

Comparison of Room Acoustics for the Small & Large Concert Halls at Vatroslav Lisinski Centre

Luca Battisti
CIRI-EC
University of Bologna
Bologna, Italy
luca.battisti5@unibo.it

Marko Horvat
Department of Electroacoustics
University of Zagreb
Zagreb, Croatia
marko.horvat@fer.unizg.hr

Kristian Jambrosic
Department of Electroacoustics
University of Zagreb
Zagreb, Croatia
kristian.jambrosic@fer.unizg.hr

Ruoran Yan
Department of Architecture
University of Bologna
Bologna, Italy
ruoran.yan2@unibo.it

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

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

Cobi van Tonder
Department of Architecture
University of Bologna
Bologna, Italy
cobi.vantonder@unibo.it

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

Abstract—A focused acoustic assessment of the 304-seat Small Hall ($\approx 2,000 \text{ m}^3$) at Zagreb's Vatroslav Lisinski Centre was conducted to verify its suitability for recitals, chamber ensembles, and spoken events. Impulse responses were captured with a 15 s exponential sine sweep at three source positions and thirty receiver points, then processed to ISO 3382-1. Early-decay time and T30 remain tightly grouped between 1.2 s and 1.6 s from 500 Hz to 4 kHz, values that foster intelligibility without sacrificing musical support. Clarity metrics reach C50 = -2 dB to 0 dB and C80 = $+1 \text{ dB}$ to $+3 \text{ dB}$, while D50 stabilises around 0.45; inter-aural cross-correlation drops to 0.21 at 4 kHz, indicating pronounced spatial width. For context, parallel measurements in the adjacent Large Hall ($\approx 42,000 \text{ m}^3$) show 0.4 – 0.6 s longer decay and 1 – 2 dB lower clarity, confirming that the Small Hall offers the sharper early-energy balance demanded by speech and small-ensemble repertoire. These results provide a quantitative basis for fine-tuning variable absorption and reinforce the hall's role as an acoustically intimate complement to the center's symphonic venue.

Keywords—*Lisinski Centre, signal processing, multi-hall comparison.*

I. INTRODUCTION

Performing-arts complexes increasingly rely on a pair of auditoria compact rooms for spoken word and chamber ensembles, and a larger space for symphonic repertoire, to cover the full spectrum of programming. Delivering acoustics that suit these divergent uses while preserving a coherent architectural identity is a recognized challenge, yet direct, matched-condition measurements of the two settings are rare. Without such data, it is difficult to judge whether each hall truly meets its intended role or whether small, targeted adjustments might widen its functional range [1].

Vatroslav Lisinski Concert Centre in Zagreb is an instructive example. The facility, completed in 1973, houses a 1840-seat Large Hall of roughly $42,000 \text{ m}^3$ and a 304-seat Small Hall of about $2,000 \text{ m}^3$. Both spaces share timber interior finishes, variable drapery, and a common technical backbone, yet they differ in geometry, stage configuration, and the distance between listeners and reflective surfaces. While previous studies have documented the Large Hall after successive refurbishments, the Small Hall has not been

surveyed under the same rigorous conditions, and no published comparison sets the two venues side by side [2].

As built in second half of the 20th century, it was common practice to design concert halls with a shoebox-shaped plan, as found in many other countries [3], as typically found in cinemas as well [4]. However, the optimal shape for both acoustics and unobstructed audience sightlines was a subject of much debate. An alternative was the vineyard shape as proposed for the Berliner Philharmonie [5]. However, the shoebox shape continues to be re-proposed for big and small concert halls [6].

The present study performed analysis of the acoustic measurements carried out in accordance with ISO 3382-1 parameters [7]. Early-decay time, reverberation, clarity indices, definition, and inter-aural cross-correlation was calculated in both halls. The analysis establishes whether the Small Hall offers shorter decay, higher clarity, and wider stereo image required for speech and chamber repertoire. It then explores how differences in volume, plan form, and surface treatment account for the measured divergence and considers the operational implications for programming and incremental acoustic upgrades within the complex, also based on occupancy condition [8].

II. HISTORICAL VALUE OF THE LISINSKI SMALL CONCERT HALL

The Vatroslav Lisinski Concert Hall was designed by a group of architects, Marijan Haberle, Minka Jurković, and Tanja Zdvořak, and construction started in 1961. The hall is named after Vatroslav Lisinski, the composer of the first Croatian opera. The Small Hall has 309 seats, divided into three sections on one level. It has also become an essential part of this Croatian temple of music, helping to make it the success it is today [2]. A view of the concert hall is shown in Figure 1.



Fig. 1. Interior view of the small hall of the Vatroslav Lisinski Small Concert Hall, Zagreb.

III. ARCHITECTURAL FEATURES OF LISINSKI SMALL CONCERT HALL

The Small Hall (Mala dvorana) occupies the eastern wing of the Vatroslav Lisinski complex and is conceived as an asymmetric fan that broadens toward the audience. Scaled from the floor plans in Figure 2, the room is 19.8 m from the stage lip to the rear wall and roughly 17 m wide on the last row, giving a floor area of about 330 m². The stage itself spans 12.0 × 7.5 m and is framed by splayed timber side walls that improve early lateral reflections [9]. Five stepped audience platforms rise from 0 m at row 3 to 0.75 m at the back, producing an average rate of 4% and ensuring unobstructed sightlines.

Seating consists of 304–305 upholstered chairs fixed to timber bases, yielding a gross volume per seat close to 7 m³, typical for chamber music spaces of this size. The ceiling height varies from 5.5 m above the stage to 6.5 m at mid-hall, where a discontinuous canopy of colored gypsum panels is suspended beneath the structural slab [10].

All vertical surfaces are clad in 25 mm hardwood veneer backed by mineral-wool infill; a portion of the panels is micro-perforated to extend absorption below 500 Hz. The stepped timber diffusers visible on the side walls (see Figure 3) supplement this treatment and break up flutter echoes generated by the shallow plan. The floor is finished in solid oak except for the black-painted birch plywood on the stage [2].

A low-profile technical gallery spanning the rear wall houses adjustable velour drapes, allowing mid- and high-frequency reverberation to be trimmed by approximately 0.2 s for spoken-word or amplified events. Lighting bridges and loudspeaker clusters are integrated between the ceiling coffers so that no equipment protrudes into the room volume [11].

Together, these features give the Small Hall a controlled, uniform sound field suited to chamber ensembles, film screenings, and conferences, while maintaining architectural coherence with the timber-lined Grand Hall.

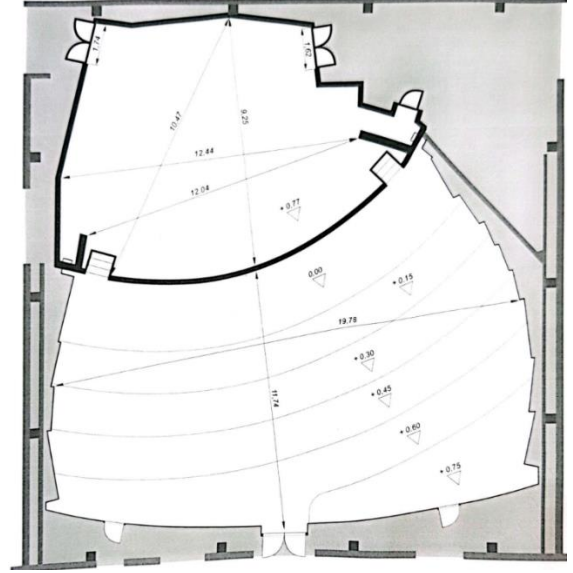


Fig. 2. Plan the layout of the Vatroslav Lisinski Small Concert Hall.

TABLE I summarizes the architectural features of the Lisinski Small Concert Hall.

TABLE I. ARCHITECTURAL FEATURES OF LISINSKI SMALL CONCERT HALL.

Description	Features
Type of plan layout	asymmetric fan shape
Total capacity (No. of seats)	305 max.
Main Hall axes (m)	19.8 × 17
Stage dimension (m)	12 × 7.5
Inclination of stalls	4%

IV. ACOUSTIC MEASUREMENTS

A campaign of acoustic measurement has been undertaken to analyse the room response of the theatre's main hall, under the current conditions. The acoustic survey was carried out with the following equipment [12]:

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

The source loudspeaker was placed 1.5 m above the stage floor, and the receivers were installed at 1.2 m to match the average ear height of seated listeners. An exponential sine sweep (ESS) [13] lasting 15 s, with a flat sound-pressure level from 40 Hz to 20 kHz, served as the excitation signal [14]. The source and equipment layout are shown in Figure 3. Measurements were conducted in an unoccupied condition,

with the equipment positioned at several selected points among the tiers of the stall, as illustrated in Figure 4.



Fig. 3. Position of the sound source (left) and the equipment setup (right) during the acoustic measurements.

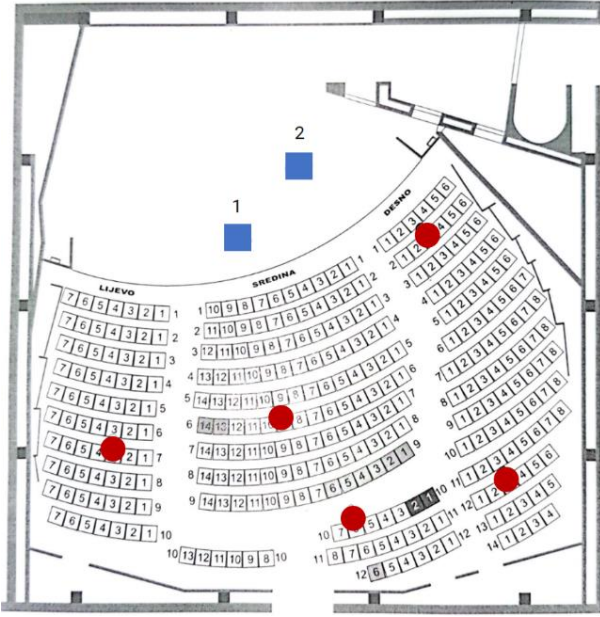


Fig. 4. Position of the equipment during the acoustic measurements highlighted: The red dots represent receivers and the blue squares represent sound sources.

V. ANALYSIS OF RESULTS

The recorded impulse responses were processed and analysed with the Aurora plug-in [15] running in Adobe Audition [16]. Monaural and binaural acoustic parameters were extracted in accordance with ISO 3382-1 [7]. Results are averaged across all receiver positions and presented as two curves: VLS for the Lisinski Small Hall and VLL for the Lisinski Large Hall.

Figures 5 to 10 summarise the measured results in the frequency domain comprised between 125 Hz and 4 kHz.

Figure 5 demonstrates that the Small Hall (VLS) exhibits a compact and well-controlled early decay: EDT rises from 1.1 s at 125 Hz to a broad maximum of 1.55 s at 2 kHz, then falls slightly to 1.40 s at 4 kHz [17]. These values place the room squarely in the range typically recommended for chamber music and spoken events. For reference, the Large Hall (VLL) traces an almost parallel trend but sits 0.4–0.6 s higher across all bands, a difference that stems from its much greater volume rather than from any change in spectral balance [18].

The same hierarchy appears in T30 (Figure 6). In VLS, reverberation increases gently from 1.20 s at 125 Hz to 1.55 s at 1–4 kHz, delivering uniform support without obscuring detail. In VLL, the curve is shifted upward, 1.9 s at 125 Hz to 2.2 s around 1 kHz—indicating the longer residual energy expected in a hall designed for large symphonic forces [19]. Crucially, both rooms follow the same shape: a modest mid-band rise caused by the timber lining and a high-frequency roll-off produced by panel and air losses.

Overall, the data confirm that the Small Hall provides the shorter decay and tighter clarity needed for recitals, conferences, and amplified speech, while the Large Hall retains the extended reverberation that gives full-orchestra repertoire the desired warmth [20].

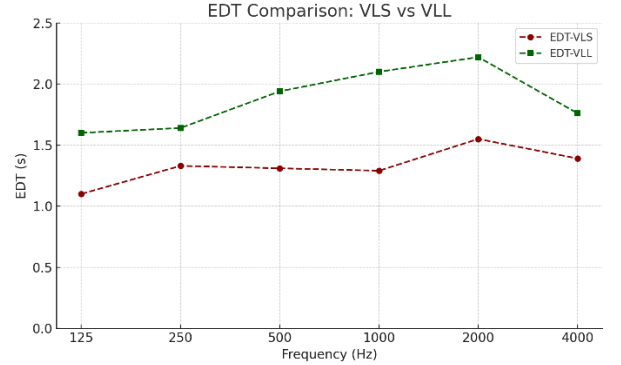


Fig. 5. Measured results of Early Decay Time (EDT).

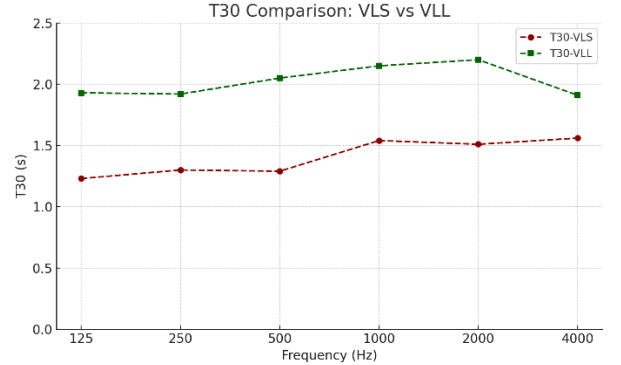


Fig. 6. Measured results of Reverberation Time (T30).

Figure 7 contrasts speech clarity (C50) in the two venues. The Small Hall (VLS) keeps C50 within -2 dB to +0 dB across the spectrum, satisfying the -2 dB to +2 dB guideline for unamplified speech [21]. The Large Hall (VLL) tracks a similar frequency profile but lies 1–2 dB lower at every octave, dipping to -4 dB at 2 kHz. The advantage in VLS stems from its smaller volume and closer side-wall distances, which raise the proportion of early energy reaching the listener [22].

Music clarity (C80) in Figure 8 shows an even larger gap. VLS ranges from +2.7 dB at 125 Hz to roughly +1 dB at 4 kHz, values that provide good note definition without excessive brightness. VLL remains near 0 dB at low-mid bands and falls to -1.8 dB at 2 kHz, a level suited to orchestral blend but less helpful for chamber detail. Both rooms recover to +0.9 dB at 4 kHz, reflecting the increased directivity of high-frequency sound and the similar seating-to-stage geometry in the front rows [23].

The Small Hall offers the stronger early-to-late balance required for spoken word and small ensembles, while the Large Hall preserves the softer definition preferred for full symphonic repertoire [24].

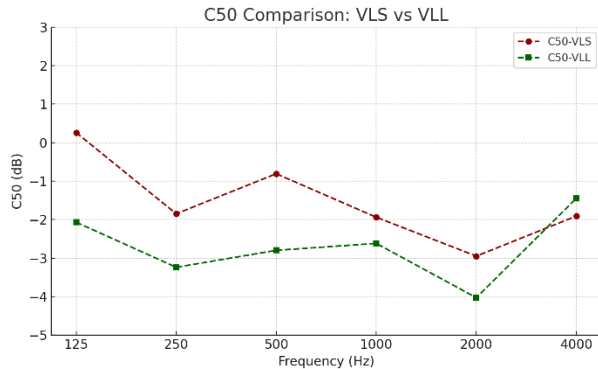


Fig. 7. Measured results of speech clarity (C50).

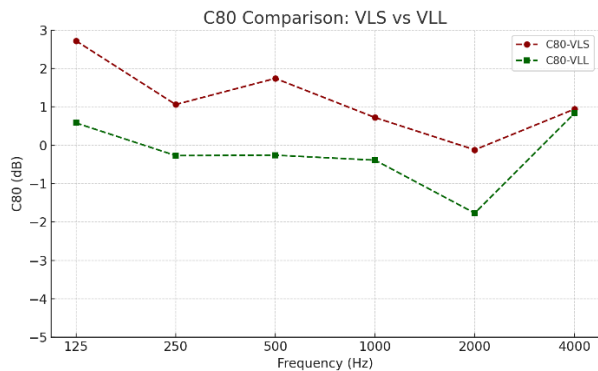


Fig. 8. Measured results of music clarity (C80).

Figure 9 confirms that the Small Hall (VLS) provides a stronger early-energy ratio at almost every octave band. D50 starts at 0.48 at 125 Hz, dips to 0.40 at 250 Hz, and stabilizes near 0.42–0.45 up to 1 kHz before falling slightly to 0.34 at 2 kHz and returning to 0.40 at 4 kHz. Except for the highest band, these values exceed those of the Large Hall (VLL) by 0.05–0.08, indicating clearer speech articulation in the smaller volume where early reflections reach the listener sooner. Both rooms stay above the 0.30 intelligibility threshold throughout the spectrum, but only VLS approaches the 0.50 target regarded as “excellent” for unamplified speech [25]. At 4 kHz VLL marginally overtakes VLS (0.42 vs. 0.40), reflecting the increased directivity of high-frequency sound and the similar stage-to-seat geometry in the first rows. Overall, the definition data reinforces the earlier findings: the Small Hall favors spoken word and chamber repertoire, while the Large Hall trades a modest loss in clarity for the longer reverberation preferred by symphonic programs [26].

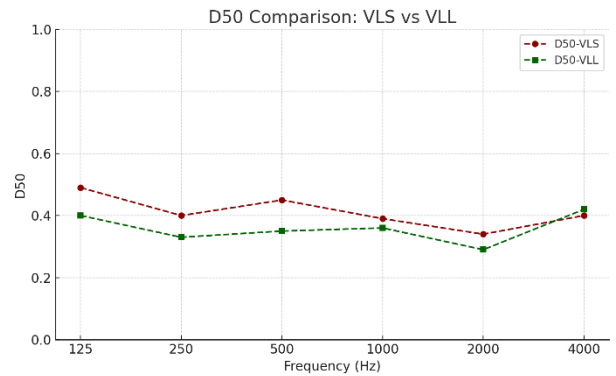


Fig. 9. Measured results of Definition (D50).

Inter-aural cross-correlation falls more sharply in the Small Hall than in the Large Hall. Below 250 Hz, both rooms remain highly correlated (≈ 0.95 at 125 Hz), consistent with the omnidirectional nature of low-frequency sound. From 500 Hz upward, however, VLS drops to 0.35 at 500 Hz and reaches 0.21 at 4 kHz, whereas VLL levels off between 0.45 and 0.36 over the same bands [27]. The 0.10–0.15 offset indicates that early lateral reflections are stronger and arrive sooner in the smaller volume, producing a broader sense of spatial envelopment. This effect is amplified by the fan-shaped plan and diffusive timber panels that place listeners closer to reflective side walls; in the larger room, the wider span and higher ceiling delay lateral energy, yielding higher mid- and high-frequency IACC values and a correspondingly narrower stereo image. The complete curves are shown in Figure 10.

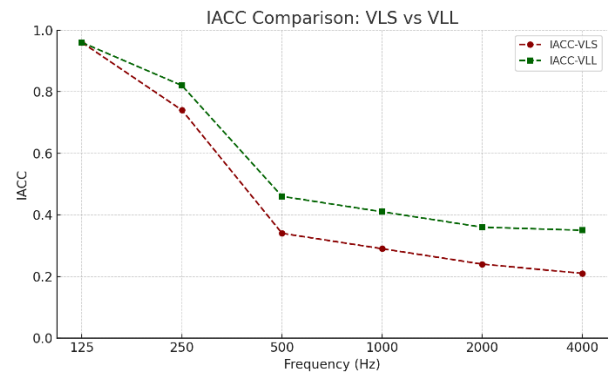


Fig. 10. Measured results of Interaural Cross-Correlation (IACC).

DISCUSSION AND CONCLUSION

The survey confirms that the Small Hall at Vatroslav Lisinski delivers a compact acoustic response tailored to recitals, chamber ensembles, and spoken-word events. Early-decay time and T30 stabilise between 1.2 s and 1.6 s from 500 Hz to 4 kHz, while speech-clarity metrics remain within, or slightly above, commonly accepted targets ($C50 \approx -2$ dB to 0 dB; $D50 \approx 0.40 - 0.48$). Inter-aural cross-correlation falls to 0.21 at 4 kHz, indicating a wide stereo image and strong spatial definition [28]. These results satisfy guidelines for rooms of similar volume and align with the design intent of providing articulate yet supportive acoustics for smaller audiences.

Comparison with the Large Hall highlights two complementary roles. The larger volume prolongs decay by

0.4–0.6 s and reduces clarity by roughly 1–2 dB across most octaves, trading intelligibility for the warmth valued in full orchestra repertoire [29]. The Small Hall counters with higher early-energy ratios, closer side-wall distances, and a steeper drop in IACC above 500 Hz, all of which enhance articulation and sense of intimacy. Together, the two venues offer the venue operator a balanced programme capacity ranging from amplified lectures to symphonic concerts [30].

Architectural factors explain the differences measured. In the Small Hall, the fan-shaped plan, stepped timber diffusers, and micro-perforated wall panels shorten the early-to-late gap and promote lateral reflections. The Large Hall's greater ceiling height, single-volume shoebox, and suspended reflector cloud store more reverberant energy but delay side-wall contribution. Both rooms benefit from timber finishes that raise mid-band reverberation by approximately 0.2 s relative to low frequencies, producing the smooth spectral decay preferred for music [31, 32].

Measurements were carried out without an audience; seating occupancy will reduce mid- and high-frequency decay by 0.1–0.2 s in both rooms and may lift C50 by up to 1 dB. Future studies should repeat the campaign with a full audience and examine the influence of variable drapery settings, particularly in the Small Hall, where speech reinforcement is frequent. Auralisation of alternative stage layouts could also support programming decisions [33, 34].

Overall, the data show that the Small Hall meets its design brief for clarity and intimacy, while the Large Hall retains adequate reverberant support for large-scale works. Limited, targeted adjustments, such as retractable banners in the Large Hall for spoken events or modest bass trapping in the Small Hall for amplified music, would further widen the usable range without compromising the acoustic identity of either space [35].

ACKNOWLEDGMENT

The measurements conducted for this research have been made possible by an Erasmus++ grant, co-funded by the European Union, KA210-VET - Small-scale partnerships in vocational education and training, titled AURALIZE - Project No. 2024-1-IT01-KA210-VET-000245142. Measurements were conducted by L. Tronchin, K. Jambrošić, M. Horvat, C. van Tonder, A. Farina, L. Battisti, and R. Yan.

REFERENCES

- [1] A. Bevilacqua, A. Martinetti, G. Tentoni. "The workmanship of luthiers in the house of violin: The Auditorium G. Arvedi of Cremona and the acoustic features suggested by Toyota and Nagata". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [2] A. Unkic. "The Vatroslav Lisinski Concert Hall (Zagreb): An exclusive space and/or a place of diversity". The Caring State and Architecture: Sites of Education and Culture in Socialist Countries, 137.
- [3] N. Granzotto, R. Yan, L. Tronchin. "Measurements of Room Acoustic and Thermo-Hygrometric Parameters—A Case Study". Applied Sciences, 2023, 13(5), 2905.
- [4] R. Yan, L. Tronchin. "Acoustic characteristics and objective evaluation of acoustic quality in historical Italian theaters". Applied Acoustics, 2025, 233, 110483.
- [5] W. Lachenmayr. "Influence of acoustics on emotional impact of music in Konzerthaus and Philharmonie Berlin". In: DAGA German Acoustic Society. Aachen, Germany, March 2016, pp. 297–300.
- [6] 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".

- 6th Building Simulation Applications (BSA), Bolzano, Italy, 26-28 June 2024.
- [7] ISO 3382-1: Acoustics - Measurement of Room Acoustic Parameters; Part 1: Performance Spaces; ISO: Geneva, Switzerland, 2009.
- [8] L. Tronchin, C. Van Tonder, A. Bevilacqua. "Acoustic analysis of the Manoel Theatre in Malta". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [9] 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>.
- [10] L. Tronchin, C. Van Tonder, A. Bevilacqua. "Acoustic analysis of the Manoel Theatre in Malta". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [11] A. Bevilacqua, F. Merli. "Different Techniques for Measuring Spatial Sound Properties of Auditoria: a Review". URICSE J. Phys., 2020, Conf. Ser. 1655, 012111.
- [12] C. Van Tonder, R. Yan, L. Tronchin. "An examination of the acoustic characterization of Teatro India Sala Oceano in Rome". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [13] A. Farina, "Advancements in impulse response measurements by sine sweeps", 122nd AES Convention, 2007, 3, pp. 1626-1646.
- [14] J. Patynen, "Investigations on the development of the frequency response over time in concert halls". Proc. of the Institute of Acoustics, 2011, pp. 159-168.
- [15] A. Farina, "Aurora listens to the traces of pyramid power". Noise & Vibration Worldwide, 1995, (26)6, pp. 6-9.
- [16] Available online (accessed on 14 August 2025) <https://www.adobe.com/products/audition.html>.
- [17] L. Cremer, A. Muller, "Principles and Applications of Room Acoustics". Peninsula Publishing: Westport, CT, USA, 1982, pp. 503-509.
- [18] 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.
- [19] R. Pompoli, N. Prodi, "Guidelines for acoustical measurements inside historical opera houses: Procedures and validation". J. of Sound and Vibration, 2000, 232, pp. 281-301.
- [20] 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.
- [21] 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". Journal of Cultural Heritage, 2024, 70, pp. 302–311.
- [22] L. Tronchin, A. Bevilacqua. "The Royal Tajo Opera Theatre of Lisbon: From architecture to acoustics". J. Acoust. Soc. Am., 2023, 153(1), pp. 400-414.
- [23] 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, pp. 1–18. <https://doi.org/10.1080/00038628.2025.2506546>.
- [24] L. Tronchin, A. Bevilacqua, R. Yan, C. Van Tonder. "Explore the acoustics of Teatro dell'Opera of Rome". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [25] L. Tronchin, C. Van Tonder, R. Yan. "A study on the spatial sound propagation characteristics of the Argentina Theater in Rome". 2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA), Bologna, Italy, 5-7 September 2023.
- [26] C.C.J.M. Hak, R.H.C. Wenmaekers, L.C.J. Van Luxemburg. "Measuring room impulse responses: Impact of the decay range on derived room acoustic parameters". Acta Acust. United Acust. 2012, 98, pp. 907–915.
- [27] 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>.

- [28] A. Bevilacqua, F. Merli, L. Tronchin. "Verdi theater of Salerno: A deepening acoustic research". In *Proceedings of the International Congress on Immersive 3D Audio (I3DA)*, Bologna, Italy, 5–7 September 2021.
- [29] L. Tronchin, A. Bevilacqua. "Acoustic discoveries of the Carinthian Gate theatre (Kärntnertortheater) of Vienna: on the trace of a lost artistic building heritage". *Discovery Analytics*, 2024, 2(15).
- [30] C. Van Tonder, R. Yan, L. Tronchin. "Teatro India Sala B: acoustic analysis and descriptions". *2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA)*, Bologna, Italy, 5-7 September 2023.
- [31] A. Bevilacqua, G. Tentoni, A. Martinetti. "Sweet melody: the acoustic analysis of the Auditorium Paganini realized inside a dismissed sugar factory". *2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA)*, Bologna, Italy, 5-7 September 2023.
- [32] R. Yan, C. Van Tonder, L. Tronchin. "Characteristics of the Teatro India Sala A of Rome: new acoustic perspectives". *2023 Immersive and 3D Audio: from Architecture to Automotive (I3DA)*, Bologna, Italy, 5-7 September 2023.
- [33] K.L. Payton U.M. Uchanski, L. B. "Intelligibility of conversational and clear speech in noise and reverberation for listeners with normal and impaired hearing". *J Acoust Soc America*, 1994, 95.3, pp. 1581–1592.
- [34] F. Bettarello, M. Caniato, G. Scavuzzo, A. Gasparella, "Indoor Acoustic Requirements for Autism-Friendly Spaces", *Appl. Sci.* 2021, 11, 3942.
- [35] F. Bettarello, L. Caniato, M. Caniato, "Seven Centuries of Church Architectural Evolution and Its Influence on Indoor Acoustics: The Case of the Dome of Conegliano in Italy" *Buildings*. 2023, 13(2), pp. 299.