Additive Manufacturing for Injection Molding: Processes and Trends

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Center for Additive Manufacturing Systems (CAMS)

Two leading universities, Georgia Tech & HUST, explore new knowledge and framework for AM to deliver high quality and industry relevant research. ➔ **Share computational tools, infrastructure, data, & network.**

Center for **Additive Manufacturing Systems**

Huazhong University of Science and Technology
& Georgia Institute of Technology

4D Printer, Ceramic Printer

New Design Software, New Materials

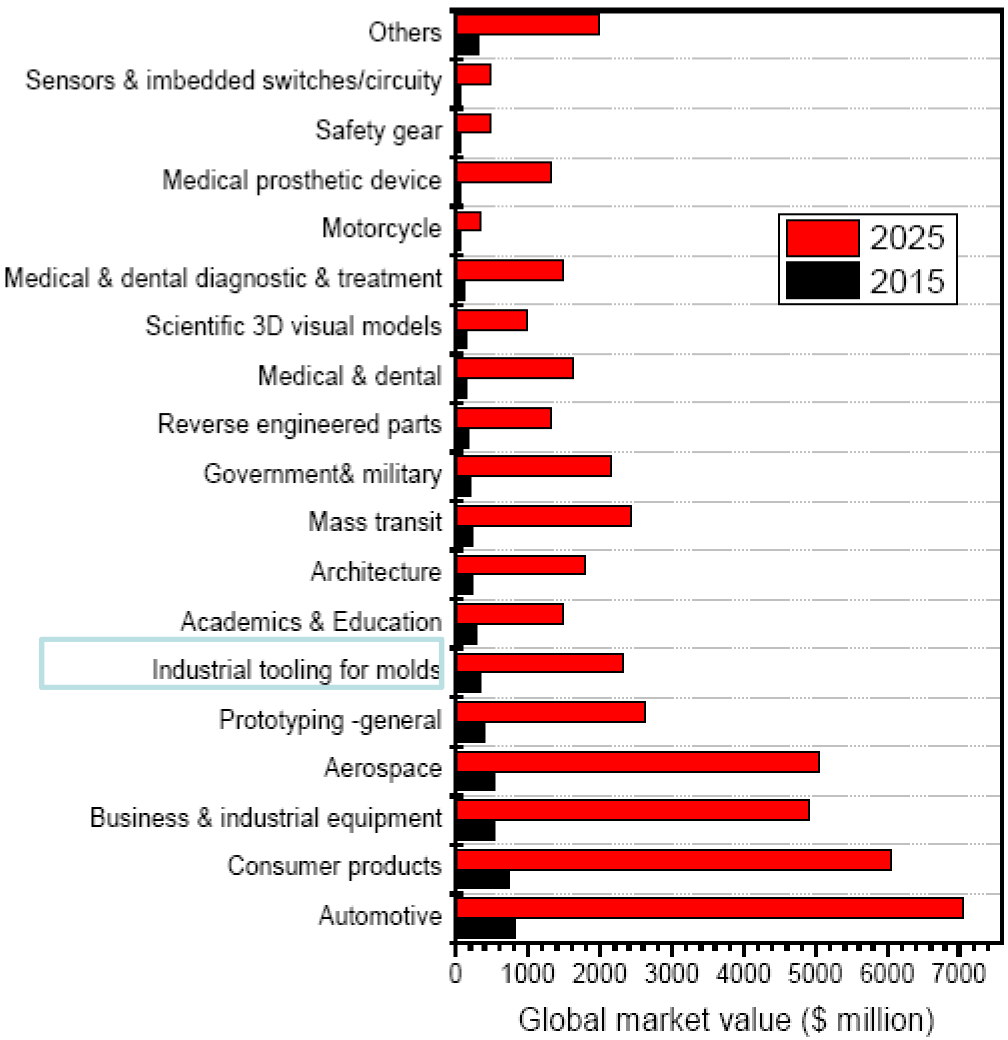
World Largest 3D Printer

Developed Commercial SLM printers

Contents

Current Status of Additive Manufacturing

Global Market Value



Market Size (2015): $5.9 billion

1) Industrial Applications (93%)
2) Consumer Market (7%)

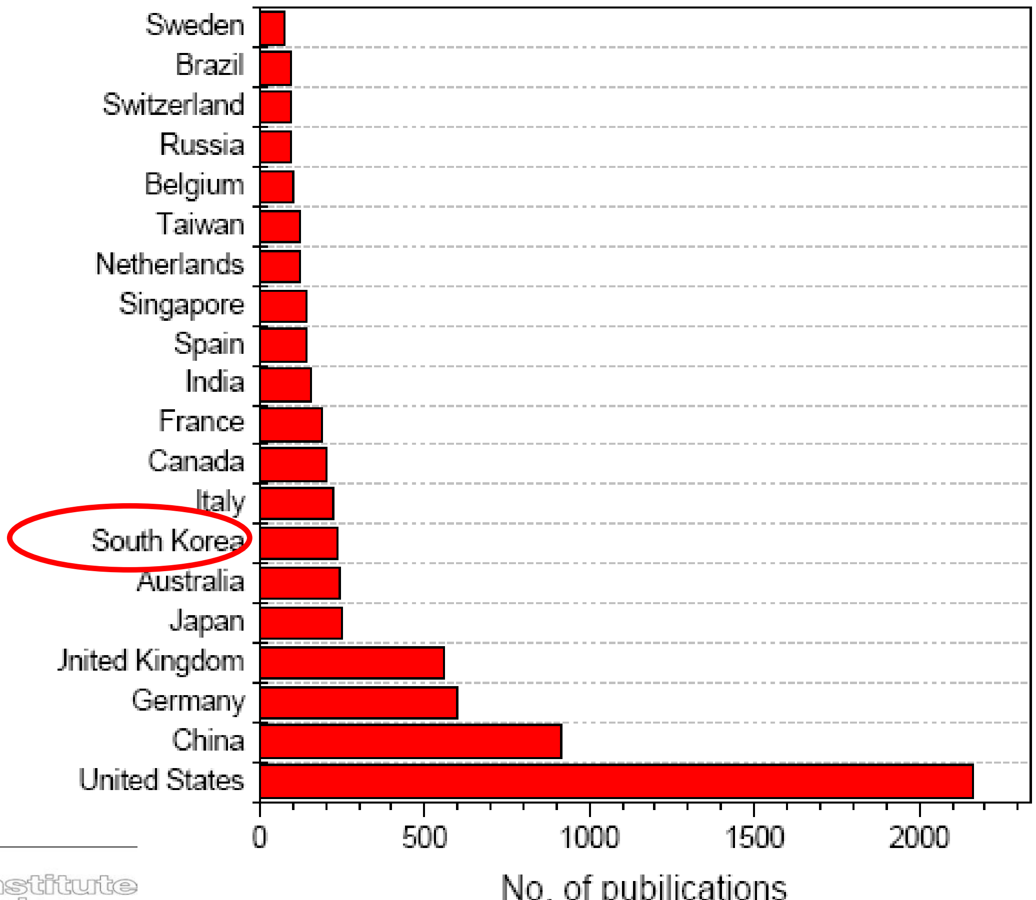
(USA: 41%, EU: 30%

Asia: 24%, Other: 2%)

H. Blum, The future of 3D printing to 2025, (2015). http://www.smitherspira.com/news/2015/june/3d-print-market-expected-to-reach-$49b-by-2025.

AM Global Research Trends

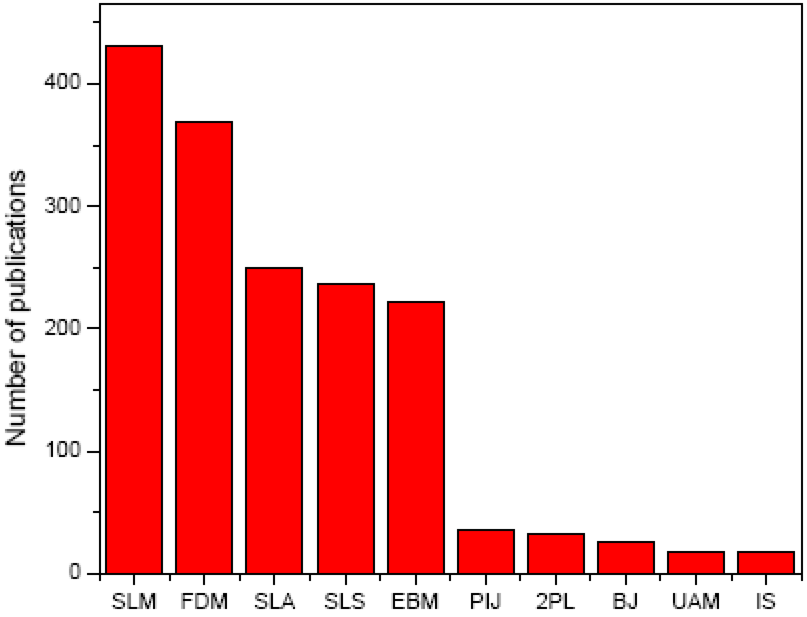
- Top 4 countries (USA / China / Germany / UK) are leading this AM-related research area

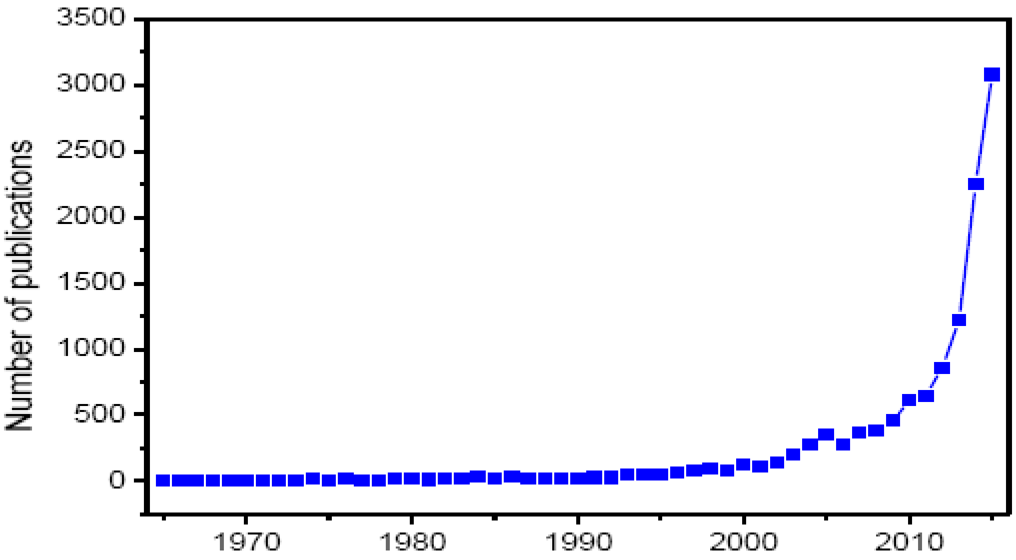


South Korea (#7)

AM Global Research Trends

- Top 5 Technologies (SLM/FDM/SLA/SLS/EBM)





# of AM Publications

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AM Technologies

- Filament (Solid) → Fused Deposition Modeling (FDM)

  Cheap, High Strength

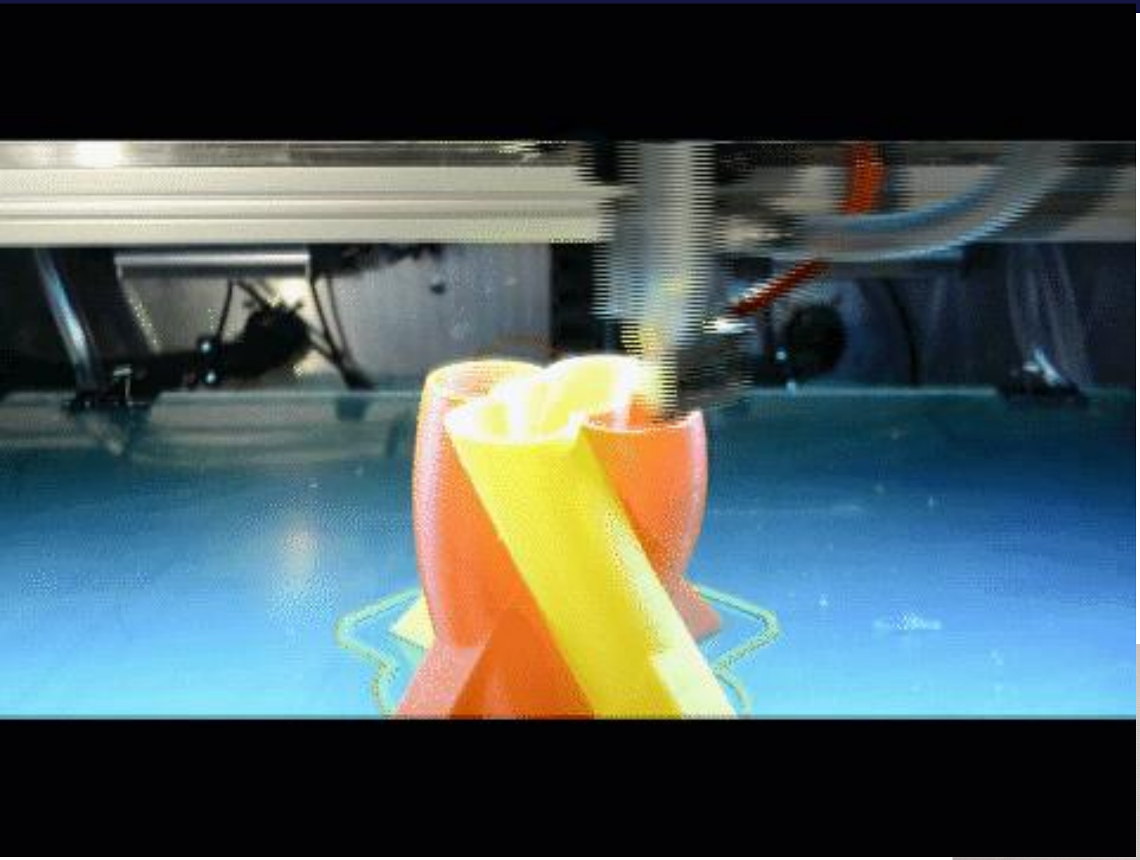
- Metal/Ceramic Powder → Selective Laser Melting (SLM)
  Electron Beam Melting (EBM)
  Selective laser Sintering (SLS)

  Expensive, but possible to achieve born qualified parts

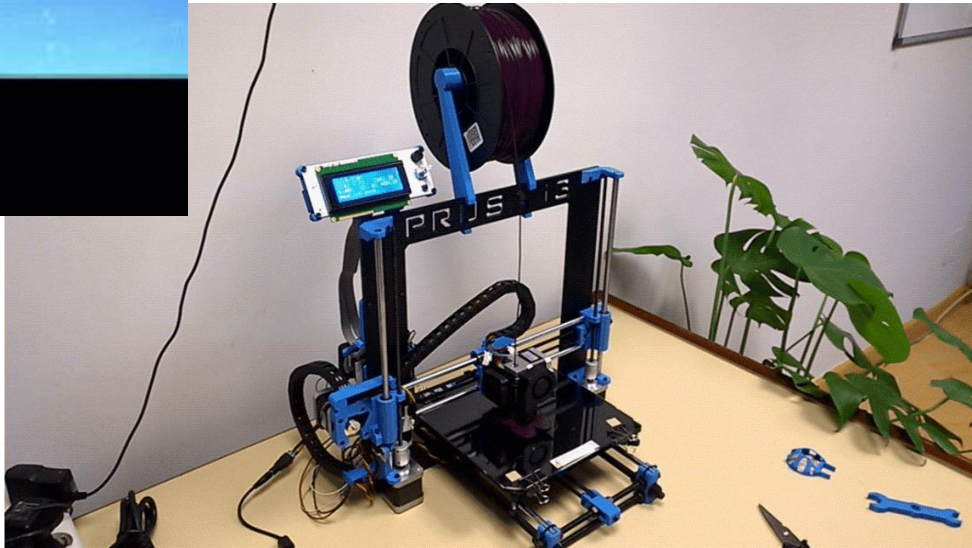
- Liquid Resin → Digital Light Printing (DLP & SLA)

  High Resolution, Fast Speed

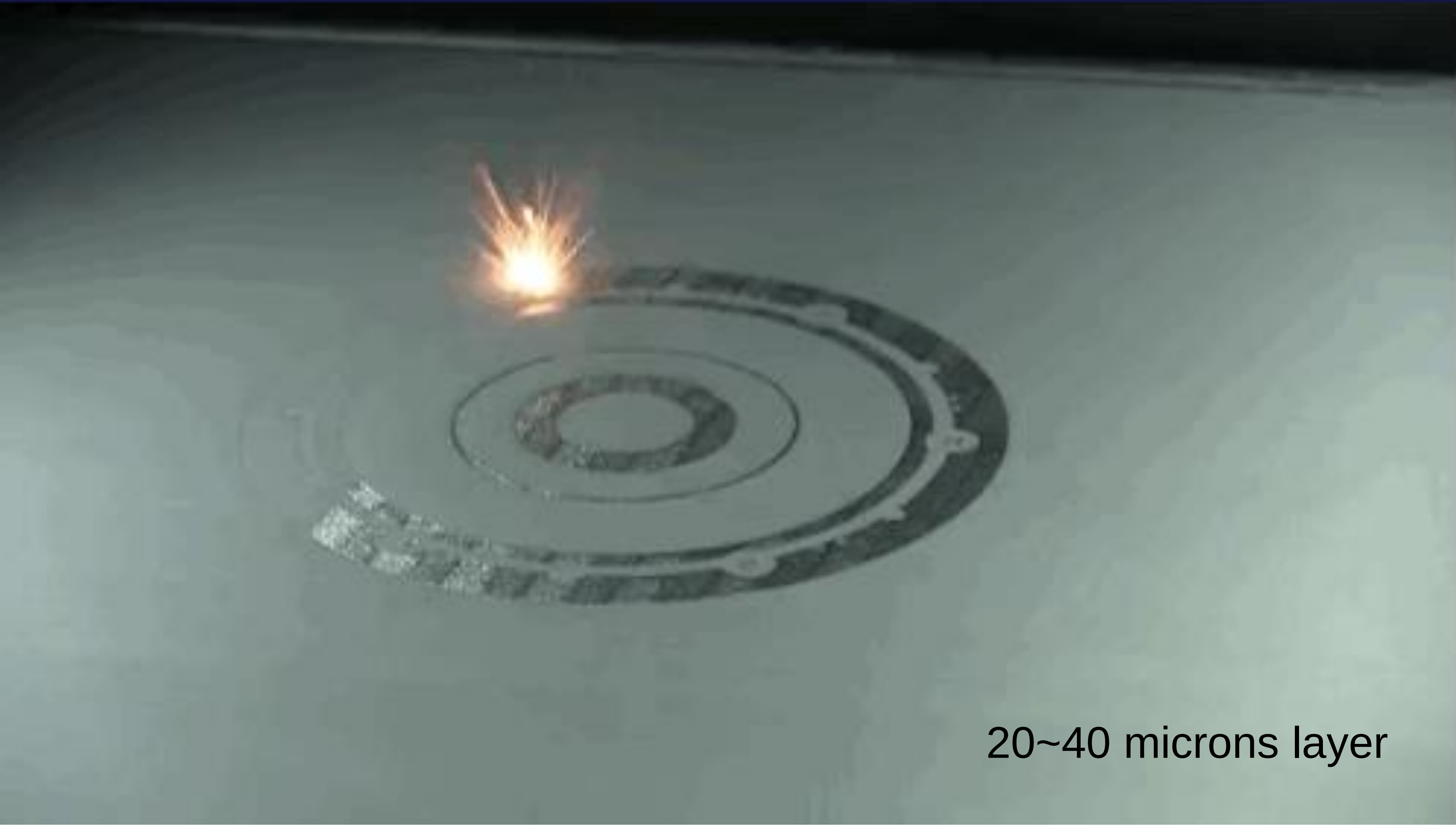
Fused Deposition Modeling (FDM)



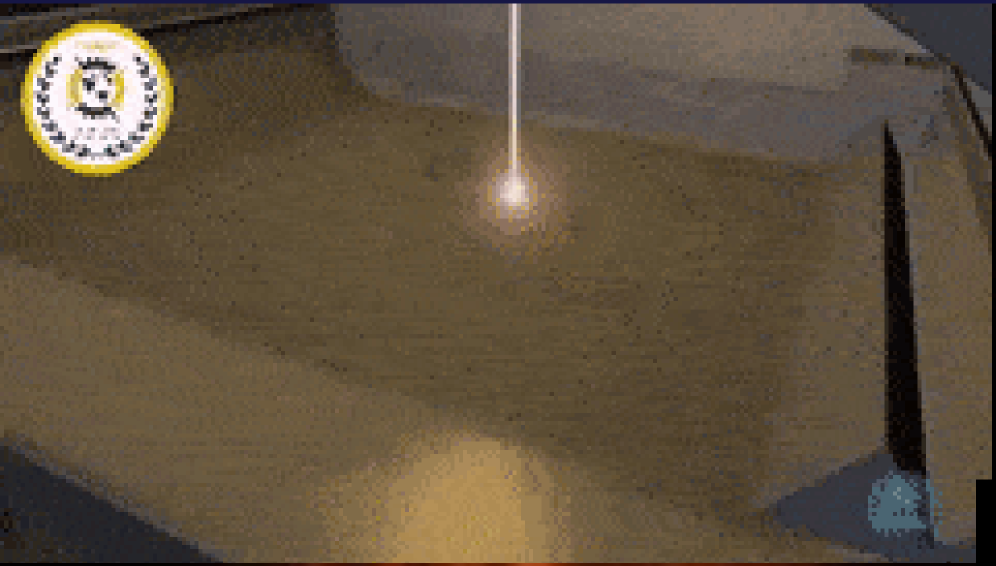
ABS/PLA/PET/etc.

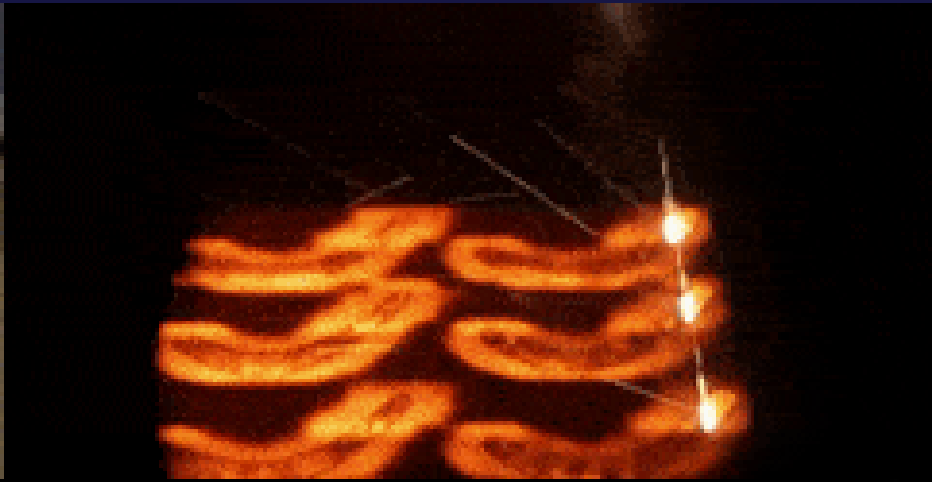


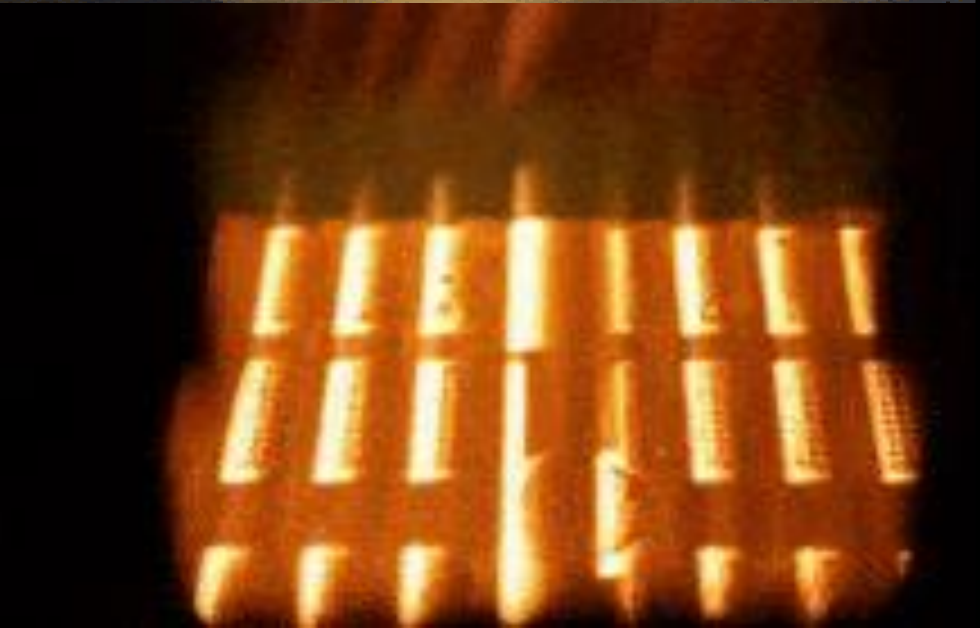
Selective Laser Melting (SLM)



Electron Beam Melting (EBM)

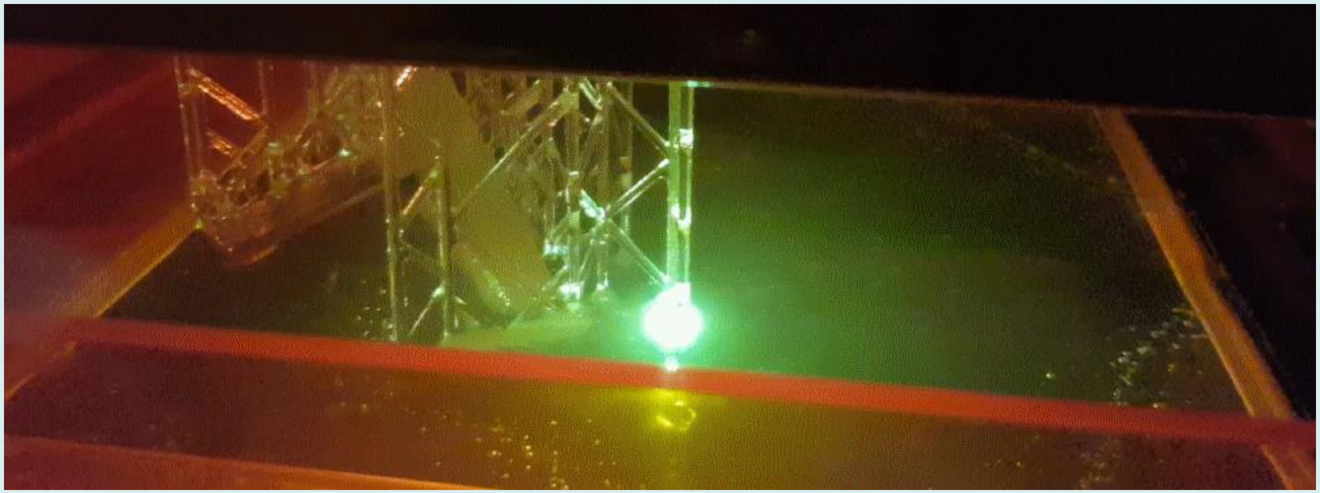


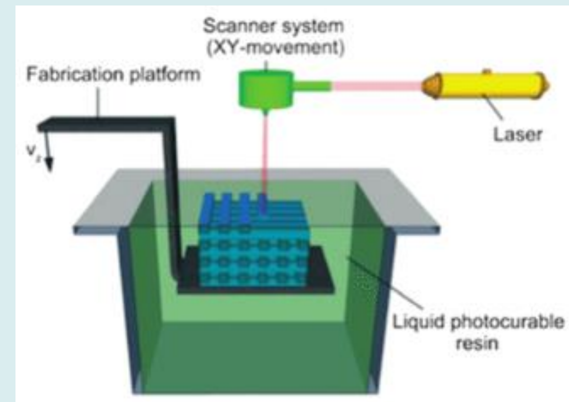




Digital Light Processing (DLP)

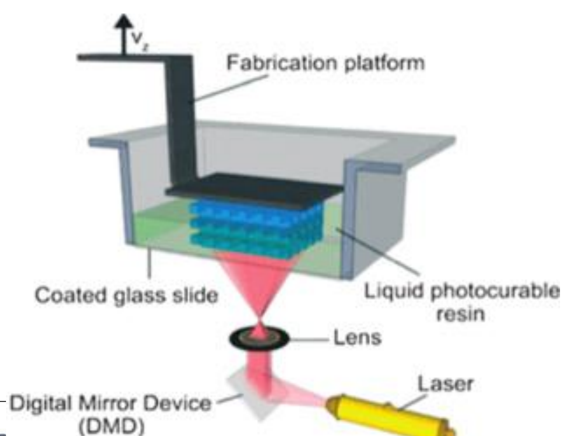
Stereolithography (SLA) → UV Laser

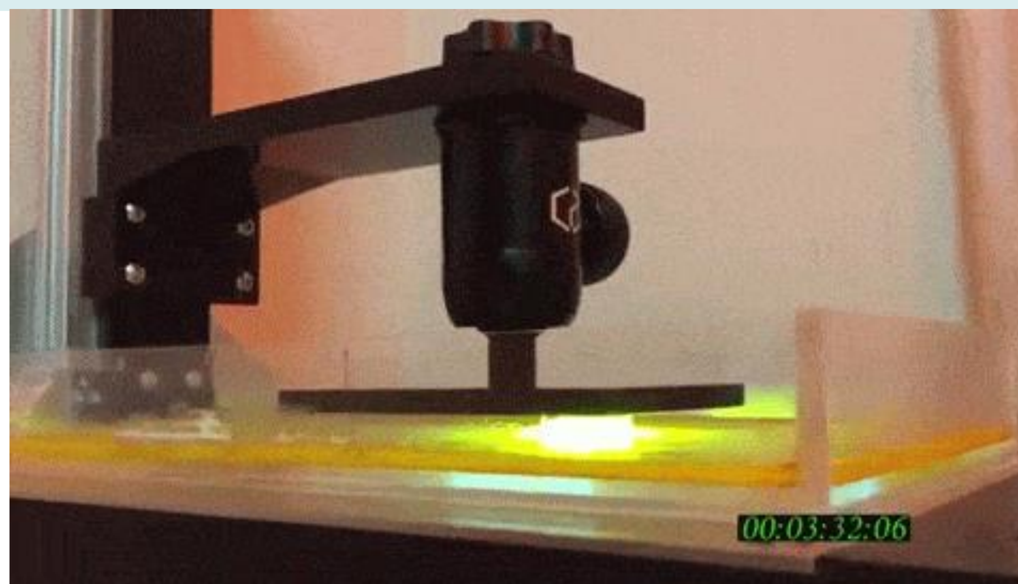


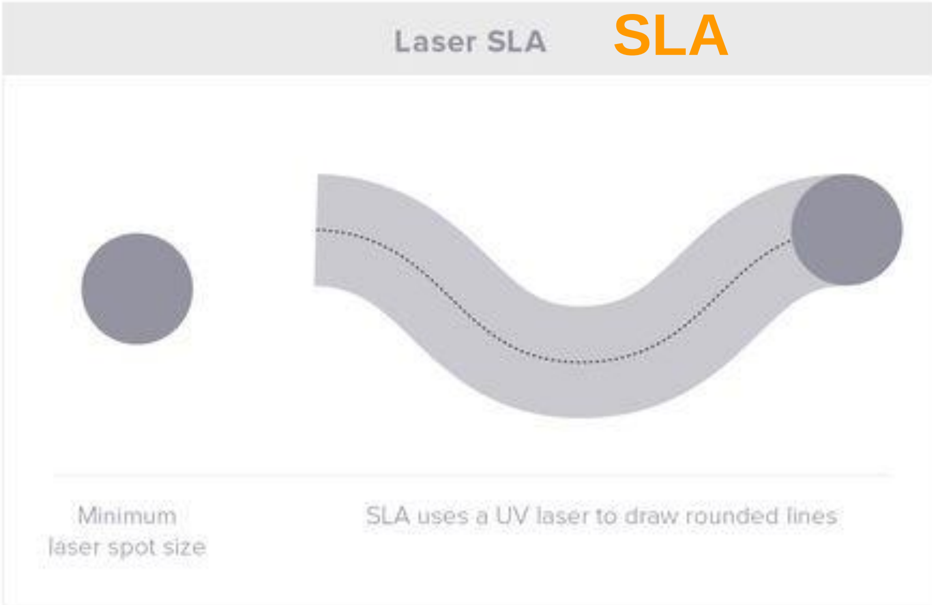


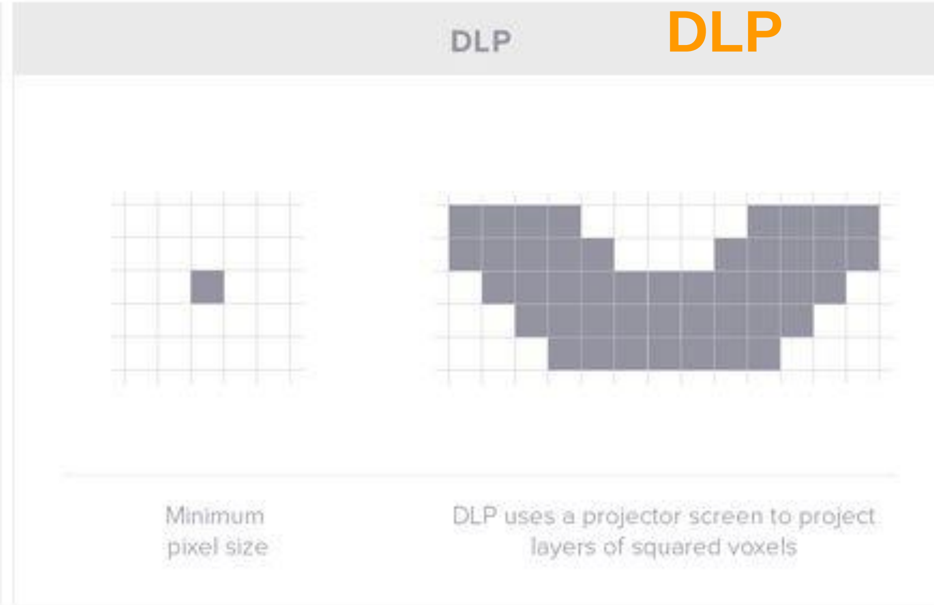
Photoreactive Liquid Resin

DLP (Digital Projector)






Laser SLA
SLA
Minimum
laser spot size
SLA uses a UV laser to draw rounded lines


DLP
DLP
Minimum
pixel size
DLP uses a projector screen to project
layers of squared voxels


SLA
DLP

SLA vs FDM

3D Printers for Injection Molding

- Fused Deposition Modeling (FDM), Composite Filament

- SLM/EBM/SLS (Metal, Ceramic, Sand Powders)

Al, Ti, SS, Inconel, etc.

SLM : around 30 metal powders

EBM : 8~10 metal powders

$100,000 ~ $2M

- DLP/SLA/Polyjet (Liquid Resin)

$1,000 ~ $800,000 depending upon build size, resolution & materials

AM for Injection Molding

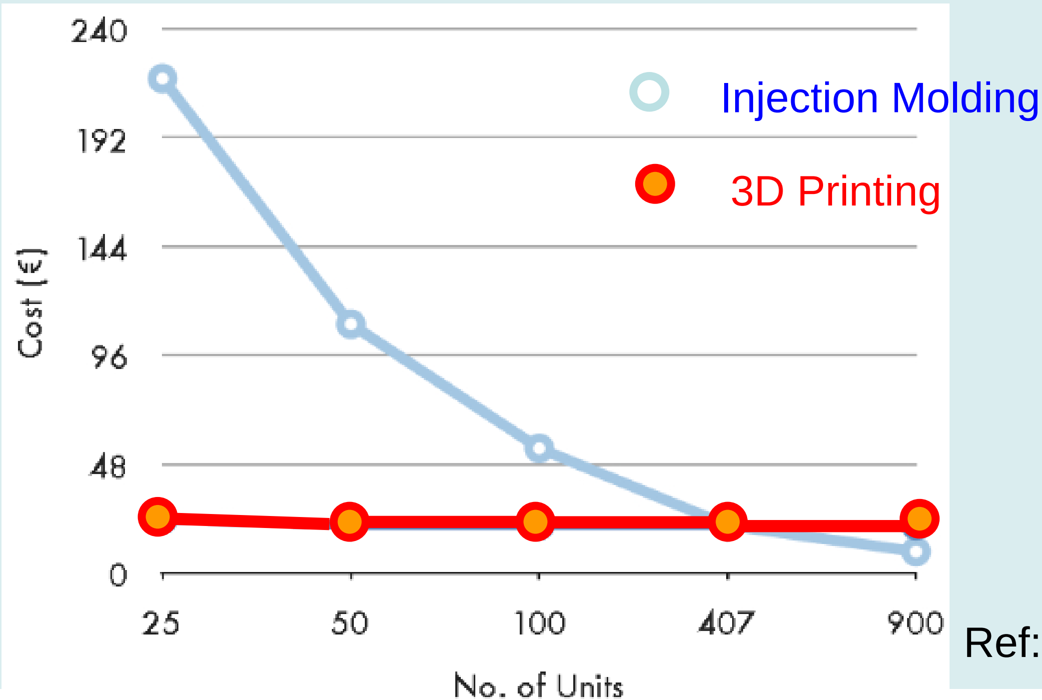
Benefits from AM in Injection Molding Industry

Ideal for low volume service parts (small batch, 10~200)

➔ **Can quickly verify new designs and produce small batches.**

➔ **Verified mold can be used as a prototype to make a high-volume mold with traditional tooling methods.**

Car Handle Product (up to 407 units, 3D printing is cheaper)

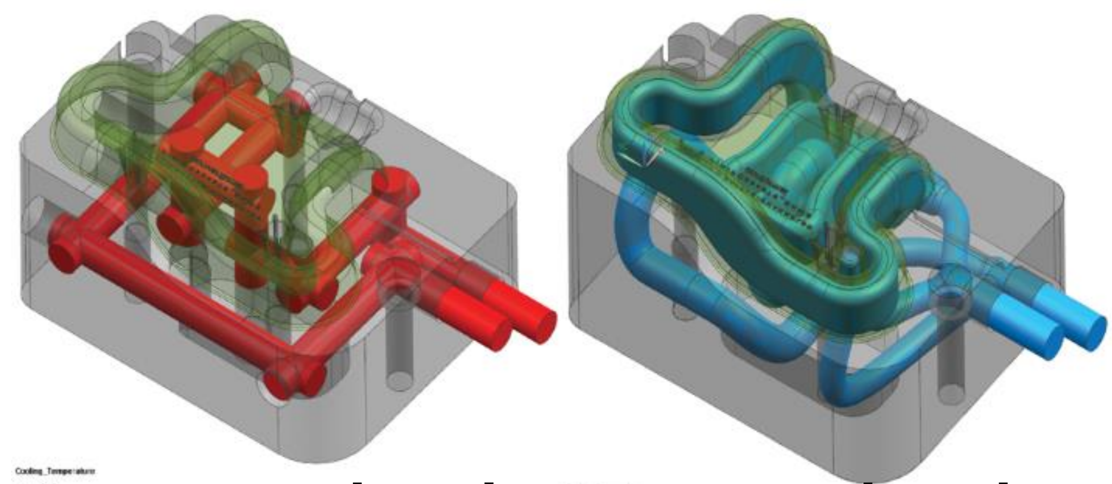


Ref:Sculpteo

Benefits from AM in Injection Molding Industry

Complex internal geometry ➔ Conformal cooling using lattice structures, micro-channels

- ➔ **Cooling cycle time improvement, 50%.**
- ➔ **Improved temperature uniformity and reduced volumetric shrinkage**
- ➔ **Useful to applications requiring repeatable tight tolerance.**



Conventional **3D Printed**

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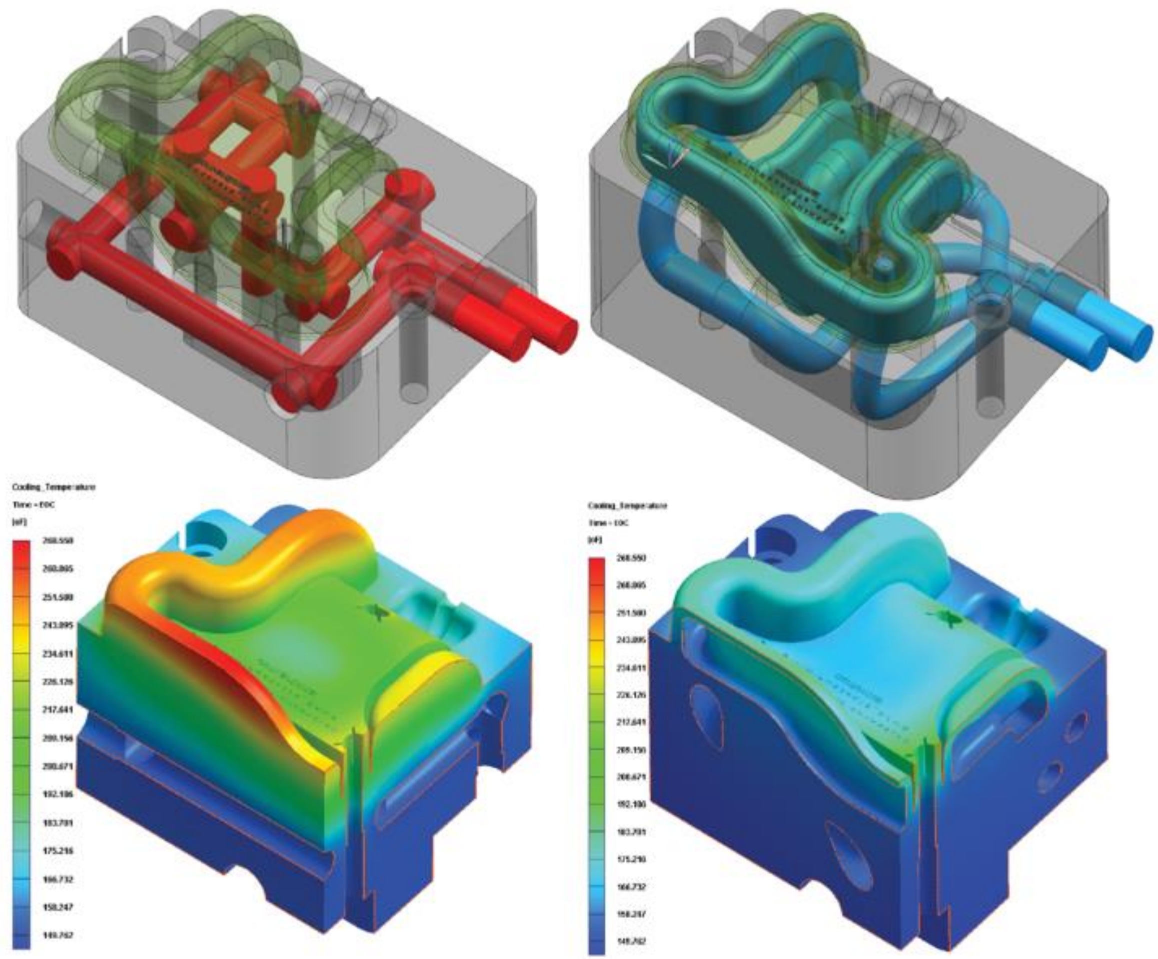
Benefits from AM in Injection Molding Industry

Optimized cooling channels ➔ Complex geometry

Simulation shows that total cycle time can be reduced upto 15~60% depending upon part complexity



Benefits from AM in Injection Molding Industry

"Lost Wax" casting with 3D printers (Print to Cast)

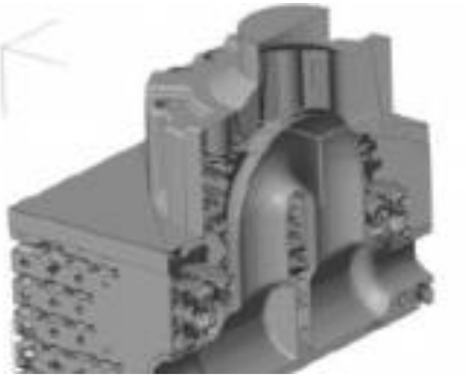
➔ DLP printers very high resolution wax printing capabilities (~40 micro meter)

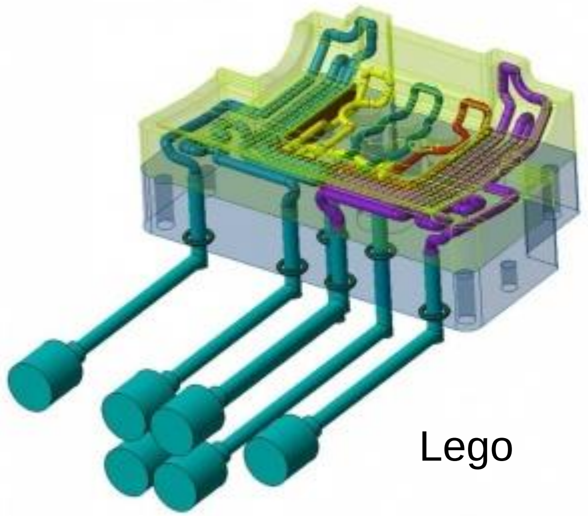
Wax Filament for FDM printers (can be polished, machined)

3D Printed Mold Examples

Metal Mold (EBM/SLM)

➔ 3D Printed metal inserts require machining for surface finish, but micro-cooling channels can be integrated.





Lego

3D Printed Mold Examples

Sand Mold (SLS)

Formula 1 Transmission Housing:

Cast material: Al alloy 356

Printed Material: Silica sand

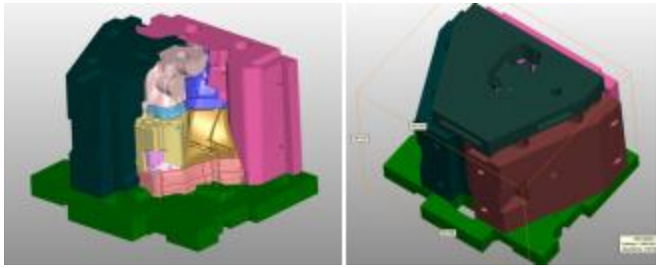
Printed Volume: 200 L

Production Time: 4 hours

Batch size: 5 pieces

Cost per part: 1500 euro

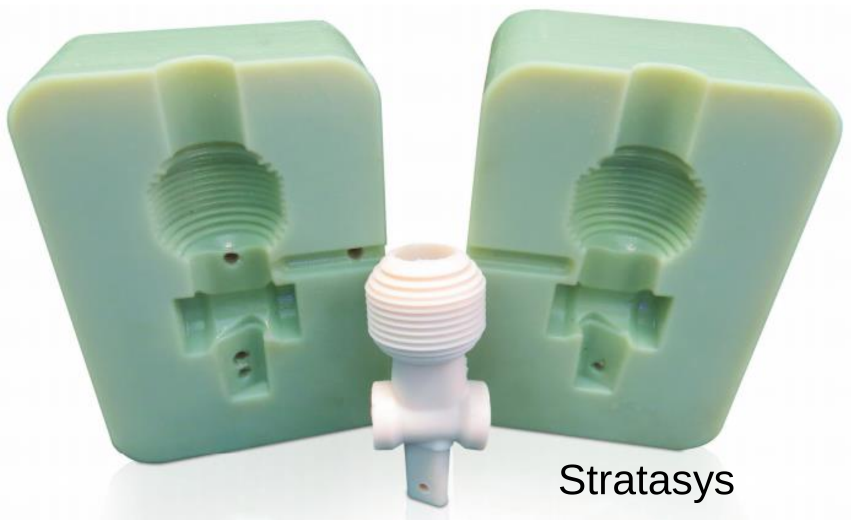
Traditional method: 15,000 euro



3D Printed Mold Examples

Thermosetting Plastic Mold (DLP)

➔ Produce 20~200 parts

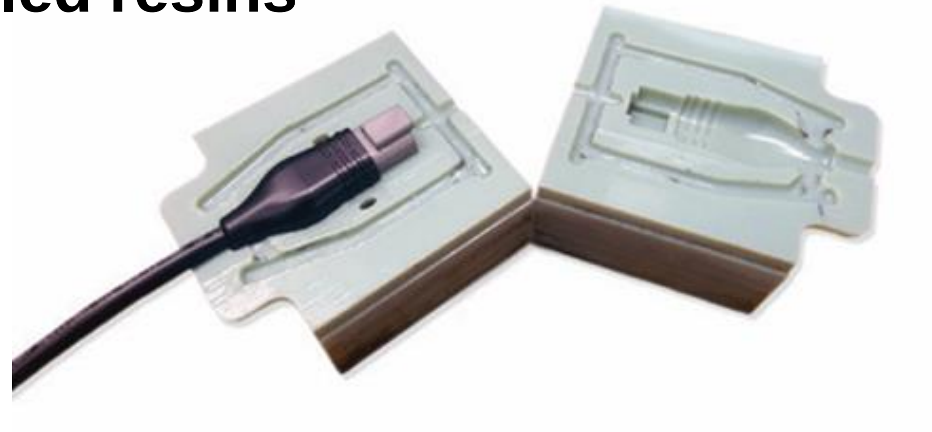


Molding temperature up to 300 ºC

Materials: PE, PP, PS, ABS, TPE, TPO, PA, POM, PC-ABS and glass-filled resins

Print size: ~10x13 inch

200 ton molding machine

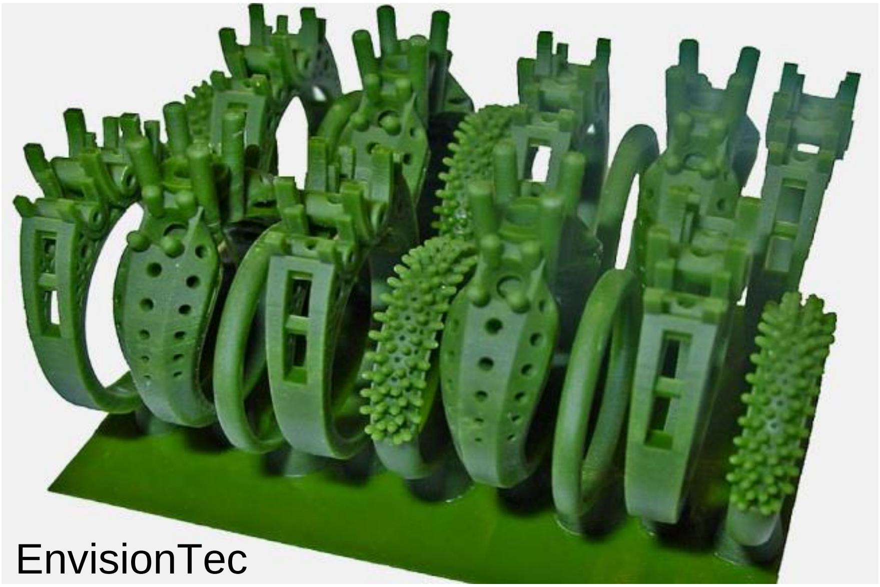


3D Printed Mold Examples

3D Printed Castable Materials (DLP)

Dental Application

Jewelry



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3D Printing vs Conventional Manufacturing Methods

3D Printing		Conventional (Casting, Forming, Machining, Stamping, etc.)
Prototyping/Short Runs Low Production Volume		Large Production Volume
Complex Geometry (Part Consolidation)		Very Large Parts
High Material Costs (but reduced waste)	VS	Low Material Costs
Non-critical Parts (speed to market)		Mission Critical Parts (surface, standards)

Current Technical Challenges in AM

Printer can create virtually any geometry but software tools are lagging behind

- Require improved software tools which are capable of handling the geometric complexities of designed components.
- Require design tools and methodologies which aid with the design for AM process to unlock the true potential of the technology.

What you design and what you get are not always the same

- There are issues in data management and data translation between CAD packages and tool path codes used by printing machines. There are no universal standards.

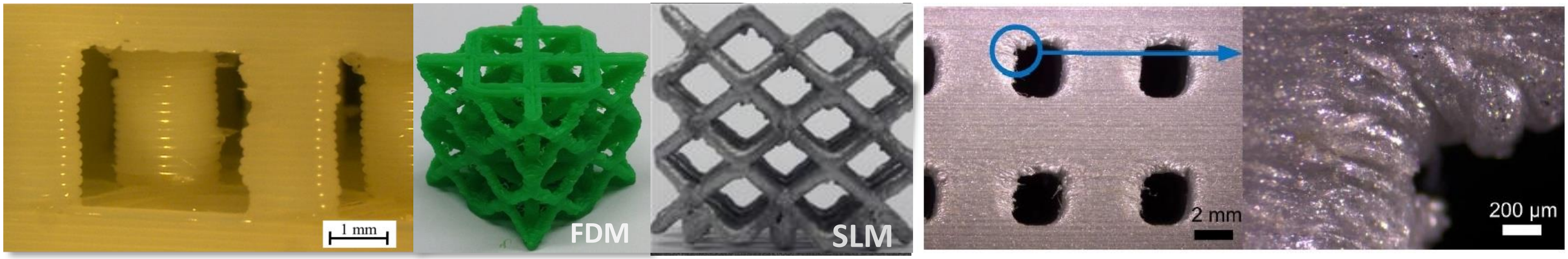
➔ Mismatch between design and build

➔ Universal market standard for data transfer/translation required

Current Technical Challenges in AM

Build quality and repeatability are still a question mark

- Not good enough to meet strict safety standards (i.e., aerospace)



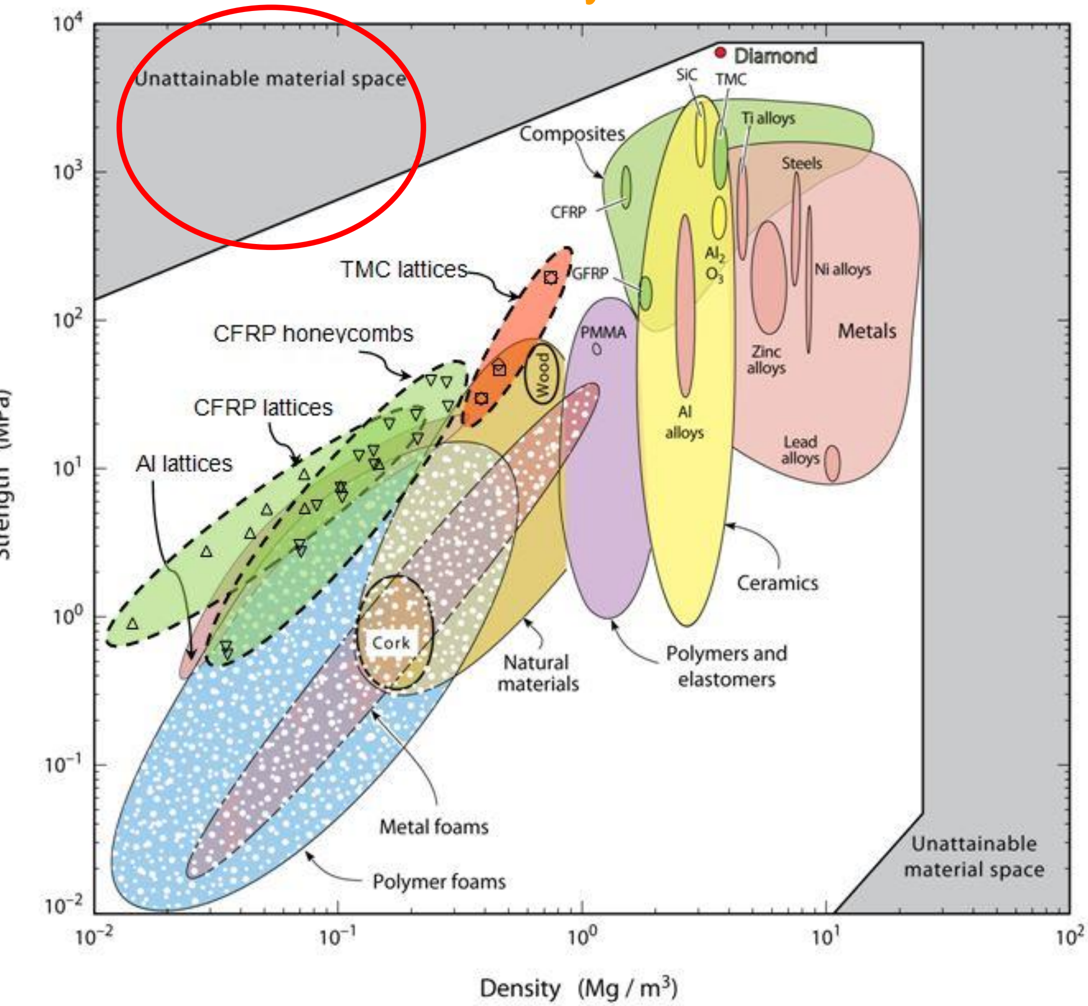
3D printers are getting faster but the manual pre- and post-processing is lagging

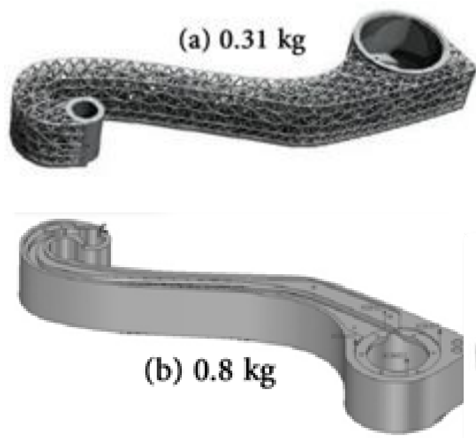
- Heat treatment, support removal, part removal from base plate, cleaning, powder sieving and many others can be a significant logistical and financial burden.

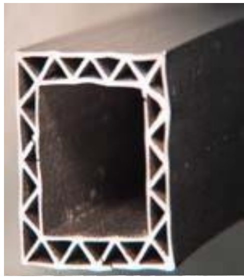
Design Approaches and Tools in AM

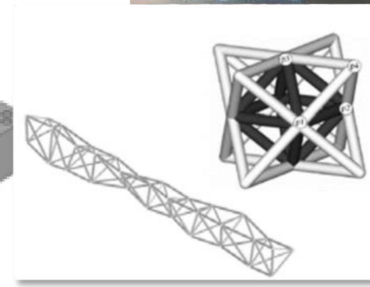
Value of Cellular/Lattice Structures

Ashby Chart





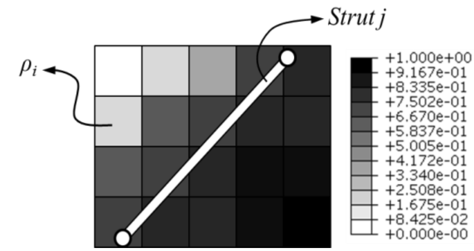


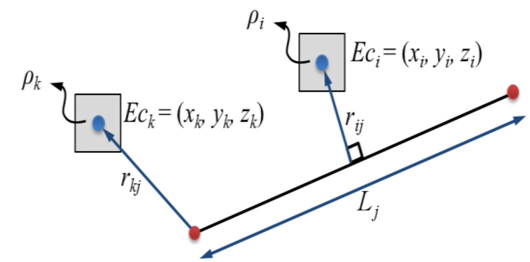


- Gap in low density and high strength region ➔ Cellular/Lattice structure
- **Light Weight & High Strength, High Energy Absorption can be accomplished via cellular structures**

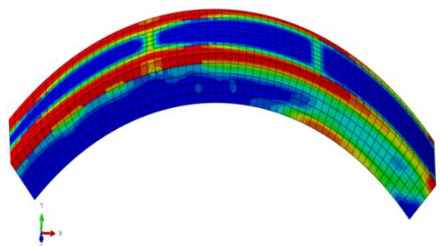
Design Methods for Lattice Structures

Relative Density Mapping (RDM) method @ Georgia Tech

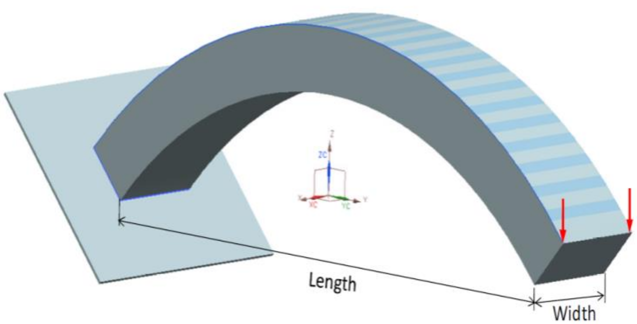


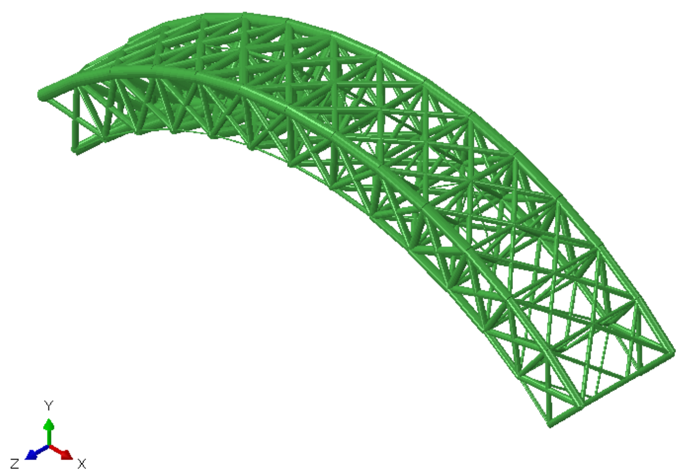


Topology optimization



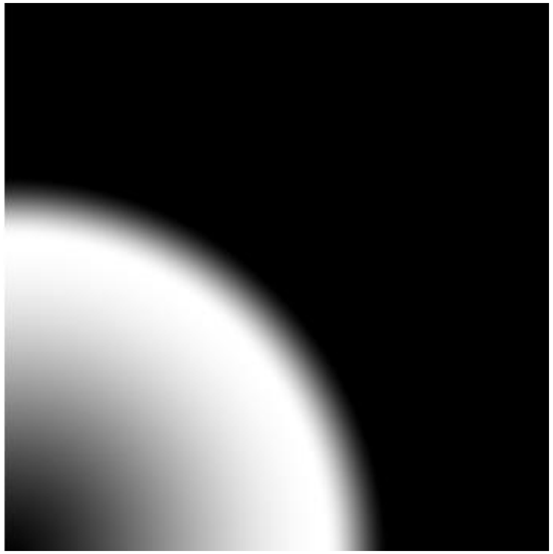
Relative Density Mapping (RDM)



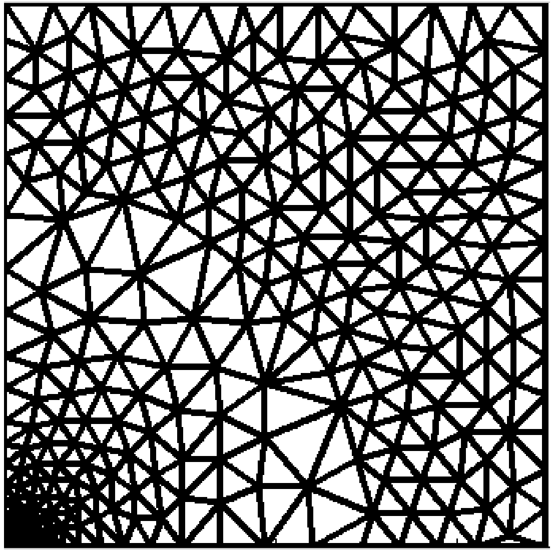


Design Methods for 3D Printed Injection Molding

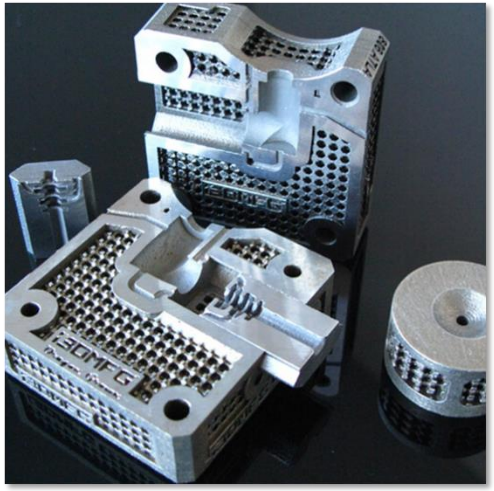
Functionally Graded Lattice (FGL) Design Method @ GT



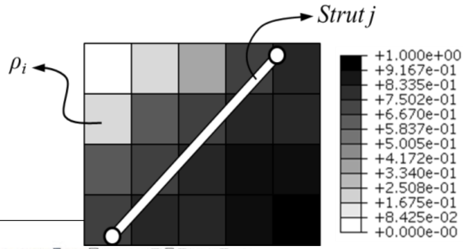
Density Distribution



FGL Generation



Non-optimal Design



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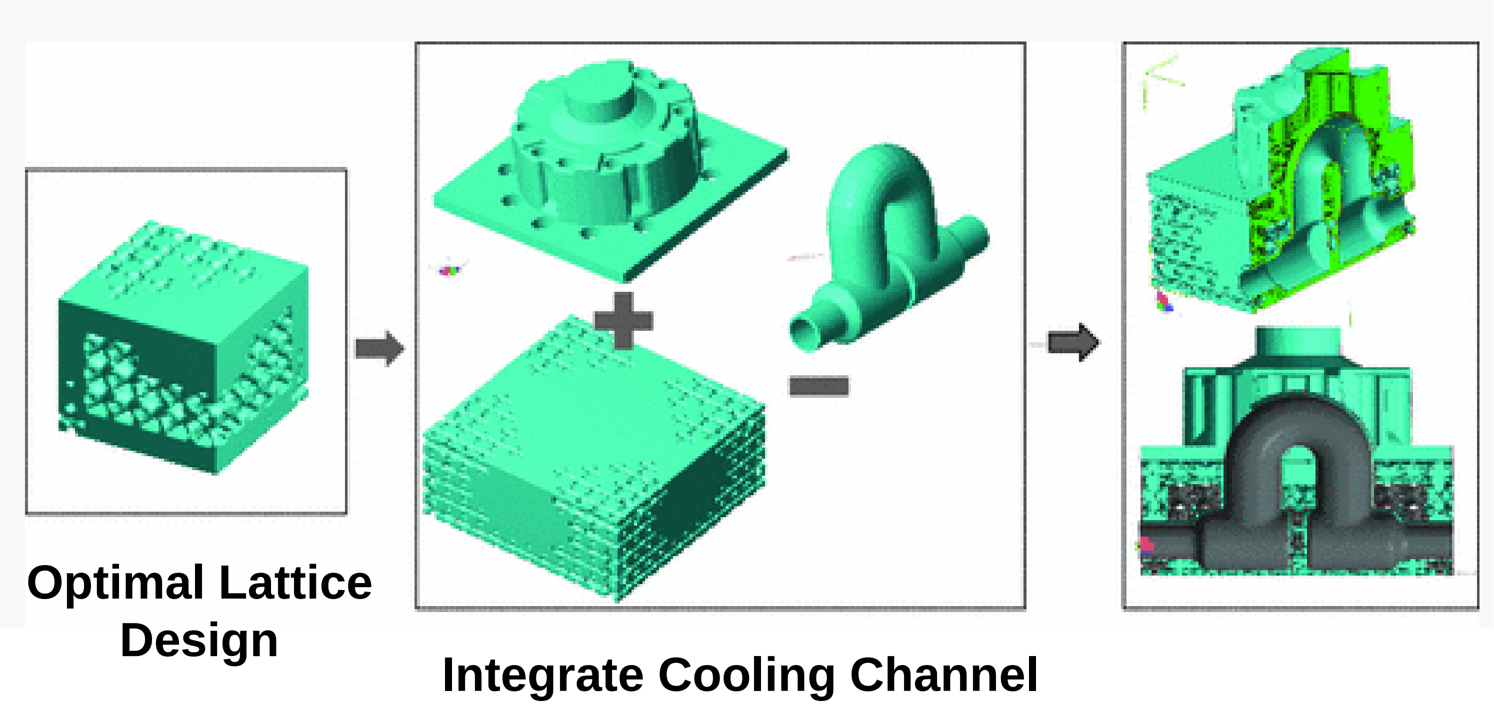
Design Methods for 3D Printed Injection Molding

Existing Injection Mold Example



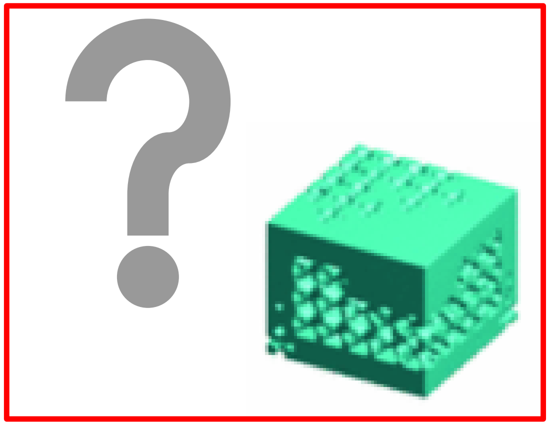
Ref: Purdue

Mechanical compliance is minimized along with mechanical & thermal loads.

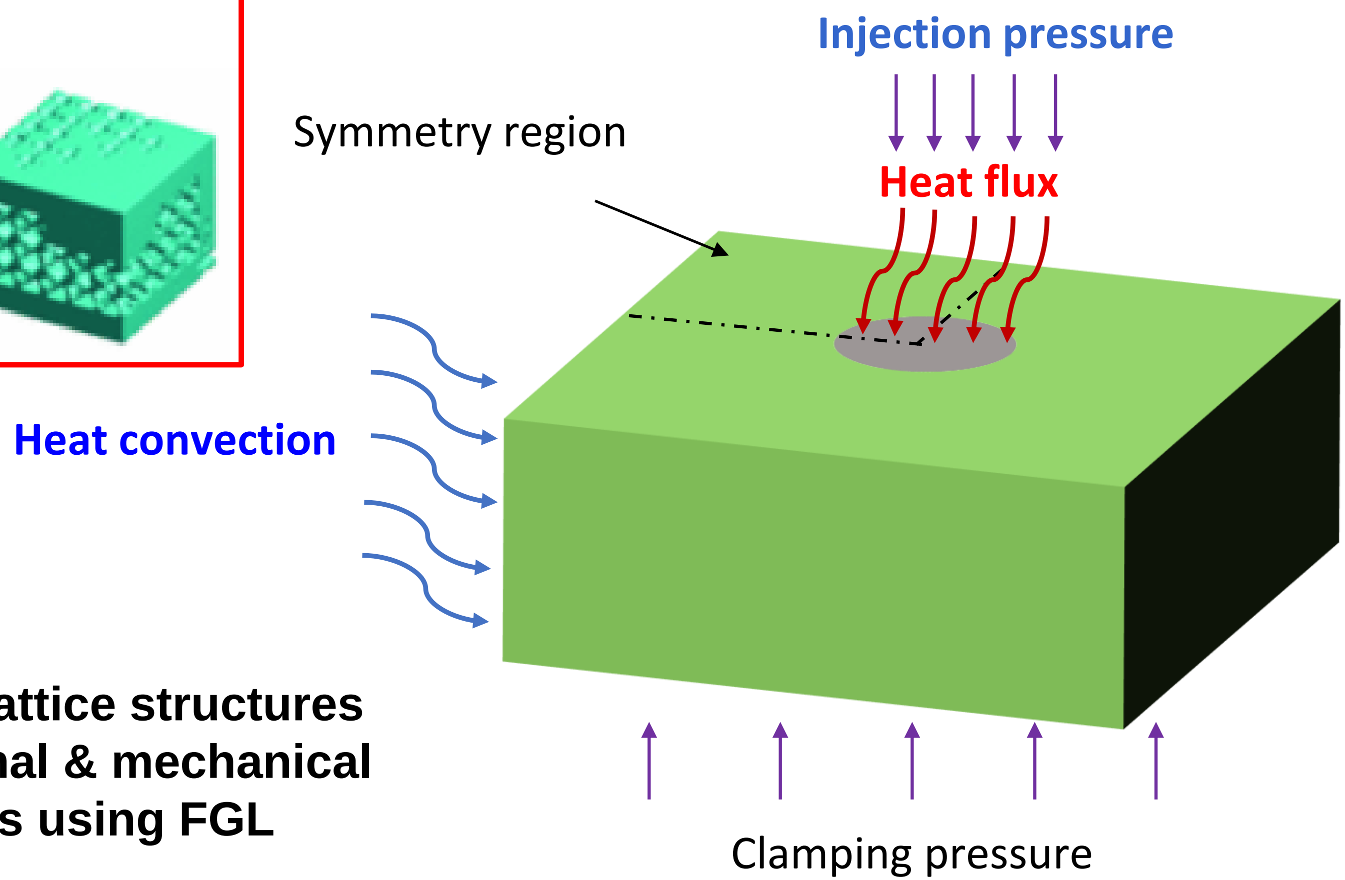
➔ Thermal compliance minimization and heat convection are not considered in the previous research.

Design Methods for 3D Printed Injection Molding

Design Process @ GT



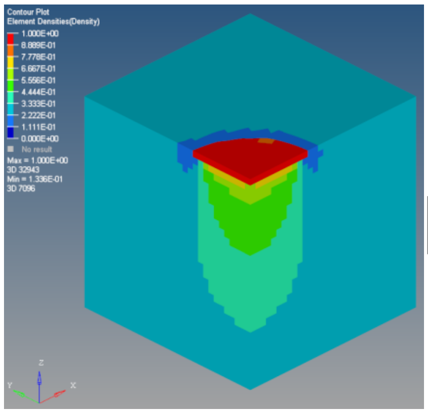
Loading/Boundary Conditions



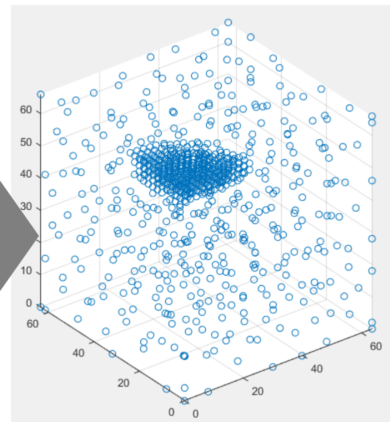
Design internal lattice structures to increase thermal & mechanical performances using FGL

Design Methods for 3D Printed Injection Molding

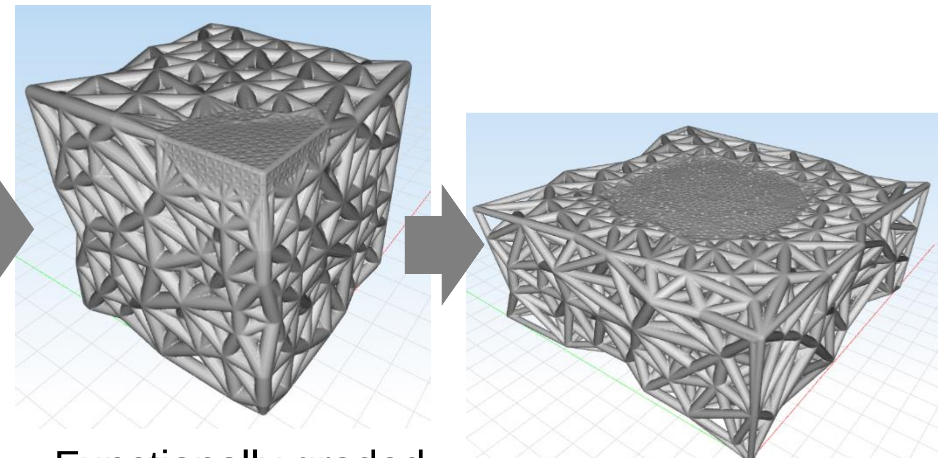
Multi-objective Topology Optimization Method with FGL @ GT



Density distribution



Nodal distribution



Functionally graded lattice generation

Topology Optimization Statement

$$\min f(\rho) = w_1\left(\mathbf{F}_m\mathbf{U}_m(\rho) + \mathbf{F}_t\mathbf{U}_t(\rho)\right) + w_2\mathbf{q}\mathbf{T}(\rho)$$

Fm: Mechanical Load, Um Mechanical Displacement
Ft: Thermal Expansion Load, Ut, Thermal Expansion Displacement
q: Nodal Heat Flux, T: Nodal Temperature

Summary

- AM-fabricated inserts for injection molding can reduce costs and timeframes drastically. ➔ Shorter time to market.

- Conformal cooling with lattice structures can improve cooling cycle time as much as 50% above compared to traditional conformal cooling. ➔Useful to applications requiring repeatable tight tolerances.

- AM is less competitive than traditional manufacturing in terms of mass production, surface finish, and large size products.

- New AM technologies keep introduce new materials and surface finishing capabilities.

AM can not replace the traditional manufacturing, but it can complement it.

Q&A