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Acoustic Assessment of the Garrett Hall of the National Theatre D. Maria II in Lisbon

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Abstract
This paper focus on the acoustic evaluation of the Garrett Hall in the National Theatre D. Maria II in Lisbon. The assessment was done using standard experimental measuring techniques for obtaining the room acoustics quality objective parameters, but also by employing a 64-channel acoustic camera so to register the 3D impulse responses for post-processing particularly the spatial information. In addition, acoustical modelling of the Hall was carried out in order to obtain further and supporting rating. The evaluation was undertaken for two configurations of the Hall, the first with the proscenium main curtain open and the second with the curtain closed.

Keywords: theatre acoustics, room acoustics, 3D impulse responses.

Resumo
Este trabalho centra-se na avaliação acústica da Sala Garrett do Teatro Nacional D. Maria II de Lisboa. A avaliação foi realizada através de técnicas experimentais padrão de medição de parâmetros objectivos da qualidade acústica de salas, mas também através da utilização de uma câmara acústica de 64 canais de modo a se obter as respostas ao impulso 3D que foram pós processadas particularmente no que concerne a informação espacial. Adicionalmente, foi também efectuada a avaliação da Sala por técnicas de modelação acústica a fim de se obterem características complementares. A avaliação foi conduzida para duas configurações da Sala, a primeira com o pano de boca de cena aberto e a segunda com a pano fechado.
Palavras-chave: acústica de teatros, acústica de salas, respostas ao impulso 3D.

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1 Introduction

With the development of cultural spaces, such as theatres, room acoustics became a critical factor in cultural activities. Due to the nature of the cultural activities developed inside theatres, speech is the main mean of contact between artists and the audience. Therefore, a theatre must be a space where good intelligibility characteristics are granted in the whole audience areas.
This work aims to thoroughly characterize, from an acoustical point of view, the National Theatre D. Maria II (TNDMII), in Portugal. This characterization is based on measurements of the most

relevant acoustical parameters, which can be directly related to their correspondent auditory subjective parameters.
The National Theatre D. Maria II opened in 1846. In its original project, the theatre was designed in a horseshoe shape, 14 metres long and 13 metres wide. Around the audience, there were four tiers: a lower gallery, two balconies divided in boxes and an upper gallery. The stage was 23 metres deep and 19,5 metres wide, with an arch shaped proscenium, 12 metres wide. In its first configuration, the room could seat up to 800 people. In 1964, the theatre was destroyed by a fire, which destroyed the building, and led to a full reconstruction. The remodelling project was focused in providing the best possible acoustical conditions, aiming at a reverberation time of ca. 1 second. After the rebuilding, the room would become slightly smaller (16 metres deep, 19 metres wide and 13 to 14,5 metres high), and the volume was decreased to 3105 cubic metres, and the seating capacity was reduced to 694 people. A photograph of the Garrett Hall in present conditions is displayed in Figure 1.

Figure 1 – Photograph of the Garrett Hall – Present Conditions, view towards the stage

The acoustical assessment and corresponding results were obtained through three different methods: standard ISO 3382 measurements, acoustic camera measurements and acoustical software simulation.
In this work, the following recommended ISO 3382 acoustic quality descriptors were considered: Reverberation Time (T_{30}), Early Decay Time (EDT), Clarity indexes (C_{50} and C_{80}), Definition index (D_{50}), Centre time (Ts), Speech Transmission Index (STI), Bass and Treble ratios (BR and TR) and Lateral Fraction (LF)[1].

[1] Due to technical difficulties, Lateral Fraction values could not be obtained using the standard measurement technique. LF values were thus obtained through the spatial weighing of the 3D acoustic camera impulse responses.

2 Acoustical Measurements

The standard acoustical measurements procedure is fully described in the ISO 3382-1 norm. Because of the limited available technical conditions and time to perform the measurements, due mainly to the COVID19 constrains, it was impossible to strictly follow all the norm's procedures. However, all the measurements made followed the best practices of acoustical studies, and guidelines to ensure the validity of the obtained data.

The standard measurements were made with a set comprised of an omnidirectional microphone and a figure-of-eight microphone with its null coincident with the axis of the omnidirectional microphone (ISO 3382 standard measurements). Moreover, for completeness purposes, 3D acoustical measurements using a 64-channel acoustic camera were carried out.

The following equipment was used: Lookline DL-303 (omnidirectional source - dodecahedron speaker), Earthworks M30 (omni) and Schoeps MK4 (fig. 8) (microphones), VisiSonics 5/64 (acoustic camera), M-Audio Fast Track Pro (USB audio interface). ARTA v1.9.3 (PC software for standard impulse response measurements) and Matlab, vR2020a (DSP of acoustic camera's recorded data). The computer simulation was developed using CATT Acoustics.

Due to considerable sound field differences between the hall and the stage, the measurements were conducted in two distinct situations: with the fire safety curtain open, to assess the acoustical behaviour of the whole enclosure, and with the curtain closed, to characterize only the sound field inside the hall.

To ensure a meaningful characterization of the acoustic field inside the whole room, measurements were made in ten positions[2].

Five measurements were made on distinct points of the audience, two on each of the two balconies and one on the presidential tribune.

Figure 2 - Measurement positions

Figure 3 - Measurement system

[2] Due to time limitations, the measurements with the acoustic camera were only conducted in the five measurement positions located in the audience, and only with the fire safety curtain opened.

2.1 ISO 3382 Standard Measurements

The following curves are average octave band values for three sets of measurement positions: audience (orange), balconies (grey) and room average (10 positions) (blue).

Reverberation time (T_{30})

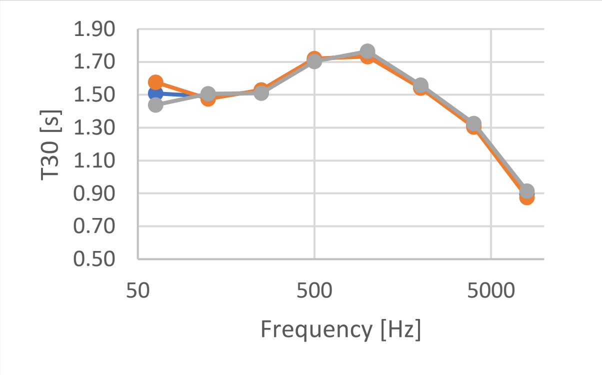

Figure 4 - Mean reverberation time graph, stage open

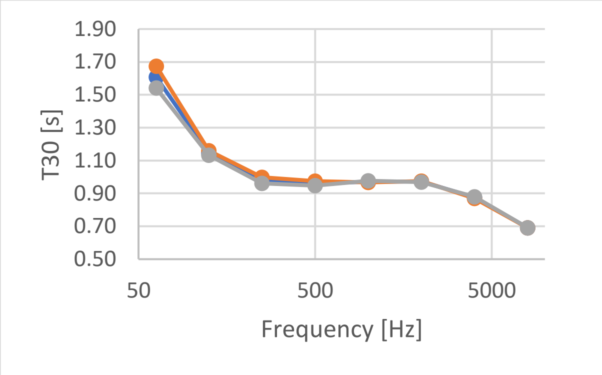

Figure 5 - Mean reverberation time graph, stage closed

Early Decay Time (EDT)

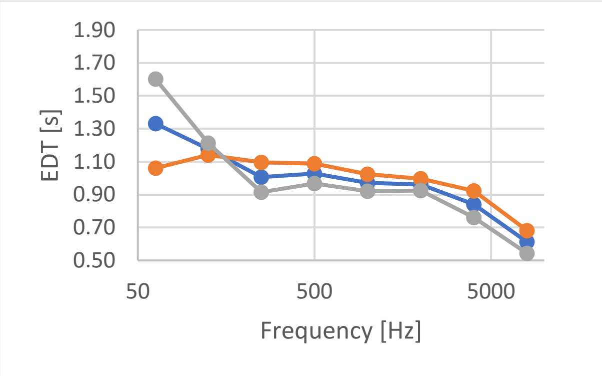

Figure 6 - Mean EDT graph, stage open

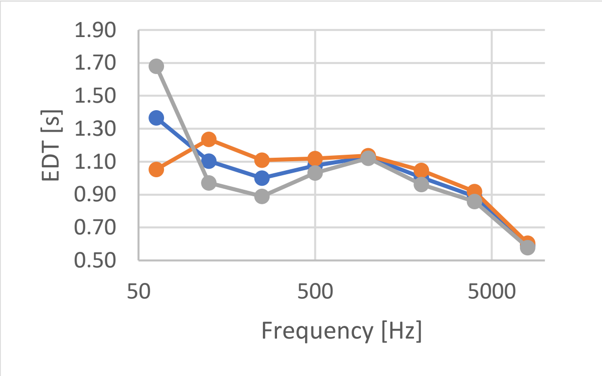

Figure 7 - Mean EDT graph, stage closed

Definition index (D50)

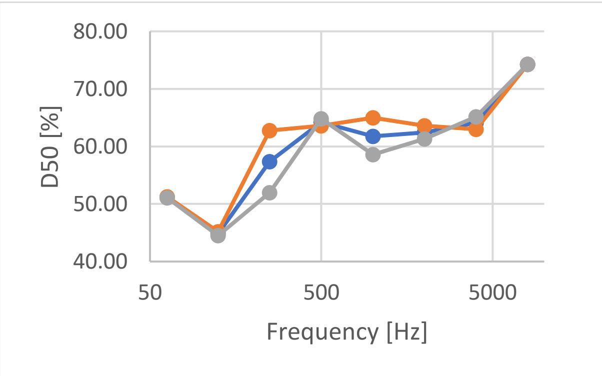

Figure 8 - Mean D50 graph, stage open

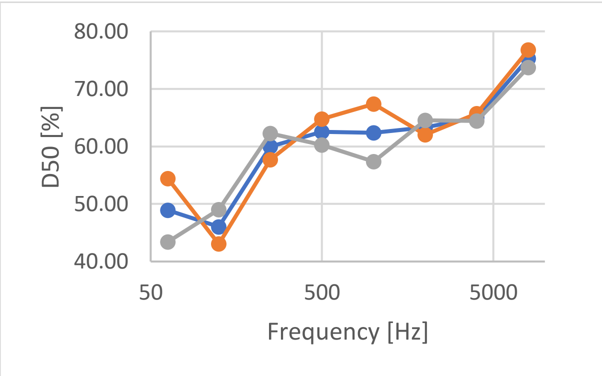

Figure 9 - Mean D50 graph, stage closed

Speech transmission index (STI)

Table 1 – Broad band STI values

Position	STI (Hall, stage open)	STI (Hall, stage closed)
MEAN - Hall	0,57	0,56
MEAN - Audience	0,61	0,61
MEAN - Balconies	0,52	0,50

2.2 Acoustic Camera Measurements

Reverberation time (T30)

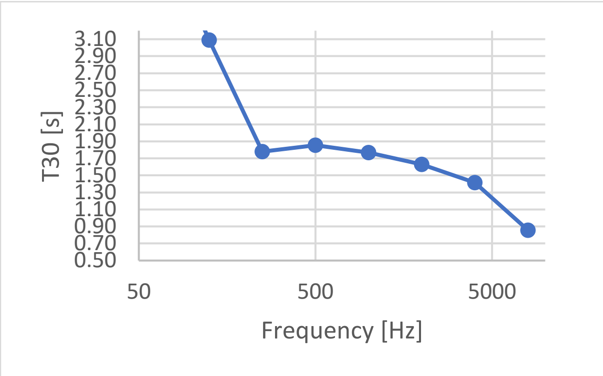

Figure 10 - Mean Reverberation time graph, stage open

Early decay time (EDT)

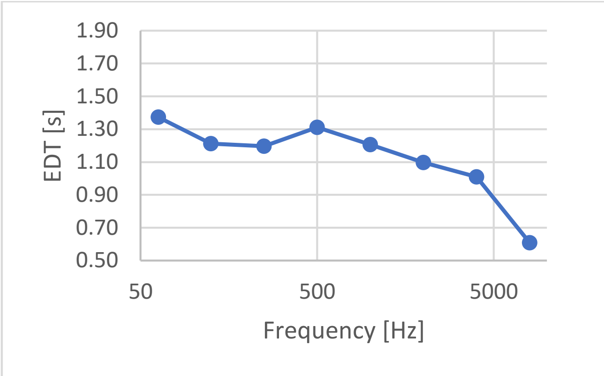

Figure 11 - Mean EDT graph, stage open

Definition index (D50)

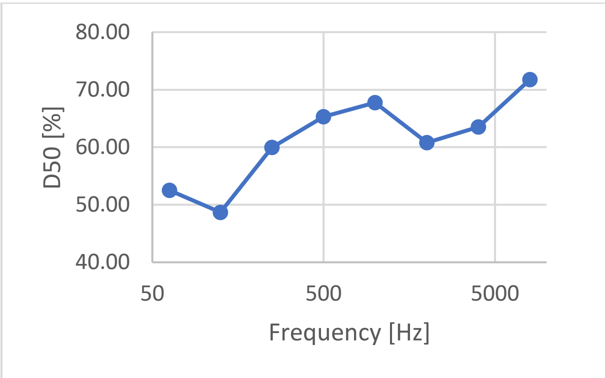

Figure 12 - Mean D50 graph, stage open

Lateral fraction (LF)

Table 2 – LF values, stage open

Position	Lateral fraction (hall + stage open)
1	0,22
2	0,21
3	0,39
4	0,38
5	0,22
MEAN	0,28

3 Computer Simulation

Values of the computer simulation are provided only for the octave bands between 125 Hz and 4 kHz.

Reverberation time (T_{30})

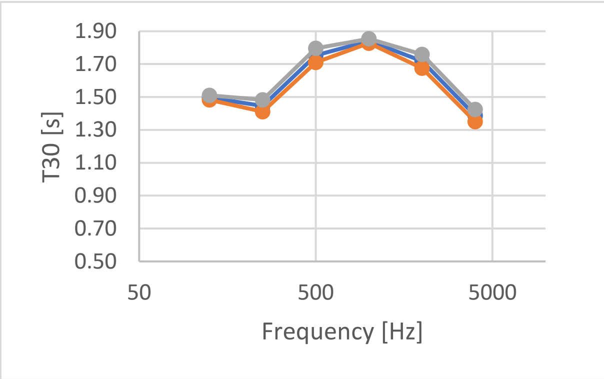

Figure 13 - Mean reverberation time graph, stage open

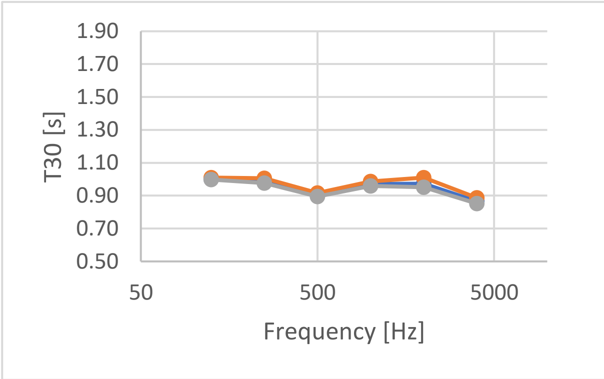

Figure 14 - Mean reverberation time graph, stage closed

Early decay time (EDT)

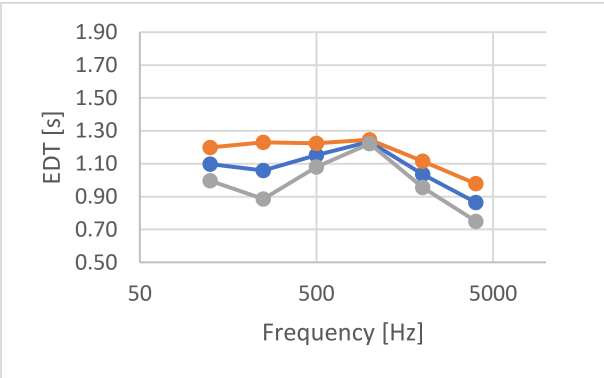

Figure 15 - Mean EDT graph, stage open

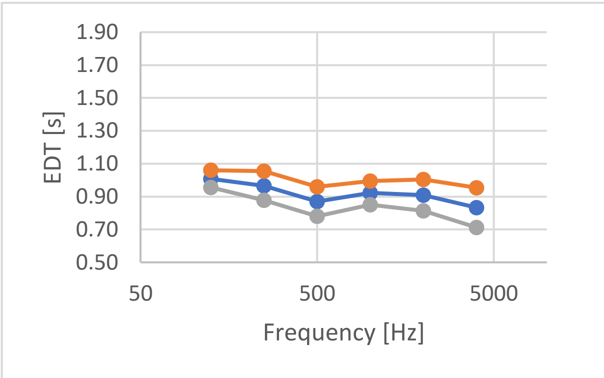

Figure 16 - Mean EDT graph, stage closed

Definition index (D50)

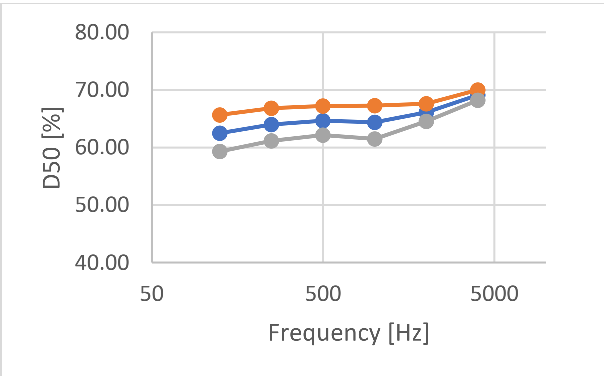

Figure 17 - Mean D50 graph, stage open

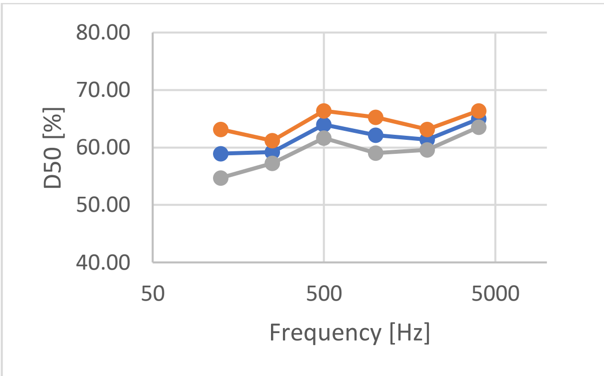

Figure 18 - Mean D50 graph, stage closed

Speech transmission index (STI)

Table 3 – Broad band STI values

Position	STI (hall, stage open)	STI (hall, stage closed)
MEAN - Hall	0,60	0,63
MEAN - Audience	0,60	0,63
MEAN - Balconies	0,60	0,64

Lateral fraction (LF)

Table 4 – LF values, stage open and stage closed

Position	Lateral fraction (hall + stage open)	Lateral fraction (hall + stage closed)
MEAN - Hall	0,21	0,22
MEAN - Audience	0,17	0,18
MEAN - Balconies	0,25	0,26

4 Results

An analysis of the graphics permits to reach two significant conclusions. Comparing the reverberation time curve of the main hall with the stage open, with the reverberation times measured with the fire safety curtain closed, one may notice that the sound field inside the stage is determinant for the reverberation characteristics of the main hall. Closing the stage, much lower reverberation times are obtained, which in turn are very similar to the prediction made in the original acoustic project. This shows that the main hall itself has not suffered any changes to its surfaces since its original rebuilt conditions.
As expected, EDT and D_{50} values do not change significantly with the stage open or closed, as these parameters are related with the early component of sound energy, while the energy from the stage, which contributes to the reverberation time increase, travels a considerable distance, arriving at the receiver later than the time periods considered in these parameters, and not in the form of discrete reflections, but as a reverberant field.

5 Conclusions

It is evident that the stage's sound field is determinant to the acoustical properties of the main Hall.
The values obtained from the standard ISO 3382 measurements using the omnidirectional microphone are considered as the most accurate ones, as they show high coherency (very high linear regression correlation coefficients) and are also very close to the expected values. The 3D acoustic camera proved to be a very versatile method, as it offers a wide variety of analysis possibilities in the assessment of the sound field. From a single measurement's data, the generation of 64 directional impulse responses spread over an entire sphere allows not only the description of the spatial characteristics of the sound field, but also the ability of virtually change the polar pattern receptivity of the camera, through the pondered sum of all the impulse responses into a single impulse response, which then corresponds to an acoustical measurement with a single microphone with a given polar pattern. However, due to the limited time resources, the

analysis of this data was only conducted in a very preliminary stage. Future work is envisaged in order to better explore the capabilities of the method.

The acoustical software simulation, if properly used, is a very important resource allowing to predict with good accuracy any room's sound field behaviour. In this work, the simulation was a fundamental aid in the characterization of the Garrett Hall. On the one hand, it acted as a means of confirmation of the measurements' significance, as the existence of some significant discrepancies between some first simulations and the measured values were not expected. On the other hand, the simulation helped in the characterization of surfaces where little information was available. Nevertheless, one must not forget that the acoustical software simulation is not a perfectly accurate method, and some deviations from reality can occur, some caused by difficulties in the characterization of the surfaces or in the determination of the actual area they occupy, and some due to the inherent simplifications adopted.

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