Sound quality of the Valli theatre: Standard outcomes and development of data presentation

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Sound quality of the Valli theatre: standard outcomes and development of data presentation

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***Abstract*— The attention by the scholars to study the Italian Opera theatres should not be stopped to the acoustic characteristics by showing the graphs related to the parameters as required by standard regulations. The development of the technology allows the employment of specific equipment capable to explore the cultural heritage more deeply. The outcomes obtained by the acoustic survey undertaken inside the Valli theatre of Reggio Emilia have been analyzed in two ways: the first methodology shows the data in line with the standard requirements indicated by ISO 3382-1; the second methodology shows a real-time impulse response (IR) highlighting specific construction elements that contribute to generate early or late reflections. The utilization of a spherical array microphone allows a full control of the spatial propagation of the sound waves. The authors are delighted to also introduce a brief history of the Valli theatre of Reggio Emilia, including the description of the architectural features that characterize this important Opera house.**

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

I. Introduction

The architectural patrimony of the cultural heritage has always been subject to acoustic studies throughout the centuries. However, the rapid development of technologies occurred in the last decades had the effect of broaden the knowledge on the acoustic response of the rooms. This paper deals with the acoustic behavior of the Valli theatre of Reggio Emilia. The results of the survey are herein shown based on the classical representation of the graphs related to the acoustic parameters and on the overlay video screen shots, highlighting the architectural components hit by the sound waves that mainly contribute to the early and late reflections.

II. Historical Background

During the night between 21st and 22nd of April 1851, a fire destroyed the Cittadella theatre, a building born in 1741 in the area where the Ariosto theatre stands actually [1]. When such architecture dedicated for the artistical performance became lost, the citizens organized themselves in finding an alternative structure where the shows could continue, but none of the existing buildings were suitable for that purpose [1]. As such, the Mayor Ghirardini wrote a letter to the Municipal Council asking about the reconstruction of the fired building to be undertaken as a priority [2]. The architect chosen to design the project of a new theatre was Cesare Costa, who suggested an alternative place where the new theatre should be erected because the reconstruction of the old one would be expensive, not in line with the safety regulations and uncomfortable for the narrow volume [2].

The works started in 1852 but the necessity of more funding brought to the idea of selling the boxes, that had been bought by aristocrats and nobles, other than professionals belonging to the middle class [2]. Many of the buildings adjacent to the project site were demolished in order to obtain materials useful for the erection of the new construction [2].

For this theatre, the lighting system supplied by gas (not composed of candles, instead) was considered an innovation for that time [3].

The curtain separating the stage from the main halls was realized in 1857 and painted by Alfonso Chierici [3]. The architectonic decorations of the audience area and the proscenium arch were realized by Girolamo Magnani, who had similar experience in the Regio theatre of Parma. The theatre opened officially in 1857 and was called *Comunicativo* [3]. The management of the artists and the shows was taken by private companies until 1957, when the City Council decided to acquire all the cultural activity of the town. Ballets and operas were alternatively promoted by the new administration and accepted by the citizens [2].

For the occasion of the death of a popular actor, the City Council decided to dedicate the theatre to Romolo Valli, which has been the official name of the theatre since 1980 [2].

III. Architectural Organization

The Valli theatre has a total capacity of 1122 seats distributed as 414 in the stalls and 520 on the elevated boxes. The stalls are separated by perpendicular corridors running along the main axes and coronated by four orders of balconies, surmounted by a gallery having a capacity of further 180 seats occasionally occupied, as shown in Fig. 1.

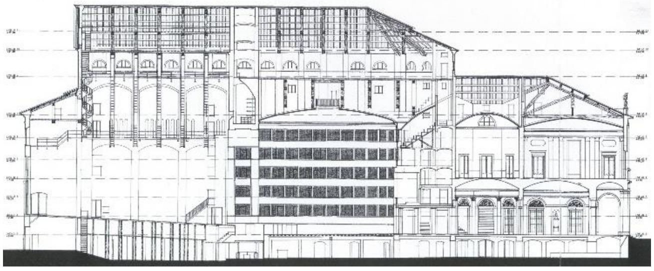

Fig. 1. Longitudinal section of the Valli theatre of Reggio Emilia.

The royal box is located at the center of the second and third order. The ceiling of the main hall is composed of eight medallions painted by Domenico Pellizzi, which represent the glory of the Italian theatre (e.g. melodrama, tragedy, comedy, etc.) [3]. Fig. 2 shows the interior design of the main hall.

Fig. 2. View of the main hall of the Valli theatre of Reggio Emilia.

Flourishing decoration are installed all around the main hall; in particular, there is a chandelier composed of 72 crystals, being 3.75 m high and having a diameter of 3.05 m.

The stage has dimensions of 20.5 × 31.2 m [L × W] and the proscenium arch 14 m large and 22.5 m high. The wooden planks of the stage are inclined of 5%, against the 2% of the stalls floor. The orchestra pit is 2.09 m high and 5.9 m deep, with 2.07 m of its depth located below the stage floor, as shown in Fig. 3.

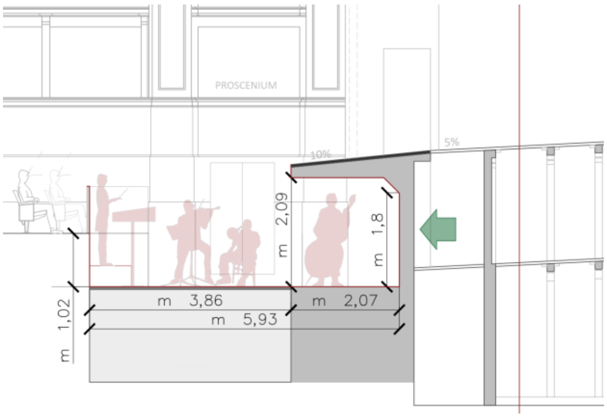

Fig. 3. Transversal section of the orchestra pit of the Valli theatre.

The Valli theatre has a horseshoe shape plan layout, as visible in Fig. 4, where the geometry of the performance space and the audience area is herein indicated.

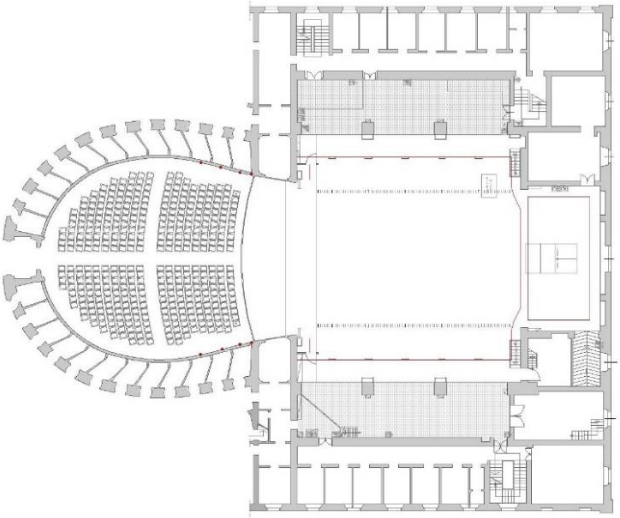

Fig. 4. Plan layout of the Valli theatre of Reggio Emilia.

Table 1 summarizes the architectural features of the Valli theatre.

TABLE I. ARCHITECTURAL CHARACTERISTICS OF THE VALLI THEATRE OF REGGIO EMILIA

Description	**Features**
Type of plan layout	Horseshoe box
Total volume (m^3)	31480
Total capacity (no. of seats)	1122
Stage dimension (m) [L × W]	20.5 × 31.2
Inclination of stage floor (%)	5%
Inclination of stalls area (%)	2%

IV. MEASUREMENTS

Acoustic measurements have been undertaken inside the Valli theatre to understand the acoustic response based on the objective parameters in line with the standard requirements as stated in ISO 3382-1 [4]. During the surveys, thermo-hygrometric conditions were taken in consideration [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. 5 shows the measurement positions of sound source and receivers across the sitting areas.

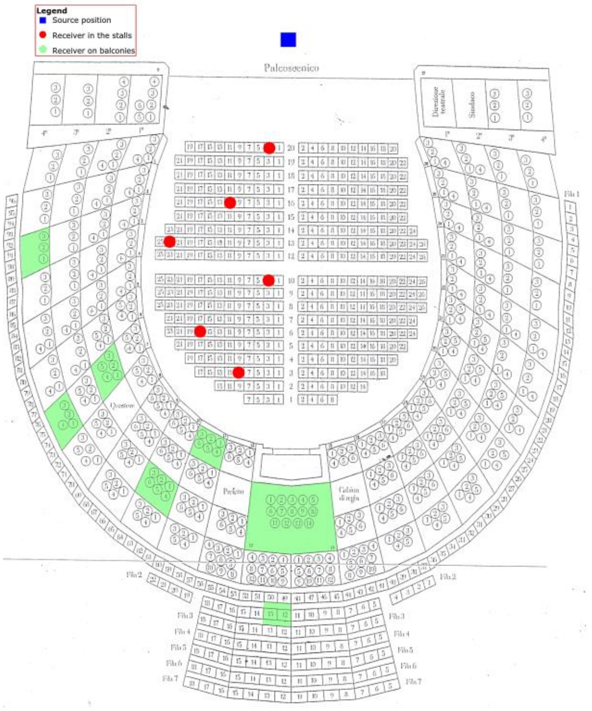

Fig. 5. Scheme of the equipment location during the acoustic measurements in the Valli theatre of Reggio Emilia.

V. RESULTS

A. *Traditional parameters*

The recorded ESS signals have been processed by using the plugin Aurora [7][8] suitable for Audition 3.0 [9]. Different acoustic parameters outlined by the international standards ISO 3382-1 have been analyzed, including the reverberation time (T_{20}), early decay time (EDT), clarity indexes (C_{80} and C_{50}), the definition (D_{50}), and strength (G) [4].

Fig. 6 to 9 show the main acoustic parameters in the octave bands between 125 Hz and 8 kHz, considered as the average results of all the measurement positions.

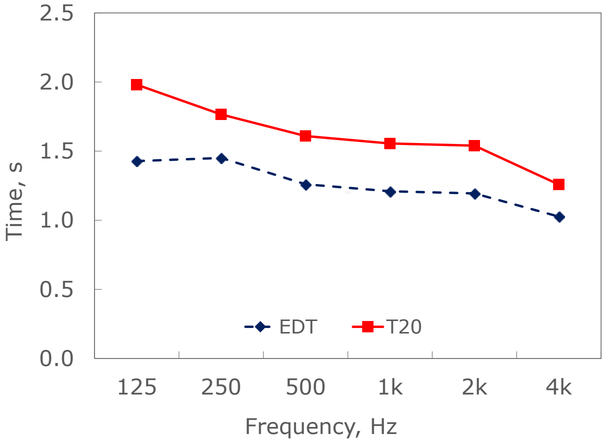

Fig. 6. Measured results of Early Decay Time (EDT) and Reverberation Time (T_{20}).

Fig. 6 shows the frequency response of the EDT and T_{20} parameters. If it is considered that the optimal values of EDT range between 1.8 and 2.6 s, as defined by Jordan [10], this target has not been achieved by the measured values related to the selected bandwidth.

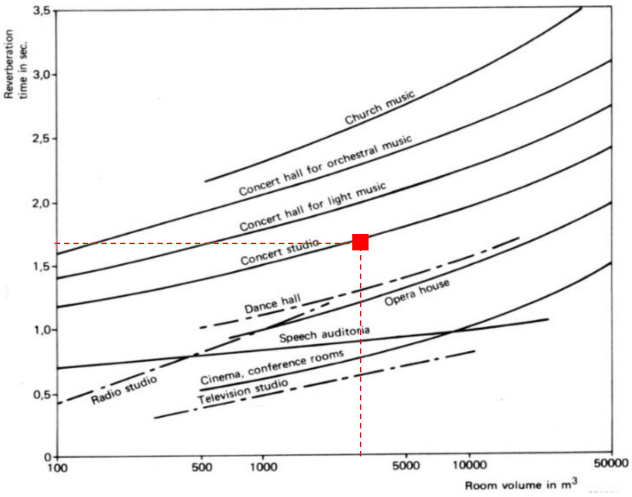

Fig. 7. Optimum reverberation time values in function of room volume.

In terms of reverberation time (T_{20}) the averaged value of all the frequency bands result within the target assigned to an Opera house of such volume size [11], as shown in Fig. 7. This means that the Valli theatre has a good response for both speech and music performance.

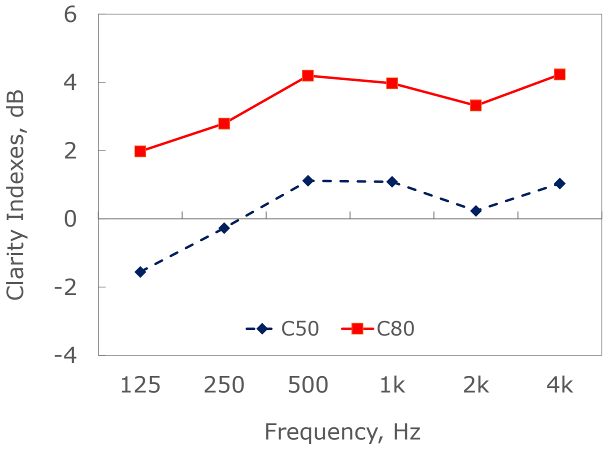

Fig. 8. Measured results of clarity indexes (C_{50} and C_{80}).

Following the research studies by Reichardt [12], the optimum values for speech clarity index (C_{50}) would be ≥ 3 dB. In the Valli theatre this parameter floats between -2 and +2 dB, at low and high frequency bands, respectively. However, this shortfall, as shown in Fig. 8, slightly below the lowest range limit is not to be intended as a negative result. In this case, the listening perception of speech finds a balance between the sound energy arriving within the 50 ms and the reflections coming after 50 ms.

In terms of music (C_{80}), the optimum values should be comprised between -2 and +2 dB, according with Jordan [11]. This target has been achieved only at 125 Hz, where the values is equal to +2 dB, while the values related to the other frequency bands are up to 2 dB higher than this latest one. Translated in other words, this outcome means that the music would be very clear, especially at high frequencies.

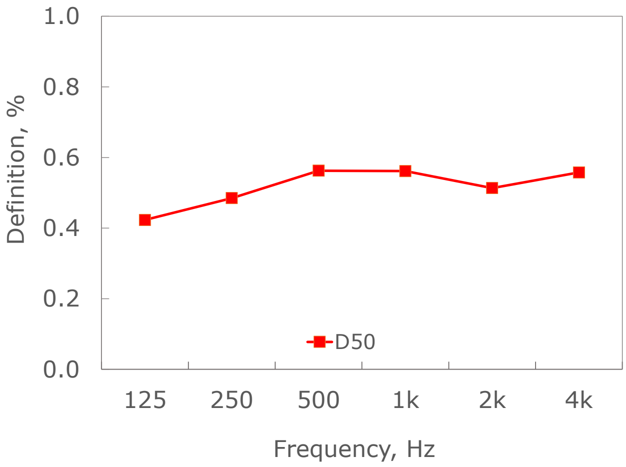

Fig. 9. Measured results of Definition (D_{50}).

A good speech definition is achieved for values higher than 0.5 (i.e. 50%), while the optimum values for music definition are lower than 0.5 (i.e. 50%) [13]. On this basis, the results obtained in the Valli theatre, as indicated in Fig. 9, are found to be around 0.5, meaning that the listening conditions are suitable for both speech and music.

In terms of strength (G) Fig. 10 shows the energy response obtained by the main hall of the Valli theatre.

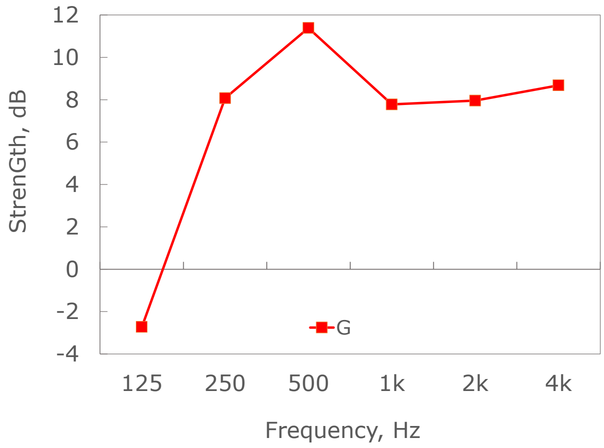

Fig. 10. Measured results of strength (G).

In particular, the best strength is obtained at mid-high frequencies range while it results weak at 125 Hz. This means that listeners have light difficulties in hearing a *fortissimo* for bass sounds [14]. As such, the players (especially singers) should put more effort in obtaining a good performance at low frequencies.

B. *Acoustic analysis of 3D sound maps*

The employment of the em32 Eigenmike® microphone during the acoustic survey allowed the authors to analyze sound maps based on the 3 degree of freedom (3dof) [17]. These maps, herein introduced as a result of video screen shots, are useful to understand the role played by the architectural and construction elements interacting with the sound waves, showing the direction of arrival of the sound reflections and their relative sound intensity.

This different approach has been possible because of the combined utilization of an omnidirectional sound source, a multichannel microphone (i.e. em32 Eigenmike®) and a panoramic camera shooting 360° images, as represented in equirectangular views. The 32 signals recorded by the spherical array microphone have been processed by extracting 122 high directivity virtual microphones with the addition of a Spatial PCM Sampling (SPS) encoding that spread the directions of arrival uniformly distributed in the space.

A color map overlay represents the data output of this process, where the soundwaves arriving at the receiver are shown to be from all the possible spherical directions. The video has been realized by processing 1024 samples at 48 kHz sampling rate. Thereafter, the elaboration of the matrix has been undertaken by using a convolution of the 32 input channels with the 32 FIR filters. At a final stage, a VST plugin (i.e. X-volver) was employed to facilitate the massive operation.

The map overlay shows the sound pressure levels received by the microphone and showing different energy in relation to the reflections with the architecture. A color scale has been setup to be between a red tinge (indicating a high level of energy) and violet shades (standing for a poor energy sound waves). Fig. 11 shows an illustration of the outcomes.

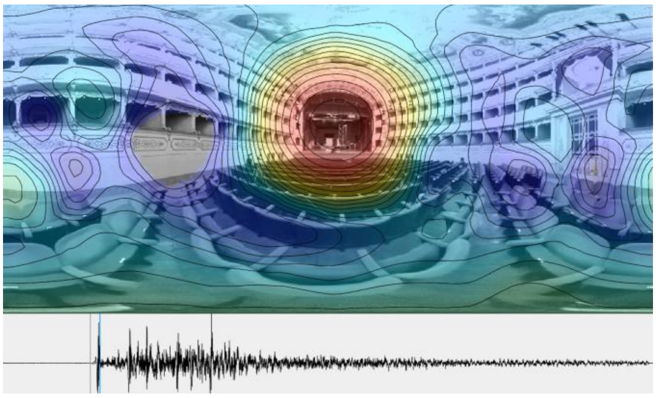

Fig. 11. Acoustical map showing the direct sound arriving at the receiver placed in the stalls.

The following shot indicated in Fig. 12 shows the early reflections hitting the side walls. As per above discussion, the overlay videoclip allows to visualize the architectural component contributing to the early and late reflections, based on the impulse response flowing in the bar at the bottom of the image.

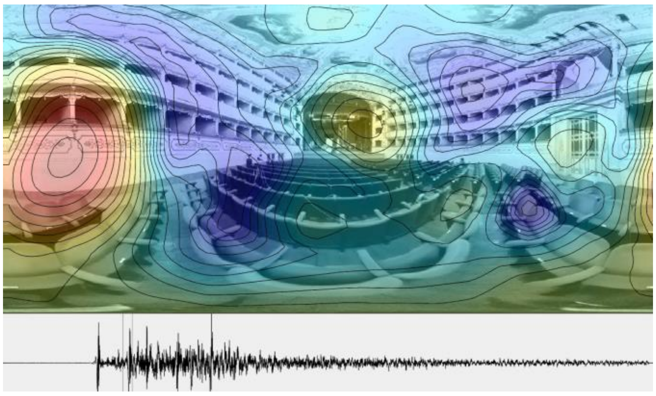

Fig. 12. Acoustical map showing the early reflections hitting the side wall.

Similarly, Fig. 13 shows the late reflections hitting the ceiling surface area.

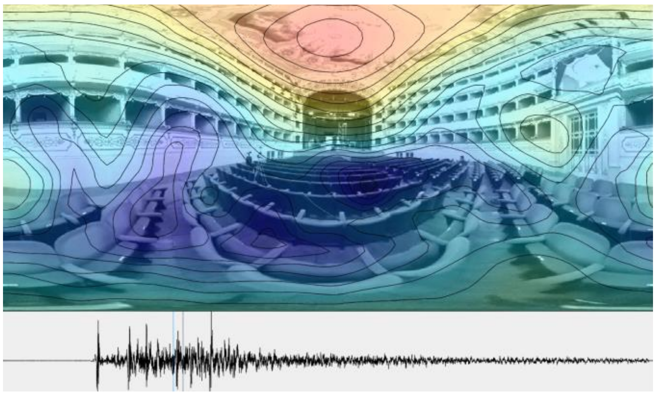

Fig. 13. Acoustical map showing the late reflections hitting the ceiling.

VI. CONCLUSIONS

This paper illustrates the results of the acoustic survey undertaken in the Valli Opera theatre of Reggio Emilia. The measurements were conducted by testing spherical arrays of a microphone and of a loudspeaker.

Overall, the results obtained from the measurement campaign showed that the theatre has a good response for both speech and music performance, with some difficulties at low frequencies in terms of strength that require the singers to put more effort at the bass tones.

This study has been extended to analyze the direction of arrival of the sound waves. By employing a multi-channel microphone (i.e. em32 Eigenmike®), 3D sound maps have been processed in order to show the direction of arrival and the intensity of the sound rays after hit the boundaries of the room. In this way it was possible to understanding which of the architectural features strongly interacts with the sound emitted by the loudspeaker during the IR.

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