Acoustic Discoveries of Another Masterpiece by Antonio Galli Bibiena: The Communal Theatre of Bologna

Antonella Bevilacqua – University of Parma, Italy – antonella.bevilacqua@unipr.it
Ruoran Yan – University of Bologna, Italy – ruoran.yan2@unibo.it

Abstract

The Communal Theater of Bologna was built in 1763, after a fire destroyed the previous Renaissance construction. The project was assigned to the architect Antonio Galli Bibiena, who belonged to a family of artists and scenographers. The interior design represents Baroque style, with its four orders of balconies surmounted by a top gallery. Acoustic measurements were carried out inside the theater in line with BS3382-1. The values measured were compared with the acoustic simulations of a digital model reproducing the shape and volume of this cultural heritage. The historical background of the building has been summarised to aid understanding of the construction development overseen by Antonio Galli Bibiena.

1. Introduction

The Communal Theater of Bologna, created by Antonio Galli Bibiena, was criticised at the beginning of the 18th century for being composed of a bell-shaped plan layout marking the main hall. This architectural choice was considered outside the traditional construction rules developed at that time, especially under the influence of Pierre Patte and his studies on the elliptical shapes of spaces for the performing arts. Nonetheless, the architect found a way to combine architectural finesse with a good acoustic response due to the specific materials employed on the finishes as well as to geometry very favourable to sound diffusion (Caniato et al., 2020; Fabbri et al., 2021; Tronchin & Farina, 1997).

The Communal Theater of Bologna was studied in depth during the 20th century, particularly after restoration work on the modification of the orchestra pit and of the initial part of the stage closer to the audience damaged by a fire. Other work was completed on the structural frame of the boxes, on the main trusses of the roof and for the allocation of the electrical system. Fortunately, the interventions did not involve the acoustics, which represent one of the best masterpieces that Antonio Galli Bibiena left to post generations (Tronchin et al., 2021a and 2021b).

2. Historical Notes

The Communal Theater of Bologna was built in the location of the previous Malvezzi Theater, a wooden structure that burned down in 1745. In 1756, the City Council approved the proposal to build a new theater in Baroque style and assigned the project to the architect Antonio Galli Bibiena (Tronchin et al., 2020a, 2020b and 2020c). In 1763, the Communal Theater of Bologna was officially opened to the public.

Fig. 1 – Internal view of the Communal Theater of Bologna

Between 1818 and 1820, the theater underwent some restoration work, including the renovation of the dome, the reconstruction of the auditorium, and the stage. The second restoration campaign

Part of
Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2023. Building simulation applications BSA 2022. bu,press.
https://doi.org/10.13124/9788860461919

took place between 1853 and 1854, when the architect C. Parmenani was responsible for the transformation work (Tronchin et al., 2020a, 2020b and 2020c). In 1865, the façade was restored along with some safety measures adopted in line with the new building regulations, as shown in Fig. 1.

In 1931, the theater experienced another fire, burning down the stage and the curtain, while many rooms survived. The restoration was completed in 1935 and, after than this event, the theater was closed again due to World War II, but it reopened in 1946 (Tronchin et al., 2006).

3. Architectural Description

The main hall of the Communal Theater of Bologna, completed in 1763, has a total capacity of 1176 seats distributed as 644 seats in the stalls and 532 seats on the elevated boxes. The preferred shape of a bell was designed by Galli Bibiena for the plan layout, having the axes measuring 22.4 m and 15.4 m (L, W), as shown in Fig. 2.

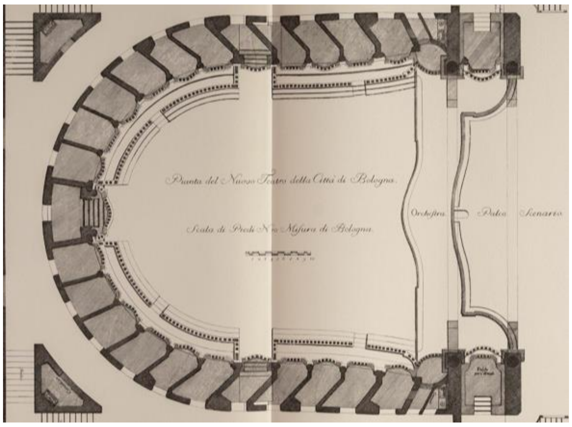

Fig. 2 – Plan layout of the Communal Theater of Bologna. Drawing by A. Galli Bibiena

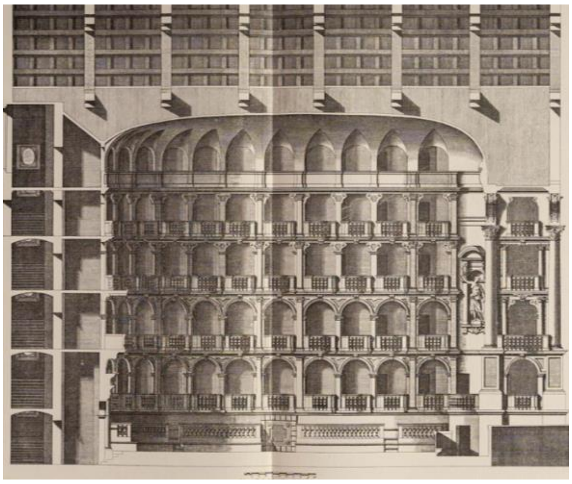

Fig. 3 – Longitudinal section of the Communal Theater of Bologna. Drawing by A. Galli Bibiena

The total height is about 16.9 m, which includes four orders of balconies surmounted by a gallery, as indicated in Fig. 3.

The architect also introduced a series of new constructive solutions, such as the use of load-bearing masonry rather than wooden frames (Amoruso, 2019).

However, these new schemes caused him serious slander, although it was proved that these innovations show excellent acoustic performance.

Fig. 4 – Wooden mechanical system located beneath the finish floor of the stalls

Beneath the floor of the main hall, a wooden mechanical system can regulate the height of the seating area, so to be at the same level as the stage, as shown in Fig. 4.

3.1 Digital Model

From the architectural drawings, a digital model was made, considering all the architectural elements and discarding the details of capitals and tiny decorations (Vorländer, 2011), as shown in Fig. 5. The layers represented in different colours were grouped based on the characteristics of the materials.

Thereafter, the model was exported in dxf format, ready to be used within Ramsete software (Farina, 1995). The attribution of the absorbing and scattering coefficients was carried out based on the acoustic measurements, as indicated in Fig. 6. The sound source and the receivers of the model were located in the same positions used for the survey (Caniato et al., 2021), in order to make the model calibration accurate (Manfren et al., 2020, 2021a and 2021b)

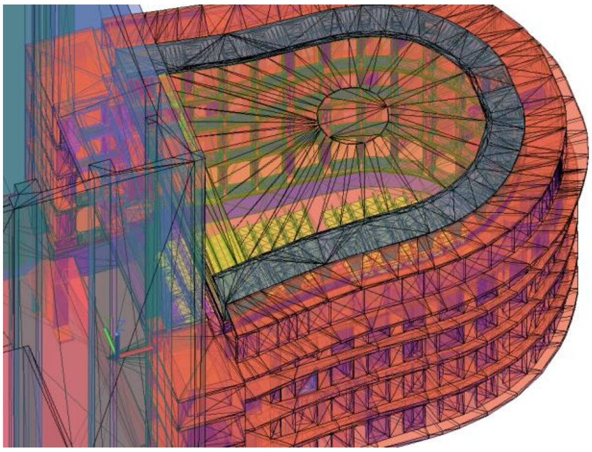

Fig. 5 – View of the 3D model

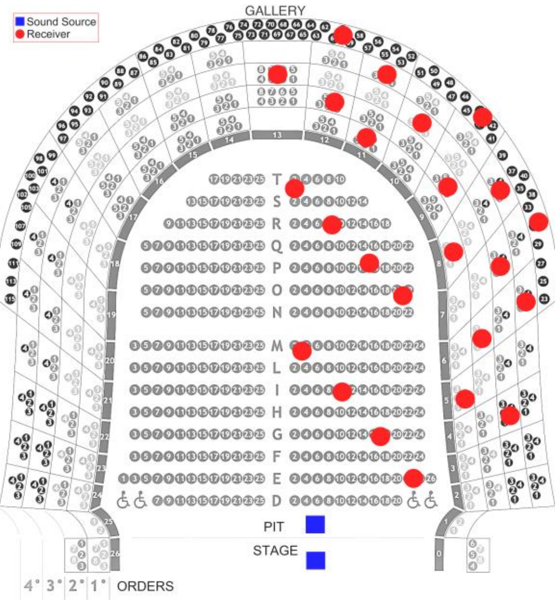

Fig. 6 – Scheme of the equipment positions during the acoustic survey

4. Acoustic Simulation

The acoustic simulations were carried out based on the absorption coefficients that were attributed by considering the materials inside the theater (Shtrepi, 2019). The simulations were calculated without any scenery on the stage, nor any audience; they faithfully represent the conditions found on site.

For the simulations, two omnidirectional sound sources were placed in the locations where they were positioned during the acoustic measurements (Iannace et al., 2000), in particular, on the stage and in the orchestra pit.

Figs. 7 to 11 show the main acoustic parameters for a bandwidth comprising a range of between 125 Hz and 8 kHz. The results shall be considered as the average of measured and simulated values related to stalls and balconies (Tronchin et al., 2021a and 2021b).

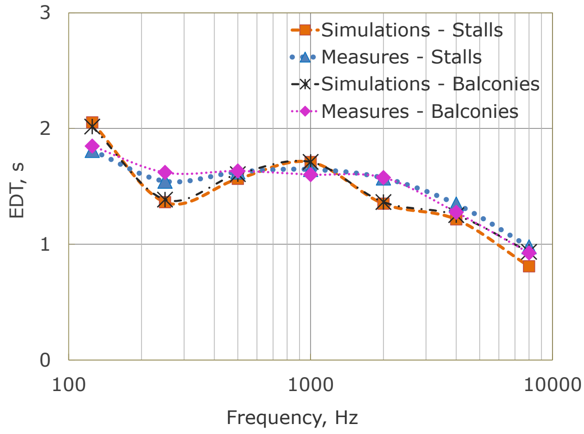

Fig. 7 – Measured and simulated values of EDT

Fig. 7 shows the comparison of the acoustic measurements and simulations of the EDT results. For this acoustic parameter, the difference between stalls and balconies is minimal across all the frequency bands. However, a drift between measurements and simulations does not exceed 5 % for the considered bandwidth (Caniato et al. 2019; Sakai et al., 2002).

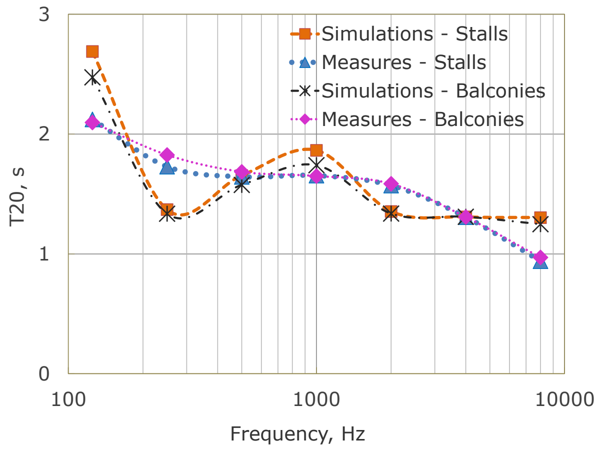

Fig. 8 – Measured and simulated values of T_{20}

Fig. 8 indicates that the T_{20} measured results around 1.8 s at mid-frequencies highlight a good reverberation time for a hall having a volume size equal to approximately 4,200 m^3, and similar to other Italian opera theaters built in the same period (Vodola, 2019). The simulated values at 250 Hz and 2 kHz were calibrated to be up to 0.5 s away from the measured results; this was assessed along with the other acoustic parameters (Bettarello et al., 2021; Guarnaccia et al., 2019).

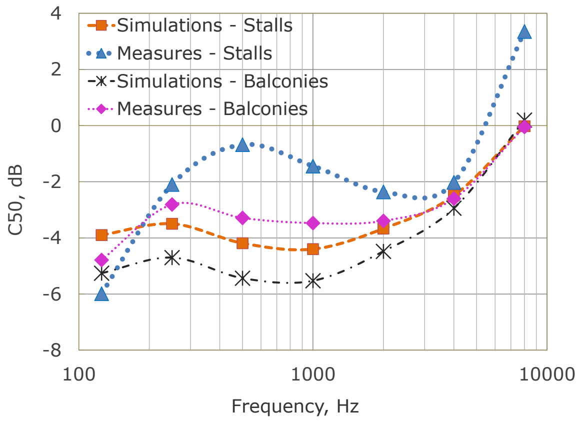

Fig. 9 – Measured and simulated values of C_{50}

Fig. 9 shows the results of the speech clarity index (C_{50}) to be between the optimal range (-2 dB and +2 dB) (Beranek, 1962) from 250 Hz onwards in relation to stalls, while the measured values in the balconies fall slightly below the lowest range limit, with the exception of 8 kHz being equal to 0 dB. The simulated values are shifted below the measurements of up to 2 dB for mid-frequency bands, while at 4 kHz the difference is minimised.

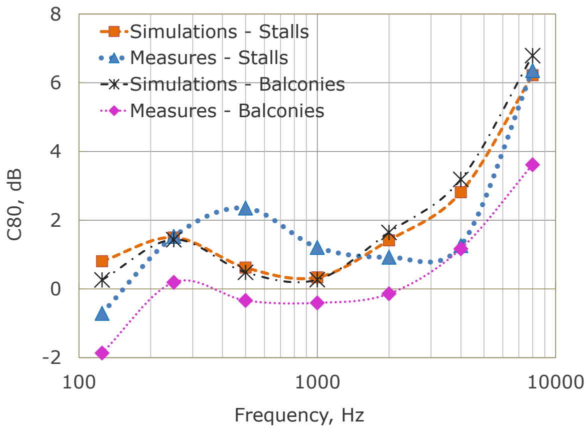

Fig. 10 – Measured and simulated values of C_{80}

In terms of music, the clarity index measured (C_{80}) falls within the optimal range (-2 dB and +2 dB) across all the frequency bands, with the exception of 8 kHz, where the values are up to 4 dB above the upper range limit. A difference of up to 2 dB was found between the measurements in the stalls and in the balconies, to be maximum at 500 Hz and negligible at 4 kHz. The difference in the simulated values between balconies and stalls is less, to approximately 1.5 dB at mid-octave and null at very high frequencies.

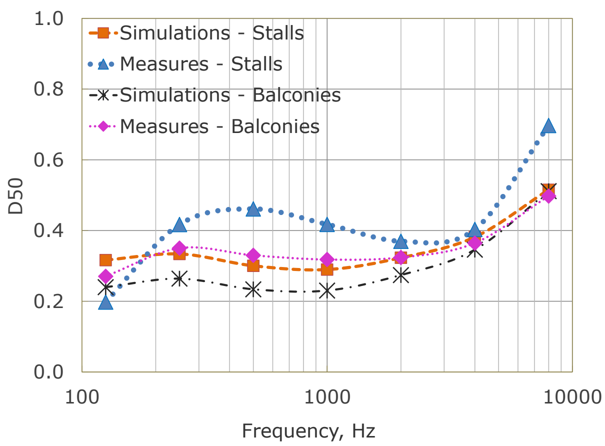

Fig. 11 – Measured and simulated values of D_{50}

Fig. 11 highlights that the measured values of definition (D_{50}) were found to be around 0.38 in the balconies and 0.42 across the stalls. This means that the acoustic response of the Communal Theater of Bologna is more suitable for music, with a shortfall at low frequency related to speech (Bettarello et al., 2010; Puglisi et al., 2021). The simulated values are shifted up to 1.5 below the trend lines related to balconies and stalls, despite the difference at high frequencies being negligible.

5. Conclusion

This paper deals with the acoustics of the Communal Theater of Bologna, one of the best architectural masterpieces designed by Antonio Galli Bibiena. The main acoustic parameters were analysed in comparison with the simulated results obtained by applying the absorbing and scattering coefficients to a digital model that faithfully reproduces the architectural composition of the theater. The results highlight an acoustic response suitable for both music and speech, while the simulated values were assessed to be within 5 % away from the values measured if averaged across all the spectrum bandwidth. The calibration process considered all the acoustic parameters as well as to be fruit of the authors' experience on acoustic simulations taken for similar room shapes.

References

Amoruso, G. 2019. "The teatro of Bologna as a transformable space: drawing, geometry and invention in the study of the wooden model of the theatre by Antonio Galli Bibiena." *Lecture Notes in Civil Engineering* 24:375-394. doi: https://doi.org/10.1007/978-3-030-03676-8_13

Beranek, L. 1962. *Music, Acoustics and Architecture*. John Wiley & Sons, Inc..

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, G. Scavuzzo, and A. Gasparella. 2021. "Indoor Acoustic Requirements for Autism-Friendly Spaces". *Applied Science* 11: 3942. doi: https://doi.org/10.3390/app11093942

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

Caniato, M., F. Bettarello, and A. Gasparella. 2021. "Indoor and outdoor noise changes due to the COVID-19 lockdown and their effects on individuals' expectations and preferences". *Scientific Reports* 11: 16533. doi: https://doi.org/10.1038/s41598-021-96098-w

Fabbri, K., L. Tronchin, and F. Barbieri. 2021. "Coconut fibre insulators: The hygrothermal behavior in the case of green roofs". *Construction and building materials* 266: 1-9. doi:

https://doi.org/10.1016/j.conbuildmat.2020.121026

Farina, A. 1995. "RAMSETE – a new pyramid tracer for medium and large-scale acoustic problems". In *Proceedings of Euro-Noise Conference*, Lyon, France.

Guarnaccia, C., L. Tronchin, and M. Viscardi. 2019. "Special issue on modelling, simulation and data analysis in acoustical problems." *Applied Sciences* 9: 5261. doi: https://doi.org/10.3390/app9235261

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(1): 239-249. doi: https://doi.org/10.1006/jsvi.1999.2696

Manfren, M., B. Nastasi, E. A. Piana, and L. Tronchin. 2019. "On the link between energy performance of building and thermal comfort: An example". In *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 enabler 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

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

Sakai, H., Y. Ando, N. Prodi, and R. Pompoli. 2002. "Temporal and spatial acoustical factors for listeners in the boxes of historical opera theatres." *Journal of Sound and Vibration*, 258(3): 527-547. doi: https://doi.org/10.1006/jsvi.2002.5274

Shtrepi, L. 2019. "Investigation on the diffusive surface modeling detail in geometrical acoustics-based simulations." *Journal of Acoustic Society of America* 145(3): EL215–21. doi: https://doi.org/10.1121/1.5092821

Tronchin, L., and A. Farina. 1997. "Acoustics of the former Teatro "La Fenice" in Venice." *Journal of the Audio Engineering Society* 45(12):1051-1062.

Tronchin, L., R. Shimokura, and V. Tarabusi. 2006. "Spatial sound characteristics in the Theatre Comunale in Bologna, Italy". Proceedings of the 9th Western Pacific Acoustics Conference (WESPAC), Seoul, Korea, June 26-28.

Tronchin, L., M. Manfren, and V. Vodola. 2020a. "Sound characterization through intensity of acoustic radiation measurement: A study of persian musical instruments". *Applied Sciences* 10(2): 633. doi: https://doi.org/10.3390/app10020633

Tronchin L., M. Manfren, and V. Vodola. 2020b. "The carabattola - vibroacoustical analysis and intensity of acoustic radiation (IAR)". *Applied Sciences* 10(2): 641. doi: https://doi.org/10.3390/app10020641

Tronchin, L., F. Merli, M. Manfren, and B. Nastasi. 2020c. "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. Dolci. 2021a. "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

Tronchin, L., F. Merli, and M. Manfren. 2021b. "On the acoustics of the Teatro 1763 in Bologna." *Applied Acoustics* 172: 107598. doi: https://doi.org/10.1016/j.apacoust.2020.107598

Vodola, V. 2019. "The renovation of the Teatro Nuovo in Spoleto: analysis of the acoustic quality of an Italian Opera House." *Journal of Physics Conference Series* 1351: 012013. doi: https://doi.org/10.1088/1742-6596/1351/1/012013

Vorländer, M. 2011. "Models and algorithms for computer simulations in room acoustics." In *Proceedings of the International Seminar on Virtual Acoustics (ISVA)*, Valencia, Spain, November 24-25.