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THE ACOUSTICS OF THE VANVITELLIANA HUNTING LODGE

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Abstract. For many centuries, circular and vaulted structures were realised and used for aesthetic and constructive needs as buildings of worship, monumental buildings or courtyards. In vaulted environments, the effects of sound reflection focus on the central area due to the focus of multiple reflections. This paper presents the results of acoustic measurements carried out in a circular plant environment with a vaulted cover of the Vanvitelliana hunting lodge near Lake Fusaro in the north of the city of Naples. In the central area of the room, due to the geometry of the environment, there are focusing sound effects that generate a "flutter echo".

Keywords: acoustic measurements, impulse response, vault, reverberation time, flutter echo

Mathematics Subject Classification: Primary 68-04, 08A72; Secondary 28-04.

1 Introduction

For many centuries, circular and vaulted structures were realised and used, for aesthetic and constructive needs, as buildings of worship, monumental buildings or courtyards. In vaulted environments, the effects of sound reflection focus on the central area due to multiple reflections, generating special sound sensations for visitors listening to these acoustic phenomena. In the central area, underneath the highest part of the vault, there are phenomena of repeated echoes. Echoes are defined as a delayed repetition of sounds. Focusing effects can cause high sound pressure levels, echo and sound coloration [1]. The aural effects of concave curved surfaces have been studied by several authors [2, 3, 4]. Concave surfaces always create a convergence of sound energy and thus reflected sound amplification (compared to a flat surface) near the focal point, along with an attenuation of sound in other areas (far from the focal point). The echoes are often excluded from the acoustic design of halls due the acoustic risks associated with irregular sound distribution, fluctuating echoes and tone colouring; but the echoes can lead to positive acoustic effects [5].

In the 16th century, numerous works were published in which there were solutions and projects for the realisation of vaults and domes. Attanasio Kircher studied the circular and the vaulted rooms, and He demonstrated as the geometric shape influences acoustic behaviour of the halls [6, 7]. Kircher understood that in an room with the shape of ellipse, the people could communicate with each other when stay in the focus points. Wulfrank et al. [8] studied the sound focusing effect in the "Wigmore Hall" in London. While in the Royal Palace of Caserta, the double elliptical vault presents a great effect and inside, on the planking level, musicians played for the king and his guests during royal receptions [9, 10]. The architect Vanvitelli did not know the fundamentals of architectural acoustics and of the sound behaviour of large places when He designing the double vault. Several centuries prior to Vanvitelli, "De Architectura" by Vitruvio had been reprinted (written in 1st century B.C.) and described the fundamentals of theatrical acoustics [11]. However, most of the studies on architectural acoustics were carried out in the 19th century by Wallace Clement Sabine [12]. When sound meets a curved surface strange effects can be heard, the whispers reflected from a giant hemispherical ceiling were described by Wallace Sabine as having "... the effect of an invisible and mocking presence". In 1935, Alvar Aalto, a famous modernist architect, used an undulating ceiling for the Viipuri Library. The ceiling wood had many concave sections, each designed to amplify the sound for particular listeners [13].

2 The Acoustics in Vaulted Spaces

In the study of the acoustics of large rooms the main acoustic defect is the echo. For an attentive listener, small defects such as insufficient reverberation or low intensity can be unnoticed, a barely perceptible echo is annoying. An echo is a delayed repetition of a sound, and is a sound sensation in which, due to reflection, the listener distinctively perceives a replica, albeit distorted, of direct sound. Since the human ear can distinguish distanced sound impulses of at least 50 milliseconds, with the reflects sound being perceived as distinct from the direct one, it is necessary for the path of the two sound impulses to have a difference of at least 17 metres. This is not the only necessary condition for the echo to occur, in addition to an adequate delay, the reflected sound needs to be sufficiently intense with respect to the other sounds that the listener perceives. For this reason, an echo is manifested for short and particularly intense sound, or in environments with highly reflective walls and at a great distance from the source. In other cases the reflects sound that arrive with a delay are not always perceivable, because they are weakened by multiple reflections or covered by background noise. In large rooms, while realizing spatial conditions for this phenomenon, the presence of more reflective surfaces can cause an echo generated by a sound fail to emerge with respect to its reverberation and subsequent sounds. Thus, an echo manifests itself in particular cases. For example, when reflected energy is concentrated by large concave surfaces, such as domes and curved walls, which produce an increase in the intensity of reflections at certain points, or when the walls of the room are sufficiently absorbent except one which generates the sound reflection responsible for the echo. Curve surfaces can cause aural illusions, due to sound focusing. Standing the right distance in front of an appropriately curved surface and the sound will be focused and amplified. What is heard depends on how far the listener and the sound source are away from surface, the size, shape and extent of the curve as well as the type of sound being made. In an existing situation, an echo can be eliminated by making the reflecting surface sound absorbing and/or diffusing. Another form of echo is a flutter echo, this phenomenon occurs more often in not very large areas when the source is placed between two parallel and reflecting walls. Multiple reflections cause a sound tail similar to the flattering of bird's wings.

3 The Vanivitelliana hunting lodge

This work presents the study of the acoustics of a particular room of the Vanivitelliana hunting lodge near Lake Fusaro in the town of Bacoli, in the North of Naples. The city of Bacoli was a renowned resort for the nobles of the Roman Empire, but after the barbarian invasions and the phenomena of Bradyseism, it was abandoned. The city was reborn during the 17th century and became one of the favourite destinations of visitors to Northern Europe. From 1752 the Fusaro area became the hunting and fishing reserve of the Bourbons that ruled the city of Naples. It is a picturesque hunting lodge located on the Lake. The architect Carlo Vanvitelli built in 1782 the “Royal Hunting Lodge” then called “Casina Vanvitelliana” on the islet of Lake Fusaro, a short distance from the shore. The architect Carlo Vanvitelli was sensitive to the charm of Greek-Roman ruins, and He was inspired by the ruins of buildings and temples. Vanvitelli, inspired by the many examples of octagonal drums, designed a pier with three octagons inside each other, the outer ones being lower so that the tallest central so that it could emerge from the others. As a whole, the building has three octagonal bodies intersecting one at the top of the other with large windows arranged on two levels; a long wooden jetty connects the building to the shore of the lake. The care for of detail, elegance of the shapes and fusion with the lake environment give it a fairy-tale appearance. The building develops over two floors and in one of the two parts, there is the staircase that goes upstairs. Fig. 1 shows the external view of the Vanivitelliana hunting lodge on the Fusaro lake [14]. While Fig. 2 shows the prospectus of the Vanivitelliana hunting lodge. The central hall on the first floor has a circular plan and faces south and north with three openings per side. This circular room has a slightly concave dome ceiling. It has a 8.40 m diameter and minimum height to the side walls of 4.50 m and maximum at 5.30 m in the centre, the volume is about 270 m^3.

Fig. 1. External view of the Vanivitelliana hunting lodge.

This room is characterized by a reverberation time at medium frequencies of about 3.0 seconds. Sound impulses are prolonged by multiple reflections and accentuate in the central position giving rise to a particular flutter echo that captures the attention of visitors. Fig. 3 shows the dimensions of the circular room on the first floor. While the Fig. 4 shows the immage of the circular room.

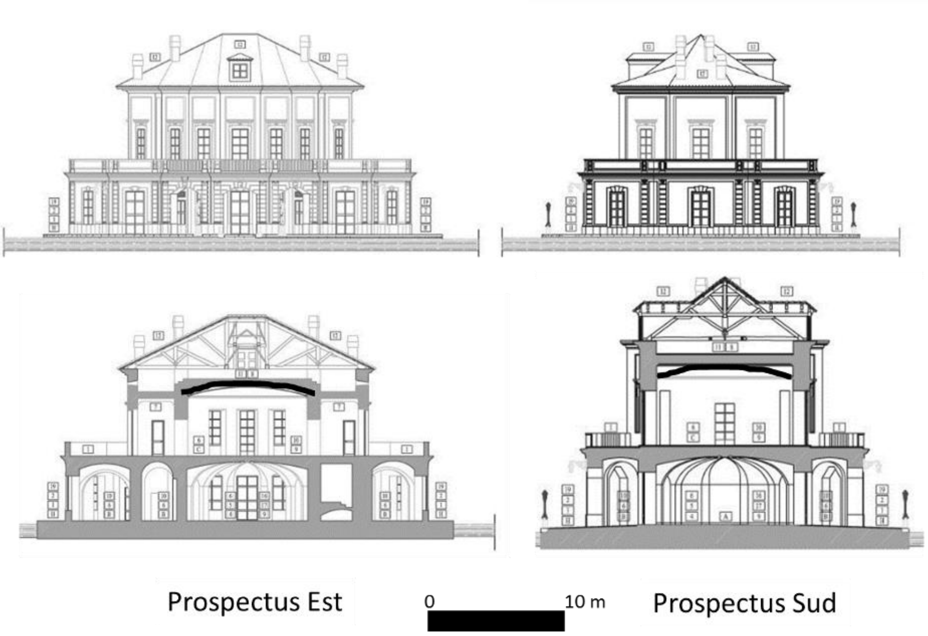

Fig. 2 Prospectus of the Vanivitelliana hunting lodge.

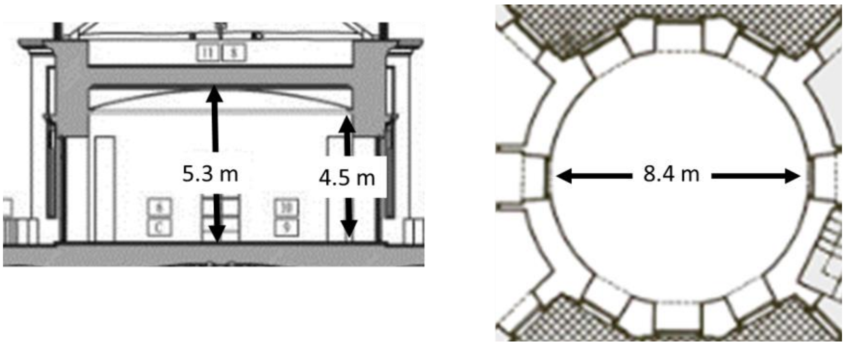

Fig. 3 Dimensions of the circular room on the first floor.

Fig. 4 Immage of the circular room on the first floor.

4 Acoustic measurements

In order to analyse the acoustic characteristics of the room, acoustic measurements were carried out using an impulsive sound source located in centre of the room, under the vault. The acoustic measurements were carried out using an impulsive sound source, which given the lack of electricity supply, consisted of toy balloons inflated with air. The height of the sound source and the microphones were maintained fixed at 1.6 m from the floor. The used microphone was a digital four channels equipment which also allowed to convert recording in an Ambisonics B-format. In fact, BRAHMA is composed of four microphones arranged in a tetrahedral array and allows to convert native format into an orthogonal sound records during post-processing. To reduce background noise, the measurements were done without visitors, so impulse responses were all recorded in empty conditions. The microphone was located along the radial direction at a constant pitch, at height of 1.60 m from the floor. The recorded impulse responses were then elaborated with the software Dirac 4.0, and the several acoustic parameters defined in the ISO 3382-1 [15], such as the early decay time (EDT), reverberation time (T30), the clarity (C80), the definition (D50), and the sound transmission index for speech intelligibility (STI) were analysed. In room acoustic evaluations, the clarity represents the degree to which different reflections arrives and are perceived by the listener, and it is assessed as an early-to-late arriving sound energy ratio. This ratio can be calculated for either a 50 ms or an 80 ms early time limit, depending on whether it relates to conditions for speech or music respectively. The definition considers the early arriving sound energy over the overall sound energy and, similarly to the clarity, it can be calculated for either a 50 ms or an 80 ms early time limit. The Speech Transmission Index (STI) represents the degree of amplitude modulation in a speech signal and it refers to the distortion in speech signals caused by reverberation, echoes, and background noise.

In particular, typical suggested values of the different monaural acoustic parameters for both the speech comprehension and music listening are [16, 17]:

- the reverberation time T30 should assume values below 1 second for a clearer perception of speeches, while it may assume greater values, around 2 seconds for music listening preference;
- the clarity C80, expressing the balance between the early and late arriving energy, should have a higher value if the goal is to separate the initial sounds from the diffuse ones and making the discrete sounds stand apart from each other. In a sound field which is not completely diffuse, the clarity C80 is uncorrelated to the reverberation time, and for the purposes of good listening conditions of music is generally reported that C80 should be in the range between -2 dB and 2 dB, while it is expected to be above 2 dB if speech perception is a priority;
- the definition D50 may assume values from 0 to 1, but for a good speech comprehension, it is often accepted that D50 should have values above 0.50;
- the indices STI can take values between 0 and 1, being greater than 0.5 for favourable speech conditions.

The acoustic procedure and post processing methodology were similar to those used in other spaces, such as the large theatre of Pompeii [18], the theatre of Benevento [19], as well as in many other ancient theatres [20, 21].

5 Discussion

Fig. 5 shows the position of the sound source in centre of the room, and the three receiver points disposed along the radial direction at the distance of 1 metre from each other, Fig. 5 shows the receiver point (1) that is at 1 metre from the sound source and it is close to the centre of the room. The receiver point (2) is at 2 metres from the sound source. While the receiver point (3) is at 3 metres from the sound source and it is close to the perimeter walls. Fig. 6 shows the impulse responses in the three different receiver points (1), (2) and (3), the figure shows the multi reflections that give the flutter echo effect in the receiver point (1); in the other points the effect of the flutter echo are very small. So the the effects of echo are concetrated in the center area of the room. Fig. 7 shows the measured values of different acoustic parameters, in the octave bands from 125 Hz to 4.0 kHz, for the three different measurement points (1), (2) and (3). The reverberation time (T30) at low frequencies exceeds the value of 10 seconds and decreases as the frequency increases, the reverberation time (T30) value is almost equal to the three measuring points. The early decay time (EDT) value at low frequencies is higher for the point located in the middle of the room, i.e. below the vault. For points (2) and (3) that are far from the centre the early decay time (EDT) values are almost equal. The clarity (C80) values reflect the trend of the reverberation time (T30), which is lower at low frequencies and increases as frequency increases; the farthest points from (2) and (3) centres have the best listening conditions for music. Parameter definition (D50) is always less than 0.5, in these environments, albeit small in size, the intelligibility of speech is always low.

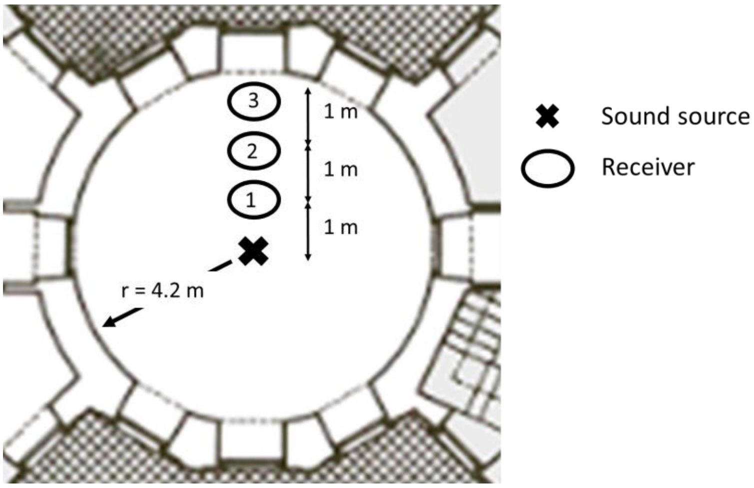

Fig.5 First measurement point.

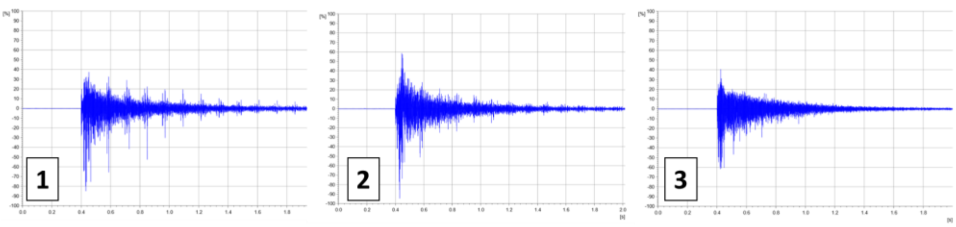

Fig.6 Impulse responses at the point 1, 2 and 3.

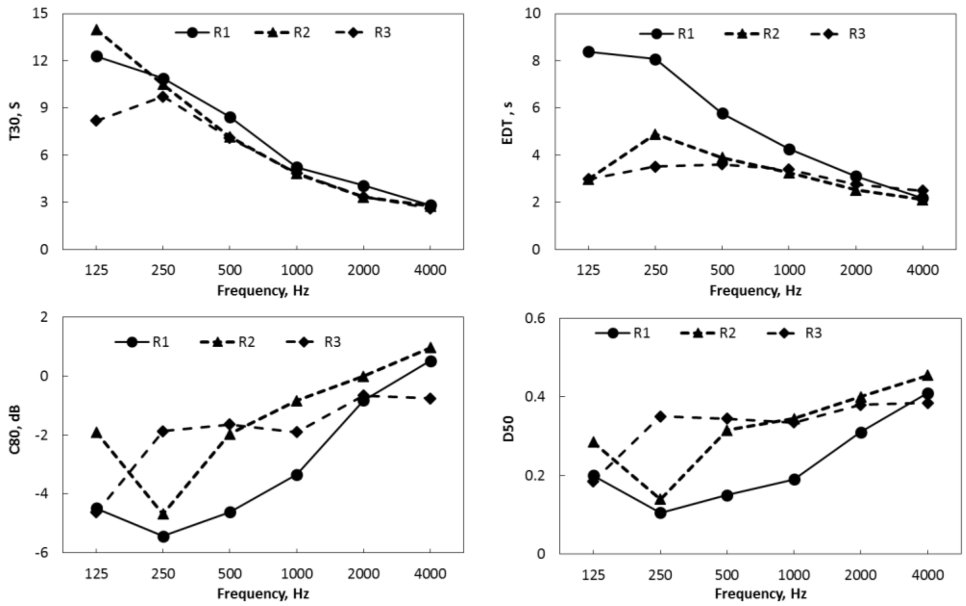

Fig.7 First measurement point. Acoustic parameters measured at the points (1), (2) and (3).

Fig. 8 shows the position of the sound source at the distance of 2 metres from the centre of the room, and the three receivers disposed along the radial direction at the distance of 1 metre from each other. Fig. 9 reports the measured values of different acoustic parameters in the octave bands, from 125 Hz to 4.0 kHz, for the three different measurement points (1), (2) and (3). The reverberation time (T30) at low frequencies exceeds the value of 10 seconds and decreases as the frequency increases, the reverberation time (T30) value is almost equal to the three measuring points. The early decay time (EDT) value at low frequencies is higher, but is similar for the three measurements points. The parameter clarity (C80) values reflect the trend of the reverberation time (T30), which is lower at low frequencies and increases as frequency increases; the farthest points from (2) and (3) centres have the best listening conditions for music. The parameter definition (D50) is always less than 0.5, in these environments, albeit small in size, the intelligibility of speech is always low. Fig. 10 shows the position of the sound source at the distance of 3 metres from the centre of the room, and the three receivers disposed along the radial direction at the distance of 1 metre from each other. Fig. 11 reports the measured values of different acoustic parameters in the octave bands, from 125 Hz to 4.0 kHz, for the three different measurement points (1), (2) and (3). The reverberation time (T30) at low frequencies exceeds the value of 10 seconds and decreases as the frequency increases. The reverberation time (T30) value is almost equal to the three measuring points. The early decay time (EDT) value at low frequencies is higher for the point located in the middle of the room, but the early decay time (EDT) values are almost equal, this valuea are under 4.0 seconds. The parameter clarity (C80) values reflect the trend of the reverberation time (T30), which is lower at low frequencies and increases as frequency increases; the farthest points from (2) and (3) centres have the best listening conditions for music. The parameter definition (D50) is always less than 0.5, in these environments, albeit small in size, the intelligibility of speech is always low.

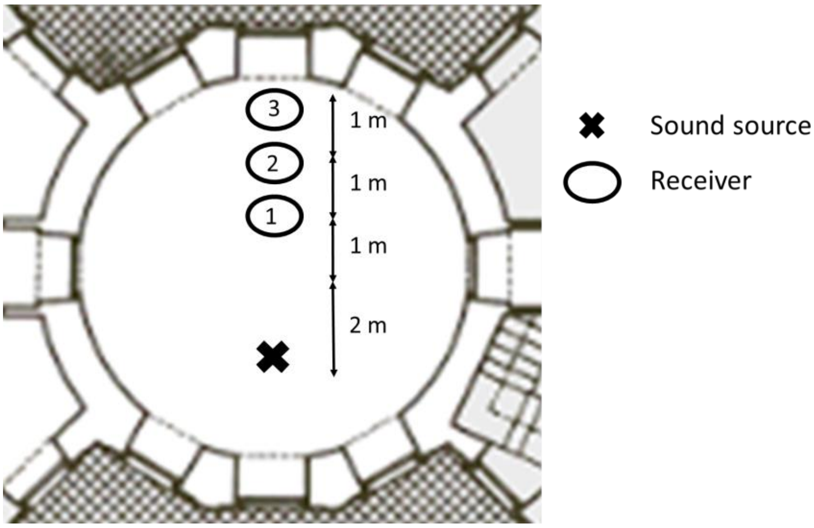

Fig.8 Second measurement point.

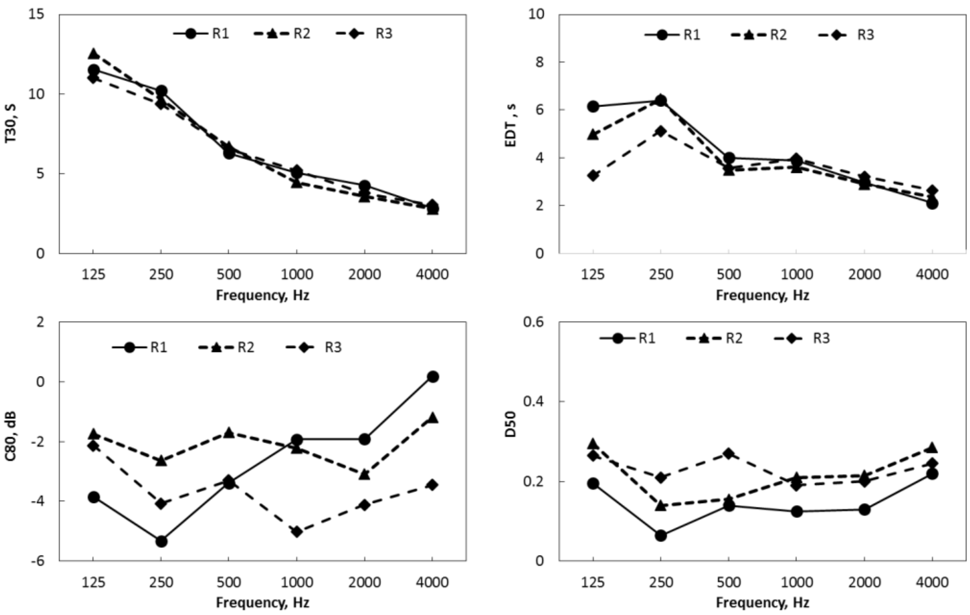

Fig.9 Second measurement point. Acoustic parameters measured at the points (1), (2) and (3).

6 Conclusions

This paper has discussed some of the aural effects that can be created by concave curved surfaces as well as the rooms where they can be heard. Vaulted rooms have particular acoustic features such as flutter echo. This effect is mainly manifested in the central area of the room and tends to decrease at the furthest points from the centre. In particular this paper has discussed the circular room located on the second floor of the Vanvitelliana hunting lodge on Lake Fusaro. The echoes can be considered acoustic faults, but in ancient and evocative buildings echoes can be an attraction for visitors.

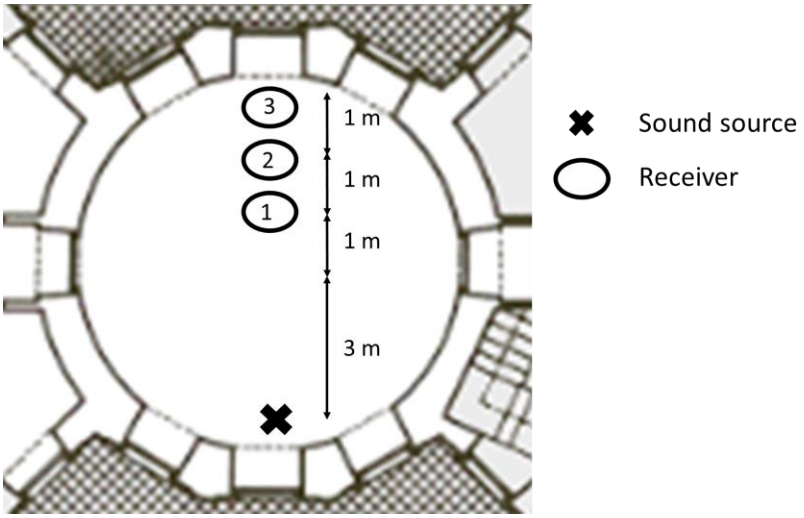

Fig.10 Third measurement point.

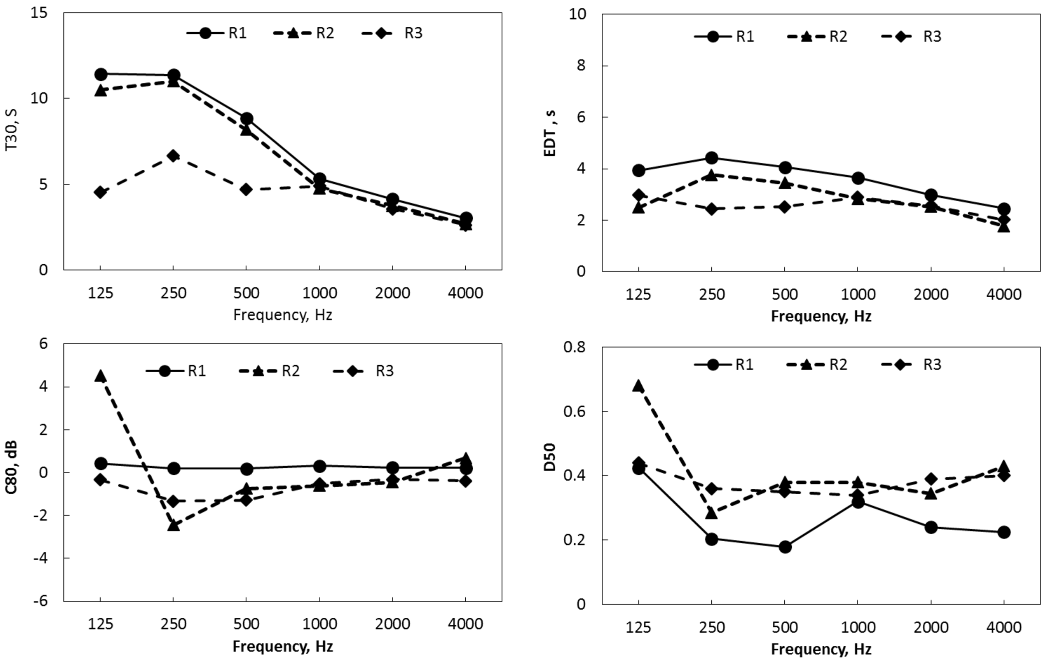

Fig.11 Third measurement point. Acoustic parameters measured at the points (1), (2) and (3).

References

[1] CREMER, L., MULLER, H. A. (translated by T. J. Schultz), *Principles and applications of room acoustics*, Applied Science Publishers, New York (1982)

[2] IANNACE, G., DI GABRIELE, M., SICURELLA, F., *Sound Focusing Effects in Horseshoe Plan Theatre,* Acoustics Australia, 44 (2), 2016, 359-368, doi: 10.1007/s40857-016-0059-2

[3] COX, T.J., *Sonic Wonderland: A Scientific Odyssey of Sound*, Bodley Head: Oxford, UK, 2014.

[4] IANNACE, G., IANNIELLO, E., *Sound-focusing effects in the plan of horse-shoe shaped opera theatres*. In: Proceedings of Acoustics ’08, Paris, France, 2008, 1639–1643.
[5] COX, T.J., *Concave acoustics*. In: Proceedings of 5th International Symposium on Temporal Design, Sheffield, UK, 2011.
[6] KIRCHER, A., *Phonurgia Nova*; Kempten: Rudolph Dreherr, Germany, 1673.
[7] TRONCHIN, L., *The ‘Phonurgia Nova’ of Athanasius Kircher: The Marvellous sound world of 17th century*. Proc. Meet. Acoust. 4, 2008, 015002.
[8] WULFRANK, T., ORLOWSKI, R.J., *Acoustic analysis of Wigmore Hall, London, in the context of the 2004 refurbishment*. In: Proceedings of the Institute of Acoustic, 28(2), 2006.
[9] BERARDI, U., IANNACE, G., TREMATERRA, A., *The Acoustics of the Double Elliptical Vault of the Royal Palace of Caserta (Italy)*, Buildings 7(1), 2017, doi:10.3390/buildings7010018
[10] BERARDI, U., IANNACE, G., IANNIELLO, C., *Acoustic intervention in a cultural heritage: The chapel of the Royal Palace in Caserta, Italy*, Buildings, 6(1) 2015, Article number 1. doi 10.3390/buildings6010001
[11] VITRUVIO, M.P., *De Architectura*.
[12] SABINE, W.C., *Collected Papers on Acoustics*, Cambridge, Mass, 1923.
[13] DECLERCQ, N. F, DEWIJNGAERT, K., VANDERHAEGHE, K., VERLEYSEN, P., *An acoustic diffraction study of a specifically designed auditorium having a corrugated ceiling : Alvar Aalto's lecture room*, Acta Acustica united with Acustica 97(4), 2011, 599-606, doi 10.3813/AAA.918440
[14] BARRELLA, G., TARÌ C., GARZONI, G.C., *Fusaro. Il restauro del complesso borbonico*, Giannini Editore, 2010.
[15] ISO 3382-1. Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters
[16] IANNACE, G., TREMATERRA, A., *Acoustic measurements and correction of a council room*, Noise and Vibration Worldwide, 45 (8), 2014, 12-16, doi: 10.1260/0957-4565.45.8.12
[17] IANNACE, G. Acoustic correction of monumental churches with ceramic material: The case of the Cathedral of Benevento (Italy), Journal of Low Frequency Noise Vibration and Active Control, 35(3), 2016, 230 – 239, doi: 10.1177/0263092316661028
[18] IANNACE, G., TREMATERRA, A., MASULLO, M., *The large theatre of Pompeii: Acoustic evolution*, Building Acoustics, 20(3), 2013, 215-227, doi: 10.1260/1351-010X.20.3.215
[19] IANNACE, G., TREMATERRA, A., *The rediscovery of Benevento Roman Theatre Acoustics*, Journal of Cultural Heritage, 15(6), 2014, 698, doi: http://dx.doi.org/10.1016/j.culher.2013.11.012
[20] BERARDI, U., IANNACE, G., MAFFEI, L. Virtual reconstruction of the historical acoustics of the Odeon of Pompeii, Journal of Cultural Heritage, 19, 2016, 555-566, doi: http://dx.doi.org/10.1016/j.culher.2015.12.004
[21] IANNACE G. The use of historical courtyards for musical performances. Building Acoustics 2016, 23(3-4), 207-222. DOI: https://doi.org/10.1177/1351010X16678219

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