Installation of Reflecting Panels in the Main Church of Aversa

Silvana Sukaj – European University of Tirana (UET), Albania – silvana.sukaj@uet.edu.al
Amelia Trematerra – Università della Campania L. Vanvitelli, Italy – amelia.trematerra@unicampania.it
Ilaria Lombardi – Università della Campania L. Vanvitelli, Italy – ilaria.lombardi@unicampania.it
Giovanni Amadasi – SCS-Controlsys – Vibro-Acoustic Padova, Italy – g.m.amadasi@scs-controlsys.com
Luigi Guerriero – Università di Salerno, Italia – lguerriero@unisa.it

Abstract

The lack of performance art spaces in Italy led the local authority to convert some abandoned religious buildings for live musical shows. The church of Aversa has been digitally rebuilt and used for acoustic simulations that focus on two scenarios: the existing conditions and the installation of some acoustic panels that help to direct the sound towards the seating area. The validation of the simulations is based on the acoustic measurements carried out inside the church that have been used to calibrate the 3D model. The results show that the acoustic parameters for music are highly improved, resulting within the optimal range as established by the criteria. To improve the acoustic characteristics of the church, the effects of inserting panels to be placed on the audience area were studied using numerical simulation. The procedure was performed with dedicated software for architectural acoustics.

1. Introduction

The lack of buildings dedicated to holding shows of different kinds has led to the conversion of some abandoned religious buildings into buildings to host musical performances. The acoustics inside churches have been the subject of numerous studies. One of the acoustic problems is due to excessive height which causes late reflections. Furthermore, finishing materials such as plaster, stucco and marble contribute to building the sound and creating excess reverberation. The complexity of church acoustics also lies in the multiple locations of the sound source, which could be on the altar (closer to the public), or in the choir of the apse. The church of Aversa was restored to host music concerts. The church was digitally reconstructed and used for acoustic simulations that deal with two scenarios: the existing conditions and the installation of some acoustic panels that help direct the sound towards the listeners. The validation of the simulations is based on the acoustic measurements carried out inside the church which served to calibrate the 3D model. The results show that the acoustic parameters for music improve (Iannace et al., 2019; Iannace et al., 2020; Merli et al., 2021; Tronchin et al., 2020). To improve the acoustic characteristics of the church, the effects of inserting panels to be placed on the audience area were studied using numerical simulation. The procedure was performed with dedicated software for architectural acoustics.

2. Historical Background

The church was built during the 17th century. The earthquake of 1732 damaged the convent, leading the nuns to collect some donations to fund the restoration works that involved the construction of a lightweight wattle vault above the nave of the church, the consolidation of the front elevation and the decoration of the floor with majolica. When the order of Poor Clares was suppressed in 1866, the church became part of the clergy and abandoned until 1961. In fact, after the abandonment, the church did not have any maintenance work. Over the years the roof has fallen, and vegetation has invaded the interior of the church. Fig. 1 and Fig. 2 show the church before the restauration works. Recently the church is under restoration works which consist of rebuilding the roof and it being

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converted into a concert hall for temporary venues besides the sacred functions. The works are to be completed in summer 2022 and this paper deals with the acoustic analysis of the church in relation to the configuration at the end of the works (Fearn, 1975; Giron at al., 2017). Because the church has excessive reverberation, panels suspended from the ceiling were designed to reduce reverberation time and make the environment more comfortable and responsive to the needs of good acoustics for listening to music (Merli et al., 2020; Sukaj et al., 2020; Ciaburro et al., 2018; Ciaburro et al., 2020).

Fig. 1 – Church without ceiling, before the restauration works

Fig. 2 – Internal view before the restauration works

3. Architectural Characteristics

The church is architecturally composed of a single nave having dimensions of 22 m and 7.2 m (L, W), for a total volume of 2000 m^3. Fig. 3 shows the plan of the church.

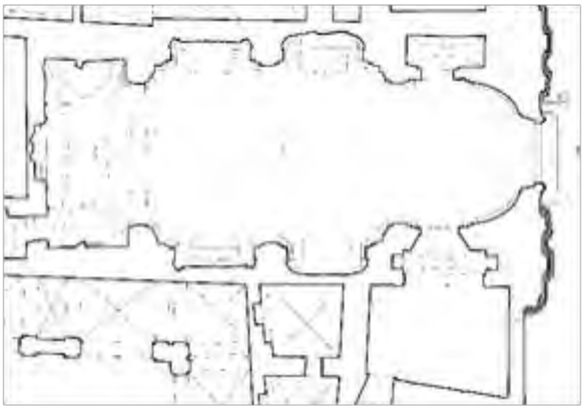

Fig. 3 – Plant of the church

The work consists of the construction of vault and arches with light wood boards, representing a delicate intervention that leaves the spectator to be imaging how the original structure could be. This solution is considered also beneficial under an acoustic perspective because the new skin is not opaque to create a detrimental excess of reverberation, but linear and purified by all frames typical of the Baroque style. Furthermore, the planks are narrow, in line with the concept of transparency that leave a free view of the double-sloped roof, as shown in Fig. 4.

Fig. 4 – Roof of the church after the restauration works

Fig. 5 shows the interior of the church. Note the floor with restored majolica tiles. Furthermore, in the church the plaster of the walls has been rebuilt with white as was originally intended.

Fig. 5 – Inside the church after the restauration works

4. Acoustic Measurements

Acoustic measurements were carried out inside the church before the restoration works by using firecrackers as an impulsive sound source. Firecrackers have the advantage of being very small, but the exposure provides excellent impact with a high S/N ratio. Firecrackers have been used by the authors in many acoustic situations, especially for large environments and in the absence of the electric current signal used to power traditional sound sources. The Brahma microphone was used as a receiver. The acoustic measurements were performed in accordance with the standard requirements outlined by ISO 3382-1. The firecrackers were ignited at a height of 1.5 m above the ground, while the microphone was placed at different positions at a height of 1.6 m. Measurements were made during the daytime, with a temperature of 13–15 °C. The sound source was placed on the altar and closer to the apse, while the microphone was moved across the nave by following a regular grid. The results of the main acoustic parameters were assessed in accordance with ISO 3382-1. Fig. 6–9 indicate the measured values of EDT, T30, C80, C50 and D50 in the octave bands comprised between 125 Hz and 4 kHz (Jordan, 1981). The acoustic parameters were assessed against the criteria for both a good speech understanding and classic music. EDT and T30 inside the church differ from the acoustic parameters desired. This is due to the excess of reverberation. This outcome is considered higher than the optimal value as shown should be 2.5 s based on the room volume of the church. Fig. 8 indicates the response of the clarity index, that shall be between -2 dB and +2 dB. The C80 values in St Spirit's church were found to be within the criteria from 1 kHz onwards, while at low frequencies the results fluctuated up to 2 dB below the lower range limit. The Speech Transmission Index (STI) parameter is a value for the definition of the intelligibility of speech in room, so it is a parameter for the evaluation of good comprehension of speech. The STI index aims to objectively quantify the comprehensibility of speech in a specific position in a room. The acoustic analysis is the starting point on which to carry out an evaluation for a study to improve the acoustics of the room. The acoustics of the church can be improved by inserting a special shell in the area where the musicians will be placed, i.e. in the altar area (Berardi et al., 2022; Bevilacqua & Iannace, 2023).

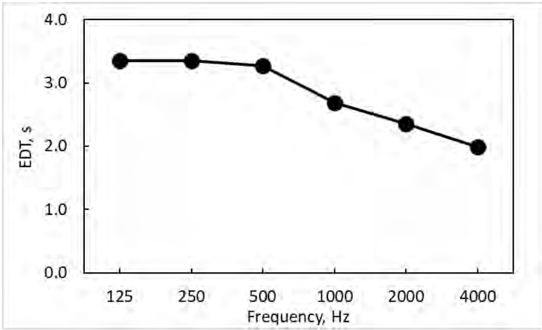

Fig. 6 – Values of early decay time (EDT)

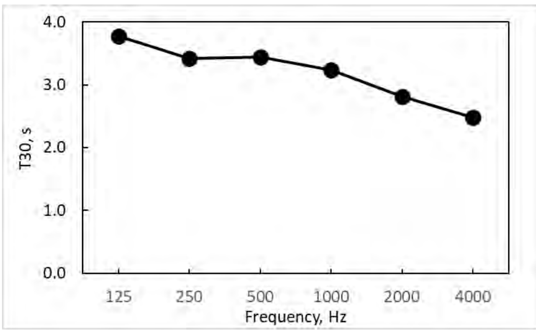

Fig. 7 – Values reverberation time (T30)

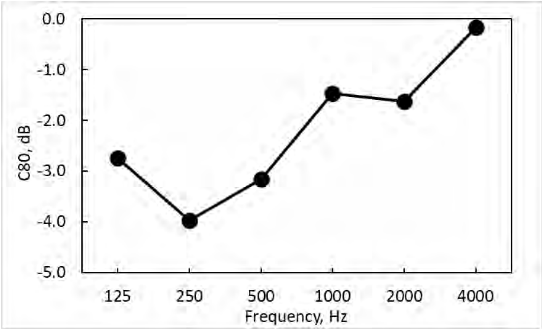

Fig. 8 – Values of Clarity (C80)

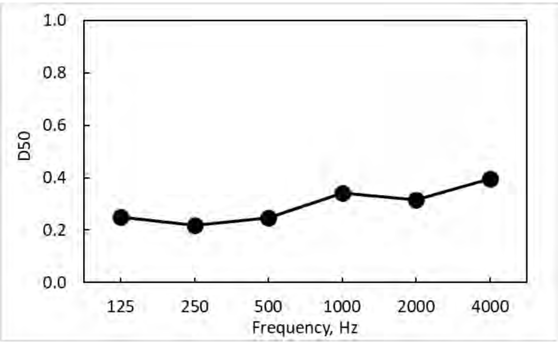

Fig. 9 – Measured values of definition (D50)

The study for the acoustic improvements will be carried out using the architectural acoustics software (Ramsete). Ramsete software for acoustic simulations is based on sound ray tracing and geometric acoustics. The sound ray tracking algorithm is able to solve sound propagation problems within environments, following the assumptions of geometric acoustics. The specular and diffuse reflections on the boundary surfaces of the environment under study are analysed. The principle is based on Snell's law for the light ray incident on a flat surface, the incident ray is reflected from the surface at an equal and opposite angle, and the energy of the reflected ray is reduced by a percentage according to the sound absorption coefficient assigned to the surface. Ray-tracing-based architectural acoustics software evaluates sound reflection in energy terms, the reflected sound is decreased by an amount equal to the absorption coefficient. Fig. 10 shows the virtual model for the Ramsete software for the church in the current state (Bevilacqua et al., 2023; Farina, 1995; Farina, 2007; Farina et al., 2022).

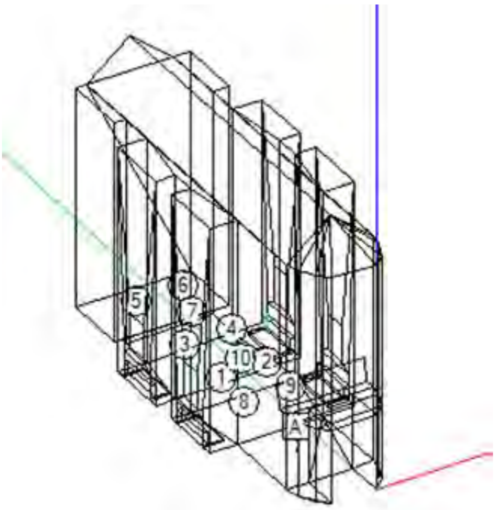

Fig. 10 – Virtual model in Ramsete software

5. Calibration of Digital Model

The measured impulse responses were elaborated with the plugin Aurora suitable for Audition 3.0. Before any simulations, the measured values were used to calibrate the digital model. The main acoustic parameter taken in consideration for this operation is the reverberation time T30 in the spectrum between 125 Hz and 4 kHz, to be considered the average of all source-receiver positions, in unoccupied conditions. Table 1 shows the absorption coefficients used for the calibration.

Table 1 – Absorption coefficients used for the calibration process

Material	**125**	**250**	**500**	**1k**	**2k**	**4k**
Floor	0.01	0. 01	0. 01	0. 01	0. 01	0. 01
Shell	0.15	0. 15	0. 15	0. 15	0. 15	0. 15
Ceiling	0.20	0.10	0.10	0.10	0.10	0.10
Walls	0.01	0.05	0.05	0.05	0.05	0.05

For example, for the ceiling, the alpha value depends on the fact that the wooden panels that make up the ceiling can be assimilated to vibrating panels that absorb low frequencies. The calibration was done on the reverberation time as this is an acoustic parameter that is independent of the position taken in the seating areas. All the other parameters are very sensitive to the distance between source and receiver, meaning that the percentage of mistake increases considerably. The calibration procedure is performed on the T30 value. The alpha values are changed so that the calculated T30 approximates the measured T30. The procedure stops when the difference between the measured T30 and the calculated T30 is less than 5%.

6. Acoustic Simulations

The acoustic parameters are analysed in the frequency band comprised between 125 Hz and 4 kHz in unoccupied conditions. Fig. 11 indicates that the averaged values of C80 are under the limits of the optimal range established for good clarity (-2 dB), for the high value of reverberation time. Fig. 12 shows the STI values are all fluctuating around 0.5, with a small difference between measured and simulated values. Overall, the results indicate that the definition is slightly more suitable for speech. The room needs acoustic correction, but the designers consider it unpleasant to install sound-absorbing panels on the side walls. To improve acoustics, the possibility of installing removable plasterboard panels on the audience is being evaluated.

7. Acoustic Correction

Because the reverberation is excessive and the acoustic conditions are far from those recommended for good music listening, it is necessary to intervene with an adequate acoustic correction. Many projects are available to improve the acoustics of rooms by inserting sound-absorbing panels or inserting sheets with sound absorption characteristics. In this specific case we intervened with an arrangement of diffusing panels in the area where people sit. In this way the sound is concentrated in the area where the spectators sit, the sound spreads evenly, allowing for good conditions for listening to music. In the proposed study the panels are made of diffusing material and have a low absorption coefficient, and they can be made with polymer-glass or plasterboard panels. Fig. 13 shows the virtual model of the new room with the diffusion panels under the audience area. Fig. 14 shows the virtual model of the new room with the panels on the audience area.

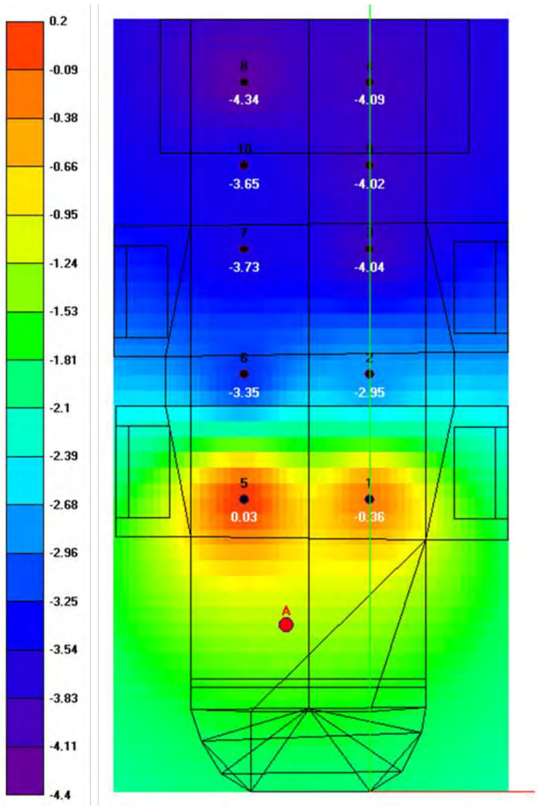

Fig. 11 – Values of clarity index (C80)

The acoustic parameters are analysed in the frequency band comprised between 125 Hz and 4 kHz in unoccupied conditions. Fig. 15 indicates that the averaged values of C80 the limits of the optimal range for good clarity is 2 dB. The numerical simulation is without an audience.

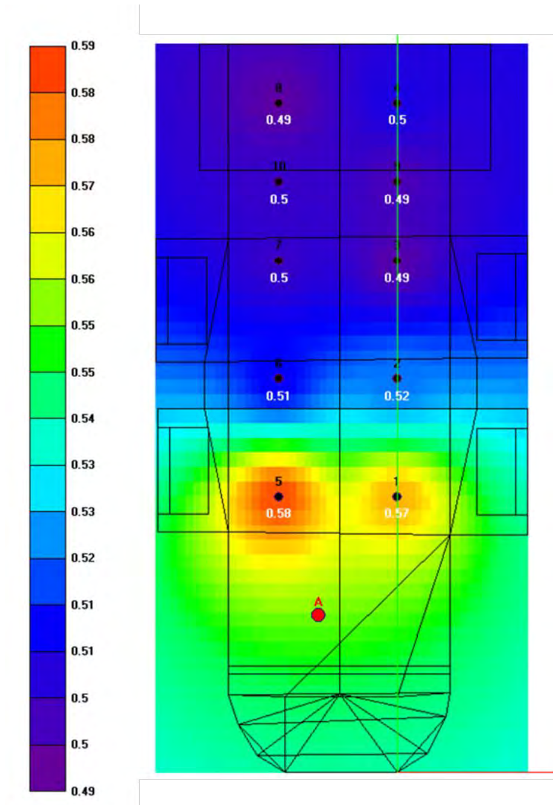

Fig. 12 – STI values

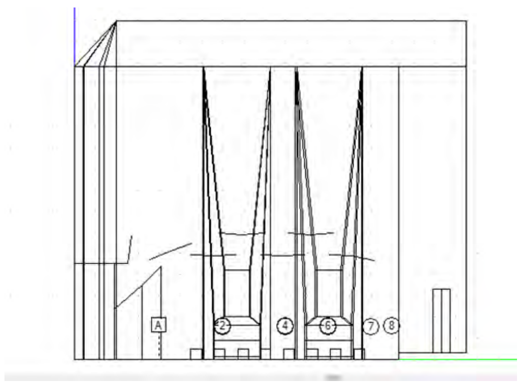

Fig. 13 – Virtual model for the Ramsete software

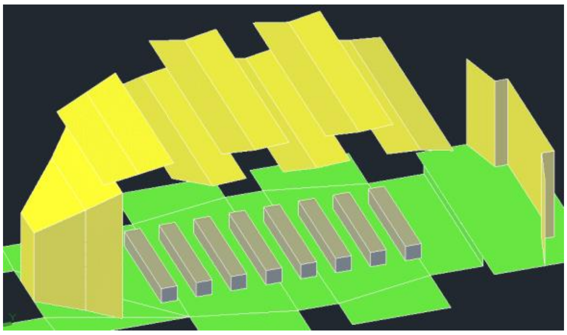

Fig. 14 – Virtual model for the Ramsete software with the panels on the audience area

Fig. 16 shows the STI values are all fluctuating around 0.6. Overall, the results indicate that the definition is more suitable for speech. The insertion of the panels makes the room have better acoustics. The sound is concentrated on the audience area, and the sound is spread evenly. The choice to insert the panels means the walls do not have to be covered with sound-absorbing panels. From an aesthetic point of view, sound-absorbing panels are not widely accepted by designers and new aesthetically acceptable but also innovative solutions are being sought. The church should become a cultural centre for listening to music and having an innovative interior design can make the hall sought after for holding concerts.

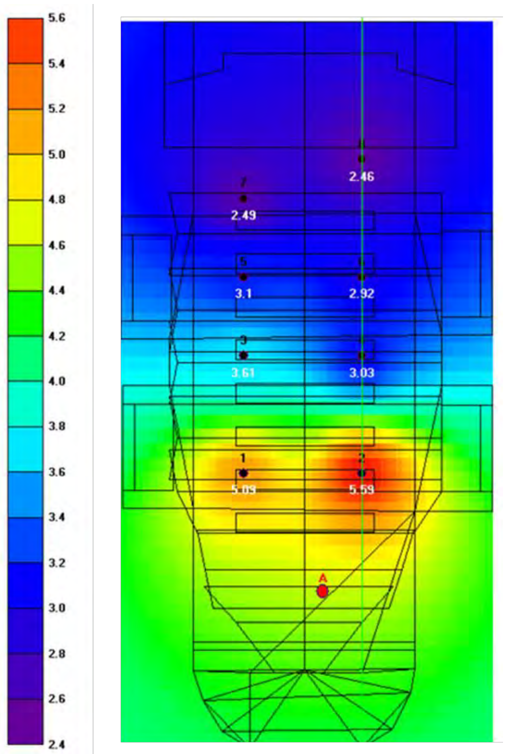

Fig. 15 – Values of clarity index (C80)

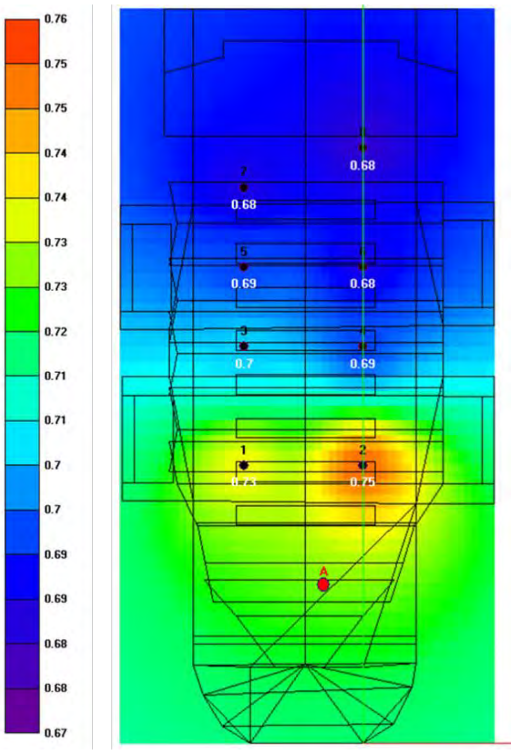

Fig. 16 – Values of STI

8. Conclusions

This paper deals with the analysis of the main acoustic parameters measured inside the St Spirit's church of Aversa. The survey was carried out before construction work began to realize a double-sloped roof and the barrelled vault of the nave, constructed with narrow wooden planks in accordance with the concept of transparency. The results indicate that the acoustic conditions of the church before the works were slightly far to be suitable for an auditorium. As such, the authors have proposed a design project that focused mainly to close the damaged roof of the church so that it would be able to host temporary musical events. It has been predicted that with the addition of the roof, the reflecting surface area will increase the values of reverberation time. Therefore, additional absorbing panels shall be calculated to be in place and to balance the values of the main acoustic parameters, which will be measured after completion of the construction works.

References

Berardi, U., Chiacchio N., Iannace G., Trematerra A., Bevilacqua A. 2022. "From sport to science: the acoustics of a pool transformed into an auditorium". *In proc. of INTER-NOISE 2022, Glasgow*, UK, 21-24 August

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

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.

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