I S A V

Journal of Theoretical and Applied Vibration and Acoustics

journal homepage: http://tava.isav.ir

Acoustical identification of historical mosques in Tabriz

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ARTICLE INFO

Article history:
Received 22 November 2022

Received in revised form
21 November 2023

Accepted 26 November 2023

Available online 7 January 2024

Keywords:
Architectural,

Acoustics,

Mosque,

Form,

Volume,

Proportions.

ABSTRACT

Paying attention to the sound quality of mosques is one of the architectural fundamentals of Islamic societies because the mosque is the most prominent ritual place of Islam, and speech and hearing are considered its main characteristics. In this research, the analysis of the most effective form in optimal sound quality was defined as the primary goal, and for this purpose, the historical mosques of Tabriz city were subjected to field analysis. The initial analysis of the samples from the perspective of the variables affecting the acoustics led to the selection of 15 samples in three volume categories and five form groups, in which the selected standards for measurement are 3382-1 and 3382-2, and the measurement equipment are the 2260 B&K investigator and the SINUS Acoustic Camera. Among the acoustic variables, Background Noise, Sound Pressure Level, and Reverberation Time were analyzed, and the results of field measurement led to the framework becoming the final goal of the study. The results of this study show that acoustic behavior in samples regardless of their size and form is almost similar, which is due to the components such as materials and their implementation, as well as the overall formal frame within mosques, which were considered the same to reduce the interventional variables. The second achievement, which is the result of a visual data collection of the quality of sound playback, identifies the mentioned components and shows that the reflection and propagation of sound in selected mosques are from architectural elements that are common in all samples and form the overall frame of space. These two achievements framed the final goal of the study in the form of determining acoustic identification for historical mosques in Tabriz. The final result of this study is the analysis of data in MATLAB software which extracts the Background Noise, Sound Pressure Level, and Reverberation Time equation based on frequency in Tabriz historical mosques and spaces with a similar model.

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1. Introduction

In architectural acoustic studies, Reverberation Time (RT) is a term that has a special position in the field of architectural acoustics. This word, which is one of the basic acoustic topics, is one of the basic definitions in sourcebooks and one of the keywords of many articles. The common definition of these books from RT is how long a sound needs to be reduced for dB60 after the source is cut off. Speech intelligibility is one of the variables involved in many acoustic studies

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http://dx.doi.org/10.22064/tava.2023.1971101.1215

and RT is one of the effective factors in it. The persistence of sound and its desired listening depends on the fact that itself in the field of architecture and interior spaces, influenced by the way of space building, volume and area of space, materials, form, etc.

Several equations have been presented to define the RT so far. The most basic one is the Sabine equation, which as mentioned above is based on the volume, area, and materials of the measurement space. It is noteworthy that volume plays an essential role in defining RT, and there are equations in space that are calculated based solely on volume. One of these equations is the optimal Reverberation Time, in which the coefficient varies based on space usage and for speech equal to 4, for orchestra is equal to 5, and for chorus music is equal to 6. [1-6].

Sound Pressure Level (SPL) is one of the other effective variables in acoustic analysis of architectural space. Basically, alignment means the ratio of measured quantity to unit base, which defines the threshold of understanding. Sound pressure level is a logarithmic equation between baseline sound pressure and measured pressure [7-9].

In the study of RT, sound pressure level, and other acoustic variables of architecture acoustic, it is necessary to know the background noise (BN). Because it determines the basic value of sound, explains the amount of differences, and how to improve the possible acoustic weaknesses of space. This characteristic has certain numbers by global standard organizations at different frequencies and based on them, the Noise Rating curves are drawn. Based on these diagrams, noise intensity at low frequencies can be higher than noise intensity at higher frequencies and each usage should be designed by adapting to a specific curve. For each curve, a certain number is defined and different usages adopt different NC numbers [10-14].

Architectural Acoustic studies are required to select a study approach after selecting the variable. The best method of study is field measurement because it includes results based on the reality of space. However, in the design stage and in situations where field study is not possible, simulation can be a suitable solution. Citing the human study, whether in the form of questionnaires and interviews that are based on perception, and field or laboratory tests on acoustic variables, is another method of architectural acoustic analysis.

Calculation and citation of equations while in all mentioned methods is used, itself is used as a separate tool. In field measurement, the basis of hardware for measuring is equations. Softwares are defined and programmed based on equations, and human tests are finally analyzed with equations. In the meantime, the type of architectural space is ineffective in choosing the method, but since the present study has been conducted on mosques, the study of literature is devoted to acoustic researches of mosques, and among them calculating and mathematical equations are used by studies in three conditions.

The first mode is dedicated to the research stage. Some studies only calculate the acoustic variables of the architecture with mathematical equations and analyze the sound quality of the space based on that [15-21]. The second mode is related to the analysis and citation stage. In many studies, the selection of the basic theory is made by referring to mathematical equations. The adjustment of measurement devices and software requires the definition of the relationship between measurement variables, and the standards are also developed based on mathematical relationships, which shows the benefit of equations in analysis and reference [22-29]. The third mode of using calculation is in the phase of comparison and after conducting the study. After collecting data with

other methods, many studies compare the results with numerical calculations in order to strengthen the validity of their analysis [30-35].

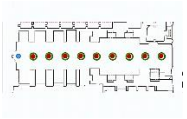
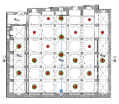
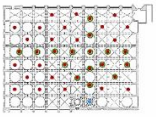
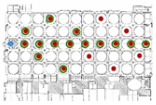
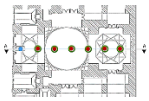
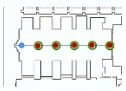
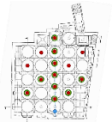
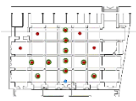
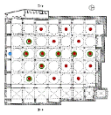
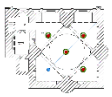
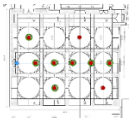
Among the researches in the field of architectural acoustics in mosques, no study relates the findings of field measurements to mathematical relationships. Perhaps the work by Al-Khateeb in 2012 is the only study that has been able to lead to the relationships between architectural factors. In this study, Al-Khateeb carried out a simulation that reaches the form factor and shape factor, which he mentions as effective architectural parameters in acoustic analysis [36]. However, the combination of field and mathematical methods in such a way that the sum of the measurement data leads to the extraction of the mathematical relationship has not been done, and this proves the strategic innovation of the present study, which is the result of the researcher's exploratory analysis after the field assessment.

2. Field measurements

2.1. Measurement methodology

The current research has been conducted on mosques in Tabriz city that have been registered with the cultural heritage organization. The initial survey with the view of architectural analysis has been done in all 56 registered historical mosques in Tabriz, and after considering the volume, plan shape, plan proportions, formal geometry, and materials and after homogenizing the effective components, formal and volumetric classification was done in it. Among the aforementioned categories, samples that acoustically have the least intervening variables are selected, and therefore, in total, 15 samples in three volume categories and five form groups were selected and analyzed. The chosen standard for the acoustic measurement of architectural spaces is ISO3382-1 and ISO3382-2 [37, 38], and based on their definitions and criteria, the plan of the samples was gridded. The largest and smallest sample sizes were measured using 38 and four points respectively, totaling more than 700, including device errors and measurement mistakes (Table 1). Three acoustic factors of the measurement including Background Noise, Sound Pressure Level, and Reverberation Time, were measured with the 2260 investigator. The measurement of the background noise in all samples was the first variable to be measured and therefore it was done in the morning between 9 and 10 (in larger samples until 11). Since the number of samples is large and the measurement requires many days; In all measurements, the same weather conditions are considered. The measurements were made in January and partly cloudy weather conditions (neither snowy nor rainy). SPL is the second measurement variable and is considered after the background noise. It has been measured from 10 or 11 until finally 2 pm. Other weather conditions are similar to BN measurements. The samples are considered empty of people so that laboratory conditions can be applied according to ISO 3382. On the other hand, the amount of sound broadcast from the omnidirectional source is in the full frequency range and covers all possible sounds in the samples. The gain of the device is 40 dB higher than the background noise, to cover the conditions of ISO 3382. RT is the last measured variable and it was measured in the samples after 3 pm. After measuring it in the distribution network in the plan of the samples which is given in Table 1; It has been averaged in different frequencies and a specific RT value has been obtained for each frequency. The sound source in all samples is set to Gain 0 with a certain octave banding to ensure background coverage. The frequency band of the source in all samples is 1/3 octave band and according to ISO 3382, it is considered from 100 to 5000 Hz.

Tabel. (1) Samples of study

	Domed	Arched	Square columnar	Transverse columnar	Longitudinal columnar
	Kabood	Jameh	Emam Jomeh	63Sotoon	Hojjatoleslam
Large					
					
	Haj Safarali	Jameh Koochak	Qizilli	Shohada	Shahidi
Middle					
					
	Milli	Haj Ghani	Haj Ghaffar	Shahid Sadooghi	Khalkhali
Small					
					

2.2. Measurement with 2260 Investigator

The results of the field measurement with the 2260 sound level meter show a similar pattern in all samples. Because the amount of noise is very dependent on the location; And on the other hand, the form and volume of the samples are different, the similarity in the sound behavior of the background noise in all the samples is beyond expectation. Samples with higher quality are naturally from the point of view of urban placement in high-traffic places, but what is of interest in this research; is the common behavior of the samples at different frequencies. Despite the existence of several oscillations in some samples, the amount of noise is often higher at low frequencies which decreases toward middle frequencies, and increases again at higher frequencies, although its value is lower than the initial frequencies. (Fig. 1)

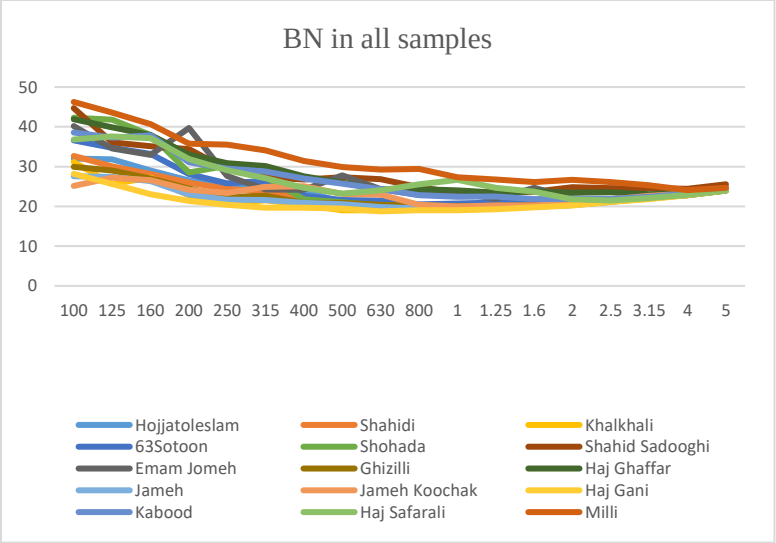


Fig. (1) Background Noise in samples

The Sound Pressure Level in which the shape of the space is expected to have a high impact; also has the same behavior in all samples. Although the SPL values at different frequencies depend on the size of the samples and are different from each other, its behavior model is the same in all samples. The Sound Pressure Level of all samples has the highest value at 250 Hz, after that the SPL drop continues up to 1250 Hz, and at the mentioned frequency, a sudden break in the values occurs and the Sound Pressure Level increases at 1600 Hz. The downward trend of SPL continues until the end of the spectrum and this behavior is repeated in all samples despite possible fluctuations in other frequencies. (Fig. 2)

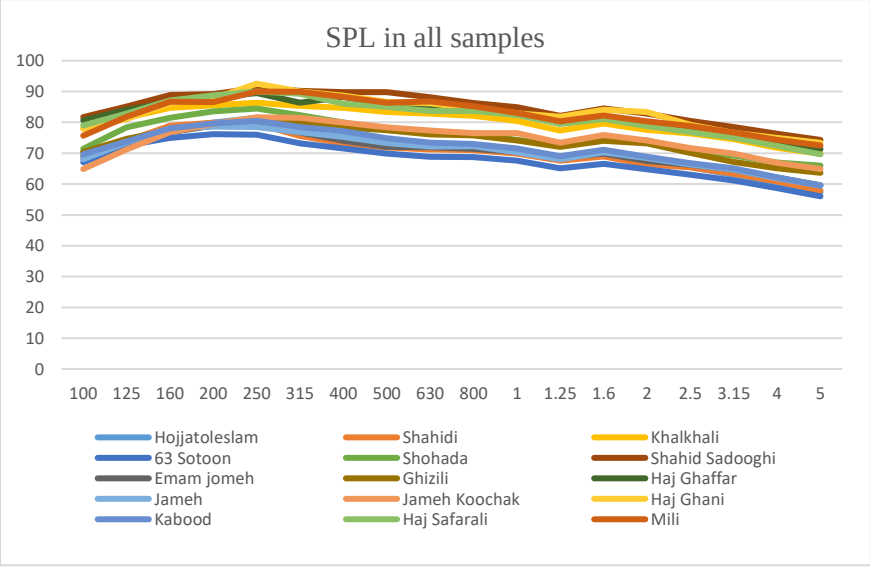


Fig. (2) Sound Pressure Level in samples

As the main characteristic of architectural acoustics, Reverberation Time shows compliance with volume more than form. The general behavior in the samples is still constant, and the initial frequencies have higher RT and high frequencies have less RT. The difference between high and low frequencies is greater in bulky samples and less in smaller samples (Fig. 3). So we can emphasize that RT differences are more related to the size of the samples rather than being dependent on the form, and it is also stated that in larger samples, the RT difference is more intense in proportion to the change in frequency. In other words, all the judgments of this research in RT should be dependent on the volume and have been analyzed based on that.

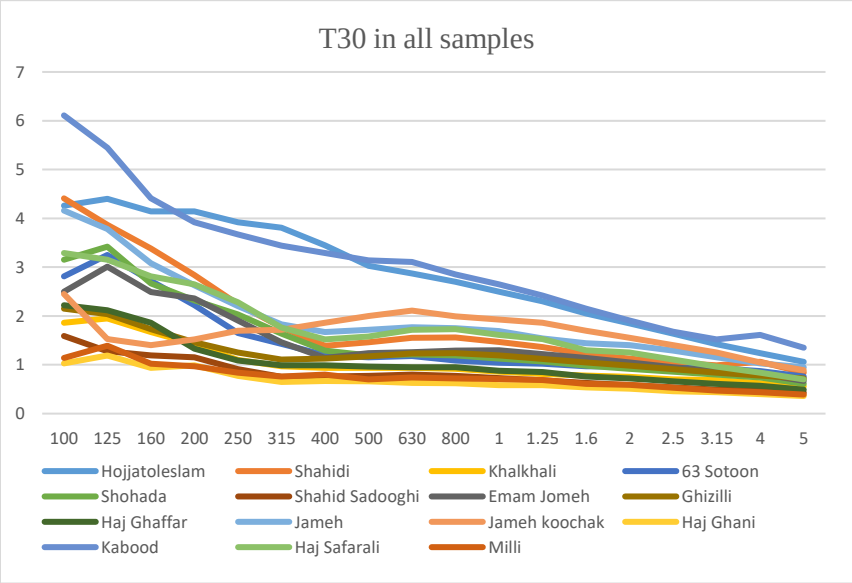


Fig. (3) Reverberation Time in samples

3. Software analysis

After the similarity of the acoustic behavior in the samples was determined by the numerical outputs obtained from the 2260 sound level meter; It seemed that the sum of behaviors in each variable can be considered subject to a specific law. The aforementioned law is defined as a mathematical equation. The samples with any volume and form function according to a specific relationship making the acoustic conditions governing the similar form and frame of mosques predictable. In other words, it can be said that the form of the historical mosques of Tabriz and possibly any other similar mosque has a regulated behavior from an acoustic point of view and has a sound identifier from an acoustic point of view. In order to achieve the mentioned relationships, the data of 2260 have been analyzed in MATLAB software and the best fitting function of the data has been presented in all the samples.

4. Findings and discussion

The background noise in all the samples is more dependent on the location of the sample. It is generally high in the initial frequencies and after a sudden decrease in frequencies less than 500 Hz, it is associated with a gradual increase in higher frequencies. The average of BN in all samples

by frequency shows that the general pattern is consistent with Figure 4, and its rule is the 2nd-degree exponential equation in terms of frequency as shown in Eq. (1)

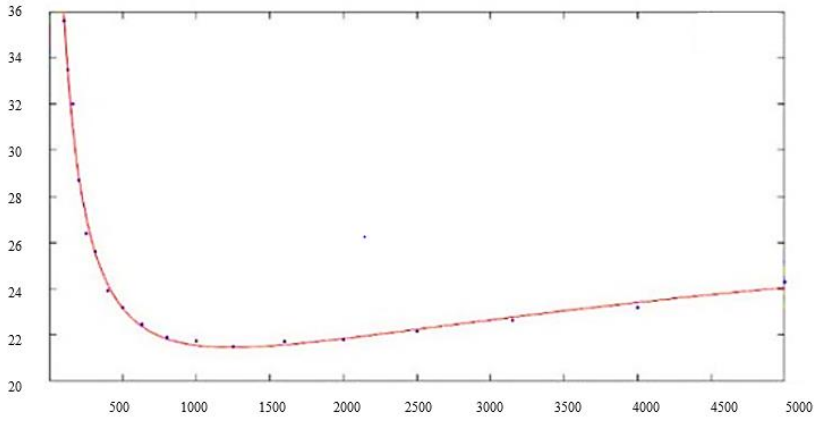


Fig. (4) Background noise identification of historical mosques in Tabriz

$$BN = 30.27*Fr^2 + (7.571e + 04) *Fr + (2.06e + 07) / Fr^2 + 4546*Fr + (3.287e + 05) \quad (1)$$

The RT pattern in the samples can also be predicted according to the 2260 measurements, and based on this, the relationship between RT and frequency in each mosque with a similar form can be recognized according to the 3rd-degree exponential correlation as given in Eq. (2) and Figure. 5.

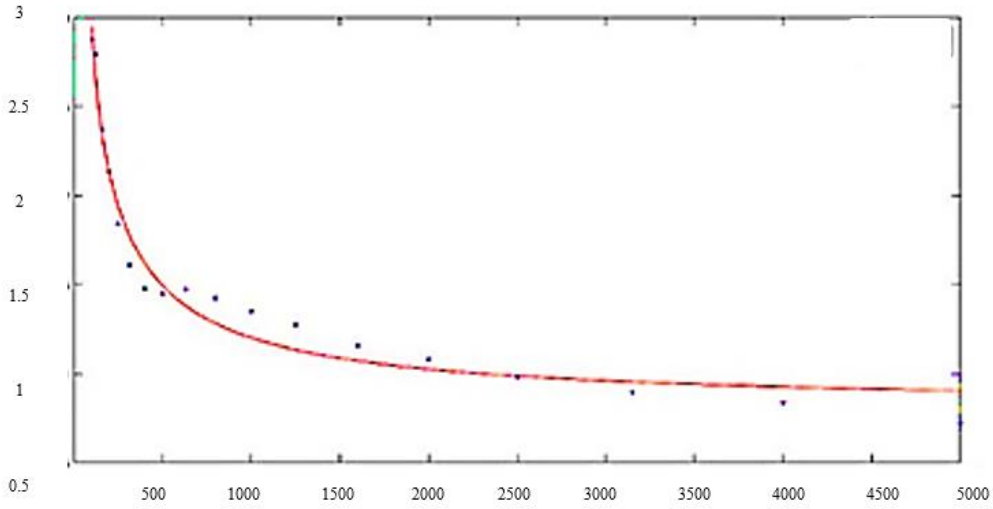


Fig. (5) RT identification of historical mosques in Tabriz

$$T30 \sim 0.8181*Fr^3 + 605*Fr^2 + 1122*Fr + 21.71 / Fr^3 + 192.1*Fr^2 - 5509*Fr - 46.37 \quad (2)$$

The Sound Pressure Level, which has more predictable behavior than RT in the samples, was shown in the measurements of 2260 volume functions. Similar formal characteristics in the architecture of historical mosques of Tabriz, such as materials, executive form, and decorations, cause the sound pressure level behavior to be the same in historical mosques of Tabriz, and in such spaces, the average SPL relates with the frequency based on the 3rd-degree expressive equation as shown in Eq. (3) and Figure 6.

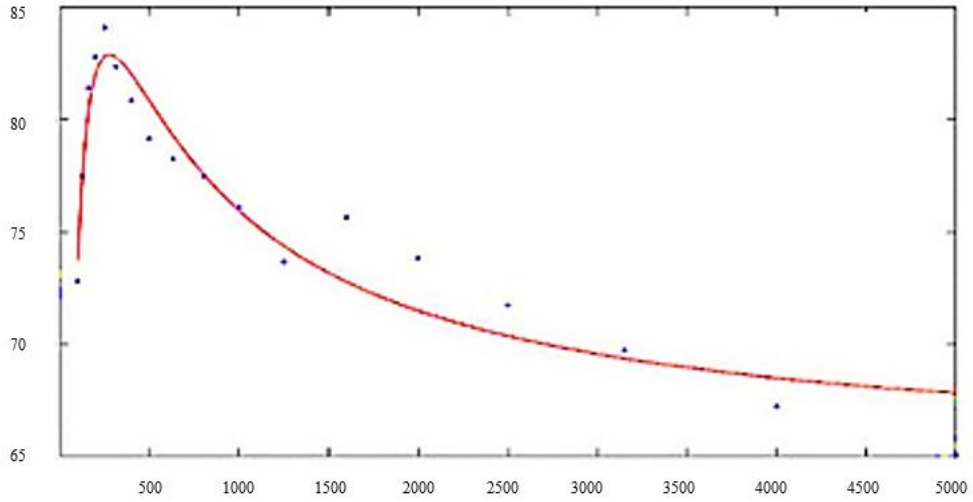


Fig. (6) SPL identification of historical mosques in Tabriz

$$SPL \sim (64.82) *Fr^3 + (3.877e + 04) *Fr^2 -1267*Fr - 42.09 / Fr^3 + 347.7*Fr^2 + (1.655e + 04) *Fr + 2511 \quad (3)$$

The comparison of the aforementioned equations with the results of studies by other researchers shows that physical and mathematical equations are used in field studies or simulations when the researcher compares the results of field or software measurements with calculations and seeks to analyze the differences [26, 28, 31, 32, 34, 35]. From this point of view, the approach of the present study can be considered innovative. At first glance, it recognizes the result of the field measurement as similar and finally provides covering functions for more than 700 measurements. It is possible and logical to standardize the measurement results if the acoustical feedbacks of space are similar, and since this has been proven in the measurements of 2260 with numbers; The extraction of the equation is correct and can be cited. Basically, no acoustic identifier has been presented for any type of architectural function, and the historical mosques of Tabriz are among the first examples with acoustic characteristics from the point of view of Noise, Reverberation Time, and Sound Pressure Level. From another point of view, Background Noise cannot have an equation, because it is completely dependent on environmental conditions, but the similarity of BN values in this study makes it possible to provide an equation for it as well. The most cited equation for RT is Sabin's formula, the interference of frequency in its analysis occurs only in the absorption coefficient of the materials that make up the space [1-6]. With this approach, the equation that the current research gives based on frequency to RT can be unique and therefore challenging. Sound Pressure Level formulas are often based on base pressure and its differences with frequency change have not been taken into account [7-9]. Therefore, the achievement of the

current research is providing an acoustic identifier to the historical mosques of Tabriz; Both in terms of the nature that regulates the results of field measurements, in terms of the interference of frequency in equations, and in terms of presenting an identifier to a type of architectural building, behaves differently from other researches.

5. Results and discussion

The effective frequencies in creating the minimum and maximum measurement variables are constant in most of the samples, which is due to the similar form of the samples and the same execution quality of the brick materials. The biggest numerical differences in Sound Pressure Level and Reverberation Time are caused by the volume, and this shows that the brick structure, similar to what is seen in the historical mosques of Tabriz, creates a predictable situation in acoustics.

By analyzing the outputs of 2260 investigator, the main result of the research can be achieved, which explains the acoustic identification of historical mosques and shows the dominance of exponential functions on the values of BN, T30, and SPL. The presented equations show that the functions of the BN, RT, and SPL will be similar in each sample, which is a remarkable achievement in the field of the architecture of mosques and their acoustics.

The results of this study can provide computational and practical strategies for the acoustical design of mosques, which can be summarized in the following points and can advance the acoustic of worship spaces in the field of mosque design:

• In the design of the Islamic worship space, the executive form plays a significant role in the acoustic quality, and therefore the architect's attention must have decided on the type of detailing before turning to the overall shape of the building. The materials used and how they are combined are the most important factors in determining the acoustic conditions of a space within the audience's perception range.

• In addition to being influenced by the design location, the Background Noise can be managed by the designer, and in the design, along with other acoustic factors, it is also influenced by the internal executive form, and therefore it can be predicted and controlled.

• The similar structure in architectural design makes the Sound Pressure Level more defined and knowing the role of materials and their combination qualities makes the building's SPL dependent only on its size. Therefore, the structure and form similar to the historical mosques of Tabriz have known fluctuations in Sound Pressure Level, but T30 and RT are affected by arrangement and secondary factors in the building. In other words, the SPL value in the space is defined by the architectural parameters, and the architect's challenge in acoustic design should be to pay attention to the architectural components, but the T30 value can also be improved with furniture and interior arrangements. The architecture similar to the historical mosques of Tabriz in terms of SPL values is completely dependent on the architectural design, and in T30's perception, in addition to the architectural components, it will also be related to the interior decoration.

• If the architect knows what group of users he is designing the building for, he can better use the architectural components. The usual design in mosques is to use this building for men's voices, and therefore, focusing attention on their speech and listening areas in the design will provide the

architectural space in its best acoustic state. If it is possible to analyze the frequencies used in the building; The design of the building will result closer to optimal acoustic conditions.

6. Conclusion

Hearing is the most preferred human feeling in successful interaction with the mosque building. Sound can give different qualities to the architectural space and people can take different senses from sounds. Spirituality can well emanate from the acoustic quality, and the mosque receives a major part of its origin from the sound. Among these, the main influence on the sound and the way it is received is related to the architecture, and in order to be able to spread the sound in the desired way, the building needs a suitable architecture and structure. In the beginning, the present research conducted a field study of 15 historical mosques in Tabriz, which were selected in five form categories and three volume categories, in order to identify the forms that can spread the sound optimally. Their executive form is similar and they all have a brick texture, which keeps the conditions of the research constant from the perspective of materials.

The study standards are 3382-1 and 3382-2, and BN, T30, and SPL were selected as the acoustical factors. The standing height was measured at several points of the samples and B&K 2260 investigator was used in this step. The results of the research include two general and important achievements. In the first place, we can point to the weak effect of differences in form versus volume and materials.

The sum of what was said in this research and its achievements shows that the architect should know acoustics. The historical architecture of mosques proves that the design of the mosque was done with any type of form and in all of them, the answer to the need for Speech Intelligibility was possible without the presence of electroacoustic equipment. Architecture always has favorable responses to acoustics, and with any form provided, you know the science of sound and you can create favorable acoustics and achieve the acoustic beauty of the space. This can be taken for granted by referring to the achievements and opinions of this research, which is being proven with a quantitative approach and with the help of other methods and technologies under the title of "Acoustic Aesthetics (AA) theory". On the other hand, the results of this research show that the form factor is considered to be one of the most important factors in determining the acoustic quality of architecture, and according to the equations extracted in this research, it can be used as a coefficient under the title of "Form-PHone coefficient (FPH)" in the existing formulas. This part of the research is being completed as the next step.

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