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Sound Behaviour of Concrete Churches. The Church of Santa Cruz de Oleiros

Ana María BUENO[1], Miguel GALINDO[2], Ángel Luis LEÓN[1]

[1] *Department of Architectural Buildings I*
University Institute of Architecture and Building Sciences (IUACC)
Higher Technical School of Architecture (ETSA)
Universidad de Sevilla
Avda. Reina Mercedes 2, 41012 Seville

[2] *Department of Applied Physics II*
University Institute of Architecture and Building Sciences (IUACC)
Higher Technical School of Architecture (ETSA)
Universidad de Sevilla
Avda. Reina Mercedes 2, 41012 Seville; e-mail: mgalindo@us.es

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The church of Santa Cruz de Oleiros, Spain (1967) shows architect Miguel Fisac's perception of sacred space after the Second Vatican Council. In this place of worship, the architect responded to the new liturgical guidelines combining geometry and architectural forms with the material of the moment, concrete. However, ordinary religious celebrations reveal acoustic deficiencies for the main use of the building. This fact is corroborated by acoustic measurements *in situ*. With a methodology that uses simulation techniques for the sound field, the analysis of the current acoustic behaviour of the room will serve as the basis for an acoustic rehabilitation proposal aimed at improving the acoustic conditions and so, the functionality of the church.

Keywords: room acoustics; concrete; worship acoustics; acoustic simulation; acoustic energy; intelligibility.

1. Introduction

Concrete became part of the building world in the first quarter of the twentieth century, also extending to places of worship. In Spain, after the civil war, the parish church became the protagonist of the century. The economic situation of the time led to the need for simple austere parishes. Architect Miguel Fisac (1913–2006) was one of the best-known professionals specializing in this type of enclosure, choosing concrete as a main construction material, both prefabricated and *in situ*. In addition, the liturgical reform established by the Second Vatican Council (1962–1965) led him to consider acoustics as a constant to be addressed and resolved in his church projects.

The acoustic properties of concrete, which generally presents low absorption and sound dispersion, led Fisac to work with geometry and architectural forms, controlling them to obtain acoustic benefit. Nevertheless, the subjective impression obtained with the habitual use of the enclosures and the acoustic measures implemented *in situ* reflect acoustic deficiencies.

This study analyses the current acoustic behaviour of these spaces, built almost entirely in concrete. Concrete was also the main material of the interior surfaces (walls and ceiling), on which no work has been published, except on churches with concrete that is coated, usually painted (Cirillo, Martellotta, 2006), and which will serve as a basis for acoustic rehabilitation proposals for the improvement of the acoustic conditions and, in turn, the functionality of these churches.

2. Santa Cruz de Oleiros church

The new liturgical determinations (*Sacrosanctum Concilium*, 1963; *Inter Oecumenici*, 1964) sought the full, conscious, and active participation of the faithful in liturgical celebrations. In addition, they incorporated the use of the mother tongue in many parts of the liturgy, so that intelligibility conditions of the oral message became essential. The use of Gregorian chant, polyphony and sacred music were also frequent, and included some instruments, particularly the organ.

These determinations led Fisac to design an assembly space with a scallop-shaped floor plan and a marked transversal axis. This provided an efficient grouping of the faithful around the presbytery, which in turn houses the different liturgical focuses: altar, seat and pulpit (Fig. 1). In order to avoid acoustic concentrations at the back wall of the church, Fisac arranged what he called *dispersive walls*, consisting of four convex semi-cylinders that also form the access atrium, the sacristy, the baptistery and the penitential chapel. The chapel of the Santísimo is projected as a lateral split in the right wing of the nave, accessible from it and from the presbytery.

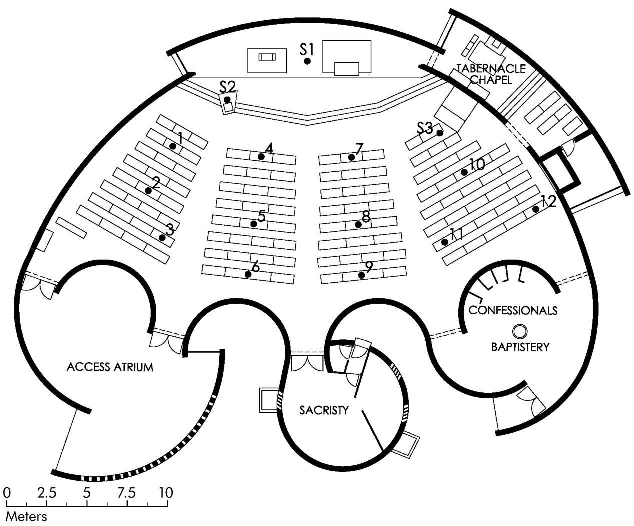

Fig. 1. Church floor plan. Source and receiver positions.

Fisac's research into the structural possibilities of concrete, as a modern material suitable for any shape and capable of completely resolving a building, led him to build the church in reinforced concrete *in situ*, except for the roof which was resolved with prefabricated pieces of concrete, large longitudinal beams and transverse ribs (Figs. 2 and 3).

In the interior, the colour of the light defines the different areas of the church. The illumination of the presbytery comes, on the one hand, from a perforation between the roof beams, shedding white light on the altar, and on the other, by arranging windows of yellow glass at both sides of the presbytery, resolving the union of the side wings with the wall of the presbytery. In addition, simple blue glazing in the openings of the dispersive walls provides light for the worship area.

Fig. 2. Interior view towards the presbytery.

Fig. 3. *Dispersive walls* and roof structure.

3. *In situ* acoustic measurement. Analysis and evaluation of current acoustic conditions

The measurements were carried out following the standard procedure (ISO 3382-1:2009), with the church empty of worshippers. The sound source was placed, at 1.5 m above floor level, in the centre of the presbytery (S1); in the pulpit (S2), next to the organ located near the presbytery; and at the concrete wall of the right wing of the nave (S3). For the receiver microphone, twelve positions were distributed throughout the congregation (pew area), at 1.2 m above floor level, so that their positions were representative of the total space, with a volume of 3702 m^3 and a useful surface, excluding the chapels, of 375 m^2 (Fig. 1). The mean values of the environmental variables recorded during the measurements were a temperature of 20.8°C and 67% relative humidity. The value of the background noise corresponds to the curve NR 32, below the maximum value recommended for places of worship (NR 35).

The impulse responses (IR) were obtained at each receiving point from sine-swept signals, with the scanning frequency increasing exponentially with time. Adjustments were made to the frequency range, to cover the octave bands from 63 to 16000 Hz, and the duration of the sweep, to achieve signal to noise ratios over 45 dB in all octave bands (Bueno *et al.*, 2012). From these IRs, the values of the acoustic parameters are derived, providing information on the subjective aspects of the listener.

The process of generation, acquisition and analysis of the signal was performed with the WinMLS2004 software through a DigigramVX Pocket v2 sound card. The generated signal fed an INTER-M 1000 power amplifier and was reproduced in the hall by an AVM DO-12 omnidirectional sound source. The impulse response was captured by various types of microphone.

For the IR, an Audio-Technica AT4050/CM5 multi-pattern microphone was used in omnidirectional configuration connected to an ARTcessories bias supply. To obtain parameters related to the perceived width of the source and the enveloping of the listener, the multi-pattern microphone was used in its omnidirectional and figure of eight configurations. In order to measure parameters related to the spatial impression a Head Acoustics HMS III torso simulator was used together with the OPUS 01 dB signal conditioner. For the recording of the background noise spectrum and speech intelligibility a B&K 4165 omnidirectional microphone with a B&K 2669 preamplifier were used, together with the OPUS 01 dB signal conditioner. When estimating intelligibility, a self-built source was used that simulates the directivity pattern of the human head. In addition, the signal was adjusted to the standard level of the human voice, which corresponds to 67 dB(A) at one meter from the source. The emission level of the source was fixed using a B&K 2231 integrating sound level meter.

In order to qualify the room correctly the measurements need to be made in the presence of the congregation, so that the real acoustic conditions occur. As this was not possible, a simulation model was developed (Álvarez-Morales, Martellotta, 2015; Martellotta *et al.*, 2011), which could reproduce the actual acoustic conditions with sufficient approximation and reliability, based on acoustic measurements performed *in situ* with the room empty (Fig. 4).

Once the objective was reached, the full occupied church hypothesis was simulated using the values of the absorption and scattering coefficients found in the literature. The simulated model is considered capable of reproducing the actual acoustic conditions when the simulated reverberation time does not differ by more than one just noticeable difference (JND), the subjective *limen* of human perception, from the measured values for each octave band (Table 1).

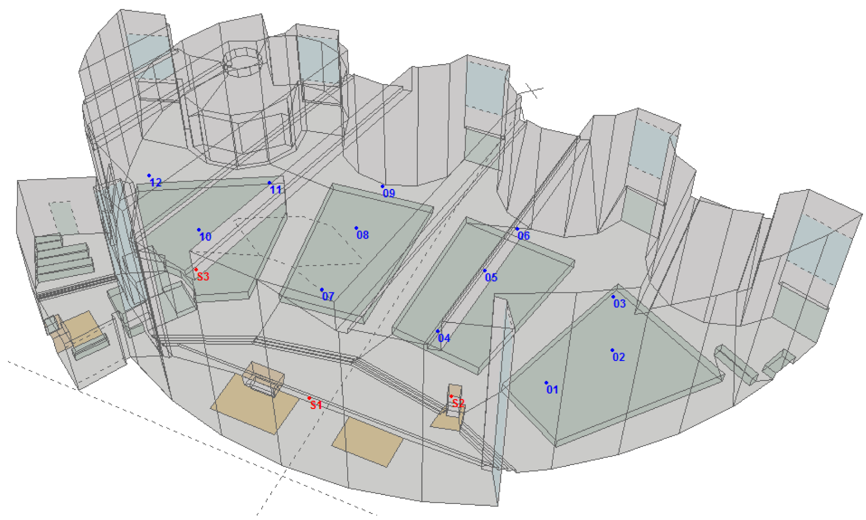

Fig. 4. Three-dimensional model for the simulation of the sound field. Source and receiver positions.

Table 1. Subjective aspects analysed and the corresponding acoustic parameters, units and JND.

Subjective aspect	Acoustic quantity	Unit	JND
Reverberance	Reverberation time: T_{30}	s	Rel. 5%
	Early decay time: EDT	s	Rel. 5%
Perceived clarity of sound	Definition: D_{50}	–	0.05
	Clarity: C_{80}	dB	1.5 dB
	Speech Transmission Index: STI	–	0.03
Subjective level of sound	Sound strength: G	dB	1 dB
Apparent source width	Early lateral energy fraction: J_{LF}	–	0.05
Listener Envelopment	Late lateral sound level: L_J	dB	–

According to ISO 3382-1, simulated values will not differ more than 5% from the measured values for each octave band. To fine-tune the process, the rest of the acoustic parameters should not differ from the simulated values by more than two JNDs (Vorländer, 2008), for each receiver and for each frequency octave band. This adjustment results in small variations in the coefficients of absorption and scattering of the least-known materials used in the church, presenting more uncertainties or showing different finishes and irregularities from those of internationally recognized values. Table 2 shows the absorption and scattering coefficients of the materials involved (Vorländer, 2008; Cox, D'Antonio, 2009; Galindo *et al.*, 2009). The values in bold are the adjusted values.

CATT TUCT v1.0f calculation software was used, with calculation algorithm 2, which allows the development of detailed auralizations, 35 000 rays and a temporal length of 8 s. To calibrate the model, it was necessary to adjust the values for the concrete of the nerves, beams and the dispersive walls. An agreement between measured and predicted results on a point-by-point basis was also obtained, with differences greater than 5% for the measured values at only 3 points in the 125 Hz octave band (6.4%, 9.2% and 6.2%).

Figure 5 shows the measured and simulated reverberation time (T_{30}), spatially averaged in octave bands for the three source positions. The optimum values recommended for word and religious music are also provided for each octave band (Beranek, 1993). As expected, the values are well above the recommended

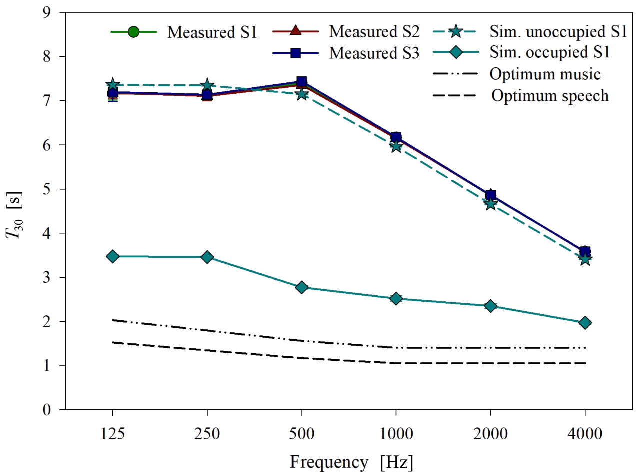

Fig. 5. Reverberation time (T_{30}) spatially averaged versus frequency in octave bands for the three source positions and optimal times.

optimum, with differences of more than 5 s at frequencies between 125 Hz and 500 Hz. The spatial dispersion, represented by the standard error, is very low. The values obtained practically coincide for the three source positions.

When performing the acoustic simulation of the occupied room, the reverberation time values decrease considerably, although they remain higher than the recommended ones. In order to avoid excessive complication of the graphs, the simulated values presented are those for source S1 exclusively, showing only the

Table 2. Absorption coefficients (α) and scattering (s) coefficients. Retouched values appear in bold.

Materials	f	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Concrete[b]	α	0.01	0.01	0.02	0.02	0.02	0.02
	s	0.10	0.10	0.10	0.10	0.10	0.10
Concrete nerves and beams[b]	α	**0.02**	**0.03**	**0.04**	**0.05**	**0.05**	**0.05**
	s	**0.15**	**0.15**	**0.20**	**0.20**	**0.25**	**0.25**
Concrete dispersive walls[b]	α	0.01	0.01	0.02	0.02	0.02	0.02
	s	**0.65**	**0.40**	**0.30**	**0.20**	0.10	0.10
Marble[a]	α	0.01	0.01	0.02	0.02	0.02	0.02
	s	0.10	0.10	0.10	0.10	0.10	0.10
Wooden pews (empty)[c]	α	0.16	0.18	**0.10**	**0.12**	**0.16**	**0.15**
	s	0.30	0.40	0.50	0.60	0.70	0.80
Wooden pews (full)[b]	α	0.57	0.61	0.75	0.86	0.91	0.86
	s	0.30	0.40	0.50	0.60	0.70	0.80
Wooden door[a]	α	0.14	0.10	0.06	0.08	0.10	0.10
	s	0.10	0.10	0.10	0.10	0.10	0.10
Glass (large area)[b]	α	0.18	0.06	0.04	0.03	0.02	0.02
	s	0.10	0.10	0.10	0.10	0.10	0.10
Carpet (thin)[a]	α	0.02	0.04	0.08	0.20	0.35	0.40
	s	0.10	0.10	0.10	0.10	0.10	0.10

[a](Vorländer, 2008), [b](Cox, D'Antonio, 2009); [c](Galindo *et al.*, 2009).

sources that present remarkable features graphically and/or with words.

This is, therefore, an excessively reverberant space due to its lack of sound absorption, an aspect that gives rise to acoustic deficiencies in the room, reflected in turn in the other acoustic parameters.

In order to describe the sound sensation of a listener, the subjective aspects will be analysed based on the objective acoustic parameters (ISO 3382-1:2009) shown in Table 1.

The first subjective aspect is that of the sensation of reverberation or permanence of sound in time. While it is true that reverberation time accounts for this, early decay time (*EDT*) is better correlated with this sensation (Reichardt *et al.*, 1974). The results recorded in Fig. 6 are very similar to those of T_{30} for the three source positions at middle and high frequencies, slightly lower and with a somewhat larger spatial dispersion. In the case of source S3, located near the organ, the values obtained, highly dependent on the early reflections, are somewhat lower for low frequencies, without exceeding the subjective thresholds (just noticeable difference, JND) allowed in the norm for acoustic parameters (Table 2). The decrease in the values for 100% occupation is almost the same as that obtained for T_{30}.

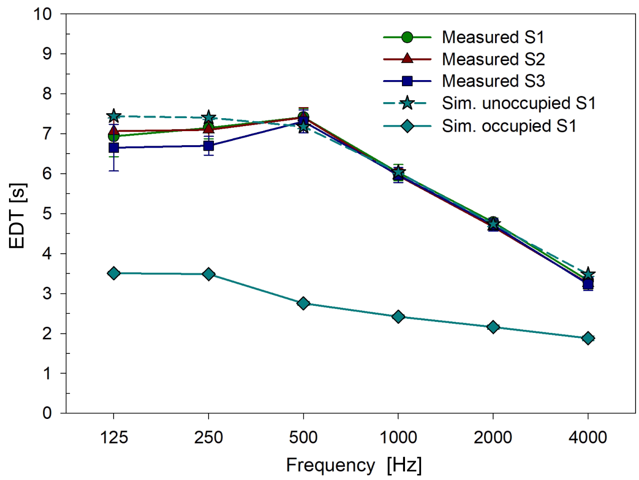

Fig. 6. Early decay time (*EDT*) spatially averaged versus frequency in octave bands for the three source positions.

These equal values for T_{30} and *EDT* could be explained by a high density of early reflections in early energy, as well as closeness to diffuse field conditions (Gade, 2007). However, the high value of reverberation time of the church implies that during the fall of the first 10 decibels of acoustic energy, most of the reflections are late reflections, (e.g. 80 ms threshold (Barron, Lee, 1988)). However, early reflections, as seen later, are not expected to behave according to diffuse field in churches (Cirillo, Martellotta, 2003).

The next subjective aspect is the perceived clarity of sound from either an oral or a musical message. For the evaluation of the oral message, the objective definition (D_{50}) acoustic parameter was chosen, while that of musical clarity (C_{80}) was selected for the musical message.

Both parameters display very low results, with measured values lower than 0.27 and −2 dB respectively for all octave bands (Figs. 7 and 8). This implies a subjective feeling between bad and poor for speech, and an adequacy exclusively for organ music (Marshall, 1994). Again, the results are similar in each of the three source positions, although in the organ (S3) they are somewhat more favourable than the pulpit (S2), which in turn displays better results than the altar (S1). The values simulated with respect to the measured ones differ in both cases in less of a JND, except sometimes for C_{80} in the 125 Hz octave band (2 JND) where phenomena arise from the wave character of sound. The ray tracing limitation precision is for octave bands below four times the Schroeder frequency (Schroeder, 1954). In the church of Santa

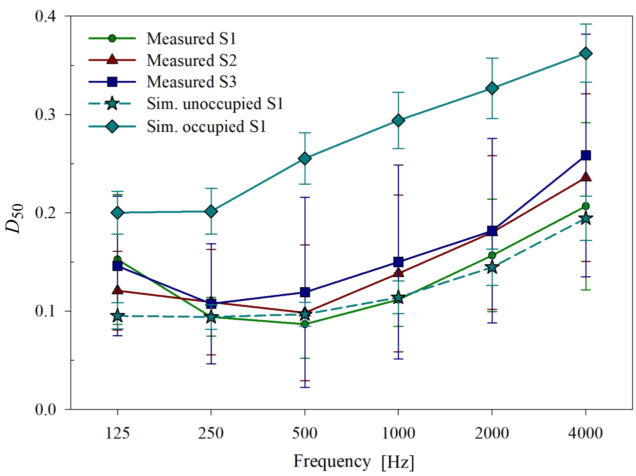

Fig. 7. Definition (D_{50}) spatially averaged versus frequency in octave bands for the three source positions.

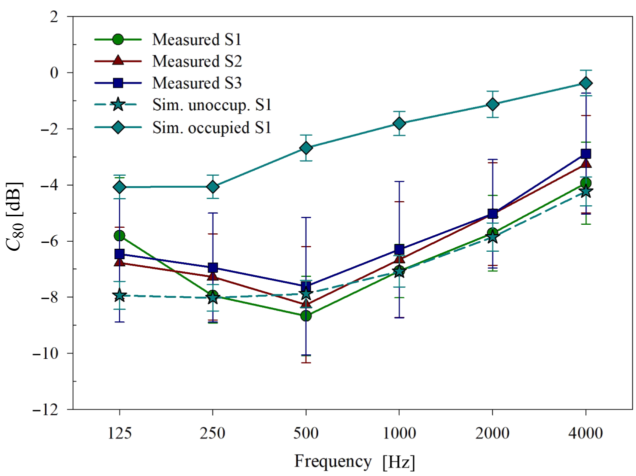

Fig. 8. Clarity (C_{80}) spatially averaged versus frequency in octave bands for the three source positions.

Cruz the values are 348 Hz and 240 Hz for unoccupied and occupied respectively.

The presence of the faithful, with 100% church occupation, significantly improves both results, although they remain inferior to the values considered desirable (Álvarez-Morales *et al.*, 2016).

Spatial dispersion is notable for both parameters and for the three sources, with standard deviations that reach 0.26 for D_{50} and 2.5 dB for C_{80} in some octave bands. Minor dispersion is obtained for the simulation. To analyse the variation of both parameters with the source-receiver distance, the averaged values (ISO 3382-1:2009) for S1 source position were analysed (Figs. 9 and 10). The receiver numbers are highlighted in the upward horizontal axis. The typical range established in the standard in non-occupied concert and multi-purpose halls up to 25 000 m^3 is included in the figures for the purposes of comparison.

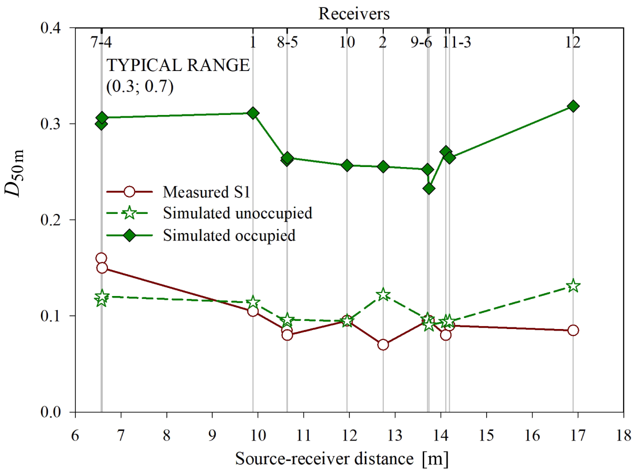

Fig. 9. Frequency weighted definition values ($D_{50\text{ m}}$) versus source-receiver distance.

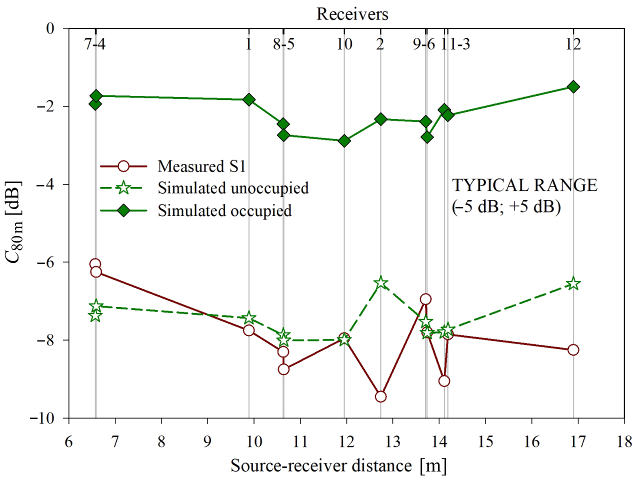

Fig. 10. Frequency weighted definition values ($C_{80\text{ m}}$) versus source-receiver distance.

$D_{50\text{ m}}$ presents small variations, less than 1 JND, with source-receiver distance, while $C_{80\text{ m}}$ can vary by more than 2 JND. So, the musical clarity perceived by the faithful could entail a change of subjective sensation in the audience. The presence of the congregation standardizes these values with maximum differences below 1 JND in both cases.

In principle, as pointed out, it could be expected that in an enclosure such as this, where concrete is the main material, we will be closer to diffuse field conditions. Nevertheless, the shape of the church and the presence of the wooden pews, with greater absorption than concrete, break the homogeneity of acoustic energy in the enclosure (Barron, Lee, 1988), causing greater attenuations of C_{80} measured values than those expected with distance.

To estimate these attenuations, the μ parameter (Zamarreño *et al.*, 2007) was calculated, and accounts for a possible lack of reflections in the first 80 ms as we move away from the emitting source and, therefore, the attenuations are higher than expected. By way of example, the impulse response normalized at point 4 for source S1 is shown in Fig. 11. In the first 80 ms from the arrival of the direct sound, a low density of early reflections is observed.

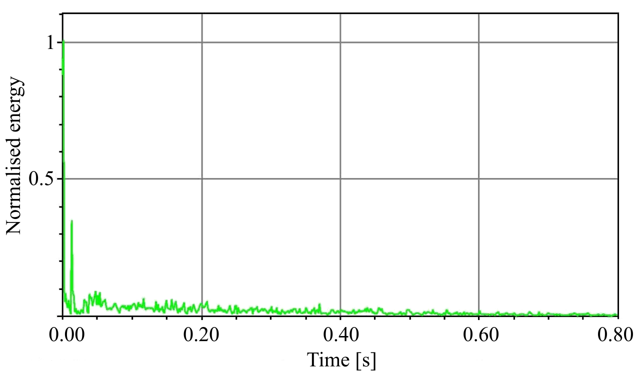

Fig. 11. Normalised energy-time curve in the first 80 ms after the direct sound. Source S1, reception point 4.

In this μ model, the early reflected energy (from the arrival of direct sound at a specific location, for 80 ms) is reduced by factor $e^{-\mu r/T}$, with respect to classic reflected energy, where T is the reverberation time. The μ parameter is calculated through non-linear regression from the experimental values of $C_{80\text{ m}}$ versus source-receiver distances.

The reference value is that proposed by Barron and Lee (1988) ($\mu = 0.04$) for large theatres. In this regard, Berardi *et al.* (2009) calculated different values of μ parameter for churches of various styles, including modern ones, when the source is located at the altar. From this typological analysis, it was possible to infer a new reference value for the parameter μ, double the value proposed by Barron and Lee (1988) for initial reflected energy, which increases depending on the specific characteristics of each formal, acoustic and stylistic configuration.

Figure 12 shows the regression obtained for source S1, with the value of the coefficient $\mu = 0.16$ and the coefficient of determination $r^2 = 0.95$. Berardi *et al.* (2009) obtained similar values for modern and early-Christian churches when the source is at the altar and the typology studied corresponds to an auditorium-like church or basilica with narrow aisles. Considering the typological recommendations suggested by Berardi *et al.*, according to the architectural characteristics, the μ value matches the suggested recommendation, due to the additional scattering of the ribbed shape of the ceiling and the back walls. However, for sources S2 and S3, the values obtained are $\mu = 0.20$ and 0.14 with $r^2 = 0.92$ and 0.88 respectively. By way of comparison, if we assume the values of μ for source S1 for sources S2 and S3 to evaluate the point-to-point differences of $C_{80\,\mathrm{m}}$ with the values obtained when $\mu = 0.16$, values higher than 1 JND are found for 83% and 58% of the points respectively. This fact highlights the importance of early reflections for each source-receiver combination, making it impossible to define a single value of μ for any church.

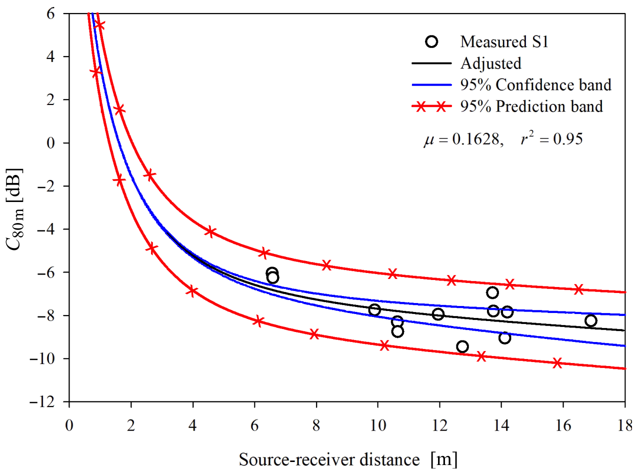

Fig. 12. Regression for the μ model. Value of the μ parameter of the church studied and the coefficient of determination of the adjustment.

To qualify the intelligibility of speech the STI index (Hougast, Steeneken, 1971), a priority in this type of enclosure, was also calculated for each reception point as a function of the source-receiver distance (Fig. 13). The scale of subjective intelligibility (IEC 60268-16:2011) is highlighted on the right vertical axis. The values obtained *in situ* for a source at the altar are in the rating limit of intelligibility between bad and poor in practically the entire worship area. When the source is in the pulpit, most receivers are in the bad zone, with values decreasing when the source-receiver distance increases.

The presence of the audience improves the results for S1 and the qualification, but it is still poor approaching fair. For S2, most of the receivers are in the fair zone, although very close to the limit with the poor zone, except for the two points closest to the pulpit. For source S2, variations in distance between the different receivers can reach 6 and 4 JND for the unoccupied and occupied configurations respectively.

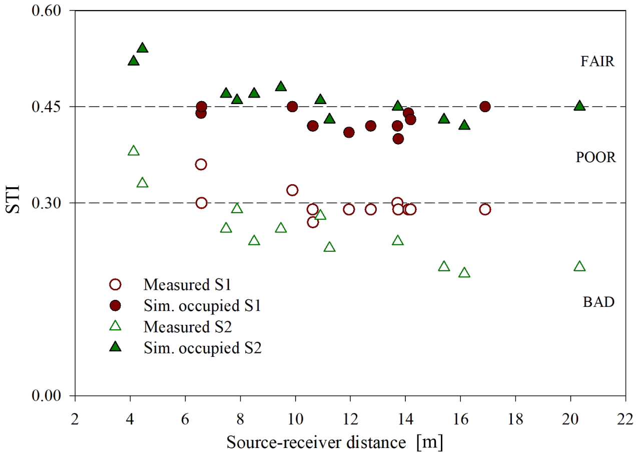

Fig. 13. Speech Transmission Index (STI) versus source-receiver distance and qualification zones.

Comparing the speech intelligibility indexes, D_{50} and *STI*, a discrepancy in qualification is observed for a full occupation of the faithful, the subjective sensation of the listeners in the different positions of the congregation zone and between the sources analysed. This is due to the need to adapt the rating recommendations and subjective limen of human perception (JND) applied to concert halls and to this specific type of venue with an additional associated religious component. It is well known that some JNDs can vary significantly from those recommended in the standard (Martellotta, 2010) or appear to be significantly higher (Vigeant *et al.*, 2015).

The subjective sound level, evaluated by sound strength (G), presents very similar elevated results for the three source positions at all frequencies, providing a very high reverberant field level (Fig. 14). This is evident from the high reverberation times obtained and the low sound absorption of the concrete.

The difference between measured and simulated values for S1 source differ less than 2 JND at all frequencies except for the 250 Hz octave band which is 2.7 JND. The presence of worshippers contributes to an increase in absorption in the pew area which is reflected in a decrease of the values averaged by octave bands. However, sufficiently high values of G. are still maintained. Maximum standard deviation at 250 Hz octave band is 1.6 dB.

Considering the attenuation of the frequency averaged value G_m with the distance (Fig. 15), maximum measured variations between receivers are observed around 3 JND. The simulated values present a greater adjustment to the measured values, due to the aver-

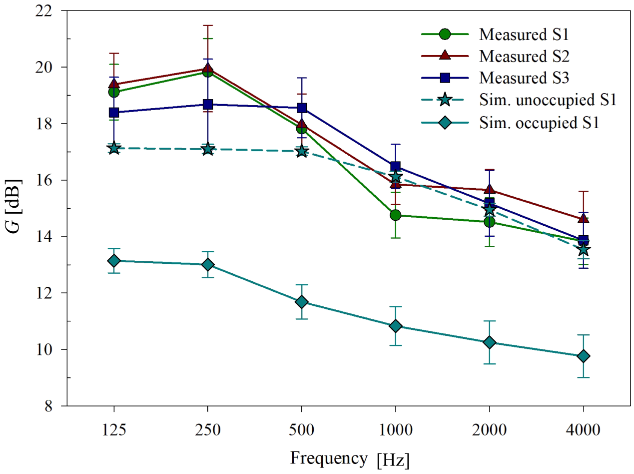

Fig. 14. Sound strength (G) spatially averaged versus frequency in octave bands for the three source positions.

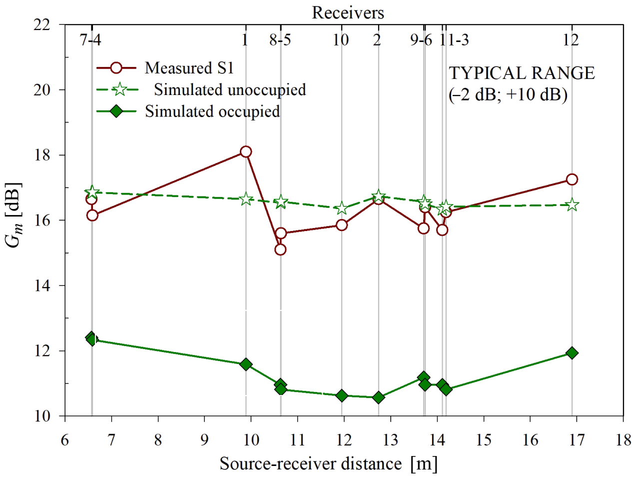

Fig. 15. Frequency weighted strength values (G_m) versus source-receiver distance.

aging of the mid frequencies, although these values are more uniform. When there is 100% occupancy, no zones of sound concentration or level deficiency are observed, and the highest values are recorded in the front and centre areas of the congregation and next to the central aisle.

Spatial impression completes the different aspects relating to the subjective perception of the listener. This spatial impression is described by two characteristics: Apparent Source Width (ASW) and the sensation of being surrounded by sound, Listener Envelopment (LEV).

Figure 16 shows the spatially averaged values versus the different octave bands of the early lateral energy fraction (J_{LF}), an objective parameter relating to ASW. Although this parameter is very sensitive to the source and receiver position, the results at each frequency are within the typical range established in the standard for non-occupied concert and multi-purpose halls up to 25 000 m^3. This is due to the auditorium-

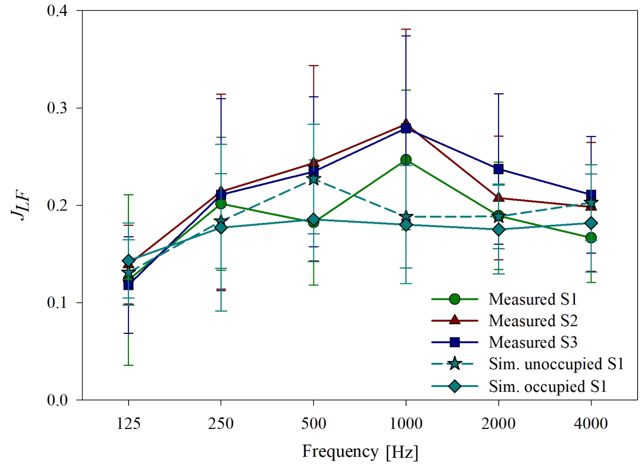

Fig. 16. Early lateral energy fraction (J_{LF}) spatially averaged versus frequency in octave bands for the three source positions.

like character of the enclosure, resulting from the openings in the concrete walls, obtaining a good number of lateral reflections. Maximum standard deviation in some octaves is 0.1.

The simulated values differ notably from the measurements of parameters highly dependent on early lateral reflections. This is common to all simulations, due to the simplification of the three-dimensional model, the possible variations of the source-receiver distance and the uncertainty in the values of the absorption and scattering coefficients of some materials. These differences become apparent in the values obtained from the standard deviation. However, the values return to maintain the typical range of values indicated. The presence of the audience does not ostensibly affect the simulated frequency values because most of the early lateral reflections come from the concrete sidewalls.

In Fig. 17, the variation with the source-receiver distance of J_{LF} as a single number is presented. An adequate perception of the ASW is obtained with the

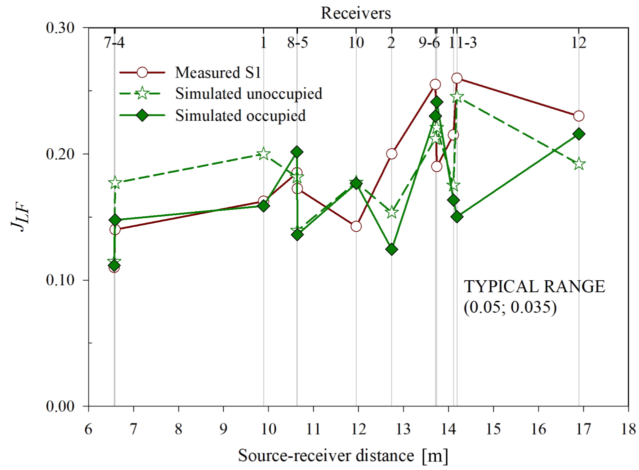

Fig. 17. Frequency weighted Early lateral energy fraction values (J_{LFm}) versus source-receiver distance.

highest values for two receivers near the concrete dispersive walls. Again, the curvature of the concrete walls increases the number of lateral reflections at these points.

Figure 18 shows spatially averaged versus frequency octave bands of the late lateral sound level (L_J), an objective parameter relating to LEV (Bradley, Soulodre, 1995). Given that this parameter is not calculated by the software no simulation results are presented.

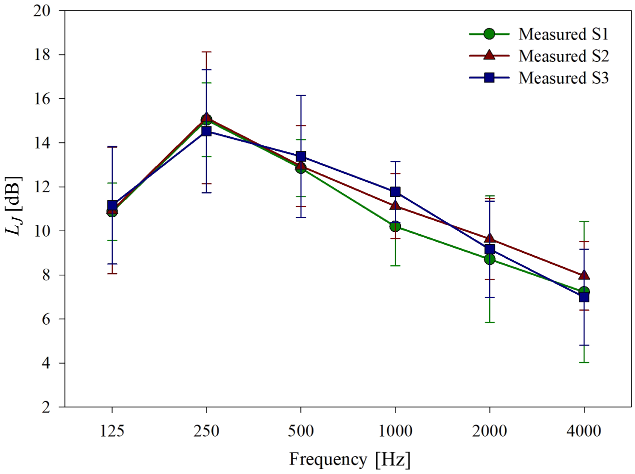

Fig. 18. Late lateral sound level (L_J) spatially averaged versus frequency in octave bands for the three source positions.

The results obtained for all the positions of the source are very high in all frequencies. As predicted, the higher the reverberation time, the greater the sensation of LEV, especially in low frequency bands 125–500 Hz (Morimoto *et al.*, 2007). Maximum standard deviation in some octaves is 3.1 dB.

Likewise, the spectral averaging values (Fig. 19) deviate from the typical range established by the standard. It follows, therefore, that in this enclosure the sound surrounding the listener is loud.

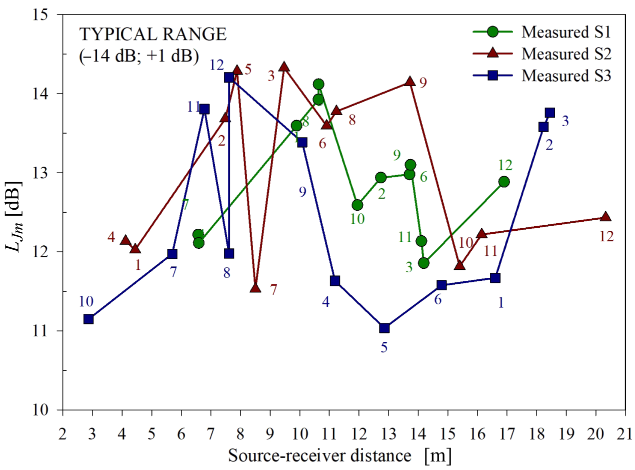

Fig. 19. Frequency weighted Late lateral sound level values (L_{Jm}) versus source-receiver distance.

Finally, Table 3 assesses the point-to-point differences between the measured values and those simulated. This table shows the percentage of points with absolute error within 1, 2 or more than 2 JND for different parameters analysed for all receivers and octave bands.

Table 3. Percentage of points for all receivers and octave bands with absolute error between the measured and simulated values within 1, 2 or more than 2 JND.

Parameter	≤ 1 JND [%]	1–2 JND [%]	≥ 2 JND [%]
EDT	50.0	34.7	15.3
D_{50}	73.6	19.4	7.0
C_{80}	76.4	18.1	5.5
G	37.5	23.6	38.9
J_{LF}	59.7	26.4	13.9

4. Conclusions

This study presents the acoustic behaviour of the church of Santa Cruz de Oleiros, Spain, almost entirely built of concrete. The absorption and dispersion characteristics of this material result in a church with a high reverberation time, which led its architect M. Fisac to investigate the structural possibilities of concrete, using geometrical and architectural forms. He thus tried to solve what he considered to be the acoustic problem in this space, while bearing in mind the new liturgical considerations established by the Second Vatican Council.

The analysis and evaluation of the results through the parameters measured *in situ* reflect that this resulted in a space with poor intelligibility of speech and limited musical clarity. Nevertheless, the sound amplification was good, with very homogenous sound distribution and a good perception of spatiality in the enclosure.

Considering the liturgical sources of the enclosure, a slight improvement in intelligibility can be seen when the speaker is on the pulpit and in musical clarity when the source corresponds to the organ.

When observing acoustic energy versus distance, the deviations found are greater than expected, and there is a high dependence on the location of the source. The importance of the early reflections in each source-receiver combination, makes it impossible to define a single value of μ for a church.

The primarily religious character of the church, where the oral message plays a prominent role, makes it necessary to resort to rehabilitations that respect its heritage character together with suitable electroacoustic support.

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