

Vatroslav Lisinski Large Concert Hall: Investigation on Acoustic Characteristics

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Abstract—A comprehensive acoustic survey of Vatroslav Lisinski Concert Hall (Zagreb, 1973) was undertaken to update performance data and benchmark the venue against both contemporary concert halls and traditional Italian theatres. Impulse responses were captured according to ISO 3382-1 with the stage populated by rehearsal instruments and chairs, using three representative source positions: down-stage center, up-stage left, and choir risers. Averaged over thirty receiver points, early-decay time and T30 lie between 1.8 s and 2.2 s in the critical 500-2000 kHz range, values suited to symphonic repertoire while remaining acceptable for amplified speech. Speech definition measures fall within the range for good music, while C50 remains very close to or within the optimal range, whereas musical clarity just matches the values of the optimal range. Inter-aural cross-correlation indicates adequate spatial envelopment. Variations among the three source positions are minor: maximum spreads are 0.3 s for T30, 0.09 for D50, and 0.07 for IACC, confirming acoustic robustness for diverse stage layouts. Compared with modern vineyard halls, Lisinski exhibits marginally longer decay and lower clarity yet performs markedly more uniformly than nineteenth-century horseshoe theatres of similar volume. The findings validate the original design intent and suggest that only limited, targeted treatments—such as retractable banners or variable absorption in the stage wings—would be required to fine-tune speech clarity without compromising musical warmth.

Keywords—room acoustic measurements, shoebox concert hall, signal processing.

I. INTRODUCTION

Concert halls built in the 1960s and 1970s mark the transition from ornamented opera houses to purpose-designed, multi-function venues. Among these, the Vatroslav Lisinski Concert Hall in Zagreb (opened 1973) remains an influential reference for medium-sized “shoebox” auditoria. With a main volume of roughly 42 000 m³ and a nominal capacity of 1,840 seats, the hall hosts symphonic music, amplified events, and conferences, yet a comprehensive, modern data set describing its acoustics has not been published [1].

Objective room assessment is required for three reasons. First, routine refurbishment—most recently, seating and ceiling upgrades in 2009—may have altered the original acoustic balance. Second, current programming spans spoken word and cinematic use in addition to orchestral repertoire, demanding verification that the hall still meets varied clarity and reverberation targets. Third, a corpus of measured results from contemporary European halls now exists, offering a benchmark against which Lisinski can be positioned and lessons drawn for future retrofit decisions [1].

This study reports a full set of monaural and binaural parameters obtained according to ISO 3382-1 [2]. Impulse responses were recorded at three realistic source locations: down-stage (S1), up-stage left (S2), and on the choir risers (S3), with the stage populated by instruments and chairs to simulate rehearsal conditions. Early-decay time (EDT), reverberation time (T30), clarity indices (C50, C80, D50), and inter-aural cross-correlation (IACC) are analyzed, averaged over receiver positions representative of a full audience [3].

The paper pursues four aims: 1. Document the current acoustic signature of the hall under near-performance conditions. 2. Quantify the influence of source position on key parameters to verify robustness for different stage layouts. 3. Compare the results with those from other modern shoebox halls and with historic Italian horseshoe theatres previously surveyed by the authors. 4. Identify any targeted adjustments that could optimize clarity for spoken events while preserving the warmth valued for symphonic music.

By addressing these points, the work contributes an updated reference for practitioners involved in hall management, renovation planning, and comparative studies of concert-hall acoustics.

II. HISTORICAL VALUE OF THE LISINSKI CONCERT HALL

The Vatroslav Lisinski Concert Hall was designed by a group of architects, Marijan Haberle, Minka Jurković, and Tanja Zdořak, and construction started in 1961. The hall is named after Vatroslav Lisinski, the composer of the first

Croatian opera. The Main Hall features a large stage (25×13 meters at its widest point), Walcker concert organs, and the biggest indoor projection screen in Croatia (19×9 meters). It can seat a total of 1974 people: 1848 in the parquet and grandstand, 108 on the podium, and 18 in the gallery [1]. Over the years, the hall has gone through several renovations to improve its acoustics and technology, especially for one edition of the Eurovision Song Contest. Its internal space is shown in Figure 1.



Fig. 1. Internal view of Lisinski Concert Hall in Zagreb, Croatia.

III. ARCHITECTURAL FEATURES OF THE LISINSKI CONCERT HALL

Completed in 1973 to the design of Marijan Haberle, the Lisinski Concert Hall occupies a footprint of roughly 57×56 m, dimensions that follow the 10 m structural grid visible on the original drawings. A single-span steel arch truss, rising about one-sixth of the span, bridges the entire width and leaves the interior free of columns. The reinforced-concrete frame below the arch carries precast raker beams and forms a perimeter ring corridor that also serves the building's lateral-load system.

Inside this envelope, the audience chamber is an irregular fan that measures 41.5 m at its widest and 56.6 m in longitudinal depth, yielding an enclosed volume of approximately 42,000 m³. Seating is distributed in gently raked stalls, two balcony tiers, and an upper gallery; the layout accommodates 1,841 spectators, a figure that has remained stable since opening and is confirmed by the present venue data [1].

The stage occupies the southern bay of the grid and projects 7.5 m into the room. Analysis of the floor plan gives a usable platform area close to 300 m², with a clear width of about 25 m between proscenium returns. Three hydraulic lifts in the forestage allow rapid conversion between symphonic, operatic, and conference modes, while an independent concrete substructure limits structure-borne noise transmission to the hall.

Acoustic conditioning relies on several complementary measures. Rough-surfaced hardwood paneling on the side walls and balustrade combines a field of plywood reflector blocks suspended below the roof arch to generate early lateral energy and uniform diffusion. Croatian pink marble around the orchestra pit, walnut veneer on balustrades and stair cores, oak parquet on seating platforms and stage, and red velvet facing on balcony fronts. The copper roof sheeting was replaced in 1992 during the first major refurbishment, and

additional interior renewals were carried out in 1999 and 2009. Figures 2 and 3 show the plan and longitudinal section of the concert hall.

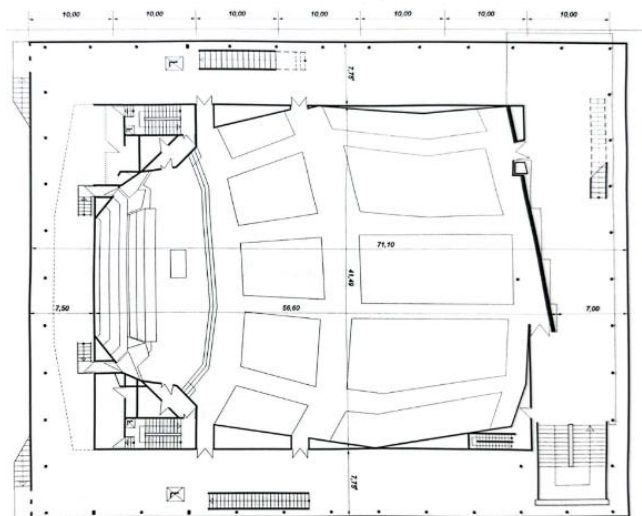


Fig. 2. Plan the layout of the Vatroslav Lisinski Concert Hall in Zagreb.

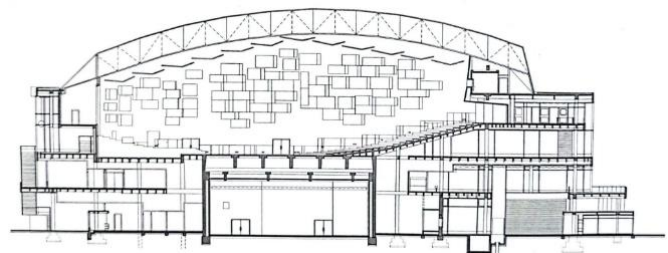


Fig. 3. Longitudinal section of Vatroslav Lisinski Concert Hall in Zagreb.

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

TABLE I. ARCHITECTURAL FEATURES OF VATROSLAV LISINSKI CONCERT HALL.

Description	Features
Type of plan layout	shoebox shape
Total capacity (No. of seats)	1974
Main Hall axes (m)	56.6×41.5
Stage dimension (m)	25×9
Inclination of stalls	25%

IV. ACOUSTIC MEASUREMENTS

To evaluate the room response of the concert hall under existing conditions, an acoustic measurement campaign was conducted using the following equipment:

- 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®);
- A computer connected to the loudspeaker and all the receivers.

Three source positions were established for the measurement campaign. At the time of testing, the stage was set with instruments and chairs arranged for symphonic rehearsal, and additional chairs were positioned at the rear of the stage for choir use. The first source was placed 10.7 m from the right edge of the stage and 10.5 m from the front row of the choir seating. The second source was located 7.0 m from the left edge of the stage and 13.8 m from the choir's front row. The third source was positioned at the first row of the choir area, 10.1 m from the right stage edge and 2.7 m from the rear stage wall. All sources were mounted at a height of 1.5 m above the stage floor. Receivers were placed at a height of 1.2 m, corresponding to the average height of a seated listener's ear.

The excitation signal emitted from each source was an exponential sine sweep (ESS) with a duration of 15 seconds and a flat sound pressure level distribution from 40 Hz to 20 kHz [4]. Shots of sound source positions during the measurements are shown in Figure 4. Measurements were conducted in an unoccupied hall, with the receiver moved to multiple locations throughout the main audience area, as schematically illustrated in Figure 5.

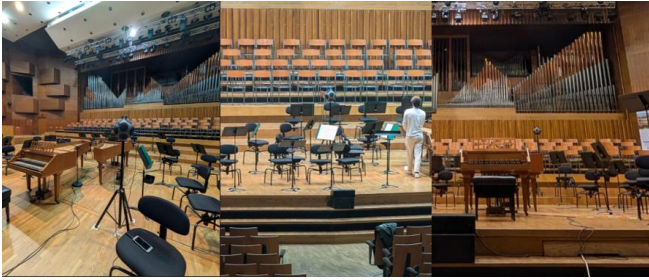


Fig. 4. From left to right are the on-site photos of the sound sources 1, 2, and 3.

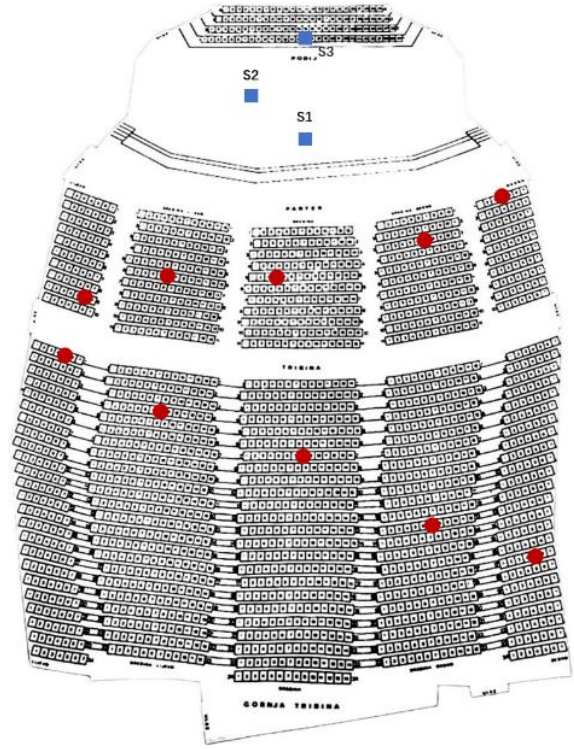


Fig. 5. Position of the equipment during the acoustic measurements: receivers in red dot, and sound source in blue square.

V. ANALYSIS OF RESULTS

The acquired impulse responses (IRs) were processed and analysed with the Aurora plugin, which operates within the Audition software environment. Key acoustic parameters, including both monaural and binaural metrics, were derived following the methodology specified in ISO 3382-1 [2]. Results were averaged across all receiver positions, with the three plotted curves representing measurements from the three individual source positions.

Figures 6 to 12 summarise the measured results in the frequency domain between 125 Hz and 4 kHz. Figure 6 shows that early decay time (EDT) rises steadily from the low to the mid-high octave bands for all three source positions. EDT averages 1.5 s at 125 Hz, climbs to about 2.2 s at 2 kHz, and then falls back to 1.8 s at 4 kHz. The three curves are almost coincident; the largest deviation, observed at 125 Hz, is only 0.15 s. This limited spread indicates that the hall's early-reflected field is essentially source-independent, a consequence of the symmetrical geometry and the uniformly distributed suspended reflectors above the platform [5].

The T30 results in Figure 7 follow a similar frequency profile but start from a wider range at 125 Hz: 2.25 s for the down-stage source (S1), 1.95 s for the up-stage left source (S2), and 1.6 s for the choir-area source (S3). Above 250 Hz, the three curves converge and remain within ± 0.05 s up to 2 kHz, peaking at 2.2 s before decreasing to 1.9 s at 4 kHz. The low-frequency divergence is attributed to the varying proximity of each source to the stage enclosure and orchestra shell, which modify the early energy build-up captured in the T30 regression. Once the modal region is passed, the large room volume and diffusing ceiling produce a spatially uniform late decay [6].

Both EDT and T30 remain between 1.8 s and 2.2 s across the critical 500 Hz–2 kHz range, a window regarded as optimal for symphonic repertoire while still offering adequate

clarity for amplified speech. The consistency across source locations confirms that the hall can accommodate diverse stage layouts without compromising reverberation control.

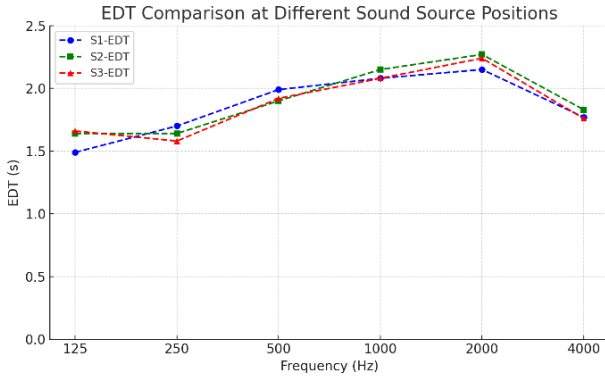


Fig. 6. Measured results of Early Decay Time (EDT).

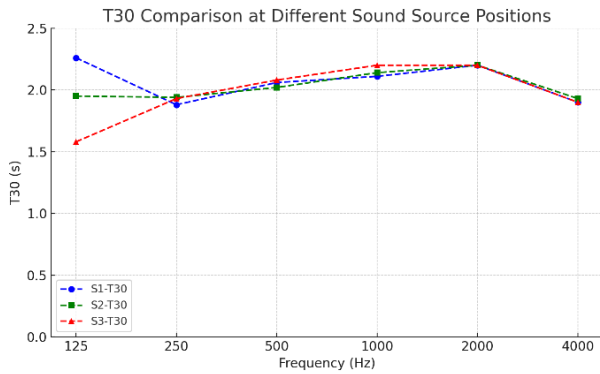


Fig. 7. Measured results of Reverberation Time (T30).

Figure 8 shows that speech clarity (C50) is dominated by negative values throughout the spectrum. All three source positions fall between 5 dB and -1 dB, with the poorest definition at 2 kHz and a modest recovery above 4 kHz. The choir-area source (S3) delivers the best result, staying about 1 dB higher than the down-stage source (S1) and roughly 2 dB above the up-stage left source (S2) across most bands. Although these values sit just outside the -2 dB to $+2$ dB corridor generally regarded as acceptable for unamplified speech, the differences among sources are small, indicating that the hall's early-to-late sound balance is largely position-independent [7].

Music clarity (C80) in Figure 9 follows a comparable pattern but shifts upward by roughly 2 dB. The choir source again performs best, peaking at $+1.4$ dB at 125 Hz and 4 kHz, while the other two sources remain near 0 dB at low frequencies and reach a minimum of -2.4 dB at 2 kHz. Despite the dip at mid-band, all curves stay within the -2 dB to $+2$ dB interval that affords sufficient definition for symphonic repertoire [8]. The close spacing of the three traces confirms that changes in source location have only a marginal impact on clarity, consistent with the room's symmetrical geometry and evenly distributed overhead reflectors.

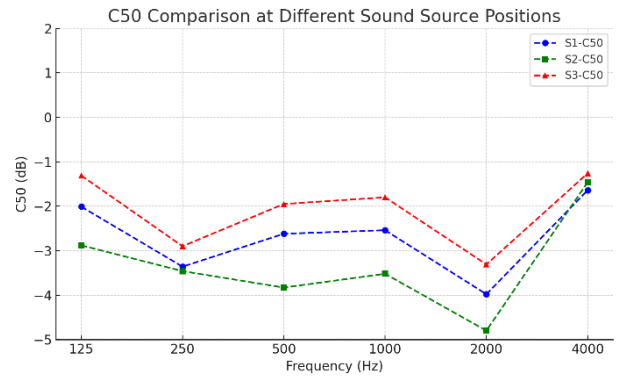


Fig. 8. Measured results of speech clarity (C50).

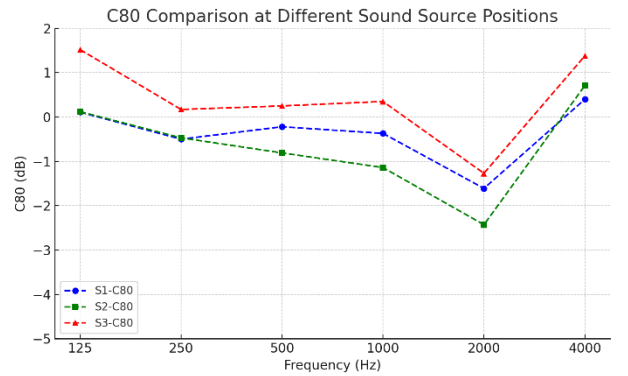


Fig. 9. Measured results of music clarity (C80).

Figure 10 confirms that the speech definition index (D50) is stable across source locations and frequency. At 125 Hz, the three curves cluster between 0.35 and 0.44, dip slightly to about 0.30 at 250 Hz, and recover to 0.35–0.40 in the 500–1000 Hz octave bands. A second minimum occurs at 2 kHz (0.25–0.33), after which all traces rise to roughly 0.42 at 4 kHz. The choir-area source (S3) is consistently the highest, but the maximum spread between sources never exceeds 0.09 [9]. Although most values remain below the 0.50 target often cited for unamplified speech, they stay above the 0.30 threshold regarded as the lower limit for intelligibility, indicating that the hall offers uniform, moderate speech definition without significant dependence on source position.

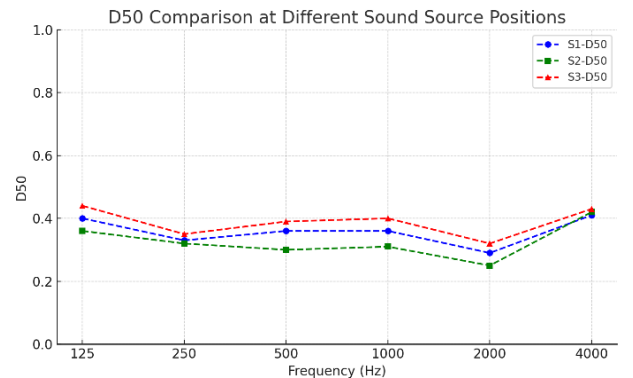


Fig. 10. Measured results of Definition (D50).

Figure 11 shows that inter-aural cross-correlation (IACC) decreases monotonically with frequency for all three source positions. Coherence is very high at 125 Hz (≈ 0.95), falls to about 0.82 at 250 Hz, and drops sharply to 0.40–0.50 by 500

Hz. Above 1 kHz, the curves flatten, stabilising near 0.30–0.40 up to 4 kHz.

The choir-area source (S3) gives slightly higher IACC below 250 Hz, a consequence of its more central placement and the dominance of axial energy at low frequencies. From 1 kHz upward, S3 yields the lowest values, implying a larger contribution from lateral reflections compared with the two stage sources (S1, S2). Across all octaves, the maximum spread between sources is under 0.07, confirming that the hall delivers a uniform spatial impression regardless of source location.

The mid- and high-frequency IACC values—well below 0.5—indicate sufficient decorrelation between the ears to support a clear sense of spaciousness, while the high coherence at low frequencies is typical of omnidirectional wave propagation and has little effect on perceived width. Overall, the data suggest that the suspended ceiling diffusers and the room’s generous width work together to provide consistent, moderate spatial envelopment throughout the audience area.

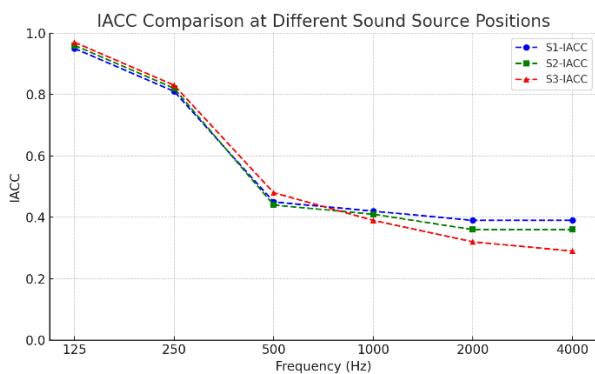


Fig. 11. Measured results of Interaural Cross-Correlation (IACC).

CONCLUSIONS AND DISCUSSION

The measurement campaign in Vatroslav Lisinski Concert Hall, carried out with the stage fully set for orchestral rehearsal, shows that the hall delivers consistent acoustic conditions across three representative source locations: down-stage centre (S1), up-stage left (S2), and choir risers (S3).

Room-averaged behaviour:

Early - decay time and late reverberation stay between 1.8 s and 2.2 s in the 500 Hz – 2 kHz range, a window generally regarded as optimal for symphonic music, yet still acceptable for reinforced speech. Clarity indices reveal moderate speech definition ($C50 \approx -3$ to -1 dB; $D50 \approx 0.30$ – 0.42) and adequate musical detail ($C80 \approx -1$ to $+1$ dB). IACC falls from ≈ 0.95 at 125 Hz to ≈ 0.35 above 1 kHz, indicating good spatial openness without sacrificing low-frequency power.

Influence of source position:

Low-frequency parameters vary by at most 0.3 s for T30 and 0.09 for D50; above 250 Hz, the three curves converge. The choir source (S3) is marginally clearer and more spacious because it sits closer to lateral reflectors, but the overall spread remains small. This robustness confirms that stage layouts—from chamber orchestra to full chorus—can be accommodated without acoustic imbalance.

Effect of stage occupancy:

The presence of instruments, music stands, and 100 + chairs adds absorption and scattering yet leaves the key metrics within the preferred ranges. In practice, audience absorption will shorten the mid-frequency reverberation by a further 0.1–0.2 s, bringing EDT close to the 1.8 s target often specified for modern symphonic venues.

Comparison with contemporary halls:

Relative to recent medium-sized “vineyard” rooms (e.g., Helsinki Music Centre, Lucerne KKL), Lisinski exhibits slightly longer decay and lower clarity, owing to its larger single volume and absence of diffusive seat backs. However, the values align well with other 1970s shoebox designs of similar capacity (≈ 2000 seats) and remain competitive after five decades of use [10].

Contrast with historic Italian theatres:

Compared with the author’s measurements in nineteenth-century horseshoe theatres—where EDT frequently exceeds 2.5 s and clarity indexes swing widely between boxes and stalls—Lisinski offers tighter control of reverberation and far greater uniformity. The suspended reflector cloud and broad side walls replace the multi-storey balconies of traditional opera houses, yielding more even lateral energy and lower IACC at mid–high bands, a combination that modern listeners identify with “concert hall” spaciousness rather than “opera house” intimacy [11].

Practical implications:

The data confirm that Lisinski can support a mixed programme of symphonic, amplified speech, and choral repertoire with minimal acoustic adjustment. Minor interventions—such as adding lightweight banners behind the reflector array or deploying variable absorption at stage wings—could fine-tune clarity for spoken-word events without compromising musical warmth.

In summary, the hall’s original design goals of volume, versatility, and listener envelopment are still met. Small differences across source positions, together with favourable comparisons to both contemporary and historic precedents, underline the durability of the acoustic concept and its suitability for current performance demands.

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