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[N422] Architecture acoustics measurements and design: a church and an auditorium

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ABSTRACT

The acoustic comfort in churches and auditoria is very important because it allows to have a good intellegibility of the acoustic message, intended as talking language and as music. In the present paper two case studies are investigated: a church and a little auditorium, in Umbria (Italy). The church (about 3200 m^3 volume) is situated in Passaggio di Bettona, the auditorium (about 600 m^3 volume) is situated in Cannara; both the buildings have no regular plant shape. In both the buildings several measurements were carried out, in many different points: reverberation time, RASTI, STI, clarity C_{80}, definition D; results show that both the rooms have no good acoustic behaviour, due to the too high reverberation time values and to the values of RASTI, STI, C_{80}, D, different from the optimal ones. So an acoustic correction of the two rooms is proposed; the optimal values of the acoustic parameters (reverberation time, RASTI, STI, C_{80}, D) are chosen and a simulation of the acoustic behaviour is made by the calculation programme "Ramsete"; then the design of acoustic correction solutions is proposed.
KEYWORDS: Architecture Acoustic, Measurements

INTRODUCTION

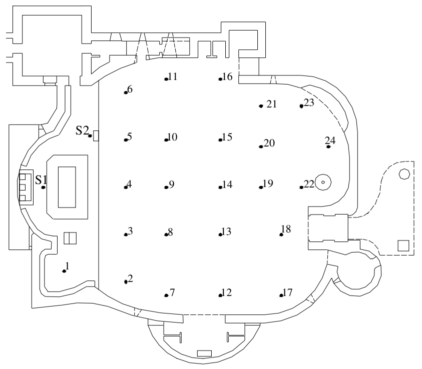
Italian country, and in particular one of its Regions, Umbria, has a great historical and artistic patrimony, mainly composed by churches. Some of them conserve their original destination and are employed as faith places; others, after their deconsacration, assume a different destination: auditorium, conference room, etc. In any case the acoustic performances of the room are very important both for language intelligibility and for music listening.
In the present paper both these situations are considered: the modern church of Madonna del Ponte, built in 1960, situated in Passaggio di Bettona and faith place for the local Christian Community, and the San Sebastiano church, built in the XIII century and situated in Cannara, which, after its deconsacration, had different destinations since the local Authorities decided to employ it as auditorium. So an evaluation of the acoustic performaces of the two churches was carried out, by means of measurements of the main acoustic parameters, such as: weighted A pressure equivalent continuous level $L_{eq(A)}$, reverberation time, RASTI and STI

indexes, Clarity C_{80}, Definition D. All the measurements define the actual situation; a comparison between the measured and the optimal values of the different acoustic parameters was made for each room: results showed that an acoustic correction of both the rooms was necessary. A simulation programme, named RAMSETE, was employed to evaluate the acoustic performances of the rooms, varying the design conditions and the material characteristics. A preliminary calibration of the model, by means of the simulation of the actual conditions of the rooms and the comparison with the measured data, was initially made. Then different simulations, corresponding to various solutions of acoustic correction, were made: as final configuration, for each one of the examined churches, the one allowing to reach the acoustic performances required was chosen; only the final solutions for the two rooms are presented.

ROOMS DESCRIPTION

The Madonna del Ponte church, built in 1960, is employed as faith place by the local Christian Community; acoustic measurements were required, due to the bad intelligibility of the language during the religious functions. The church has a circular plan (about 300 m^2), a maximum height of about 8 m, for a total volume of about 3200 m^3 (see Fig. 1a and 1b). The walls are plastered, the ceiling is covered by stucco and the floor by terracotta tiles.
The San Sebastiano church, built in 1200, loose its religious destination in 1890, when it was turned to storehouse until 1970; then it was decided to restore it and to give it a new destination: restoring process was recently completed and the auditorium destination was chosen by the local Authorities. The church is situated in the historical centre of Cannara; it has a rectangular plan (13 x 6 = 78 m^2), a maximum height of 7.9 m, for a total volume of about 600 m^3 (see Fig. 1c and Fig. 1d). Three altars are present in the church; the walls and the ceiling are covered by stuccoes, the floor by terracotta tiles. A gallery for the chorus is finally present in the wall in front of the principal altar.

a) 

b) 

c) 

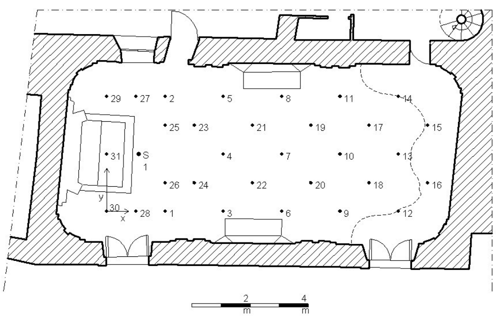
d) 

Fig.1: The San Sebastiano (a, b) and the Madonna del Ponte (c, d) churches with measurement points.

MEASUREMENTS RESULTS

Measurements in the Madonna del Ponte church were carried out employing “Aria System” by 01 dB, while in the San Sebastiano church they were carried out employing SYMPHONIE system (01dB Stell): both the systems are connected to a PC for the data acquisition, a noise dodecahedron source and a standard ½” condenser microphone. Measurements of $L_{eq(A)}$, T_{30}, T_{20}, EDT, RASTI, STI, C_{80} and D were carried out in the points reported in Fig. 1 for Madonna del Ponte and San Sebastiano churches.

As an example, results related to the $L_{eq(A)}$ distribution in San Sebastiano church are reported in fig. 2; for the sake of brevity, all the mean values of the measured parameters are reported in Fig. 10, 11, 12, 13, 14, 15, 16, 17, together with the optimal values of the same parameters and with the values obtained by the simulation after the acoustic corrections, described in Design Proposals.

In Madonna del Ponte church the $L_{eq(A)}$ values are in the 70.0 – 72.0 dBA range; the T_{30} mean values are in the 4.77 s (f = 500 Hz) – 2.12 s (f = 5000 Hz) range, too high for the language intelligibility (Fig. 10); the C_{80} values are in the - 3.55 dB (f = 500 Hz) – -0.78 dB (f = 4000 Hz) range (Fig. 11), while the D mean values are in the 22% (f = 500 Hz) – 36 % (f = 4000 Hz) range (Fig. 12). Finally RASTI and STI mean values are in the 0.37 – 0.51 range, corresponding to a average quality of the language intelligibility.

In San Sebastiano church the $L_{eq(A)}$ values are in the 65.8 – 70.5 dBA range (Fig. 2); the T_{30} mean values are in the 3.36 s (f = 125 Hz) – 0.88 s (f = 8000 Hz) range, too high for the music listening, overall at low frequencies (Fig. 14); the C_{80} values are in the -3.62 dB (f = 125 Hz) – +5.33 dB (f = 8000 Hz) range (Fig. 15), while the D mean values are in the 20 % (f = 125 Hz) – 62 % (f = 8000 Hz) range (Fig. 16). Finally RASTI and STI mean values are in the 0.45 – 0.54 range (Fig. 9), but they are only significant for language listening and not for music listening.

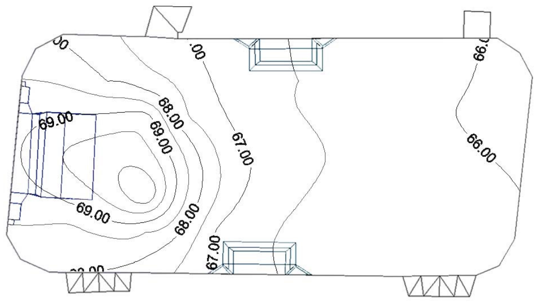


Fig. 2: $L_{eq(A)}$ (dBA) in the San Sebastiano church

SIMULATION PROGRAMME: DESCRIPTION AND CALIBRATION

RAMSETE is a sound field simulation and previsional programme based on geometrical acoustics and employs a pyramidal divergent ray tracing algorithm. The theoretical fundamentals of the model are omitted for the sake of brevity; they are described in the Literature (2, 3).

The internal and external churches surfaces modellization was realized employing the Autocad 14 programme. Then each material was characterized by an absorption coefficient, taken from RAMSETE library. The models of the external and internal surfaces of the two churches are represented in Fig. 3 and in Fig. 4.

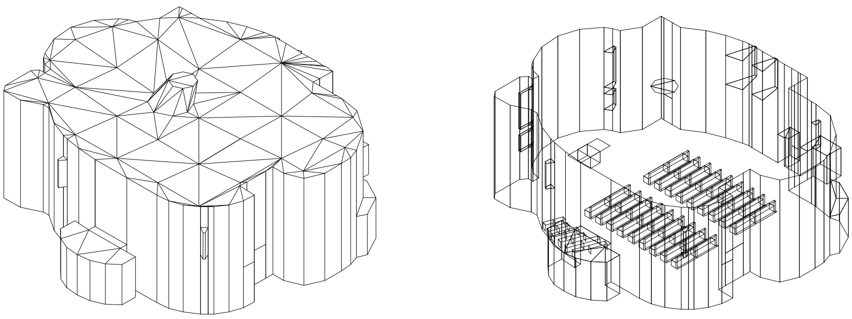


Fig. 3: Madonna del Ponte church model

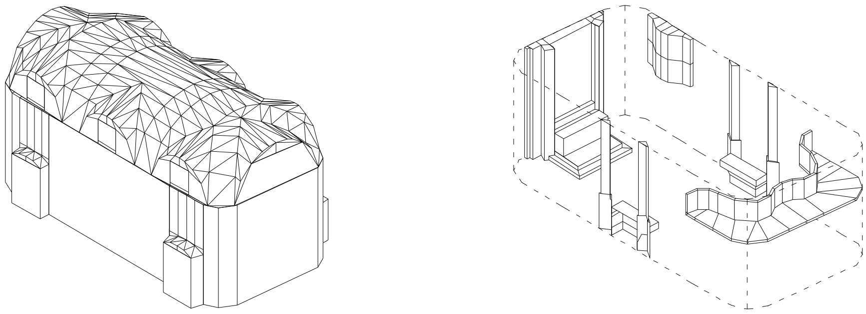


Fig. 4: San Sebastiano church model

The aim of the model calibration is to obtain the convergence of the acoustics parameters evaluated by RAMSETE to the measured values. So the model represents the real acoustic behaviour of the room and it is possible to employ it for simulating the different design conditions. The model calibration consists in an iterative process in the calculation of acoustic power level, absorption coefficients of the materials and of two parameters α and β which characterize the acoustic decay. L_{eq}, T_{30}, C_{80}, D and STI were calculated with RAMSETE, by means of an iterative calculation; results are shown in Fig. 5, 6, 7, 8, 9 (San Sebastiano church): the difference between the measured and the calculated data is negligible for all the considered parameters. Analogous results were obtained for Madonna del Ponte church, but they aren't reported for the sake of brevity.

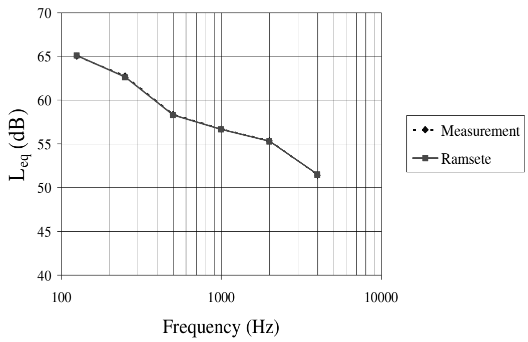


Fig. 5: measured and previsional mean L_{eq} (San Sebastiano church)

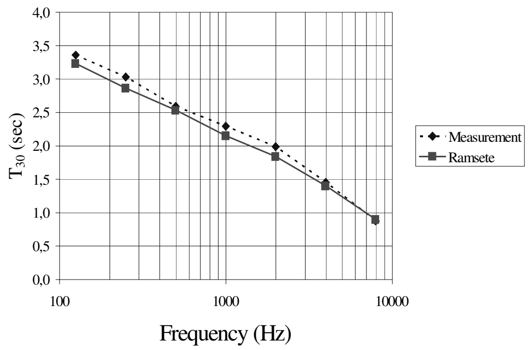


Fig. 6: measured and previsional mean T_{30} (San Sebastiano church)

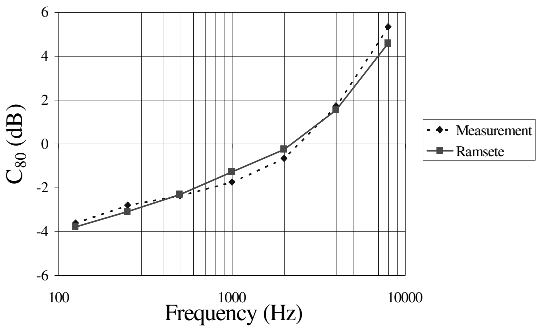


Fig. 7: measured and previsional mean C_{80} (San Sebastiano church)

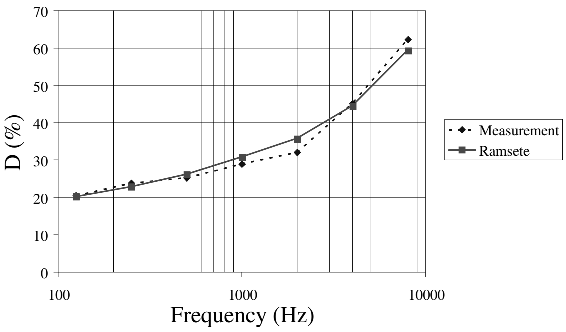


Fig. 8: measured and previsional mean D (San Sebastiano church)

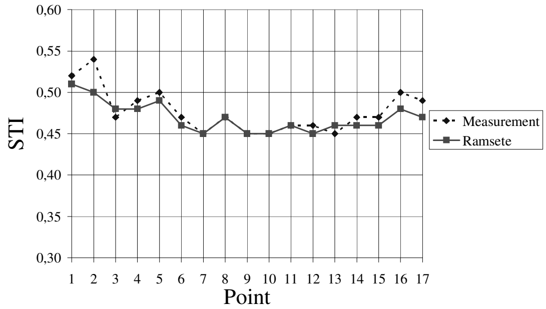


Fig. 9: measured and previsional mean STI (San Sebastiano church)

DESIGN PROPOSALS

<u>Madonna del Ponte Church</u>

The acoustic corrections proposed for the Madonna del Piano church are listed below:

- installation of wood fibre panels over the lateral and bottom walls (from the floor to the false ceiling); the total area of the panels is 280 m^2;
- installation of 6 loudspeakers, model 101 BOSE.

The acoustic characteristics of the materials employed in the design condition simulation are reported in Tab. 1a.

<u>San Sebastiano Church</u>

The acoustic corrections proposed for the San Sebastiano church were decided in agreement with the Umbria Superintendence for Architectural Monuments, because of the bonds imposed. The corrections are listed below:

- restoration of the lime plaster on the walls and on the ceiling, now very damaged; the new plaster will have an absorption coefficient at high frequencies lower than the actual one;
- installation of n. 54 stuffed and removed pit stalls, with absorption coefficients similar to those of people sitting;
- installation of a wood dais in front of the principal altar, to make the source higher than the audience;
- installation of n. 7 removable glass panels, of 2 x 1.2 m dimensions, with an absorption coefficient which diminishes when the frequency increases.

The acoustic characteristics of the materials employed in the design condition simulation are reported in Tab. 1b.

Tab. 1: acoustic characteristics of the materials employed in the design condition simulation: a) San Sebastiano church; b) Madonna del Ponte church.

a)

Material	Frequency (Hz)					
	125	250	500	1000	2000	4000
plaster (walls)	0.042	0.048	0.055	0.066	0.090	0.140
plaster (ceiling)	0.040	0.050	0.060	0.070	0.070	0.060
tiles (floor)	0.030	0.030	0.040	0.040	0.040	0.040
painted wood	0.110	0.120	0.120	0.120	0.100	0.100
Marble (altars)	0.010	0.010	0.020	0.030	0.030	0.040
glass	0.350	0.250	0.180	0.120	0.070	0.040
wood panels	0.265	0.417	0.523	0.556	0.556	0.488
audience	0.500	0.660	0.800	0.880	0.830	0.700

b)

Material	Frequency (Hz)						
	125	250	500	1000	2000	4000	8000
ceiling	0.030	0.040	0.050	0.060	0.070	0.080	0.090
walls	0.030	0.040	0.050	0.060	0.070	0.080	0.090
chorus	0.040	0.050	0.060	0.070	0.070	0.060	0.060
wood	0.110	0.120	0.120	0.120	0.100	0.100	0.100
altars	0.040	0.050	0.060	0.070	0.070	0.060	0.060
floor	0.040	0.035	0.042	0.050	0.055	0.060	0.043
glass	0.350	0.250	0.180	0.120	0.070	0.040	0.030
audience/pit stalls	0.500	0.660	0.880	0.880	0.830	0.700	0.680
glass panels	0.180	0.060	0.040	0.030	0.020	0.020	0.020

DESIGN SIMULATIONS

The results of the two simulations are reported in Figures 10, 11, 12, 13, 14, 15, 16 and 17; the measured values of the considered acoustic parameters are reported with the optimal data and with the results of the simulation.

For Madonna del Ponte church, destined to religious functions listening, the optimal data of the acuostic parameters are reported below (5, 6):

- T_{30} = 1.35 s at 500 Hz; the trend vs the frequency is reported in Fig. 10;
- C_{80} > 2 dB;
- D < 50 %.

Simulation results after the acoustic correction show that all the parameters are in the optimal range, for all the frequencies between 125 and 4000 Hz, except for the values at 125 Hz; STI values are in the 0.62 ÷ 0.74 range, so a “good” intelligibility of the language is guaranteed: the STI values before the acoustic correction were in the 0.45 ÷ 0.54 range.

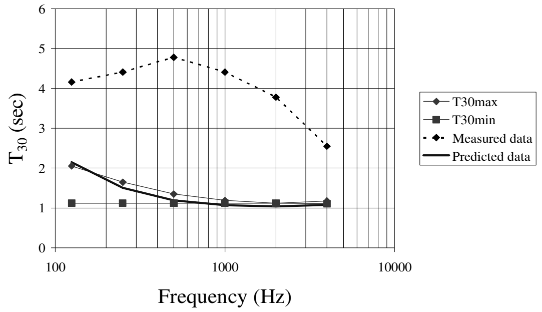


Fig. 10: T_{30} measured, optimal and simulated data (Madonna del Ponte church)

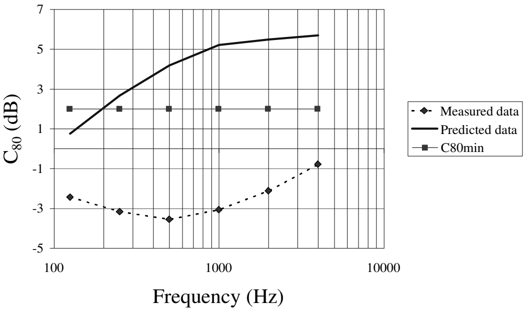
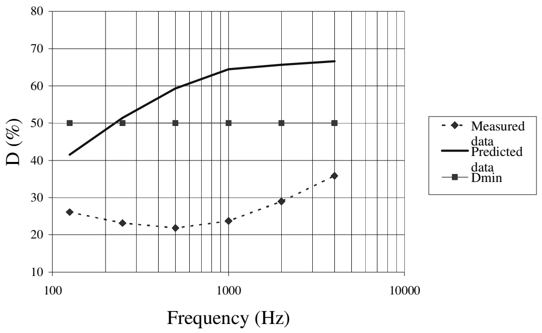


Fig. 11: C_{80} measured, optimal and simulated data (Madonna del Ponte church)



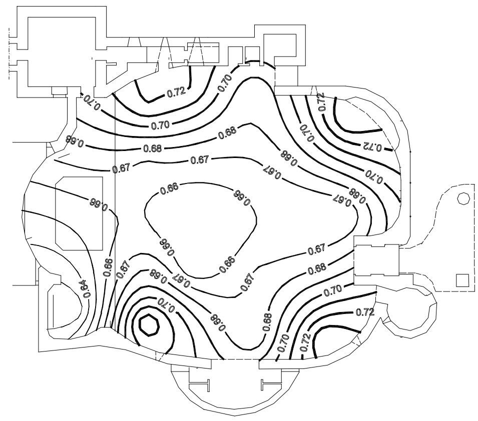


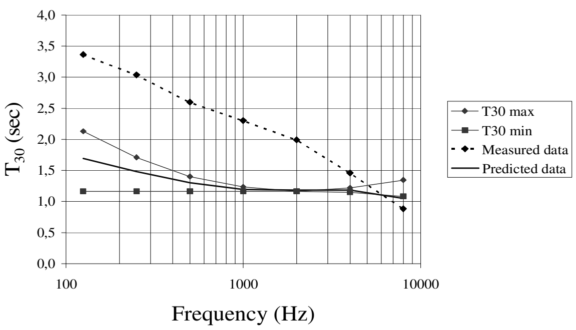
Fig. 12: D measured, optimal and simulated data (Madonna del Ponte church)

Fig. 13: STI simulated data (Madonna del Ponte church)

For San Sebastiano church, destined to auditorium, the optimal data of the acuostic parameters are reported below (5, 6):

- T_{30} = 1.4 s at 500 Hz; the trend vs the frequency is reported in Fig. 14;
- C_{80} = -2 ÷ + 2 dB;
- D > 50 %.

Simulation results after the acoustic correction show that all the parameters are in the optimal range, for all the frequencies between 125 and 8000 Hz, except for C_{80} at 8000 Hz; STI values are the same as in the actual configuration. An amplification plant could be installed if the room will be employed also as conference hall.



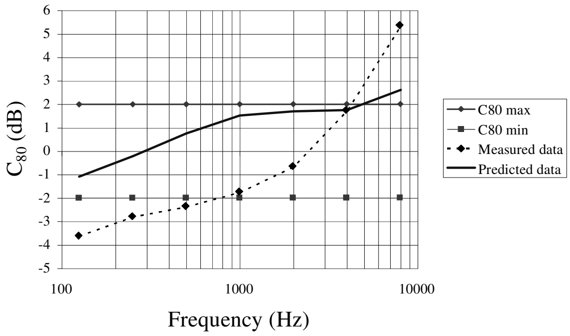
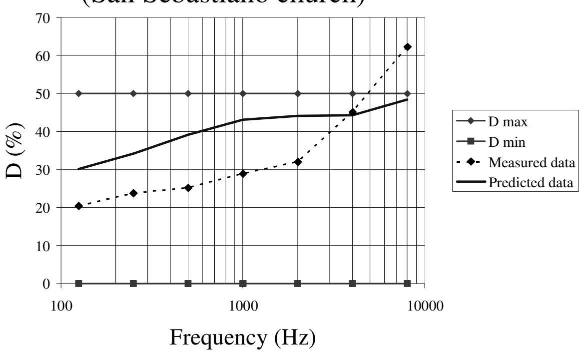


Fig. 14: T_{30} measured, optimal and simulated data (San Sebastiano church)

Fig. 15: C_{80} measured, optimal and simulated data (San Sebastiano church)



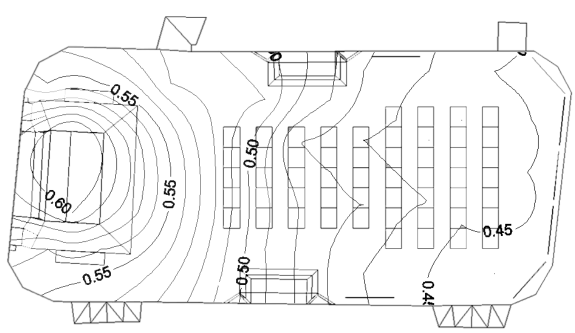


Fig. 16: D measured, optimal and simulated data (San Sebastiano church)

Fig. 17: STI simulated data (San Sebastiano church)

CONCLUSIONS

Umbria region, in Italy, is rich of numerous historical buildings, expecially with a religious destination; in the present paper the acoustic behaviour of two churches is examined: a modern one (1960), situated in Passaggio di Bettona, destined to religious functions, and an ancient one (XIII century), situated in Cannara, now deconsacrated and destined to auditorium.

A campaign of acoustic measurements to characterize the actual state of the churches was carried out; measurements of pressure equivalent continuous level $L_{eq(A)}$, reverberation time, RASTI and STI indexes, Clarity C_{80}, Definition D in a great number of points were executed and the results were compared with the optimal values of the different parameters for church and auditorium destination.

Results showed that both the churches need of acoustic correction. So a simulation of the acoustic field with RAMSETE programme was carried out and all the acoustic parameters were calculated. The programme, based on geometrical acoustics, employs a pyramidal divergent ray tracing algorithm; it was calibrated employing the measurements results and simulating the actual configuration of the rooms. Then some corrections were proposed, in agreement with the Umbria Superintendence for Architectural Monuments, because of the bonds imposed in the ancient church. The acoustic field was then simulated and all the acoustic parameters were calculated considering different design configurations; for each church, the configuration allowing to obtain the optimal values of all the acoustic parameters was finally chosen for the realization.

LIST OF SYMBOLS

- C_{80}: Clarity [dB];
- D: Definition [%];
- EDT: Early Decay Time [s];
- f = frequency [Hz];
- L_{eq}: pressure equivalent continuous level [dB];
- $L_{eq(A)}$: A weighted pressure equivalent continuous level [dBA];
- RASTI: rapid STI [-];
- STI: Speech Transmission Index [-];
- $T_{20,}$ T_{30}: reverberation time [s].

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