



A Research and Industry Roadmap: Barriers and Opportunities for Increased, Lower Cost Additive Manufacturing Integration for Investment Casting Foundries

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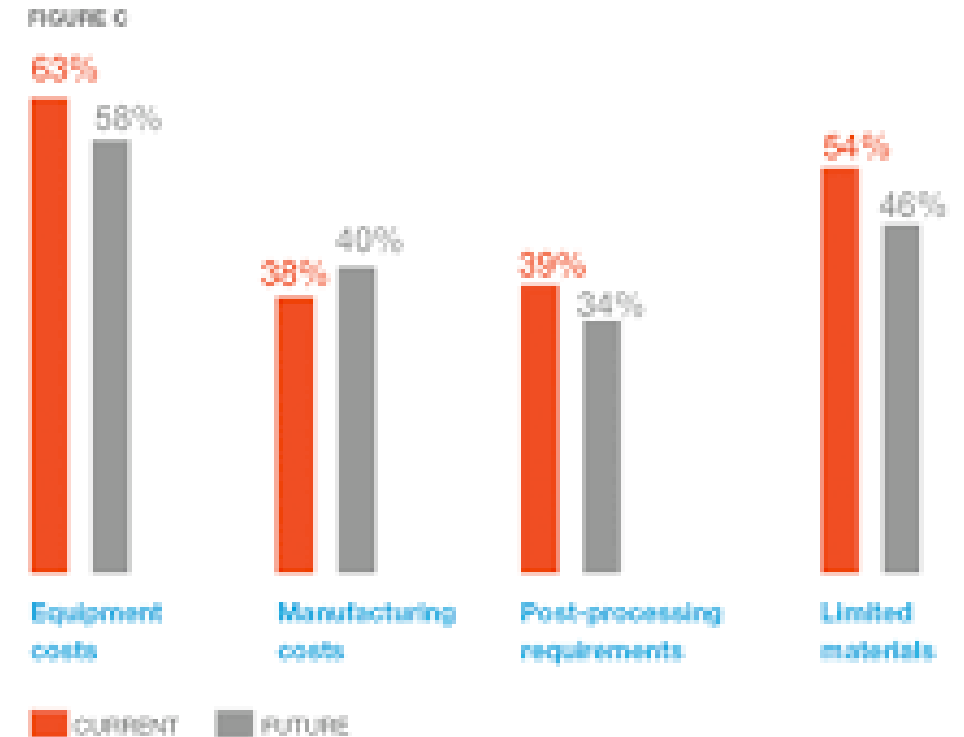


- **Presentation outline:**
 - **Barriers to entry for 3D printing**
 - **Integration Timeline**
 - **Printer Capabilities and Costs**
 - **Additive Technologies and Flow Chart**
 - **Skillsets needed**
 - **SLA Printers**
 - **Multi/Poly Jet Printers**
 - **FDM Printers**
 - **Dimensional Shrinkage and Surface Finish**
 - **Summary and Future Work**
 - **Acknowledgments**



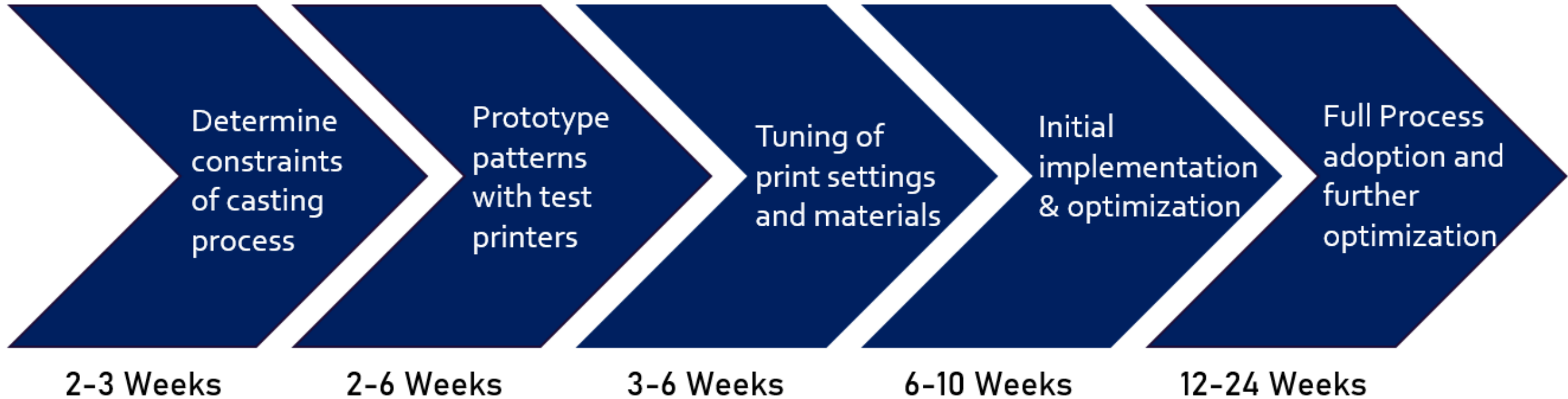
■ Main Barriers to Entry

- Capital Cost
- Technical Experience
- Knowledge of printer Capabilities
- Defined Production Process



Top challenges to widespread 3D printing adoption: Stratasys Direct (2018) Top Challenges To Widespread 3D Printing Adoption | Stratasys Direct. Available at: <https://www.stratasys.com/en/stratasysdirect/resources/articles/3d-printing-adoption-challenges/> (Accessed: 22 May 2023).

Timeline for integration of Additive Manufacturing



Printer Capabilities and Costs

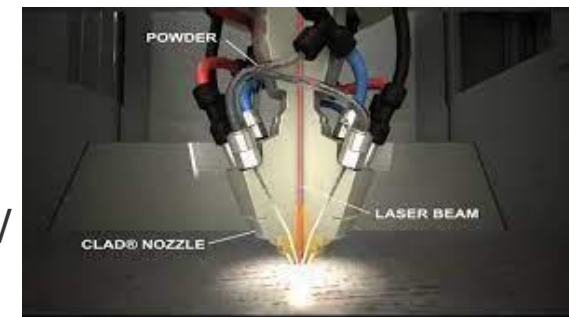
- **Professional**
- Prices range \$1,200 - \$25,000 USD
- Typically, SLA & Specialty FDM
- Ideal for high complexity/precision parts made from polymers or bonded ceramics



- **Hobby Grade**
- prices range \$100 - \$2,000 USD
- Typically, FDM & DLP
- Ideal for medium sized, Low-Complexity/precision parts



- **Industrial**
- Prices > \$25,000 USD
- Typically, Multi jet or selective laser sintering
- Ideal for extreme complexity/precision parts made from metals or ceramics

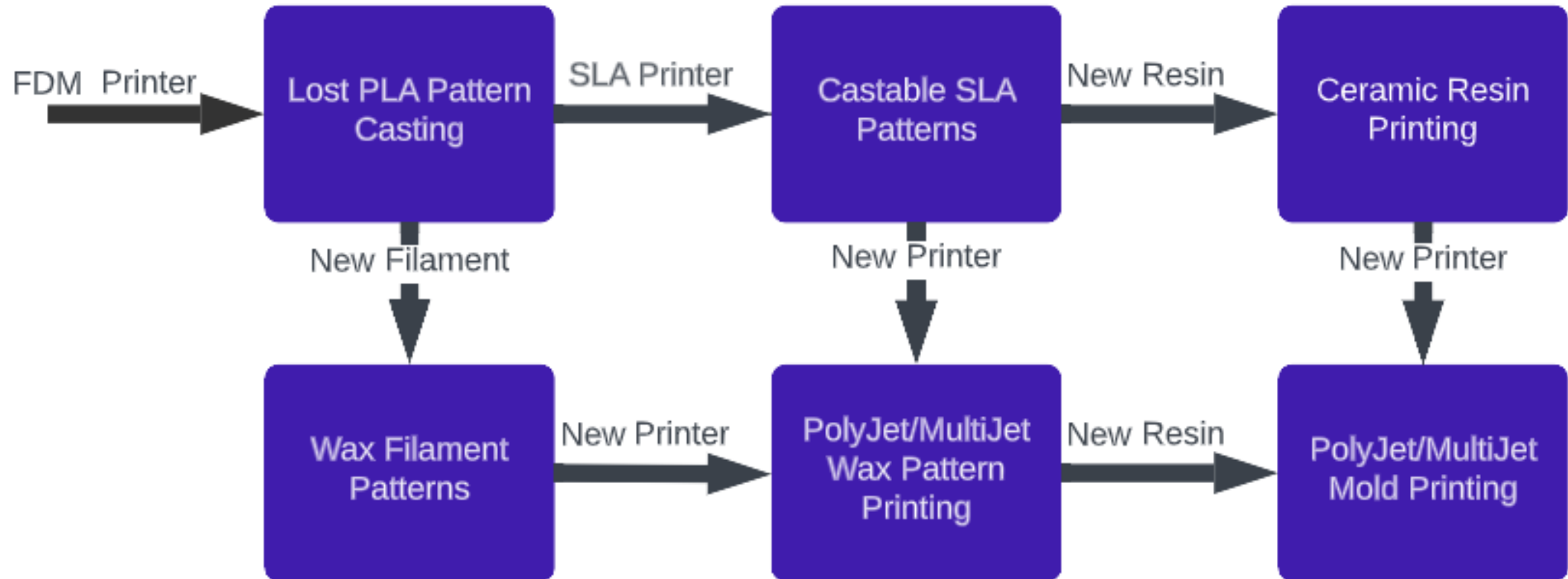


Various Printing Methods (Applicable to Investment Casting)



FDM	DLP	SLA	Ceramic Resin	Multi Jet
Use: Prototyping Pattern Making	Use: Prototyping Pattern Making	Use: Prototyping Pattern Making	Use: Mold Making	Use: Prototyping Pattern Making Mold Making
Pros: Low Costs Ease of Adoption	Pros: Low Costs High detail	Pros: Ultra Fine Detail	Pros: Significantly cuts lead time	Pros: Ultra Fine Detail Multi Material Printing
Cons: <ul style="list-style-type: none"> Rough Finish Slight Shrinkage Dimensional Accuracy 	Cons: <ul style="list-style-type: none"> Resin safety concerns Generation of part support material 	Cons: <ul style="list-style-type: none"> Resin safety concerns Generation of part support material High Price 	Cons: <ul style="list-style-type: none"> Resin safety concerns High Price (both machine and material wise) Very High Price 	Cons: <ul style="list-style-type: none"> Resin safety concerns High Price (both machine and material wise) Very High Price

Additive Technology Flowchart for Investment Casting

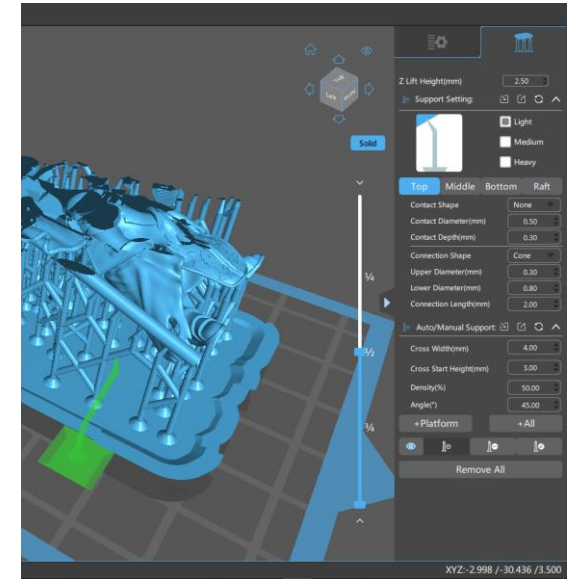
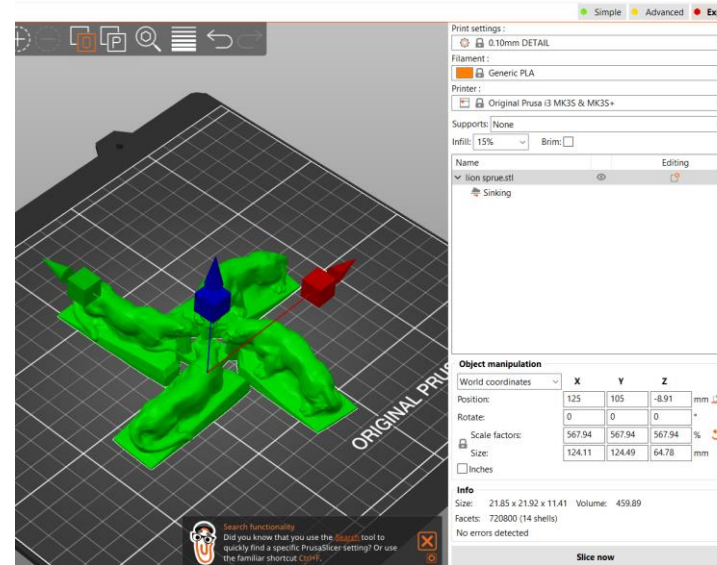


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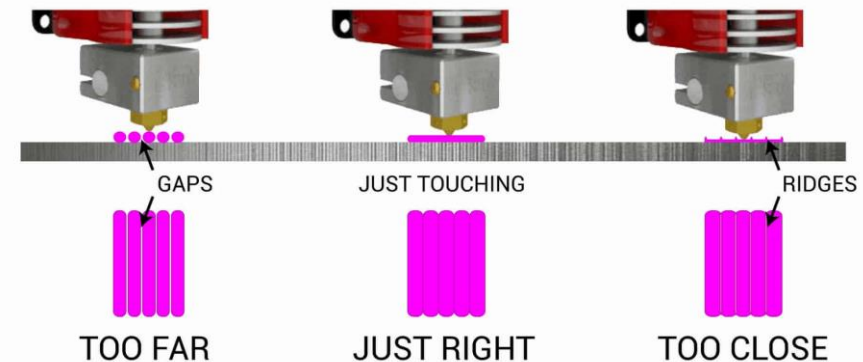
■ Skillset required

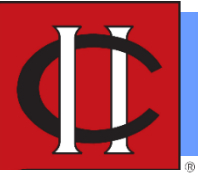
- Capital Cost
- Technical Experience
- Knowledge of printer Capabilities
- Defined Production Process
- Many Online Tutorials and Training Programs



3D PRINTING BED LEVELLING GUIDE

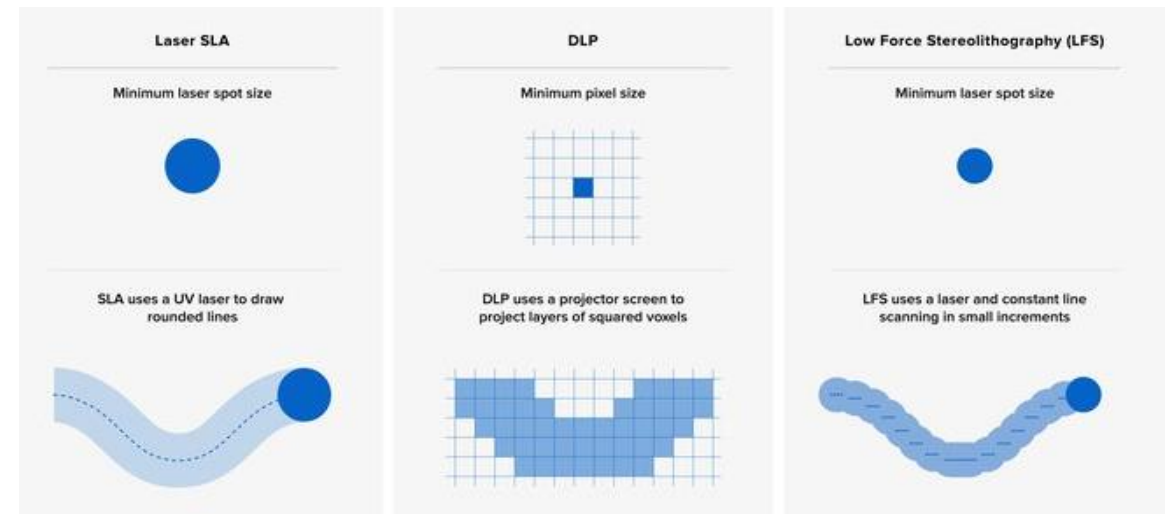
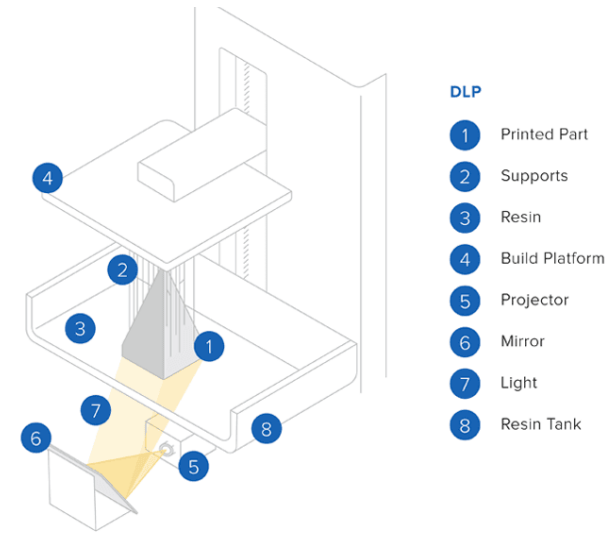
EXAMINE THE GAP/OVERLAP BETWEEN THE EXTRUDED LINES





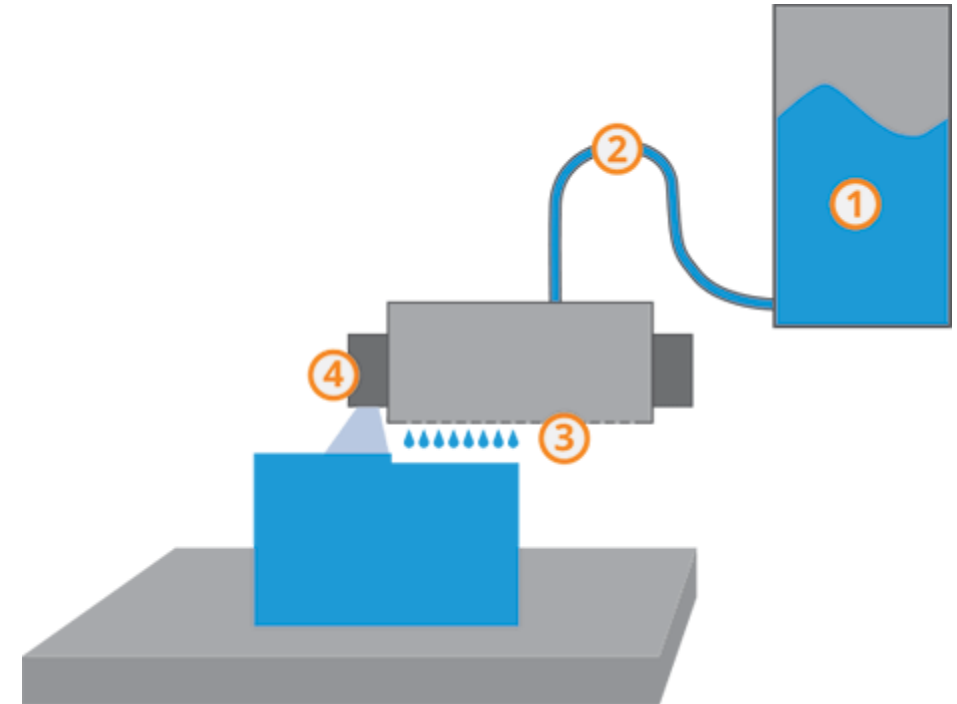
■ SLA/DLP Printers

- UV bonded Resin
- SLA utilizes a guided laser
- DLP utilizes a pixelated screen
- Extreme precision and accuracy
- Resin is potentially harmful to work with



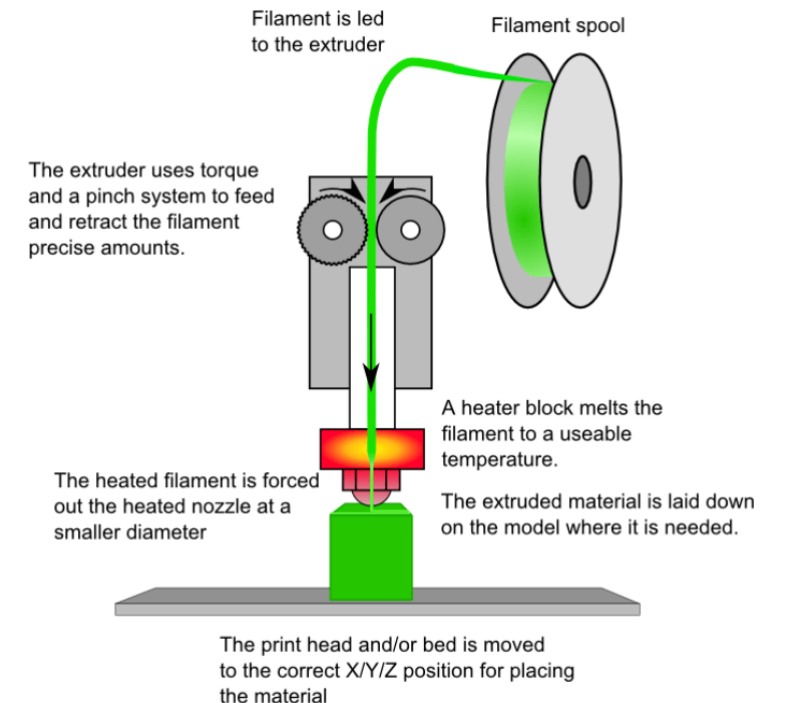
■ Multi/Poly-jet Printers

- Multiple UV bonded Resins (wax patterns or ceramic molds)
- Prints resin onto object and immediately cures
 - Similar to ink on paper printing/ drying
- Extreme precision and accuracy
- Can print dissolvable support material allowing for geometry impossible from other methods



■ FDM Printers

- Utilizes extruded material built up in layers
- Cheapest additive manufacturing process
- Easiest to learn
- Potential issues with slight shrinkage and surface finish



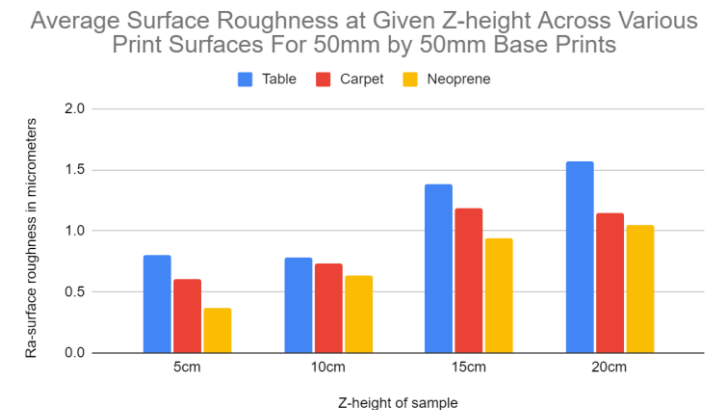
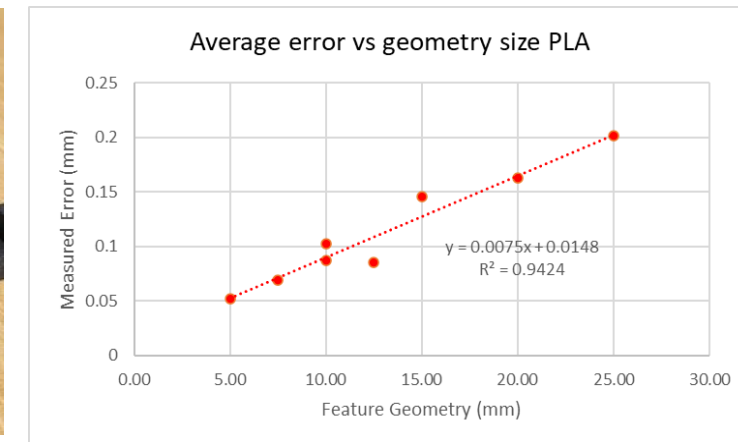
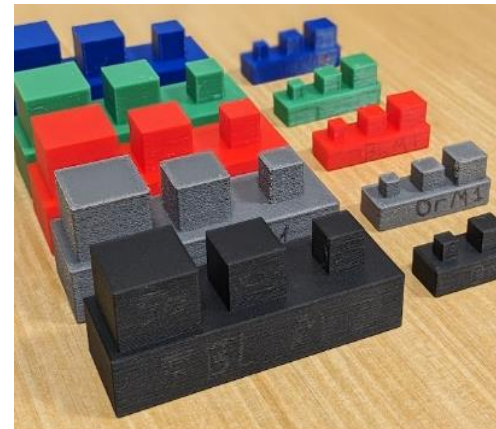
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■ Dimensional Shrinkage and Surface Finish (FDM)

■ Ongoing Research

- Shrinkage occurs on FDM printed parts
- Can be calculated by analyzing dimensional error across geometries
- Through analyzing scatter plots of error, consistency and accuracy can be gauged

- In addition to shrinkage, vibrations can cause surface roughness in parts, which increases with height
- This can be mitigated through printing on a dampened surface and keeping parts close to the build plate





■ Summary and Future Work

- For small to medium batches of parts, 3D printed patterns are cost effective
- Printing Process determined by the size, complexity, and accuracy of the part
- Additive manufacturing will continue to become further integrated into manufacturing for prototypes and custom jobs
- For Dimensional accuracy test artifact and shrinkage offset tuning, scan QR code



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