Acoustic Study of the Manuel de Falla Auditorium: Design Evolution and Acoustic Simulation

G. Vallejo Ortega¹, J. I. Sánchez Rivera²

Department of Applied Physics, School of Architecture, University of Valladolid, Spain ¹gvallejortega@yahoo.es;²jignacio@arq.uva.es

Abstract- This paper presents the most important conclusions of the acoustic study made in the Auditorium of the Manuel de Falla Centre in Granada (Spain). This auditorium was built by the architect José María García de Paredes in 1978 and reopened in 1987, making it one of his most important and beloved works. In the context of the concert rooms in Spain, its position is emblematic because it acts as a starting point in the modern conception of these halls. This paper is divided into two parts:

• Description of the project progress up to the final construction of the auditorium: preliminary references of musical rooms, first sketches and blueprints, the evolution of the construction project from the moment the architect comes in touch with the acoustical consultant Lothar Cremer, as well as the changes made in the room in its reopening are analyzed.

• Presentation of the acoustic simulation results: sound rays trajectories from the source to the receivers are analyzed and the acoustic parameters that define its sound quality are evaluated using the CATT Acoustic software.

Keywords- Manuel de Falla Auditorium; García de Paredes; Lothar Cremer; Acoustic Modelling by Computer; Acoustic Parameters

I. INTRODUCTION

This paper analyzes the acoustics of the Manuel de Falla Auditorium in Granada (Spain), a work built by José María García de Paredes in 1978 and reopened in 1987. It shows the relationship between its geometry and the parameters that characterize the sound of the enclosure, parameters which were analyzed by simulation. It also describes the project phases prior to its construction, which mark the evolution of the auditorium design and have a large impact on the acoustic outcome. The acoustic work of García de Paredes has been partially studied in some works [1-6] and the doctoral thesis [7] of the authors of this paper. The Manuel de Falla was his first auditorium and for us has a particular interest for the following reasons:

- The Manuel de Falla Center is listed as a cultural heritage for its architecture integrated into the surroundings of the Alhambra
- García de Paredes had a personal and family links with Granada and Manuel de Falla, hence this work is a tribute to the Spanish composer.
- The acoustical consultant for this auditorium was Lothar Cremer. This fact connects the hall with the most advanced acoustic theories of the time when the auditorium was constructed.
- Taking into account that the modern auditoriums were practically nonexistent in Spain before the 80s, analyzing this hall is a starting point for the study of the Spanish auditoriums of the last three decades.
- Complementing the studies prior to the construction of the auditorium through the acoustic simulation.

II. MANUEL DE FALLA CENTRE

A. The Architect

José María Garcia de Paredes was born in Seville (Spain) in 1924 and died in Madrid (Spain) in 1990. Architect for the Madrid School of Architecture (1950), he won the National Prize of Architecture in 1956. In the same year he married María Isabel de Falla, the niece of the Spanish Composer Manuel de Falla. Within the production of García de Paredes, the auditoriums constitute a body of work of singular importance as he designed and built more than a dozen of large auditoriums, including the notable Auditorio Nacional de Musica (Madrid, 1988).

B. Development of an Ambitious Project

Manuel de Falla (1876-1946) lived in Granada in the years 1919-1939, settling in a house called "El Carmen de la Antequeruela Alta", near the Alhambra. The idea of building what would eventually be the Manuel de Falla Centre had a long evolution. In 1962 the City Council of Granada decided to buy the house where the composer lived, to turn it into a museum. The next step was the idea of building an auditorium for the International Music Festival, integrated into a building capable of holding the Summer Course of Music, as well as space to install the archives and the library of the composer. In 1965 the House-Museum of Falla was opened, and in 1973 the City Council asked Garcia de Paredes to write the construction project for the Centre. Halls like the Boston Symphony Hall or the Gothenburg Konserthus were references for the auditorium's acoustic, while the Teatro Scientifico of Mantua, the Bayreuth Festspielhaus and the Berlin Philharmonie exemplified the search for a musical space.

1) First Sketches (1966):

The drawings in Figure 1 show a first floor lentil-shape room based on the hall projected for the Madrid Opera Competition in 1964. The stage was supported on the wall that holds a street called "el Paseo de los Mártires" and the audience was distributed in the stalls on the grand floor and in three wide balconies.

The planning data of the hall would be a capacity of 1198 people [754 in the stalls (420 m^2) and 444 in the three balconies (221 m^2)], a reverberation time of 1.5 s and a volume of 7100 m³ (5,9 m³ per person) with a ceiling measuring 13.8 m average height.



Fig. 1 Sketch (1966)

2) Early Changes (1967-1969):

In the years 1967-1969 the architect developed a new solution. The auditorium, which had the same layout of the audience and stage with respect to the exterior, was geometrized as an asymmetric fan-shaped hall with flat planes and side access. Two levels were planned: the stalls and the first floor. The first floor was divided into two uneven balconies. This division helps to obtain more lateral reflections.

The capacity would be 1387 seats, 641 in the stalls and 746 on the balconies (504-242). Finally, the exterior architecture, which was more radical in the Alhambra's surroundings, was discarded.



Fig. 2 Lower and higher floors. Solution 1967-1969

3) The Blueprints (1970-1973):

• Blueprint November 1970

The building was subject to an important change: the hall was rotated 90° and its access was planned in a longitudinal axis at the same level as the stage.

There were two public areas on both sides of the stage, zone A and B, with independent and complementary uses of the only space with a ceiling which forms a stretched catenary section. It took the advantages of a narrow rectangular hall and gave a feeling of sound proximity due to the central position of the orchestra.



Fig. 3 Blueprint November 1970

• Blueprint June 1973

In the draft of June 1973 (Figure 4), immediately prior to his first meeting with Lothar Cremer, the rectangular geometry with the audience distribution in front and behind the stage was proposed again. It is remarkable that the section design of the outer covering is similar to the one of the Berlin Philharmonie, and the division of the ceiling into concave sections with flat planes is also visible. The first sound ray tracings are also implemented, although somewhat still imprecise. The polyhedral lamps, which act as diffusers, were projected too.



Fig. 4 Blueprint June 1973

4) The Construction and Lothar Cremer's Advise (1973-1978):

García de Paredes contacted Lothar Cremer to seek advice for the Manuel de Falla until its construction in 1978. Since their first meeting took place on 27th August 1973, they most likely discussed June's blueprint of that year, referred to above. As seen in Figure 5, instead of dividing the ceiling into concave surfaces with flat planes, the ceiling is now fragmented into small convex sections carefully designed to get the maximum sound field diffusion.



Fig. 5 Sound ray tracings in the longitudinal section: project that led to the construction in 1978

In addition, instead of rigid divisions between zones A and B, curtains were proposed, and the materials as well as the air conditioning ducts were discussed. The stands of zone B behind the stage are more inclined to optimize the balance between the strings and metals. The ceiling over the stage should descend to avoid acoustic reflectors over the orchestra; in this way, the ceiling is the one responsible for the reflections on the stage and the audience located on both sides of it. The above mentioned polyhedral lamps are seen as a good solution to act as additional acoustic diffusers. The architect agreed to the proposed changes and the hall was inaugurated on 10th June 1978.

The sound ray tracing made by the architect is particularly interesting (Figure 5). Following Cremer's methodology, he calculates the extension that covers the reflections of each panel, taking their extremes as a reference, and also the path difference for each trajectory between the first reflection and the direct sound in order to verify the absence of echoes. The chamfered inclination of the extreme walls to prevent corner echoes is also considered.

Not only the ceiling of the room, but also the ceilings of the side galleries are noteworthy. They are designed using two cylindrical panels (Figure 6), which have the function to act as reflectors for the audience located into the galleries.



Fig. 6 Design of the ceiling panels placed in the side galleries

5) The Fire and Reopening:

The auditorium suffered a fire in August 1986, after which it was completely destroyed. It was rebuilt and reopened a year later, on 4th June 1987. During the reconstruction some modifications were made: the location of the recording cabins, the shape of the ceiling in the extreme zones where the cabins were, and the presence of lifting platforms on the stage. A new tuning of ceiling panels was also launched to gain reverberation in the low frequencies. This last project will be our reference in the acoustic simulation.

III. ACOUSTIC STUDY OF THE AUDITORIUM

A. Sizing and Capacity

The auditorium is located on the ground floor. As seen in Figure 7, its geometry is basically rectangular, with dimensions of 50×21 m in width. The height of the ceiling ranges from 2.5 m at the ends of the room to 13 m from the bottom of the hall A (or rather, zone A of the hall).



Fig. 7 Longitudinal y transverse sections. Plan (level 0.00 below left and 4.59 below right)

The volume is about **10,000 m³**, deriving a volume of 7.6 m³ per person. Since the room modeling considers audience boxes, the volume drops to 9140 m³. The floor area, including the two symmetrical side galleries that give access to zone A (level 0.00), is about 1,300 m², 800 m² of which correspond to the audience areas.

The asymmetrical layout of the audience in the hall determines three configurations: total configuration (capacity of 1311 seats), partial A configuration (capacity of 897 seats) and partial B configuration (capacity of 414 seats). The arrangement of the stands and their slope gives a good visibility from any part of the audience area. In each stand, the access to the seats is achieved through two symmetrical corridors.



Fig. 8 Interior of the room: total configuration and partial A configuration

B. Modelling and Materials

For the simulation an acoustic model based on a drawing of the hall in three dimensions was created (Figure 9). The geometry was characterized using the AutoCAD software and then we operated with the CATT Acoustic programme. We obtained 1808 3D faces and 0.3 % of lost rays, achieving this way an almost complete closure of the room geometry.



Fig. 9 Modelling of the room

Some adjustments have been made in the simulation process:

- The curved lines of the ceiling section of the hall and the side galleries were replaced by straight lines, because the programme does not allow curved lines.
- The audience was modelled by boxes of 0.8 m height. We also included as audience boxes some stairs which separate a public area from a wall or two public areas. The audience area in the simulation was 815 m².

- The lamps were modeled with 24 3D faces each, considering an octagonal base and their upper and lower part as pyramids of 8 faces.
- The stairs were modeled as inclined planes. In order to avoid significant reflections, they were considered as highly diffusing surfaces in all octave bands (50%).

For Garcia de Paredes, the choice of materials intended to obtain a balance between reflective surfaces, diffusing and absorbing, taking into account the use of the room: "As important as the election of the geometry, was the choice of the coating materials... Therefore, according to the criteria of a number of experts and musicians a reverberation time of 1.85 seconds was defined for the mid frequency bands (500 Hz and 1000 Hz) as the most adequate for a hall of these characteristics." [8]

Therefore, the search for a reverberation time of 1.85 s was the starting point to find a balance between the absorption of the different materials. This is seen in the design of the ceiling, which reflects the sound to the orchestra and audience areas. It is designed as small convex sections (Figure 10), which also contributes to the diffusion of sound (see the ray trajectories, Figure 5), reinforced by the presence of polyhedral lamps that are arranged lengthwise in four rows. In addition, the absorption of these curved ceiling panels is used, if compared to other hall materials, as an element of balance. This is in fact explained by Lothar Cremer in this quote: "As the upholstered seats and the public clothes absorb more the mid and high frequencies, we needed some absorption factors for the low frequencies. These factors were obtained by the convex curved wooden panels which seem equal if seen from the exterior, but they are tuned in a different way in their interior" [9].



Fig. 10 Curved ceiling panels

Table 1 shows the materials with their absorptions at the octave bands of 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz and 4 kHz [10-12].

TABLE 1 ABSORPTION OF THE MATERIALS IN THE	OCTAVE BANDS
THE PROPERTY AND A PR	OCTITIE DITIED

Materials	Absorption	Diffusion
Glued wood for the stage floor (without musicians)	447667	10 10 10 10 10 10 10
Diffusing glued wood for the wood stairs	447667	50 50 50 50 50 50 50
Wood with air space for the ceiling panels	19 14 9 6 6 5	10 10 10 10 10 10 10
Wood with diffusion for the organ	19 14 9 6 6 5	30 40 50 60 70 70
Plaster for sidewalls	2 2 3 4 5 5	10 10 10 10 10 10 10
Concrete for columns, pillars and side walls	2 2 3 4 5 5	10 10 10 10 10 10 10
Terrazzo for the side floors and audience corridors	1 1 2 2 2 2	10 10 10 10 10 10 10
Diffusing terrazzo for the terrazzo stairs	1 1 2 2 2 2	50 50 50 50 50 50 50
Curtains of the stage	3 12 15 27 37 42	30 40 50 60 70 70
Occupied chairs (unoccupied) ⁱ	15 34 70 74 82 65 (6 11 29 36 44 44)	30 40 50 60 70 70
Stage with musicians ⁱⁱ	10 21 41 65 75 71	30 40 50 60 70 70
Glass of the recording cabins	263322	10 10 10 10 10 10 10
Diffusing glass for the lamps	1864322	30 40 50 60 70 70
Iron for the emergency exit doors	2 3 3 4 2 3	10 10 10 10 10 10 10
Window surface for the open exit in the zone B	99 99 99 99 99 99	30 40 50 60 70 70

C. Acoustic Simulation

We consider an omnidirectional source A0 centered on the width of the stage, 2 m away from its edge and 1.5 m high, which emits a sound pressure level of 90 dB at 1 m distance in all octave bands (125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz and 4 kHz). Thirty-nine receivers were also placed on one side of the plane of symmetry xz, distributed in zone A (stalls, side areas and boxes), stage (boxes) and zone B (see Figure 11).



Fig. 11 Position of the source and receivers in the audience area

Data provided by the simulation are classified into two sections:

- Geometrical analysis: sound ray trajectories source-receptor.
- Results of acoustic parameters: SPL, G, RT, BR, Br, C₈₀, LF and RASTI.

The simulation was made in the occupied and empty room. Although the auditorium was designed as a concert hall, it was also planned to be used for conferences and theatre, so the chosen acoustic parameters characterize the rooms intended for music, word or both functions. They are showed in the occupied room, unless otherwise specified. Moreover, we considered the simulation with and without lamps in order to study their behaviour as diffusers.

1) Geometrical Analysis: Results per Receiver:

We analyzed the trajectories of the issuing rays from the source to the receptors, considering the reflections of order less or equal to three (echogram). For each receiver we studied the continuity of the reflections, where they come from, how they are spread over each time interval (0-20 ms, 20-50 ms, 50-80 ms and 80-150 ms) and the sequence of intensities, in order to ensure the absence of echoes. We examined how to change the echogram from receiver to receiver along the axial directions (x, y) of the hall, with and without the polyhedral lamps. The conclusions are:

- The number of reflections in the different parts of the room is uneven. The seats which benefit from the reflections the most are located in the lower part and the first rows of the higher part of zone A, as well as in the side galleries, where there is a balance between the reflections from the ceiling and walls. Cremer assessed "the locations near the walls of the side galleries as exceptionally good" [9]. Although there are significant exceptions, in the rest of the room the number of reflections decreases.
- With regards to the origin of the reflections, the most involved surfaces are the side walls (stalls and stage) and the ceiling. In zone A, the contribution of the back wooden wall of the stage, as well as the balustrades and the walls of the side galleries is also remarkable.

In the absence of lamps, the ceiling gives direct reflections to 28 receivers. It means that 8 receivers located in the stalls of zones A and B as well as in the outside part of the side galleries do not get reflections. The reason for this consideration is the change of the ceiling design, which can be noted by comparing the projects of 1978 and 1986. In the sound ray tracing performed by the architect for the project of 1978 (Figure 5), the intention of giving direct reflections to all the receptors in these parts of the hall is clearly visible. In the proposal of 1986 this intention is not so explicit, as no sound ray tracing is drawn in the longitudinal section (see Figure 6).

- The lamps intercept direct reflections from the ceiling which, in the absence of those lamps, would reach the receivers 6, 16, 36 and 39. Besides, sound ray collisions with the lamps have also been detected in some second and third order reflections. Therefore, the lamps partially fulfill their role as diffusers, breaking some sound ray trajectories.
- The ceiling curved panels of the side galleries participate, alone or in cooperation with the walls, in the reflections on the localities inside them (receivers 22, 23 and 24), fulfilling their role in these areas.
- The receivers 32, 35 and 38 of zone B capture two first-order reflections delayed approximately by 100ms, coming from the balustrades of the higher stall of zone A (Figure 11). Taking into account that there are intermediate reflections between these and the direct sound (the delay is reduced to 50 ms maximum with a global loss of 8dB), it is estimated that these reflections will not be perceived as echoes.



Fig. 12 Echograms of the receivers 32, 35 and 38

2) Results of Acoustic Parameters:

• Sound Pressure Level SPL and Loudness G

Figure 13 shows the sound pressure level SPL and loudness G in the band of 1 kHz. In the thirty-nine receivers, the SPL values exceed 69 dB for all the frequency bands.



Fig. 13 Values of the sound pressure level and loudness G in the band of 1 kHz

The average value of loudness for the receivers in the midrange is $G_{mid} = 8.7 \text{ dB}$ for the empty room. This result is higher than recommended by the literature [13]. In the occupied room its value in the mids range decreases to 4.7, which gives us a hint about the difference in behavior of the hall when it is empty and occupied.

Reverberation Time RT

Figure 14 shows a table and graphs of different values of the reverberation time, some of them are obtained through its corresponding formula (Sabine and Eyring), and others are calculated from the geometry of the room with their coating surfaces, as T-15 and T-30. There is a good correspondence between the calculated values of the reverberation time for all the frequencies bands. It means that from one frequency band to the next, the values fluctuate with a similar trend. The averaged value obtained for the mid frequencies RT_{mid} with the descriptor T-15 is 1.51 s, whereas the value RT_{mid} with T-30 is 1.68 s. Sabine's formula gives a result of 1.51 s, the same as the obtained through T-15. As the software manual [10] considers the values from the descriptor T-30 as the best estimate of the reverberation time, we took this reference, obtaining **RT**_{mid} = **1.68** s. Though it is lower than what the architect and the acoustical consultant claimed, this result enables the optimal use of the hall for chamber music, but is slightly low for symphonic music. For use of the word, the reverberation time would be too high. The parameters BR and Br take the values BR \approx 1.68, Br \approx 0.79, so the room gives a high response in bass and somewhat low in treble.



Fig. 14 Values of the reverberation time: table and graphs

A study of the reverberation time in the empty room has also been made, considering the absorption of the seats without audience and the stage without musicians. Using the descriptor T-30, the obtained value in the mids is $RT_{mid} = 2.85$ s, a value too high and problematic for a rehearsal of the orchestra. This result is due to the different absorption of the chairs when empty and occupied.

• Clarity C₈₀

Figure 15 shows the values of clarity C_{80} in the frequency band of 1 kHz. The average value for the 39 receivers in the three frequency bands of 500 Hz, 1 kHz and 2 kHz, is $C_{80}(3) = 3.9$ dB, higher than recommended by the literature [13] for a hall which is intended for music. This result is directly related to the lack of reflections after 80 ms detected in the echograms of several receptors.



Fig. 15 C₈₀ in the band of 1 kHz

• Early Lateral Energy Fraction LF

Figure 16 shows the values in the empty room of the early lateral energy fraction in the frequency band of 1 kHz. The average percentage value in the bands 125 Hz, 250 Hz, 500 Hz and 1 kHz for the receivers is LF(4) = 22.4, higher than the minimum recommended limit [13]. This means that the spatial impression of sound is good, which is favoured by the rectangular geometry of the room. Nevertheless, the irregularity of the obtained values, sometimes very different in receivers which are placed contiguously, must be noted, as verified in some echograms.



Fig. 16 LF in the band of 1 kHz

• RASTI

Figure 17 shows the values of RASTI in the audience area. In most of the points the percentage value is higher than 50. The graph provides the values for the thirty-nine receivers; the average percentage value is **58**, labelling the intelligibility as **"fair**". Thus, the hall could also be used for lectures and congresses.



Fig. 17 RASTI values for the audience area (picture) and receptors (graph)

IV. CONCLUSIONS

1) García de Paredes went through a long evolution in the planning of this auditorium, initially focusing on the search for capacity, a reverberation time and geometry. His first years of working alone resulted in a design of the hall starting from the rectangular geometry and applying the criterion of dividing the audience in front of and behind the stage.

2) The contact of the architect with the acoustician Lothar Cremer is fundamental to the understanding of the final outcome of the auditorium, particularly in the project that led to its construction in 1978. It is evident in the treatment of geometrical acoustics by working with an optical model of the hall and performing section drawings. Cremer also had influence on the choice of materials for the achievement of a suitable reverberation time; it had a particular incidence in the evolution of the ceiling design in its concept, shape and function.

3) The analysis of the echograms shows that the number of reflections in the different parts of the room is uneven. The most advantaged seats are located in the lower part and the first rows of the higher part of zone A,

as well as in the side galleries, due to the reflections from walls and balustrades. The ceiling also provides, in the absence of lamps, an important number of direct reflections, but not all the receivers located in its scope get reflections from it. The ceiling panels of the side galleries fulfill their role as reflectors there, and so do the lamps as diffusers, breaking some of the sound ray trajectories. Echoes are not detected.

4) The hall has a good visibility throughout the audience area due to the design of the stands. Neither the vision nor the direct sound is obstructed by the viewer placed in front.

5) The simulation of the hall was performed with the programme CATT Acoustic. The parameter results are shown in table 2.

Acoustic parameter	Value simulation
Sound pressure level SPL	> 69dB in all seats
Strength factor G _{mid}	8.7 dB
Reverberation time RT _{mid}	1.68 s
Bass Ratio BR	1.68
Brightness Br	0.79
Clarity $C_{80}(3)$	3.9 dB
Early lateral energy fraction LF (4)	22.4
RASTI (%)	58

TABLE 2 PARAMETER RESULTS

ACKNOWLEDGEMENTS

The measurements of the chairs absorption that were put in the simulation were performed in the years of its reopening by García BBM acoustics consulting firm. We thank Vicente Mestre (García BBM) for the provision of this unpublished material. The photographs and drawings of the auditoriums are taken from the books about José María García de Paredes [8] [14].

REFERENCES

- [1] Vallejo Ortega, G.; Sánchez Rivera, J. I. Acoustic study of Granada Manuel de Falla Auditorium. *Proceedings of the* 39th International Congress INTER-NOISE, Lisbon, 13-16 June 2010, archive 564.pdf.
- [2] Vallejo Ortega, G.; Sánchez Rivera, J. I. Estudio acústico del Auditorio Manuel de Falla de Granada: evolución del proyecto de construcción. Actas del 41° Congreso Español de Acústica "Tecniacústica", León, 13-15 October 2010, archive ASL 13.
- [3] Vallejo Ortega, G.; Sánchez Rivera, J. I. Simulación acústica del Auditorio Manuel de Falla de Granada. Actas del 41° Congreso Español de Acústica "Tecniacústica", León, 13-15 October 2010, archive ASL 14.
- [4] Vallejo Ortega, G.; Sánchez Rivera, J. I. Acoustic study of Madrid Auditorio Nacional de Música, *Proceedings of the* 8th International Conference on Auditorium Acoustics, Dublin, 20-22 May 2011, pp. 338–345.
- [5] Vallejo Ortega, G.; Sánchez Rivera, J. I. Acoustic study of Madrid Auditorio Nacional de Música: Comparison between simulation and measurements, *Proceedings of the 41th International Congress INTER-NOISE*, New York, 19-22 August 2012, archive in12 874.
- [6] Vallejo Ortega, G.; Sánchez Rivera, J. I. Lothar Cremer in Spain: his influence on the architect García de Paredes, *Proceedings of the 41th International Congress INTER-NOISE*, New York, 19-22 August 2012, archive in12 870.
- [7] Vallejo Ortega, G. *La obra acústica del arquitecto García de Paredes*, doctoral thesis unpublished. Valladolid University (Spain), 2011.
- [8] García de Paredes, A; García de Paredes, J. M. Auditorio Manuel de Falla, Granada, 1975-1978, Colegio de Arquitectos de Almería, 1995.
- [9] Cremer, L. Medios acústicos en el Auditorio Manuel de Falla, *Revista Arquitectura* Colegio Oficial de Arquitectos de Madrid, N°215, Noviembre-Diciembre 1978, pp. 74.
- [10] CATT-Acoustic v8.0 User's Manual, SPECTRA D'Sign Kopiering AB, Gothenburg, 2002.
- [11] Beranek, L. Concert & Opera Halls. How They Sound, A.S.A., New York, 1996.
- [12] A. García Sanchermés and V. Mestre Sancho, *Measurements of the chairs absorption performed by García BBM acoustic firm*, unpublished.

[13] A. Carrión Isbert, *Diseño acústico de espacios arquitectónicos*, Edicions de la Universitat Politècnica de Catalunya, Barcelona (España), 1998.

[14] Hernández Pezzi, C. José María García de Paredes, Colegio de Arquitectos de Málaga, Málaga, 1992.

ⁱ The values are for the occupied chairs and, in brackets, for the empty chairs. The chairs are Castelli brand. The consultant firm García BBM gave us the absorption value per chair:

- Occupied: < 8 18 37 39 43 34>
- Empty: < 3 6 15 19 23 23>

For the calculation we considered a density of occupancy of 1.9 persons/m^2 .

ⁱⁱ We considered a low density of musicians on the stage, which is lower than 1 person/m².