Effects of Different Architectural Choices for Auxetic Metamaterials on Impact Mitigation

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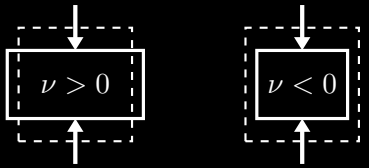
TNO TU Delft

July 22, 2024

Auxetic materials appear promising for impact mitigation

- 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
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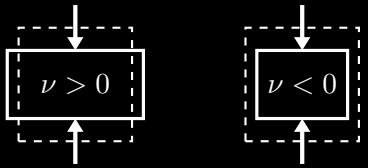

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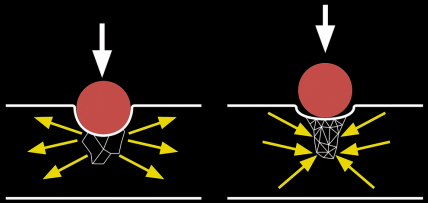

non-auxetic and auxetic material under impact (Kolken et al. 2017)

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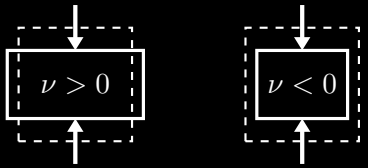
- auxetic materials are materials with a negative Poisson's ratio
  - materials that contract laterally when compressed
- promising capabilities for impact mitigation
  - natural densification at the impact location
  - better involvement of lateral material
- auxetic materials hardly found in nature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



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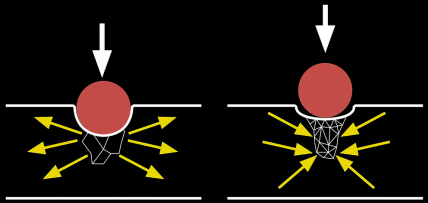

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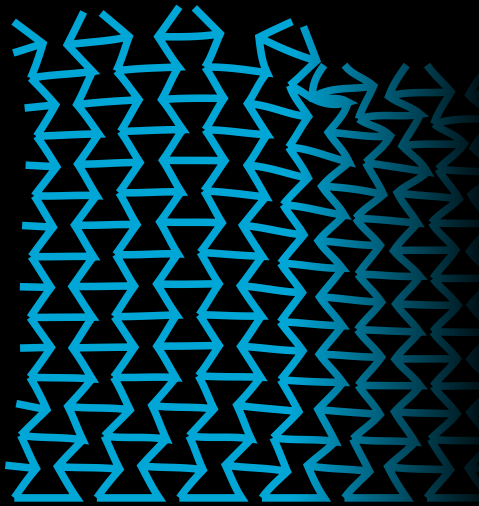
Modelling of lattices with rods to reduce runtime

- Architectures defined as assembly of rods



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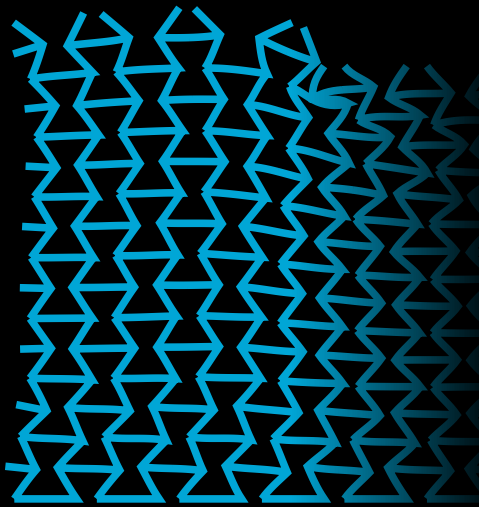

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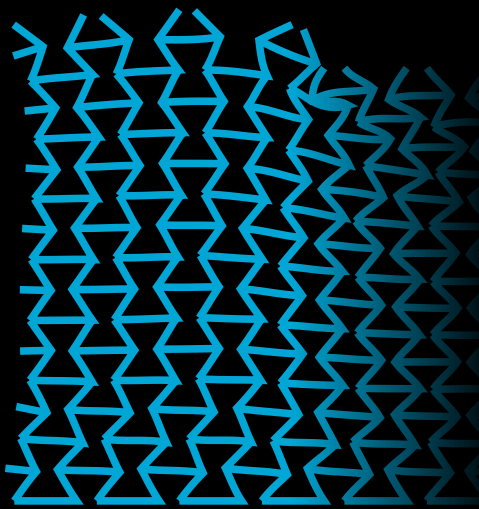

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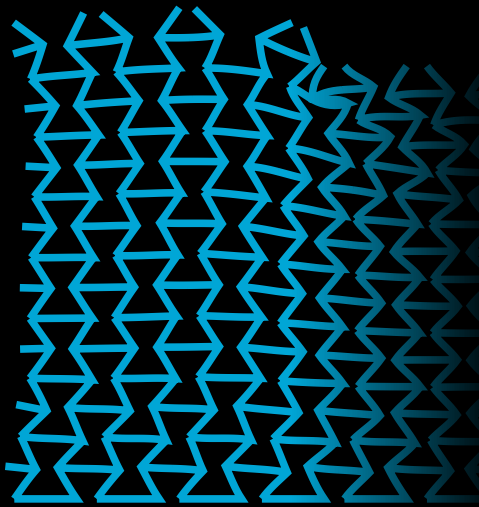
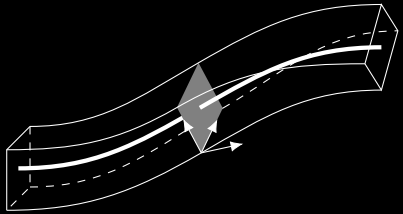
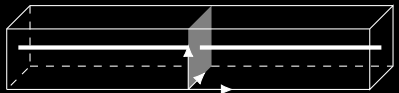
- Time marching with an explicit predictor-corrector scheme
- Time step adaptivity using a Milne-device



Fast computation by using beam-type elasto-plasticity

- Steel as material ($E = 210\,\text{GPa}$, $\nu = 0.265$)





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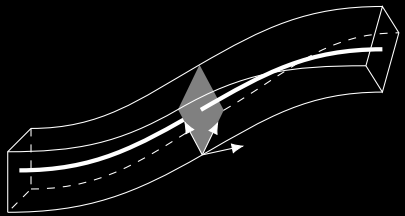

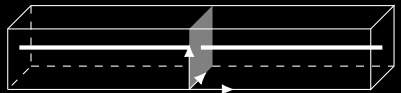

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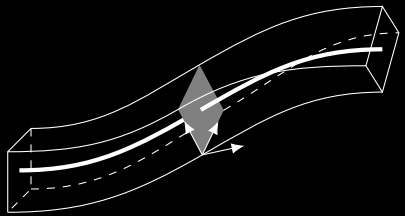

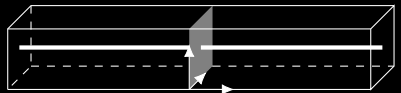

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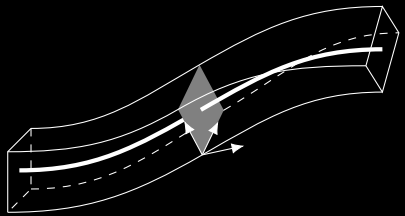
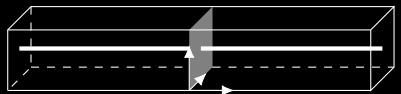
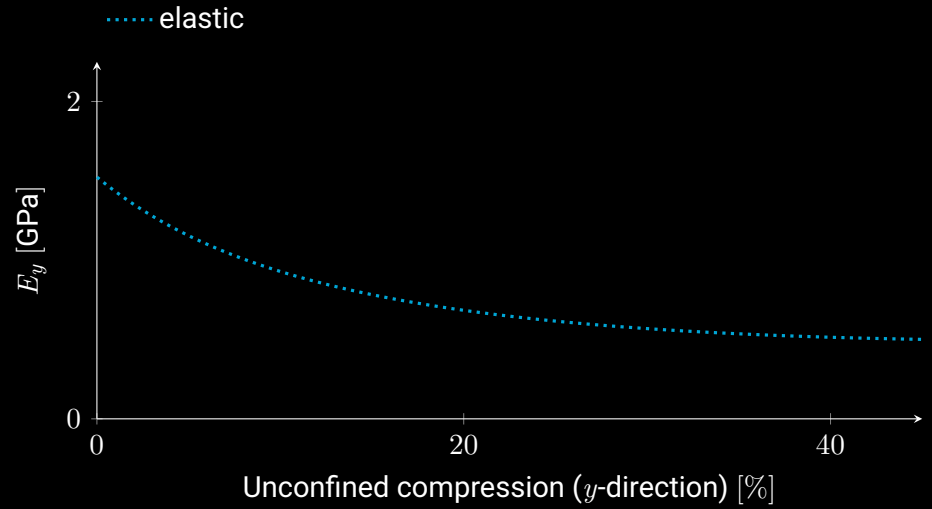
- Yield surface and hardening parameters taken from Herrnböck et al. (2021 & 2022)
- Geometric scaling of the hardening parameters introduced
- Size-objective formulation for the entire material model





Changes in geometry lead to changes in stiffness



Gärtner et al. *Mechanics of Materials* 191 (2024)

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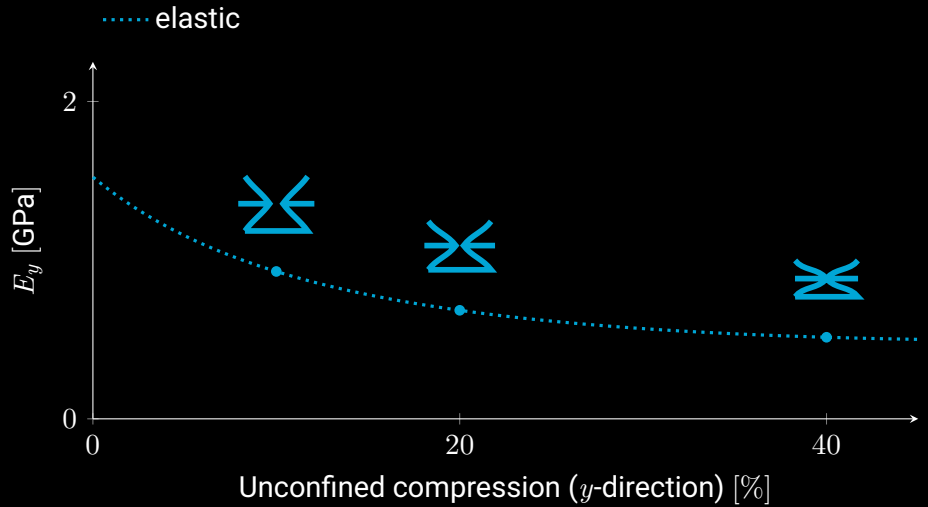

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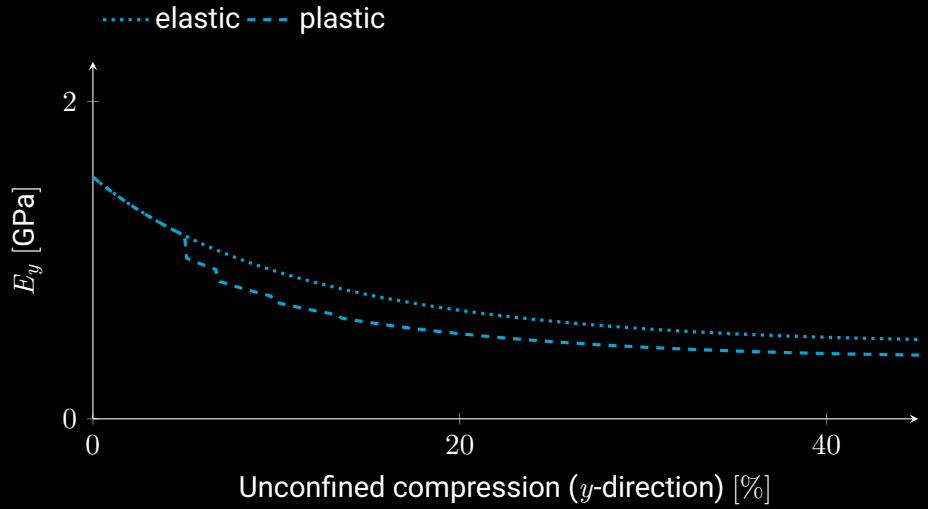
Plasticity & contact have some effect



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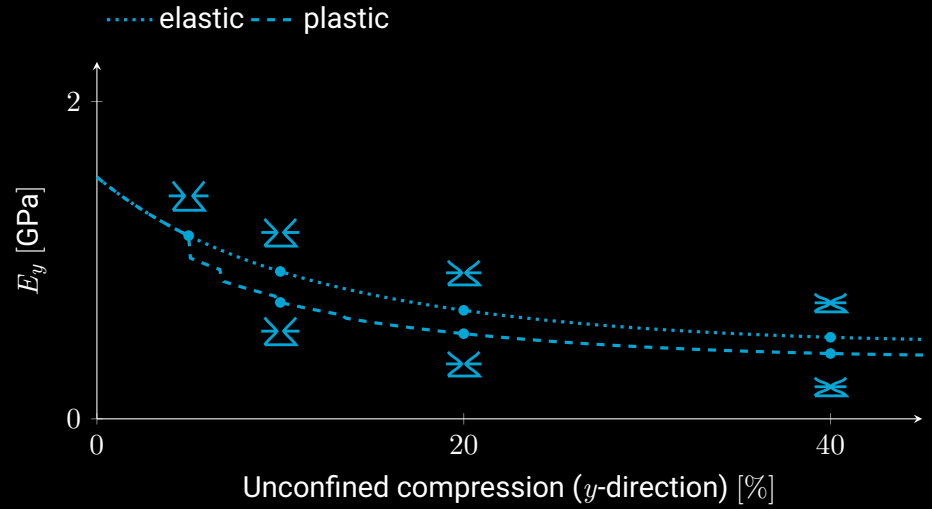

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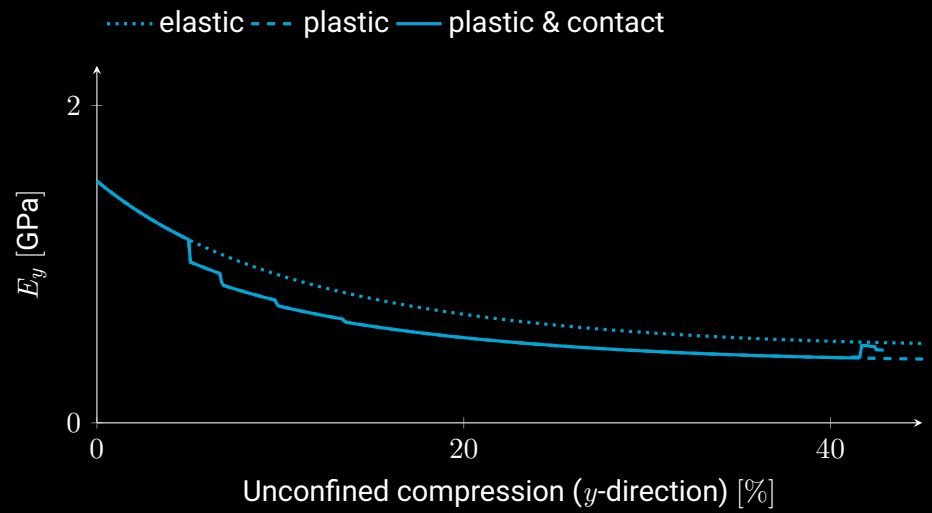

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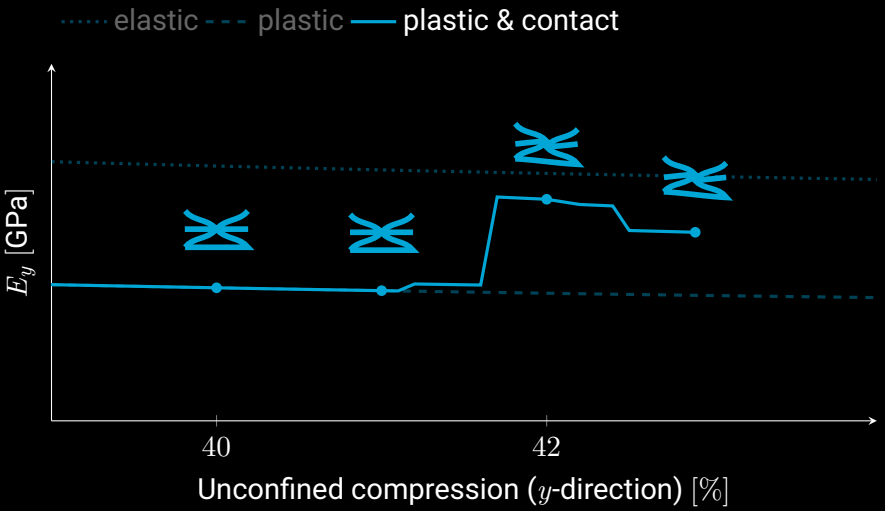
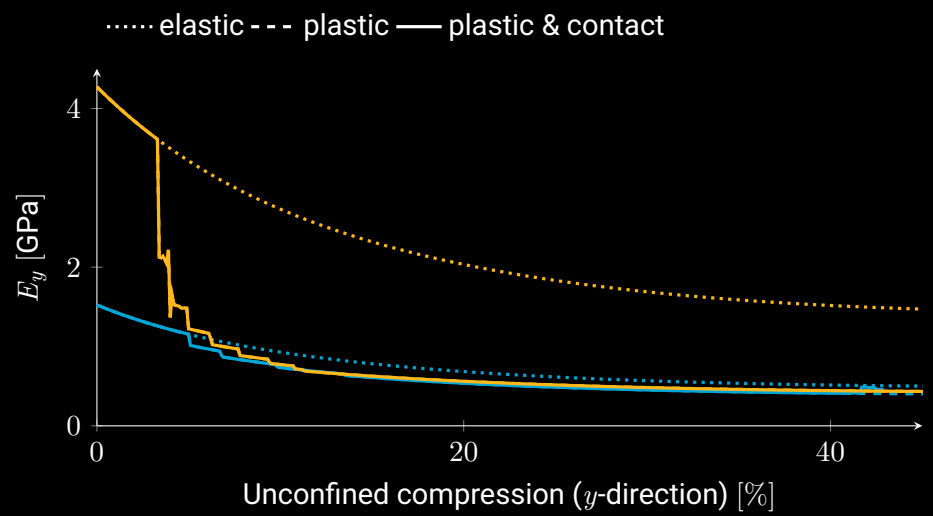
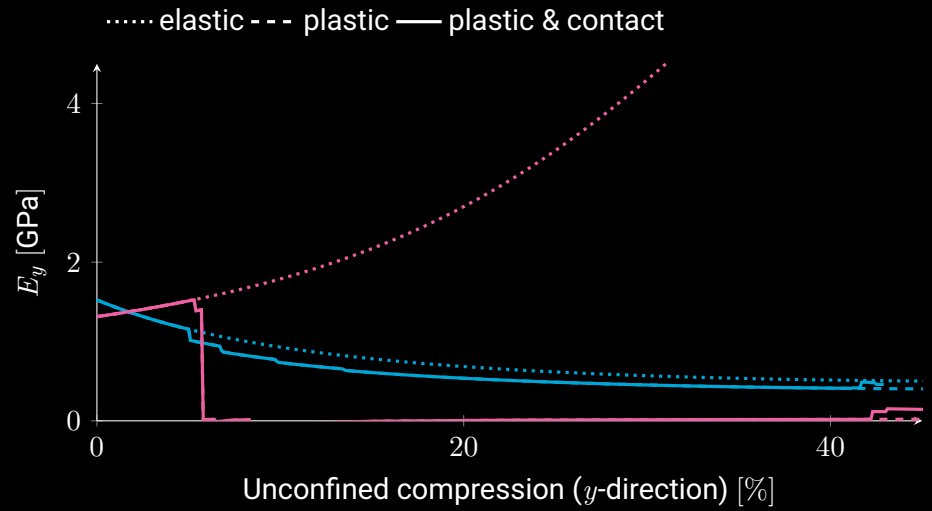


Rod thickness has little influence after onset of plasticity



Plasticity can induce buckling



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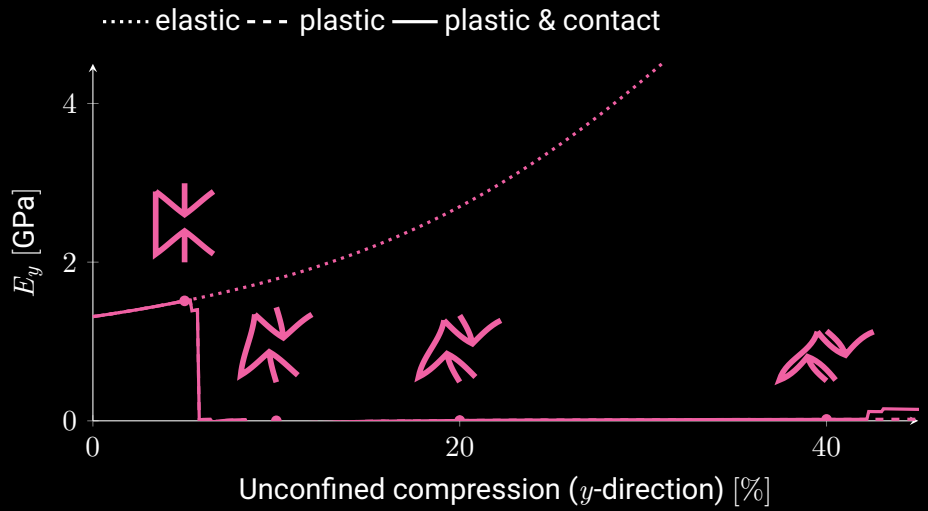

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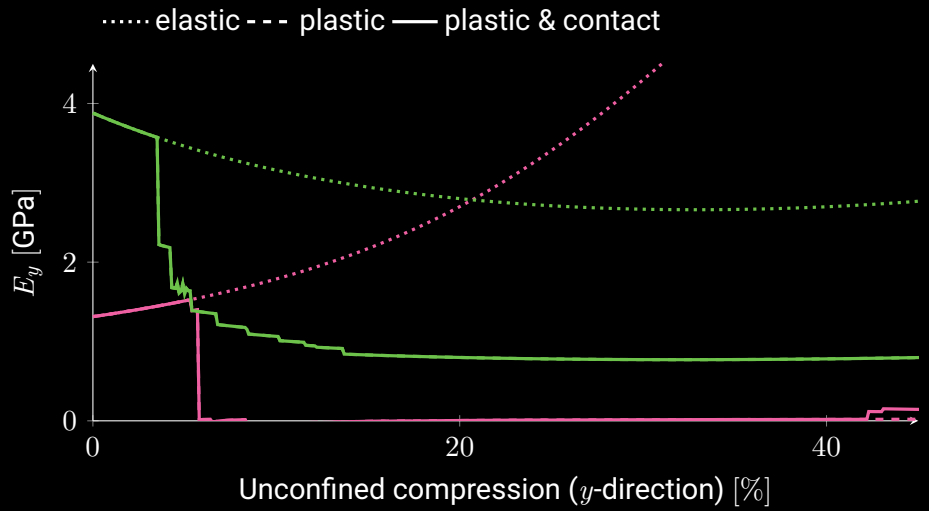
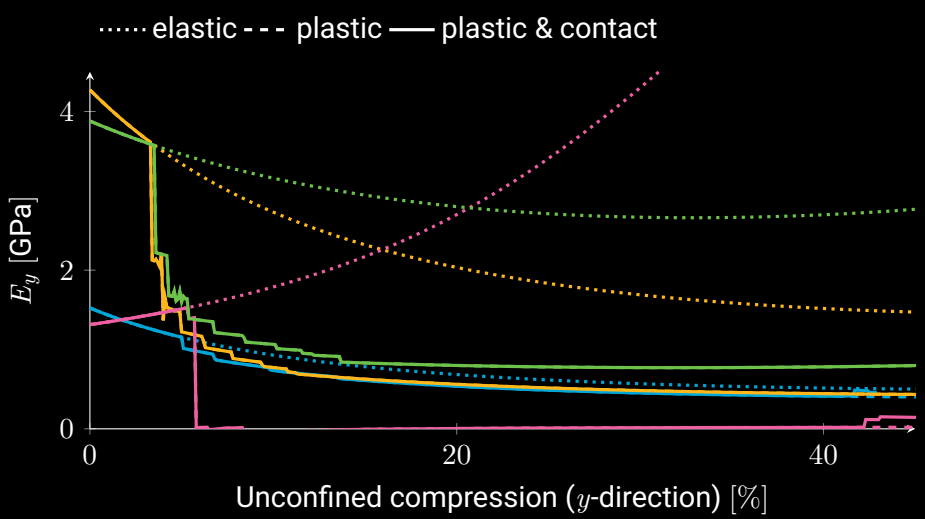
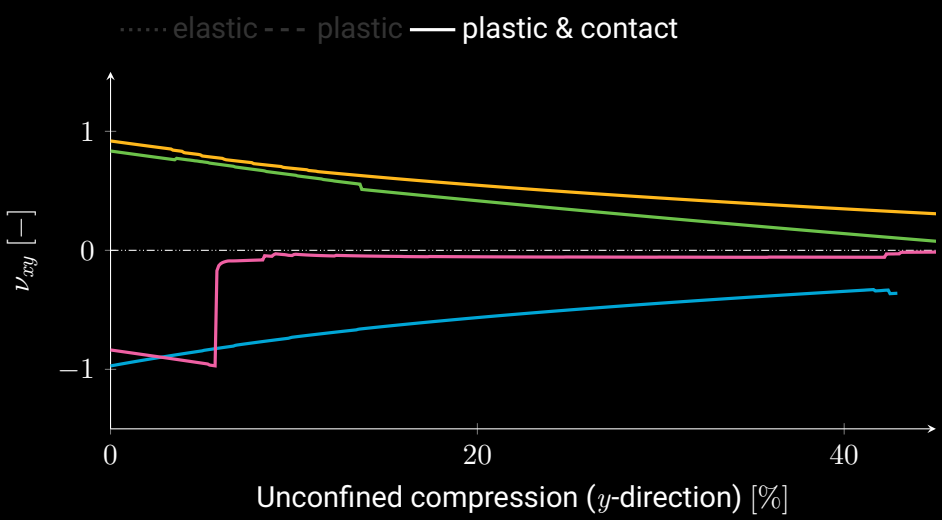


Development of stiffness differs for architectures

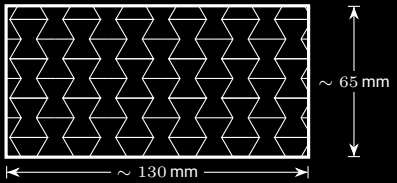


Poisson's ratio tends to 0 with compression



Impact compression tests

- Impact simulation conducted with patches of $\sim 130\,\text{mm} \times 65\,\text{mm}$



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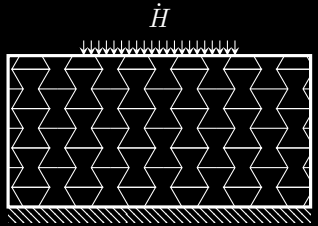

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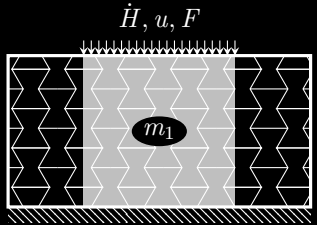
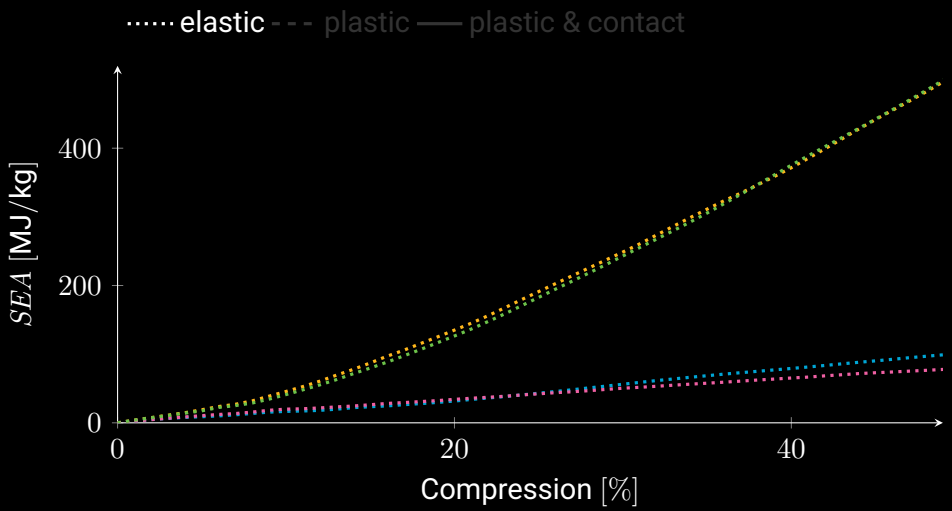
- Evaluating force over the middle patch
- Evaluating the specific energy absorption (SEA)

$$\text{SEA} = \frac{1}{m_1} \int F \, \mathrm{d}u$$



Auxetic honeycombs are less affected by plasticity



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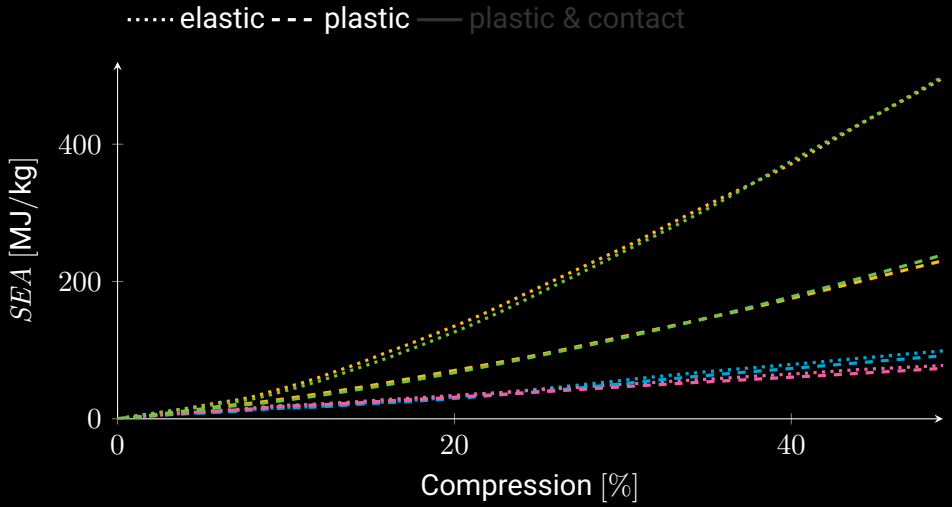

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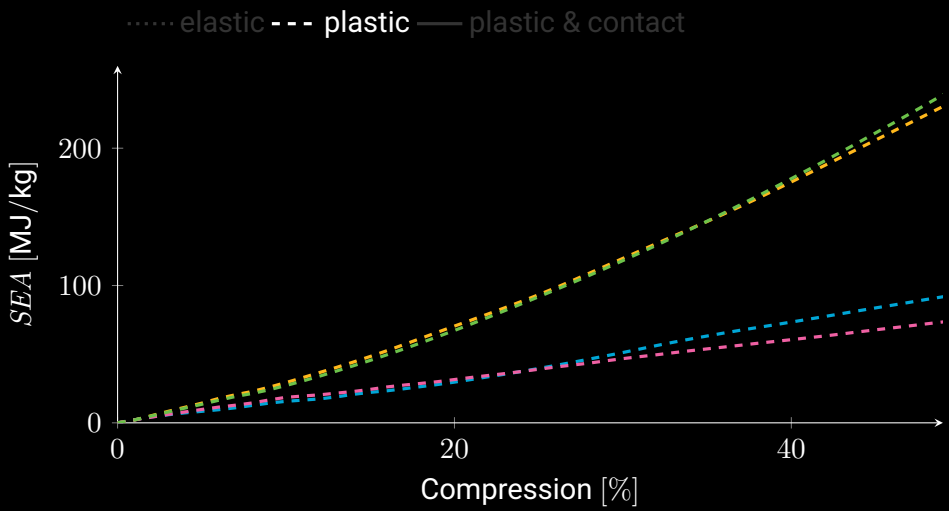

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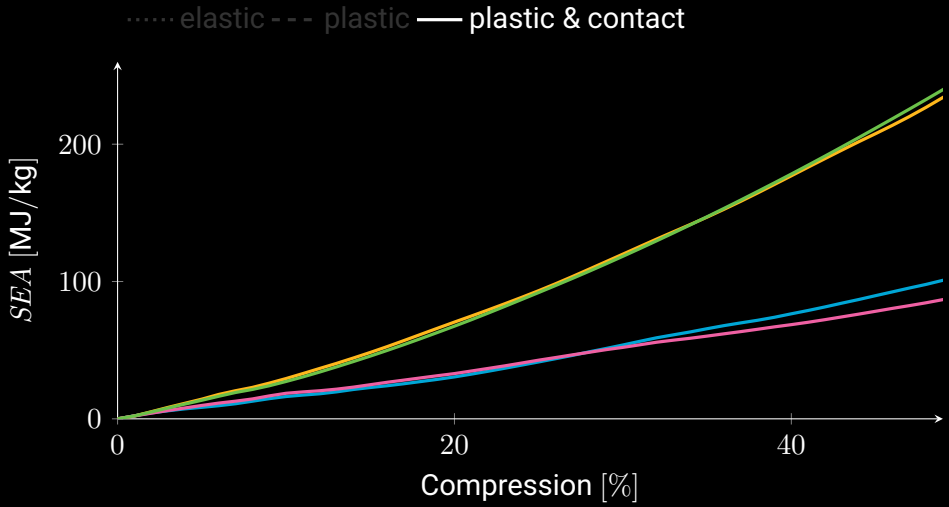

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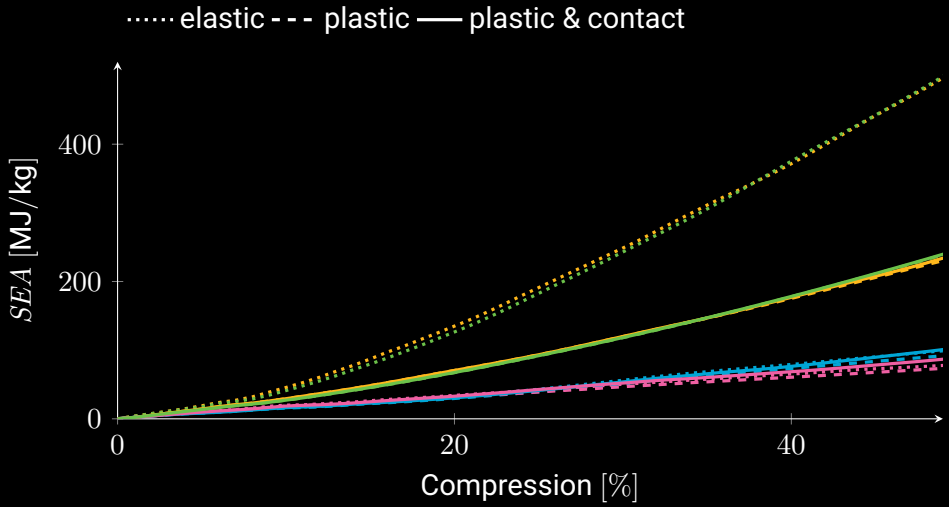

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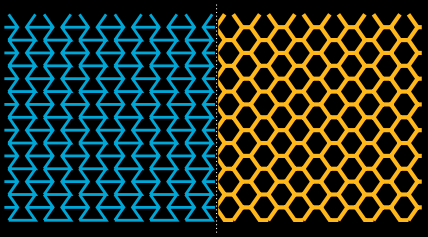

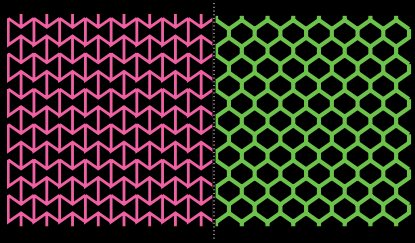

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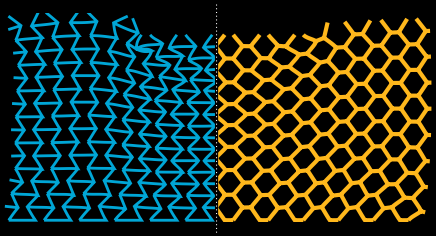

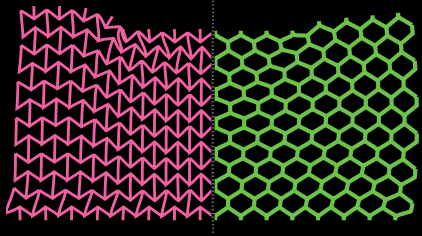

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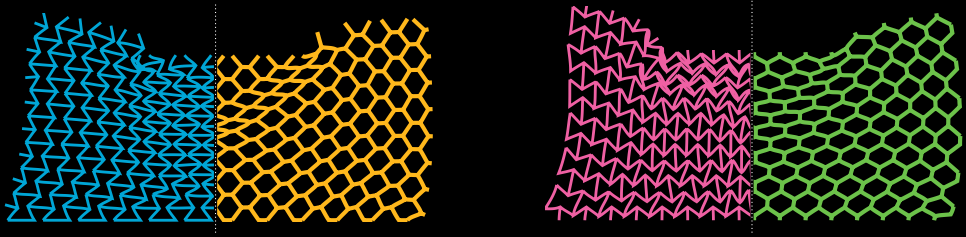

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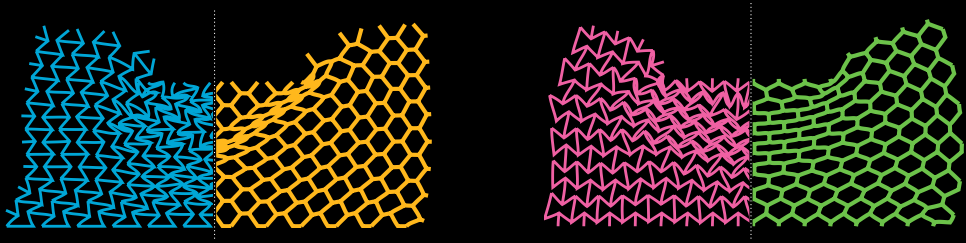
  $\Rightarrow$ Dependency on architecture under investigation



Thank you!

Comments?

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References

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

[2] H. M. A. Kolken et al. “Auxetic mechanical metamaterials”. In: *RSC Adv.* 7 (9 2017), pp. 5111–5129.

[3] Ludwig Herrnböck et al. “Geometrically exact elastoplastic rods: determination of yield surface in terms of stress resultants”. In: *Computational Mechanics* 67.3 (2021).

[4] Ludwig Herrnböck et al. “Two-scale off-and online approaches to geometrically exact elastoplastic rods”. In: *Computational Mechanics* 71.1 (2022).

[5] T. Gärtner et al. “Geometric effects on impact mitigation in architected auxetic metamaterials”. In: *Mechanics of Materials* 191 (2024), p. 104952.