



**The International Conference on
Computational & Experimental Engineering and Sciences
Singapore ♦ August 3-6, 2024**



**College of Design
and Engineering**

LattSAC: Design of Heterogeneous Lattice Structures for Acoustic Applications

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Department of Mechanical Engineering

National University of Singapore

Presentation Outline

Introduction

- Lattice Structures for Acoustic Properties
- Some Questions

Mathematical Modelling

- Unit Cells: Strut Lattice, Plate Lattice, TPMS Lattice
- Semi-Empirical Approach

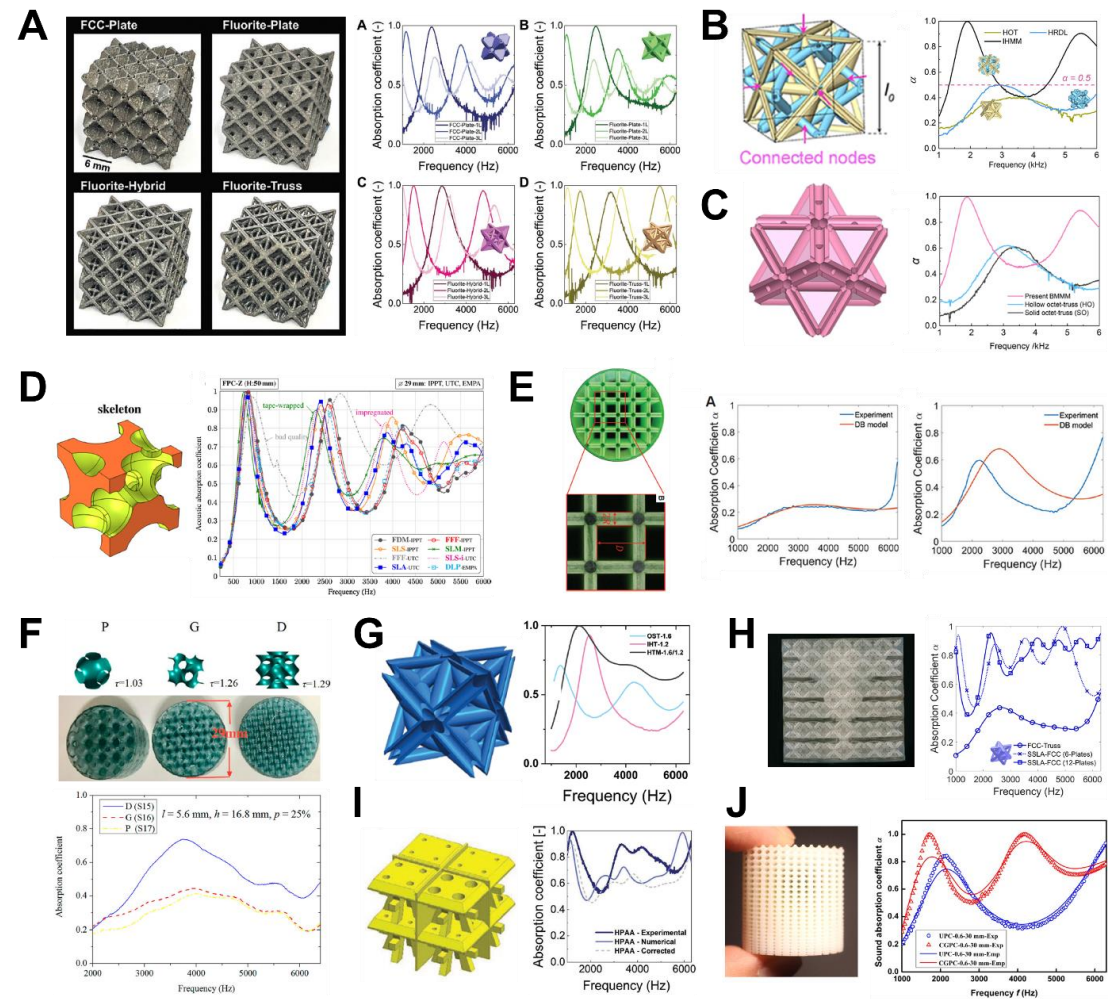
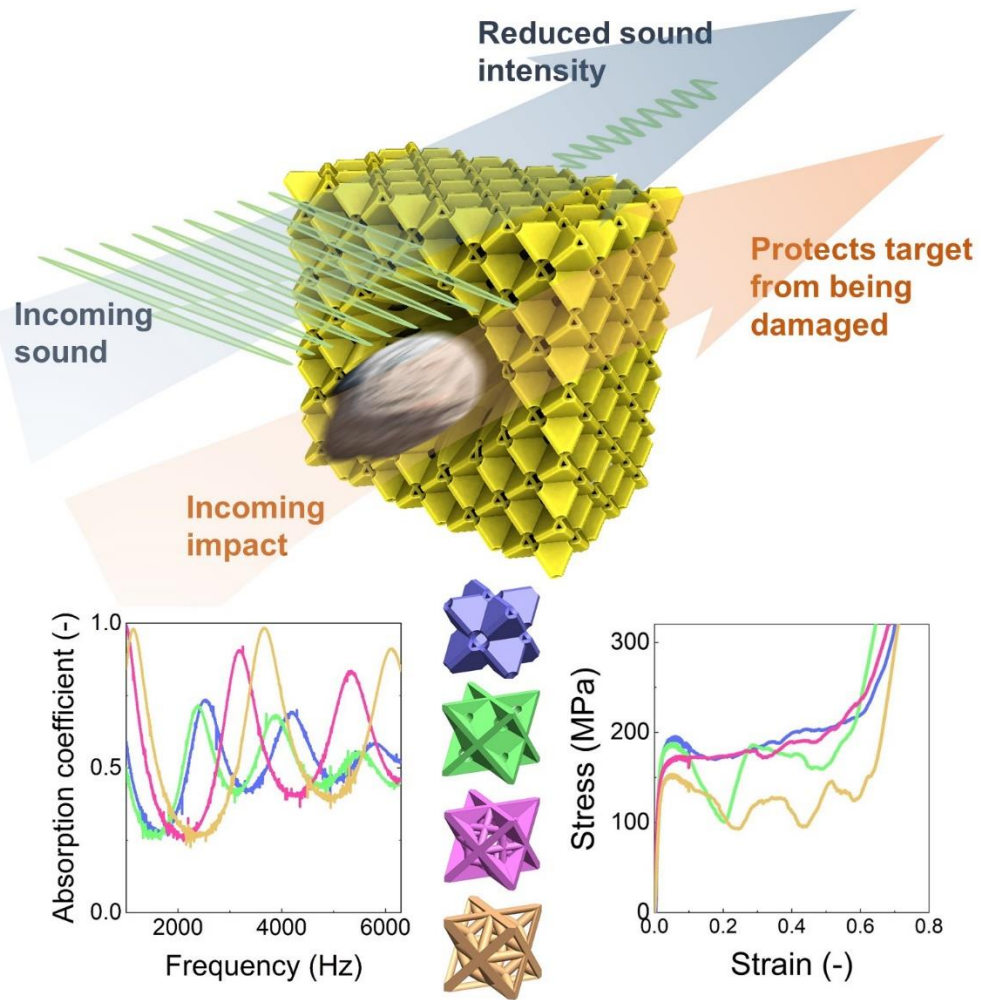
LattSAC Application

- Key Functionalities
- Example Cases

Concluding Remarks

- Lattices as Multi-functional Intelligent Materials
- Beyond LattSAC

Lattice Structures for Sound Absorption



| Lattice Structures for Sound Absorption?

Acoustic Properties of Lattices Less Known

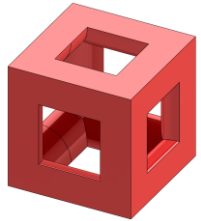
- Commonly Seen: Lightweight, Stiffness, Energy Absorption
- Recent Topic: Lattices for Acoustics
- Other Potential Functionalities?

Lattice Structures has Unlimited Design Space

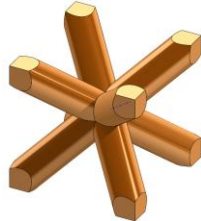
- Unlimited unit cells and geometries.
- Unlimited permutations of unit cells.
- Interactions between acoustic mechanisms.

Unit Cells

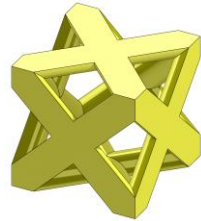
Strut Lattices:



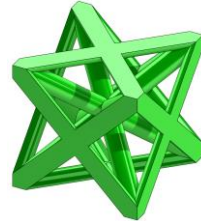
Simple Cubic
(SC)



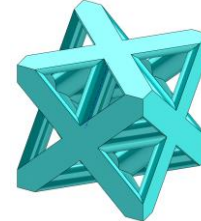
Body-Centered
Cubic (BCC)



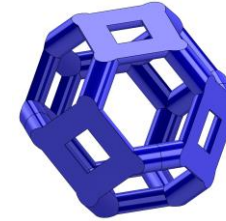
Face-Centered
Cubic (FCC)



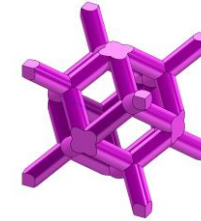
BCC+FCC



Octet

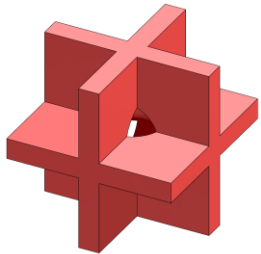


Kelvin-Cell

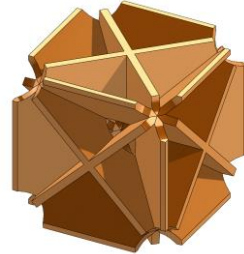


Rhombic
Dodecahedron

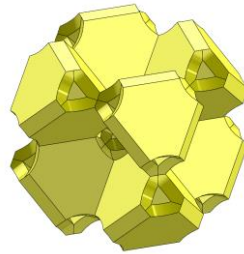
Plate Lattices:



Simple Cubic
(SC)



Body-Centered
Cubic (BCC)

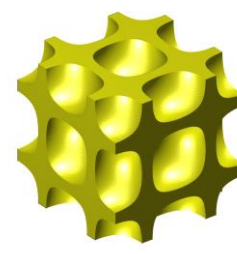


Face-Centered
Cubic (FCC)

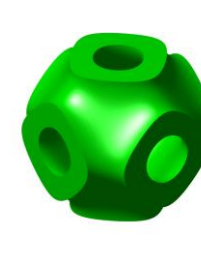
TPMS Lattices:



Gyroid (Sheet)



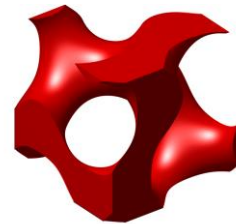
Diamond (Sheet)



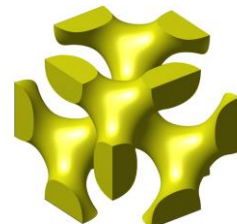
Primitive (Sheet)



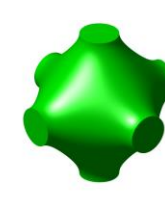
I-WP (Sheet)



Gyroid (Solid)



Diamond (Solid)



Primitive (Solid)



I-WP (Solid)

Mathematical Model

Strut Lattices:

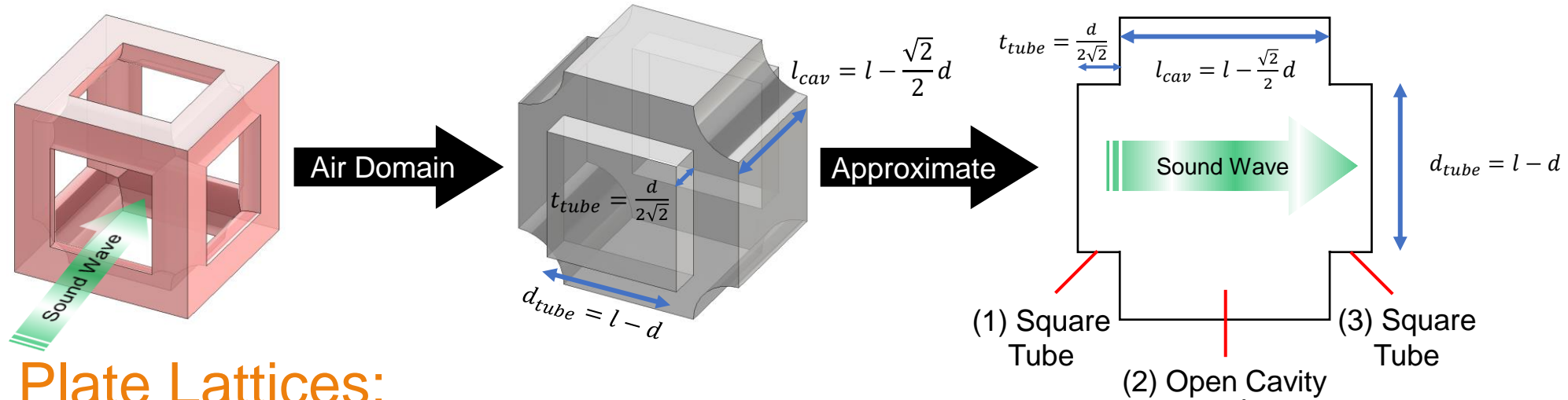
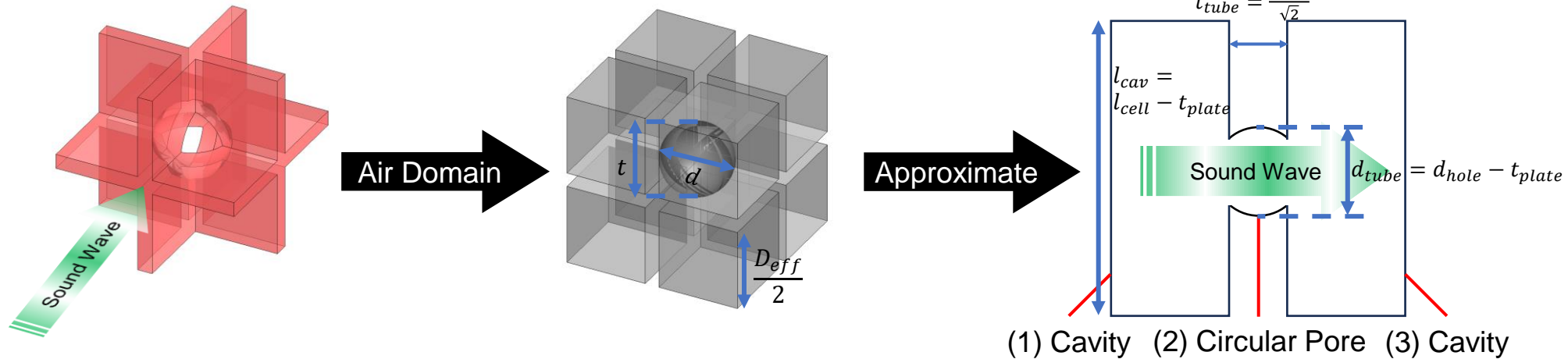
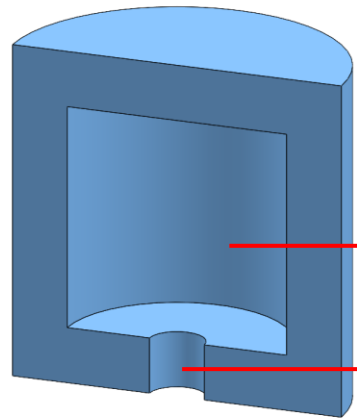


Plate Lattices:



Mathematical Model

Microperforated Panel (MPP) Model:



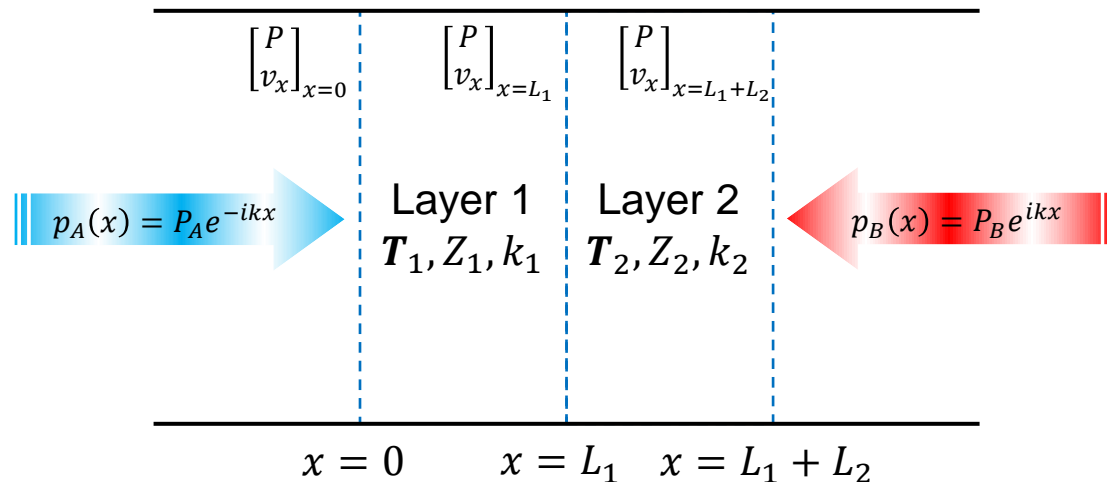
Cavity V

Neck

$$Z_r = \frac{32\eta t_{tube}}{\varepsilon d_{tube}^2} \left(\sqrt{1 + \frac{k^2}{32}} + 2\delta_1 R_s \right) + j \frac{\omega \rho_0 t_{tube}}{\varepsilon} \left(1 + \frac{1}{\sqrt{9 + \frac{k^2}{2}}} + \delta_2 \frac{d_{tube}}{t_{tube}} \right)$$

- Correction Factors δ_1 and δ_2 to be optimized for each individual experiment case.
- Given geometry parameters, predict δ_1 and δ_2 using regression models/NNs.

Transfer Matrix Method (TMM):



$$\begin{Bmatrix} p \\ v_y \end{Bmatrix}_{x=0} = [\mathbf{T}_{layer\ 1}] [\mathbf{T}_{layer\ 2}] \dots [\mathbf{T}_{layer\ n}] \begin{Bmatrix} p \\ v_y \end{Bmatrix}_{x=L}$$

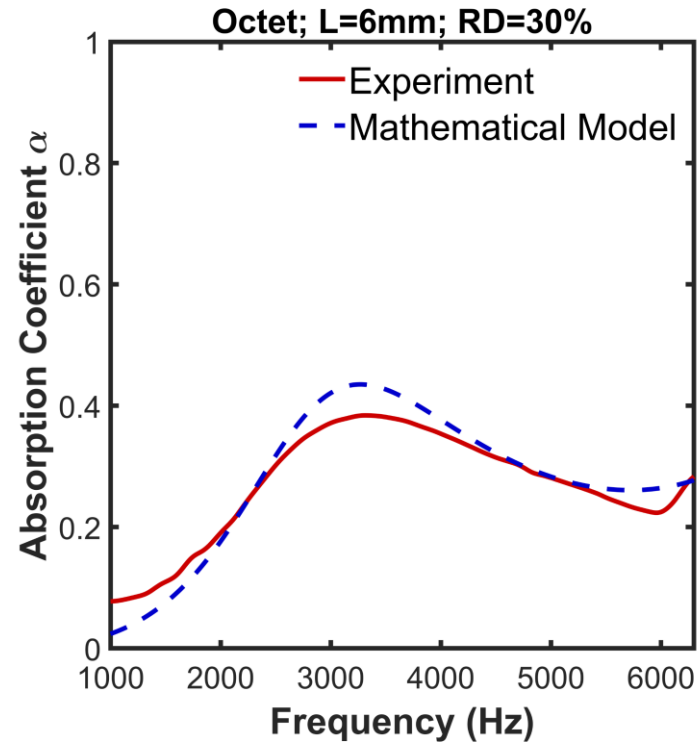
$$= [\mathbf{T}_{total}] \begin{Bmatrix} p \\ v_y \end{Bmatrix}_{x=t} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{Bmatrix} p \\ v_y \end{Bmatrix}_{x=L}$$

$$[\mathbf{T}_{layer\ x}] = \mathbf{T}_r \mathbf{T}_c \mathbf{T}_r$$

$$= \begin{bmatrix} 1 & Z_r \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(k_0 l_{cav}) & jZ_0 \sin(k_0 l_{cav}) \\ j\frac{1}{Z_0} \sin(k_0 l_{cav}) & \cos(k_0 l_{cav}) \end{bmatrix} \begin{bmatrix} 1 & Z_r \\ 0 & 1 \end{bmatrix}$$

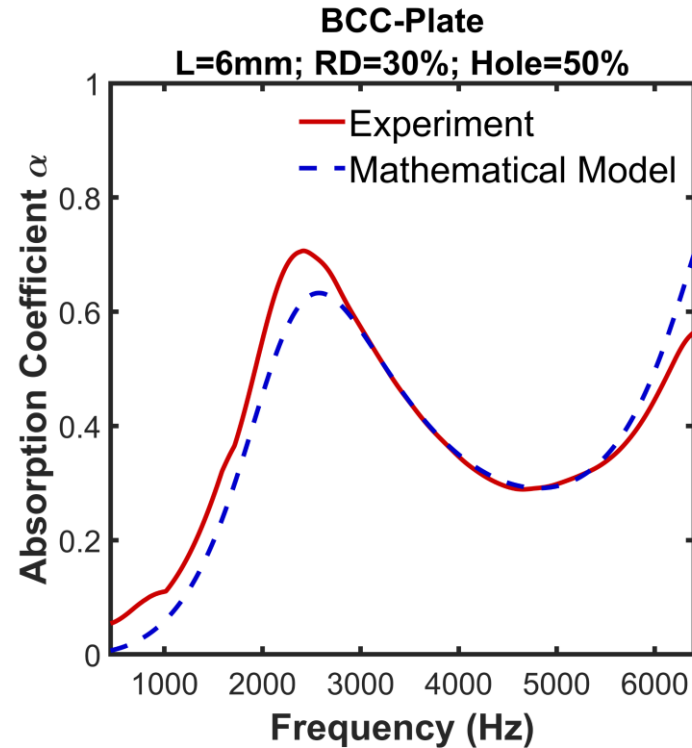
Model Accuracy

Strut Lattices:



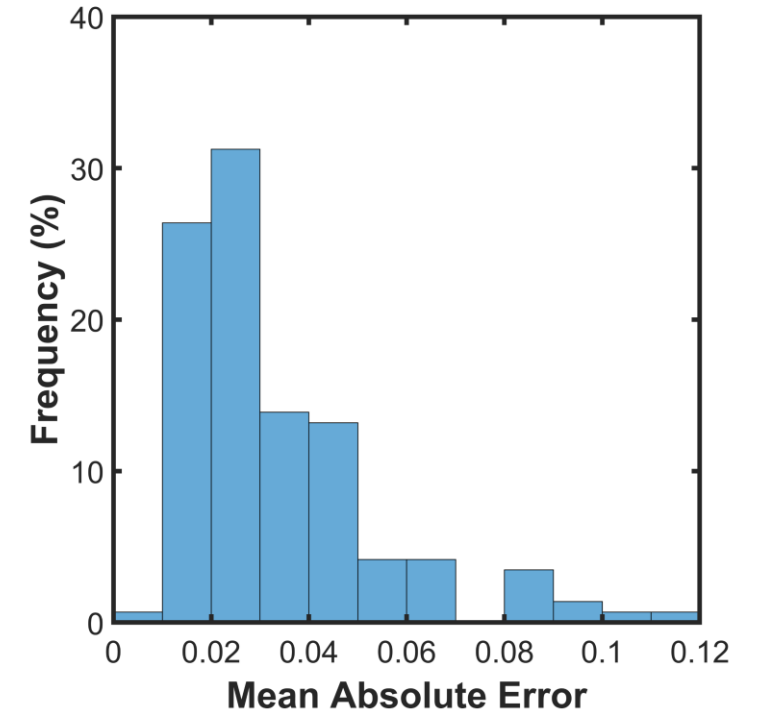
Mean Absolute Error: 0.0256

Plate Lattices:



Mean Absolute Error: 0.0449

Histogram of Errors:

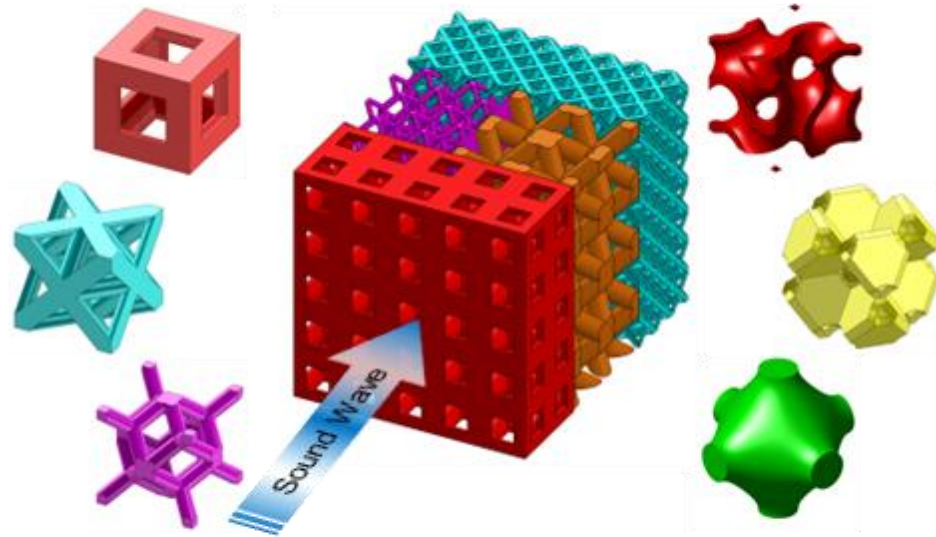


Mean Absolute Error: 0.0336

The LattSAC Application

LattSAC

Design your own Lattice Sound Absorber



Zhai Group
nature-inspired
Advanced Materials Engineering



NUS
National University
of Singapore

*Desktop Application

Download and Install for Free:

<https://github.com/JunWeiChua/LattSAC>



The LattSAC Application

Lattice Properties Lattice SAC Plots and Data Instructions About This Application

Cross Section: Length/Diameter (mm):

Thickness (mm):

Number of Layers: Frequency: Hz to Hz

Layer Number:

Part 1 Part 2 Part 3 Part 4

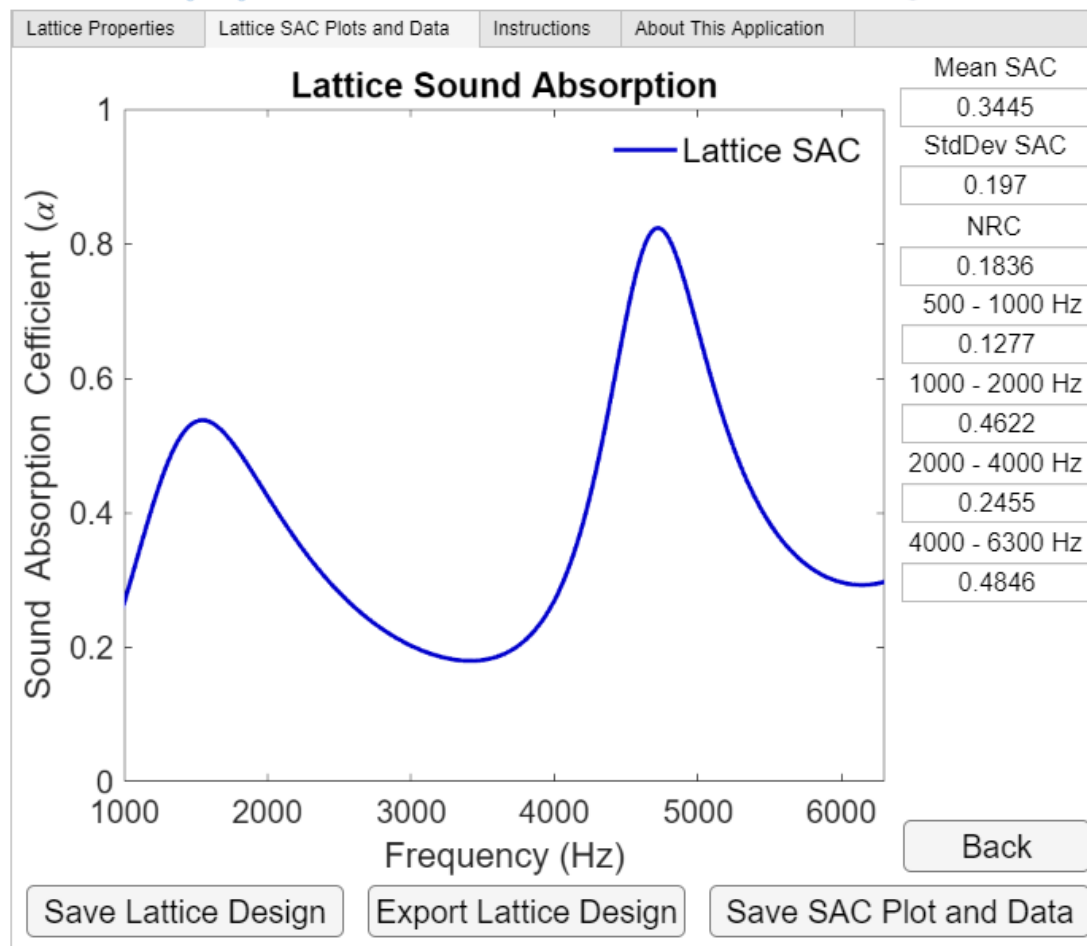
Strut Edit Strut Edit Choose Cell Type Edit Choose Cell Type Edit

Surface Ratio: Surface Ratio: Surface Ratio: Surface Ratio:

Unit Cell: SC
Cell Type: Strut
Cell Length: 8.00000
Rel Density: 0.15000
Strut Length: 8.00000
Strut Width: 2.21312
Strut Width (1mm): 0.27664
Number of layers: 2
Surface Ratio: 0.800

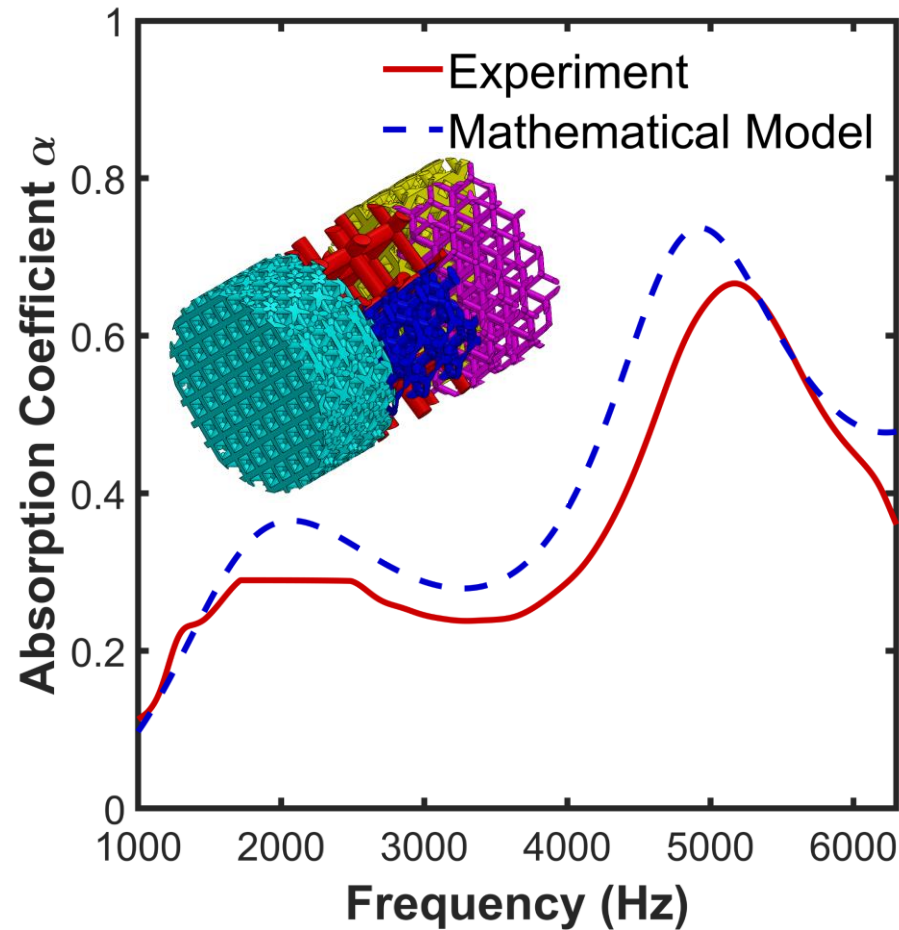
Unit Cell: Kelvin Cell
Cell Type: Strut
Cell Length: 6.00000
Rel Density: 0.20000
Strut Length: 2.12132
Strut Width: 1.18906
Strut Width (1mm): 0.19818
Number of layers: 2
Surface Ratio: 0.200

Load Lattice Reverse Plot Sound Absorption Refresh Reset



Example Cases

Heterogeneous Design:



Lattice Properties | Lattice SAC Plots and Data | Instructions | About This Application

Cross Section: Length/Diameter (mm):

Thickness (mm):

Number of Layers: Frequency: Hz to Hz

Layer Number:

Part 1: Surface Ratio:

Part 2: Surface Ratio:

Part 3: Surface Ratio:

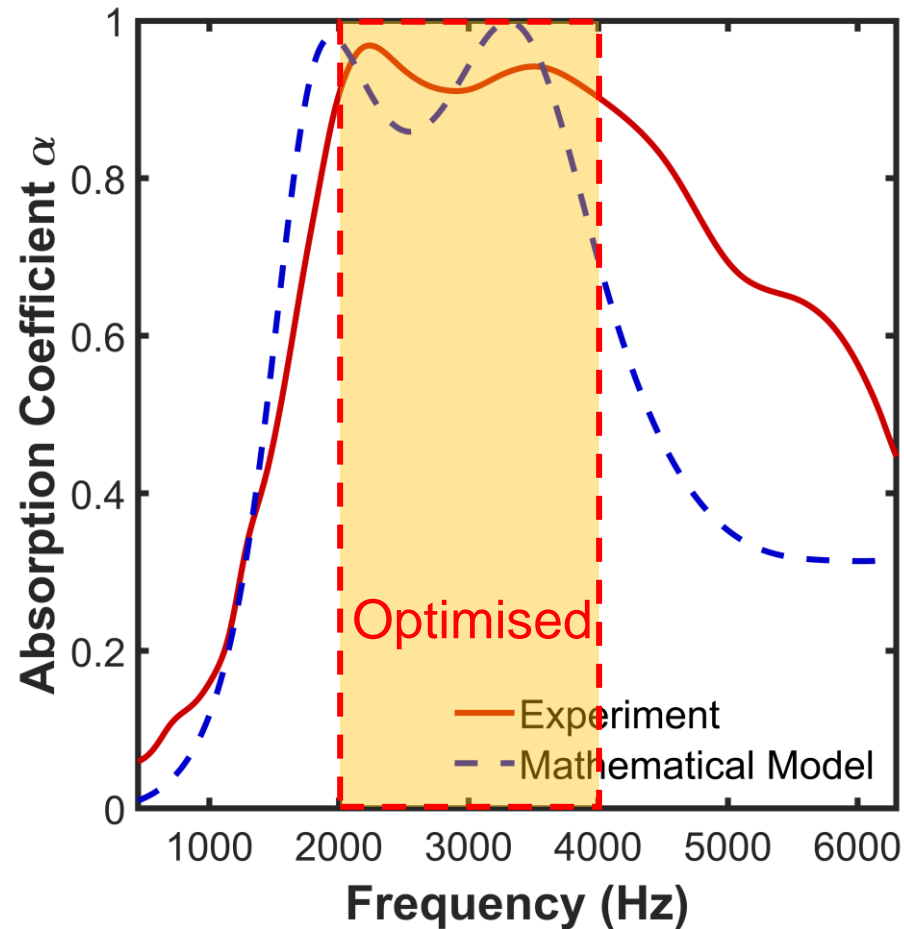
Part 4: Surface Ratio:

Unit Cell: SC
Cell Type: Strut
Cell Length: 8.00000
Rel Density: 0.15000
Strut Length: 8.00000
Strut Width: 2.21312
Strut Width (1mm): 0.27664
Number of layers: 2
Surface Ratio: 0.800

Unit Cell: Kelvin Cell
Cell Type: Strut
Cell Length: 6.00000
Rel Density: 0.20000
Strut Length: 2.12132
Strut Width: 1.18906
Strut Width (1mm): 0.19818
Number of layers: 2
Surface Ratio: 0.200

Example Cases

Optimization for Performance:



Lattice Properties | Lattice SAC Plots and Data | Instructions | About This Application

Cross Section: Length/Diameter (mm): (Slider: 10 to 50)

Thickness (mm): (Slider: 10 to 50)

Number of Layers: Frequency: Hz to Hz

Layer Number:

Part 1: Surface Ratio: (Slider: 0 to 1)

Part 2: Surface Ratio: (Slider: 0 to 1)

Part 3: Surface Ratio: (Slider: 0 to 1)

Part 4: Surface Ratio: (Slider: 0 to 1)

Unit Cell: FCC-Plate
Cell Type: Plate
Cell Length: 5.07319
Rel Density: 0.21971
Hole Diameter: 2.56016
Hole Diameter (1mm): 0.50464
Plate Thickness: 0.32208
Plate Thickness (1mm): 0.06349
Cross Section: Circle
Number of layers: 4
Surface Ratio: 1.000

Concluding Remarks

Design of Heterogeneous Lattices for Acoustic Applications

- Provision for Radical Heterogeneity
- Fast Estimation of Acoustic Performances with Reasonable Accuracies.

Lattices as Multi-functional Intelligent Materials

- Large Design Space + Additive Manufacturing => Heterogeneity
- Multi-Functionality: Lightweight, Mechanical, Acoustic, Thermal, etc.

Beyond LattSAC

- Ever-Expanding Library of Unit Cell Designs.
- Optimization for High SAC/STL at Targeted Frequency Ranges.
- Optimization for Simultaneous Mechanical + Acoustic Properties.



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THANK YOU

LattSAC GitHub:



LinkedIn Account:



Other Research Works:



Email: chua.junwei@u.nus.edu