

Additive Manufacturing Technology and Trends

MCA Session Topic: Generalizing Fundamental AM Principles

6/25/25

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Deep Dive Goal

- ~~1. Conceptualization and CAD~~
- ~~2. Conversion to STL/AMF~~
- ~~3. Transfer to AM Machine and STL File Manipulation~~
- ~~4. Machine Setup~~
- 5. Build***
- ~~6. Removal and Cleanup~~
- ~~7. Post-Processing~~
- ~~8. Application~~



- “We Can De Build It”
- *Deep Dive isn’t done until everyone performs build processes with 0 compromises
- “Tradeoffs” != “Compromises” (find print setting tradeoffs to exceed your 3D printing goals)

“Build It” here... Build It Anywhere

Machine Movements

Active vs. Passive

Motors & Gears

Motors & Jets

Mirrors & Motors & Masks

Mirrors & Lasers & Lenses

Materials & Bonding Methods

Plastic Filament, Heat & Pressure

Glue & powder

Resin & UV

Resin & Lasers

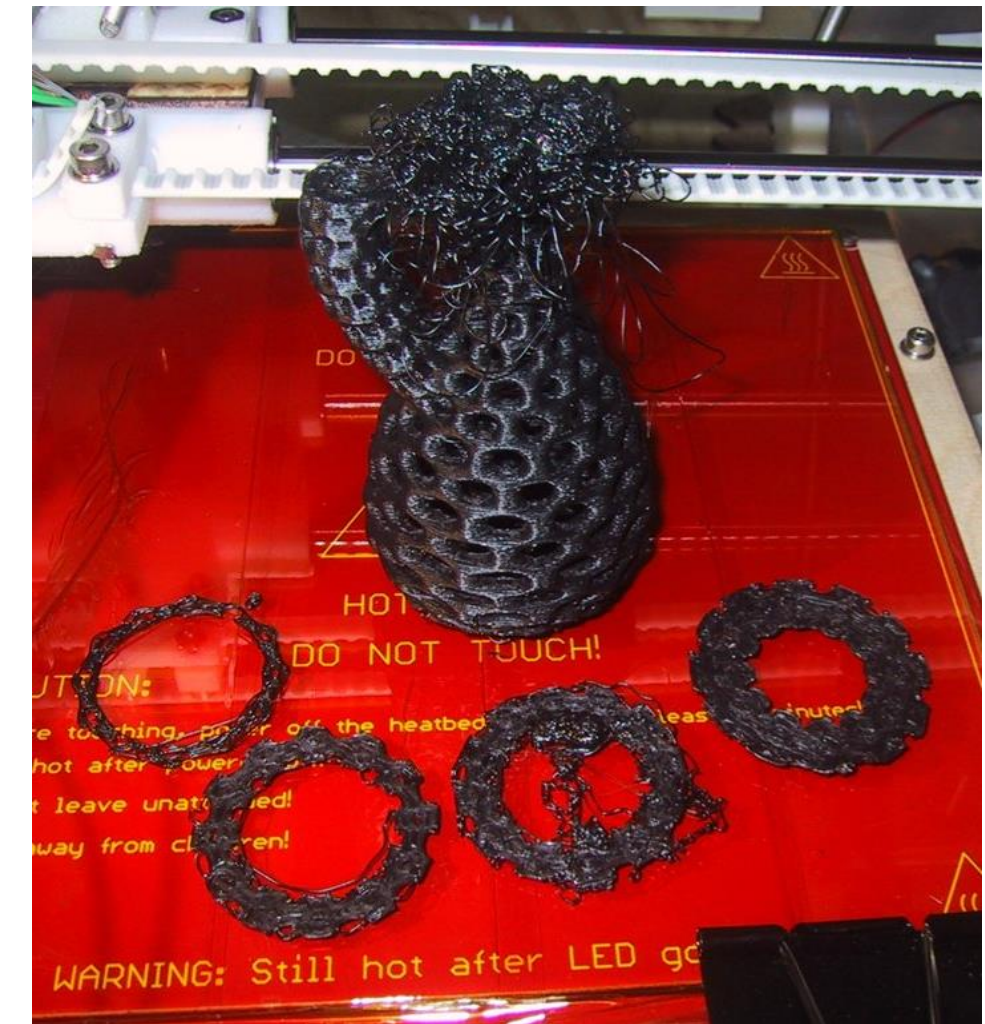
Special Powders & Lasers

Machine Movement Overview

- ◉ Machine component movements and material bonding methods must work together
- ◉ A machine with specific movements can use different materials
- ◉ Material properties are part of designing an AM machine
 - This makes AM fundamentally different than any other manufacturing technology
 - The machine component movement capabilities are always better than the tolerances of the produced part
 - Analogous to designing a Quality Assurance device
- ◉ Non-linear relationship between machine movement accuracy and final part accuracy

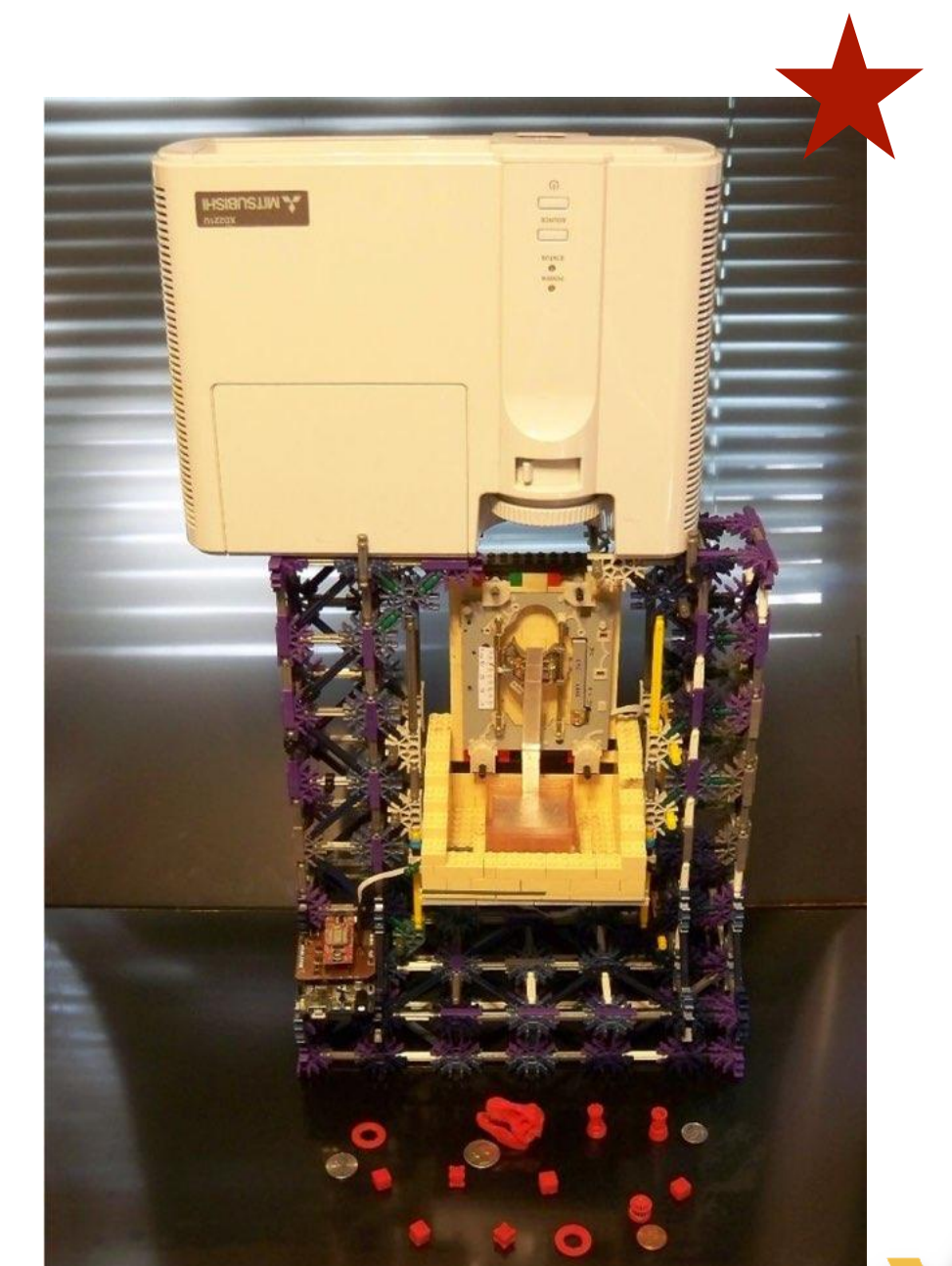
Materials & Bonding Methods Overview cont...

- ◉ Poor quality materials can cause good machines to make really bad parts (and vice versa)
 - As the quality of the material increases, the machine approaches its full potential
 - Expensive and inexpensive can degrade in quality for many reasons



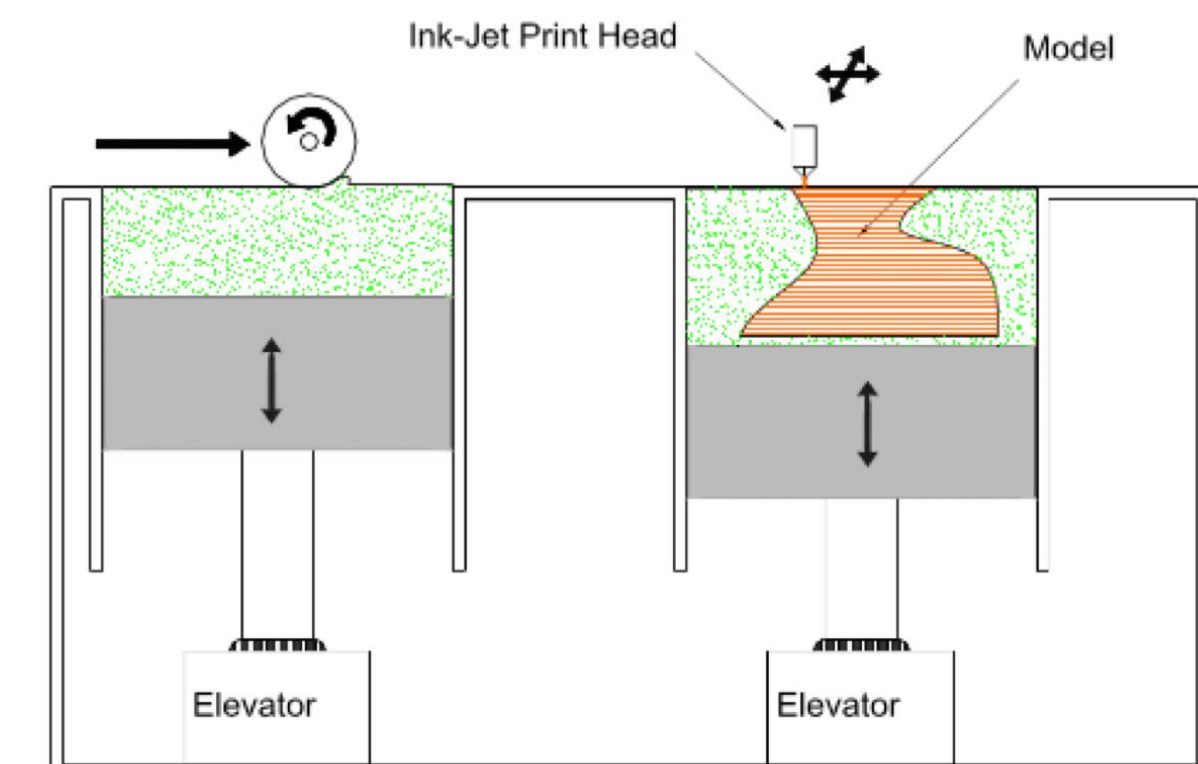
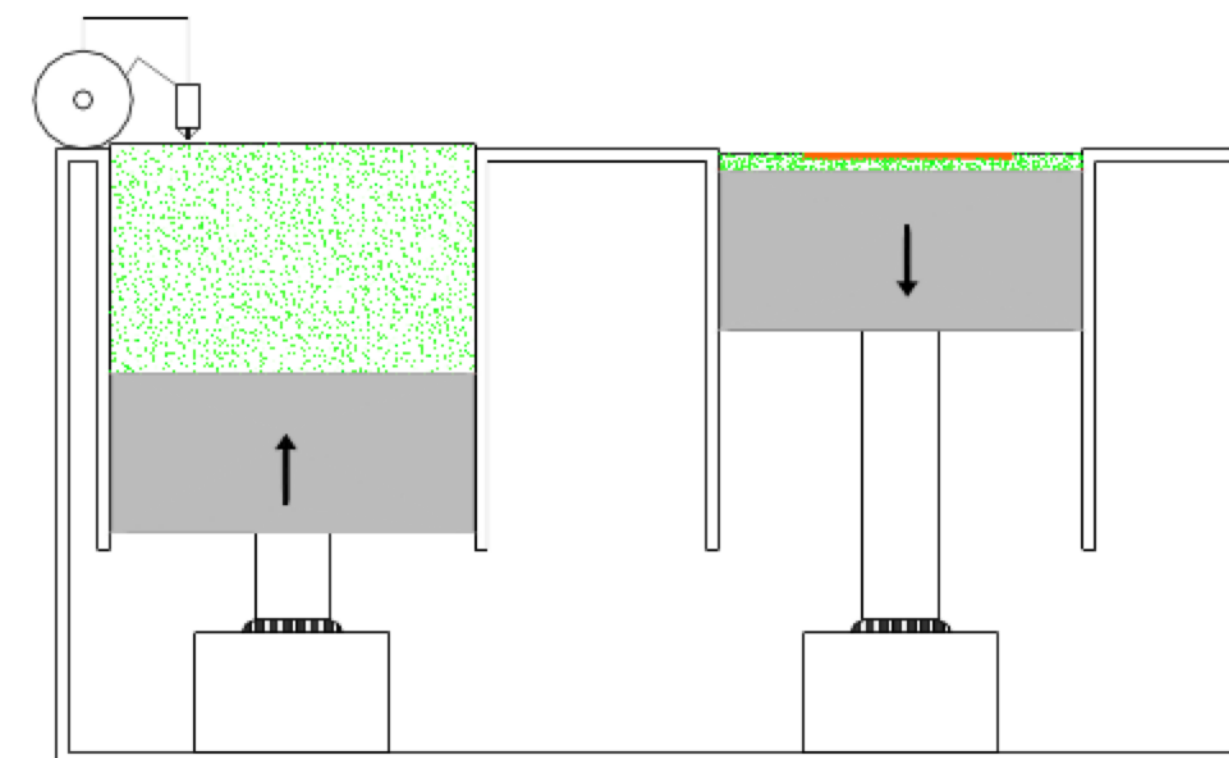
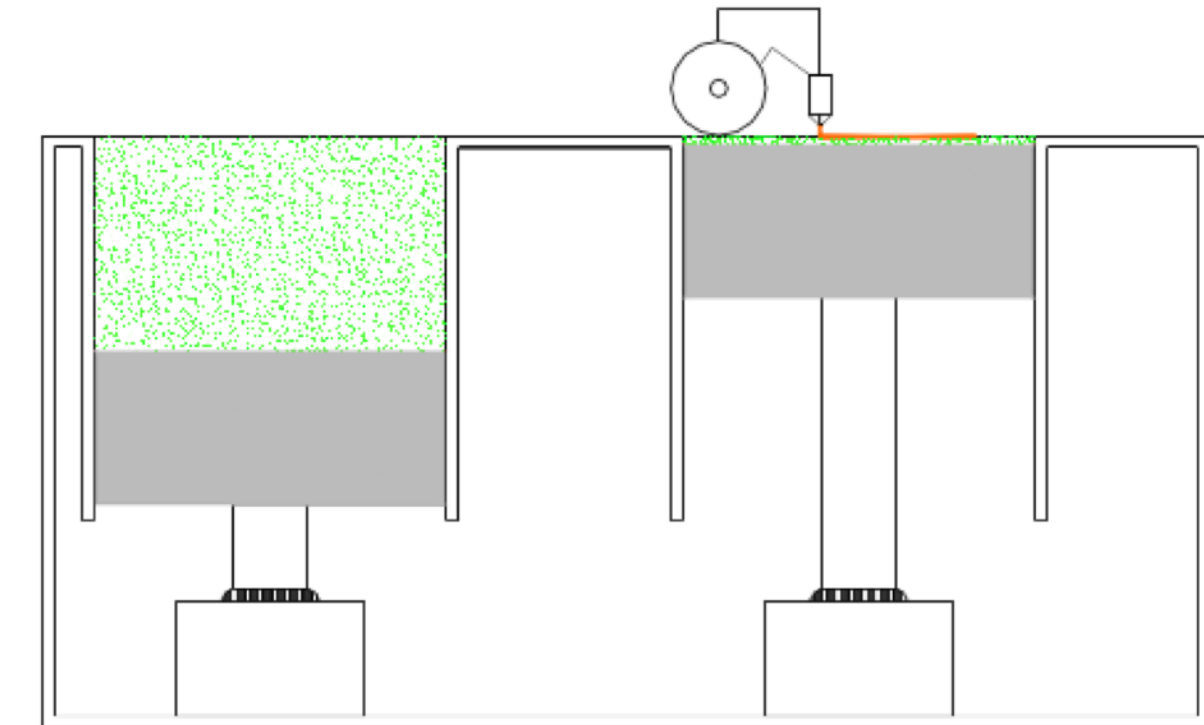
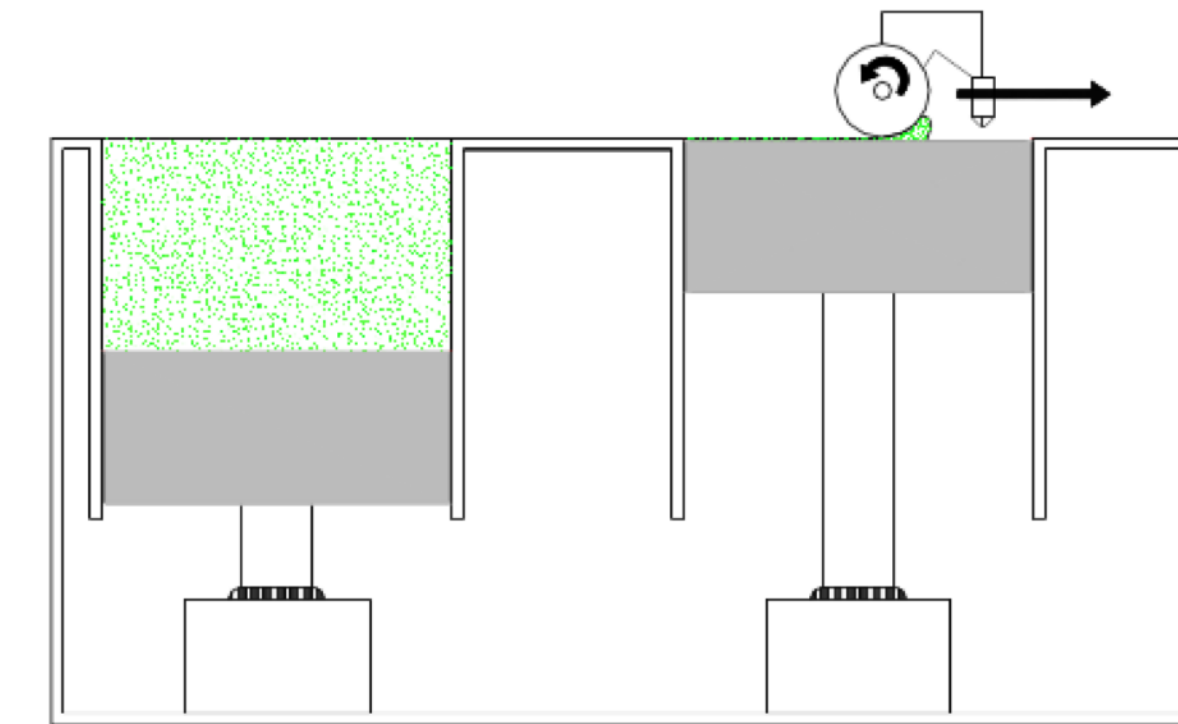
Materials & Bonding Methods Overview

- ◉ High quality materials can cause good machines to make really bad parts (and vice versa) ★
- Some materials present unique challenges that depend more on the part's features than on the machine's capabilities
- Geometric features and machine processes require extra attention when using materials with “special” material properties
- Example: “~~Metal 3D Printers~~” Direct Metal Laser Sintering (DMLS) machines can produce Titanium and Ceramic parts



“3D Printer”

- Layers are formed through fusing powder using a liquid binder
 - Liquid binder is added via an ink-jet type printing process
 - Un-fused powder serves as passive support structure
- Process Sequence:
 - Sweep powder from source to build chamber
 - Glue powder using inkjet head
 - Move down a layer
 - Sweep and repeat



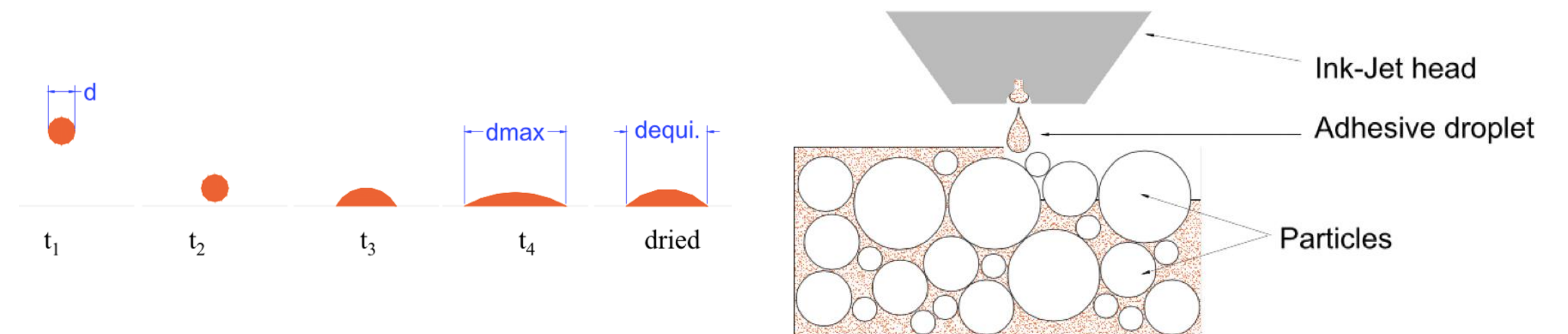
“3D Printer”

● Binder-Particle Interaction Considerations

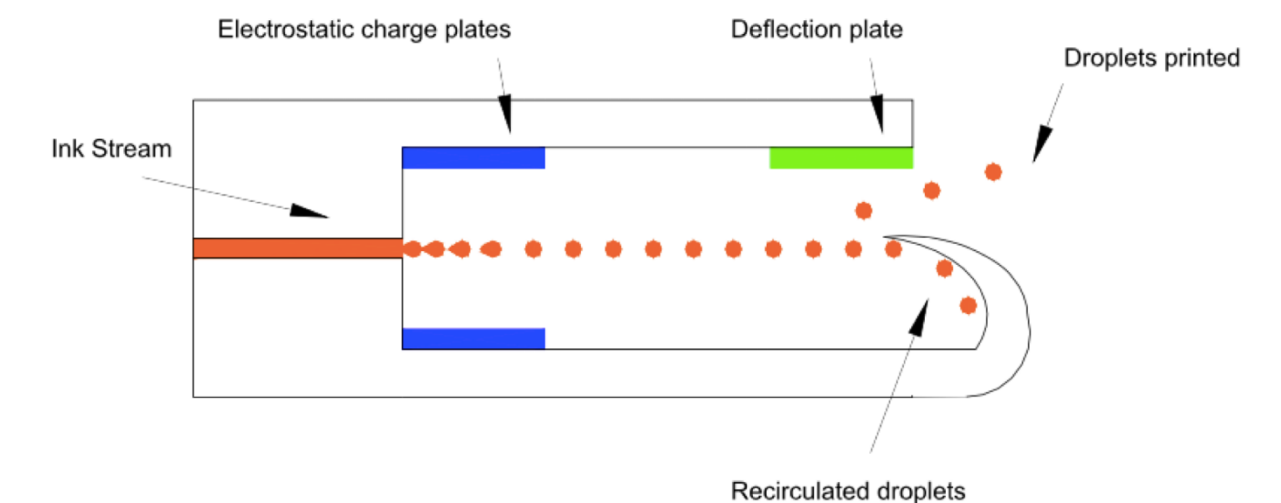
- Different droplet technologies affect part quality
- Droplet and particle size are related, they both affect part quality

● Layer Generation Deposition Methods

- Continuous Ink Jet
- Drop-on-Demand
 - Piezoelectric
 - Thermal inkjet



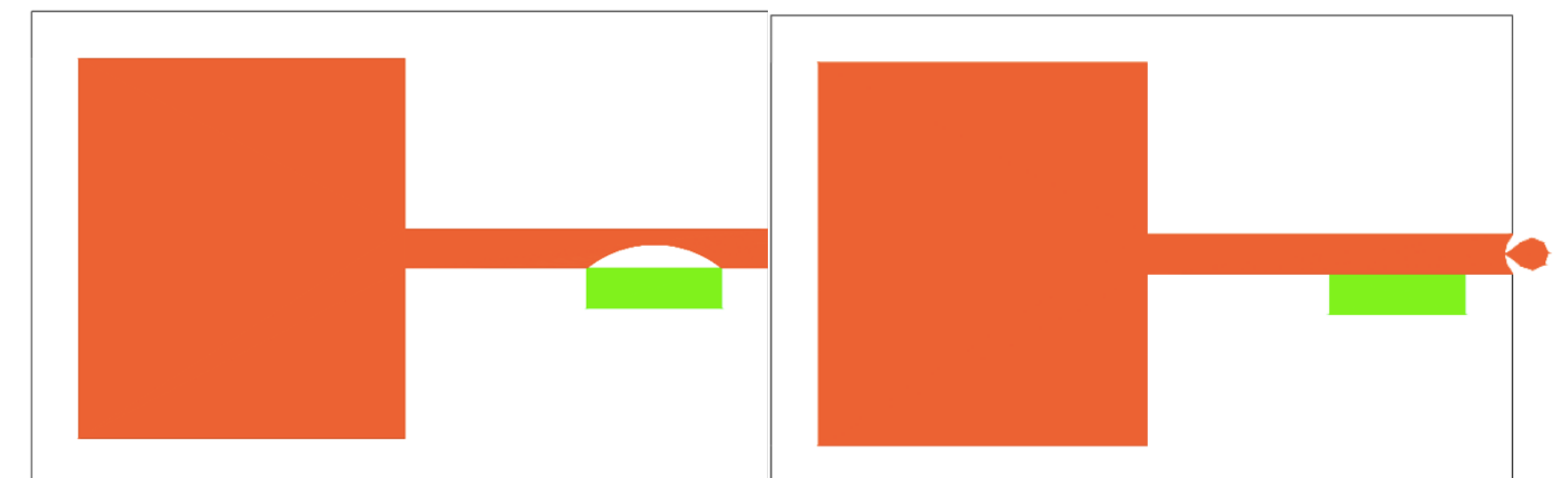
Continuous Ink Jet



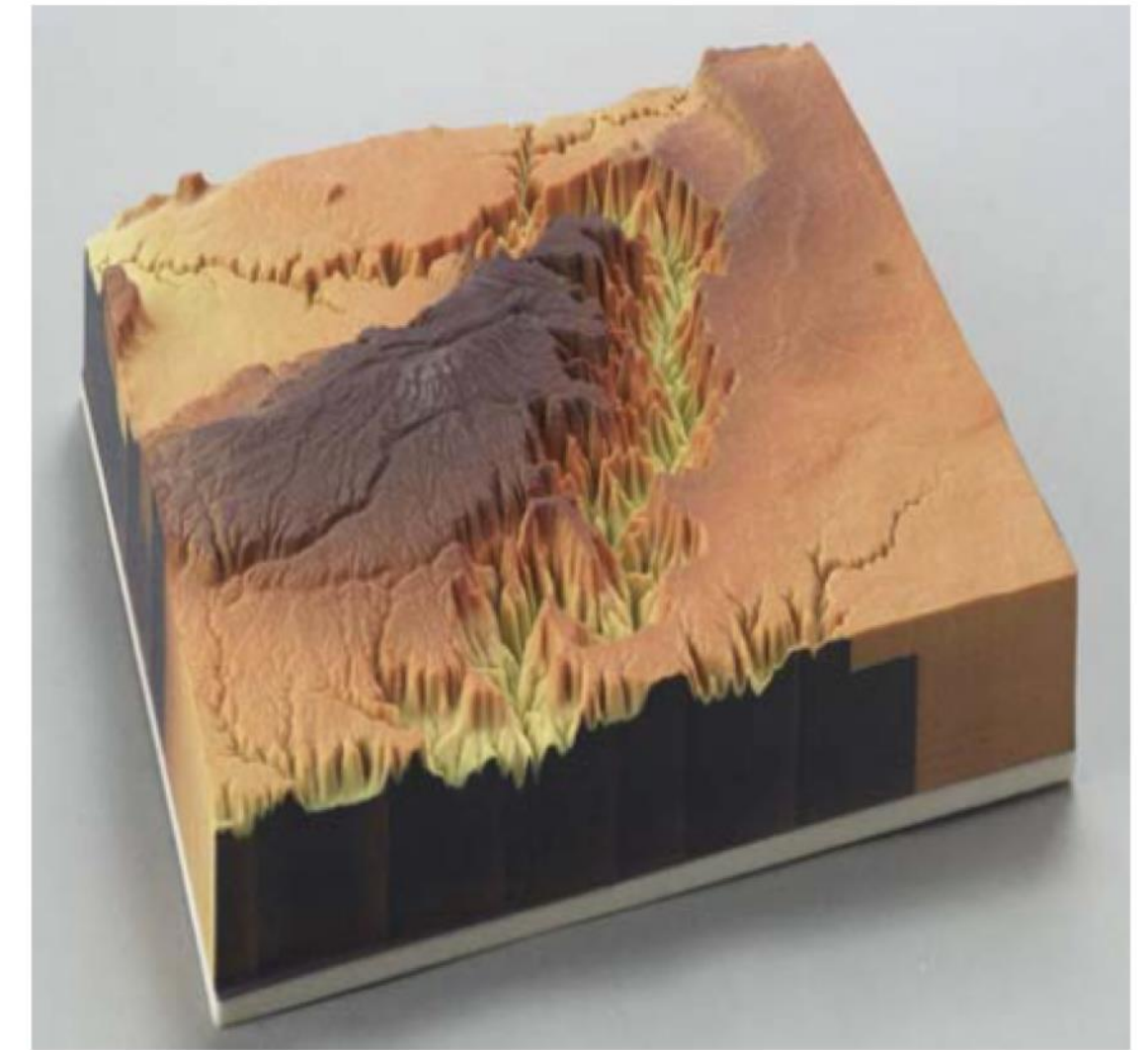
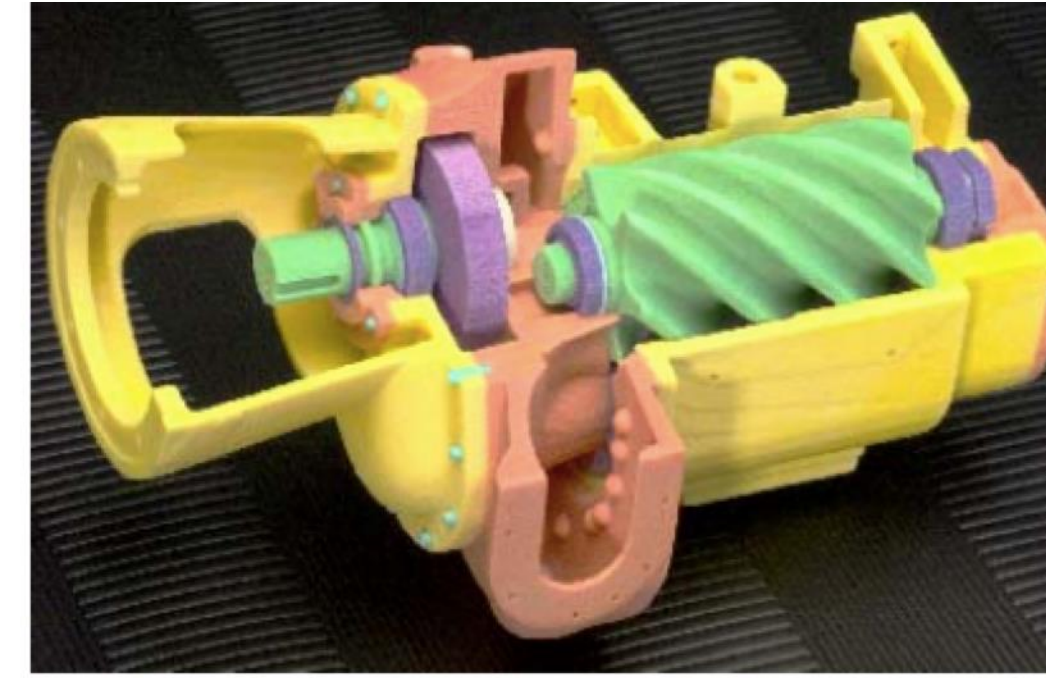
Piezoelectric



Thermal Inkjet



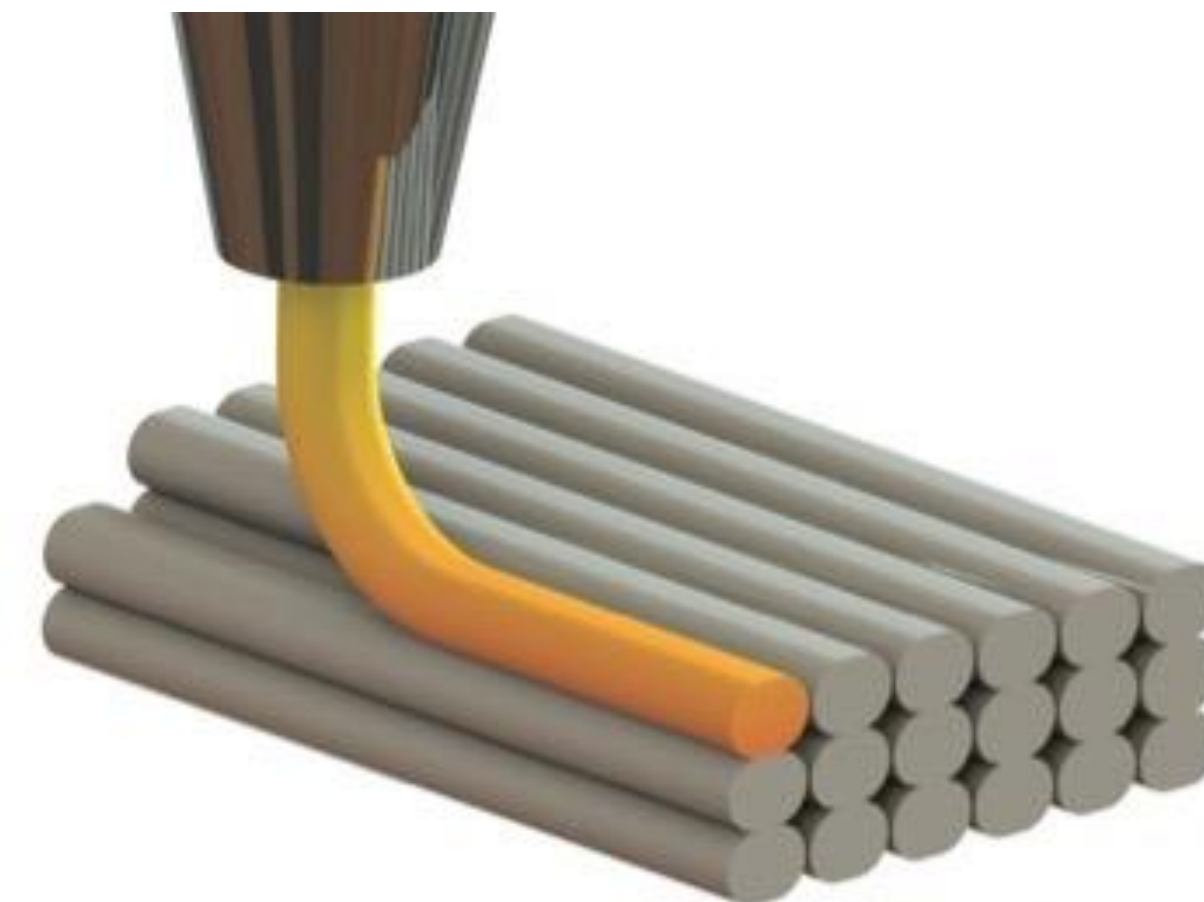
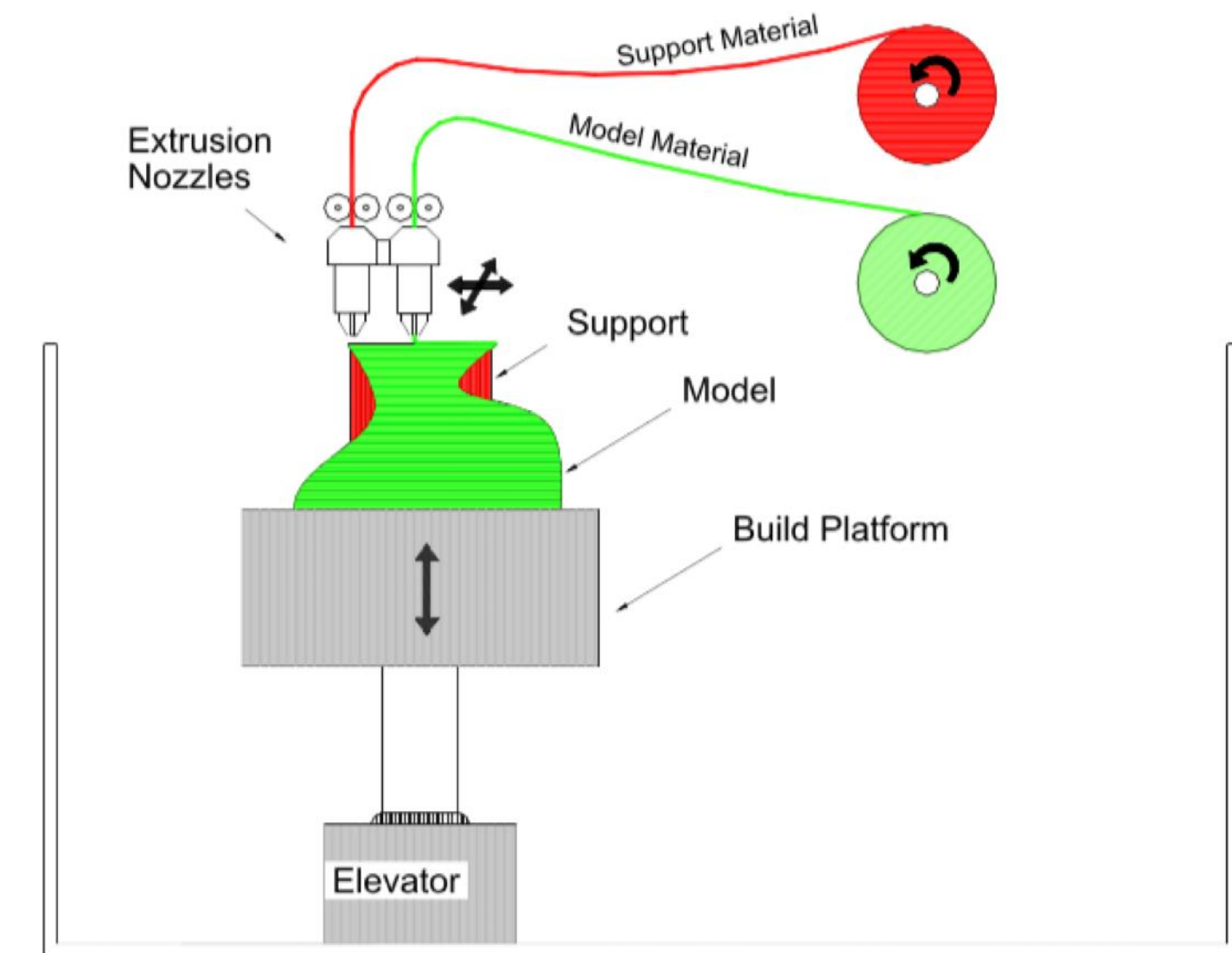
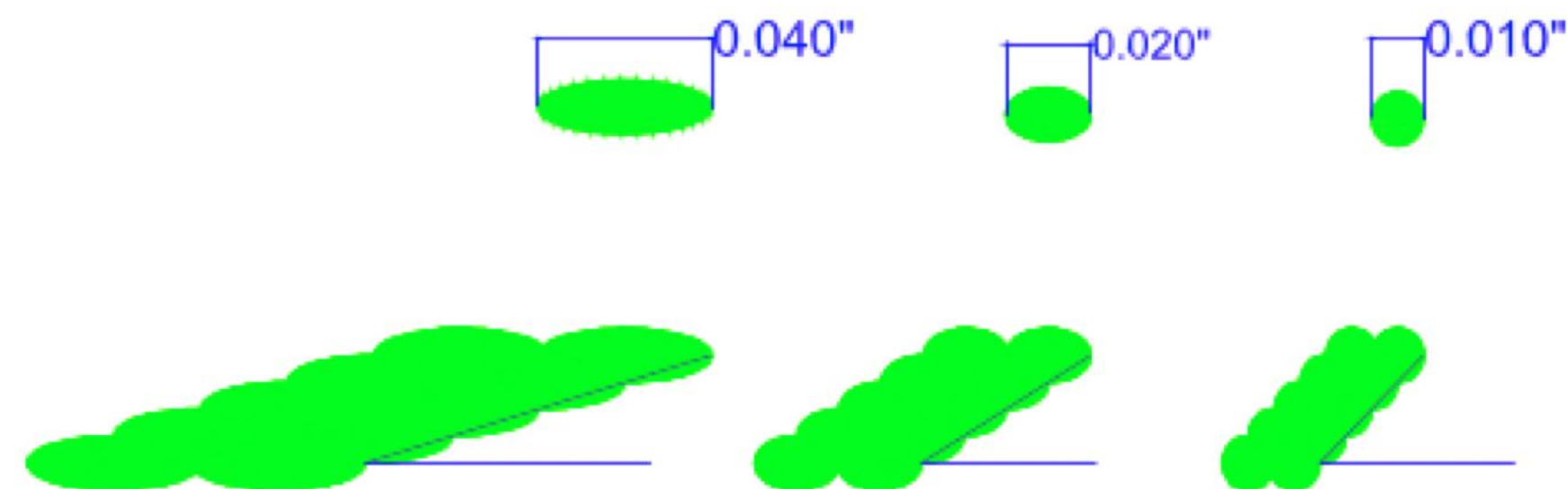
“3D Printer” Example Parts



Fused Deposition Modeling (FDM)

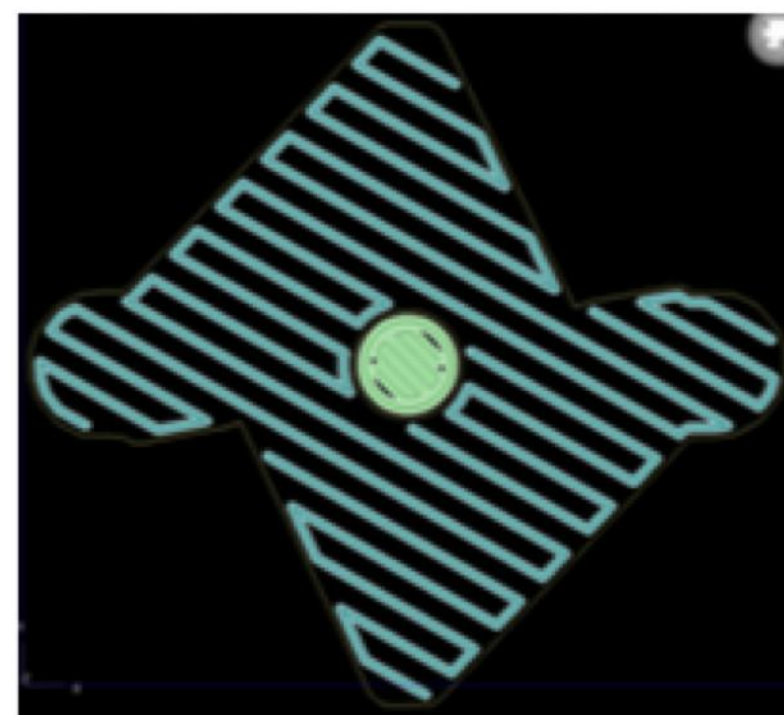
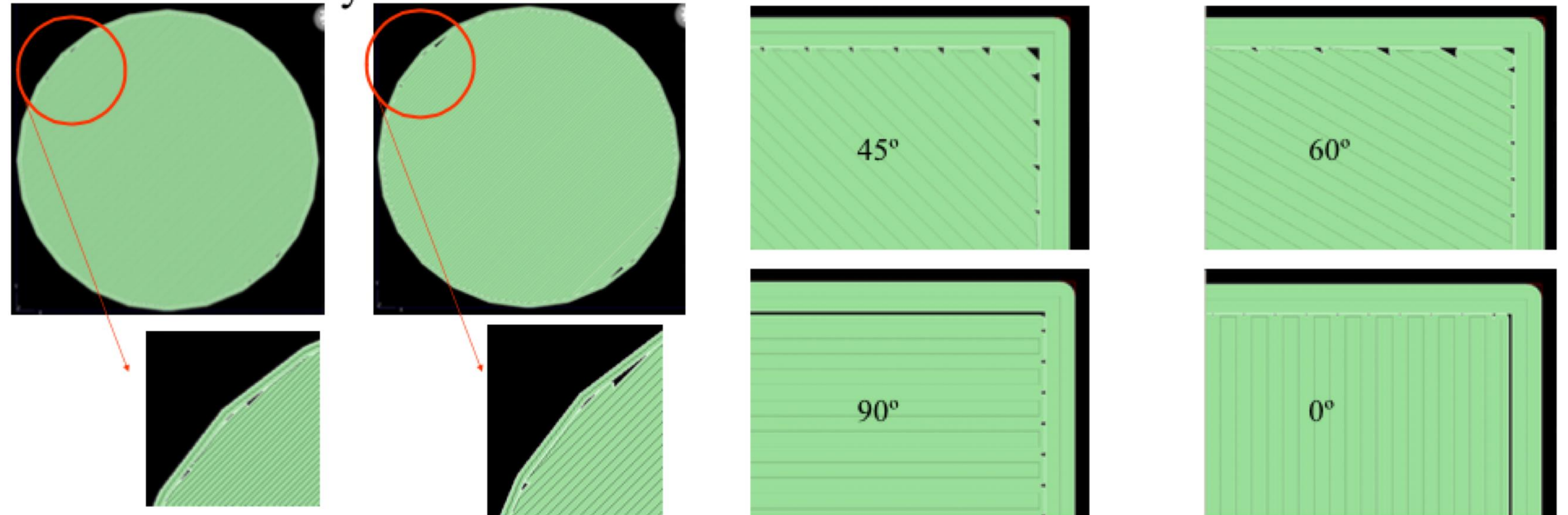
- Extruder nozzles moved via x-y device
- Traversal speed is regulated by the desired beadwidth (bead width varies ~ 0.010"-0.040")
- Combination of material feedrate and traversal speed (for a given nozzle diameter) controls the bead width
- Bead width affects the ability of the process to fill the interior region completely (raster filling)
- Also dependent on raster orientation and contour shape

- Supports: affected by "bead" width
- Support angle
 - From horizontal, minimum angle such that at least $\frac{1}{2}$ Bead will lie on top of layer below



FDM Build Process Induced Error

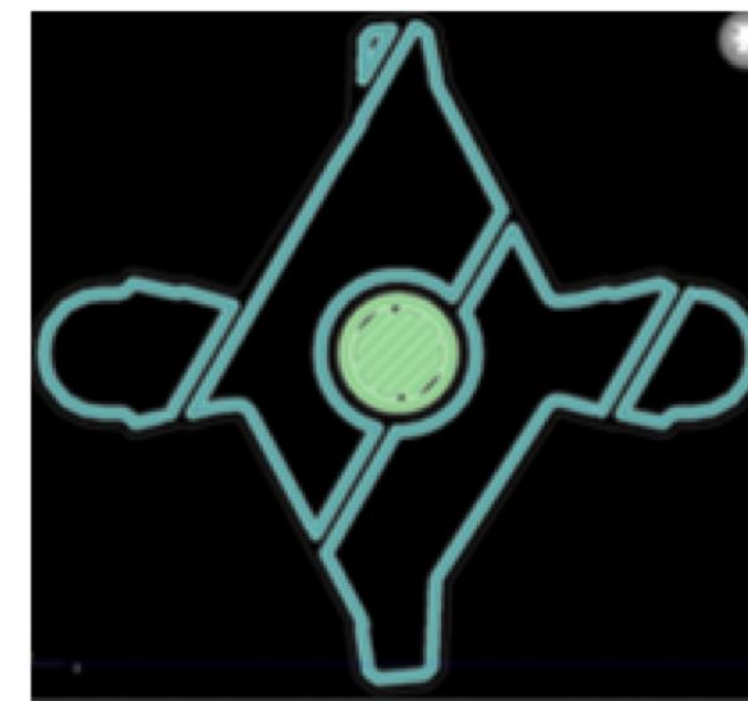
- Part “raster” fill types
- Raft/Base/Support styles



BASIC

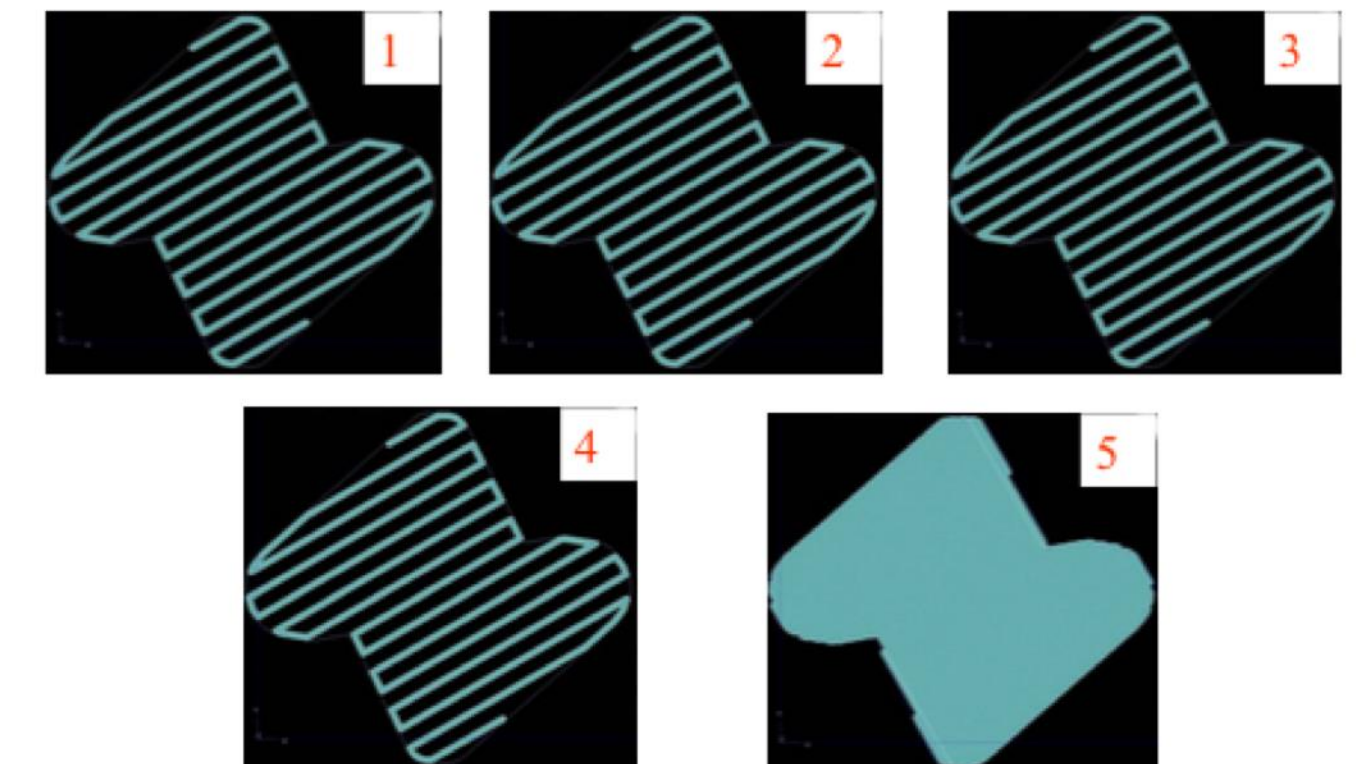


SPARSE



BREAKAWAY

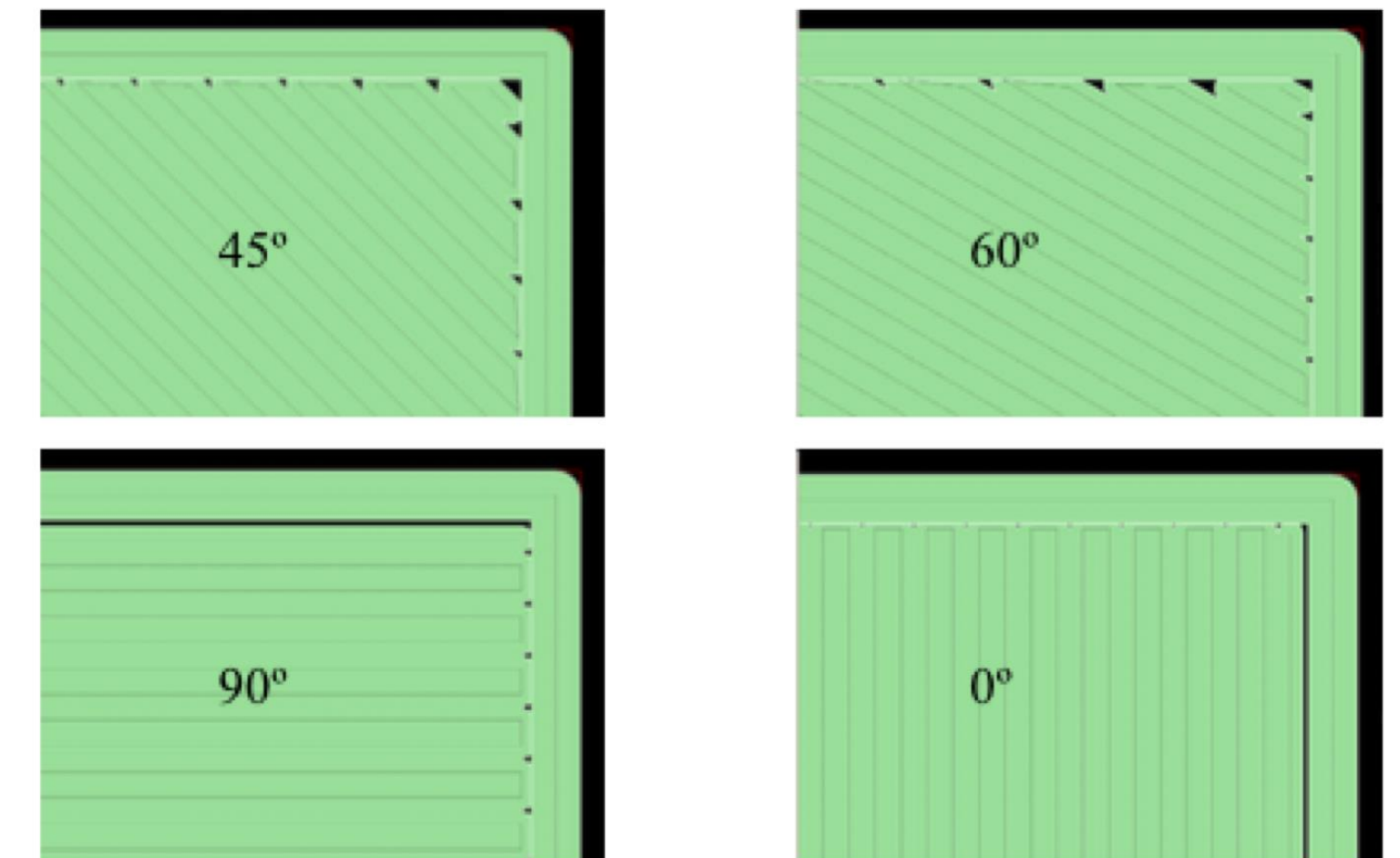
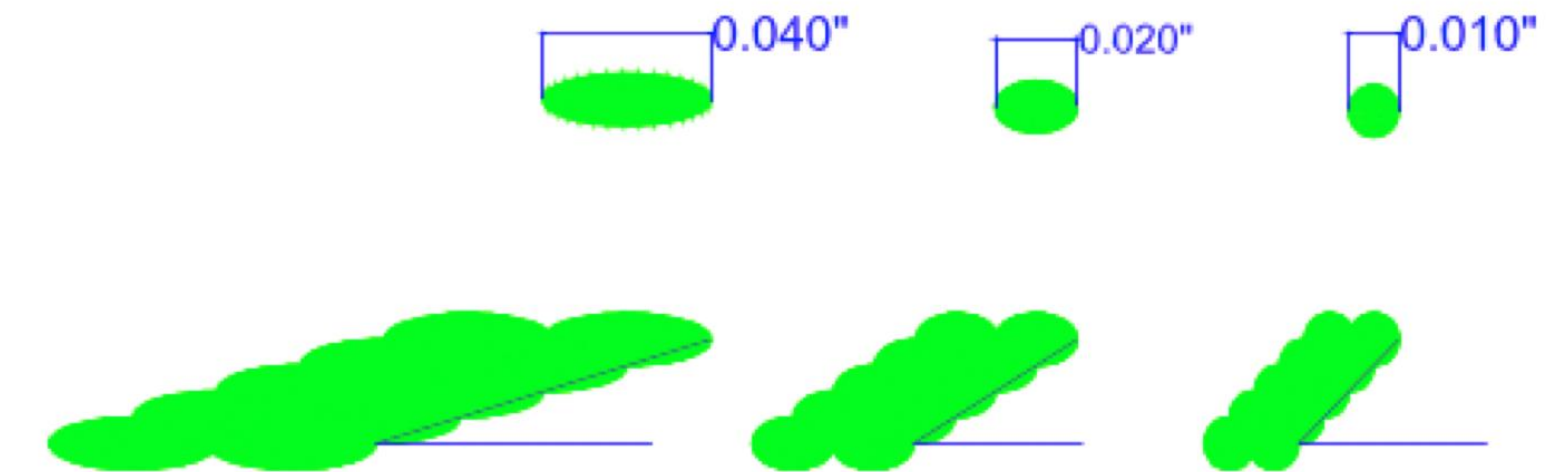
- Supports- begin with a “base” set of layers



FDM: Materials

- Materials used in FDM are closer to functional materials, ABS and Polycarbonate
 - ABS (Acrylonitrile-Butadiene-Styrene)
 - Good strength, good hardness, available with water soluble supports
 - Tg: 212°F
 - Tensile strength (2000psi-7000psi)
- Polycarbonate (“Lexan”)
 - Better strength, better hardness, not currently available with water soluble supports
 - Tg: 293°F
 - Tensile strength (10,500psi)
- Anisotropic properties (inter laminate strength)
 - machine movements’ affect on bead shape assumes material is heated “just right”...
 - Material properties are a function of material, process temp and movement precision
 - Tg: 428°F

- Supports: affected by “bead” width
- Support angle
 - From horizontal, minimum angle such that at least ½ Bead will lie on top of layer below



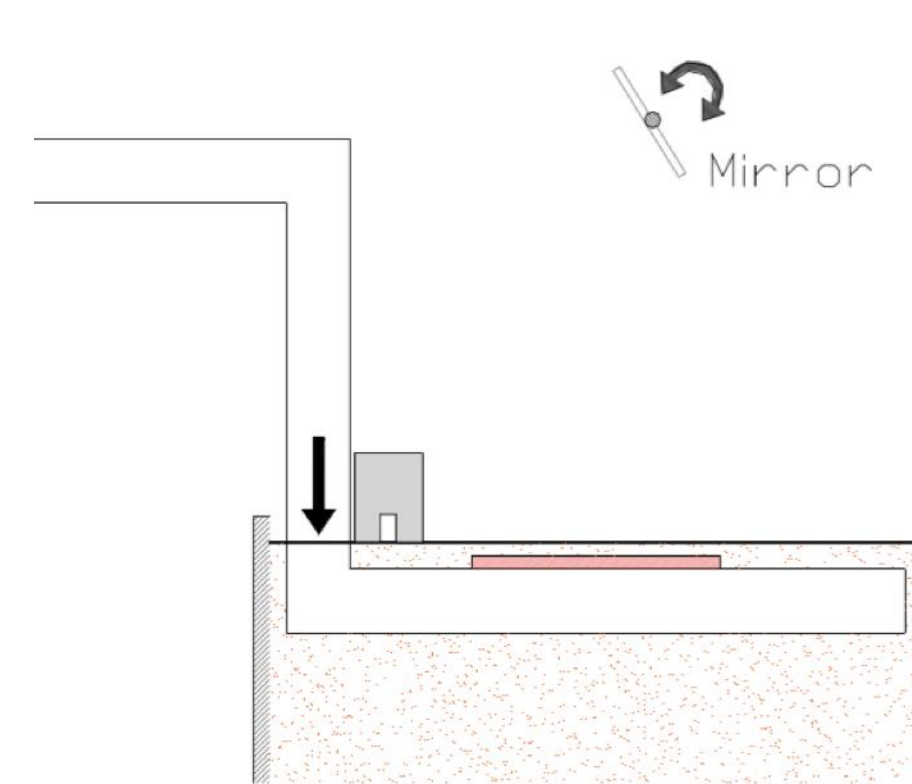
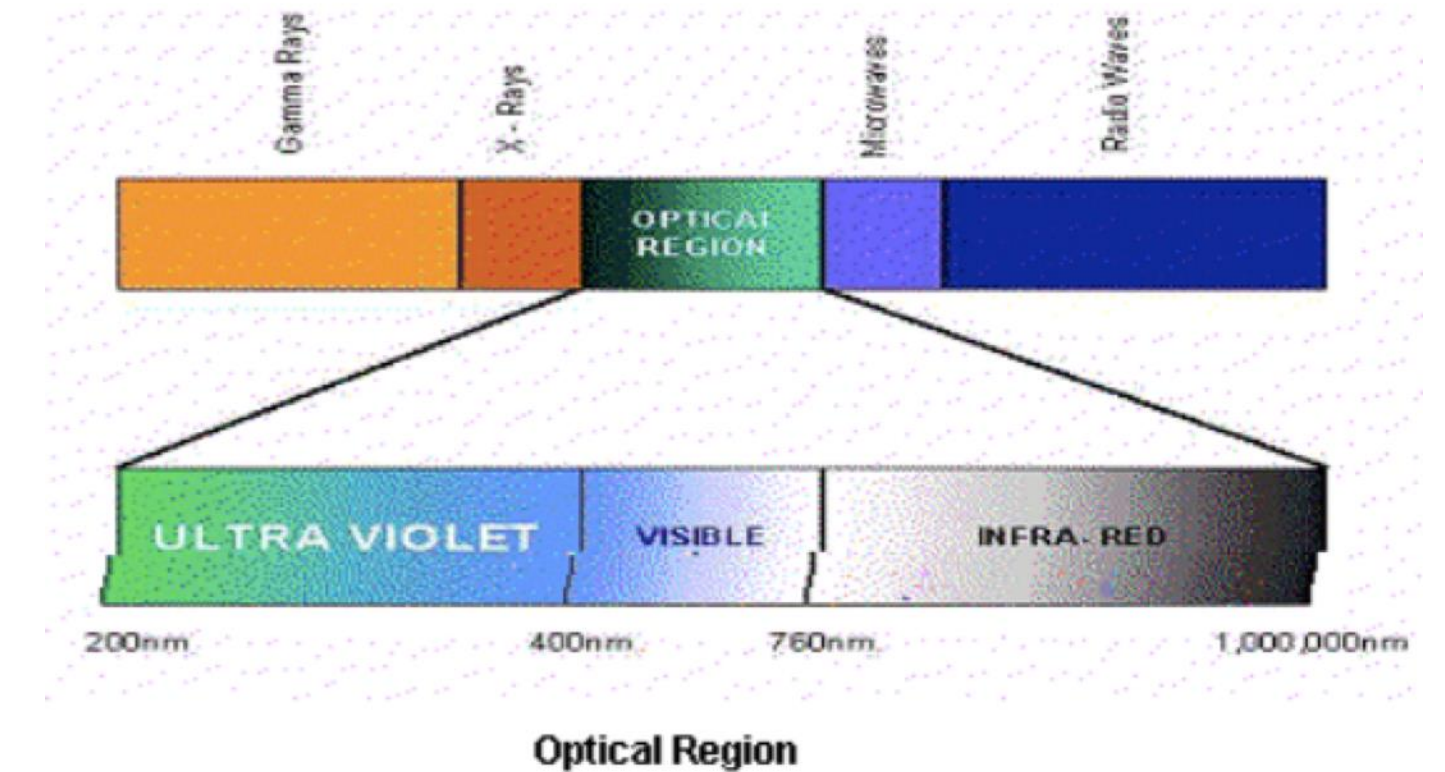
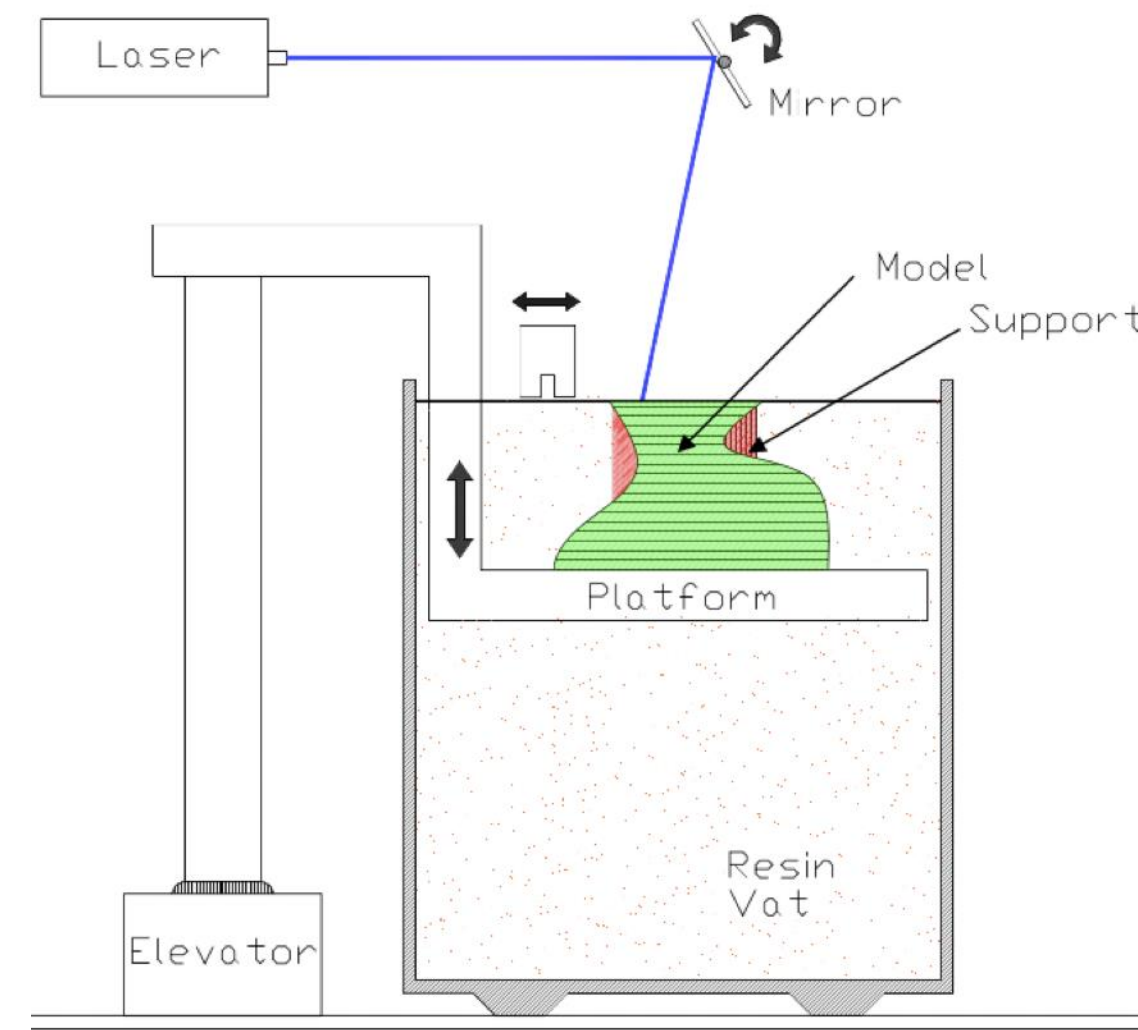
FDM Machine Examples

- ◉ Build speed is average to slow ($< 200\text{mm/s}$)
- ◉ Layer thicknesses are limited (0.004" to 0.013")
- ◉ Large price range in machines, ~\$20,000, up to \$400K

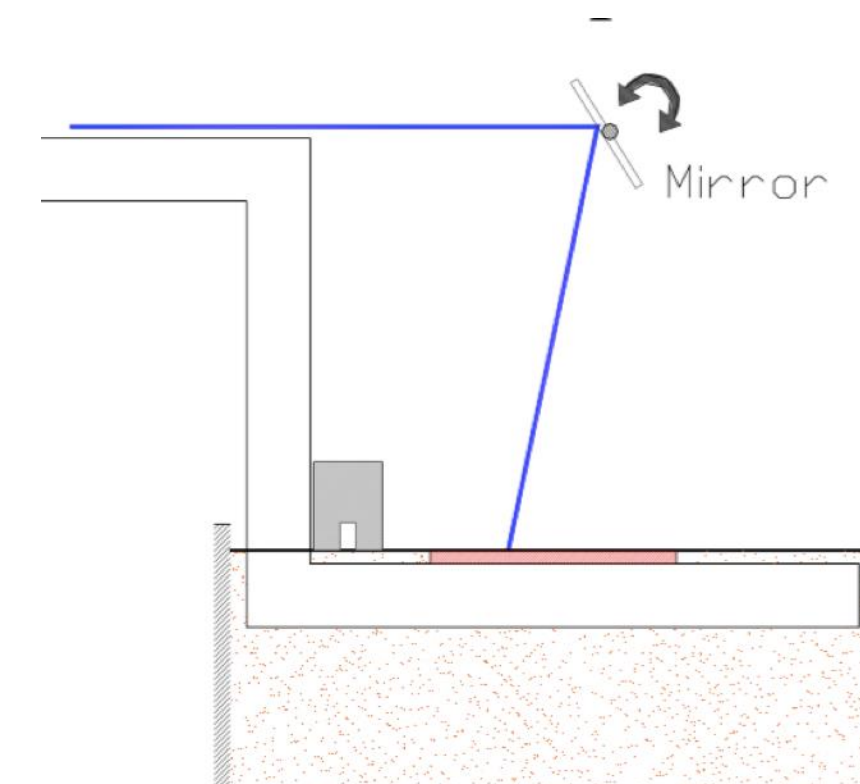


StereoLithography (SLA)

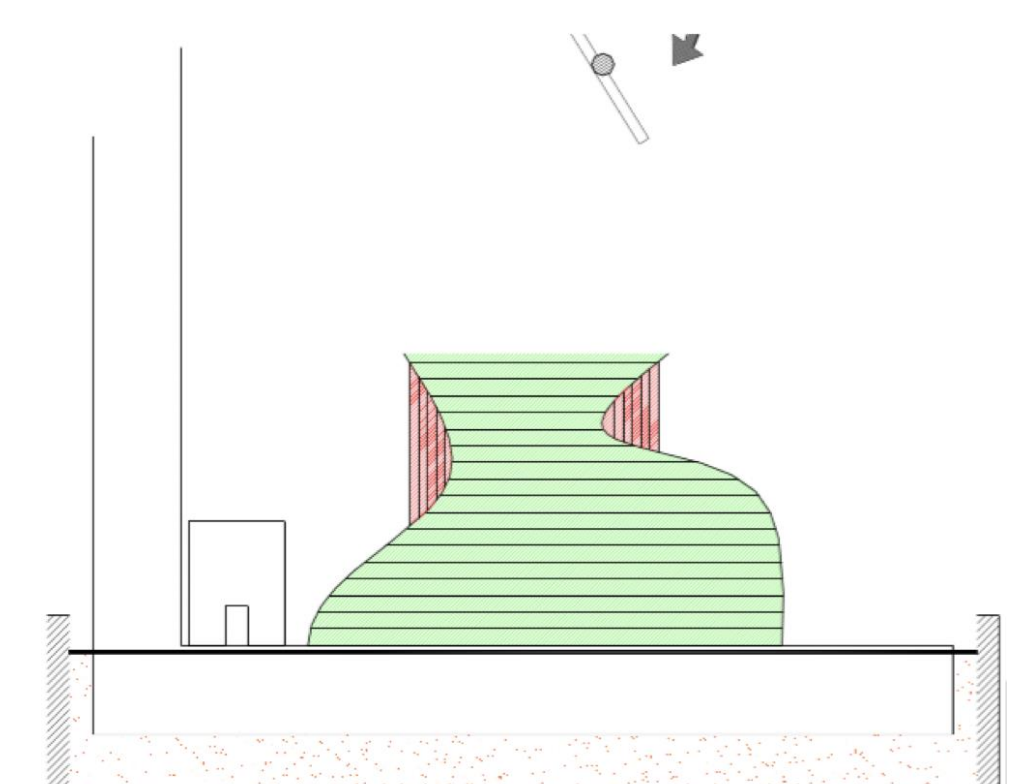
- A build platform moves down
- Passive since surrounded by resin
- Overhanging features still need support
- Layers are formed by curing photosensitive resin using a laser
- Resin is contained in a vat
- A build platform in the vat is used to position the next layer just below the surface of the resin
- Each layer is cured and fused to the preceding layer, forming a solid part



Platform is submerged one layer depth



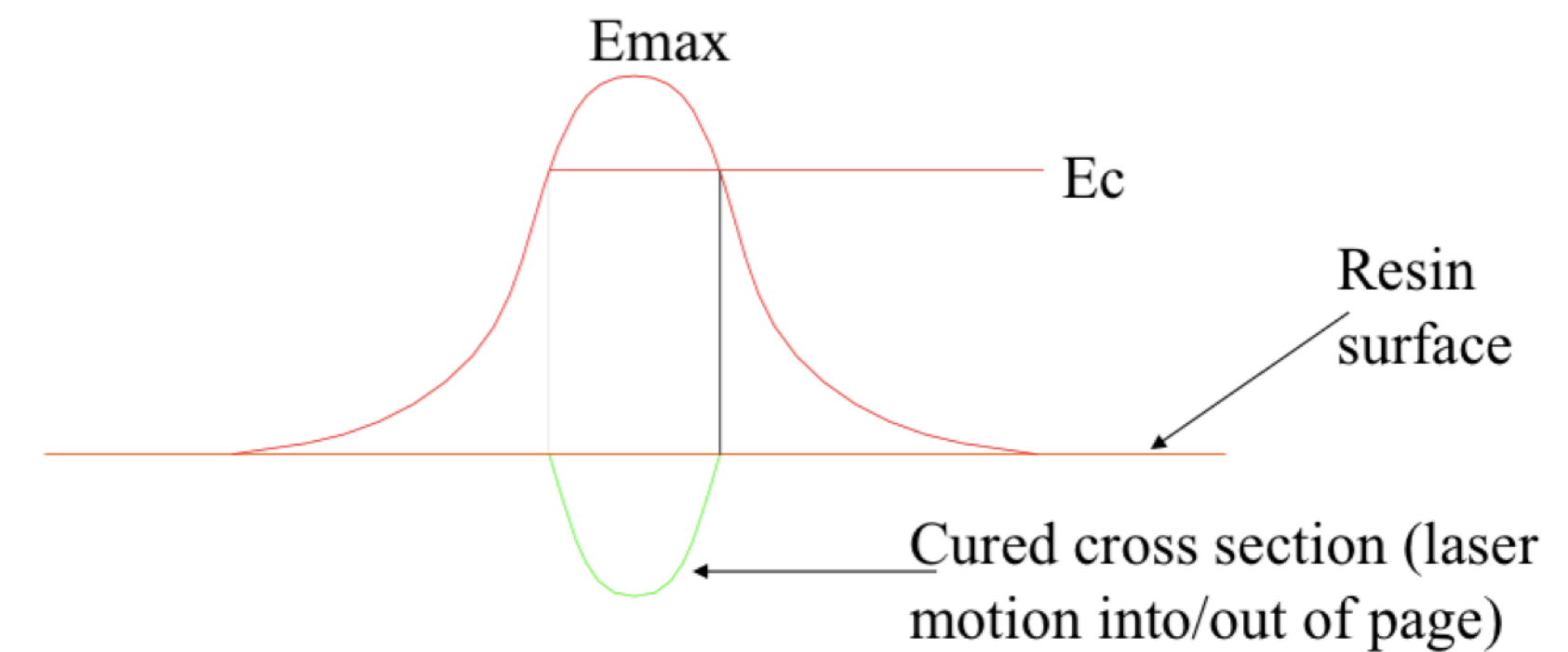
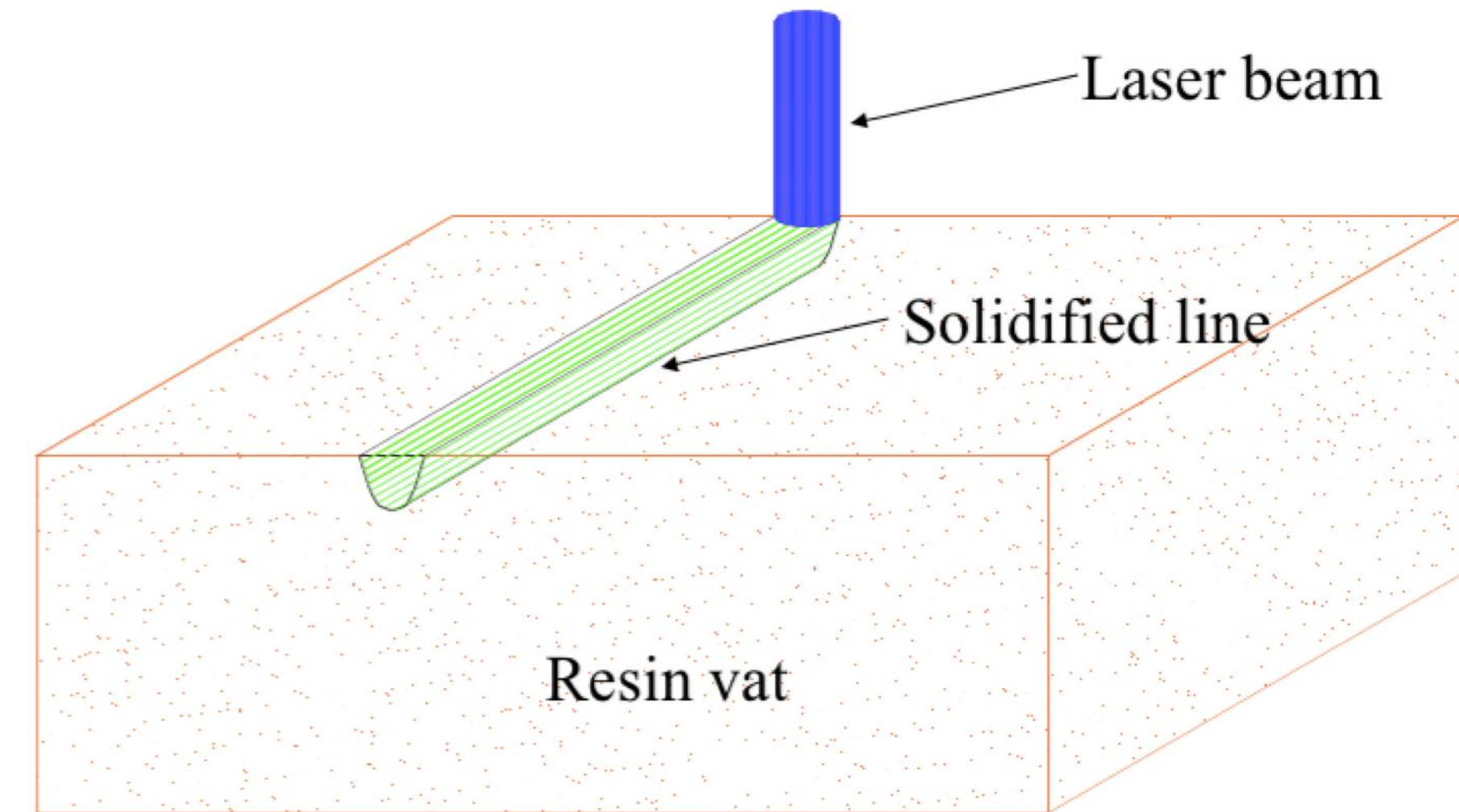
Curing a layer with the laser



Model is Raised from the Vat

SLA: Laser Solidified Shape Considerations

- ◉ In addition to the material considerations the system must be able to accurately focus the UV light (where accuracy may depend on the users needs)
- ◉ Laser spot diameter (0.010in - 0.030in) or (0.254mm - 0.762mm) for borders and interior filling, respectively (as available)



Exposure of the laser energy to the resin

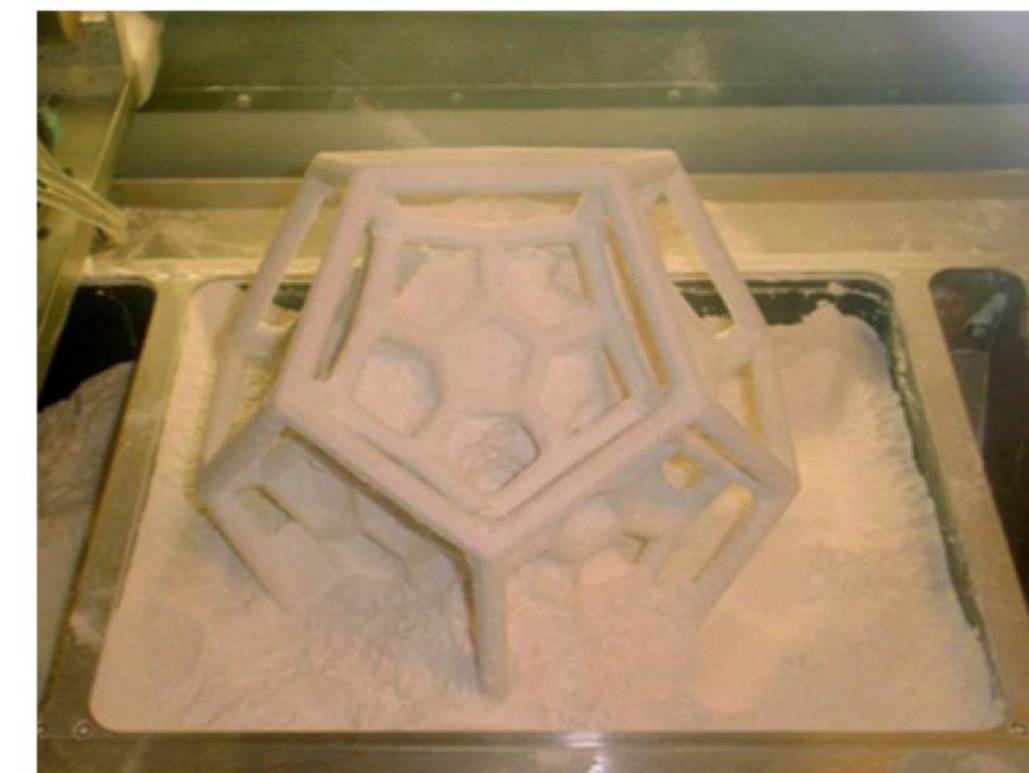
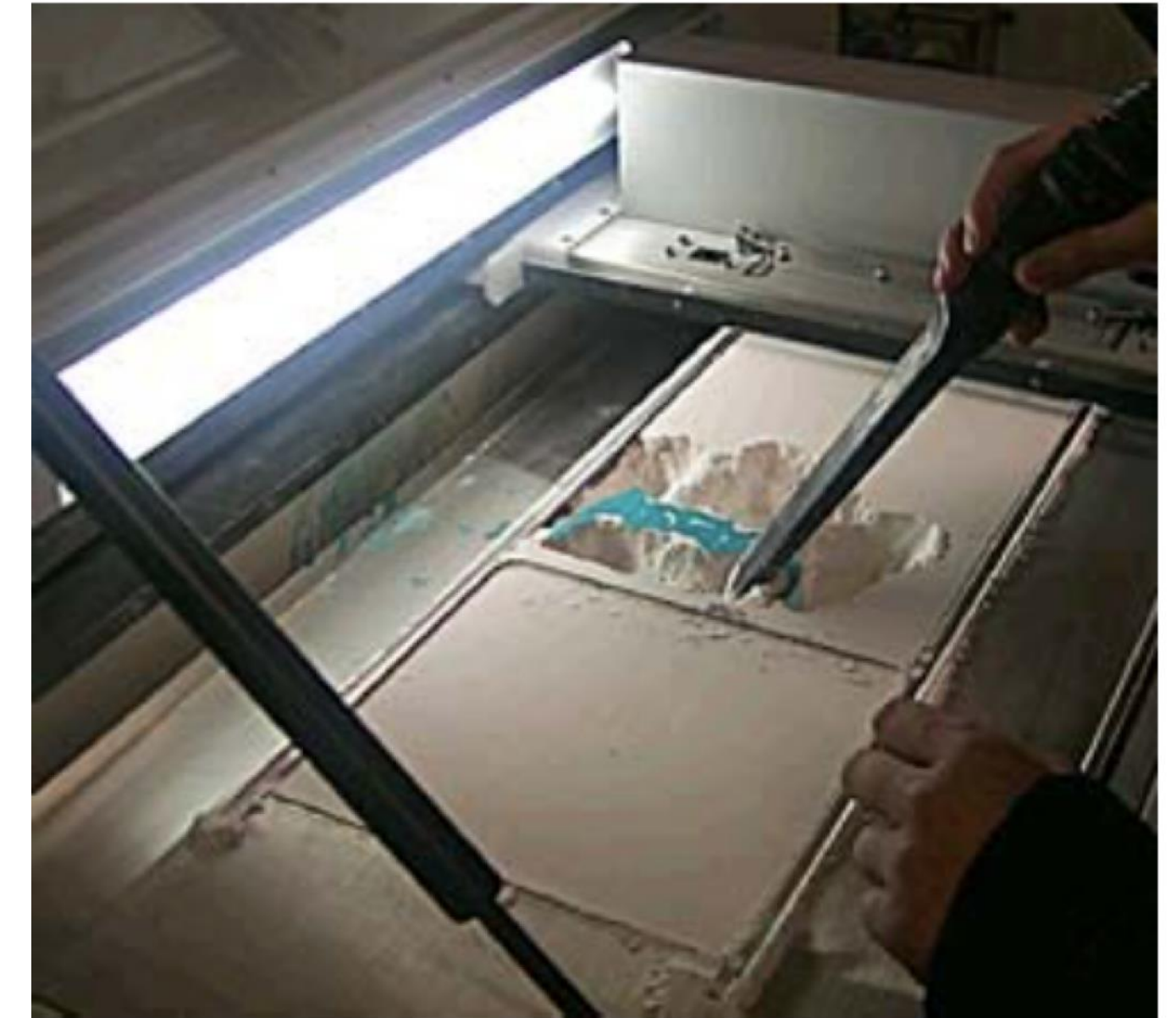
E_c : Critical Exposure, below which polymerization does not occur

Post Processing, Maintenance, & Quality Assurance

- ◉ ***“I’m melting”***: water soluble supports
- ◉ ***“I’m not melting but I am feeling a bit hygroscopic”***: help control the wet filament population, have your filament stored and adsorbed
- ◉ ***“I think I’m melting”***: FDM vs. FFF (why your extruder is probably clogged)
- ◉ ***“I wish I was melting”***: you can’t “print metal” but you can sinter it
- ◉ ***“I overcooked it”***: laser power and angle of incidence in a heated build chamber
- ◉ ***“I wasn’t roughhousing”***: post-processing steps non-AM quality assurance inspection standards applied to AM parts
- ◉ ***“I’m not done with it, but it printed”***: the often forgotten but beneficial post-processing steps
- ◉ ***“I’m for sure melting”***: how to make fully dense metal parts using AM processes/techniques

Post Processing: 3D Printers

- Inkjet binder is not very strong
- Infiltration with other liquids
 - Wax 100% infiltration, not very strong, improves surface
 - Cyanoacrylate, lower quality but better strength than wax, $< 1/8$ " penetration depth
 - Elastomeric Urethane, higher strength and flexibility, $< 1/2$ " penetration depth
 - Epoxy, best strength, may be machinable, $< 1/2$ " penetration depth
- Infiltration by
 - Dipping (wax)
 - Spraying, Brushing, Dripping



Post Processing: SLA

1. Remove the build platform



2. Put the build platform on the jig



3. Use the removal tool to remove print



4. Agitate part in IPA



5. Repeat with a second rinse



5. Remove the supports



Post Processing: FDM

- Traditionally Polyvinyl Acetate (PVA)
- Stratasys: “Water Works” PVA for ABS
- 3D Systems: Infinity Rinse Away

- Support Materials
 - Plastics
 - Water Soluble (“WaterWorks” option)
 - Can be removed in soapy water bath
 - Automated with Ultrasonic excitation
 - Not available for all materials as of yet

