

Mausoleum of Theodoric: acoustic measurements within the lower floor

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Abstract—The Mausoleum of Theodoric the Great is the most famous example of Ostrogothic building in Italy. Due to its position in Ravenna, visitors often expect to see rich mosaics, rather than the actual austere structure. To improve the attractiveness of the monument, the cultural administrators have started augmenting the visitor experience by adding reproduced music and even holding concerts in the ground-floor hall. This article is the first acoustical characterization of the ground floor hall using Ambisonics impulse responses and acoustic maps. The reverberation time and the Clarity measurements should guide music selection.

Keywords—acoustic measurements, Ravenna, Italy, signal processing, late antiquity.

I. INTRODUCTION

The mausoleum of Theodoric the Great is probably the most famous example of 6th-century architecture in Italy. In this paper, we analyse the acoustics of its ground-floor hall, in which concerts now take place.

Due to its high reverberation times, the hall is used as a performance space for specific music styles from the classic repertoire, while the public listens from the outside [1]. The measurements and analysis of the acoustic characteristics of this room provide insight into the original uses of the space and to guide its current re-use by enabling the administrators to select suitable musical pieces.

II. HISTORICAL VALUE OF THE MAUSOLEUM OF THEODORIC

Built around 520 AD by order of Theodoric the Great, king of the Ostrogoths, the mausoleum is one of the most important burial monuments from late antiquity. Today, it is protected as a UNESCO World Heritage Site[2]. The building reflects Theodoric's wish to bring together Roman traditions and Gothic culture, creating something both powerful and unique. Made entirely of Aurisilian limestone, the structure was built using a dry-stone technique, meaning no mortar was used between the large blocks [3]. The building has a ten-sided plan and rises on two stacked levels, topped by a truly impressive stone dome. The dome, carved from a single giant block, measures 10.76 meters wide, 3.09 m high, and weighs more than 290 tons, something unique in ancient architecture [4]. The lower level is especially interesting. It may have served a ceremonial or religious purpose, and possibly even as a tomb for Theodoric's family. Inside, the space follows a Greek cross plan and is covered by a vaulted ceiling [5]. Along nine of the ten walls are small niches, and the tenth side has the entrance. Some carved shell symbols hint at Christian influence, while a few rough, unfinished stones show that some parts may have been left incomplete. Now surrounded by a peaceful public park, this lower space is not only the core of the monument but also a place where architecture, memory, and power come together, connecting Roman heritage with Gothic identity in one powerful design [6].

Recognized as a UNESCO World Heritage Site, the mausoleum continues to be a testament to the complex layers of power, religion, and identity in post-Roman Europe. Figure 1 shows one of the moments during the site survey on the lower floor.

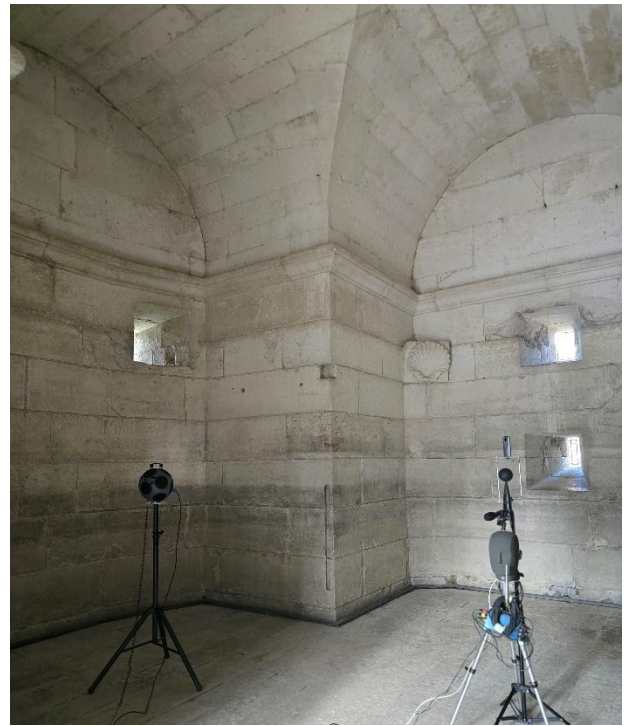


Fig. 1. Internal view of the Mausoleum of Theodoric in Ravenna, Lower Floor.

III. ARCHITECTURAL CHARACTERISTICS OF THE MAUSOLEUM OF THEODORIC

The Mausoleum of Theodoric in Ravenna has two distinct levels, each serving a symbolic and functional purpose, reflecting both Gothic traditions and late Roman funerary practices [7]. The lower level, accessible through a modest entrance, likely served for ceremonial or liturgical functions, possibly used by visitors, clergy, or mourners. It may have housed offerings or relics, and its design resembles that of Roman mausolea used for rituals of remembrance. The space is plain and austere, emphasizing a somber atmosphere suited to prayer or memorial rites [8].

The lower floor has a decagonal layout in plan, which is quite rare in classical architecture and likely chosen for symbolic or structural reasons. The internal space measures approximately 10.5 m in diameter, while the height reaches a maximum of 5 m. The walls are massive, around 1.2 to 1.3 meters thick, built using large, squared blocks of limestone (Istrian stone), giving the space a heavy and grounded feel.

The ceiling is formed with a stone cross-vault, with ten arched niches corresponding to the decagonal exterior walls. These vaults help distribute weight from the upper floor and the monolithic dome [9]. The space is minimally lit, with small slit windows in a few of the niches, creating a subdued, almost crypt-like atmosphere. Figure 2 shows the architectural organization in plan.

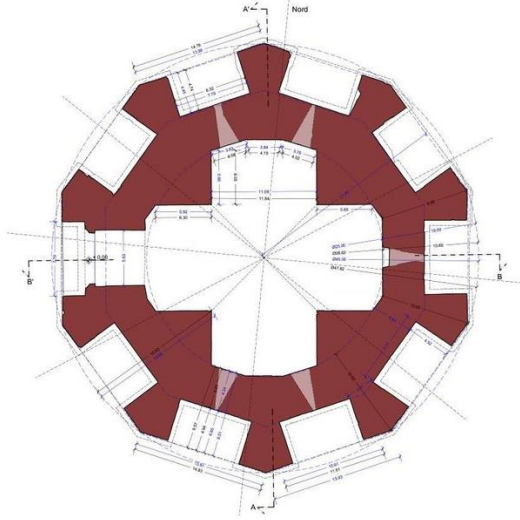


Fig. 2. Plan layout of the Mausoleum of Theodoric, Lower Floor, Ravenna.

IV. ACOUSTIC MEASUREMENTS

A campaign of acoustic measurement has been carried out to record the room response based on the excitation signal. The equipment used for the survey is the following [10]:

- Equalised omnidirectional loudspeaker (Look Line);
- Microphones:
 - a) Binaural dummy head (Neumann KU-100);
 - b) B-Format (Sennheiser Ambeo);
 - c) Omnidirectional microphone (Bruel&Kjaer);
 - d) 64-channel spherical array (MH Acoustic em64 Eigenmike®);
- Personal Computer connected to the loudspeaker and all the receivers.

The sound source was placed in two specific positions, at a height of 1.6 m, as shown in Figure 1, while the receivers were moved across the space, by maintaining the distance as following the standard requirements. The excitation signal emitted by the sound source was an Exponential Sine Sweep (ESS) [11] having a duration of 15 s in a uniform sound pressure level between 40 Hz and 20 kHz. The measurements were carried out in unoccupied conditions [12].

V. ANALYSIS OF RESULTS

A. ISO 3382 acoustic parameters

The recorded IRs were processed and analysed with Aurora, a plugin supported by Audition software. The main acoustic parameters were obtained in accordance with ISO 3382-1 [13]. The data are the average values of all measurement positions. Figures 3 to 5 summarise the measured results in the frequency domain between 125 Hz and 4 kHz.

Figure 3 shows that the difference between EDT and T30 values is noticeable at low frequencies only, up to 7.0 s for EDT and 9.0 s for T30. Nevertheless, the mid frequencies are found around 4.0 s and the high octaves around 2-3 s. This means that the choirs singing in this place for religious services should be very supported by the room's response [14]. Since the surfaces of the room are all stone, this is a response typical of other churches, even if the volume shape is different [15, 16].

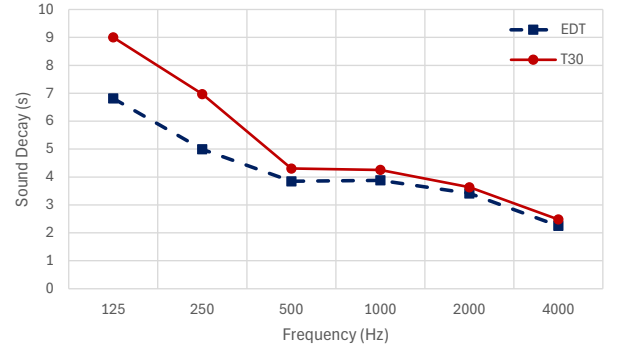


Fig. 3. Measured results of Early Decay Time (EDT) and Reverberation Time (T30).

The clarity index has been assessed for both speech and music. In particular, Figure 4 illustrates the similarity in trendline between the two responses, with a shift equal to approximately 2 dB. The C50 has been found lower than C80, around -7 dB if averaged across the bandwidth, with a peak down to -8.5 dB [17]. Similarly, C80 results have been found slightly better, around -5 dB, but always below the minimum range limit established for optimal range (-2 dB, +2 dB). This means that the high level of reverberation has a negative impact on speech clarity [18]. Regarding the music clarity, it was a common practice to have the vocal songs supported by the architecture, so the clergy should not put so much effort into multiple services running on the same day [19].

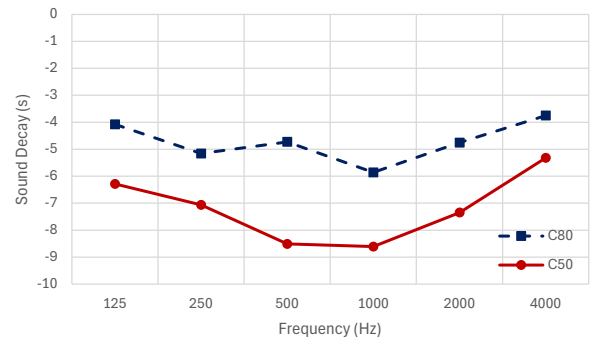


Fig. 4. Measured results of clarity indexes: C50 and C80.

B. Acoustic maps

The use of the spherical array microphone em64 Eigenmike® and the panoramic camera (Ricoh Theta V) enabled the elaboration of the sound maps. The impulse response from this type of microphone records the sound rays reflected from all directions after interacting with the architecture [20].

The combination of audio and video is illustrated in a video overlay, where the contour levels are coloured according to a scale that goes from blue (low energy) to red

(high energy). This combination was realised with a Matlab script created at the University of Parma.

Figure 5 shows the direct sound wave hitting the microphone. The sound energy arrives at the receiver with a sound level of 105 dBA. The reverberant room already highlights in yellow patches the reflection observed on other surfaces of the room [21].

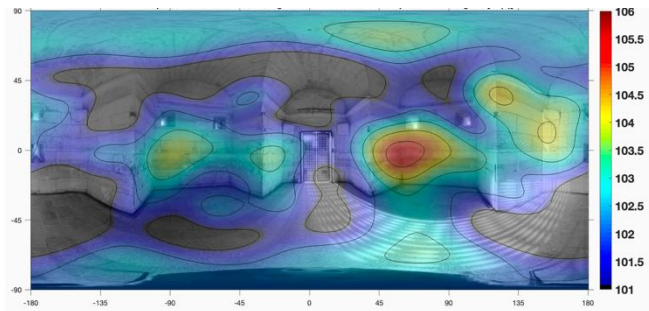


Fig. 5. Direct sound (in red) hitting the microphone probe positioned near the center of the ground-floor hall

Due to the highly reverberant environment and consequently the very diffuse field created in this room, the direct sound is accompanied by the early reflection already coming from the right-hand side of the acoustic map. Therefore, by measuring the acoustic response from the edge of one of the niches, it is easier to separate the direct sound, coming from the loudspeaker, and the first reflection coming from the closest wall [22].

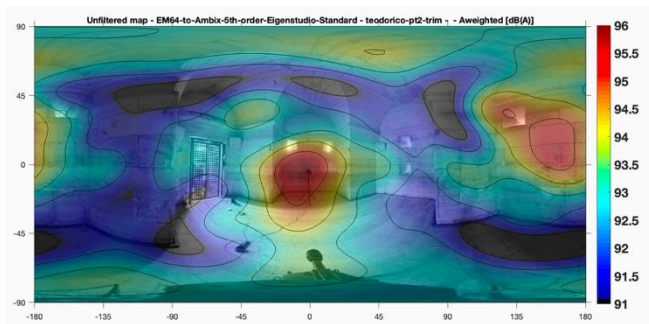


Fig. 6. Evident direct sound coming from the loudspeaker, and reflection from the closest wall are evident in this map from the second measurement position, on the edge of one of the niches.

VI. CONCLUSIONS

This paper shows that the lower level of the Mausoleum of Theodoric is very reverberant, with a reverberation time around 4 s at mid-frequencies [23]. This means that, although it is a very limited space, it reverberates like a large church due to the highly reflective property of the cladding walls [24].

Another analysis has been done with a multichannel microphone, which detects the sound directionality from all directions [25, 26]. In particular, it is noticeable that the direct sound detected by the microphone is accompanied by the early reflection already coming from the closest wall, as this room highly resonates to any minimal sound [27].

Future research studies will be focused on a comparison between central plan layouts of funerary spaces like Mausolea, including the circular shape and polygonal shapes other than decahedral [28].

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