MEASURED ACOUSTIC PARAMETERS VERSUS PREDICTED ONES IN TWO MUDEJAR-GOTHIC CHURCHES

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ABSTRACT

In this work we have undertaken an acoustic simulation of the sound field in two churches in the historical centre of the city of Seville. The simulation has been carried out through the CATT-Acoustic v7.2f programme, which has been based on the reverberation times measured in those spaces. We have focused on Sound Pressure Levels L_p, Clarity C_{80}, Definition D_{50}, and RASTI indices data in relation to their spectral variations and spatial distributions and their comparison with the equivalent experimental results.

INTRODUCTION

Mudejar churches were built in the Spanish Middle Ages, reaching their greatest splendour in the thirteenth and fourteenth centuries. They usually had a vaulted presbytery as a result of the stylistic evolution from Romanesque to Gothic, and their three naves had a timber roof trusses following Moorish tendencies. Many of these original roofs have been lost to fire. All these churches are used today for worship and other cultural uses in the city of Seville, (south of Spain). We have undertaken a profusely analysis of several objective acoustical parameters in a set of nine churches of this architectural typology [1]-[3]. In this work, we have chosen two of the set, Sta Marina and S. Marcos concretely, to carry out the computer simulation and to establish the comparison between experimental and calculated data. Both, simulations and measurements of the acoustical parameters refer to the unoccupied churches. The most relevant geometrical and acoustical parameters of the churches are shown in table 1

Figure 1 is a scaled drawing of the ground plan with the reception points for impulsive measurements, the longitudinal and the cross section of Sta Marina and S. Marcos churches.

Table 1. Significant data on Mudejar-Gothic Churches.

Church	Sta. Marina	S. Vicente	S. Julián	S. Gil	S. Pedro	Sta. Catalina	S. Marcos	S. Isidoro
Volume (m^3)	9840	6920	6230	6200	6110	4360	4067	3950
Nave length (m)	34	27	27	25	20	22	26	26
Width (m)	18	18	15	16	17	12	17	14
Mean height (m)	15	11	13	14	16	12	10	11
Volume/place (m^3/per.)	16.5	21.0	17.5	19.0	20.5	16.0	13.0	14.0
Acoustic radio (m)	2.76	3.87	2.40	3.03	3.46	3.12	2.02	2.50
Interior *	(b)(c)	(a)(c)	(b)(c)(f)	(a)(d)(f)	(a)(c)(e)	(a)(c)(e)	(b)(c)	(a)(c)

(*) Side naves very adorned with altars, altarpieces and pictures (a), less adorned (b). Apse with brick or brick plastered (c), with curtains (d). Presbytery with carpets (e). Ceramic baseboard of about 1.50 m high (f).

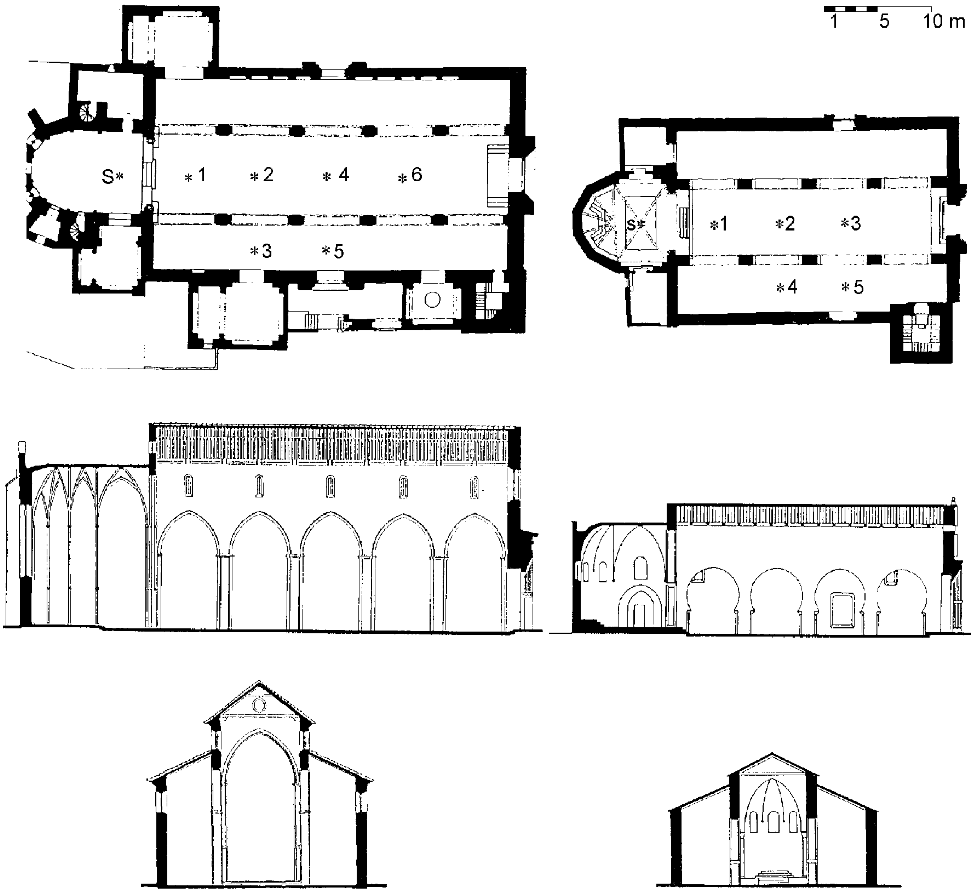

Figure 1. Ground plant with its reception points (top), longitudinal (middle) and cross section (bottom) of Santa Marina (left) and San Marcos (right) churches.

Sta Marina shows three naves of five sections with pointed arches likewise S. Marcos has three naves of four sections with horseshoe arches. Both show a similar interior inner (see table 1), their floor is of ceramic, and the furniture is composed of wooden pews in the principal naves and seats in the lateral ones.

Three types of measurements were carried out: impulse measurements, steady-state measurements and tests with a band filtered and amplitude modulated noise to study the intelligibility. Impulsive signals were generated by firing a blank cartridge from a 9mm pistol at the place where the source would be located in normal use. At each reception point the microphone signal was recorded using a Sony PC 204 DAT. In all cases, omnidirectional B&K 4165 microphones were used with their respective preamplifiers and polarization sources from the same manufacturer. The first stage of this analysis is laboratory processing of the signals using a B&K 2133 analyser to find reverberation time T in the bands of interest with Schroeder's integrated impulse method. The second stage requires the conversion of individual analogue recordings to a "wav" file using a PC Sound Blaster AWE34 sound card at a sampling frequency of 44.1 kHz. Afterwards, these data were processed with the MATLAB language to separate the range of interest (50-80 ms) and obtain the indices [2].

The steady-state sound levels in these places were obtained using a reference source (B&K 4205) placed on the altar. For this source we know the octave band sound power spectrum. After calibrating the system, a 30s recording was made on the DAT for each position and later processed in the laboratory with the analyser to obtain the global and the octave bands levels by averaging for 20s [1].

RASTI index measurements have been carried out using the Brüel&Kjær speech level meter type 3361. The data acquisition process was controlled by a portable computer via RS-232 that was charged with configuring the receiver parameters, receiving the data and storing them for

Table 2. Measured T_{meas} and simulated T_{sim} reverberation times.

	Santa Marina		San Marcos	
Freq. (Hz)	T_{meas}	T_{sim}	T_{meas}	T_{sim}
125	3.75	3.57	3.71	3.74
250	3.62	3.51	4.01	4.04
500	3.96	4.00	3.95	4.03
1000	4.00	4.02	4.01	4.02
2000	3.57	3.69	3.57	3.42
4000	2.62	2.61	2.58	2.55

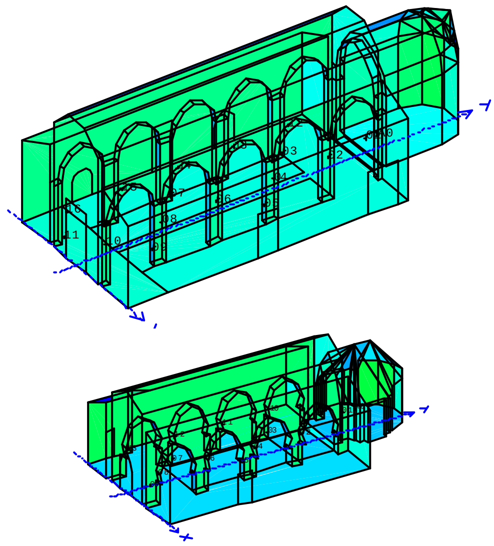

Figure 2. 3D-Models used for Catt simulation (Sta. Marina (left), S. Marcos (right)).

their subsequent analysis and processing. The microphone, which was set up at about ear-height of a sitting person (~1,20 m from the floor) was moved from one reception point to another. In each church we took measurements at several points (~10) distributed over the audience area. The emitter was put in all cases on the altar, which is the customary location of the natural source. The emission reference level was adjusted to ref.+10 dB of the equipment when the tests were performed without using the electroacoustic support system. Although measurements with electroacoustic support have been taken, they are not included in this work.

Concerning the computed predictions, they have been accomplished with a commercially available programme CATT-Acoustic v7.2f [4]. This is a room acoustic prediction programme based on the Image Source Model (ISM) for early part echogram qualitative detail, Ray-tracing for audience area colour mapping and Randomised Tail-corrected Cone-tracing (RTC) for full detailed calculation enabling auralization. RTC employs randomised cone-tracing (cone tracing which handles diffuse reflection in the same manner as ray-tracing does) for the full response but handles the direct sound, first order specular and Lambert's diffuse reflections, and second order specular reflections deterministically. A round robin test of geometric room acoustic computer models [5], showed that the common feature of the most successful predictions was the inclusion of some form of diffusion modelling.

The programme is configured for auto number and auto time to determine the number of rays N, to be used and the time t_R to be considered each ray in its path. N= 52440 and t_R=4015 ms for Sta Marina church and N=36798 and t_R= 3869ms for S. Marcos church respectively. The early part is limited to 1s. Using an iterative procedure we have adjusted the absorption coefficients of the different wooden ceilings, which are the most singular ones, until we obtained the simulated reverberation times in a range of $\pm$10% of the in situ experimental results (see table 2). Those absorption coefficient values are contrasted with other similar data in the bibliography.

The churches have been drawn in AUTOCAD and through AUTOSLIP commands they have been exported as a CATT file (file. geo). Figure 2 shows a view of the 3D model created in CATT for both churches. In the calculus we have considered the air absorption and the sound velocity at the atmospheric conditions of 20ºC and 50% relative humidity, similar to that at the measurement time. The background noise in each simulation process coincides with the measured noise spectra. An omnidirectional source with the known sound power spectrum of the real one has been used to obtain simulated sound pressure levels, and microphones have been placed at 1,20 m above floor level.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3 shows the measured and computer calculated values of the sound pressure levels (relative to that produced by the sound source in a free field at 10m) versus source-receiver distance at broadband, 500 and 2000 Hz octave bands in Sta. Marina (left) and S. Marcos (right) churches. The same graphics show the theoretical curves obtained through classical

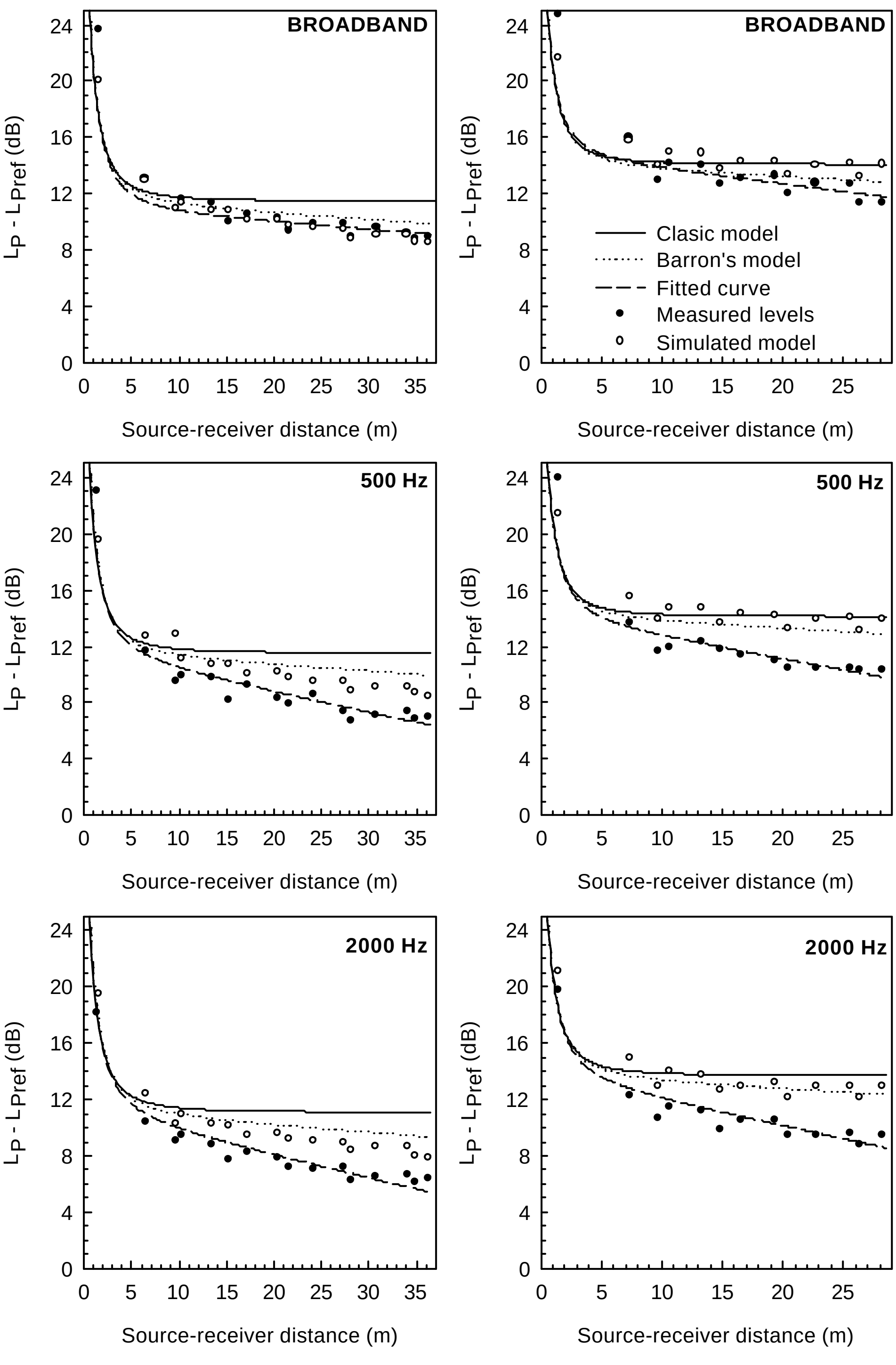

Figure 3. Sound pressure level L_P-L_{Pref} (dB) versus source-receiver distance (m) for Sta. Marina (left) and S. Marcos (right).

diffuse field model, Barron's modified model [6] and a fitted curve of the experimental results [1]. We can see that the simulated levels decrease beyond the critical distance according to Barron's and the adjusted one models.

Figures 4 and 5 compare the measured and simulated D_{50}(%) (top) and C_{80}(dB) (bottom) as a function of distance at the same octave bands for Sta. Marina and S. Marcos churches. The graphics also show the theoretical lines of the analytical model, which has been published before [3]. In all cases both set of values show similar spectral and positional patterns and they show that these two acoustic quality descriptors are rather sensitive to local variations, there being also an acceptable agreement with the predicted theoretical model.

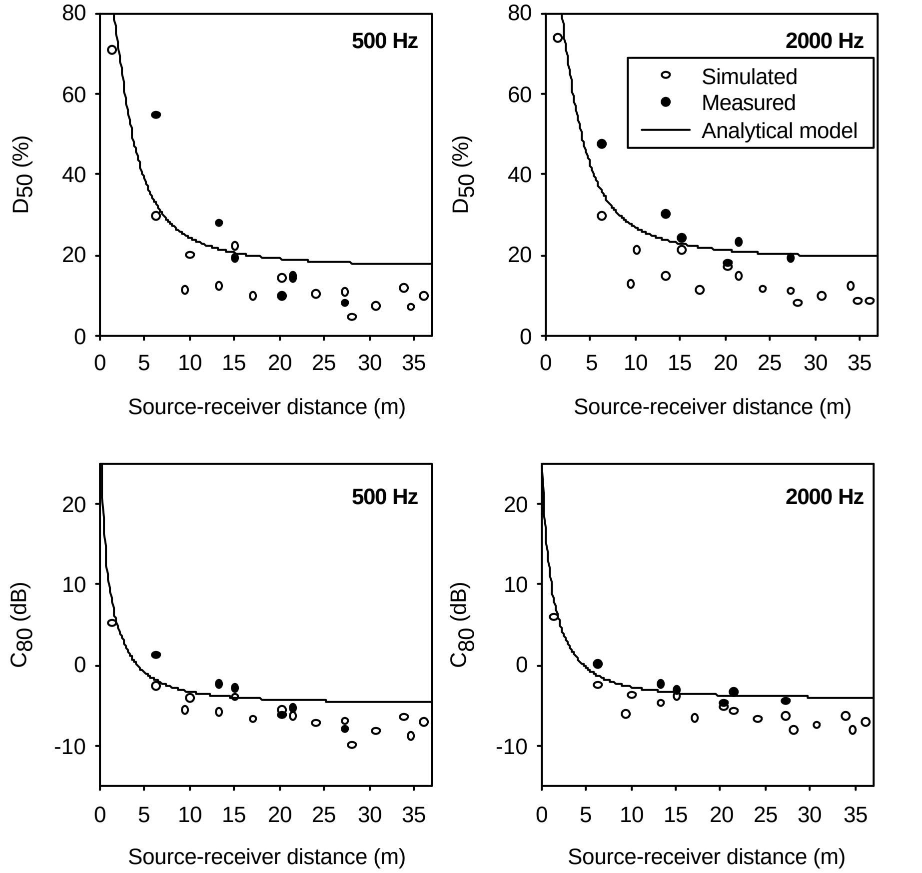

Figure 4. D_{50} (%) and C_{80} (dB) versus source-receiver distance (m) in Sta. Marina church.

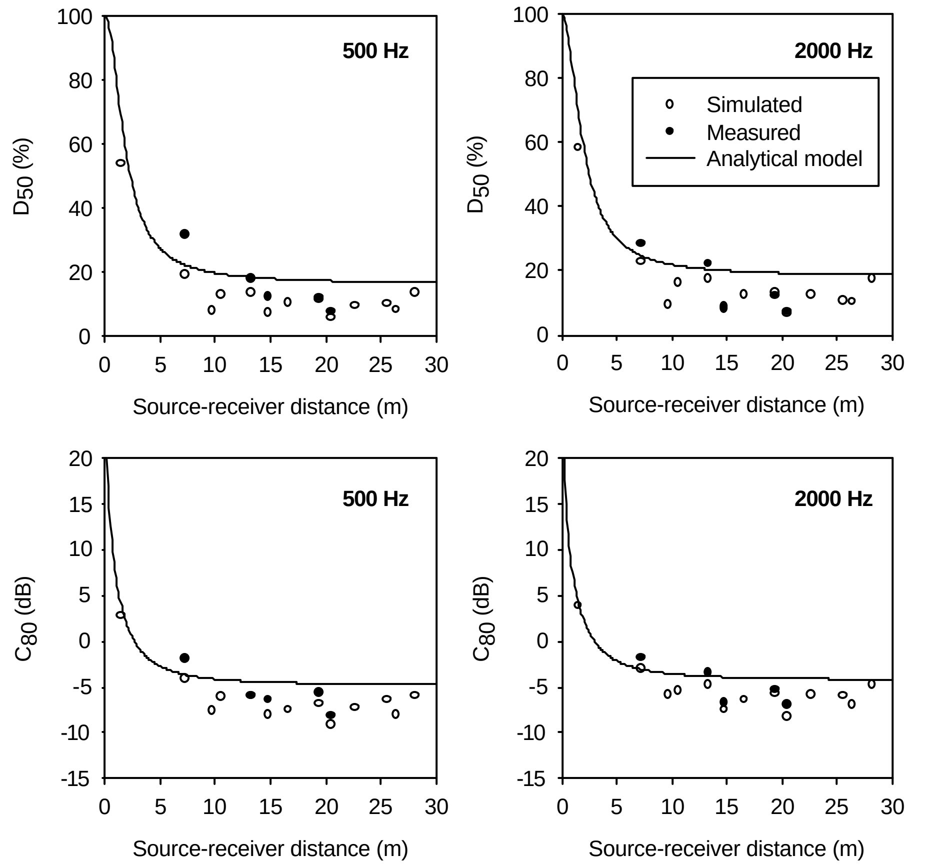

Figure 5. D_{50} (%) and C_{80} (dB) versus source-receiver distance (m) in S. Marcos church.

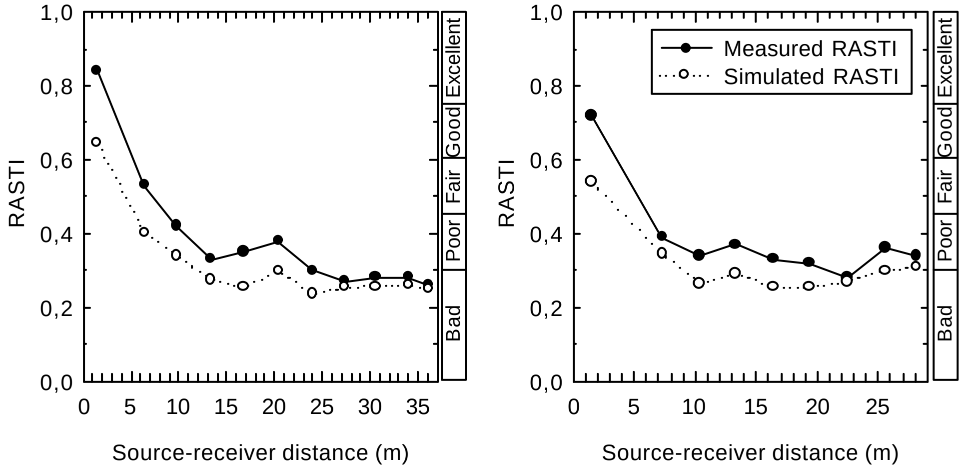

Figure 6. RASTI index versus source-receiver distance (m) in Sta. Marina (left) and S. Marcos (right).

Figure 6 shows the variation with source-receiver distance for the RASTI index in Sta. Marina (left) and S. Marcos (right) churches. We can emphasise that the spatial variations of the RASTI indices follow a very similar trend between experimental and calculated data. It is appropriate to remind that the simulated RASTI values are obtained through their corresponding simulated impulse response. In another paper [7] at this Forum, we compare RASTI indices, which have been measured using both experimental techniques: modulated noise and MLS signals.

CONCLUSIONS

This achieved agreement is a good point about the ability of the model, the software and the calculation method implemented. We can point out that if at least we have experimental results of the reverberation times it is possible to fit the acoustic characteristics of the surfaces of the model, allowing the simulation to obtain acoustic parameters in concordance with the experimental ones. Alternatively, it would be desirable to have suitable experimental methods to be able to measure "in situ" absorption and scattering coefficients. This would allow us, to fit the entrance data, which normally presents the most uncertainty in order to obtain reliable results.

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