Multi-objective shape optimization of architected materials

Federico Bosi*†[1,2], Farooq I Azam[1], and Pj Tan[1]

[1]University College, London – United Kingdom
[2]University of Applied Sciences and Arts of Southern Switzerland – Switzerland

Abstract

Architected lattices are a type of metamaterial with distinctive mechanical properties that conventional materials cannot achieve. These properties arise from a carefully designed geometry and/or the combination of different materials. Recent advancements in lattice materials have been supported by the development of small-scale additive manufacturing techniques. These methods allow for precise manipulation of geometric features at the micro and nanoscale, offering greater control over macroscopic properties and enabling the creation of lattices with exceptional mechanical performance. Architected materials, known for their enhanced mechanical and functional properties, are widely used in high-strength lightweight materials, energy storage, and other fields. While traditional periodic lattices usually consist of unit cells with struts (or walls) of uniform cross-section, strategically redistributing material along the length of the struts shows promise in improving the lattice's mechanical behavior, especially in bending-dominated architectures (1).

In this study, we present analytical and machine-learning-assisted approaches for the parametric shape optimization of two- and three-dimensional lattices, aiming to improve stiffness while increasing the plastic and buckling strengths by rationally redistributing the material of regular lattices along the cell walls. First, an analytical multi-objective shape optimization is shown for a two-dimensional bending-dominated hexagonal honeycomb and compared to a finite element-based Bayesian optimization that allows exploration of a wider design space (2). This numerical method is then extended to plate and shell lattices, where a Genetic Algorithm is used to optimize the shape of representative three-dimensional unit cells, highlighting the influence of the bending- and stretching-dominated response on the effectiveness of the material redistribution strategy. Experiments conducted on additively manufactured polymeric and metallic microlattices validate the theoretical predictions and showcase the improvement in mechanical properties achievable through the redistribution of solid material (3).

References

(1) A. Simone, L. Gibson: Effects of solid distribution on the stiffness and strength of metallic foams. Acta Materialia 46:2139–2150, 1998.

(2) I. Kuszczak, F.I. Azam, M.A. Bessa, P.J. Tan, F. Bosi, Bayesian optimization of hexagonal honeycomb metamaterial, Extreme Mechanics Letters, 2023.

---

*Speaker

†Corresponding author: f.bosi@ucl.ac.uk

(3) F.I. Azam, P.J. Tan, F. Bosi, Multi-objective parametric optimization of architected hexagonal honeycomb with stepped struts, Materials and Design, 2025.