Comparative analysis of acoustic parameter measurements over time: A case study of the National Theatre in Zagreb

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Introduction

Multi-year acoustic assessments are essential for evaluating the stability and possible variation of room acoustic performance over time. In historic theatres, where both architectural preservation and active use intersect, repeated measurements help detect subtle changes due to aging materials, renovations, or evolving operational conditions.


Figure 1: Internal view of the National Theatre, Zagreb.

This study presents a comparative acoustic analysis of the National Theatre in Zagreb, Croatia, based on measurement campaigns conducted in 2022 and 2025. Identical measurement procedures were adopted across both campaigns to allow direct comparison.

The results are analysed following ISO 3382-1, with particular attention to provide insights into the temporal stability of acoustic characteristics in historic performance spaces and contributes reference data for monitoring heritage buildings in continued use.

History and architecture

The Croatian National Theatre, located in the heart of Zagreb, is one of the most important symbols of the country's cultural and artistic identity. It was opened in 1895, thanks to Emperor Franz Joseph I, and designed by the famous Viennese architects Herman Helmer and Ferdinand Fellner, who built many beautiful theatres across Europe. Inside, the audience seating is arranged across three levels. A view of the theatre is shown in Figure 1. Table 1 instead reports main architectural features

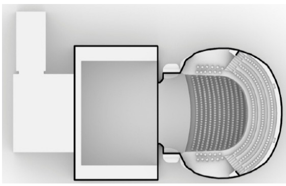
Figure 2: Plan the layout of the National Theatre

Description	Features
Type of plan layout	U-shape
Total capacity	765
Main Hall axes	17.6 × 17.6 m
Stage dimension	24.1 × 15 m
Inclination of stalls	0%

Table 1: Architectural features of National Theater, Zagreb

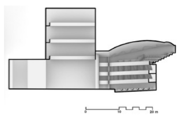
Figure 3: Longitudinal section of the National Theatre

Overhead, the main auditorium is enclosed by an ornate vaulted ceiling, centrally adorned with a chandelier. The orchestra may be positioned in the dedicated orchestra pit. The first-order box partitions are embellished with statues symbolizing the Muses. The plan and longitudinal sections are shown in Figures 2 and 3.

Experiments

An acoustic measurement campaign was conducted to assess the current room response characteristics. The 2025 measurements equipment strictly replicated the 2022 survey, in exception for a new sound source point. The set of devices was

- 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®

The loudspeaker was mounted at a height of 1.5 meters from the stage floor, while microphone positions were set at 1.2 meters above the ground to simulate the average ear height of a seated listener. An Exponential Sine Sweep (ESS) signal, spanning the 40 Hz to 20 kHz frequency range and lasting 15 seconds, was used as the excitation signal.

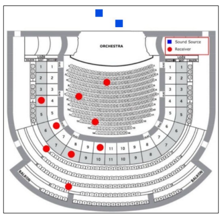

Figure 4: Position of source and receiver during the acoustic measurements.

All measurements were performed under unoccupied conditions. Microphones were distributed across various listener positions, covering both the stalls and the elevated boxes. Receiver placements were identical to those used in the previous campaign to ensure consistency and to isolate any variations from temporal changes. The source and receiver locations are shown in Figure 4.

Results

ISO acoustic parameters

The collected impulse responses (IRs) were post-processed and analysed to extract key room acoustic parameters, including both monaural and binaural metrics following the procedures defined in ISO 3382-1. The final results reflect the averaged values across all receiver locations.

Reverberation time

Both Early Decay Time (EDT) and Reverberation Time (T30), parameters exhibit a similar overall trend: values systematically decrease as frequency increases. In terms of EDT (Figure 5), a noticeable difference is observed between the past and current measurements. T30 (Figure 6) shows a more consistent pattern between all curves. Both past and current data for boxes and stalls are closely aligned. The overall reverberant field of the space has remained stable over time.

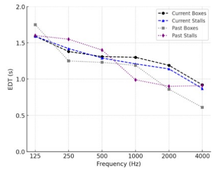

Figure 5: Comparative results of Early Decay Time (EDT).

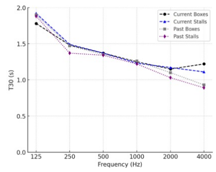

Figure 6: Comparative results of Reverberation time (T30).

Clarity index

C80 values increase with frequency. Compared to the past data, the current boxes show lower C80 values across most frequencies, indicating a slight reduction in perceived clarity in that area. Current stalls exhibit improved clarity. A spatial redistribution of clarity is recorded. Figure 7 displays the clarity index C80.

Definition

D50 in Figure 8 increases steadily with frequency in all cases. The current stalls consistently exhibit higher values than the current boxes, indicating improved speech intelligibility in the stalls. Compared to past values, current boxes show a modest increase only at higher frequencies (2000–4000 Hz). The past boxes continue to show the highest D50 overall.

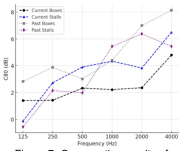

Figure 7: Comparative results of Clarity index (C80).

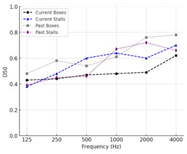

Figure 8: Comparative results of Definition (D50).

Acoustic maps

The direct sound wave impacting the microphone probe is distinguishable as the initial and most intense energy front as shown in acoustic map of Figure 9. The wavefront appears sharply defined and symmetrical. The highest sound pressure level is concentrated in the range represented by the red contour zones.

The wavefront's shape and uniform intensity distribution also suggest a clear line of sight and low diffraction interference at this measurement position.

Figure 10 captures a prominent reflection arriving from the left side wall, with sound energy concentrated in the red and orange contours. The lateral arrival direction suggests that the sound wave has traveled across the room before reflecting off the vertical boundary, contributing to spatial impression and listener envelopment. The smooth surface of the side wall results in a coherent reflection pattern with minimal diffusion.

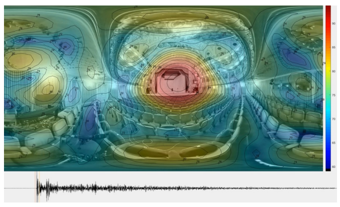
Figure 9: Direct soundwave hitting the microphone probe

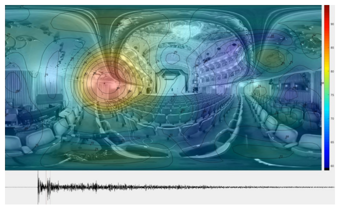
Figure 10: reflection hitting the side wall.

Conclusions

This study presented a comparative acoustic analysis of the National Theatre in Zagreb, based on measurements conducted in 2022 and 2025. Key acoustic parameters were examined across audience areas to assess temporal changes and spatial variations.

Results show that reverberation times remained consistent over time, indicating stable reverberation characteristics. However, changes in clarity-related parameters (C80, D50) suggest a redistribution of acoustic energy, with improved performance in the stalls and slightly reduced clarity in the boxes.

Acoustic maps provide visual confirmation of direct sound arrival and early and late reflections. These insights enhance understanding of the theatre's acoustic behavior and support future preservation or adjustment efforts.

Acknowledgement

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.