On the Acoustics of the Vianna da Motta Auditorium in Lisbon

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Abstract
This paper addresses the acoustic signature of the Vianna da Motta Auditorium in the Lisbon School of Music of the Polytechnic Institute of Lisbon, in Portugal. The study undertaken envisages to correlate the measured objective acoustical parameters with the subjective acoustic impressions of the music performances inside the auditorium. The objective acoustical assessment resorted to the normalized ISO3382 procedures, but also to binaural measurements with a dummy head, to spherical array measurements with a 64-channel acoustic camera and to modelling in acoustical software.

Keywords: auditorium acoustics

1 Introduction

This paper focus on the acoustic assessment of the Vianna da Motta Auditorium in the Lisbon School of Music, Polytechnic Institute of Lisbon. This assessment, that was done for the first time, was undertaken through a combination of different acoustic characterisation methods: standard ISO 3382 measurements, spherical beamforming measurements and acoustical software simulation.

Figure 1 – Photographs of the Vianna da Motta Auditorium. Left: view towards the stage. Right: view towards the audience area.

The Vianna da Motta Auditorium has a volume of ca. 4650 m^3 and a seating capacity for 448 persons, distributed by 16 rows of 28 seats. The stage possesses a flat wooden floor on joists, the audience area is tilted approximately 20º in relation to the horizontal plane and has two wooden flights of stairs in between the rows of chairs. The walls surrounding the audience go continuously around the stage in a roughly trapezoidal shape

and consist entirely of large-scale shape-optimised reflection phase grating diffusors. Figure 1 shows two photographs of the Auditorium.
The Vianna da Motta Auditorium presents many similarities with the Théâtre Auditorium de Poitiers (TAP), in France, both designed by a team with the same leading architect (Carrilho da Graça). Although TAP is a larger room (10500 m^3, 600 to 1100 seats), one can see numerous similarities especially when it comes to the large-scale audience and stage diffusors, which are both built with massive wood in various dimensions to optimize diffusion but also limiting absorption (that can be a problem in classical diffuser patterns) [1].
The venue has the purpose of hosting mostly classical music (symphonic orchestra, chamber orchestra and brass orchestra), but sometimes also hosts contemporary music.
For some time now, there have been some complaints regarding some acoustic aspects of the Auditorium, particularly from the musicians and sound engineers, concerning mainly the too high sound pressure levels in fortissimo of some music pieces and a lack of clarity and sound source localization. As a mean of attempting an acoustical improvement inside the auditorium, heavy fabric curtains are often placed along the corners of the stage (see Fig 2). For testing this acoustical treatment, the determination of the metrics was done also considering the presence of the mentioned curtains.

Figure 2 – View of the stage showing the heavy fabric curtains placed along its corners

In this work, the following room acoustic metrics were measured (according to the ISO 3382 standard) and simulated: gain (G), reverberation time (T_{30}), early decay time (EDT), clarity indexes (C_{50} and C_{80}), definition (D_{50}), centre time (T_s), bass and treble ratios (BR, TR), early lateral fraction (J_{LF}) and IACC.

2 Acoustical measurements

Acoustical measurements were done according to the ISO 3382 standard [2]. In addition, these tests were complemented with measurements using an exact spherical beamforming technique implemented by the authors and employing a rigid spheric acoustic camera [3].
For the standard ISO 3382 measurements, two different systems were used:

- 1 omnidirectional Earthworks M30 microphone and 1 figure-of-eight Schoeps Colette MK8 microphone arranged in a compact set, feeding their audio signals through a Behringer UMC404HD USB audio interface to a computer with ARTA 1.9.3 software;
- 1 binaural microphone, Binaural Enthusiast dummy head, feeding the two-channel audio signals through a M-Audio Fast Track Pro USB audio interface to a computer with Audacity 3.0.2 and GNU Octave 6.2.0 programming software.

Both measurement systems were operated simultaneously, and "side by side", using an exponential sine sweep signal generated in the ARTA software and emitted from a Lookline DL303 dodecahedron speaker that was set up at a centred position of the stage. Nine different receiver positions in tandem across the audience and three additional locations on the stage were considered. IACC values were determined with the binaural microphone.

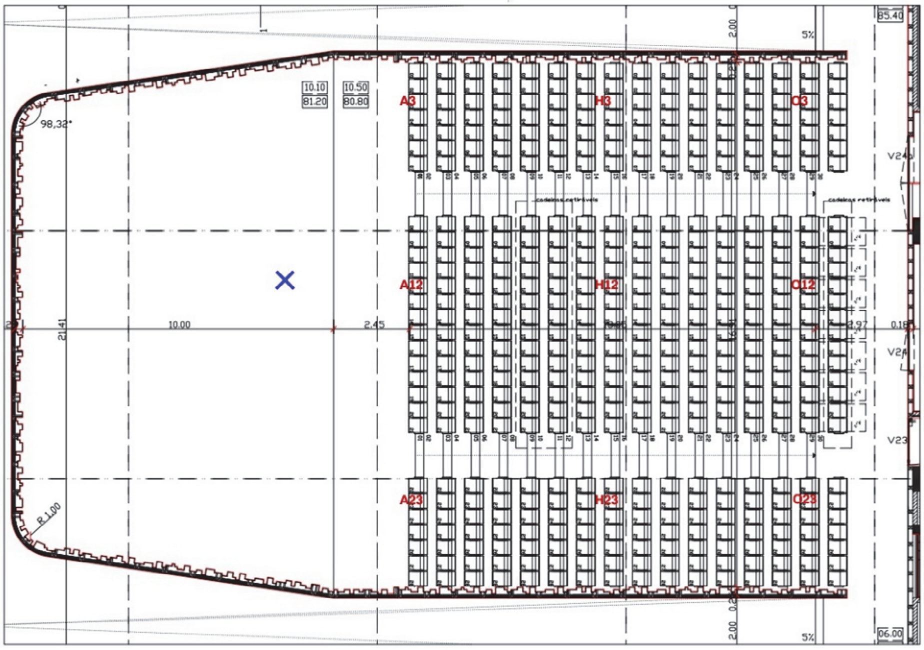

Figure 3 – Measurement points (in red) and source location (in blue)

For the spherical beamforming measurements, a VisiSonics 5/64 acoustic camera was used with its OEM acquisition software. The "raw" audio signals were afterwards post-processed in the GNU Octave 6.2.0 programming environment. Details of this processing can be found in [3]. The J_{LF} values were determined with spherical beamforming and are reported in this paper.
Figure 4 shows some photographs of the measurement hardware used for the acoustical measurements, and Figure 5 shows the 3D directional sound energy at measurement position H3 in function of distinct time intervals recorded through the 64 channels of the spheric acoustic camera. From this figure, one can see that the first early reflections from the audience's left side wall, which is covered by the large-scale diffusor, are rather weak, this fact being consentaneous with the obtained lateral fraction of only 0.21. It can also be seen that the Auditorium portrays a very high degree of late energy diffuseness (Figure 5, right).

Figure 4 – Photographs of some of the measurement hardware. Left: omni and figure-of-eight mic set and binaural microphone. Right: omni mic and spheric acoustic camera.

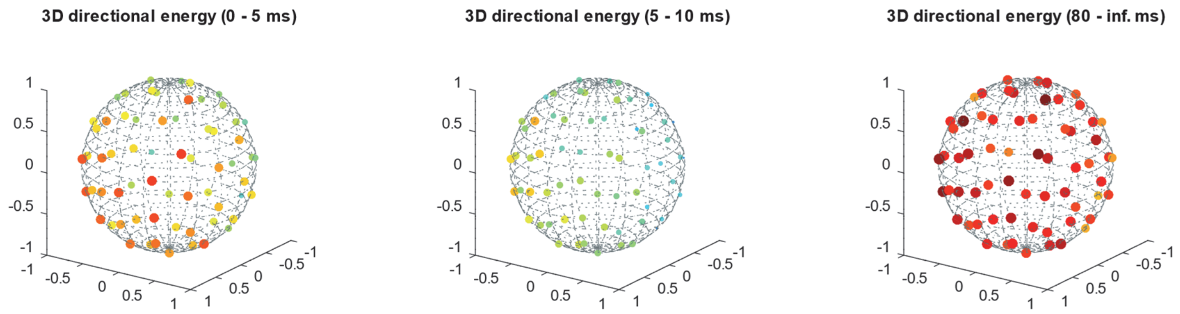

Figure 5 –3D directional sound energy at measurement position H3 in function of the time intervals [0, 5], [5, 10], [80, ∞], in ms. Colours represent SPLs in dB, following the visible spectrum (low values -> dark blue, high values -> dark red). Higher SPL values correspond to larger dots.

As mentioned previously, measurements were carried out inside the Auditorium in the two conditions: without and with the fabric curtains set up in the stage's corners.
Table 1 shows the measured values for some of the different metrics considered, under the two absorption conditions.

Table 1 – Measured room acoustic metrics in the Vianna da Motta Auditorium, without and with the heavy fabric curtains

Frequency octave bands [Hz]	63	125	250	500	1000	2000	4000	8000	
T_{30} [s]	1.77	1.82	2.00	1.75	1.80	1.75	1.43	1.03	without curtains
	1.70	1.90	1.89	1.57	1.60	1.58	1.34	1.00	with curtains
EDT [s]	1.47	1.86	1.83	1.67	1.77	1.61	1.31	0.82	without curtains
	1.14	1.58	1.66	1.49	1.50	1.40	1.25	0.74	with curtains
G [dB]	10.9	11.0	11.4	10.9	11.0	10.9	10.0	8.6	without curtains
	10.8	11.2	11.2	10.4	10.5	10.4	9.7	8.4	with curtains
C_{80} [dB]	0.89	-2.48	-1.25	-0.83	-0.56	-0.43	1.00	5.03	without curtains
	2.83	1.06	0.30	1.51	1.25	1.61	2.84	7.12	with curtains
D_{50} [%]	29.2	17.6	31.0	33.4	33.0	33.8	39.6	58.9	without curtains
	45.5	41.0	39.8	46.2	44.3	47.2	52.8	72.3	with curtains
T_s [ms]	123.0	155.5	134.7	122.9	125.0	118.2	95.3	58.3	without curtains
	101.4	121.8	117.8	98.0	98.9	93.0	76.5	43.2	with curtains
IACC	0.96	0.96	0.86	0.49	0.33	0.44	0.63	0.82	without curtains
	0.96	0.96	0.83	0.49	0.33	0.38	0.50	0.66	with curtains
JLF	-	0.43	0.39	0.18	0.18	0.21	0.24	0.24	without curtains
	-	0.42	0.39	0.17	0.17	0.22	0.23	0.24	with curtains
							BR	1.09	without curtains
								1.19	with curtains
							TR	0.90	without curtains
								0.92	with curtains

Figure 6 shows the graphics concerning the reported metrics' values, also for both conditions of the Auditorium, without and with the stage corner's heavy fabric curtains.

Figure 6 – Vianna da Motta Auditorium acoustic parameters, measured without (blue) and with stage's corner heavy fabric curtains (orange)

3 Acoustical software simulations

The computer acoustical simulations were done using the software CATT acoustics (versions 9.1f and TUCT v2). Figure 6 displays screenshots of the elaborated models, for both conditions of the Auditorium.

The two elaborated models were validated through comparison with the measured metrics' values. The materials employed in the Vianna da Motta Auditorium are typical for a room like this, and tabulated values could be easily allocated to the different surfaces. The most difficult task consisted in the correct acoustic characterisation of the large-scale phase grating diffusor present in the Auditorium, both from the absorption and from the scattering point of view. The following values, based on tabulated data [4] and on the models' calibration, were determined as the most correct ones:

Table 2 – Acoustic characteristics of the large-scale phase grating diffuser

f (Hz)	125	250	500	1k	2k	4k	8k	16k
α	0.07	0.07	0.07	0.06	0.07	0.07	0.09	0.10
s	0.40	0.60	0.95	0.90	0.88	0.91	0.50	0.80

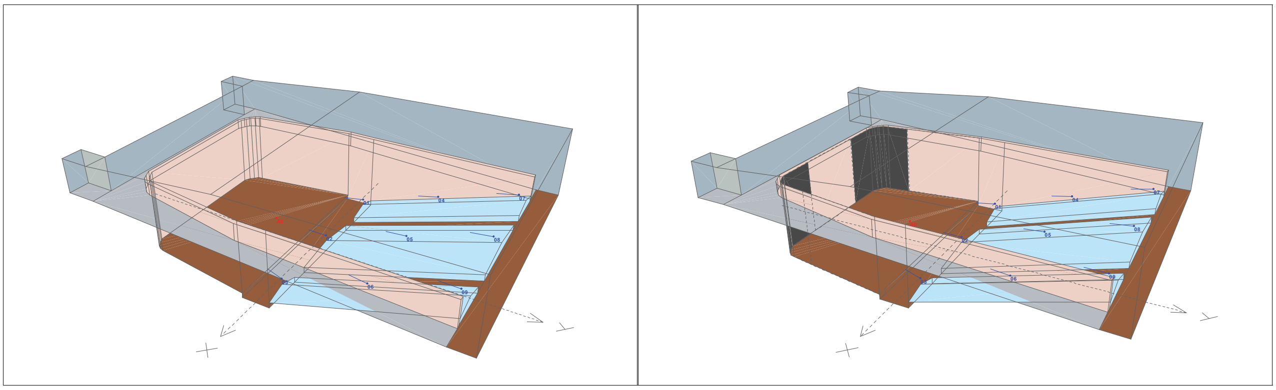

Figure 6 – CATT models of the Vianna da Motta Auditorium; left: without stage's corner heavy fabric curtains; right: with stage's corner heavy fabric curtains

Figure 7 shows the validation of the two elaborated acoustic models for the case of the reverberation time T_{30} and the music clarity C_{80}.

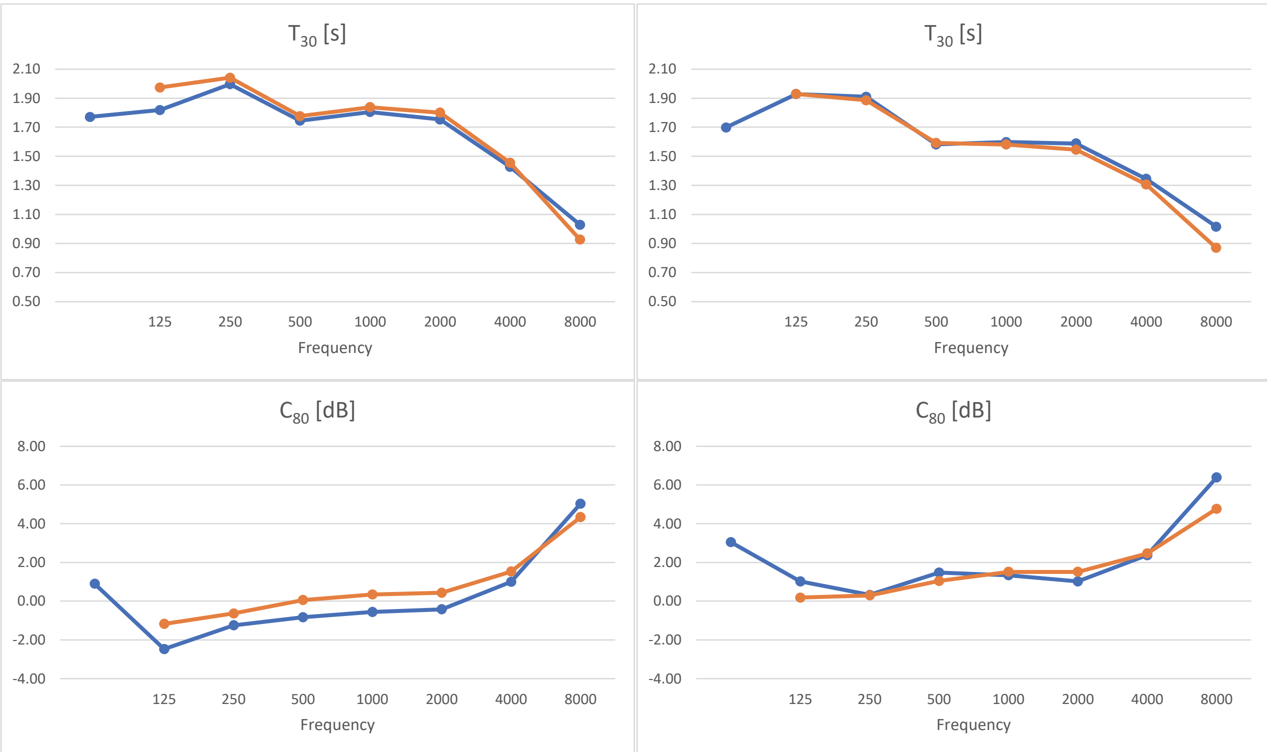

Figure 7 – Measured (blue) and calculated (orange) values for two acoustic metrics; left: without stage's corner heavy fabric curtains; right: with stage's corner heavy fabric curtains

4 Discussion and Conclusions

The following Table 3 shows the mid-frequency values (500 Hz to 2000 Hz averages) of some important acoustical parameters measured in the Auditorium, under the two absorption conditions, compared to some recommended values for unoccupied halls (adapted from [5]):

Table 3 – Measured mid-frequency room acoustic metrics in the Vianna da Motta Auditorium, without and with the heavy fabric curtains, compared to recommended values for unoccupied halls (adapted from [5])

metric	measured without fabrics	measured with fabrics	recommended orchestral music	recommended chamber/piano music
T_{30} [s]	1.77	1.58	1.80 - 2.00	1.30 - 1.50
EDT [s]	1.68	1.46	1.80 - 2.20	1.20 - 1.40
G [dB]	10.9	10.4	3.0	10.0
C_{80} [dB]	-0.6	1.5	-1.0	3.0
1-IACC	0.58	0.60	0.70	0.60
J_{LF}	0.19	0.19	0.20 - 0.25	0.15 - 0.20

Analysing the results of the measurements, under the two absorption conditions, without and with the heavy fabric curtains, one can clearly see that the values determined for the Auditorium “as it is” are more in line with the ones recommended for orchestral music. However, a very large difference in the G values is observed, which is certainly the reason for the complaints of musicians and sound engineers of too high sound pressure levels with some musical programmes.

The introduction of the heavy fabric curtains at the stage’s corners accomplished various changes in the acoustical parameters of the Auditorium. As expected, definition and clarity associated values, such as D_{50}, C_{80} and T_s have increased while reverberance associated values have decreased. When comparing the values of the metrics obtained under this more absorbent acoustical condition to recommended values, one sees that they are very more in line now with the optimal setting for chamber/piano music. The measured gain G is similar under both absorption conditions (a difference of 0.5 dB is hardly noticeable), which means that the curtains applied at this location are not totally effective in controlling this parameter, but the measured gain G is consentaneous with the recommended value for this musical programme.

The 1-IACC and J_{LF} values do not show a noticeable difference under the two absorption conditions, since they are mainly influenced by the lateral walls reflections which are not covered by the added absorption, and they are right in the desired scope of values for both orchestral music and chamber and piano music.

One can therefore conclude that the Vianna da Motta Auditorium “as it is”, seems more adequate for orchestral music and the heavy fabric curtains solution improves on the acoustical characteristics of the venue for the purpose of chamber and piano music. However, the very strong G parameter presented by the Auditorium is very difficult to change due to the impossibility of altering the geometry of the room and the relation between volume and number of seats. Therefore, substantial improvements on the location of sound absorption materials will have to be made if one aims at numbers closer to the desired G values for orchestral music, and this will be addressed in a future paper. Since this venue belongs to an educational facility and both orchestral and chamber music are played in the Vianna da Motta Auditorium, all foreseen changes to be considered must be able to accommodate both styles of music.

It is important to note that all the values discussed in this paper were obtained without the occupation of the audience. Considering this occupation, an improvement of some metrics can be observed (according to the computer simulation), but the gain G still maintains a very high value (ca. 9.5 dB) for orchestral music programmes. However, since the venue is frequently used as a rehearsal space for the several orchestras present in the Lisbon School of Music, these acoustical problems persist since the rehearsals are done without an audience.

Acknowledgments

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