

Mausoleum of Theodoric: acoustic measurements within the funerary room

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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 first-floor hall. This article is the first acoustic characterization of the first-floor hall using Ambisonics impulse responses and acoustic maps. In particular, 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 first-floor hall, in which concerts now take place [1]. Due to its high reverberation times, the hall is used as a performance space for musicians, while the public listens from the outside [2]. By measuring and quantifying the acoustic characteristics of this room, we hope to 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 IN RAVENNA

The Mausoleum of Theodoric in Ravenna, built in 520 AD by the Ostrogothic king Theodoric the Great, holds significant historical, architectural, and cultural value. It stands as a unique example of early medieval funerary architecture, distinct from both Roman and Byzantine styles [3]. The structure is notable for its use of large stone blocks, a rarity in Italian construction of the time, and for its monolithic dome, an enormous single piece of Istrian stone over 10 meters in diameter, weighing approximately 230 tons. This engineering feat shows the technical skill and ambition of Gothic builders. Architecturally, the mausoleum reflects a fusion of Roman traditions with Germanic influences [4], symbolizing the transitional moment from the ancient world to the medieval period. Culturally, it represents the assertion of Gothic identity in Italy and Theodoric's desire to legitimize his rule by creating a lasting monument [5]. 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 [6]. Figure 1 shows one of the moments during the site survey on the upper floor.



Fig. 1. Internal view of the Mausoleum of Theodoric in Ravenna, Upper 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 upper chamber, reached by an external staircase, was Theodoric's burial space. It holds the central sarcophagus (now empty) and is crowned by the massive monolithic dome, which adds monumental grandeur [8]. This upper level, elevated and isolated, underlines Theodoric's elevated status and possibly conveys the idea of his soul being closer to the divine. Such separation between the lower ceremonial level and the sacred upper level follows the Gothic emphasis on hierarchical spatial symbolism [9].

The upper floor is circular in plan, sitting atop the decagonal lower floor. This shift in geometry, from a ten-sided base to a circular upper chamber, enhances the symbolic meaning and vertical hierarchy of the structure. The internal diameter is approximately 10.5 m, the same as the lower level, ensuring spatial continuity and structural balance [10]. The most remarkable feature is the monolithic dome, characterized by a 10.76 m dome; its height from base to crown is estimated to be 3 m, with a total weight of 230–260 tons. It is a single piece of Istrian stone, carved off-site and transported. This upper level reaches about 6–7 m in height, from the upper floor to the apex of the dome. There are six small arched windows placed symmetrically around the circular wall, allowing filtered natural light inside [11]. These punctuations soften the interior austerity and emphasize the dome's curvature [12]. Figure 2 shows the architectural organization in plan.

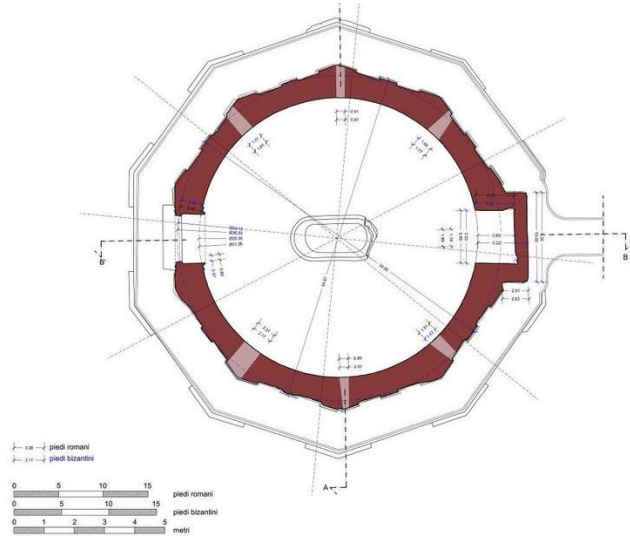


Fig. 2. Plan layout of the Mausoleum of Theodoric, Upper Floor, Ravenna.

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:

- 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 stated by regulation. The excitation signal emitted by the sound source was an Exponential Sine Sweep (ESS) 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 [13].

V. ANALYSIS OF RESULTS

A. ISO 3382 acoustic parameters

The recorded IRs were processed and analysed with Aurora, a plugin supported by Audition software [14]. The main acoustic parameters were obtained in accordance with ISO 3382-1. 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 in EDT values between stalls and balconies is minimal, except for 250 Hz, where it is about 1 s. EDT and T30 present a similar trendline, going from 7.0 s at 125 Hz to about 3.0 s at 4 kHz, as typical of very reverberant rooms [15]. Overall, the EDT value at mid frequencies is around 5.0 s, meaning that the

acoustic response of the hall is highly reverberant and similar to other churches clad with stone sheets [16].

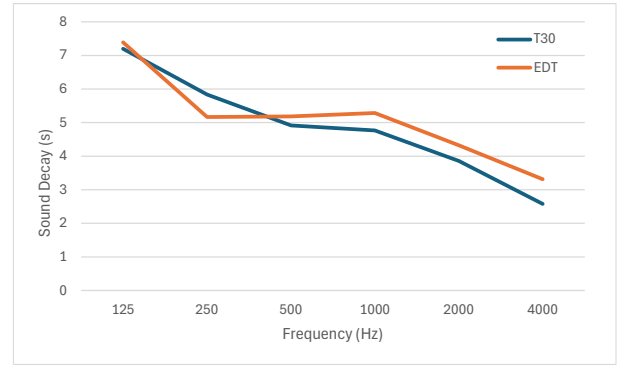


Fig. 3. Measured results of Early Decay Time (EDT) and Reverberation Time (T30).

The clarity index has been assessed for both speech and music. In particular, Figure 4 illustrates that a difference of about 1.5 dB is observed between C80 and C50, which is higher than the just noticeable difference (JND) [17]. C80 fluctuates around -6 dB, with a downward decrease at 1 kHz, while C50 fluctuates around -8.5 dB, with a small improvement at high frequencies.

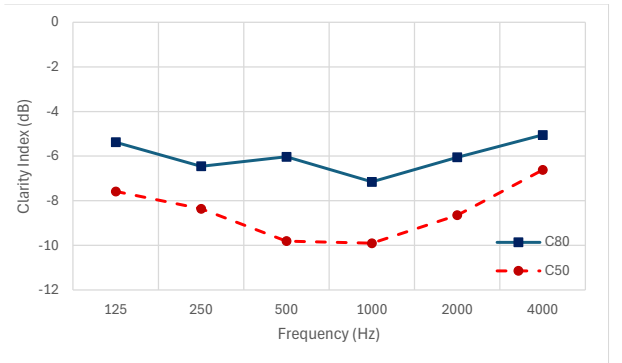


Fig. 4. Measured results of Clarity Index.

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 recorded the sound rays reflected from all directions of the circular room of the funerary space [18].

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) [19]. 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 101 dBA. The reverberant room already highlights in yellow patches the reflection observed on the opposite surface of the room [20, 21].

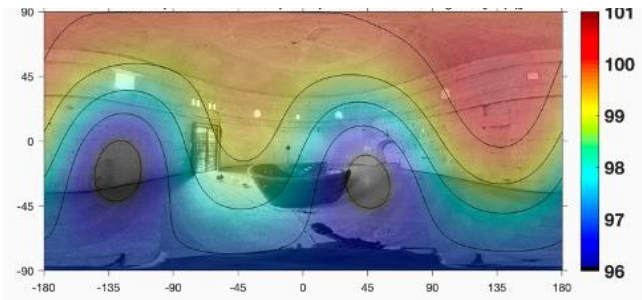


Fig. 5. Direct sound energy detected with the multi-channel microphone in the First Floor of the Mausoleum of Theodoric.

Figure 6 shows the reflections captured at another receiver point. Similarly, the early reflections come from diametral opposite sides, at the same energy magnitude [22, 23].

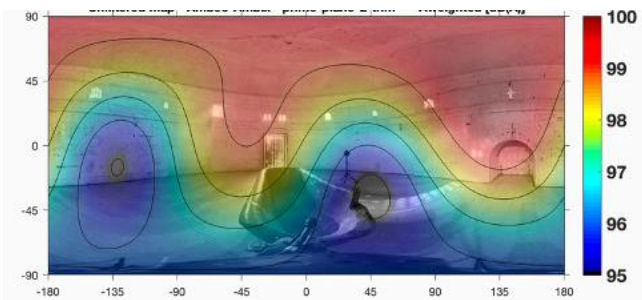


Fig. 6. Early reflection hitting the microphone probe positioned in the second receiver position of the Mausoleum of Theodoric.

VI. CONCLUSIONS

This paper illustrates the room response of the funerary room of King Theodoric within the upper level of its Mausoleum in Ravenna. Based on standard analysis of the acoustic parameters, this room is observed to be very reverberant, with a reverberation time around 5.0 s at mid frequencies [22]. These results are found to be very similar to large churches or cathedrals, as similar stone cladding on walls represents the main reflecting surface, favouring the sound energy to bounce between parallelly opposite walls [24]. The main factor contributing to raising the reverberation time, other than stone walls, is the geometry of a perfectly circular room surmounted by a stone vault [25].

A further analysis involves a visual study of sound directivity and intensity when the sound wave bounces within the space, specifically from the back of the stalls [26]. The 64-channel microphone is considered appropriate for tracing very accurately the spatial sound rays in the time domain of the impulse response [27, 28]. This additional analysis highlights the sound arriving at the microphone from two diametral opposite sides, as the sound bounces off the opposite surface of the circular wall [29, 30].

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