The Evolution of the Acoustics of a Medieval Church

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1 Introduction

Churches are acoustically complex spaces due to both their large dimensions as well as the acoustically reflective materials used. Over time, the long reverberation times of churches have allowed for the development of sacred music; in fact, the sound tail inside the churches improves the listening to organ music as well as songs, increasing the participation of the faithful in religious functions. In recent decades, churches have been used both for classical and symphonic music concerts as well as conferences and conventions, but the results have not always been positive since the acoustic properties of the churches are different from those of theatres [1]. Furthermore, the Second Vatican Council amended the Catholic liturgy, giving more importance to the verbal communication, although this requirement was not supported by the passive acoustics of the churches with long reverberation times and reduced speech intelligibility [2]. In the years, in order to improve listening conditions, electroacoustic systems are often placed inside churches. However, speech intelligibility can be improved by means of an acoustic correction of the spaces through the reduction of the reverberation by inserting appropriate sound-absorbing materials.

Traditional porous sound-absorbing materials with a suitable thickness, absorb sound energy at medium and high frequencies and are successful for acoustic corrections [3, 4]. However, monumental churches have various problems due to both the presence of low frequencies components of the sound tail as well as the difficulty of using traditional materials for historical and architectural needs: the walls cannot be covered with traditional materials. Therefore, there is a need to experiment innovative solutions for the acoustic correction of the rooms, such as transparent micro-perforated sheets for medium and high frequencies and acoustic resonators for low frequencies. Acoustic resonators can be obtained by perforating ceramic tiles and installing them at an appropriate distance from the rigid wall in order to obtain an adequate sound absorption at low frequencies. This paper is dedicated to the investigation of the acoustic characteristics of the cathedral of Carinola, in Italy which was subject to a restoration for improving its acoustics.

2 Acoustic measurements

The church has a volume of 7.500 m^3 and an internal plant surface of 5.000 m^2. The church has a central large nave and three lateral smaller naves, following a typical Medieval plan. The acoustic measurements were carried out with an omnidirectional sound source located on the altar and 12 microphone points of measurement placed in different positions in an area occupied to the listeners, in accordance with ISO 3382 [5]. The sound source was powered with a MLS signal. During the acoustic measurements the background noise was lower than 35 dBA, the church was empty and the furniture were hard chairs. Figure 1 shows the plan of the church with the indication of the position of the source and of the receiver microphone points. The sound source was placed at a height of 1.6 m from the floor and the microphone at a height of 1.3 m, in an area occupied to the listeners. The monaural acoustic parameters analysed are EDT, T30, C80, and D50. Table 1 shows the average values of the acoustic parameters in the octave band from 125 Hz to 4 kHz. The values of EDT and T30 exceed on average the 4 seconds, the average values of C80 = -5 dB, while the average values of D50 = 0.25. The average value of the parameter STI = 0.33. The church does not meet the criteria of good listening for the music and the speech [2, 5].

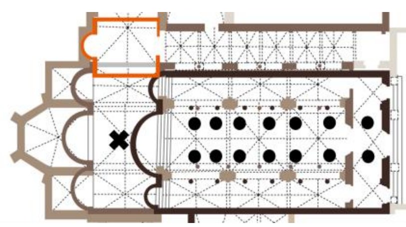

Figure 1: Plan of the church with the indication of the position of the source and of the receivers.

Table 1: Average acoustic parameter measured.

Freq [Hz]	125	250	500	1000	2000	4000
EDT, s	4.8	4.5	4.0	3.7	3.1	2.5
RT, s	4.7	4.6	4.0	3.6	3.0	2.5
C80, dB	-5.1	-6.3	-5.5	-3.9	-3.3	-2.4
D50	0.2	0.1	0.2	0.2	0.2	0.3

Figure 2 shows the reverberation time parameter trend, with distance sound source-receiver at the frequency of 1000 Hz. The parameter does not change with the distance sound source-receiver, proving that the acoustic field is diffuse.

In the late 1960s, Shankland published studies on more than Roman and Medieval churches discussing their acoustic qualities. In all the environments considered the sound was judged to be very widespread and without audible echo due to the richness of the architectural and sculptural details. Figure 3 shows the trend of the reverberation time measured in the considered church compared to others [6].

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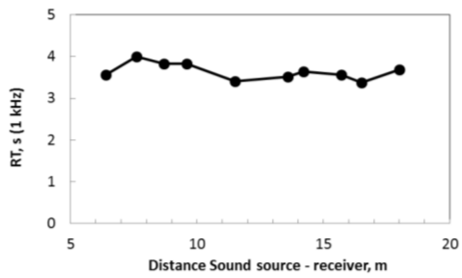

Figure 2: Reverberation time parameter, with distance sound source receiver at the frequency of 1000 Hz.

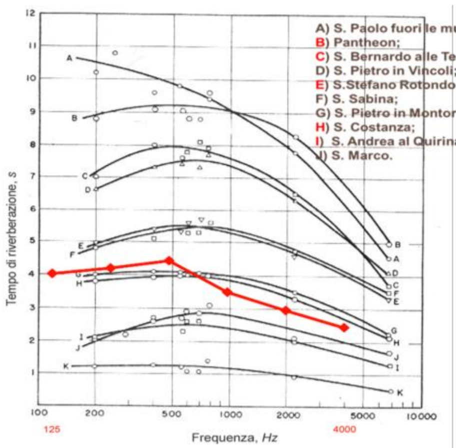

Figure 3: Comparison of reverberation times measured in different churches and in the present case study (in red).

3 Acoustic correction and discussion

The results showed in the previous section show that the church has inadequate acoustic characteristics for a good speech intelligibility, and requires intervention to fully adhere to the suggestions of the Second Vatican Council. The CAD model, shown in Figure 4, was imported into ‘‘Odeon’’ Room Acoustics Software. The sound source is placed on the altar and the receivers among the seats of the audience. The first step, the acoustic model calibration, consisted of setting the absorbent coefficient values for all the virtual model surfaces and the scattering coefficient ones. The procedure was stopped when, for each octave band frequency from 125 Hz to 4.0 kHz, the calculated reverberation time value (T30) was within ±5% of the measured one. Table 2 shows the values of absorbent coefficient used in the modeling.

A practical problem for medieval churches that traditional sound-absorbing materials such as polyester cannot be used for acoustic corrections for artistic conservation needs. A possible solution was hence to cover the side walls of the church with sound-absorbing plaster. This solution is not invasive and allows the preservation of the church from a monumental point of view. Table 2 report the sound absorbing values of the sound-absorbing plaster selected.

Figures 5 show the spatial average distribution of RT and EDT at 1000 Hz modelled with the plaster intervention. These figures show the reduction of these acoustic parameters and the clear improvement of the relative listening quality within this church.

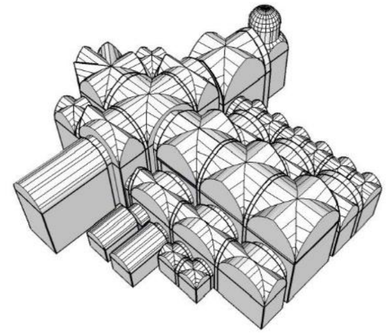

Figure 4: 3D model of the church used to test possible interventions for its acoustic correction.

Table 2: Values of absorbent coefficient of used in modelling.

Freq, Hz	125	250	500	1000	2000	4000
Plaster	0.03	0.04	0.04	0.05	0.06	0.08
Marble	0.11	0.12	0.13	0.14	0.15	0.16
New plaster	*0.2*	*0.3*	*0.6*	*0.7*	*0.8*	*0.8*

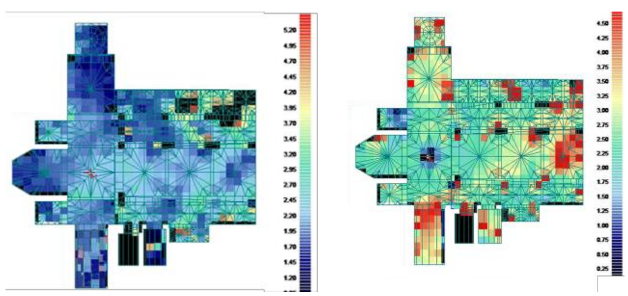

Figure 5: Distribution of the RT (left) and EDT (right), at 1000Hz.

4 Conclusion

This paper presented the study of the intervention for the acoustic correction of the Medieval cathedral of Carinola in Italy. The intervention aimed to shortening the reverberation time by substituting the plaster with a sound absorbing plaster. Acoustic interventions showed the homogeneity of acoustic across the floor plan and the possibility to obtain a reverberation adequate for an easier speech perception.

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