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Materials by Design Across Scales

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Hitachi Energy

Västerbergslagens Ingeniörsklubb (VBIK)
Jan 21st, 2026

Department of Materials Science and Engineering

- Nanotechnology and Functional Materials
- Applied Materials Science
- Biomedical Engineering
- Microsystems Technology
- Solar Cell Technology
- Solid State Physics
- **Applied Mechanics**



Uppsala University, since 1477

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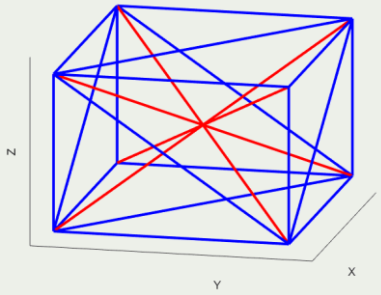
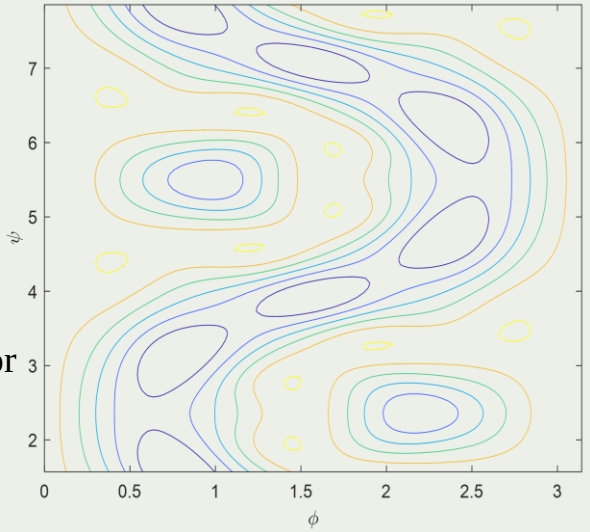
Division of Applied Mechanics (Tillämpad mekanik)
mahmoud.mousavi@angstrom.uu.se

Architectured materials for tailored elasticity

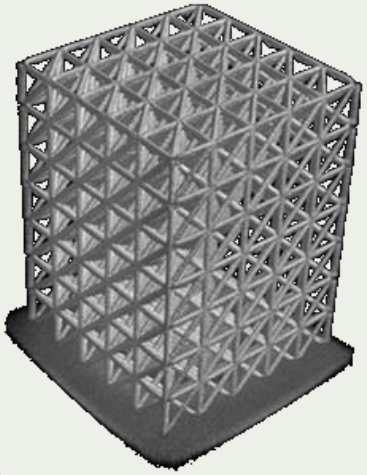
Coupling normal and shear

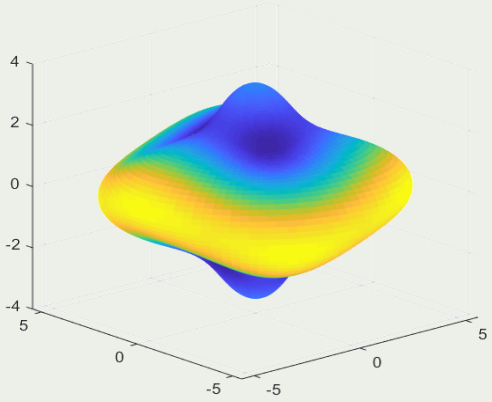


Irregular tetrahedron



Distance function for anisotropy identification





Trigonal symmetry

$$\mathbb{C} = \begin{bmatrix} 8.59 & 2.86 & 1.40 & 0 & -0.29 & 0 \\ 2.86 & 8.59 & 1.40 & 0 & 0.29 & 0 \\ 1.40 & 1.40 & 5.06 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.40 & 0 & 0.29 \\ -0.29 & 0.29 & 0 & 0 & 1.40 & 0 \\ 0 & 0 & 0 & 0.29 & 0 & 2.86 \end{bmatrix}$$

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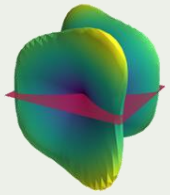
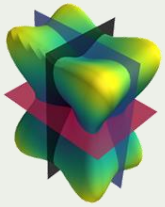
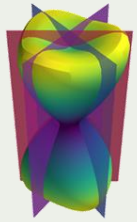
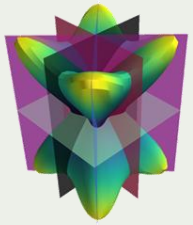
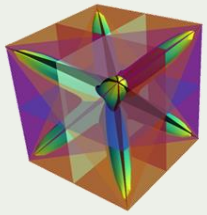
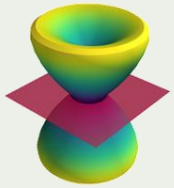
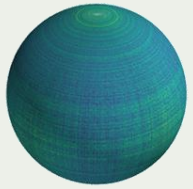
- Molavitabrizi D., Suzuki A., Kobashi M., Mousavi S.M., 2023, Mechanical coupling and tuned anisotropic elasticity: Numerical and experimental material design for shear-normal and shear-shear interactions. Materials and Design 230:111950.

Architectured materials for tailored elasticity

No symmetry	One plane	Three planes	Five planes	Nine planes	Inf+1 planes	Inf planes
Triclinic	 Monoclinic	 Orthotropic  Trigonal	 Tetragonal	 Cubic	 Transverse isoptropic	 Isotropic

- M. François et al., 1998, Determination of the symmetries of an experimentally determined stiffness tensor: Application to acoustic measurements, IJSS 35: 4091-4106

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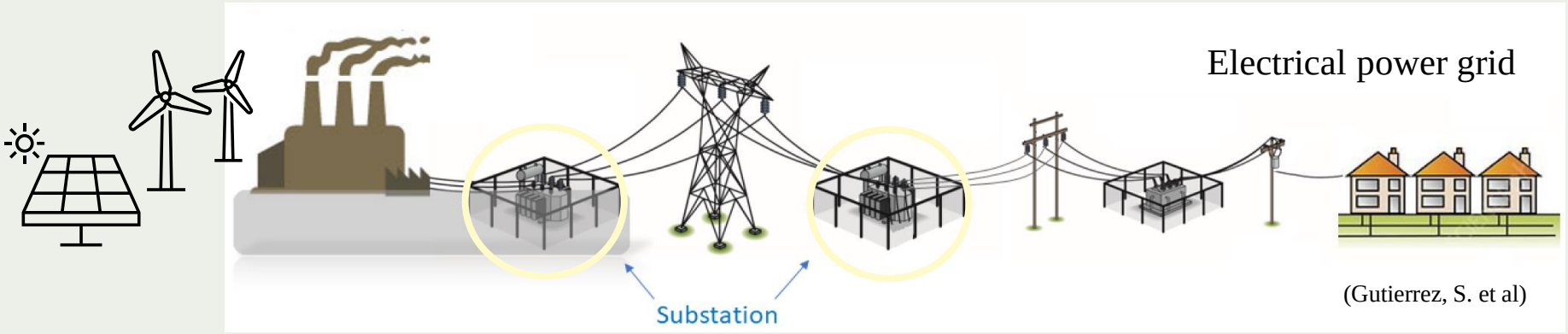
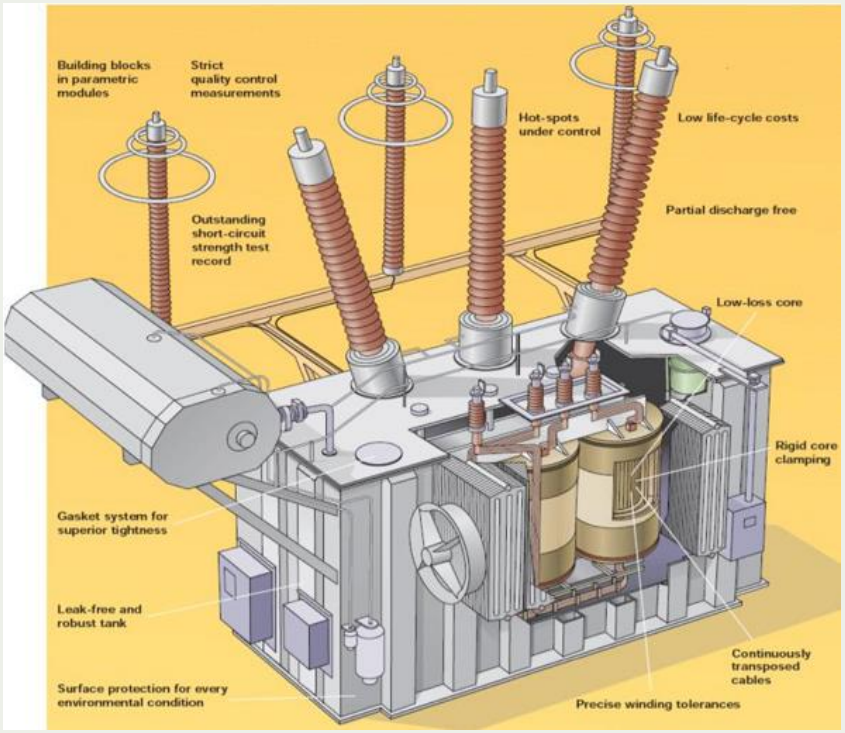
Architectured materials for energy dissipation



(Gutierrez, S. et al)



Transformer as source of noise:

- Vibrations produced by electromagnetic forces
- Harmful noise for the environment
- Wear of the electrical parts

Feasibility of vibration damping using architectured viscoelastic materials?



Mechanics of Materials (2025**)**, 201:105216.

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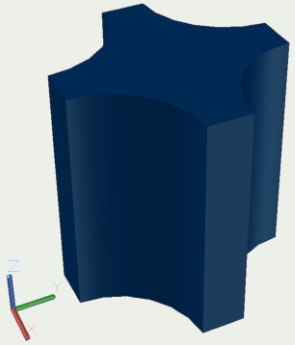
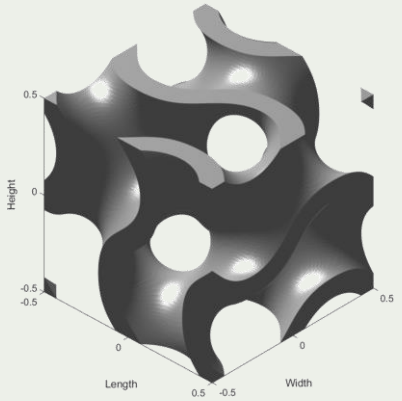
Industry PhD program

Hitachi Energy

Architectured materials for thermal management

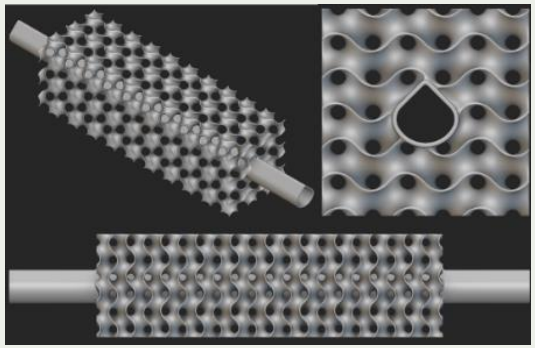


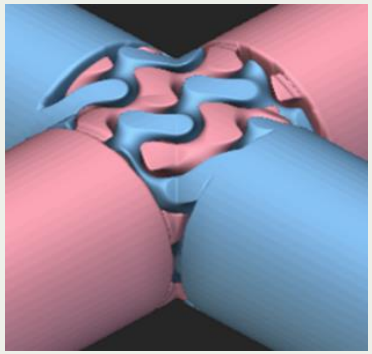
Tetragonal symmetry



Cubic symmetry

Ghaderidosst M. et al., 2022, Micro-architectured materials for thermal management, Huawei Technologies Sweden AB. https://www.diva-portal.org/smash/get/diva2:1678107/FULLTEXT01.pdf





Fluid-Solid Interaction

Nadukkandy S., (2023), Master Thesis, Uppsala University.

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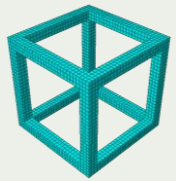
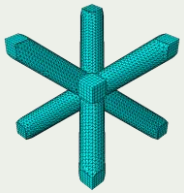
GKN AEROSPACE

Architectured materials for hydrogen storage

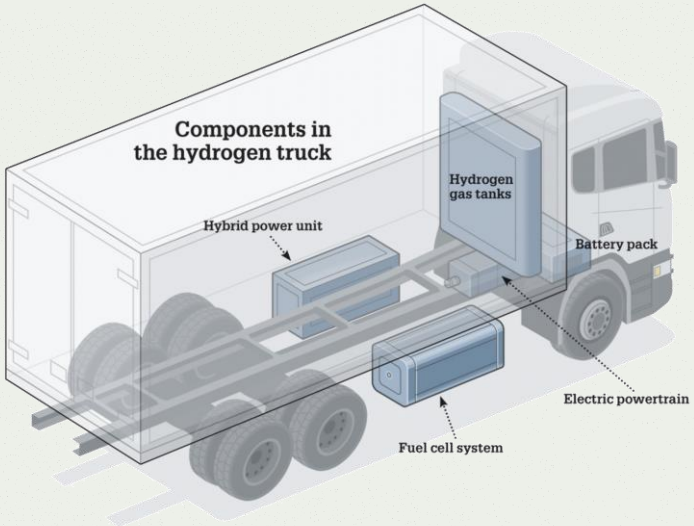
Bridging the chemistry and mechanics

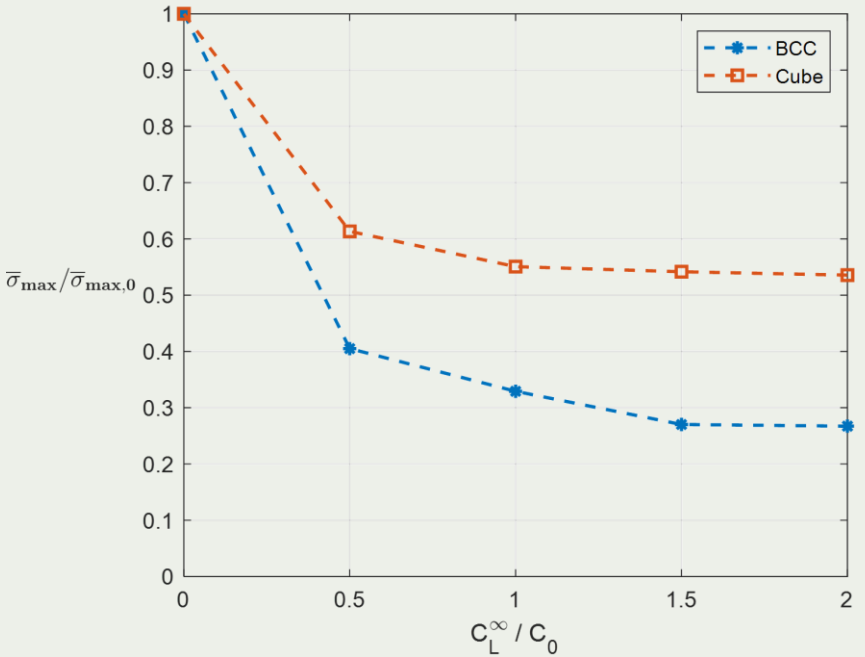
$$\mu = \mu_0 + RT\ ln(C_L) - V_H\sigma_H$$











Engineering Fracture Mechanics (2022) 274:108762.

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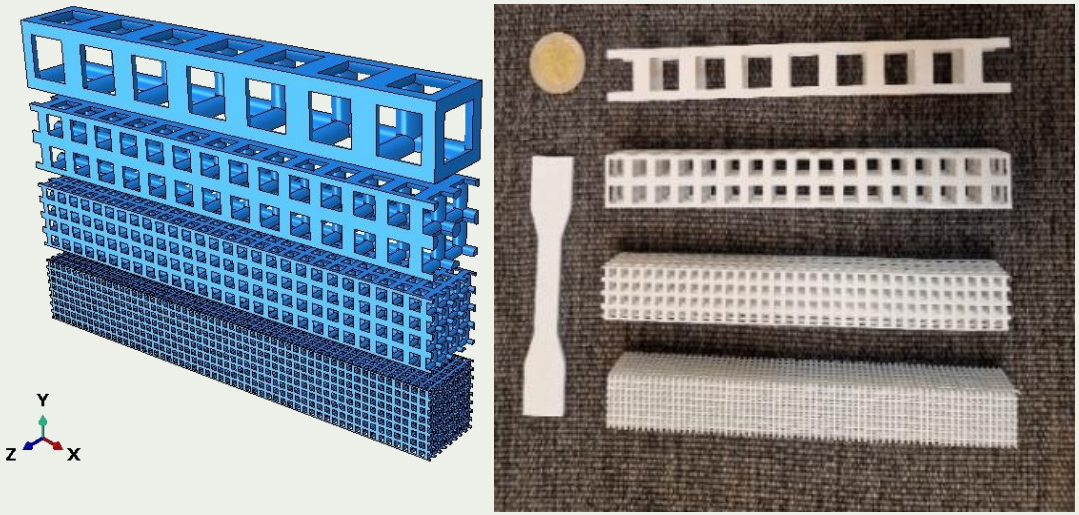
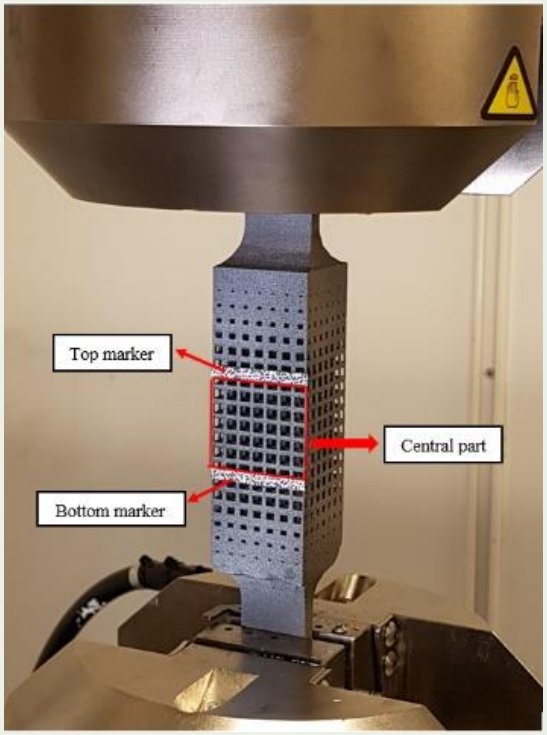
Architectured materials across scales

Size effect & separation of scales



$$W^M = \frac{1}{2}\left(\left(\boldsymbol{\varepsilon}^M\right)^T : \boldsymbol{C}^M : \boldsymbol{\varepsilon}^M\right) + \boldsymbol{\varepsilon}^M : \boldsymbol{B}^M \vdots \nabla\boldsymbol{\varepsilon}^M + \frac{1}{2}\left(\left(\nabla\boldsymbol{\varepsilon}^M\right)^T \vdots \boldsymbol{D}^M \vdots \nabla\boldsymbol{\varepsilon}^M\right)$$

Continuum Mechanics and Thermodynamics (2023) 35, 2255–2274.



International Journal of Solids and Structures (2023) 252:111783.

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Architectured materials across scales

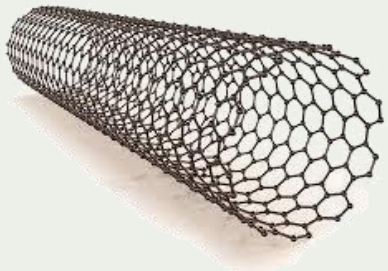
Graphene-based architectures

- Graphene
- Graphite
- Hard carbon
- Soft carbon

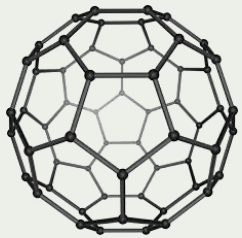


Chemical Engineering Journal (2022) 447:137468.

- CNT (Carbon NanoTubes)



- Fullerene



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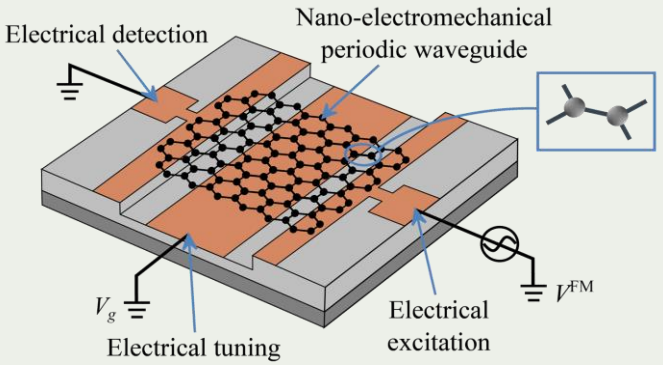
Architectured materials across scales

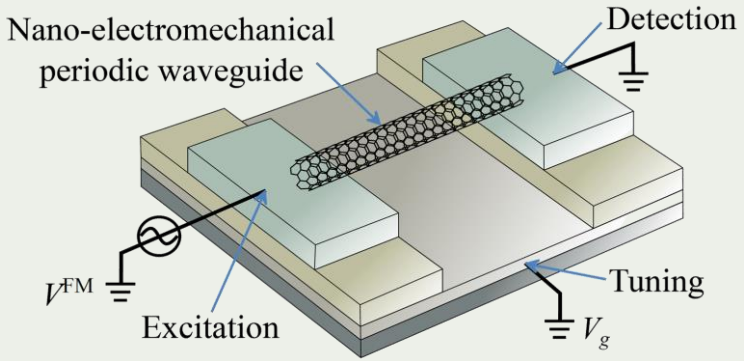
Graphene-based architectures

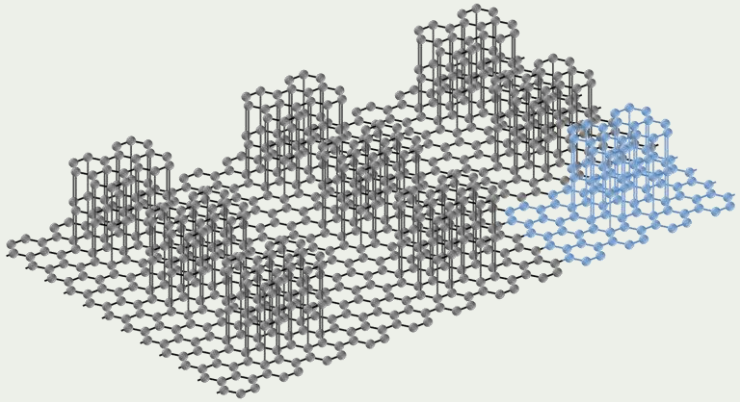
- Elasticity: Numerical and experimental (in progress)
- Wave propagation

Single-layer graphene



Carbon nanotube





Multi-layer graphene

Bo Yang et al., **2024**, Thin-Walled Structures 198: 111713

Bo Yang, Mahmoud Mousavi, **2024**, International Journal of Mechanical Sciences 267: 109014

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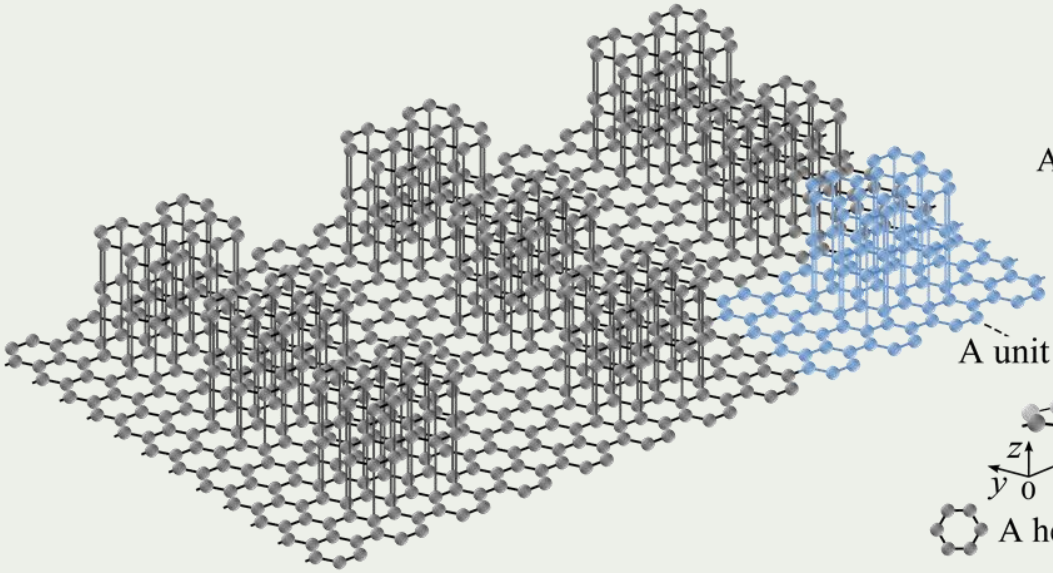
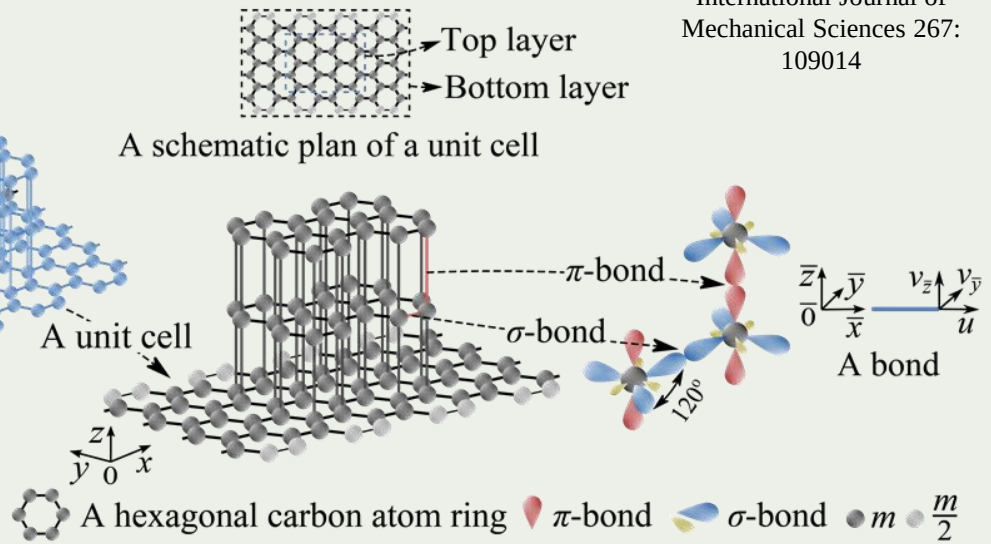
Architectured materials across scales

Multi-layer graphene: Mechanics

Bo Yang, Mahmoud Mousavi, **2024**, International Journal of Mechanical Sciences 267: 109014



(a) A multilayer graphene-based periodic waveguide



(b) A unit cell in the periodic waveguide

Bond (beam) modeled as second strain gradient continuum (Mindlin, 1965)

$$\overline{\mathcal{U}} = \frac{1}{2}\boldsymbol{\varepsilon} : \mathcal{L} : \boldsymbol{\varepsilon} + \frac{1}{2}\boldsymbol{\xi} \vdots \mathcal{A} \vdots \boldsymbol{\xi} + \frac{1}{2}\boldsymbol{\zeta} :: \mathcal{B} :: \boldsymbol{\zeta} + \boldsymbol{\varepsilon} : \mathcal{C} :: \boldsymbol{\zeta} + \mathcal{B}_0 :: \boldsymbol{\zeta}$$

$$\mathcal{T} = \frac{1}{2}\rho \int_0^{d_L} \int_A \left[\left(\dot{\mathbf{D}}\right)^2 + l_1^2 \left(\dot{\mathbf{D}}'\right)^2 + l_2^4 \left(\dot{\mathbf{D}}''\right)^2 \right] \mathrm{d}A\mathrm{d}\bar{x}$$

Green-Lagrange strain for geometric nonlinearity

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial X_j} + \frac{\partial u_j}{\partial X_i} + \frac{\partial u_k}{\partial X_i}\frac{\partial u_k}{\partial X_j} \right)$$

$\boldsymbol{\xi} = \nabla\nabla\mathbf{D}$, and $\boldsymbol{\zeta} = \nabla\nabla\nabla\mathbf{D}$

Hamilton principle $\int_{t_1}^{t_2} (\delta\mathcal{T} - \delta\mathcal{U} + \delta\mathcal{W})\mathrm{d}t = 0$ ⇒ Governing equations and BCs

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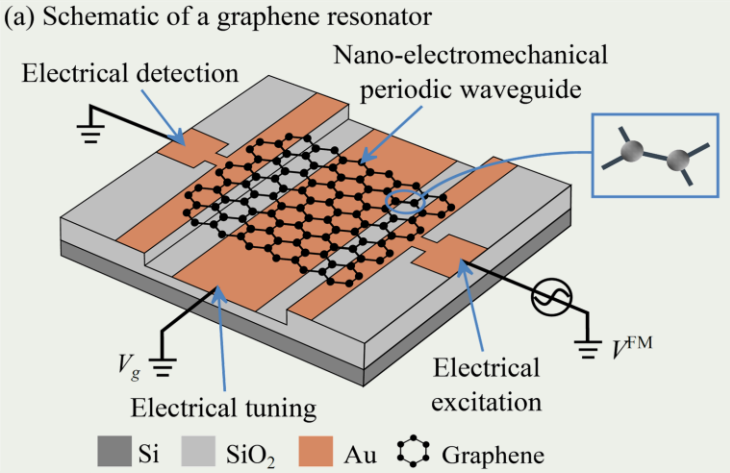
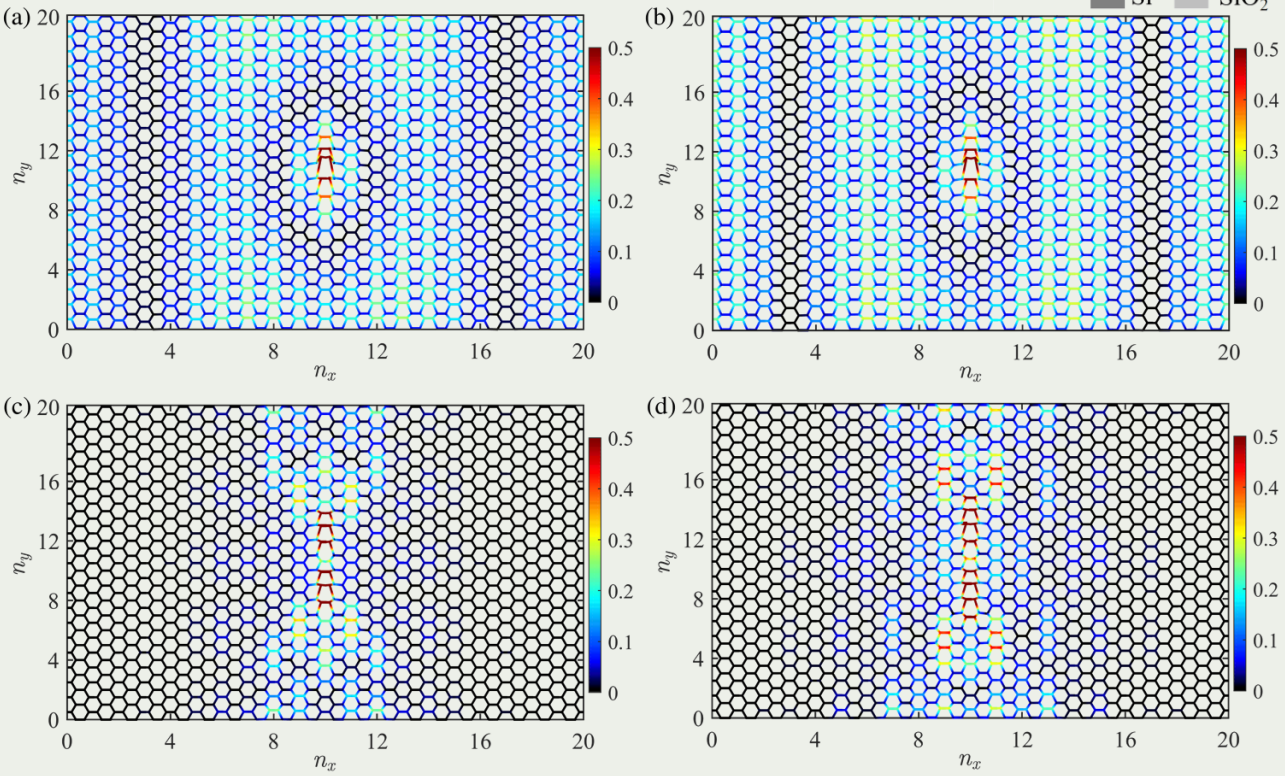
Architectured materials across scales

Wave propagation in single-layer graphene



Directional patterns of the harmonic displacement



Bo Yang et al., **2024**, Thin-Walled Structures 198: 111713

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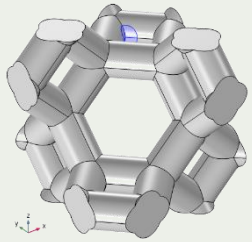
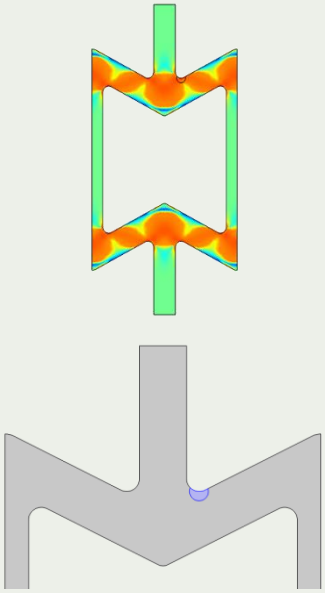
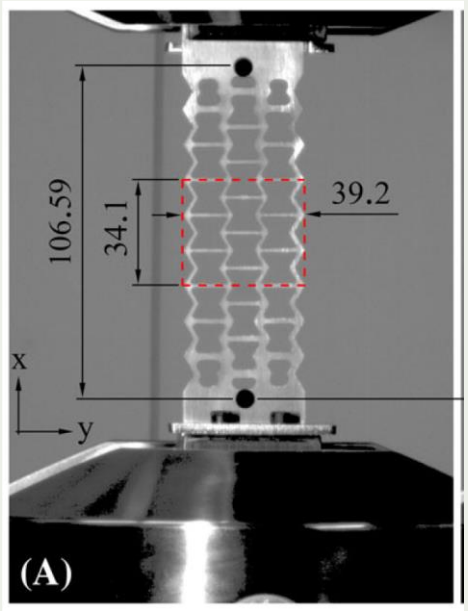
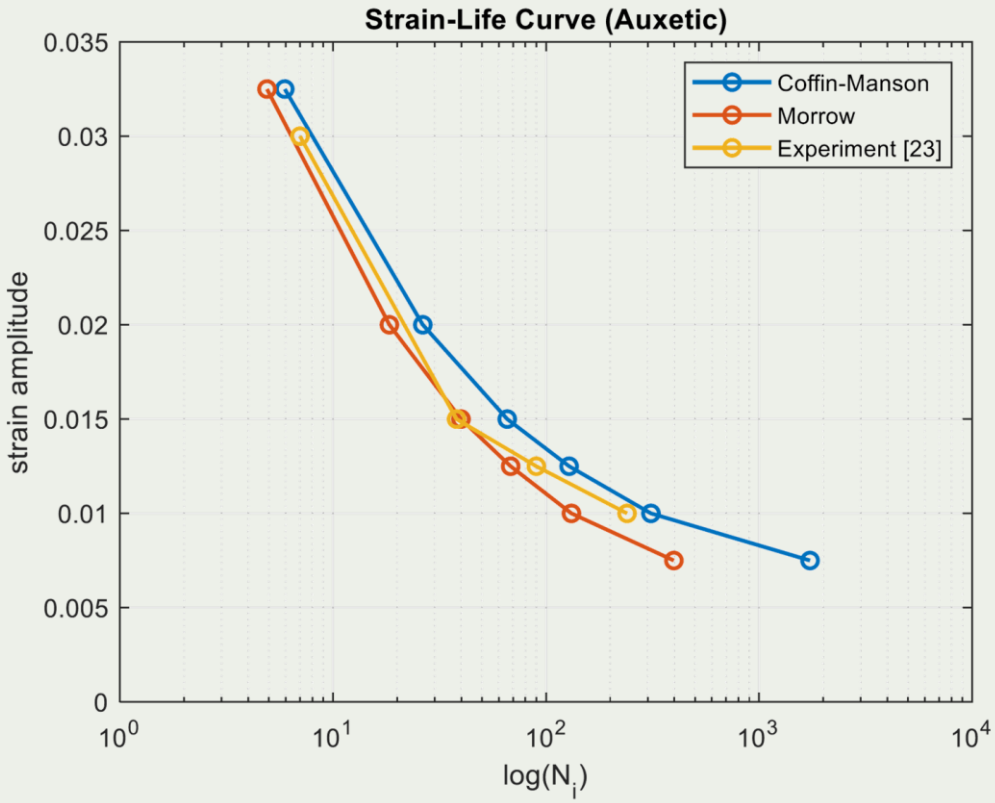
Architectured materials under cyclic actuation

- Low-cycle fatigue analysis
- Computational homogenization
- Elastoplastic material model
- Theory of Critical Distance









- *European Journal of Mechanics - A/Solids* (2021) 92:104480.
- *Fatigue & Fracture of Engineering Materials & Structures* (2019) 42: 1022–1036.

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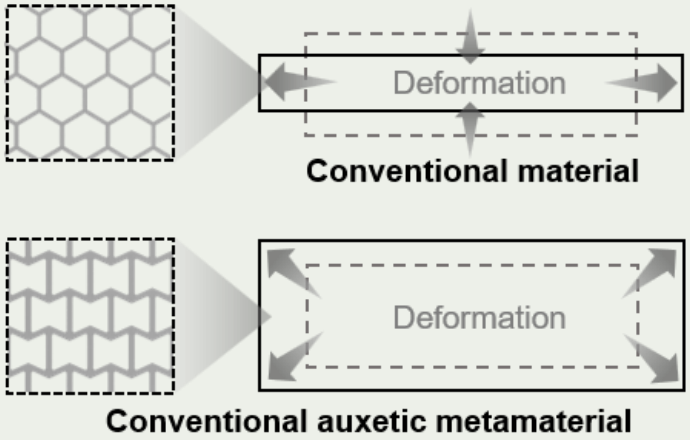
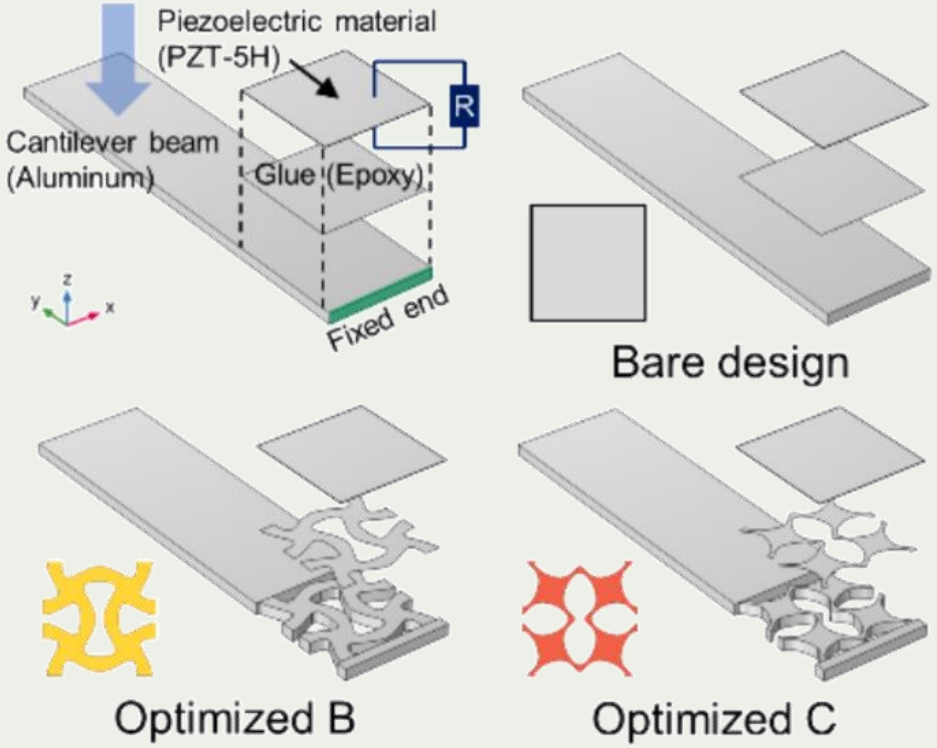
Architectured materials: multi-functionality

- Auxetic architectures
- Enhanced fatigue life

$$P_{opt} = \frac{f A_P t_P d_{31}^2}{\varepsilon_0 \varepsilon_{33}} (\overline{\sigma_{11}} + \overline{\sigma_{22}})^2$$





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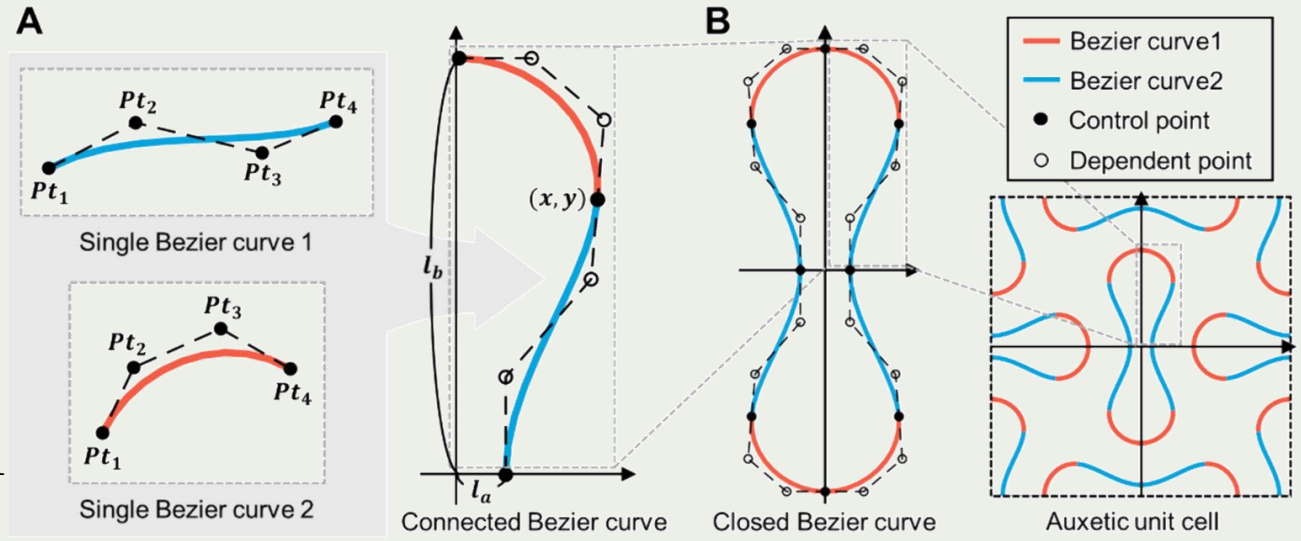
KAIST 1971

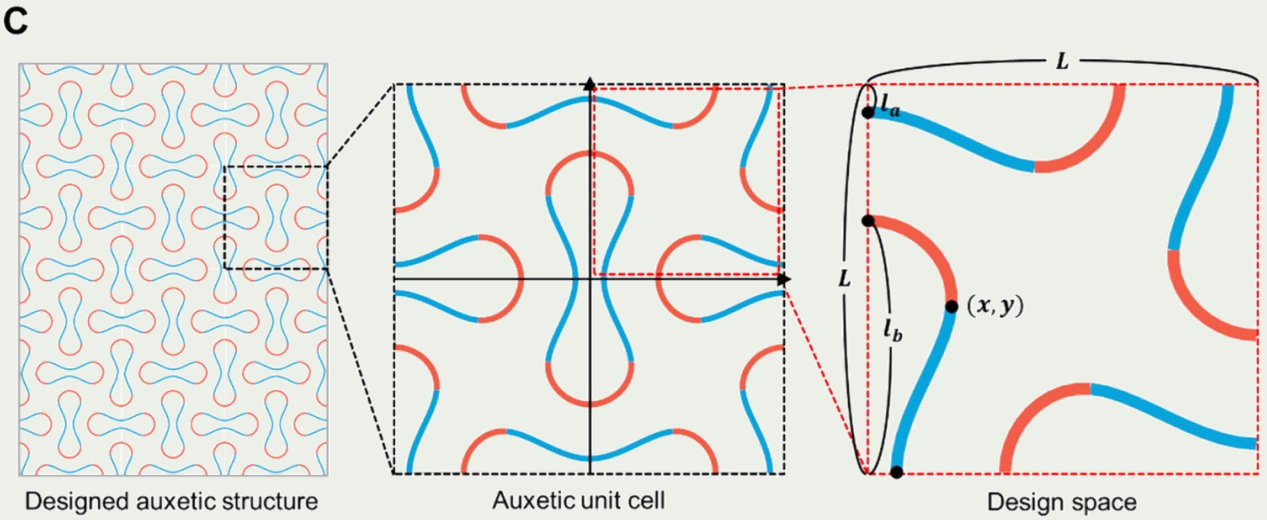
Materials & Design (2025) 252:113798.

Architectured materials: multi-functionality

A cubic Bézier curve constructed using four control points

$$\boldsymbol{B}(t) = (1-t)^3\mathbf{P}_0 + 3(1-t)^2 t\mathbf{P}_1 + 3(1-t)t^2\mathbf{P}_2 + t^3\mathbf{P}_3$$





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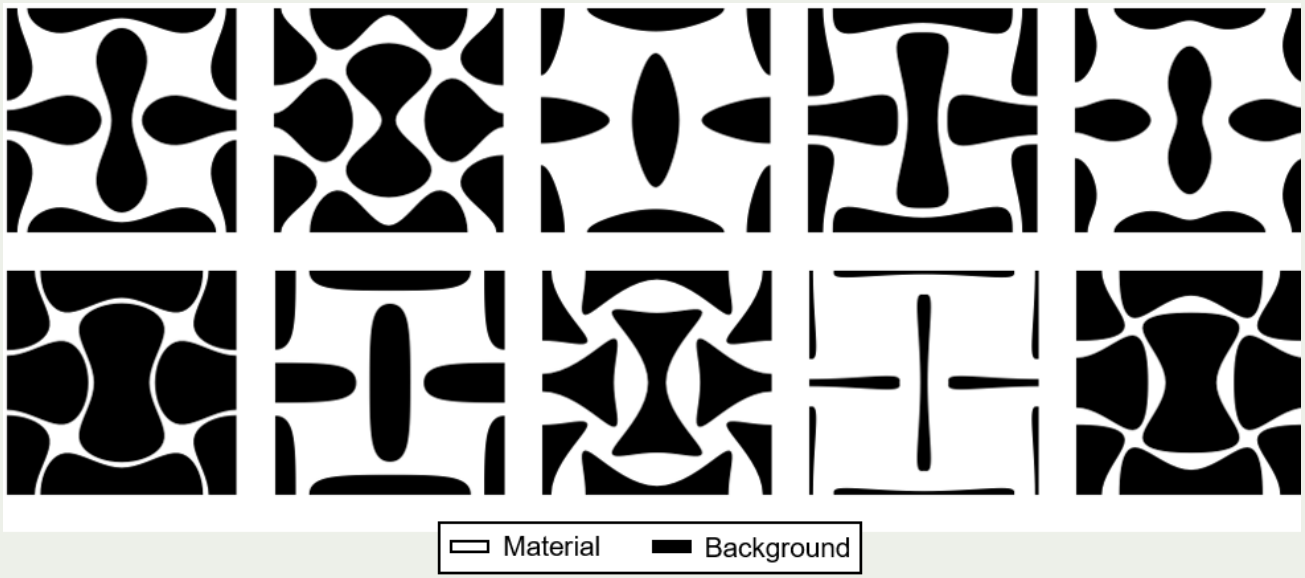
Architectured materials: multi-functionality



Unit cell shaped by smooth Bézier curves

Thickness ratio(φ): $\frac{1}{9} < \varphi = \frac{l_a + l_b}{0.9L} \leq 1$

Aspect ratio(τ): $\frac{1}{9} < \tau = \frac{l_a}{l_b} < 1$

Shape parameter(x, y): $0.2 < x, y < 1$

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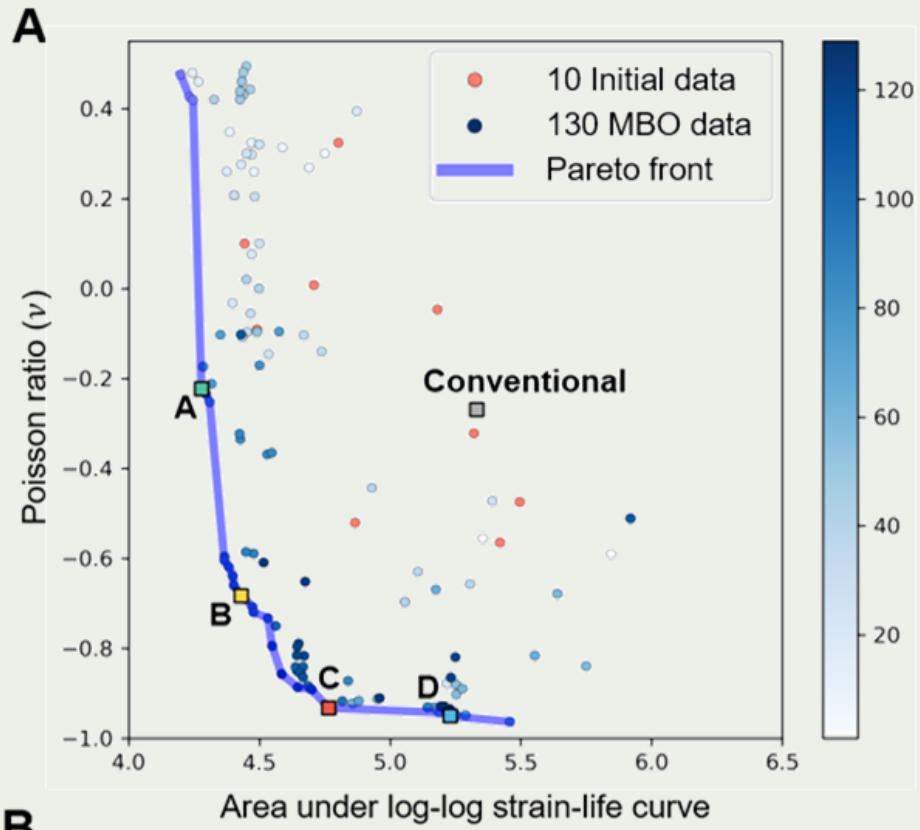
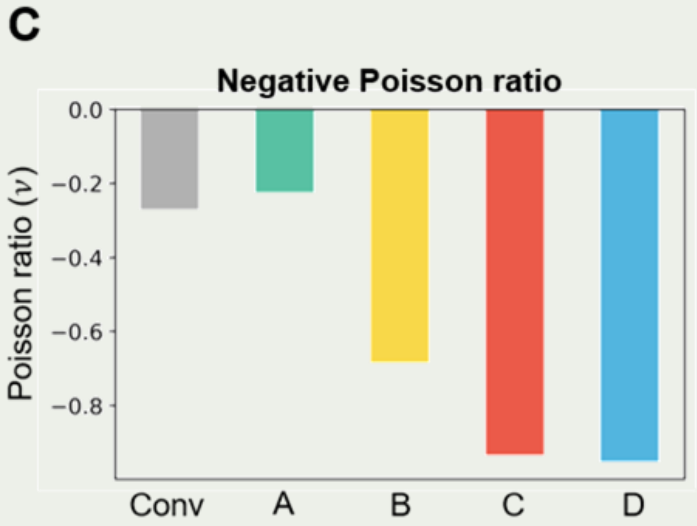
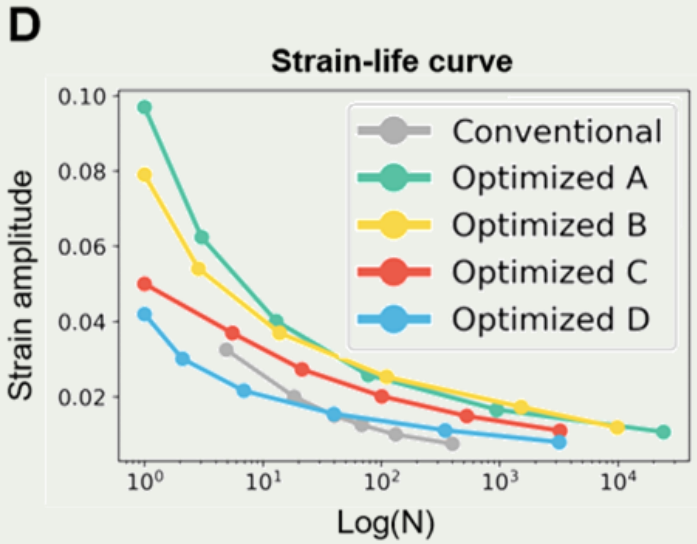
Architectured materials: multi-functionality







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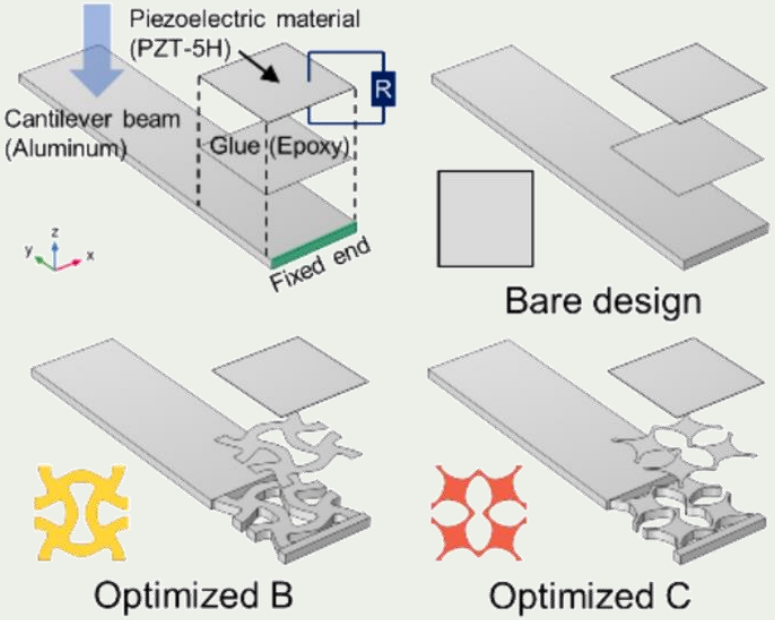
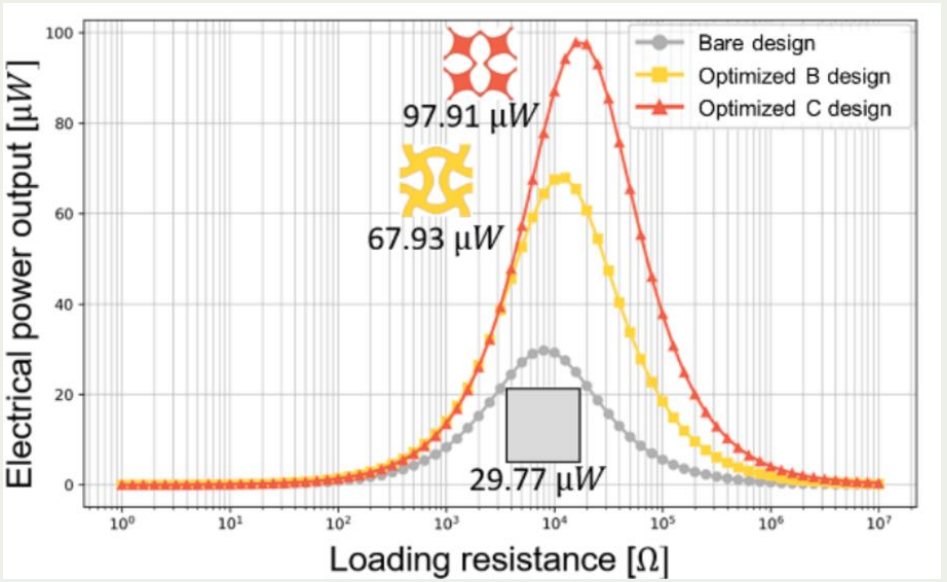
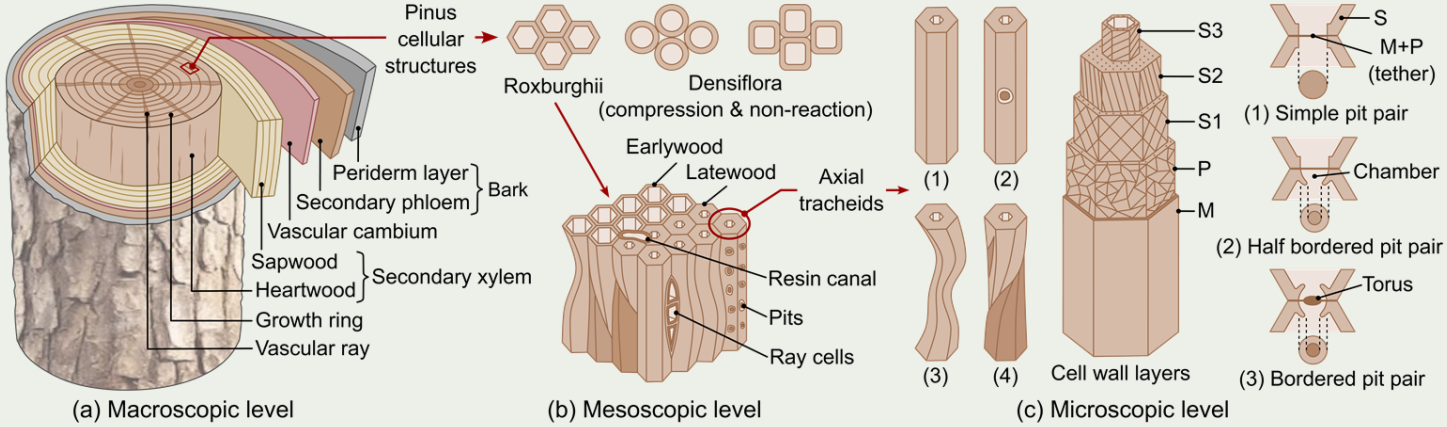
Architectured materials: multi-functionality

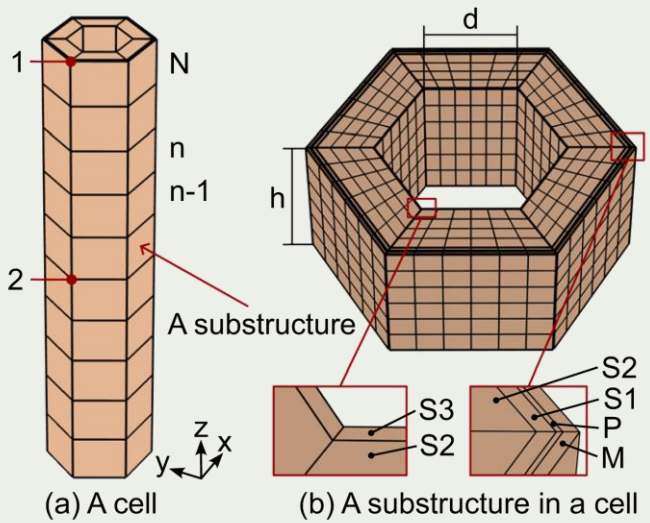


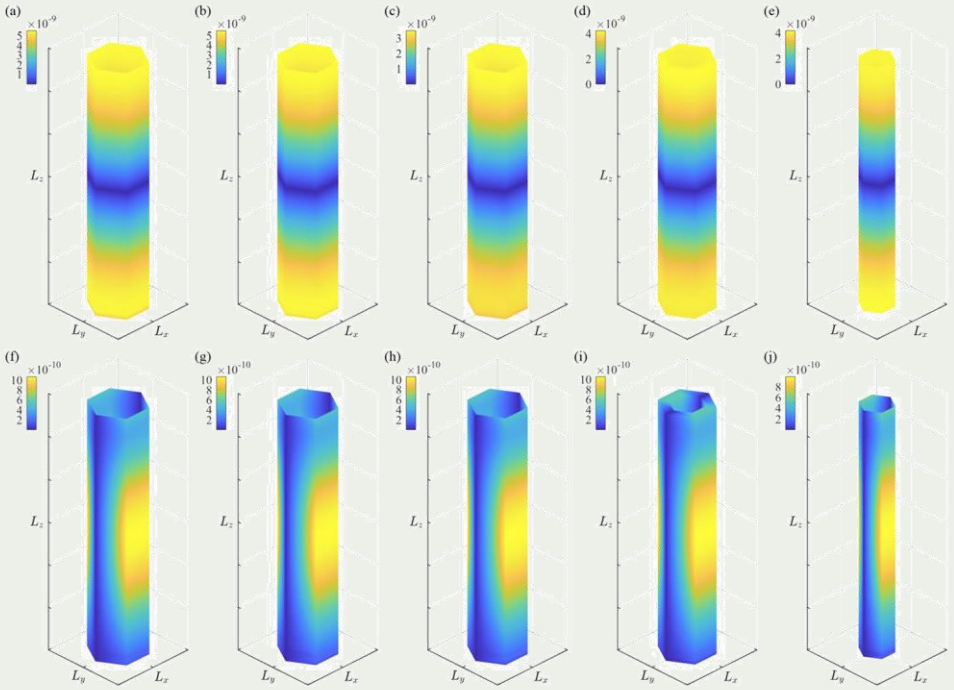


Architectured materials: Nature

Acoustics of wood







Displacement field of different layers in a cell at 35 MHz. **a**–**e** Displacement field of layers M, P, S1, S2, and S3 along the *z*-direction, respectively. **f**–**j** Displacement field of layers M, P, S1, S2, and S3 along the *y*-direction, respectively

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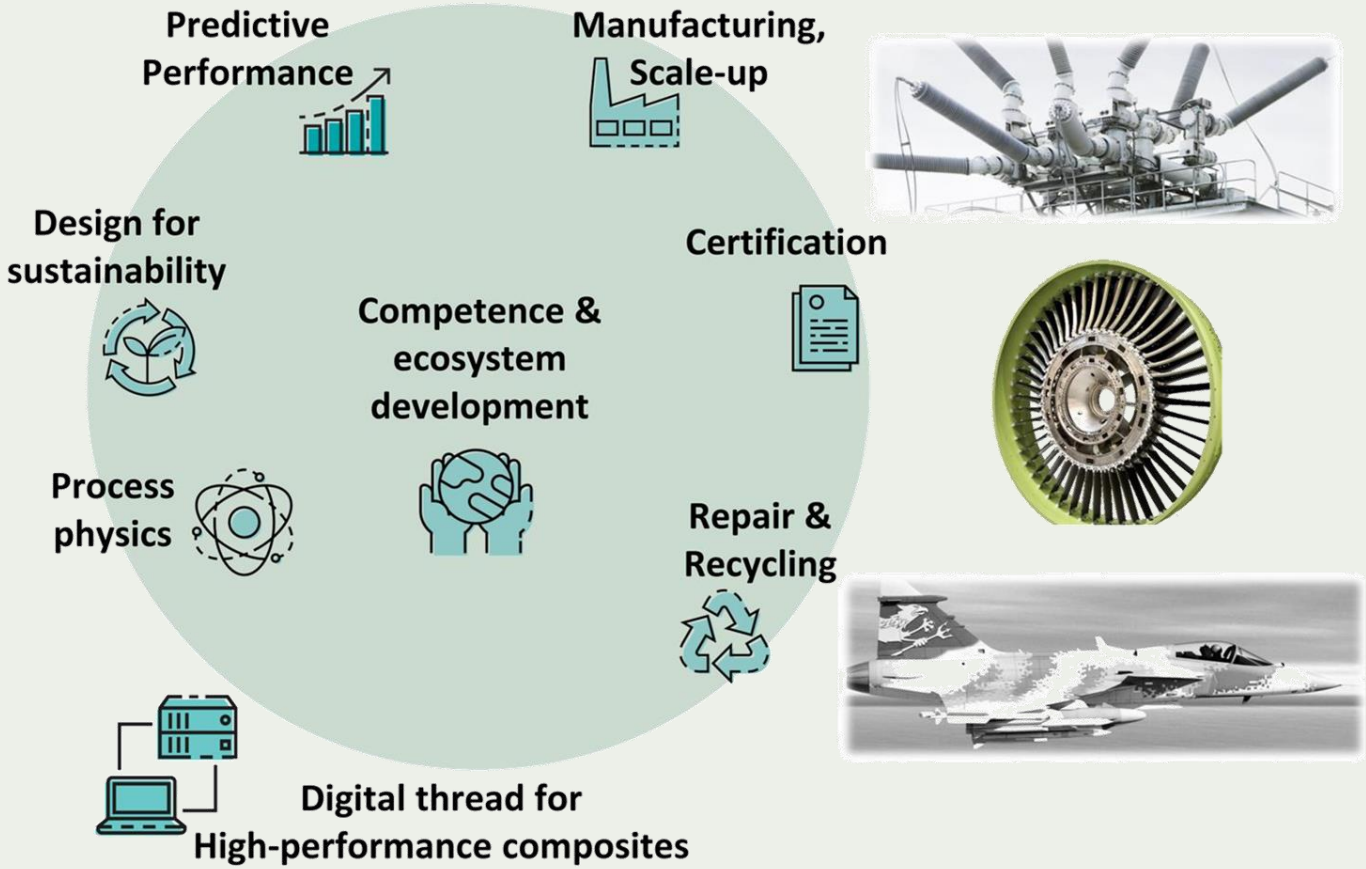
Planning grant for Vinnova cluster of excellence:
Efficient Digital Thread for Composite Structures: From Process Physics to Predictive Performance



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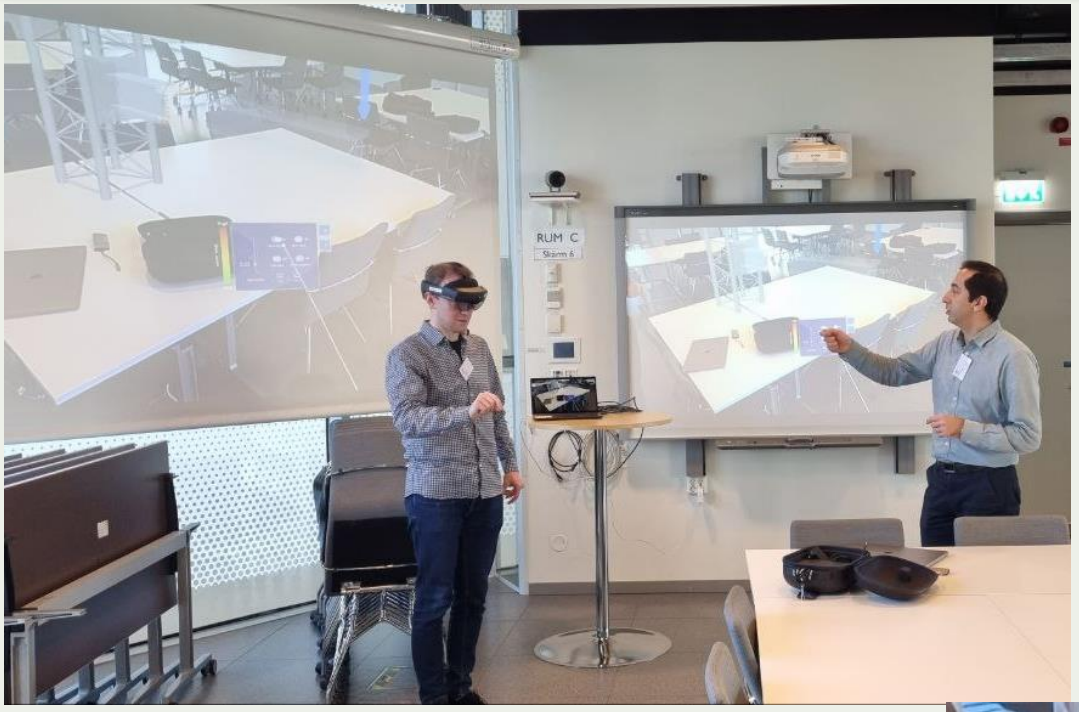

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Architectured materials

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