

## Acoustic Rehabilitation of the Church of Santa Ana in Moratalaz, Madrid

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The church of Santa Ana in Moratalaz, Madrid, Spain (1965–1971), is an emblematic work of the architect Miguel Fisac. In his long career include interventions in the religious field, constituting one of the most important contributions to Spanish religious architecture of the last century. This church is a singular place of worship and architecturally significant, in which the acoustics played an important role in the configuration of the spatiality of the church. This paper studies the acoustic behaviour of the church and its relationship with its unique structural, spatial and coating material characteristics. The analysis of the current acoustic conditions, with high reverberation times (up to 6 seconds) and poor intelligibility on the audience, serve as the basis for making an acoustic rehabilitation proposal that contributes to improving the sound conditions of the building for the intended use, without distorting the spatial, formal and material aspects with which the architect conceived the project.

**Keywords:** room acoustics, worship acoustics, acoustic simulation, sound-reinforcement, acoustic rehabilitation.

### 1. Introduction

The parish church of Santa Ana (1965–1971), located in the neighbourhood of Moratalaz in Madrid (Spain), was the first church that the architect Miguel Fisac designed in accordance with the liturgical guidelines set by the Second Vatican Council (1962–1965), constituting a turning point in his broad career in religious architecture.

The liturgical reform undertaken by this ecclesiastical council marked the full and active participation of the congregation, established the symbolic nature of the celebrations and stressed the importance of the word and the preaching of the priest, who now officiates looking towards the congregation and speaks in their language. For Fisac, these aspects had very important formal and acoustic implications, completely changing the programme of the church. From that moment, and in the context of where the congregation should listen and understand the liturgical act, this architect considered the acoustic problem as a constant to be addressed and resolved in his religious architecture. The importance of these facts in the acoustics of

churches and the need for its study has been suggested by other authors (BUDZYŃSKI, 2011).

Miguel Fisac (1913–2006) was one of the iconic architects who contributed to the development of twentieth-century Spanish architecture. Constructive sincerity, faithfulness to the programme and adaptation to the site, are the characteristic features of his architecture, which also reflect his status as an innovative architect and a constant researcher into the possibilities of concrete, both in its structural and its formal and plastic aspects.

His professional career, of more than 60 years and whose legacy includes more than 400 built projects, covered all fields of architecture, but his interventions in the religious field, both churches and convent complexes, marked a new understanding of ecclesiastical space, making one of the most important contributions to the religious architecture of the past century.

With this background, the church of Santa Ana in Moratalaz was chosen in order to study its current acoustic conditions and, from that study, to make a proposal of intervention to improve its sound performance in its intended purpose.

## 2. The church of Santa Ana

Fisac designed the church with an oval plan of marked transverse axis to achieve an effective grouping of the assembly around the presbytery, because he thought that this would be the form that the same

assembly would take if it met in a free space. He reinforced this arrangement by having the floor slope down towards the presbytery (Fig. 1).

Unable to place absorbent materials in the church due to economic reasons, he invented some shapes for the rear wall of the oval to disperse the sound waves,

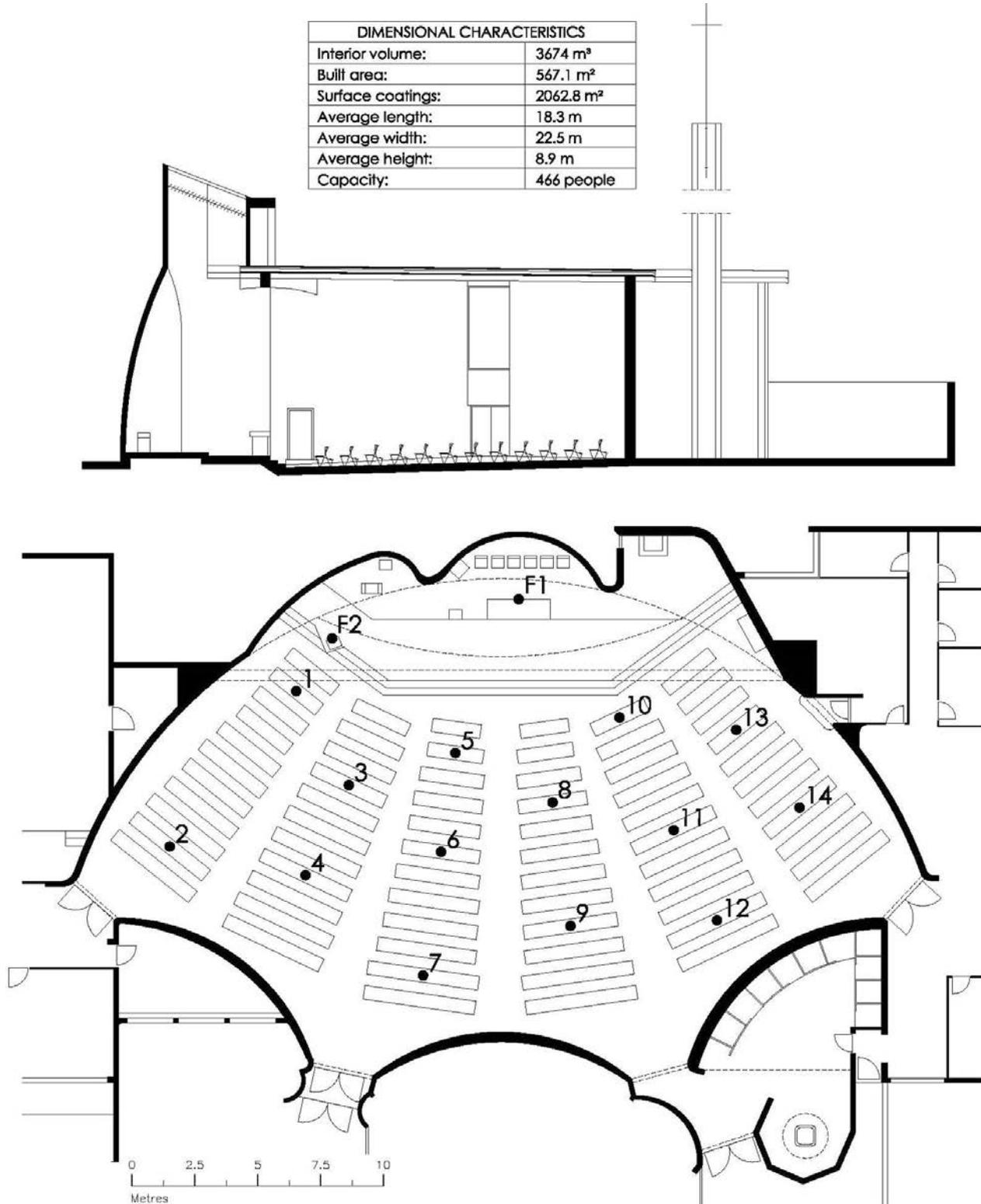


Fig. 1. Longitudinal section and plan: positions of sources and receivers.

thus avoiding acoustic concentrations that would disrupt hearing. Therefore, “the acoustics were the configuring element in the appearance of the church” (FISAC, 1965), and the reason why convex surfaces appear on the rear face of the oval, serving as *dispersive walls* (Fig. 2) whose widened curved edges facilitate access to the church from the atrium, the sacristy, the penitential and baptismal chapel and parish premises, while allowing natural and artificial lighting of the assembly space from above.



Fig. 2. *Dispersive walls*.

The rationale of the anterior wall that forms the presbytery, arises from its adaptation to the different moments of the liturgy (Fig. 3), which Fisac materialized and distributed based on three concavities: the first for the Liturgy of the Word with the pulpit and chair, the second for the altar and with the tabernacle in the third recess.



Fig. 3. Presbytery.

The material used in the church, as in the entire parish complex, is exposed concrete, poured *in situ* on all vertical surfaces. The roof is solved by concrete

*bone-beams* (Fig. 4) precast up to a 20 m span, according to the architect's patent, arranged in the nave parallel to the longitudinal axis which unites the presbytery and the *dispersive walls*. The roof, of precast pieces supported by the perimeter load-bearing walls of the church, is interrupted on reaching the presbytery to give way to a large rising rooflight (Fig. 5). To form the rooflight, the heads of the above mentioned beams are brought together in a concrete beam, poured *in situ*, hanging from an arch, and visible from the exterior.



Fig. 4. Rooflight and *bone-beams*.



Fig. 5. Rooflight above the presbytery.

Finally, for the overhead lighting in the presbytery and the natural and artificial lighting of the assembly space to be responsive to the acoustic requirements and supply the necessary light dispersal (FISAC, 1965), Fisac ordered, in both cases, normal reinforced glass and a lattice of aluminium slats, coloured gold above the presbytery and blue in the nave recesses. Today, in the light wells located above the access doors, the arrangement described above has been replaced by stained glass, with only the rooflight remaining as per its original concept.

### 3. *In situ* acoustic measurements

#### 3.1. Experimental method and measurement equipment

The measurements were carried out following the standard procedure included in the International Standard Organization norm [ISO 3382-1:2009], with no congregation in the church. Two source positions were used, located at 1.5 m above floor level, corresponding to the natural positions of the celebrant (Fig. 1). The first was placed on the altar and the second on the pulpit. The fourteen reception points were placed at 1.2 m above floor level in the area of the pews used by the congregation. Environmental conditions were monitored during the measurement period. The temperature was maintained at around 30°C and relative humidity at around 22%. The background noise spectrum was recorded by averaging four minutes at point 6 (Fig. 1). In Fig. 6 the recording is superimposed on the Noise Rating (NR) curves, and corresponded to an index NR 30, which is below the maximum recommended value for buildings of worship (NR 35).

At each receiving point, impulse responses (IR) were obtained from swept sine wave signals, where the frequency was increased 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. The acoustic parameter values were derived from these IR.

The process of generation, acquisition and analysis of the signal was performed with the WinMLS2004 software through a Digigram VX 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

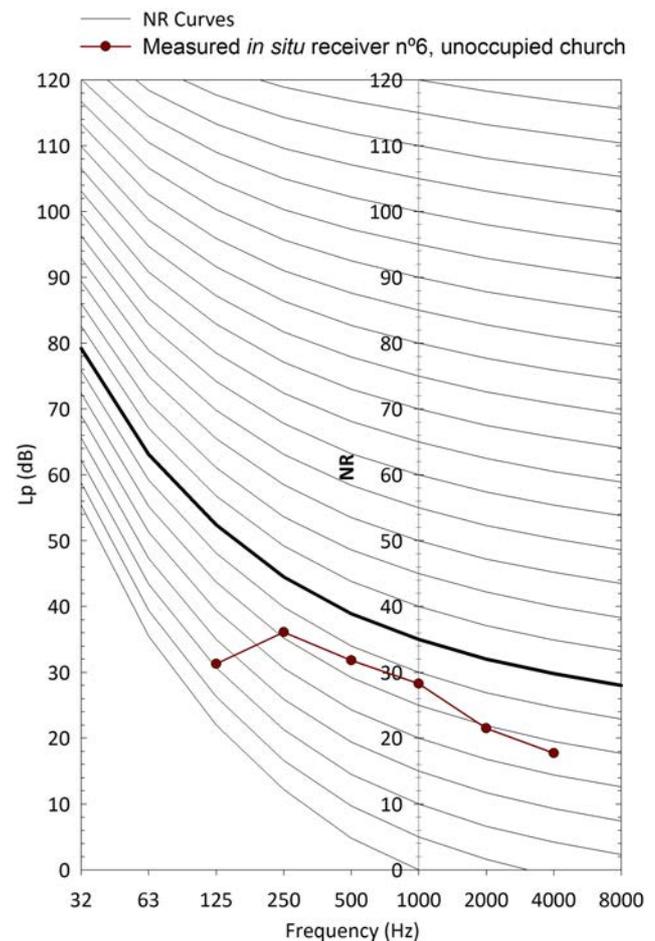


Fig. 6. NR curves and background noise spectrum recorded.

measure parameters related to the spatial impression a Head Acoustics HMS III torso simulator was used together with the OPUS 01dB 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 01dB 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.

#### 3.2. Analysis of results

The acoustic parameters studied from the experimental measurements (BUENO *et al.*, 2011a) are those considered in the ISO Standard 3382-1:2009 and its appendices, which provide information about the subjective listener aspects such as perceived reverberance, perceived clarity of sound, subjective level of sound, apparent source width and listener envelopment.

Table 1. Acoustic quantities grouped according to listener aspects.

Subjective listener aspect	Acoustic quantity	Typical range*	Santa Ana church
Subjective level of sound	Sound strength, G (dB)	-2 dB; +10 dB	17.7
Perceived reverberance	Early decay time, EDT (s)	1.0 s; 3.0 s	5.7
Perceived clarity of sound	Clarity, $C_{80}$ (dB)	-5 dB; +5 dB	-6.6
	Definition, $D_{50}$	0.3; 0.7	0.14
	Centre time, $T_S$ (ms)	60 ms; 260 ms	412.5
Apparent source width (ASW)	Early lateral energy fraction, $J_{LF}$	0.05; 0.35	0.16
Listener envelopment (LEV)	Late lateral sound level, $L_J$ (dB)	-14 dB; +1 dB	12.6

\* Frequency-averaged values in single positions in non-occupied concert and multi-purpose halls up to 25,000 m<sup>3</sup>.

The church has a reverberation time ( $T_{30}$ ) of 5.73 s, (single number frequency averaging). In order to characterize the acoustics of the church, Table 1 presents also the values of the spatially and frequency averaged objective parameters as recommended by the above standard, along with its relationship to the subjective aspects of the listener.

Figures 11 and 12 show the results of some acoustic parameters related to those subjective aspects mentioned above. It can be seen that the values associated with reverberation, speech intelligibility and musical clarity are far from the recommended values, thus leading to poor acoustics, even if the subjective level of sound is adequate. Regarding the measured parameters related to spatial impression (BUENO *et al.*, 2011a), the values of the late lateral sound level ( $L_J$ ) correspond to a sound sensation envelopment of the listener at all frequencies, and those of the early lateral energy fraction ( $J_{LF}$ ) give rise to a small source width. Therefore, the listener is immersed in the speech or music with a clear location of the sound source. This fact is confirmed from the inter-aural cross correlation coefficients (late and early,  $IACC_L$  and  $IACC_E$ ).

Furthermore, it confirms that the position of the source at the altar or the pulpit does not produce significant differences in any of the acoustic parameters analysed.

#### 4. Simulation of the sound field

A three-dimensional model was developed using CAD software which reproduced the interior of the church from the geometric point of view. Subsequently the geometry was exported and uploaded to the acoustic simulation software CATT-Acoustic v8.0k, in which the acoustic absorption and scattering coefficients of the different surfaces lining the interior of the church are assigned. It also defines the positions of sources, their emission levels and directivities as well as the locations of the receptors, so that the source-receiver distances do not exceed those determined from the measured impulse responses by more than 20 cm. Finally, the conditions of temperature (30°C), relative humidity (22%) and air density (1.15 kg/m<sup>3</sup>) were incorporated. The model of the hall, with a volume of 3674 m<sup>3</sup>, was composed of a total of 257 plans, which form a 2063 m<sup>3</sup> surface area of coatings (Fig. 7).

A new software developed by CATT-Acoustic: *The Universal Cone-TracerCATT TUCT v1.0f* was used to calculate the sound field simulation. As an innovation, it eliminates any type of idealized recreation of the reverberant tail in the late part of the echogram, which is why a greater number of cones must be considered to ensure sufficient precision in the impulse response that requires its use in auralization.

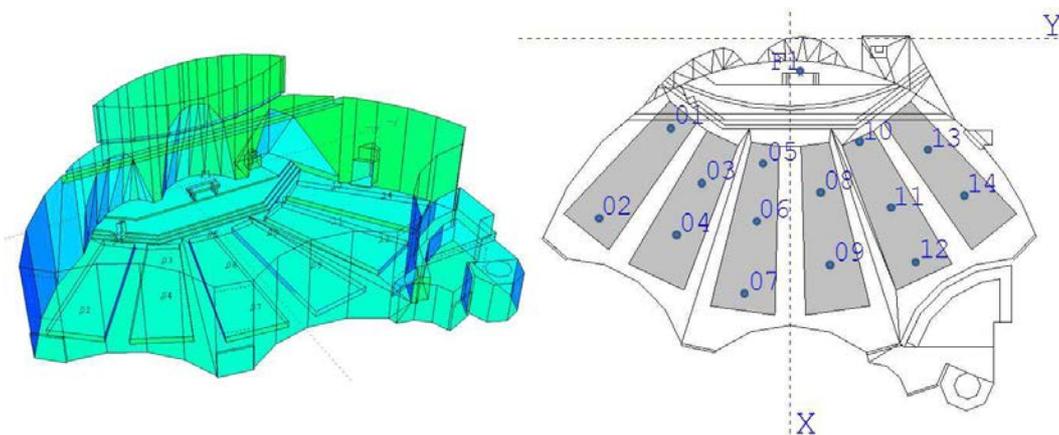


Fig. 7. Three-dimensional model of the current state of the church of Santa Ana at Moratalaz.

The conditions for calculating the simulation were as follows:

- Calculation Algorithm: 2, complete calculation, detailed auralization;
- Number of rays/cones: 30000;
- Echogram / impulse response: 6 s;
- Air absorption: on;
- Calculation time: 35 hours, 11 minutes.

#### 4.1. Computer model calibration

The objective of this phase was to obtain a three-dimensional model with an acoustic behaviour as close as possible to that of the hall and whose acoustic characteristics were determined with measurements made *in situ*. To this end, the absorption and scattering coefficients of the materials with more uncertainty were modified in the model, to adjust the estimated  $T_{30}$  of the model, with the values measured *in situ* for different octave bands, based on there being no congregation and with the source at position 1, coinciding with the altar (Fig. 1). As a valid criterion of calibration (GALINDO *et al.*, 2009), it is estimated that the match is appropriate if they differ less than the perceptible threshold *Just Noticeable Difference* (JND) which corresponds to 5% of the values measured in each octave band.

Table 2 shows the sound absorption and scattering coefficients of the coating materials existing in the hall, highlighting the materials that were adjusted for the calibration of the reverberation time  $T_{30}$ . For the absorption coefficients, the values provided by the literature (VORLÄNDER, 2008; COX, D'ANTONIO, 2004) were chosen. In the three materials adjusted, the absorption coefficient values for the mid and high frequencies also corresponded to those established internationally, while it was in the low frequencies where the adjustment was made. This fact is due to the frequency behaviour of the reverberation time (Fig. 11). The roof of the church, consisting of precast concrete *bone-beams* which cross a large span, acts as a resonator, increasing the absorption at low frequencies. The rooflight, with anodized aluminium slats, together with the windows represent large areas with vibration capability and can be considered in a similar manner. That is why the absorption coefficient values of these elements increased at low frequencies, especially in the 125 Hz octave band.

However, in addition to this, a preliminary estimate of the absorption coefficient was made which took the actual surface of the adjusted materials into account. It is recognized (MARTELOTTA, 2009) that in simulating a straight surface, a surface with irregularities must affect not only the coefficient of scattering but also that of absorption. It is therefore the combined effect

Table 2. Sound absorption coefficients ( $\alpha$  above) and sound scattering coefficients ( $s$  below) of the existing materials in the ecclesial enclosure (%).

Material	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Marble, granite	1	1	1	1	2	2
	10	10	10	10	10	10
Exposed concrete	1	1	2	2	2	2
	10	10	10	10	10	10
Exposed concrete <i>dispersive walls</i>	1	1	2	2	2	2
	40	25	15	10	10	10
Concrete <i>bone-beams</i> (1)	16	6	3	3	3	3
	15	15	20	20	25	25
Rooflight (1)	34	15	4	3	2	2
	15	15	20	20	25	25
Windows (1)	24	10	4	3	2	2
	10	10	10	10	10	10
Wooden door	14	10	6	8	10	10
	10	10	10	10	10	10
Fabric	3	4	11	17	24	35
	10	10	10	10	10	10
Empty wooden pew	16	18	16	16	17	7
	30	40	50	60	70	80
Occupied wooden pew (2)	57	61	75	86	91	86
	30	40	50	60	70	80

(1) Calibrated materials; (2) Pews occupied to 100% (presumed at 2 persons/m<sup>2</sup>).

of the resonator and the irregularities of the surfaces which led to the estimate of the absorption coefficients reported in Table 2.

A default value of 10% was allowed for scattering coefficients in all octave bands analysed, except in the following cases: for the empty/occupied wooden pews, the values of GALINDO *et al.*, (2009) and COX, D'ANTONIO (2004) were chosen, respectively, for the rooflight, the ceiling of reinforced concrete *bone-beams* and the dispersive walls, the values were estimated from the size of the irregularities (the average structural length and the average structural depth) for the corresponding wavelengths involved.

#### 4.2. Analysis of results

The results of the parameters calculated in the acoustic simulation, related to the sensation of reverberation, speech intelligibility, musical clarity and sharpness of the sound are very similar to those obtained in experimental measurements, from the impulse response for all the octave bands studied (Figs. 11 and 12). Therefore, it can be stated that the acoustic behaviour of the model, calibrated with the reverberation time  $T_{30}$ , is very similar to the real acoustic behaviour of the hall in its original state. This degree of approximation between measured and simulated values is evident if we allow the JNDs recommended in ISO 3382-1:2009 for average values in frequency, and accept them as valid for each octave band. There is a consensus (VORLÄNDER, 2008) that accepts differences of fewer than 2 JND for acoustic simulations.

The technique of cone tracing, on which the calculation algorithm of the simulation software is based, presents a limitation in precision at frequencies below  $4f_s$ ,  $f_s$  being the Schroeder frequency which is defined by the equation:

$$f_s \approx 2000 \sqrt{\frac{T_{30}}{V}} \quad [\text{Hz}] \quad (1)$$

where  $V$  [ $\text{m}^3$ ] is the volume of the hall.

In this study, the Schroeder frequency of the original hall is  $f_s = 69$  Hz, so the results of the simulations will be more reliable for frequencies above 276 Hz, i.e. for octave bands above 500 Hz. When all the wooden pews in the enclosure were fully occupied, the frequency becomes  $f_s = 50$  Hz, allowing reliable results in the 250 Hz octave band. This does not imply that the results of lower frequencies should be rejected, but that they must be taken with caution.

The sound strength of the church merits special mention, where good results were obtained from 500 Hz. The low frequencies are the bands with more questionable values, where the results differ by more than 2 JND. This is because the sound strength (G) value was estimated from the impulse response, as it

was not possible to perform a calibration of the whole measurement chain. Furthermore, all the energy contribution, within 5 ms after the arrival of direct sound, is taken to be direct sound by the program as default, which results in a high resolution in frequency for the octave bands involved.

The least adjusted results were found in the parameters related to the apparent width of the source, envelopment and binaural hearing, represented here only by  $IACC_E$ . The differences slightly exceeded 2 JND in the majority of the octave bands analysed.

Finally, it should be noted that the behaviour against distance, represented by their standard deviations, presents trends and values, per receiving point, that were very similar to those for the parameters of the hall when they were estimated with a single number (recommended average values). Again, the most disparate values occurred with the subjective sensation of spatial impression (BUENO *et al.*, 2011b).

### 5. Acoustic rehabilitation proposal

In order to improve the acoustic behaviour of the church, the introduction of a series of corrective measures is proposed, under two conditions: respect for the architect's project idea in terms of spatial concept, shapes and textures of primary materials, as this is an architecturally protected building, and that the proposals were reversible by the simple removal of the added elements.

The acoustic rehabilitation proposal is based on two actions: 1) the introduction of a series of absorbent coverings in acoustically strategic areas, which would reduce the current high reverberation times, and adjust them to those considered optimal (KNUDSEN, HARRIS, 1998) for religious speech and musical applications. It also seeks to improve other parameters such as speech intelligibility and musical clarity, reducing the energy of long reflections and increasing the signal to noise ratio at the different reception points: 2), given the importance of the intelligibility of speech in the hall, assessed by the STI index, a proposal was considered for the installation of a public-address system (electroacoustic support), to attempt to achieve good intelligibility throughout the hall.

Regarding the pews, it is recommended that their absorption be very similar whether they are occupied or empty, so that the size of the congregation does not affect the acoustics of the hall.

The arrangement of the materials proposed for the acoustic conditioning of the church are shown in Fig. 8. Their characteristics are described below:

- Wool carpeting, 2.3 kg / $\text{m}^2$ , on the floor of the presbytery.
- Rockwool wall panel, 40 mm thick, attached by an auxiliary structure in the high wall that forms

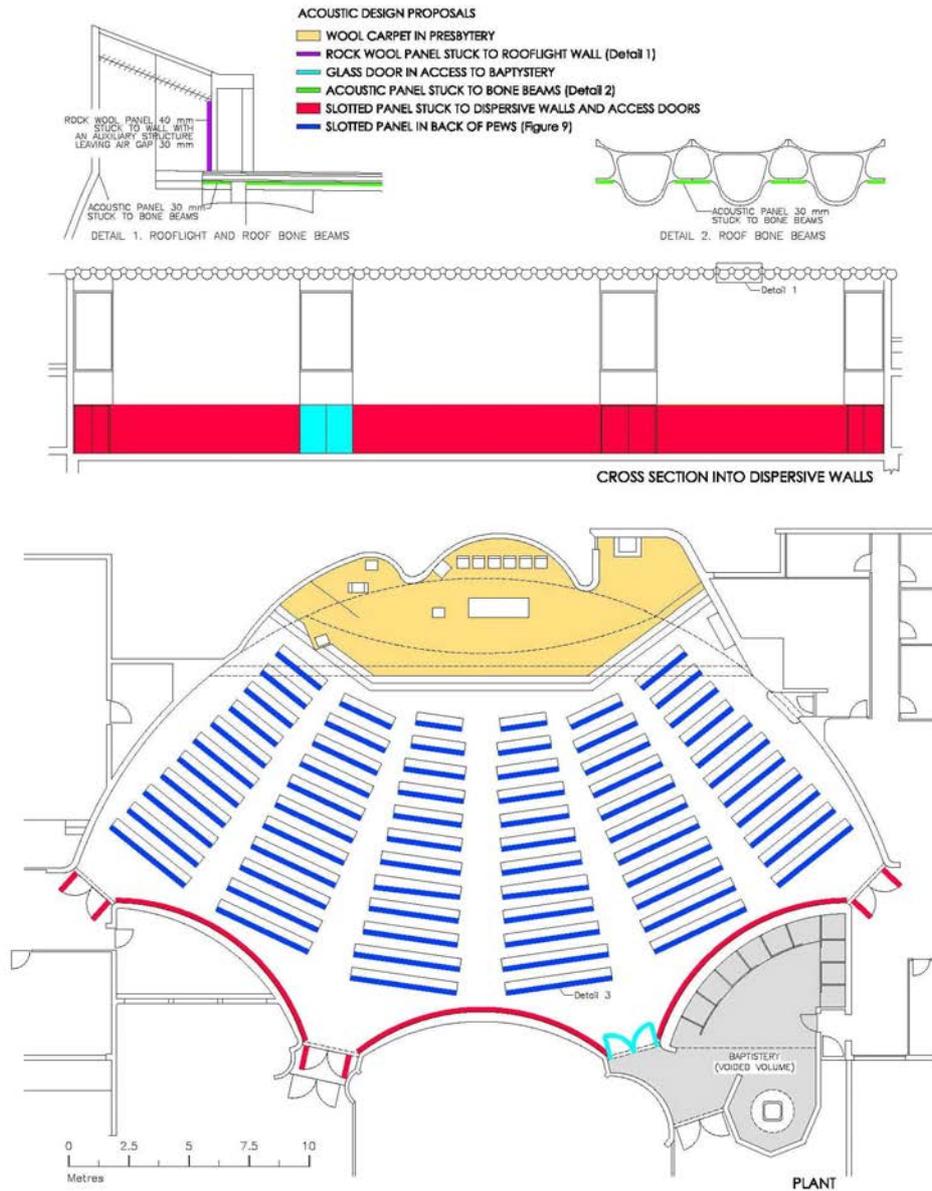


Fig. 8. Section and plan: proposed placement of materials.

the roofflight. This operation is only visible from the presbytery.

- Glass door in the access to the baptistery, to decrease the volume of the hall by separating this chapel.
- Acoustic rock wool panel, 30 mm thick, attached to the flat edges of the *bone-beams* of the roof.
- Plinth, 2.15 m high, mounted on the curved walls at the back of the room (*dispersive walls*). The plinth is formed by a 12.5 mm thick rib slotted, wooden panel (slots 8 mm), acoustic felt, 40 mm thick mineral wool and a 30 mm thick air chamber.
- New backs to the wooden pews in the same rib slotted panel described above (Fig. 9).

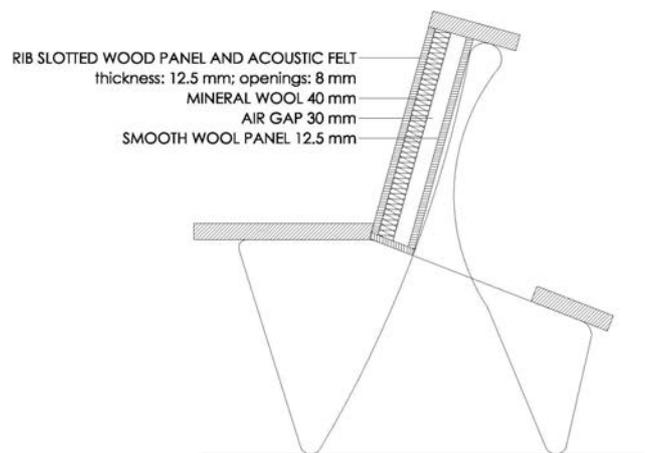


Fig. 9. Pew section.

5.1. Acoustic simulation of the sound field of the proposed rehabilitation

To check the suitability of the proposal, these new coverings were incorporated into the previously calibrated three-dimensional geometric model, with subsequent acoustic simulation of the sound field. As in the *in situ* measurement and in the simulation of the current state, the source was placed at position 1, coinciding with the altar. Only this position was simulated, because, as was confirmed with the results of the *in situ* measurement, the acoustic conditions of the hall do not change with the different positions of the source (Fig. 10).

The absorption and scattering coefficients of the new materials are specified in Table 3. The values

were obtained from various published sources which are given at the foot of the table. The values corresponding to the compound materials such as the acoustic panel cover of the *bone-beams* and the new empty wooden pews were calculated from the geometric proportions of the elements that make up the whole.

5.2. Analysis and evaluation of the acoustic conditions of the rehabilitation proposal

This section shows (Figs. 11 and 12) the results of the main acoustic parameters associated with each aspect of the subjective sensation of the listener. The spatially averaged results at the frequencies included between 125 and 4000 Hz are shown, as well as their

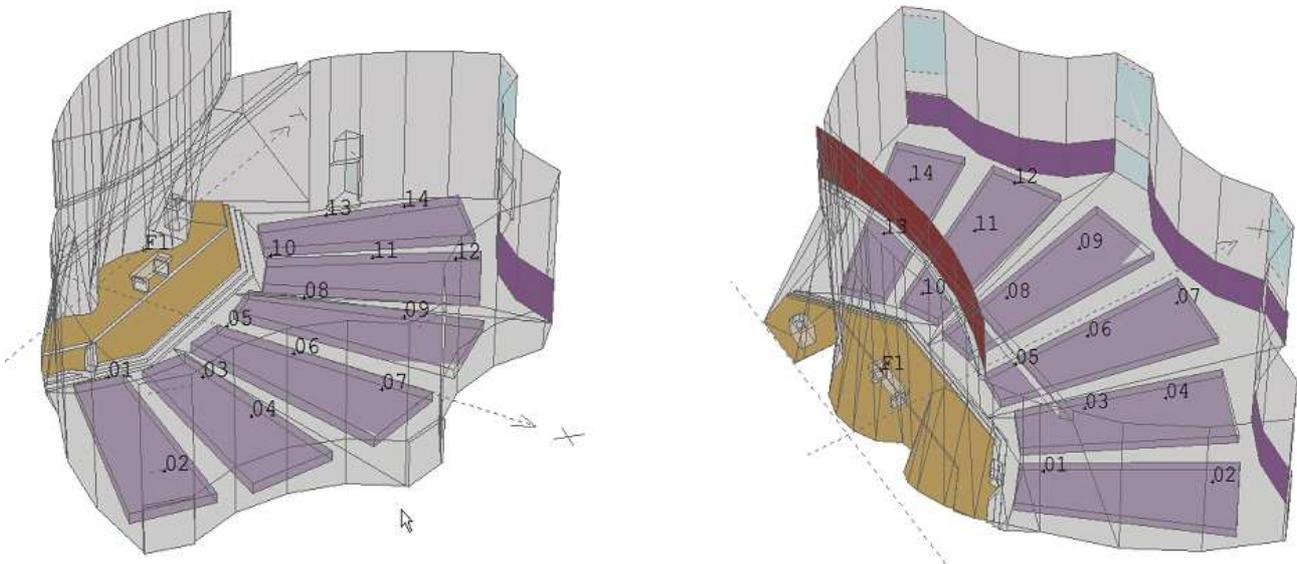


Fig. 10. Three-dimensional model after the rehabilitation of the Santa Ana church in Moratalaz.

Table 3. Sound absorption coefficients ( $\alpha$  above) and sound scattering coefficients ( $s$  below) of the materials introduced into the ecclesial enclosure (%) for its acoustic rehabilitation.

Material	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Wool carpet 2.3 kg/m <sup>2</sup> (1)	17	18	21	50	63	83
	10	10	10	10	10	10
Presbytery wall panel (2)	25	75	99	99	99	99
	10	10	10	10	10	10
Glass door (3)	18	6	4	3	2	2
	10	10	10	10	10	10
Concrete bone-beams (Table 2) with acoustic panel (2)	17	19	31	31	31	31
	15	15	20	20	25	25
Dispersive wall panels (2)	35	70	85	7	55	45
	40	25	15	10	10	10
Empty wooden pew (Table 2) with slotted panel (2)	24	40	45	39	33	23
	30	40	50	60	70	80

(1) (HARRIS, 1994); (2) Panel manufacturer; (3) (VORLÄNDER, 2008; COX, D'ANTONIO, 2004).

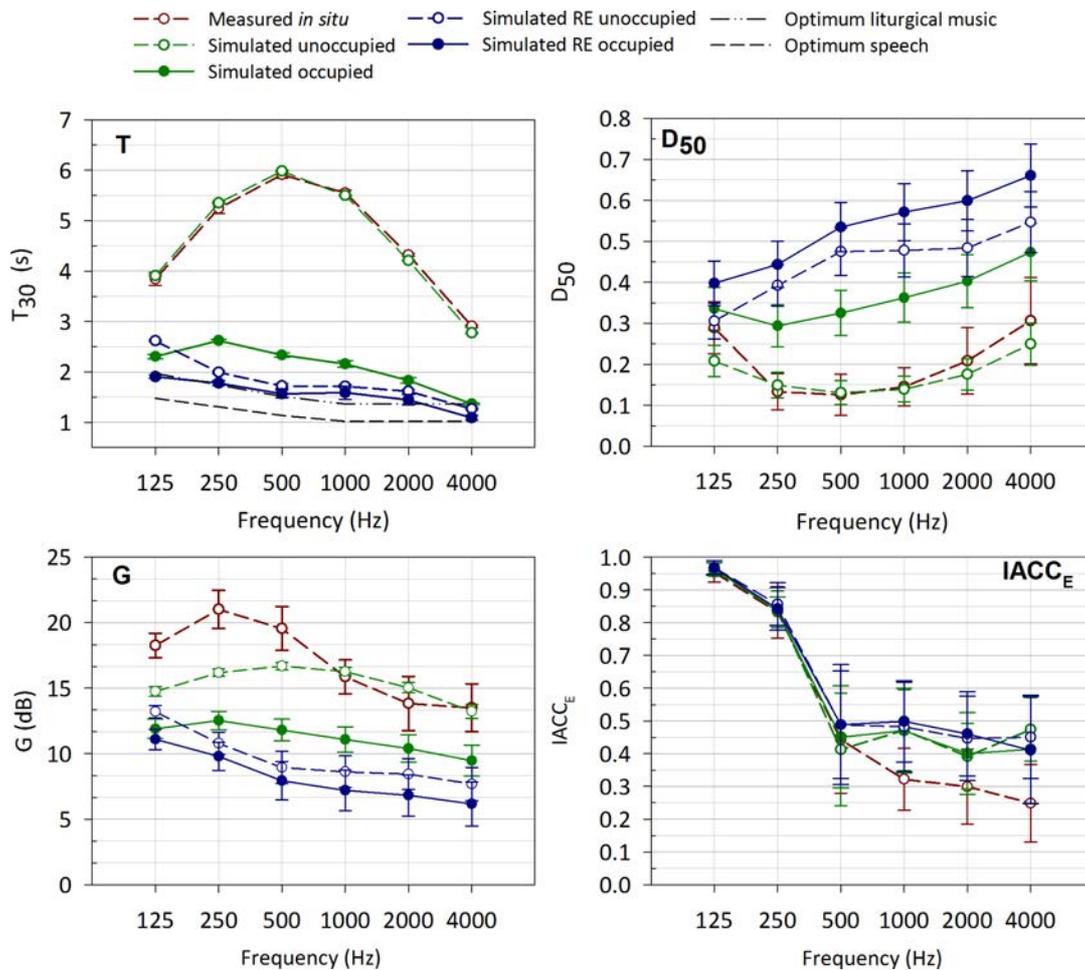


Fig. 11. Frequency behaviour of some spatially averaged acoustic parameters ( $T_{30}$ ,  $D_{50}$ ,  $G$  and  $IACC_E$ ), corresponding to the measurement *in situ*, simulation of the current state and acoustic rehabilitation proposal (Source 1).

spatial distribution using the standard deviation. The graphs of each parameter systematically show the results of the measurement performed *in situ*, the simulations of the current state in its empty and occupied configurations, as well as the values of the simulations of the proposed acoustic rehabilitation (RE), with the hall empty and occupied to 100%.

As can be seen in Fig. 11, the proposed rehabilitation will significantly reduce the reverberation time of the hall, evaluated with  $T_{30}$ , for both empty and occupied hall configurations. In the case of an occupied hall, the reverberation times obtained are consistent with the optimal settings for religious music. For the Definition ( $D_{50}$ ), the results of this parameter were also significantly improved, with frequency values that fit the recommended range. The proposed rehabilitation decreases the values of  $G$  at all frequencies, but maintains a range suitable for the intended use. In addition, the listener continues to maintain good conditions of spatial impression, remaining enveloped in the sensation of sound and able to spatially locate the possible sources.

### 5.3. Improved intelligibility: Public-Address System

In order to evaluate the results of the intelligibility in the church, the Speech Transmission Index (STI) (HOUTGAST, STEENEKEN, 1971) values obtained are shown in Fig. 12. The values recorded at each receiving point against the source-receiver distance, together with the subjective intelligibility scale, are shown for each of the hypotheses tested.

As can be seen, the STI values of the church, for both those measured *in situ* and those simulated with the empty hall, classify it as poor and/or bad in the hearing zone intended for the congregation. The values become acceptable in the case of the hall being occupied.

With the proposed rehabilitation, and the addition of the new coatings, the intelligibility results are improved significantly. In the case of the empty hall, intelligibility is classified fair to good, while the occupied hall is considered good in almost all respects. The average increase of this parameter is 57% and 20% respectively for the empty and occupied hall.

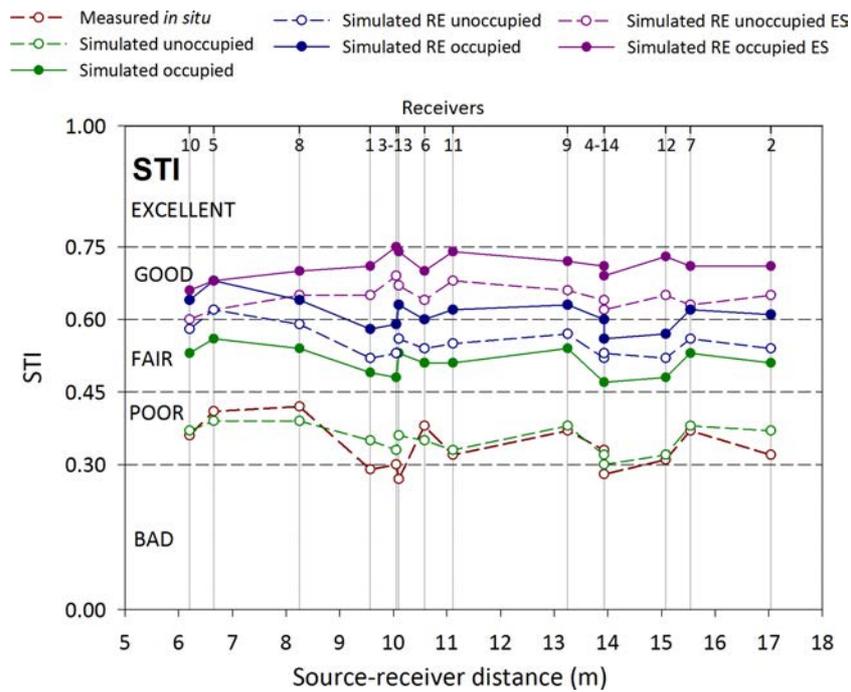


Fig. 12. STI against distance for each receiver and intelligibility grading scale.

However, given that one of the most important objectives of a church, from the standpoint of sound, is to have good speech intelligibility, the effect that the addition of a suitable loudspeaker system would have was also studied. In addition, the use of electro-acoustic support systems is frequent in almost all these buildings (CARVALHO, SILVA, 2010).

The proposed and simulated system consists of two column loudspeakers (brand Duran Audio BV, model Axys Intellivox DC180), arranged in the presbytery (Fig. 13). These speakers incorporate Digital Directivity Control (DDC) technology which allows control of the vertical directivity pattern of the loudspeaker and

directs the sound toward the listener, while maintaining uniform coverage in the hearing plane and keeping the beam away from surfaces that can cause undesirable reflections. The system allows very high ratios to be obtained between direct and reverberant sound, a situation that favours appropriate speech intelligibility.

As can be seen in Fig. 12, the use of electro-acoustic support (ES) in the hall provides a uniform sound distribution in the hearing area, improving the STI results by about 18 y 16% for the church empty and occupied, respectively. In both cases the intelligibility was classified as good, although some values in the occupied configuration bordered on excellent.

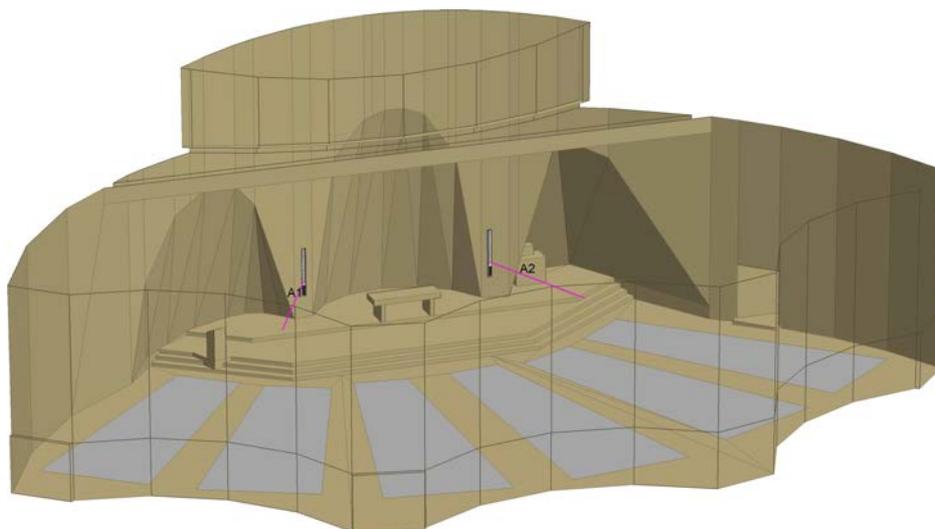


Fig. 13. Three-dimensional model: situation of the loudspeakers.

## 6. Conclusions

The church of Santa Ana at Moratalaz is an emblematic work of the Spanish architecture of the twentieth century where the architect's concern for acoustic issues is manifest. In this church, M. Fisac combined his knowledge, intuition and research talent to attain some acoustic objectives with the limited means at his disposal for the construction of this ecclesiastical space. The attainment of these intentions, from the standpoint of sound, were made using one of the few tools at his disposal as an architect: the suitable design of the architectural geometry and forms, without losing sight of the purpose of building spaces with high value designs. In the case of the Church of Santa Ana, the application of his knowledge resulted in a diffuse hall, with a very homogeneous sound distribution and good spatial impression. This is evident in the parameters measured *in situ*.

However, despite M. Fisac being aware of it, he failed to provide the necessary sound absorption that he would have wished, through being unable to use absorbent materials due to economic reasons. This lack of sound absorption led to high reverberation times and, therefore, poor speech intelligibility and musical clarity.

The proposed acoustic rehabilitation achieves the correction of these deficiencies by introducing absorbent elements in a fully reversible manner and does not distort the spatial, formal and material aspects which the architect conceived for the project, while being compatible with the church's status as an architecturally protected building.

The Speech Transmission Index (STI) merits special mention due to the main use of the building. Although the introduction of corrective measures improve the intelligibility of the church in the two configurations studied, the additional use of the proposed public address system achieves a good intelligibility classification whether the church is occupied by the congregation or not. It is in the occupied configuration where some STI values are at the threshold of being classified as excellent for intelligibility.

This work, in addition to demonstrating the validity of the experimental method and the architectural rehabilitation proposal, aims to give a valid solution to a real problem of the building with its normal use, it could be implemented in reality to improve the acoustic conditions of the church during the liturgical celebrations.

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