Inverse Design of Architected Metamaterials for Targeted Responses under Different Strain Rates

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17th WCCM & 10th ECCOMAS

Munich, 23 July 2026

Architected Materials for Leightweight Design

- negative Poisson's ratio

Gärtner et al. 2024

Architected Materials for Leightweight Design

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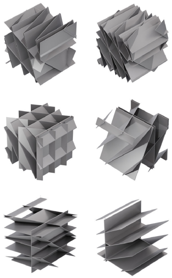

Meyer et al. 2024

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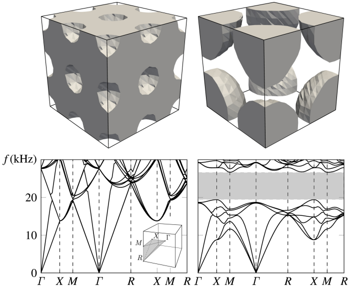
- acoustic bandgaps



van den Boom et al. 2023

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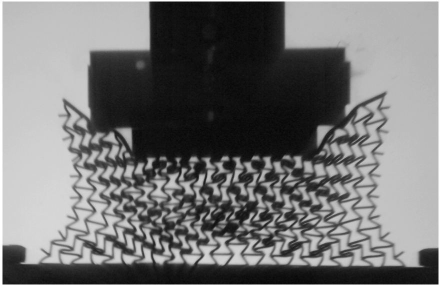

Gärtner et al. 2025a

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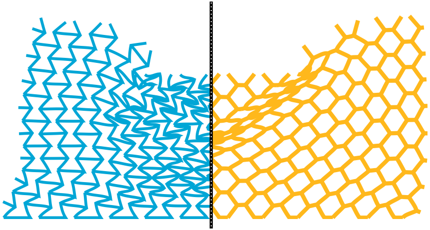
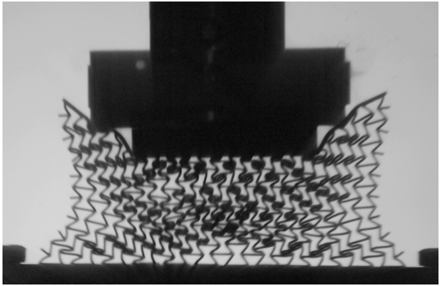
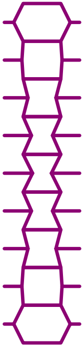




Gärtner et al. 2025a

Representation of the Material by Single Column

- Response of patch dominated by vertical differences (cf Gärtner et al. 2025b)



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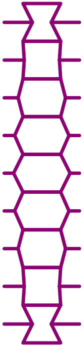

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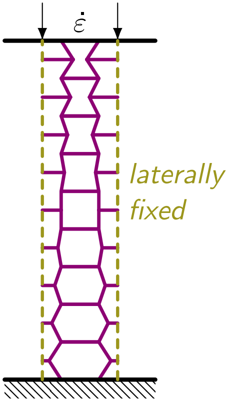

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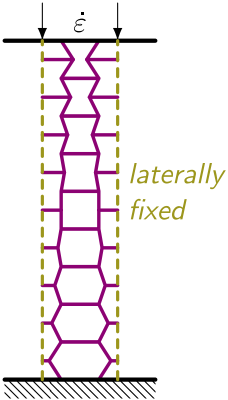

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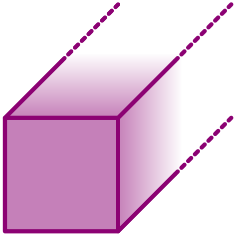
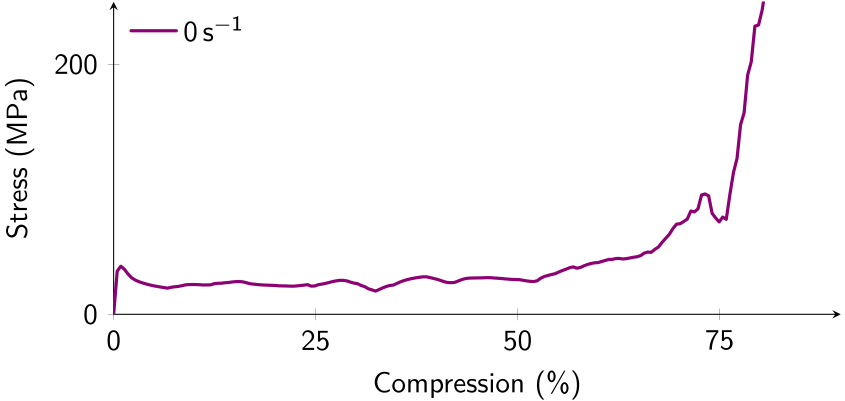
- Representation of the lattice by discrete beams
- Generic steel as material



$$E = 210\,\mathrm{GPa}$$
$$\nu = 0.3$$
$$\varrho = 7850\,\mathrm{kg\,m^{-3}}$$
$$\sigma_y = 450\,\mathrm{MPa}$$

Nonlinear Response under High Strain-rates



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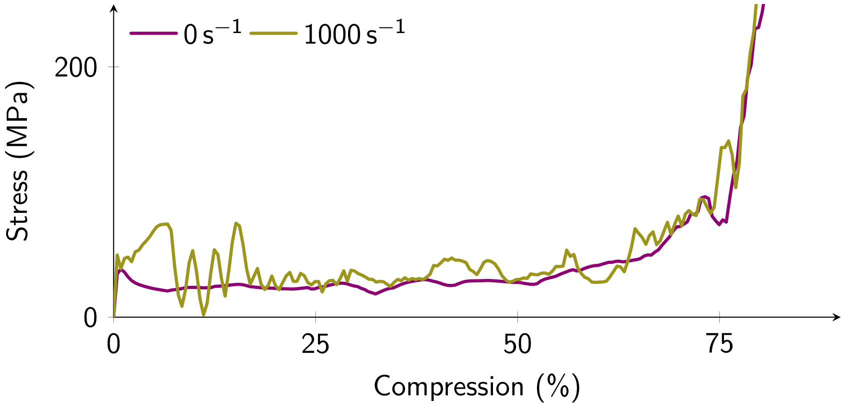

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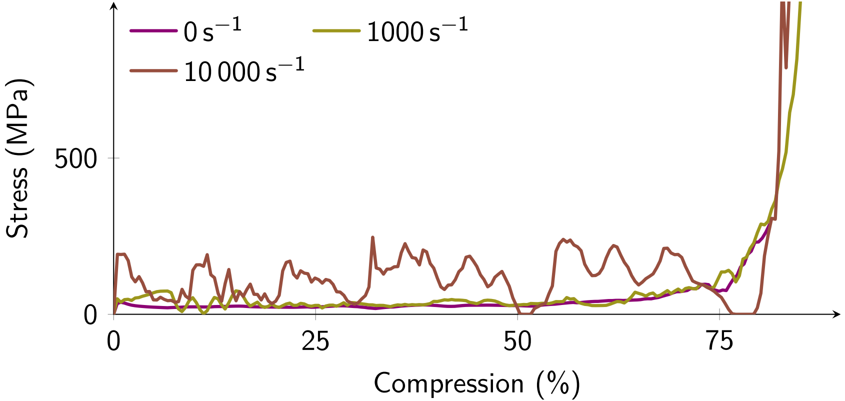
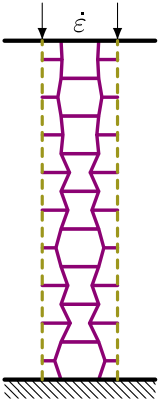
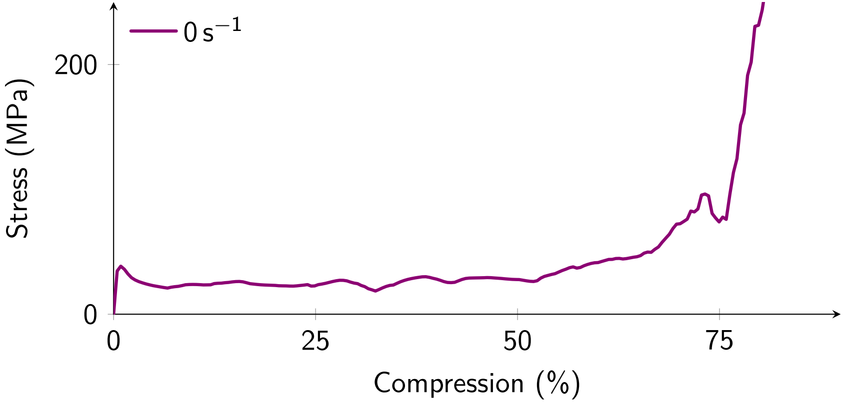


Description by Characteristic Parameters





Shinde et al. 2024; *ISO 13314* 2011; Zimmerman et al. 2026

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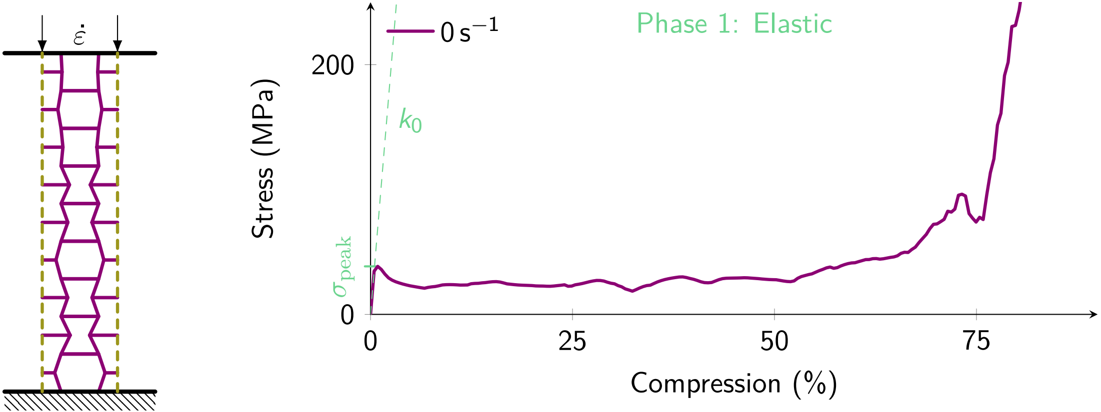

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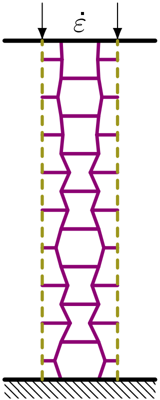

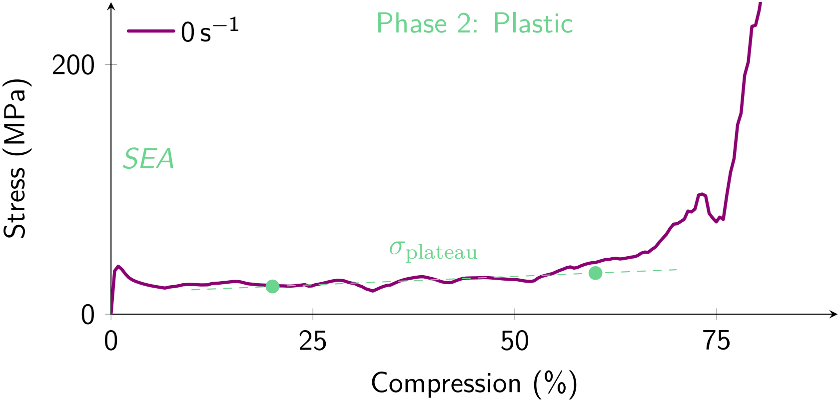

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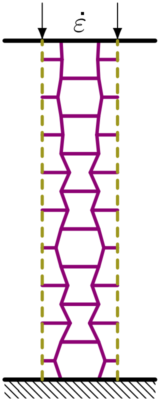

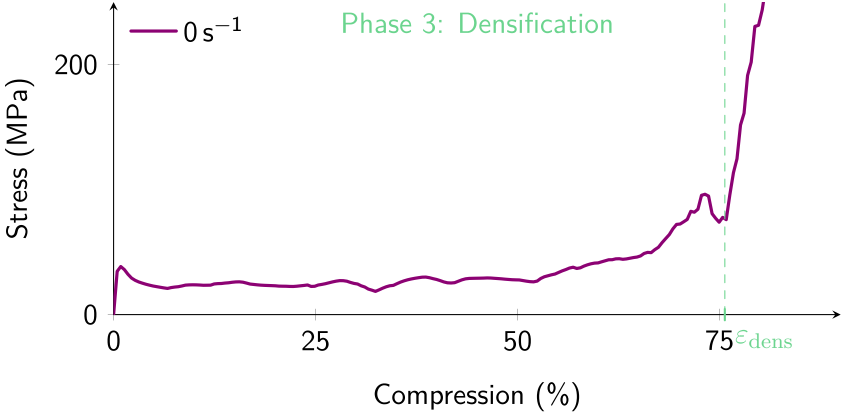

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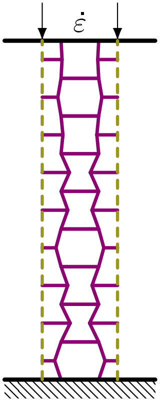

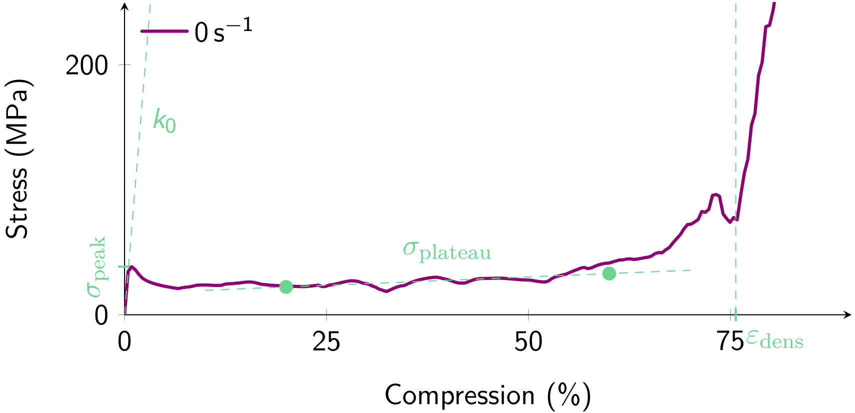

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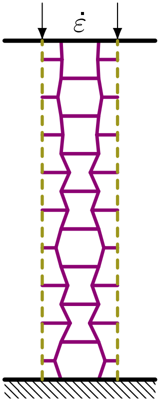

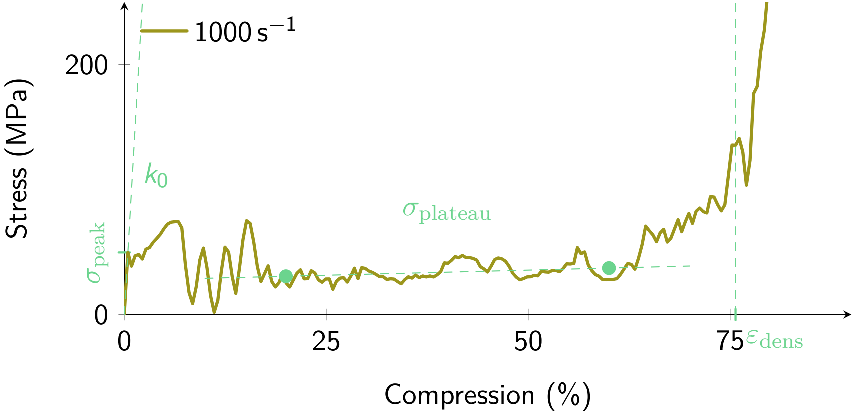

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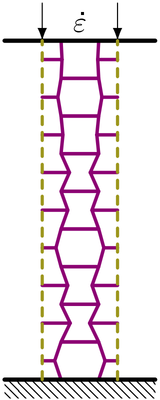

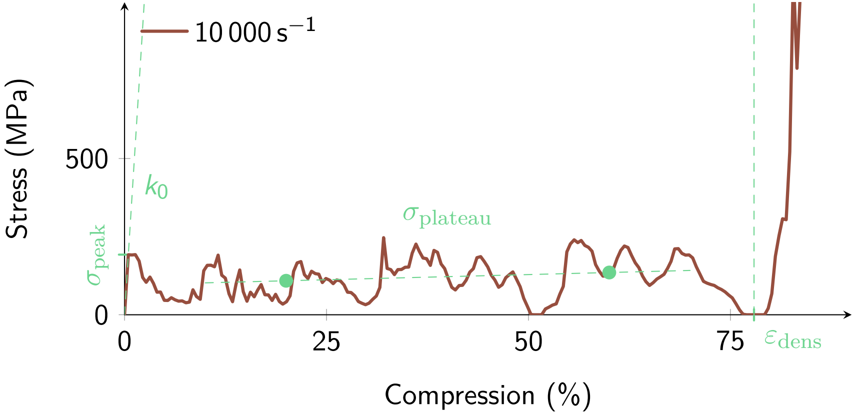

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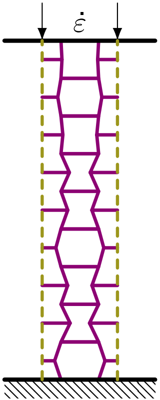
Design Variables to Characteristic Parameters



+ Vast design space for relatively simple configuration
– Direct numerical simulation prohibitively expensive

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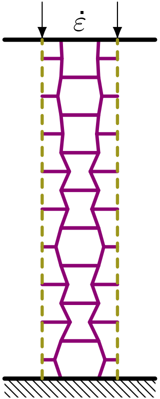

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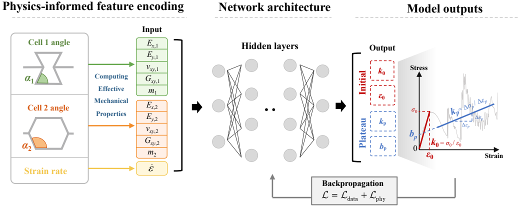
  Surrogate mapping for design variables to characteristic parameters



(Wang, Gärtner, and Aldakheel *under review*)

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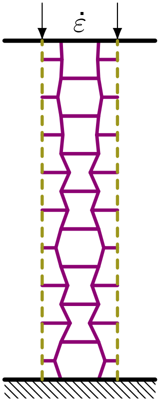

- \+ Vast design space for relatively simple configuration
- – Direct numerical simulation prohibitively expensive
- Solution:
  Surrogate mapping for design variables to characteristic parameters
  (Wang, Gärtner, and Aldakheel *under review*)
- First model is successful but handles only two unit cells
- Current trials with property-convolution along the unit cells
- Folding collection of effective properties of single unit cells to distribution over the entire column

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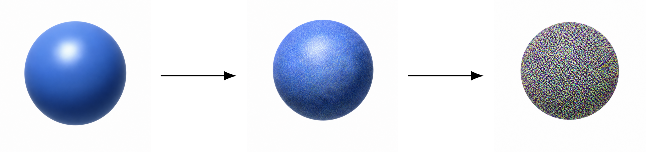
1. Adding Noise:



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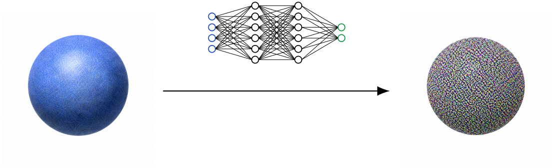
2. Predicting Noise:



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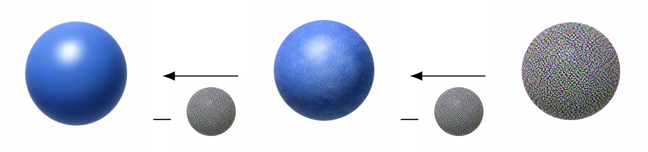
3. Removing Noise:



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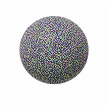

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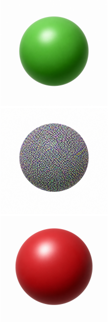
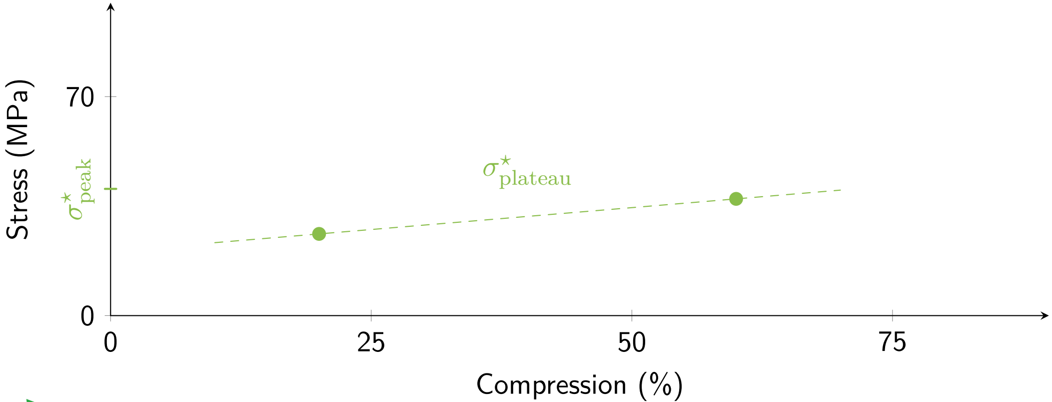
- Conditional Diffusion to design lattices with targeted properties
- Design variables of unit cells as “image”
- Characteristic parameters & strain rate as conditioning



Inverse Design Fits the Given Target

Target: mean values of the data distribution (at $\dot{\varepsilon} = 0\,\mathrm{s}^{-1}$)



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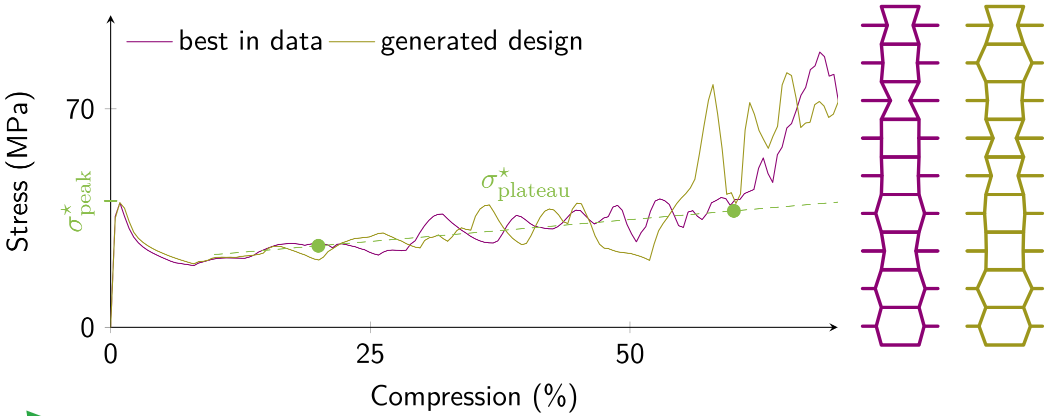
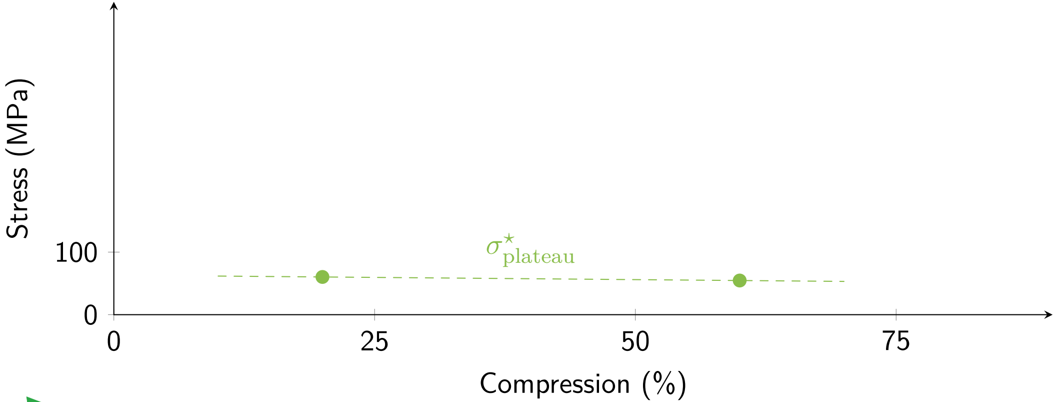


Inverse Design For Better Characteristics

Target: low σ_{plateau}; high SEA (at $\dot{\varepsilon} = 10\,000\,\text{s}^{-1}$)



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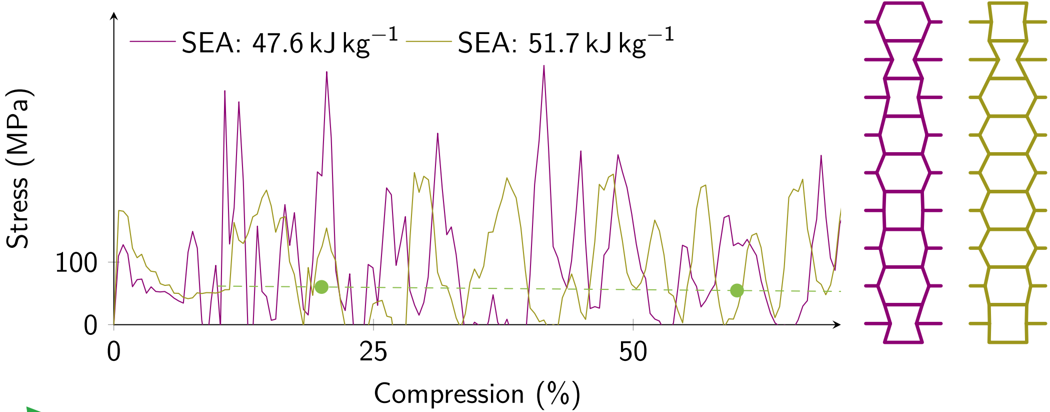
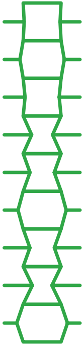
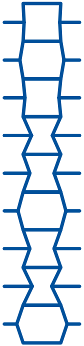


Summary & Next Steps



- Highly nonlinear behavior of cellular materials under compression
- Simple description by phases allows further handling



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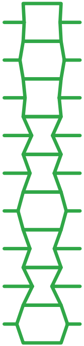

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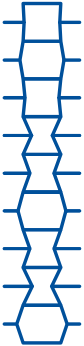
- Inverse model able to generate designs with new properties



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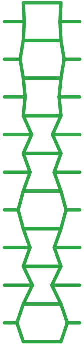

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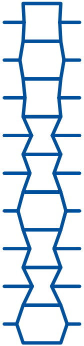
- Possibility of different cell sizes in convolution



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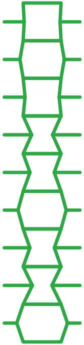

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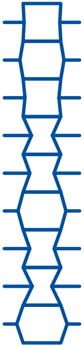
- Ensure stability of forward surrogate extension
- Possibility of different cell sizes in convolution
- Extend the inverse model for different boundary conditions
- Extend the framework to two and three dimensions



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17^{th} WCCM & 10^{th} ECCOMAS

Munich, 23 July 2026

Thank you!

Questions?

http://go.lu-h.de/data-exp

References I

[1] T. Gärtner et al. “Geometric Effects on Impact Mitigation in Architected Auxetic Metamaterials”. In: *Mechanics of Materials* 191, 104952 (May 2024), p. 104952.

[2] Paul P. Meyer, Thomas Tancogne-Dejean, and Dirk Mohr. “Non-Symmetric Plate-Lattices: Recurrent Neural Network-Based Design of Optimal Metamaterials”. In: *Acta Materialia* 278 (2024).

[3] Sanne J. van den Boom et al. “A Level Set-Based Interface-Enriched Topology Optimization for the Design of Phononic Crystals with Smooth Boundaries”. In: *Computer Methods in Applied Mechanics and Engineering* 408 (Apr. 1, 2023), p. 115888.

References II

[4] T. Gärtner et al. "(In)Efficacy of Architected Auxetic Materials for Impact Mitigation". In: *International Journal of Impact Engineering* 206, 105402 (Dec. 2025).

[5] T. Gärtner et al. "Force Transmission and Dissipation in Dynamic Compression of Architected Metamaterials". In: *Materials Today Advances* 28, 100656 (Dec. 2025).

[6] Mandar Shinde et al. "A Critical Assessment of the Onset Strain of Densification in the Evaluation of Energy Absorption for Additively Manufactured Cellular Materials". In: *Manufacturing Letters*. 52nd SME North American Manufacturing Research Conference (NAMRC 52) 41 (Oct. 2024), pp. 708–719.

References III

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[9] Haoning Wang, T. Gärtner, and F. Aldakheel. "Geometry-informed surrogate modeling for architected metamaterial design under high-rate loading". unter review. 2026.