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Acoustics exploration of the Galli theatre of Rimini after the restoration works of 2015

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Abstract—The acoustic studies of the Italian Opera theatres have been improved their accuracy by the development of a new generation technology. An acoustic survey has been undertaken inside the Galli theatre of Rimini in order to show the acoustic parameters as required by the regulations (ISO 3382-1). Furthermore, a multichannel spherical array microphone has been employed to add value to this acoustic investigation by illustrating the impulse response (IR) through an overlay video. The outcomes of this additional provision have been recorded with some snaps related to different moments of the IR decay. The authors of this paper illustrate also a brief history of the Galli theatre of Rimini, including the description of the architectural features that characterize this important Opera house.

Keywords—acoustic measurements, acoustic parameters, spherical array microphone, Italian Opera theatre.

I. INTRODUCTION

The historical background of the Galli theatre of Rimini records a few documents that resulted important for the faithful reconstruction of the building after the damage caused by the bombing of the World War II. The enthusiasm of exploring the architecture is again possible due to the restoration works realized during the second half of the 20th century. Also, the reconstruction of the indoor acoustics has been taken in consideration due to the installation of different diffusing panels above the wooden doors of the boxes. An acoustic survey in 2018 fell into one of the mandatory duties of scholars and researchers in order to consider the main acoustic parameters as outlined by ISO 3382-1. A complete investigation of the theatre that this paper has dealt with regards the realization of a video that shows the impulse response (IR) recorded during the acoustic measurements. This represents a methodology of showing the specific architectural components that contribute to mark the overall acoustics.

II. HISTORICAL BACKGROUND

For the occasion of the realization of a new theatre project, the architect winning the competition was Luigi Poletti (1792-1869), who expressed in his work all the neoclassic style coming from his studies in Rome [1].

The result was an Italian Opera theatre having some noticeable variations: each order of balconies is composed of 23 boxes, with a double height related to the first order. The neoclassic style applied is visible from the columns designed in Corinthian style to support the top gallery [1]. This theatre is not provided of a royal tribune, quite unusual to be a project of 1841.

The realization of the theatre happened throughout a period of approximately 10 years, in line with the financial

availability of the aristocracy that mainly supported its costs [1]. In 1846 the exterior walls have been complete, but then only approved in 1852. In 1859 the theatre has been dedicated to the King Vittorio Emanuele II [1].

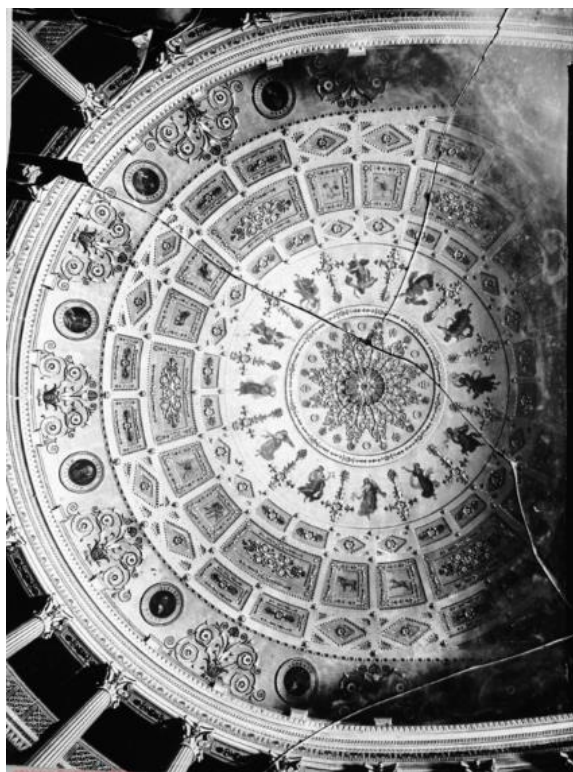


Fig. 1. Ceiling view of the Galli theatre of Rimini, 1923.

During the World War I (1916-1923) the theatre has been damaged by a great earthquake, that provoked the crack onto the ceiling of the main hall [2], as shown in Fig. 1. Restoration works were necessary to consolidate the historical structure and, for this occasion, the electrical system has been realized as an additional sight comfort to the low-intensity candles [2]. Further works of the same period involved the widening of the orchestra pit by cutting off the stage floor [2].

The memory that the citizens of Rimini remember very well is the bombing of 1943, that caused the damage of the roof and part of the stage [2], as shown in Fig. 2. In the same period, the theatre after becoming a military barrack was subject to looting that plundered finest furniture of the theatre [2].

In 1947 the theatre has been dedicated to the musician Amintore Galli (1845-1919), that was also a famous composer at global level, to be the writer of the workers' anthem [1].

The restoration works for a complete reconstruction started in 1975, comprising renovation of the foyer, the renewal of paintings and decorations, and the isolation of the entire structure. It was necessary to wait 2010 for the reconstruction of the stage and the main hall by the architect A. Nicolini [2].



Fig. 2. External view of the Galli theatre of Rimini, after the bombing of the World War II, 1943.

A complete reconstruction of the theatre happened between 2010 and 2015, including the whole consolidation and the restoration of all the finishes [2]. After a long campaign of works, the theatre reopened in 2018.

III. ARCHITECTURAL ORGANIZATION

The main hall of the Galli theatre has a total capacity of 700 seats distributed as 268 in the stalls, and 324 on the three orders of elevated boxes and 108 seats in the gallery [2]. The dimensions of the main axes of the horseshoe shape plan are 22 m and 16 m [L, W], which are coronated by three orders of balconies, surmounted by a gallery having a capacity of 108 seats [2]. The total height of the main hall is 20 m. The floor of the stalls is composed of oak planks, slightly inclined (2%) towards the stage [2], as shown in Fig. 3.

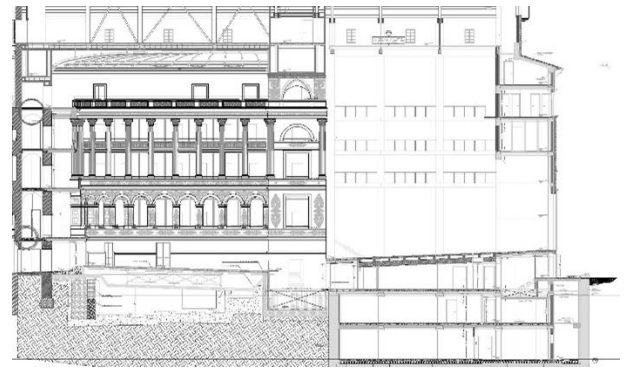


Fig. 3. Longitudinal section of the Galli theatre of Rimini.

The main colors decorating the hall range between ivory and gold; in addition, the re-pomegranate has been used on seats and for the upholstery of the boxes [2].

The stage has a whole area of 358 m² and the proscenium arch is 13 m large and 17 m high [2]. The wooden planks of the stage are inclined of 2%. The orchestra pit is 5.5 m deep and 12 m wide [2]. The main hall of the Galli theatre has a horseshoe shape plan layout, as visible in Fig. 4.

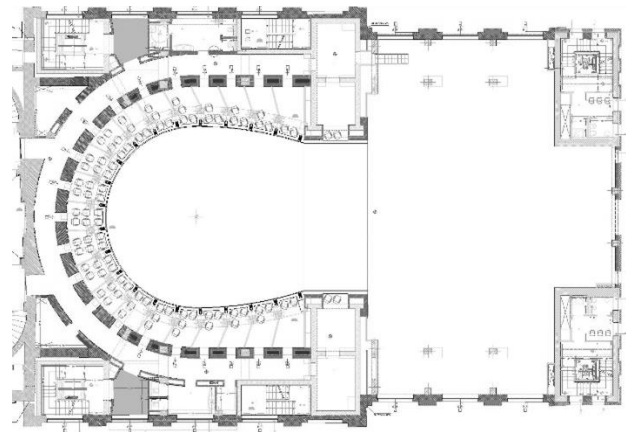


Fig. 4. Plan layout of the Galli theatre of Rimini.

Table 1 summarizes the architectural features of the Galli theatre of Rimini.

TABLE I. ARCHITECTURAL CHARACTERISTICS OF THE GALLI THEATRE OF RIMINI

Description	Features
Type of plan layout	Horseshoe box
Total capacity (no. of seats)	700
Stage dimension (m) [L × W]	30 × 16
Inclination of stage floor (%)	2%
Volume of the flytower (m ³)	8640
Inclination of stalls area (%)	2%
Volume of the main hall (m ³)	5780
Total volume (m ³)	14420

IV. MEASUREMENTS

An acoustic survey was undertaken inside the theatre for the occasion of the reconstruction works [2]. In order to understand the acoustic behavior of the reconstructed volume some objective parameters have been used as outlined by the

standards ISO 3382-1 [3]. During the surveys, thermo-hygrometric conditions were taken in consideration [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;
- 360° camera (Rico Teta V).

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 across the stalls and in the boxes. 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 or acoustic chamber mounted.

Fig. 5 shows the measurement positions of sound source and receivers placed across the sitting areas.

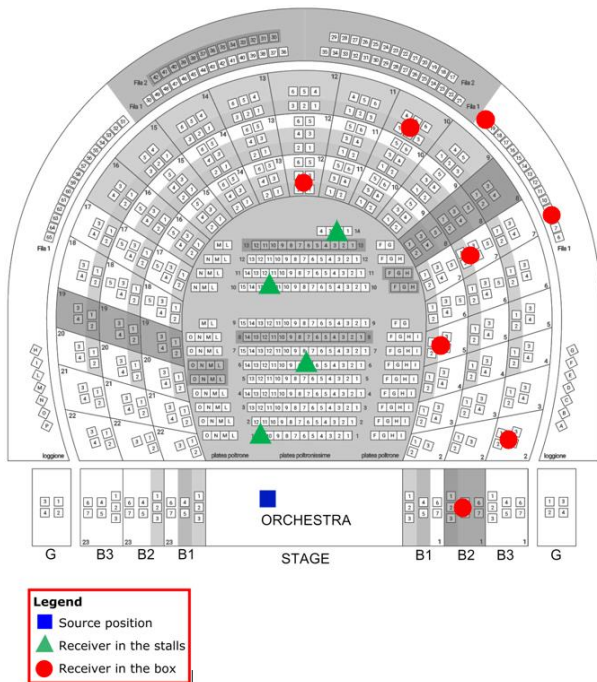


Fig. 5. Scheme of the equipment position during the acoustic measurements inside the Galli theatre of Rimini.

V. RESULTS

A. Traditional parameters

The recorded ESS signals have been processed by using the plugin Aurora suitable for Audition 3.0 [6]. The main acoustic parameters considered in this research work include the reverberation time (T_{20}), early decay time (EDT), clarity indexes (C_{80} and C_{50}), definition (D_{50}), strength (G). These acoustic parameters are reported in the octave bands between 125 Hz and 4 kHz, considered as the average results of all the measurement positions.

Fig. 6 to X show the graphs of the acoustic parameters obtained by the measurements performed inside the Galli theatre.

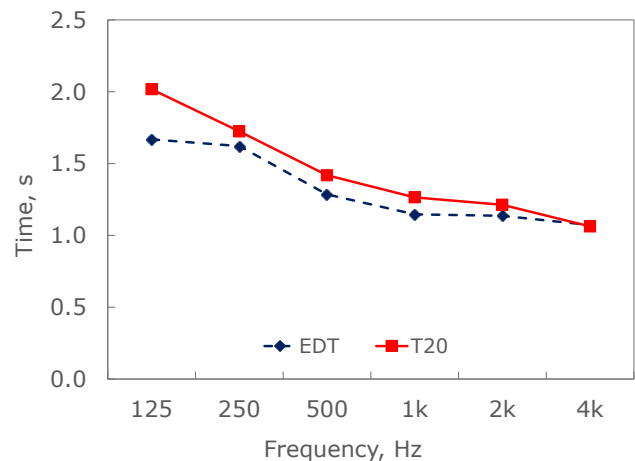


Fig. 6. Measured results of Early Decay Time (EDT) and Reverberation Time (T_{20}).

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 [7], this target has been achieved at low frequency bands, with a shortfall up to 0.8 s at high frequencies.

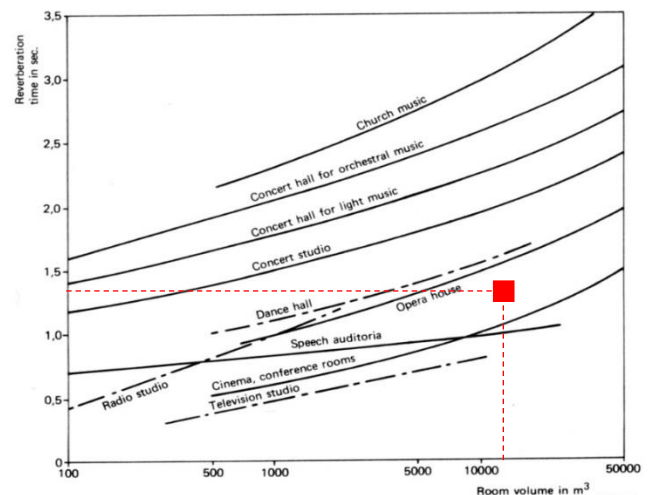


Fig. 7. Optimum reverberation time values in function of room volume.

In terms of reverberation time (T_{20}) the averaged value of all the frequency bands results slightly below the target assigned to an Opera house of such volume size, as shown in Fig. 7. This might be translated by saying that the Galli theatre of Rimini has an acoustic response slightly death for musical performance.

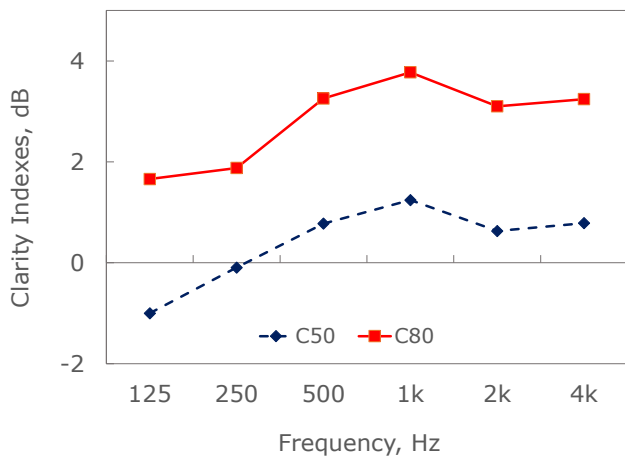


Fig. 8. Measured results of clarity indexes (C₅₀ and C₈₀).

The research studies by Reichardt [8] state that the optimum values for speech clarity index (C₅₀) should be ≥ 3 dB. In the Galli theatre this parameter fluctuates between -1 and +1 dB, found to be at low and high frequency bands, respectively. Based on results of Fig. 8, the good response of C₅₀ has not been achieved in any of the frequency bandwidth. However, a similar shortfall has been found in other Italian Opera theatres [9], meaning that they should not be intended as negative results.

In terms of music (C₈₀), the optimum values should be comprised between -2 and +2 dB, according with Jordan [7]. This target has not been achieved in any frequency bands, except at 125 and 250 Hz. Translated in other words, this outcome means that the music would be rather clear, especially at high frequencies.

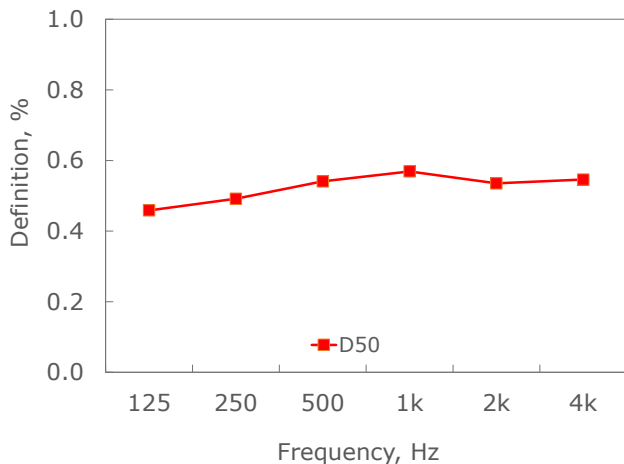


Fig. 9. Measured results of Definition (D₅₀).

By literature [10], a good speech definition is defined to have values higher than 0.5 (50%), while an optimal music definition should have values lower than 0.5 (50%). On this basis, the results obtained in the Galli theatre of Rimini are found to be fluctuating around 0.5 (50%) across all the frequency bands. This means that the listening conditions are suitable for both speech and music.

In terms of strength (G) Fig. 10 shows the energy response obtained inside the Galli theatre.

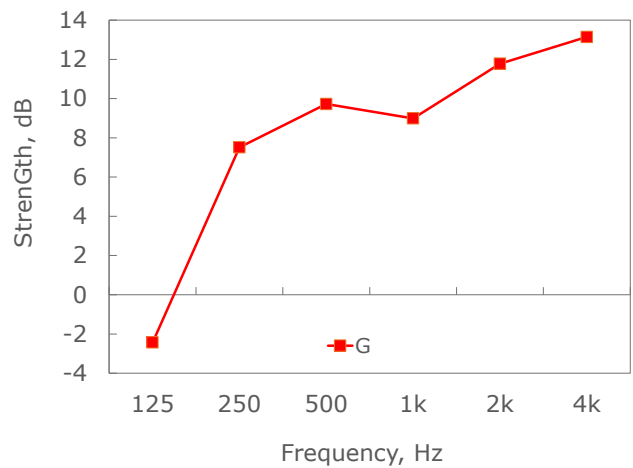


Fig. 10. Measured results of strength (G).

By averaging the values of all the measuring points, the best strength is obtained at mid-high frequencies while it results weak at 125 Hz. This means that listeners have light difficulties in hearing a *fortissimo* for bass sounds. As such, the players (especially singers) should put more effort in obtaining a good performance at low frequencies [11].

Considering the strength in function of the distance existing between the source and the receiver, Fig. 11 show the results related to the stalls. Values have been compared by grouping data acquired by the receivers placed in equivalent distance from the sound sources.

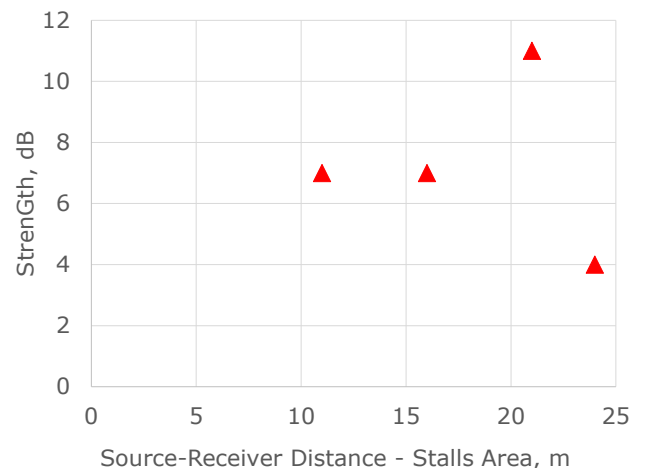


Fig. 11. Results of strength (G) in function of the receivers' distance.

Fig. 11 shows a good G value for the seats located at three quarter of the whole length of the main hall. At this position G achieves values more than 10 dB. This result is mainly due to the vertical walls of the perimeter that are closer by the seats located at this distance from the receiver, representing strong reflecting surfaces for the sound rays hitting these partitions [12]. This result has not been found in the last row of seats (at 24 m from the source) where the value drops significantly because the listener is not enveloped by the sound from all the directions and receives less energy from the direct sound.

B. Acoustic analysis of 3D sound maps

Sound maps having a 360° view have been obtained by the data analysis of the IRs gathered by the spherical array microphone.

In particular, the combination of a multichannel microphone and the panoramic photo (a 360° image represented in an equirectangular view) allow the creation of an overlay video capable to illustrate the contour levels of the sound energy at different intensity overlapped to the equirectangular view [13].

The video has been realized by convolving 32 microphone input signals with the 32 FIR filters. This process was necessary to obtain the 32 virtual microphone outputs [14]. Fig. 12 shows a screen shot taken from the video recording the IR inside the Galli theatre of Rimini.

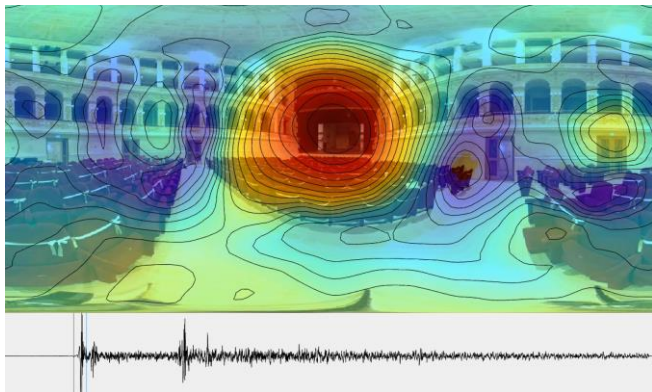


Fig. 12. Acoustical map showing the direct sound arriving to the receiver placed in the stalls.

Differently from Fig. 12, where the flowing IR has been crystalized at the direct sound wave, Fig. 13 shows the late reflections hitting the side walls of the main hall. 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 image.

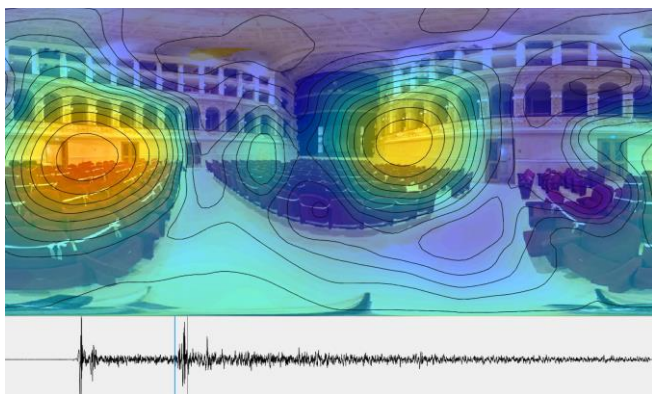


Fig. 13. Acoustical map showing the early reflections hitting the side walls.

VI. CONCLUSIONS

This paper deals with the results obtained by the acoustic survey undertaken inside the Galli theatre of Rimini.

Measurements based on ISO 3382-1 were conducted in situ in unoccupied conditions by different types of microphones, including a multichannel spherical array.

Overall, the results obtained from the measurement campaign showed that the Gallitheatre has a good response for speech performance, with some difficulties at low frequencies in terms of strength that require the singers to put more effort at the bass tones. In terms of music, the theatre results slightly deaf compared to Opera houses of similar volume size, even this shortfall has been found in other Opera theatres of great importance.

The study has been extended to analyze the directivity of sound waves bouncing at the boundaries of the enclosed space. Such maps, extracted from an overlay video, indicate the direction of arrival of the sound rays and their relative intensity, contributing to understanding the specific role of architectural elements at different seat position.

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