commonly used for polymers that can be extruded into wire form
- Some experimental work has been done on filaments loaded with metals and ceramics



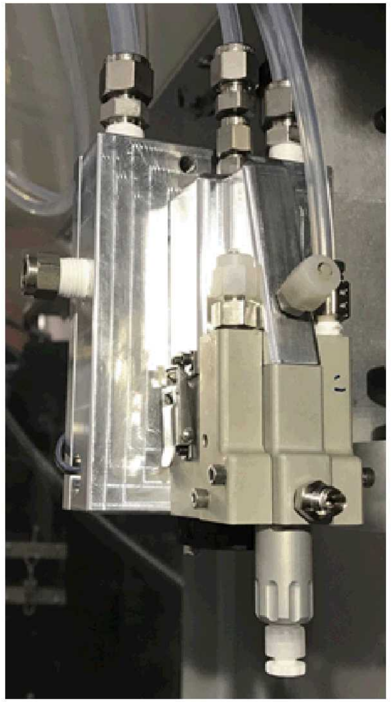


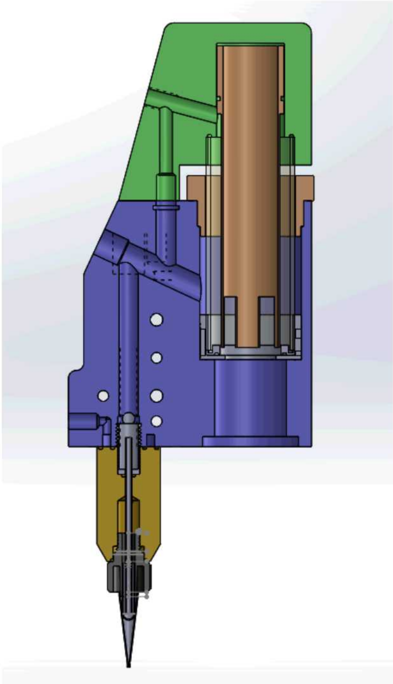
http://3dprintingforbeginners.com/a-comprehensive-introduction-to-3d-printing-technology/



NanoJet

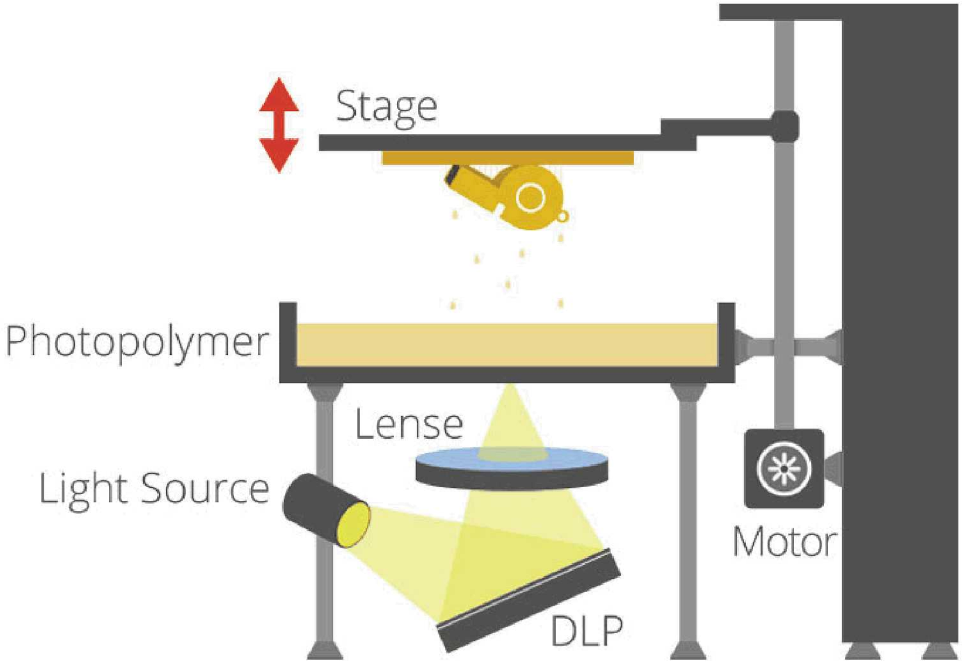
- Invented at Sandia National Labs
- Atomized cartridge of ink
- Carrier gas transports ink particles to the substrate
- Aerodynamic focusing of particles controls deposition width
- Layer heights 0.5-5 micron
- Deposition widths 0.05 – 0.15mm
- Generally prints 2D/ coatings because layer thickness is so small
- Loaded inks generally have the particles in Nano sizes





Stereolithography

- Uses UV curable resins and inks
- Extremely high resolution
- Can have excellent surface finish
- Some printers can print base ball sized parts in 10-20 minutes
- Great for intricate features and large amounts of detail
- Resins can be loaded with metals and inks (but this is still very experimental)
- Many systems are available at affordable prices for high end hobby uses



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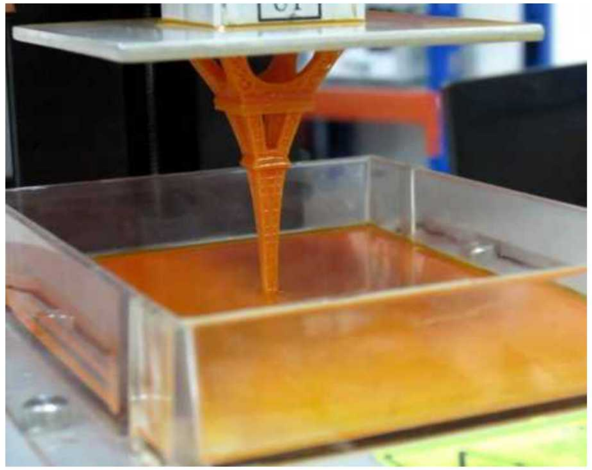
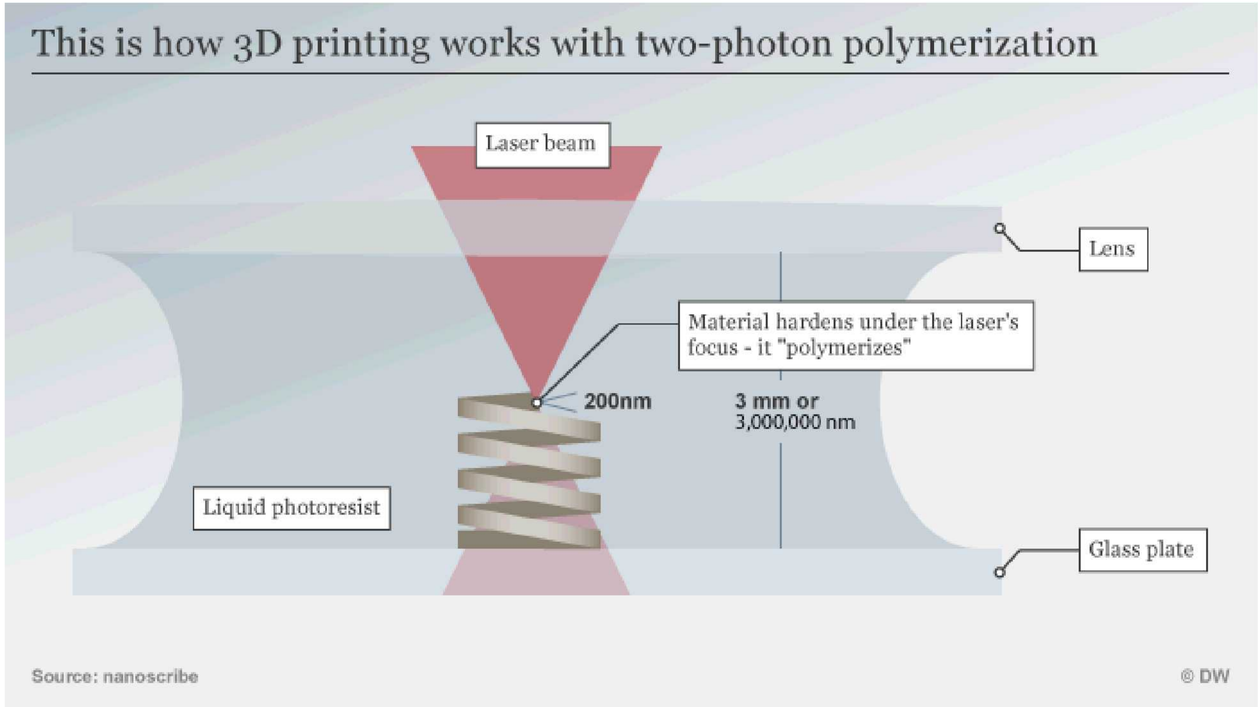


http://3d.krakatoaranch.com/index.php/2016/12/11/3d-printer-tech-stereo-lithography-apparatus-sla-digital-light-processing-dlp/

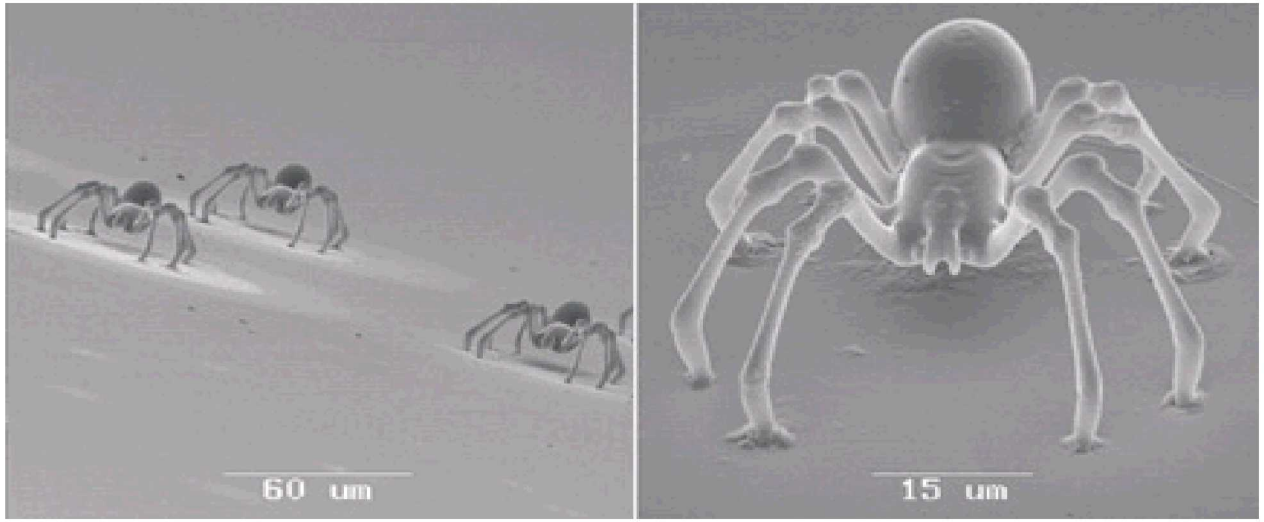
https://www.cnet.com/videos/formlabs-announces-second-high-resolution-laser-drawn-resin-3d-printer/

2 Photon Nano

- Uses near infrared laser to cure UV curable photoresists
- Resolution on the micron and sub-micron level can be achieved
- Cannot generally print parts more than a few millimeters
- Applications in microelectronics, biological, batteries and others



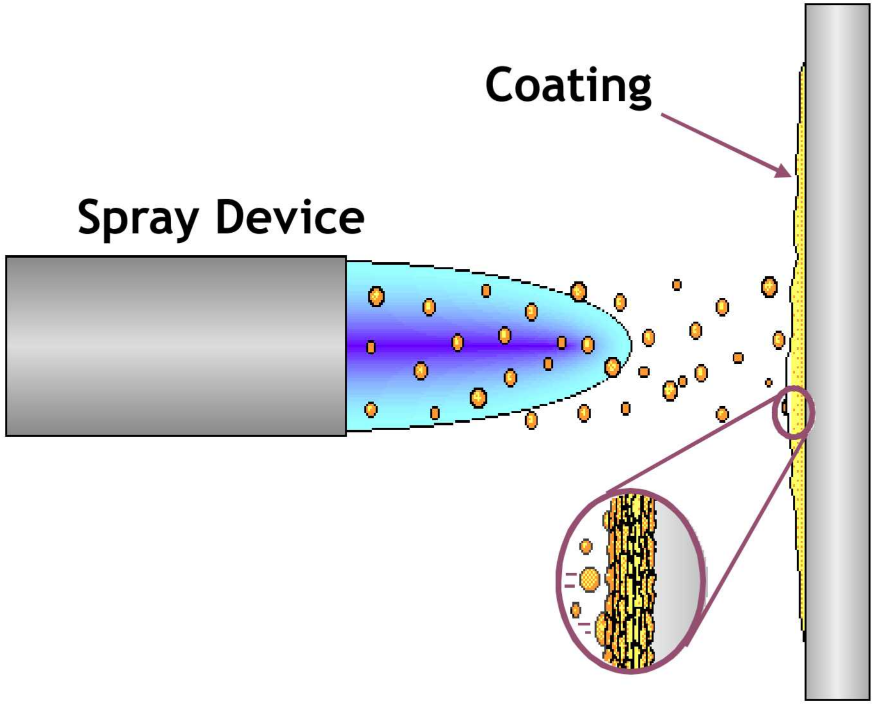
https://www.dw.com/en/a-micro-robot-for-use-in-the-body/a-39095362



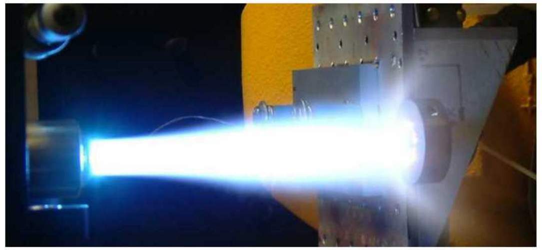
https://nationalpost.com/news/nano-technology-laser-printers

Thermal Spray

- Thermal spraying = coating processes in which heated/melted materials are deposited onto a surface.
- High deposition rate over large area. *mostly constrained by line-of-sight.
- Thickness range ~ 20 um to several mms, depending on process/feedstock.
- Quality assessed by measuring porosity, oxide content (in metallic coatings), hardness, bond strength and surface roughness. Generally, the coating quality increases with increasing particle velocities.



Particle Temperature & Velocity at impact determine coating microstructure and properties.

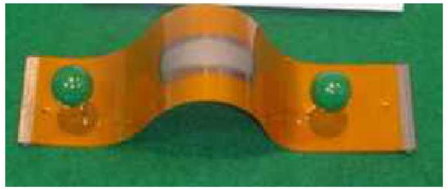


Thermal Spray

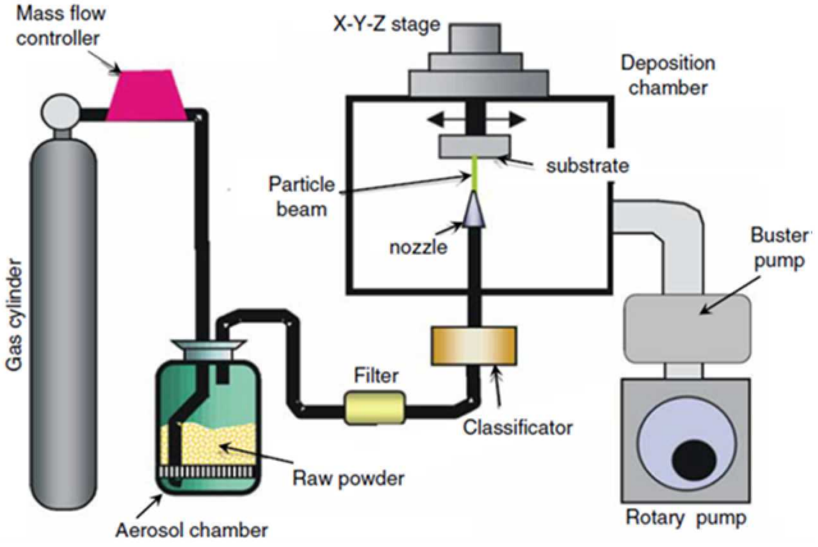
Aerosol Deposition

- Solid Sub-micrometer Particle Deposition
- High density, nanocrystalline coatings, upto 100 μm thick possible
- Metallic, Ceramic, Polymer, Composites
- Compressive Residual Stress

Ceramics are conventionally processed at > 700^{o}C. A room temperature (RT) process eliminates high processing temperature, enabling materials integration.

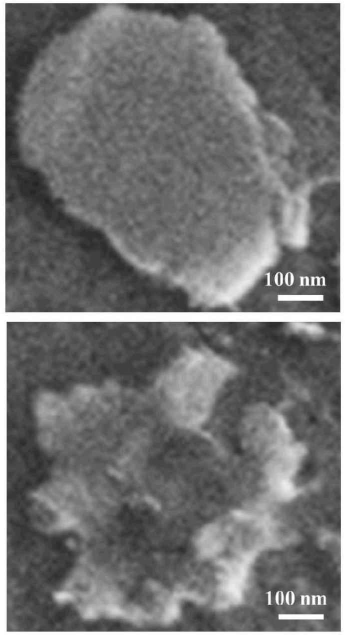


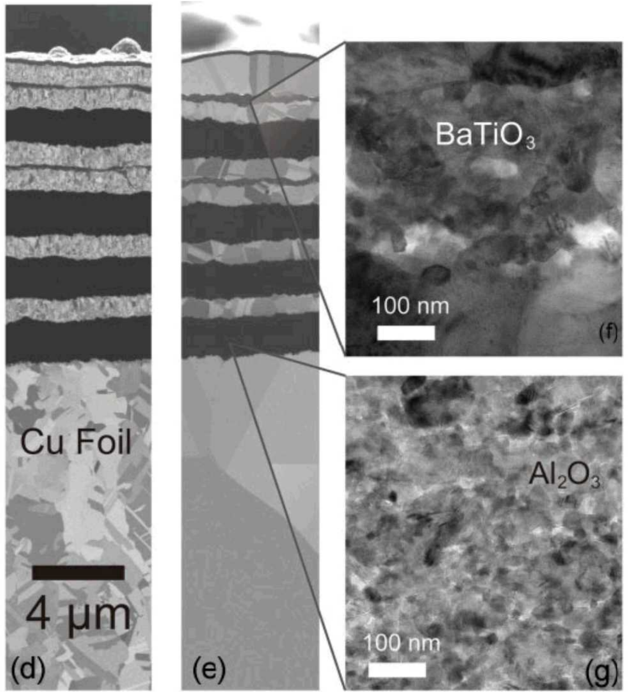
AD Flexible electronics from J. Akedo. *JTST.,* 2007:17:181



Schematics of AD system from J. Akedo. *JTST.,* 2008:17:181

Al_2O_3 single splat particles in AD
Sarobol et al. SAND2016-2870



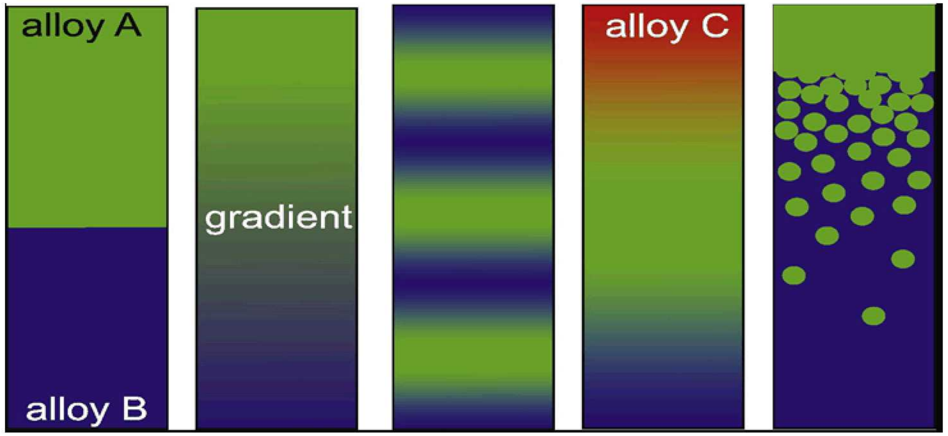


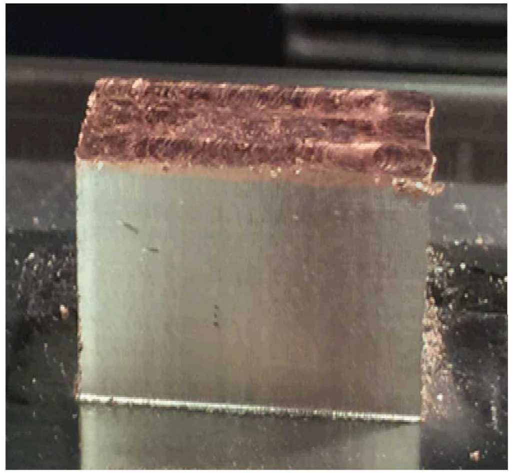
$BaTiO_3/Al_2O_3/Cu$ multi-layered structure produced by AD and electroplating from Y. Imanaka *et al*. *Adv Engr Mater.,* 2013:15:1129

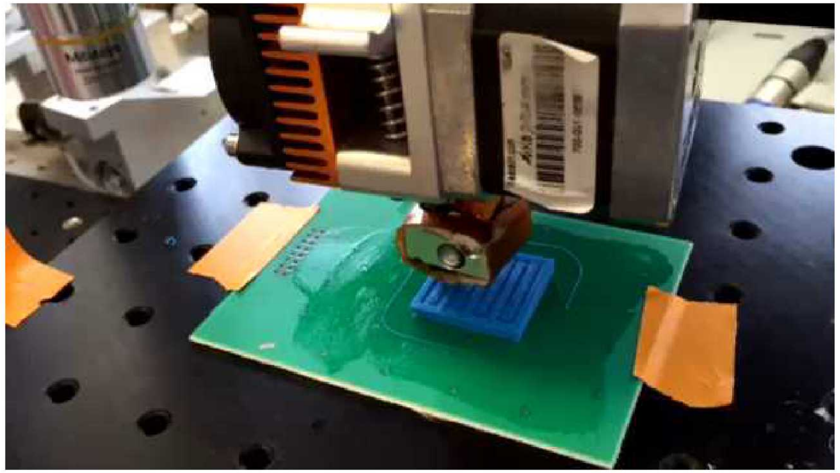
Other Additive Manufacturing Techniques

Functional Grading and Multi-Material Printing

- Applications where different properties are desired in different areas of a part
- Can be used for embedded sensors or circuitry
- Can make printing of two or more incompatible materials possible
- Must make sure that desired materials can be cured/post processed in the same environment

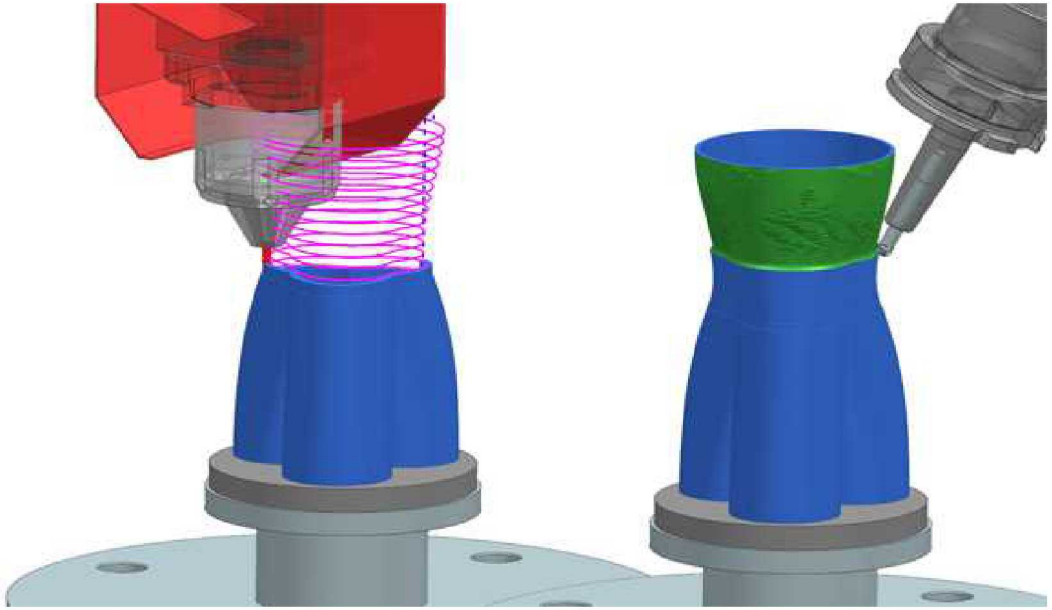






Hybrid Additive Subtractive

- Print desired net shape and then use a machining tool on the same piece of equipment to machine high tolerances into the part
- Increases surface finish to those achievable by machining
- Reduces waist, time and money
- Toolpath generation is currently very difficult especially on 4+ axis machines



http://www.digitaleng.news/virtual_desktop/2016/10/the-race-is-on-to-fill-the-am-gap/

https://www.economist.com/babbage/2013/12/31/adding-and-taking-away

Additive Repair

- Utilizes Hybrid Additive Subtractive capabilities for repair of broken parts.
- Material is build up in desired area and then machined into tolerance.
- Repair procedures have been certified for expensive parts by companies such as Rolls Royce and the U.S. Air Force
- Saves money when used on expensive and hard to machine parts

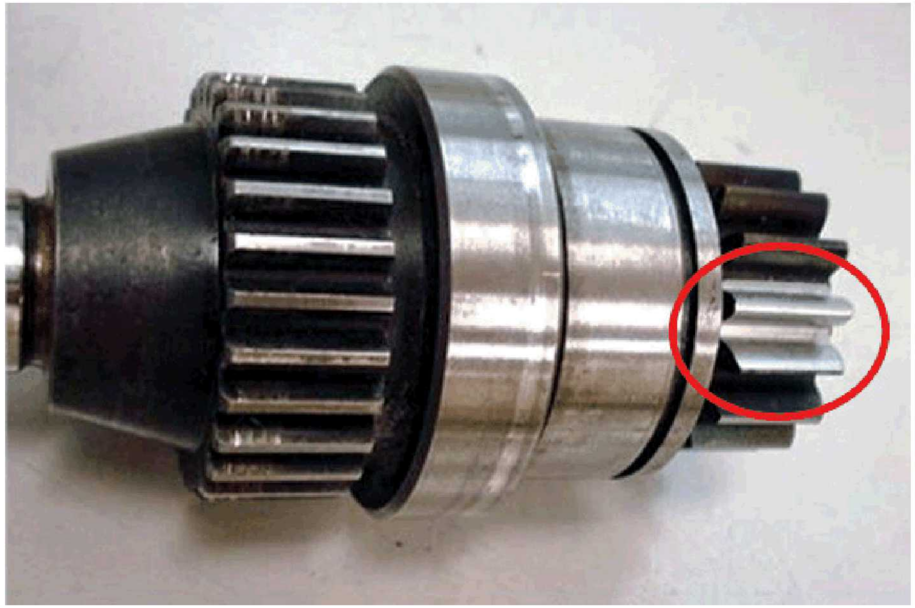


Photo provided by RIT

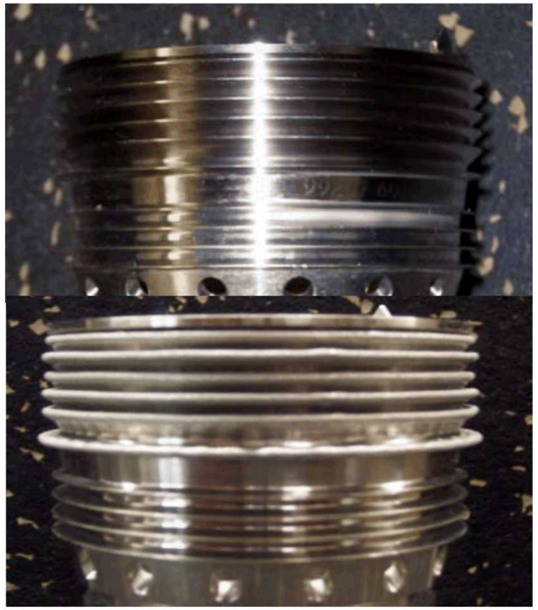


Photo provided by RPM Technologies

Photo provided by Optomec

Design Considerations

This section covers considerations that a designer should have when choosing a print technology

Feature Resolution

- Every print technology can achieve different feature resolution. Designers must be familiar with the tool they plan to use so they are aware of limitations
- Feature resolution can vary from material to material on the same print technology
- Feature resolution can be different in the z-direction than in the x-y-directions.

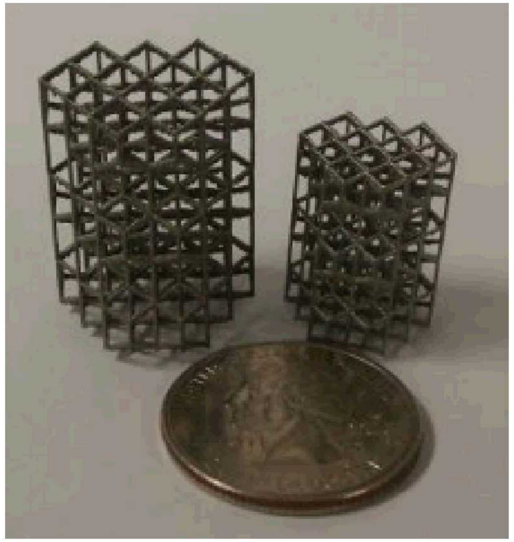


Photo provided by Proto Labs Design Guide


http://www.fabbaloo.com/blog/2017/6/1/vader-systems-unique-3d-metal-printing-process

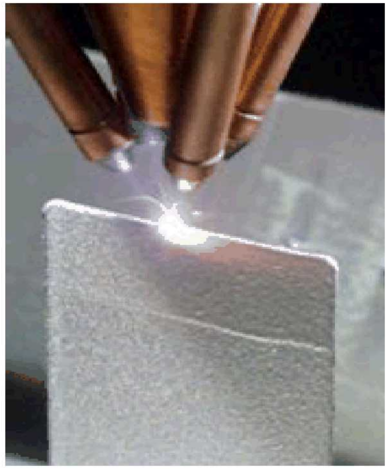


Photo provided by Optomec

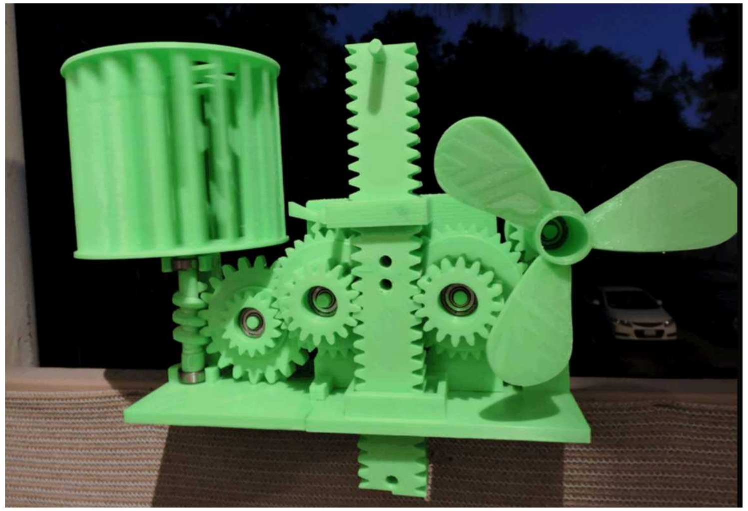


Photo provided by Thingiverse

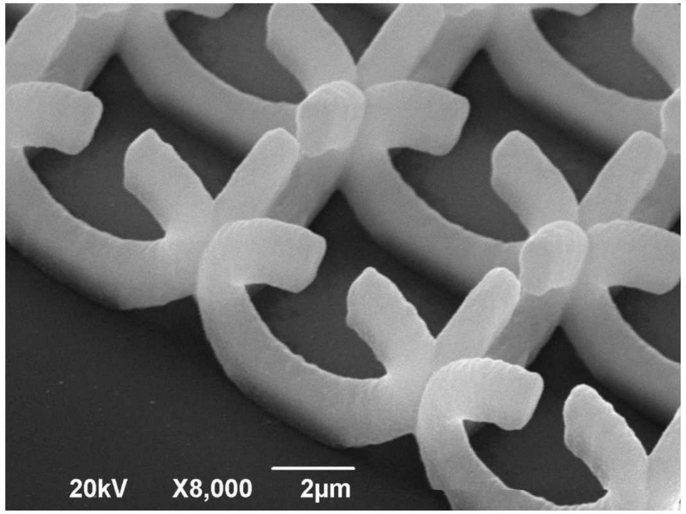


Photo provided by Nanoscribe

Surface Roughness

- Some print technologies can achieve very smooth finish while others may require post processing for desired applications
- Surface roughness can vary across the part depending on conditions in local area (overhangs and bridges can change surface finish)
- Surface finish can be modified by mechanical or chemical methods

https://rigid.ink/blogs/news/how-to-smooth-pla-to-a-mirror-finish

http://www.fabbaloo.com/blog/2017/6/1/vader-systems-unique-3d-metal-printing-process

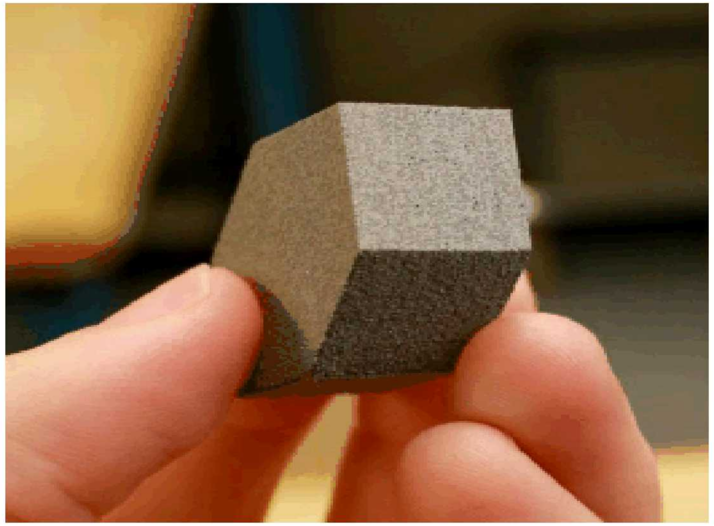
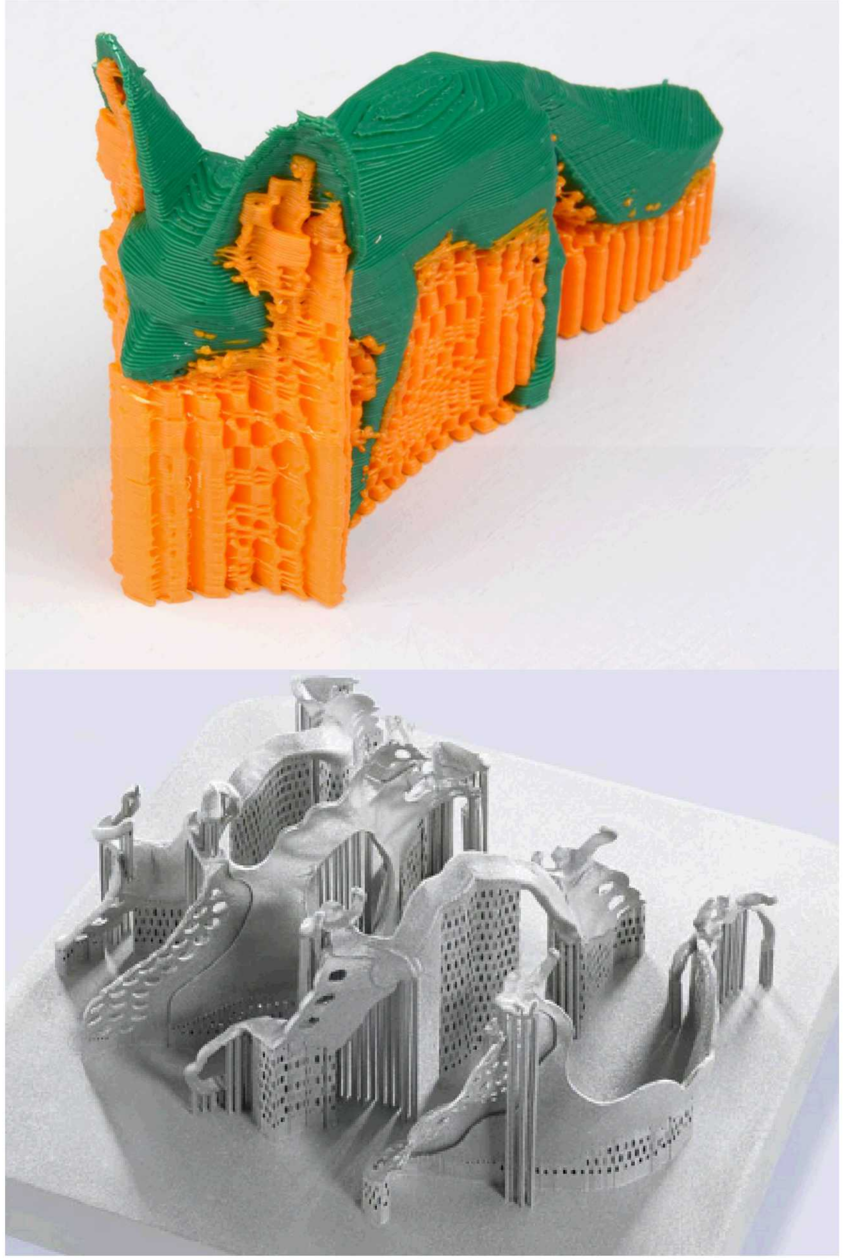


Image provided by Proto Labs design guide

Support Requirements

- Most print technologies require support for large overhangs and bridges
- Two main types of supports
  - Use same material as printed part (this is harder to remove, and creates a rough surface finish)
  - Use a different material than the printed part (usually a material is selected that can easily be removed)
- Usually support material s not printed solid, making it weaker and easier to remove



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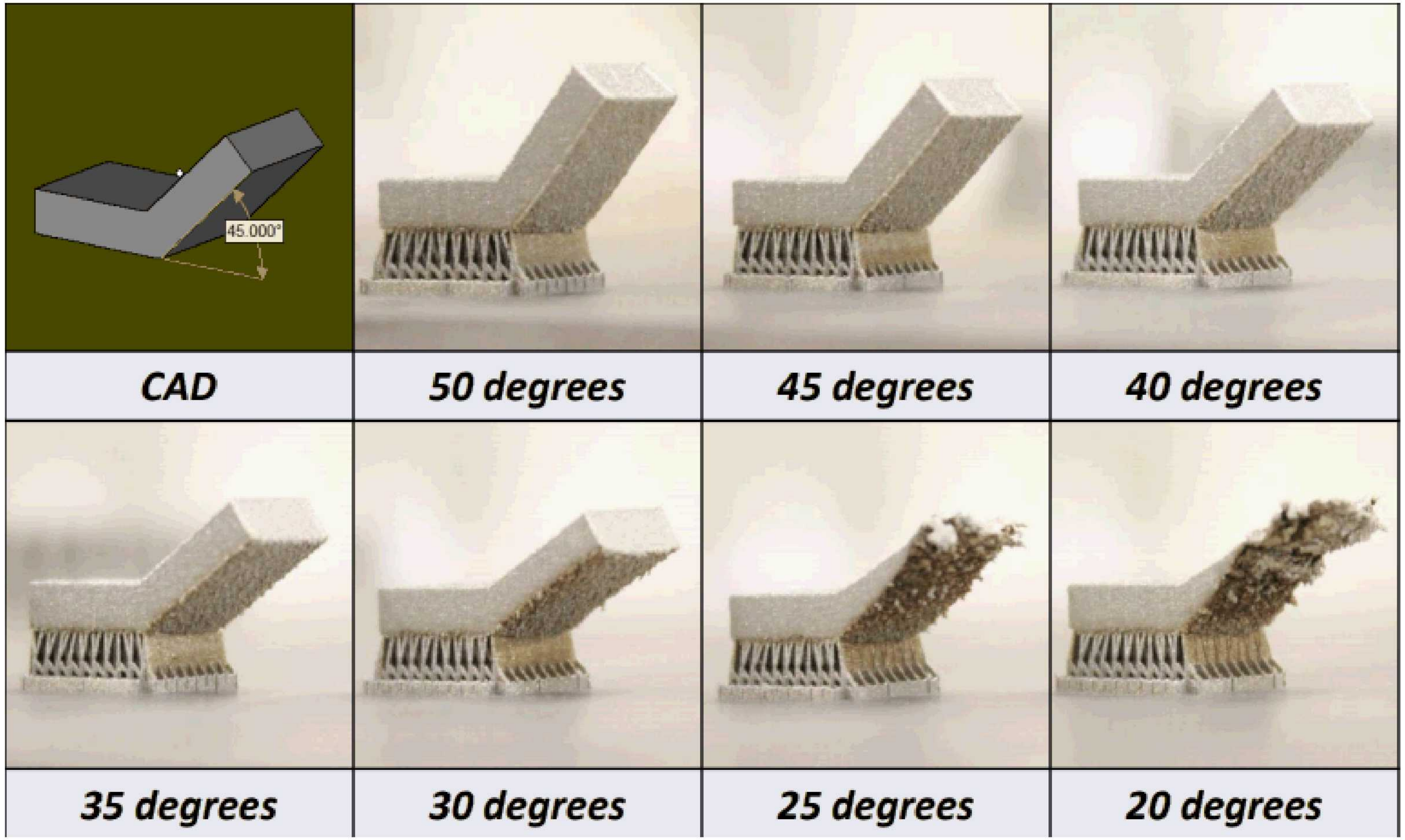
Self-Supporting Angles

- Most printers can only handle a certain level of overhang without supports
- Surface roughness often gets worse as limits are reached
- Once limits are reached support material must be used to create desired geometry



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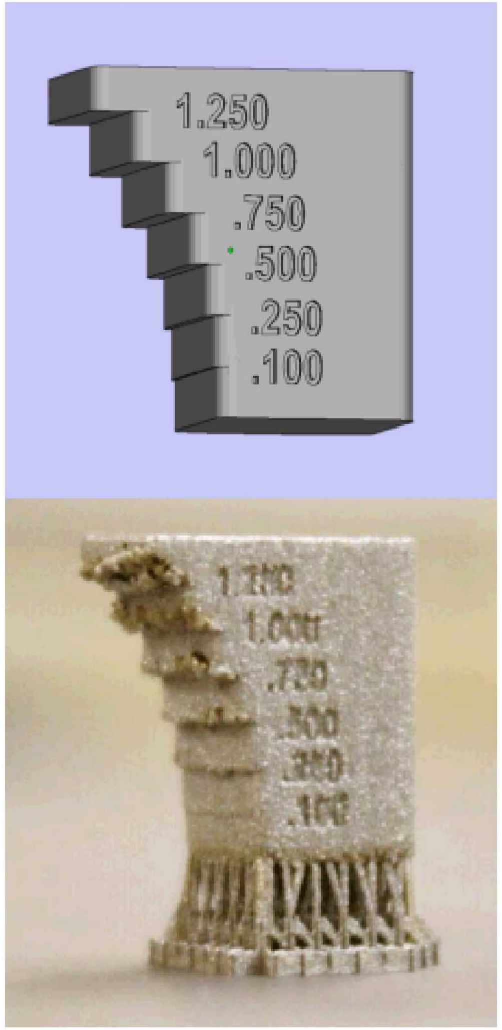
Overhangs

- Most printing technologies cannot provide overhangs of substantial length
- Once limits are met, support material must be used to provide necessary support
- Designs that provide a self supporting angle instead of a flat overhang are superior
- Overhangs have and impact on surface roughness especially on the lower side of the overhang



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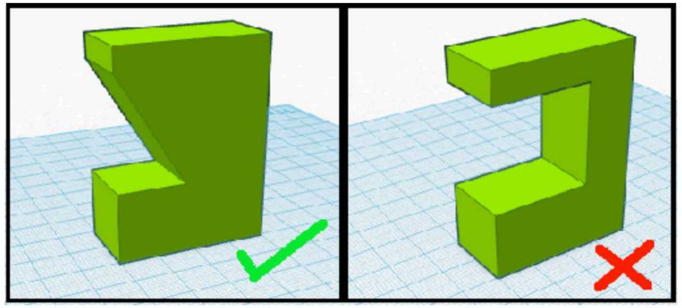
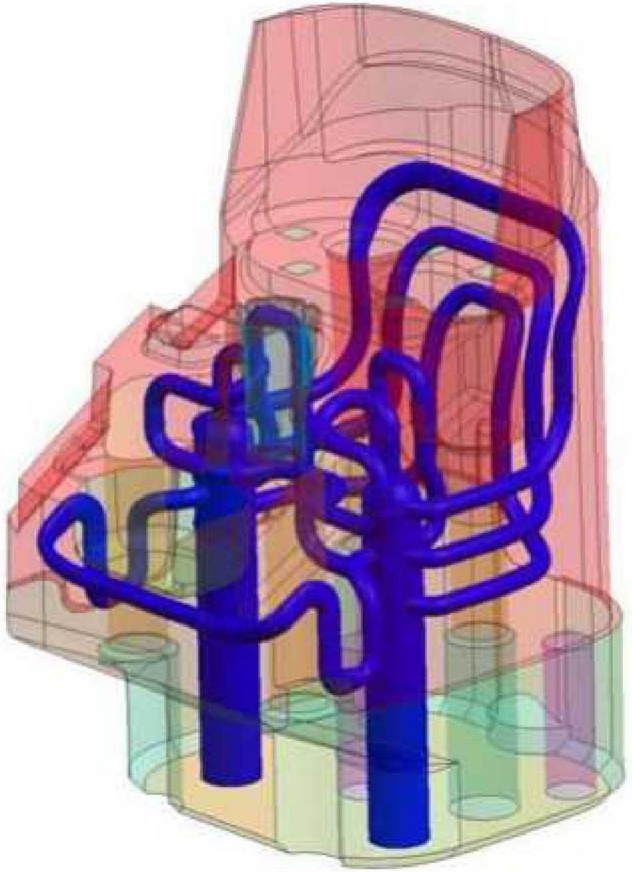


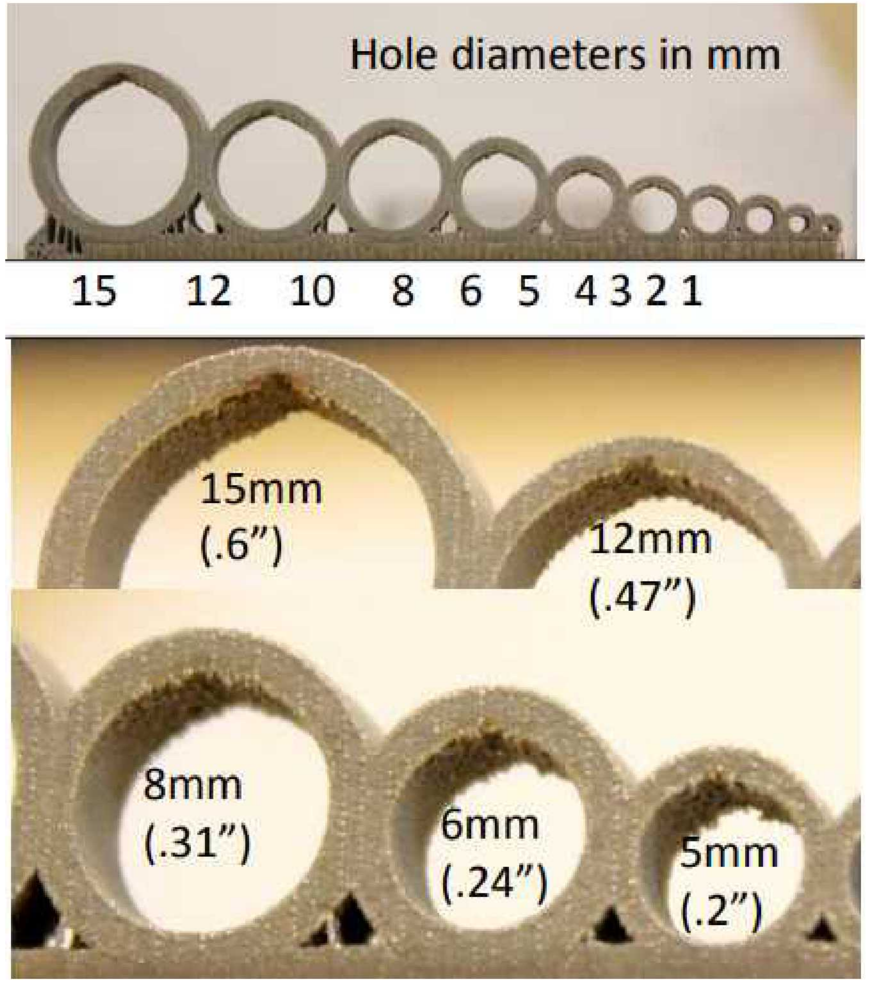
http://www.maker.si/howto3dprint/

http://www.maker.si/howto3dprint/

Channels and Holes

- Many print technologies cannot provide channels and holes
- If channels and holes can be printed, there is generally a limiting feature size that can be maintained
- Orientation of the hole matters – For example vertical holes are generally easy to produce while horizontal holes may be impossible to create
- For some print technologies paths to the surface must be maintained to enable removal of excess material/powder





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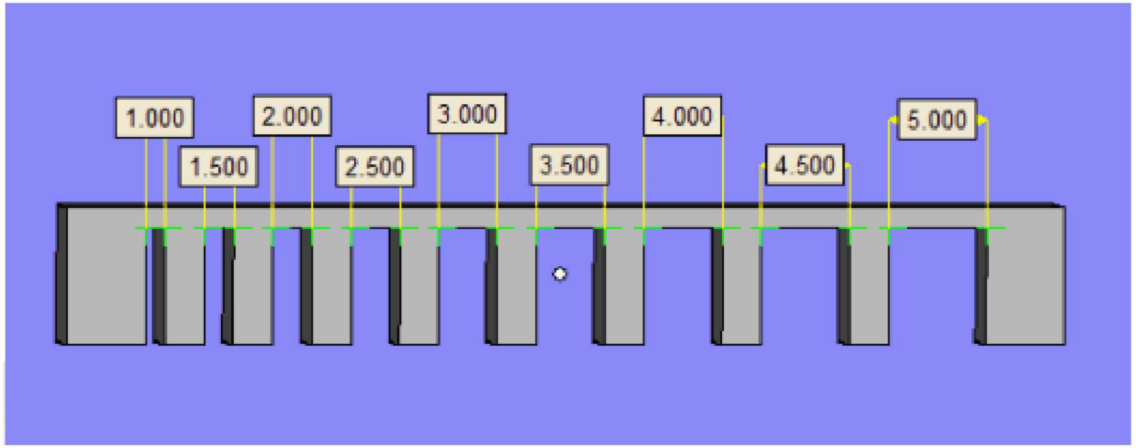
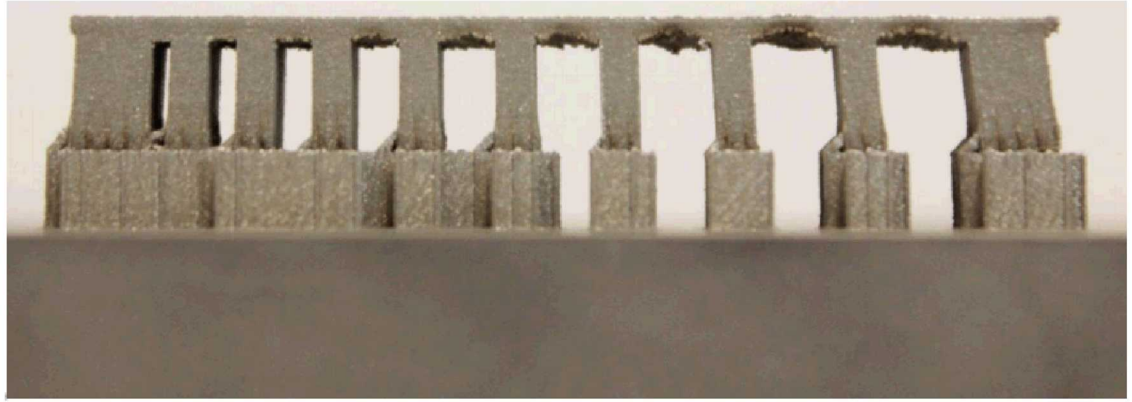
Bridges

- Most print technologies can handle the creation of small bridges
- Once limits are met support material must be used to support the gap
- Bridges have an impact on surface roughness especially on the lower side of the bridge
- Designing the bridge pillars as self supporting angles instead of vertical walls can be helpful



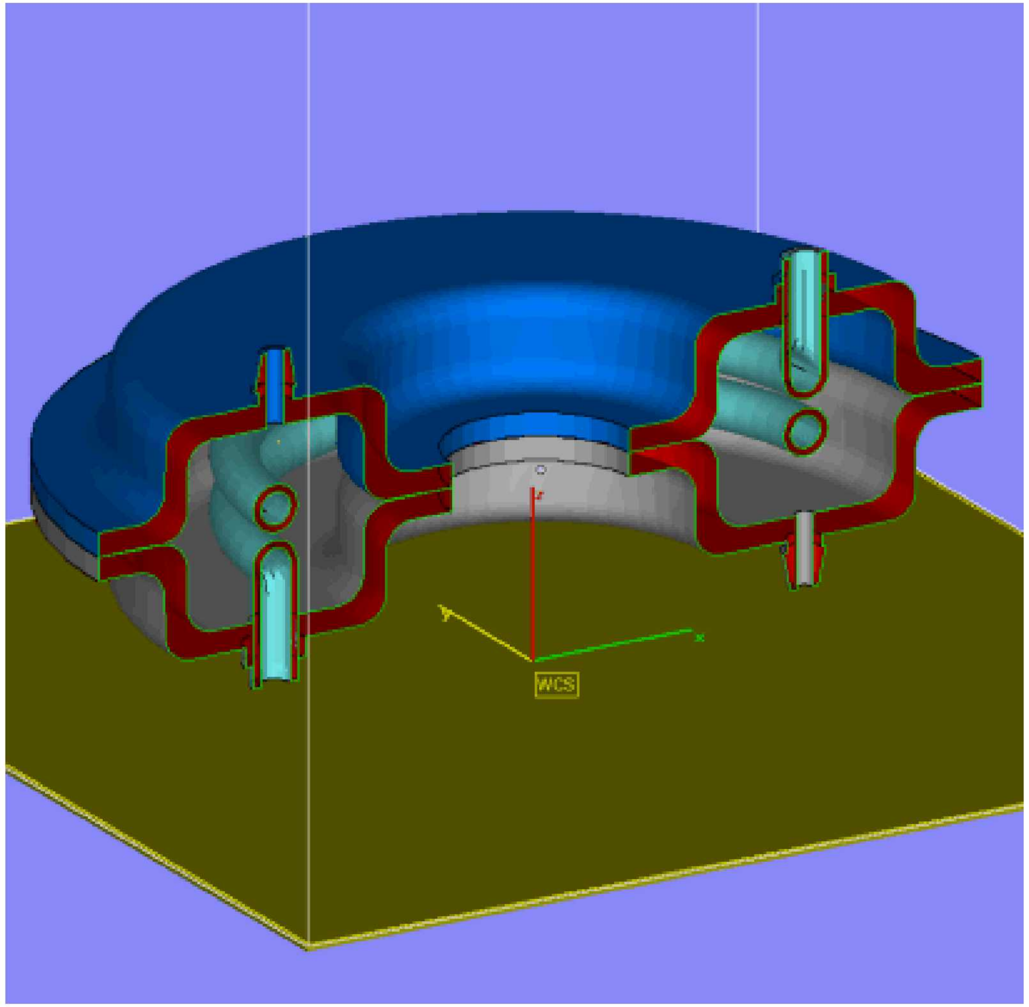


Images provided by Proto Labs design guide

Design of Example Part

Initial Design - Rev1

What makes this part hard to print?



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Initial Design - Rev1 - Analysis

- Not designed for additive manufacturing
- 3 component design
- All three components have overhangs or holes that cannot be printed without support
- Expensive ($$$) to remove support material from internal holes and channels
- Poor surface finish
  - From support
  - From overhangs
- Not likely to hold high tollerances

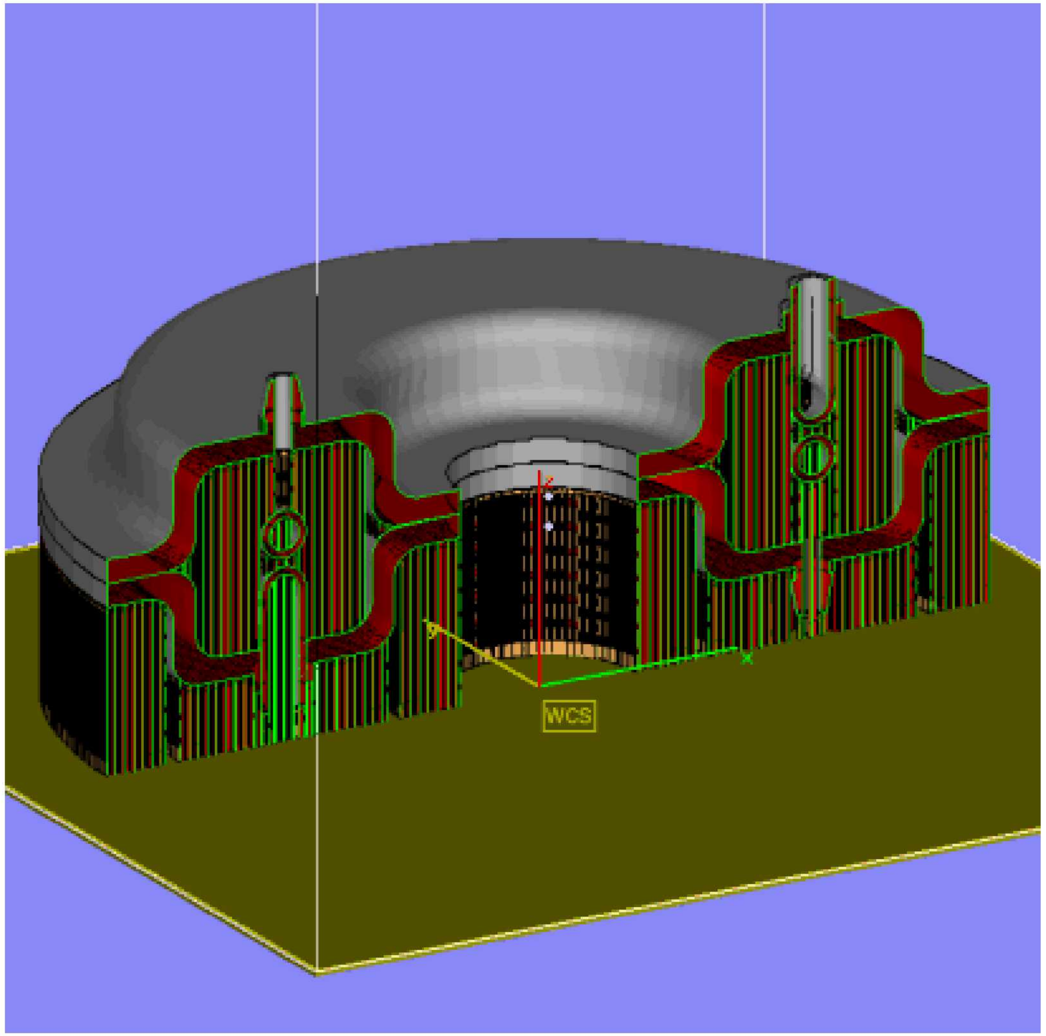

Image provided by Proto Labs design guide

Improving the Design

Additive manufacturing can be used to reduce the number of components….

What if it is not necessary to have 3 separate components?

Improved Design - Rev2

What is better about this design?

What makes this hard to print?

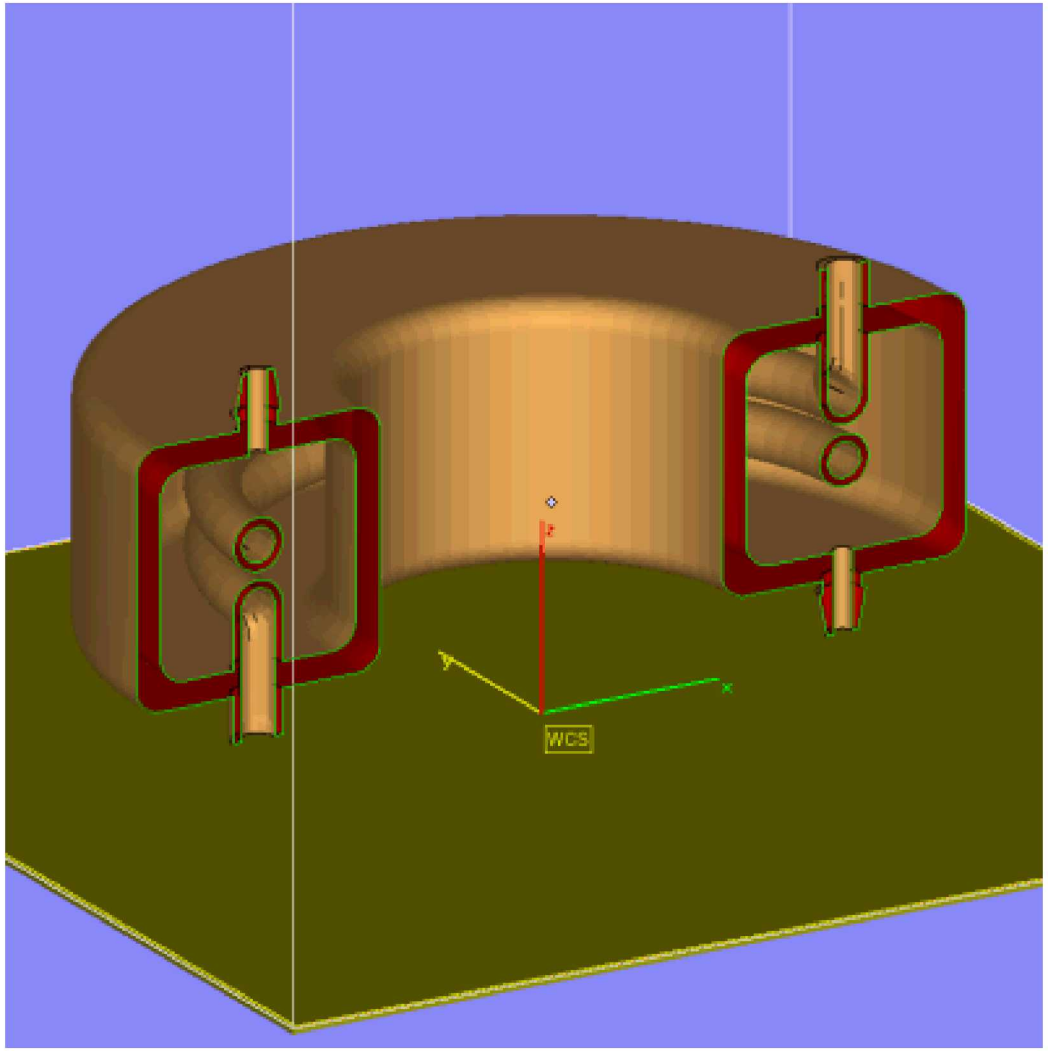

Image provided by Proto Labs design guide

Improved Design - Rev2 - Analysis

- Improvements
  - Reduction of components
  - Reduction of print time
  - Reduction of weight
- Challenges
  - Not designed for additive manufacturing
  - All holes and channels have overhangs that cannot be printed without support
  - Expensive ($$$) to remove support material from internal holes and channels
  - Poor surface finish
    - From supports
    - From overhangs
  - Not likely to hold high tolerances

Design is improved and cheaper to manufacture, but still has all the same challenges

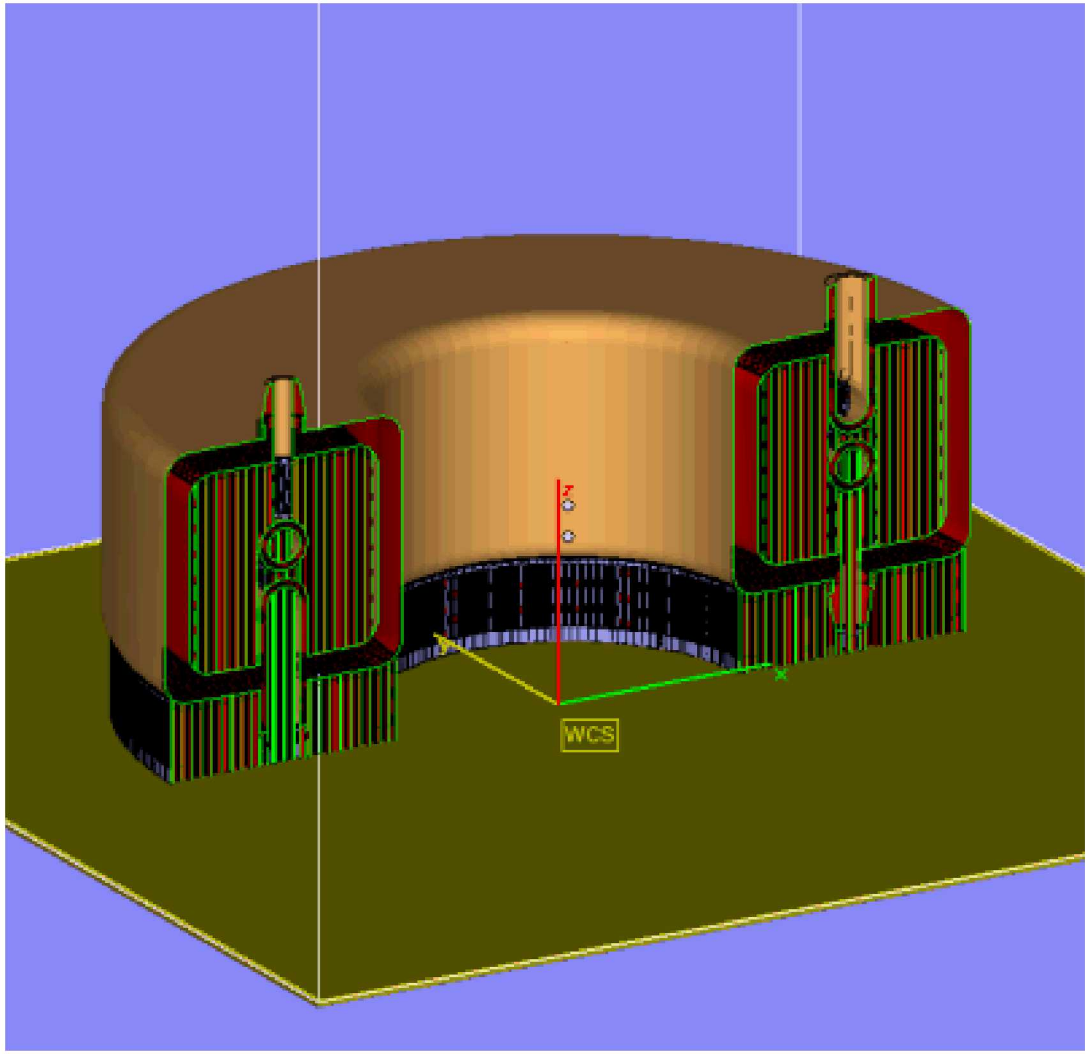

Image provided by Proto Labs design guide

Improving the Design

Additive manufacturing can be used to make shapes that cannot typically be easily manufactured….

What if the case doesn't have to be square?

What if the tubes don't have to be round?

Optimized Design - Rev3

What is better about this design?

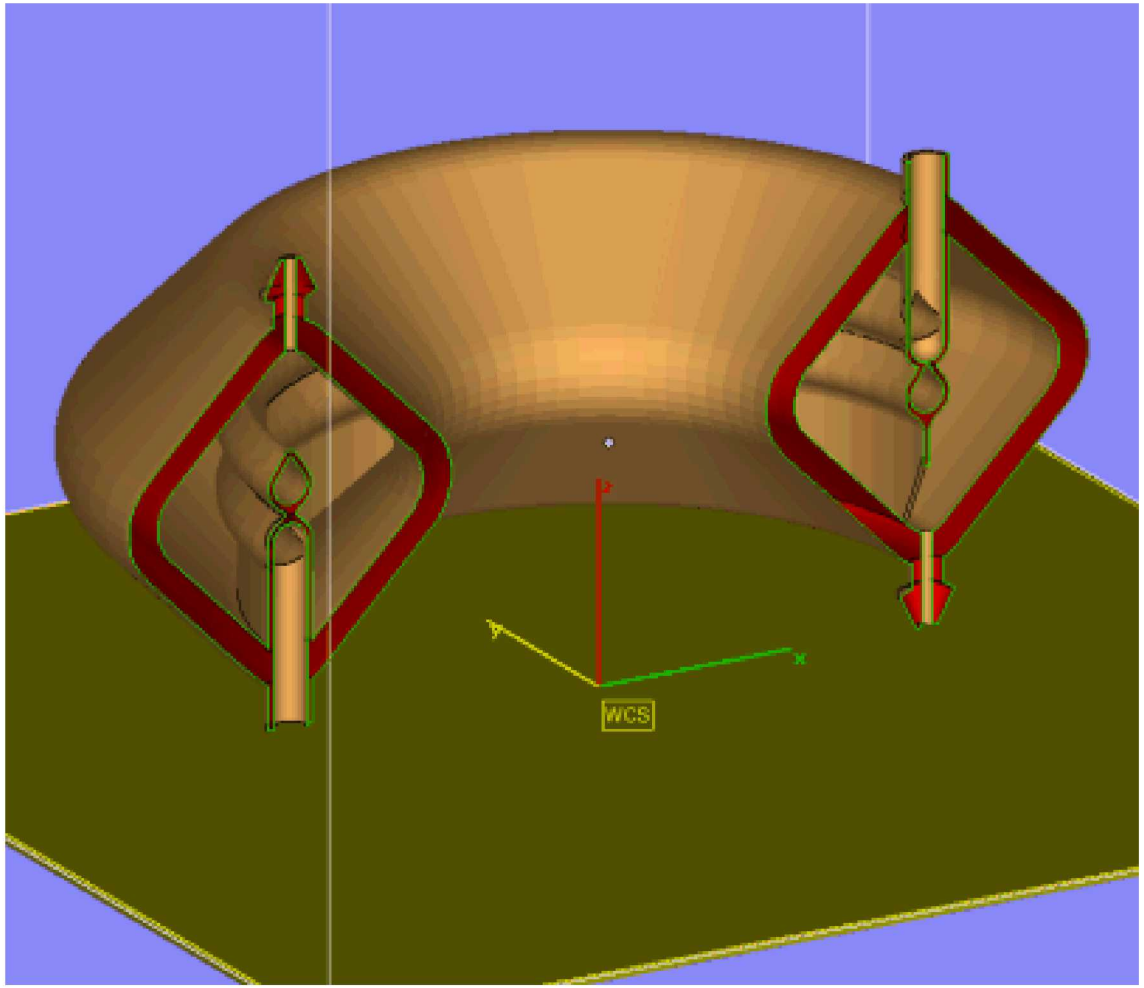

Image provided by Proto Labs design guide

Optimized Design - Rev3 - Analysis

- Improvements
  - Self-supporting features eliminate need for most supports
  - Supports that are needed are a low cost ($) to remove
  - Best surface finish of proposed designs
  - Likely to hold better tolerances

What could still be improved?

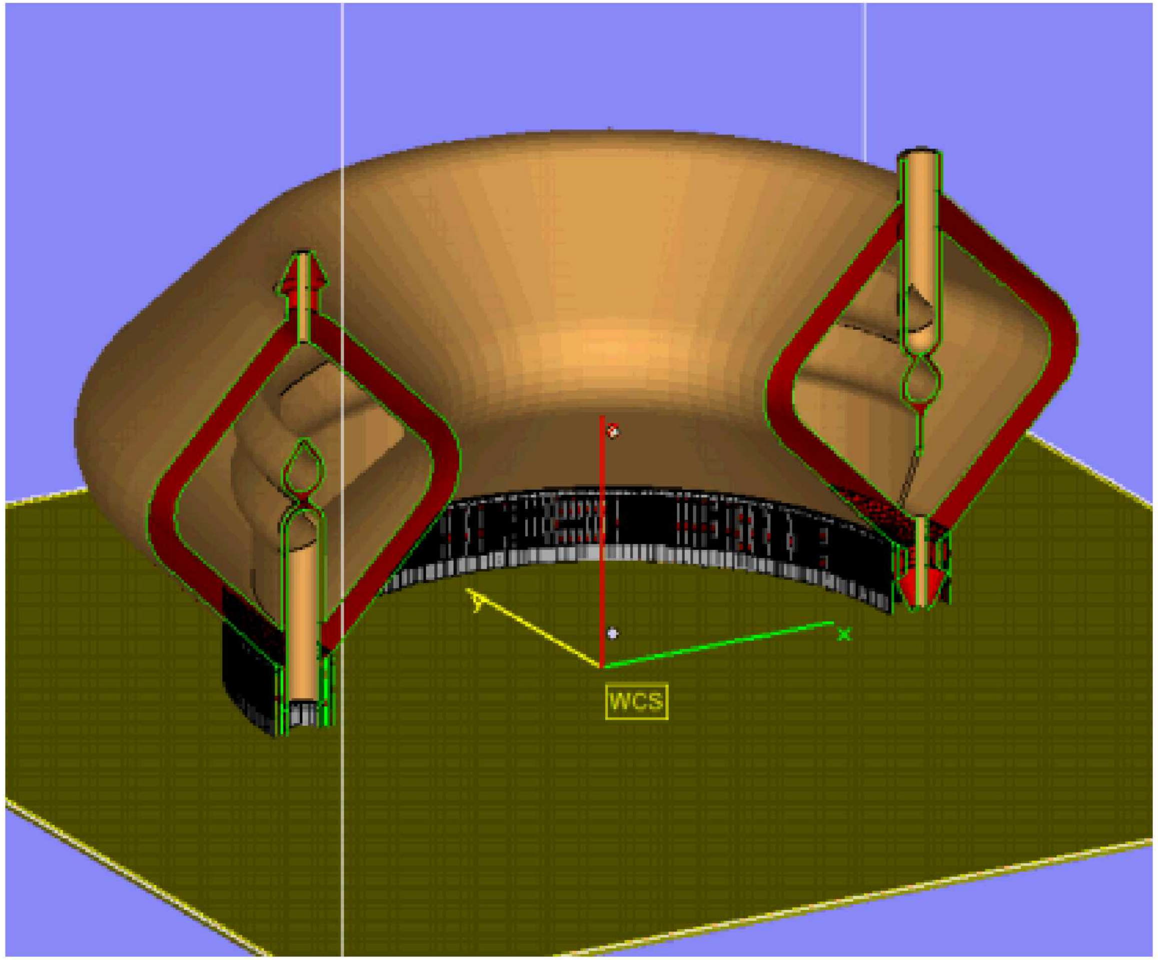

Image provided by Proto Labs design guide

Conclusions

- Numerous printing technologies available for production
- Multi-Material, functional grading, hybrid additive-subtractive, and additive repair offer capability of expanding AM capabilities
- Knowledge of print capabilities offers designer opportunities to reduce time, reduce cost, and increase performance of parts

Questions?