Acoustic engineering simulation of Isfahan Shah Mosque with Odeon software

Mohammad Hossein Hashemian[1,*]
[1] Master of Architecture and energy, Tehran University,Tehran, Iran

ABSTRACT

The traditional buildings of Iran and the world have various characteristics, and one of these characteristics is the acoustic characteristics of these buildings. In the past, since the technical knowledge of acoustic engineering did not exist with the current quality, designers, and builders used different methods to solve the acoustic issue of these buildings for different applications. There is still no detailed information about their design and implementation methods. However, in this article, the acoustic characteristics of some religious buildings of the past in Iran and the world have been investigated. By choosing one of them as the most complete method and in a way with the most targeted acoustic design, we analyze and reverse engineer this building. It can be said that among Iranians and tourists who visit Iran's historical monuments. The acoustic feature of Isfahan Shah Mosque has unique features. In this building, when a person sings or speaks on a marked stone under the ground, the sound is heard with better quality in other parts of the mosque's naves. In this research, this building belonging to the Safavid era will be subjected to a detailed acoustic analysis so that the method considered in this method can be used in today's architecture, especially sustainable architecture.

Keywords: **Engineering, Acoustics, Simulation, Analysis.**

1. *INTRODUCTION*

(Style: Times New Roman, 10pt, Upper Case)

In this part, we will examine some of the historical buildings of Iran and the world in which acoustic engineering has been done, and then we will verify the most targeted acoustic engineering, which is Shah Mosque of Isfahan with Odeon software, and the advantages of its design in other parts will discuss.

1.1. Aali Qapu mansion

Safavid architecture is regarded as one of the pinnacle periods of Iranian-Islamic architecture. The architectural remnants from this era include the Aali Qapu mansion, which exemplifies the application of elements and arrays in the geometry of space. This is the introductory scientific acoustic design course in architecture. The sound absorbers and high-framed porcelain home in Isfahan, known as kavaki, exude an aura of authenticity and distinctiveness. The objective of the acoustic form's design was to provide acoustics by eliminating disruptive sounds and reverberations [1].

The initial construction of the Aali Qapu building took the shape of a sizable rectangular cube, measuring approximately 20 meters by 19 meters and standing 13 meters tall. It featured two interior floors, resulting in the absence of exterior windows beyond the fifth floor. During this period, the market building stood at 40.6 meters. This meant that the market occupied a single floor, with the actual stores situated at the termini of each entrance. The front portion of the building was entirely exposed to the square and considerably reduced in size compared to its present state. It has been utilized as a portico for the distribution of commercial goods; however, its significance lies in the distinction in the frequencies of instrumental sounds that are produced as a result of the formation of a unique environment and the incorporation of small hollow volumes. Thus, the quality of the sound perception is exceptionally high [2].

The hall, also known as the music hall, is comprised of a chalipah-shaped central hall, two smaller side halls, and several rooms featuring unique spaces in the corners. These rooms are structurally and architecturally distinct from the remainder of the building. This area is embellished with two distinct components: painting and plaster of the Tongbori variety. Additionally, the ceiling and walls are adorned with stucco in the majority of its approximately twenty distinct varieties. The designs of these hollow forms are frequently influenced by the profile forms of porcelain and dinnerware. The absence of sound reflection in this setting results in a highly authentic and transparent perception of sound generated in the same manner [2]. (Figure 1)

Aali Qapu was constructed during the Safavid era by eminent architects and artists employing every scientific and artistic principle and technique they had learned. As an architectural element that consistently directs the observer's gaze upwards, muqarnas manifest in an alternative configuration within this structure, which is frequently employed in a permeable and hollow state [2].

Fig. 1. *Aali Qapu mansion.*

An additional structure, the Sheikh Lotfullah Mosque, which is regarded as one of the most magnificent works of the Safavid era, featured muqrans similar to these. Furthermore, apart from their aesthetic appeal, the tongbori and Muqarnas-kari patterns present in these two majestic structures serve the purpose of sound reflection prevention and regulation [2].

An assortment of Muqarnas unique to Chini houses are on display in the music halls of Aali Qapu Mansion and Sheikh Lotfollah Mosque, among other locations. In contrast to other wrought Muqarnas, these are not ordinary; rather, they are hollow and hollow. The dome-shaped area, Muqarnas, and embellishments in Aali Qapu Mansion and Sheikh Lotf Allah Mosque not only encased the structure but also, by virtue of Muqarnas being a type of concave cavity, confined air within them. Furthermore, by covering the surfaces in multiple layers, these apertures functioned; this serves as an illustration of the co-organization between the architectural design of the space and the geometry of the Muqarnas. Additionally, ornamentation placed in the space's corners functions as a sound reflector [2].

In fact, these plasters function as a kavaki to produce sounds that are distinct and fluid. When viewed through the acoustic point of view, the room resembles a complex resonator with multiple permissible vibration modes. A permanent vibration occurs within the resonator when the sound source is utilized, and this vibration corresponds to the frequency of the sound source. Furthermore, transient free vibration is generated when typical vibration modes within the room combine [3].

This method is still employed to install artificial ceilings in conference rooms at present. Serving the same purpose as the muqrans in these two structures, cavity absorbers are in fact diminutive air containers that communicate with the wall's surface via a constricted aperture. The air within the cavity of these absorbers functions elastically. Cavity absorbers exhibit an exceptionally high absorption coefficient within a limited frequency range. The absorbers in question operate at low frequencies. To achieve this, porous blocks featuring shell plates that are spaced apart are employed [2].

According to Bani Asadi's [4] research on the acoustic engineering of Aali Qapu Mansion, depending on the quality and standard of hearing, music or sound can be categorized into sluggish and rapid performances. Furthermore, music can be distinguished based on this criterion. In high-rise buildings, fast-paced music that exudes elegance (such as traditional music) should be performed with a low voice. Conversely, sluggish music and sounds, including orchestral music, opera music, and church music, should be played at a higher volume. This is due to the presence of lengthy compositions within this genre of music.

In his study on the analysis of time, volume, and background in the music room of the Aali Qapu building in Isfahan, Sadegh Abadi asserts that the sound level, time, and volume of the given area can be quantified and compared to established criteria using a 2260 measuring device [5]. In comparison to the optimal time and consumption chart, the outcomes demonstrate that the building's time and energy usage are optimal. Furthermore, apart from the distinct geometric characteristics of the area, the constriction of this chamber functions as a cavity, effectively enhancing the low frequencies present in space.

1.2. Yazd Grand Mosque

In this part, the acoustic research of Yazd Grand Mosque is given from an article entitled "Acoustic Quality Evaluation of Yazd Grand Mosque" written by Samira Safi, Abbas Narimani, and Nariman Farahza [6].

Recently, mosques, which are significant structures for Muslims, have not been provided with adequate acoustic quality. Consequently, one of the mosques from the Islamic era, the Yazd Grand Mosque, possesses a commendable acoustic quality; it has been analyzed to serve as a model in terms of proportions, materials, and volume.

Yazd Grand Mosque is widely regarded as an architectural marvel of the Islamic and Iranian traditions. This mosque, which is over a millennium old, is regarded as one of the most aesthetically pleasing structures in the country and a remarkable architectural and historical achievement of Iran. This expansive mosque is distinguished by its two towering and distinctive minarets, as well as its elevated minarets, stucco, nave, courtyard, dome, tiling, and tiling, which are the most authentic examples of Iranian architectural innovation. The porch, dome, and surrounding area comprising this structure constitute its most aesthetically pleasing features. Fig.2

Fig. 2. *view of the dome of Yazd Grand Mosque [6]*

The square-shaped dome has two arched passages on its sides and a large central aperture within the porch. These corridors led to the porches of Gholam, where 9th-century pavilions were erected. The gates surrounding the two shrines on each side of the dome are covered with mesh tiles, and the shrine on the eastern side has two exquisite altar stones that date back to the ninth century. The blue hexagonal tiles covering the porch plinth and the dome are adorned with mosaic tiles in the center of each. The universal dome arches of the eastern nave are centered by octagonal stone skylights. This hot-house has an altar with a broad aperture, five- and seven-pointed arches, and exquisite inscription patterns. It was determined to examine the dome and portico sections because of the significance of the dome area with its eastern and western porticoes and the range of diverse materials present. The chosen space has a capacity of 19510 cubic meters. The study design and methodology include simulation and precise computations using EASE 4.3 software; ultimately, conclusions and conjectures are drawn by contrasting the simulation's outputs with those of field observations and measurements. Fig 3-5.

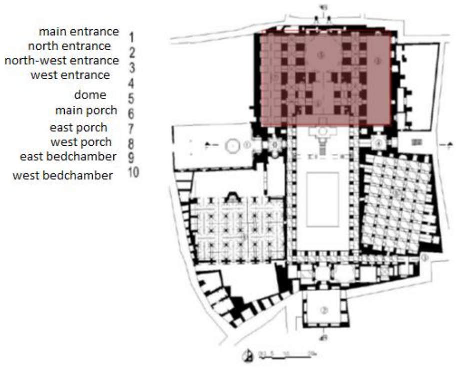

Fig. 3. *The plan of Yazd Grand Mosque, simulated parts are shown [6]*

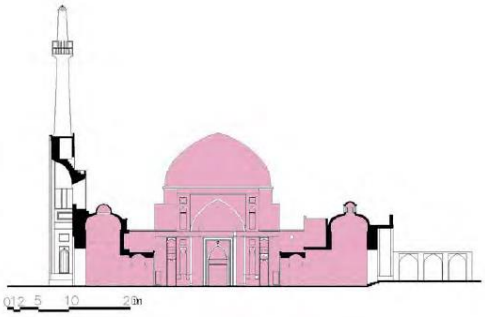

Fig. 4. *Section A-A of the Yazd Grand Mosque plan [6]*

Fig. 5. *The interior of the western portico, the dome, the eastern portico, Yazd Grand Mosque [6]*

Several levels, including mesh brick levels, portico niches, and the Muqarnas used in the portico altar, were eliminated since the EASE 3/4 program only allows up to 35,000 levels for analysis and the CAD model has been simplified (Fig. 6, 7). The surfaces' corners have been eliminated, and the brick band that exists between the brickwork has significantly affected the low frequencies, virtually increasing their RT.

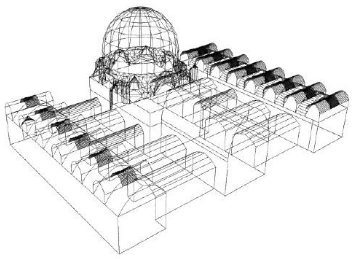

Fig. 6. *Simulation of the dome of the Yazd Grand Mosque with the porticoes around it in CAD [6]*

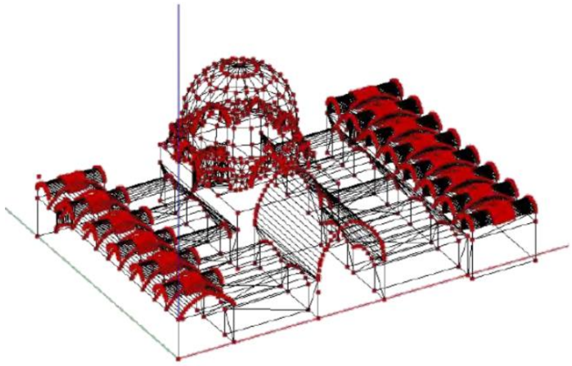

__Fig. 7.__ Simulating the dome of Yazd Grand Mosque with the porticoes around it in the EASE program [6]

Muqarnas is used in the mehrab area, the corners of the dome, and the corbels in the eastern and western porticoes of the replicated space. Each component of the room is given the materials with attention. We should have the intended sound performance since the room is filled with reflecting and sound-absorbing materials. This shape exhibits its impact in a pure form, as per the reduced model of the dome in the dome's space. Because of the model's simplicity, the dome echo in space is partially to blame for the high time and RT measurement at low frequencies (Fig 8). Additionally, the lack of obstructions like small walls and columns (places where women pray) increases the opportunity for sound to bounce about the mosque. However, due to the fact that people make sound in this range while speaking, the graph is based on frequencies between 300 and 4000 Hz. This mosque belongs to group F, according to (Fig. 8), and its time and reading diagram, demonstrates a favorable diagram in the intended frequencies. Table 1 is where absorption coefficients are obtained. Brick surfaces having joints between them and brick grid surfaces are not taken into account in the simulation. The bands on brick surfaces will serve as cavity absorbers for low frequencies. The trials were out on Tabriz's Qajar-era mosques provide an excellent example of this issue.

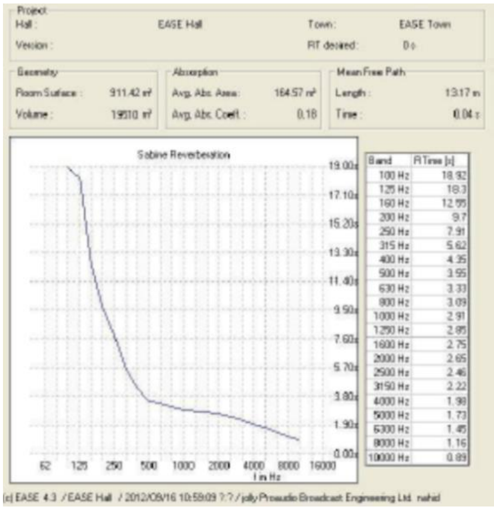

__Fig. 8.__ Diagram and reading of sound in different frequencies for the space of the dome and the surrounding porticoes, Yazd Grand Mosque [6]

__Table 1.__ Sound absorption coefficient at different frequencies - Yazd Grand Mosque [6]

surface	125 HZ	250 HZ	500 HZ	1000 HZ	2000 HZ	4000 HZ
Chalk	0.14	0.10	0.05	0.04	0.04	0.03
carpet	0.02	0.06	0.14	0.37	0.60	0.65
Marble or (glossy polished brick)	0.01	0.01	0.01	0.02	0.02	0.02

Sabin's equation of time and strength states that the time and strength will decrease with the growth of the required surface, given that for every 1 square meter of brick, accounting for the joints between them, we will have an increase of 1.4 square meters. The time and reading (T) at low frequencies reduce by about 40% as a result of the increase of 0.4 square meters (S). We will improve the low-frequency voice intelligibility by cutting down on reading and time. The amount of time spent reading at low frequencies rises when this issue is not present. Both time and consumption will sharply decline as a result of the level rise. Fig.9 displays the computations' outcome as a diagram.

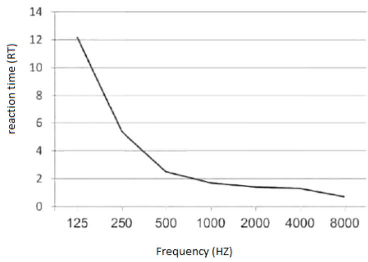

Fig. 9. *Time and duration diagram with an increase of 1.4 square meters in the mosque [6]*

This graph indicates acoustic comfort based on the reading from low to high frequencies and the decreasing course of time. Not to mention that the minimum RT is around 0.7 and the maximum RT is approximately 5.4 between the frequencies of 3000 and 4000 Hz. Using the following formula, Grand Mosque's average RT is 2.46, which is an acceptable value for a mosque with a huge capacity.

The findings illustrate the connections between reading volume, time, and geographical coverage. We are able to see the appropriate sound distribution (SPL level of appropriate sound) throughout the mosque thanks to the acoustic simulation that was conducted in various areas of the building. The time and sound reading that controls the area exhibits a declining tendency from low to high frequencies, in line with the guidelines and norms mentioned in the ROOM ACOUSTICS discussion. This outcome is the consequence of the space's brick and tile decorations, which are appropriate and varied, particularly in the manner the brick is placed and its regular brick row.

$$RT_{SPEECH} = \frac{RT250 + RT500 + RT100 + RT2000 + RT4000}{5} \qquad (1)$$

1.3. Isfahan Shah Mosque

The Shah Mosque of Isfahan, situated in the southern section of Naqsh-e-jahan Square, is a remarkable example of Iranian architecture from the Safavid era. This structure has distinctive characteristics, one of which being the existence of a certain stone under the south dome. Placing the sound source just beneath the dome and in the center of a certain stone allows for sound reflection from various levels in the dome and naves, resulting in the distribution of reverberating sound across the naves. (Fig 10)

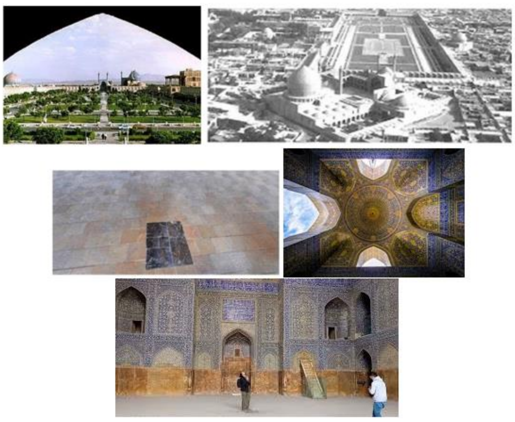

Fig. 10. *Isfahan shah mosque dome.*

According to Khoyini [7], an analysis of the Shah Mosque of Isfahan reveals that 1500 individuals were able to perceive the compressed sound emanating from the mosque's chapels and dome as a result of a deliberate mechanism. Furthermore, he emphasizes that an architect and mathematician was responsible for the dome's design.The crucial aspect of the research by Khoini et al. is that the type and characteristics of the dome of the first shell (inner dome) are not specified in detail; rather, the method of sound transmission is deduced from the general shape of the dome. This omission allows for a more comprehensive and detailed analysis. (Fig. 11)

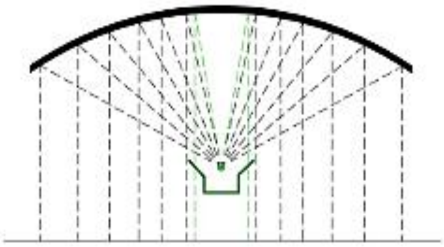

Fig. 11. *How to analyze sound transmission in Isfahan Shah Mosque [7].*

Zohra Thor and Samiha Yilmazer [8], in their analysis of the Kokatip Mosque in Ankara, have provided insights into the improvement of sound quality while recognizing deficiencies in sound transmission and perception. For instance, they have implemented perforated panels to diminish sound volume and readings.

Adel Abdou, by handling various research on the atmosphere of the dome of Saudi mosques, acknowledges the weakness of acoustic engineering of the mosques and reminds that these mosques require to enhance the acoustic engineerin [9].

Many studies were done on various churches in Europe, all of which noted the lack of spaces for listening to sounds and music and the requirement to optimize present situation [10-17].

The research handled on Middle Eastern mosques and European churches noted that these religious and ancient buildings have weaknesses in acoustic design [10-26].

It can be deduced from a review of the studies that most issues raised in the field of comparing or examining the geometrical parameters of mosques and churches have been examined through the lens of acoustic indicators. Time and duration have been the most significant and recurring factors among the indicators that have been examined in the studies. Additionally, in the majority of conducted studies, the research method may specify whether the data was obtained through measurement, simulation, or a combination of both. It is crucial to conduct research in this area due to the paucity of studies concerning the optimization of software geometric parameters in relation to acoustic aspects (such as reading and time).

It is imperative to note that reverse engineering is executed in a manner consistent with the understanding and knowledge of scientists during that era regarding fundamental sciences like physics and related fields like acoustics. Moreover, the structure of the presentation and transfer of knowledge is not inherently complex. Obviously, in the current acoustic sciences, the refining of this knowledge or architectural method necessitates additional research and more fundamental concepts than its predecessors, which are also discussed below.

2. Research method:

2.1. Inverse analysis of the arches of the first shell of the dome of Shah Mosque in Isfahan

The findings of 2015 analysis conducted for this project suggest that the Shah Mosque of Isfahan effectively transmits sound to its congregation despite encountering an echo. This is achieved through the strategic placement of the arches' centers and the distinctive shape of the first shell dome. Given that the auditory content comprises church music, opera, and calls to prayer, the optimal duration for this task is between 1.4 and 3.4 seconds to ensure optimal execution. On the basis of the analysis conducted in this regard and the arch shape of previous domes, in which the arc of a circle has been utilized in various ways predominately, it is hypothesized that the initial structure of the Shah Mosque dome may be responsible for the sound reflection.

In the cross-section of this mosque, the first shell has been analyzed to obtain the type of form, arches, and centers, which are visible in Fig. 12.

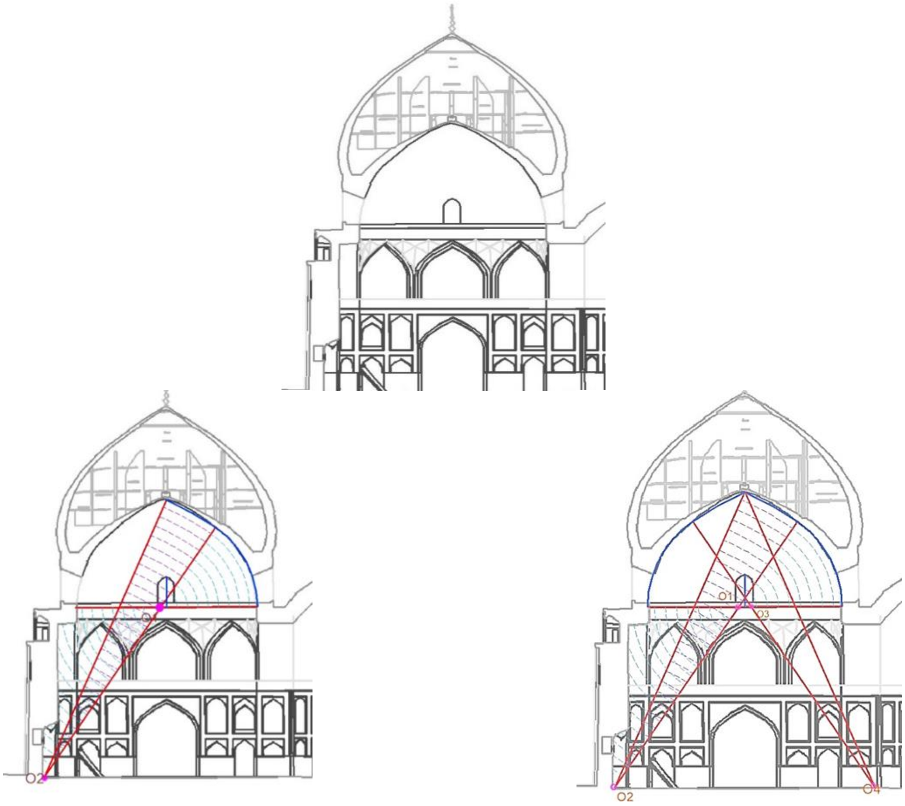

Fig. 12. *Sectional analysis of Isfahan Shah Mosque (domed space). [27]*

The reverse analysis conducted on the initial shell identified four focal points and four arcs (the coordinates of the focal points are denoted as O1, O2, O3, and O4, respectively). The two foci, denoted as O1 and O3, are situated along the entrance line of the arch, with a comparatively small distance separating them from both sides of the axis of symmetry of the arch. As seen in the image, the remaining two foci (O2 and O4) lie beyond the theoretical base or stem of the arc. (Fig.13)

According to the laws of sound, sound emitted from its point of alignment beneath the dome (on the ground) encounters two distinct categories of arcs; by projection, these two arcs expand to four. In contrast to foci O1 and O3, which are represented by the larger arcs, foci O2 and O4 have arcs that extend beyond the stem or base of the arch.

When sound waves strike these arcs, one mode exists at the foci of O1 and O3, and another mode exists at the foci of O2 and O4, in accordance with the principles of sound design.

Sound waves are transmitted from the O2 and O4 arches outside the dome and into the point foci O2 and O4, which reflect the wave back outside the dome and distribute it throughout the contiguous naves. However, when the wave is reflected by the arcs O1 and O3, it propagates through space as depicted in Figure 13. It is subsequently gathered to some degree once more after re-absorbing the reflection from the surfaces at the focal points O2 and O4, and further dissipates in the nightstands, resulting in the phenomenon known as echo. Perhaps this is how the sound is echoed in the naves; it is like how sound is generated between two mountains.

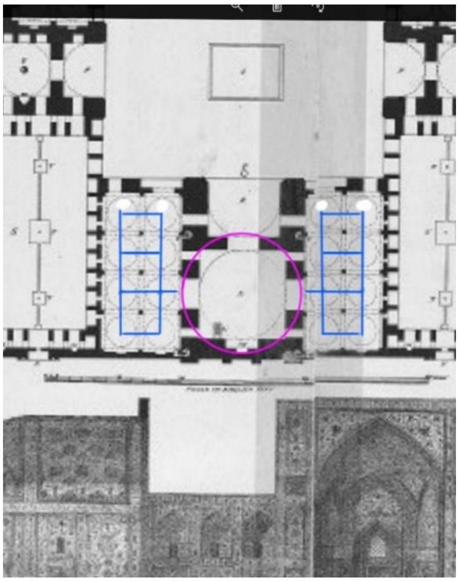

Fig. 13. *Analysis of wave propagation through the location of the foci, Isfahan Shah Mosque. (Dome space) [27]*

The purple circle in Figure 13 represents the O2 and O4 foci, which indicates the region where the waves congregate or land by rotating around the center. This area is situated beyond the dome area, as depicted in the figure. Additionally, the blue lines denote the trajectory of the waves emanating from the O2 and O4 foci.

2.2. Simulating the acoustic characteristics of Isfahan Shah Mosque with Odeon software

The cross-section map and plan of the mosque were constructed at the outset of the project to facilitate a detailed examination of the arch of the dome (the first casing). Based on the hypotheses made, the arch of the dome was redrawn and matched with the arch of the section. The type of arch obtained was of the four-part form with the following structure.

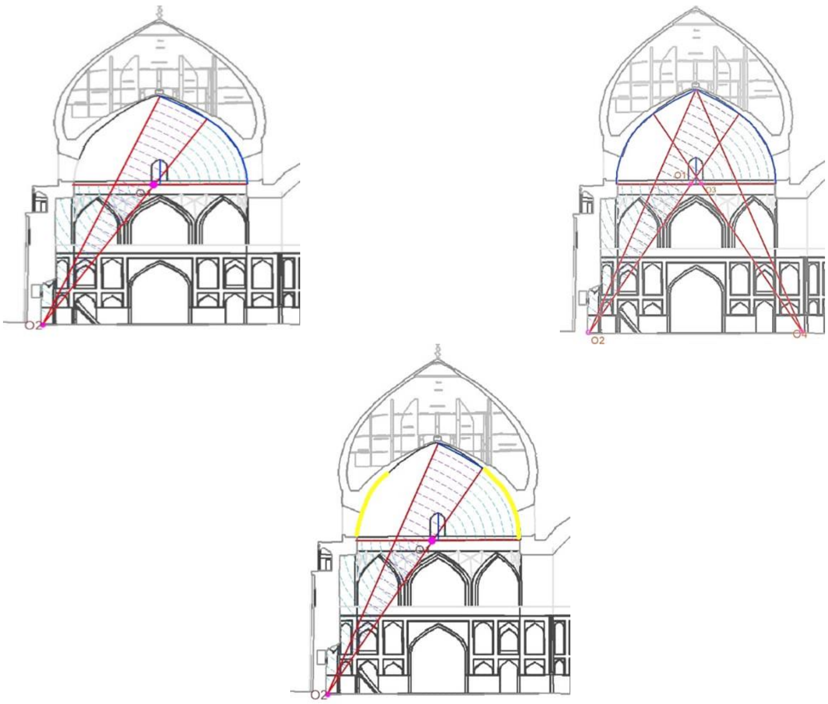

Fig. 14. *Investigation of the type of arch in the dome of Shah Mosque in Isfahan [27].*

The arrangement of the arches was scrutinized to ensure that their midpoint was positioned on the plan between the dome and the naves. This likely maintains the voice's intensity, similar to how a magnifying glass concentrates light to increase its temperature.

The architect of the structure intended to position the sound source at a specific location beneath the dome's apex in order to deliver an adequate quantity of sound power to the naves.

It appears acceptable for the dome's listeners that the second arc of the dome (highlighted in yellow at the bottom of Figure 14 extends the sound wave below the dome. Naturally, it also creates an echo, which is appropriate for the worship sounds in the mosque, such as the call to prayer, the Qur'an, and the prayer speaker; nevertheless, it is inappropriate for sounds like music. In spite of the presumptions, the model was transferred to Odeon, a specialized acoustic software, after being modeled in Sketchup. (Fig. 15)

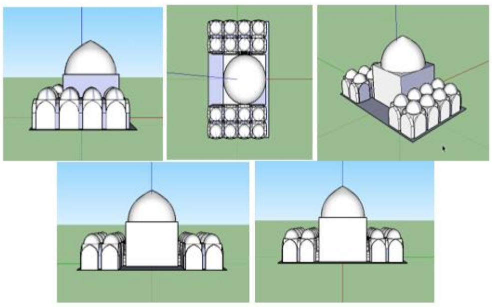

Fig. 15. *Modeling of the Shah Mosque in Sketchup software.*

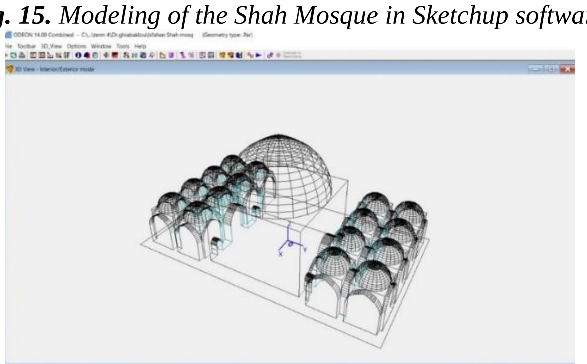

Fig. 16. *Shah Mosque, modeled in Odeon.*

The fundamental assumption is that at position number 1, the call to prayer is being recited by the person looking upwards at a sound intensity level of 80 dB, which improves the sound's reflection and transmission to the shrines, despite the fact that this is a rather low level. This problem should be addressed in the seminar hall so that the speaker's voice may be amplified and there is no need for them to look up. This can be achieved by carefully designing the bows and choosing their focal point. (Fig. 16 & 17)

Places 1 and 2:

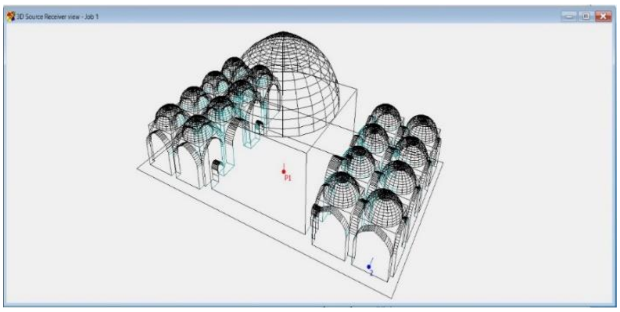

Fig. 17. *Location of the muezzin and hypothetical audience in the Shabestan.*

In the software, you can see how the sound is transmitted (Fig. 18):

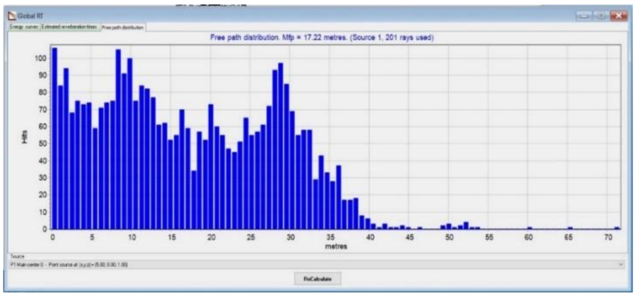

Fig. 18. *The amount of distance that the wave travels in the mosque.*

The sound waves produced in the mosque's dome may be heard for around 40 meters, and it seems that the sound is transmitted throughout the whole structure, according to Figure 19. The most crucial aspect is the sound intensity level along the path, which, in accordance with requirements, is among the strong noises at 80 dB up to about 30 meters when the wave enters the naves.

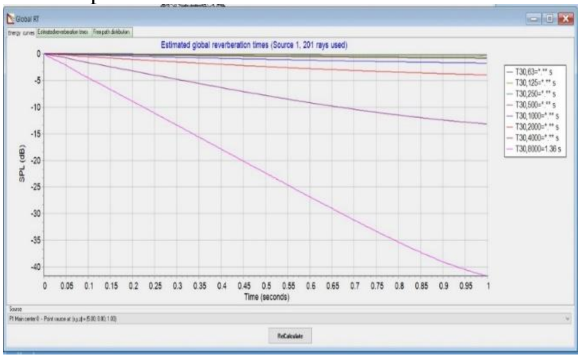

Fig. 19. *The reduction of sound energy in terms of time and decibels.*

It appears that the energy or intensity of the sound has maintained its value in the mosque to a suitable extent. Figure 20 illustrates the decrease in sound energy or sound intensity, which is close to 40 dB for a frequency of 8000 and seems appropriate. For frequencies below 4000, under 1 second, this value was less than 10 dB.

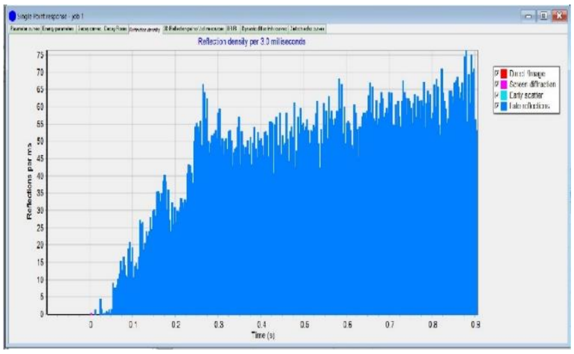

Fig. 20. *The amount of sound reflection according to time.*

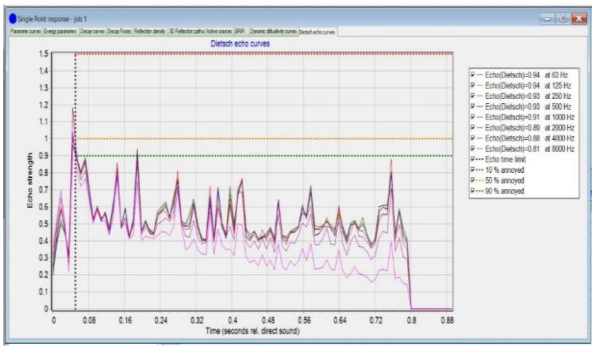

Fig. 21. *Sound echo level according to time.*

The optimal value for the echo level is 0.8 to 1 second for spoken language, 1.5 seconds for classical and Iranian music, 1.8 seconds for symphonic music, and 2.5 seconds for romantic and ritual music. As depicted in Figure 15-4, the degree of sound attenuation has not yet progressed to the point where sound quality is compromised. The figure illustrates a 10% decline in sound quality attributed to sound echo, with the green dashed line representing this reduction. Furthermore, the level of echo has been determined to be acceptable. (Fig. 21)

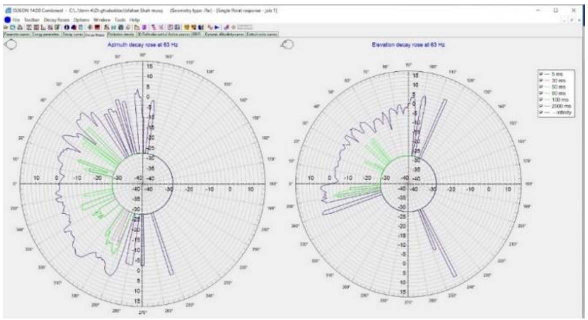

Fig. 22. *The listening angle of the sound for the listener in the designated place at the frequency of 63 Hz.*

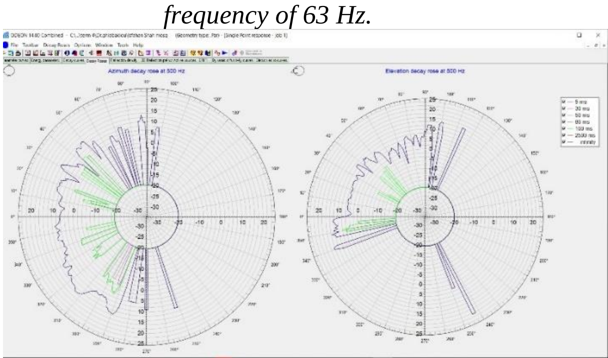

Fig. 23. *Sound listening angle for the listener at the specified location at the frequency of 500 Hz.*

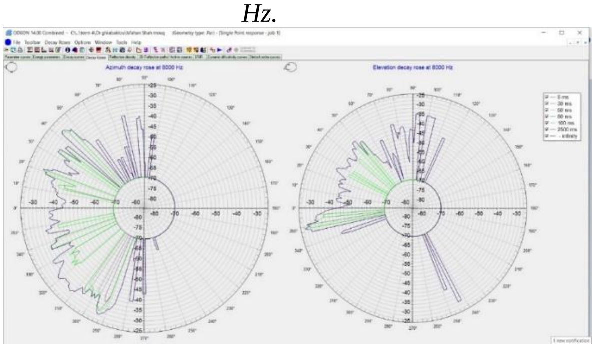

Fig. 24. *The listening angle of the sound for the listener in the designated place at the frequency of 8000 Hz.*

Based on the listening direction of the individual positioned in the nave of the mosque, as depicted in figures 22-24, it appears that the sound reaches the ear of the listener in an appropriate direction, namely one that is upwardly inclined and faces the listener. This orientation enables the listener to identify the source of the sound.

Table 2. *Results of analysis of sound parameters at different frequencies.*

Band (Hz)	63	125	250	500	1000	2000	4000	8000
T_s(ms)	526	525	508	508	480	464	357	209
SPL (dB)	41	40.9	44.5	49.3	45	34.4	22.4	1.7
C (50) (dB)	-24.9	-25.4	-25.4	-26.3	-26.0	-27.9	-24.7	-18.1
LF (80)	0.452	0.467	0.464	0.473	0.496	0.510	0.450	0.434
Echo(Dietsch)	0.94	0.94	0.93	0.93	0.91	0.89	0.88	0.81

Receiver Number: 1 Person Mean free path: 15.84 m.

Ts is one of the factors listed in Table 2 that serves as an indicator of sound intelligibility. A high level signifies significant sound reflection, while a low level signifies intelligibility of sound. The quantity of reflection is greater at low frequencies, approximately 8000 Hz, than at high frequencies, according to the analysis. As per the definitions of acoustic engineering, the ear perceives two sounds (main and reflection) as a single sound when they are perceived within a time interval of 50 thousandths of a second. However, the time interval within the mosque was between 20,000 and 50,000, indicating that the clarity of the sound is adequate. Additionally, C50 indicates the intelligibility of sound across a range of frequencies from 63 to 8000 Hz. Based on the principles of acoustics, this value should fall within the range of 5 to -30 dB. Consequently, the level of reflection suggests that the clarity of the sound is satisfactory. Additionally, the reflection level should fall between 0.9 and 0.4, which is approximately within its range. (Table. 3)

Table 3. *Analysis results of sound quality parameters.*

SPL(A)	*49.0 dB*
SPL(Lin)	*52.4 dB*
SPL (C)	*52.3 dB*
STI	*0.23*
RASTI	*0.19*
BR (SPL)	*-4.4 dB*
AI	*1.00*
Alcons(STI)	*47.75%*
Density (reflection)	*47.35 /ms*

The sound pressure level (SPL), which varies by approximately 50 decibels, signifies that the volume of sound is of an average nature for the individual listening. The mosque exhibits a relatively low Speech Transmission Index (STI), potentially indicating one of its shortcomings. Obviously, this quantity may be deemed permissible in environments that feature religious or church music. The quantity of STI or Aicons exceeds 45% (47.75%), suggesting an acceptable degree of sound fidelity.

3. Conclusion

In the traditional buildings of Iran and the world, the issue of acoustics is very important. Therefore, acoustic engineering has been done in some of them. By examining the mentioned historical buildings and their acoustic characteristics, it was determined that the best building in terms of acoustic engineering is the Shah Mosque of Isfahan. The cause of which has not been clearly identified yet. In this article, this review was done much more carefully than another research. It seems that this method of acoustic engineering can be used in today's buildings and reduce the use of electronic amplifiers and reduce energy consumption. It seems that if we want to find a name for this new method of acoustic engineering, we can use the word "passive acoustic engineering". A method that can develop the topic of sustainable architecture in the field of acoustics. It can be said that one of its problems in the design is the form of the arches, and because they are not flat, either inside or outside, they can cause design problems. This topic can be considered as a future topic as a proposal for acoustic engineering through this method in the current period. Fig 25.

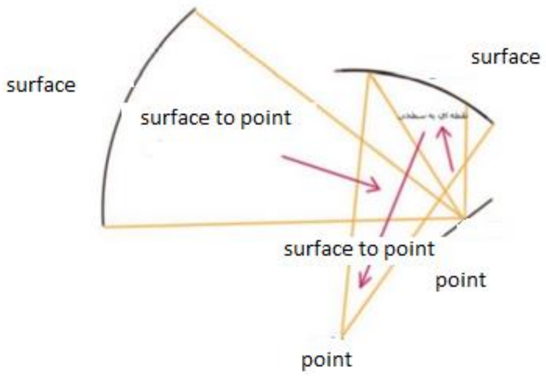

Fig. 25. *New sound transmission in acoustic engineering*

REFERENCES

[1] M. Bemanian, S. Lashkarbolouck, H. Ahangari, Investigating the history of acoustic architecture in Iran and related architectural patterns [Internet]. The second international conference on agriculture, natural resources, environment and medicinal plants (2016). https://civilica.com/doc/517738/certificate/print/

[2] D.N. rezayi, Y. Saber Zaimian, H. Sayyadmanesh, Z. Poorsafar, Chini khaneh in architecture (case study of Ali Qapu Mansion and Sheikh Lotfollah Mosque in Isfahan) [Internet]. International conference on civil engineering, architecture and urban planning of contemporary Iran (2018) https://civilica.com/doc/710378/certificate/print/

[3] S. Abedi, S. Jamei, Investigating the effect of acoustics in Ali Qapu Mansion, Isfahan [Internet]. International conference on human, architecture, civil engineering and the city (2015) https://civilica.com/doc/410110/certificate/print/

[4] Asadi bani, Review of Ali Qapu's music room in terms of live performance of Iranian music [Internet]. The second international congress of new horizons in architecture and urban planning with a development and technology approach (2016) https://civilica.com/doc/531611/certificate/print/

[5] M. Mohammad Sadeghabadi, Analysis of time measurement and background RT in the music room of Ali Qapu mansion in Isfahan. Sci *J. Sound Vib* 4 (2015) 32–7. https://jvs.isav.ir/article_14551.html

[6] S. Safi, A. Ghafari, N. Farahza. Evaluation of the acoustic quality of Yazd Jame Mosque [Internet]. Second International Conference on Acoustics and Vibrations (2013) https://civilica.com/doc/188731/certificate/print/

[7] R. Khoeini, Z. Torabi, F. Yonu, Study of Echo Feature in Imam Mosque in Isfahan and its function in new building like amohitheater. (2016) 228–38.

[8] Z. Sü, S. Yilmazer, The acoustical characteristics of the kocatepe mosque in ankara, Turkey. Archit Sci Rev 51 (2008) 21–30. https://doi.org/10.3763/asre.2008.5104

[9] A.A. Abdou, Comparison of the acoustical performance of mosque geometry using computer model studies. In: Eighth International IBPSA Conference. Eindhoven Netherlands (2003).

[10] S. Girón, L. Álvarez-Morales, T. Zamarreño, Church acoustics: A state-of-the-art review after several decades of research. J Sound Vib 411 (2017) 378–408. https://doi.org/10.1016/j.jsv.2017.09.015
[11] M. Sender, S. Planells, R. Perelló, J. Segura, A. Giménez, Virtual acoustic reconstruction of a lost church: application to an Order of Saint Jerome monastery in Alzira, Spain. J Build Perform Simul 11 (2018) 369–90. https://doi.org/10.1080/19401493.2017.1340975
[12] E. Alberdi, F. Martellotta, M. Galindo, Á.L. León, Dome sound effect in the church of San Luis de los Franceses. Applied Acoustics 156 (2019) 56–65. https://doi.org/10.1016/j.apacoust.2019.06.030
[13] A.P.O. Carvalho, FMCLM Pereira, Acoustics of Portuguese romanesque churches. Proceedings of the International Congress on Acoustics (2019) 2343–50. https://hdl.handle.net/10216/121939
[14] C. Honored, S. Dominic, Applied sciences Evaluation of Acoustic Similarities in Two Italian (2020)
[15] N. Kanev, Resonant Vessels in Russian Churches and Their Study in a Concert Hall. Acoustics 2(2020) 399–415. https://doi.org/10.3390/acoustics2020023
[16] F. Merli, A. Bevilacqua, Using a Church as a Temporary Auditorium. Acoustical Design of S. Domenico of Imola. *J. Phys.: Conf. Ser* 1655(2020) 12146. https://doi.org/10.1088/1742-6596/1655/1/012146
[17] Nowoświat, M. Olechowska, M. Marchacz, The effect of acoustical remedies changing the reverberation time for different frequencies in a dome used for worship: A case study. Appl. Acoust 160 (2020) 107143. https://doi.org/10.1016/j.apacoust.2019.107143
[18] O. Yilmaz Kahraman, Acoustical Properties of Contemporary Mosques: Case Study of "Bedirye Tiryaki Mencik Mosque", Manisa. Ybl j. built environ, 5 (2017) 14–30.
[19] Z. Sü Gül, M. Çalışkan, Z.S. Gul, M. Caliskan, Acoustical Design of Turkish Religious Affairs Mosque. J Acoust Soc Am 133 (2013) 3404.
[20] Z. Sü, S. Yilmazer, The acoustical characteristics of the kocatepe mosque in ankara, Turkey. Archit Sci Rev 51 (2008) 21–30.
[21] A.A. Abdou, Comparison of the acoustical performance of mosque geometry using computer model studies. In: Eighth International IBPSA Conference. Eindhoven Netherlands (2003).
[22] A.A. Abdou, Measurement of acoustical characteristics of mosques in Saudi Arabia. J Acoust Soc Am 113 (2003) 1505–17.
[23] F. Aletta, J. Kang, Historical Acoustics: Relationships between People and Sound over Time. Acoustics 2 (2020) 128–30. https://doi.org/10.3390/acoustics2010009
[24] F. Bisegna, D. Ambrosini, IR thermography as a preliminary tool in acoustical inspection of ancient historical structures. Conference Proceedings - 2017 17th IEEE International Conference on Environment and Electrical Engineering and 2017 1st IEEE Industrial and Commercial Power Systems Europe, EEEIC / I and CPS Europe 2017 (2017) 0–3. https://doi.org/10.1109/EEEIC.2017.7977841
[25] A.A. El-Khateeb, M.R. Ismail, Sounds From the Past The Acoustics of SULTAN HASSAN MOSQUE and MADRASA. In: Building Acoustics. SAGE Publications Sage UK: London, England (2007) 109–32.
[26] M. Lannie, G. Lokshin, Acoustics of Hazrati Imam Mosque in Tashkent. (2014)
[27] M.H. Hashemian, American Academic Research, USA (2022) A Review of Acoustic Engineering Design in Historical Buildings: Hashemian, Mohammad Hossein: 9781947464193: Amazon.com: Books. Available from: https://www.amazon.com/Review-Acoustic-Engineering-Historical-Buildings/dp/1947464191