Design for Additive Manufacturing

Opportunities, Barriers, and Democratization

German-American Frontiers of Engineering Symposium
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Product, Process, and Materials Design Laboratory
and Laboratory for Freeform Fabrication
Mechanical Engineering Department
The University of Texas at Austin

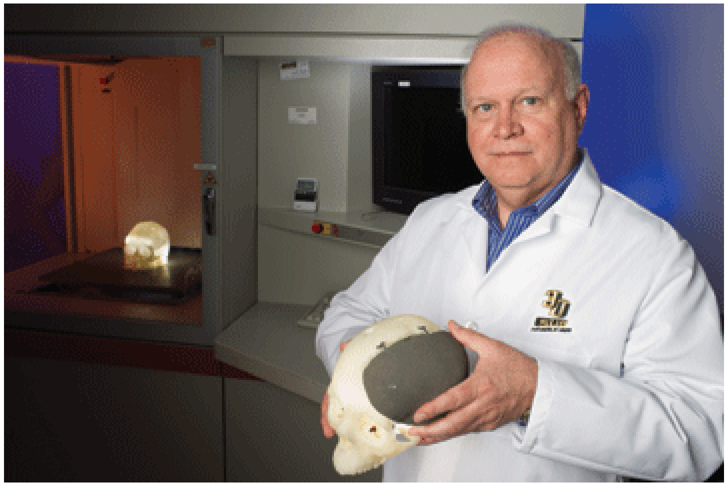
What if you could make ANYTHING?
…any form, any shape
…any internal composition

What would you design?

Would you design/build form-fitting customized parts?

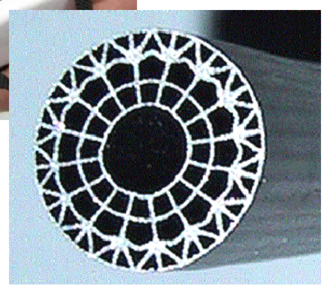
Invisalign

Crawford, Neptune, et al.



Walter Reed Army Medical Center (Designnews.com)

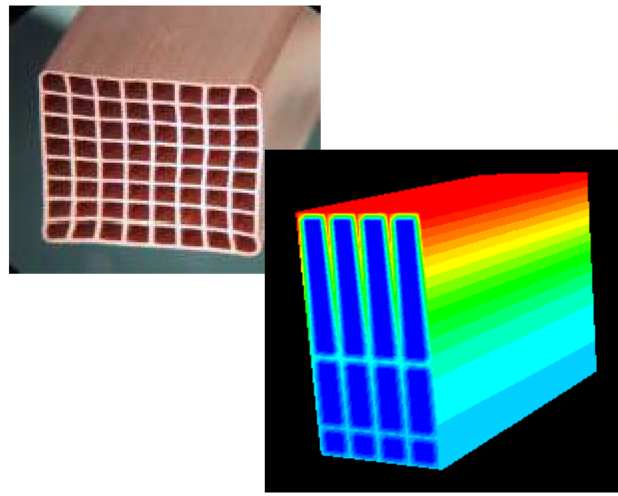
Would you design/build lightweight multifunctional structures?

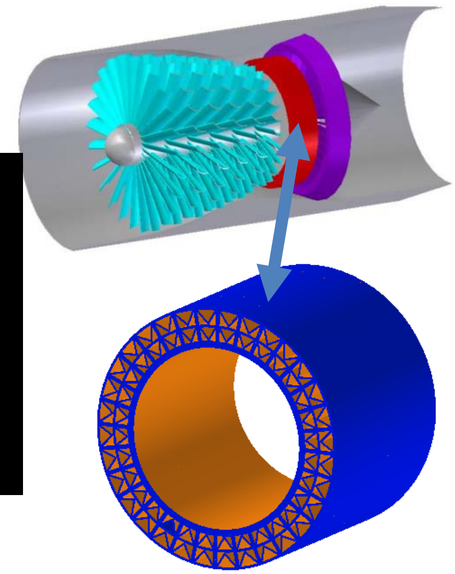


Energy Absorption
Specific Strength &
Stiffness

C. Williams, VT and D. McDowell, Ga Tech

Structural Heat Exchange and Active Cooling

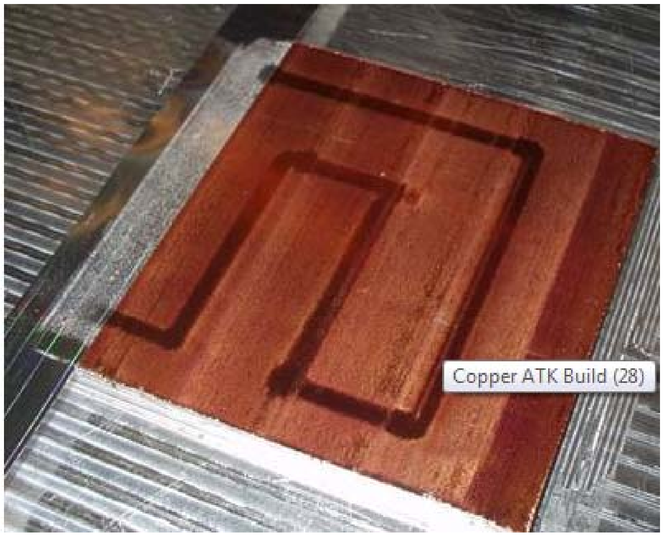




Aerospace Weight Reduction
GE/EADS via Ponoko.com

Compliance
R. Neptune, UT Austin

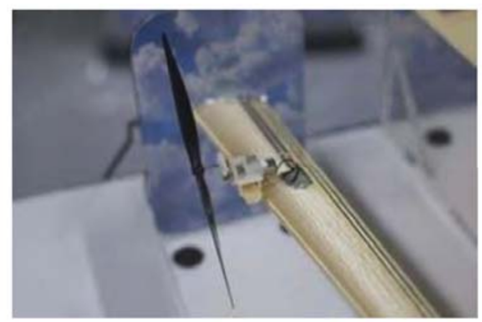
Would you functionally grade material for multifunctionality?



Brent Stucker, U of Louisville

Functionally graded baseball cleats

Objet Geometries



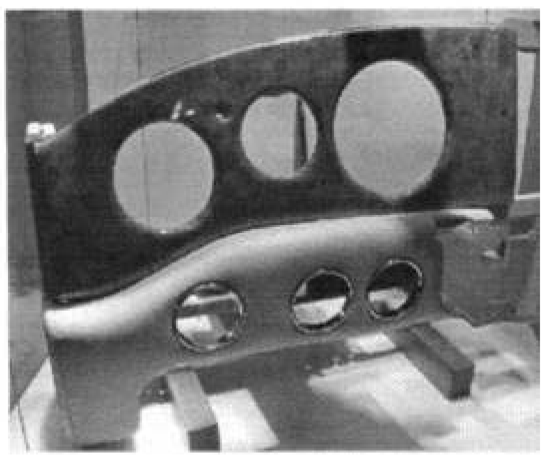
UAV Smart Wing

Wohlers Report 2012, Courtesy of Optomec and Aurora Flight Sciences

Would you focus on small (single) lot production with no tooling costs and free complexity?

Wohlers Report 2012, Courtesy of RAMPART CubeSat team

Wohlers Report 2012, Courtesy of Olaf Diegel



Wohlers Report 2008, Courtesy of Bentley

Mydea Technologies Corporation

What are the challenges in designing for Additive Manufacturing?

What are the challenges in Design for Additive Manufacturing (AM)?

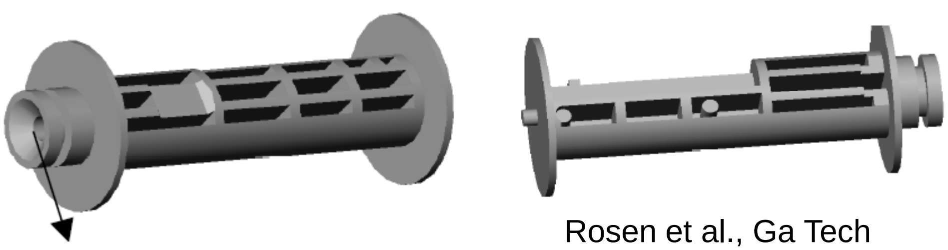
- Early stage, conceptual design
  - Avoid fixation on current designs
  - Avoid locking into current Design for Manufacturing (DFM) and Design for Assembly (DFA) practices
- Embodiment design
  - Model/optimize topology, material distribution, hierarchical (complex) structure with CAD/CAE tools
  - Incorporate AM-specific capabilities and constraints into part design (Design for AM practices)

Avoiding fixation on current designs and DFM and DFA restrictions

Reverse Engineering and Experience/Fixation

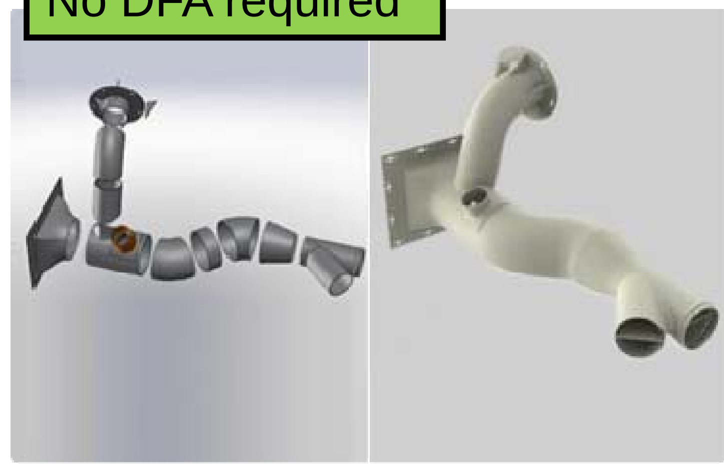
Shapeways.com (nervoussystem)

No DFM required



Rosen et al., Ga Tech

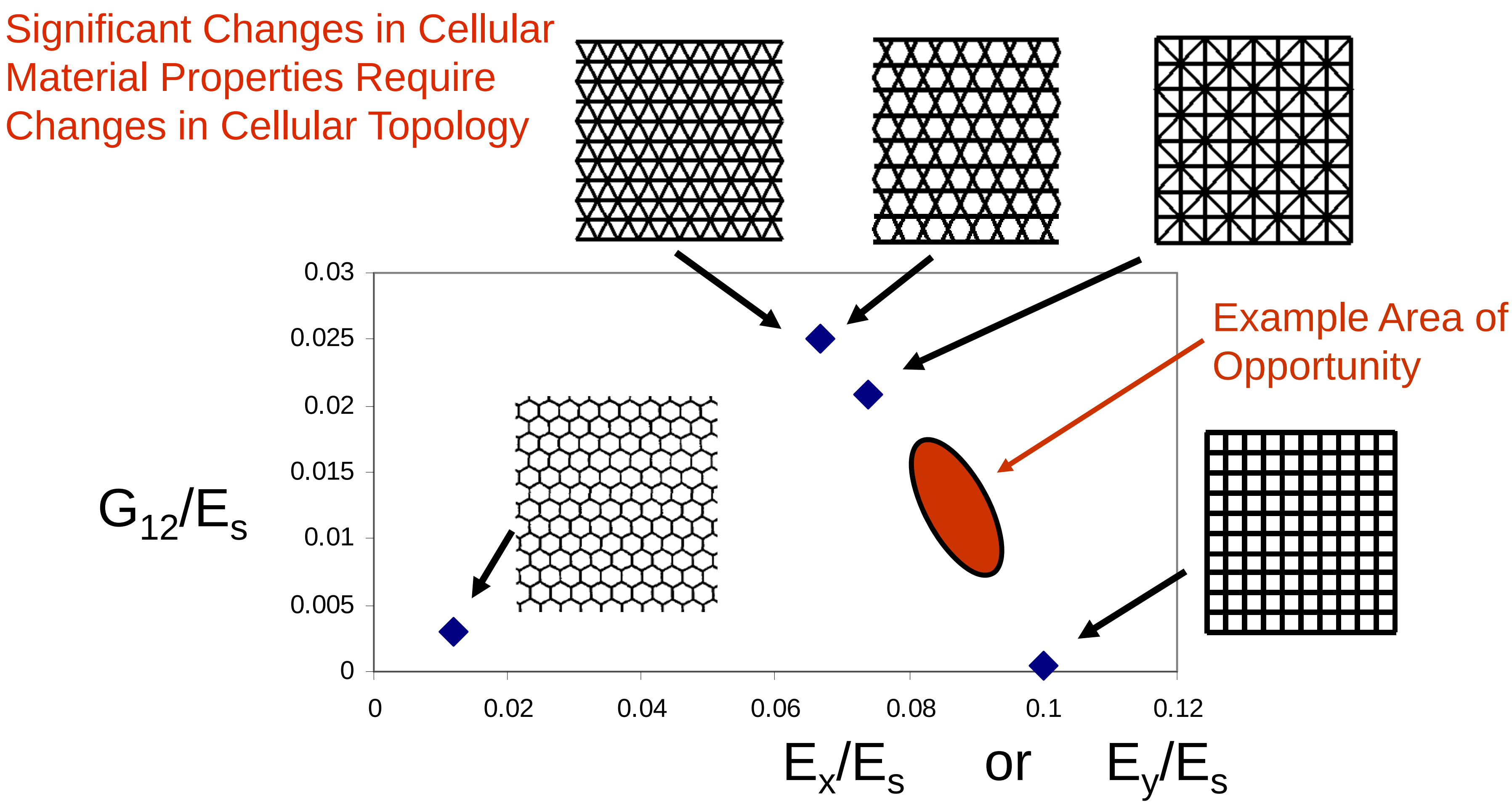
No DFA required



rbmsolutions.com

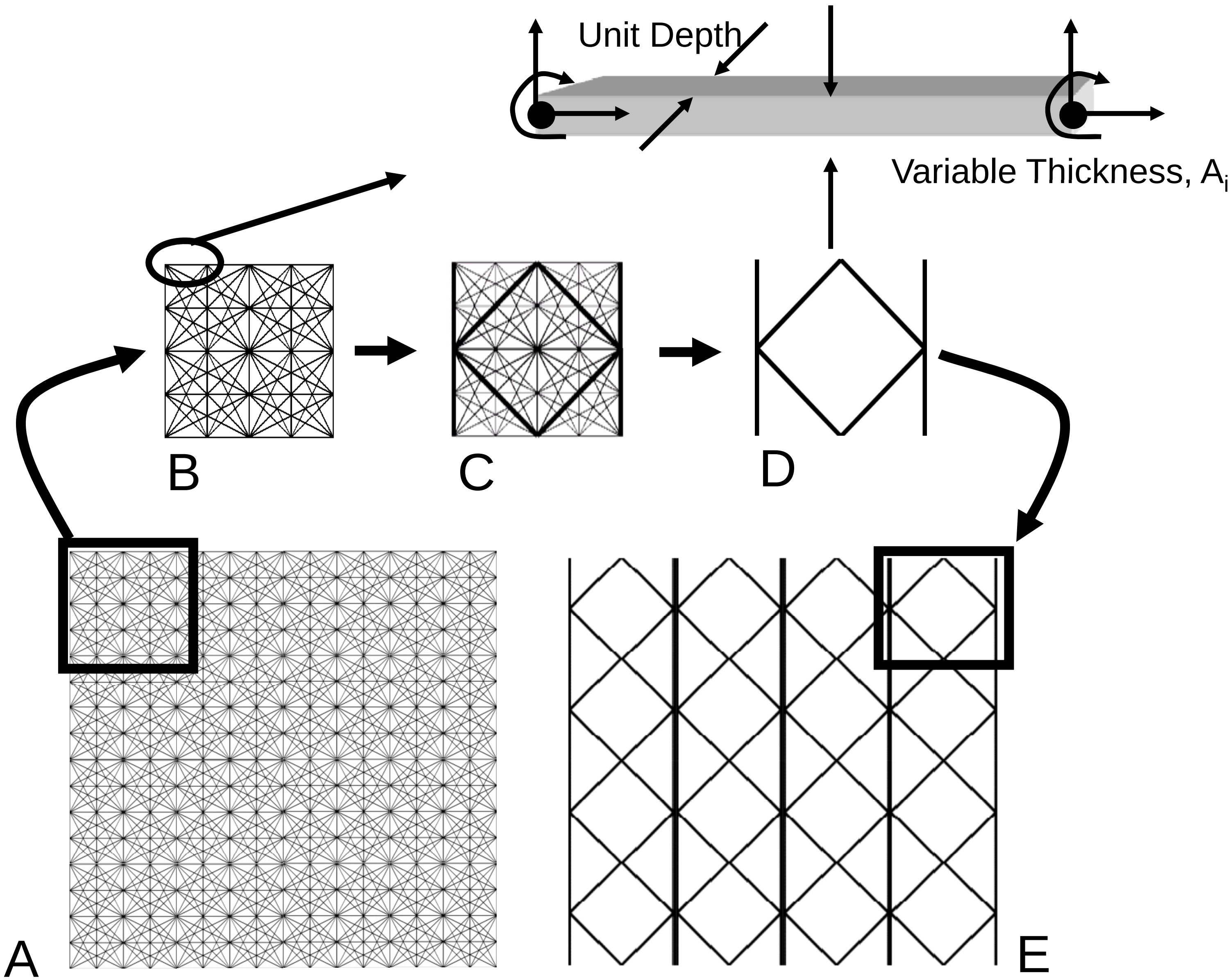
13 parts	1 part
Stamping + sheet metal forming + fasteners	Selective laser sintering
	Lighter weight

Topology Design is Needed for Lightweight, Multifunctional Structures

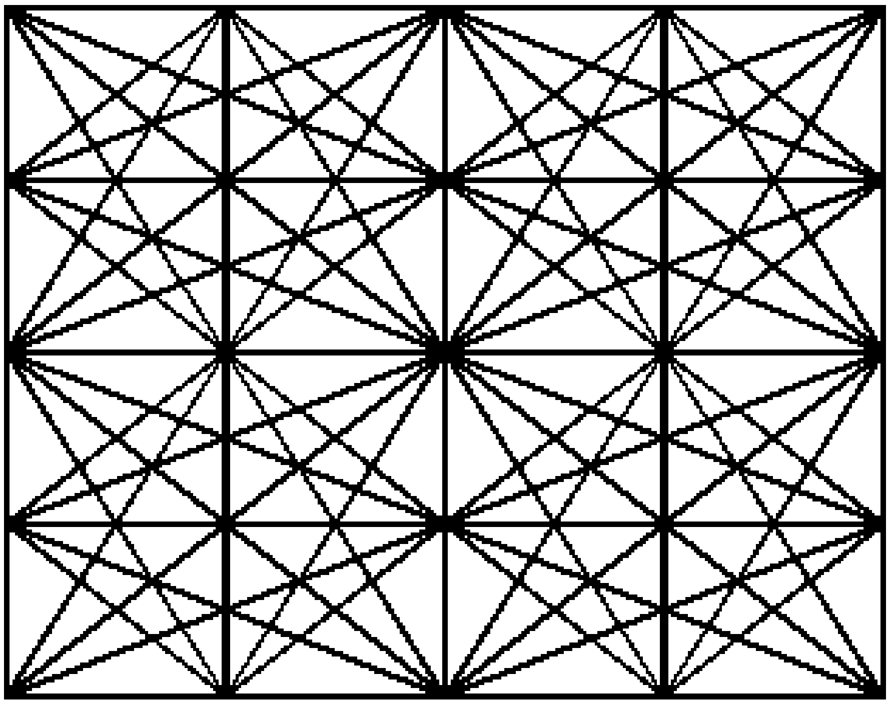


(Seepersad, Allen, Mistree, McDowell, *Journal of Mechanical Design*, 2006)

Ground Structure Method for Topology Design

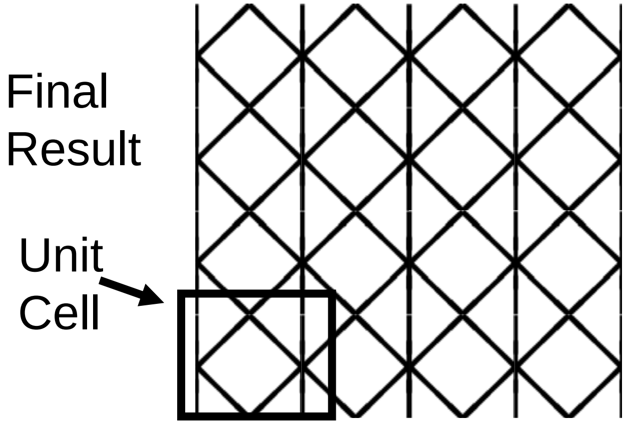


Simple Topology Design Demo



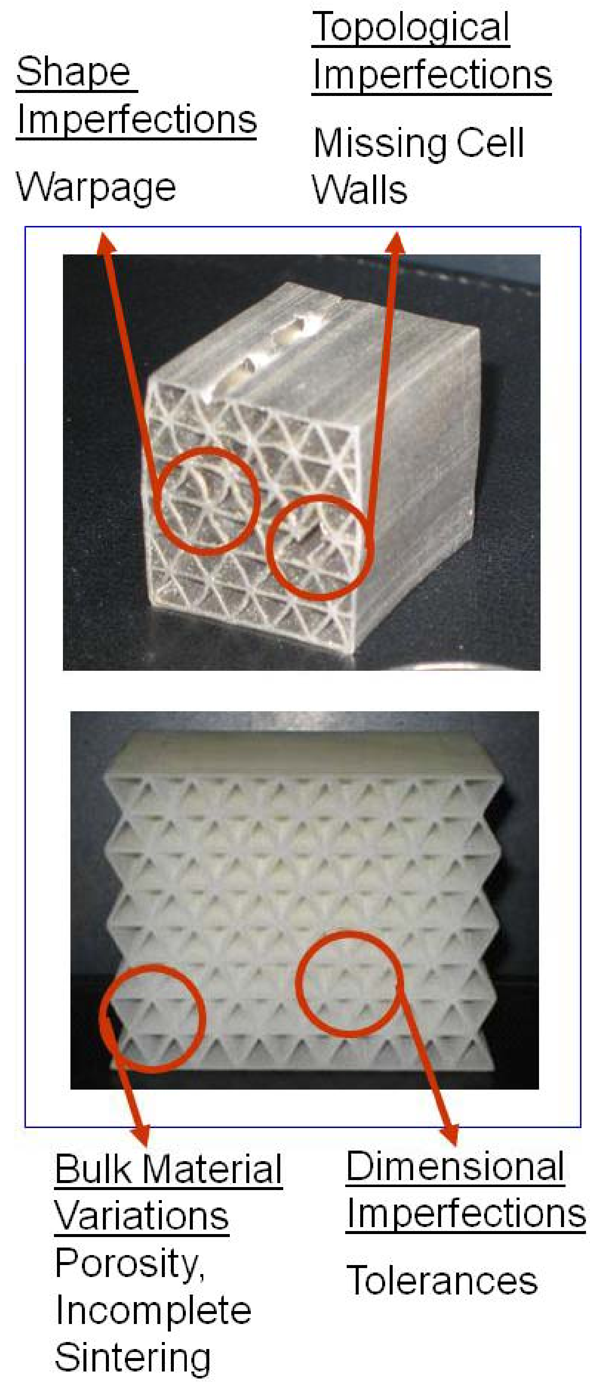
- 5x5 node ground structure
- 2 orthogonal planes of symmetry
- Every pair of nodes connected in each quadrant
- 36 elements per quadrant; 132 total
- Thick elements 1000 x thicker than thin elements in final image

Objective: Automatically determine the distribution of material to meet structural performance objectives



What about imperfections?

- Missing cell walls?
  - Up to 50% reduction in modulus and yield strength with a 5% density of missing/broken cell walls;
  - Resistance to defects depends on cell shape
- Variations in cell shape?
  - Up to 25% (or more) reduction in elastic buckling and plastic yield strength for hexagonal cells
  - Why? Higher bending moments and stresses in relatively longer cell walls

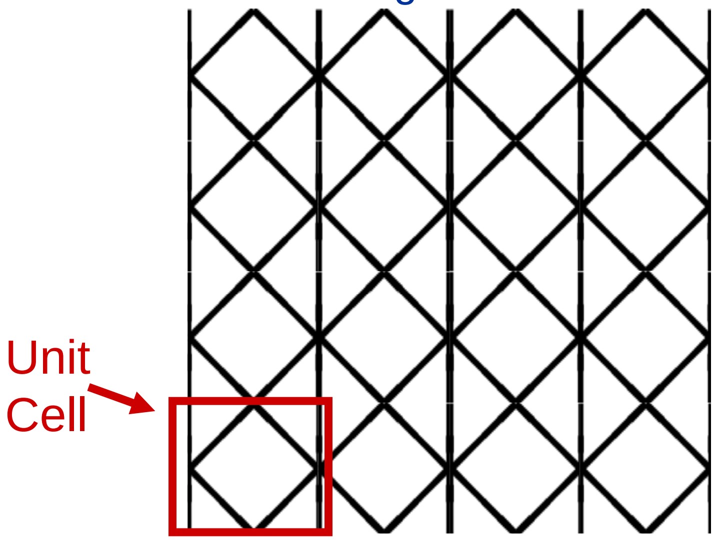


(Gibson and Ashby, 1997, *Cellular Solids*; Silva et al., 1995, *IJMS*; Wang and McDowell, 2003, *IJMS*)

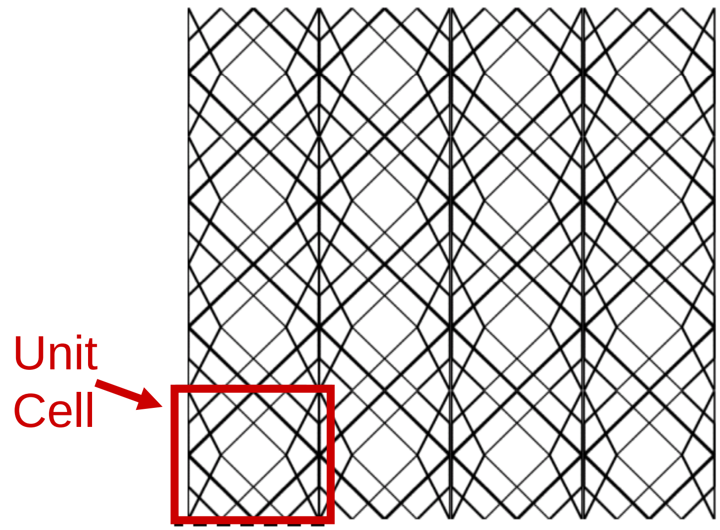
Tailored Lightweight Structures w/ and w/o robustness to imperfections

(Seepersad, Allen, McDowell, Mistree, 2008, *Journal of Mechanical Design*)

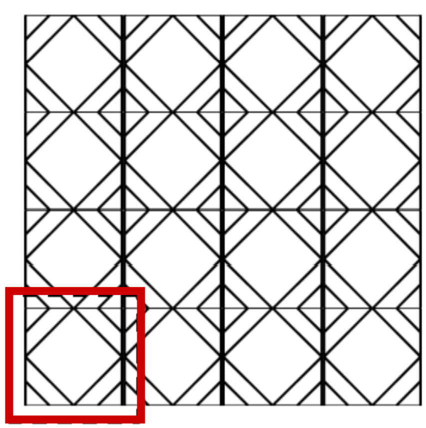
Robust Design for Tolerances

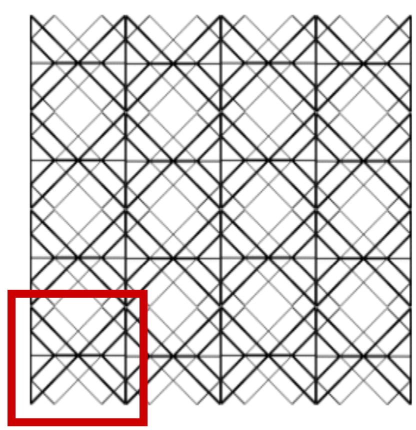


Non-Robust Design for Tolerances



Topologically Robust Designs

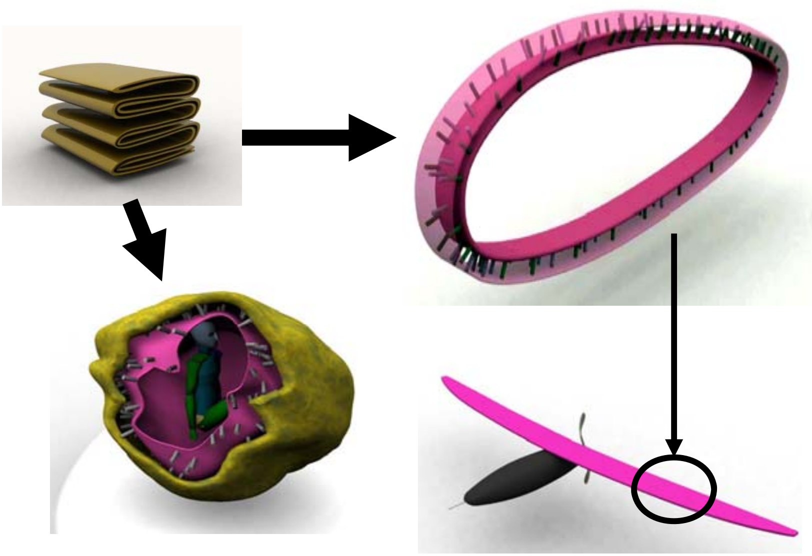




Lower Standard Deviation of Elastic Properties, σ_{Cij}

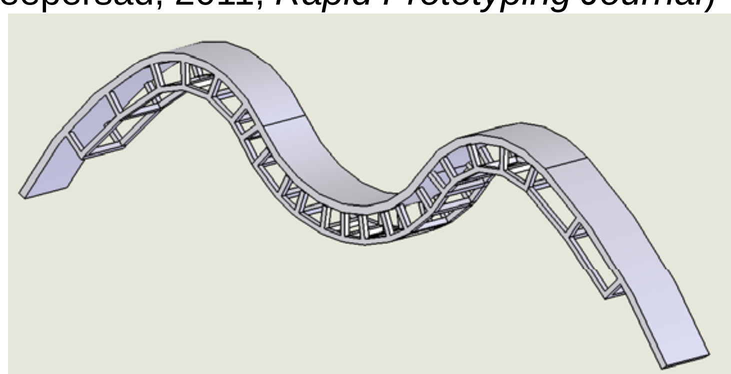
- due to topological noise
- calculated via experiments with initial gnd structure
- lower by as much as 50% vs. above designs
- balanced by higher dimensional variation

What about non-uniform topologies? Customized Mesostructure for Freeform Deployable Structures

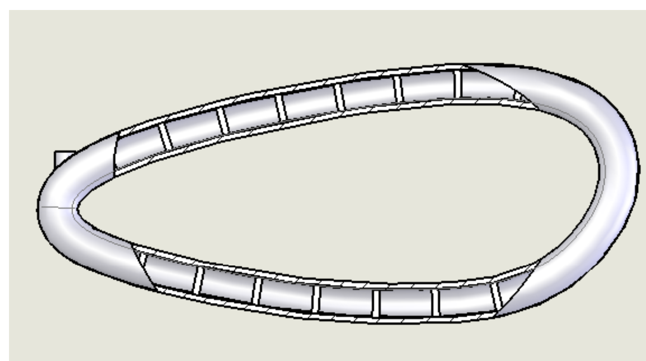


- Freeform deployment by adding lattice to skin of part:
  - ***open lattice*** for direct reinforcement of surface
  - ***closed lattice*** arrangement for pneumatic inflation
- SLS with Duraform® FLEX
- Freeform geometry, Multifunctionality, Portability

(Maheshwaraa, Seepersad, Bourell, 2007, *Rapid Prototyping Journal*)
(Maheshwaraa, Seepersad, 2011, *Rapid Prototyping Journal*)

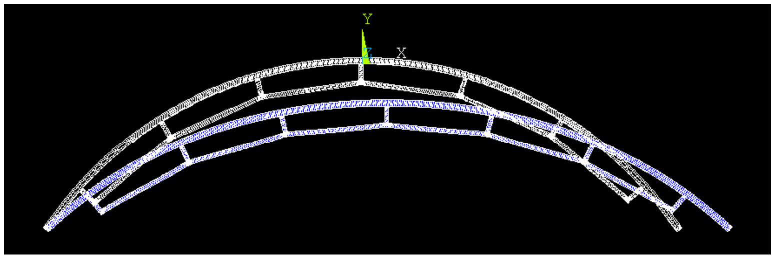


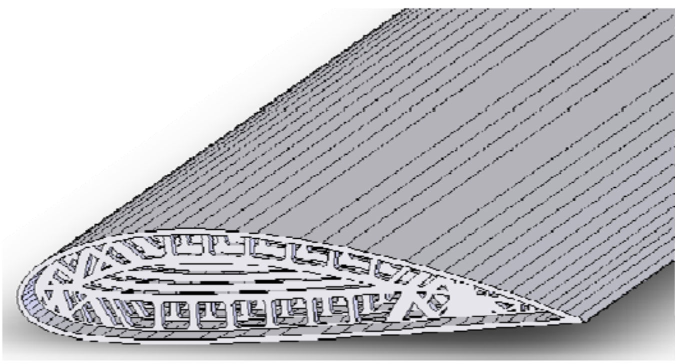
Open lattice Structure

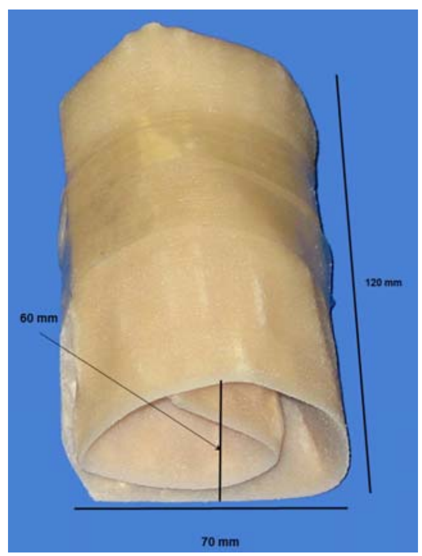


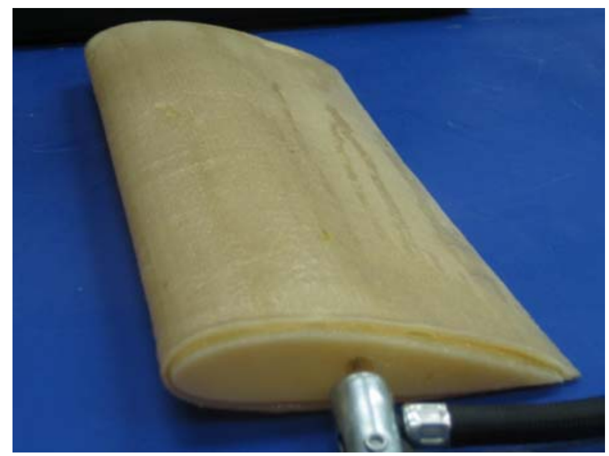
Closed lattice Structure

Physical Prototypes—Open and Closed Lattice Skins



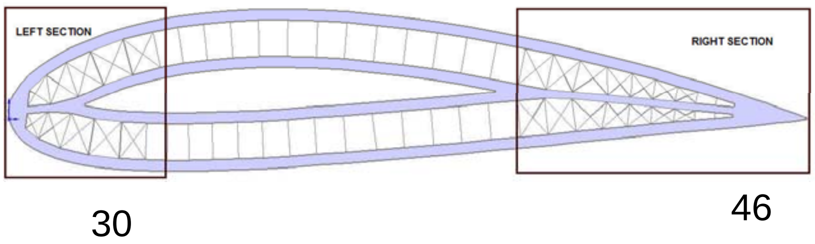




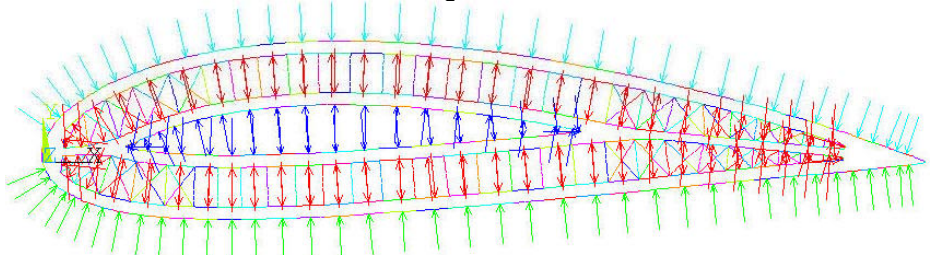


Topology Optimization of Closed Lattice Structure

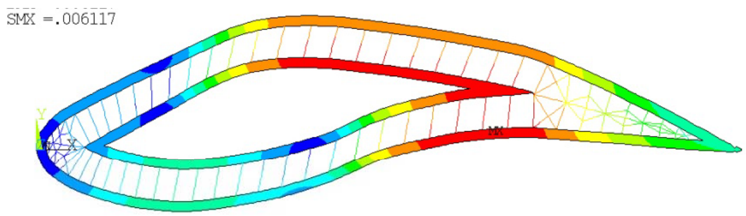
Ground Structure with 76 Lattice Elements



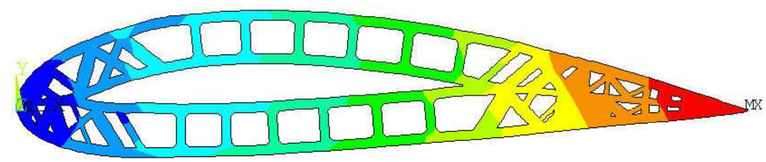
Loading



<u>Before Topology Optimization</u>

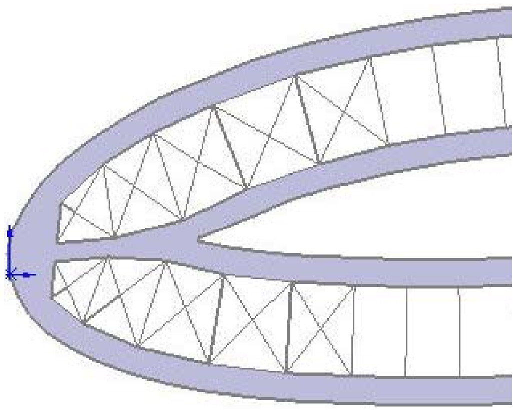


<u>After Topology Optimization</u>

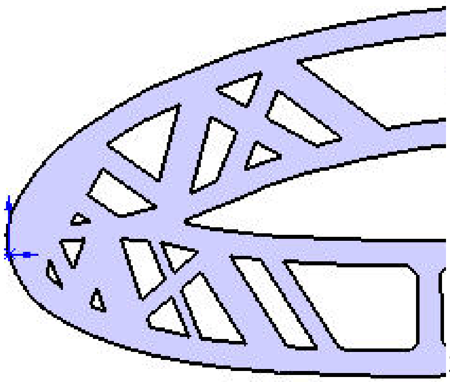


2% deflection

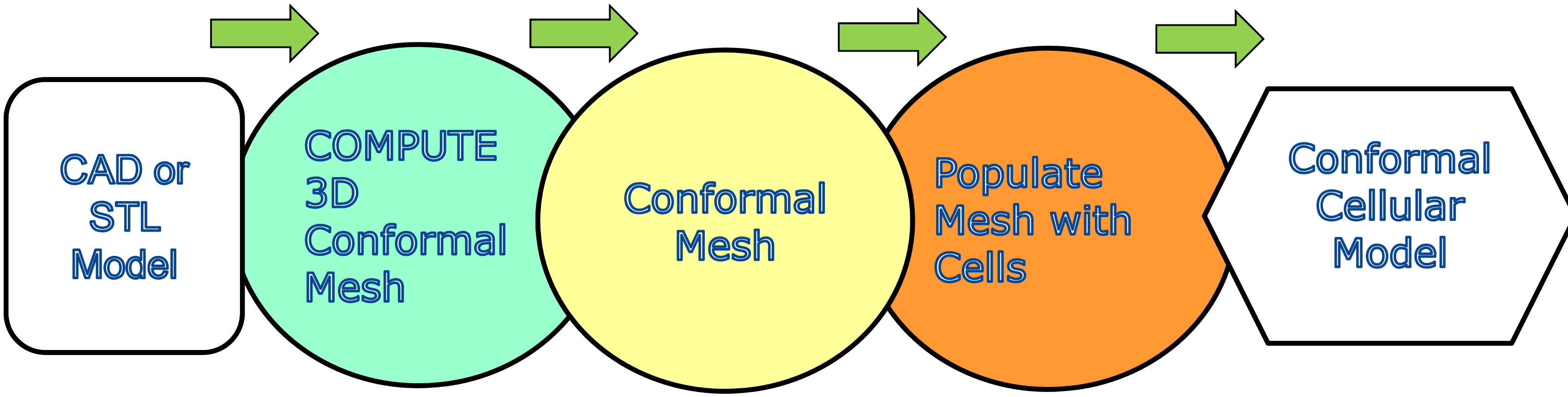
<0.5% deflection

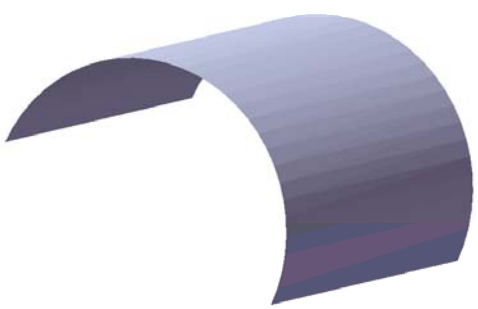


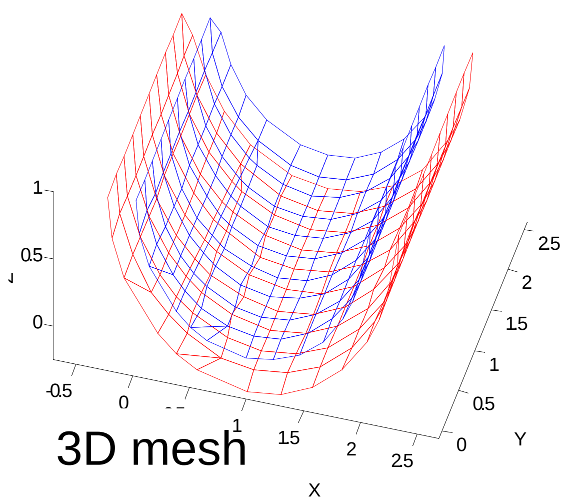
<u>Process</u>
iSIGHT design integration software running ANSYS via APDL file



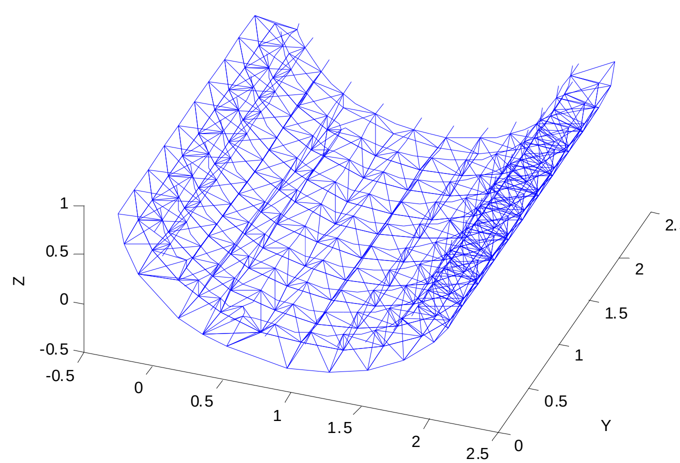
What about 3D customization? Conformal Lattice Structures





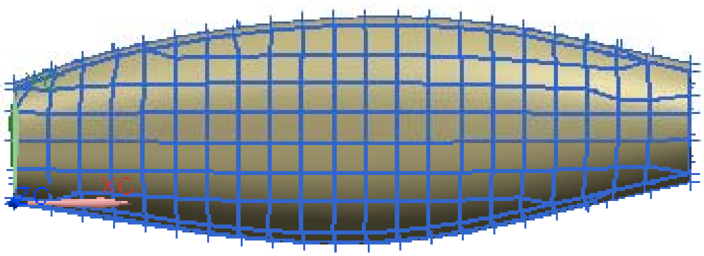


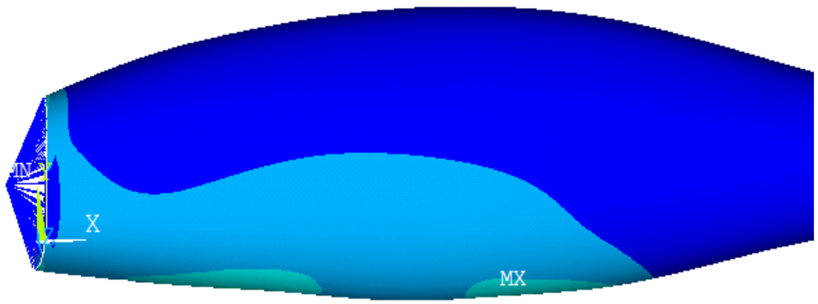
3D mesh

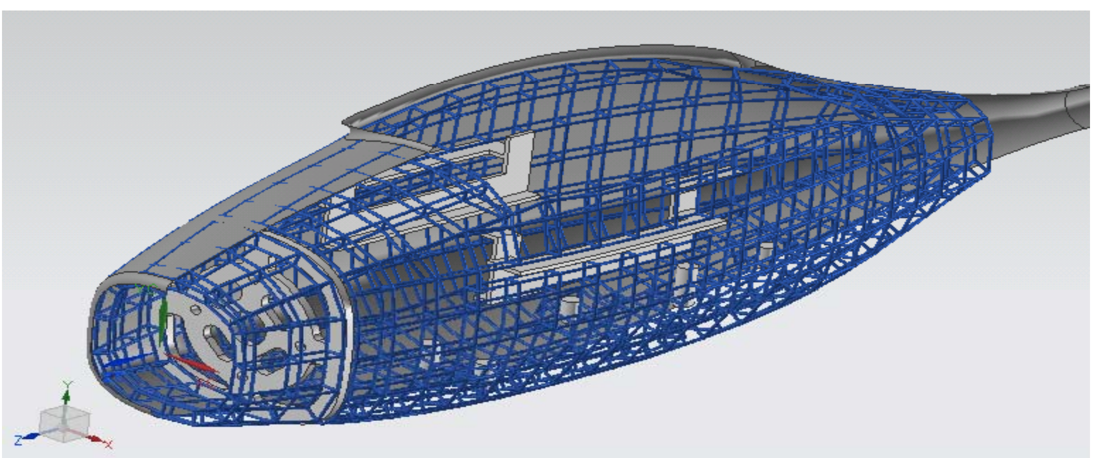


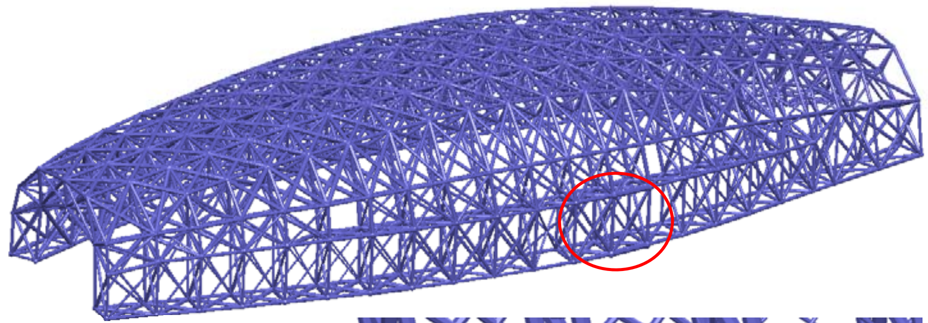
David Rosen, Georgia Tech
(Nguyen, *et al.*, 2012, SFF Symposium)

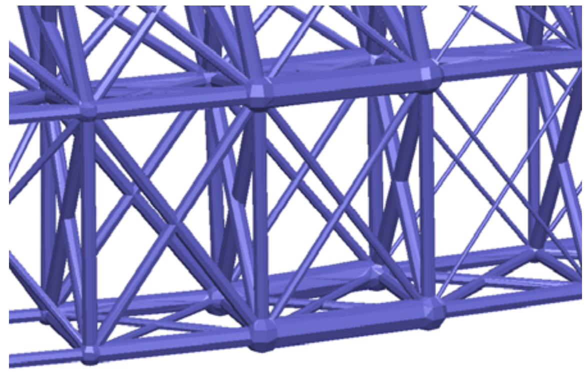
Optimization of Conformal Lattice Structures







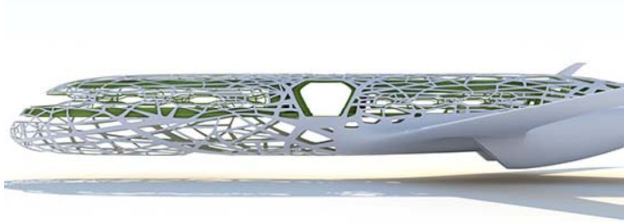




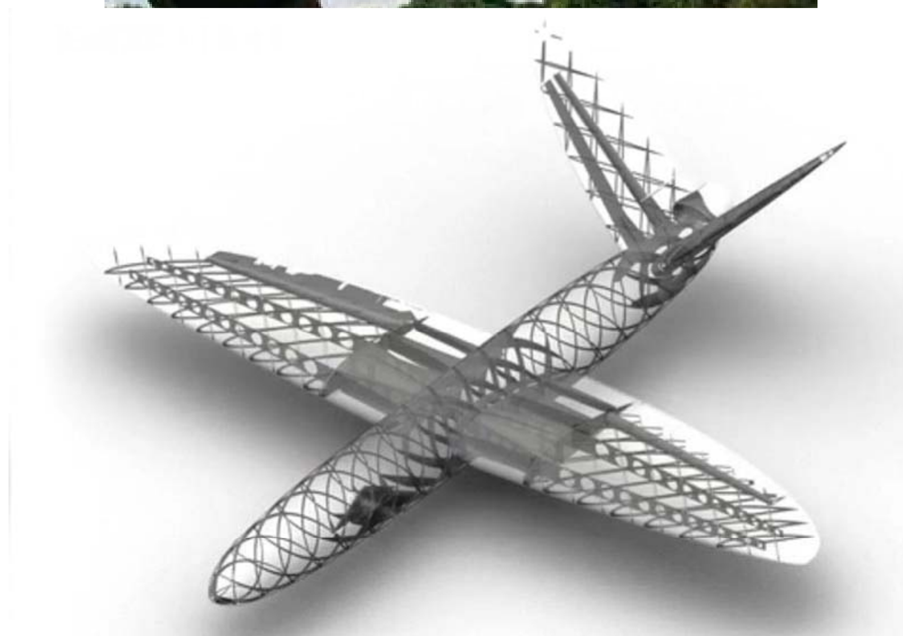
David Rosen, Georgia Tech
(Nguyen, *et al.*, 2012, SFF Symposium)

Industrial Examples of Topology Design for AM

Aerospace Weight Reduction
GE/EADS via Ponoko.com

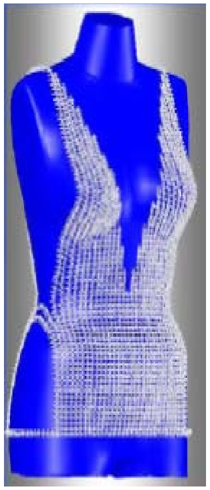


Airbus and smithsonianmag.com



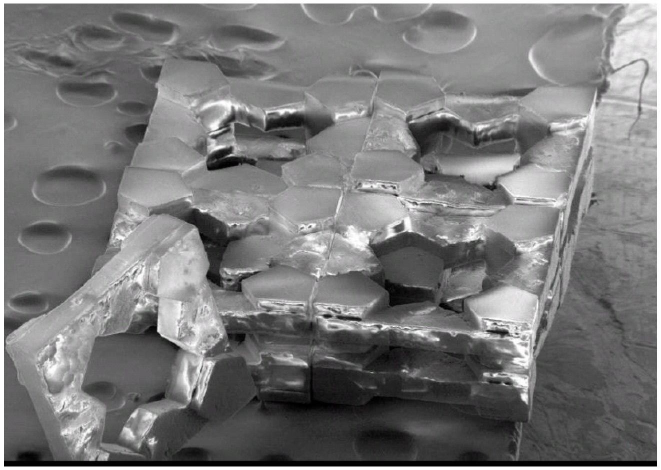
U of Southampton; Newscientist.com; ponoko.com

Additional AM drivers for new CAD/CAE tools



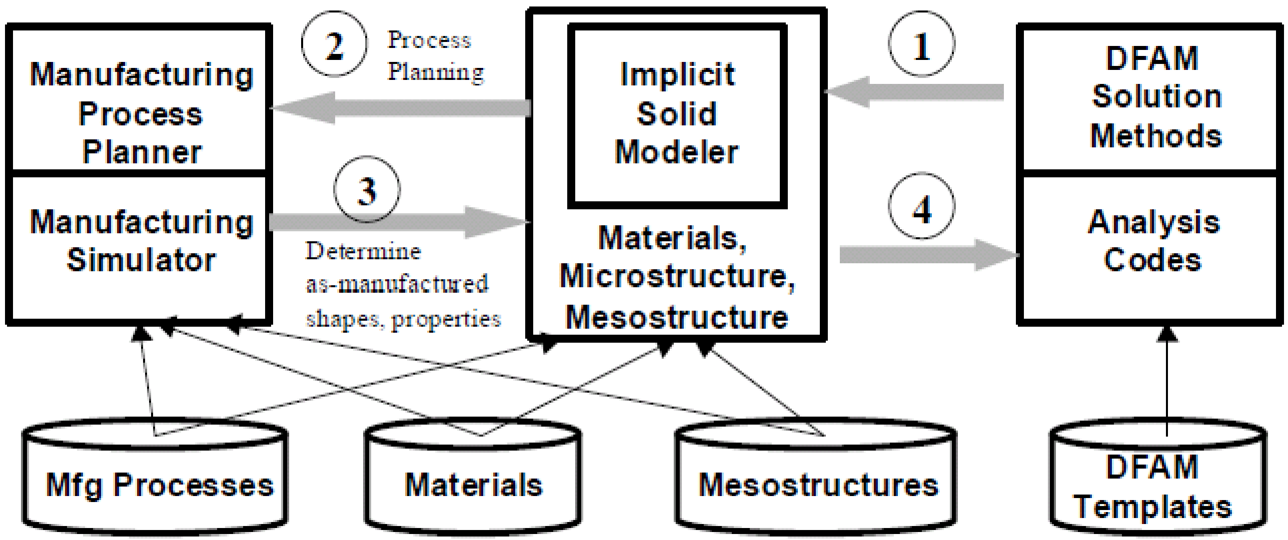
www.lboro.ac.uk

- CAD/CAE systems are limited
  - Numbers of features
  - Representations of graded materials in one feature
  - Co-simulation of AM process and structure



Broader Design for AM systems and tools

THE GOAL …

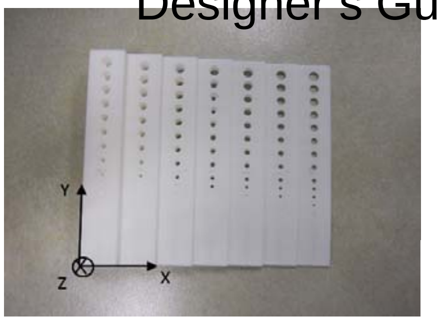


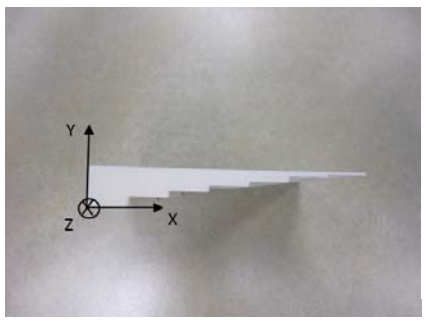
David Rosen, Ga Tech

Broader Design for AM systems and tools

A Step in the Right Direction …

Designer's Guides for AM





Diameter [mm]		V1	Plate Thickness [mm]						
			12.7	9.327	7.152	5.253	3.755	1.877	0.939
1	4								
2	3.75								
3	3.5								
4	3.25								
5	3								
6	2.75								
7	2.5								
8	2.25								
9	2								
10	1.75								
11	1.5								
12	1.3								
13	1.1								
14	1								
15	0.8								
16	0.6								
17	0.5								
18	0.4								
19	0.3								
20	0.25								
21	0.125								

(Seepersad, *et al.*, SFF Symposium, 2012)

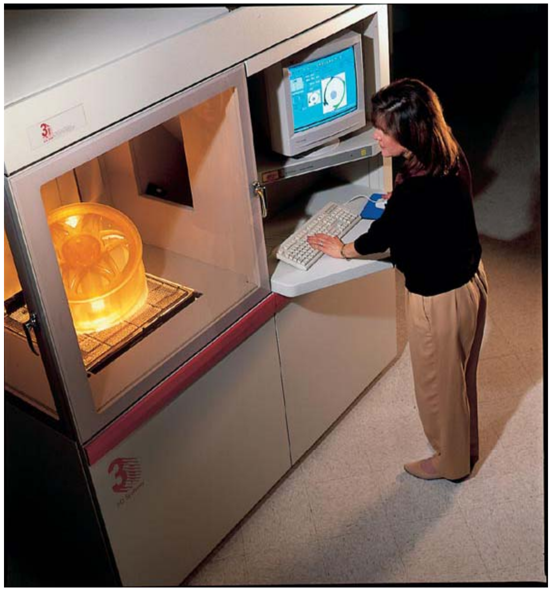
Despite the engineering challenges …AM is already beginning to democratize design and manufacturing.

AM enables democratization of design

From Industrial Class Machines …. To Personalized Printers

3D Systems

Makerbot



3D Systems

3D Systems

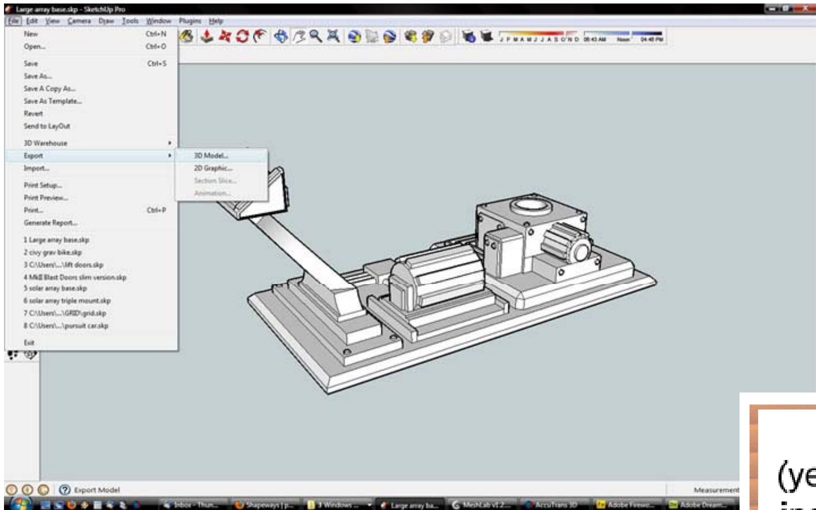
AM enables democratization of design

DreamVendor – An AM Vending Machine at Virginia Tech

Christopher Williams, Va Tech

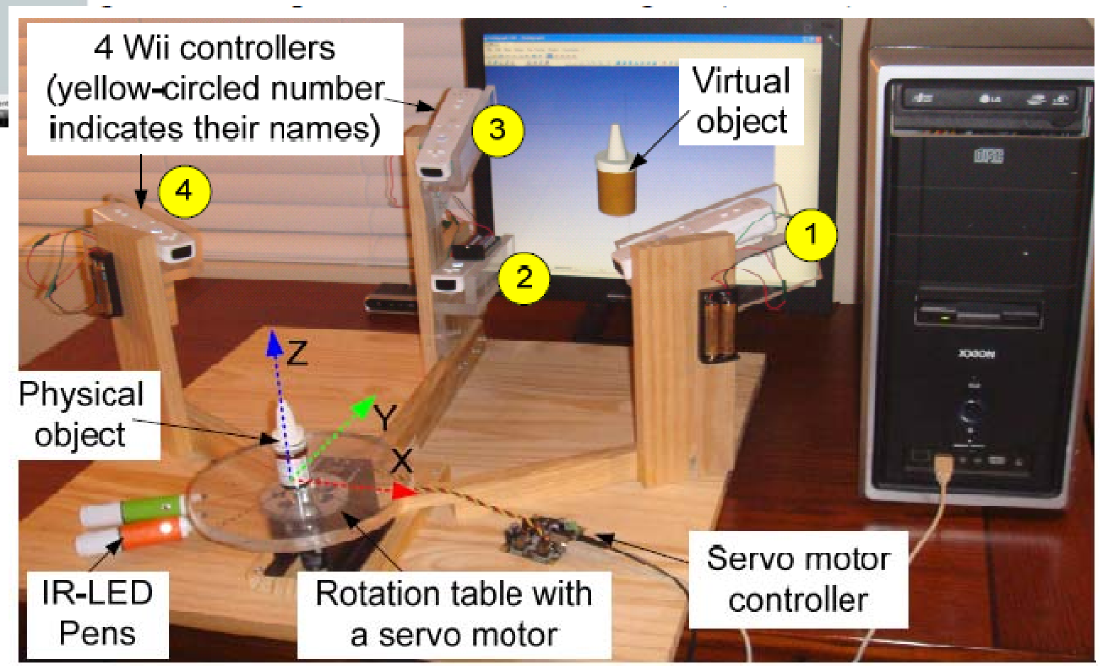
AM enables democratization of design

Simple designer tools to support AM



Google Sketchup
via Shapeways

Touch Reverse
Engineering
Yong Chen, USC

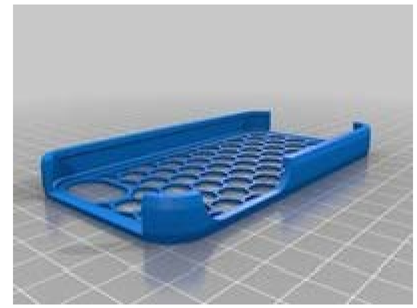


AM enables democratization of design

3D Printing Marketplaces and On-line Communities

Shapeways.com

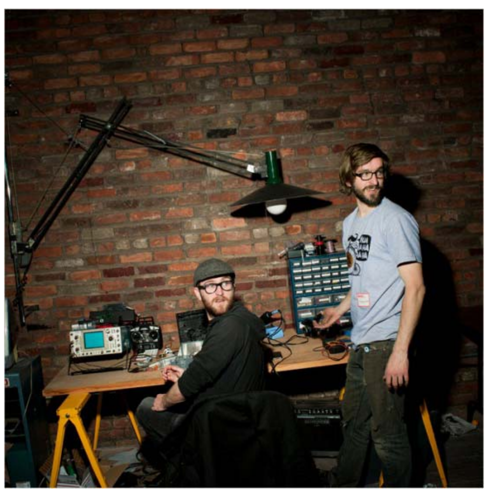
Thingiverse.com



Meet the Makers

Harvest Technologies (David Leigh)

UT Austin AM course (UT Austin ME)



Detroit Builder’s Co-op (NY Times)

Fab-at-Home (Hod Lipson and Evan Malone)