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Auditoria in North Portugal: Some case studies

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RESUMO: Esta comunicação é parte de um trabalho mais alargado sobre a caracterização acústica de Auditórios. Pretende-se coleccionar informação sobre dados arquitectónicos e renovações, sobre os critérios acústicos que serviram de base para a definição das soluções aplicadas ao projecto e dados sobre as características acústicas de salas, maioritariamente localizadas a Norte de Portugal. Os parâmetros acústicos serão obtidos por medições efectuadas usando um software comercial de medições acústicas e por simulação em computador usando software comercial de previsão de acústica de salas e auralização. Numa fase posterior, prevê-se o uso de Redes Neuronais. Este modelo computacional exige elevado número de dados para treino, pelo que se recorrerá também a valores disponíveis na literatura da especialidade e medidos em outros espaços nacionais e internacionais. Os resultados serão comparados e relacionados com as propriedades geométricas e com as características absorventes, reflectoras e difusoras dos materiais presentes nas salas. Serão igualmente utilizadas técnicas de Auralização, por convolução de sons registados em câmara anecóica com as respostas medidas e estimadas das salas a sinais impulsivos. A reprodução sonora foi pensada apenas para uso de auscultadores, ainda que o uso mais conveniente de altifalantes seja hoje, já possível.

ABSTRACT: This paper is one part of a more complete project about acoustics of Auditoria. 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 properties of halls mainly situated at North Portugal. Acoustical parameters will be obtained by measurements using a commercial room acoustics measuring software and by computer simulation using a commercial room acoustic and auralization software. In a more advanced stage we intend to use also Neural Networks. This computational method requires a large amount of data for training, so we will also use measured data obtained from literature and also by measurements in other national and international spaces. Data results will be compared and related to geometrical and acoustical properties like absorbent, 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, although nowadays a more convenient use of loudspeakers is also possible.

1. INTRODUTION

In this paper we will present two case studies: 1) an auditorium highly absorbent mainly for cinema presentations, but also used for all kinds of music concerts (CMM); 2) an auditorium with all the surfaces made reflective, for musical theatre and modern ways of performing arts (TeCA); We will present the main properties, main results and conclusions of the acoustical evaluation of these spaces. Acoustical measurements and room acoustic simulation were used to evaluate the acoustical main parameters and data was compared and related to geometrical and acoustical properties. By convolving anechoic recordings with measured and predicted impulse responses, auralizations were performed to simulate the acoustical sound quality. We will be able 'to see and hear' the expected improvements in acoustical quality, after implementation of some real or virtual solutions, to improve room acoustics properties.

2. AUDITORIA DETAILS

2.1 Centro Multimeios de Espinho

Centro Multimeios de ESPINHO is a recent and modern cultural building located in ESPINHO, a small town near by the sea, at about 30km south of Porto. It was meant to be a cultural reference for the city in which two main events are very famous: The International Animated Film Festival - CINANIMA - and an International Music Festival. The CMM integrates an auditorium, a planetarium, a small conference room and a space for temporary art exhibitions.

The Auditorium itself (CMM) is geometrically fan shaped approximately 18 m long, 24 m wide and 11,5 m high. The main Hall has an average volume of 3000 m^3 and a seating capacity of 280 places, distributed into 10 rows, defining a rake angle of 20 degrees. The acoustical seating area is 230m^2. All chairs are highly upholstered. The stage has a maximum volume of 1700 m^3 but its configuration can be adjusted according the actual use, allowing different volumes, by moving back and forth, the structure of a movable large projection screen.

Constructively, the roof was built with two galvanized iron sheets filled with rock wool over a metal structure. To reinforce the sound insulation a ceiling composed by double gypsum boards, 26 mm thick were applied to the roof structure over rock wool panels. The lateral and rear walls are heavy masonry lined up with perforated metal sheets, over rock wool panels, air space varying between 25 to 100mm. The stage walls, also in heavy masonry, are partially lined with absorbent cellulose fibers. The stage floor is on thick wood, covered with a carpet only for cinema presentations. Stalls are covered with heavy carpet directly over concrete floor. All doors are fire safe, steel hollow core, steel faces lined with thin wood, but no special qualified seals around perimeter were applied.

2.2 Teatro Carlos Alberto

Teatro Carlos Alberto (TeCA) is an auditorium from late nineteenth century, recently reconstructed on a traditional, but recently re-qualified urban area, in Porto, and it's meant to present musical theatre and modern ways of performing arts.

Basically, the complete hall is rectangular in plan, with an approximate volume of 7400 m^3. The main hall has an average volume of 3000 m^3 and the audience area is variable 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. 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, in gypsum board panels over brickwork are plane, smooth, and parallel to the main walls. 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 only over the rear audience area, 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. TECHNICAL PROCEDURES

To evaluate the interior acoustical properties of these auditoria, computer simulation and acoustical measurements were performed.
For measurements we used swept sine and maximum length sequence (mls) signals, emitted and post-processed by measuring software for audio, acoustics and vibrations [1]. In some spaces we also used a shotgun and balloons to obtain impulse responses of the room and we post-processed them using the same software. Measurements according to ISO standard [2] were done using a PC processor 660 MHz with a professional high quality sound card, a sound level meter with a condenser microphone. We had considered one omni directional sound source (A0) on stage and several receivers at main audience. The halls were unoccupied. Due to lack of specific hardware, we only did one-channel measurements.
For computer simulations we used a predictive room acoustics and auralization software [3]. For each auditorium we defined one simple model (A) and one with some reflectors (B).
Absorption data was obtained from literature [4] and scattering coefficients were estimated from visual evaluation and following also some guidelines in literature [5, 6, 7].
Auralization was accomplished using the same prediction and auralization software, by convolving anechoic recordings obtained from specialised audio libraries with measured and calculated impulse responses. The sound reproduction was thought for high quality headphones.

4. DATA RESULTS

4.1 Centro Multimeios de Espinho

Model “A” was used for first evaluation of cinema acoustics. Our goal was to evaluate reverberation times and speech intelligibility. Measured and predicted values for reverberation times were in good agreement. Results were higher than the optimum recommended values for cinema, but lower than the maximum values allowed, as shown in figure 1. RASTI values were higher than 75% all over the audience area, for a background noise, due to HVAC system, according to NC30 noise criteria curve. We also did measurements and calculations of main room acoustical parameters, for mid frequency range (500Hz - 1 kHz), averaged over eight receivers and three sound source positions. Results for D50 predicted values are presented in figure 2.

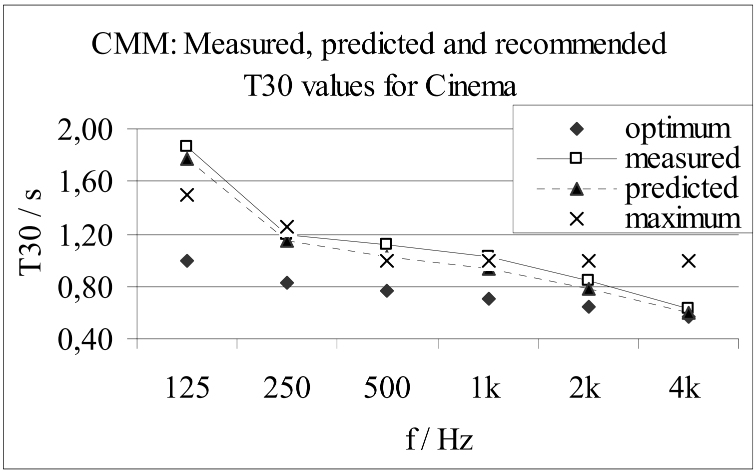

Figure 1 - T30 *values for cinema, CMM*

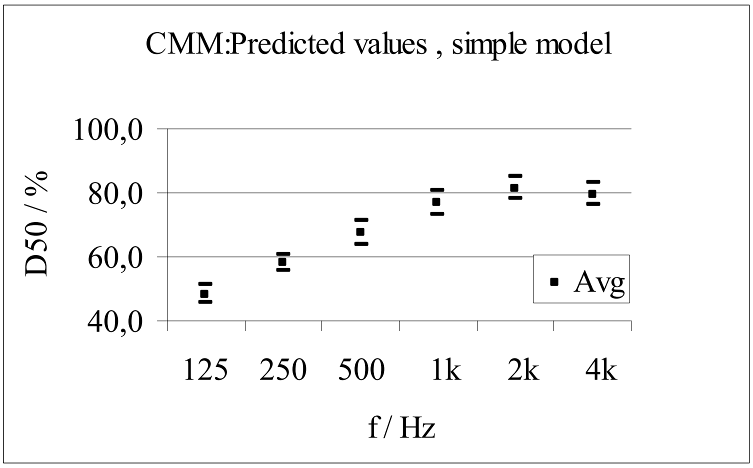

Figure 2 – *D50 averaged predicted values, CMM*

Model "B" was used for room evaluation for music presentation. We simulate two symmetrical lateral reflectors (LR), properly orientated to improve early reflections to the audience area before being absorbed in lateral walls.

Audience area mapping, with and without LR, are presented in figure 3, showing the differences in C80 values at 1 KHz. These differences can also be seen in figure 4, representing binaural impulse responses for receiver R5.

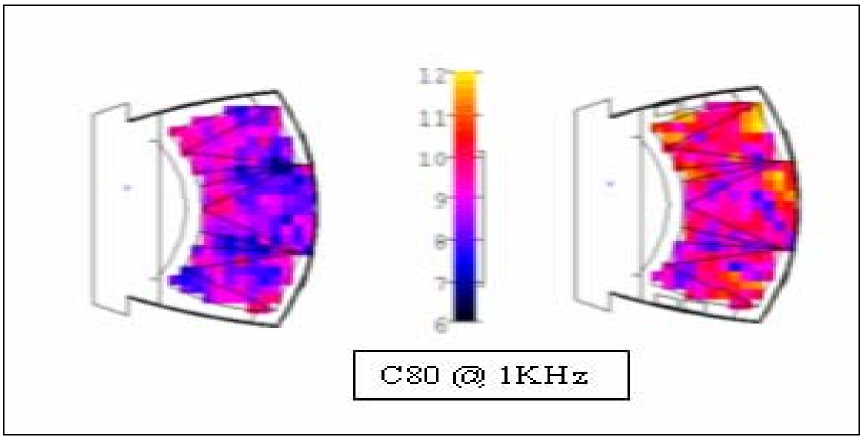

Figure 3- Audience area mapping, CMM

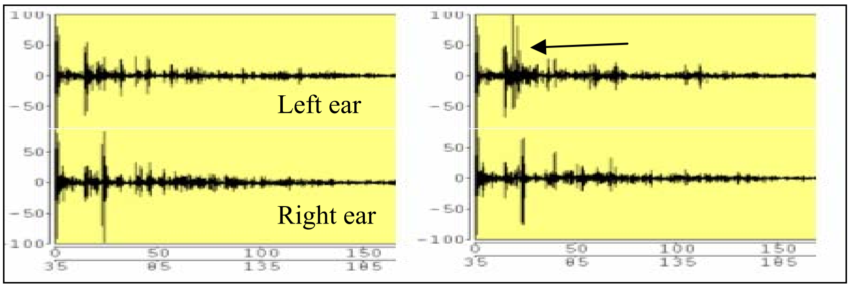

Figure 4 - *Binaural Impulse Response without (left) and with side reflectors, CMM, R5*

An electro-acoustical sound system was also an objective to be considered in the study of this hall. We simulated two loudspeakers “Klein und Hummel TS60”, placed symmetrically both sides of the opening stage. For 1 KHz the covered area exactly matches the limits of the auditorium showing that this solution can be a possibility to consider for certain cases.

5.2 Teatro Carlos Alberto

In Table 2 we present the measured and predicted acoustical parameters obtained for the simplified model. To evaluate the speech intelligibility, we selected D50 to take into account the initial reflection density. Figure 5 shows the predicted and measured D50 values at central point R7, considering an omnidirectional sound source, at position A0.

Figure 6 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.

Table 2 - *Measured and predicted values, TeCA*

Acoustical parameters	Measured	Predicted
T_{mid} ,s	1.3< T_{mid} <1,4	1.7 < T_{mid} < 1.8
EDT_{mid},s	1,2< EDT_{mid} <1,4	1,1< EDT $_{mid}$ ≤ 1.5
D_{50}, %	40 < D50 < 60	45 < D_{50} ≤ 55
C_{80}, dB	2< C80 < 4	2,5 < C_{80} < 4
T_s, ms	65 < Ts < 87	73 < T_s < 88

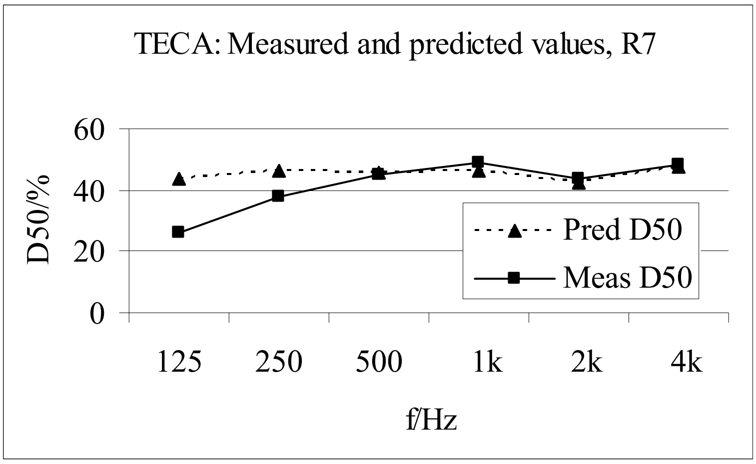

Figure 5 - *D50 measured and predicted values, TeCA*

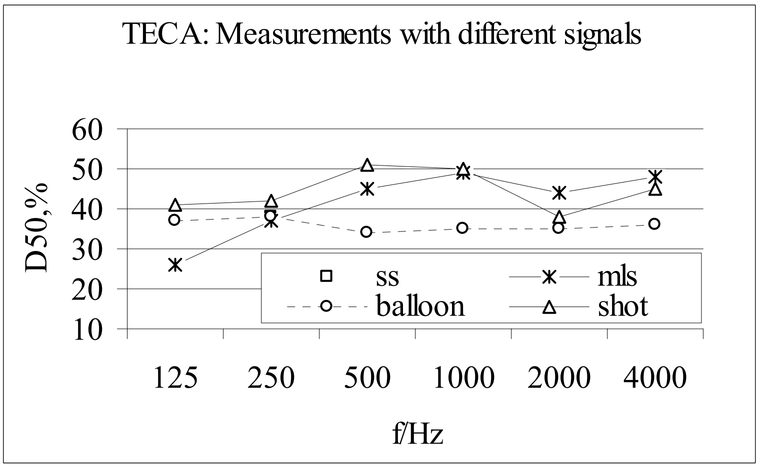

Figure 6 – *D50 values at central point R7, TeCA*

To evaluate the improvement of speech intelligibility, first we simulated the presence of two lateral reflectors. 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 rows in movable audience area, considering a movable sound source from position A0 to A1. The contribution of lateral reflectors for speech intelligibility was not more than 10%. Secondly we studied the influence of one panel over front stage (OSR), three over audience reflectors (OAR), and all these reflectors together (AR). Considering the same four receivers, we can see in figure 7, the influence of all reflectors on D50 values.

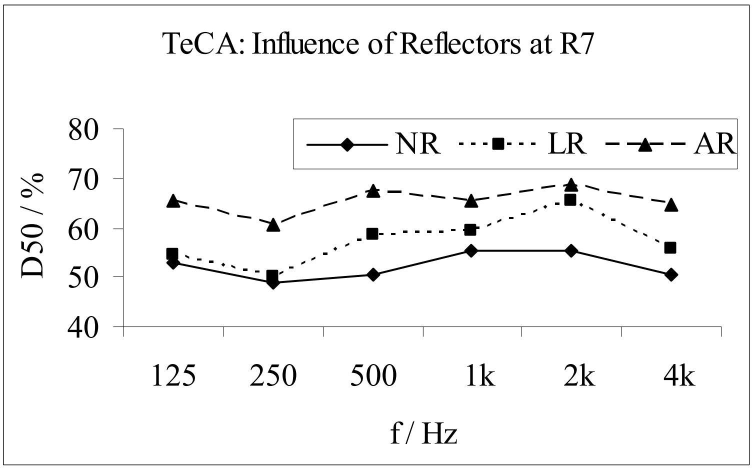

Figure 7 - *D50 values showing improvement in speech intelligibility, TeCA*

5. CONCLUSIONS

Comparing the simple model measured values with acoustical criteria, we concluded that there's a need to improve acoustics in both auditoria, considering their multipurpose use.
In CMM, mainly a cinema it's noticeable the lack of early lateral reflections affecting clarity. In TeCA, mainly a musical theatre, there's a need for speech intelligibility improvement. The situation in both cases can be partially solved by lateral reflectors in order to re-direct sound to audience area.
Measured and predicted values show acceptable agreement, although predicted T30 values at medium frequencies are higher than the measured ones. The parameters values are very much dependent on the definition of the volume and absorption data. Also, the importance of diffusion effects was enhanced by calculations done with scattering coefficients different values.
Comparing measurement results of different signals, we believe that measured values using swept sine are the most reliable; with 'mls' signals, showing a good signal to noise ratio, values are 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.
Auralisation also proves to be a helpful tool for finding decisions for room acoustical improvements in both auditoria. For checking the quality of sound based on room simulation data we first had to compare signals convolved with measured impulse responses with those convolved with the synthetic impulse responses which was generated by the room simulation

software. The good coincidence of both sound impressions was the prerequisite for the validity of further comparisons of various details of room acoustical properties.
In CMM e.g. these auralizations enabled a clear binaural impression of the efficiency of side reflectors for improving the sound quality for music in this highly absorbent room: a strong new peak in the impulse response (figure 4) confirms the subjective effect of a broadening of the apparent source width which could be perceived during listening via headphones.
In TeCA, actors had complained about lack of reflections from the side areas under the balconies when speaking on the proscenium (A1). The simulation of side reflectors in the critical areas close to the stage could help optimizing their size and orientation by listening to the corresponding auralizations. These reflectors have already been realized and are appreciated by the actors, although their size and orientation could not be optimized.

As a final conclusion we can state 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.
The process of auralization was very well succeeded. This technique seems to be an interesting tool to verify the usefulness of reflections. If properly used, can be a very attractive way to show architects, by listening, the influence of some optional materials on the corresponding sound quality of a space!

6. REFERENCIAS

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