Title: Architectured materials design with machine learning

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Background: Material design based on micro-architectures delivers a promising tool to replace the traditionally homogeneous materials with tailored heterogeneity, and it finds many applications in industry for weight-saving, impact energy absorption, load carrying, vibroacoustic control, and heat exchanging. Thanks to the progress of additive manufacturing along with the advances in computational engineering, the mechanical properties of the so-called architectured materials (Fig. 1) is possible to be captured. The inverse problem of identifying the tailored topology which can deliver a desired property, however, is still a challenge. Recent advances in machine learning and deep learning seems to provide a tool for overcoming this challenge [1,2].

Architectured materials design is a part of ongoing research collaboration between Hitachi Energy and UU Division of Applied Mechanics.


(a)

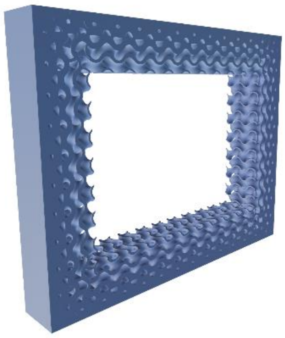
(b)

Fig. 1: (a) TPMS (Triply periodic minimal surface) unit-cells [3,4] (b) Structural design with TPMS

Goal: In this project, computational homogenization [5] and machine learning [2] is employed to address the inverse problem of identifying the TPMS unit cell for a given stiffness (elasticity tensor). The given elasticity tensor is confined to the anisotropy which is feasible with the library of TPMS unit cells [4]. The supervision team will provide detail support on the subject of solid mechanics (and in particular anisotropic elasticity) and finite element method (FEM).

To achieve the project goal, following work packages are envisaged:

Work packages:
- Literature review on
  - Architectured materials (in particular TPMS)
  - Machine learning for material design
- CAD construction of TPMS unit cells (suggested approach with available Matlab code [6])
- Computational homogenization of elastic TPMS unit cells (the code in Freefem++ will be provided with instruction)
- Design of unit-cell with machine learning for a given elasticity
- Tentative: Use of HPC for optimization of TPMS

Suggested computing platform for homogenization with FEM: Freefem [7] (code will be provided)
Suggested platform for CAD generation: MSLattice [6] (an available Matlab code)
Suggested computing platform for Machine learning: to be identified.

References:

[1] Kollmannsberger et al., 2021, Deep Learning in Computational Mechanics: An Introductory Course. Springer.
[2] Kumar et al., 2020, Inverse-designed spinodoid metamaterials. npj Computational Materials.
[3] Hsieh, 2020, Mechanics of Minimal Surface-based Architected Materials. Doctoral dissertation, University of California Irvine.
[4] Wohlgemuth et al., 2001, Triply Periodic Bicontinuous Cubic Microdomain Morphologies by Symmetries. Macromolecules: 34, 6083-6089. (https://www.msri.org/publications/sgp/jim/papers/morphbysymmetry/table/index.html)
[5] Molavitabrizi, Mousavi, 2020. Elasticity of Anisotropic Low-Density Lattice Materials. J. Eng. Mater. Technol. 143 (021007).
[6] Al-Ketan et al., 2020, MSLattice: A free software for generating uniform and graded lattices based on triply periodic minimal surfaces. Mat Design Process Comm e205.
[7] Hecht F. 2012, New development in FreeFem++. Journal of numerical mathematics, 20(3-4), 251-266.