Additive Manufacturing and Topology Optimization

MEE 342

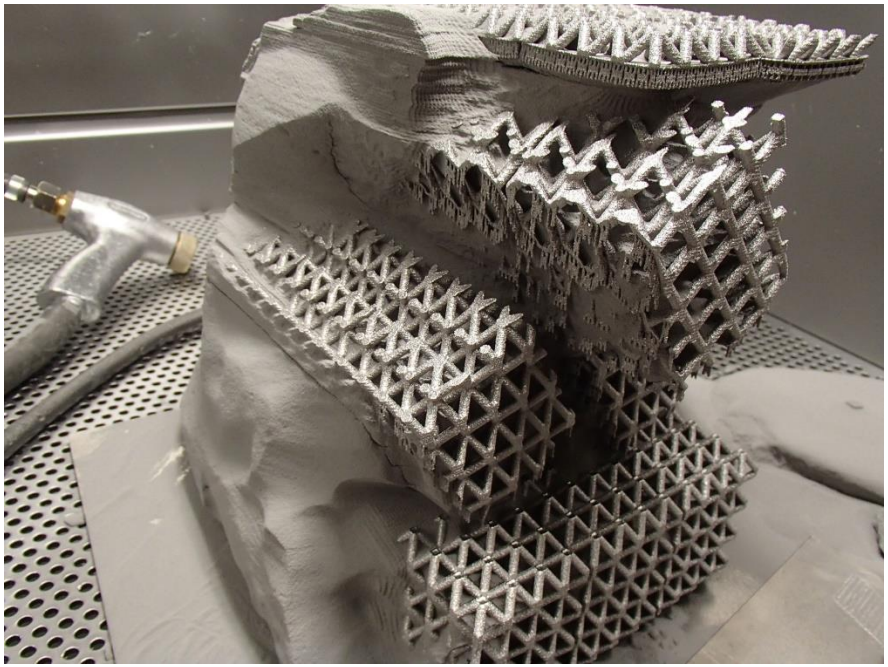
AM methods

- Material extrusion aka Fused Deposition Modeling (FDM): create layers by mechanically extruding molten thermoplastic material (e.g., ABS or PLA, and processing ceramic and metal pastes) onto a substrate.

Price: ~$1000

AM methods

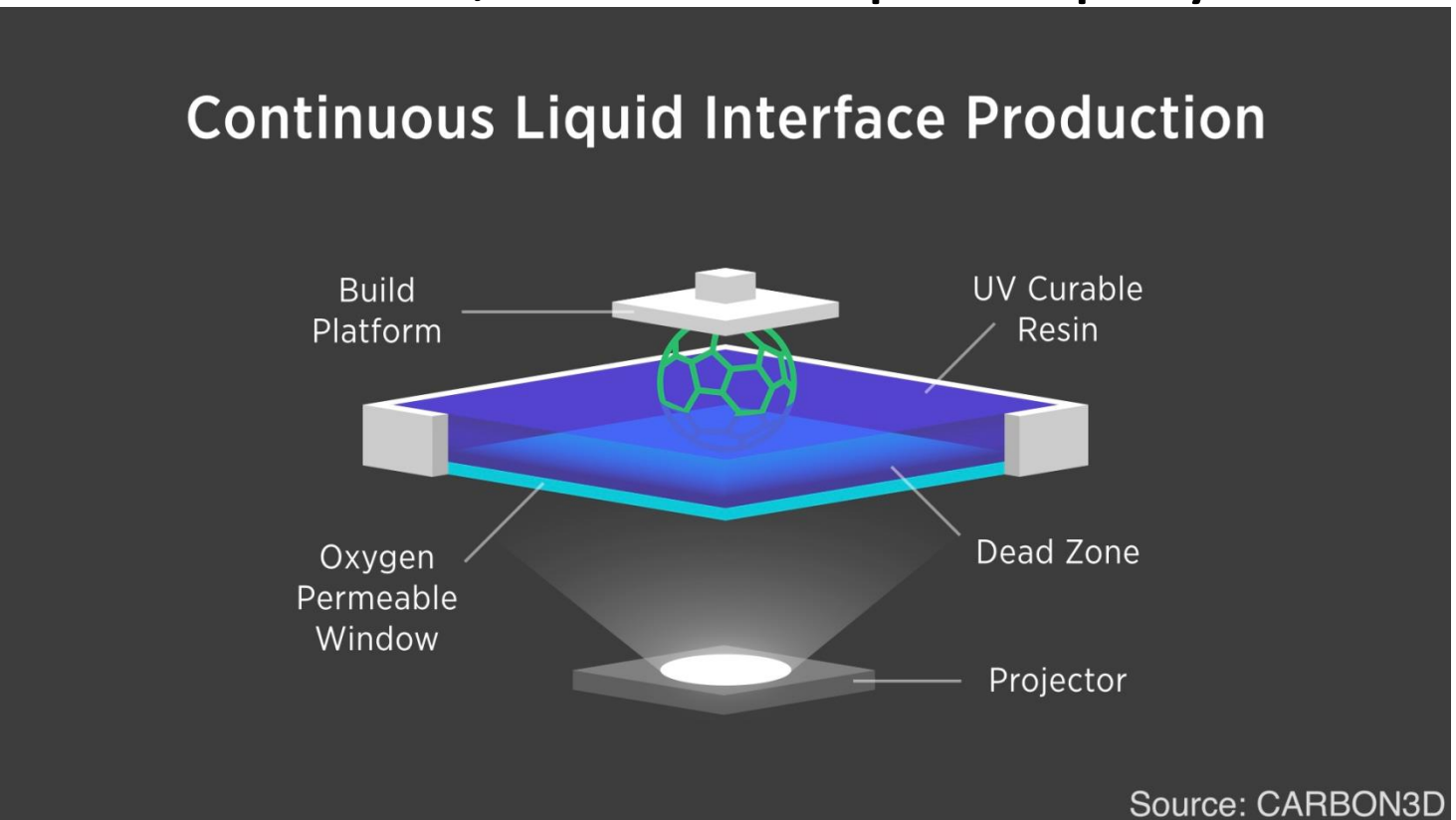
- Powder bed fusion (Direct metal laser sintering, selective laser melting and electron beam melting): use an energy beam (e.g. laser or electron beam) to selectively melt a powder bed.



Price: ~$1,000,000

AM methods

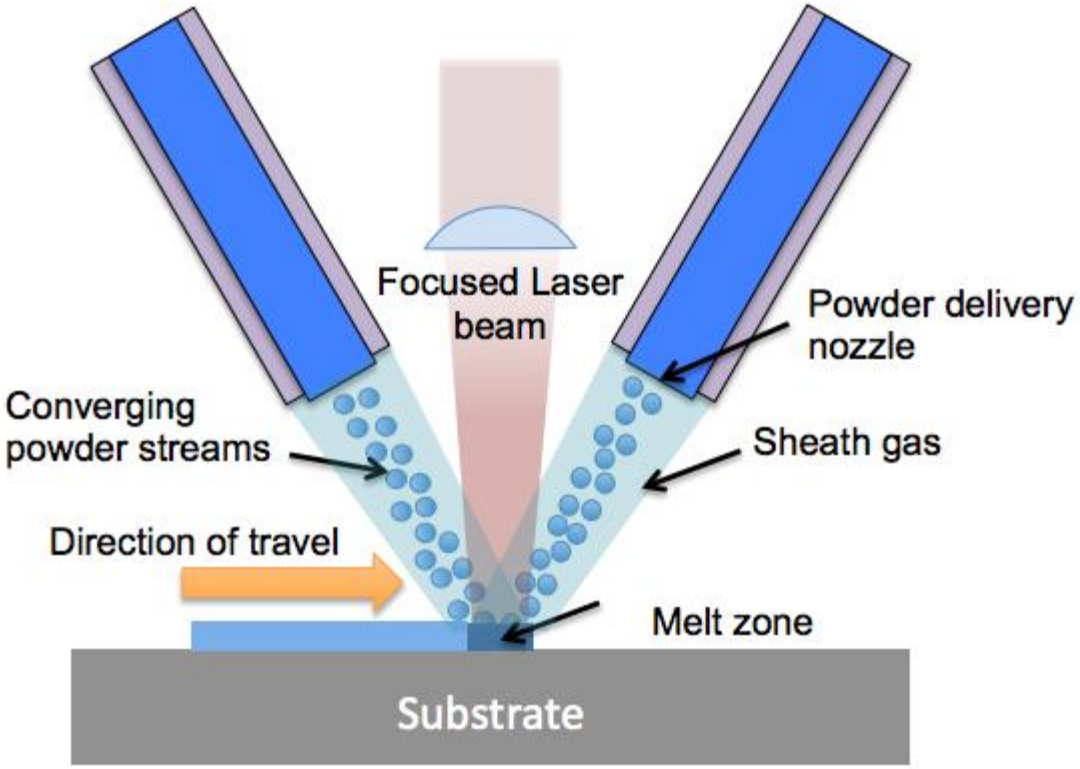
- Vat photopolymerization aka stereolithography method (SLA): ultraviolet laser was used to selectively polymerize the UV curable resins to create a layer of solidified material, limited to photopolymers



Price: ~$1000

AM methods

- Direct energy deposition: metallic powder or wire is fed directly into the focal point of an energy beam to create a molten pool



Price: $?

Classification of AM

CATEGORIES	TECHNOLOGIES	PRINTED "INK"	POWER SOURCE	STRENGTHS / DOWNSIDES
Material Extrusion	Fused Deposition Modeling (FDM)	Thermoplastics, Ceramic slurries, Metal pastes	Thermal Energy	• Inexpensive extrusion machine • Multi-material printing • Limited part resolution • Poor surface finish
	Contour Crafting			
Powder Bed Fusion	Selective Laser Sintering (SLS)	Polyamides /Polymer	High-powered Laser Beam	• High Accuracy and Details • Fully dense parts • High specific strength & stiffness • Powder handling & recycling • Support and anchor structure
	Direct Metal Laser Sintering (DMLS)	Atomized metal powder (17-4 PH stainless steel, cobalt chromium, titanium Ti6Al-4V), ceramic powder		
	Selective Laser Melting (SLM)			
	Electron Beam Melting (EBM)		Electron Beam	• Fully dense parts • High specific strength and stiffness
Vat Photopolymerization	Stereolithography (SLA)	Photopolymer, Ceramics (alumina, zirconia, PZT)	Ultraviolet Laser	• High building speed • Good part resolution • Overcuring, scanned line shape • High cost for supplies and materials
Material Jetting	Polyjet / Inkjet Printing	Photopolymer, Wax	Thermal Energy / Photocuring	• Multi-material printing • High surface finish • Low-strength material
Binder Jetting	Indirect Inkjet Printing (Binder 3DP)	Polymer Powder (Plaster, Resin), Ceramic powder, Metal powder	Thermal Energy	• Full-color objects printing • Require infiltration during post-processing • Wide material selection • High porosites on finished parts
Sheet Lamination	Laminated Object Manufacturing (LOM)	Plastic Film, Metallic Sheet, Ceramic Tape	Laser Beam	• High surface finish • Low material, machine, process cost • Decubing issues
Directed Energy Deposition	Laser Engineered Net Shaping (LENS) Electronic Beam Welding (EBW)	Molten metal powder	Laser Beam	• Repair of damaged / worn parts • Functionally graded material printing • Require post-processing machine

Classification of additive manufacturing processes by ASTM International (2013)

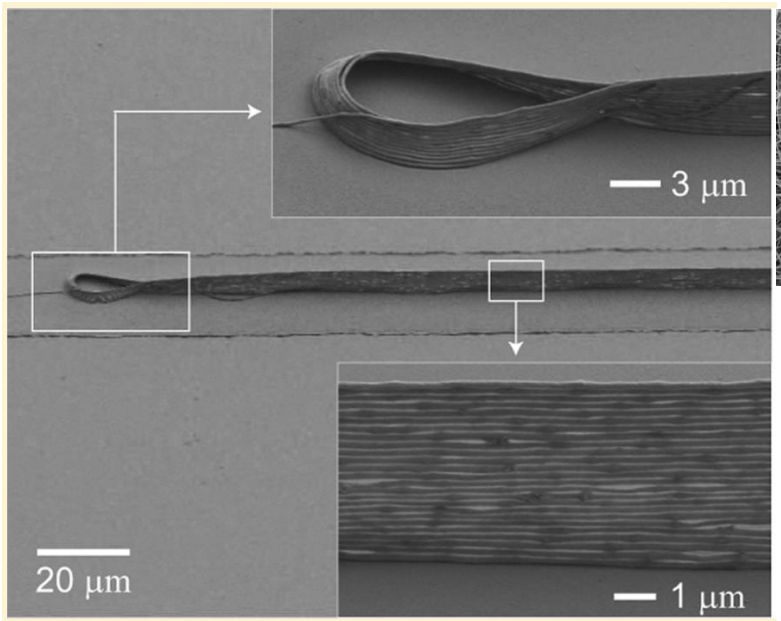
Barriers and challenges

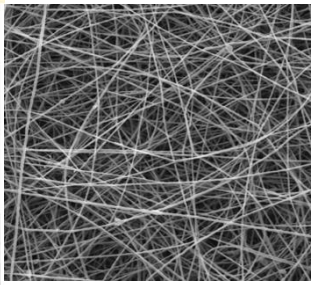
- Personal fabrication vs. mass manufacturing
  - Suitable products for AM: Customized, low-volume, complex, e.g., aerospace/high-end automotive components, bio-medical products, jewelry, home accessories.

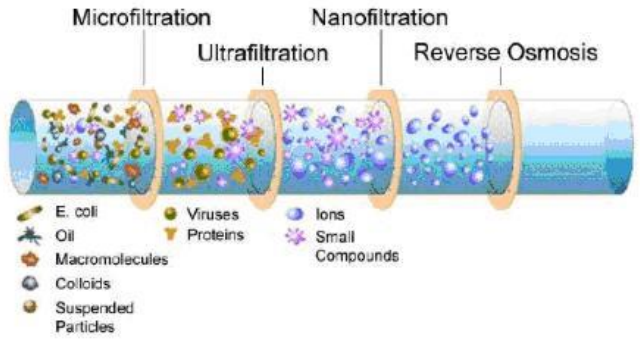


Barriers and challenges

- Building scalability vs. layer resolution
  - Layer resolution for commercially-available AM systems: ~0.1mm (Makerbot Replicator 2) to 25mm
  - Full spectrum of build sizes in research







Lee and Kim (2014)

Building nanoscaffolds, nanofilters, nanorobots, and nanoelectrodes with electrospun polymer nanofibers

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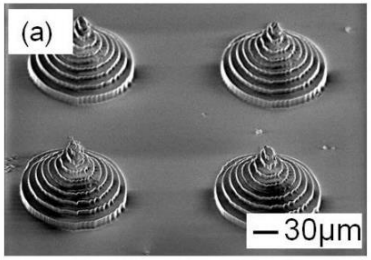
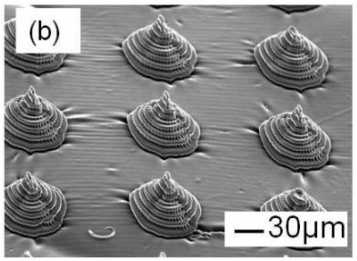
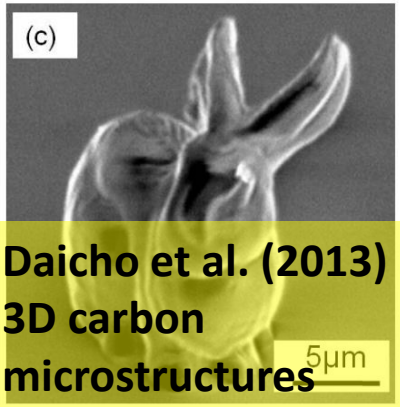
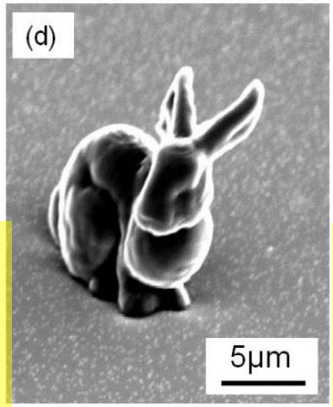






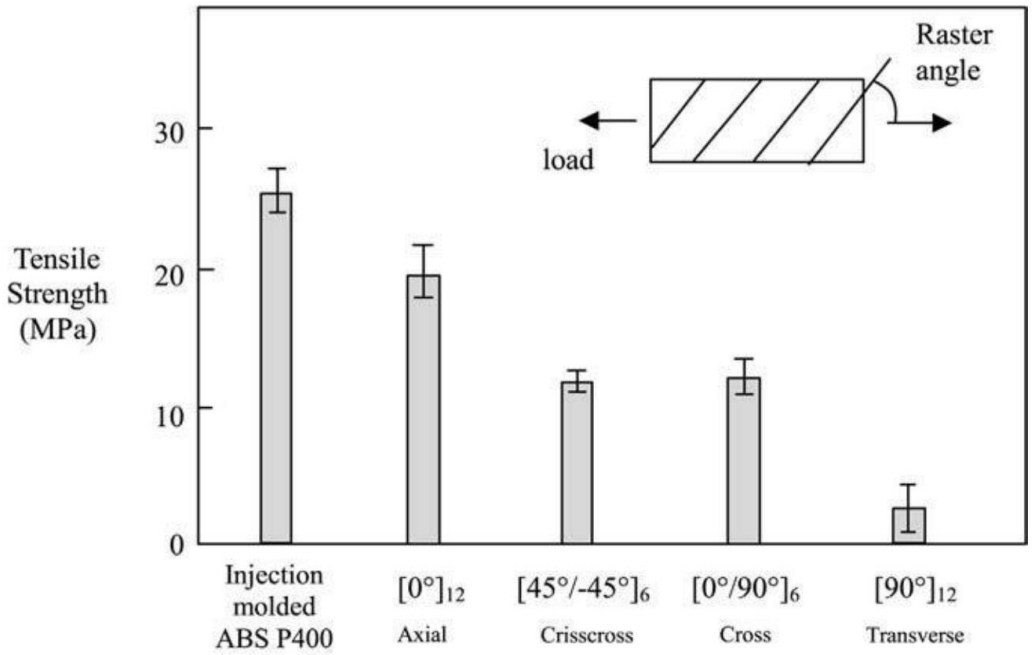


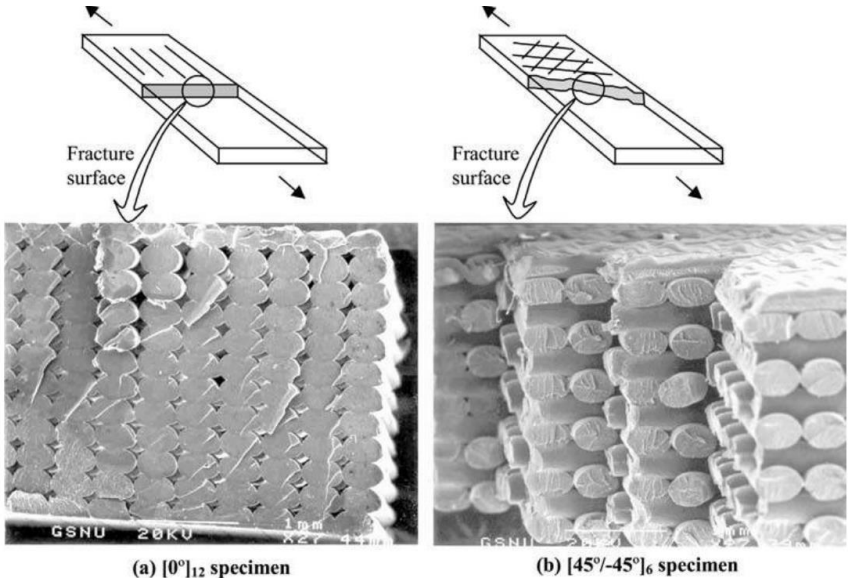
Daicho et al. (2013) 3D carbon microstructures

Khoshnevis et al. (2006) Mega-scale fabrication

Barriers and challenges

- Material heterogeneity and structural reliability
  - Limited AM materials
  - Anisotropic mechanical properties

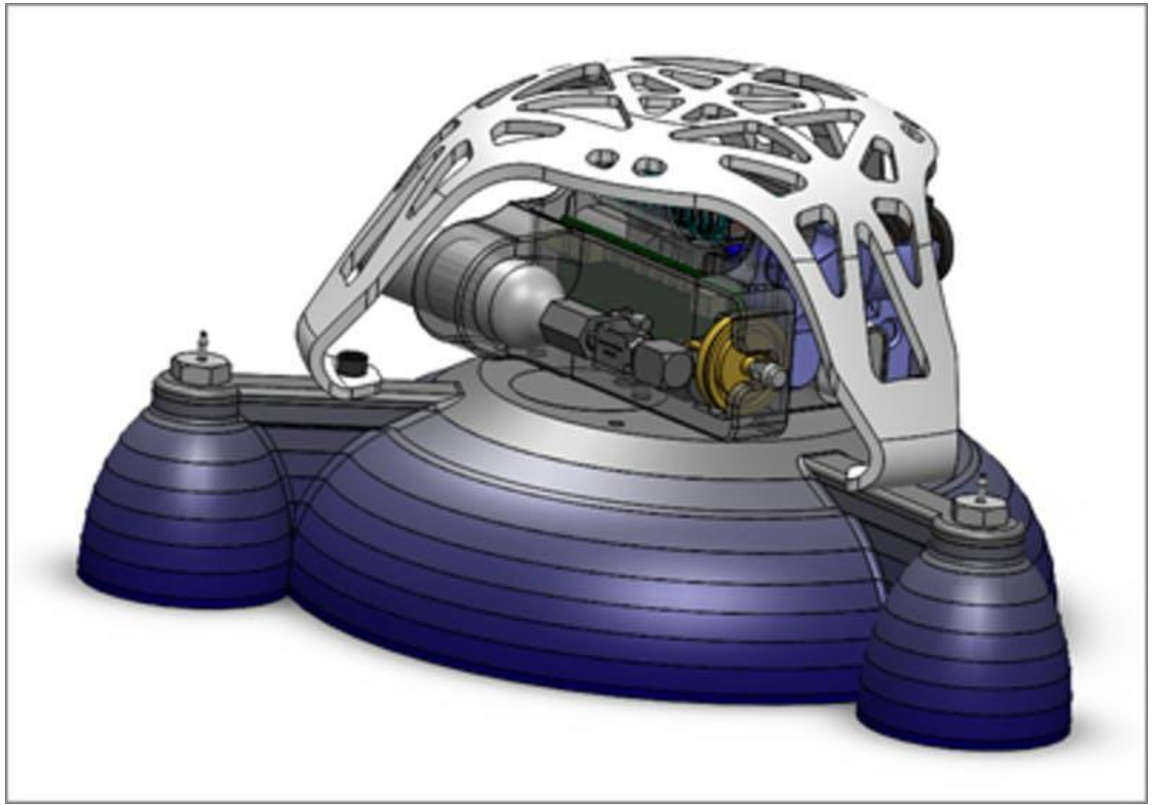




(a) $[0^o]_{12}$ specimen (b) $[45^o/-45^o]_6$ specimen

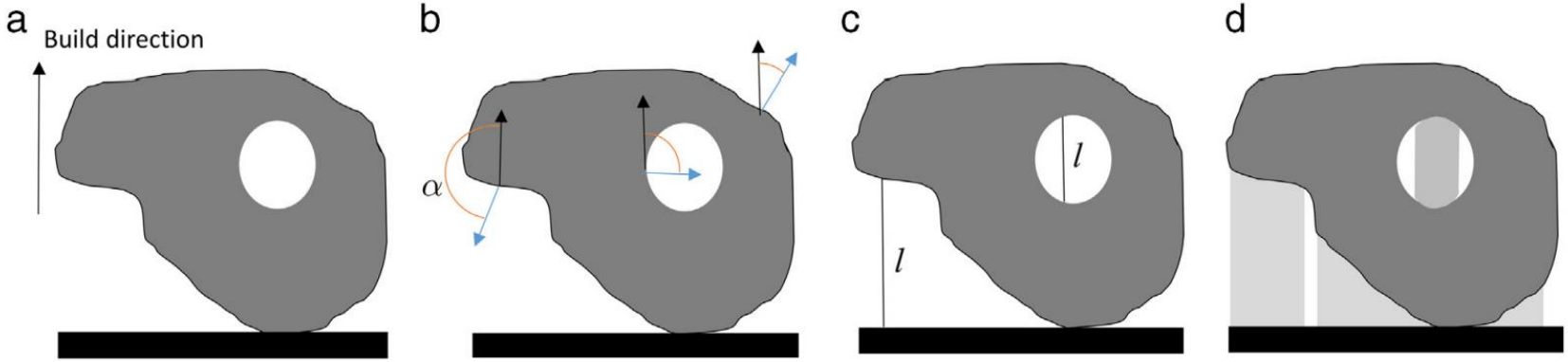
Barriers and challenges

- Material heterogeneity and structural reliability
  - Functionally-graded materials have uncertain behavior at the material interfaces

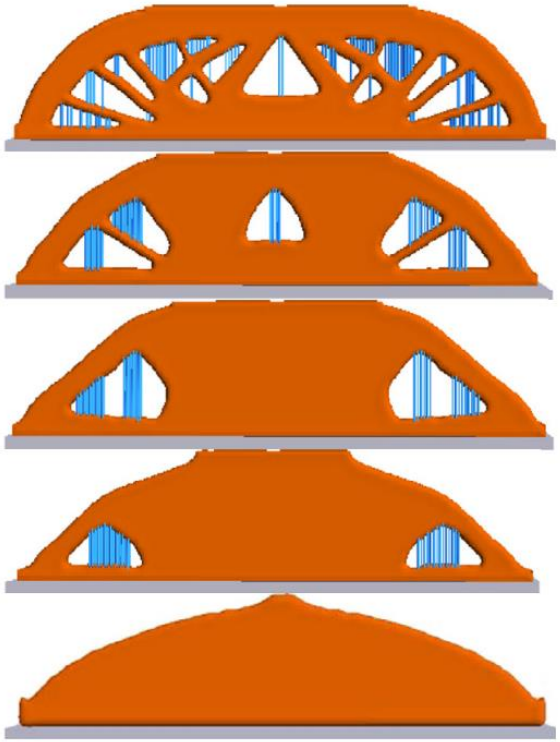


Barriers and challenges

- Use of support material



(a) Build-direction. (b) Subtended angle. (c) Support length. (d) Support volume.

Final topology	Support volume constraint	Support volume achieved	Relative compliance
	*N/A*	100%	1.29
	80%	62%	1.34
	60%	59%	1.42
	40%	42%	1.56
	0%	0%	1.75

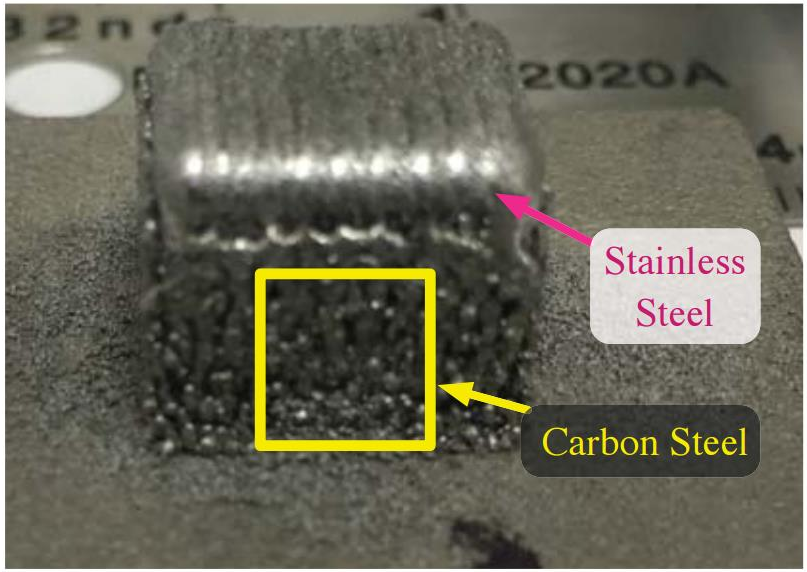
Mirzendehdel et al. (2016)

Effect of support constraint on optimized design

Barriers and challenges

- Removal of support material

Before etching



After etching

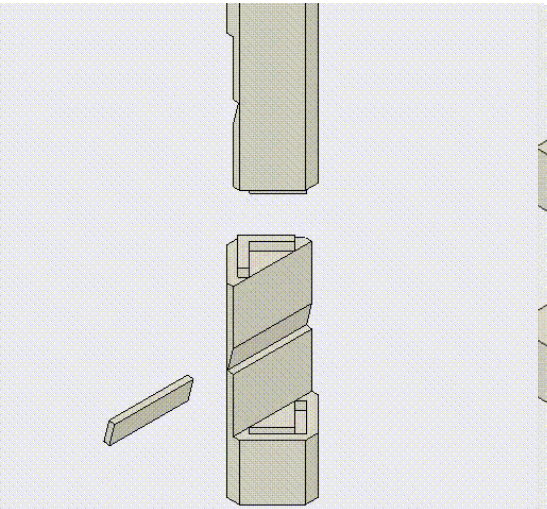
Lefky et al. (2016) Dissolvable metal supports for printed metal parts (from Dr. Owen Hildreth's group)

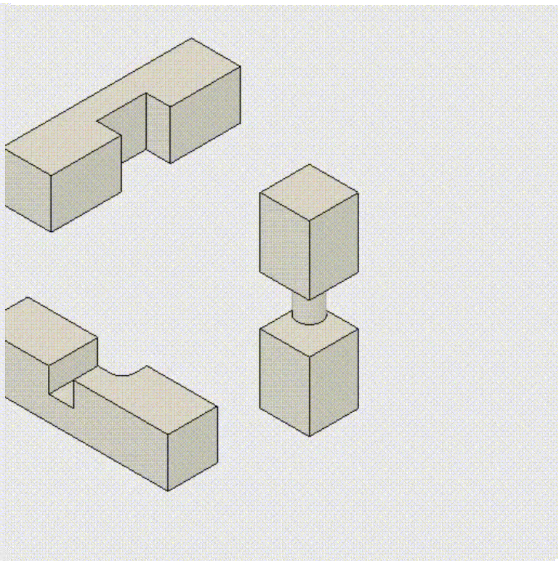
Burr Puzzles and ancient wood joinery

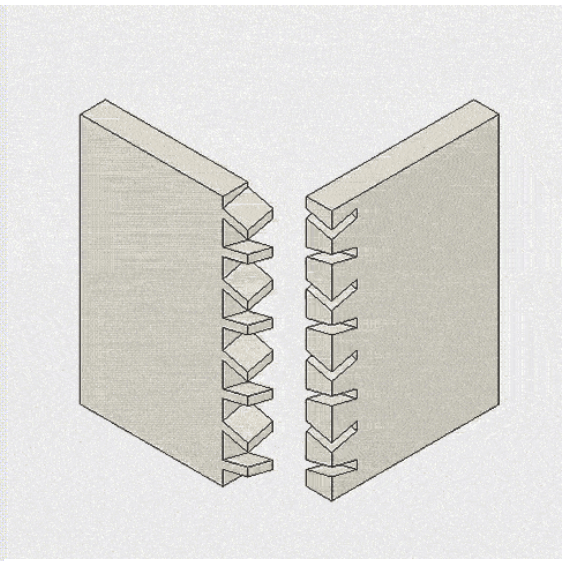
- Burr Puzzle: interlocking puzzle consisting of notched sticks, combined to make one three-dimensional, usually symmetrical unit.

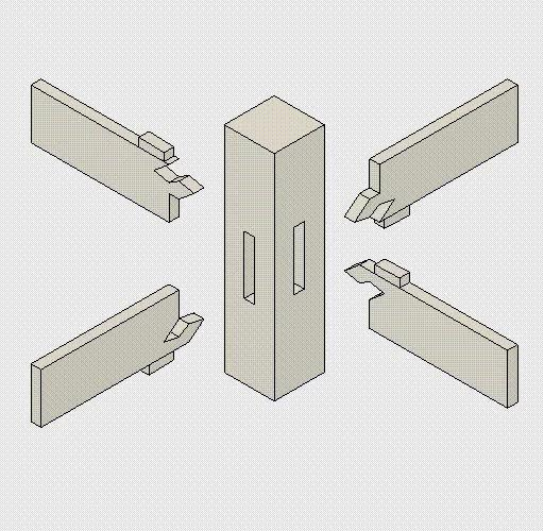

Commonly used in architectures in Asian countries

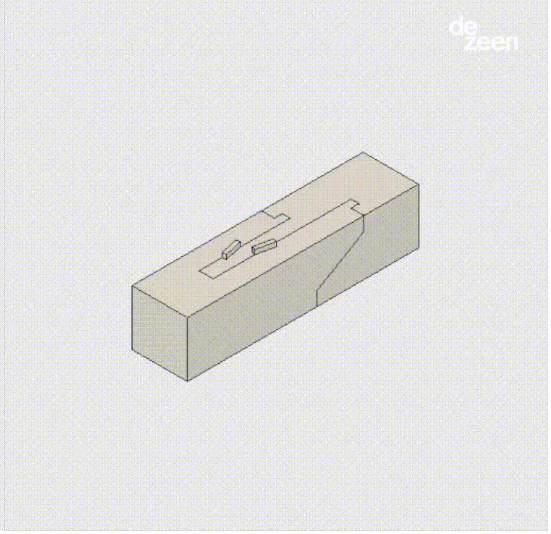
Burr Puzzles and ancient wood joinery



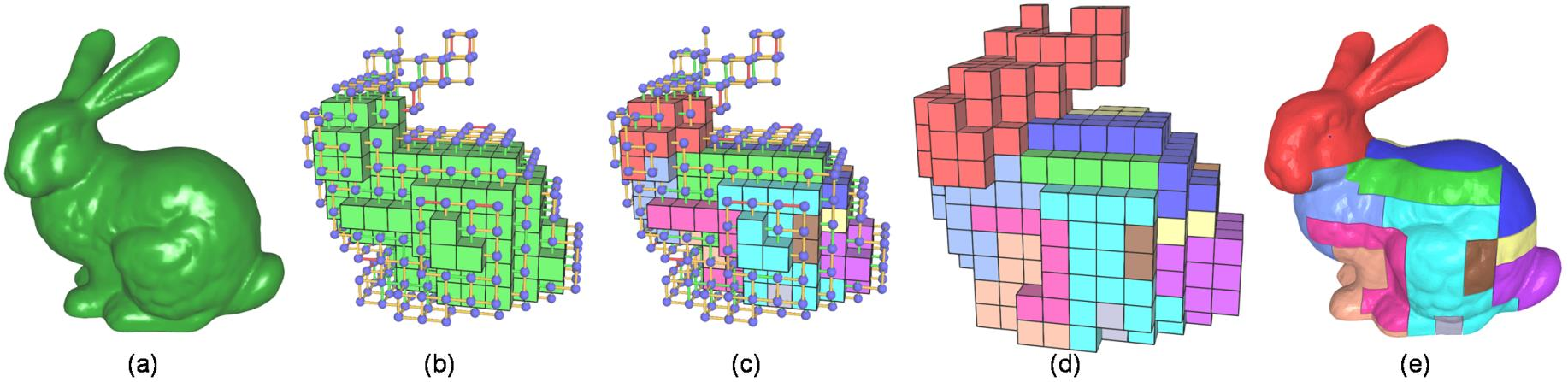


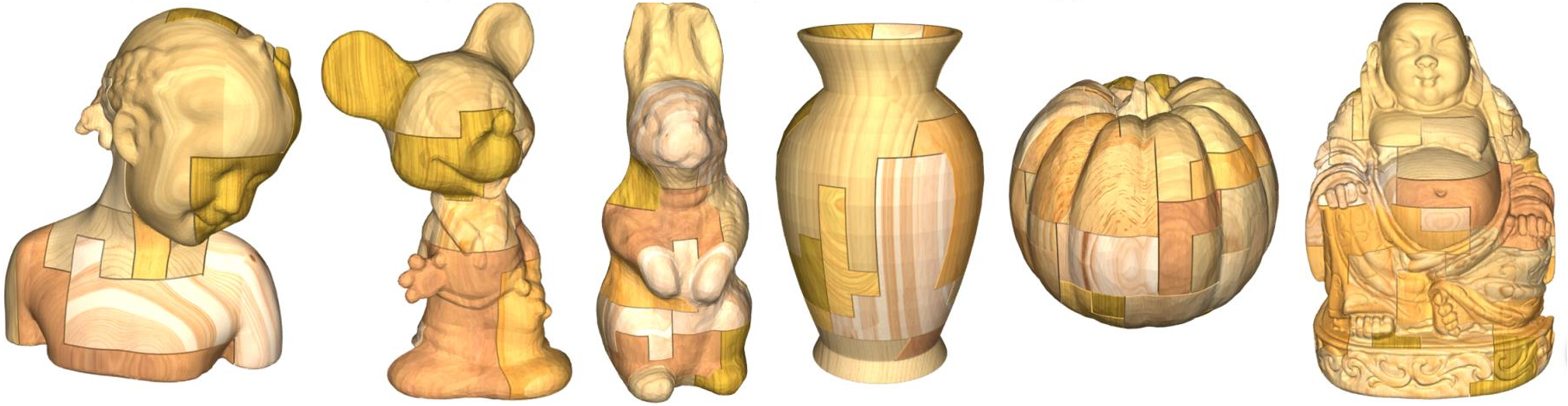


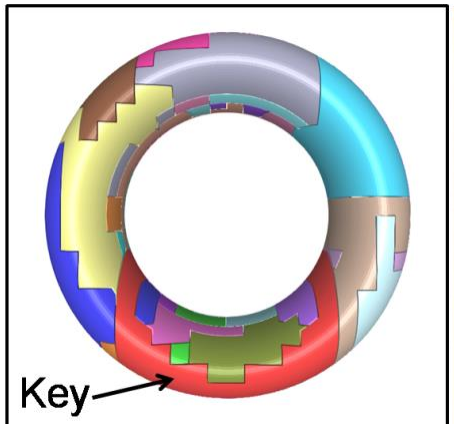


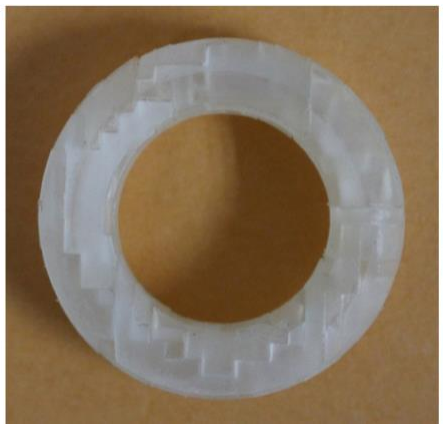


3D printing Burr Puzzles









Song et al. (2015) Printing 3D Objects with Interlocking Parts