

On the Prints of Another Horseshoe-Shaped Historical Building: Acoustic Studies of the Bonci Theatre of Cesena

Antonella Bevilacqua – University of Parma, Italy – antonella.bevilacqua@unipr.it

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

Abstract

The Bonci theatre in Cesena was built in 1846, becoming a stable public construction after a period when theatrical shows used to be privately performed inside aristocratic palaces. The architectural design, to be composed of 5 orders of balconies and the shape of the plan layout follow, in reduced dimensions, the Alla Scala theatre in Milan. Acoustic measurements were taken across the stalls and inside some selected boxes according to BS3382-1. The main acoustic parameters gathered by the measured values were compared with the acoustic simulations of a 3D model, which faithfully reproduces the Bonci theatre. The scope of this paper is the analysis of the acoustic behavior of the Bonci theatre, which can be used to calibrate a digital model before the executions of any acoustic simulations. This practice is fundamental for the accuracy of the results, which shall be carried out by comparing the measured with the calibrated values. A review of the historical background has been introduced to allow an appreciation of the architectural value of this cultural heritage.

1. Introduction

The acoustic discoveries of cultural heritage buildings have always been appreciated by the amateurs that experience these places on a regular basis. Additionally, this enriches the knowledge of experts and scholars focused on existing architectural patrimony of important value (Bettarello et al., 2021; Dordevic, 2016; Vecco, 2010). On this basis, this paper deals with the acoustic characteristics of Bonci theatre of Cesena, measured in line with the standard requirements outlined by ISO 3382 (Iannace & Ianniello, 2008; ISO, 2009; Tronchin et al., 2021a). The shape of the horseshoe plan layout is typical of a 19th century opera theatre character-

ised with four orders of balconies and a top gallery at the last level (Azzaroni et al., 1997; Battaglia et al., 1992; Iannace & Ianniello, 2008). The results highlight that the acoustic response of the Bonci theatre is suitable for both speech and music, which is what these building types were built for (Farina, 2007; Jordan, 1981; Tronchin et al., 2006). The acoustic parameters meet the criteria of a theatre having similar room volume. This analysis shall be considered as a preparatory study taken into account before any acoustic simulations are carried out upon a digital model.

2. Historical Background

Bonci theater in Cesena was formerly known as Spada theatre in the Aledossi Palace (Azzaroni et al., 1997; Iannace et al., 2019; Puglisi et al., 2021). In 1822, the community of Cesena wanted to purchase the noble theatre from the gonfalonier and build new walls and a solid public theatre (Iannace et al., 2000; Tronchin & Knight, 2016; Tronchin et al., 2020).

In 1842, the construction of Bonci theatre was planned under the supervision of the architect Ghinelli, but, due to financial difficulties, the project started the year after. In 1846, the main frame of the building, decoration, scene construction and furniture of the theater were completed (Battaglia et al., 1992).

Part of

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Fig. 1 – Internal view of the Bonci theatre in Cesena

Bonci theater represents the paradigm of an Italian theater, with harmonious internal space organization, reflecting the perfect combination of functionality with aesthetics (Tronchin & Bevilacqua, 2022). The internal decorations show the characteristics of the neoclassical style, as indicated in Fig. 1. Bonci theater is characterized by four orders of balconies and a top gallery (*loggione*). The plan layout of the theater presents a horseshoe shape geometry. In particular, the final design opted for a total number of 23 boxes per balcony, to be 1.7 m wide at the parapet line.

The main hall is richly decorated, and the ceiling, with its allegorical representations, is embedded in a circular panel carved with gold-plated vine patterns. The walls of the main hall are treated with polished plaster, as shown in Fig. 2. The interior design of the boxes is also characterised by polished and stuccoed walls.



Fig. 2 – Decorations of the ceiling

Due to the existence of underground waterways, the foundation of the theater is built on wooden poles, which support a peripheral wall cage containing separated functional units and a large roof supported by huge trusses (Farina & Tronchin, 2000; Tronchin, 2021).

Nowadays, the theater is considered a real “machine” for the artistic shows that run throughout the year.

3. Architectural Organization

Bonci theater has a horseshoe-shaped plan layout, as shown in Fig. 3, having a total capacity of 930 seats, distributed as 364 in the stalls, 130 in the top gallery (*loggione*), and the rest across four orders of balconies composed of 25 boxes.

The surface area of the fly tower is a square of 24 m side having a height of 18 m and an inclination of 5%. The proscenium arch is 12 m wide with a height of up to 7.8 m.

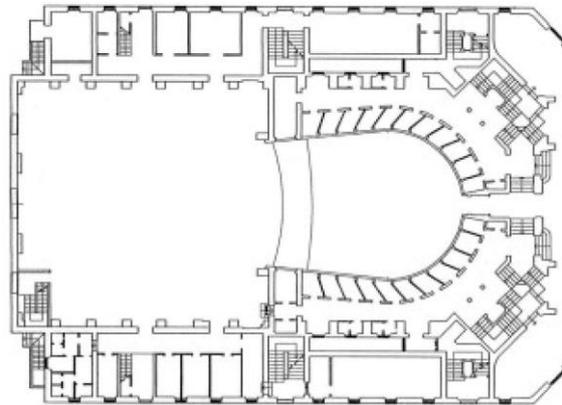


Fig. 3 – Plan layout of Bonci theater of Cesena

4. Acoustic Measurements

Acoustic measurements were carried out inside Bonci theater by using the following equipment:

- Equalised omnidirectional loudspeaker (Look Line);
- Binaural dummy head (Neumann KU-100);
- B-Format (Sennheiser Ambeo);

The sound source and the receivers were located across the stalls and in some selected boxes at different orders, as shown in Fig. 4.

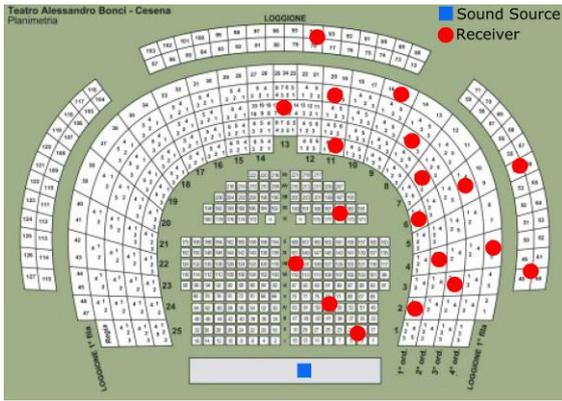


Fig. 4 – Equipment positions during the acoustic survey

The sound source was placed on the stage at a height of 1.4 m and the receivers were moved across the stalls and in the boxes by recording the Impulse Responses (IRs). The excitation signal (Bettarello et al., 2010) was the Exponential Sine Sweep (ESS) (Farina, 2007; Tronchin et al., 2021b), which was 15 s long, by covering a spectrum bandwidth ranging between 40 Hz and 20 kHz. The measurements were taken in unoccupied conditions.

5. Results

The recorded IRs were processed with the Aurora plugin, suitable for Audition 3.0, to gather the main acoustic parameters that are shown in Figs. 5 to 10 for the octave bands going from 125 Hz and 8 kHz.

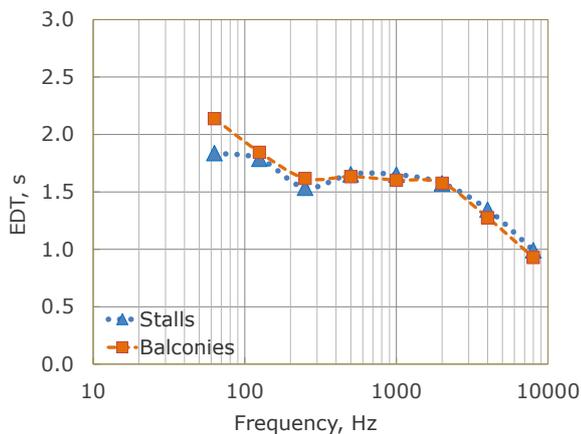


Fig. 5 – Measured values of Early Decay Time (EDT)

Fig. 5 shows the measured values of Early Decay Time (EDT), found to be very similar between

stalls and balconies. Between 250 Hz and 2 kHz, the values fluctuate around 1.6 s, while at lower frequencies the results rise to 2.2 s and at higher octaves the values drop to 1.0 s. The overall outcome is within the optimal range set for opera houses (Farina & Tronchin, 2005; Farina et al., 1998; Tronchin & Bevilacqua, 2021).

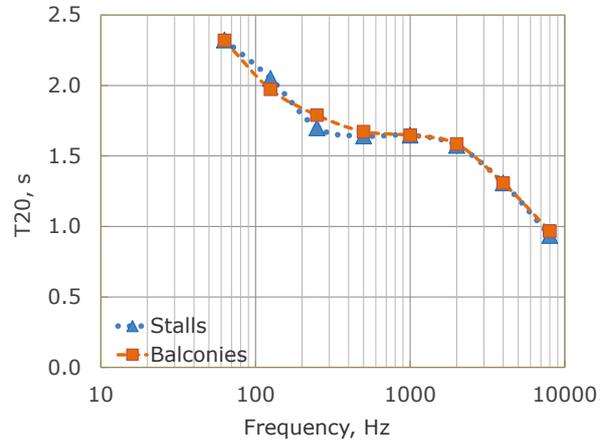


Fig. 6 – Measured values of reverberation time (T_{20})

Fig. 6 indicates that the averaged values of T_{20} are around 1.7 s at mid-frequencies, found to be very similar for stalls and balconies. This result meets the criteria of an opera house of such a volume size, as indicated in Fig. 7.

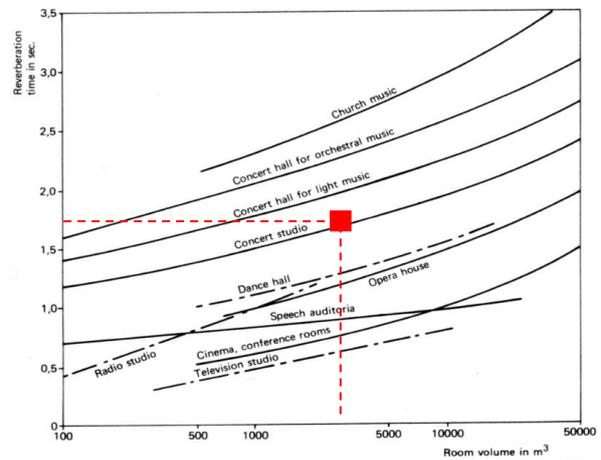


Fig. 7 – Optimal T_{20} values at 500 Hz, based on room volume

Fig. 8 shows the results of speech clarity index (C_{50}), found to be better in the stalls than on the balconies (Tronchin et al., 2006). The values in the stalls meet the optimal range (-2 dB to +2 dB) (ISO, 2003; Puglisi et al., 2021) for the mid-frequencies; the results of 63 Hz and 8 kHz are not included in the target set by the criteria. On the balconies, the

results are slightly below the lower range limit, except at 8 kHz, where the value is within the optimal range.

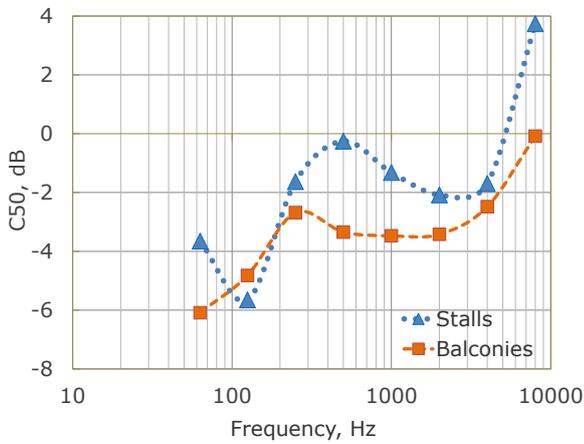


Fig. 8 – Measured values of speech clarity index (C₅₀)

In terms of music, Fig. 9 indicates that the clarity index related to music (C₈₀) for both stalls and balconies was found to be within the optimal range for the mid octaves. This outcome highlights the suitability of Bonci theater for both opera and symphonic music (Beranek, 1962; Iannace et al., 2019; Tronchin, 2005).

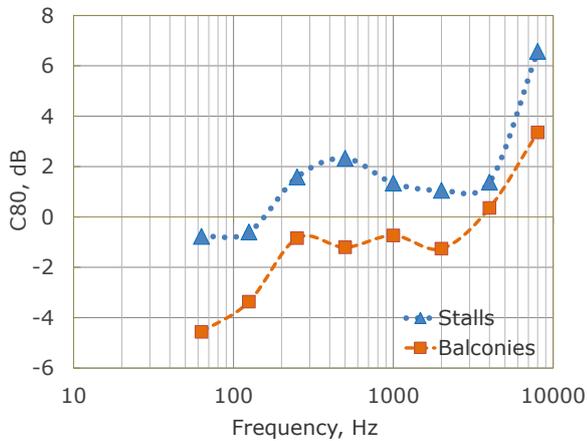


Fig. 9 – Measured values of music clarity index (C₈₀)

The results related to definition (D₅₀) turned out to be 0.4 in the stalls and 0.3 on the balconies, as indicated in Fig. 10. This means that the definition is slightly better for music even if the overall outcome confirms what has been assessed for the other acoustic parameters (Iannace et al., 2000; Tronchin et al., 2020; Tronchin et al., 2021b).

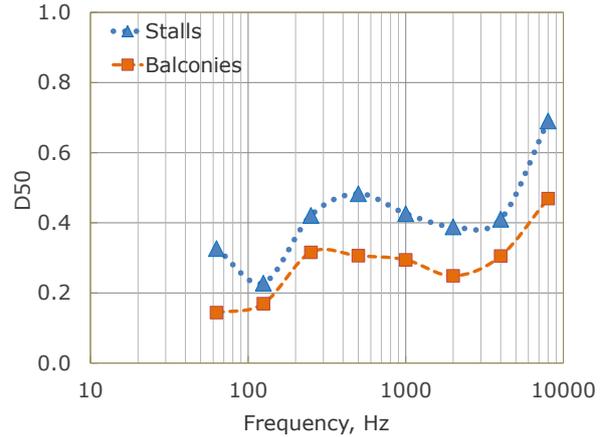


Fig. 10 – Measured values of D₅₀

6. Conclusion

The assessment of the acoustic measurements taken inside Bonci theater in Cesena outlines a good response regarding both speech and music. The best results were found at mid-frequencies, while a shortfall was found at the octaves below 125 Hz, and the results above 4 kHz were found to be slightly above the upper range limit. Based on the acoustic survey, future research studies will be focused on the acoustic simulations (Caniato et al., 2019 and 2020b) of a certain typology of scenery, with and without the audience, in order to highlight the differences of the acoustic parameters in stalls and balconies, as well as for energy building and musical instrument simulation (Fabbri et al., 2014; Manfren et al., 2019, 2021a, 2021b and 2022; Tronchin et al., 2020). On the basis of this, this preparatory analysis would be of fundamental importance during the calibration process of the digital model (Caniato et al., 2020a), where the absorption coefficients would be applied to all the 3D elements.

References

- Azzaroni, G., F. Dell'Amore, P. G. Fabbri, R. Pieri, and A. Maraldi. 1997. *Un palcoscenico per Cesena. Storia del Teatro Comunale*. Il Ponte Vecchio, Cesena.
- Battaglia, F., M. Gradara, G. Conti, and G. Foschi. 1992. *Il Teatro Comunale Bonci e la Musica a Cesena*.
- Beranek, L. 1962. *Music, acoustics and architecture*. Wiley: New York.
- Bettarello, F., P. Fausti, V. Baccan, and M. Caniato. 2010. "Impact Sound Pressure Level Performances of Basic Beam Floor Structures". *Building Acoustics* 17(3):305-316. doi: <https://doi.org/10.1260/1351-010X.17.4.305>
- Bettarello, F., M. Caniato, and A. Gasparella. 2021. "The Influence of Floor Layering on Airborne Sound Insulation and Impact Noise Reduction: A Study on Cross Laminated Timber (CLT) Structures". *Applied Science* 11(13): 5938. doi: <https://doi.org/10.3390/app11135938>
- Caniato, M., F. Bettarello, C. Schmid, and P. Fausti. 2019. "The use of numerical models on service equipment noise prediction in heavyweight and lightweight timber buildings". *Building Acoustics* 26(1): 35-55. doi: <https://doi.org/10.1177/1351010X18794523>
- Caniato, M., F. Bettarello, P. Bonfiglio, and A. Gasparella. 2020a. "Extensive Investigation of Multiphysics Approaches in Simulation of Complex Periodic Structures". *Applied Acoustics* 166: 107356. doi: <https://doi.org/10.1016/j.apacoust.2020.107356>
- Caniato, M., C. Schmid, and A. Gasparella. 2020b. "A comprehensive analysis of time influence on floating floors: Effects on acoustic performance and occupants' comfort". *Applied Acoustics* 166: 107339. doi: <https://doi.org/10.1016/j.apacoust.2020.107339>
- Dordevic, Z. 2016. "Intangible tangibility: Acoustical heritage in architecture." *Structural Integrity and Life* 6: 59-66.
- Fabbri, K, L. Tronchin, and V. Tarabusi. 2014. "Energy Retrofit and Economic Evaluation Priorities Applied at an Italian Case Study". *Energy Procedia* 45: 379-384. doi: <https://doi.org/10.1016/j.egypro.2014.01.041>
- Farina, A. 2007. "Advancements in impulse response measurements by sine sweeps." In *Proceedings of the 122nd AES Convention*.
- Farina, A., and L. Tronchin. 2000. "On the "virtual" reconstruction of sound quality of trumpets." *Acta Acustica united with Acustica* 86(4): 737-745.
- Farina, A., and L. Tronchin. 2005. "Measurements and reproduction of spatial sound characteristics of auditoria." *Acoustical Science and Technology* 26(2): 193-199. doi: <https://doi.org/10.1250/ast.26.193>
- Farina, A., A. Langhoff, and L. Tronchin. 1998. "Acoustic characterisation of "virtual" musical instruments: using MLS technique on ancient violins." *Journal Of New Music Research* 27(4): 359-379. doi: <https://dx.doi.org/10.1080/09298219808570753>
- Iannace, G., and E. Ianniello. 2008. "Sound-focusing effects in the plan of horse-shoe shaped opera theatres." In *Proceedings of European Conference on Noise Control*: 1639-1643.
- Iannace, G., C. Ianniello, L. Maffei, and R. Romano. 2000. "Objective measurement of the listening condition in the old Italian opera house Teatro di San Carlo." *Journal of Sound and Vibration* 232: 239-249. doi: <https://doi.org/10.1006/jsvi.1999.2696>
- Iannace, G., G. Ciaburro, A. Trematerra, and C. Foglia. 2019. "Acoustic correction of a renaissance period hall." *Canadian Acoustics* 47(2): 57-66.
- ISO. 2003. *ISO 9921:2003. Ergonomics - Assessment of speech communication*. Geneva, Switzerland.
- ISO. 2009. *ISO 3382-1:2009. Acoustics - Measurement of Room Acoustic Parameters; Part 1: Performance Spaces*. Geneva, Switzerland.
- Jordan, V. L. 1981. "A group of objective acoustical criteria for concert halls." *Applied Acoustics* 14: 253-266. doi: [https://doi.org/10.1016/0003-682X\(81\)90021-9](https://doi.org/10.1016/0003-682X(81)90021-9)
- Manfren, M., B. Nastasi, E. A. Piana, and L. Tronchin. 2019. "On the link between energy performance of building and thermal comfort: An example." *AIP Conference Proceedings* 2123: 1-9. doi: <https://doi.org/10.1063/1.5116993>
- Manfren, M., B. Nastasi, L. Tronchin, D. Groppi, and D. A. Garcia. 2021a. "Techno-economic analysis and energy modelling as a key

- enablers for smart energy services and technologies in buildings." *Renewable and Sustainable Energy Reviews* 150: 1-14. doi: <https://doi.org/10.1016/j.rser.2021.111490>
- Manfren, M., M. Sibilla, and L. Tronchin. 2021b. "Energy Modelling and Analytics in the Built Environment—A Review of Their Role for Energy Transitions in the Construction Sector." *Energies* 14: 1-29. doi: <https://doi.org/10.3390/en14030679>
- Manfren, M., P. A. B. James, and L. Tronchin. 2022. "Data-driven building energy modelling – An analysis of the potential for generalisation through interpretable machine learning". *Renewable and Sustainable Energy Reviews* 167: 1-13. doi: <https://doi.org/10.1016/j.rser.2022.112686>
- Puglisi, G. E., A. Warzybok, A. Astolfi, and B. Kollmeier. 2021. "Effect of competitive acoustic environments on speech intelligibility." *Journal of Physics* 2069(1): 175180. doi: <https://doi.org/10.1088/1742-6596/2069/1/012162>
- Tronchin, L. 2005. "Modal analysis and intensity of acoustic radiation of the kettledrum." *The Journal of the Acoustical Society of America* 117(2): 926-933. doi: <https://doi.org/10.1121/1.1828552>
- Tronchin, L. 2021. "Variability of room acoustic parameters with thermo-hygrometric conditions." *Applied Acoustics* 177: 1-14. doi: <https://doi.org/10.1016/j.apacoust.2021.107933>
- Tronchin, L., and A. Bevilacqua. 2021. "Acoustic study of different sceneries at the São Carlos national theatre of Lisbon." *Applied Acoustics* 180: 1-11. doi: <https://doi.org/10.1016/j.apacoust.2021.108102>
- Tronchin, L., and A. Bevilacqua. 2022. "Historically informed digital reconstruction of the Roman theatre of Verona. Unveiling the acoustics of the original shape." *Applied Acoustics* 185: 1-18. doi: <https://doi.org/10.1016/j.apacoust.2021.108409>
- Tronchin, L., and D. J. Knight. 2016. "Revisiting Historic Buildings through the Senses. Visualising Aural and Obscured Aspects of San Vitale, Ravenna." *International Journal of Historical Archaeology* 20: 127-145. doi: <https://doi.org/10.1007/s10761-015-0325-2>
- Tronchin, L., R. Shimokura, and V. Tarabusi. 2006. "Spatial sound characteristics in the Theatre Comunale in Bologna, Italy." In *Proceedings of the 9th Western Pacific Acoustics Conference (WESPAC)*, Seoul, Korea, June 26-28.
- Tronchin, L., F. Merli, M. Manfren, and B. Nastasi. 2020. "The sound diffusion in Italian Opera Houses: some examples." *Building Acoustics* 27(4): 333-355. doi: <https://doi.org/10.1177/1351010X20929216>
- Tronchin, L., F. Merli, and M. Manfren. 2021a. "On the acoustics of the Teatro 1763 in Bologna." *Applied Acoustics* 172: 107598. doi: <https://doi.org/10.1016/j.apacoust.2020.107598>
- Tronchin, L., F. Merli, and M. Dolci. 2021b. "Virtual acoustic reconstruction of the Miners' Theatre in Idrija (Slovenia)." *Applied Acoustics* 172: 1-9. doi: <https://doi.org/10.1016/j.apacoust.2020.107595>
- Vecco, M. 2010. "A definition of Cultural Heritage: From the tangible to the intangible." *Journal of Cultural Heritage* 11: 321-324. doi: <https://doi.org/10.1016/j.culher.2010.01.006>