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APPLICABILITY OF MULTI-OBJECTIVE OPTIMIZATION IN CLASSROOM ACOUSTICS DESIGN USING ANALYTICAL AND GEOMETRICAL ACOUSTIC MODELS

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ABSTRACT

The purpose of this study is to investigate the applicability of multi-objective optimization in classroom acoustics design. Specifically, typology, extension and position of acoustic materials have been optimized in order to improve acoustic quality of classrooms. It is addressed to architects, acousticians and professionals that are involved in acoustic design. One typical sized elementary classroom has been selected for this study and a basic geometric model has been built in Grasshopper, that serves as the environment for parametric investigation and improvement of acoustic parameters. Reverberation time and STI have been determined using analytical models and geometrical acoustic (GA) simulations carried out with Pachyderm software. Finally, Octopus has been used to perform multi-objective optimization runs considering as objectives the optimization of the acoustic parameters and the acoustic design/renovation costs. The results show that the GA simulations and the analytical models are compatible for the solutions without scattering properties.

1. INTRODUCTION

Acoustics of classrooms design is still neglected worldwide, even though it is essential to guarantee effective teaching and learning processes, especially at the baseline levels of the education [1]. As in other countries, also in Italy, poor acoustic quality is common in the educational panorama; there is lack of acoustic expertise in architects, engineers, school principals and teachers. Optimization techniques have rarely been used in this specific acoustic field or, in general, for acoustic design purposes compared to structural or form-finding ones. Starting from these considerations, investigations on acoustic and cost-effective solutions for classrooms have been proposed in this study. Results allow professionals to choose different optimization sets depending on the material or on the type of acoustic treatment they have in mind, and easily define the best solutions for a classroom or similar rooms, thus allowing promotion of awareness on the consequences of their choices since the early design phases.

2. METHOD

2.1 Parametric and acoustic models

A parametric model of a typical Italian classroom has been created in Grasshopper [2] and used as case-study. By using Grasshopper sliders, the existing room within a virtual model has been developed. Side walls were identified by a number from 0 to 3 (Fig.1). The sliders allowed to change to room dimensions and the dimensions of windows, doors, walls and ceiling areas covered by acoustic panels, etc. (Fig.1).

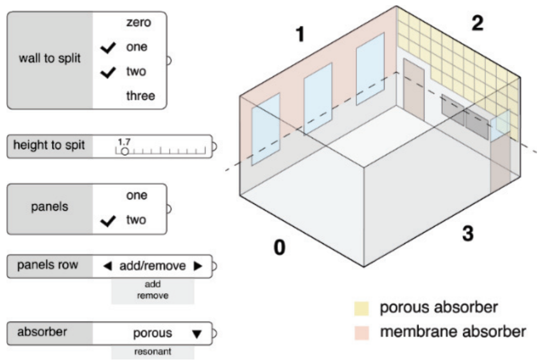
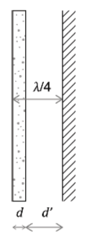
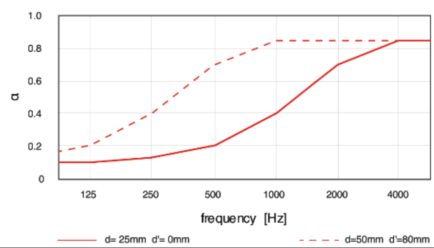


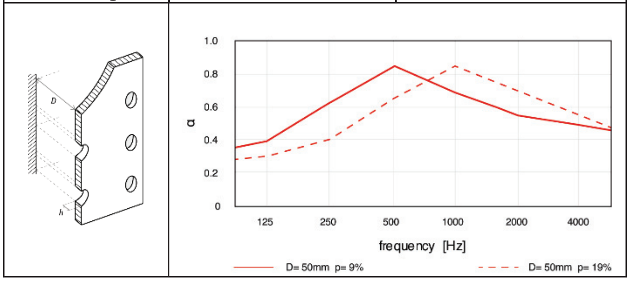
Fig. 1. Available GH slider for wall treatment.

Reverberation time (RT) and Speech Transmission Index (STI) are the acoustic descriptors chosen to characterize classroom acoustics. Ad-hoc Python [3] algorithms, which implemented Sabine and Eyring reverberation time equations and the Hopkins-Stryker formula for sound pressure level [4], with and without the Barron and Lee correction [5], have been implemented as baseline analytical models, and the GA software Pachyderm [6] has been used for simulations. The optimization process with analytical formulas also included the parametrization (and related optimization) of the sound absorption curves of acoustic materials, like porous absorbers, multiple resonators, membrane absorbers and baffles, starting from their physical and geometrical properties (Tab.1-4).

parameter	treatment position	variability range
thickness - d	wall	25 ÷ 50 mm
	ceiling	
air-gap – d'	wall	0 ÷ 100mm
	ceiling	0 ÷ $h_{air\text{-}gap}$
		

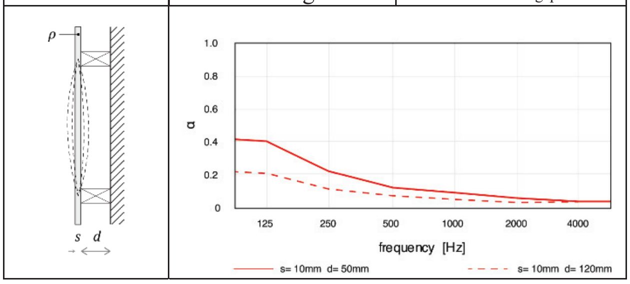
Tab. 1. Input-data range and sound absorption curve for porous absorbers.

parameter	treatment position	variability range
air-gap - D	wall	40 ÷ 120mm
	ceiling	0 ÷ $h_{air-gap}$
perforated area - p	wall	9% - 15% - 19%
	wall	



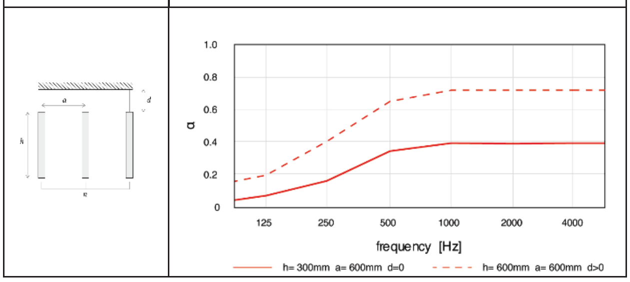
Tab. 2. Input-data range and sound absorption curve for resonant absorbers, h=12.5mm.

parameter	treatment position	variability range
density - ρ	wall	700 kg/m3
	ceiling	
thickness - s	wall	9 ÷ 25mm
	ceiling	
air-gap - d	wall	40 ÷ 120mm
	ceiling	0 ÷ $h_{air-gap}$



Tab. 3. Input-data range and sound absorption curve for membrane absorbers.

parameter	treatment position	variability range
height - h	300 - 600mm	
spacing rows - a	300 - 600 - 900 - 1200mm	
baffles number - n	6 - 9 - 14 - 26	
suspension distance - d	0 ÷ 300mm	



Tab. 4. Input-data range and sound absorption curve for baffle system.

The optimization process carried out with GA simulation takes into account the effect on results of the scattering properties of surfaces [7] and of the different position of acoustic materials. In this case, absorption and scattering coefficients were not parametrized in Pachyderm and a database of acoustic materials, compatible with those available for models, has been provided to select materials suitable for the process.

2.2 Multi-objective optimization

The developed algorithms were coupled to Octopus plug-in [8] and used to perform multi-objective optimization runs aiming to reach a tradeoff between acoustic performance and design costs. Octopus is an evolutionary simulator that can approach optimal solution sets through iterative tests and routines that are repeated many times. Unlike Grasshopper, it allows the flexibility to input multiple objectives instead of just one. Reverberation Time (RT) in octave bands from 0.125 to 4 kHz, Speech Transmission Index (STI) and the budget for acoustical treatment have been chosen as the objectives to optimize. Variables involved in the optimization procedure to achieve the aforementioned objectives, in the case of the analytical models, were the typology and the extension of the acoustic materials, as well as their acoustic absorption thanks to the optimization of their physical and geometrical characteristics. Particularly, the thickness of the porous layer, the thickness and density of the panel and air gap of the membrane absorbers, the holed percentage, the thickness of the massive layer and of the airgap of the resonant absorber, the geometry of the acoustic baffles. In the case of GA simulation, the optimization process included typology, extension and position of a list of acoustic materials, and also comprised sound scattering. All the runs were performed using the same experimental setup. A single source and a total of four receivers were placed in the room model at fixed positions according to the requirements of the UNI 11532 [9]. The settings within Octopus were mostly kept to their defaults, applying Hype reduction and mutation. Population size has been set to 30 instances per generation, which results in a total combined amount of over 1000 evaluated solutions.

3. RESULTS

The results show compatible acoustics for the analytical models and the GA simulations. However, significant differences in the calculation time were found. For the analytical models 1500 runs in about 2 hours was carried out, while 750 runs in about 20 hours were performed for the GA simulation. Tab. 5 shows statistics of performed optimizations in Octopus. Multi-objective optimizations have not a unique solution but have a set of optimal ones that represents the Pareto front [10]. Fig. 2 shows the Pareto front for the RT- STI - budget based optimizations for the three models. Results are quite similar for the two analytical models, while the GA algorithm shows a dispersion of solutions due to the low number of runs and the inclusion of the position of the acoustic materials in the optimization process.

Octopus optimization	Sabine and Hopkins-Stryker	Eyring, Hopkins-Stryker, Barron and Lee	Pachyderm Acoustic
number of variables or genomes	28	28	32
number of objectives	8	8	8
total number of evaluated solutions	1500	1500	750
amount of completed generations	30	30	15
total runtime [h]	1.4	1.8	20.8
average evaluation time for each solution [s]	3.4	4.3	100.1
pareto optimal solutions in final gen. [%]	78	89	33

Tab. 5. Statistics of performed optimizations.

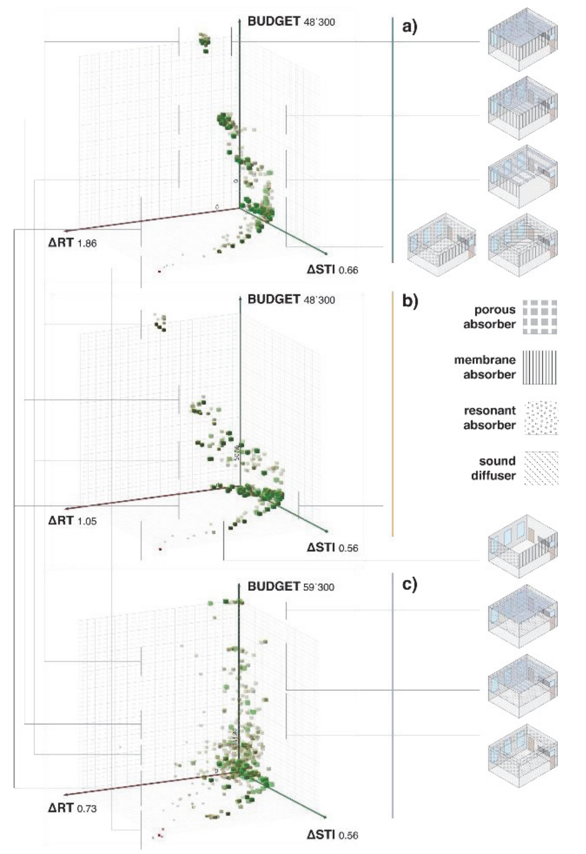


Fig. 2. Final generation of Pareto-front solutions from RT-STI-budget based optimizations: a) Sabine and Hopkins-Stryker formula, b) Eyring and Hopkins-Stryker formula with Barron and Lee correction, c) Pachyderm.

From a more detailed analysis of the Pareto front, valuable information can be obtained about the typology, position, and extension of the acoustic treatments of walls and ceiling. Figure 3 shows the results of this analysis for the best configurations found by performing the GA simulation. The most performative solutions, in the case of a ceiling acoustic treatment (Figure 3c), include baffles (8% of solutions), a totally sound-absorbing ceiling (AC100, 60%) or a sound-reflecting ceiling (RC100, 2%), a combination of sound-absorbing and sound-reflecting or sound-diffusing surfaces (AR-C, 30%). The reflective or scattering surface can be positioned above the teacher position (AR-CF, 75%) or in the center of the ceiling (AR-CC, 25%).

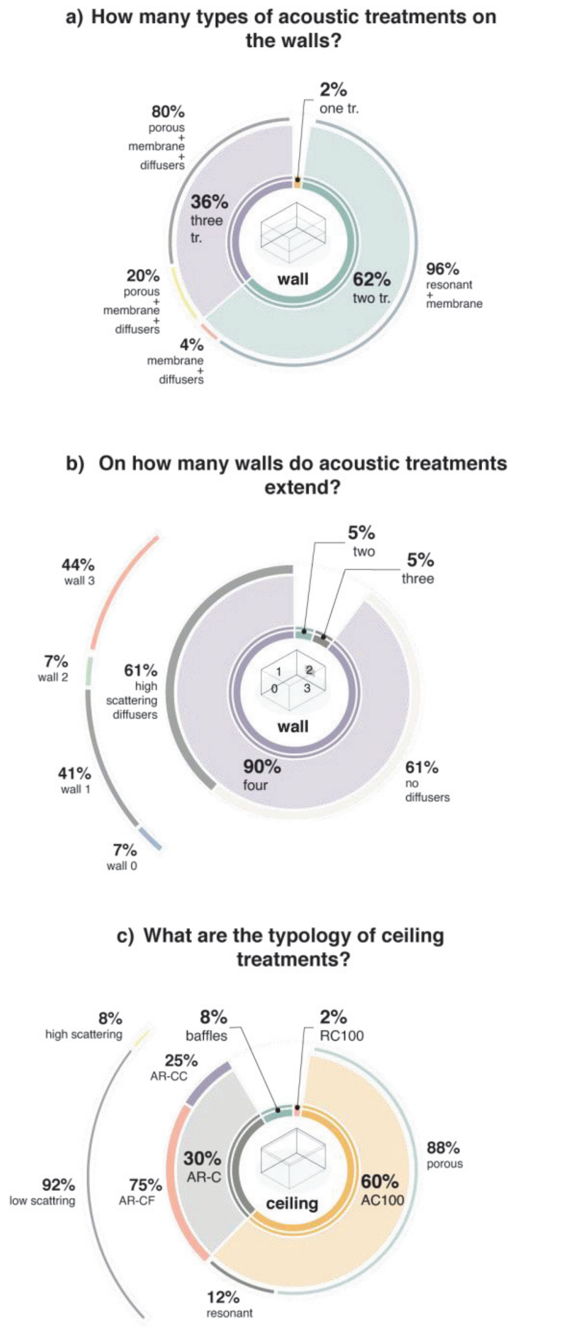
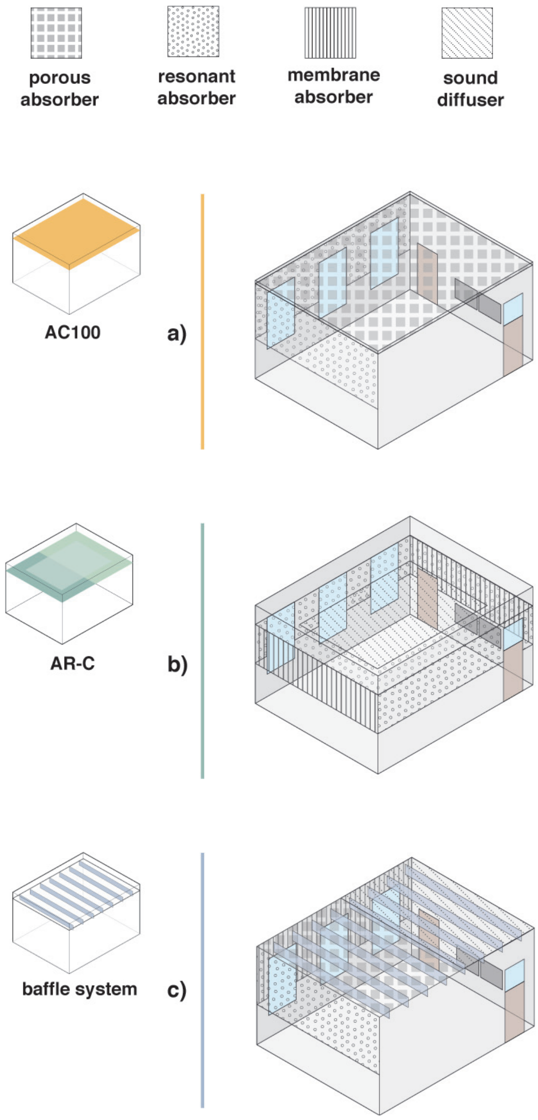


Fig. 3. Analysis of the best configurations performed by Pachyderm software.

The optimization was aimed to reach the optimal reverberation time of 0.6s, averaged across 250Hz to 2kHz, and to get the highest value of the average STI across for the measurement positions in the room. Fig. 4

shows the least expensive among the best configurations related to the different ceiling treatments, i.e. a totally sound-absorbing ceiling (AC100), a combination of sound-absorbing and sound-reflecting or sound-diffusing linings (AR-C) and baffles, for the GA model. Results in Fig.4(a, b, c) are comparable both in terms of RT and STI. A higher budget for the treatments shown in figure 4b and 4c compare the one in figure 4a is due to the high price of baffles and diffusers and does not lead to a significant improvement of the analyzed acoustic parameters.



ID configuration	$RT_{0.25\text{-}2kHz}$	STI	BUDGET
a	0.58s (0.04)	0.69	4˙300€
b	0.63s (0.02)	0.65	10˙300€
c	0.64s (0.06)	0.65	15˙500€

Fig. 4. Comparison among the least expensive among the best configurations related to the different ceiling treatments performed by the GA software Pachyderm.

4. CONCLUSION

Results from Pareto front show that some low-cost solutions are comparable among the three models, even though the most accurate should be considered GA simulation. Parametric optimization is far from trivial and though there is great interest in the potentials of parametric analysis, most practitioners in these fields tend not to be particularly well-versed in Grasshopper. So, further developments include a user-friendly interface to allow an easy approach for non-expert practitioners.

5. REFERENCES

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