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Exploring the acoustics of the “Teatro Grande” of Brescia

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***Abstract*— One of the tasks of scholars and scientists is to highlight the values of the cultural heritage, a great patrimony that all the new generations should be acknowledged. One of the aspects that should be explored besides the construction restoration of all the historical buildings, especially Opera theatres, is the acoustics. This article deals with the acoustic investigation performed in relation to the Teatro Grande of Brescia. The outcomes have been analyzed by following both the standard requirements stated in ISO 3382-1 and by creating an overlay video that shows a real-time impulse response (IR). This latest innovative aspect calls the attention to the interactions existing between the sound waves and the construction elements of the room’s boundaries. This additional value has been realized by using a multichannel spherical array microphone, that allows a control of the sound propagation through the space. The authors of this paper introduce also a brief history of the Teatro Grande of Brescia, including the description of the architectural characteristics of this important historical building.**

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

I. Introduction

The Teatro Grande of Brescia is one of the Opera houses located in northern Italy considered one of the most prosperous places where the artistic activities are widely promoted. The acoustic characteristics of this building have been investigated by meeting the approach outlined by the current regulations and also by visualizing the directions of the sound rays bouncing inside the main hall. As such, the main acoustic parameters have been introduced and commented besides the representation of a few shots taken from the video of the real-time impulse response (IR).

II. Historical Background

The Teatro Grande has been built in the same place where the 1st theatre of the city was born in 1664 [1]. The project site belonged to the Venetian Republic and then was acquired by the Errants’ Academy, which provided to build an own rehearse place in 1643 [2].

The palace of the Academy was composed of a wide saloon on the first floor and by a porch on ground floor that was included into the theatre in 1710 [1]. Of the palace of the 17th century, only the elevation is left, having a vertically linear design marked by three windows facing Corso Zanardelli [3]. In 1780 a porched entrance has been added and realized by the architects A. Vigliani and G. Turbini; this entrance is characterized by a stairwell conducting to the Statues Room, realized by G. Magnani in 1863 [3]. This path crosses also the Ridotto (Foyer), before arriving into the theatre [4].

The Ridotto, shown in Fig. 1, has been realized by the architect A. Marchetti in 1769 as the reference room for the academic Errants [4].

Fig. 1. Ridotto (Foyer) of the Teatro Grande of Brescia.

All the decorations of the foyer were realized by the venetian F. Battaglioli and F. Zugno. For the lighting system, crystals have been added to each light point [5].

In 1735 the main hall of the Teatro Grande was occupied by the academic Errants and this place was realized by A. Righini and A. Cugini, two theatrical architects and scenographers working with Bibiena’s family [6]. Originally, this room had “U” shape of the plan layout, been demolished and rebuilt between 1806 and 1810 [5].

The existing main hall of the Teatro Grande of Brescia has been drawn by the architect Luigi Canonica and finished in 1810 when it was open for a fabulous Opera performance [6]. The neoclassic decoration has been executed by G. Teosa, who decided to evoke the battles won by Napoleon [3]. All the decoration of the main hall has been weighed down in 1863 by further ornaments in neo-baroque style, with the exception of the royal box which still preserves the original design [3].

The painter L. Campini drew the affresco of the main vault, representing allegoric figures as Dance, Comedy, Tragedy and Music [6].

Many restoration works occurred during the last centuries but since 1930 the theatre has been preserving the existing image that we can see by entering inside the main hall [6]. Works that did not involve the structure and the architectural organization occurred after 1930, mainly on the restoration of fragile materials as *papier mache*, painted wood and stuccos that still require maintenance and care [3].

III. Architectural Organization

The main hall of the Teatro Grande, realized in 1810, has a total capacity of 931 seats distributed as 400 in the stalls and 531 on the elevated boxes [1]. The dimensions of the main axes of the horseshoe shape plan are 22 m and 17 m [L, W], which are coronated by three orders of balconies, surmounted by two galleries having a capacity of 122 and 136 seats respectively [6]. The floor of the stalls is composed of oak planks, slightly inclined towards the stage, as shown in Fig. 2.

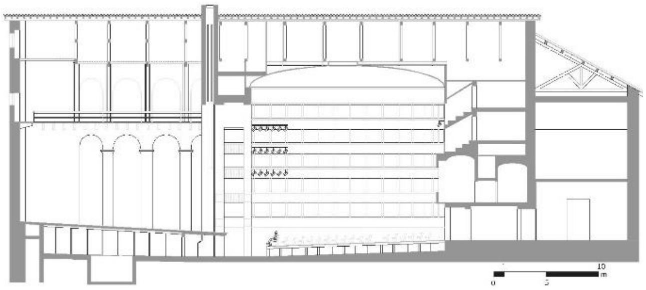

Fig. 2. Longitudinal section of the Teatro Grande of Brescia.

The royal box is located at the center of the second and third order and it has a circled plan surmounted by a small dome. The ceiling of the main hall was painted by Magnani and it is composed of oval medallions on a blue-sky background, where female angels represent the glory of the Italian theatre (e.g. dance, music, tragedy and comedy) [7]. Fig. 3 shows the interior design of the main hall.

Fig. 3. View of the main hall of the Teatro Grande of Brescia.

Flourishing decoration are installed all around the main hall, having red-pomegranate colors on floor finishes, seats, upholstery and on the boxes' walls. Other dominant colors are ivory and gold, used on the wooden decorations [7][6].

The stage has a whole area of 360 m^2 and the proscenium arch is 13 m large and 12 m high. The wooden planks of the stage are inclined of 5%, against the 4% of the stalls floor. The orchestra pit is 2 m high and up to 4 m deep [8].

The existing main hall of the Teatro Grande 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. The different types of spectators were allocated in the audience area by respecting important rules: the middle class was sitting in the stalls, the noble class on the levels of balconies and the lower class on the top gallery [8][6].

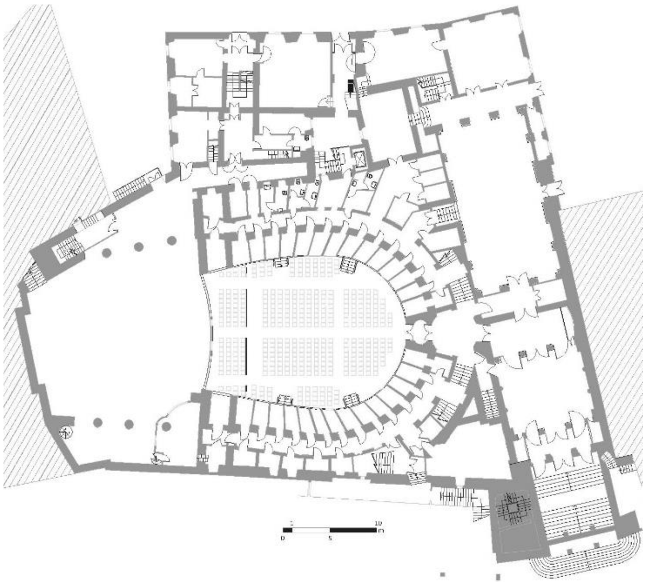

Fig. 4. Plan layout of the Teatro Grande of Brescia.

The main hall has been built in the courtyard of the old palace; this explains the irregular geometry of the stage, to be found not perpendicular to the main axis of the stalls nor parallel to the main axis of the foyer.

Table 1 summarizes the architectural features of the Teatro Grande.

TABLE I. ARCHITECTURAL CHARACTERISTICS OF THE GRETHEATAT RE OF BRESCIA

Description	Features
Type of plan layout	Horseshoe box
Total volume (m^3)	10580
Total capacity (no. of seats)	931
Stage dimension (m) [L × W]	18.5 × 26
Inclination of stage floor (%)	5%
Inclination of stalls area (%)	4%

IV. Measurements

Acoustic measurements were undertaken inside the theatre to gather the data useful to analyze the behavior of the main volume when interacting with sound waves. During the surveys, thermo-hygrometric conditions were also taken in consideration. 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 installed at 1.4 m from the stage 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) having a duration of 15 s in a uniform sound pressure level for the range between 40 Hz and 20 kHz [10]. The measurements were undertaken in unoccupied conditions and without any scenery nor acoustic chamber mounted.

Fig. 5 and Fig. 6 show the measurement positions of sound source and receivers placed across the sitting areas.

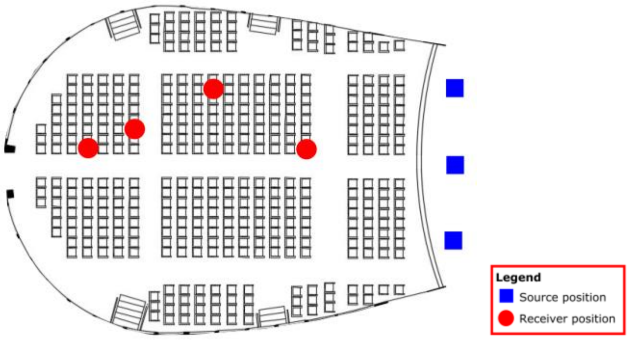

Fig. 5. Scheme of the equipment location during the acoustic measurements in the stalls of the Teatro Grande of Brescia.

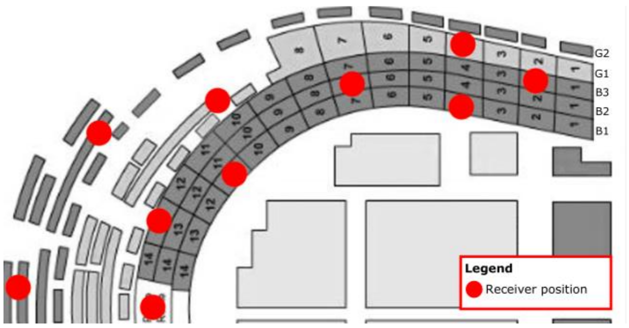

Fig. 6. Scheme of the equipment location during the acoustic measurements on the different orders of balconies of the Teatro Grande of Brescia.

V. Results

A. Traditional parameters

The recorded ESS signals have been processed by using the plugin Aurora suitable for Audition 3.0 [11]. Different acoustic parameters defined by the international standards ISO 3382-1 [12] have been analyzed and commented, to be including are the reverberation time (T_{20}), early decay time (EDT), clarity indexes (C_{80} and C_{50}), definition (D_{50}) and strength (G). The main acoustic parameters are reported in the octave bands between 125 Hz and 4 kHz, considered as the average results of all the measurement positions [13].

Fig. 7 to Fig. 13 show the graphs of the main acoustic parameters.

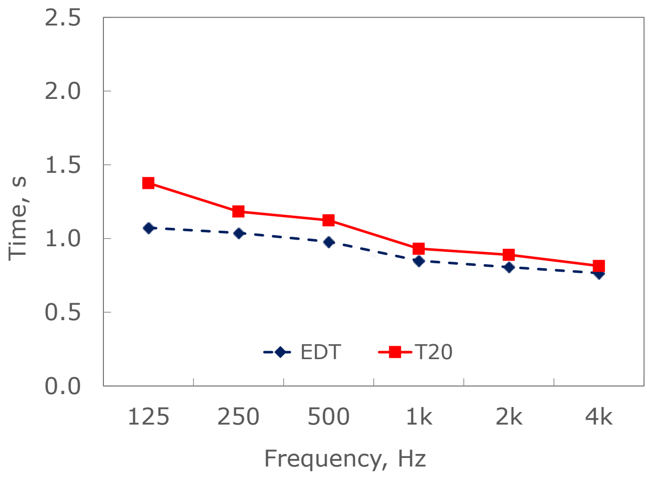

Fig. 7. Measured results of Early Decay Time (EDT) and Reverberation Time (T_{20}).

Fig. 7 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 literature [14], this target has not been achieved by the measured values related to the selected bandwidth.

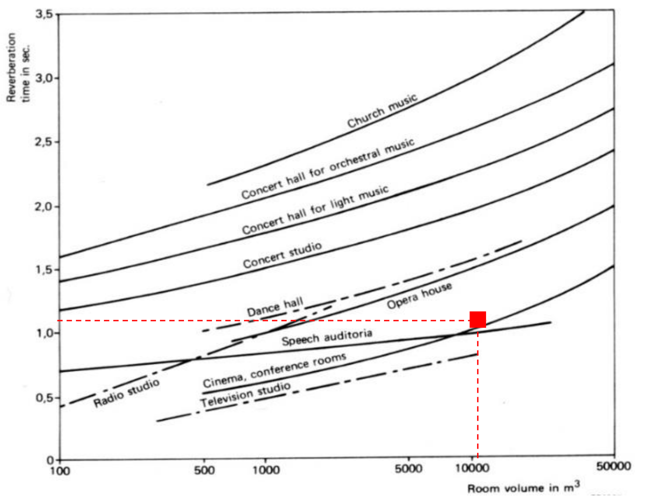

Fig. 8. Optimum reverberation time values in function of room volume.

In terms of reverberation time (T_{20}) the averaged value of all the frequency bands result slightly below the target assigned to an Opera house of such volume size, as shown in Fig. 8. This means that the Teatro Grande of Brescia has a response mores suitable for speech than for musical (Opera and symphonic) performance, which instead requires a higher reverberation time.

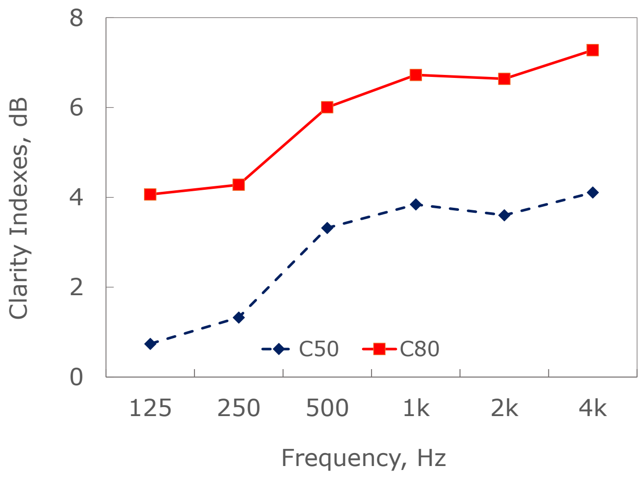

Fig. 9. Measured results of clarity indexes (C_{50} and C_{80}).

Following the research studies by Reichardt [15], the optimum values for speech clarity index (C_{50}) would be ≥ 3 dB. In the Teatro Grande this parameter floats between +1 and +4 dB, at low and high frequency bands, respectively. Based on results of Fig. 9, the good response of C_{50} has been achieved at frequencies higher than 500 Hz. However, the shortfall at low frequencies found to be slightly below the lowest range limit is not to be intended as a negative result.

In terms of music (C_{80}), the optimum values should be comprised between -2 and +2 dB, according with Jordan [14]. This target has not been achieved in any frequency bands, found to be above the upper range limit. Translated in other words, this outcome means that the music would be very clear, especially at high frequencies.

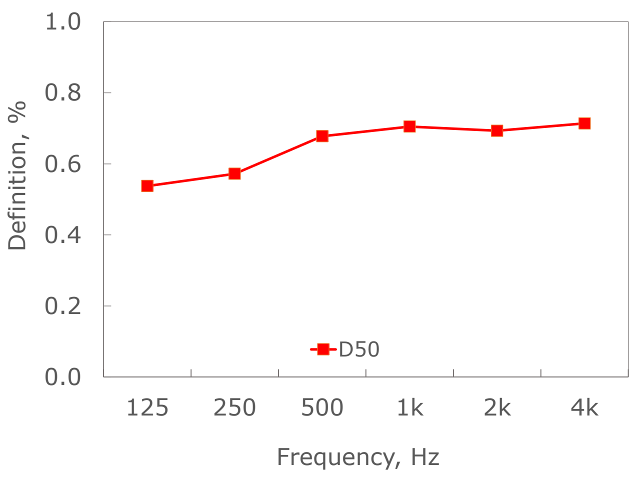

Fig. 10. Measured results of Definition (D_{50}).

It has been studied that 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%) [16]. On this basis, the results represented in Fig. 10 are found to be around 0.5 (50%) at low frequencies and 0.7 (70%) at mid-high frequencies. This means that the listening conditions are very suitable for speech, with a good outcome also for music.

In terms of strength (G) Fig. 11 shows the energy response obtained inside the Teatro Grande. Values have been compared by grouping the data acquired in the stalls and in the boxes.

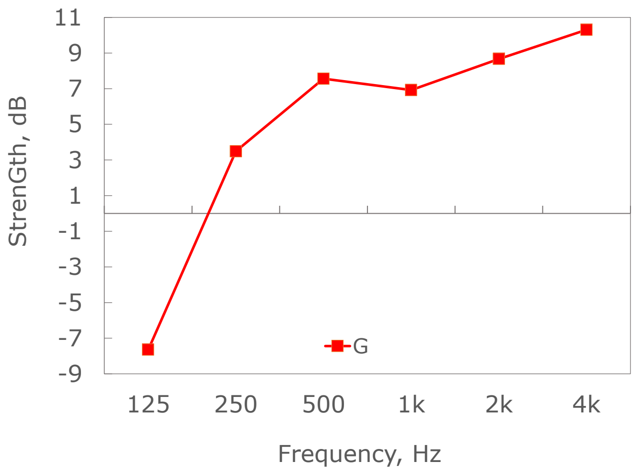

Fig. 11. Measured results of strength (G).

By averaging the values of all the measuring points, 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 [18]. As such, the players (especially singers) should put more effort in obtaining a good performance at low frequencies.

Considering the strength in function of the distance existing between the source and the receiver, Fig. 12 and Fig. 13 show the results related to the stalls are and the orders of boxes, respectively.

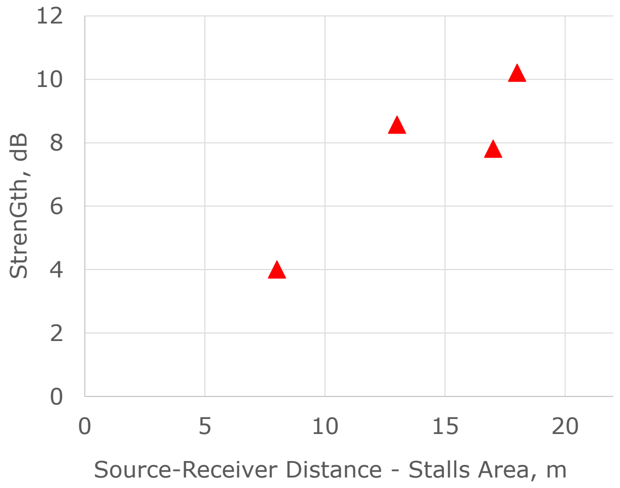

Fig. 12. Results of strength (G) related to the stalls area.

Fig. 12 shows a good G value for the seats located at the back of the main hall, achieving values between 8 and 10 dB. This is due to the vertical walls of the perimeter that are closer by the seats located at the back of the main hall, representing strong reflecting surfaces for the sound rays hitting these partitions [18].

For a more detailed analysis related to the different orders of balconies, Fig. 13 shows how the G values resulted higher inside the boxes close to the longitudinal axis of the main hall (Central) than the lateral ones.

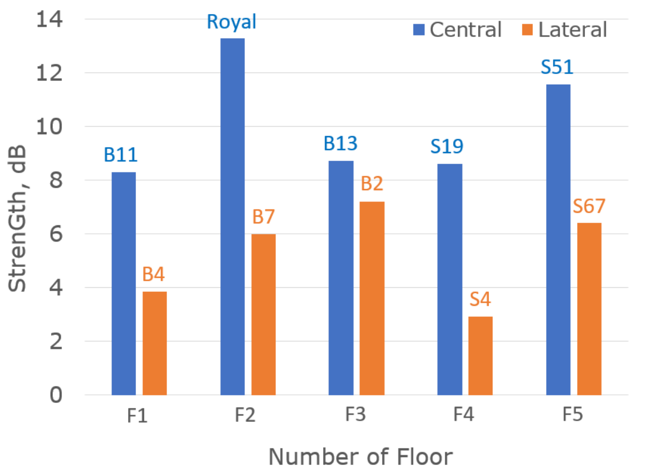

Fig. 13. Results of strength (G) related to the orders of balconies. B stands for the number of box related to the first three floors, while S stands for the number of seat on the top 2 galleries.

The strength of the boxes frontal to the stage achieves values between 8 and 13 dB across all the orders of balconies, while for the lateral boxes, more distant to the longitudinal axis, the values are weaker [20].

B. Acoustic analysis of 3D sound maps

The employment of the spherical array microphone (i.e. em32 Eigenmike®) [21] allowed the authors to elaborate sound maps obtained for each source-receiver combination. These maps have been created by a video-overlay that reproduces the recorded IR.

This different data analysis is obtained by a combination of the omnidirectional sound source, the multichannel microphone (i.e. em32 Eigenmike®) and the panoramic camera (i.e. Rico Teta V, capturing a 360° image herein 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) [22]. By using this methodology, it was possible to encoding the direction of arrival of all the sound rays, including the direct sound and the reflections occurred after hitting any surface.

The colors shown in the map overlay are comprised between red tinge (indicating the high level of sound energy) and blue-violet shades (representing a poor energy sound wave). Fig. 14shows an illustration of the outcomes.

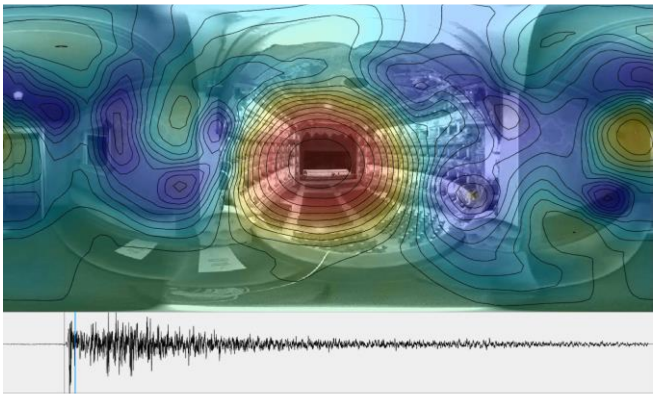

Fig. 14. Acoustical map showing the direct sound arriving at the receiver placed in the 11th box of the third livel of balconies.

Fig. 15 shows the late reflections hitting the ceiling surface area. As per above discussion, the overlay videoclip allows to visualize the surface areas that contribute to create the early and late reflections. The bar at the bottom of the image indicates the flow time of the IR.

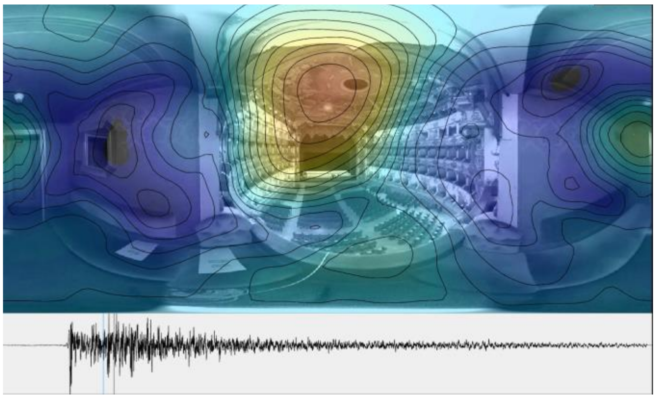

Fig. 15. Acoustical map showing the direct sound arriving at the receiver placed in the 11th box of the third livel of balconies.

VI. CONCLUSIONS

This paper deals with the representation of the acoustic results obtained by the survey undertaken in the Teatro Grande of Brescia. Measurements were conducted by using an omnidirectional sound source and four types of microphones.

Overall, the results obtained from the measurement campaign showed that the theatre 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.

This acoustic study has been extended to analyze the specific trajectory of the sound waves during the IR. The capabilities of the multi-channel spherical microphone (i.e. em32 Eigenmike®) allowed the authors to render 3D sound maps, obtained for each source-receiver combination. Such maps indicate the direction of arrival of the sound rays and their intensity, contributing to understanding the specific role of the specific construction elements interacting with the sound waves.

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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.