Auditoria in North Portugal

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Abstract

The work presented in this paper is one part of a more complete project about acoustics of some important Auditoria in North Portugal. We intend to collect detailed data about the main architectural properties (and renovation facts), the acoustical design criteria underlying the defined acoustical solutions, as well as the acoustical main parameter values. Acoustical measurements and predictive tools like like room acoustic simulation and Neural Networks will be used to evaluate the acoustical main parameters. Data will be compared and related to geometrical and acoustical properties like reflecting and scattering areas. Auralization will be used to give emphasis to the acoustical quality of the sound in each hall, by convolving anechoic recordings with measured and predicted impulse responses. The sound reproduction is thought for high quality headphones but the more convenient use of loudspeakers will also be considered.

1. Introduction

In this conference we will present a recently renovated hall for musical theatre: Carlos Alberto Theatre (TeCA), an auditorium from late nineteenth century, first opening at 1897. Musical comedies and light opera, magical arts and circus performances were then, the main areas of entertainment. During the second decade of last century, it became a Cinema. After some years of glory, this old cinema enters a depressive period. In 1980, some important reconstruction was done to make it a National Auditorium (ANCA), to present high quality repertoire in theatre, music, ballet and opera. Twenty years later, Porto was the European Capital of Culture and the opportunity came for new project renovation. For the first time, acoustics was thought as an important part of the reconstruction project. However, due to some undefinition about its main goals and objectives, this project was developed without a consistent coordination, under the pressure of time and severe money restrictions. In consequence the architectural project was redefined several times to reduce costs and in the end, only some acoustical guidelines were followed. The auditorium re-opened by December 2003, to host new ways of performing arts, under the direction of National Theatre S. João Company (TNSJ). In this paper we will present the results and conclusions of the acoustical evaluation of the hall and the expected improvement after some new proposals for better speech intelligibility.

2. Auditorium main details

Basically, the complete Hall is rectangular in plan, with an approximate volume of 7400 m^3. The opening stage is 9.2x8 m, the floor area 170m^2 and the fly tower is 18 m high. The audience area is variable depending on the type of performance, allowing a maximum of 368 seats: the front audience with 152 movable seats distributed in 8 rows, the three first being at floor level, the last 5 defining a very smooth slope of 9 degrees; the rear audience with 144 fixed chairs distributed over eight rows defining a slope of 19 degrees. For certain cases, the area of movable seats can be used as a performing area and the seating capacity is then reduced to a minimum value of 216 seats. For most common spectacles, only the first three rows are moved out and the hall capacity is then 311 seats. All chairs are in wood, seat and front back medium upholstered except for the 72 special “high feet” seats at first and second balconies, which are clearly less upholstered.

Constructively the stage ceiling was rebuilt as a concrete slab and its interior surface was made absorbent. The walls were maintained in rough granite painted dark. The floor is typically a hollow wooden theatre stage. The main audience floor is in wooden board over a floating floor. The wall surfaces are in wood panels 30mm thick, glued to a double gypsum board, which is structurally disconnected from the old stoned walls by a resilient system. The front of the balconies and projection booth walls are plane, smooth, and vertical, in gypsum board panels over brickwork. The original structural ceiling was maintained in wood trusses and binding joists, the top roofing on zinc. Below the wooden structure, gypsum panels following the roof slope were installed to reinforce the sound insulation. A second lower ceiling, also in gypsum board panels, is applied over the rear audience area only, for hiding some air-conditioned ductwork. Over the movable seats, there are two technical metallic grids: the upper one, with a wire mesh of about 80% of opening area, defining a second fly space; the lower one, the truss, with a widely open structure. We assumed the two grids were not working as semi transparent surfaces, since all the surfaces above are highly absorbent.

3. Acoustical Criteria

Table 1 shows the “optimal” values to be used as a reference, for the project, considering the main purposes of the hall [1].

Table 1: Parameters ‘optimum’ values

Acoustical parameters	Theatre	Music
T_{mid} ,s	$0.8<T_{mid}<1.3$	$1.3 <T_{mid}<1.7$
EDT,s	$0.6 <EDT_{mid}< 0.8$	$0.9<EDT_{mid}< 1.5$
D_{50}, %	D50≥ 65	$45<D_{50}< 60$
C_{80}, dB	C80> 6	$-2\ C_{80}< 4$
G, dB	G> 0	4 <G< 5
T_s, ms	$T_s<80$	$80 <T_s< 150$

Variable acoustics was out of question, so we had to compromise and that was really a very difficult task, because some undefinition about the main use expected for the hall. Only in the last construction phase, TNSJ decided for modern musical theatre, and this may include different natural and electro-acoustical sound sources, directivities, power emission, localizations and aim points. The audience area may also change for each performance and so, the estimation of total absorption area is even more uncertain and acoustics very difficult to predict.

4. Technical procedures

To evaluate the interior acoustical properties of this auditorium we did computer simulation using commercial software for Room Acoustics Prediction [2] and we performed acoustical measurements.

For computer simulation we’ve considered two approaches: a simplified geometric model of the room and a model considering the presence of some reflectors to improve acoustics for a certain performance. First we had considered one omni directional sound source at position A0 on stage and 11 receivers, two of them on an extended stage area for a particular performance allowing a maximum capacity of 332 seats. Lately we considered two sound sources: an omni directional (A0), and a singer (A1) and only four of the previous receivers. In both cases the absorption data was obtained from literature [2,3] and scattering coefficients were estimated from visual evaluation, following some guidelines from researchers on this subject.

For measurements we used swept sine and MLS signals emitted and post-processed by measuring software for audio, acoustics and vibrations [4]. We also used a shotgun and balloons to obtain impulse responses of the room and we post-processed them using the same software, in two different versions. For both cases, due to lack of specific hardware, we only did one-channel measurements.

Auralization was accomplished using the same prediction software [2], by convolving anechoic recordings obtained from specialised audio libraries with measured and predicted impulse responses. High quality headphones should be used to sound reproduction.

5. Data Results

5.1. Simplified model

In Table 2 we present the measured and predicted acoustical parameters obtained at first evaluation (NR). To evaluate the speech intelligibility, we selected D50 to take into account the initial reflexion density, as we can see in figures 1 to 3.

Figure 1 shows the predicted and measured D50 values at central point R7, considering an omnidirectional sound source, at position A0.

Figure 2 shows the measured values at the same point, obtained using the four different types of excitation signals: swept sine, mls, shotgun and pop up balloons, located at the same source position.
Figure 3 shows the measured values at R2, R4, R7 and R10, for each octave band, using swept sine.

Table 2: Measured and predicted values

Acoustical parameters	Measured	Predicted
T_{mid} ,s	$1.29 < T_{mid} < 1{,}41$	$1.7 < T_{mid} < 1.8$
EDT_{mid},s	$1{,}2 < EDT_{mid} < 1{,}4$	$1{,}1 < EDT_{mid} \leq 1.5$
D_{50}, %	40 < D50 < 60	$45 < D_{50} \leq 55$
C_{80}, dB	2< C80 < 4	$2{,}5 < C_{80} < 4$
G, dB	5 < G < 8	5 < G < 8
T_s, ms	65 < Ts < 87	$73 < T_s < 88$

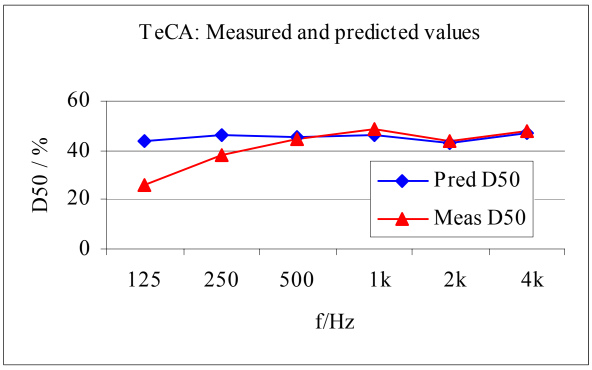

Figure 1: D50 measured and predicted values

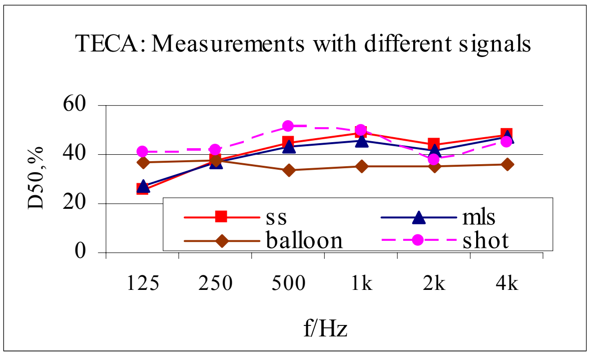

Figure 2: D50 values at central point

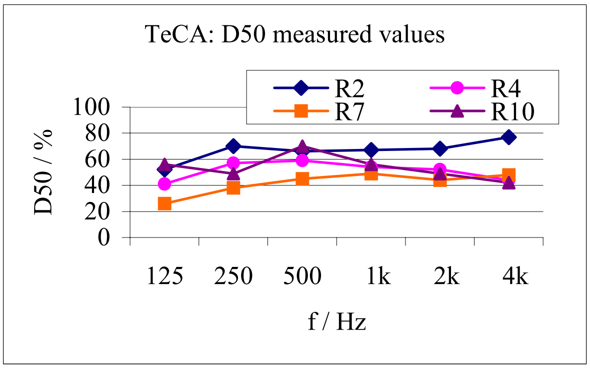

Figure 3: D50 values for some receivers

5.2. Model with reflectors

5.2.1. Lateral reflectors

We simulated the presence of two lateral reflectors (LR) to evaluate the improvement of speech intelligibility. We defined two vertical wooden panels, 2m wide, 3,8m high and 20mm thick defining an angle of 30 degrees with central line of auditorium, to be allocated laterally both sides the extended stage, under first balcony. These reflectors were meant to re-direct reflections to mid seats in movable audience area, considering a sound source varying from position A0 to A1. Predicted D50 values at the same four receivers with lateral reflectors can be seen at figures 4.

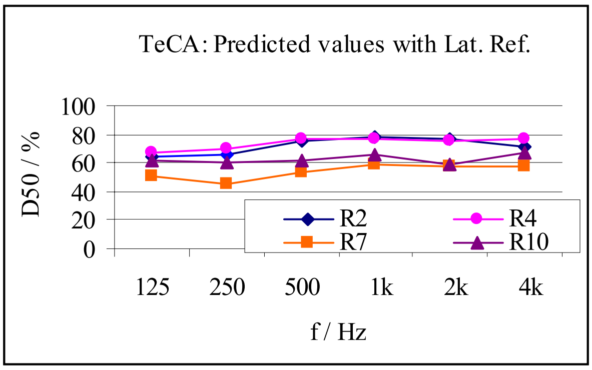

Figure 4: D50 predicted values with lateral reflectors

The contribution of lateral reflectors for speech intelligibility was not more than 10%. Looking for better improvement we studied the influence of scattering coefficients associated with reflectors. We conclude that with low values we could get better results, even very dependent on the receiver location and naturally on frequency.

5.2.2. Overhead reflectors

We also tried overhead wooden: one over front stage (OSR) and three over audience reflectors (OAR) and also all reflectors together (AR). Considering the same four receivers, we can see in figure 5, the influence of these reflectors on D50 values. In figure 6 we present a four-view plot file [2] to show the location of the main four receivers evaluated.

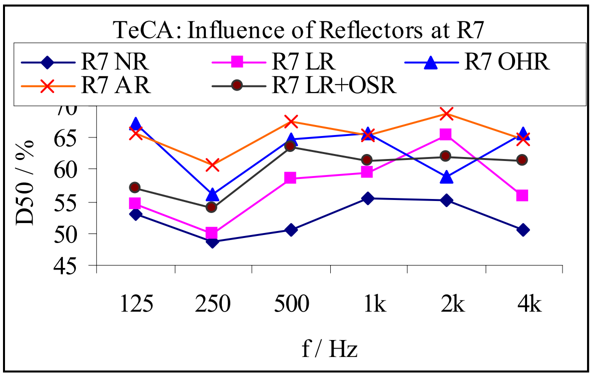

Figure 5: Influence of Reflectors on R7.

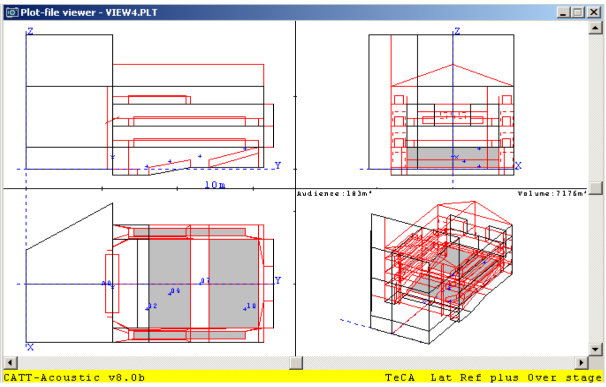

Figure 6: Plot file view of TeCA auditorium

6. Discussion

Comparing measured values with acoustical criteria, we conclude that the hall is more adequate for music and there's a need for speech intelligibility improvement. Measured and predicted values show acceptable agreement, although predicted Tmid is significatively higher that measured ones. As we can see, predicted and measured D50 values for simplified model are very similar, except at low frequencies. Comparing measurement results of different signals, we believe that measured values using swept sine are the most reliable values; with 'mls' signals the values are very coincident, showing a good signal to noise ratio but more sensitive to distortions at higher levels. For shotgun we got higher values for frequencies equal and below 1000Hz and lower values for higher frequencies. Results from balloons show a low signal to noise ratio due to its low energy content, which explains the unexpected low D50 values at medium frequencies. Speech intelligibility is on the limit to be just acceptable, for the measured audience seats. Background noise levels were according NR30.

7. Conclusions

We find a high degree of confidence on measurements done using swept sine excitation. The experiences done with gunshots were considered to be an acceptable basis for further case studies, allowing an easier to handle hardware and a good approach for preliminary and expeditious measurements. Results from balloons clearly show the influence of signal-to-noise ratio, so precautions concerning background noise, especially in large halls are recommended.

The differences from predicted and measured values show us that we need to improve our skills using the simulation software, especially concerning: 1) a more appropriate selection of absorption coefficients from international literature, to best translate the typical behavior of real materials applied; 2) a more accurate feeling to 'guess' scattering coefficients by roughness visualization.

The process of auralization was very well succeeded and it seems to be an interesting way to control useful reflexions for a better room response. This technique, if properly applied, can be a very attractive way to show architects, by listening, the influence of some optional materials on the sound quality of a space!

The application of all these prediction tools and techniques to this particular case, allows us to see and hear the need to improve the overall quality of the hall, especially for drama and speech intelligibility. This conclusion was also confirmed by evaluating the quality index according Arau's theory [1].

8. Acknowledgements

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9. References

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