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An Analysis of Prayer Room Acoustics in the Pusdai Mosque in West Java †

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Abstract: Aside from being a place for congregational prayers, the West Java Pusdai Mosque is also a center for preaching and other Islamic activities in West Java. Therefore, as a place of worship for Muslims, this mosque needs to maintain a comfortable atmosphere. The comfort or solemnity of worship can be affected by the noise of the surrounding environment or the acoustics of the room. This study aims to analyze the acoustic quality of the prayer room in the Pusdai Mosque, which is influenced by several factors. This research was conducted by observing and simulating, using the Ecotect v5.50 software. A simulation was carried out with the creation of a 3D model and the addition of both the absorption coefficient of the material in the room and speakers to it. In addition, research was also strengthened by conducting literature studies on scientific articles. The simulation was carried out to determine the reverberation time and sound distribution produced by the sound sources or speakers that could indicate the acoustic quality of the Pusdai Mosque. The acoustic quality of the Pusdai Mosque is greatly influenced by the interior materials and the shape of the ceiling. Based on the results of this analysis, the Pusdai Mosque has room acoustic defects. This is due to the large use of sound-reflecting materials and the form of the ceiling, which is quite complex. This causes a lot of sound reflection to occur, causing the reverberation time to exceed the optimum limit of a 500 Hz frequency (conversational space). This causes the speaker's voice to become an echo or hum. Therefore, the Pusdai Mosque needs to improve its room acoustics in order to create comfort and solemnity in worship. Improvement can be made by adding sound-absorbing material.

Keywords: acoustic; mosque; Pusdai; Ecotect

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1. Introduction

The Pusdai Mosque is located in a multi-mass area of religious buildings that is the center of *dakwah* and Islamic activities in West Java. One concern for the Pusdai Mosque is to create a comfortable atmosphere so that the congregation can worship solemnly. This solemnity is influenced by several factors, both from the outside and from within the mosque itself. If the noise that enters the building from the outside exceeds the standard, it reduces the comfort of the congregation [1].

In addition, conditions inside the mosque also affect the comfort of worship. Mosques need good-quality acoustic space so that the voice of the *imam* or *khatib* can be clearly heard by the congregation. Room acoustics can be said to be good if the reverberation time of the voice during speech or speaking reaches the optimum value and the sound distribution is evenly distributed. Therefore, reverberation time is one of the most important factors for determining the quality of room acoustics [2,3]. Room acoustics can be influenced by several factors, such as loudspeakers, the shape and size of the room, the shape of the roof or ceiling, the material, and the number of room users [4–6].

Previous research states that *tajug* roofs or ceilings have better sound quality than dome roofs but can cause reverberation if not built with the right acoustic material [7,8]. Materials with an optimum absorption coefficient are good for room acoustics. Good sound-absorbing materials are porous or fibrous materials [9]. In addition, in other studies, flat ceilings and leveled ceilings can also evenly distribute sound [10].

The Pusdai Mosque has a unique spatial form. The Pusdai Mosque uses a combination of two architectural styles, namely Sundanese architecture and Islamic architecture, by using a combination of flat roofs and four-stacked pyramid roofs [11]. In addition, the corridor area is also unique because of its complex or leveled ceiling shape and is equipped with a significant number of loudspeakers hanging from the ceiling. Most of the materials used in this mosque are brick, concrete, and granite. These things can certainly affect the acoustic quality of the Pusdai Mosque.

Therefore, this study aims to examine and discuss the acoustic quality of the Pusdai Mosque by involving several influential factors. This study will discuss the acoustic conditions and reverberation time received by the congregation, which can affect the solemnity of worship. In addition, this study will also discuss the influence of the shape of the space, loudspeaker conditions, materials, and the capacity of the congregation on the acoustics of the mosque.

2. Methods

This research analyzes the reverberation time and sound distribution through rays and particles in the Pusdai Mosque prayer room. Simulation results are then compared with acoustic standards. This research was conducted via field observations and simulations with Ecotect v5.50 software as well as literature studies in order to obtain the necessary information and strengthen the research. Ecotect v5.50 was the software used to identify reverberation time, delay time, and echo [12].

Before conducting acoustic simulations, background noise simulations were carried out to replicate those that entered the building and to determine the comfort of the congregation in response to outside noise. After that, a 3D model was simulated in Ecotect by entering several factors. Next, the model was analyzed with regard to the sound distribution of each speaker through rays, particles, and the resulting reverberation time analysis. From the simulation, the value was compared with acoustic standards to determine the acoustic quality and comfort of the sound received by the congregation.

3. Results and Discussion

3.1. Background Noise

The Pusdai Mosque is located on Diponegoro Street, Cibeunying Kaler, Bandung City, West Java. The mosque area is directly adjacent to major roads to the north, east, and south, as shown in Figure 1. This potentially leads to high levels of background noise entering the building and affecting the comfort of worship. Based on SNI 03-6386-2000, the acceptable noise limit for places of worship is 30–35 dB(A) [13]. Background noise analysis was conducted by taking field measurements using the Noise Meter mobile application and with a simulation using Ibana software ver 1.2 Rev. 122.

The average background noise from all sides entering the building is obtained from the analysis. The graph in Figure 2 shows that the background noise value entering the Pusdai Mosque prayer area is quite low and below the optimum limit (30–35 dB(A)), therefore indicating that this background noise is safe and not disturbing. This is due to the location of the Pusdai Mosque prayer area, which is quite far from the sound source.

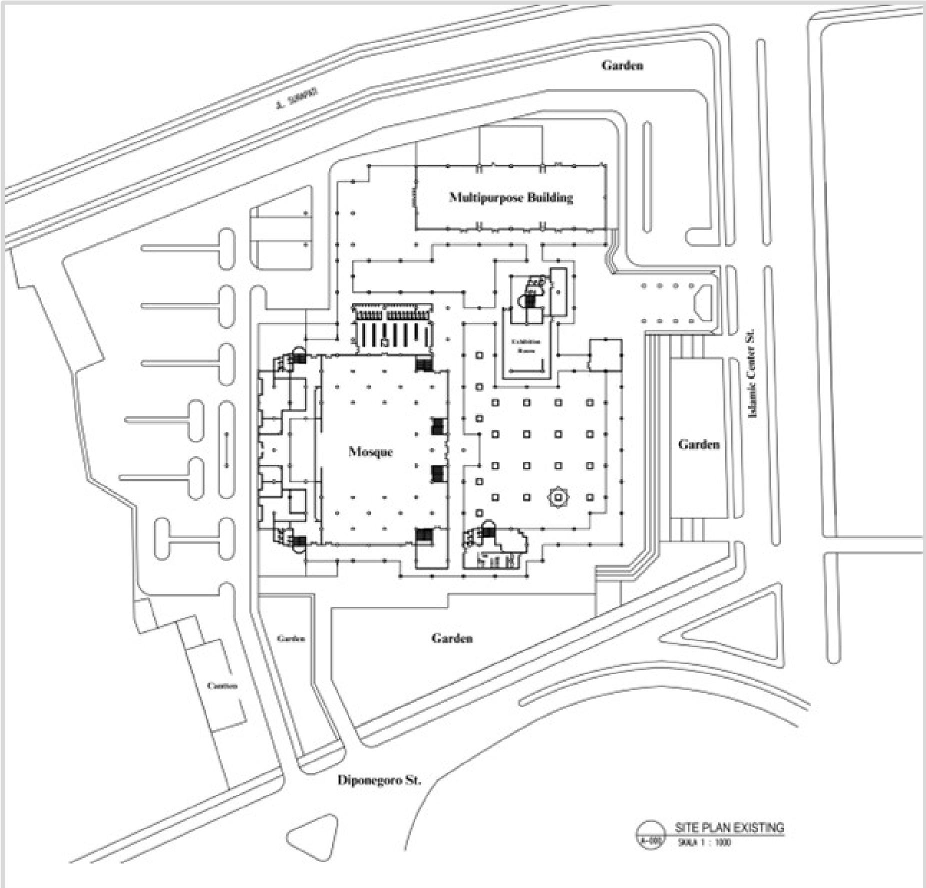


Figure 1. Pusdai Mosque site plan. Source: (Pusdai, 2022).

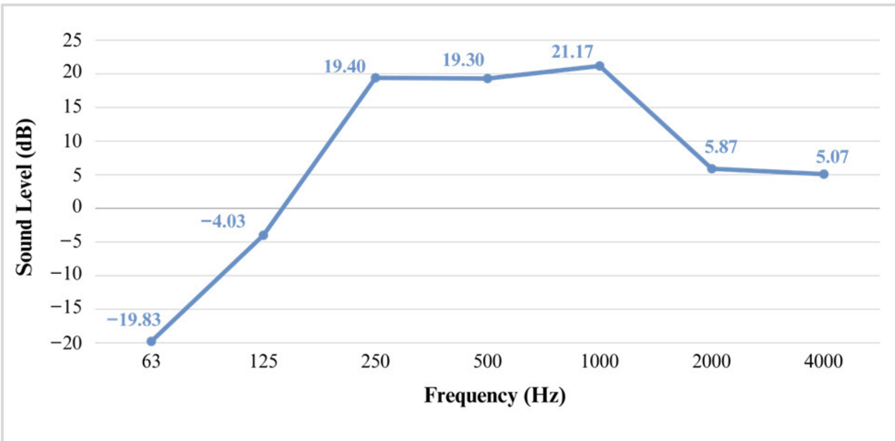


Figure 2. Background noise level chart.

3.2. Room Design

The Pusdai Mosque has a fairly large space, measuring ± 60 m × 40 m, with corridors surrounding the main prayer area, as shown in Figure 3a. Based on information from the Secretary of the Pusdai Mosque Prosperity Board, Faturahman, this mosque can accommodate as many as 4600 people. The mosque has two floors, and the height of each floor is ±4 m; it also has a four-stacked pyramid roof with a height of 22 m, as shown in Figure 3b.

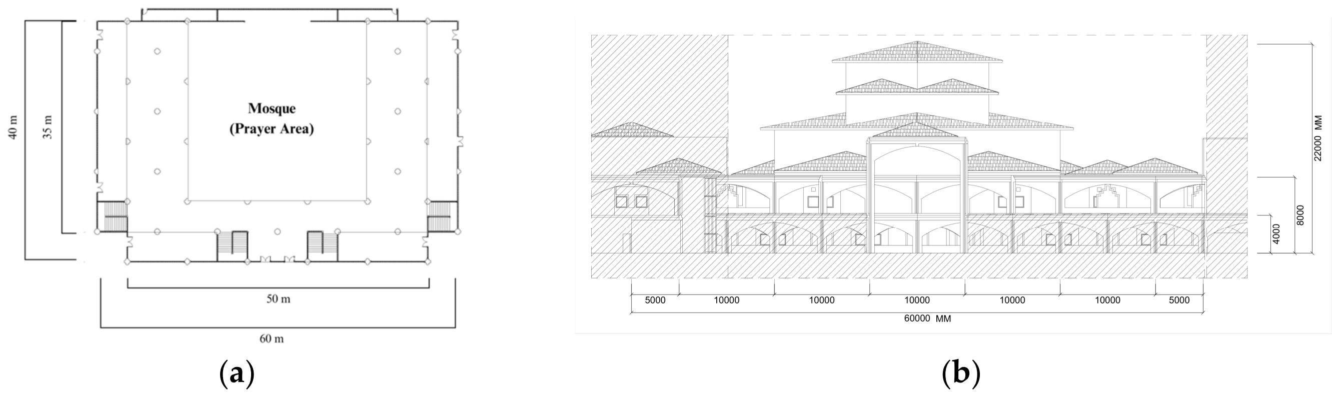


Figure 3. (**a**) Floor plan of Pusdai Mosque; (**b**) east elevation of Pusdai Mosque. Source: (Pusdai, 2022).

The simulated 3D model was simplified due to the limitations of Ecotect [14]. Based on Ecotect calculations, the prayer room at the Pusdai Mosque has a volume of 22,889.850 m^3 with a surface area of 30,196.316 m^2. The Pusdai Mosque uses eight different types of materials and 21 loudspeakers with the same specifications. From Figures 4 and 5, it can be seen that most of the materials used in the Pusdai Mosque are brick, concrete, and granite.

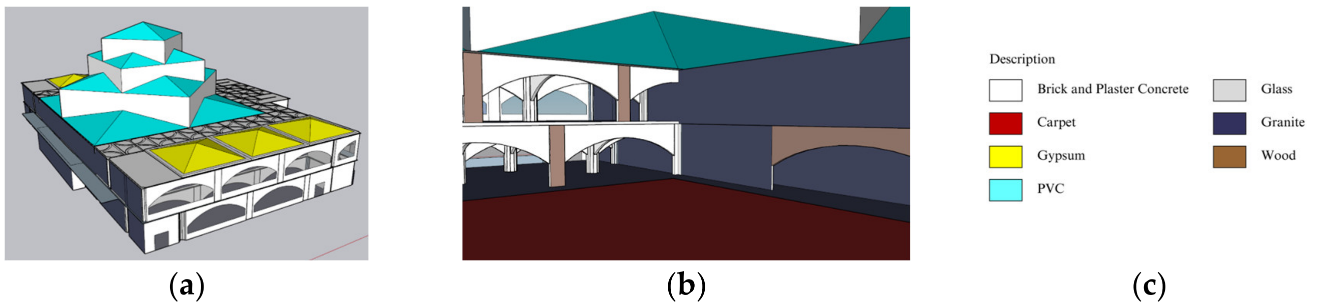


Figure 4. (**a**) Exterior material colors; (**b**) interior material colors; (**c**) description of colors.

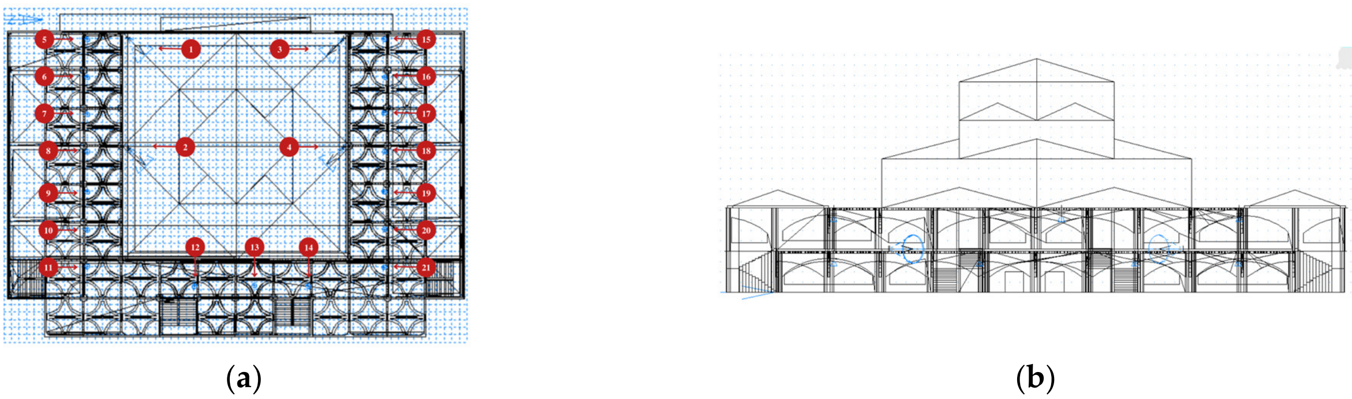


Figure 5. (**a**) The position of the 21 loudspeakers is indicated by the number inside the circle; (**b**) side view of the speaker position marked in blue.

Table 1 shows the absorption coefficient of the materials used in the Pusdai Mosque. Based on the data, it can be seen that the Pusdai Mosque uses many materials with low absorption coefficients. This is because the material used is a type of material that reflects sound. Sound will bounce if it hits hard, tight, and firm surfaces, such as concrete, brick, glass, granite, and PVC [15]. This likely affects the acoustic quality of the Pusdai Mosque.

Table 1. Material absorption coefficient.

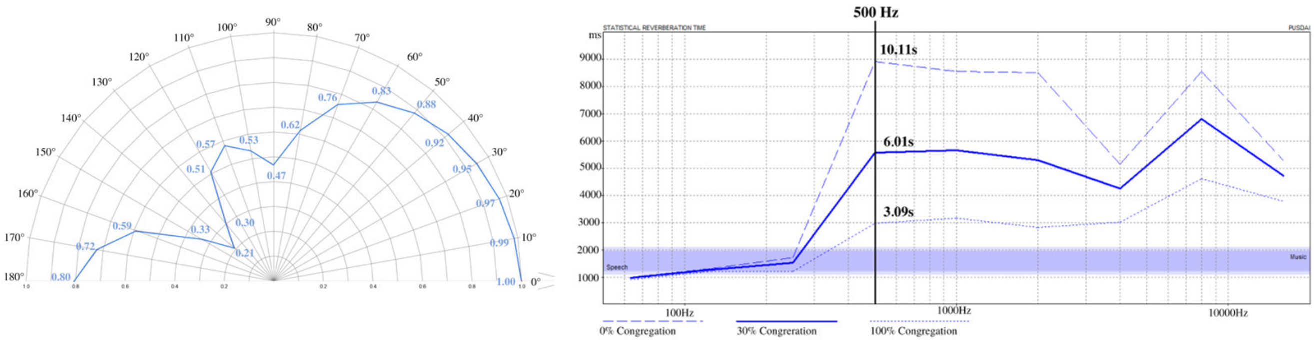
Materials	Frequency (Hz)								
	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**1600**
Granite	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Carpet	0.08	0.08	0.08	0.30	0.60	0.75	0.80	0.80	0.70
Wood	0.18	0.18	0.12	0.10	0.09	0.08	0.07	0.07	0.06
Gypsum	0.29	0.29	0.10	0.05	0.04	0.07	0.09	0.09	0.08
PVC	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Brick	0.10	0.07	0.03	0.02	0.02	0.02	0.03	0.02	0.03
Concrete	0.12	0.09	0.07	0.01	0.01	0.01	0.02	0.01	0.02
Glass	0.18	0.15	0.10	0.03	0.01	0.01	0.01	0.02	0.02

Source: [16,17].

3.3. Reverberation Time

Ecotect was used to analyze the reverberation time, after inputting the type of material and the number of speakers used in the room. The Pusdai Mosque uses a significant number of loudspeakers for the prayer area, namely 10 loudspeakers under the ceiling of the first-floor corridor, seven loudspeakers under the ceiling of the second floor, and four loudspeakers mounted on the walls around the main prayer area.

Figure 5a,b shows the positions of the speakers on Floors 1 and 2 of the Pusdai Mosque. All of the speakers used have the same type and frequency, which is 500 Hz, with a range width or azimuth angle of 180° and axial rotation angel of 45°. Figure 6a shows the distribution pattern of the sound produced by the speakers.



(**a**) (**b**)

Figure 6. (**a**) Loudspeaker sound distribution pattern; (**b**) reverberation time chart.

Figure 6b shows the reverberation time from the Ecotect simulation results. The graph in Figure 6b shows the difference in reverberation time with different percentages of the number of congregations, starting from 0%, 30%, and 100% of the capacity of a 4600-person congregation. The simulation was carried out at a percentage of 30% capacity, because the Pusdai Mosque is often only filled with about 30% of the total congregation capacity that the mosque can hold (Faturahman, 2020).

Based on the recommendation from Ecotect, this reverberation time calculation uses the Norris–Eyring formula. The optimum value of the reverberation time suitable for speech (500 Hz) at the Pusdai Mosque is 1.21 s. The simulation results show that the acoustic quality of the Pusdai Mosque is not good, because the average reverberation time value exceeds the optimum value, especially at the center frequency (500 Hz) that is generally used for speech.

Table 2 shows that the reverberation time at frequencies of 125–16,000 Hz is far from the optimum reverberation time. This is caused by several factors. When viewed from the shape of the room, the shape of the Pusdai Mosque room provides a good acoustic response. This can be seen from the shape of the leveled ceiling and terraced pyramid roof. However, the Pusdai Mosque uses a lot of sound-reflecting materials such as the use of concrete on the first-floor ceiling; granite for the floor and front wall; and the use of brick, concrete, and glass walls [17].

Table 2. Reverberation time.

Reverberation Time Optimum (s)	Frequency (Hz)	Absorption Total (m^2)	Percentage of Congregation		
			0% (s)	30% (s)	100% (s)
1.21	63	23,132.95	1.11	1.08	1.01
	125	22,736.88	1.48	1.43	1.33
	250	22,186.50	1.93	1.69	1.30
	500	21,645.49	10.11	6.01	3.09
	1000	21,132.99	9.70	6.13	3.30
	2000	20,384.00	9.64	5.72	2.93
	4000	19,293.25	5.81	4.69	3.23
	8000	17,524.90	9.64	7.48	4.91
	16,000	14,331.40	5.92	5.23	4.10

This causes the sound produced from the source to experience a lot of reflection, resulting in a long-lasting reverberation time. This reduces the clarity of the voice of the preacher or imam. Accordingly, the prayer room at the Pusdai Mosque, which has a volume of 22,889.850 m^3, also causes the sound to reverberate or buzz, as it was not designed using acoustic materials.

In addition, the number of space users or congregations also affects the reverberation time of the sound. The more users, the smaller the reverberation time produced. At a frequency of 500 Hz, the reverberation time produced when the percentage of congregants is 100% (4600 congregants) is 3.09 s. Meanwhile, when the percentage of congregants is only 30% (1380 congregants), the reverberation time increases to 6.01 s. This is because the human body is also a sound absorber [18]. However, in Figure 6b and Table 2, the reverberation time generated at the Pusdai Mosque is shown to still exceed the optimum value, despite being filled to full congregation capacity (4600 congregants). This indicates that the Pusdai Mosque has poor acoustic quality, which results in the voice of the preacher or imam sounding less clear and echoing or reverbing.

3.4. Rays and Particles

A simulation of rays and particles is useful for seeing the spread or travel of sound produced by each speaker. From this simulation, the effect of the shape of the space and material on sound reflection can also be seen. In addition, this simulation shows the areas that are effective for generating sound or producing echoes or reverb.

Figure 7a–d shows the spread of sound with four loudspeakers facing the main prayer room—namely loudspeakers 1, 2, 3, and 4—with the setting of generate rays using a circular pattern, an angular increment of 5.0°, and as many as eight bounces. This is in line with what Ridhatiana accomplished during a simulation of acoustics at the Al-A'zhom Grand Mosque, Tangerang City. The range of normal bounces is 8–32 bounces [19].

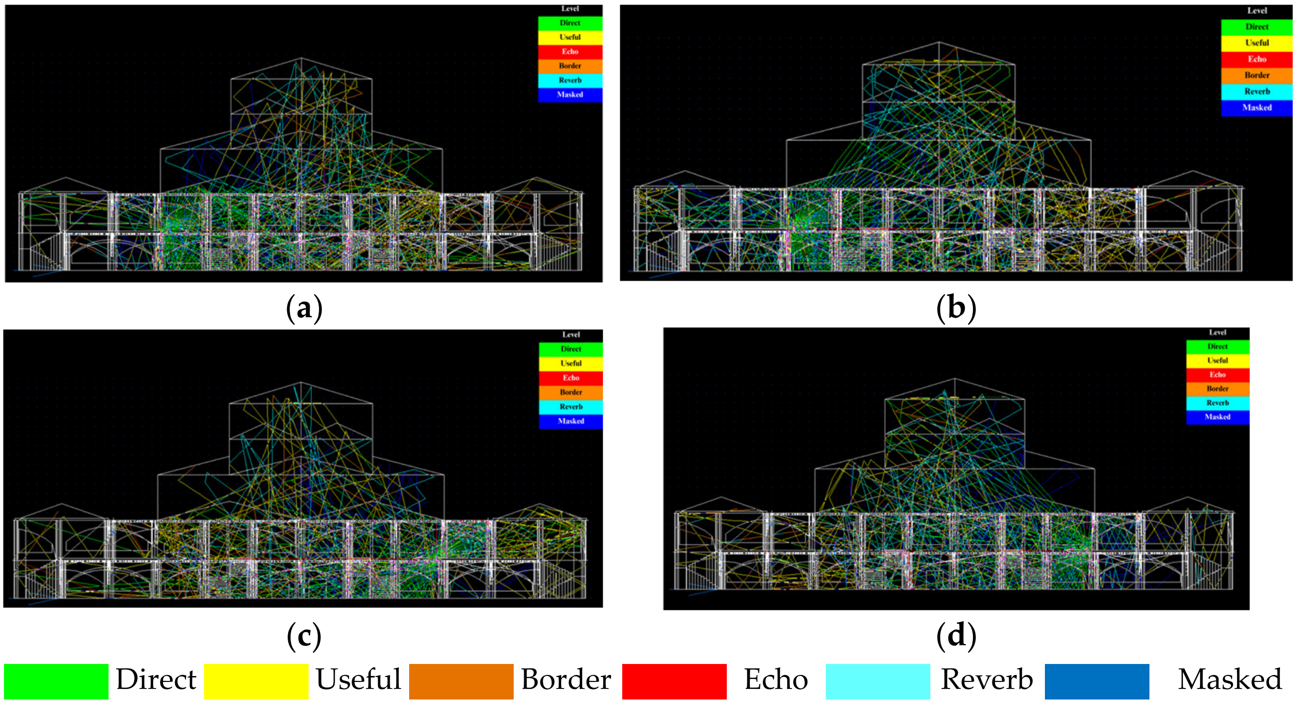


Figure 7. (**a**) Sound spread loudspeaker 1; (**b**) sound spread loudspeaker 2; (**c**) sound spread loudspeaker 3; (**d**) sound spread loudspeaker 4.

The simulation results show that the sound distribution produced by the four loudspeakers still produces a significant amount of reverb sound in the middle area to the roof, which is the area that causes the sound to reverb. The shape of the space can affect the direction of sound dispersion produced by the loudspeaker. The four figures show that a multilevel pyramid-shaped ceiling creates a diffuse sound reflection. This is good for room acoustics. However, the material used also needs to be considered so as to not produce echoing or reverberating sounds. Most of the ceilings at the Pusdai Mosque use concrete and PVC materials, which have a low absorption coefficient.

In addition, the ceiling in the corridor area around the prayer area also has a complex and leveled shape, as shown in Figure 8a.

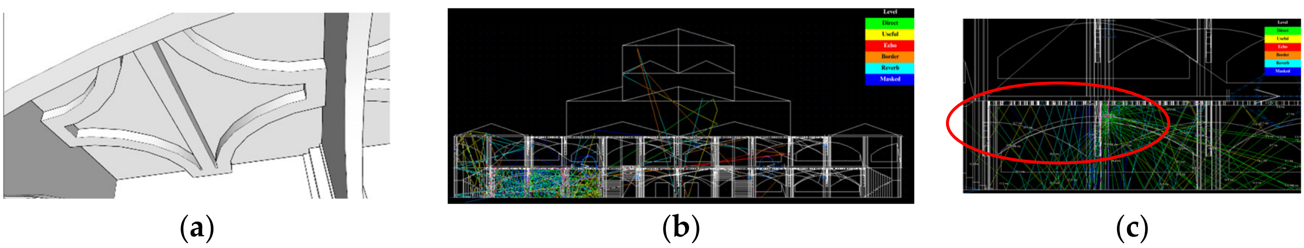


Figure 8. (**a**) Corridor ceiling design; (**b**) sound spread of loudspeaker 11 in the corridor; (**c**) speaker 11 sound spread due to ceiling design.

Figure 8b shows that the spread of sound from one of the loudspeakers (loudspeaker 11) that hangs on the ceiling of the corridor causes many reflections that produce reverb sounds. In addition, the sound produced is only centered under the speaker. The shape of the ceiling in this corridor results in diffuse sound reflections, as shown in Figure 8c. However, due to its complex shape and the use of reflective materials, there is a significant amount of sound reflection, resulting in reverberation.

4. Conclusions

Based on the analysis conducted, it can be concluded that the Pusdai Mosque has a spatial acoustic defect because the reverberation time exceeds the optimum time. Background noise or noise that enters the building has no effect on the acoustic space of the Pusdai Mosque because the noise level is low.

Based on the results of the analysis obtained, the acoustic space at the Pusdai Mosque is strongly influenced by the volume of space, the number of congregations, the shape of the ceiling, and the materials used. Most of the materials used at the Pusdai Mosque are sound-reflecting materials, such as brick, concrete, glass, granite, and PVC. These materials have a low sound absorption coefficient. This excessive sound reflection eventually causes the sound to echo or hum. This reduces the clarity of the sound. The congregation or listeners are less able to properly and clearly hear the voice of the preacher or imam.

This can lead to reduced solemnity in worship. Therefore, it is necessary to improve the acoustic design of the Pusdai Mosque. Acoustic improvements can be made by adding sound-absorbing materials. For example, granite on the floor can be replaced with a layer of parquet wood, which has a better absorption coefficient [19,20]. In addition, the shape of the ceiling can be changed to a less complex shape to avoid many sound reflections.

Further research and simulations are needed to discover the best acoustic modeling for the Pusdai Mosque. This is because acoustics greatly affect the comfort or quality of the speaker's voice received by the listener.

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