Design of Multiphysical Coupled Metamaterials: A Review

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Material properties

- Mechanics: bulk modulus, shear modulus, Poisson's ratio
- Thermal: thermal conductivity, thermal expansion
- Electrical: electrical conductivity, permittivity
- Magnetic: magnetic permeability, remanence and coercivity
- Acoustic: speed of sound, sound absorption coefficient
- Optical: refractive index, light absorption coefficient

Ambient conditions

- Temperature
- Humidity
- Electric field strength
- Magnetic field strength
- Atmospheric pressure
- Light intensity

Designing Metamaterials with Multiple Properties

Title:

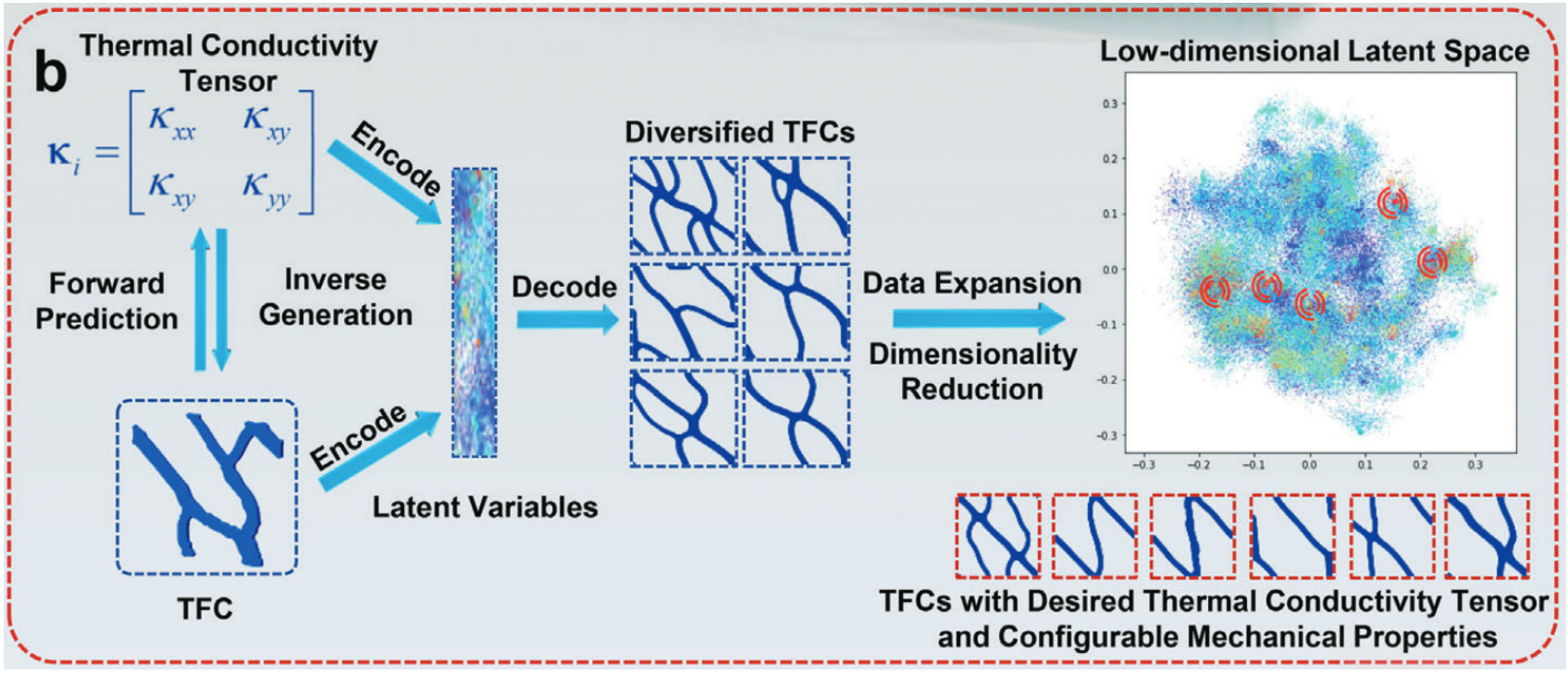
Thermal Metamaterials with

Configurable Mechanical Properties

Authors: Y Wang, W Sha

Journal: Advanced Science

Published: September 2024


b
Thermal Conductivity Tensor
$\kappa_i = \begin{bmatrix} K_{xx} & K_{xy} \\ K_{xy} & K_{yy} \end{bmatrix}$
Encode
Forward Prediction
Inverse Generation
Decode
Diversified TFCs
Data Expansion
Dimensionality Reduction
Low-dimensional Latent Space
Encode
Latent Variables
TFC
TFCs with Desired Thermal Conductivity Tensor and Configurable Mechanical Properties

Designing Environment-Dependent Metamaterials

Title:

Algorithmic encoding of adaptive responses in temperature-sensing multimaterial architectures

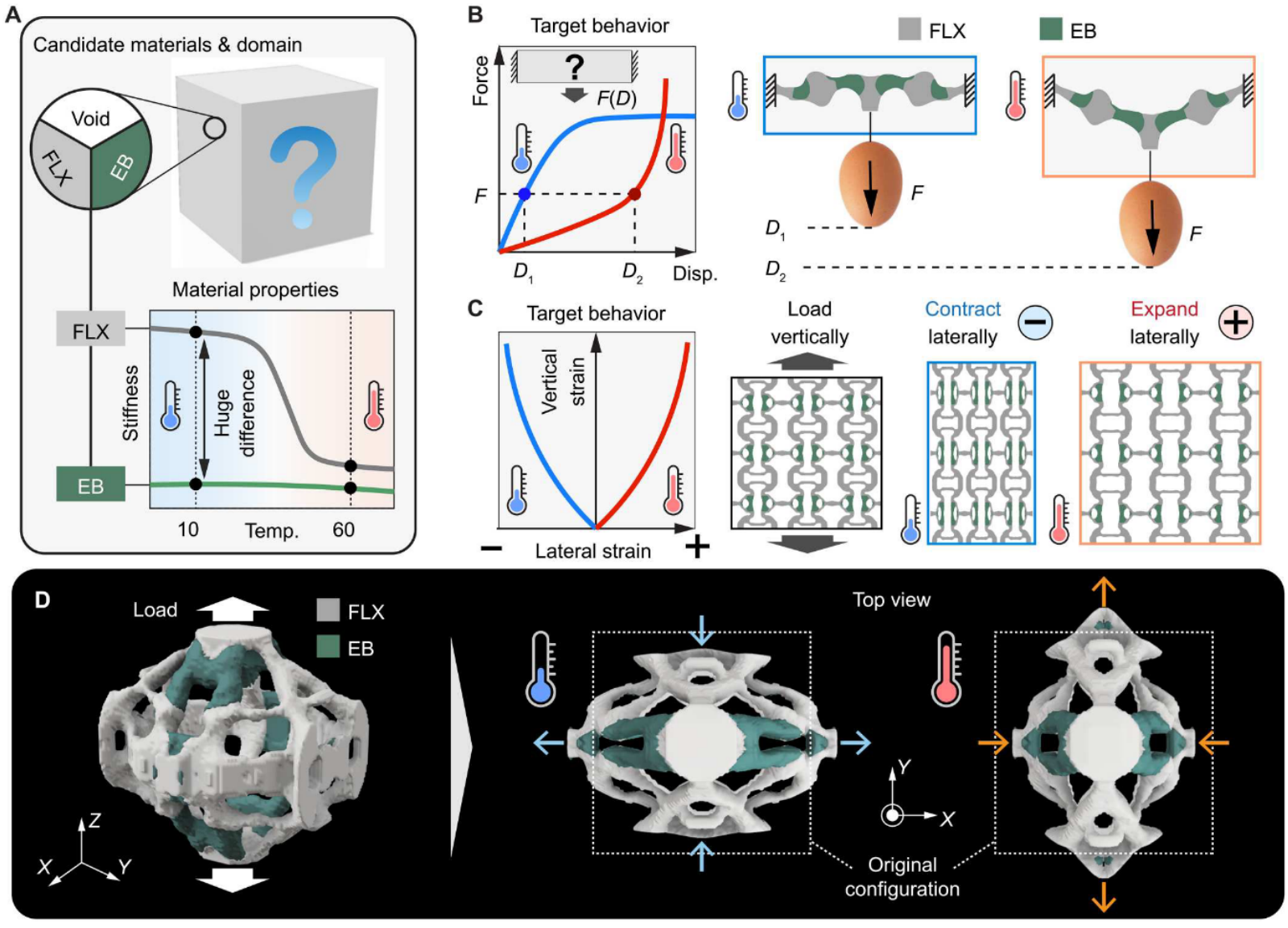
Authors: Shelly Zhang

Mission Lab, University of Illinois

Journal: Science Advances

Published: November 2023

Citations: 2


A
Candidate materials & domain
Void
FLX
EB
Material properties
FLX
EB
Stiffness
Huge difference
10
Temp.
60
B
Target behavior
Force
?
F(D)
F
D1
D2
Disp.
FLX
EB
F
F
D1
D2
C
Target behavior
Vertical strain
Lateral strain
Load vertically
Contract laterally
Expand laterally
D
Load
FLX
EB
Z
X
Y
Top view
Y
X
Original configuration

Current Challenges and Limitations

- High Computational Cost
- Lack of Adaptability
- Limited Design Diversity

Why Deep learning works?

- The mathematical representation of an image is a matrix
- the mathematical representation of an optimized structure is also a matrix

Deep learning: traditional prarmeter

Title:

A Novel Topology Optimization

Approach using Conditional Deep

Learning

Authors: S Rawat

Published: January 2019

Citations: 74

Fig.5 Optimal structures from the conventional algorithm

Fig. 6 Unprocessed quasi-optimal structures generated from CWGAN

Deep learning: Boundary condition

Title:

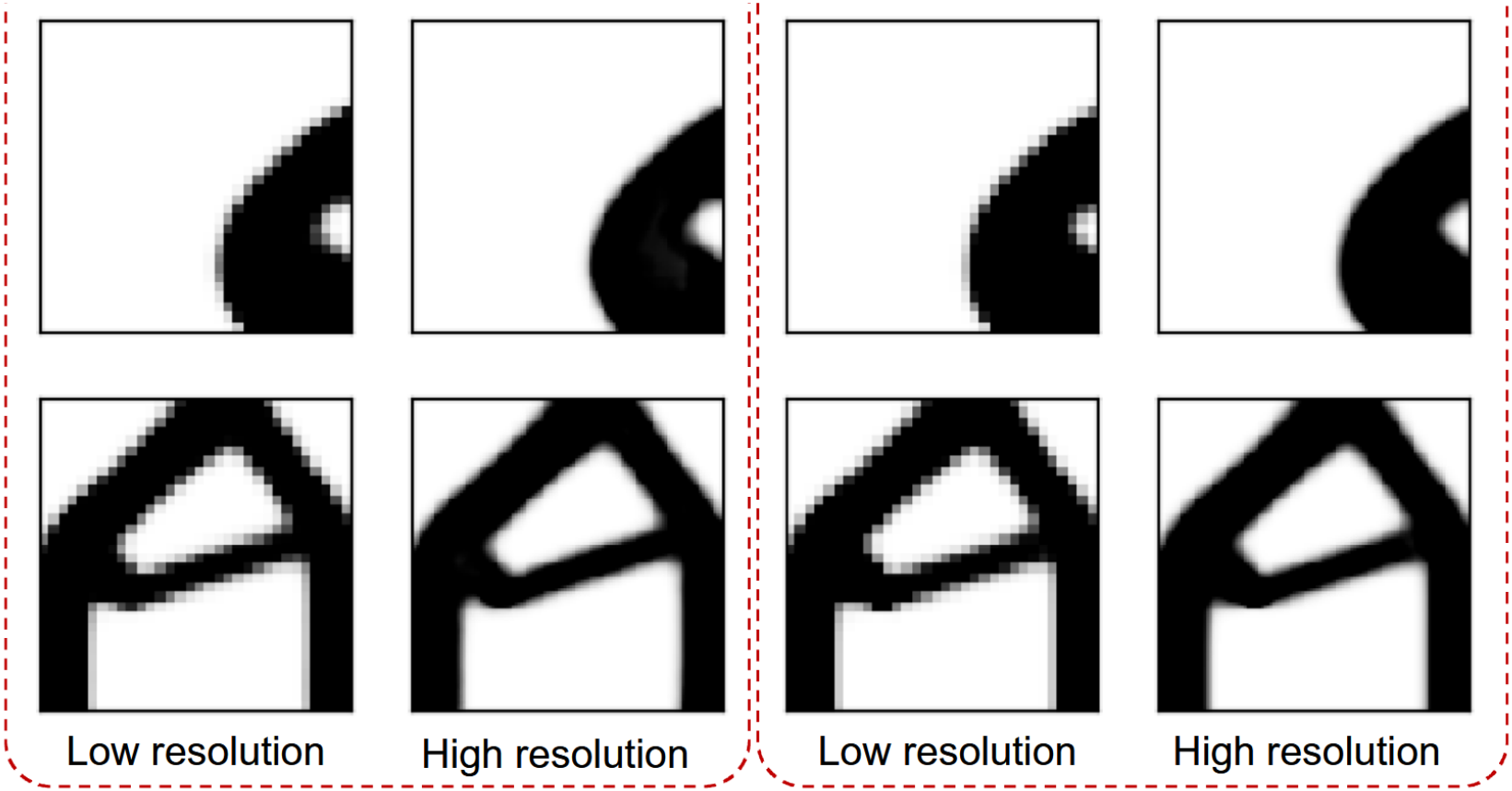
Deep learning for determining a near-optimal topological design without any iteration

Authors: Yonggyun Yu

Journal: Structural and Multidisciplinary Optimization

Published: March 2019

Citations: 363


Low resolution
High resolution
Low resolution
High resolution
Predicted structure
Optimized structure

Deep learning: physical field

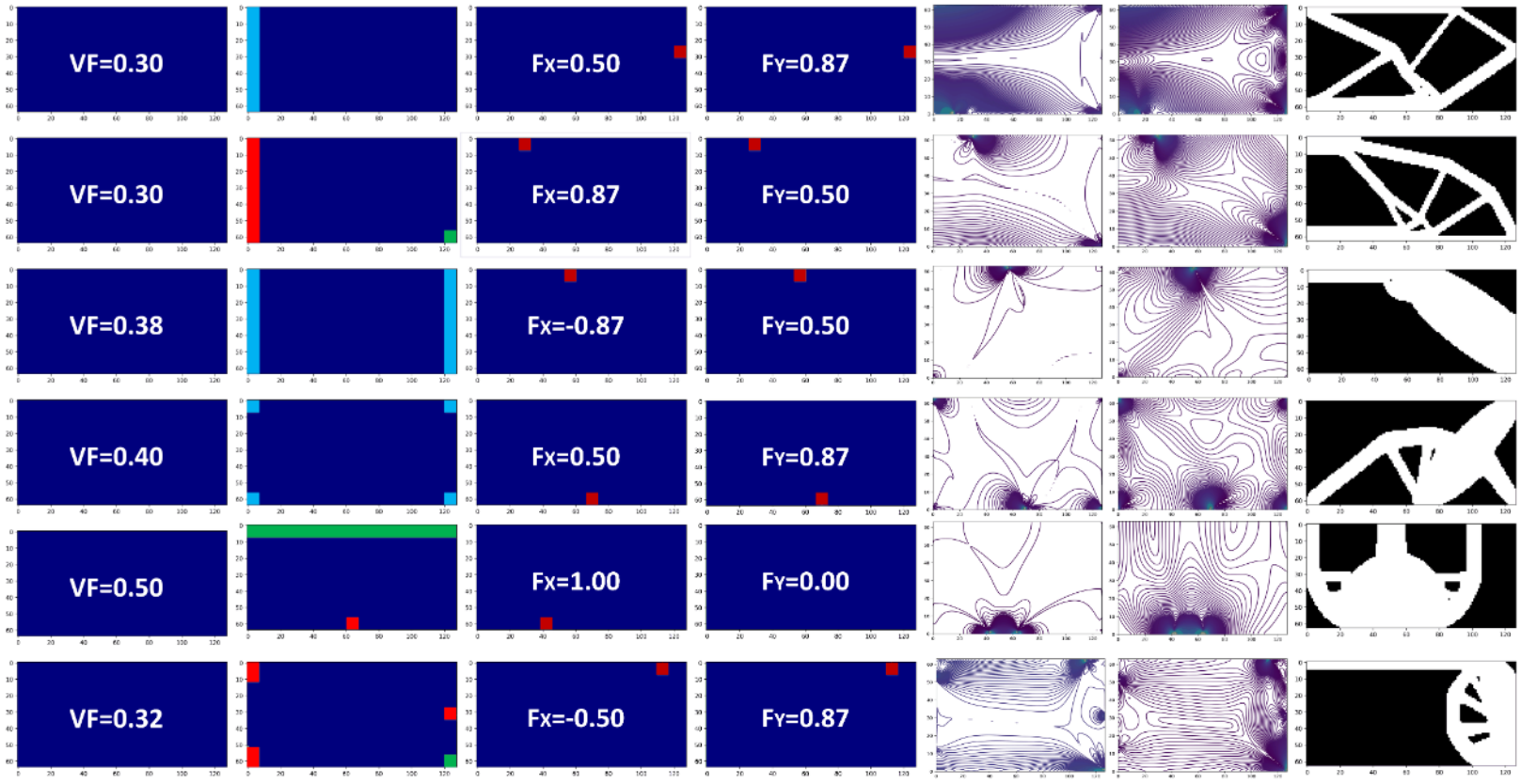
Title: TopologyGAN: Topology Optimization Using Generative Adversarial Networks Based on Physical Fields Over the Initial Domain

Authors: Levent Burak Kara

Journal: Journal of Mechanical Design

Published: March 2020

Citations: 223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Fx=0.50
Fy=0.87
VF=0.50
Fx=1.00
Fy=0.00
VF=0.32
Fx=-0.50
Fy=0.87
Domain + VF
Displacement BC
Load in Y-axis
Load in Y-axis
Strain Energy Density
von Mises Stress
Optimal Structure

Deep learning: optimized single physical field

Title:

Topology Optimization Integrated Deep Learning for Multiphysics Problems

Authors: Hesaneh

Journal: AIAA SCITECH 2022 Forum

Published: January 2022

Citations: 9

Deep learning: style transfer

Title:

Multidisciplinary topology optimization using generative adversarial networks for physics-based design enhancement

Authors: Corey M. Parrott

Journal: Journal of Mechanical Design

Published: March 2023

Citations: 10

Thanks!