From Theatre to Cinema to Theatre Again: The Acoustic History of the Vittorio Emanuele II Theatre of Benevento Through Simulations

Gino Iannace – University of Campania, Italia – gino.iannace@unicampania.it
Antonella Bevilacqua – University of Parma, Italia – antonella.bevilacqua@unipr.it
Umberto Berardi – Toronto Metropolitan University, Toronto, Canada – uberardi@torontomu.ca

Abstract

The Vittorio Emanuele II Theatre of Benevento was designed with a horse-shoe shaped plan, following the architectural trend 1860. The project, originally designed by architect Francesconi, was modified after World War II due to the development of cinema, which replaced traditional theatrical performances. To accommodate this shift, the room volume was reduced, as the screen was installed at the fire curtain level, effectively eliminating the fly tower. Additionally, the wooden balustrade was replaced with glass to provide a clearer view of the screen.
Acoustic measurements were carried out inside the theatre according to ISO 3382-1. The main acoustic parameters were evaluated and compared with the theatre's original function as a performance venue. The measured and simulated results indicate that the acoustic response is well-suited for an amplified audio system, though it is perceived as drier compared to its historical function.

1. Introduction

Benevento is a city located in southern Italy, historically known as a centre of sound, first with the presence of the Witch Valley, later with the Roman Theatre, which served as a cultural hub during the Roman Empire, and finally with the construction of the Vittorio Emanuele II Theatre, one of the opera houses dating back to the 19th century. Throughout its history, this theatre has undergone different renovation works, not only to comply with safety regulations but also to accommodate the evolving needs of the local community for new types of events.

2. Historical Background

In 1850 a commission composed of representatives from the City Council and the Vatican was established to select the architect, contractor, and location for a new opera house.
The design project was awarded to architect P. Francesconi during a period when the entire city was undergoing to urban transformations approved by Pope Pius IX. Francesconi designed a horseshoe-shaped layout featuring three levels of balconies and a top gallery (*loggione*), as shown in Fig 1.

Fig. 1 – Internal view of the Vittorio Emanuele II theatre of Benevento

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A distinctive feature of this opera house is the presence of a resonance box beneath the stalls floor, 1.28 m deep, a construction technique also used in other opera theatres to improve low frequencies.
The completion of the works was delayed from 1854 to 1862, with a final quality check conducted in 1866, the same year as its official opening.
Throughout the following century, different restoration projects took place, including the addition of two doors on the stage, the transition from candlelight to electric lighting, and the renovation of the roof above the stalls.

3. Architectural Characteristics

The main hall features a horseshoe-shaped plan (Tronchin et al., 2022; Merli et al., 2020; Bevilacqua et al., 2022), and measures 11.3 m along the main axis, with a maximum width of 13.8 m. The audience is composed of 43 boxes distributed across four orders of balconies, with walls completely covered in fabric. The total seating capacity is 400 seats, including the stalls. Table 1 reports the geometric data of the volumes.

Table 1 – Main acoustic features

Stage	Proscennium	Main Hall (Stalls & Boxes)
Surface 200 m²	Surface 19 m²	Surface 140 m²
Height 16.8 m	Height 10.6 m	Height 12.9 m
Volume 3350 m³	Volume 200 m³	Volume 1799 m³

4. Acoustic Measurements

Acoustic measurements were performed inside the Benevento Theatre at selected positions across the sitting area. Fig. 2 illustrates the equipment positions during the survey. The instrumentation used for the survey was the following:

- Omnidirectional sound source;
- Microphone (Brahma);

An exponential sound sweep (ESS) signal with a duration of 15 s, covering a frequency range from 40 Hz to 20 kHz, was used to generate the impulse response (IR).

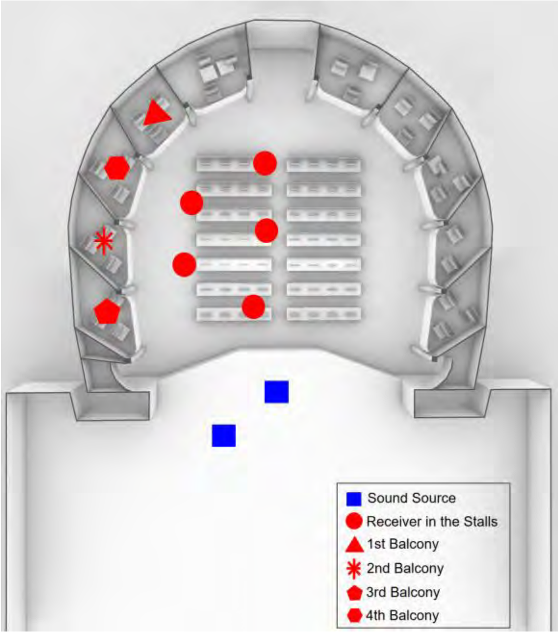

Fig. 2 – Equipment location during the acoustic survey inside the Vittorio Emanuele II theatre of Benevento

The acoustic measurements were performed in line with the standard requirements outlined by ISO 3382 (ISO, 2008).

5. Calibration of Digital Model

The measured impulse responses were processed using the Aurora plugin suitable for Audition 3.0 (Farina, 1995; Farina, 2007; Farina, et al., 2022). Before running any simulations, the measured values were used to calibrate the digital model. The main acoustic parameter considered for this operation was the reverberation time (T30) across the spectrum from 125 Hz to 4 kHz, averaged over all source-receiver position under unoccupied conditions. Table 2 shows the absorption coefficients used for calibration, while Fig. 3 shows the model calibration based on the reverberation time T30 (Bevilacqua et al., 2023a; Bevilacqua et al., 2023b). The theoretical study will be carried out using the architectural acoustics software Ramsete, which is based on sound ray tracing. Ramsete operates according to Snell's law: when a sound ray strikes a flat surface, it is reflected at an angle equal to the angle of incident. The reflected sound energy is reduced by a percentage corresponding to the absorption coefficient assigned to the surface. In ray-tracing-based acoustics simulations, sound reflection is evaluated in terms of energy, meaning that the reflected sound energy is decreased in proportion to the absorption coefficient.

Table 2 – Absorption coefficients used for the calibration process

Material	125	250	500	1k	2k	4k
Floor - Stalls	0.15	0.25	0.35	0.43	0.45	0.45
Perimeter Walls	0.18	0.25	0.27	0.28	0.30	0.28
Balustrades	0.63	0.70	0.74	0.75	0.75	0.75
Box Partitions	0.63	0.70	0.74	0.75	0.75	0.75
Stage Floor	0.55	0.50	0.40	0.30	0.30	0.27
Fly tower walls	0.28	0.28	0.26	0.27	0.25	0.26
Seats	0.64	0.75	0.80	0.82	0.83	0.83

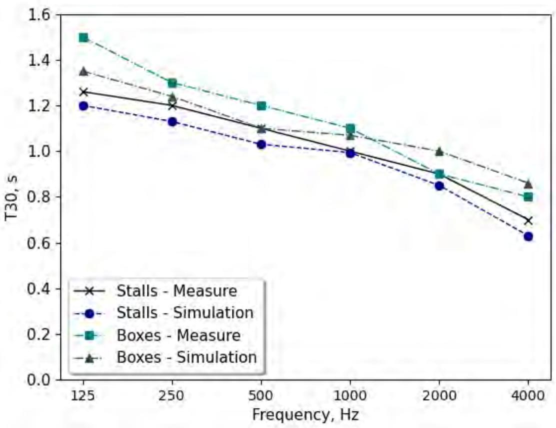

Fig. 3 – Calibration of simulated results with measured values of T30

The calibration was performed on the reverberation time, as this acoustic parameter is independent of the measurement position within the seating areas. In contrast, other parameters are highly sensitive to the distance between the source and receiver, leading to a significant increase in potential error.

6. Acoustic Simulations Reproducing the Condition of the Theatre Transformed Into a Cinema

After World War II, the opera theatre in Benevento was transformed into a cinema (Dolci et al., 2021). The architectural changes included replacing the wooden balustrades with glass, adding more seats allocated to the stalls, and installing a white synthetic fabric screen in place of the heavy dark red curtain. This change was made to improve movie projection clarity without any color distortion.
The acoustic simulations presented in this paper reflect the condition of a cinema set up inside the theatre. As such, the results shown in the following graphs compare two scenarios:

- The measured data mirroring the current state of the theatre, which is quite similar to its condition in 1860, and
- The simulated data representing the theatre's transformation into a cinema.

The main acoustic parameters are analyzed in the frequency band between 125 Hz and 4 kHz, averaged for the stalls and balconies, under unoccupied conditions.

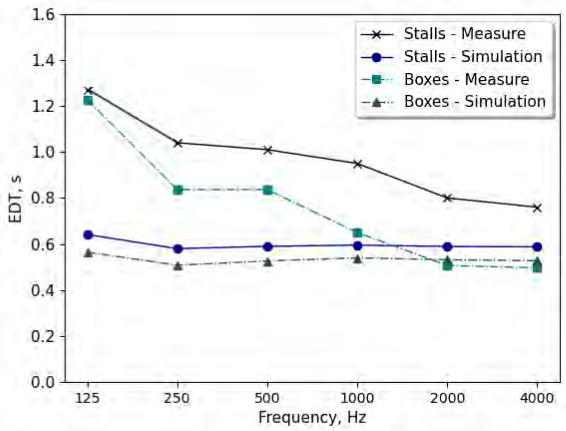

Fig. 4 – Values of early decay time (EDT)

Fig. 4 shows that the current EDT values are around 1.0 s in the stalls and 0.7 s in the boxes at medium frequencies, with a downward trend for the measured values in the boxes. These results fall below the minimum threshold of the optimal range established for opera theatres (Ciaburro et al., 2020; Fearn, 1975). The simulated EDT values show little difference between stalls and balconies, at around 0.6 s and 0.55 s, respectively. This means that the cinema configuration produces a drier acoustic response compared to the existing condition.

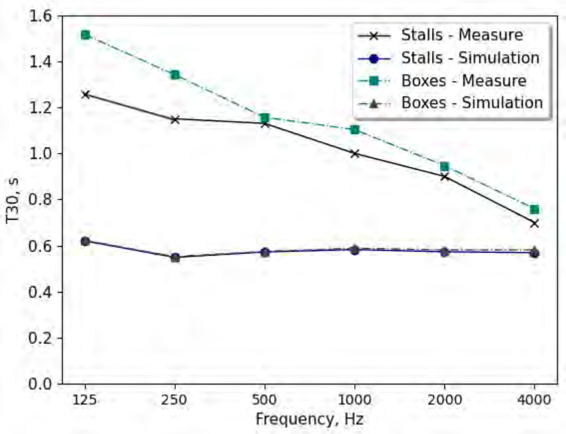

Fig. 5 – Values of reverberation time (T30)

Fig. 5 shows that the T30 values from the cinema simulation are around 0.6 s. This consistent difference, compared to the measured values, is primarily due to the reduction in room volume, as the simulation does not account for the volume of the fly tower behind the screen. A secondary factor influencing this reduction in reverberation is the addition of seats with light upholstery. The reverberation time in the current state is suitable for both music and prose, while the results for the cinema setup are also appropriate for an amplified audio system (Jordan, 1981; Merli et al., 2021; Sukaj et al., 2021; Berardi et al., 2022).

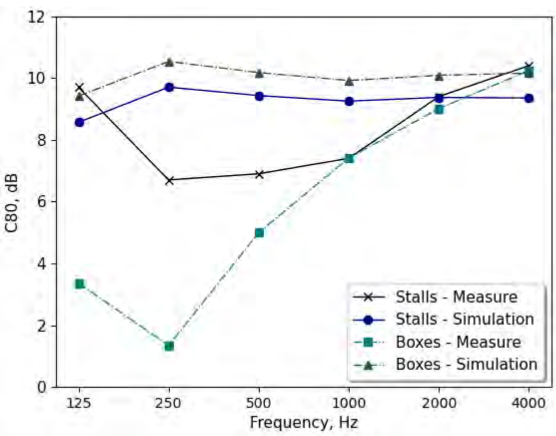

Fig. 6 – Values of clarity index (C80)

Fig. 6 indicates that the averaged values of C80 are above the upper limit of the optimal range established for good clarity (+2 dB), meaning that the energy content of early reflection predominates over the reverberant tail.

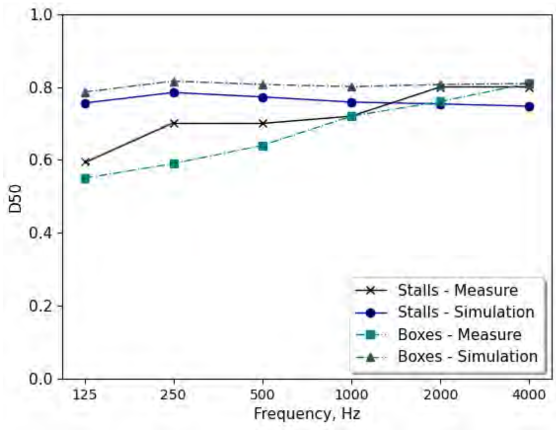

Fig. 7 – Values of definition (D50)

Fig. 7 shows the D50 values fluctuate around 0.7 (70%), with a small difference between measured and simulated values. Overall, the results indicate that the definition is slightly more suitable for speech. This outcome should be compared with the sound transmission index (STI) values, which are found to be 0.84 for male voice, placing it in the "excellent" category for speech comfort, in accordance with the intelligibility rating defined by ISO 9921 (Giron et al., 2017; Iannace et al., 2019; Iannace et al., 2020).

7. Discussion

The acoustic simulations carried out for the adaptation of the theatre into a cinema screen show that the acoustic response is suitable for the new function of the space, especially because the cinema is equipped with an amplified audio system, which requires a drier environment than what existed before. This was achieved by reducing the volume of the fly tower, which had significantly contributed to increasing the reverberation in the space. Given the upholstery of the seats, it is assumed that there would not be much difference between unoccupied conditions, as measured and simulated, and full occupancy by spectators.

8. Conclusions

The long story of the Vittorio Emanuele II Theatre in Benevento has been analyzed with the aid of acoustic simulations, which were based on a campaign of acoustic measurements. After calibrating the model, representing the existing condition, with the measured data, the model was used to simulate the theatre's condition when it was transformed into a cinema. This transformation involved the removal of the fly tower, leading to a significant reduction in room volume, replacing the wooden balustrade with glass for increased transparency and better sightlines to the screen, and adding more seats to the stalls to expand the overall capacity.

Regarding the acoustic response for an amplified audio system, the simulated values were found to be suitable for the new function that occurred after World War II. However, the drier environment was intentionally created. In addition, this study provided an analysis of the measured acoustic data, which were found to be lower than the limit in terms of EDT, aligning with speech understanding in terms of reverberation and definition, and with clarity values found to be above the upper limit established in the literature.

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