Architectural Choices for Auxetic Metamaterials and their Effects on Impact Mitigation

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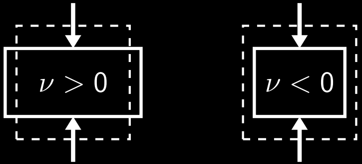
July 27, 2023

Impact Behaviour of Auxetic Materials

- auxetic materials are materials with a negative Poisson's ratio
  - materials that contract laterally when compressed



non-auxetic and auxetic materials
(Lim 2015)

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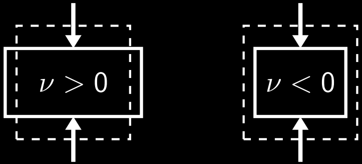
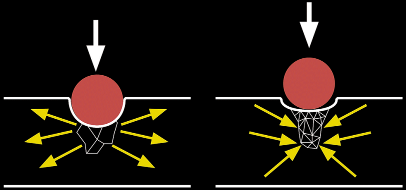
- promising capabilities for impact mitigation
  - natural densification at the impact location
  - better involvement of lateral material



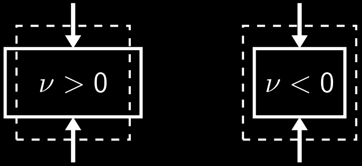
non-auxetic and auxetic materials (Lim 2015)



non-auxetic and auxetic material under impact (Kolken and Zadpoor 2017)

Impact Behaviour of Auxetic Materials

- auxetic materials are materials with a negative Poisson's ratio
  - materials that contract laterally when compressed
- promising capabilities for impact mitigation
  - natural densification at the impact location
  - better involvement of lateral material
- auxetic materials hardly found in nature
- assumptions don't take material architecture into account



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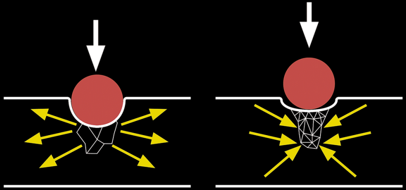

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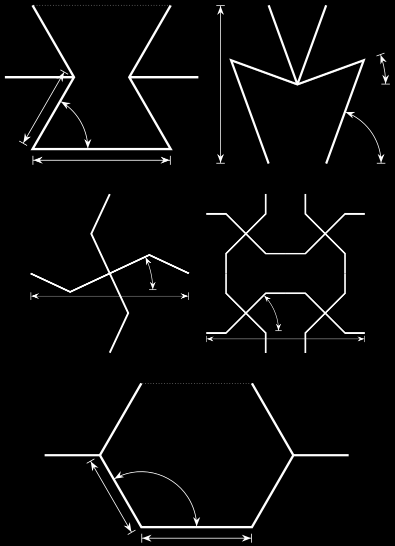
Architecture Selection

- four auxetic and one non-auxetic designs investigated
  - two different auxetic mechanisms
  - materials without rotational similitude also 90° rotated



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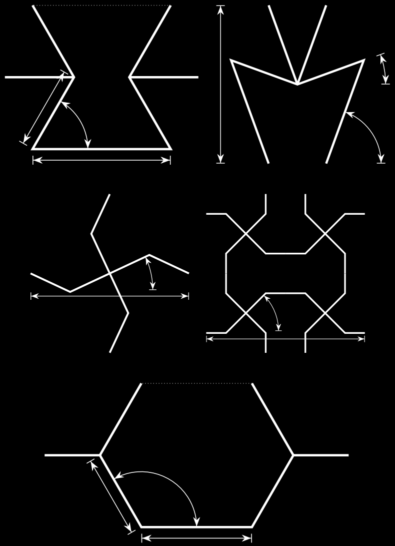

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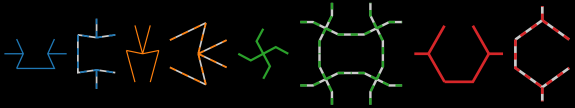
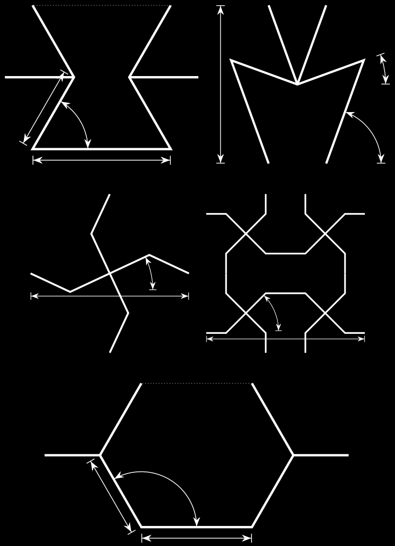
Architecture Selection

- four auxetic and one non-auxetic designs investigated
  - two different auxetic mechanisms
  - materials without rotational similitude also 90° rotated
- geometric parameters and beam thickness as variables
- all structures tuned to

$$E_y^\star = 300\,\mathrm{MPa}$$

$$\rho^\star = 785\,\mathrm{kg\,m^{-3}}$$





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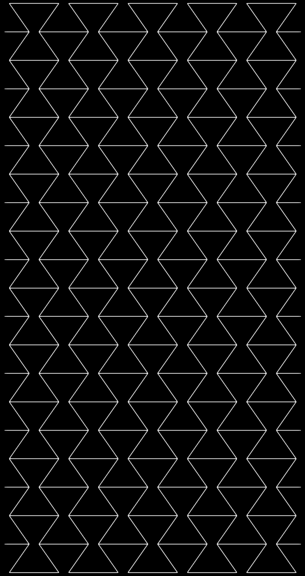
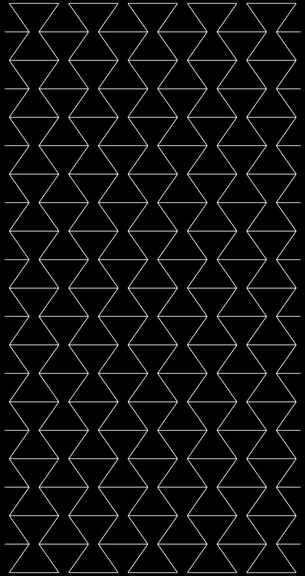
Lattice Simulation

- architectures defined as assembly of rods



Lattice Simulation

- architectures defined as assembly of rods
- rods represented as geometrically nonlinear Timoshenko beams
- FE-implementation of Simo-Reissner-elements in JEM/JIVE[1]



[1] C++ FE-Toolkit

Lattice Simulation

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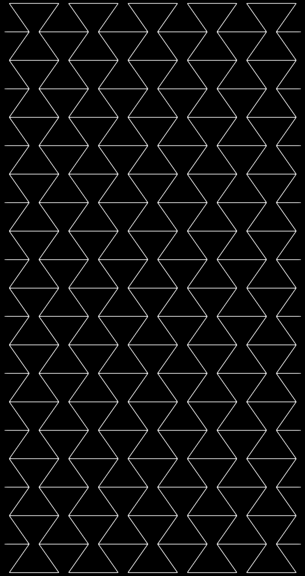
- purely elastic material behavior
- no contact detection



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- purely elastic material behavior
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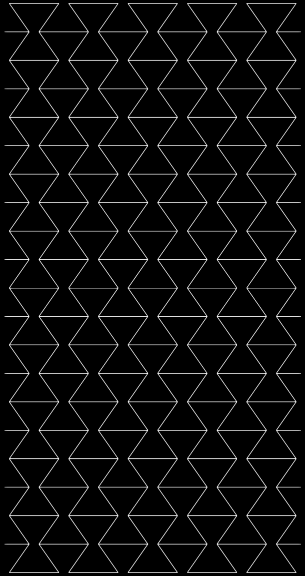
- time marching with predictor-corrector scheme
- time step adaptivity using a Milne-device



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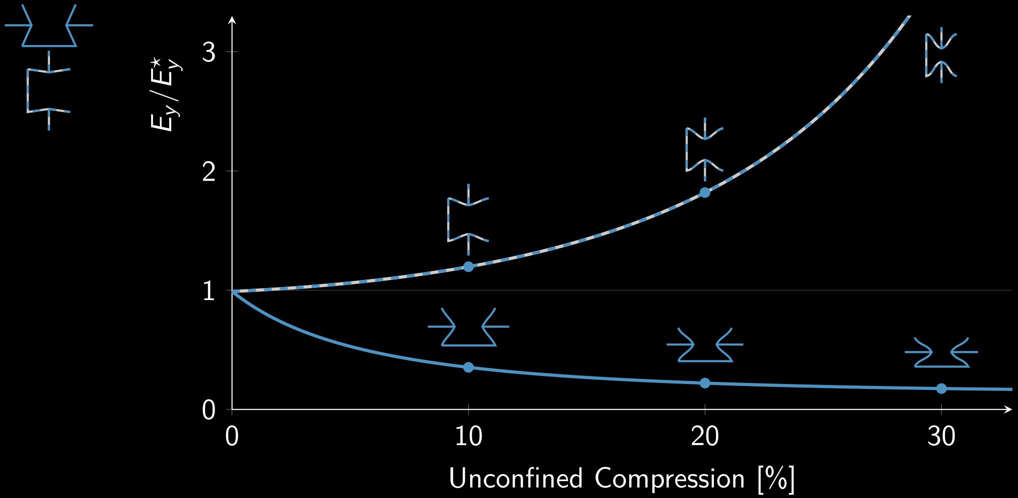
Change in E_y due to Loading-Direction of Beams



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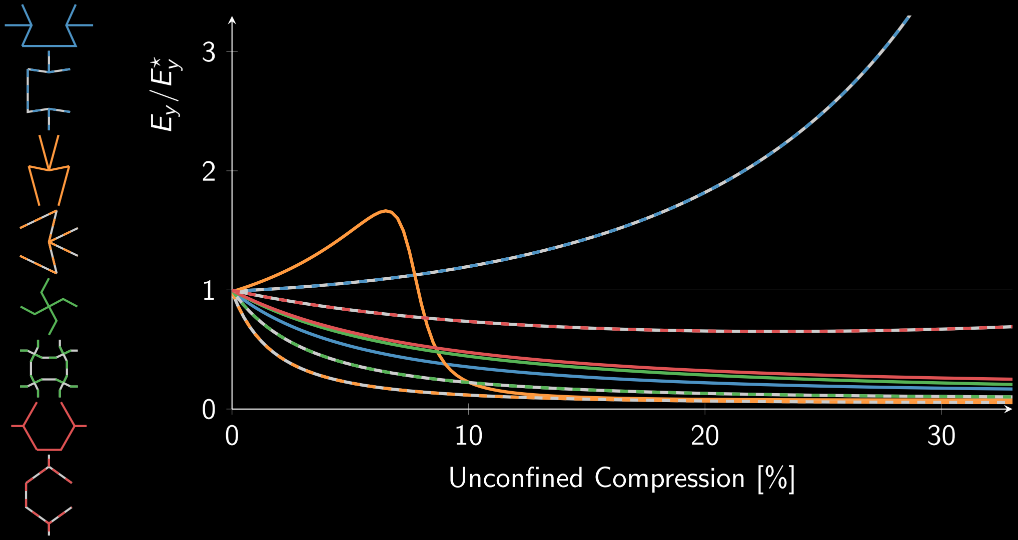

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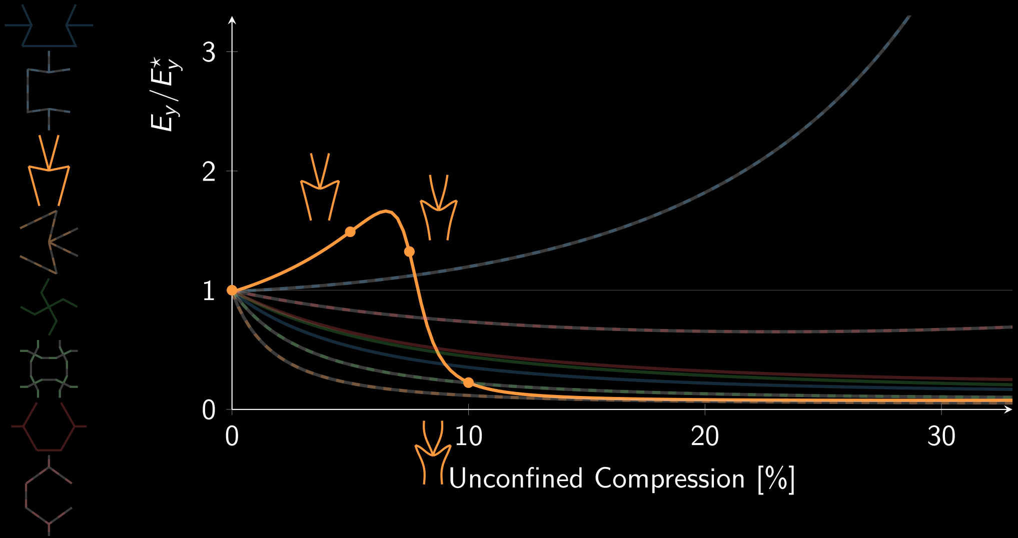
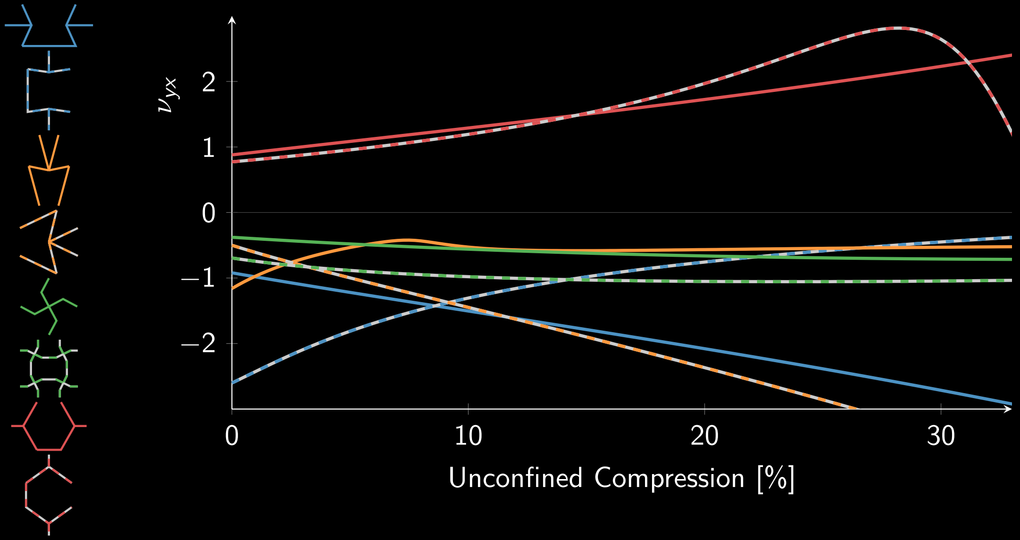


Influence of Geometry on Poisson's Ratio



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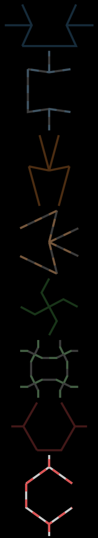
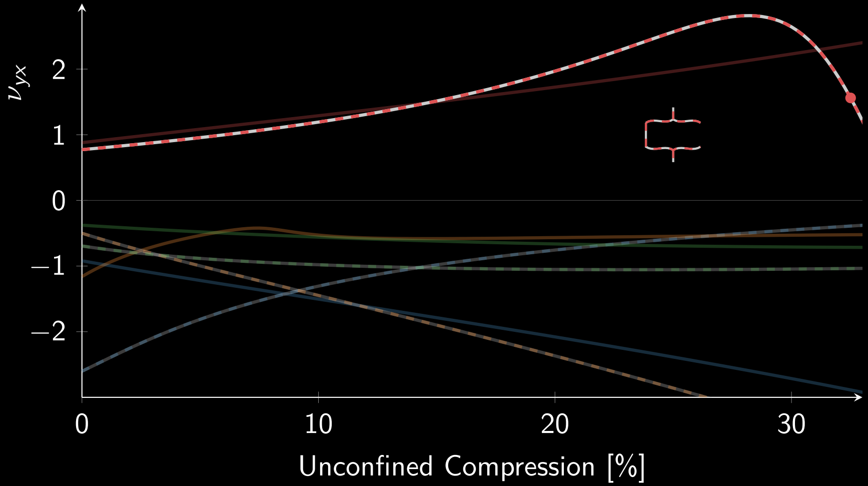
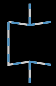
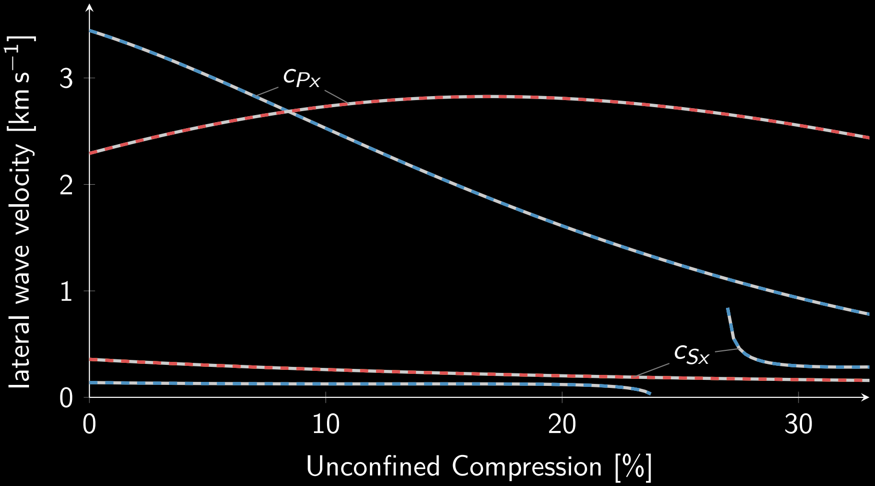




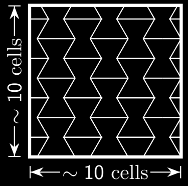
Pressure Waves Dominant over Shear Waves





Setup for Impact Simulation

- impact simulation conducted with patches of $\sim 10 \times 10$ unit cells



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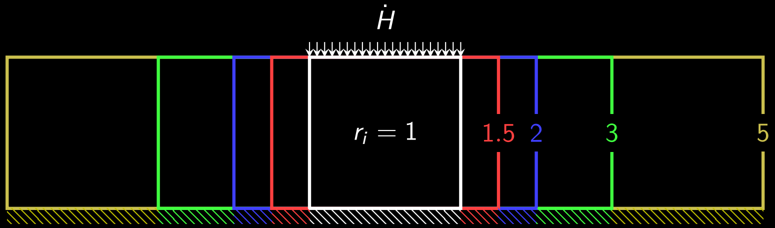
Setup for Impact Simulation

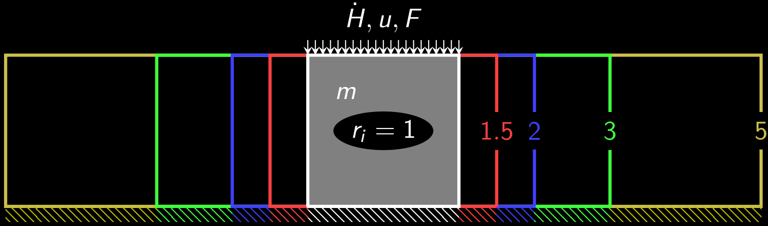
- impact simulation conducted with patches of $\sim 10 \times 10$ unit cells
- different compression speeds $\dot{H}$
- different localization ratios r_i



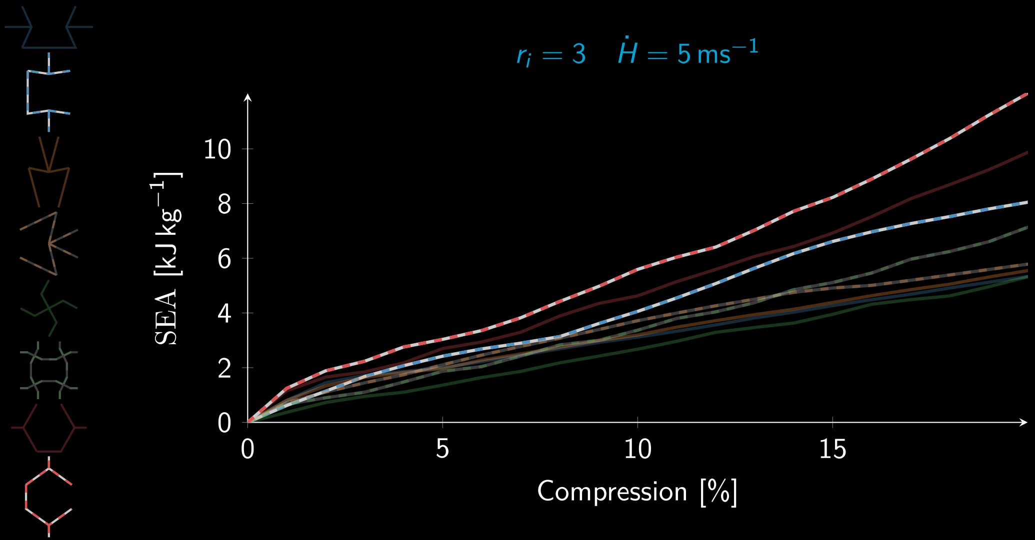
Setup for Impact Simulation

- impact simulation conducted with patches of $\sim 10 \times 10$ unit cells
- different compression speeds $\dot{H}$
- different localization ratios r_i
- evaluating the specific energy absorption (SEA)

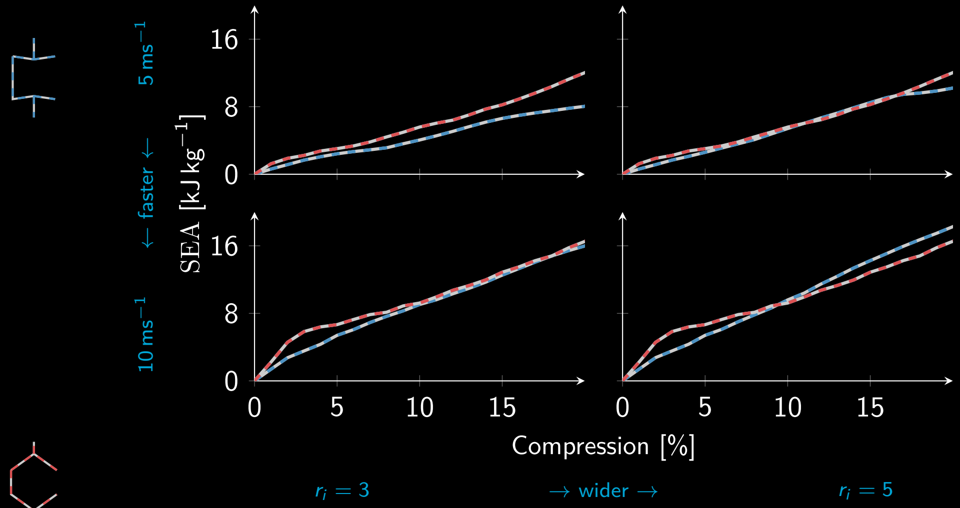
$$\mathrm{SEA} = \frac{1}{m} \int F \, \mathrm{d}u$$



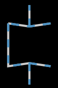
No Benefit of Auxeticity in Moderate Localization

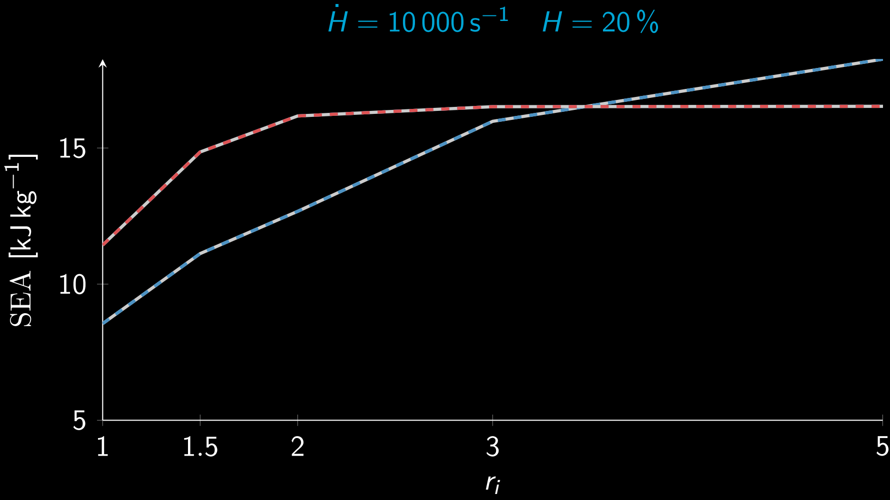


Benefit arises upon Severe Localization & Higher Strain Rates



Re-entrant Honeycomb performs better upon Severe Localization





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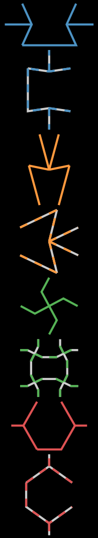
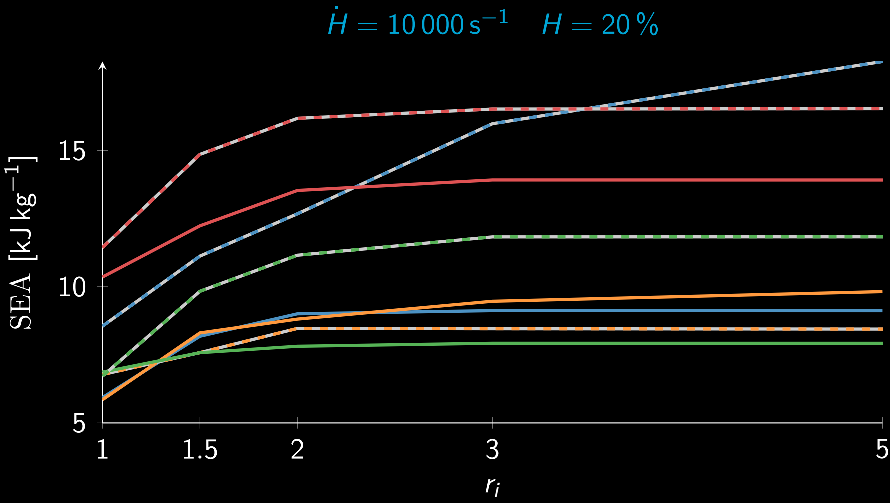
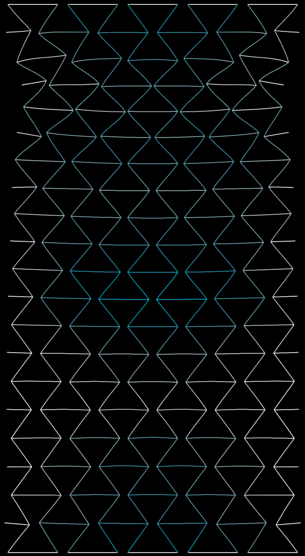



Concluding Remarks

- Lattice materials as such do not follow linear continuum assumptions
- Different architectures vary strongly in deformation behavior



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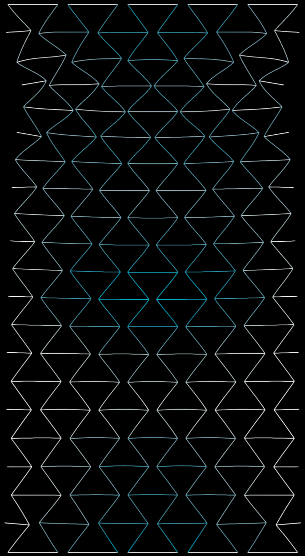
- Auxeticity is not the simple solution for impact protection



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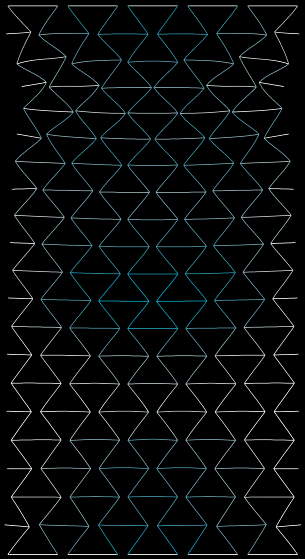
- Auxeticity is not the simple solution for impact protection
- The development of material properties is more important than the initial value



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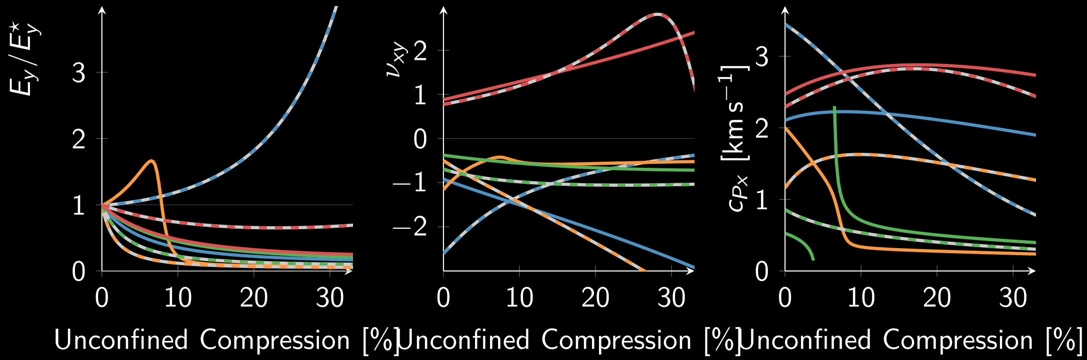
Thank you!

Uniaxial Compression



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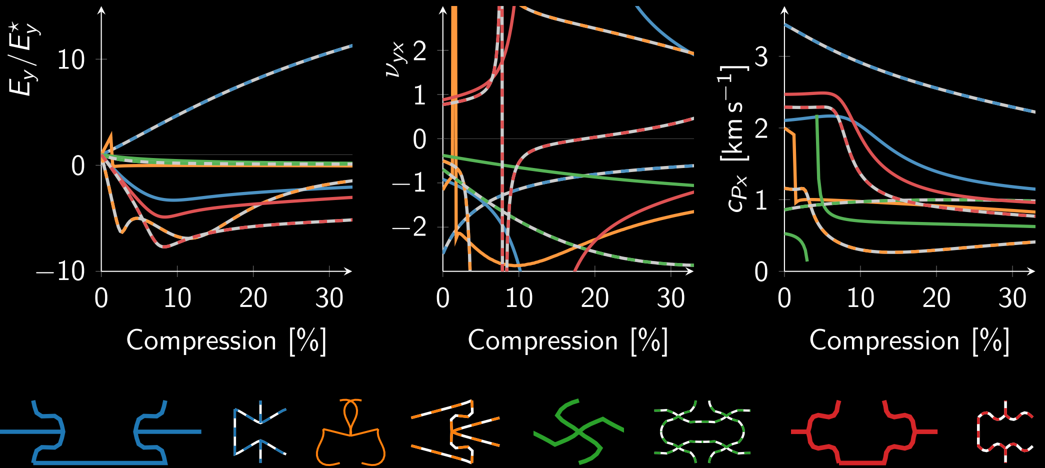
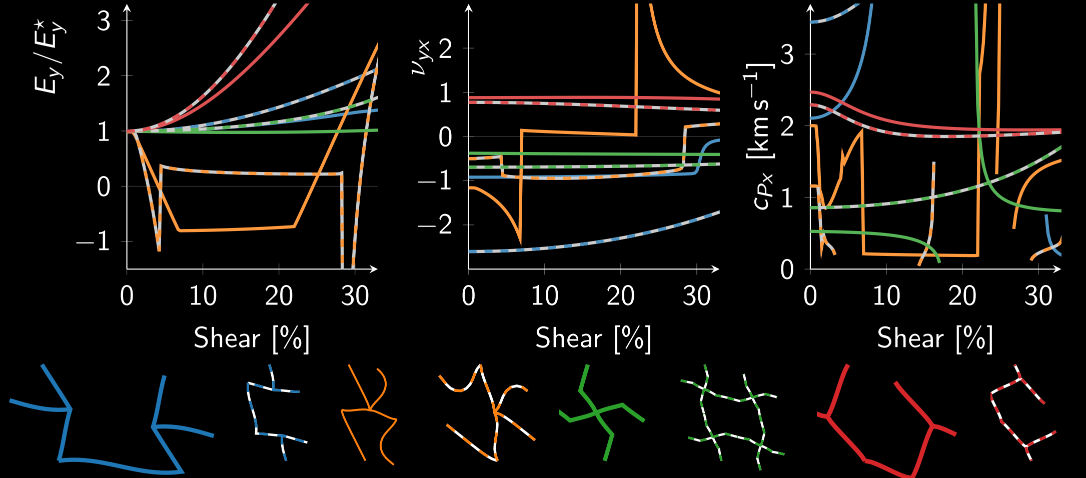
Gärtner et al, 17USNCCM, Auxetic Architectures

Planar Compression



Shear Deformation



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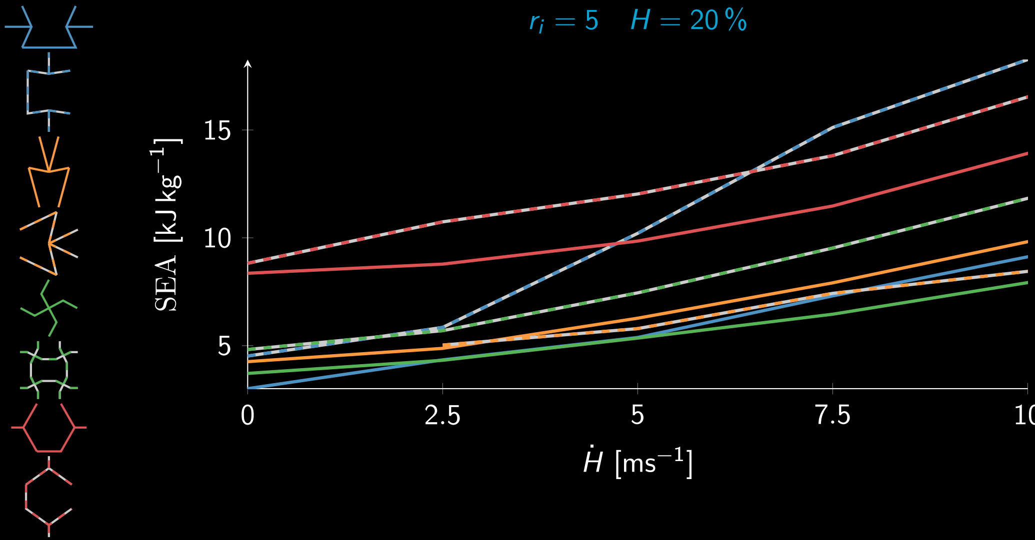
Speed Comparison



Modulus Computation

Constrained Modulus

$$\begin{bmatrix} \delta H_{11} & 0 \\ 0 & 0 \end{bmatrix} = \mathbb{S}^4 : \delta \mathbf{P}$$

$$\delta H_{11} = \frac{1}{M_x} \delta P_{11}$$

Young's Modulus / Poisson's Ratio

$$\begin{bmatrix} \delta H_{11} & 0 \\ 0 & \delta H_{22} \end{bmatrix} = \mathbb{S}^4 : \begin{bmatrix} \delta P_{11} & \delta P_{12} \\ \delta P_{21} & 0 \end{bmatrix}$$

$$\delta H_{11} = \frac{1}{E_x} \delta P_{11}$$

$$\delta H_{11} = -\nu_{xy} \delta H_{22}$$

References

[1] Teik-Cheng Lim. *Auxetic Materials and Structures*. Engineering Materials. Singapore: Springer Singapore, 2015.

[2] H. M. A. Kolken and A. A. Zadpoor. "Auxetic mechanical metamaterials". In: *RSC Adv.* 7 (9 2017), pp. 5111–5129.

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