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The Impact of Geometrical Structure of Domes on the Acoustic Performance within Mosques

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Abstract: Mosques are considered as one of the most significant architectures for Muslim, where they have evolved to attain the Islamic requirements. Various worship activities are done within these public architectures and these activities required various acoustical needs. The geometry of mosques and their ceiling is largely impacted on the acoustical characteristics. The domes are the most shape that utilized to construct the mosque ceiling. The geometric architecture of the domes represents one of the key factors that impact on the performance of acoustics within the mosque. Thus, this paper aims to determine the impact of geometric architecture of domes on the quality of acoustical characteristics within the mosque. The mosque of King Abullah has been selected as a case study to address this issue. Further, many mosques have been studied from the literature to determine the impact of the geometrical structure of the domes on the acoustic characteristics and speech intelligibility. Many parameters have been utilized to measure the acoustical performance like RT, clarity, dome volume, dome shape, dome height and the material utilized to cover the dome surfaces. Based on the studies within the literature and the case study within this paper, the impact of the geometrical structure of the domes has been determined, also the impact of these parameters on the sound quality within the mosque has been determined at the end of this paper.

Key words: Mosque, geometry, dome, clarity, RT, acoustical performance and speech intelligibility.

1. Introduction

Mosques are considered as one of the most significant architectures for Muslim, where they have evolved to attain the Islamic requirements. Various worship activities are done within these public architectures, where these activities required various acoustical needs. Further, the sounds and speech intelligibility are very significant, particularly for sacred tones that should be effective and spacious. There are many acoustical parameters control the sound spaciousness and the intelligibility of speech, such as: transmission index of sound, pressure distribution of sound and reverberation time [1].

The geometry of mosques is largely impacted on the acoustic characteristics. Hence, the impact of mosque geometry had been studied by various researchers. Setiowati [2] was one of those researchers, who studied the impact of geometry within three various mosques within Indonesia. The study aimed to examine the mosque acoustical performance without any strengthen system of sound. The elected mosques have various opening area, ceiling, floor shape, materials and volume. However, they have identical height. The results of this study indicated that the opening area as well as the shape and materials of the ceiling were the key factors that made the "Reverberation Time (RT)" poor.

Domes are considered as an essential part of mosque characteristics. The first use of domes refers to "Ottoman Era". Although domes have greatness aesthetics and size, they frequently cause flaws within the mosques acoustical performance. Further, domes are considered as one of the most impacted factors on the speech intelligibility within the mosques. However, only a few numbers of research works are obtainable on the impact of dome architecture on the performance of acoustics within the mosques [3].

The ceiling or roof architecture design impacts on the acoustical behavior, where this design impacts on

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the distribution of sound within the mosque. The dome shape of the ceiling had been designed to create the focusing sound. Based on this, Seogijanto and Henriza [4] observed the acoustics within a mosque that has five various shapes of the ceiling. The simulation was utilized to identify the reflected rays percentage numbers in order to identify the reflection characteristic of the ceiling. The best acoustical performance was in the flat ceiling, while the acoustical performance within dome and pyramidal shapes was less efficiency. Further, the study observed the scattering and focusing impacts from the ceiling.

The scale model has been utilized in Ref. [5] to examine the impact of mosque dome on the acoustical performance. The impact of coupling among the volume of the dome and the residual volume of the mosque on the RT was discussed within the study. The results indicated that the value of RT within dome can be reduced at lower frequencies if a floor with reflective conditions is utilized. Further, the RT can be reduced through increasing the coefficient of absorption for the surface material of the dome.

In Ref. [6], the results of acoustic measurements that obtained from many studies that conducted on many local mosques were discussed. The results indicated that the shape of the dome has a significant impact on the performance of acoustics within the mosque. Further, the author suggested that different shapes of domes can be considered, but these shapes should be well organized to prevent the sound focusing and late reflection problems.

2. Literature Review

A study to investigate the impact of the pyramidal dome on the mosque acoustics had been conducted in Ref. [7]. Because view researches are available on the impact of the dome on mosque acoustics, this study had been conducted. The study had been conducted on the "Sayyidina Abu Bakar Mosque" in Malacca. The speech intelligibility was evaluated based on two key parameters: clarity and RT. Version 9 of "CATT Indoor Acoustic Software" was utilized to model the geometry details of the mosque. The library of software was utilized to elect the materials' absorption coefficients. Further, omnidirectional sources of sound were utilized, where these sources were situated at Mihrab inside the mosque. At 0.5 m height, the receivers were distributed crossways the floor.

Further, three various inclined angles were modelled for the pyramidal dome to study the impact of this dome on the characteristics of acoustics. The height of the dome was represented byt, while the wall height was represented by w. Also, the angle among the horizontal surface and inclined surface was given by α.

The variation within the height of the dome was utilized to define the angles. Also, the value of w was modified to keep the mosque volume. This step was performed to prevent the impact of volume variation on the parameters of acoustics and to confirm that the design analysis only depends on the dome characteristics. Fig. 1 illustrates the CATT model of the observed mosque with various configurations of pyramidal dome, where three various values of α were utilized: 31, 20 and 9 degrees [7].

The RT had been measured to investigate the characteristics of acoustics within the mosque. This parameter can be defined by the time required to reduce the energy of sound by 60 dB after turning off the source of sound. The results showed that the increasing of angle led to increasing the reflections within the dome and this impacted negatively on the speech intelligibility. In addition, the clarity had been measured to identify the speech intelligibility, where this parameter can be defined by the ratio between the late and early arriving sound. The results indicated that the increase in dome angle led to trapping the energy of sound and this increased the late reflections which obtained poor speech clarity [7].

In Ref. [8], three main mosques that referred to the XVI century had been studied to determine how the geometric structure of dome impact on the characteristics of acoustics within the mosque. The

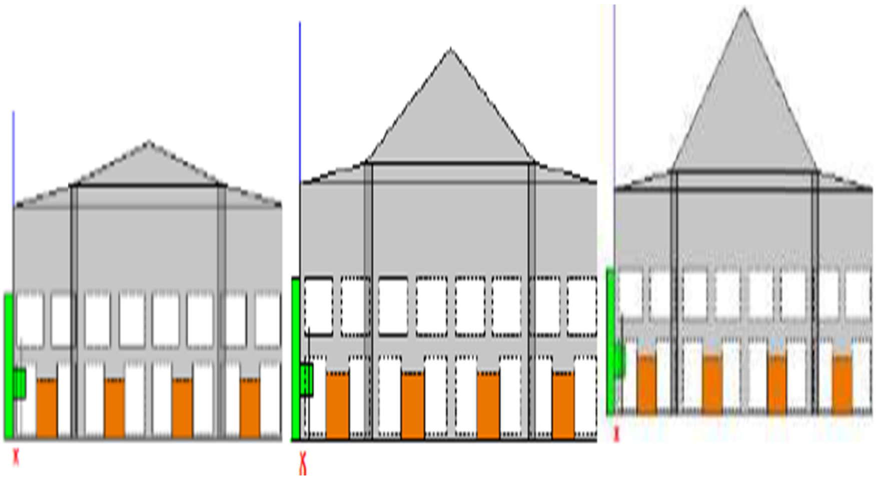

Fig. 1 The CATT model of the observed mosque [7].

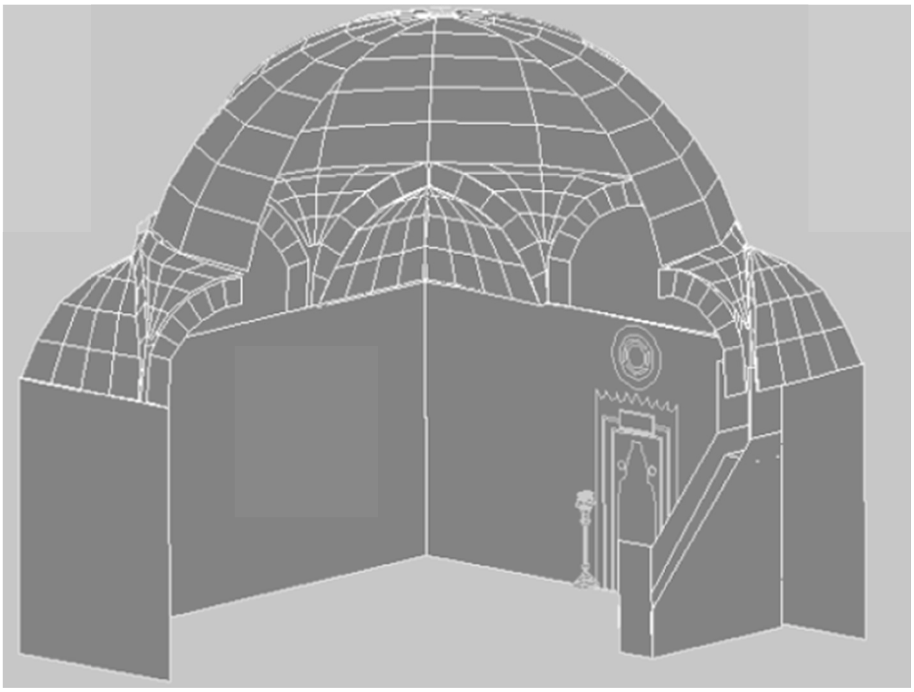

Fig. 2 The 3D-model of Cenabi Ahmet Pasa Mosque [8].

investigated mosques are: Cenabi Ahmet Pasa Mosque, Mihrimah Sultan Mosque, and Suleymanlye Mosque. These mosques located in Turkey and they had the conventional Ottman architecture. Further, all these mosques characterized by the large dome domination over a body with cubical shape.

(1) Cenabi Ahmet Pasa Mosque

This mosque located in Ankara and it was built during the period of 1565 and 1566. The mosque had a great dome located above the portal. Turkish triangles with non-structural shape were utilized to fill the void among the base and dome. The diameter of the dome is 14.40 m. Further, squinches were utilized to support the transition between the square base and the structure of the dome. Fig. 2 illustrates the 3D-model of the mosque.

In addition, two sources of sound were utilized within the mosque; one at the Mihrab and the other at the corner of the speaker. Also, four receivers were situated at various locations that corresponding to the sources of sound. Plaster was utilized to cover the internal walls of the dome and the mosque. The characteristics of acoustics were measured by two main parameters: RT and clarity. Table 1 illustrates the results of clarity and RT at 1,000 Hz at various locations of receivers and sources within the mosque.

(2) Suleymanlye Mosque

This mosque located in Istanbul and it was built during the period of 1550 to 1557. The architecture of the mosque is unique, simple and pure, where it is considered as the largest semi-domed mosque with square base. The mosque has two semi-domes that aligned with the Mihrab direction. Single dome is centrally covered the mosque, where it is supported by two semi-domes in the sides. Also, the dome has a uniform diameter, which equals to 27.25 m. The height between the impost and the foundation equals to 33.70 m. The inner height of the mosque equals to 14.05 m. Hence, the dome height from the keystone to the ground equals to 47.75m. Fig. 3 illustrates the interior scenery of the mosque.

Two various sources of sound were utilized, where they situated at the corner of the speaker and Mihrab. Further, eight various receivers were situated at various locations and the majority of these receivers was located within the area covered by the domes. The plaster was utilized to cover the interior surfaces of the domes and the mosque. Table 2 illustrates the results of clarity and RT at various locations of receivers within the mosque.

Table 1 The results of clarity and RT for Cenabi Ahmet Pasa Mosque [8].

	S1R1	S1R2	S1R3	S1R4	S2R1	S2R2	S2R3	S2R4
Clarity (dB)	-5.9	-5.7	-5.7	-5.9	-5.8	-5.9	-5.9	-5.7
RT (s)	3.3	3.4	3.5	3.5	3.5	3.3	3.4	3.4

Fig. 3 The interior scenery of Suleymanlye Mosque [8].

Table 2 The results of clarity and RT of Suleymanlye mosque [8].

	S1R1	S1R2	S1R3	S1R4	S1R5	S1R6	S1R7	S1R8
Clarity (dB)	-6.7	-6.4	-6.4	-7.2	-6.6	-6.2	-6.8	-6.9
RT (s)	6.3	5.1	6.1	6.6	6.2	6.5	6.2	6.2

(3) Mihrimah Sultan Mosque

This mosque located in Istanbul, where it was built in 1560's. The architecture of the mosque is characterized by the complexity. The mosque height from the dome center to the foundations equals to 37 m. Single dome at the mosque's center and other six domes are included within the mosque. The diameter of the central dome equals to 20 m, while the diameter of each other domes equals to 6 m. Four huge arches are carried the dome in each side. Only one source of sound is utilized within this mosque, while six receivers that located at various locations are utilized in the mosque. Fig. 4 illustrates the locations of the receivers and the source within the plan of the mosque.

The surfaces of the dome are covered by plaster. The measured values of clarity and RT are shown in Table 3.

Based on the above studies of the three mosques and the obtained measurements, the geometrical structure of the dome within Cenabi Ahmet Pasa Mosque impacts on the acoustical characteristics of the mosque by the focusing and echo problems. Further, the large volume of the Suleymanlye Mosque dome increases the values of RT as compared with the other two mosques and this reduces the index of clarity, which is directly impacted on the speech intelligibility. Hence, Suleymanlye Mosque has the lowest values of index clarity and the highest values of RT. Further, the values of RT obtained from the three studies are considered as large values and this impacted on the values of clarity index and the speech intelligibility. Thus, the observed mosques are not appropriate for the natural environment of speech.

Further, 25 mosques with domes had been studied and investigated in Ref. [9]. The investigated mosques were located in Johor, where they distributed over eight areas within Johor. The distance travelled to perform this investigation was 3,000 km with period approximated to one month. Various parameters of the dome were measured to determine how they can impact on the characteristics of acoustics. The parameters involved; dome type, material that covered the surfaces of the dome and the dome dimensions. The investigated mosques had three dome types; seven mosques had type I, 13 mosques had type II two and 5 mosques had type III. Table 4 illustrates the dimension of the surveyed domes.

Based on the values measured on Table 4, there is a variation within the dimensions of the dome. Thus, the acoustic performance is not constant in all mosques. The large dimensions have a larger impact than the smaller dimensions. Thus, the increasing in dome dimension leads to increasing the number of reflections, path length and energy amount within the dome and this weakens the acoustical performance and the speech intelligibility.

3. Case Study: King Abdullah Mosque

As shown within the previous sections, the dome is considered as a good design for lightweight and spaciousness ceiling. But, there are many conditions should be taken into account when the dome is included within the mosque design. The unsuitable design of the architecture of the dome can impact on the acoustical performance and the speech intelligibility. Within this section, the impact of geometrical architecture of the domes on the performance of the acoustics within the mosques had been addressed and discussed. The Mosque of King Abdulla has been taken as a case study to address this issue.

The mosque of King Abdullah is considered as a huge building that situated near to the Parliament of Jordan. The mosque houses about 3,000 worshipers, also it composed of a large number of rooms and small areas. This mosque was built in 1980s. The mosque has a huge dome with a diameter equals to 35 m diameter and volume equals to 12,700 m^3. Fig. 5 illustrates the structure of King Abdullah Mosque.

However, the large volume of the mosque dome generated great acoustical problems. The high values of reverberation time were one of these problems, where

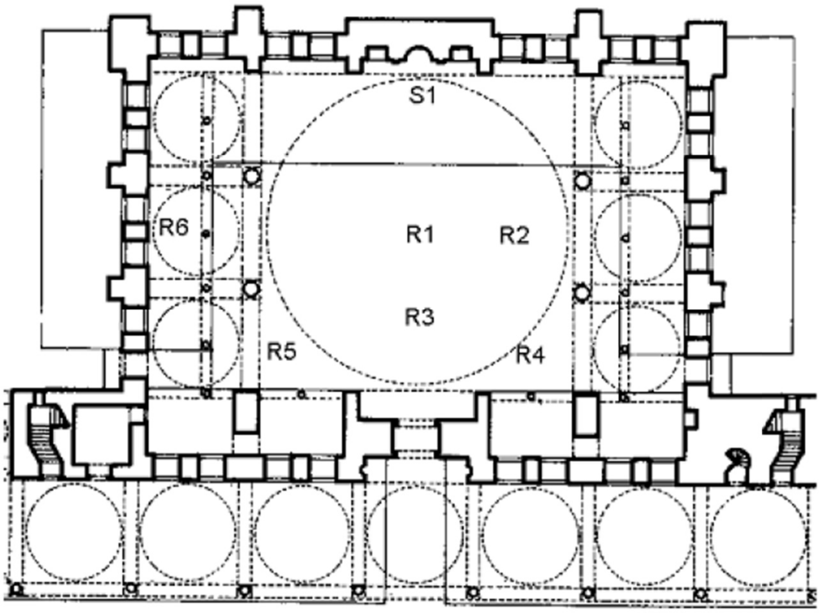

Fig. 4 The locations of the receivers and the source within Mihrimah Sultan Mosque [8].

Table 3 The results of clarity and RT for Mihrimah Sultan Mosque [8].

	S1R1	S1R2	S1R3	S1R4	S1R5	S1R6
Clarity (dB)	-6.2	-6.2	-6.4	-6.5	-6.9	-6.8
RT (s)	3.9	3.7	3.9	4.0	3.9	4.0

Table 4 The dimension of the surveyed domes [9].

Dimension name	Min	Med	Max	Average
Diameter (m)	3	8	22	10
Height from the dome top to its mouth (m)	2	8	18	8
Height from the mosque floor (m)	8	16	34	18
Volume (m^3)	9	262	3700	627
Surface area (m^2)	18	170	926	247

Fig. 5 The structure of King Abdullah Mosque.

these values were extended between 15 s for the mid-frequencies and 22 s for the frequencies lower than 500 Hz. These values were very high and impacted on the speech intelligibility. Further, the index of speech intelligibility was extended between 0.35 and 0.7, hence these values were very low. Because the building of mosque became completed, the volume of the mosque and the dome became constant and cannot be reduced to solve these problems. One of the key solutions that performed to solve these problems is by treating the utilized materials within the mosque. Thus, the old materials have been changed and replaced by appropriate new materials. After that, the values of RT have been measured and the results indicated that the values for mid-frequencies became around 1 s. In addition, electro-acoustic system has been utilized to solve the sound clarity problem, where the results indicated that measurements of clarity index are very excellent, where the level of sound inside the mosque becomes uniform.

4. Conclusion

Due to the importance of mosques for Muslims to perform their worship activities, the acoustic characteristics should be managed in a suitable way. The acoustic characteristics are varied from one mosque to another and this referred to the variations within the mosque structures. Thus, the geometrical structure of dome within the mosque is considered as one of the key factors that impact on the quality of sound level. Within this paper, the impact of the geometric structure of the dome on the acoustical performance has been studied. Many mosques from the literature and the mosque of King Abdullah have been investigated to determine how the structure of the dome impact on the acoustical performance within the mosque. Based on these studies, the following points have been concluded:

- The volume of the dome has a great impact on the acoustical performance and speech intelligibility, where the increase in dome volume increases the number of reflections and this makes the quality of acoustic characteristics poor and reduces the speech intelligibility.
- The location of the dome from the source of sound impacted on the sound level and speech intelligibility.
- The material utilized to cover the surfaces of dome impacted on the speech intelligibility and acoustical characteristics and this can be determined based on the absorption coefficient of the materials.
- RT, clarity and speech intelligibility index are the main parameters that utilized to determine the acoustical performance.

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