

Acoustic investigation of architectural spaces with an emphasis on traditional architectural decorations (the case study of the sound room of Ali-Qapu Palace)

Abstract

The architecture¹ of the Safavid² period is one of the best architectural styles in Iran, both in terms of construction and decorations and innovations. Safavid kings tried to create lasting art for all generations due to their great interest in architecture and urban planning. Among the lasting works of Safavid art, we can mention the Ali Qapu Palace of Isfahan, which is built on six floors. The biggest rooms of the palace are on the last floor of the mansion and Shah Abbas used to receive his special guests in them. On this floor, we reach one of the masterpieces of Iranian architects; the music room or the sound room, the central part of which is designed in the shape of a cross and has an area of about 63 square meters. Introducing the favorite pottery of the Safavid kings, that is, Carafes³, thermoses, and jugs, and the most widely used forms of Tongbori, that is, jars. Safavid systems also introduce the most widely used pottery. Probably, some Tongboris were also influenced by metal and glass samples. The vertical surfaces of the walls and the horizontal divisions of Aliqapu have influenced the form of Tongboris. The present research is about this music room. In this research, as the background and basics of the research, after analyzing the acoustic basics, while emphasizing the clarity of speech and reverberation time as measured variables; Then, we have introduced the history, name of Ali Qapu Palace, the Tongs and the shapes and containers of the walls in a descriptive way and with library tools; In the field of his case study and fundamental study, he has used a completely quantitative approach and accurate calculation method with two simulation tools (walls without Tong and roof without muqarans) and field measurement to compare their results. The results of this research consider the role of Tongs and muqarans in reducing sound energy, reducing reverberation time, and improving speech clarity very necessary and necessary.

Keywords: ali qapu, acoustics, tangbari, sound room, speech intelligibility, Isfahan

Research questions:

- 1) What is the effect of the form and materials of Ali Qapu Palace, the Tongboris and the decorations of the walls and ceiling on the acoustic level and the clarity of speech of the building?
- 2) How many types of Tongboris are used in palace decorations?
- 3) What method has been used to measure and evaluate the Speech intelligibility and its timing?

¹*Ali Qapu Palace* (Persian: واپاق‌یولع, 'Ālī Qāpū) or the *Grand Ali Qapu* is an imperial palace in Isfahan, Iran. It is located on the western side of the Naqsh-e Jahan Square, opposite to Sheikh Lotfollah Mosque, and had been originally designed as a vast portal entrance to the grand palace which stretched from the Naqsh-e Jahan Square to the Chahar Baq Boulevard. The palace served as the official residence of Persian Emperors of the Safavid dynasty.

²*The Safavid era* is one of the golden eras of Iranian architecture and art influenced by Shiite and Iranian thought, especially during the 42-year reign of Shah Abbas I, in which thinking, ideology and economics grew because of the silk trade. As a result of the centralized consolidation of power and economics following the political formations, the state sought its ideas in the field of art and architecture.¹

³A *Carafe* (/kəˈræf/) is a glass container with a flared lip used for serving liquids, especially wine and coffee. Unlike the related decanter, carafes generally do not include stoppers. Coffee pots included in coffee makers are also referred to as carafes in American English.

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Introduction

The initial study about the nature of sound is attributed to Pythagoras (580-500 BC).² He succeeded in inventing a single

instrument which consisted of a sound frame with a movable bridge and a string drawn on it. By using this device, he found that two instruments drawn in a longitudinal ratio of 1 to 2 produce notes that are separated by an octave. A higher instrument creates a shorter note.³

Abu Ali Sina¹ said in Ala'i's Daneshnameh² about hearing and sound: "Hearing is related to sound. The cause of sound is air waves. The wave is caused by strong and fast movement of air. In other words, if one object hits another object, it causes the air to jump... because this collision is intense and accelerated; it causes a wave in it. Expansion wave propagation is very fast. Now when this wave is heard, it is heard inside the ear cavity; and as a result, the static air inside the ear also vibrates. This air wave inside the ear (vibrates the eardrum) and informs the auditory nerve".^{4,5} Both architectural and sound design deal with temporal and spatial factors, because humans use both sides of the brain to perceive sound, the right hemisphere for spatial awareness and the left hemisphere for temporal perception.^{6,7} Maybe architects pay more attention to spatial criteria from a visual point of view, while acousticians pay more attention to time criteria, which is shown by the next reverberation time.^{3,8} The current research, which was carried out in line with the branch of acoustic architecture; Speech intelligibility has been selected as one of the most important acoustic parameters in architecture for study. Speech intelligibility or SI is measured by several variables including reverberation time, which will be emphasized in this research. The working method in the research is in the form of a field study after studying the literature on the subject and knowing the acoustic science and history of Ali Qapu. In this study, measuring RT, which is the most relevant factor with Speech intelligibility; Using B&K's sound measuring equipment, loudspeakers have been placed in several different positions in the building. After entering the results into the software, it has presented the average amount of reverberation time in the building, which is far lower than the simulation mode and has an inverse mode at low frequencies. In our initial findings, we came to the importance of the primacy of form over materials, and since the Ali Qapu building is also in terms of architectural form, materials, patterns and Tongboris music room are sound absorbers and provide us with a complete acoustic space.

Research background

Many studies have been done about the Ali Qapu building and its unique features, but no article or treatise have mentioned the acoustics of the sixth floor of the Ali Qapu Palace. In most of them, only the examination of Tongbori⁴ decorations and the shapes of cups and Carafes types have been mentioned. For example, in the article "A Study on the Motifs of Stucco Carvings in Ali Qapu's Music Room",⁹ the author only mentions the introduction of Safavid works and

finally the type of stucco of Ali Qapu's acoustic room. In the article "Coexistence of Tongbori arrays and pottery forms of the Safavid period",¹⁰ the author investigated the reasons for the use of porcelain and various types of pottery forms, most of which are in Tongbori motifs and sound chamber Muqarnas⁵. Finally, it has been concluded that the spiritual dimensions and behavioral tendencies of the Safavid kings, especially Shah-Abbas I, the builder of the Aali Qapu Palace, had an effect on this building. As Shah-Abbas's simple life, being a people and avoidance of diversity has resulted in the simplicity and lack of variety of the Tongbori forms of Aali Qapu.

Or in another article titled "A Comparative Study of Common Bases of literature in Verse and Traditional Arts in Khosrow and Shirin Poems and Ali Qapu Palace",¹³ the author considers Ali Qapu's decorations to be the richest indicator of the culture and civilization of his era. In such a way that first it is imprinted in the thought of the artist and architect (reality), then it is expressed (intermediate) and finally it is formed on the surface of the earth or space (permissible). In the music hall, apart from the display of decorations, the main purpose is to reflect the songs of the composers and musicians by means of hollow forms. In the music hall, apart from the display of decorations, the main purpose is to reflect the songs of the composers and musicians by means of hollow shapes. In the end, the author of the article believes that the music hall has a significant affinity with the piece "Shirin Exit from Khargah"⁶, which depicts the moment of the meeting of two lovers. The status of time and form is the same space that reveals its active and passive aspects simultaneously through movement. This integration, which shows simultaneous movement systems, is embodied in architecture",¹⁴ such as the music hall of the Ali Qapu Palace, which creates a continuous flow of harmonious spatial events based on numbers and geometry. In fact, it is creating space, in a way that draws the audience to another world and time and induces a romantic mood.¹³ In the article "Explaining the theory of the preference of form over material in the acoustic behavior of the architectural space", Ghaffari¹² examines with the help of acoustic analysis the mausoleum of Seyyed Hamza, which is a building with a variety of Āina-kāri⁷ (mirror work). Therefore, it can be said that the final theory of this research proves the preference of form over materials in order to create optimal acoustic conditions. Finally, it should be said that in all the articles, they acknowledge that the sixth floor of the building is acoustic and sound-proof; but no one has tried to quantitatively determine the reverberation time or the level of its voicing using phonological tools. In this article, the authors are trying to briefly introduce the building and finally examine the sound system of the sixth floor.

¹Ibn Sina (Persian: ابن سینا; 980 – June 1037 CE), commonly known in the West as *Avicenna* (*/ˌævɪˈsɛnə, ˌɑːvɪ-/*), was a Persian polymath who is regarded as one of the most significant physicians, astronomers, philosophers, and writers of the Islamic Golden Age, and the father of early modern medicine.¹¹

²Daneshnameh means book of science in Persian language and Ala'i refers to the name of the Kakuyid ruler Ala al-Dawla Muhammad who supported the writing. The book is also known as "*Hikmat-e 'Alā'i*".

³**Reverberation Time** or **RT** is a term that has a special place in the field of acoustic science. This word, which is one of the basic topics of acoustics; It is considered among the basic definitions of source books and among the keywords of many ISI articles. The common definition of these books refers to the time that a sound needs to decrease by 60 dB after the source is cut off.¹²

⁴**Tongbori**: One of the innovations of the Safavids, which is a type of wall decoration and plastering, and its name, is due to the shape of the containers that are used in its decoration, such as: Tong, Jam (goblet) and Carafes. Tongbori and quasi Tongbori type decorations are painted on plaster and are placed in the empty space of a wall made of plaster and wood, which is already made and has a division. Patterns are designed on the thin surface of plaster and wood, and the desired points are freed from wood and plaster, and a layer of simple gilding is applied on the main background of the paintings. This type of decoration is an innovative method of the Safavid era.⁹

⁵**Muqarnas** (Arabic: صندقوم; Persian: سندقوم), also known in Iranian architecture as **Ahoopāy** (Persian: ایابوآه) and in Iberian architecture as **Mocárabe**, is a form of ornamented vaulting in Islamic architecture. Muqarnas is a symbol of plurality in unity and unity in plurality and shows the concept of "Allah is the light of the heavens and the earth" and its circular lines are the symbol of the universe (Ardalan& Bakhtiar, 2012:73). Muqarnas is an allegory of the overflow of light in the world of God's creations, which spreads light, mercy, meaning and spirituality like a chandelier on the heads and souls of worshippers.^{16,1}

⁶هانگرخ زانوریش نددم نوریب

⁷**Āina-kāri** (Persian: آینه کاری; Urdu: آینه کاری) is a kind of interior decoration where artists assemble finely cut mirrors together in geometric, calligraphic or foliage forms (inspired by flowers and other plants). Mirror work is one of the fine arts that is used in the interior facade of buildings, on top of plinths, porches, naves, etc. According to religious instructions, a person should not see his face in a mirror during worship, so decorative mirrors were placed in a broken state in such a way that a person could not see his face by standing in front of it.^{17,18}

Research methodology

In this research, primary information has been collected through field and documentary methods. The theoretical foundations of the research have been collected and classified through books, report articles and specialized websites. In this article, it has been tried to take a serious look at the influence of governance in architecture and urban planning with an analytical-descriptive and comparative view by referring to historical works and documents and letters left from the Safavid era. And in the meantime, you can also check the construction method of Ali Qapu Palace. Fortunately, many articles and travelogues have been written about this palace, which can be the light of our path in this research and provide us with a lot of knowledge. In this article, in order to investigate the sound system and formic analysis of the building, a field survey and a visit to the building of Aali Qapu Palace have been carried out; which finally leads to the extraction and analysis of data in order to investigate how Tongs behaves in reducing noise and their acoustic effectiveness.

Case study: A review of the history and designation of Ali Qapu Palace (Government House blessed by Naqsh-e Jahan)

The Safavids were among the survivors of Sheikh Safi al-Din (744-850), who founded the Safavid Tariqat in the city of Ardabil... The Safavid government was a religious government, and the lineage of Ismail and his successors reached Ali Ibn Abi Talib (a.s.). And they claimed the authority of the Shia imams. The description of Shah Ismail's childhood and his emergence as the worldly and spiritual leader of the Safavid Empire includes events that are of particular importance in the early history of the Safavid Empire. These years can be seen as the sources of Ismail's taste and the clues of Safavid art and architecture.¹⁵ Shiism, which had scattered bases in Iran in previous periods, was declared the official religion of the Safavid government; and from this time onward, by separating from its Sunni neighbors, Iran found a kind of national identity that has continued until our time.¹⁹ In the 1530s, the Safavids mostly lost control over the major Shia shrines in Najaf and Karbala, Iraq; and they gave religion to their rivals, the Sunni Ottomans. In 1589/977 A.H., the shrine of Mashhad in Khorasan was also dedicated to the Shibanians of the Sunnis. A decade later, when it was recaptured, it did not remove the stigma of defeat from the lap of the Safavids; Until Shah Abbas I rebuilt the shrine of Mashhad after taking full control of it and assigned endowments to it in the winter of 1601/1009. Moving the capital from Qazvin to Isfahan was another political and security strategy of Shah Abbas. After moving the capital to Isfahan, Shah Abbas started urban planning and construction work in Isfahan, and one of these construction works was Ali Qapu Palace.

Name of Ali Qapu: Iskander Beg Turkman referred to the royal palace of Naqsh Jahan as "the blessed government house of Naqsh Jahan".²⁰ Since the time of Shah Abbas II, this building is known as Ali Qapu. But Qoli Beg Shamlu called it "Seven Asham Alaqapi" in his description of the events of 1053 AH.²¹ Sykes and Sanson wrote it "Ali Qapu (Ali Qapu = Allah Qapu)".^{22,23} Chardin calls it Aali Qapu because of its tall gate.²⁴ Honarfar and Hillenbrand consider Ali-qapu to be taken from (Bab Ali) Palace of the Ottoman Sultan in Istanbul.^{25,26} The likes of Blunt and Tavernier, Mohammad Mehdi Esfahani and Tahvildar Esfahani have a different analysis and refer to Aali Qapu⁸ as "Ali Qapu"⁹ and its name is because of the respect they have for Ali (AS). Esfahani believes that the door of Ali-Qapu was blessed by Najaf Ashraf, and for this reason he called it "Ali-Qapu".²⁷⁻³¹

This building was completed in the early 11th century and was the seat of the state administration and the king's court. Contemporary historians have called it Daulat Khanah Mubarak Naqsh Jahan. This building has six sections and each section has its own special array.³² Ettinghausen and Ehsan YarShater write about this Palace as follows: "This palace is in a sense the first unit of the series of royal buildings, which mainly continues in the form of booths inside the garden to Zayandeh Rood. Vertical passages include the famous open air platform as well as rooms of various sizes. The platform rests on wooden columns and overlooks the square; and rooms with an excellent system of arched arches, which are generally covered with thin plaster, show the themes of palace life in the style of baroque and more or less rococo restoration of vases, vases, cups and other symbols of happy life.³³ The Ali Qapu building was started by Shah Tahmasab in three floors, but in the following years, Shah Abbas expanded it to its present form after the capital was changed from Qazvin to Isfahan in 1598 AD/1007 AH. The famous painter of the Safavid court, Reza Abbasi, and his students created art on its walls. In the third Ashkob¹⁰, the largest room was the special place of Shah Abbas's enthronement. Ashkob 6th was special for the king's official reception and the place for musicians. The biggest hall of this building is in this Ashkob. Its arrays are plasters in the sky in the shape of dishes and carafe. This same hall is known as the music room in the eyes of the people (Figure 1).³⁴

Professor Galdieri writes about the space of the 6th floor of Aali Qapu: "From the shape of the Muqarnas decorations of the arches and the plaster mesh decorations, in the form of containers and carafes, as well as the plaster material used in them, it is understood that These small semi-arches, including nested stalactites, and all the decorations of the sound room could have functioned as a harmony box, and thus give the hall a high sound quality. In fact, the reflections from the songs were captured by these hollow shapes and natural sounds were heard without sound reflection".³⁵ Architecture is the art of ordering space. Geometric spaces with precise mathematical principles create a space where the principle of unity is revealed in the components. This unity is rooted in the components of our traditional architecture and has caused a sacred quality to manifest in the forms of the earth. Art is one of the dimensions of human experiences and a manifestation of emotional perceptions, which is an attitude towards taste and feeling. If we consider the three principles of "truth", "beauty" and "goodness" as concepts related to art, it is natural that these three principles can have different meanings depending on the perspective and culture of each nation (Figure 2).³⁶

Principles of acoustic design

Acoustics is a relatively new science and discipline, having been studied in the 17th century, while the first fundamentals of the method were established at the beginning of the 19th century. This field was established substantially during the 20th century. This is quite a complex issue of human perception of sound, which depends on the sound pressure, its frequency. This is also a relative matter; and this reciprocal relationship is based on logarithmic references as well as the individual characteristics of a particular person.³⁷ The history of acoustic design began with the construction of the ancient Greek theater. But they do not have proper arrangements (Mazzoni, 2011). But later, especially in the amphitheater of the Colosseum, the scene was covered by curtains or painted wooden panels, which played an important role in sound reflection. From ancient times until today, the circular shape has fascinated many architects; however, it has many audio problems such as audio focusing, echo distortions and whisper gallery effect.⁸

¹⁰Each floor of the building

وېباځلې اړخ
وېباځلې اړخ



Figure 1 Front and back view of Ali Qapu Palace, source: Authors.

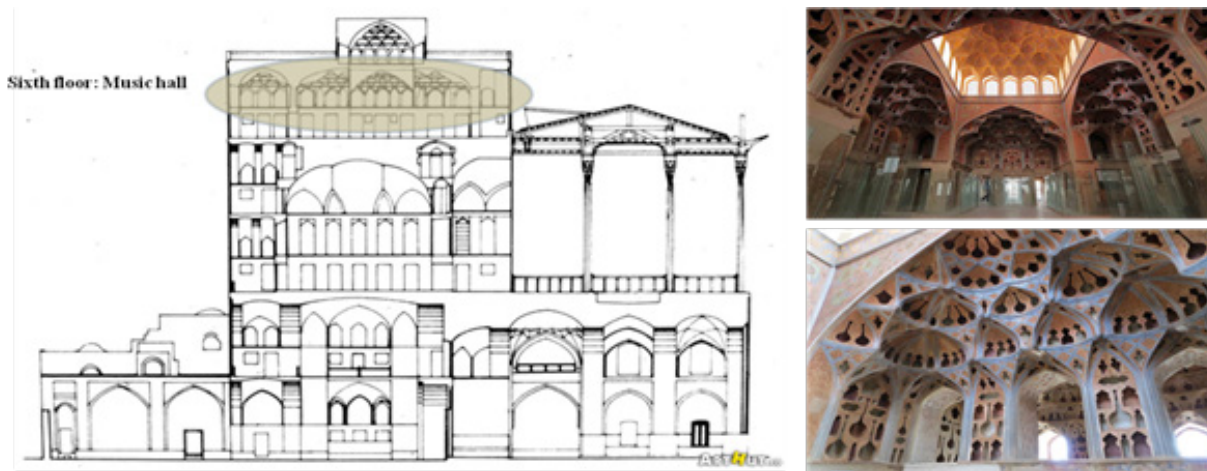


Figure 2 Aali Qapu cut and photos from the inside of the 6th floor (music hall).

“Finally, in 1895, a young physicist named *Wallace C. Sabine* tried to solve the acoustic problem of the hall of the Fogg Museum.³⁸ After that, acoustic design is one of the active fields in physics and architecture. In fact, the geometry of the space is directly effective in its acoustic behavior and specifically affects the way people perceive it from an acoustic point of view. The two components of sound pressure level and reverberation time, which clarify the acoustic behavior of spaces, as two important and effective variables in acoustic desirability, are affected by the geometry of the space.³⁹ In general, the effective factors in the transmission of sound between the transmitter and the receiver can be examined in five cases: 1. Sound reflection by surfaces (floor, walls, floors and obstacles); 2. Refraction from the edges (edges of obstacles and containers and glasses); 3. Scattering from hard surfaces (such as irregular facades); 4. Failure by temperature and wind; and 5. Weakening of sound waves by absorption of air (inside the constrictions with sound reflection inside them).⁴⁰ According to the results of the research, the factors affecting the acoustic behavior of small-scale urban spaces can be summarized according to the table below.

According to what has been said, in order to determine the acoustic behavior of spaces and the factors affecting them, which is done based on the evaluation of the sound pressure level and time and reading as basic variables, one should pay attention to the indicators specified in Table 1. In the current research, sound pressure level and reverberation time are measured as two basic acoustic variables to determine the acoustic behavior of the studied spaces. Also, the

effect of the degree of confinement, static or dynamic, crowding and lighting of the spaces as effective spatial qualities on the mental perception of the sound dimension have been investigated. Acoustic science, in a narrow view, measures parameters that include Speech intelligibility. Speech intelligibility refers to the clear and clear hearing of words, which is abbreviated with the symbol SI; and it is mainly considered as one of the topics of the psychological field of acoustics; In terms of the physics of sound, it does not have a specific and single definition. From this point of view, variables such as 50C or STI, ALcons, 80C and rapid sound transmission index are a way to define speech clarity. STI or sound transmission index and RASTI, which are called rapid sound transmission index; the most convergent parameters are speech clarity¹² Speech intelligibility is a subjective response and its quantitative measure is the number of meaningless words that have phonetic balance and are correctly noted by a group of trained listeners. The results can be expressed as a percentage score of words or on a scale that covers from zero to 10. On the scaling spectrum, the counting index (AI), less than 0.3 generally means that the speech is unintelligible, but if the AI is more than 0.7; Speech clarity is excellent (B&K, 2010). Another parameter of the acoustic field that is also used in the measurement of speech clarity is the reverberation time. Aliqapu music room due to plaster surfaces and having Tongboris which includes nested stalactites, absorbs sound in low and high frequencies, which creates excellent speech and AI above 0.7. Therefore, no sound has leaked out of this room, and the sound of the music reaches the audience without any distortion or reflection (Table 2).

Table 1 Effective factors in the acoustic behavior of small spaces; Source: Author

Criterion	Source	Indicator	
Liu ⁴¹	confinement	Metric properties	
Long ⁴¹ ; Liu ⁴²	Spatial proportions: volume, dimensions and size		
Hornikx ⁴⁰	Materials, geometry and form	horizontal shell (floor and ceiling)	Shells
	Materials, geometry and form	vertical shell (walls)	
Ariza-Villaverde ⁴³	Dimensions and size	Physical barriers	
Hornikx ⁴⁰	Materials		
Yang ⁴⁴	The position of the audio source and the listener		
Zhang ⁴⁵	sound intensity	Audio sources	
Morillas ⁴⁶	Frequency spectrum		

Table 2 Table of speech clarity variables; Source³⁹

Standard value	Swing range	Independent variables		
0.05-1	0.05- A function of space volume	RT		
with variable frequency	0.5-70db	SPL		
0.7-1	0.75-1	STI	Speech Intelligibility	Dependent Variable
1-17%	0.5-8%	ALCONs		
0-5	1.5-5	C50		
0.3>0	0.6-0.95	AI		
volume, size of internal surfaces, form, sound absorption coefficient of materials, width, length, height proportions				Independent variables of reverberation time

Music hall muqaranes

Aesthetics of Iranian art is based on ornament; ornament is not only a kind of imitation and inspiration from nature, but also includes insight from Islamic beliefs and thoughts. Ornament is some a religious art because it has dimensions that are more or less subsidiary not inherent and from a religious point of view has supreme effects on function and nature of architectural elements that most of the time are mystic and allegoric and understanding of this matter is possible only through interpretation. Manifestation of religion in art is only by way of creation and representation of dimensions, images and forms that are combined with religious principles and reached supremacy in it. In a way that the principle of ornament in addition to religion is related to myth and most the times is the basic meaning of ornament.¹⁸ “Muqarans is the product of the same type of geometrical test that led to the invention of the flat group, and it implies the classical aesthetic opinions based on proportion and not as they said the fear of the Muslim soul from emptiness”.⁴⁷ The music hall of this building has a collection of very exquisite and delicate decorations. Beautiful stucco paintings are hung from the walls and at the end of this hall, a combination of glass and ceramic decorations cover the walls. The walls are decorated with geometric, Islamic motifs and forms similar to musical instruments. This mansion has been a place of reception for dancers and musicians.¹³ During the Safavid era, stalactic (hanging) Muqarans became popular and these are in the form of musical instruments in the form of Jam, Tong and Carafe, Which is made of plaster frames and is called *Muqarans Tongbori*; which acts as a sound absorbing panel. The Tongboris of Aali Qapu Palace has made this work more prominent than other palaces. These curved and perforated walls, which are built into the wall in the shape of a Jam and Carafe, look very interesting in terms of sound energy control.

These walls are similar to sound absorbing panels, and as it has been said, these Tongboris walls have absorbed the unwanted reverberation of bass sounds.⁴⁸ In the article “The coexistence of Tongbori arrays and the form of Safavid period pottery”, the author has divided the Tongbori motifs used in Hasht-Behesht and Aali Qapu Palace into two decorative and functional categories. Vases and Qandil are known as decorative and practical motifs, which are divided into four categories: altars, Flat, drinking and food containers, are more numerous than decorative ones. In the table below, all the Tongbori motifs used in the Muqarans of Ali Qapu Palace are shown in [Table 3](#).

Galdieri³⁵ and Pirmia³⁴ considered this building to be the official reception place for the king and the gathering of dancers and musicians. The musicians were stationed in the upper two earrings of this floor, which are full of Reza Abbasi’s paintings. When some musicians started playing songs in this building, their sound could not be heard anywhere in the palace, because the created holes break the sound inside the room. Shah Abbas used to receive his special guests in this place. He used this room so that the sound of his confidential discussions would not be heard in other places of the palace.⁹ The rooms of Ali Qapu palace, which were a place for public and special entertainments and receptions, showed a wide pavilion of Tongbori arrays for the purpose of keeping the royal china collection.^{26,58} Basically, the Safavid kings were very interested in collecting and keeping exquisite porcelain and earthenware.¹⁹ Olearius, the German ambassador, mentioned out the four hundred exquisite Chinese dishes in the china room of Sheikh Safi al-Din Khānegāh and Shrine Ensemble. He narrated the Safavid kings’ interest in these dishes and their use in entertaining the king, courtiers and high-ranking delegations.⁴⁹

Therefore, it appears from various sources that the Safavid kings had a great interest in exquisite porcelain dishes, such as Carafe, tong, plates, bowls, and jugs. On the other hand, Shah Abbas had dual Shiite and Sufi tendencies. Perhaps, in addition to his religious activities, as a complete mentor of the Sufi order, he was thinking of establishing the cult of elders of this religion. Sufis and dervishes considered wine-drinking tools and utensils, such as tongs, Jams, and Carafe, to be necessary for their Sufi gatherings. Of course, he also had great devotion to his ancestors, the holy sheikhs of the Sufi order, and sought their blessings during his pilgrimages. He was under the influence of this sect and their rituals.^{50,10} One of the functions of Ali Qapu Palace, which was shown in its music hall, was the holding of *bazm*¹¹ gatherings. The walls of the Ali Qapu Music Hall, compared to Hasht Behesht Pavilion, follow more vertical and tall proportions and these tall walls played a key role in blocking the sound of the musicians' music from the residential environment around the palace.⁵¹ But to decorate these walls with vertical proportions, a proper plan was needed. The implementation of these *tongboris*, which had a great effect in modulating and breaking the sound echo.¹⁹ Technically and acoustically, these have been directly related to the main function of Aali Qapu Music Hall, and they have been the best design for decorating the surfaces of the walls of this hall (Figure 3) (Figure 4).



Figure 3 Part of the narrowness of the ceiling of the sound room; Source.²⁸



Figure 4 A view of the tongbori and muqarans work of the sixth floor wall; Source: Authors.

Looking at the miniatures and wall paintings of the Safavid period, the most important Terracottas of this period are known. In

¹¹*Bazm* is a ritual feast with hours of drinking wine accompanied by poetry, music and dance. It seems that its origin goes back to the ancient ceremony where the blood of a bull was eaten, which was considered a sign of the king's power. Later, wine replaced bull's blood; Wine was served in gold, silver or ceramic vessels

these works, which contain images of royal assemblies, daily life, and professions, pottery vessels including cups, vats, Carafe, and tong can be seen. In the paintings of Kikhosro and Kikavos, all kinds of pottery vessels are depicted, including tong, plate, and pitcher, as well as Iranian and Chinese blue and white vessels (image 5). In this picture, the vessels with dark blue color are purely Iranian samples and the light blue or white vessels with dark blue motifs represent Chinese blue and white pottery.¹⁵ Among other paintings, there is the image of a young Sufi in meditation. In this work, a young man is depicted in a state of meditation with a Kashkul, one of the important accessories of Sufis, which is one of the other examples of the presence of Safavid era pottery forms in paintings^{52,10} (Image 6). In images 7 and 8, other examples of the presence of *khomreh*, tong, Carafe, bowl, pitcher and plate in Safavid paintings are displayed (Figures 5–8).



Figure 5 Picture 5: Kikhosro and Kikavos (Canby, 2008, p. 19).

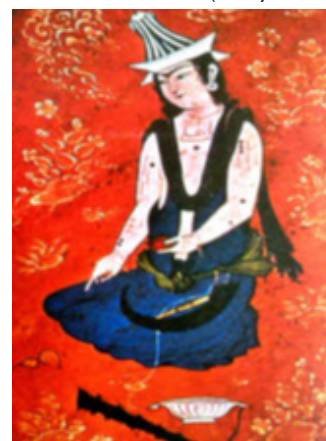


Figure 6 Sufi meditating, (Robinson, 2000).



Figure 7 Golgasht, (Gray, 2006, p. 224).



Figure 8 A work by Reza Abbasi www.slidshare.net.

Recommendations

From an acoustic point of view, hollow Tongbori plaster works like an amplifier or a speaker, which played an essential role in concentrating the sound. Just as bass and higher sounds need a bigger amplifier and lower sounds need a smaller amplifier. The small and large forms of Tong and Carafe in the divisions of Tongbori arrays are not unrelated to the pitch of the sound and are of great value in raising and clarifying low sounds. Also, the different depth of the hollow space of these arrays has been used to control frequencies with different scales and prevent disturbing sounds, and in other words, they reduce the duration of undesirable reverberation of bass sounds.⁵³ In this regard, the field measurement of the research was designed according to the space form, in several different positions and states, in which the location of the test equipment was set differently. This is necessary in order to achieve more accurate results with regard to the variety of forms and decorative shapes used in the walls and ceiling, and the final result of the measurement is considered the result of different measurement situations. Every measurement position and arrangement, each of which is mentioned under the title of experiment; it has been repeated many times and the overall result has been considered as the achievement of each experiment. The measurement results in Diagram 1 show the changes of RT in relation to the position of the sound meter (Mic) and the sound source in different positions. According to Diagram 1, the reverberation time (RT) for the frequency of 63 Hz equals 40.52 seconds, at the frequency of 125 Hz equals 38.52 seconds, at the frequency of 250 Hz equals 14.23 seconds, at the frequency of 500 Hz equals 8.56 seconds, at the frequency of 1000 Hz equals 7.56 seconds, at the frequency of 2000 Hz equals 6.48 seconds, at the frequency of 4000 Hz equals 4.20 seconds and at the frequency of 8000 Hz equals 1.25 seconds.

Of course, the author tried to design the space without Tongboris in a hypothetical experiment using Ease3.4 software, and the result of the experiment was much more interesting. Because the reverberation time went much higher at frequencies lower than 250 Hz, which reached 75 at the frequency of 63 Hz, but after passing 250 Hz, it gradually decreases. Therefore, the effect of Tongboris can be seen in lower frequencies. These plaster arrays transform a space with completely unfavorable acoustic conditions into a space with a very low reverberation time and therefore favorable from the acoustic point of view. In addition, the reverse directions of the graph in these two

modes and at low frequencies indicate changes in the relationship between frequency and reverberation time due to Tongboris chalk, which reduces the sound energy at low frequencies and reduces the reverberation time. The inverse relationship between time and frequency becomes a direct relationship with the addition and involvement of Tongboris and directs the important influence from the field of measurement tools to the form created by them. In general, it should be said that the frequencies of the speech domain (500-8000 Hz) show better behavior in such an environment (Diagram 1).⁵⁴⁻⁶⁰

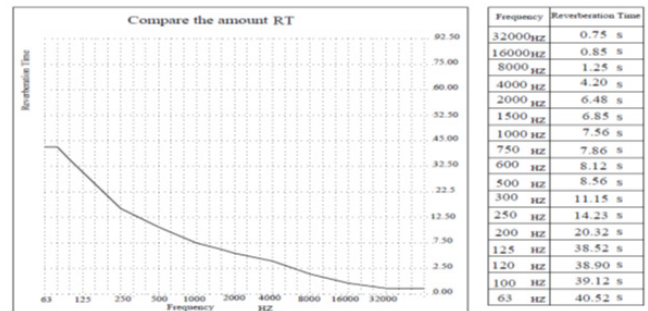


Diagram 1 Reverberation time taking into account the roof's Tongboris and Muqarnas; Source: Authors.

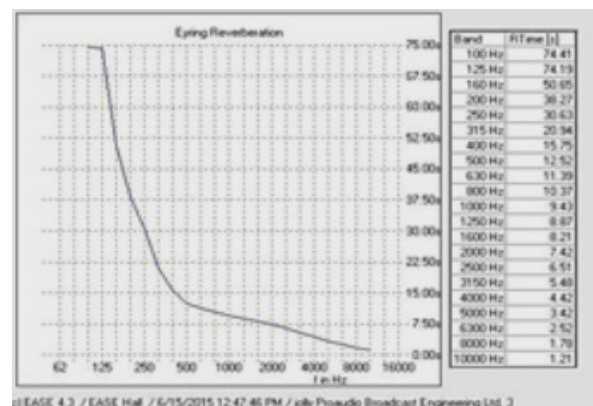


Diagram 2 Reverberation time without considering Tongboris and Muqarnas works.

Conclusion

The relationship between the forms used in Tongboris is with the technical considerations of architecture and the principles of level composition. In most cases, priority has been given to shapes that can be adapted to the primary divisions of Tongbori and the framing of the wall surface. In Ali Qapu Music Hall, architectural divisions and levels follow more elongated and vertical forms, and the overall height of this space is higher than the height of Hasht Behesht's Tongbori room. Therefore, forms with a vertical and elongated axis such as Carfare, teapots, vases, and tongs are in perfect harmony with the vertical divisions of the walls of the Ali Qapu Palace; and forms with a horizontal axis such as bowls and plates are less used in this palace. Therefore, the architectural form and volume of the building, on the one hand, and the divisions of the walls and arches on the other hand, were decisive in the choice of the form and the implementation of narrow arrays.

The current research proves that in the field of acoustics, with any material, as long as it has a suitable form, it is possible to create a suitable architecture and suitable materials. The ability of materials is limited due to its nature; but the form has a wider range in terms of aesthetic capabilities. Formatting is designer-oriented; while it is

simply not possible to interfere with the nature of the material and, as a result, change the behavior of the material. In simpler language, it can be said that materials do not have wide capabilities; but the form can create infinite possibilities in all aspects and at the same time meet the needs of aesthetics. The findings of acoustic science so far introduce gender as a factor with the first degree of importance for an element and its determination in sound factors. But this research, with the help of Proof by contradiction and by analyzing examples that contradict this claim, proves that the acquisition factors of materials are preferable to their attribution parameters. The theory of this study is the result of looking at the relationship between Mahoe Suri¹² factors and the extrinsic nature of an element in the acoustic field. How art forms and works of art have acted as a cavity and reduce the sound energy in low frequencies. The nature of a material can be completely ignored under the influence of extrinsic and induced factors from the environment and transferred from the priority of acoustic science to the next levels. For this reason, the material used in Moqrans and Tongbori is important. Building form, which is an acquired factor for the material, and the material, is one of its intrinsic and attributed factors. Architecture and Mahoe Suri covers it to its advantage. The form has overshadowed the material; the inherent properties and Mahoe Suri cover it in its favor.

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Conflicts of interests

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