DESTRUCTIVE INTERFERENCES CREATED USING ADDITIVE MANUFACTURING

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1 Introduction

The broad absorption of low-frequency noise typically requires the utilization of large thicknesses of sound absorbing materials. As this creates space issues, there is a demand for thin broad low-frequency absorbers. This research aims to develop an acoustic panel for low-frequency broad sound absorption. For this scope, passive destructive interference resonance tubes were created through the project "*Architectonics Using Destructive Interference Acoustics*". As the work deals with complex geometries, the ability of digital fabrication to enable design freedom and to support the production of complex geometries was explored.

Sound-absorbing technologies are often constrained by conventional techniques represented by porous absorption, typical of energy-dissipative materials, and reactive absorption, typical of vibrating panels and perforated ones. However, another way to absorb a sound is by generating destructive interference reflections, a principle generally used in active noise control applications [1].

Destructive interference means that two interfering sound waves that are in counter-phase, cancel each other. Digital fabrication may play an important role in developing customized sound absorbing components capable of generating destructive interference reflections below 500 Hz. The innovative samples were inspired by recent studies using 3D manufacturing for creating highly absorbing materials [2]. The project consisted in developing and testing various prototyping methods via digital fabricated prototypes, after having encoding rules for the geometric design generation.

2 Previous studies

In order to have destructive interferences, it must be created a pathway open at both ends that provide two entry points for the soundwaves, so that at some point within the tunnel, the waves will be at 180˚ phase difference resulting in cancelling each other out [3]. The benefit of this strategy is that it does not require active components to reduce noise.

For a sound path tube with destructive interferences, Setaki et al. presented a set of formulas to calculate the frequency of maximum absorption [2]. This is inversely proportional to the tube length ($f=(2n-1)c/2L$), so that a long tube is required to absorb low frequency. Meanwhile, Cai et al. focused on the design of coplanar Helmholtz resonators using quarter-wavelength resonance tubes [3]; this last design is a tube with a single hole of entry for the soundwave and with a rigid termination at the other end of the tube to generate an out-of-phase reflection. Cai et al. found that the opening of the tube contributes to most of the damping due to the friction loss [3].

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3 Methodology

The results of the studies of Costa [4] were used to calculate the length and radius diameter of the tubes for low frequency absorption. Table 1 shows the parameters of the absorbers that were tested. As evident the tubes had to have a significant length, especially for absorbing at frequencies below 200 Hz.

Table 1: Geometrical characteristics of the created resonators.

Frequency (Hz)	Radius (mm)	Path length (mm)	Frequency (Hz)	Radius (mm)	Path length (mm)
100	8.4	850	**250**	**7.2**	**340**
125	**8.2**	**680**	315	6.9	270
160	7.8	531	400	6.6	210
200	7.4	425	**500**	**6.5**	**170**

A parametric script using Grasshopper through Rhinoceros where the parameters could be changed to create a new resonance tube was created. Due to goal of testing the resonators within the impedance tube, the overall diameter of the module had to be 10 cm. This raised the challenge of efficiently organizing the resonance tube while still limiting the overall depth of the absorber. Figure 1 shows the modules that were designed. Originally, the two openings proved to be in odd locations, e.g. close to each other (see the 250 Hz sample). Thinking to assembly more resonators together, these openings would create clustered holes with large spacing in between; the openings were hence spread toward the edge to create a more uniform pattern if more absorbers are put together. Then, the optimal setup to increase the path density within the cylindrical volume was searched: this ended having three central circles surrounded by a ring of more circles to allow both ends of the tube on the top face.

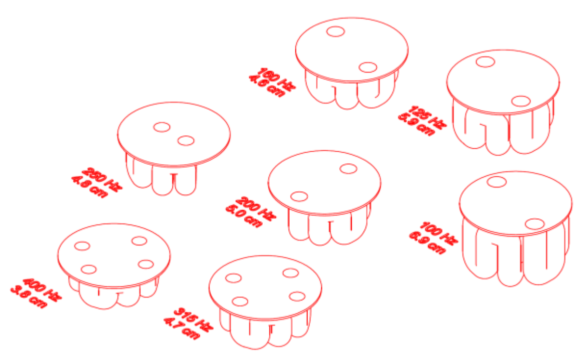

Figure 1: Drawings of the investigated sound absorbers.

Figure 1 shows that each system had a different depth, from 3.8 cm up to 6.9 cm. For the aesthetics, the openings of the resonance tubes were considered fairly distributed.

The equipment used for the fabrication of the modules was a Dimension SST 1200es. This 3D printer model uses Fused Deposition Modelling (FDM), a technique that takes solid filament and heats it at the head. The model is fabricated layer by layer as the melted filament is extruded and hardens. The printed layers accumulate and harden over each other, culminating in a finished model. FDM requires a secondary soluble material used as temporary structural support which is removed after the printing is submerged into hot water. One aspect about the FDM that needs to be kept in mind is that the layering nature of the FDM method causes slight undulations on the sides of the tubes, so the resonator walls may present some air pockets within each layer which may cause sound leakages and anomalies in its acoustic behavior (Fig.2).

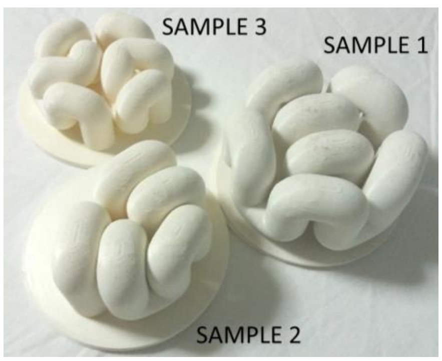

Figure 2: Photos of the 3D printed passive resonators.

The material used for this study was low-density ABS plastic. It was decided to investigate if the acoustic results were caused by the modules having one or two openings per tube. This prompted an investigation on how sealing one end of the tube could affect the performance of the modules. Based on the three fabricated modules (Fig.2), with theoretical maximum absorption at 125 Hz (#2), 250 Hz (#1), and 400 Hz (#3), 2 mm thick plates were fabricated so that they could be attached to the face allowing to cover one of the openings.

4 Results and conclusions

An impedance tubes was used for the testing the effectiveness for the three samples in Fig.2. Table 2 reports their one-third octave band sound absorption coefficients.

Figure 3 shows the sound absorption behaviour. The results show that the untapped samples result in high absorption than when a single hole (two in the case of sample #3) was open. This may partially be explained by the increase availability for the sound to travel into the tube, but it is clearly an effect of the resonance created in the tube. As evident the untapped samples (higher number of holes), especially for the sample #2, show sound absorption peaks in general agreement with the theoretical expectations. Although, the strong peaks, the absorption coefficients in Table 2 still result in low values. Future work will consider to create square panels arranging different resonance tubes and targeting different frequencies to investigate how multiple modules perform together.

Table 2: Sound absorption results for the samples in Fig. 2 (in bold the frequency where the maximum absorption is expected).

Frequency (Hz)	Sample 1 *(2 central holes)*		Sample 2 *(2 edge holes)*		Sample 3 *(4 edge holes)*	
	1 hole	2 holes	1 hole	2 holes	2 holes	4 holes
100	0.07	0.00	0.00	**0.00**	0.00	0.00
125	0.35	0.25	0.26	**0.19**	0.23	0.24
160	0.52	0.39	0.39	**0.26**	0.24	0.29
200	0.55	**0.61**	0.36	0.21	0.18	0.27
250	0.40	**0.53**	0.31	0.25	0.17	0.20
315	0.33	**0.48**	0.51	0.19	**0.15**	0.13
400	0.37	0.48	0.22	0.47	**0.36**	0.14
500	0.39	0.44	0.25	0.18	**0.54**	0.14
630	0.26	0.55	0.20	0.14	0.28	0.19
800	0.26	0.37	0.18	0.12	0.18	0.64
1000	0.26	0.48	0.25	0.26	0.15	0.19
1250	0.19	0.37	0.25	0.18	0.43	0.08
1600	0.22	0.31	0.21	0.12	0.17	0.09
2000	0.17	0.20	0.00	0.03	0.61	0.19
2500	0.39	0.48	0.42	0.43	0.31	0.45

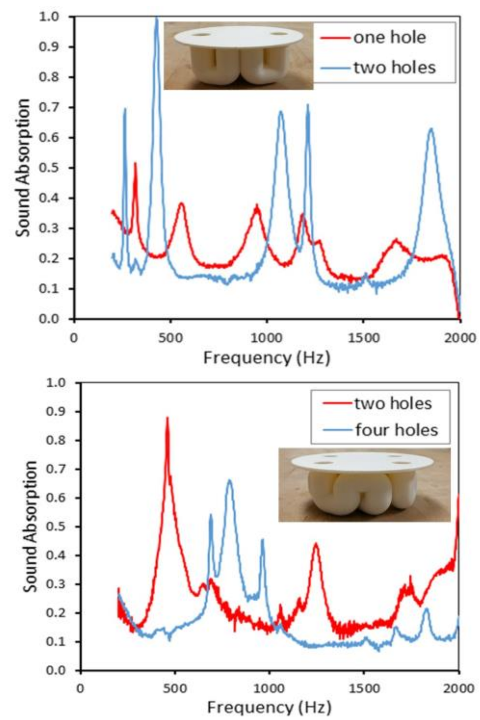

Figure 3: Sound absorption results for samples #2 and #3.

References

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