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Acoustic parameters of the Municipal Theatre of Piacenza shown on different ways of representation

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***Abstract*—The Italian Opera theatres are always subject to scientific studies that try to investigate as deeply as possible this historical heritage to preserve the architectural and acoustical information for future generations. This paper deals with two ways of data representations based on the outcomes derived from the variety of equipment used during the measurements. In particular, a methodology in line with standards and regulations has been introduced to representing the graphs of the main acoustical parameters; besides, a video of the real-time room impulse response (RIR) has been snapped with a few shots in place of visualizing the sound reflections that occurred inside the entire volume. After a brief description of the historical background of the Municipal Theatre of Piacenza, the authors introduce the two methods just discussed to highlight the completeness of data representation regarding any type of room that is intended to be analyzed acoustically.**

Keywords—acoustic parameters, spherical array, spatial PCM sampling, Italian Opera theatre, 3dof.

I. Introduction

This paper deals with the historical background of one of the opera theatres realized in Italy during the modern age. The acoustic parameters have been outlined in function of the architectural features characterizing the geometry and the volume shape. A campaign of measurements has been undertaken by using both an omnidirectional microphone, commonly employed in accordance with the standard requirements of the ISO 3382-1, and a multi-channel spherical array microphone, which allowed to render acoustic video-maps and visualize the architectonic components that contributes to determining the reflections.

II. Historical Background

The municipal theater of Piacenza was designed by the architect Lotario Tomba and it was open the first time in 1804 [1]. It is considered the first stable opera house of its region since the artistical shows were at that time conventionally performed inside the biggest saloon of the Duke's palace by building a temporary construction, having the characteristics to be very light and to be erected easily and fast [2].

In 1830 Alessandro Sanquirico, the architect and painter of the Teatro Alla Scala of Milan modified the main elevation by protruding a porch composed of 3 arcades surmounted by a terrace where 4 columns in ionic style support a triangular gable protecting the heraldic coat of arms of the city [3].

Restoration and modernization work also occurred during the history of the theatre. The first and significant intervention was the installation of the electrical system in 1895 [1]. Almost a century later (1976), taking advantage of a general renewal of the safety conditions inside the theatre to comply with the national standards and regulations a long campaign of restoration works took place, including the provision of fire exits and the integration of the fireproof curtain to separate the audience area from the scenic tower [1]. Besides, the consolidation of the wooden beams brought to the creation of a small auditorium having a capacity of 300 seats.

Fig. 1. Perspectival view of the Municipal Theatre of Piacenza.

Throughout the centuries, many painters and artisans completed the indoor finishes of the theatre by adding baroque details such as carvings and gilded wooden decorations [5]. Recently, specifically in 2001, a chandelier composed of 3450 crystal drops and leaves has been introduced, contributing to make the space more elegant and shining other than to improve the scattering effect by spreading the sound energy, as it is visible in Fig. 1.

Nowadays the theatre is considered one of the reference artistical centres in Italy, hosting important personalities and famous artists of the opera, and since 2004 it has been representing the official theatre of the Youth Cherubini Orchestra.

III. Geometrical and Architectural Organization

The shape of the main hall is a 3/4 ellipse, an innovative geometry adopted in place of the traditional "U" shape or the horseshoe box, very popular between the 17th and 19th centuries [1]. Other than following the laws and the rules of the optimum acoustics, the ellipse has been considered a suitable geometry to highlight the aesthetics and the elegance of this place [1].

Fig. 2 shows the longitudinal section and the plan layout having a 3/4 elliptical shape. The ellipse was considered a multifunctional shape, able to follow the rules of acoustics and optics and to keep in the meanwhile the purity and the linearity of the Neoclassicism [4][5].

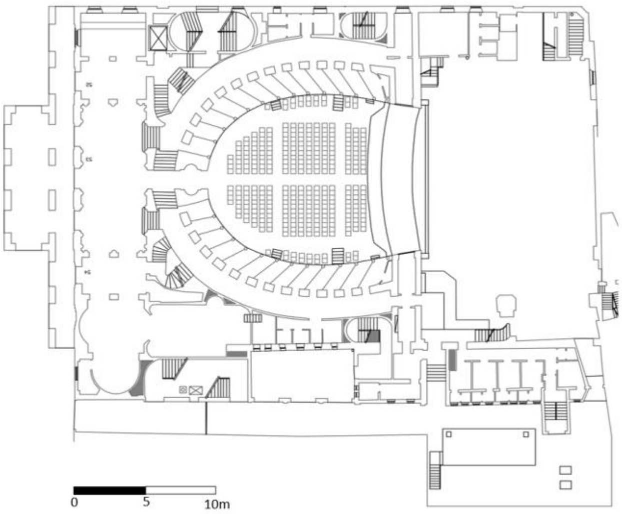

Fig. 2. Plan layout of the Municipal Theatre of Piacenza. Provision courtesy from the Theaters of Piacenza Foundation.

The drawing of the section, as illustrated in Fig. 3, indicates the presence of the orchestra pit, having a maximum width of 3.9 m along the central longitudinal axis. The installation of a mechanical system below the pit floor allows the disposition of two different configurations based on the accomplishment of temporary needs. In particular, the pit floor can be lifted at the same level of the stalls or lower than 0.9 m when Opera is performing. The measurements undertaken for this specific article have been completed with the pit floor raised at the level of the stalls.

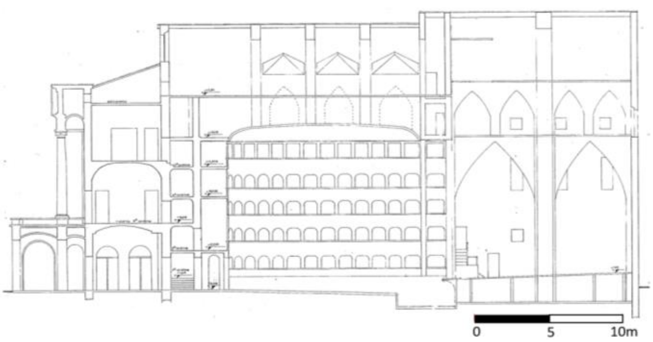

Fig. 3. Longitudinal section of the Municipal Theatre of Piacenza. Provision courtesy from the Theaters of Piacenza Foundation.

The theatre of Piacenza has the stalls separated into two sectors by a corridor running along the longitudinal axis; furthermore, other two transversal corridors were necessary to be in place, corresponding to the direction of the fire exits. The elliptical stall area is coronated by 2 orders of boxes, surmounted by 2 galleries and crowned by a *loggione* [1]. The total capacity is of 1121 seats distributed as 406 in the stalls, 264 on the 2 orders of boxes, 306 in the 2 galleries and 145 in the *loggione*.

The proscenium arch is 13.5m large, while the stage has dimensions of 22.5×15.5 m [L×W] with a wooden floor having an inclination of 5%, slightly more than the floor of the stalls which has a 3% slope [1]. Table 1 summarizes the architectural features inside the theatre.

TABLE I. Architectural characteristics of the Municipal Theatre of Piacenza

Description	Features
Type of plan layout	Ellipse
Total capacity (n. seats)	1121
Inclination of stalls area (%)	3
Inclination of stage (%)	5
Stage dimension (m) [L×W]	22.5 × 15.5
Volume (m^3)	7900

IV. Measurements

An acoustic survey was undertaken inside the theatre to understand the acoustic behavior of the Municipal theatre of Piacenza.

Two different measurement techniques were used, the first, more traditional, intended to measure the monaural and binaural parameters, while the second, more innovative, intended to "capture" all those effects necessary for an acoustic rendering for virtual reality applications.

A. Measurement of monaural and binaural parameters

The objective parameters have been analyzed in line with the standard requirements stated in ISO 3382-1 [6][3]. The acoustic survey was carried out with the following equipment:

- Omnidirectional sound source (Look Line Model 103);
- Microphones:

a) Omnidirectional microphone (Bruel&Kjaer 4189);

b) 32-channel spherical array (Mh Acoustic em32 Eigenmike®);

The sound source was placed at 2 m from the finished floor in the central position (C) of the stage, while the receivers where installed at the height of 1.2 m at three different positions in the stalls (1, 2 and 3) and at one position in the second order of balconies (Box 8) [11]. **Error! Reference source not found.** shows the measurement positions of the sound source and the receivers across the sitting areas.

The excitation signal emitted by the sound source was the Exponential Sine Sweep (ESS) [9] having a duration of 10 s in a uniform sound pressure level for the range between 40 Hz and 20 kHz .

The measurements were undertaken in unoccupied conditions and without any scenery nor acoustic chamber mounted, except the presence of some curtains [10].

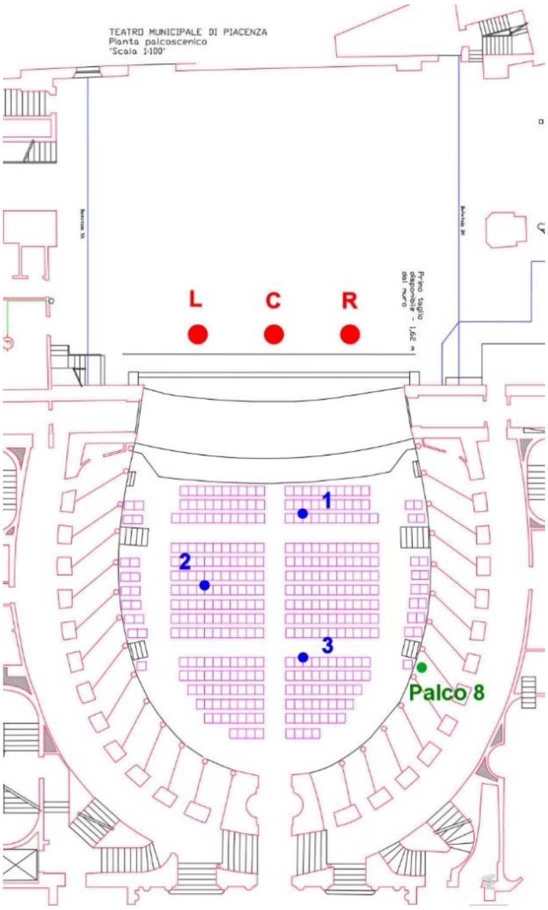

Fig. 4. Source and receiver positions during the acoustical measurements.

B. *MIMO Measurement*

The MIMO measurements are oriented to get high order Ambisonic (HOA) MIMO IR matrices, essential to perform an advanced real-time auralization. One of the applications that it can be used for is having a performer playing or singing live music that can be traceable with an acoustical feedback, audio rendering the virtual performance as it has been done in the real theatre.

The measurements were performed by using the following equipment:

- Prototype spherical array loudspeaker equipped with 32 channels [7][8];
- *32-channel spherical array (Mh Acoustic em32 Eigenmike®);*
- Antelope Audio Orion 32 audio interface with USB and MADI connectivity;
- Amplifier (32 channels, class D);
- Ricoh Theta V 360° cam.
- Personal Computer.

The sound source and microphone array were both connected via MADI interface to the ORION 32, which in turn was connected to the PC via USB interface.

The test signal, the same as in the previous measurements, was played by each of the 32 loudspeakers of the sound source, one at a time.

Measurements were repeated for each of the nine pairs Source (L, C, R) - Receiver (1, 2, 3 and Box 8)

The acquisition of the signals by the spherical microphone array and their subsequent processing allowed the definition of nine HOA MIMO IR matrix to be used in the auralization. Fig. 5 shows the setting of the measurement chain used.

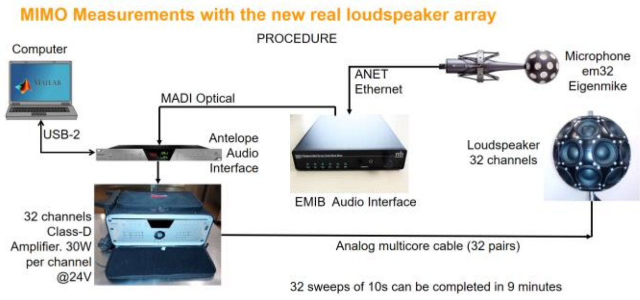

Fig. 5. Setting of the measurement chain.

V. RESULTS

A. *Traditional acoustic parameters*

The recorded RIRs signals have been processed and analyzed by using Aurora, a plugin appropriate for Audition CC [12]. From this type of data processing, the main acoustic parameters have been obtained as defined in the international standards ISO 3382-1 [13][6].

TABLE II. in combination with Fig. 6 to Fig. 9 report, in numerical and graphical form respectively, the main acoustic parameters in the octave bands between 125 Hz and 4 kHz, considered as the average results of all the measurement positions [14].

TABLE II. SUMMARY TABLE OF MEASURED ACOUSTIC PARAMETERS.

Freq. [Hz]	125	250	500	1000	2000	4000
Signal [dB]	80.5	90.1	93.3	92.0	93.4	94.1
Noise [dB]	20.4	17.5	13.8	11.1	8.3	12.4
strenGth [dB]	11.5	21.1	24.3	23.0	24.4	25.1
C50 [dB]	-2.6	0.0	1.2	1.1	-0.2	1.4
C80 [dB]	0.2	2.7	4.4	4.3	3.5	4.8
D50 [%]	35.9	50.3	56.8	56.3	49.1	56.7
ts [ms]	134.1	91.1	65.5	63.8	68.6	56.3
EDT [s]	1.8	1.3	1.0	1.0	1.0	0.9
Tuser [s]	1.9	1.6	1.3	1.1	1.0	1.0
T20 [s]	2.0	1.7	1.3	1.1	1.0	0.9
T30 [s]	2.1	1.8	1.3	1.1	1.0	0.9
Jlf	0.1	0.1	0.1	0.1	0.1	0.1
Jlfc	0.2	0.1	0.1	0.2	0.2	0.2
Lj [dB]	6.8	15.8	18.2	16.8	18.8	19.1

Fig. 6 shows the room impulse response (RIR) in terms of EDT, T_{20} and T_{30} acoustic parameters.

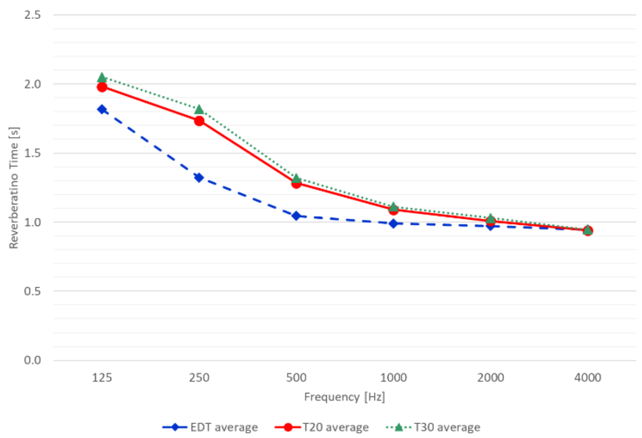

Fig. 6. Measured reverberation time.

The optimal values of EDT, as defined by Jordan [15], have been achieved only at low frequencies. At mid-high frequencies, the EDT is around 1 s, considered slightly lower than the minimum range limit. This result can easily drive to a feeling of a dry ambient.

Based on room volume and measured data, it is possible to see that the parameter T_{20} results slightly below the reference curve of an opera house as it is suggested by Fig. 7, where the optimum values are in function of the T_{20} at 1 kHz and the volume size [16]. This result is considered a compromise suitable for both music and prose performance, as the Opera houses have been designed for.

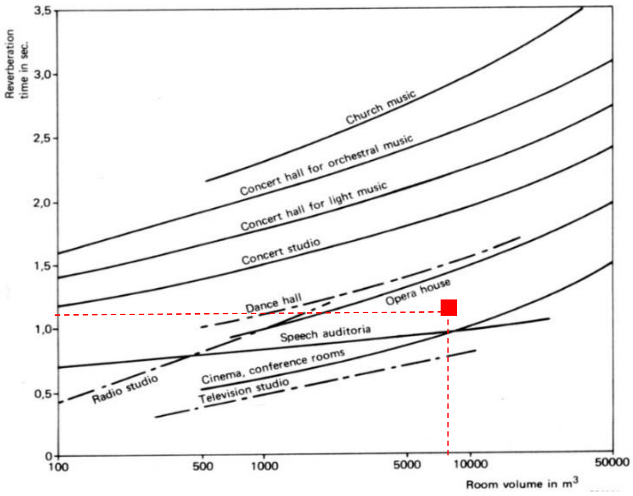

Fig. 7. Optimum reverberation time values in function of room volume.

The results shown in Fig. 8 indicate that the clarity index for speech (C_{50}) is slightly lower than the optimum values; this occurred across all the frequency bands and particularly at low frequencies, as the values do not achieve the target set to be > 3 dB. This could be translated in light difficulties in speech understanding, especially at low frequencies; however, the overall response should not be considered a negative result [17].

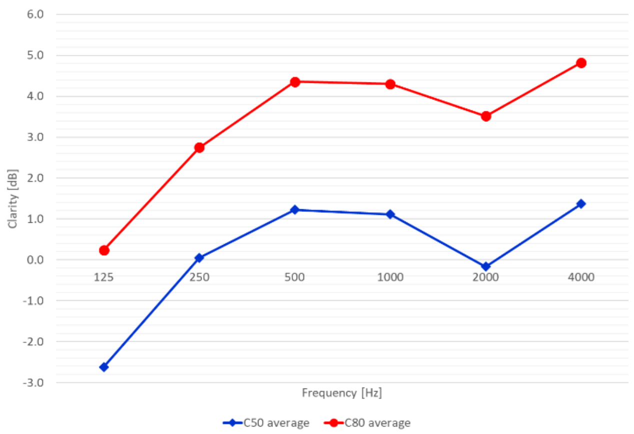

Fig. 8. Measured results of clarity indexes (C_{50} and C_{80}).

In terms of music (C_{80}), the clarity index results moderately higher at mid-high frequencies considering that the values should not exceed 2 dB as the upper range limit. However, the music played inside the theatre can only be perceived as slightly dry, without disrupting the balance of the other parameters [18].

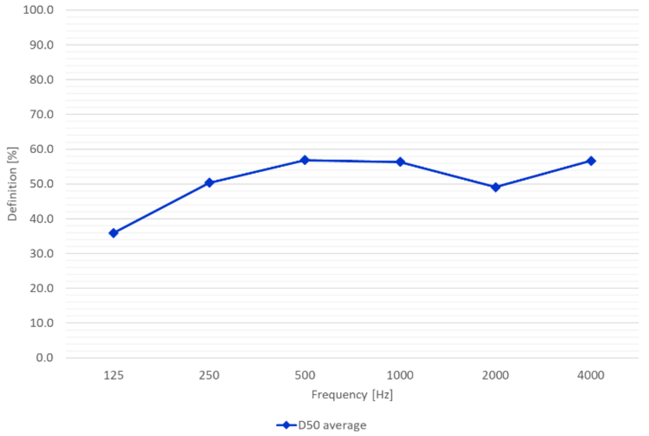

Fig. 9. Measured results of definition (D_{50}).

By literature [19] it has been establish that a good speech definition is achieved for values higher than 0.5 (i.e. 50%), while for a good music definition the values of D_{50} should be lower than 0.5 (i.e. 50%). The results shown in Fig. 9 indicate that the room response is suitable for both speech and musical performance, having an averaged value floating around 0.50 (i.e. 50%).

B. Acoustic analysis of 3D sound maps

The alternative elaboration technique of how to show the acoustics of a room regards the data analysis obtained by a combination of the spherical array loudspeaker and the 32-channel microphone (i.e. em32 Eigenmike®) [20]. Additionally, a 360° camera contributed to visualize all the possible directions where the sound rays captured by the microphone are coming from. The 32 signals have been processed by extracting 122 high directivity virtual microphones with the Spatial PCM Sampling (SPS) encoding [21]. The result is a color map overlay composed of consecutive short frames and showing the beamformed multichannel RIR as a combination of one source-receiver position.

Because the sound pressure levels arriving at the microphone have a different energy, a color scale has been attributed to the contour levels, where the red and warm colors represent the sound waves having more energy and the blue-violet colors characterizing poor sound energy. A panoramic image, realized with a 360° camera, represents the background of the sound energy playback to best visualize the direction of the arrival sound rays.

Examples of such acoustic maps are given in Fig. 10 to Fig. 11, related to the sound source placed in the center of the stage while the receiver is at the last row of the stalls.

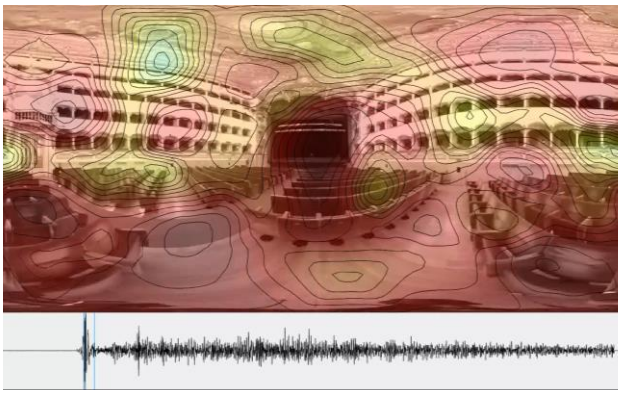

Fig. 10. Acoustical map showing the direct sound arriving at the receiver.

A few captured moments of the RIR inside the Municipal theatre of Piacenza visualize the specific architectural elements that contribute to the early and late reflections through an equirectangular view. Fig. 11 visualizes the early reflections hitting the sidewalls of the main hall and the floor along the central corridor.

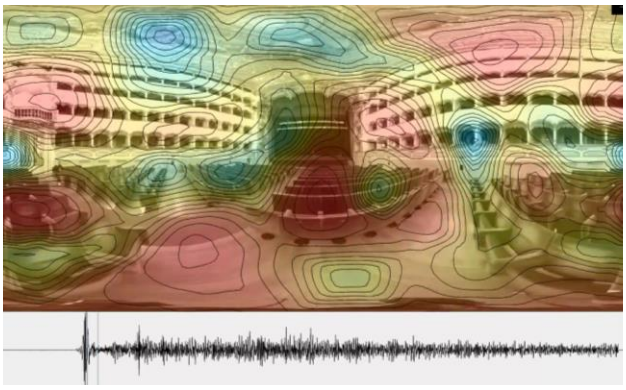

Fig. 11. Acoustical map showing early reflections of the sound energy.

VI. Conclusions

This paper introduces two types of results' representations in relation to the acoustical measurements undertaken inside the Municipal Theatre of Piacenza and conducted in unoccupied conditions. The results show that the acoustical parameters in function of the finishes and volume size are suitable for both music and prose performance. The acoustic analysis that is conventionally undertaken for the determination of the parameters in line with the standard ISO 3382-1, has been extended to the visual study of the direction and intensity of the sound reflections occurring at specific surface area of architectonic and construction elements.

The use of the 32-channel loudspeaker and 32-channel microphone is considered good for tracing sound rays in the frequency range between 63 Hz and 4 kHz, because of its stable flat response. Unfortunately, tests on high frequencies show that above 8 kHz spatial aliasing effects occur, disrupting the spatial control of the sound rays. Future research studies are directed to increase the number of channels (from 32 to 64) for both microphone and loudspeaker in order to widening the effectiveness of the beamforming as well as at high frequencies.

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