A case study on room acoustic solutions for social gathering places

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Introduction

This project proposes a comprehensive engineering approach involving the metamaterial design, simulations, and manufacture of new metamaterial lamps for improving sound absorption and reducing reverberation time in social gathering places. The case presented is a real restaurant in the Netherlands. The chosen space has dimensions 8 m x 3.5 m x 3 m and can accommodate 12-16 persons.

Fig. 1 Photo of the interior of the chosen space (left), T_{20} from the measurements and numerical model (right).

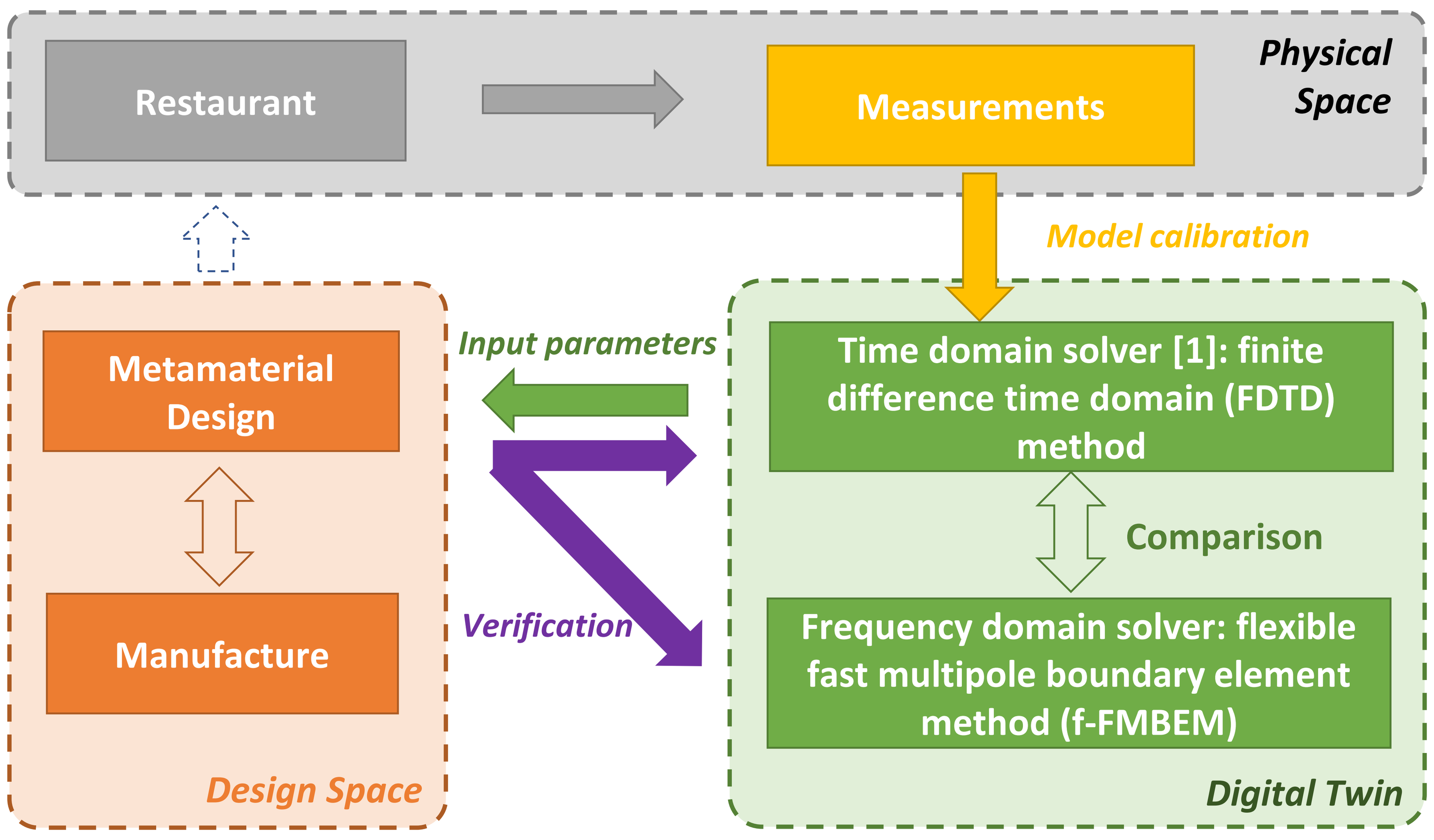


Fig. 2 Diagram of the case study.

Simulation: model calibration

The f-FMBEM and FDTD solvers are compared in both time-domain and frequency-domain on several cases to ensure the correctness of the solutions given by the two numerical solvers.

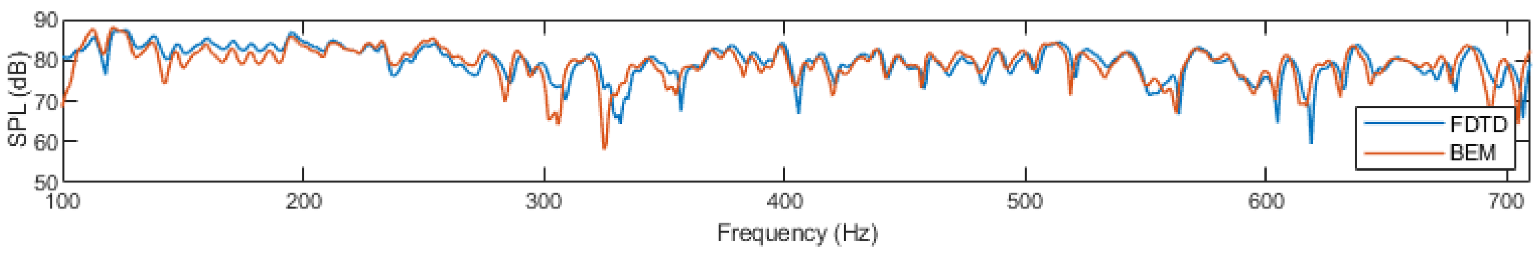


Fig. 3 Comparison of f-FMBEM and FDTD in frequency-domain.

FDTD simulations are used to calibrate the material properties of the model according to the measured T_{20} and create the *Digital Twin*. The acoustic parameters, such as frequency band, surface area, location and impedance for the new treatment are then provided for the metamaterial design to achieve the desired reduction of T_{20}.

Metamaterial design & Manufacture

Prototype description:

Multiple ducts combined to create multiple absorption peaks.

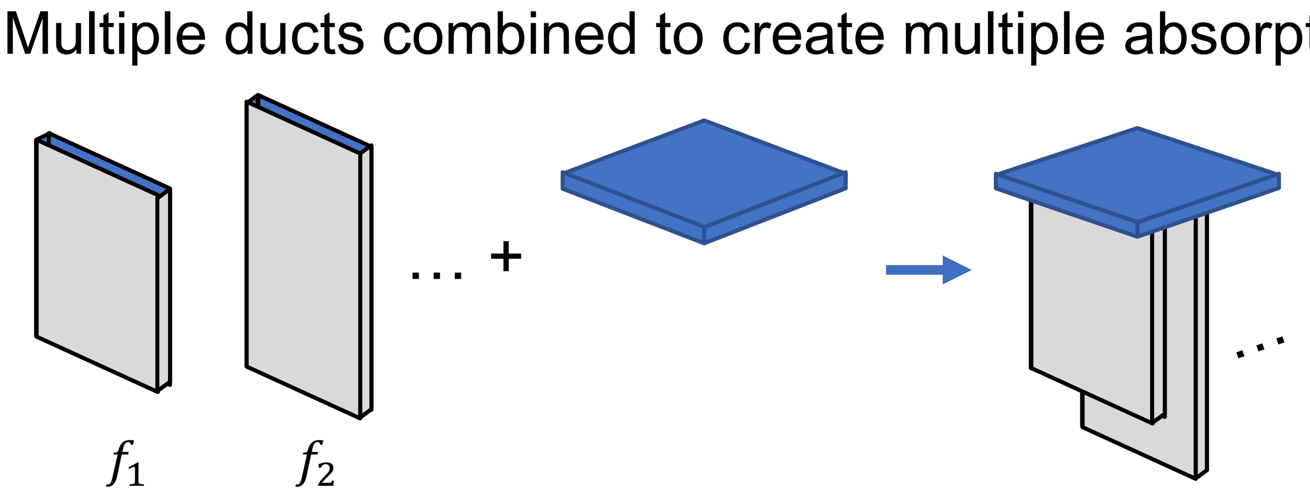


Fig. 4 Description of the prototype design.

Analytical model:

Numerical model derived for the design; a good match observed with simulation results

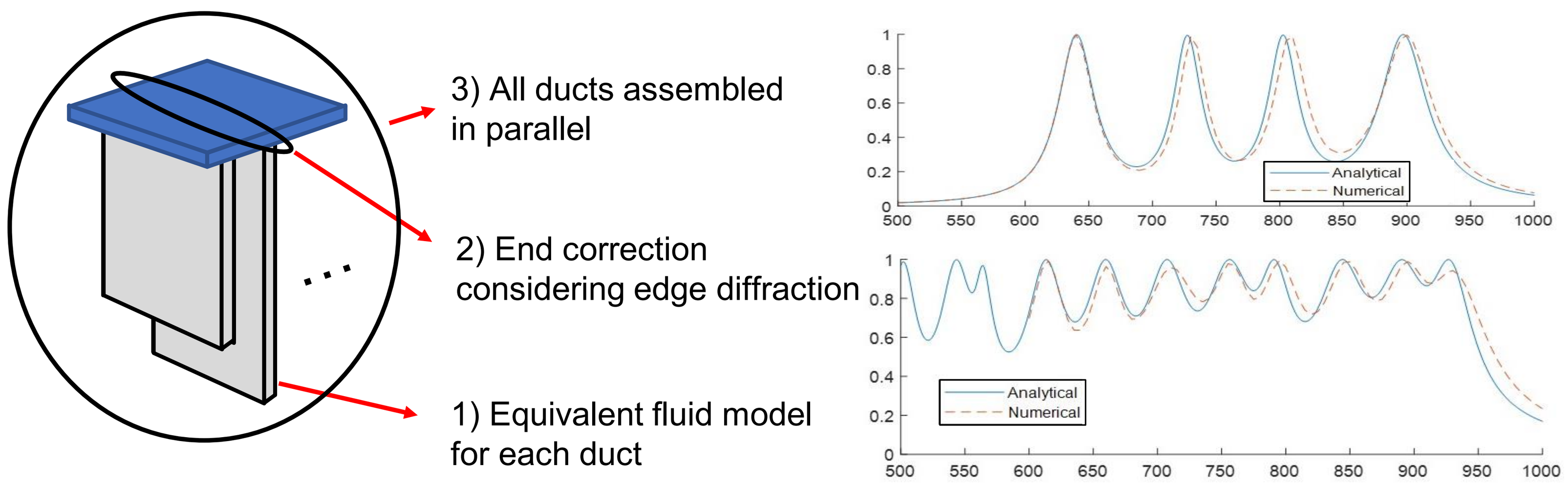
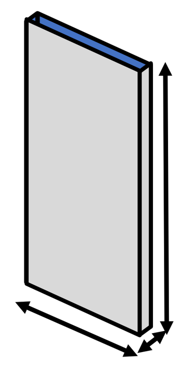


Fig. 5 Validation cases, top: 4 ducts design; bottom: 10 ducts design

Optimization & result:

Optimization performed on the geometry to maximize the absorption; a set of duct geometries obtained.



- **Maximized:** absorption from 500 Hz to 1000 Hz
- **Variables:** Dimensions of ducts
- **Patch size**: 30 cm*30 cm
- **Nr. Of ducts**: 15

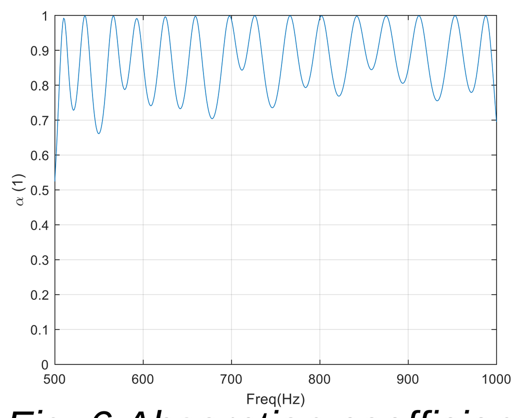


Fig. 6 Absorption coefficient of the optimized structure

Lamp design & Manufacture:

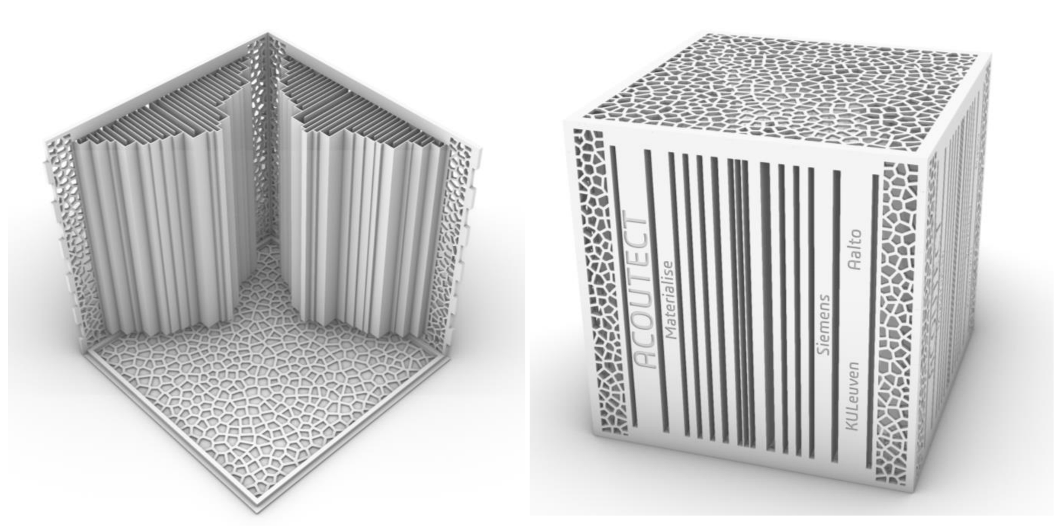
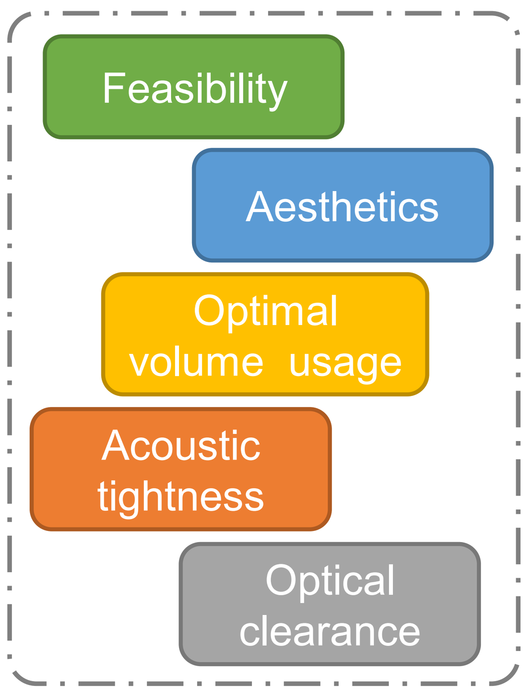


Fig. 7 Design of the acoustic metamaterial lamp with different positioning of ducts inside of the volume.



Simulation: verification of the design

The metamaterial lamps are evaluated in the digital room. f-FMBEM analyzes the room modes and computes the sound pressure level (SPL) over the target frequency band. The reverberation times are extracted to evaluate the improvement of the design. The analysis can also provide insights to the spatial arrangement of the lamps.

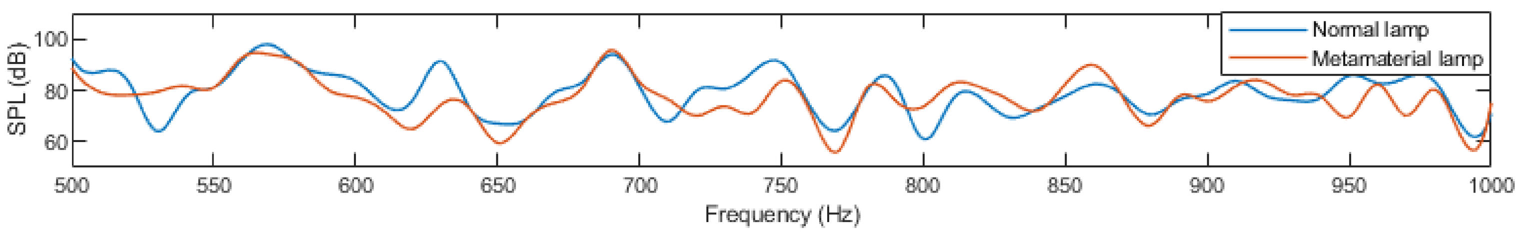


Fig. 8 Average SPL comparison at 1.2 m height horizontal plane, new treatment shows 16 dB maximum reduction, and 2 dB average reduction

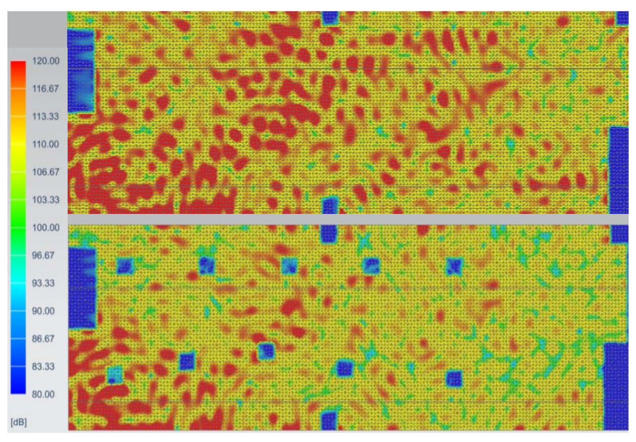


Fig. 9 Top view of frequency response at 850 Hz: original room (top) and room with metamaterial lamps (bottom)

Table. 1 Reverberation time comparison

1/3 octave band	Original room	Room with new treatment
500	1.32 s	0.62 s
630	1.28 s	0.58 s
800	1.19 s	0.61 s
1000	1.29 s	0.76 s

The numerical study verifies that the new metamaterial lamps can mitigate many of the high modes in the room over the target frequency band and significantly reduce the reverberation time of the original room.

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[1] Saarelma, J. (2013). Finite-difference time-domain solver for room acoustics using graphics processing units. *Master's thesis, Aalto University, Finland.*