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Sound field in several theatres of Cádiz, before and after its restoration

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Abstract

In order to recover the historical and architectural heritage in our region, the Andalusian Goverment is carrying out since recent times a quite interesting an important project called "Rehabilitation Plan of Theaters in Andalusia". This ambitious project, still running, includes the rehabilitation of more than thirty andalusian theaters, and inside it we are playing the role of "acoustic consultors" at the request of the region administration.

Five of these theaters belonging to the the Cadiz's province has been already rehabilitated and reopened for different uses. They are: Manuel de Falla Theater, in Cadiz, Villamarta Theater in Jerez de la Frontera, Principal Theater in Puerto Real, Olivares-Veas Theater in Arcos de la Frontera, de las Cortes Theater, in San Fernando. They are characterised because they cover a quite wide range of volumes (scene excluded), oscillating between 790 m^3, in Olivares-Veas Theater, and 8114 m^3, in Manuel de Falla Theater, and seats that oscillate between 221, in Olivares-Veas Theater, and 1221, in Villamarta Theater.

This paper will be devoted to show the results, experimental and modelled, obtained for severals room acoustic parameters, before and after the perfomed restoration in the five theaters previously mentioned. These results will be discussed according to the diferent uses foreseen for these theaters and consequently the success of the restoration perfomed in them will be evaluated from the acoustical point of view.

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1 Introduction

With this work we intend to state some conclusions of general character with regard to the global acoustic performance of a group of five important Andalusian theaters located in the province of Cádiz. This work is inserted in an extensive research project that includes a larger group of around thirty-five theaters that belong to the aforementioned rehabilitation plan and which have been analyzed by our team.

Table 1 shows the group of theaters that have been studied and which are in the province of Cádiz. They have been put in order from lesser to larger volume, including some of their main characteristics.

Table 1. Group of theaters studied in the province of Cádiz.

nº	THEATER	Location	Year cons.	Year rehab.	V (m^3) audit.*	Seating
1	Olivares-Veas T.	Arcos de la Frontera	1910	1993	790	221
2	Principal T.	Puerto Real	1859	1993	2214	444
3	Las Cortes T.	San Fernando	1804	1999	2492	360
4	Villamarta T.	Jerez de la	1928	1993	7988	1221
5	Falla T.	Cádiz	1905	1985	8114	1038

(*) Volumes shown do not include the volume of the stages

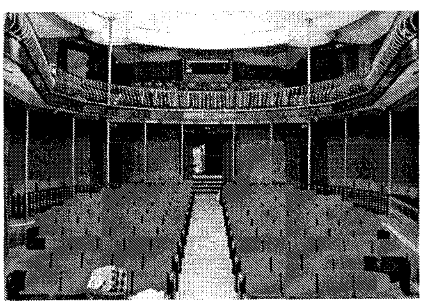

Figure 1: Olivares-Veas T.

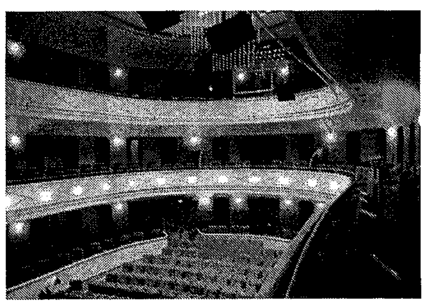

Figure 2: Principal T.

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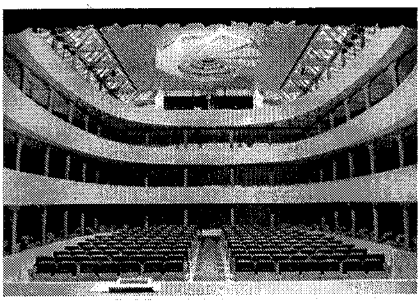

Figure 3: Las Cortes T.

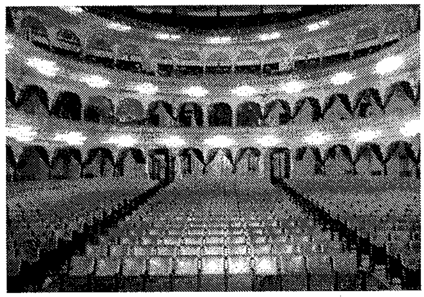

Figure 4: Falla T.

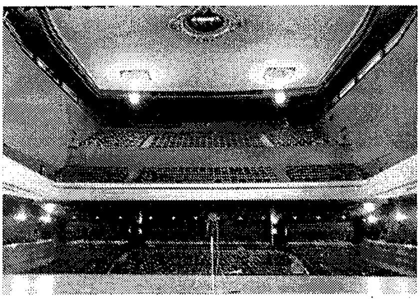

Figure 5: Villamarta T.

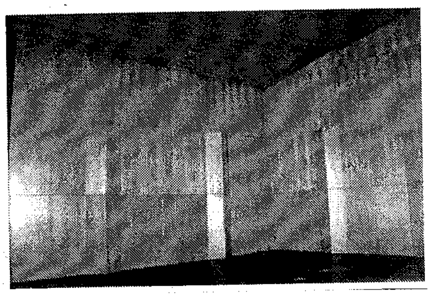

Figure 6: Villamarta T. (acoustic shell)

2 Reverberation time

Reverberation time has been measured using the Integrated Impulse Method [1] averaging all spots of the space for each of the auditoria. Figures 7 and 8 show values corresponding to the average reverberation time (Tr_{mid} 500-1000 Hz) measured in empty auditoria, as well as those obtained by means of simulation for a 100% occupation. The latter have been determined by means of computer models that use Sabine's formulas.

Results are shown for two different states: the first one corresponds to the original state, prior to rehabilitation; the second one after architectural and acoustic rehabilitation. In the case of Villamarta theater, results have been completed with the data obtained when using the acoustic shell which this theater is provided with. Measurements and simulated values have been compared to those given by Beranek [2] for a group of 14 Opera Houses with good acoustics.

In order to carry out the analysis, the aforementioned data have been shown according to the volume of the different auditoria, together with the optimum reverberation time values as proposed by Cremer [3] (Figures 7 and 8).

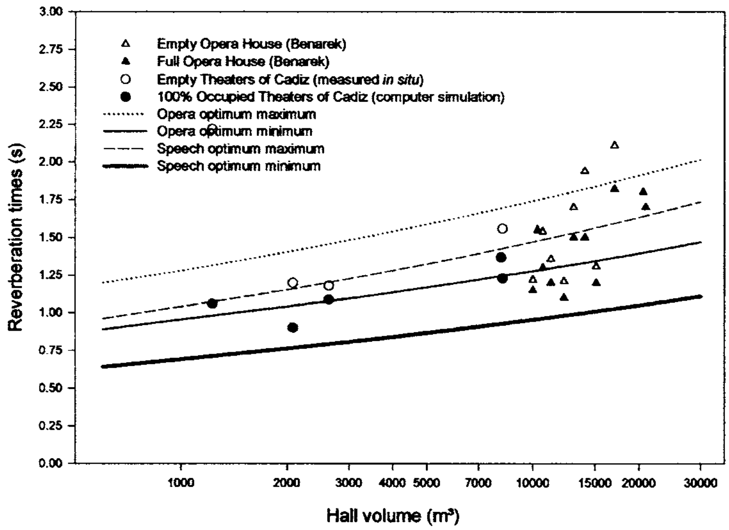

Figure 7: RT_{mid}, measured *in situ* and simulated. Original condition.

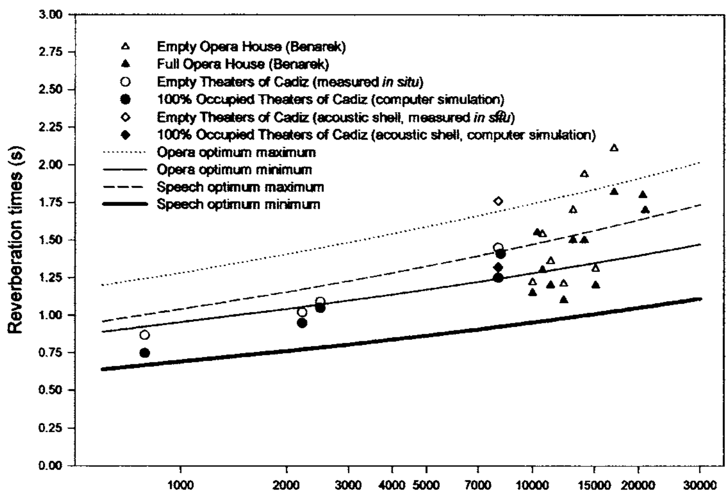

Figure 8: RT_{mid}, measured *in situ* and simulated. After rehabilitation

3 Sound distribution

Sound field uniformity in the theaters has been estimated by means of measuring the acoustic pressure levels in different spots of the pit, boxes and amphitheaters. In Leon et al [4] the data acquisition system for sound distribution was shown.

Results obtained in the 5 auditoria are presented in figure 9, where global sound pressure levels are shown in relation to the distance between the emitter and the receiver, refered to the acoustic level produced by an omnidirectional source in open air at a distance of 10 m and emitting with the same power. Together with the results two theoretical estimations have be en presented: the classical one and the one proposed by Barron and Lee [5].

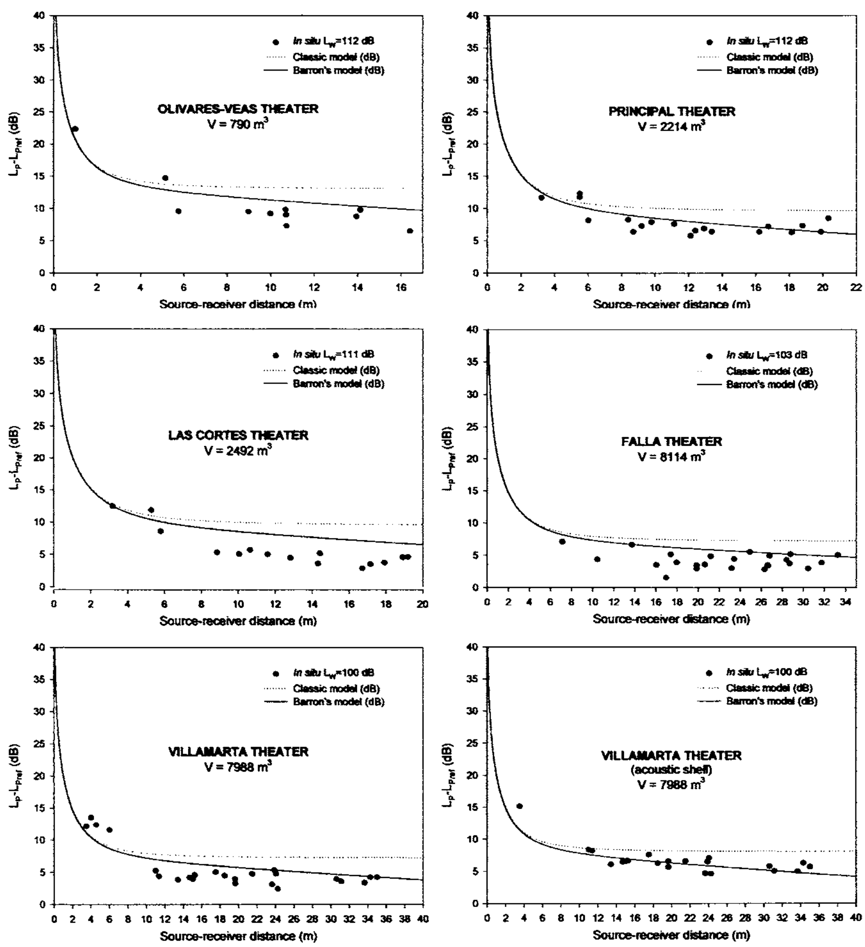

Figure 9: Global levels sound pressure distribution.

4 Intelligibility

Given the multifunctional use that these rehabilitated theaters have, one of the main uses is that of speech. In order to measure intelligibility the RASTI index has been used [6] (Rapid Speech Transmission Index), a simplification from STI (Speech Transmission Index).

In figure 10 RASTI values have been shown for the five theaters, also distinguishing for each of them the stalls pit, the boxes and the amphitheaters in each level. In each case an average of measurement spots has been made.

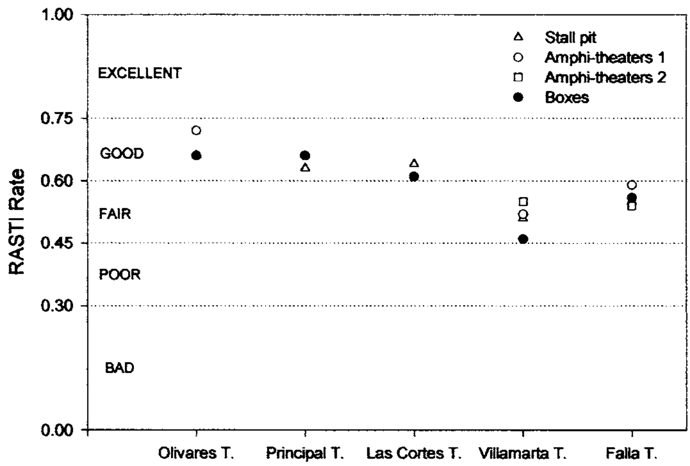

Figure 10: RASTI index for the five theaters, divided by zones.

5 Acoustic qualification parameters

In each of the auditoria the following parameters have been simulated: speech clarity (C_{50}), definition (D_{50}), musical clarity (C_{80}) and lateral energy fraction (LF).

Results have been obtained by means of computer models for each case, using CATT-Acoustics v.7.2.f simulation software. Values are shown in three different states: a) Original state, prior to rehabilitation; b) after architectural rehabilitation; and c) after rehabilitation but, in those cases in which it has been projected, including the implementation of an acoustic shell in the stage.

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5.1. Speech clarity (C_{50}) and definition (D_{50})

To analyze speech clarity, C_{50} speech average has been used, simulated with auditoria occupied by the audience (Figure 11). In the case of D_{50} definition, levels computed are those corresponding to the 1000 Hz band (Figure 12).

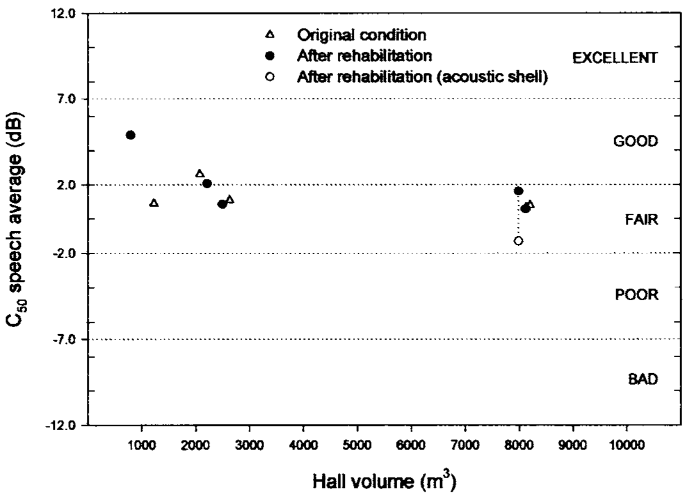

Figure 11: Speech clarity (C_{50}) Average.

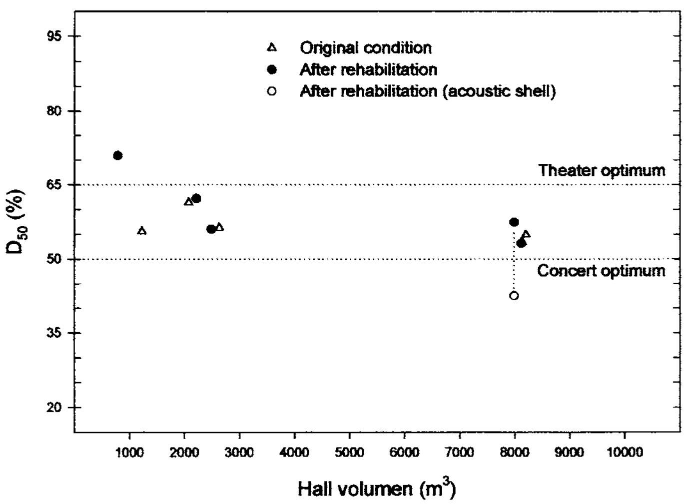

Figure 12: Definition (D_{50}) Average 1000Hz.

5.2. Musical clarity (C_{80})

Musical clarity analysis has been carried out in relation to $C_{80}(3)$, the average value, estimated with auditoria occupied by the audience (Figure 13).

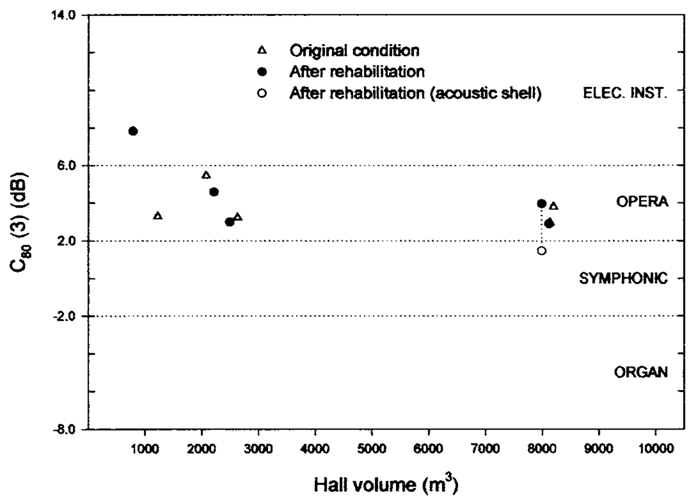

Figure 13: Musical clarity (C_{80}) Average.

5.3 Lateral energy fraction (LF)

To analyze lateral energy fraction (LF), the LF_{E4} average value for octave bands from 125 Hz to 1 kHz has been used, with auditoria occupied by the audience.

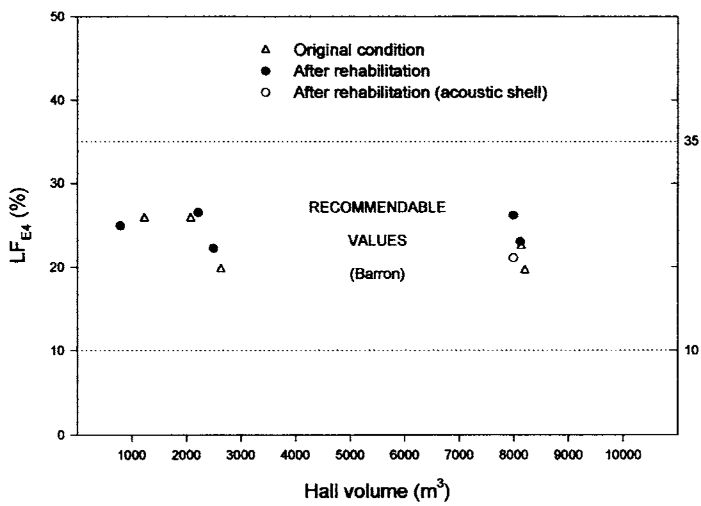

Figure 14: Lateral energy fraction (LF) Average.

6 Conclusions

6.1. Reverberation time

According to our criteria, from all the optimum reverberation time formulations, those proposed by L. Cremer [3] do better adjust to the performance of the theaters in Cádiz. These optimum reverberation times, taken as a reference for acoustic corrections, have proved to be adequate to obtain good results in auditoria with multifunctional use.

6.2.Sound distribution

In each case results show an attenuation for a distance similar to what Barron and Lee's model [5] present, but with values slightly inferior to those proposed by this authors. The reason why may be that the aforementioned model was formulated for concert halls with volumes appreciably larger to the theaters studied in this work and, therefore, with higher sound absorption. Also, it should be pointed up that theaters do have a stage volume which is not present in concert halls.

6.3. Intelligibility

It may be noted that qualification goes from acceptable (theaters with larger volume) to good (smaller theaters). Measurements were taken in the absence of audience, which makes it foreseeable to improve all the results thanks to a better absorption when in presence of audience.

6.4. Acoustic qualification parameters

Results obtained for C_{50} indicator (Figure 11) show how auditoria with smaller volumes do present higher speech clarity indexes, allowing to qualify this indicator as valid. For larger theaters, qualification has been acceptable, in accordance to the multifunctional use of these buildings. C_{50}, lower levels, around -2 dB, have been obtained when an acoustic shell was provided within the theater stage.

Direct relation between D_{50} definition and C_{50} speech clarity leads to a similar interpretation of this parameter in both cases. That is, except for auditoria with smaller volumes, all theaters are within the range characteristic of Opera Houses.

The analysis of musical clarity has been carried out starting from $C_{80}(3)$, average value estimated for occupied auditoria. Performance of theaters in relation to this indicator, as shown in figure 8, is typical of Opera Houses. In the same way, and just as it happens with other parameters and indicators, small theaters show higher values for musical clarity.

Besides, as in the case of Villamarta theater which includes an acoustic shell, values are displaced to the range of values between -2 and +2 dB, adequate for concert halls as stated by Barron.

With regard to the analysis of lateral energy fraction (LF), and in contrast to results obtained by Bradley [7] in his analysis of concert halls, data measured in this work show very little dispersion. Lateral energy fraction in theaters of Cádiz, both in their original state and in their final state, is in between 20 and 30% (Figure 10). This performance seems to be independent of the volume of auditoria.

References

[1] Schroeder, M.R. *New method of measuring reverberation time,* J.Acoust. Soc. Am. 37, 409-412, *1965.*

[2] Beranek, L.L. *Concert and opera halls: how they sound,* ASA: New York, 1996.

[3] Cremer, L., Muller, H.A. y Schultz, T.J. *Principles and applications of room acoustics.* Volume 1. Applied Science Publishers: London, 1982

[4] Leon, A.L., Navarro, J., Sendra, J.J., Zamarreño, T., Algaba, J. y Galindo, M. La valoración acústica en los proyectos de rehabilitación de teatros. El ejemplo andaluz. *Proc. of the II Congreso Iberoamericano de Acústica,* Spanish Acoustical Society: Madrid, 2000.

[5] Barron, M. y Lee, L-J. Energy Relations in Concert Auditoriums.I. *J.Acoust. Soc. Am.,* 84 (2), p.p. 618-628, 1988

[6] Hougast, T. y Steeneken, H. J. M., A review of the MTF concept in room acoustics and its use for estimating speech intelligibility in auditoria. *J. Acoust. Soc. Am.. 77* (3) 1069-1077, 1985

[7] Bradley, J.S. A comparison of three classical concert halls. *J.Acoust. Soc. Am.,* 89, p.p.1176-1 192, 1991