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Verdi theatre of Salerno: a deepening acoustic research

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Abstract— The Verdi theatre of Salerno is one of the Italian Opera theatres by having the horseshoe shape of the plan layout. This paper deals with the illustration of the acoustic measurements undertaken inside the main hall by graphs representation according to ISO 3382-1 as a basic evaluation. In addition, some shots extrapolated from the video of the impulse response (IR) are herein introduced to complete and deepening the acoustic study and also to show an alternative way of representation that can help the soundwaves tracing, in terms of directivity. The use of a multichannel spherical array microphone was of paramount importance for the spatial control of the wavefront propagation.

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

I. INTRODUCTION

The theatre of Salerno has been dedicated to Verdi composer at the threshold of the 20th century (i.e. 1901). This theatre represents another example of horseshoe box performing arts spaces disseminated in Italy, given the culture of considering this shape as the best in combining the acoustics with the optimal view for the audience.

The last decades of research studies have been focused on the convergence between sound field and image-view in order to achieve the virtual reality of the immersive environments. This process has been developed rapidly due to the evolution of both equipment and, consequently, methodology applied on. The multichannel spherical array microphone is the core of the analysis process focused on the localization of the sound source playing inside any geometry of a space. As such, a video representing the directional of arrival of the sound rays are herein introduced besides the acoustic analysis of the main parameters in line with the current standards and regulations.

II. HISTORICAL BACKGROUND

The necessity of building a new theatre in Salerno have been rising since 1843 when the supervisor of the county proposed two available sites: one in *Largo St Teresa* on the west side of the city, and the other one in *Largo della barriera fuori Porta*, on the opposite side [1].

For twenty years different causes slowed down the process of the established erection, including the availability of the financial resources and the choice of one of the sites [2]. A new debate on the matter rised after the dissolution of the Italian Kingdom [2]. In this occasion, the construction of a Municipal theatre has been proposed again by the local authority in 1863, in particular by the mayor M. Luciani. The winning project, where the theatre should be located in the site of St Teresa, was owned by the architects A. D'Amora and G. Manichini, who took the St Carlo theatre of Naples as the representative model [3].

The structure was finished in 1869, after that all the decorations could complete the building, which were led by the painter G. D'Agostino, who supported the Neoclassic style on the main elevation of the hall [3]. The interior design was inspired by Piermarini for the La Scala theatre of Milan and by Piccolini, but the main objective was to make the Verdi theatre as a temple of music [1]. The decoration of the curtain separating the stage from the hall represents the expulsion of the Saracens from Salerno, supported by other nearby cities like Benevento and Capua [3]. Fig. 1 shows the interior design of the Verdi theatre of Salerno.



Fig. 1. Perspectival view of the Verdi theatre of Salerno.

The refine decoration realized by D'Agostino are angels sustaining a medallion and then some female characters are drawings a cameo showing the features of a poet, a painter and a musician [1]. The main artists represented in the medallions are composers like Bellini, Cimarosa, Rossini, also writers like Goldoni, Tasso, Alighieri and artists like Michelangelo, Raffaello, Giotto Leonardo and other more.

During the first decades of the 20th century, some refurbishment works have been undertaken inside the theatre, in particular regarding the two new accesses to the stalls and the suppression of two boxes of the first order [4]. In the same occasion, few changes to the internal partitions between the boxes of the 3rd and 4th order have been made in a similar way [4].

Due to the heavy earthquake, the theatre has been closed for 14 years, between 1980 and 1994, when was reopened for the occasion of the 50th anniversary of the celebration called Salerno Capitale [3].

The first Opera performed inside the theatre was *Rigoletto* in 1872. The theatre in 1901 has been dedicated to the composer G. Verdi who died in the same year [3].

III. ARCHITECTURAL ORGANIZATION

The main hall of the Great theatre, realized in 1810, has a total capacity of approximately 650 seats distributed as 220 in the stalls and 430 on the elevated boxes [3]. The dimensions of the axes of main hall are 65 m and 35 m, and the space is coronated by four orders of balconies, surmounted by a gallery (*loggione*) [1].

All the boxes have wooden structure, by having carpet on floor and wooden ceiling. The access to the boxes is given through an *anticamera* (pre-box) having dimensions of $1.9 \times 2.3 \times 2.3$ m [L \times W \times H] [3]. The boxes are furnished with wooden chairs partially upholstered [3].

The orchestra pit has dimensions of 12×4.9 m [L \times W], composed of a wooden floor and plastered wooden walls [3].

The floor of the stalls is composed of oak planks, slightly inclined towards the stage, as shown in Fig. 2.

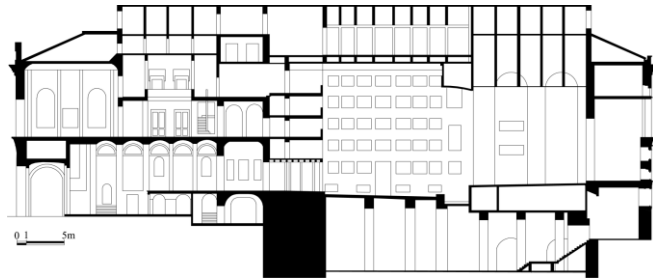


Fig. 2. Longitudinal section of the Verdi theatre of Salerno.

Flourishing decorations are installed all around the main hall, having red-pomegranate colors on seats, upholstery and on the boxes' walls. Other dominant colors are blue and gold [3].

The stage has a whole area of 372 m^2 and the proscenium arch is 10.8 m large and 10 m high. The wooden planks of the stage are inclined of 5%, as well as the stalls floor [3].

The main hall of the Verdi theatre has a horseshoe shape plan layout, as visible in Fig. 3. The different classes of society were allocated in the audience area by respecting some rules; in particular, the middle class has reserved seats in the stalls, the noble class on the elevated levels and the lower class on the top gallery.

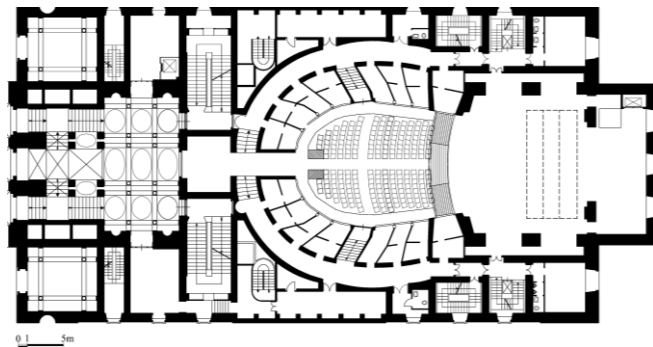


Fig. 3. Plan layout of the Verdi theatre of Salerno.

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

TABLE I. ARCHITECTURAL CHARACTERISTICS OF THE VERDI THEATRE OF SALERENO

Description	Features
Type of plan layout	Horseshoe box
Total capacity (No. of seats)	650
Stage dimensions (m) [L \times W]	15×22
Volume of the flytower (m^3)	6696
Volume of the main hall (m^3)	4262
Total volume (m^3)	10958
Inclination of stage floor (%)	5%
Inclination of stalls area (%)	5%

IV. MEASUREMENTS

Acoustic measurements were undertaken inside the theatre according to the standard requirements outlined in ISO 3382-1 [5]. During the surveys, thermo-hygrometric conditions were taken in consideration [6]. 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®);
- 360° caera (Rico Teta V);
- 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 were installed at the height of 1.2 m on stalls and boxes. The sound signal used for the room excitation was the Exponential Sine Sweep (ESS) [7] 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. 4 shows the measurement positions of sound source and receivers installed across the sitting areas.

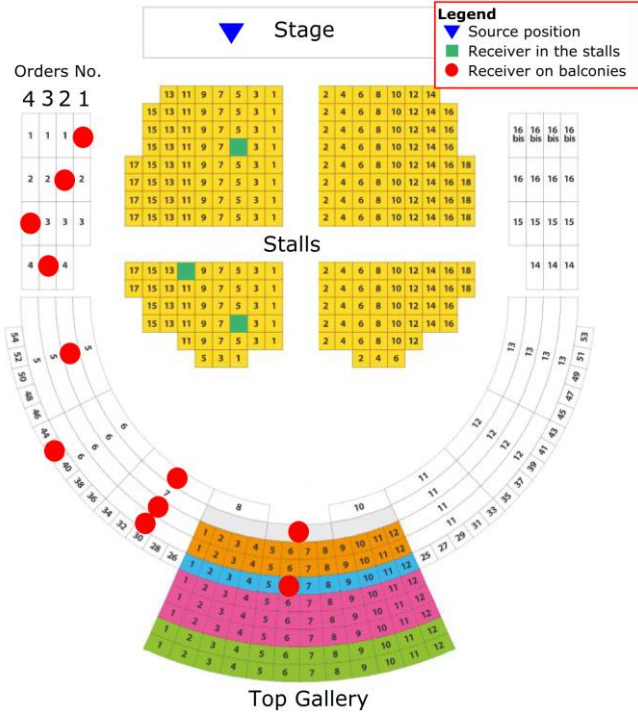


Fig. 4. Scheme of the equipment position during the acoustic measurements inside the Verdi theatre of Salerno.

V. RESULTS

A. Traditional parameters

The recorded ESS signals have been processed by using the plugin Aurora suitable for Audition 3.0 [8]. The main acoustic parameters analyzed in this paper are defined by the international standards ISO 3382-1 [5]: reverberation time (T_{20}), early decay time (EDT), clarity (C_{80} and C_{50}), and definition (D_{50}). The main acoustic parameters are reported in the octave bands between 125 Hz and 8 kHz, considered as the average results of all the measurement positions.

Fig. 5 to Fig. 8 show the graphs of the main acoustic parameters measured inside the Verdi theatre of Salerno.

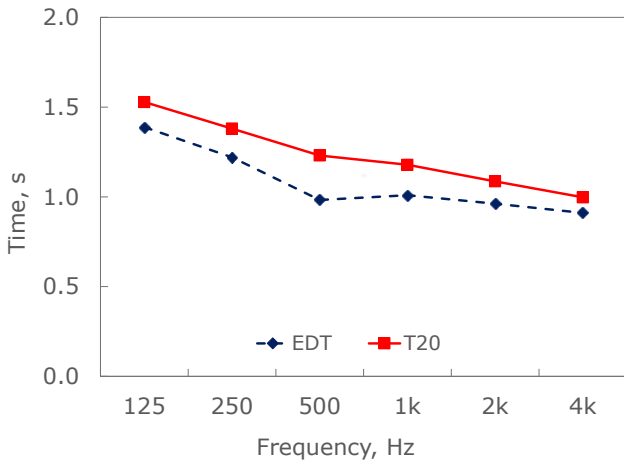


Fig. 5. Measured results of Early Decay Time (EDT) and Reverberation Time (T_{20}).

Fig. 5 shows the frequency response related to EDT and T_{20} . If it is considered that the optimal values of EDT range between 1 s, for a speech intelligibility, and 2.6 s, for music

understanding, this target has been achieved by the low frequency, while the mid-high frequency bands are slightly below the range limit.

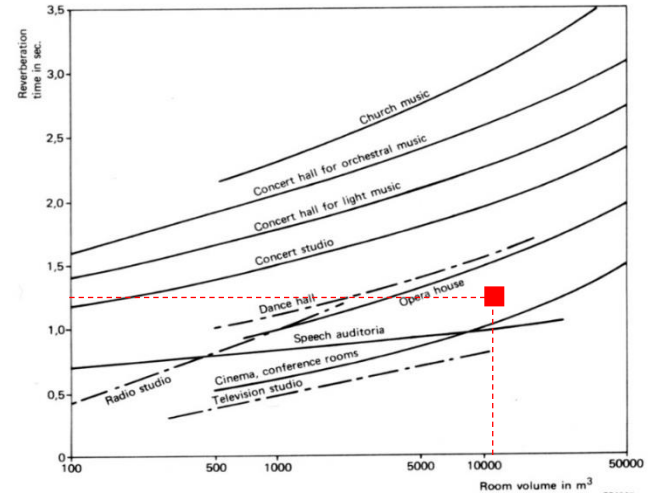


Fig. 6. Optimal reverberation time values in function of room volume.

In terms of reverberation time (T_{20}) the averaged value across all the frequency bands results slightly below the target assigned to an Opera house of such volume size, as shown in Fig. 6. This means that the Verdi theatre of Salerno has a response more suitable for speech than for musical performance [9].

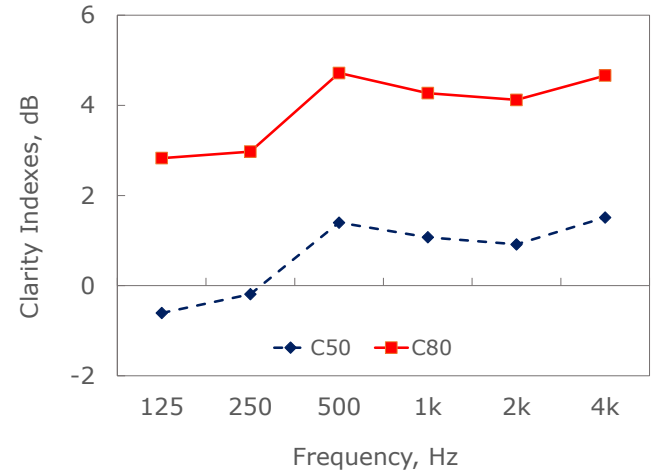


Fig. 7. Measured results of clarity indexes (C_{50} and C_{80}).

The research studies undertaken by Reichardt [10] determined that the optimal values for speech clarity index (C_{50}) should be ≥ 3 dB. In the Verdi theatre of Salerno this parameter floats between 0 and +2 dB. Based on the results shown in Fig. 7, the C_{50} response is slightly below the lower range limit at all frequency bands. However, this shortfall shall not be intended as an adverse impact since the results are not lower than zero, except for the 125 Hz.

In terms of music (C_{80}), the optimal values should be comprised between -2 and +2 dB, according to Jordan [9]. This target has not been achieved in any frequency bands inside the Verdi theatre, found to be above the upper range limit. Translated in other words, this outcome means that the music could be perceived as very clear, especially at 500 Hz.

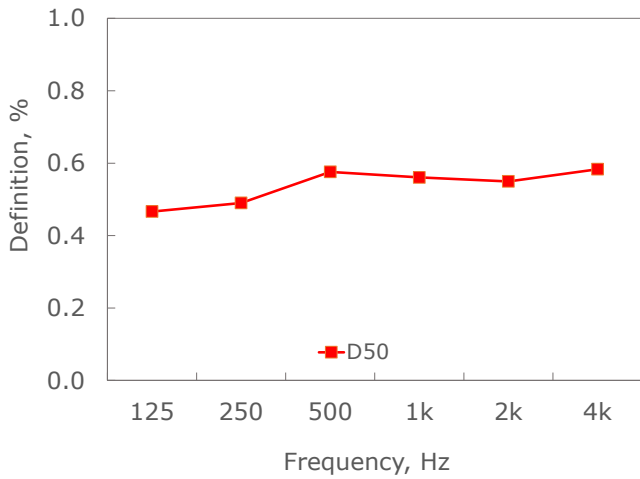


Fig. 8. Measured results of Definition (D_{50}).

A good speech definition is defined to have values higher than 0.5 (i.e. 50%), while the optimal values for music definition should be lower than 0.5 (i.e. 50%) [11]. On this basis, the results obtained in the Verdi theatre of Salerno are found to be floating around 0.5 (50%), meaning that the listening conditions are suitable for speech and for music also.

B. Acoustic analysis of 3D sound maps

In order to understand the specific architectural components contributing to the early and late reflections, the employment of the spherical array microphone was of paramount importance. As such, having a uniform distribution of the capsules over the spherical probe, the receiver is capable of detecting the directivity of the sound rays and relative sound intensity.

A different data analysis could be possible through the combination of a multichannel microphone and a panoramic camera. The result is a video overlay obtained by overlapping the IR with a 360° image, represented in an equirectangular view. The 32 microphone signals have been processed by extracting 122 high directivity virtual microphones (with 8th order cardioid setup) with the addition of the Spatial PCM Sampling (SPS) encoding that spread the directions uniformly distributed in the space [13].

The color tonality shown on the maps ranges between red-orange tinge and blue shades, representing a high and low level of sound energy, respectively. Fig. 9 shows an illustration of the outcomes.

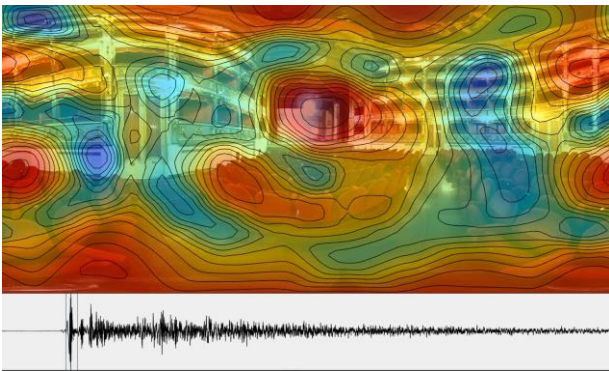


Fig. 9. Acoustical map showing the direct sound arriving to the receiver placed in stalls.

The following shot, represented by Fig. 10, shows the early reflections hitting the side walls of the main hall and back wall of the fly tower. As per above discussion, videoclip allows to link the view of the contours levels with the impulse response flowing in the bar at the bottom of the image.

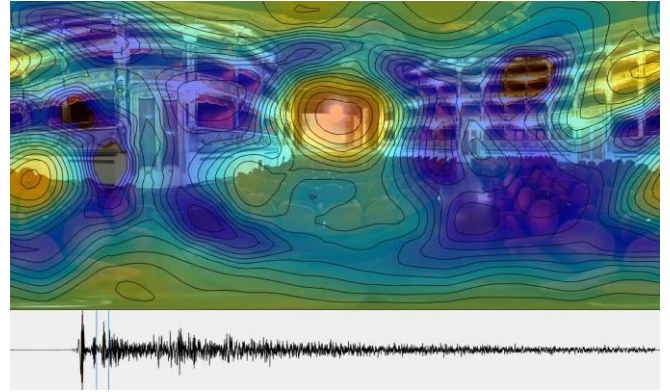


Fig. 10. Acoustical map showing the early reflections.

VI. CONCLUSIONS

This paper deals with the history and architectural description of the Verdi theatre of Salerno. After a wide overview, this study focused on two main analyses of the acoustic data: a first method in line with the current standard requirements, and the other one showing additional understanding of the acoustic behavior of such Opera house.

Overall, the results obtained from the acoustic survey showed that the theatre has a good response for both speech and musical performance.

In addition, 3D sound maps obtained for each source-receiver combination indicate the direction of arrival of the sound reflections and their energy intensity.

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