Acoustic response of the Goldoni theater of Bagnacavallo

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***Abstract*—Many Italian Opera theatres have been already studied under acoustic perspective. The fast updates of the innovative technology on the market drive the authors to undertake a deep investigation of the acoustic behavior of the Goldoni theatre. In particular, the results obtained have been analyzed in order to present an overlay video of the impulse response (IR) besides the main acoustic parameters outlined by the standards. The utilization of a multichannel spherical array microphone allowed the realization of this supplementary investigation that give a clearer idea of the sound propagation in such space. This paper also deals with the description of the history and of the architectural features that that characterize the Goldoni theatre.**

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

I. Introduction

The innovation of the spherical array microphones by increasing the number of channels contributed to deepening the acoustic behavior of the historical buildings, especially of those that are protected by heritage associations like Unesco. As such, one of the tasks of the acoustic researchers is to share the outcomes given by the employment of such technologies and the advancements gained in that specific field. This paper deals with the history of the Goldoni theatre of Bagnacavallo and the representation of both acoustic parameters and direction of arrival of sound rays during the recorded impulse response (IR). The intention of the authors is not to substitute the standard methodology with the innovative approach, but to add a value to the requirements outlined by regulations by pulling over an alternative procedure of representation.

II. Historical Background

Since 1648 in Bagnacavallo a wooden structure used for the audience of the theatrical shows inside the Abbondanza Palace had been functioning [1]. The existence of this temporary structure is documented in one of the meetings verbalized by the city council. Additionally, in 1791 Filippo Bibiena was assigned to paint a scenery in order to show some marine characters [2]. The decision of dedicating a proper space to the theatre has been taken in 1796, when the city council bought the Brandolini palace to be dedicated to a public theatre because a fire started from the adjacent wheat storage destroyed all the wooden structure. The new project has been assigned to the architect Cosimo Morelli [1].

In 1839 the city council authorized the architect Filippo Antolini for construction of a new arched porch on the main elevation. The porch realized by Antolini dominates the main square of the town, having five arches framed by columns in Ionic style [3]. In correspondence of the arches, five windows have been opened and surmounted by shelves on the horizontal architraves. Given the good result, the architect Antolini replaced Morelli even for the realization of the theatre [2].

Antolini lead the building works until 1845, when the theatre opened with the first show (i.e. Ernani) composed by G. Verdi. The theatre was dedicated to Carlo Goldoni in 1907 in memory of the famous playwriter whose father was an illustrious doctor in Bagnacavallo [3].

The decorations of the interior design have been undertaken by Francesco Migliari, in particular the paintings on the continuous balustrades of the balconies at different orders other than the vault of the main hall [1]. Such decorations on the stuccos realized by Antonio Tognetti highlight a certain linearity of the space created by the horizontal white strips of the balustrades in contrast with the red colors of the curtains [3]. The vault having an umbrella shape recalls all the colors used on the architectural elements of the main hall, having red shades just above the arcades of the top gallery then transformed to the green and golden geometrical design [2]. At the center of the vault the oval representation has been decorated with white colors, from which a great chandelier lights all the volume.

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

At the sides of the proscenium arch medallions have been realized by carving the wood, representing the citizens of Bagnacavallo that have mainly contributed to the development of culture and arts [2].

The theatre is composed of three orders of balconies surmounted by a gallery, as visible in Fig. 1, located at the perimeter of a horseshoe shaped plan of the stalls.

The first restoration works happened in 1920's and after the World War II. In 1986-87 some refurbishment works

involved the structural solidity of the wooden partitions other than the creation of the fire exits in line with the safety regulations [1].

Most of the scenery have been destroyed for the occasion of the restoration works, and some machineries are in precarious conditions, like the drums used to create the thunder and the rain noise, as well as the machineries used to the movement of the curtain separating the stage from the audience areas [2].

Nowadays the theatre is florid of artistical performance program, managed by the *Accademia Perduta Romagna Teatro* that promotes shows in relation to prose and musical concerts [3].

III. Architectural composition and Organization

The Goldoni theatre is composed of 17 boxes for each order of balconies with the exception of the first order having the main door instead of the central box[3]. The three orders of balconies are marked by continuous balustrades and by the partitions of the boxes that vertically move the repetition of the modules; the top gallery (*loggione*) is characterized by semicircular arches.

The Goldoni theatre has a total capacity of 373 seats, with 112 in the stalls and 261 seats on the elevated boxes [2]. A corridor in the stalls area running along the main axis divides the seats in two sectors. The main hall is coronated by a top gallery (*loggione*) where the junction to the ceiling has the shape of an umbrella [1].

The stage has dimensions of 19.2 × 13.7 m [L × W] and the proscenium arch is 9 m large. The architect Antolini drew the main hall of the Goldoni theatre with a plan layout having a horseshoe shape, as shown in Fig. 2.

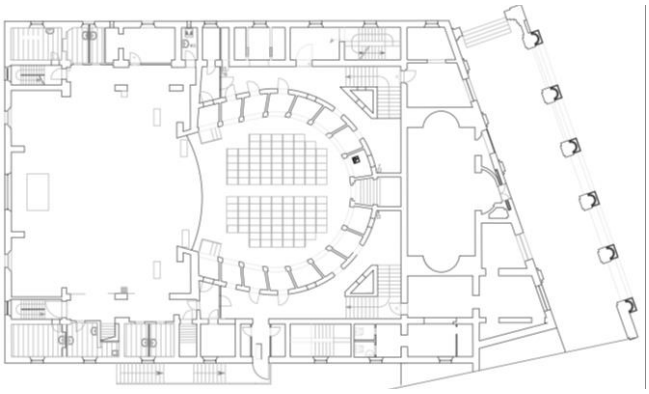

Fig. 2. Plan layout of the Goldoni theatre of Bagnacavallo.

Table 1 summarizes the architectural features of the Goldoni theatre.

TABLE I. Architectural characteristics of the Goldoni theatre of Bagnacavallo

Description	Features
Type of plan layout	Horseshoe box
Total capacity (no. of seats)	373
Stage dimension (m) [L × W]	19.2 × 13.7
Inclination of stage floor (%)	5%
Flytower volume (m^3)	3200
Main hall volume (m^3)	1400
Total volume (m^3)	4600

IV. Measurements

An acoustic survey inside the theatre has been undertaken 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 [4]. 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 the height of 1.4 m from the finished floor, while the receivers where 1.2 m high. The excitation signal emitted by the sound source was the Exponential Sine Sweep (ESS) [5] 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. 3 shows the measurement positions of sound source and receivers across the sitting areas.

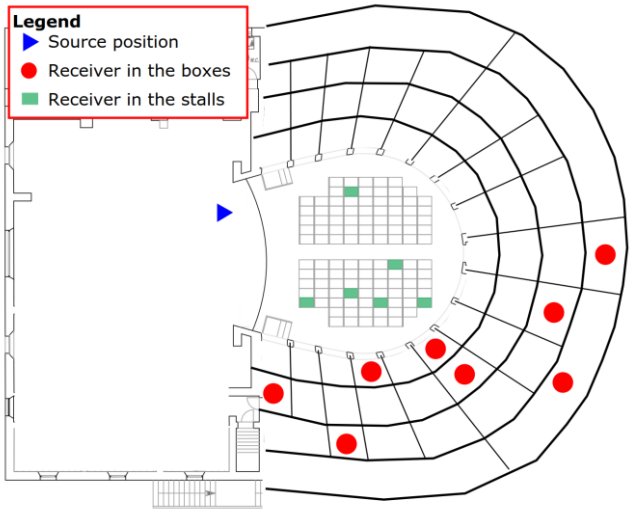

Fig. 3. Scheme of the equipment location during the acoustic measurements in the Goldoni theatre of Bagnacavallo.

V. Results

A. Traditional parameters

The recorded ESS signals have been processed by using the plugin Aurora suitable for Audition 3.0 [6][6]. Different acoustic parameters outlined by the international standards ISO 3382-1 have been analyzed [7][7]: the reverberation time

(T_{20}), early decay time (EDT), clarity indexes (C_{50} and C_{80}) and definition (D_{50}) to cite some. Fig. 4 to Fig. 7 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.

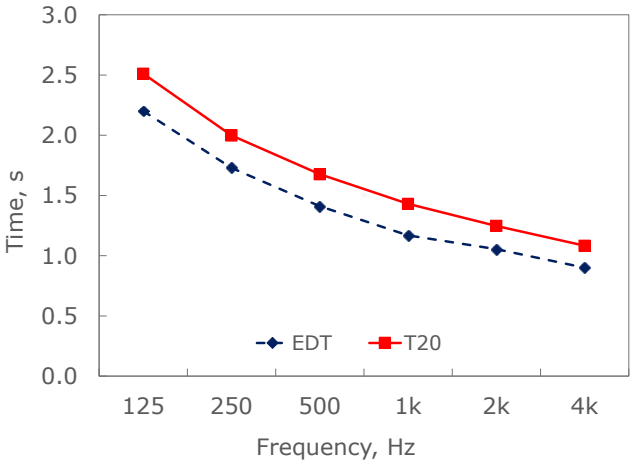

Fig. 4. Measured reverberation time.

Fig. 4 shows the results obtained by the room impulse response (RIR) in terms of EDT and T_{20}. In particular, both EDT and T_{20} have similar trends; the EDT values match the target defined by Jordan [8][8] only at low frequencies, if the best range is comprised between 1.8 s and 2.6 s. The EDT values at frequencies higher than 500 Hz are found to be below the lower range limit.

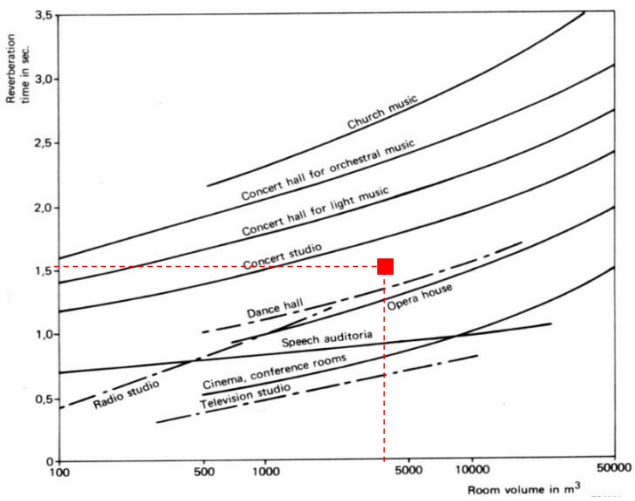

Fig. 5. Optimum reverberation time values in function of room volume.

In terms of reverberation time (T_{20}), the averaged value across all the frequency bands has been found to be within the reference curves assigned to an Opera theatre of such volume size [9], as shown in Fig. 5Fig. 5. Therefore, the Goldoni theatre of Bagnacavallo can be considered suitable for both speech and musical (Opera and symphonic) performance [10][10].

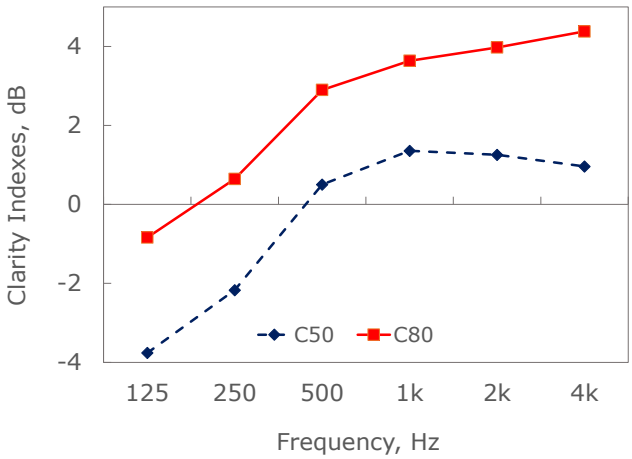

Fig. 6. Measured results of clarity indexes (C_{50} and C_{80}).

The clarity index related to speech (C_{50}) does not match the target defined by the literature (i.e. > 3 dB) [11]. Therefore, the words can be perceived slightly unclear, especially at 125 Hz and 250 Hz.

The clarity index related to music (C_{80}) results at low frequencies within the optimum target of -2 dB and +2 dB [11] but from 500 Hz onwards it is up to 2.5 dB above the upper range limit.

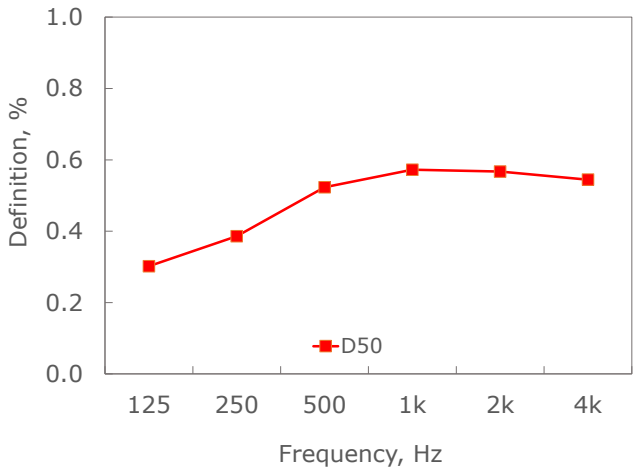

Fig. 7. Measured results of definition (D_{50}).

By literature [12] it has been established that a good speech definition can be achieved for values higher than 0.5 (i.e. 50%), while a good music definition should have values of D_{50} lower than 0.5 (i.e. 50%). The results of the acoustic definition shown in Fig. 7Fig. 7 indicate that the averaged value fluctuates around 0.5 (i.e. 50%), meaning that the Goldoni theatre is good for both prose and musical performance.

B. Acoustic analysis of 3D sound maps

The utilization of a spherical array microphone (i.e. em32 Eigenmike®) [13] allows the capabilities of creating such data elaboration able to understand the direction of arrival of the sound rays. The video-overlay, realized for each source-receiver position, gives the possibility to visualize the architectural elements interacting with the sound waves after hitting the boundaries of the room.

The combination of a multi-channel microphone with an omnidirectional sound source and a panoramic camera made

the outcome previously described to be possible. In particular, the 32 signals recorded by the microphones have been processed by extracting 122 high directivity virtual microphones (with 8th order cardioid setup). These were then encoded by a Spatial PCM Sampling (SPS) [14] and elaborated in order to have a 360° image represented video as the output data, given by the convolution of 32 input channels with 32 FIR filters.

The map overlay shows the sound pressure levels represented by contour levels in front of an equirectangular 360° image placed on background. The color scale refers to red colors for high levels of energy and to blue shades for low levels of sound energy.

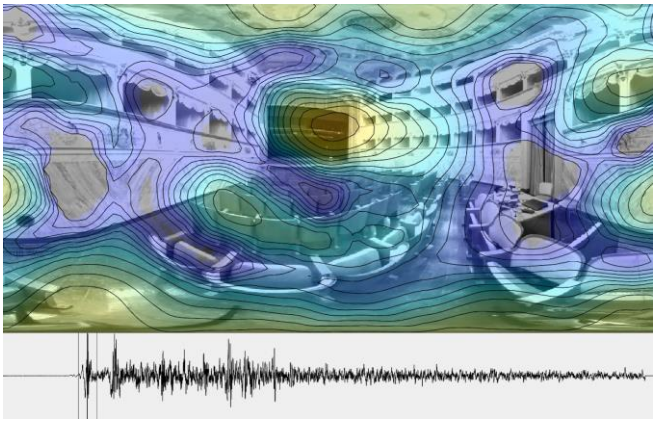

Fig. 8. Acoustical map showing the direct sound emitted on the stage and arriving to the receiver.

Fig. 8 shows the sound emitted by the source placed on the right side of the stage and arriving to the receiver placed on the last row of the stalls.

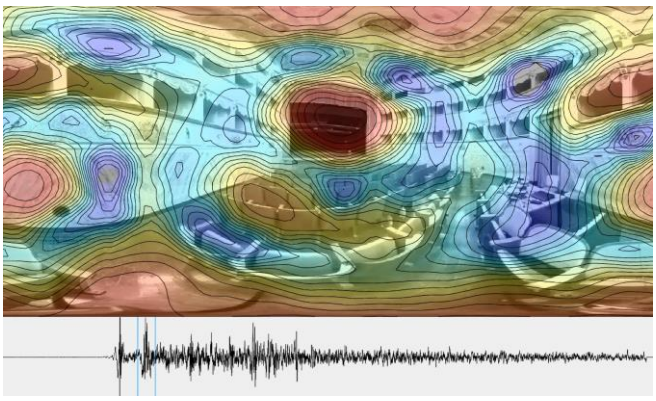

Fig. 9. Acoustical map showing the strong early reflections of the sound energy hitting the ceiling.

Fig. 9Fig. 9 shows the strong early reflections hitting the ceiling and the back wall of the main hall, as the red colors indicate.

VI. Conclusions

This paper deals with the results obtained by the acoustic survey undertaken in the Goldoni theatre of Bagnacavallo. Measurements were conducted in unoccupied conditions by employing an omnidirectional sound source and four types of microphones.

Overall, the results show that the Goldoni theatre has an acoustic behavior suitable for both musical and prose performance. This outcome has been represented by the graphs of the main acoustic parameters.

An extended acoustic study included also the specific direction run by the sound waves. The utilization of a multi-channel spherical array microphone (i.e. em32 Eigenmike®) allowed the elaboration of 3D maps that can be obtained for each source-receiver combination. An example herein introduced is given by some screen shots of the overlay video, where the acoustic contour levels and their relative sound intensity are overlapped to the 360° image represented in equirectangular format.

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