Developing acoustically effective foams via cellular structure

Camille PERROT[1, a], Arnaud DUVAL[2], Valérie MARCEL[2], Minh Tan HOANG[1,2]

[1]*Université Paris-Est, Laboratoire Modélisation et Simulation Multi Echelle, MSME UMR 8208 CNRS*
[2]*Faurecia Interior Systems, Acoustic TechCenter, Mouzon, France*
[a)] *Email: camille.perrot@u-pem.fr*

Improving the performances of an acoustic material corresponding to a given manufacturing process

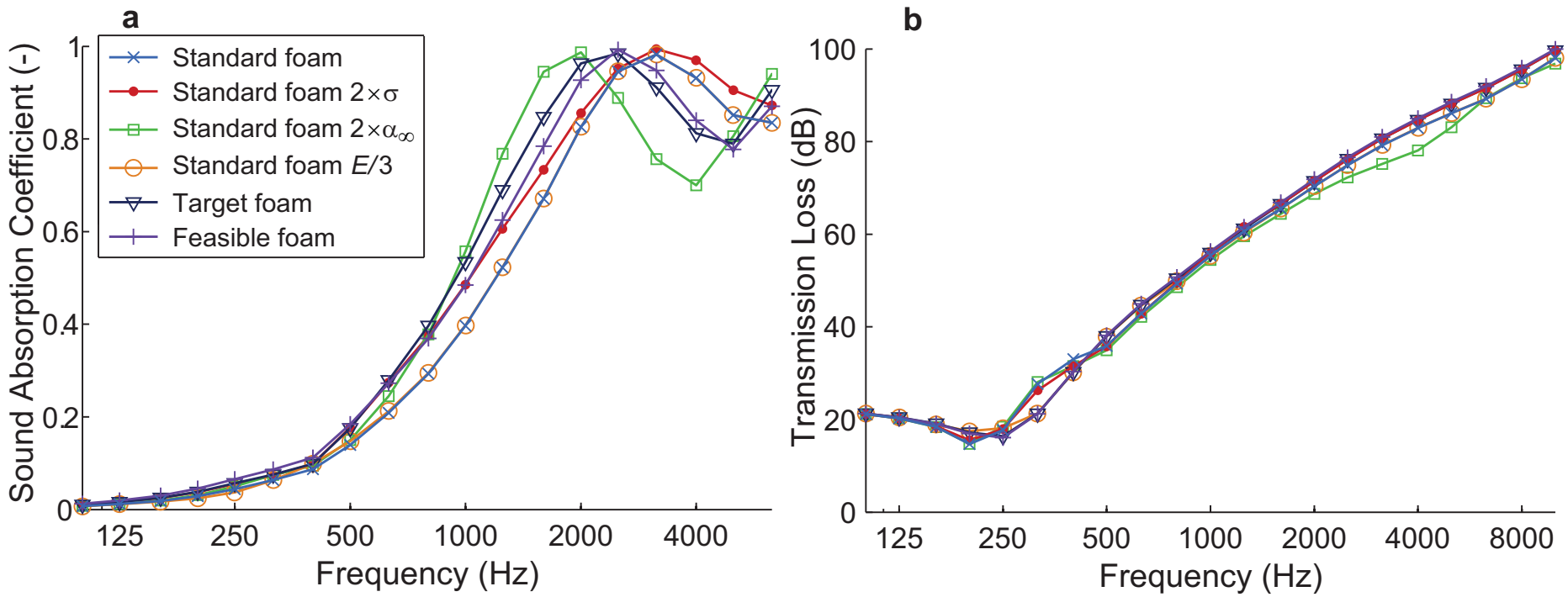
- **Problem statement**: Starting from an existing material whose macroscopic properties are supposed to be known, how to improve its acoustic performances in collaboration with the manufacturer?

- **Methodology**:
  - ✓ Use a simple parametric study at macro-scale in order to identify potentially interesting sets of macroscopic parameters to be reached - within a realistic range of variation.
  - ✓ Translate the identified sets of macroscopic parameters into corresponding microstructures to be manufactured.

- **Originality**: To show that the micro-macro approach can be used to support the development of acoustically effective foams.

Developing foams via cellular structure

Numerical experiments at macro-scale

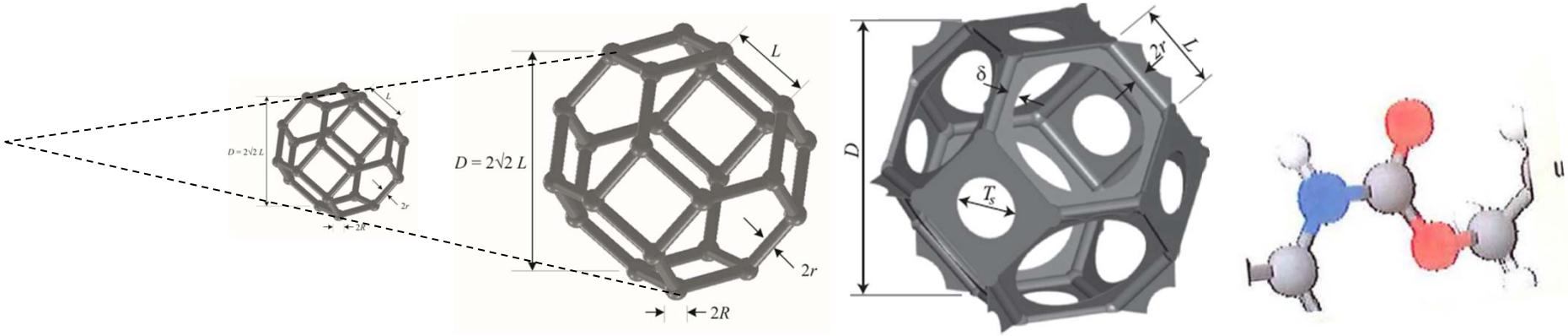


Targeted poroelastic parameters

Foam		ϕ	Λ' (μm)	σ (N.m^{-4}.s)	Λ (μm)	α_∞	E (Pa)
Standard	(H_0)	0.95	150	20 000	50	1.3	40 000
Insulating	(H_{1b})	0.95	150	40 000	50	1.3	13 333
Absorbing	(H_{2b})	0.95	150	40 000	50	2	40 000

Guidelines for the translation of the targeted poroelastic parameters into a feasible cellular structure

- k_0 - homothetic transformations
- α_∞ - Membrane effect
- E - Control the quantity of “urethane” bounds



Translation of the macroscopic parameters into a corresponding local geometry

1) Defining an open cell local geometry model

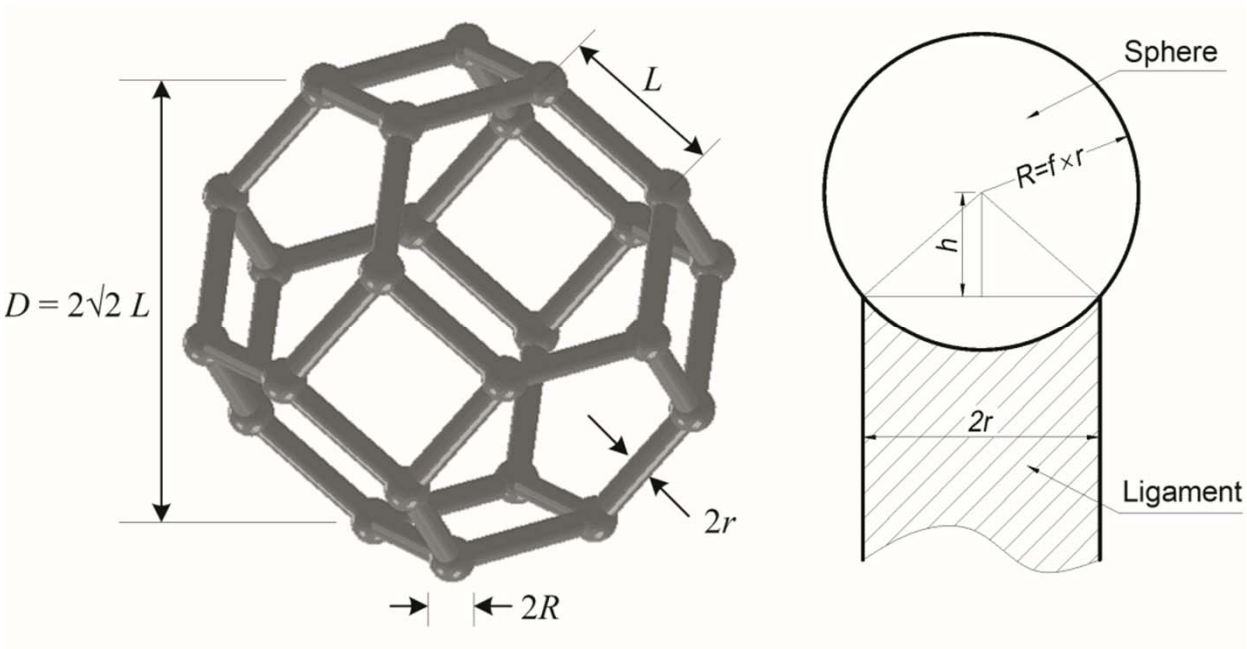


Fig. 1: Basic 3D periodic foam model geometry

→ Algebraic equations linking micro- to macro- geometric properties

Translation of the macroscopic parameters into a corresponding local geometry

2) Scaling the unit cell from the prescribed porosity and permeability

- $\phi_{\exp} \rightarrow \left(\frac{2r}{L} \right)$

- $k_0 = D_h \times k_d$

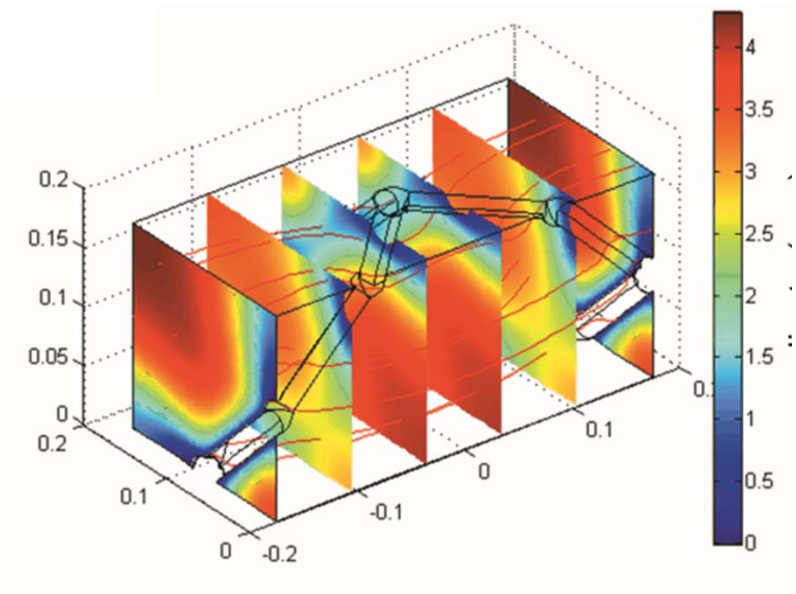


Fig. 2: 1/4th of a reconstructed foam sample period.
Low-frequency scaled velocity field k^*_{0xx} [x 10^{-9} m^2]

→ Compute all the transport parameters from first-principle calculations

Translation of the macroscopic parameters into a corresponding local geometry

3) Increasing the closure rate of membranes up to the targeted tortuosity

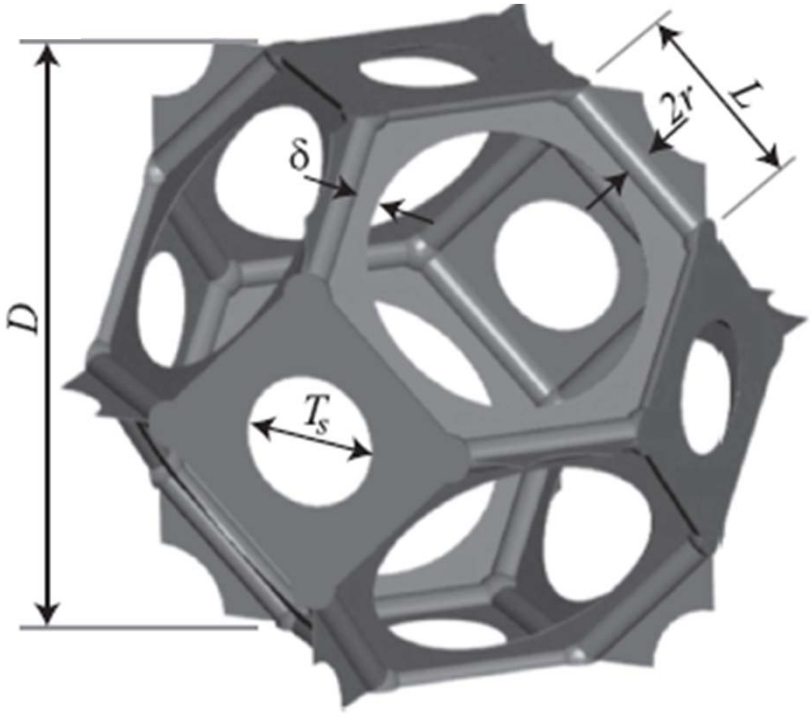


Fig. 3 Membranes implementation using an iterative algorithm on δ from a 3D open cell model with a testing instruction on the tortuosity

Illustration of the solution fields allowing to compute transport and elastic properties of the microstructures

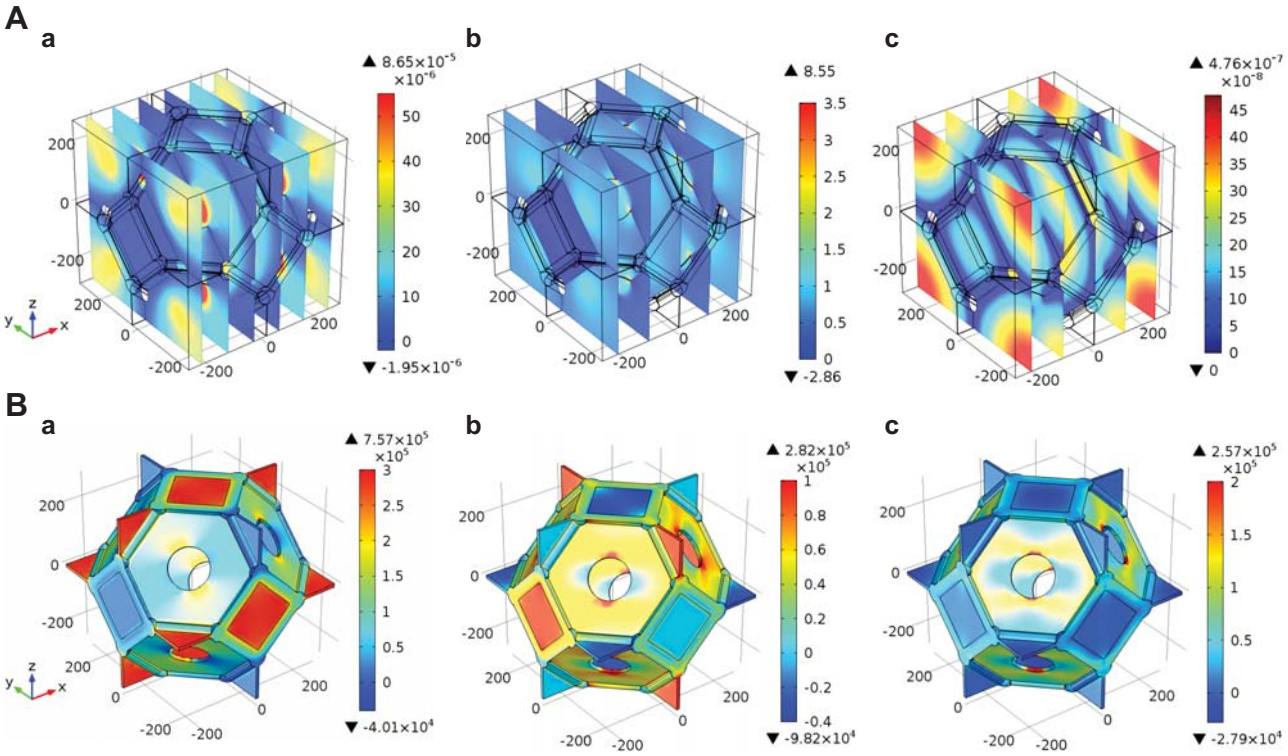


Fig. 4 A(a) Viscous flow, A(b) potential flow, A(c) thermal conduction; and B(a) stress field σ_{11}, B(b) stress field σ_{22}, B(c) stress field σ_{12}

Comparison between measurements and computations for the manufactured materials

Foam	Method	ϕ	Λ' (µm)	σ (N.m^{-4}.s)	Λ (µm)	α_∞	k_0' ($\times 10^{-10}$m^2)
H_0	Measurements	0.95 ± 0.01		18 000 ± 4 808			
	Characterization		452 ± 210		85 ± 8	1.49 ± 0.15	30 ± 13
	Computation		201 ± 35		78 ± 18	1.39 ± 0.32	53 ± 25
	Direct		214	13 630	90	1.26	54
H_{1b}	Measurements	0.93 ± 0.01		36 116 ± 8 185			
	Characterization		164 ± 20		68 ± 19	2.25 ± 0.14	24 ± 7
	Computation		147 ± 23		51 ± 10	1.45 ± 0.29	29 ± 12
	Direct		143	41 535	48	1.51	28
H_{2b}	Measurements	0.97 ± 0.01		35 139 ± 6 921			
	Characterization		226 ± 76		53 ± 22	2.32 ± 0.68	68 ± 18
	Computation		179 ± 46		53 ± 11	1.77 ± 0.47	46 ± 28
	Direct		172	77 637	51	2.40	45

Comparison between measurements and computations for the manufactured materials

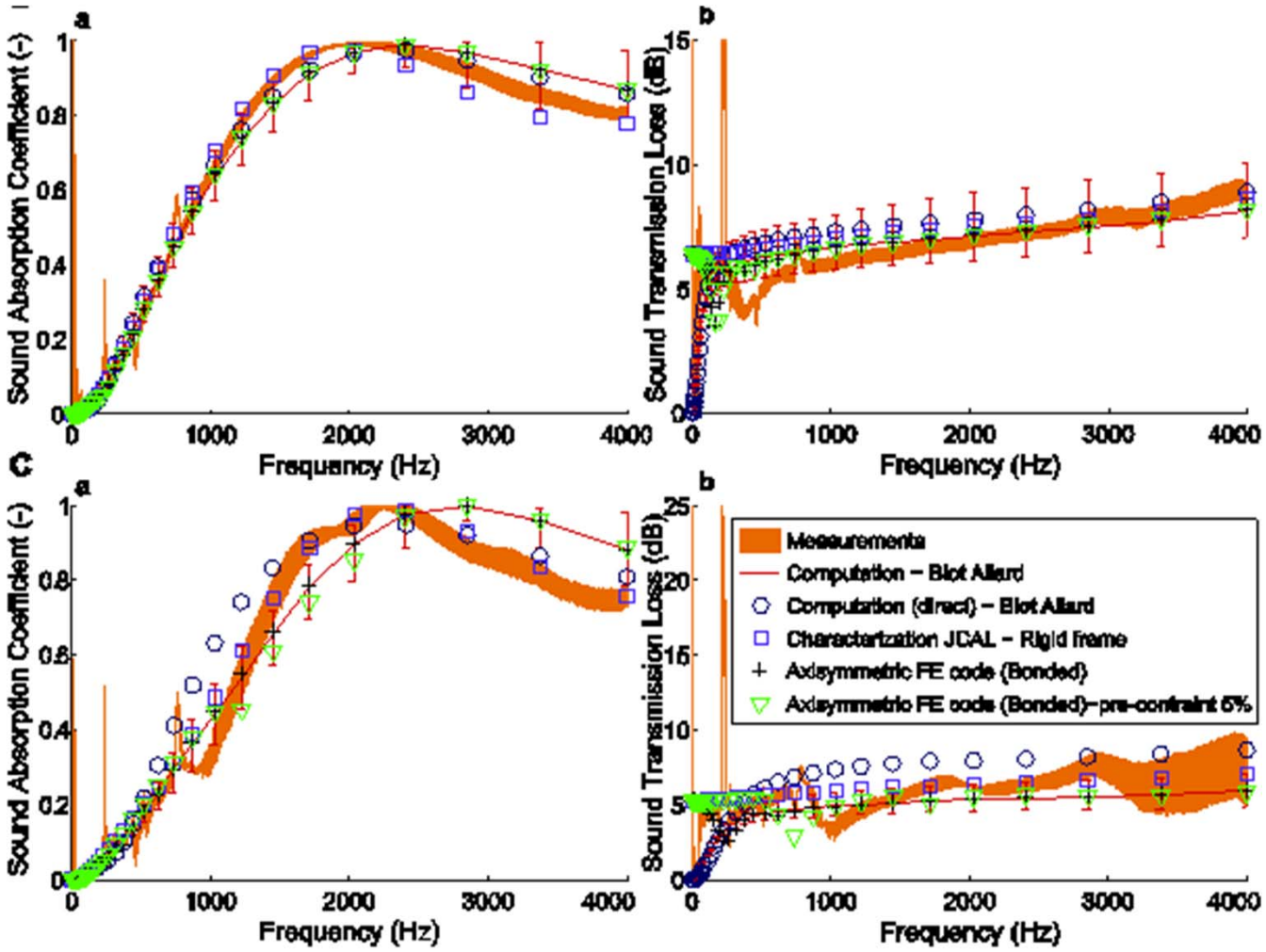
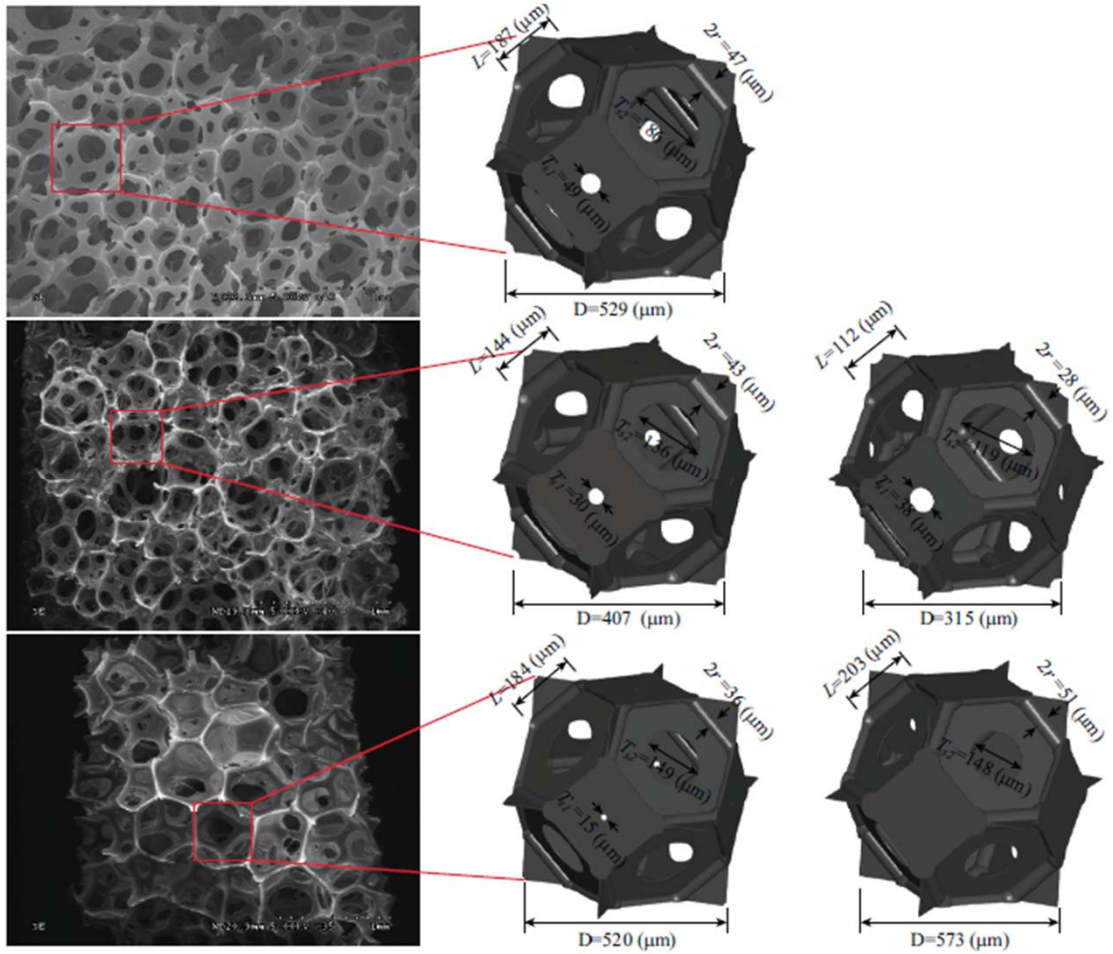


Fig. 5: Acoustical properties of the poroelastic materials as manufactured and corresponding computations

Cellular structures as manufactured, modelled, and recommendations



A continuity between microstructure, properties and manufacturing of poroelastic foams has begun to emerge

- A unified set of transport and elastic calculations has ben carried out.
- The tetrakaidecahedron with membranes is an appropriate 3D local geometry to achieve long-wavelength acoustics simulations of real foam samples.
- The above results were used to support the development of light weighted acoustically effective foams.
- The next step is the development of acoustically effective foams directly from an optimization of the cellular structure.

Comparison between the sound insulation properties of two materials: a soft felt, and a cellular foam sample