

A Rare Event for the Teatro Comunale in Bologna: Acoustic Response without Seats

Van Duong Fabio Rimoldi
Department of Architecture

University of Bologna
Bologna, Italy
vanduong.rimoldi@studio.unibo.it

Antonella Bevilacqua
*Department of Engineering and
Architecture, CIDEA*

University of Parma
Parma, Italy
antonella.bevilacqua@unipr.it

Haruna Saito
Department of Architecture

University of Bologna
Bologna, Italy
haruna.saito2@studio.unibo.it

Adriano Farina
CIRI-EC
University of Bologna
Bologna, Italy
adriano.farina3@unibo.it

Ruoran Yan
Department of Architecture
University of Bologna
Bologna, Italy
ruoran.yan3@unibo.it

Matteo Fadda
Department of Architecture
University of Bologna
Bologna, Italy
matteo.fadda2@studio.unibo.it

Lamberto Tronchin
Department of Architecture
University of Bologna
Bologna, Italy
lamberto.tronchin@unibo.it

Abstract— With advancements in technology, acoustic measurements have become increasingly precise, allowing for a faithful reproduction of the acoustic conditions in opera theatres. The recorded impulse responses have been analyzed for the house of sound in Bologna designed by Antonio Galli Bibiena. This iconic heritage building is undergoing a period of renovation that also involves seats, representing a great opportunity to investigate the contribution of seat absorption to the overall acoustics. The monoaural and binaural acoustic parameters are processed according to standard requirements. The results show that the room response without seats makes the Teatro Comunale very reverberant, with the order of 2.8 s at mid octaves. Besides the traditional acoustic parameters, the acoustic maps highlight the contribution of different architectural elements within an opera theatre, given by the visualization of sound reflections bouncing within a room.

Keywords—acoustic measurements, Bologna, signal processing, stalls without seats.

I. INTRODUCTION

The dynasty of Bibiena was established in Bologna and was known in the community for their ability to create new iconography for theatres. The drawings by Antonio (1697-1774) are many, all distinguishable by his preference for curves instead of linear aesthetics, as dictated by the Baroque style [1].

However, the bell-shaped plan layout is unusual for the 18th century since many other shapes were proposed [2]. An example is the elliptical shape proposed by Pierre Patte [3], which was implemented in the Communal-Pavarotti Theatre of Modena [4] and the National Theatre of Lisbon [5], to cite a few examples, but also the horse-shoe shape typical of *Teatro all'Italiana* since it has been proposed in many royal courts [6].

Many studies in acoustics are centered on the alignment between sound and landscape to enhance a more faithful virtual reality of digital realms. This process is rapidly developing due to the evolution in terms of performance of both technology and methods of post processing data [7].

This paper treats the acoustic analysis of the Teatro Comunale in Bologna, Italy [8]. The multichannel spherical array microphone represents the key factor in enabling a whole detection of sound waves arriving at the probe. As such, an overlay response in the time domain illustrates the direction of sound waves' arrival that completes the traditional acoustic analysis as typically carried out by describing the main parameters [9].

II. HISTORICAL BACKGROUND OF TEATRO COMUNALE IN BOLOGNA

Teatro Comunale in Bologna was built after Teatro Malvezzi fell in ruin in 1745. The local authority deliberated on the realization of a new theatre to be built in brickwork [10]. The decision to organise the main hall in a bell-shaped geometry was criticized because it was considered not suitable for a good acoustic response. Antonio Galli Bibiena proposed his innovation, also supported by musicians and spectators. Teatro Comunale opened in 1763 with the execution of *Il trionfo di Clelia* by Gluck [10]. Figure 1 shows an internal view of the theatre before the renovation works.



Fig. 1. Internal view of Teatro Comunale in Bologna, Italy.

This theatre has hosted renowned musicians such as Mozart, Rossini, Verdi, and Toscanini, and it continues to stage operas today. In 1931, a fire destroyed the stage and the curtain [10], but the theatre was restored and reopened in 1935. In 2024, restoration works started inside the theatre, involving the change of seats to align with current regulations in terms of safety and comfort.

III. ARCHITECTURAL CHARACTERISTICS OF TEATRO COMUNALE IN BOLOGNA

Teatro Comunale in Bologna has a bell-shaped plan offering a seat capacity up to 1176, organized as 644 in the stalls and 532 on different levels. Also, the proscenium, as typical of the 18th century, has boxes across the first three orders only [1]. The main hall has dimensions of 22.4 m (L) and 15.4 m (W), as shown in Figure 2. The maximum height taken at the centre of the hall is 16.9 m; this is justified by the four orders of balconies with the addition of a top gallery.

Notably, Teatro Comunale in Bologna is one of the few opera theatres in the world still maintaining the floating floor structure of the stalls [10].

In terms of finish material, the stalls are composed of wooden planks. Also, the walls of boxes are in timber, as well as the balustrade at all levels, which is not made by a solid panel but by Baroque-style bars [11], allowing the sound to pass across, surmounted by a 2 cm cushioning mat. The walls around the stalls are painted and in solid timber

A wide chandelier dominates the vault at the center of the main hall, which is painted in Baroque style, with golden and dark green colors.

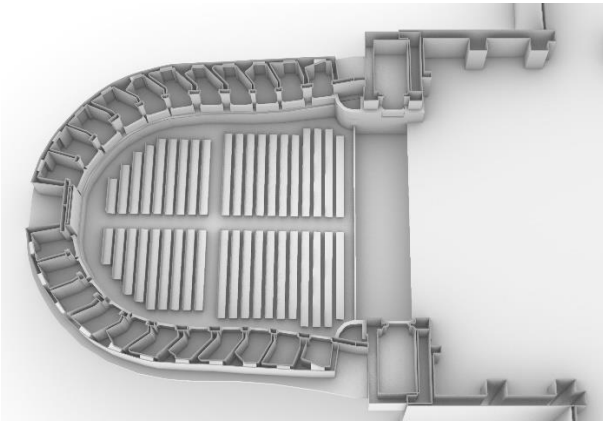


Fig. 2. Plan the layout of Teatro Comunale in Bologna.

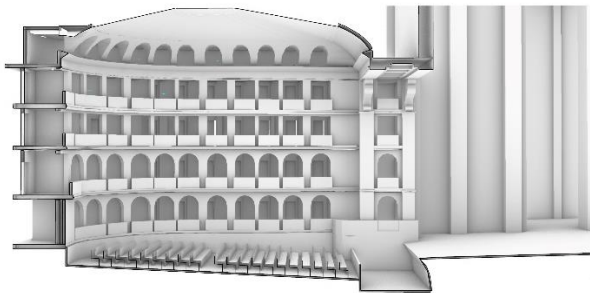


Fig. 3. Longitudinal section of Teatro Comunale in Bologna.

TABLE I summarizes the architectural characteristics of the Teatro Comunale.

TABLE I. ARCHITECTURAL CHARACTERISTICS OF TEATRO COMUNALE IN BOLOGNA.

Description	Features
Type of plan layout	Bell shape
Total capacity (No. of seats)	1176
Main Hall axes (m)	22.4 × 15.4
Stage dimension (m)	23 × 24
Inclination of stalls	2%

IV. ACOUSTIC MEASUREMENTS

An acoustic measurement campaign was conducted to investigate the theatre's distinctive room response in the absence of seating, due to renovation works scheduled for 2025. The survey employed the following instrumentation:

- Equalised omnidirectional loudspeaker (Look Line);
- Microphones:
 - a) Binaural dummy head (Neumann KU-100);
 - b) B-Format (Sennheiser Ambeo);
 - c) Omnidirectional microphone (Bruel&Kjaer 4189);
 - d) 64-channel spherical array (MH Acoustic em64 Eigenmike®);
- Personal Computer connected to the loudspeaker and all the receivers.

The sound source was positioned on the stage at a height of 1.4 m, while the receivers were placed at various locations throughout the stalls and balconies, as illustrated in Figure 4. The source emitted a 15-second Exponential Sine Sweep (ESS) signal with a uniform sound pressure level spanning 40 Hz to 20 kHz. All measurements were performed in the unoccupied theatre.

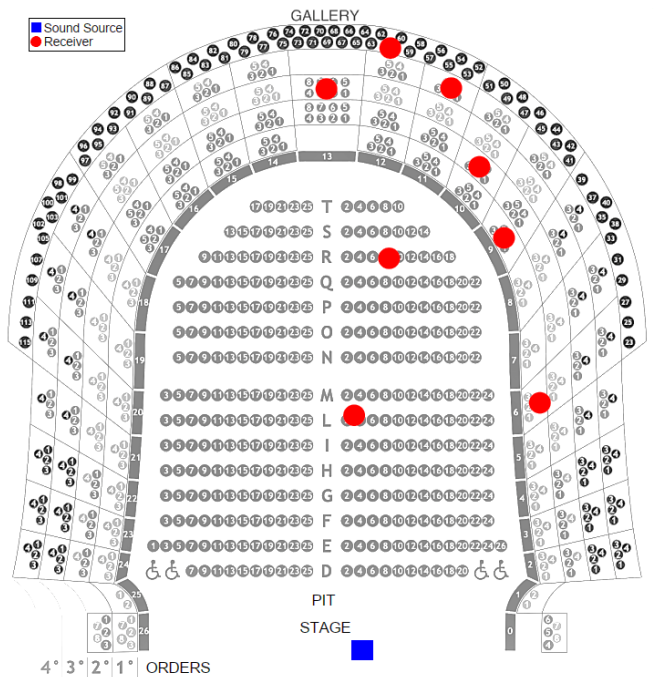


Fig. 4. Position of the receivers during the acoustic measurements highlighted with the red dot, and the sound source in blue.

V. ANALYSIS OF RESULTS

A. Analysis based on standard requirements

The recorded IRs were processed and analysed with Aurora, a plugin supported by Audition software [12, 13]. The main acoustic parameters were obtained according to ISO 3382-1 [14]. The data are the average values of all measurement positions, split between stalls and balconies.

Figures 5 to 8 summarise the measured results in the frequency domain going from 125 Hz and 4 kHz.

Figure 5 shows that the difference in EDT values between stalls and balconies is minimal. Stalls and balconies present a similar trendline, going from 2.4-3.2 s at 125 Hz to 1.7-2.6 s at 4 kHz. These values are very high for a room size like the Teatro Comunale. According to Jordan [15], the EDT values in opera theatres should range between 1.8 s and 2.5 s. However, it has to be remembered that these measured values are related to the room without any seats [16].

In terms of reverberation, the T30 results in Figure 6 are very similar between balconies and stalls, around 3.0 s at 500 Hz. This indicates that the seats are important architectural elements within a theatre that help to reduce the reverberation due to their absorption properties of the upholstery [17].

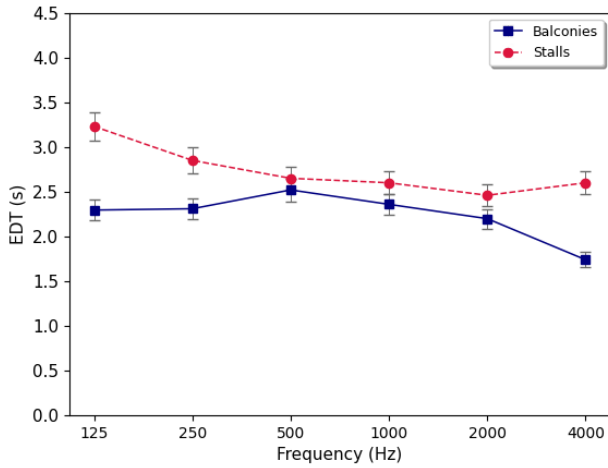


Fig. 5. Measured results of Early Decay Time (EDT).

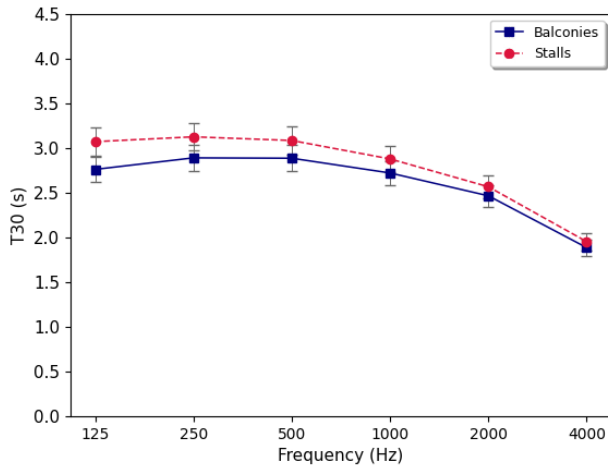


Fig. 6. Measured results of Reverberation Time (T30).

The clarity index has been assessed for both speech and music. In particular, Figure 7 illustrates the dissimilarity in

trendline among all responses. The C50 values in the balconies are around -3 and -2 dB. In contrast, in the stalls, the C50 values are irregular, going from -4 dB at low frequencies to -2 dB at high frequencies, with a downward peak at 500 Hz around -6 dB [18].

Regarding the music clarity, C80 values in balconies are around zero, falling within the optimal range limits, while in the stalls is irregular as C50 values, ranging from -3 dB to +1 dB with downward peaks at 500 Hz and 2 kHz, reaching about -2.5 dB [19].

Figure 8 illustrates the response for balconies and stalls in terms of Interaural Cross-Correlation (IACC). The difference between the two seating areas is evident in the peaks recorded in the stalls, specifically at 500 Hz and 4 kHz. At this latest octave band, the lateral reflections are stronger in the balconies than the stalls, which is directly proportional to the distance between the receiver and the nearest wall [20].

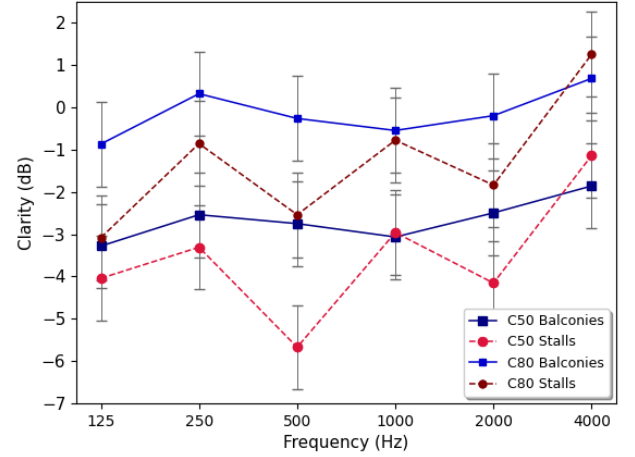


Fig. 7. Measured results of speech and music clarity.

This is explained by the receiver position during the measurements: in the balconies, the lateral walls are closer to the microphones, while in the stalls, the distance between the microphones' position and the side walls is wider, contributing less to a stereophonic response [21]. Overall, this response is typical of IACC values found in other opera theatres [22].

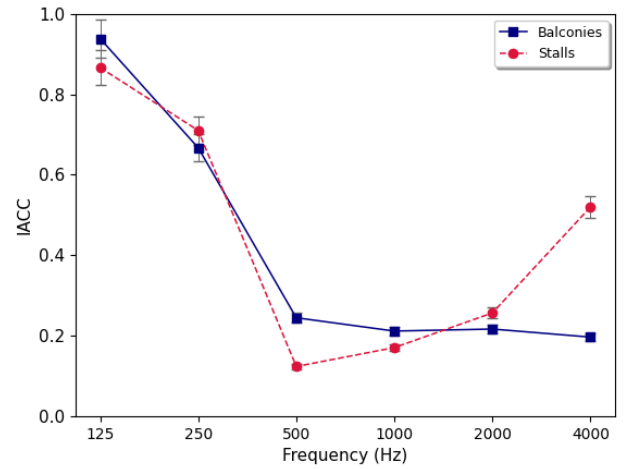


Fig. 8. Measured results of Interaural Cross-Correlation (IACC).

B. Acoustic maps

The use of the spherical array microphone, em64 Eigenmike®, and the panoramic camera (Qoocam) enabled the creation of directivity maps from data gathered in the same positions. The impulse response from this type of microphone records all the sound rays reflected from all directions after interacting with the boundary surfaces [23].

The combination of audio and video is illustrated in a video overlay, where the contour levels are coloured in blue to denote a low energy content and in red to denote a high sound level. This combination was realised with a Matlab script created at the University of Parma [24].

Among all receiver positions, a full analysis of acoustic maps is realised for a microphone position installed in the stalls (L4) [25]. Figure 9 shows the direct sound arriving from the sound source installed centrally on the stage that hits the microphone probe in front at an energy of around 92 dBA.

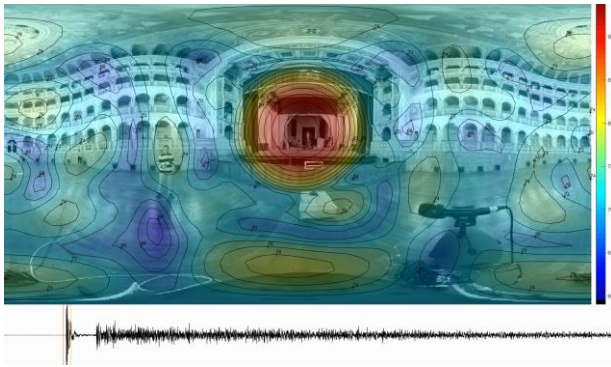


Fig. 9. Direct sound hitting the microphone probe in position L4 in the stalls of Teatro Comunale in Bologna, Italy.

It is interesting to note that the early reflection is coming from the proscenium arch, as visible on the left-hand side of Figure 10, at the order of 80 dBA. This is important for opera singers when they play in the upward zone of the stage during arias, highlighting the contribution of this important architectural element to the overall structure [26].

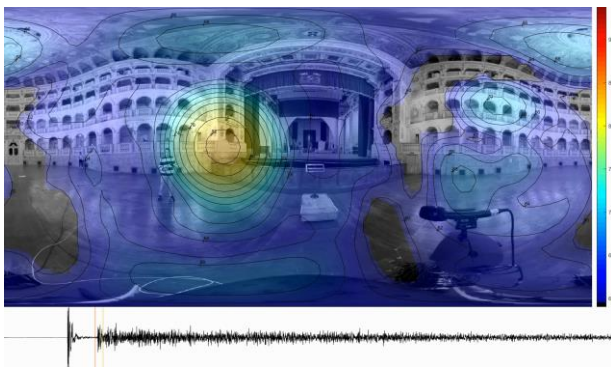


Fig. 10. Early reflection hitting the microphone probe in position L4 in the stalls of Teatro Comunale in Bologna, Italy.

Another strong reflection comes later, as visible in the bottom cursor of Figure 11, which involves the side wall at a sound energy equal to 80 dBA. This small percentage of energy loss visualizes the energy decay of a typical impulse response until the complete absorption by the room [27].

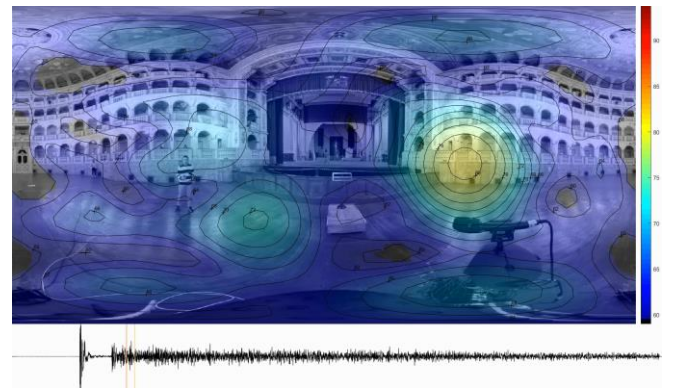


Fig. 11. Late reflection hitting the microphone probe in position L4 in the stalls of Teatro Comunale in Bologna, Italy.

VI. CONCLUSIONS

This paper illustrates the room response of Teatro Comunale in Bologna without seats and in unoccupied conditions. The two forms of result representation from the acoustic measurements indicate that the parameters are slightly higher than those of an opera theatre with a comparable volume [28], underscoring the crucial role of seat absorption during live performances.

A further analysis involves a visual study of sound directivity and intensity when the sound wave bounces within the main hall. The 64-channel microphone is considered appropriate for tracing the spatial sound rays along the duration of the impulse response [29, 30].

Next steps to complete these research studies will focus on the comparison between the measured values taken before the renovation works and the results obtained without seats concerning the Teatro Comunale in Bologna.

ACKNOWLEDGMENT

This research has been granted by the Emilia-Romagna European Regional Development Fund (ERDF) Programme 2021-2027 under AGORA project (un Atelier sonoro per il Gioco, la Ricerca, l'Acustica – progetto innovativo per l'inclusione delle persone vulnerabili tramite il suono immersivo 3D delle piazze), CUP E97G22000580007.

REFERENCES

- [1] A. Bevilacqua, L. Tronchin. "The Bell-Shaped Opera Houses Realised by Antonio Galli Bibiena: Acoustic Comparison between the Communal Theatre of Bologna and the Scientific Theatre of Mantua". *Acoustics* 2023, 5, pp. 586–600.
- [2] A. Bevilacqua, L. Tronchin. "Investigations on the acoustic response of two heritage buildings designed by Galli Bibiena and disappeared from history in the 18th century: The Nancy and Tajo opera theatres". *J. Cult. Heritage*, 2024, 70, pp. 302–311.
- [3] P. Patte, "L'Essai sur l'architecture théâtrale", Paris, 1782. Italian Translation by G. Ferrario, "Storia e descrizione dei principali teatri antichi e moderni", Sala Bolognese, Torni, 1977.
- [4] A. Bevilacqua, F. Merli, A. Farina, E. Armelloni, A. Farina, L. Tronchin. "3dof representation of the acoustic measurements inside the Comunale-Pavarotti Theatre of Modena". 2021 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 08-10 September 2021.
- [5] L. Tronchin, A. Bevilacqua. "Acoustic study of different sceneries at the São Carlos national theatre of Lisbon". *Applied Acoustics*, 2021, 180, 108102, pp. 1-11.
- [6] F. Merli, A. Bevilacqua, L. Tronchin. "The "Real Teatro di Corte" of "Reggia di Caserta". Spatial sound propagation". 2021 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 8-10 September 2021.

- [7] A. Bevilacqua, S.F. Gelati, F. Merli. "Indoor environmental quality of the Valli Theatre: outcomes on sound, light and thermo-hygrometry". E3s Web of Conferences 2021, 312: 12005, DOI:10.1051/e3sconf/202131212005.
- [8] A. Bevilacqua, R. Yan. "Acoustic Discoveries of Another Masterpiece by Antonio Galli Bibiena: The Communal Theatre of Bologna". Building Simulation Applications (BSA), Bolzano, Italy, 2022 30 June –1 July 2022, doi: 10.13124/9788860461919.
- [9] L. Tronchin, A. Bevilacqua. "3D Acoustic Map Analysis of the National Theatre of Zagreb". Appl. Sci. 2024, 14, 4365. <https://doi.org/10.3390/app14114365>.
- [10] G. Amoroso. "The teatro of Bologna as a transformable space: drawing, geometry and invention in the study of the wooden model of the theatre by Antonio Galli Bibiena." Lecture Notes in Civil Engineering, 2019, 24, pp. 375-394. Doi: https://doi.org/10.1007/978-3-030-03676-8_13.
- [11] L. Tronchin, A. Bevilacqua. "Acoustic discoveries of the Carinthian Gate theatre (*Kärntnertortheater*) of Vienna: on the trace of a lost artistical building heritage". Discov Anal, 2024, 2, 15. <https://doi.org/10.1007/s44257-024-00020-3>.
- [12] Available online (accessed on 14 August 2025) <https://www.adobe.com/products/audition.html>.
- [13] A. Farina, "Aurora listens to the traces of pyramid power". Noise & Vibration Worldwide, 26(6), pp. 6-9, 1995.
- [14] ISO 3382-1: Acoustics - Measurement of Room Acoustic Parameters; Part 1: Performance Spaces; ISO: Geneva, Switzerland, 2009.
- [15] V.L. Jordan, "A group of objective acoustical criteria for concert halls". Appl. Acoust., 1981, 14, pp. 253-266.
- [16] L. Tronchin, A. Bevilacqua, R. Yan. Acoustic Characterization and Quality Assessment of Cremona's Ponchielli Theater. Appl. Sci. 2023, 13, 4057. <https://doi.org/10.3390/app13064057>.
- [17] M. Barron. "Measurement of the absorption by the auditorium seating – A model study". Journal of Sound and Vibration, 2001, 239(4), pp. 573-587.
- [18] A. Bevilacqua, A. Farina, L. Saccenti, A. Faria. "New method for the computation of acoustic parameters according to the updated Italian Legislation". 154th AES Convention, Espoo, Helsinki, Finland, 13-15 May 2023.
- [19] A. Bevilacqua, L. Tronchin. "Evaluation of Acoustic Features after Refurbishment Works Inside Two Historical Opera Theatres Located in Italy". Acoustics, 2021, 3, pp. 316–336. <https://doi.org/10.3390/acoustics3020022>.
- [20] H. Kuttruff, "Room Acoustics". Ed. Spon Press, 5th edition, pp. 131-135, 2009.
- [21] R. Wenmaekers, C. Hak. "The sound power as a reference for sound strength (G), speech level (L) and support (ST): uncertainty of laboratory and in-situ calibration". Acta Acust. United Acust. 2015, 101, pp. 892–907.
- [22] R. Yan, L. Tronchin. "Acoustic characteristics and objective evaluation of acoustic quality in historical Italian theaters". Applied Acoustics, 2025, 233, 110483.
- [23] A. Farina, A. Capra, L. Chiesi, L. Scopece. "A spherical microphone array for synthesizing virtual directive microphones in live broadcasting and post-production". In Proceedings of the 40th AES Conference, Tokyo, Japan, 8–10 October 2010.
- [24] A. Farina, A. Amendola, L. Chiesi, A. Capra, S. Campanini. "Spatial PCM sampling: A new method for sound recording and playback". In Proceedings of the 52nd AES International Conference, Guildford, UK, 2–4 September 2013.
- [25] A. Bevilacqua, G. Iannace, L. Tronchin. "Acoustic Competition for the Golden Medal of Crowd Noise Level: Insights on the Stadia and Sport Buildings in Ancient Times". Applied Sciences Switzerland, 2024, 14(18), 8221.
- [26] B.N. Gover, J.G. Ryan, M.R. Stinson. "Measurements of directional properties of reverberant sound fields in rooms using a spherical microphone array". J. Acoust. Soc. Am. 2004, 116, pp. 2138–2148.
- [27] M. Park, B. Rafaely. "Sound-field analysis by plane wave decomposition using spherical microphone array". J. Acoust. Soc. Am. 2005, 118, 3094–3103.
- [28] L. Tronchin, A. Bevilacqua. "How Much Does the Variety of Scenery and the Different Percentages of Audience Occupancy Affect the Indoor Acoustics at the National Theater of Zagreb?" Appl. Sci. 2022, 12, 6500. <https://doi.org/10.3390/app12136500>.
- [29] A. Bevilacqua, L. Tronchin, G. Iannace. "Acoustic analysis on alternative use of stadia: from circus maximum of Rome and Hippodrome of Constantinople to San Siro Stadium in Milan". Architectural Science Review, 2025, 2.
- [30] L. Tronchin, A. Bevilacqua, R. Yan. "A Project Focused on Sound Diffusion: The Acoustics of the Auditorium Yves St Laurent of Marrakech in Combination With its Innovative Architectural Design". Building Simulation Applications (BSA), Bolzano, Italy, 29 June – 1 July 2022, pp. 111–116.