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Technical Note

Acoustical design and experimental verification of school music rooms: A case study

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ABSTRACT

This paper presents an approach to acoustical design and the results of a survey in music rooms in an Italian public school (Liceo Statale "Alfano I" in Salerno, Italy). The locations selected are devoted to orchestral performances and to recording.

The purpose of correcting or insulating the spaces was to obtain a good acoustics in locations used at a reasonable cost. The acoustic correction was achieved by using sound-absorbing panels made from low-density polyethylene foam with a closed calibrated cell structure, placed on the walls and on the ceiling, and sound-insulation panels made of geometrically spherical composites. The optimal distribution of the sound absorbing panels was made using commercial software for simulating a scattering of sound pressure levels in a room. Reverberation time was measured at various frequencies with a class A phonometer, using an Integrated Impulse Response, in accordance with the international standard ISO 3382. For each measurement position variations of reverberation time in terms of time and frequency are measured. The results show a substantial accordance with the simulation in the design phase, allowing the authors to conclude that the proposed development is characterized by good performance in terms of cost-benefit.

1. Introduction

The design of a successful concert hall continues to be a difficult task and contemporary challenge for scientists and other experts working in this field [1–3]. It is well known that acoustics in a physically confined environment differs from those in an open space. This is the consequence of the presence, next to the direct sound waves (source–listener), of sound waves reflected in various ways from the surfaces delimiting the environment. The acoustic quality of a room is determined by the respective amount or overlap of the two sound fields: direct and reverberant (or diffuse). The optimal combination of the two fields varies with the type of audio signal transmitted in the room: speech or music of various kinds. For concert halls it is desirable that each impulse (musical note) is longer than for conference rooms or theatres; the length of these impulses, 'sound tail', varies with musical genres. Nowadays applications of computer models and acoustic predictive software make the acoustics of the halls of the future predictable [4].

In room acoustics, as in many other technical fields, the computerization has continued to dominate the field as new ways for simulating sound fields in enclosed spaces were created. Through simulation it is possible to demonstrate what a new concert hall which is still on the drawing board will sound like when completed. In this regard, visualization techniques of sound propagation in a room is very effective not only for academic purposes but also for applied acoustical design work on various kinds of auditoria. For this purpose, computer simulation techniques as ray-tracing and image-source methods have been developed and being widely used [5,6].

In general, the acoustic treatment of a closed environment is complex because of the broad spectrum of audible frequencies (20 Hz–20 KHz), also at low audio frequencies the effects of modal resonance dominate the acoustics of a room, while at high frequencies the sound behaves like light rays.

This paper presents the acoustical design approach and the experimental verification of concert hall and recording studio of an Italian public school (Liceo Statale "Alfano I" in Salerno, Italy).

The authors used as a reference point the international standard UNI EN ISO 3382:2001 which defines, in its Introduction, acoustic quality of rooms principally through reverberation time. This along

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with the homogeneity of sound levels was used as the main indicator. The value of the reverberation time that combines the two opposing requirements of intelligibility and sufficient intensity level is "optimal". It must adopt a value, dependent on the auditory environment, that offers the best mix of reverberation for the quality of listening experience [7]. Hereafter, the degree of diffusion, characterized by the "scattering coefficient" of surface materials, that is one of the most important factors in determining the acoustical qualities of concert halls, was investigated [8].

2. Acoustic correction

In order to obtain a good acoustic effect for the concert hall and the acoustic insulation of the connected recording studio in respect of the budget for the intervention, were observed from the authors the following project phases [9]:

- analysis of the room at low frequencies, since, in these conditions, achieving the standard measurement for reverberation time can be difficult due to the particular acoustic characteristics of the environment, which negatively impacts on the listening experience. At low frequencies we are not in diffuse field conditions, therefore we do not experience homogeneous frequency and spacing, and, by analyzing the spectrum of the reverberation times, it is possible to notice spaced peaks corresponding to the resonance frequencies of stationary waves [10] that are in the environment. Generally, resonances occur when any closed route of the venue is a multiple of one of the wavelengths that form the sound, and, as is known, are present in the parallel and reflective walls. The air in a room has an infinite number of normal modes of vibration, also called natural [11]. Each room can be schematized as an acoustic complex resonator characterized by an infinite number of modes of vibration, each with a precise resonant frequency: when one of these frequencies is produced within the environment, there is a corresponding standing wave. In this context the concept of limit frequency or Schroeder frequency assumes fundamental importance, that is the lower limit of frequencies in which the sound field has statistical properties: in relation to frequencies that are lower than that of the Schroeder frequency predominate modal characteristics related to environment. In the case being considered, by approximating the geometry of the section of the rectangular concert hall, the frequency of Schroeder has been determined in the following relationship:

$$f_{lim} = \frac{5000}{(Vk_{n,mod})^{1/2}} \cong 2000\left(\frac{T}{V}\right)^{1/2} \quad (1)$$

where $k_{n,mod}$ represents the average value of the damping constant of many modes, T is reverberation time and V is volume of the room. It is interesting to note that modal description is important only in small environments, as in the case under consideration.
Hereafter identification of the possible resonance frequencies was undertaken using the following expression:

$$f_{123} = \frac{v}{2}\sqrt{\left(\frac{n_1}{a}\right)^2 + \left(\frac{n_2}{b}\right)^2 + \left(\frac{n_3}{c}\right)^2} \quad (2)$$

where a, b, c are the three dimensions of the room, v = 343 m/s is the sound speed, n_1, n_2, n_3 are integer numbers: when two of them are zero we speak of axial mode, when only one of the three is a zero value we refer to the tangential mode and no zeros values referred to as the oblique mode.

Table 1
First axial resonance.

Mode order in the three coordinates			Natural freq. (Hz)	Mode order in the three coordinates			Natural freq. (Hz)	Mode order in the three coordinates			Natural freq. (Hz)
n_1	n_2	n_3	f_{123}	n_1	n_2	n_3	f_{123}	n_1	n_2	n_3	f_{123}
1	0	0	15	2	0	0	31	3	0	0	46
0	1	0	61	0	2	0	122	0	3	0	183
0	0	1	12	0	0	2	25	0	0	3	38

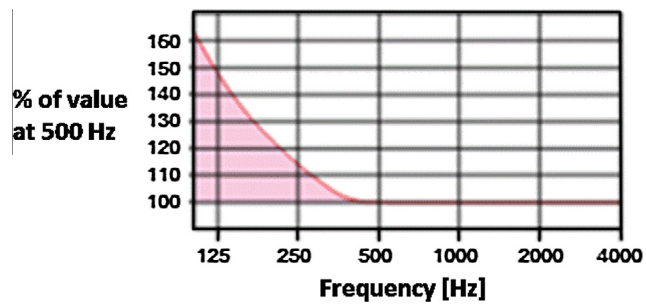

Fig. 1. Recommended percentage increase in reverberation times at lower frequencies for rooms specifically for music [12].

Fig. 2. Picture of the concert hall.

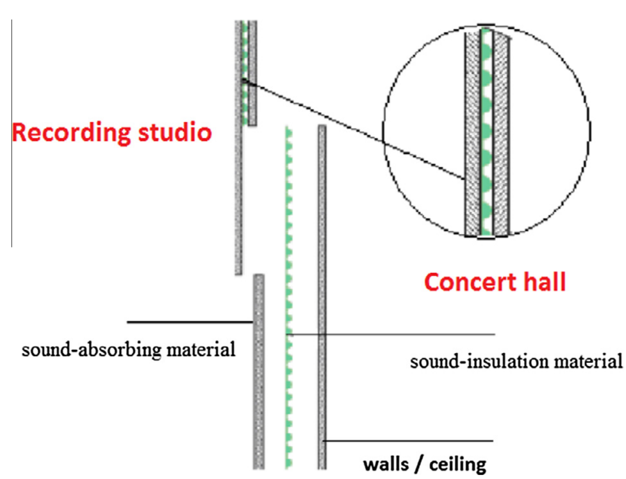

Fig. 3. Section of sandwich system.