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Acoustical characterization of Taramati Baradari

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Abstract
India has a very rich and diverse cultural heritage and when studying from one built form to another, it can be observed that each plan and architectural form has a very close association with the purpose it was built for. The use of daylight in these structures is very well documented and studied, the acoustics of the structure are hidden, especially for a place of worship and performance. It needs special attention and should be addressed subjectively. The effect of architectural form and elements on the acoustics of the structure needs to be documented and studied. It should be documented using acoustical instruments like omnidirectional sound source and handheld analysers and ODEON and EASE 4.3, a simulation of the space should be done to understand the original setting of that structure. Taramati Baradari in Hyderabad will be used as a case study.
Keywords: Conservation, Acoustics, Taramati Baradari, Performance structure, and EASE 4.3.

1. Introduction

Taramati Baradari is a structure located in the Ibrahim Bagh, a garden in Hyderabad, India. It was built during the reign of the seventh Sultan of Golconda, Abdullah Qutb Shah, in the early 17th century. The Taramati Baradari is a square pavilion with a central hall and a unique acoustical design.

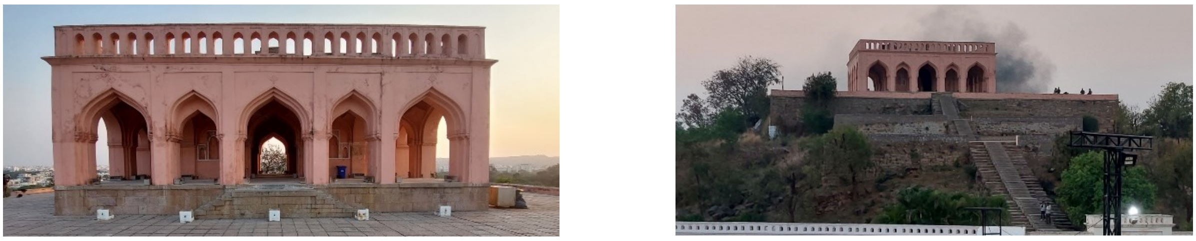

Figure 1: North Elevation of Taramati Baradari and Distant view of Taramati Baradari (author generated)

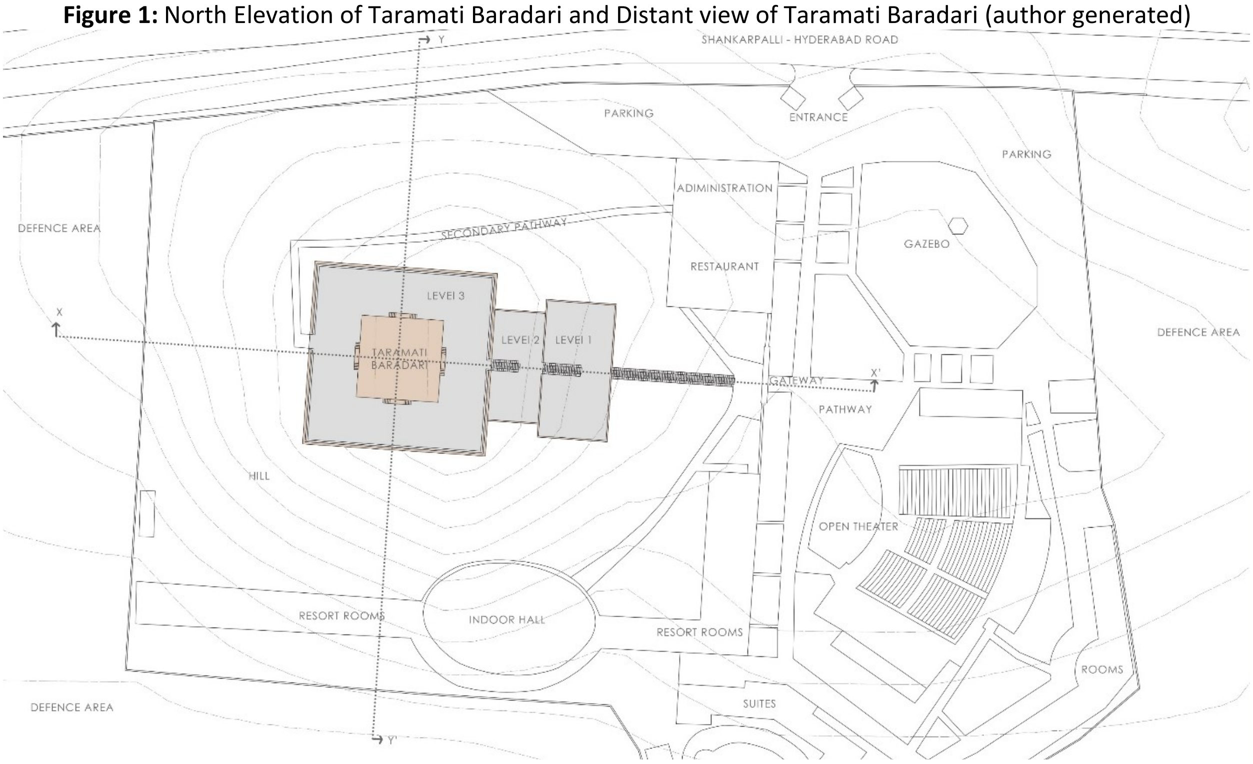

Figure 2: Site Plan of Taramati Baradari (author generated), NTS

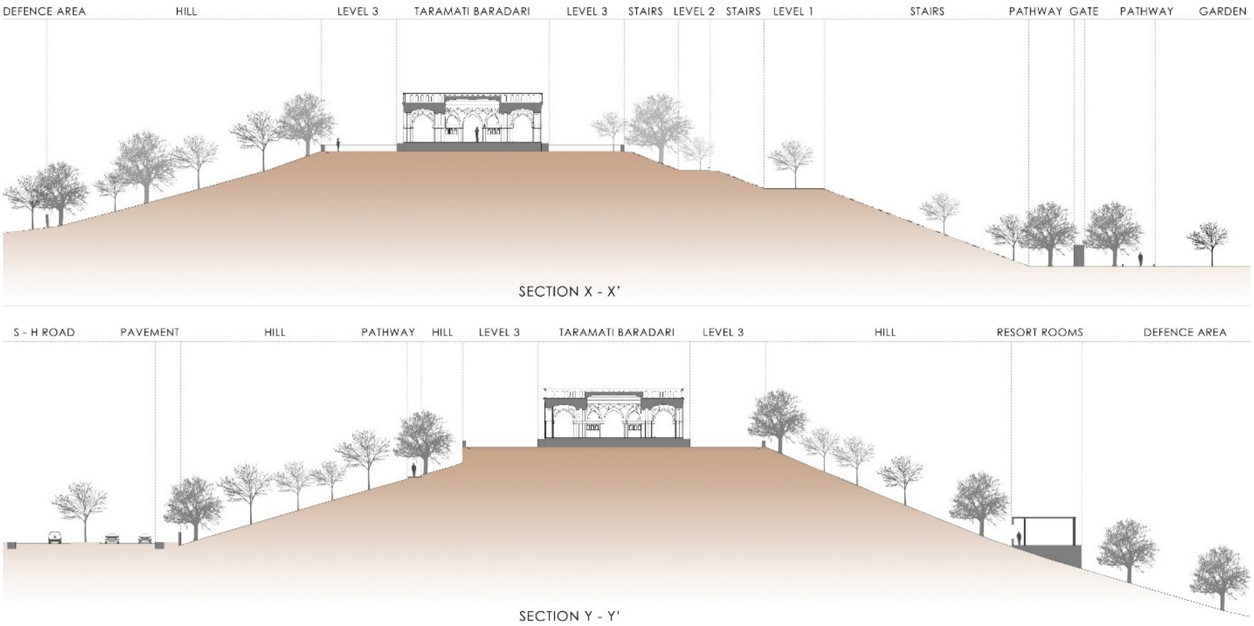

Figure 3: Sections of Taramati Baradari (author generated), NTS

Taramati Baradari is a masonry structure made from granite and finished in lime plaster, with four open arches on each side of central pavilion and five arches on each side of outer verandah. The structure is elevated on a platform, with five flights of stairs leading up to it. At the centre of the pavilion lies a grand hall that measures approximately 12 meters by 12 meters. The hall's acoustical design is one of its most remarkable features - even a whisper from one end of the hall can be heard at the other end, making it an ideal venue for musical and dance performances.

Table 1: Physical attributes of Taramati Baradari

Name of the monument	Construction Material	Openings	Elements like dome, pendentives and squinches, jalis	Historic use of structure	Acoustic study potential of the building	Spatial organization
Taramati Baradari	Stone masonry finished in lime stucco plaster.	4 doors on each side.	Pendentives acting as resonators.	Performance space used for dancing and singing	Flat dome with acoustical property	Square pavilion at the center with verandah on all four sides

Table 2: Spatial Variables of Taramati Baradari

Name of the monument	Orientation (wind direction, water & various physical features)	Volume	Internal height of the structure	Plan form
Taramati Baradari	A larger volume results in a longer reverberation time, especially in the lower frequencies	357 cubic meters	5.95m	Square plan form surmounted by shallow dome

Acoustical Characterization - Acoustic characterization of structure deals with the evaluation of the acoustic quality within a certain space.

2. Literature Review

The literature review includes acoustical studies done at various religious spaces, including the mosques, churches, and monasteries.

This facilitated in developing an insight into the methodology adopted and to deduce impressions of different researchers in this area. Most of these studies are in the European and American context, while a few belongs to the Indian context. As a reference for this research, studies on Catholic, Orthodox, and Muslim worship spaces of large volume and reverberant spaces in project CARISHMA was analysed and also the acoustical characterization of the Buddhist temple of Deekshabhoomi in Nagpur, India was referred to devise the methodology for the research.

3. Measuring methods

The research aims at unfolding the acoustic dimension of Taramati Baradari, a monument created in the 17th century as a space for the performance of Taramati, a royal courtesan in the Qutb Shahi dynasty also known as Golconda dynasty.

In situ measurements with impulse sound and measuring the energy decay curve are proposed for measuring sound parameters such as background noise, reverberation time, early decay time (EDT). The impulse sound may be electronically generated or initiated manually with the help of a balloon burst.

Source type identification - At the study instance, since the monument is surrounded by defence area, balloon burst was the technique used to generate the impulse sound and the energy decay curve. Omnidirectional loudspeakers are widely acknowledged as the optimal choice for conducting acoustic measurements of this nature. However, due to the presence of a defence area surrounding the site, utilizing such measurement techniques is not feasible. In such circumstances, an alternative method for measuring reverberation time, frequency decay, and frequency response is through the use of hand claps. It should be noted that the reliability of reverberation times and frequency responses below 300Hz is compromised since hand claps lack sufficient low-frequency energy.

Therefore, a balloon blast was employed as an impulse source. While this impulsive sound source does not guarantee consistent measurements and fails to adequately cover low-frequency information, it was observed that the results obtained using this approach did not significantly deviate from the outcomes achieved through repeatable measurements.

During the acoustical measurement process, balloons with a size of approximately 40-42 cm, maintaining a consistent level of inflation, were utilized. The decision to opt for larger-sized balloons stems from their ability to emit more energy, while a higher inflation level enhances the presence of high-frequency content. Moreover, the larger size of the balloons contributes to a greater degree of omnidirectionality, particularly for mid-range frequencies. Balloons, especially those of larger size and higher air pressure, are deemed to be the most suitable choice. Consequently, the bursting of the balloons served as the method to generate impulse sound for recording the decay of energy at various positions.

The source was put at three different locations to understand the probable location from where Taramati used to perform.

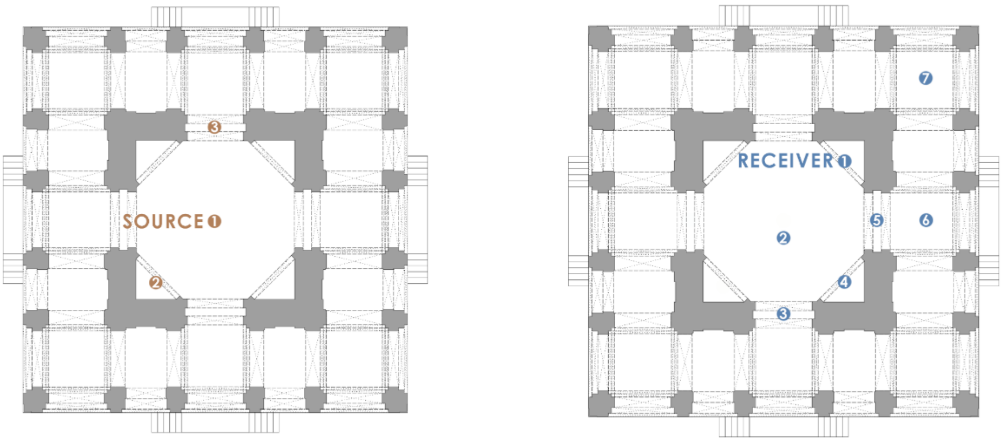

Figure 4: Sound source locations and Sound receiver locations for Taramati Baradari (author generated), NTS

Seating pattern – There is no documentation of the seating pattern of the baradari. It was due to this reason that during the acoustics measurements, three probable locations were identified from where the performance might have happened and based on the positions for receivers were identified.

In Source 1, the performance would traditionally occur at the centre of the baradari (pavilion), while the viewers would be situated in the corners of the baradari. In Source 2, the performance would typically be staged from one corner of the baradari, with the remaining sides and centre being occupied by the viewers.

In Source 3, the performance would take place at the centre of one of the sides of the baradari, most likely the eastern side, with the Golconda fort serving as a backdrop. The viewers would occupy the remaining part of the baradari.

Identification of source and receiver locations for in situ measurements was made according to the architectural symmetry of the space.

Receiver positions - The receiver positions were ascertained to be placed at 1.2 m above the floor. The receiver at location 2 was used to compare the three sources as it has the symmetrical sound reflection.

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

Reverberation parameters – T_{10}, and T_{20} - Reverberation represents the degree of vivacity of the hall. It is the time required for a sound to decay by 60 dB. Reverberation time in terms of T_{10} and T_{20} has been evaluated. Acoustical tests were conducted within the specified structure using impulse response signals within a frequency spectrum of 125Hz to 8kHz. Since the measurements were taken by recording an impulse response created by balloon burst with the help of hand-held analyzer and microphone, it was difficult to derive all acoustic parameters through recorded decay curve. Hence, only T_{10} and T_{20} were evaluated from the recorded data.

Figure 5, 6, and 7 is plotted with T_{10}, and T_{20} values recorded at receiver 2 and generated from all three sources in in unoccupied conditions. It was noted that T_{10} and T_{20} follow almost different envelopes for all three sources. For source 1, peaks at 500Hz, and the minimum value at 8 kHz. And for source 2 and 3, peaks at 250Hz, and the minimum value at 8 kHz. The unoccupied mode is observed to give highest T_{20} values of 4.15 s at 500Hz and lowest value of 0.9 s at 8 kHz. A sweeping change is observed between 125 and 250Hz in unoccupied condition for source 1 with a steady slope toward the higher reverberation time till 500Hz frequency and then a gradual slope towards the frequency of 8kHz. A modest change in the slope from lower frequency to higher frequency is observed in the unoccupied condition for source 2 and 3, with (the peak) value of 2.45 s at 250Hz and (the lowest) value of 0.89 s at 8 kHz.

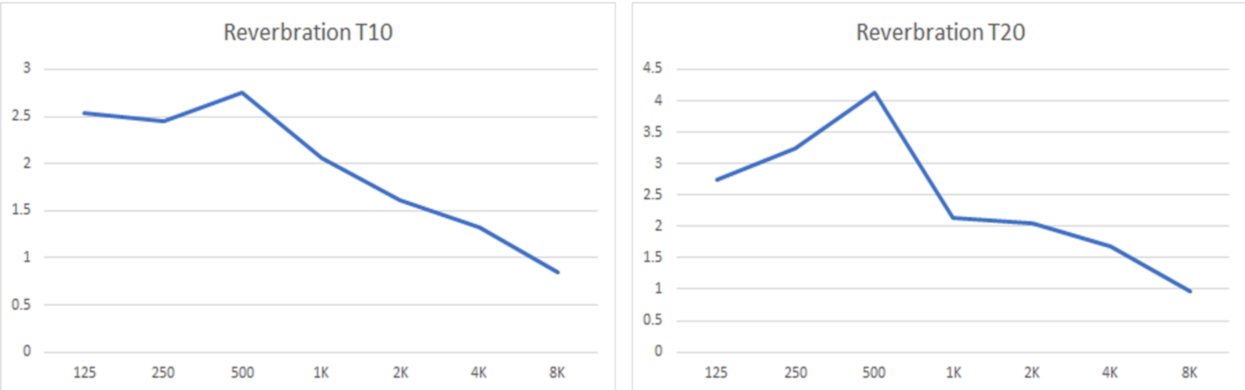

Figure 5: Source 1 – Receiver 2 (author generated)

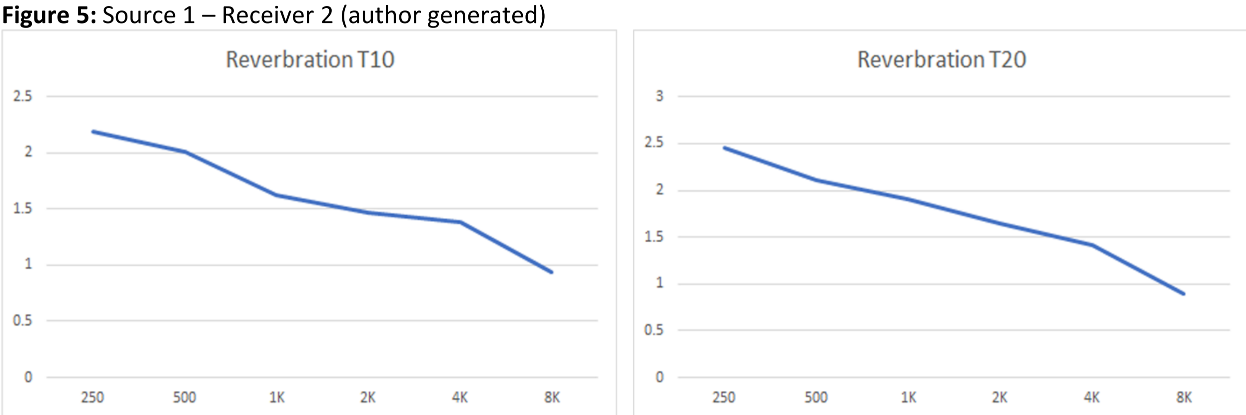

Figure 6: Source 2 – Receiver 2 (author generated)

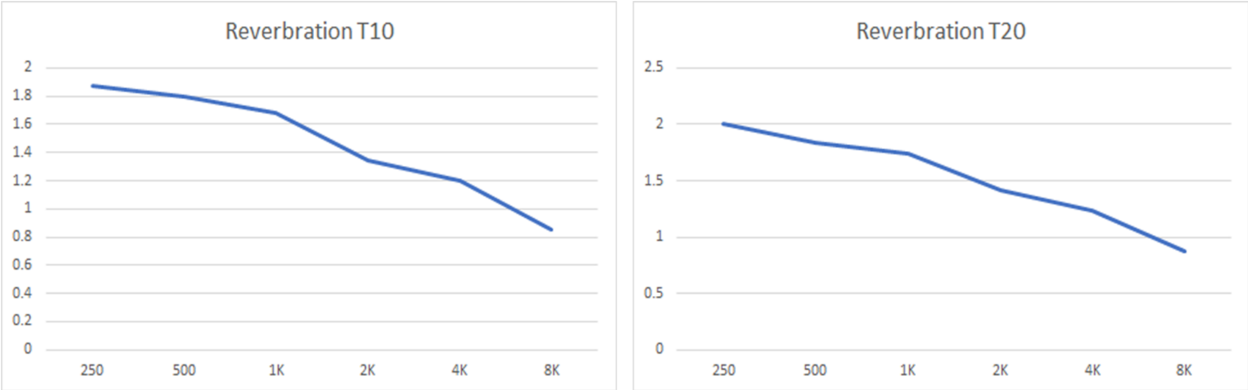

Figure 7: Source 3 – Receiver 2 (author generated)

The ISO 3382-1 recommends that the results for T_{10} and T_{20} can be presented as a single number frequency averaging, wherein the single number frequency averaging denotes the arithmetical average for the octave bands, 500Hz to 1kHz. Hence, it can be said that the reverberation T20 for Taramati Baradari at sound source 1 which shows the maximum reverberation is 3.12 s.

5. Discussion

In-situ measured reverberation times and sound distribution patterns can be used to calibrate the digital simulation model of the Baradari and the model can be used to predict the acoustical characteristics for two conditions compatible repair condition and the 'revival of the original condition.

More information related to the sound absorption properties of the historic materials needs to be obtained to better understand and predict the original acoustical characteristics through simulations.

This will help protect intangible cultural heritage such as the acoustics of the built environment, a highly fragile and elusive quality attached to the heritage structures.

6. Conclusions

The article provides a summary of a study conducted on the reverberant field of Taramati Baradari in Hyderabad, India. The research methodology involved capturing the impulse response generated by bursting a balloon at three distinct locations within the Baradari. Additionally, seven receiver positions were strategically placed across the audience area. The analysis of the experimental data revealed that, on average and across the entire Baradari, the initial reverberation time for middle frequencies in an unoccupied condition was found to be 2.75 seconds.

Further investigation is warranted to thoroughly examine the acoustical characteristics of the Baradari, as the measurements were conducted subsequent to contemporary repairs. To progress with the study, simulations can be employed to explore two additional conditions: compatible repairs during both occupied and unoccupied conditions, and the restoration of the original conditions during both occupied and unoccupied conditions. By comparing the reverberation times under these various scenarios, a better understanding of the changes in the Baradari's acoustical properties can be obtained.

By employing simulations, it becomes possible to investigate various parameters related to perceptual aspects. The following parameters can be studied for each aspect of perception: Reverberation: Early Decay Time (EDT), T_{10} (time taken for sound level to decay by 10 dB), and T_{20} (time taken for sound level to decay by 20 dB), Sound Level: Sound Pressure Level (SPL), and Reference Level (e.g., A-weighted SPL), Clarity (Musical and Speech): C80 (Clarity index based on early reflections and direct sound), and C50 (Clarity index based on early reflections, direct sound, and late reverberation), Speech Intelligibility: Speech Transmission Index (STI), and Speech Intelligibility and Music Clarity: Ts (time taken for speech or music to decay to a certain level). By analysing these parameters through simulation, a comprehensive understanding of the perceptual aspects, including reverberation, sound level, clarity, and speech intelligibility, can be obtained.

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8. Conflict of Interests
The authors declare no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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