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NUS National University of Singapore | College of Design and Engineering

LattSAC: Design of Heterogeneous Lattice Structures for Acoustic Applications

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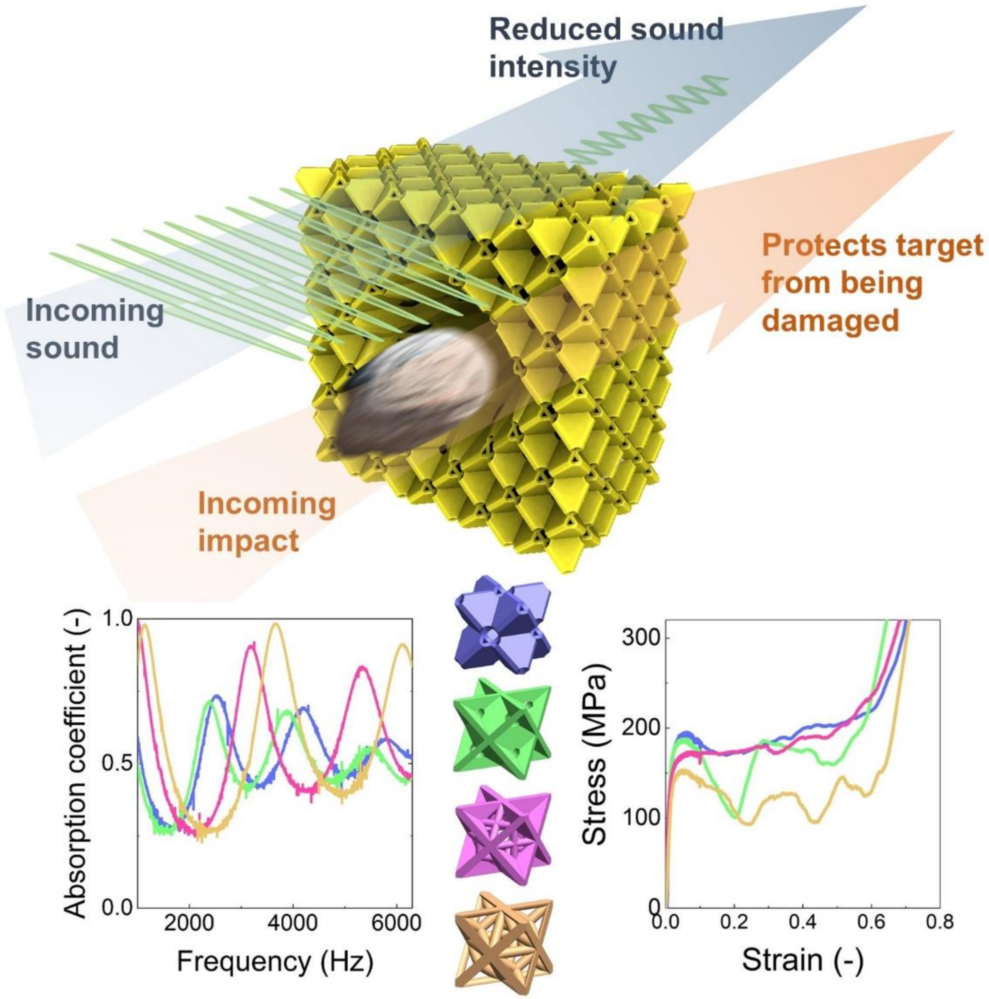
Department of Mechanical Engineering

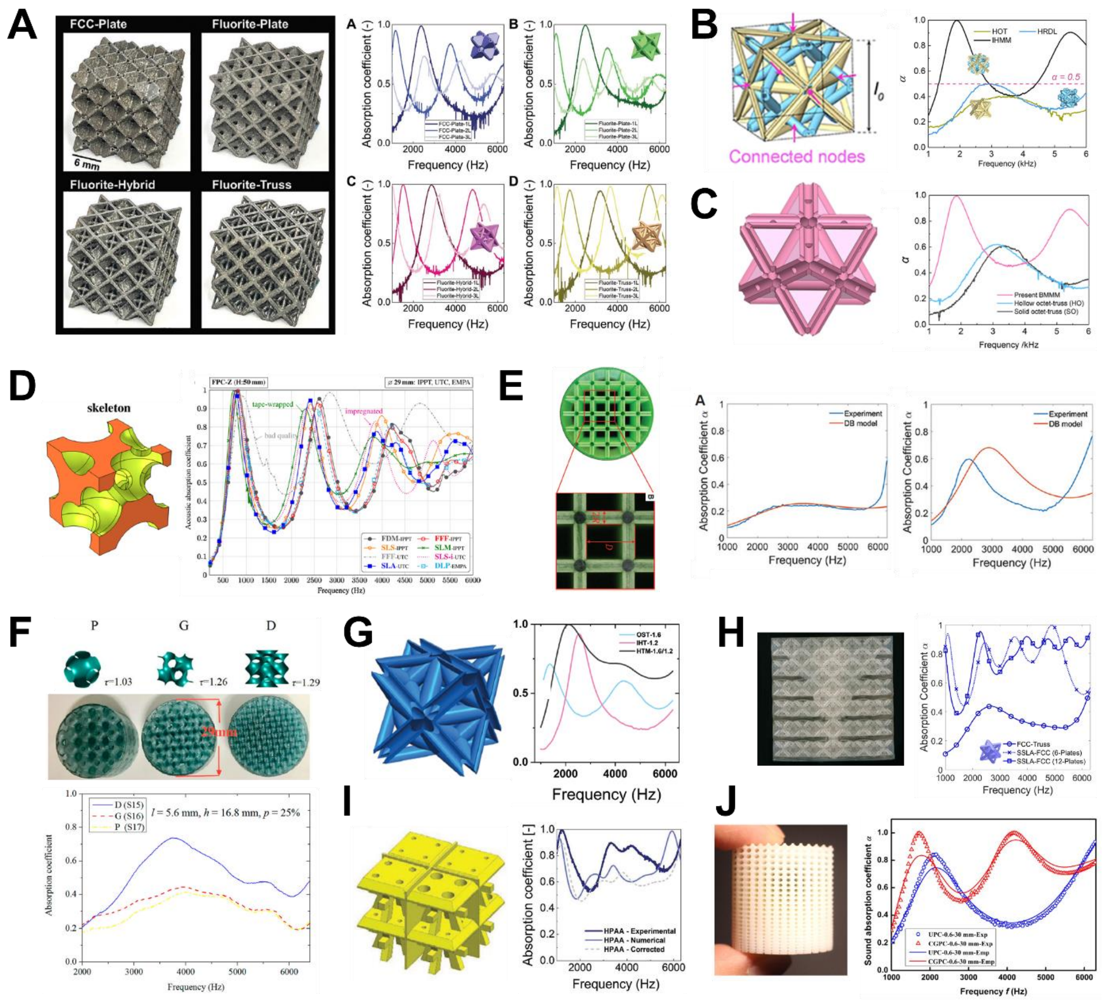
National University of Singapore

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

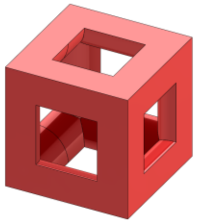
- Commonly Seen: Lightweight, Stiffness, Energy Absorption
- Recent Topic: Lattices for Acoustics
- Other Potential Functionalities?

Lattice Structures has Unlimited Design Space

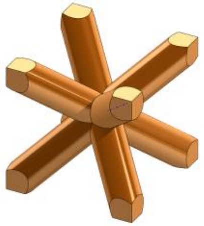
- Unlimited unit cells and geometries.
- Unlimited permutations of unit cells.
- Interactions between acoustic mechanisms.

Unit Cells

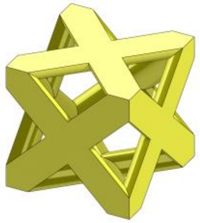
Strut Lattices:



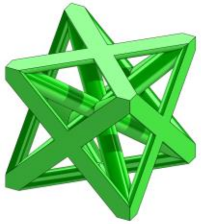
Simple Cubic (SC)



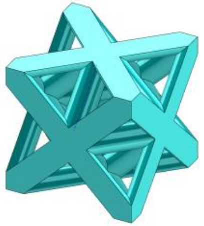
Body-Centered Cubic (BCC)



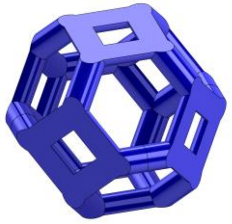
Face-Centered Cubic (FCC)



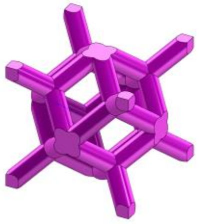
BCC+FCC



Octet

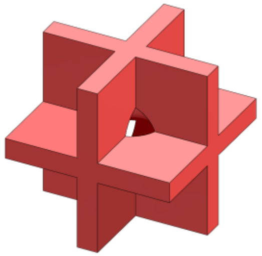


Kelvin-Cell

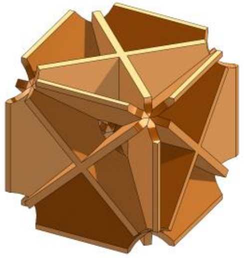


Rhombic Dodecahedron

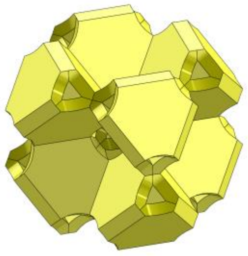
Plate Lattices:



Simple Cubic (SC)

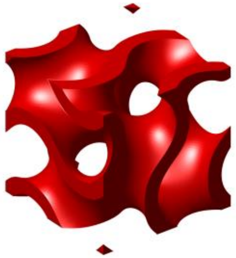


Body-Centered Cubic (BCC)

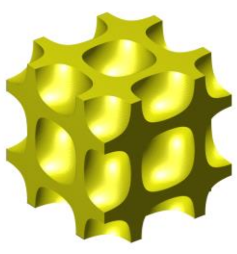


Face-Centered Cubic (FCC)

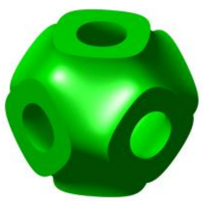
TPMS Lattices:



Gyroid (Sheet)

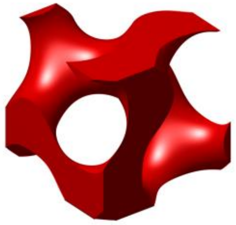


Diamond (Sheet)

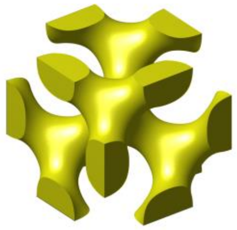


Primitive (Sheet)

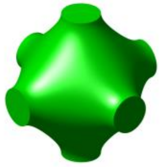
I-WP (Sheet)



Gyroid (Solid)



Diamond (Solid)



Primitive (Solid)

I-WP (Solid)

Mathematical Model

Strut Lattices:

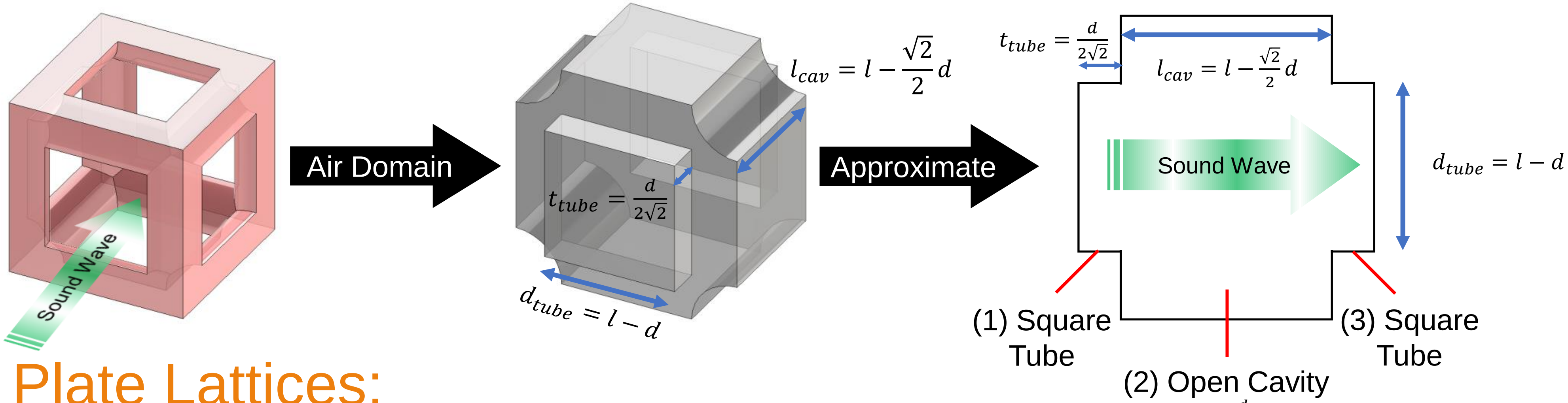
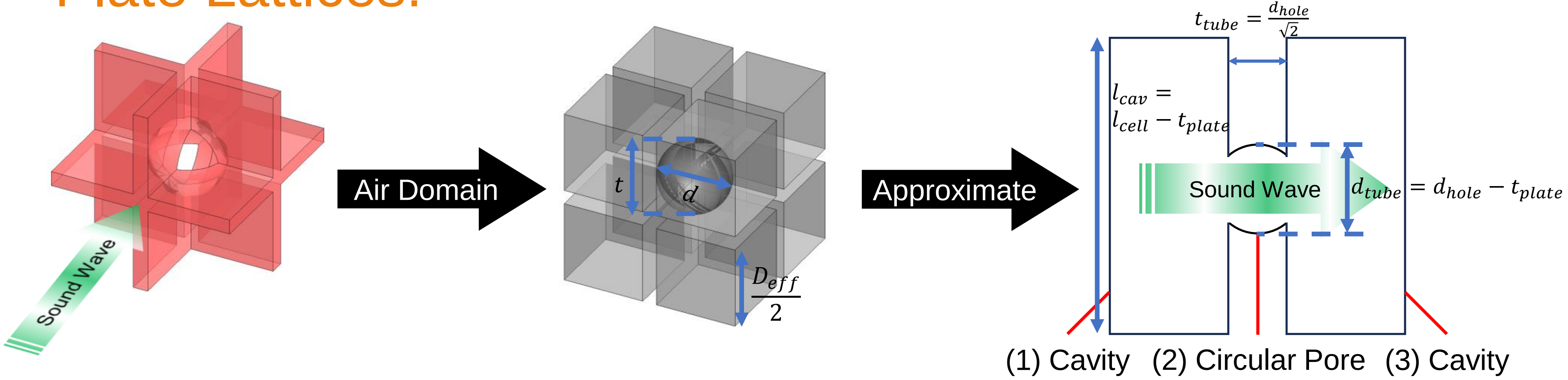
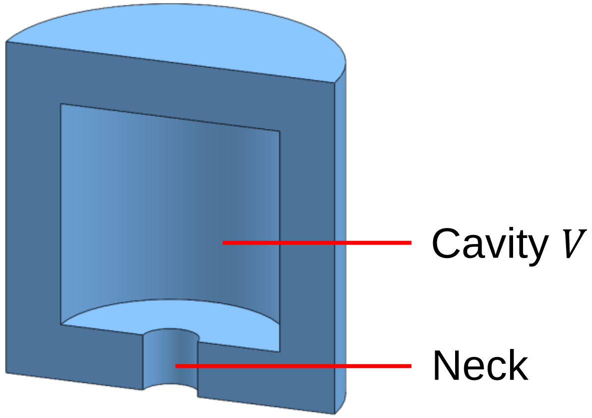


Plate Lattices:



Mathematical Model

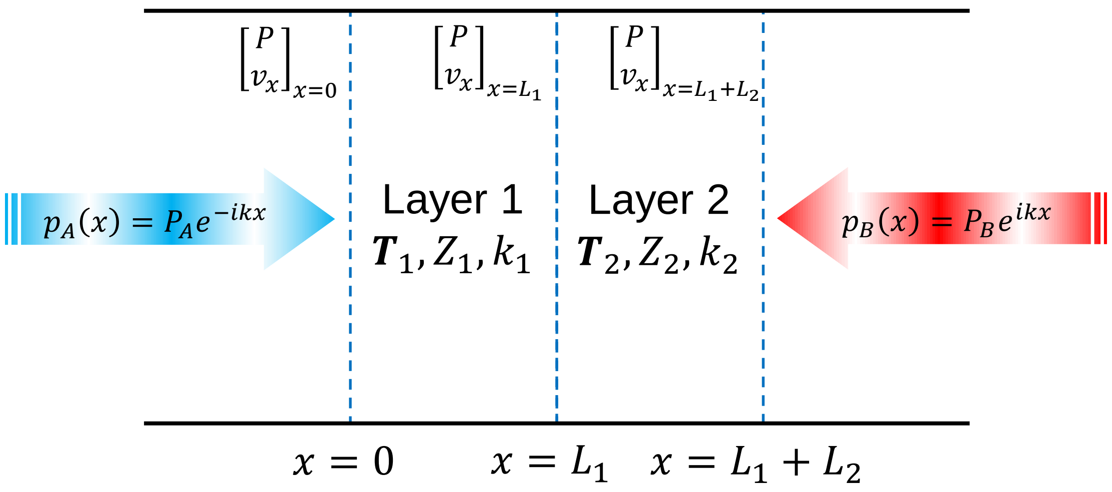
Microperforated Panel (MPP) Model:



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

- 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):



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

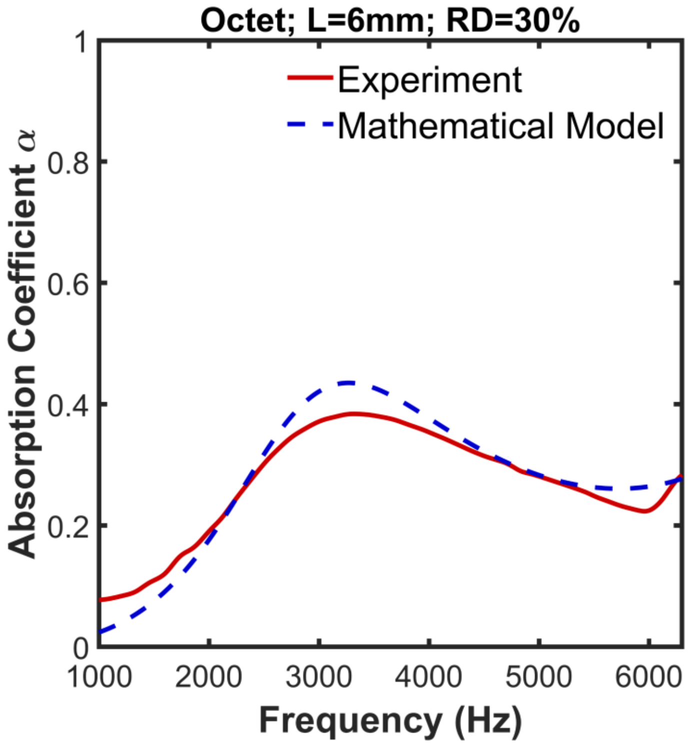
$$= [\boldsymbol{T}_{total}]\begin{Bmatrix} p \\ v_y \end{Bmatrix}_{x=t} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}\begin{Bmatrix} p \\ v_y \end{Bmatrix}_{x=L}$$

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

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

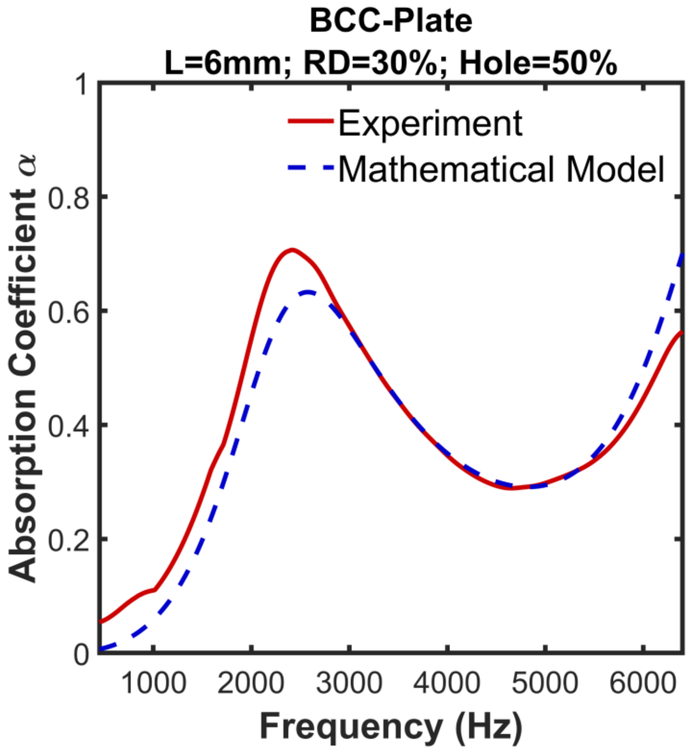
Model Accuracy

Strut Lattices:



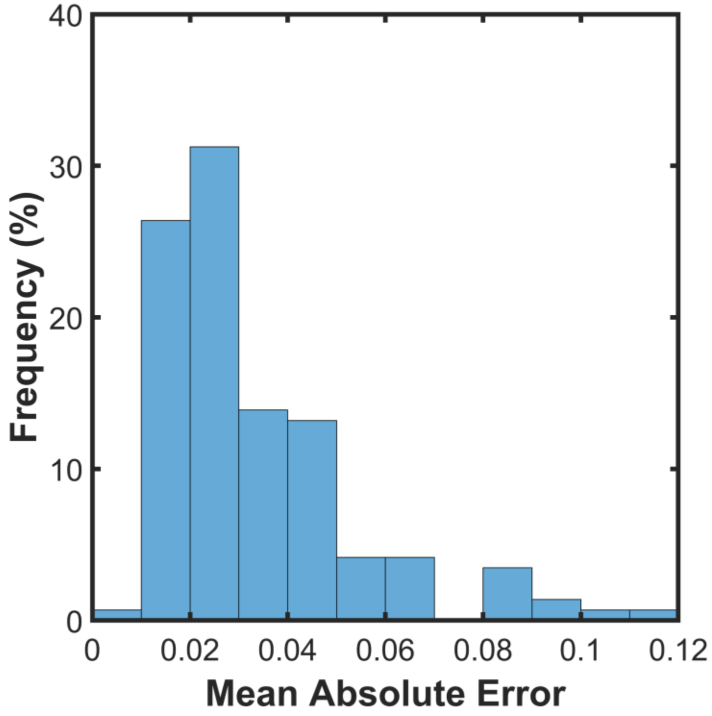
Mean Absolute Error: 0.0256

Plate Lattices:



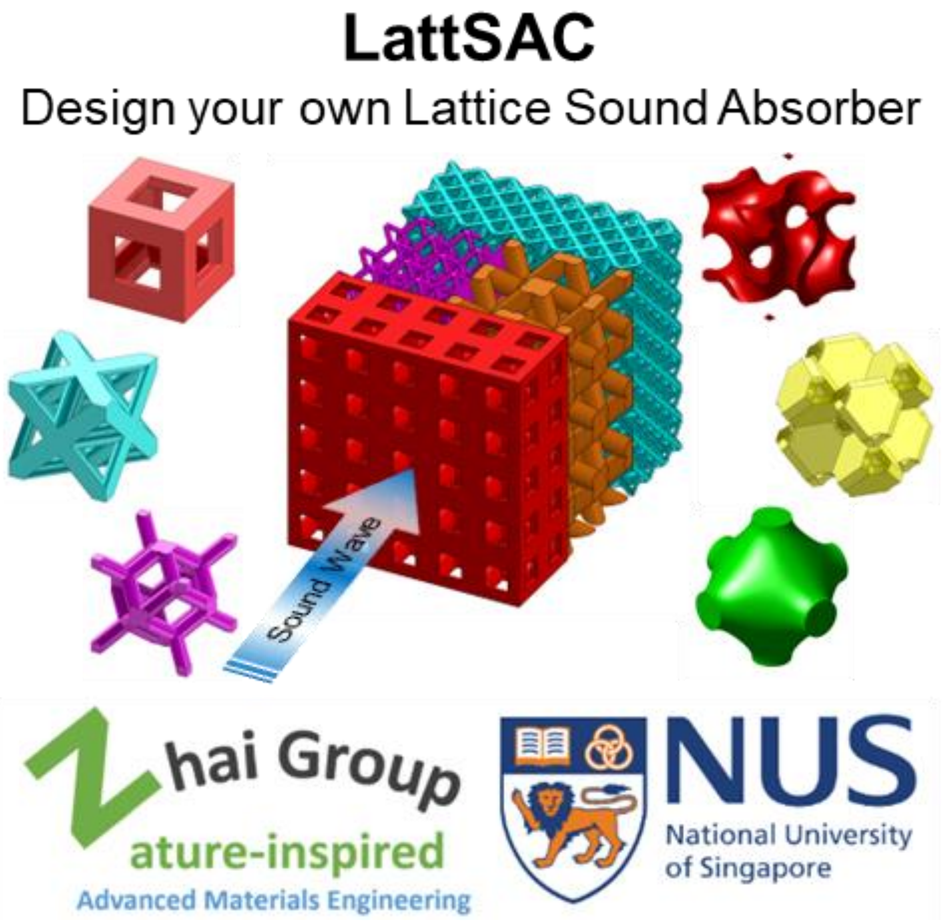
Mean Absolute Error: 0.0449

Histogram of Errors:



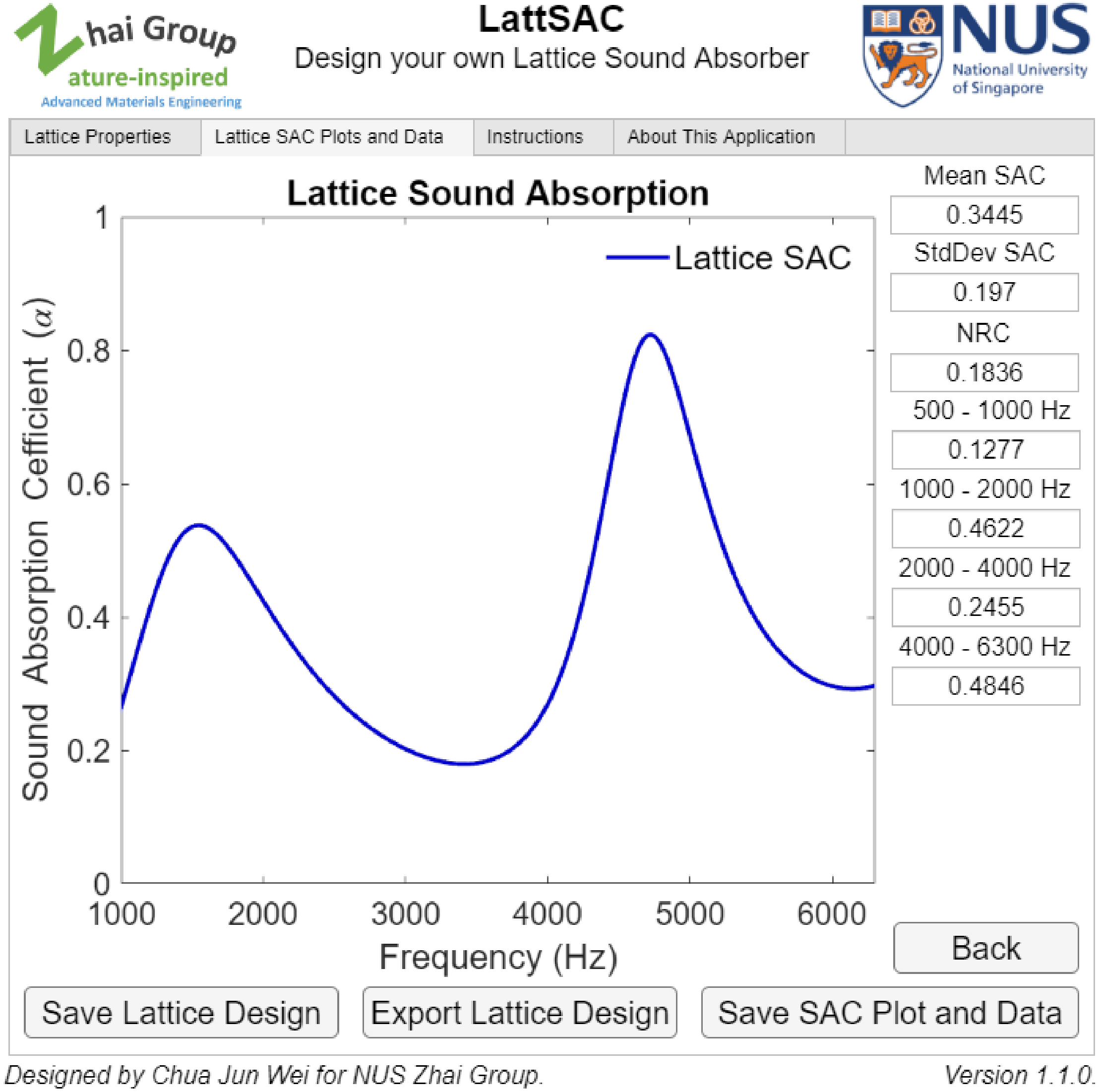
Mean Absolute Error: 0.0336

The LattSAC Application



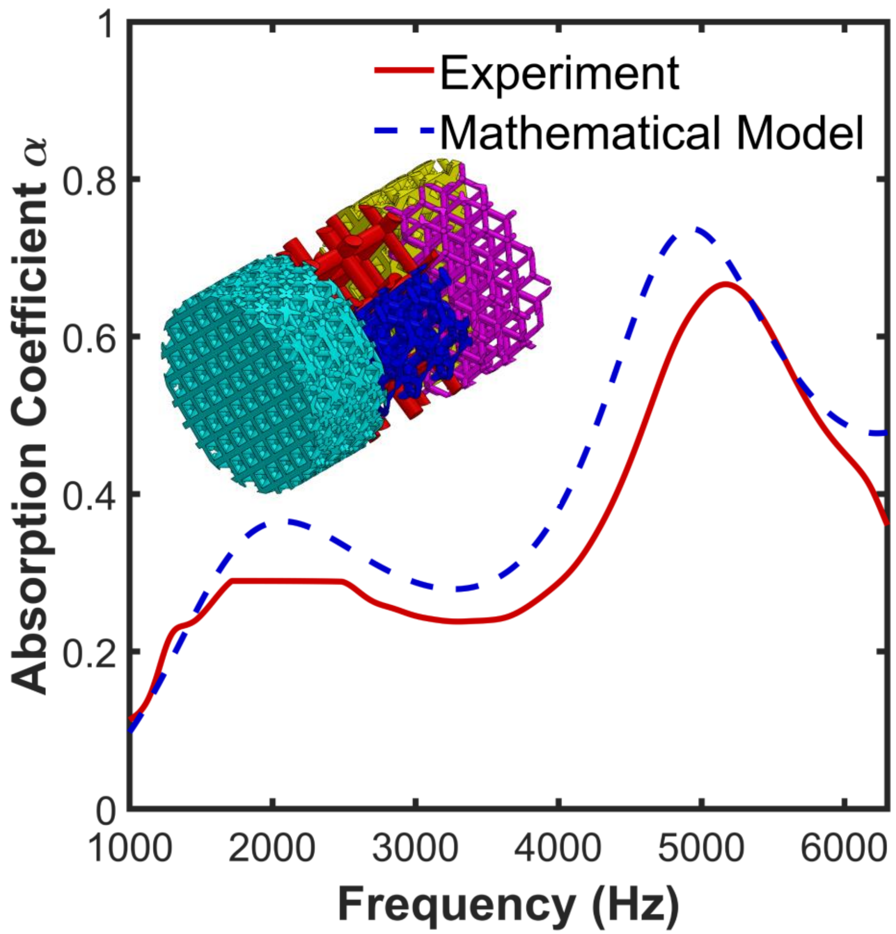
*Desktop Application
Download and Install for Free:
https://github.com/JunWeiChua/LattSAC

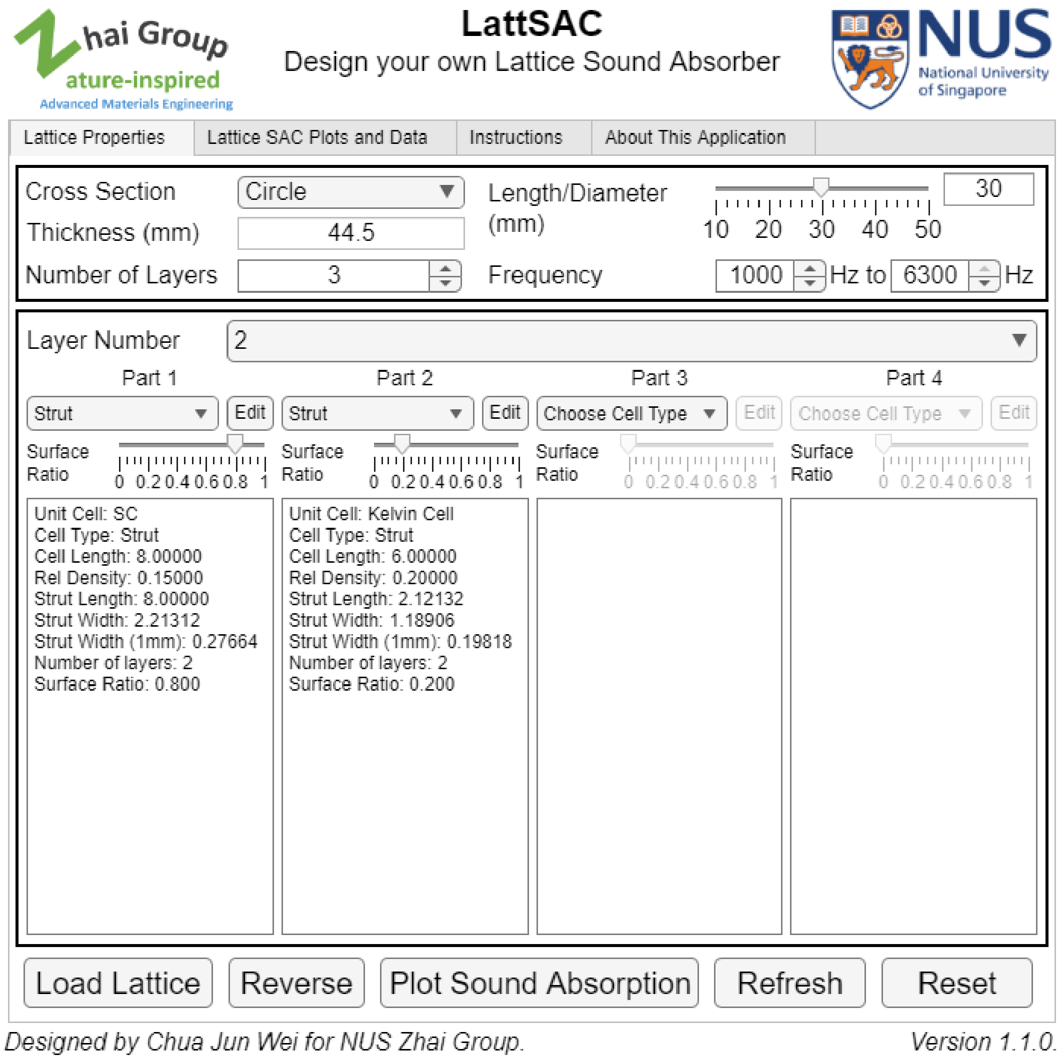
The LattSAC Application



Example Cases

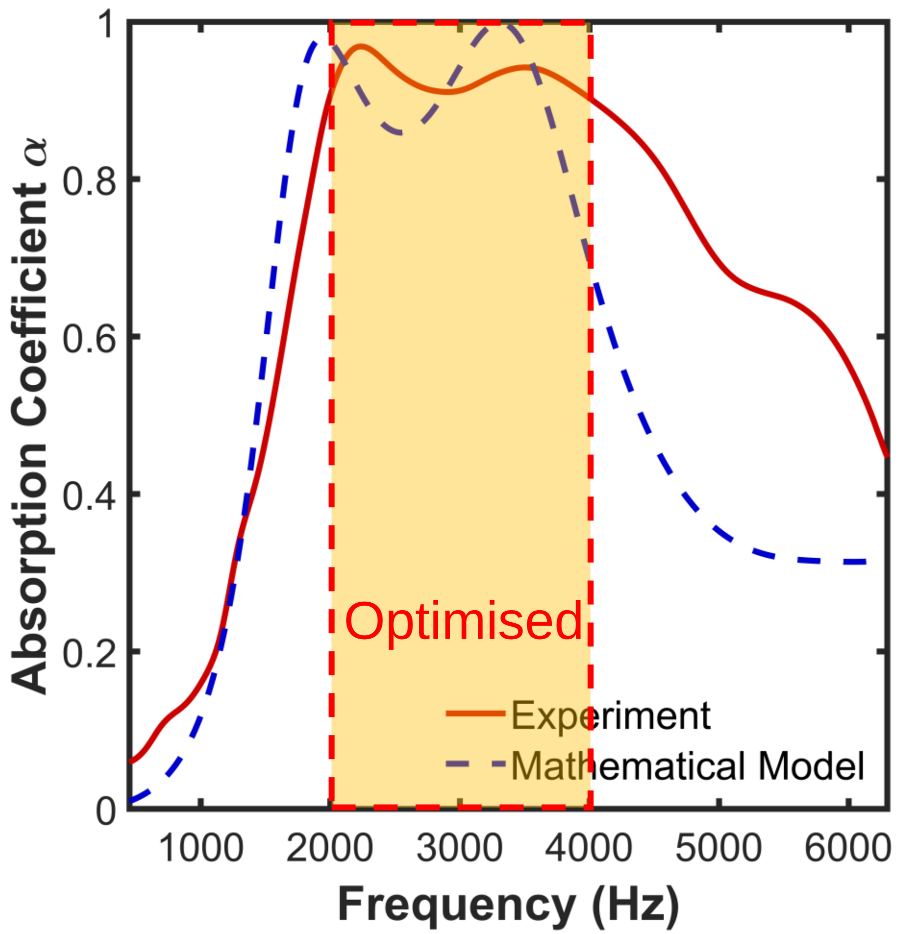
Heterogeneous Design:

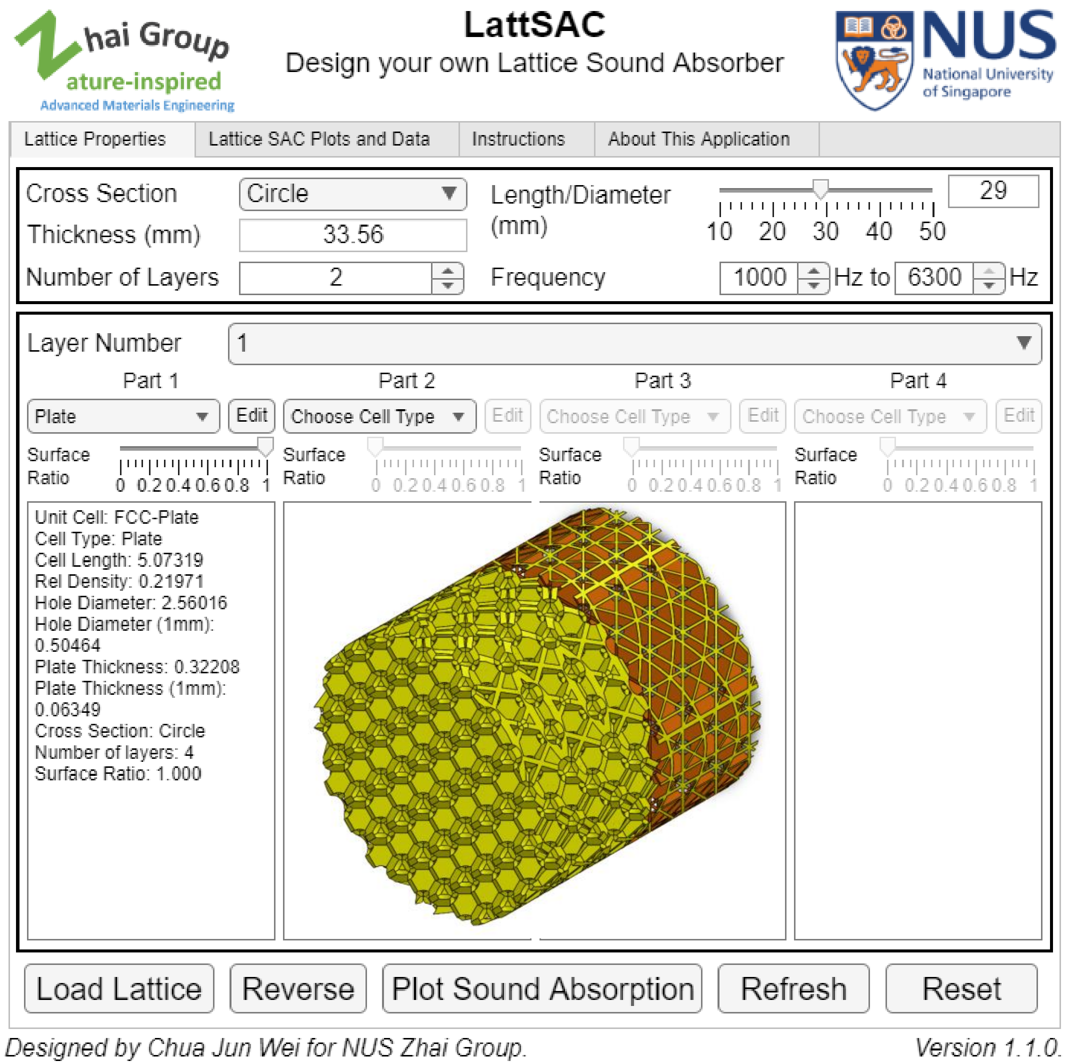




Example Cases

Optimization for Performance:





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.

THANK YOU

LattSAC GitHub:

LinkedIn Account:

Other Research Works:

Email: chua.junwei@u.nus.edu