

## Simulation of Acoustic Conditions within the Markanda Temple, India

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### Abstract

The ancient religious structures hold a significant wealth of knowledge, with their acoustics being a part of their inheritance. Hindu temples in Central India built during the 12<sup>th</sup> century exemplify this. However, the challenge lies in evaluating the acoustics under occupied conditions due to the various configurations of sound sources and worshippers' positions. While existing literature offers calculation methods for predicting reverberation time, this paper introduces a novel and intriguing approach. We simulate the acoustics in the pavilion and sanctum space under occupied conditions using the advanced acoustics simulations software 'ODEON'. This innovative method allows us to obtain a comprehensive set of acoustic parameters. Due to its reverberant nature, the study examines the Markanda temple in Gadchiroli district, allowing for a better understanding of occupancy-related variations. Nevertheless, the results indicate that the impact of occupancy was limited due to the absorbing elements on the floor in the form of carpet, resulting in 'fair' acoustic conditions for speech intelligibility.

**Keywords:** Cultural Heritage; Acoustic Simulation; Hindu Temple Architecture; Speech Intelligibility; Architecture.

### 1. Introduction

India has a rich, ancient, and diverse history. Throughout history, we have worked to preserve cultural heritage through restoration and conservation strategies, safeguarding it and making it available to international and local people. India has 42 cultural sites designated as UNESCO World Heritage. These sites are assessed based on their exceptional universal values (OUV).

The soundscape technique can potentially be important to retain. The phrase soundscape refers to the acoustic environment (Schäfer, 1976). It is important to analyze and save acoustic parameters for multiple reasons. One reason is that any of the world's acoustically pleasing spaces could be destroyed or harmed by accidents or natural disasters. Therefore, it is crucial to conduct acoustic measurements and archive data. For example, when the renowned Gran Teatro La Fenice in Venice burned down in 1996, one of the world's best-sounding opera houses was lost. However, some of its acoustic characteristics were preserved because acoustical measurements had been taken two months before the incident (Brezina, 2013; Farina, Angelo, 1975). Therefore, the research aims to conduct acoustical measurements of unexplored Hindu temples in India, with Markanda temple as a case example. The Markanda temple complex, a heritage site selected for our research, is known as the 'Khajuraho of Vidarbha.' Located in the Chamorshi town of Gadchiroli district, Maharashtra, India, this 12th-century temple complex is situated on the banks of the Wainganga River. The temple complex, with its rectangular layout and dimensions of 35.9 meters in width and 30.10 meters in length, extending from north to south direction, provides a unique setting for our acoustic simulations (Cunningham, 1895; Narad et al., n.d.) (Fig 1). It is a pilgrimage site for Lord Shiva's followers during the annual Mahashivratri festival. During this festival, temples host various activities, such as Vedic chanting and congregational activities, such as singing devotional songs. These temples have unique, distinctive characteristics and are currently under the restoration process of the temple's outer walls (Fig 2). The Markanda temple, constructed using basalt gneiss stone, consists of three linked areas: the Sanctum (Garbha Griha), vestibule (Antarala), and Pavilion (Mandapa). Approximately two centuries ago, the temple faced considerable destruction when it was struck by lightning. This event caused the upper spire, known as the shikhara, to fall onto the roof of the pavilion, resulting in damage to the outer shikhara. (Fig 3). Table 1 describes the Physical attributes of the Markanda temple.

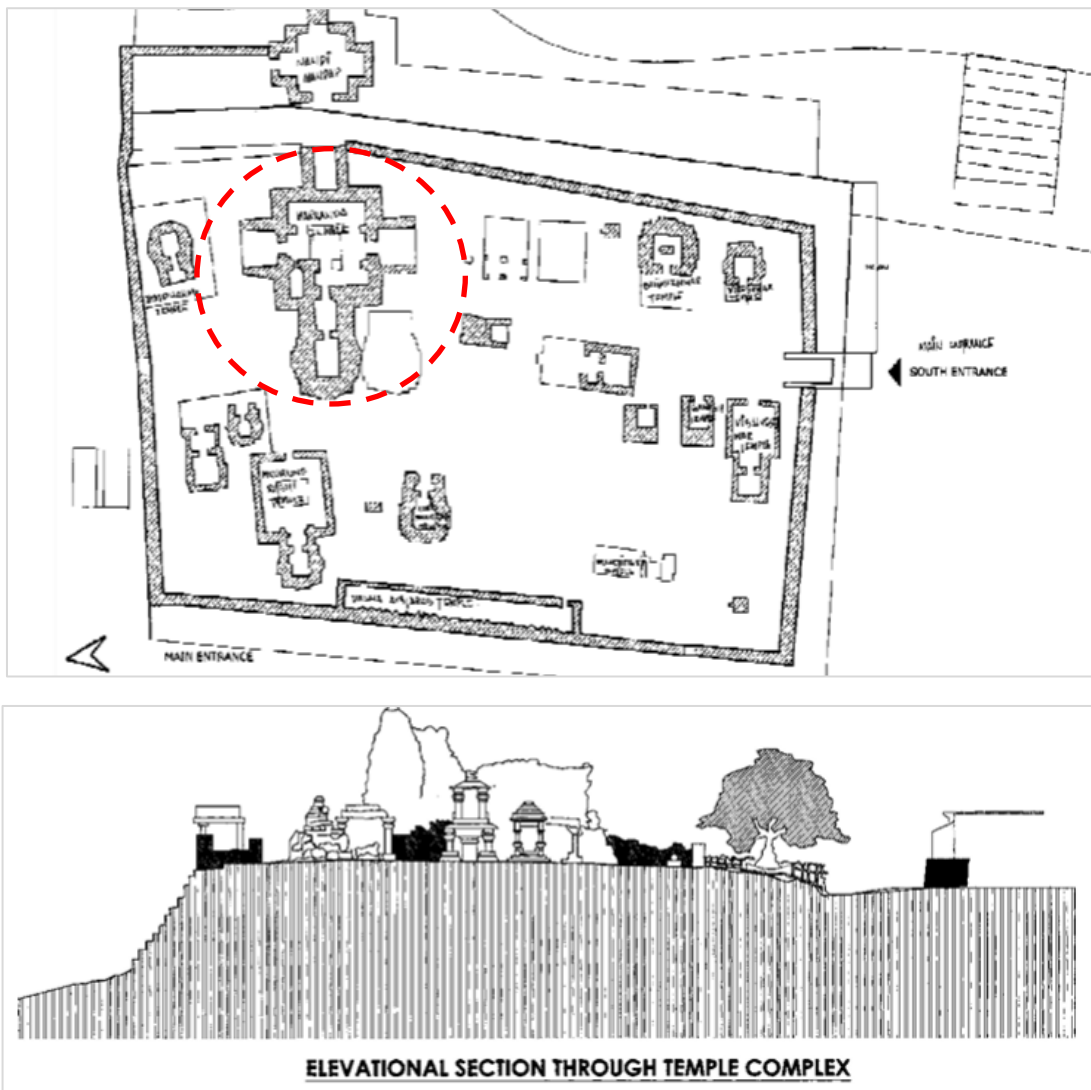


Figure 1. Site Plan of the Markanda Temple (Narad et al., n.d.)



Figure 2: Exterior view of the Markanda temple.



Figure 3: Current restoration of the temple.

**Table 1:** Physical attributes of Markanda temple (Dandge & Patil, 2024) .

	Internal Spatial organization	Construction Date	Plan Typology	Internal Volume (m <sup>3</sup> )	Total Surface Area (m <sup>2</sup> )	Construction Material	Ceiling Type
<b>Markanda Temple</b>	Sanctum		Enclosed from three sides	63.7	97.3		Tiered
	Vestibule	12 <sup>th</sup> century	Enclosed from two sides	31.25	64	Basalt gneiss	Tiered
	Pavilion		Enclosed	332.8	394.4		Arcade
	Combined		Enclosed	427.75	-		-

**2. Temple Sound Spaces**

Indian temples were constructed using various materials based on what was available in different regions, ranging from timber and brick to bamboo, mud, plaster, and stone across India. The design of worship spaces in these temples was carefully considered to create a complex acoustic environment that catered to spiritual needs and enhanced faith by evoking a sense of the divine presence (Ajinkya Umbarkar, D V Nandanwar, 2019; Aziz Amen, 2017; Aziz Amen & Nia, 2018; Ho et al., 2023). In Hindu temples, particular attention was given to two chambers with reverberant acoustic qualities: the Garbha-Griha, where the deity is enshrined, and the Antarala, a chamber located in front of the Garbha-Griha (Prasad & Rajavel, 2010).The conch's ability to be heard from a distance was believed to amplify the divine influence emanating from the temple beyond its boundaries.

In an Indian Hindu temple from the end of the 1st millennium, three distinct sound spaces can be identified according to a text: the central cella (first sound spaces), the temple enclosure (second sound spaces), and the outer space which includes the street surrounding the temple where a small icon of the main deity is carried in procession, as well as bodies of water like tanks, rivers, and seashores where the icon is bathed (third sound space)(Colas, 2019).

**2.1. Acoustical studies on Hindu temples**

Certain studies in the literature talk about Hindu temples' architectural features and parts that help produce musical sounds. These investigations include the impact of Vedic chanting and the appraisal of musical instruments' acoustic properties, such as gongs, bells, and conch shells, examined in the anechoic and community rooms of a modern Hindu temple in New Jersey (Prasad & Rajavel, 2013) . In a different study, the ability of the musical stone pillars of the Maha mandapam in the Vitthala temple, Hampi, to produce music when touched with a finger was examined through a scientific analysis of their acoustic properties (Patil & Gajbhar, 2012). The study methodically investigates the musical pillars' acoustic characteristics using non-destructive testing methods. Furthermore, a scientific investigation found that the temple's pillars make a sound like a bell, indicating a notable similarity between the pillars' resonance characteristics and those of a real bell (Kumar et al., 2008).Previous studies in this area have focused on the architectural features of Hindu temples and found considerable differences between their sound field characteristics based on factors such as volume, ceiling type, spatial design, and building materials. As such, there is still a dearth of research on the acoustic properties of Hindu temples. It is imperative that these uncharted regions of Hindu temples and their acoustical properties be investigated (Dandge & Patil, 2024).

**3. Material and Methods**

The research aims to explore the acoustic dimension of the revered Markanda temple, a temple built in the 12th century that stands as a testament to our rich cultural heritage. The guidelines of the ISO 3382-1:2009 (3382-1 & Acoustics measurement of room acoustic parameters—part 1:performance spaces (2009), 2009) were adhered to when conducting the acoustic study. Initially, acoustic measurements were taken at the Markanda temple to ensure no worshippers or priests were present. A sound source was placed at the center of the pavilion at a height of 1.5 meters above the ground, connected to a power amplifier. Room impulse responses were recorded using an omnidirectional microphone and portable analyzer at six receiver positions (R1-R6), each positioned at a height

of 1.2 meters to simulate the ear level of a praying individual. Sine sweep excitation signals were used to produce precise outcomes, covering a frequency range of 125 Hz to 4000 Hz (Fig 4). There is no documentation of the seating pattern in a Hindu temple. It was due to this reason that during the acoustics measurements, the sound source location at the center of the pavilion was identified (Table 2) (Fig 5). The floor plan of the Markanda temple with sound source and receiver positions is shown in (Fig 6) .3D virtual models of the Markanda temple were created using SketchUp software, converted to a parametric file format, and analyzed using Odeon software to recreate the sound fields of the Markanda temple (Fig 7).

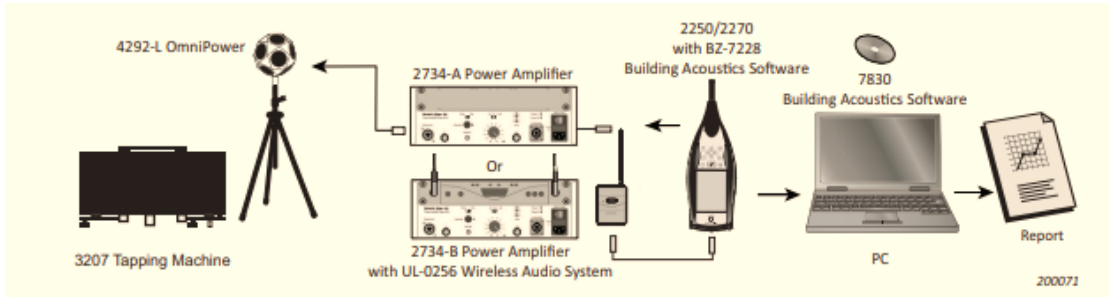


Figure 4: Acoustical Measurement Setup.

Table 2: Seating pattern of devotees singing *bhajan* and *kirtan*.

Facets of the Hindu temple	Attributes	Parameters of the Attributes
Temple in Two-dimension	Garbha Griha is the focal point	All sources and receivers face the deity.
Arrangement of spaces	Composition of temples with respect to the functional spaces	Garbha Griha, Antarala, Mandapa, entrance porch and Nandi Mandapa

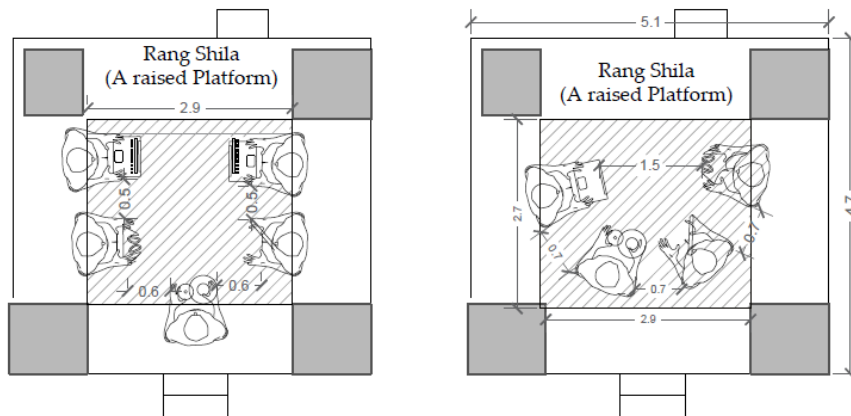
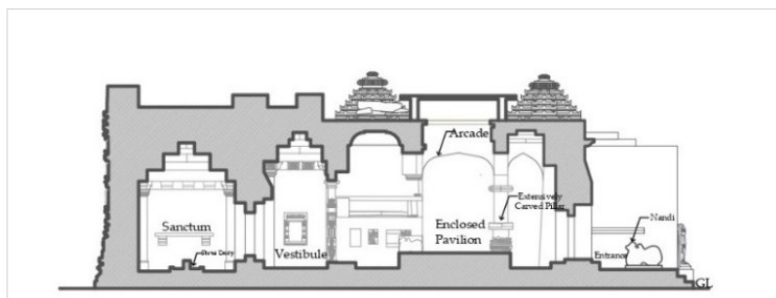
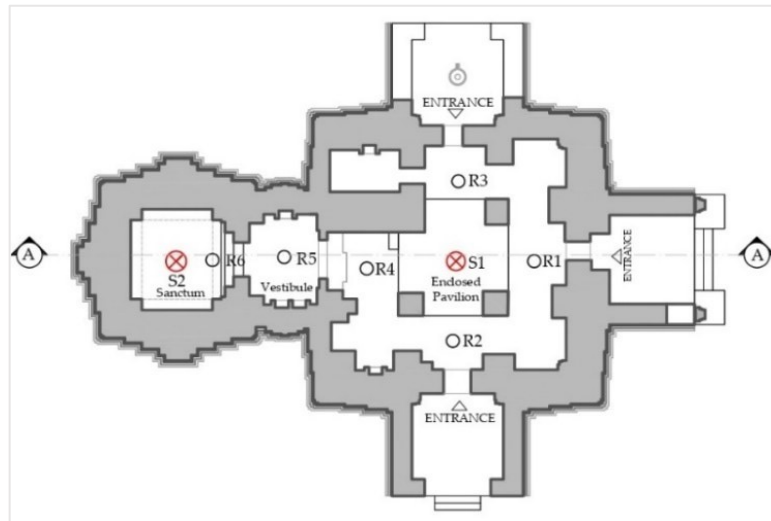


Figure 5. Seating pattern (Author)





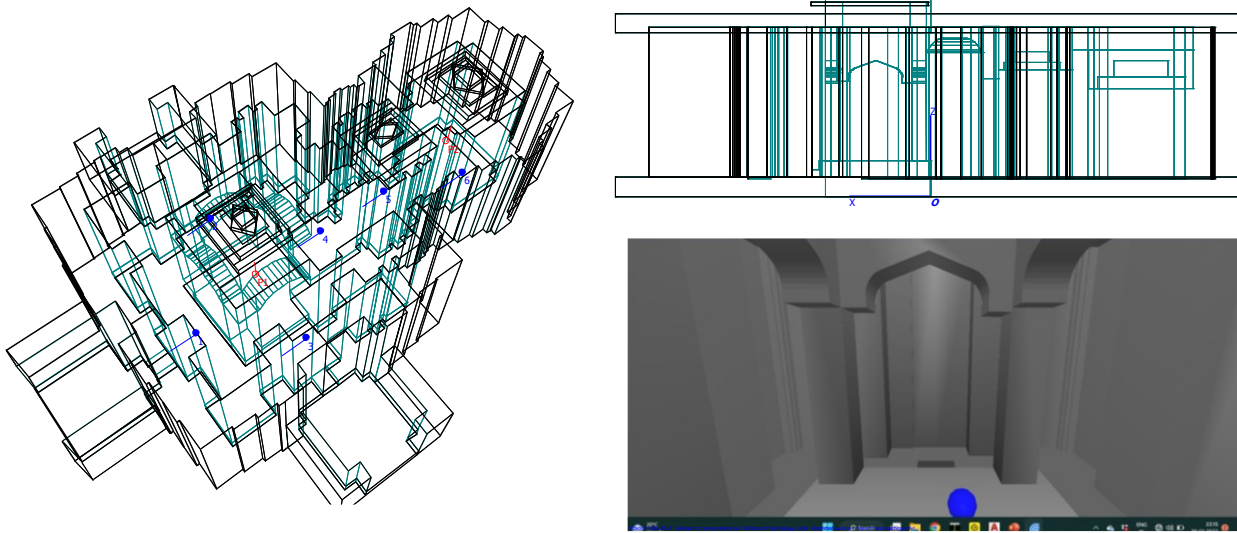
**Figure 6:** Floor plan of Markanda temple with sound source (S1 and S2) and receiver positions (R1-R6).

The material's surface and the acoustic model's simplification were taken into account when determining the absorption coefficient and scattering coefficient, which were then repeatedly adjusted based on variations between the simulated and observed values of the sound fields. By using this method, the study identified reference values for the scattering and absorption coefficients of commonly used materials in ancient temples (refer to Table 1)(Adeeb & Gül, 2022; Alayón et al., 2021). The simulations were finalized by placing sound sources and receivers within the 3D virtual model (refer to Fig 7). For the simulations, the sound source was positioned in two different locations. Initially, a spot for musical activities that aligned with the on-site measurements was selected at the center of the pavilion (S1). In the second simulation, the sound source was placed 1.5 meters inside the sanctum (S2), where a solitary priest stands before the deity, reciting Vedic mantras and performing aarti.

**Table 1:** Absorption and scattering coefficient used in Markanda temple.

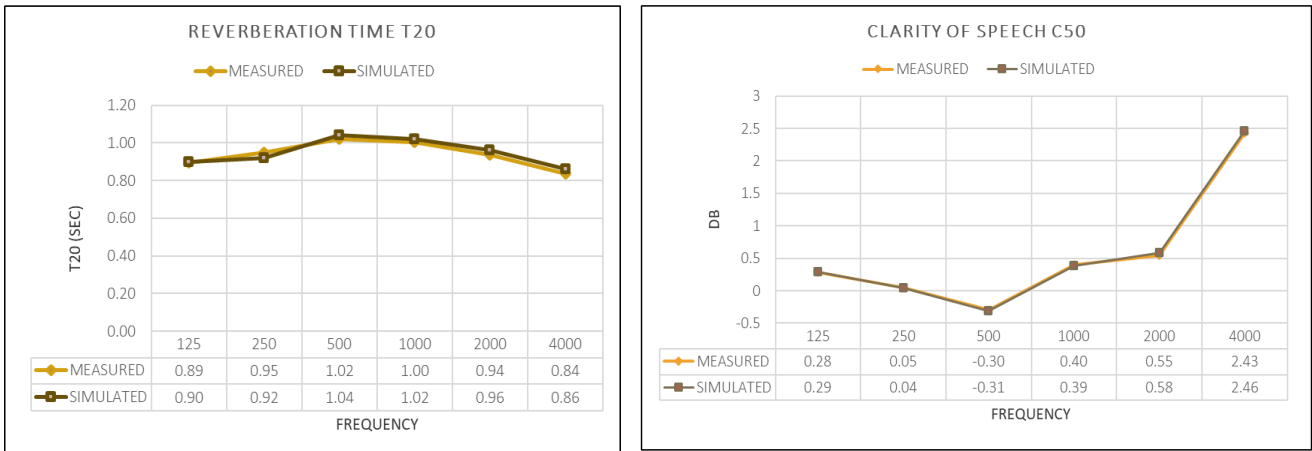
Material Name	Scattering coefficient	Absorption coefficient of material							
		63Hz	125Hz	250 Hz	500Hz	1 KHz	2 KHz	4 KHz	8 KHz
Hard stone	0.7	0.02	0.20	0.03	0.03	0.04	0.05	0.05	0.05
Outer wall		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00





**Figure 7:** 3D Virtual model with sound source and receiver positions.

In-situ observations were utilized to calibrate the three-dimensional virtual models through adjustments to the absorption and scattering coefficients. The resulting absorptions and scattering coefficient values are presented in Table 1. During the calculation of simulated errors, the Just Noticeable Difference (JND) for each chosen indicator was taken into account, ensuring that the simulated errors were below the JND threshold to evaluate the accuracy of the simulation results. The iterative calibration process was repeated until the T20 and C50, readings fell within the 1 JND range. Specifically, discrepancies of 5% relative difference for T20, 1 dB for C50, and 0.3 for STI were observed prior to this iterative calibration process (Bradley et al., 1999) (Fig 8).



**Figure 8:** Simulated and measured values for T20 and C50 indicators.

**4. Results**

Acoustics parameter—Based on the literature review, the following parameters have been observed and investigated during measurement and analysis.

Reverberation parameters—T20, C50, and STI—Reverberation represents the degree of vivacity of the hall (Akhtar & Kawathekar, 2023). It is the time required for a sound to decay by 60 dB. Reverberation time in terms of T20 has been evaluated for a frequency spectrum of 125Hz to 4kHz.

Figure 9 plots T20, C50, and STI values recorded at two sound source positions with spatially averaged receivers (R1-R6) for occupied and unoccupied conditions.



Figure 9. Shows T20, C80, and STI simulated occupied and unoccupied values within the Markanda temple.

#### 4. Discussions

The average T20<sub>occu</sub> value for the sound source in the sanctum (S2) at the Markanda temple is 0.91 seconds, much higher than 0.72 seconds at 125 Hz for the sound source at the center of the pavilion (S1). These results have given the absorptive qualities of the people in the temple's pavilion area, which were employed in the computer simulations. The Markanda temple simulation findings demonstrated that, in all frequency ranges, the sound source (S1) has substantially higher highest spatially averaged C50<sub>occu</sub> values than the sound source (S2). The sound source located within the sanctum (S2) of the Markanda temple has lower clarity, with a C50<sub>occu</sub> value of -4.73 dB at 125 Hz, compared to a higher value of +2.09 dB for the same frequency in (S1). Furthermore, it is possible to argue that the tiered ceiling in the sanctum and the associated volume with highly reflective material contribute to the high T20<sub>occu</sub> values seen for the sound source in the sanctum (S2). A priest chanting Vedic texts in the sanctum while using gongs and conch shells is one example of a high-pitched sound that may be easier to understand due to the retroreflection phenomenon, which is facilitated by the tiered ceiling and causes little sound energy to be reflected in areas that are not close to the sound source. The averaged STI<sub>occu</sub> values for the Markanda temple are 0.76 for the (S1) sound source position, which shows a slight improvement compared to the unoccupied (S1) position. The overall average STI value for position S2 is

0.63, although the Speech Transmission Index (STI) decreased to a minimum of 0.57 (indicating "fair" speech intelligibility) in aisle space inside the pavilion.

## 6. Conclusions

The article summarizes a study conducted on the reverberant field of the Markanda temple in Maharashtra, India. The research involved using omnidirectional sound sources at two specific locations within the temple and strategically placing six receivers across the pavilion.

- In the temple, higher T20occu values and lower clarity C50occu values were observed at frequencies below 250 Hz.
- The findings suggest that prolonged sound decay contributes to a moderate reverberant sound field in the temple, which is beneficial for activities like Vedic chanting and singing devotional songs. The temple's enclosed pavilion and reflective basalt stone create an immersive sound environment during music rituals. Rituals performed by a priest in the sanctum remain contained, allowing for focused praying and chanting.
- With higher C50occu values, the temple's sound field is suitable for musical rituals. The tiered ceiling in the pavilion aids in sound diffusion and clarity.
- While speech intelligibility in the temple is generally rated as "good," uneven distribution of sound energy affects intelligibility for some receiver positions in the pavilion when the sound source is within the sanctum.

## Acknowledgments

The author would like to thank Archeological Survey of India, Nagpur Circle, for providing access to the site and Dr. Amit J Wahurwagh, Ar. Prateek Barsagade, Ar. Surabhi Mendhe and Ar. Parikshit Mudholkar for assisting in site measurements.

They would also like to thank the Ar. Shivani Sharma for providing architectural drawings.

## Conflict of Interests

The Author(s) declare(s) that there is no conflict of interest.

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