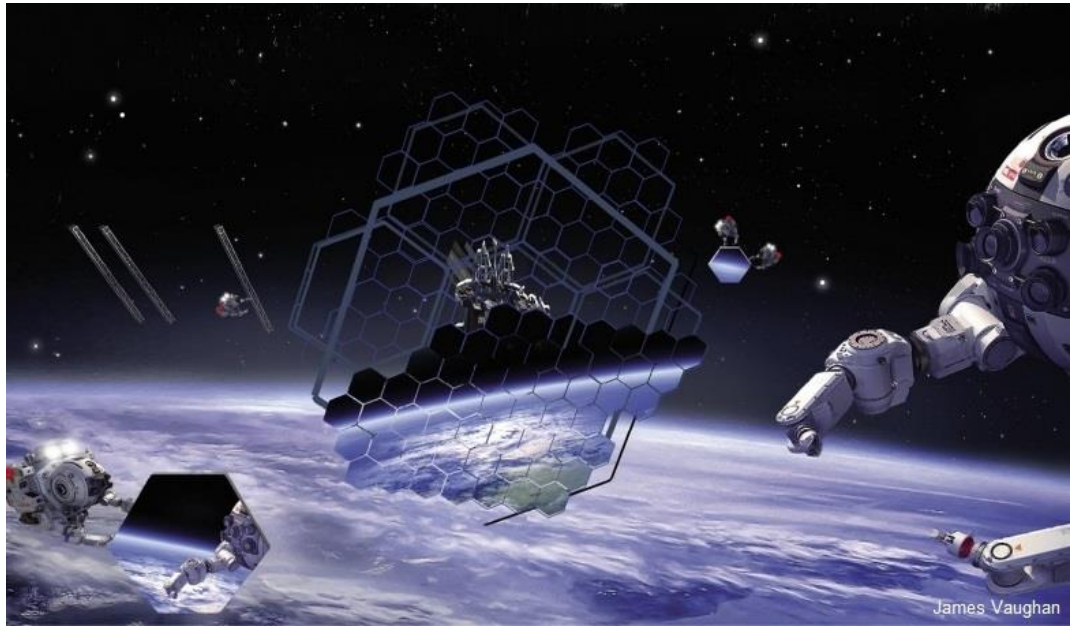
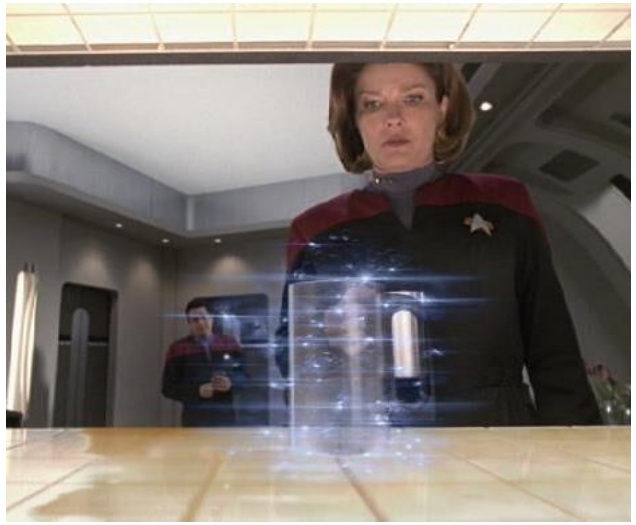
Automated Material Design

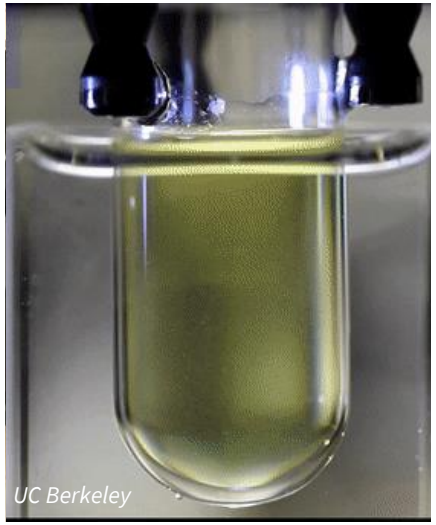
A new paradigm for smart structures in the space environment

Derek Aranguren van Egmond
Dominik Dold
Advanced Concepts Team, TEC-SF, European Space Agency

The Future In Reach







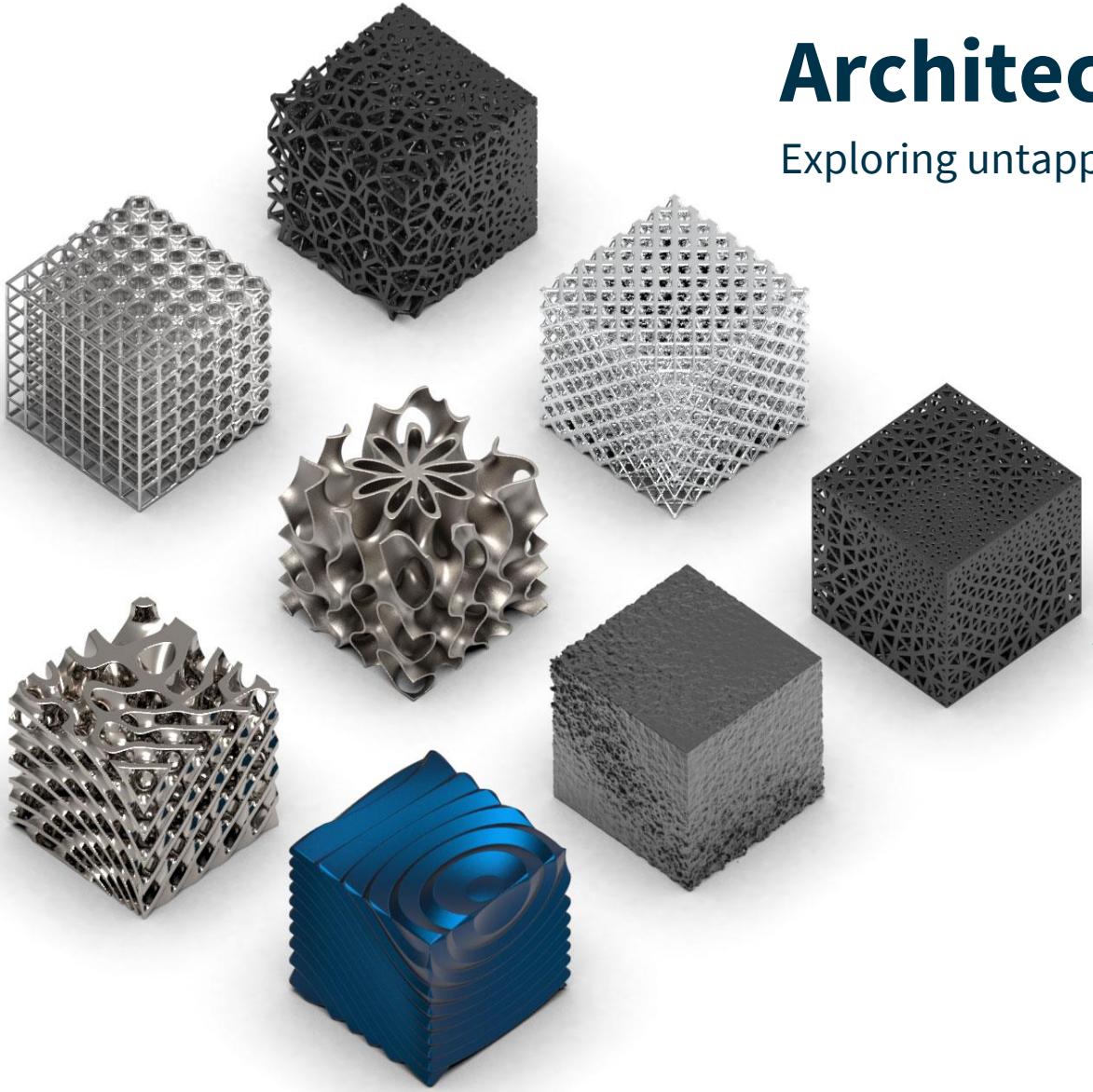
Coming soon…
Replicators!

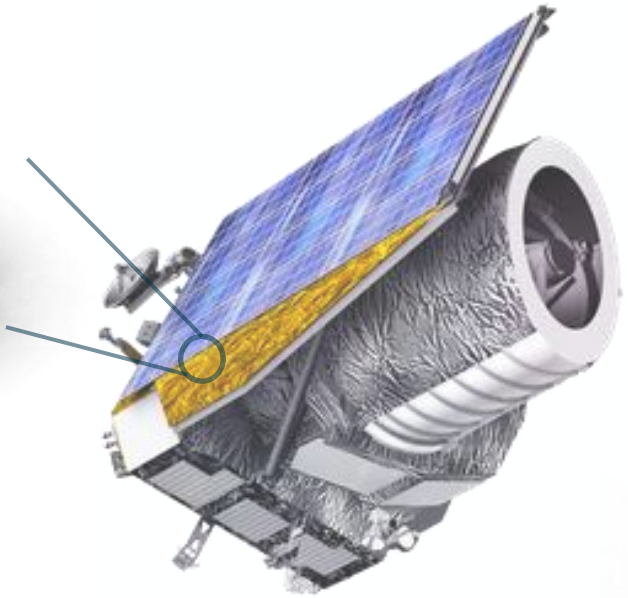
Our Sci-Fi future in space is not too far off now…

- ESA already making great strides on **in-space manufacturing**
- Technologies to augment ISM **already exist** & are advancing rapidly:
  - Exotic 3D printing feedstocks
  - Functional materials
  - Soft robotics
  - Dynamic, programmable structures

Architected Materials

Exploring untapped material property spaces through geometry and chemistry

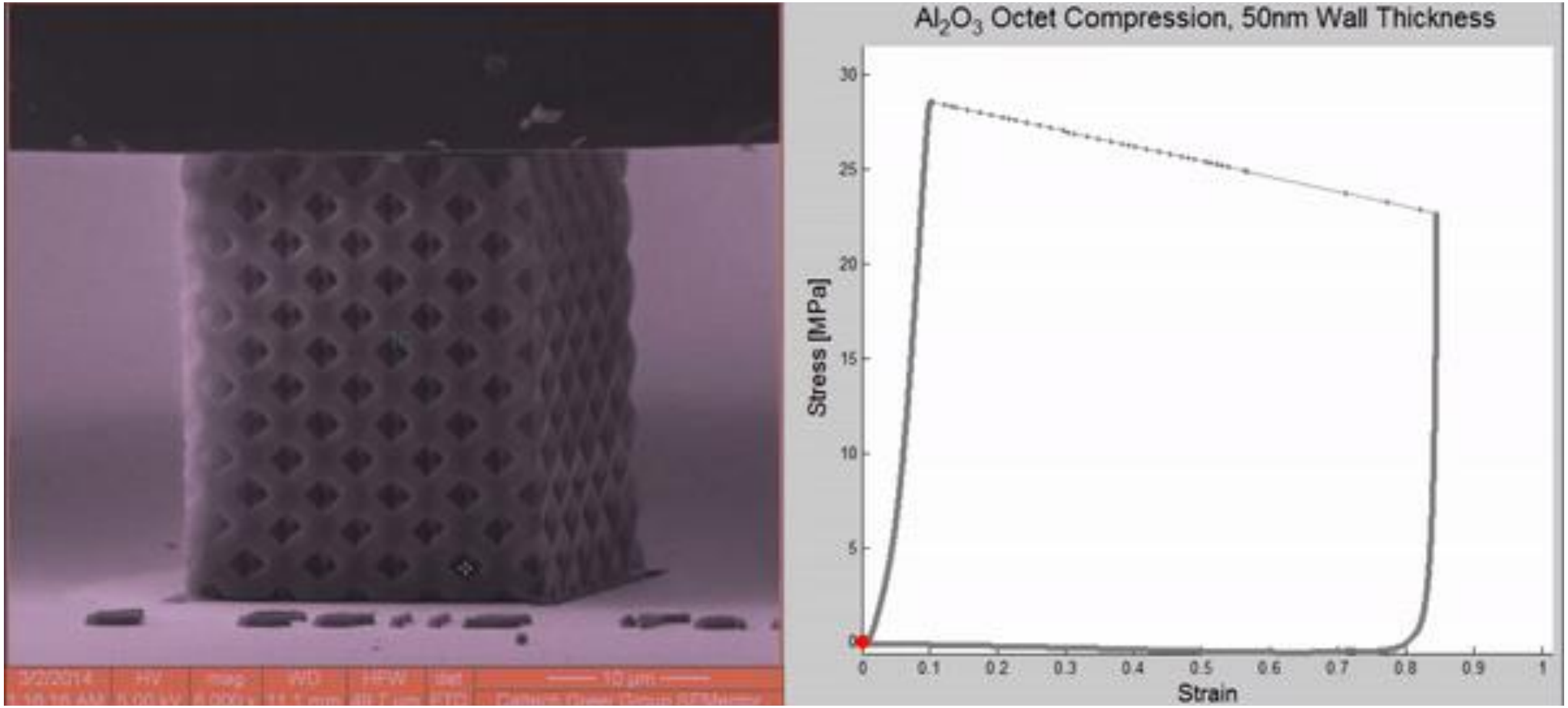




Source: ESA x Skidmore, Owings & Merrill

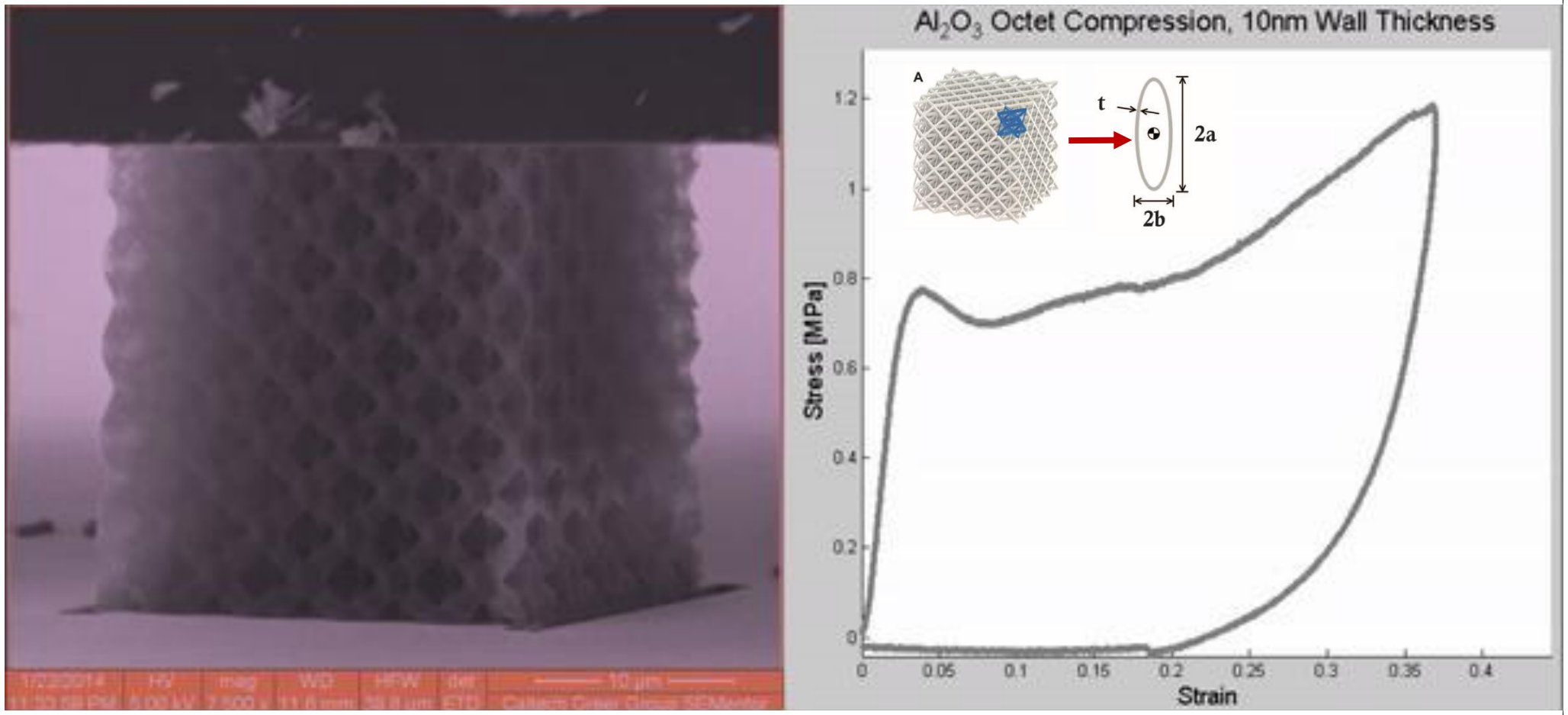
Source: nTopology

Extreme Mechanics in Al_2O_3 Nano-lattices



Meza, L. R., Das, S. & Greer, J. R. Strong, lightweight, and recoverable three-dimensional ceramic nanolattices. *Science* **345**, 1322–1326 (2014).

Extreme Mechanics in Al_2O_3 Nano-lattices



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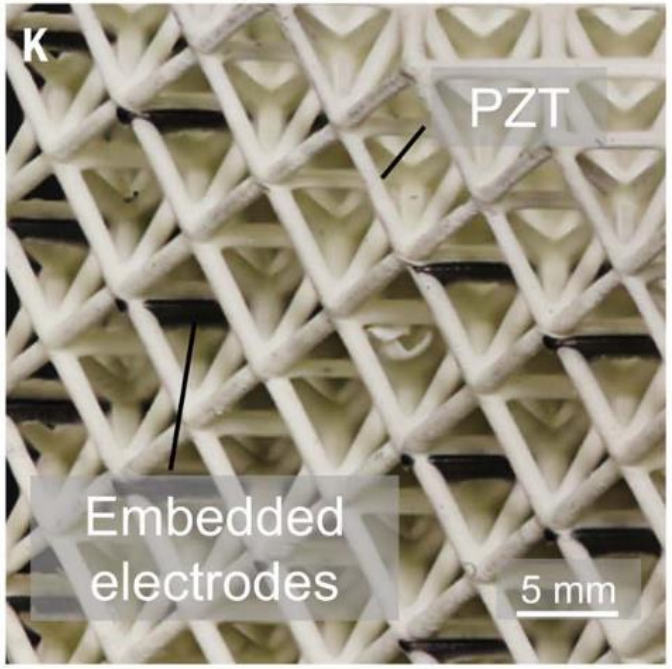
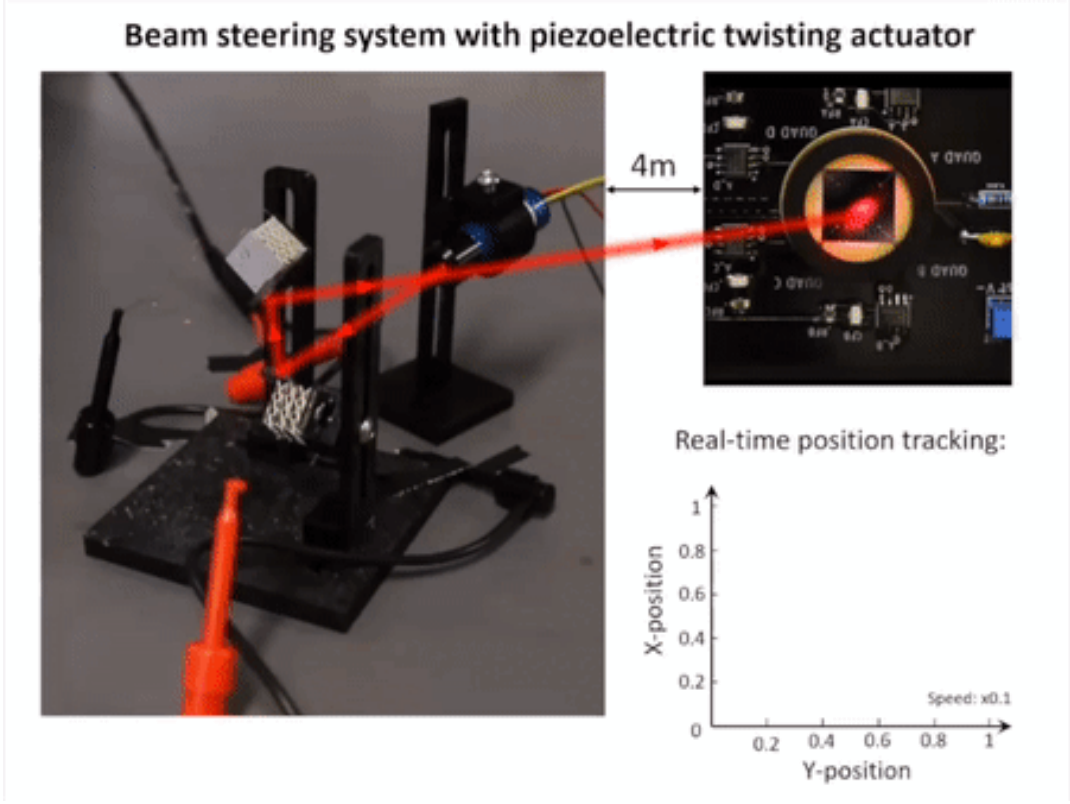
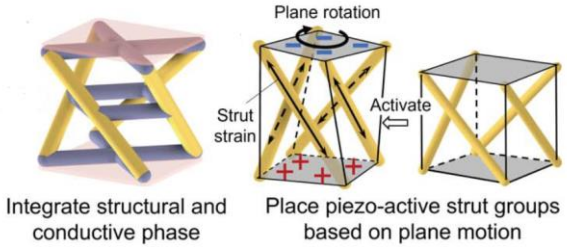
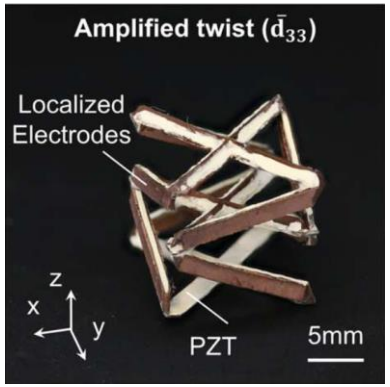
Functional Lattice Materials

The promise of 3D printing: “Robotic Metamaterials”









Cui, H. *et al.* Design and printing of proprioceptive three-dimensional architected robotic metamaterials. *Science* **376**, 1287–1293 (2022).

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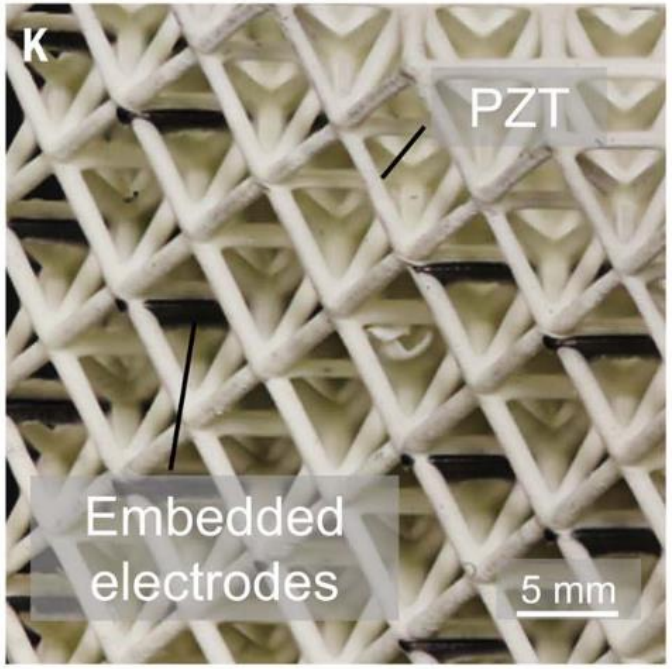
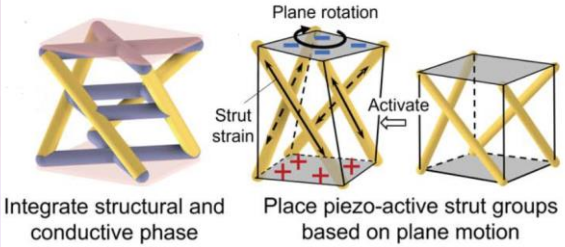
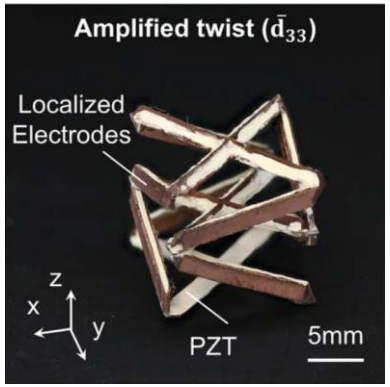


	Walk		Jump		Turn	
V_f	0	0	1	0	1	0
V_b	0	1	0	1	0	1
V_t	0	1	0	1	0	1
ø	50%		1%		50%	
f	<220Hz		<100Hz		260Hz	





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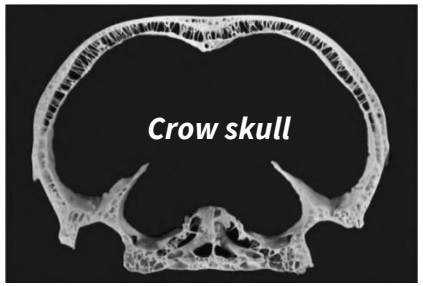
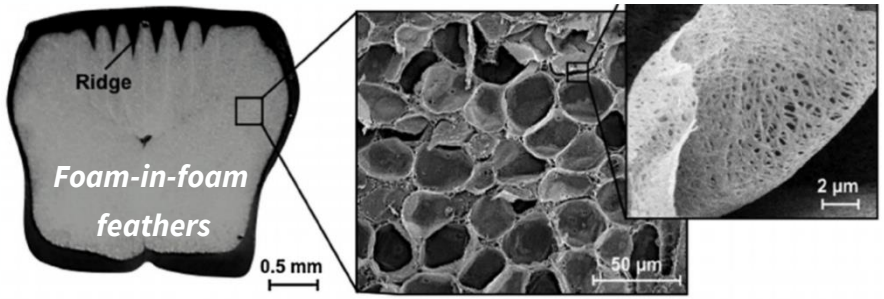
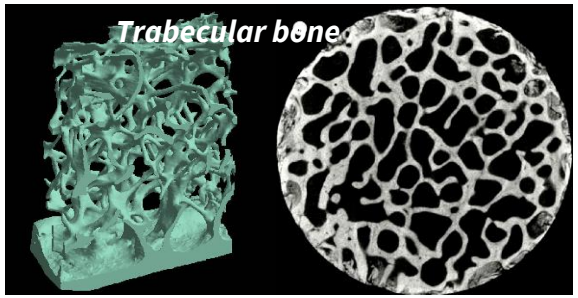
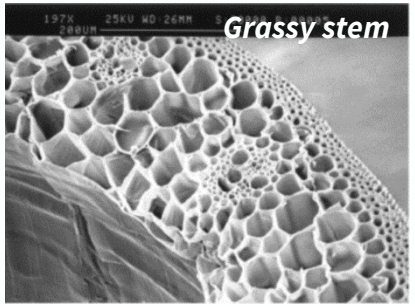
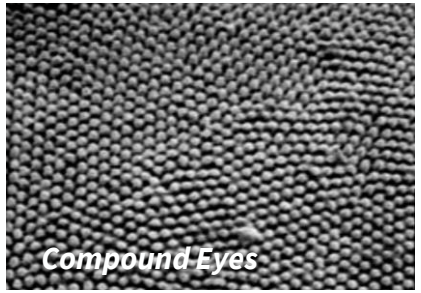


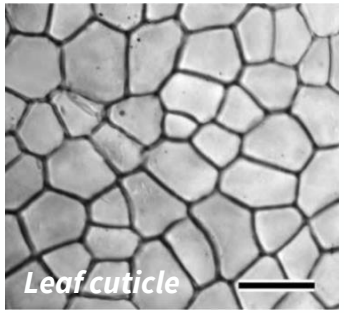


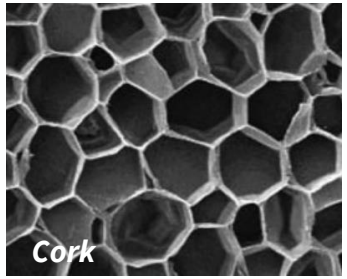


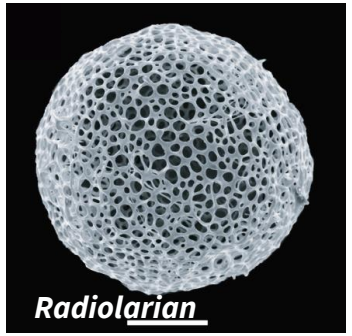


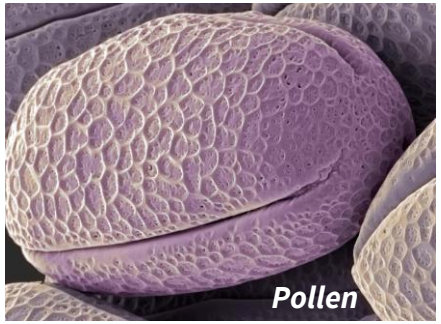


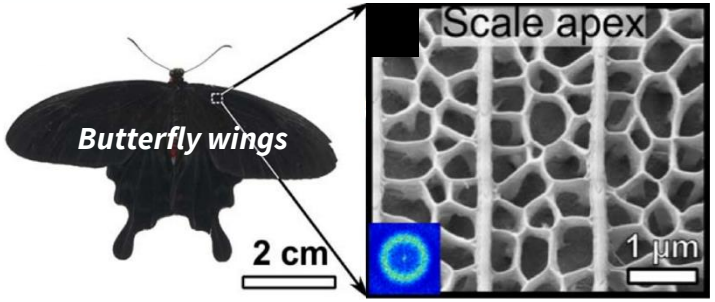
Structural lattice materials exist **all throughout** biology

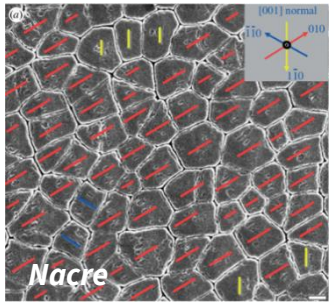






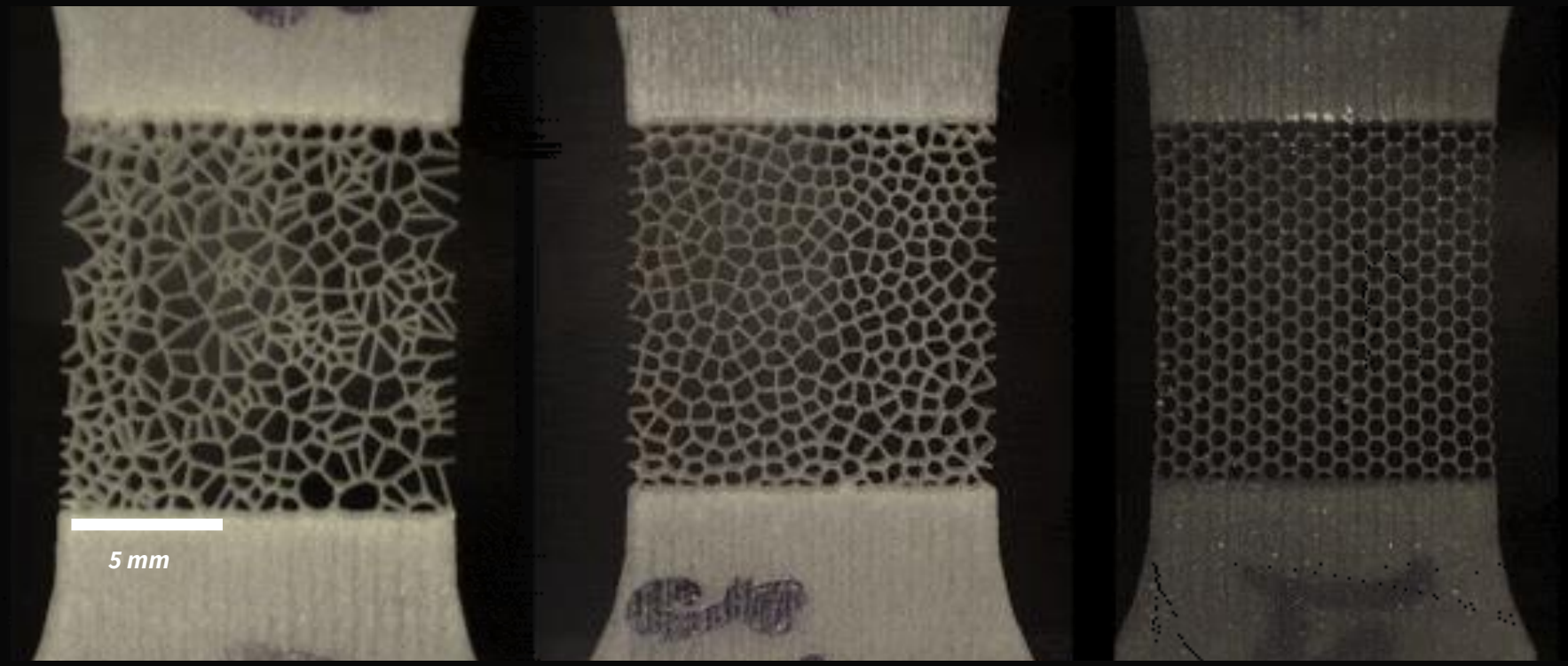


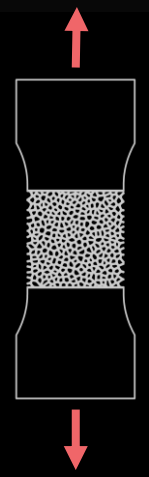




Tensile Properties of Disordered Honeycombs

$\delta = 0.1$ $\delta = 0.8$ $\delta = 1.0$ (RHH)



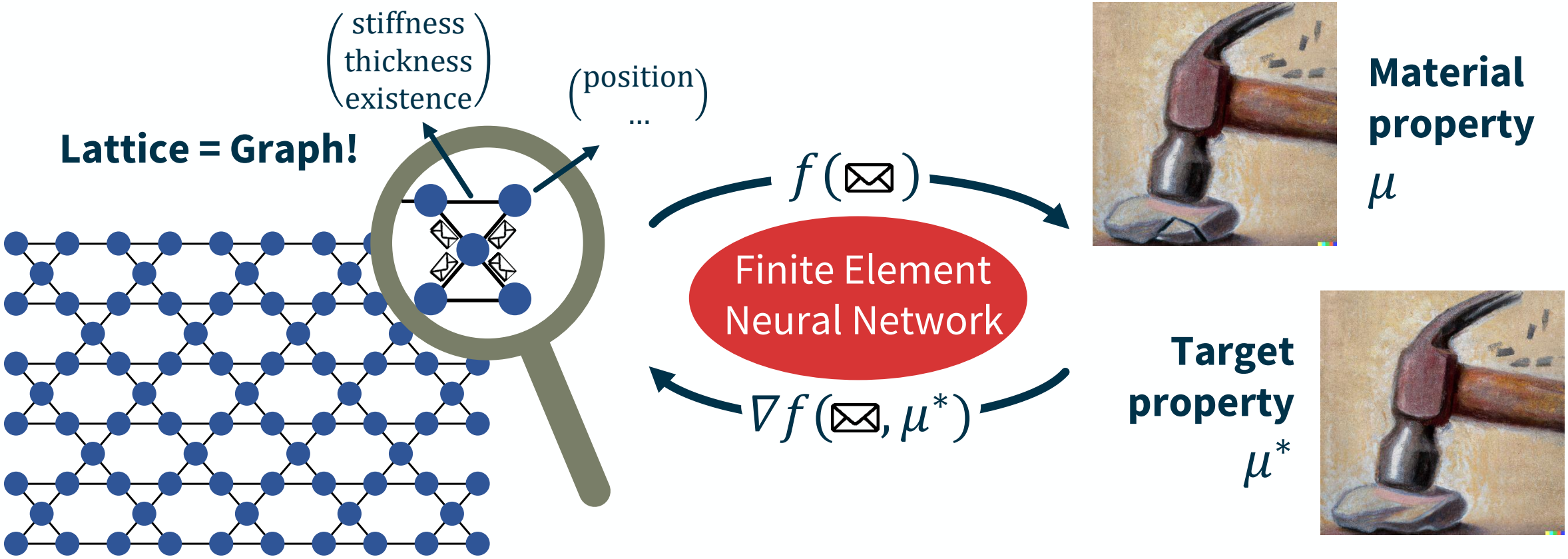


Crack direction and stiffness changes drastically with small change in disorder

8x speed

Aranguren van Egmond, D. *et al.* The benefits of structural disorder in natural cellular solids. *arXiv:2110.04607 [cond-mat, physics:physics]* (2021), *Under Review*

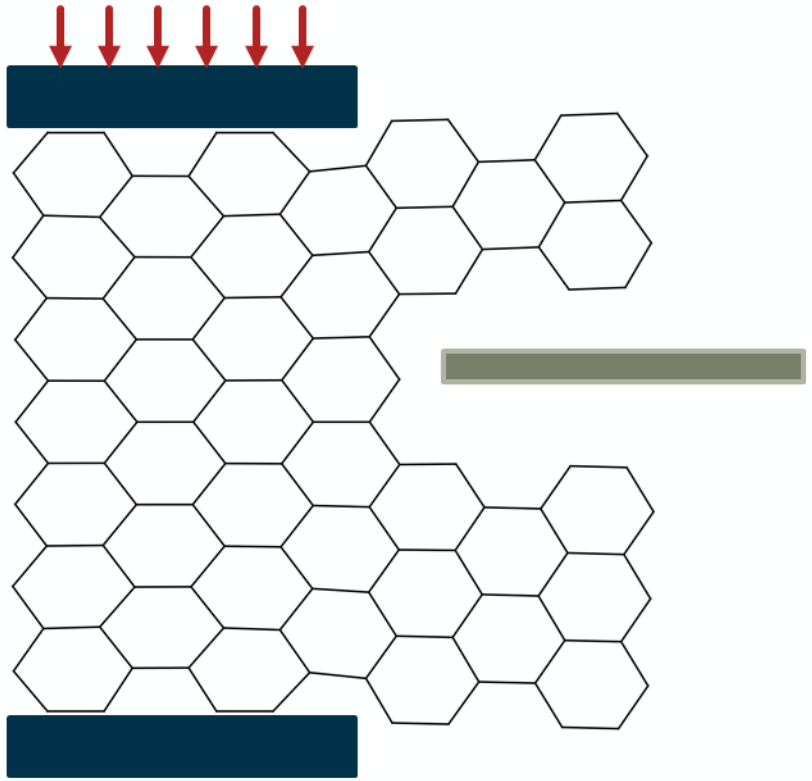
Computing on Lattices: Property Prediction

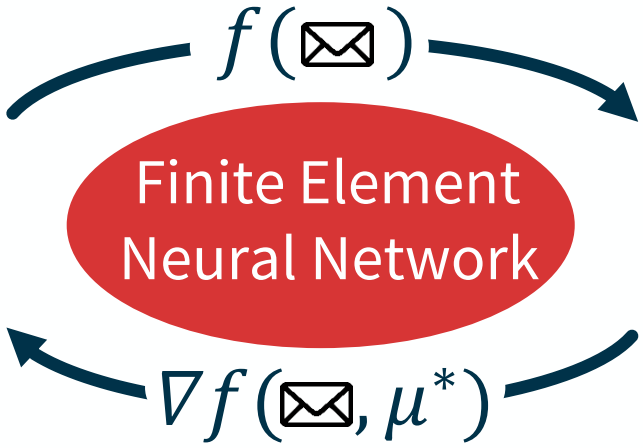


Dold, D., Aranguren van Egmond, D., et al.: Differentiable graph-structured models for inverse design of lattice materials, *In prep.*

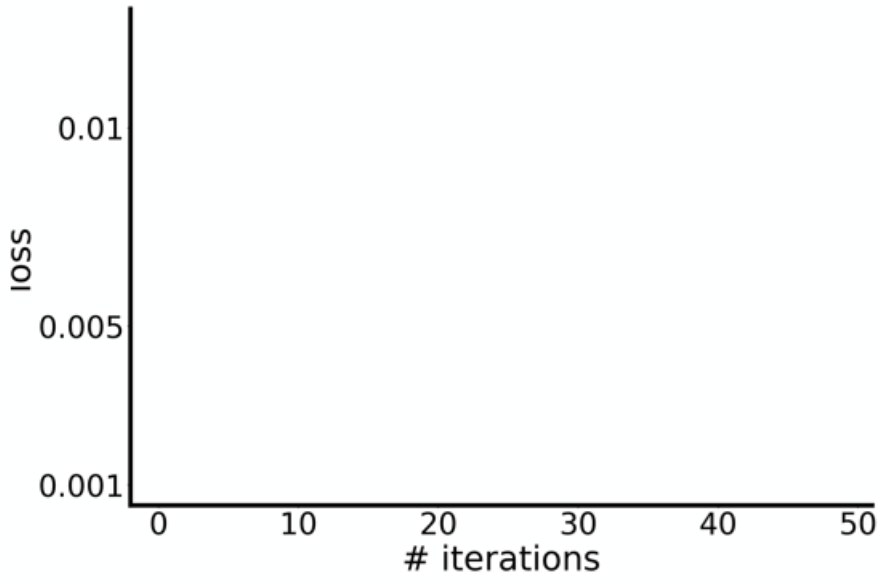
Inverse design using differentiable graphs

Deformed lattice





Distance to target property



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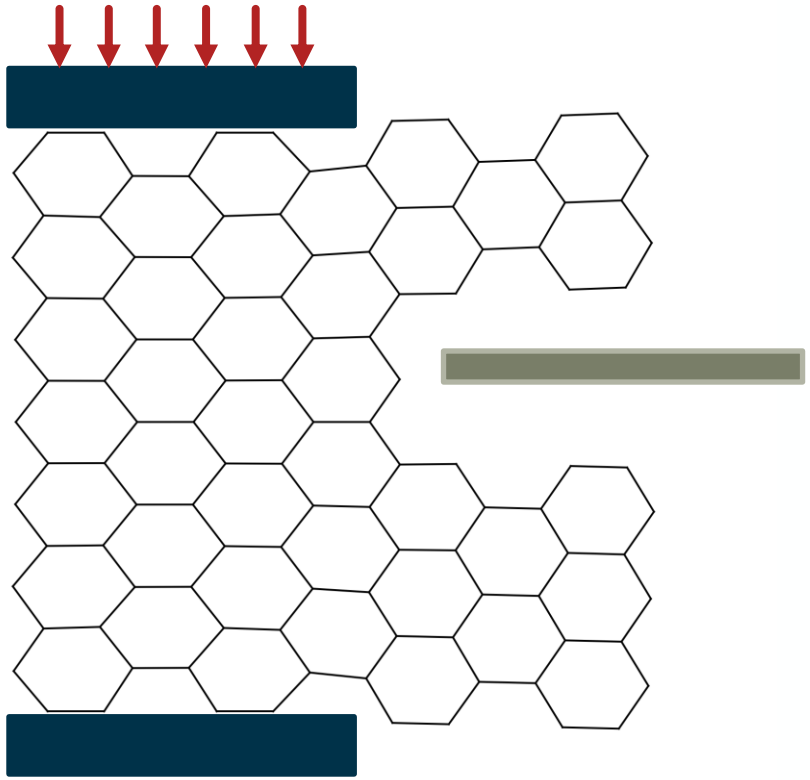

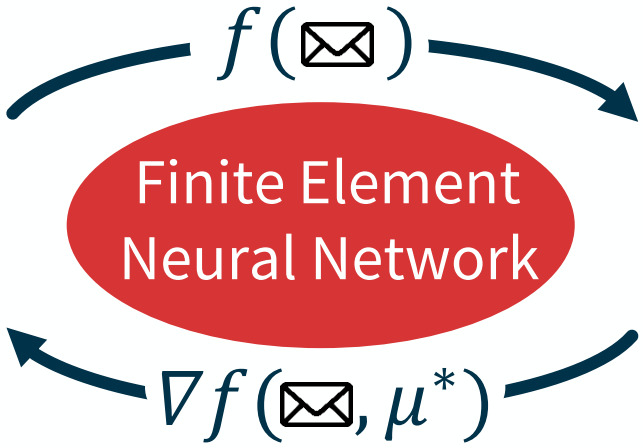

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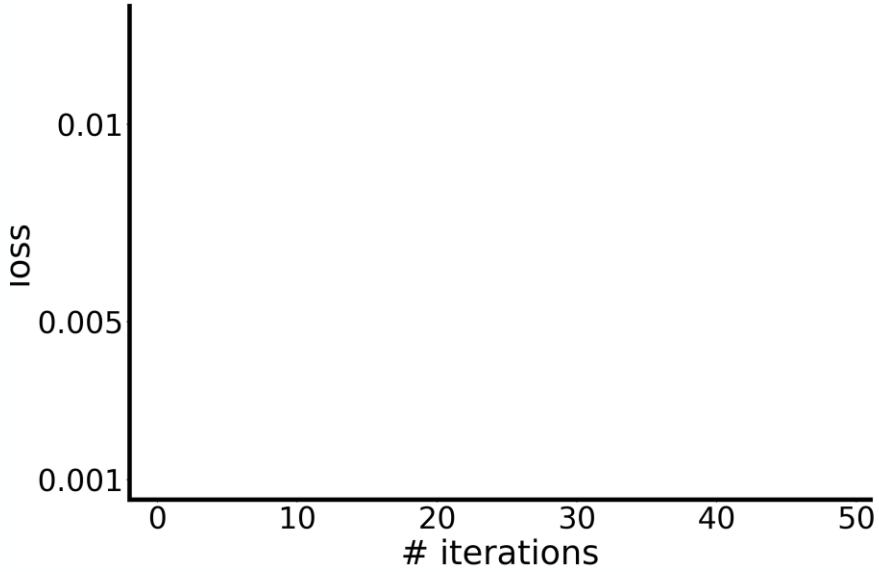

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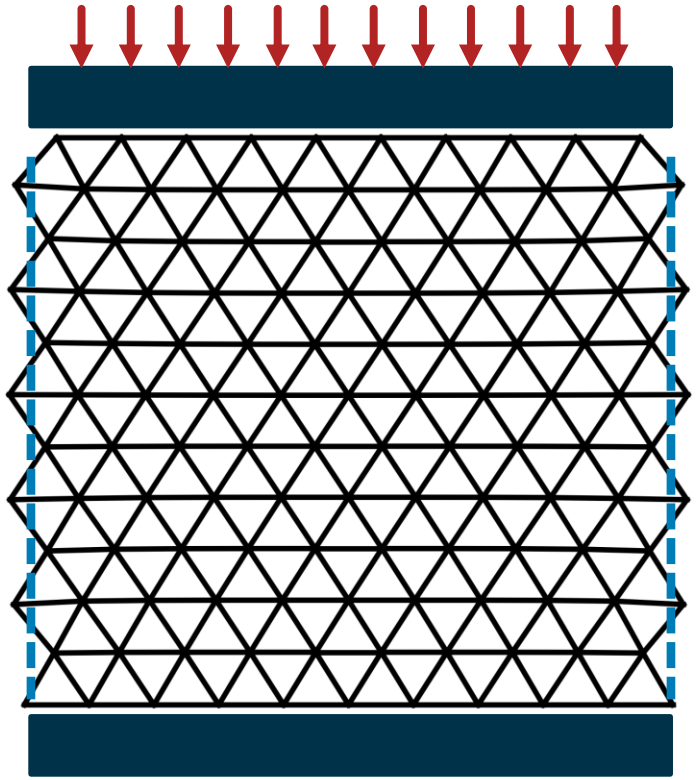
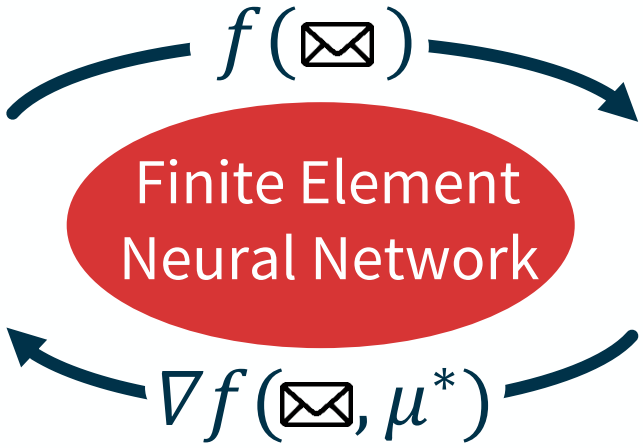
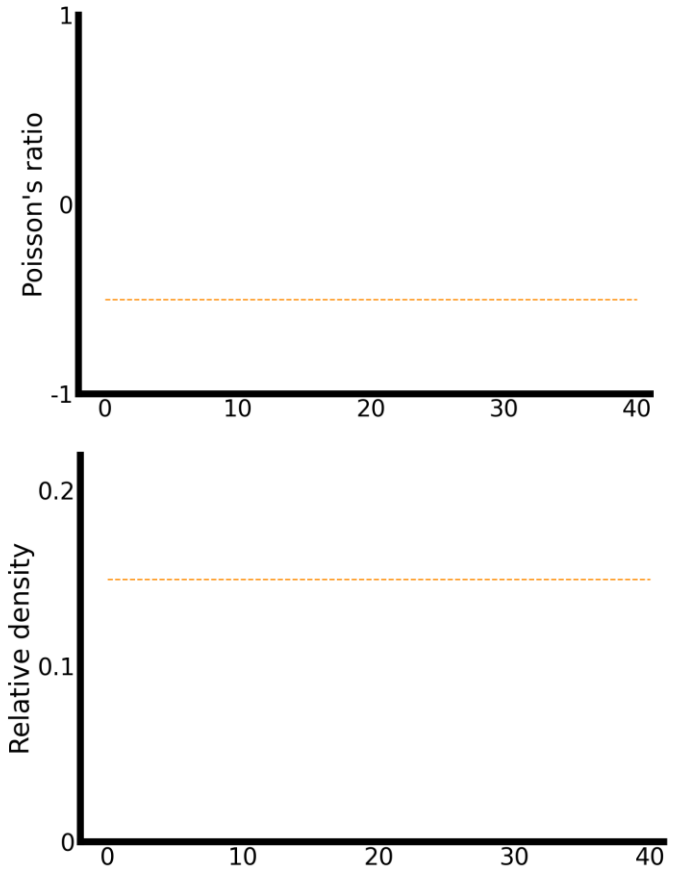




Target Poisson's ratio



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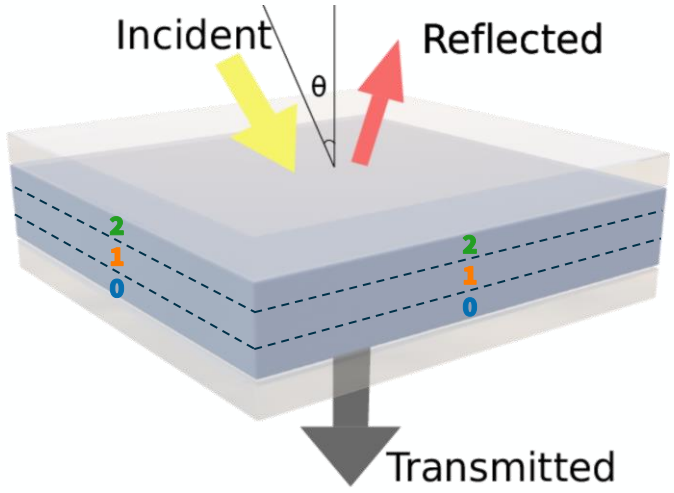
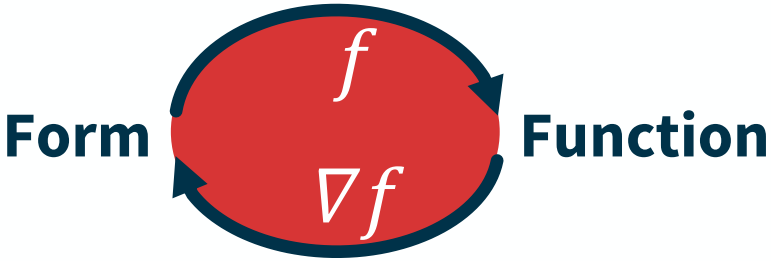
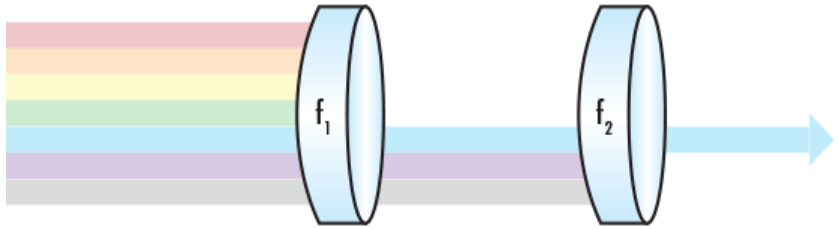
From Graphs to Optical Nanomaterials

Not just for mechanical properties!

Example: Inverse Design of Optical Band-pass Filter







Gómez, P., Toftevaag, H. H., Bogen-Storø, T., Aranguren van Egmond, D. & Llorens, J. M. NIDN: Neural Inverse Design of Nanostructures. Preprint at http://arxiv.org/abs/2208.05480 (2022), *Under Review*

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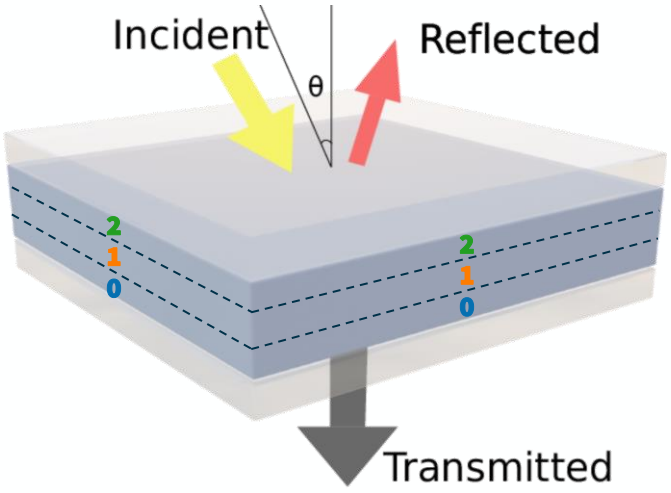

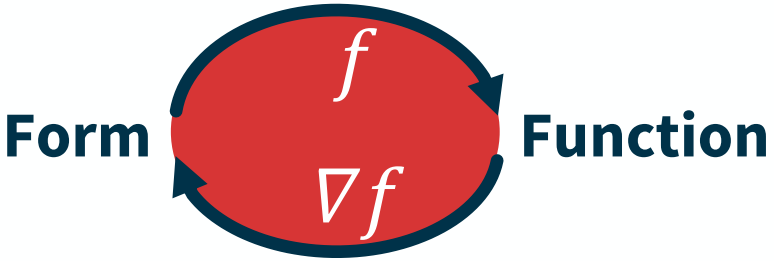

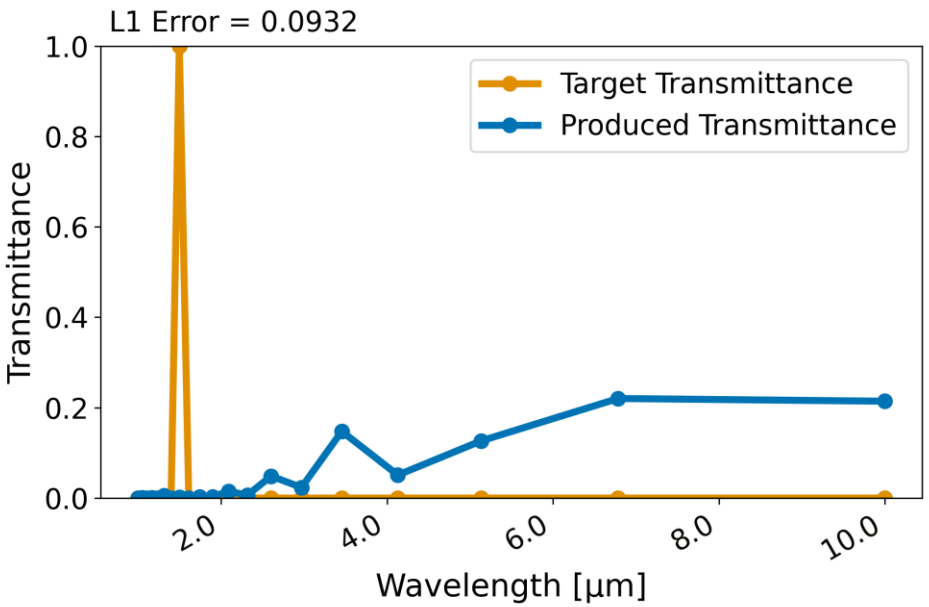

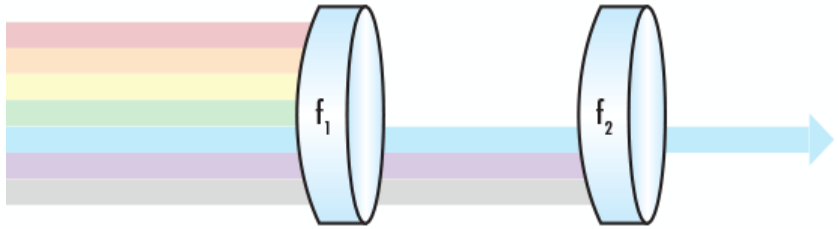

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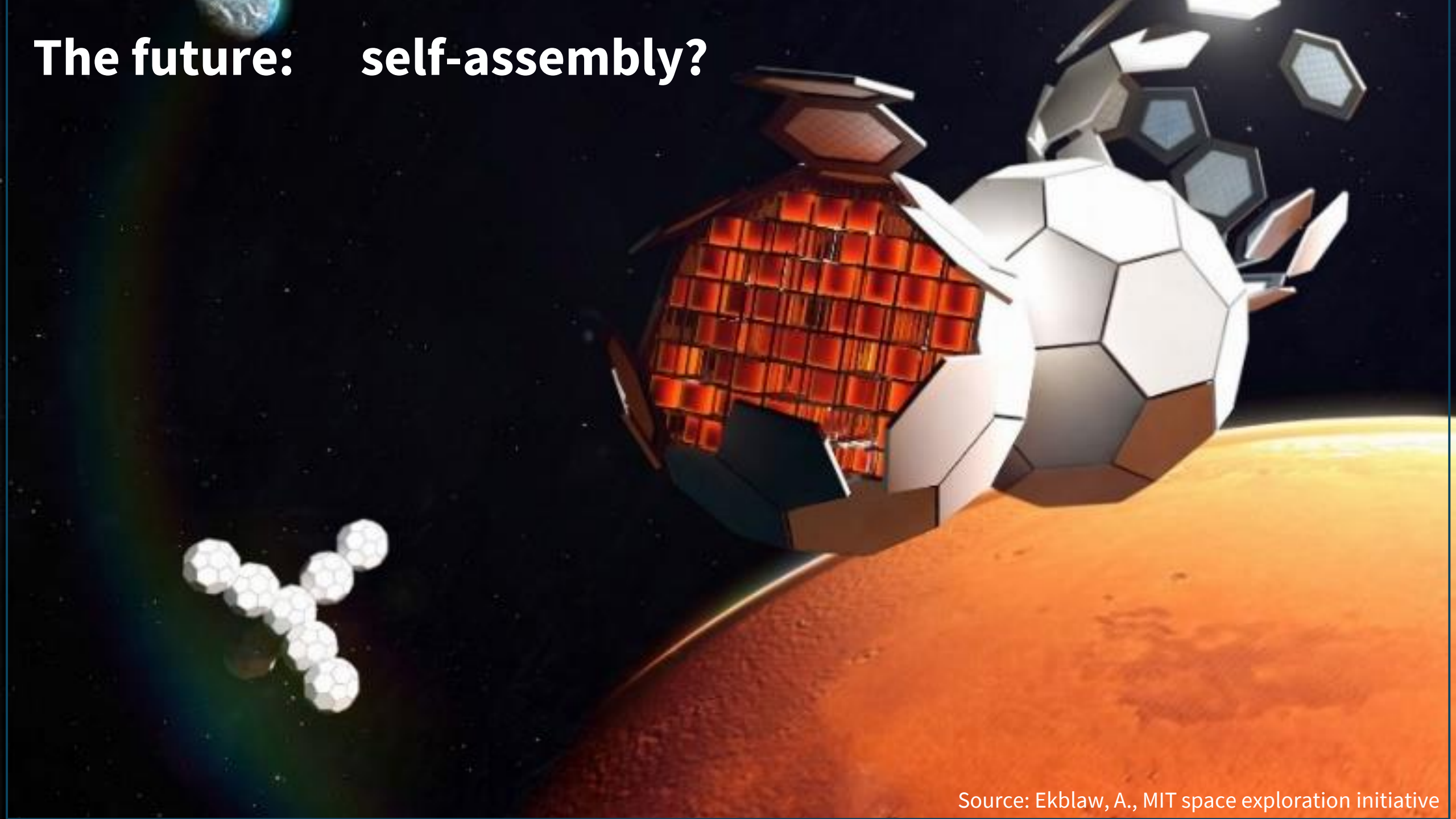
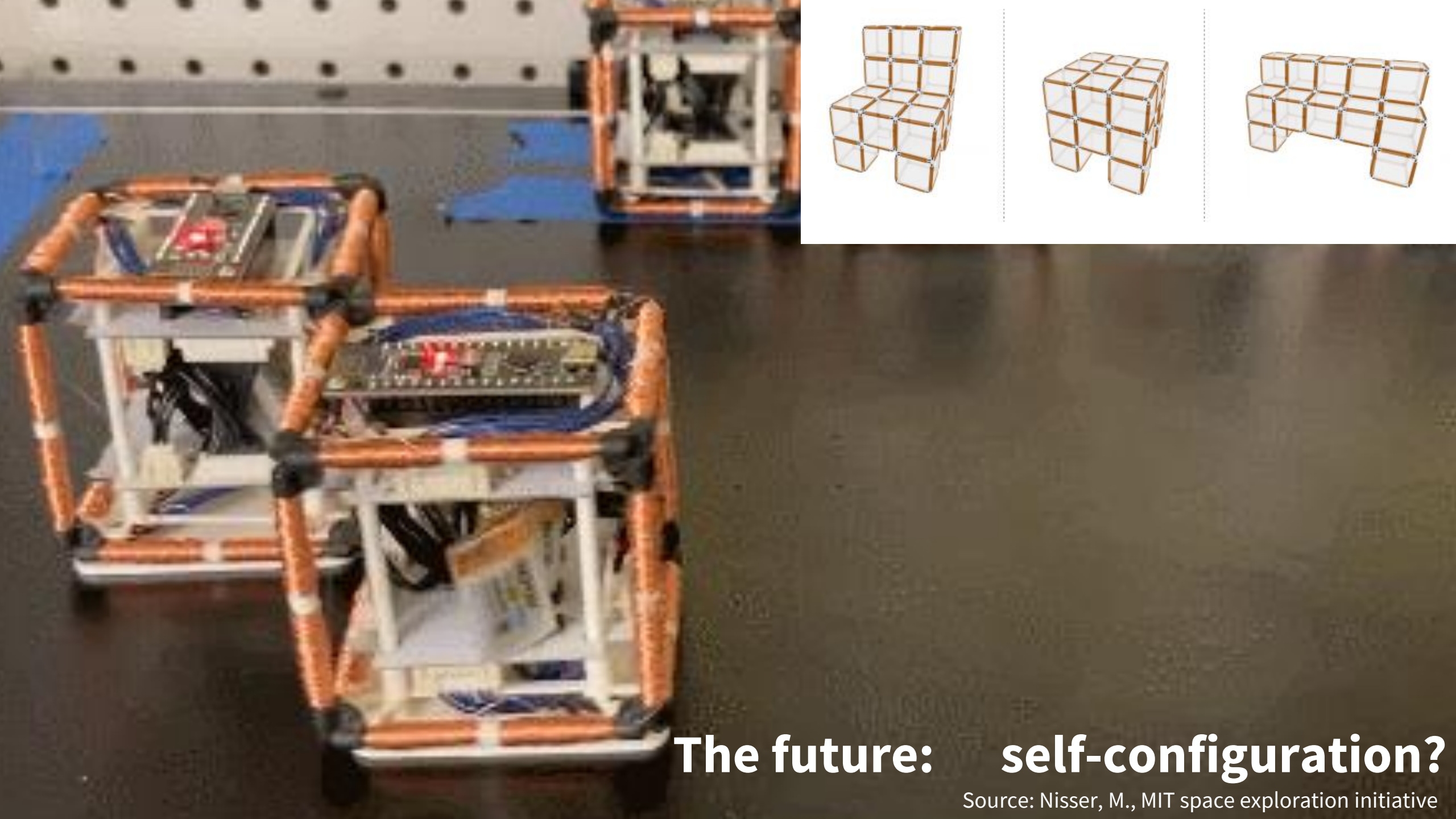
Reconfigurable Spacecraft

The future: self-assembly?



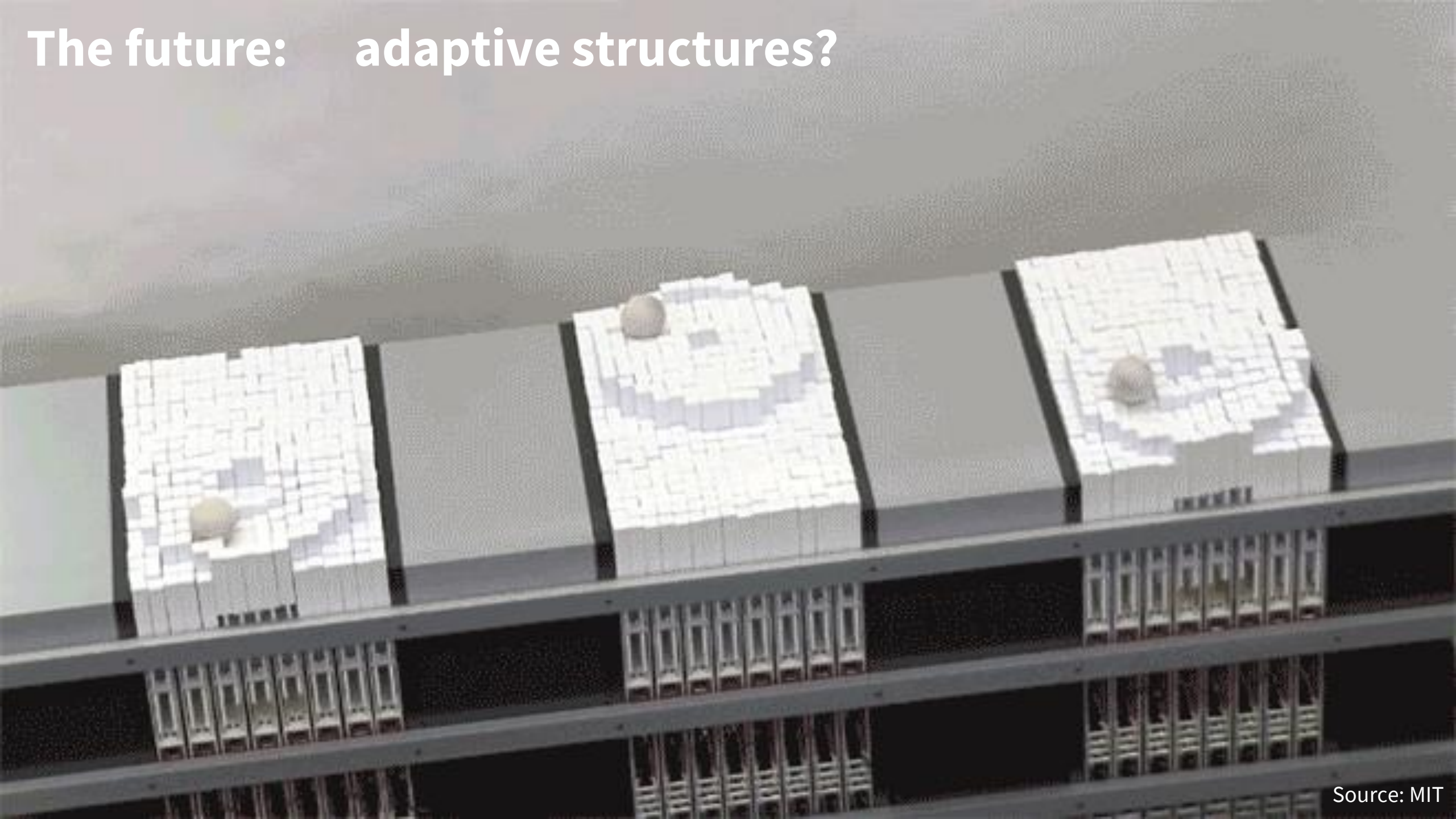
Source: Ekblaw, A., MIT space exploration initiative



The future: self-configuration?

Source: Nisser, M., MIT space exploration initiative

The future: adaptive structures?

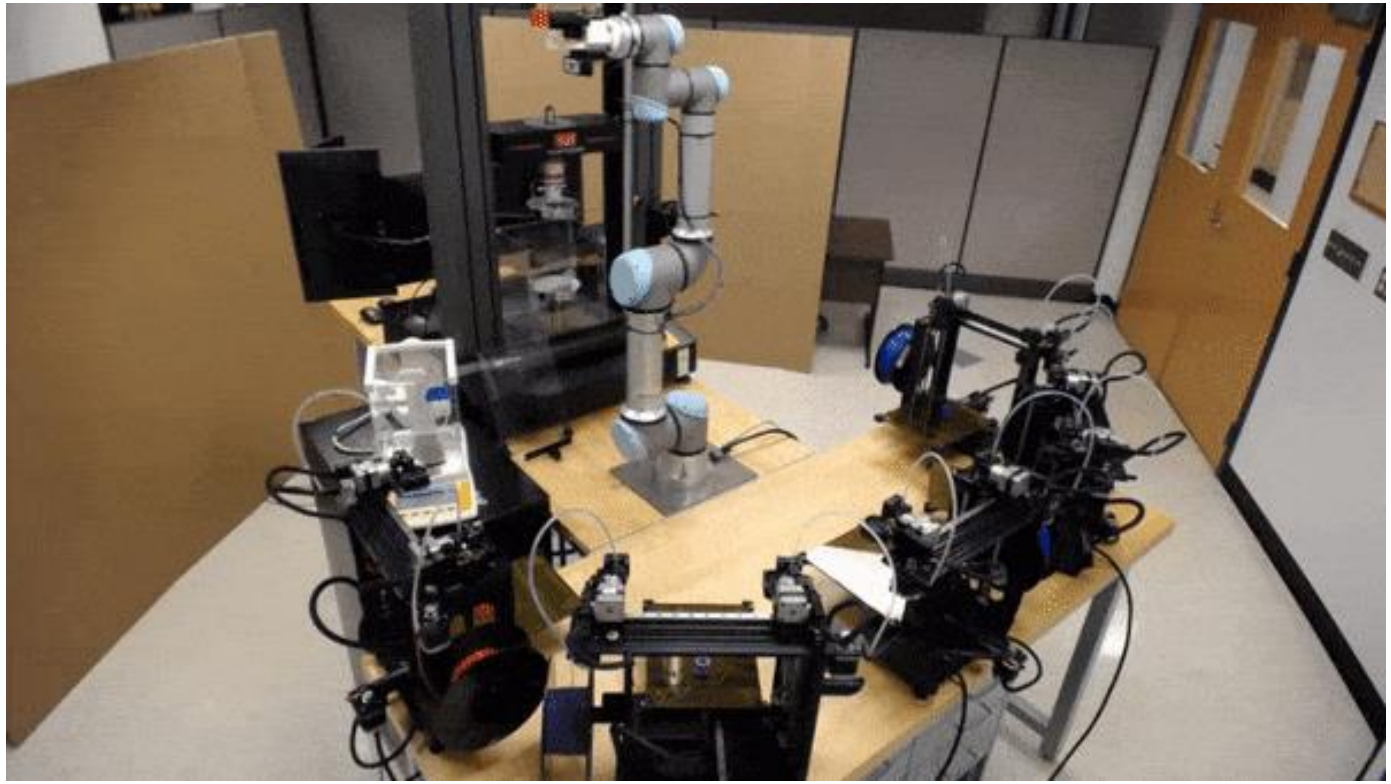


Source: MIT

Thank you!

Functional Lattice Materials

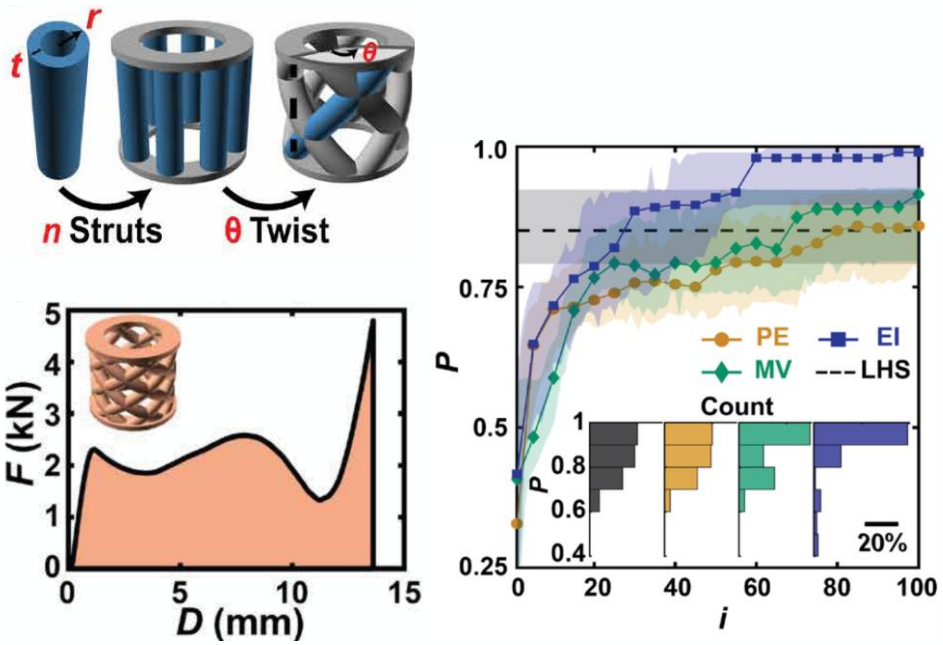
Robotic experiments: accelerated discovery of efficient lattice topologies



Gongora, A. E. *et al.* A Bayesian experimental autonomous researcher for mechanical design. *Sci. Adv.* **6**, eaaz1708 (2020).

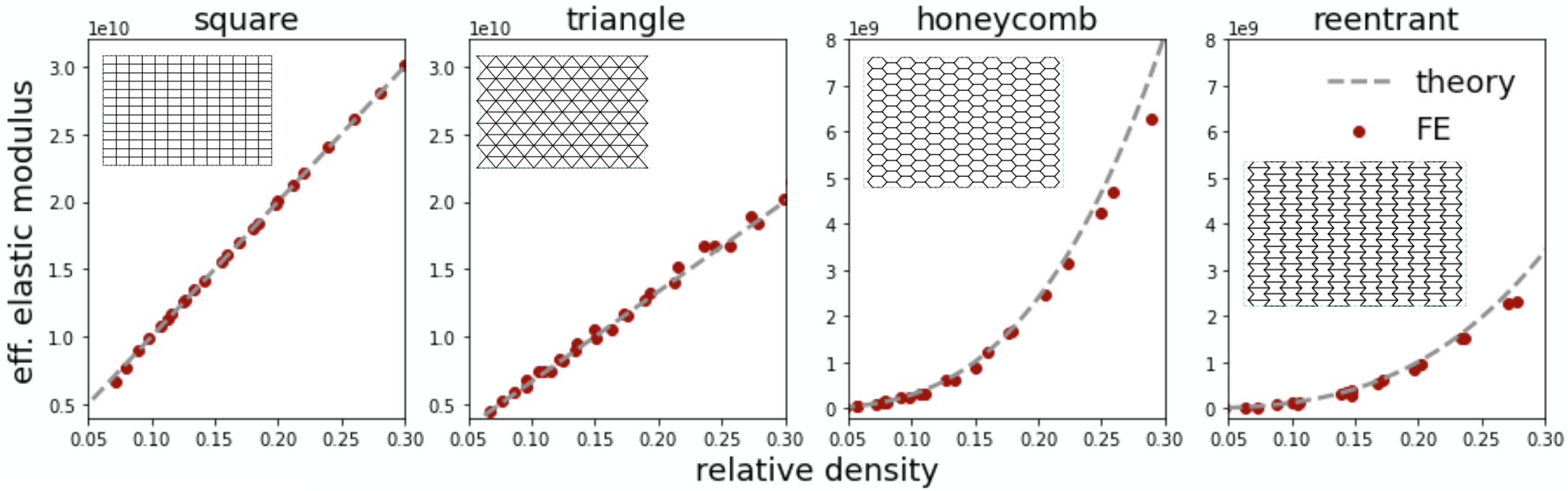
Autonomous material design based on Bayesian ML + mechanical experiments

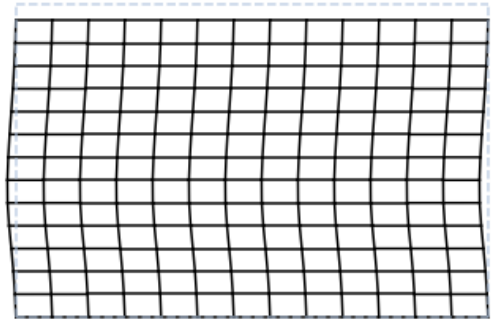
- Intelligent-throughput data generation
- BO compares real mechanical performance based on variation of unit-cell parameters

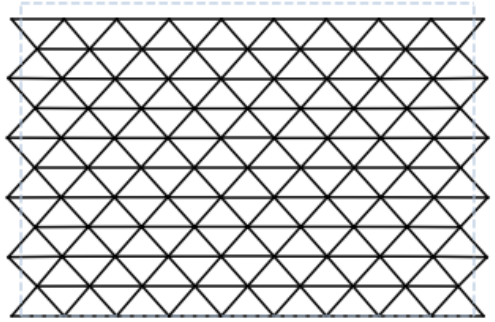


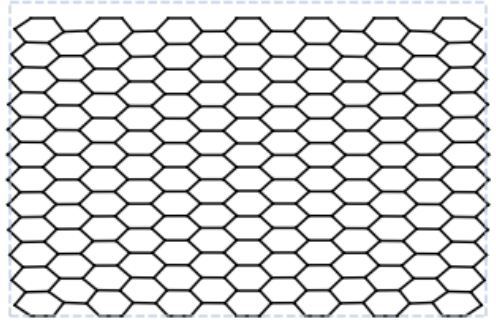
Validation of FE solver for lattice materials

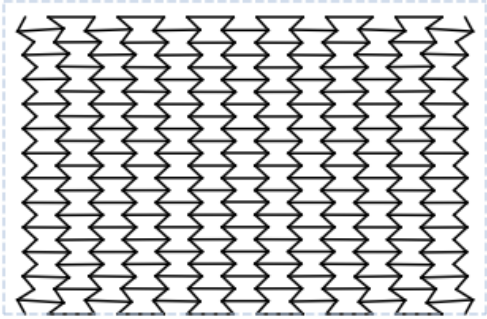
Analytical models vs. simulated elasticity results



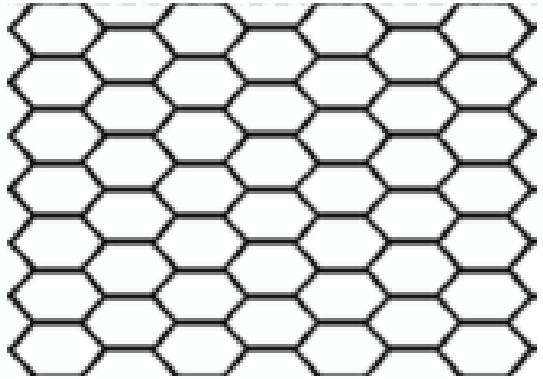






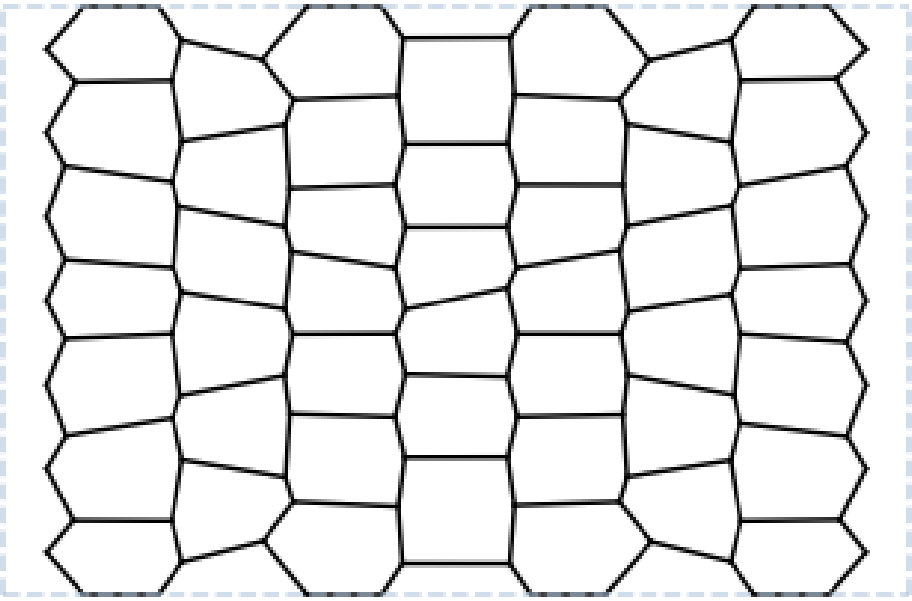


Re-configuring and optimizing honeycombs for stiffness

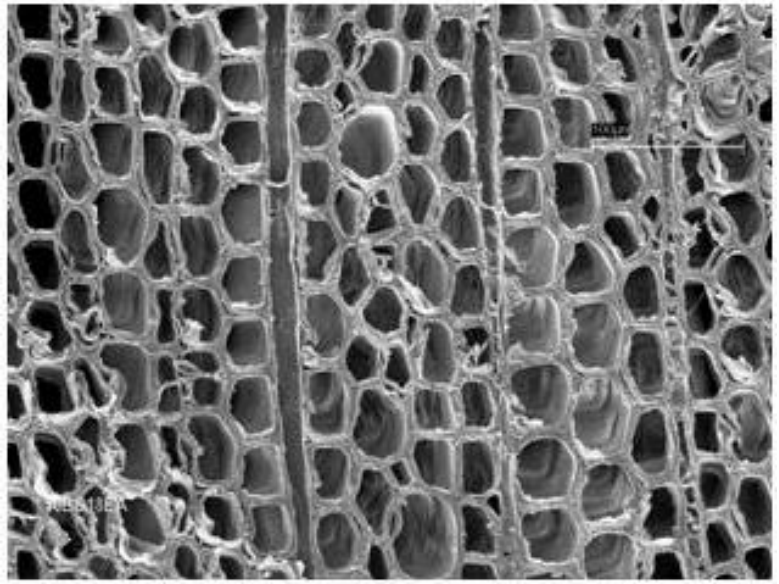


Stiffness opt.,
node movements

Coincidence?



Cellular structure of **wood** (pinewood bark)



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