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Acoustic discoveries of the Masini theater of Faenza

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***Abstract*—The Italian Opera theatres have been deeply studied throughout the centuries, with a particular attention given by the scholars during the last decades, when the latest generation of technology allow the possibility to investigate such cultural heritage more deeply. The results obtained by the acoustic survey have been analyzed in accordance with the standard requirements referenced for building acoustics. In addition to the standard analysis, an overlay video shows a real-time impulse response (IR) and relative interactions existing between the sound wave and specific construction elements. This supplementary investigation was possible to be realized by using multichannel spherical array equipment, that made it possible to obtain a control upon the sound propagation through the space. The authors of this paper illustrate also a brief history of the Masini theatre, including the description of the architectural features that characterize this important historical building.**

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

I. Introduction

The rapid development of the technologies during the last decades helped researchers to attend complementary studies on the theatres' patrimony, considered part of the cultural heritage to be preserved for the next generations. As such, the necessity to broaden the knowledge of the acoustic response and the architectural characteristics of these performing arts places became of primary importance. The intention of this paper is focused to understand the acoustic behavior of the Masini theatre of Faenza, one of the Opera houses located in northern Italy considered one of the flourishing places where the artistic activities are memorably promoted.

II. Historical Background

The history of the Masini theatre started in 1673, when the Academy of Remoti were used to rehearse and practice their activities inside the main hall of the City Council Palace (Palazzo del Podestà) [1]. In 1714 the Academy promoted the construction of three orders of wooden lodges organized in the same main hall of the palace [1]. The first drawing that can be considered a project was proposed in 1777 by the architect Giuseppe Pistocchi; this project was not considered suitable to be erected given its limited capacity to accommodate a small number of occupants. As such, the architect revised his project with the necessity to demolish some old properties close by the project site. The construction of the new theatre started in 1780 and was completed in 1787 [1].

Fig. 1. View of the main hall from the stage.

The theatre is composed of four orders of balconies surmounted by a gallery, as visible in Fig. 1, located at the perimeter of a horseshoe shaped plan of the stalls, even if the circumference is the main matrix of the geometry [2]. In particular, the corridors, balconies and stalls are inscribed in three concentric circles [2]. Fig. 2 shows a view of the main hall's geometry.

Fig. 2. Perspectival view from the gallery of the stalls area.

The great strike hit by the architect Pistocchi is the articulated composition of the perimeter wall of the stalls. The uniformity of the continuous balconies has been substituted by an architectural distinction of the different orders of boxes [2]. As it is possible to see in Fig. 3, the morphological configuration of the columns marks vertically the boxes. The architectonic refinement also consists of the style variance of the columns, starting from the first order having a simple elegance (Doric style) and passing to the articulated Corinthian capitals [1]. Furthermore, the Corinthian columns have a double height to be related to the second and the third order of boxes. A coronation of grace is shown at the level of the fourth order of balconies, where 18 statues in place of simple columns evoke the Roman decorations set at the level of the *ambulacrum* as to be crowning all the *cavea* [1].

Fig. 3. View of the perimetral boxes of the Masini theatre of Faenza.

The first restoration works happened in 1826 for the occasion a general cleaning of the hall due to the blackening smokes caused by the use of oil lights [3]. In the same time, the local authority proposed to widen the proscenium arch, and to reduce the dimensions of the central box other than the lateral balconies of the proscenium, having double height [1]. That proposal has been denied by the architect Filippo Antolini, who preserved the entire architecture at its original shape and configuration, without any modifications to the historical building. The restoration works been authorized included an overall cleaning, the strengthening of the ceiling, a compensation of some parts of the statues, a renewal of the gilding painting and a remarking of the boxes' walls with a glossy stucco [2].

In 1838 some refurbishment works involved the extension of the porch of the main elevation: the five intercolumns were increased to nine [1]. Other than a small intervention related to the structural consolidation of the theatre, the time comprised between 1850-53 was focused on a second campaign of refurbishment works because of the general decay and precariousness of the theatre. The works directed by the engineer Ignazio Bosi involved the roof raising and widening in order to obtain a room for the preparation of the scenery; this caused a following painting of the ceiling as well as of other decorations [2].

Another intervention was focused on the enlargement of the proscenium, which determined the existing geometry of the plan layout. To achieve this objective, it was necessary the demolition of the proscenium boxes, rebuilt in a rear position, and the demolition of the proscenium arch, substituted with an architrave beam [1]. Fortunately, this latest modification has been deleted in 1869 by the engineer Achille Ubaldini, who restored the original proscenium arch [2].

Further works happened in 1908, related to services and corridors, and during 1940-45 also. But the longest refurbishment works occurred between 1984 and 1990, when safety regulations were applied to the structure by limiting as much as possible the intentional modifications [2]. Appropriate fireproofing measures were applied to the original beams in order to guarantee the minimum standards to be in line with the regulations [1]. In the same occasion, the creation of safety exits did not compromise the original structure given the construction of existing stairs used by the guardian while living in the gallery. The remaking of the finish floor presents the actual materials: wooden planks in the boxes, venetian stucco in the perimetral corridors at all levels, tiles in the gallery. All the service systems (i.e. electrical, heating, etc.) were adapted to the standard requirements.

III. ARCHITECTURAL COMPOSITION AND ORGANIZATION

The Masini theatre is composed of 19 boxes for each order of balconies [4]. In addition, the central balcony and the lateral balconies located at the level of the proscenium arch have a double height and are decorated by statues supporting laurel wreaths [4].

The Masini theatre has a capacity of 190 seats in the stalls and 280 seats on the elevated boxes. Two perpendicular corridors in the stalls area divide the seats in three sectors. The main hall is coronated by a gallery having a capacity of further 50 seats, occasionally occupied [4].

The stage has dimensions of 20 × 12 m [L × W] and the proscenium arch is 10 m large. The architect Pistocchi drew the main hall of the Masini theatre with a plan layout having a horseshoe shape, as shown in Fig. 4.

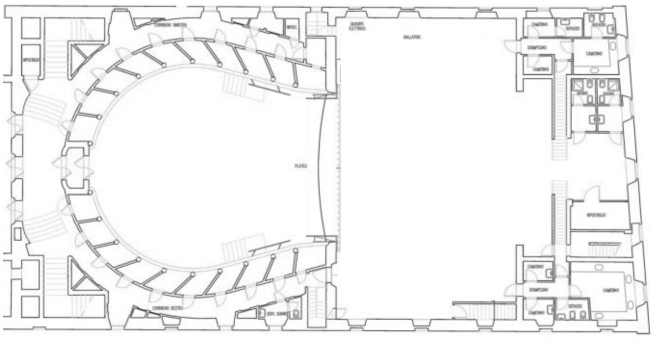

Fig. 4. Plan layout of the Masini theatre of Faenza.

Under architectural perspective, the first order of balconies is composed of columns in Doric style, precisely evoking the temple of Paestum [1]. The parapet of the second order is made up of ceramic panels in a sequence of bas-relief metopes; the subjects represented are taken from the Greek and Roman mythology (e.g. the rape of Europe, the death of Dido, Perseus and Andromeda, Apollo and Daphne, Horatii and Curiatii) [4]. The second and the third orders are framed by double height Corinthian columns supporting the structural beams, while the boxes of the fourth order are separated by statues representing Olympus gods and Muses (e.g. Orpheus, Proserpina, Jupiter, Mars, Cupid, Juno, etc.). The presence of a gallery crowning the balconies is an elegant solution to make slender the ceiling that has a big rosette decoration in the middle. Fig. 5 shows the vertical organization of the Masini theatre of Faenza, highlighting the inclination of the stage floor and of the stalls.

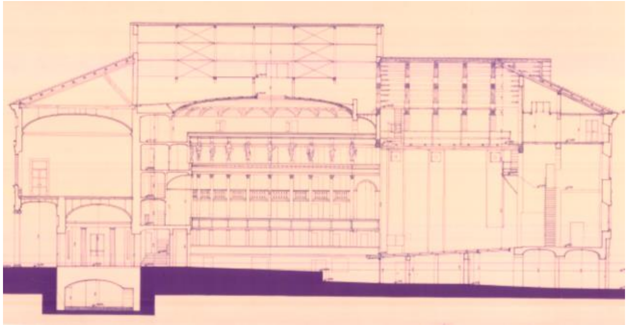

Fig. 5. Longitudinal section of the Masini theatre of Faenza.

TABLE I. summarizes the architectural features of the Masini theatre.

TABLE I. ARCHITECTURAL CHARACTERISTICS OF THE MASINI THEATRE OF FAENZA

Description	Features
Type of plan layout	Horseshoe box
Total volume (m^3)	7090
Total capacity (no. of seats)	520
Stage dimension (m) [L × W]	20 × 12
Inclination of stage floor (%)	7%
Flytower volume (m^3)	4760
Inclination of stalls area (%)	2%
Main hall volume (m^3)	2330
Total volume (m^3)	7090

IV. MEASUREMENTS

An acoustic survey was undertaken inside the theatre to understand the behavior of the existing volume under acoustic perspective. The analysis of the objective parameters has been done in line with the standard requirements outlined in ISO 3382-1 [5]. The acoustic survey was carried out with the following equipment:

- Equalised omnidirectional loudspeaker (Look Line);
- Microphones:
  a) Binaural dummy head (Neumann KU-100);
  b) B-Format (Sennheiser Ambeo);
  c) Omnidirectional microphone (Bruel&Kjaer);
  d) 32-channel spherical array (Mh Acoustic em32 Eigenmike®);
- Personal Computer connected to the loudspeaker and all the receivers.

The sound source was placed at 1.4 m from the finished floor, while the receivers where installed at the height of 1.2 m on stalls and boxes. The excitation signal emitted by the sound source was the Exponential Sine Sweep (ESS) [6] having a duration of 15 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.

Fig. 6 shows the measurement positions of sound source and receivers across the sitting areas.

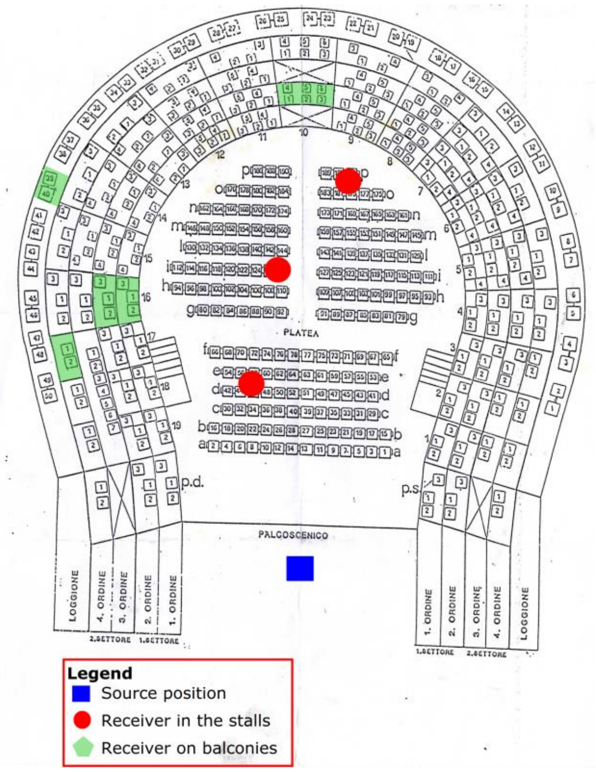

Fig. 6. Scheme of the equipment location during the acoustic measurements in the Masini theatre of Faenza.

V. RESULTS

A. *Traditional parameters*

The recorded ESS signals have been processed by using the plugin Aurora suitable for Audition 3.0 [7]. Different acoustic parameters defined by the international standards ISO 3382-1 have been analyzed [8], like the reverberation time (T_{20}), early decay time (EDT), clarity (C_{50} and C_{80}), definition (D_{50}) to be included. Fig. 7 to Fig. 10 report the main acoustic parameters in the octave bands between 125 Hz and 4 kHz, considered as the average results of all the measurement positions.

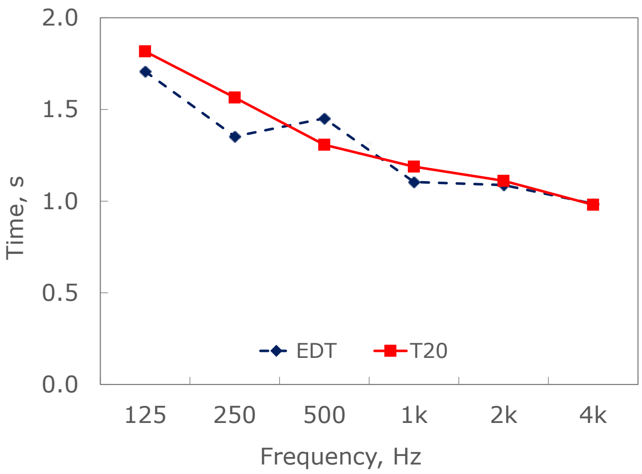

Fig. 7. Measured reverberation time.

Fig. 7 shows the room impulse response (RIR) in terms of EDT and T_{20} acoustic parameters. In particular, both EDT and T_{20} have similar results; the EDT values match the target defined by Jordan [9] only at 125 Hz, if the best range is considered between 1.8 s and 2.6 s. The EDT results at frequencies higher than 125 Hz are found to be below the lower range limit.

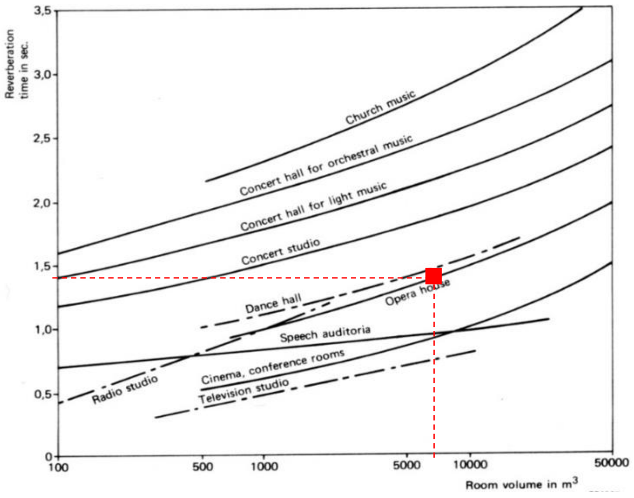

Fig. 8. Optimum reverberation time values in function of room volume.

In terms of reverberation time (T_{20}), the averaged value across all the frequency bands result within the target assigned to an Opera theatre of such volume size [10], as shown in Fig. 8. This means that the Masini theatre of Faenza has a room response suitable for both speech and musical (Opera and symphonic) performance [11].

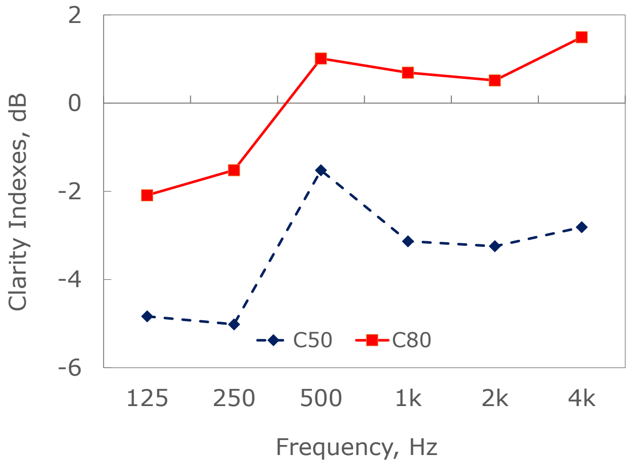

Fig. 9. Measured results of clarity indexes (C_{50} and C_{80}).

The clarity index related to speech (C_{50}) does not match the target of >3 dB, as defined by the literature [12]. This means that the words can be perceived as not clear enough, especially at low frequencies.

In terms of music (C_{80}) the results indicated in Fig. 9 are within the optimum target comprised between -2 dB and +2 dB [12], meaning that the listening to music is perfect inside the Masini theatre.

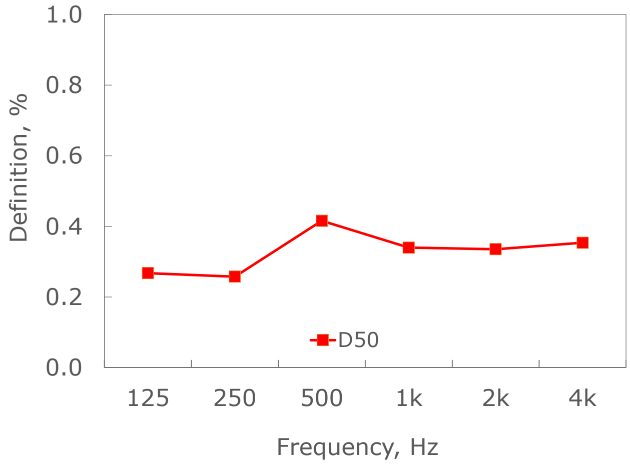

Fig. 10. Measured results of definition (D_{50}).

By literature [13] 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. 10 indicate that the room response is more suitable for musical performance, having an average value of approximately 0.37 (i.e. 37%).

B. Acoustic analysis of 3D sound maps

By taking advantage of the em32 Eigenmike® microphone's capabilities [14], sound immersive maps were obtained for each source-receiver position. Such maps have been elaborated to visualize the architectural elements interacting with the sound waves hitting the boundaries of the room. This outcome is an additional understanding of the trajectories run by the late reflections that have been analyzed in combination with the relative sound intensity.

This different data analysis methodology is obtained by the employment of the last generation of equipment, to be included an omnidirectional sound source, a multichannel microphone (i.e. em32 Eigenmike®) and a panoramic camera.

The 32 microphone signals have been processed by extracting 122 high directivity virtual microphones (with 8^{th} order cardioid setup) encoded by a Spatial PCM Sampling (SPS) [15]; the elaboration of the output sound signal has been overlapped with a 360° image represented in an equirectangular view.

The result obtained by this process is a color map overlay showing the soundwaves arriving at the receiver from all the possible directions based on the spherical array of the microphone. The video has been realized by processing 1024 samples at 48 kHz sampling rate. A convolution of 32 input channels with 32 FIR filters has been found to be necessary to elaborate the matrix obtained by 32 virtual microphone outputs.

The map overlay shows the sound pressure levels represented by contour levels. The color scale is comprised between red colors indicating a high level of energy and blue shades meaning a poor energy sound.

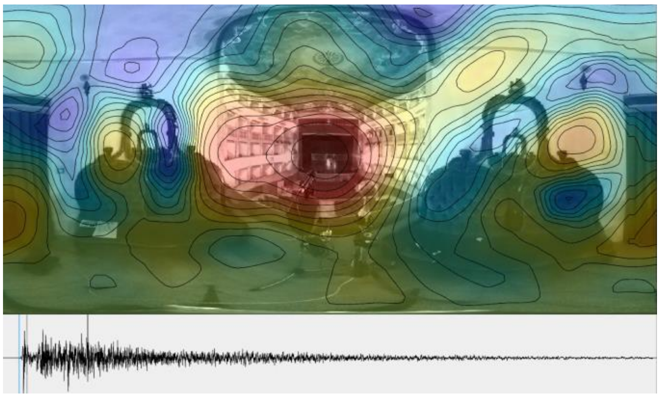

Fig. 11. Acoustical map showing the direct sound arriving at the receiver placed in the centered box of the second level of balconies.

Fig. 11 shows the sound emitted by the source placed in the center of the stage arriving at the receiver placed on the second level of balconies, at the row No. 10. The direct sound is spreading across all the space, arriving frontally to the spherical microphone.

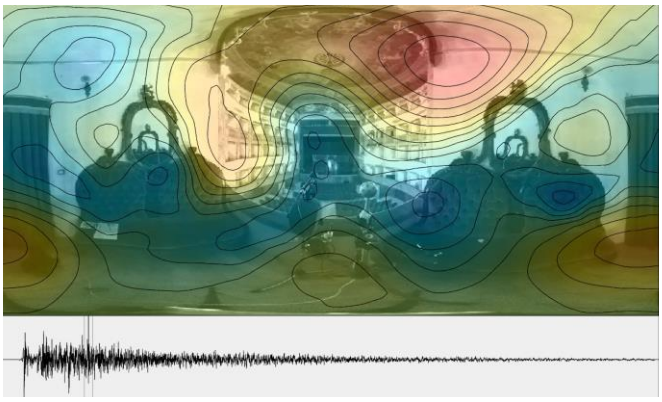

Fig. 12. Acoustical map showing early reflections of the sound energy.

Fig. 12 shows the early reflections hitting the up-right corner of the box's edge. This asymmetry is due to the position of the microphone, closer to the right-hand side wall.

VI. Conclusions

This paper deals with the results obtained by the acoustic survey undertaken in the Masini theatre of Faenza. Measurements based on ISO 3382-1 were conducted in situ in unoccupied conditions by employing an omnidirectional sound source and four types of microphones.

The results obtained from the measurement campaign showed that the Masini theatre is more suitable for musical performance, given the values within the optimum range of target, even if speech and prose presentations are not so far from this objective.

The acoustic study of representing graphs related to the main acoustic parameters has been extended to include also the specific path run by the sound waves. The usage of a multi-channel microphone (i.e. em32 Eigenmike®) allowed the elaboration of 3D sound maps that can be obtained for each source-receiver combination. These maps extrapolated by the overlay indicate the direction of arrival of the sound reflections and their relative intensity, contributing to understanding the specific role of the boundary surfaces of the room interacting with the soundwave.

We suggest that you use a text box to insert a graphic (which is ideally a 300 dpi TIFF or EPS file, with all fonts embedded) because, in an MSW document, this method is somewhat more stable than directly inserting a picture.

To have non-visible rules on your frame, use the MSWord "Format" pull-down menu, select Text Box > Colors and Lines to choose No Fill and No Line.

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