Acoustic Correction of the Regional Theatre of Bejaia (Algeria)

Feriel Saidane – Saad Dahleb University, Algeria – saidane_feriel@univ-blida.dz
Gino Iannace – University of Campania "Luigi Vanvitelli", Italy – gino.iannace@unicampania.it

Abstract

Theatres must have an adequate reverberation time depending on their intended use. In this paper the acoustic characteristics of the regional theatre of Bejaia (Algeria) built in 1936 is discussed. The hall has a regular geometry with the shape of a shoebox, with a capacity of 420 seats. Measurements of the acoustic characteristics were carried out using the bursting of an air-inflated balloon. The room has an excessive reverberation time, which is not suitable for the performance of prose shows, and so it is necessary to carry out an adequate acoustic correction to reduce the reverberation time and increase the STI to improve speech understanding. The aim of this work is to analyze, using architectural acoustics software, the conditions for improving the acoustics of the room in order to reduce the reverberation time. The study uses numerical modeling to evaluate the effects of modifying the material of the stage tower or inserting surfaces with adequate acoustic absorption.

1. Introduction

In Algeria, the French colonists (1830–1962) started a series of works to gradually equip the territories with public buildings, including the construction of theatres. The aim of this work is to evaluate the acoustics of the Bejaia theatre, built in the 20th century. In this theatre, acoustic measurements were carried out in order to evaluate the average values of the acoustic characteristics measured. The measurements were carried out in accordance with the ISO 3382 standard (ISO, 2008). The acoustic measurements evaluate compliance with the acoustic parameters with respect to optimal conditions and to propose possible modifications. In order to improve the acoustics of the room, the study to evaluate the changes to be made was carried out with the aid of architectural acoustics software (Bevilacqua et al., 2023; Ciaburro et al., 2018). The most commonly used acoustic parameter is the reverberation time: a short reverberation time means few reflections of the sound inside the room and good speech understanding.

2. The Regional Theatre of Bejaia

The regional theatre of Bejaia was built in 1936 in Art Deco style, a modernist expression used in the first half of the 20th century. Fig. 1 shows the external view of the theatre.

Fig. 1 – External view of the theatre

The hall has a shoebox shape, with a capacity of 420 seats distributed between the stalls, the ground floor boxes, the two side galleries and the balcony. The dimensions of the main hall are 11 m x 21.3 m and the stage is 11 m x 7.6 m. The stage appears to be 1.2 m higher than the floor level of the hall. The walls are covered with plywood sheets, the floor with red carpet, while the ceiling is made of plaster in the peripheral part and a raised glass dome with a rectangular base. Fig. 2 shows the plant and the section of the theatre.

Part of
Pernigotto, G., Ballarini, I., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2025. Building simulation applications BSA 2024. bu,press.
https://doi.org/10.13124/9788860462022

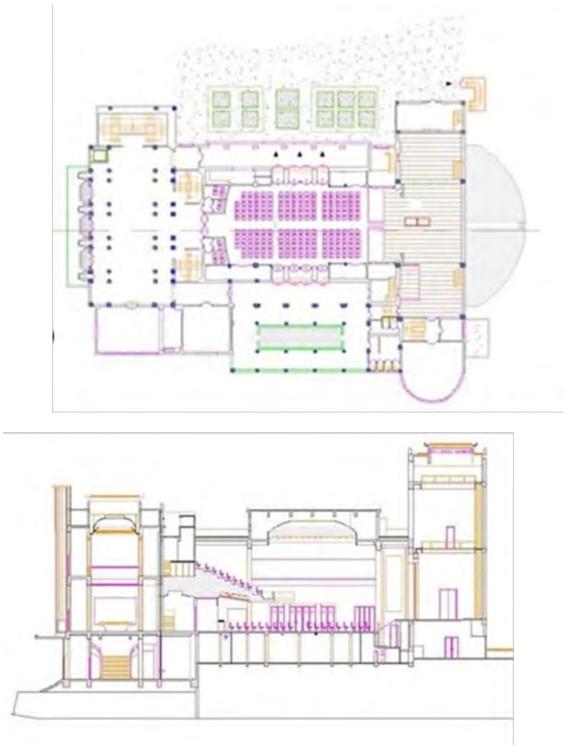

Fig. 2 – Plant and Section - The dimensions of the main hall: 11 m x 21.3 m

Furthermore Fig. 3 shows the interior views of the main hall of the Bejaia regional theatre.

3. Acoustic Measurements

The acoustic measurements were carried out inside the theatre and were carried out according to the requirements of the ISO 3382-1 standard (ISO, 2008), considered the international reference standard for objective acoustic parameters, used to better describe the perception of the sound field. Below is a brief definition of the main acoustic parameters analysed (Farina, 1995; Farina, 2007; Iannace et al., 2019; Merli et al., 2020).

The Early Decay Time (EDT) consists of the time it takes for the sound pressure level to decrease by 10 dB after the sound source is turned off. It is measured in seconds.

- Reverberation time (T30), similar to EDT and also defined in seconds, consists of the time required for the sound pressure level to decrease by 30 dB.
- Clarity Index (C80) is calculated on the basis of the energy that arrives within the first 80 ms expressed in decibels and is used to evaluate good musical performance.
- The Definition (D50) is calculated based on the energy arriving within the first 50 ms and is used to evaluate the speech understanding.

Fig. 3 – Interior views of the theatre

The acoustic measurements were performed in unoccupied conditions. The sound source was placed on the stage at a height of 1.6 m, in the actor's position, and the receivers were uniformly distributed on one side of the stalls, the balconies and the gallery thanks to the axial symmetry of the rooms, to a height of 1.2 m from the arrival floor, simulating the ears of seated spectators. Fig. 4 shows the location of the sound source and receivers. The following equipment was used: balloon bursts; audio recorder (type Zoom H4n) (Merli et al. 2021; Iannace et al., 2020). Plastic balloons inflated with air were used. The explosion of the balloons provides a good S/N ratio and allows us to obtain a good value of the impulse response. This type of sound source, characteristic for its ease of use, had been used by the authors in previous measurement campaigns in other closed places with success.

Fig. 5 shows the average measured values of acoustic parameters initial decay time EDT; Fig. 6 shows the average measured values of acoustic parameters T30 reverberation time; Fig. 7 shows the average measured values of acoustic parameters Clarity Index C80; while Fig. 8 shows the average measured values of acoustic parameters D50 Definition.

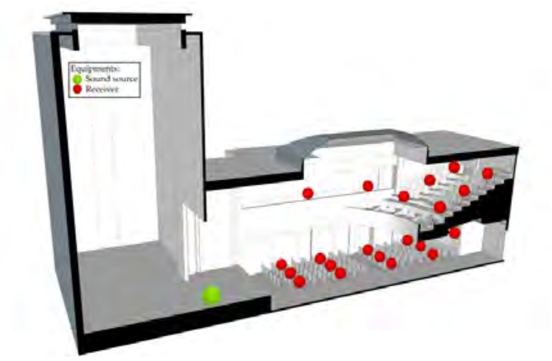

Fig. 4 – Positions of sound sources and receivers

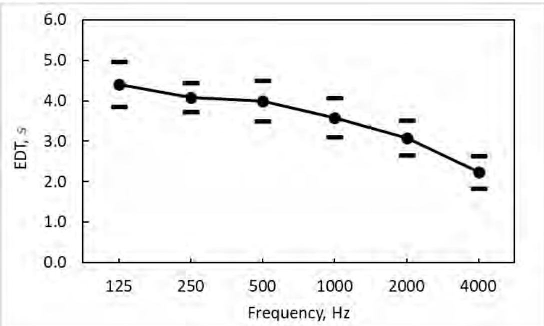

Fig. 5 – Average measured values of EDT

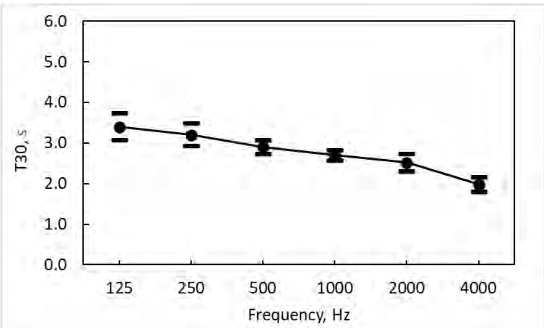

Fig. 6 – Average measured values of T30

The graph relating to the EDT shows the average values of 3.0 s, so if we compare them with the optimal values defined by Jordan, which vary between 1.8 and 2.6 s, we observe that the optimal values are not reached in theatre (Bevilacqua et al., 2022; Jordan, 1981; Fearn, 1975). The trend of the T30 line seems stable at medium-low frequencies, with values fluctuating around 2.5 s. While in musical terms, the Clarity C80 values remain below the range limit (-2 < C80 < 2 dB). D50, Definition, results remain below 50% in all frequency bands. For the definition, where the value the highest of 0.4 (40%) from Bejaia's theatre at 4 kHz. While average values STI = 0.35, is poor.

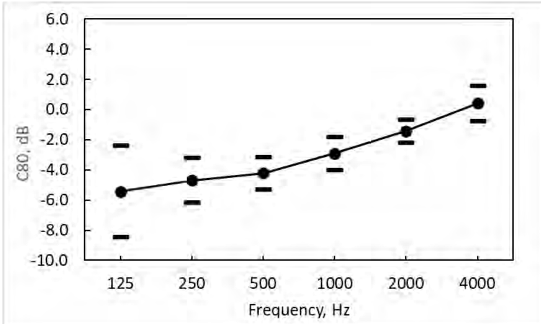

Fig. 7 – Average measured values of C80

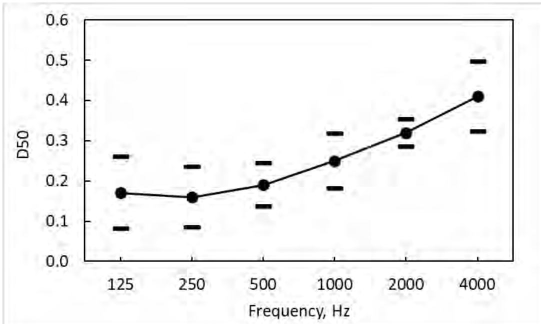

Fig. 8 – Average measured values of D50

Fig. 5–8 show the acoustic characteristics of the values of the standard deviations measured. At low frequencies it is possible to notice the greater difference in the standard deviations of the measured values. This means that at low frequencies the greatest differences between the measured values of the acoustic characteristics are present.

4. Theatre Acoustic Correction

For the measured characteristics of the theatre, some corrections should be made to improve the acoustic quality, reducing the reverberation time through the introduction of absorbent materials applied to the walls. Therefore, the use of acoustic simulation makes it possible to evaluate these corrections. A simplified geometric model was created by simplifying the surfaces of the room with flat surfaces. The software uses the sound ray tracing model, straight lines that simulate the sound rays are sent from the source point (Tronchin et al., 2020; Sukaj et at., 2021). When the lines meet the boundary surfaces, these are reflected with an angle equal and opposite to that of incidence in accordance with Snell's law. The energy of the sound beam is reduced by a rate equal to the sound absorption coefficient of the wall. The calculation is performed as a function of the frequency since the value of the absorption coefficient is a function of the frequency in the octave bands from 125 Hz to 4000 Hz. The calibration is considered completed and correct when the difference between the value of the measured T30 and the calculated one is less than 5%. Fig. 9 shows the virtual model used by Ramsete software (Bevilacqua et al., 2023; Ciaburro et al., 2020; Farina et al., 2022; Giron et al., 2017).

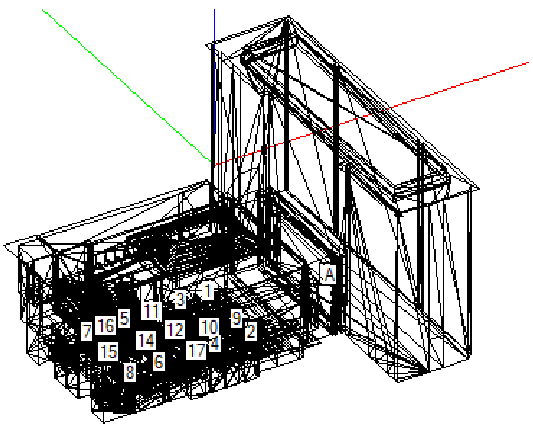

Fig. 9 – Virtual model used by Ramsete software

Fig. 10 shows the spatial distribution of T30 after the calibration procedures at the frequency of 1000 Hz.

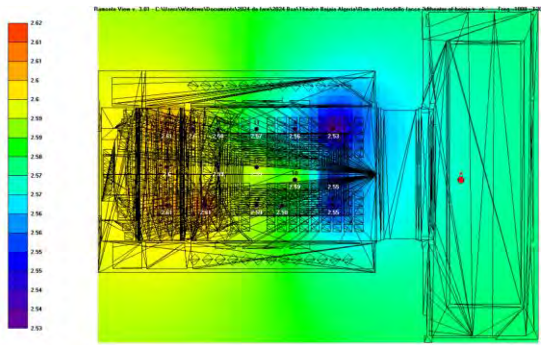

Fig. 10 – Spatial distribution of T30

The room presents an almost uniform value of the spatial average distribution. The average value is around 2.5 s which gives the room poor acoustic characteristics for understanding speech. Fig. 11 shows the spatial distribution of STI after the calibration procedures.

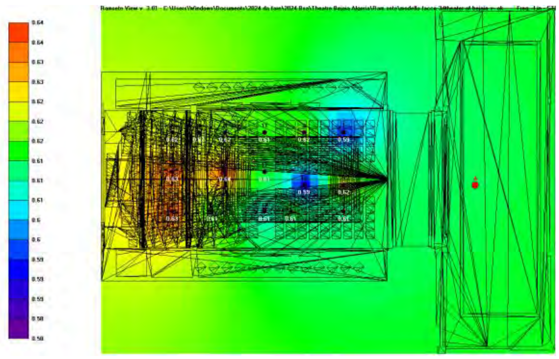

Fig. 11 – Spatial distribution of STI

The acoustic characteristics of the theatre in its current state highlight an excessive sound tail which does not allow the theatre to have good acoustics both for understanding speech and for listening to music. Generally, this type of theatre is used for prose performances, therefore understanding speech should be given priority. To evaluate possible interventions for acoustic correction so as not to distort the aesthetic appearance, covering the walls with a sound-absorbing material fabric can be considered. In this way, using the Ramsete software, by replacing the absorption coefficient of the walls in their current state, it is possible to evaluate the new acoustic characteristics. After acoustic simulation, Fig. 12 shows the spatial distribution of T30 after the acoustic correction at the frequency of 1000 Hz. In this way, the room presents a uniform value of the spatial average distribution. The average value is around 1.5 s which gives the room good acoustic characteristics for understanding speech. Fig. 13 shows the spatial distribution of STI after the acoustic correction. The average value is around 0.7 which gives the room good acoustic characteristics for understanding speech.

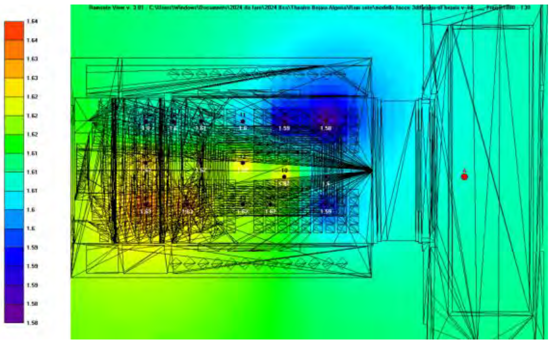

Fig. 12 – Spatial distribution of T30

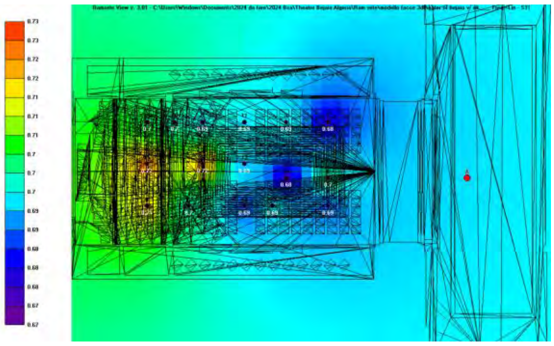

Fig. 13 – Spatial distribution of STI

5. Conclusion

In this work, the acoustic characteristics of the Bejaia regional theatre in Algeria were analysed. The hall has a regular geometry with the shape of a shoebox, with a capacity of 420 seats distributed between the stalls, the ground floor boxes and the two side galleries and the balcony. The theatre was built in the last century. The acoustic measurements carried out with the balloon bursting technique gave a T30 value at a frequency of 1000 Hz of approximately 2.5 s. The theatre does not have good characteristics for understanding speech. To evaluate possible acoustic corrections to improve speech understanding using architectural acoustics software, the possibility of covering the walls with a sound-absorbing sheet was evaluated. The simulations formed a reduction in reverberation time, and an increase in STI.

References

Bevilacqua, A. Sukaj, S. Ciaburro, G. Iannace, G. Trematerra, A. 2022. "How a quartet of theatres plays under an acoustic perspective: a comparison between horseshoe shaped plans in Campania". *Building Acoustics*, 29(3): 317-329

Bevilacqua, A. Iannace, G. 2023. "Acoustic study of the Roman theatre of Pompeii: comparison between existing condition and future installation of two parametric acoustic shells". *J. Acoust. Soc. America*, 154(4)

Bevilacqua, A. Farina, A. Saccenti, L. Farina, A. 2023. "New method for the computation of acoustic parameters according to the updated Italian Legislation". *In proc. of 154th AES Convention*, Helsinki, Finland, 13-15 May

Ciaburro, G., Berardi, U., Iannace, G., Trematerra, Lombardi, I., Iannace, G., Trematerra, A. 2018. The acoustic of a courtyard. *In Proc of INTER-NOISE 2018 - 47th International Congress*

Ciaburro, G., Iannace, G., Lombardi, I., & Trematerra, A. 2020. Acoustic design of ancient buildings: The odea of Pompeii and Posillipo. *Buildings*, 10(12), 224

Farina, A. 1995. "Aurora listens to the traces of pyramid power". *Noise and Vibration Worldwide*. 26(6): 6–9

Farina, A. Bevilacqua, A. Farina, A. 2022. "Acoustic design review for the historical Aula Magna at the University of Parma. Measurements and Simulation tools to predict the amount of absorption to be in place". *In proc. of 152nd AES Convention, The Hague, Netherlands*, 10-12 May

Farina, A. 2007. "Advancements in impulse response measurements by sine sweeps". *In proc. of 122nd AES Convention*, 3: 1626-1646

Fearn, R.W. 1975. Reverberation in Spanish, English and French churches. J. Acoust. Soc. *Am.*, 43(3): 562-567

Giron, S., Alvarez-Morales, L., Zamarreno, T. 2017. Church acoustics: a state-of-the-art review after several decades of research. *J. Sound and Vib.*, 411.

ISO 3382:2008. Acoustics — *Measurement of room acoustic parameters*. Geneva, Switzerland

Iannace, G., Ciaburro, G., Abeti, M. 2019. The acoustics of the church of the holy family in

Salerno (Italy). *In Proc of 18th Conference on Applied Mathematics, APLIMAT 2019*, 1, 539–551

Iannace, G., Ciaburro, G., & Trematerra, A. 2020. The acoustics of the holy family church in Salerno. *Canadian Acoustics*, 48(1)

Jordan, V.L. 1981. "A group of objective acoustical criteria for concert halls". *Appl. Acoust*. 14: 253-266

Merli, F. Bevilacqua, A. 2020. "Using a church as a temporary auditorium. Acoustical design of S. Domenico of Imola". *J. Of Physics.: Conf. Series* 1655, 012146. https://doi.org/10.1088/1742-6596/1655/1/012146

Merli, F. Bevilacqua, A. Tronchin, L. 2021. "The acoustic study of the palatine chapel inside the Reggia of Caserta". *In Proc of Immersive 3D Audio (I3DA) Conference, Bologna, Italy, 7-9 September*. https://doi.org/10.1109/I3DA48870.2021.9610961

Sukaj, S., Ciaburro, G., Iannace, G., Lombardi, I., Trematerra, A. 2021. The Acoustics of the Benevento Roman Theatre. *Buildings*, 11(5), 212

Tronchin, L. Bevilacqua, A. 2020. "Evaluation of acoustic similarities in two Italian churches honored to S. Dominic". *Appl. Sciences*, 10, 7043, https://doi.org/10.3390/app10207043