engineering proceedings

MDPI

*Proceeding Paper*

# Acoustic Analysis of Room in Pusdai Mosque in West Java †

**Fadilatun Nur Latifah *, Rezky Sepvingga Putri, Fahman Syukur, Wida Hamidah Sutarno, Beta Paramita and Try Ramadhan**

Architecture, Faculty of Technology and Vocational Education, Universitas Pendidikan Indonesia, Bandung 40152, West Java, Indonesia; sepvinggaputri@upi.edu (R.S.P.); fahman@upi.edu (F.S.); widahamid@upi.edu (W.H.S.); betaparamita@upi.edu (B.P.); tryramadhan@upi.edu (T.R.)

* Correspondence: fadilatunnurlatifah@upi.edu; Tel.: (+62)-85846064393

† Presented at the 1st International Online Conference on Buildings, 24–26 October 2023; Available online: https://iocbd2023.sciforum.net/.

**Abstract:** Aside from being a place for congregational prayers, the West Java Pusdai Mosque is also a center for preaching and Islamic activities in West Java. Therefore, this mosque needs to create a comfortable atmosphere as a place of worship for Muslims. 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 room at the Pusdai Mosque which is influenced by several factors. The research was conducted by observing and simulating using the Ecotect v5.50 software. The simulation is carried out by creating a 3D model by adding the absorption coefficient of the material and adding speakers. In addition, research is also strengthened by conducting literature studies on scientific articles. The simulation was carried out to determine the reverberation time and sound distribution produced by sound sources or speakers which can 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 the 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 for the frequency of 500 Hz (conversational space). This causes the speaker's voice to become an echo or hum. Therefore, the Pusdai Mosque needs to improve the room acoustics to create comfort and solemnity in worship. The improvement that can be done is by adding sound-absorbing material.

**Keywords:** acoustic; mosque; Pusdai; Ecotect

**Citation:** Latifah, F.N.; Putri, R.S.; Syukur, F.; Sutarno, W.H.; Paramita, B.; Ramadhan, T. Acoustic Analysis of Room in Pusdai Mosque in West Java. *Eng. Proc.* **2023**, *53*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Published: 24 October 2023



## 1. Introduction

The Pusdai Mosque is located in a multi-mass area of religious buildings which is the center of *da'wah* or *syiar* and Islamic activities in West Java. This is a concern for the Pusdai Mosque to create a comfortable atmosphere so that the congregation can worship solemnly. This solemnity are influenced by several factors, both from outside and from within the mosque itself. If the noise from outside that enters the building exceeds the standard, it will certainly reduce 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 heard clearly 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 becomes one of the important factors as a determinant of the quality of room acoustics [2,3]. Room acoustics can be influenced by several factors, such as louspeakers, 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 quality than dome roofs, but can cause reverberation if not using 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 distribute sound evenly [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 quite many 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. After that, the simulation results are compared with acoustic standards. The research was conducted by conducting field observations and simulations with Ecotect v5.50 software as well as literature studies to find out the necessary information and strengthen the research. Ecotect v5.50 is software used to identify reverberation time, delay time, and echo [12].

Before conducting acoustic simulations, background noise simulations were carried out that entered the building to determine the comfort of the congregation due to outside noise. After that, the 3D model is simulated in Ecotect by entering several factors. Next, the model was analyzed regarding the sound distribution of each speaker through rays and particles and the resulting reverberation time analysis. From the simulation, the value will be 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*

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 will potentially lead 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 is done by taking field measurements using the Noise Meter mobile application and simulation using Ibana software.

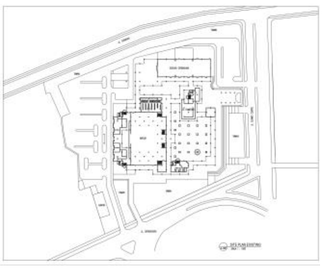


**Figure 1.** Pusdai Mosque Site Plan. Source: (Pusdai, 2022).

From the analysis, the average background noise from all sides entering the building is obtained. 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)) so 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.

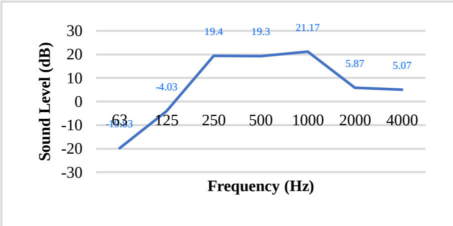
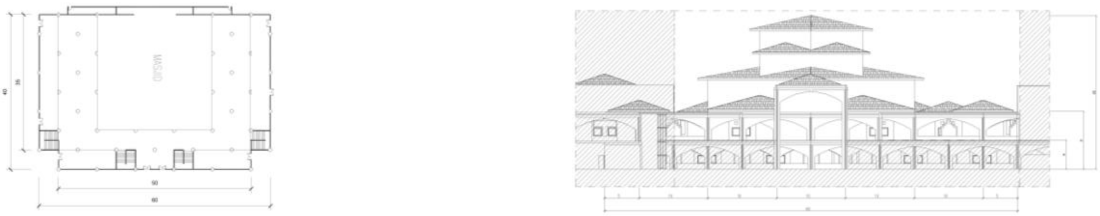



**Figure 2.** Background Noise Level Chart.

*3.2. Room Design*

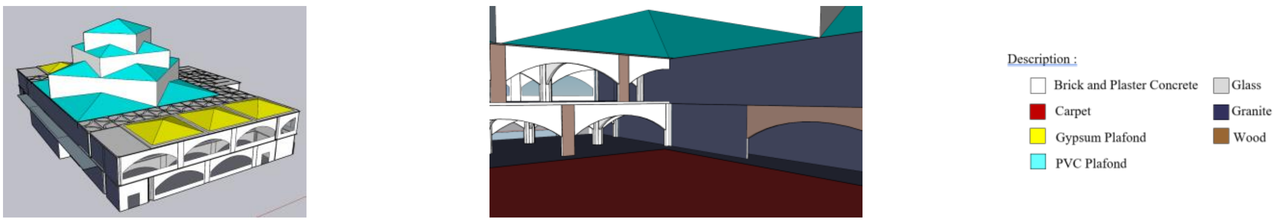
The Pusdai Mosque has a fairly large space, measuring ± 60 m × 40 m with corridors surrounding the main prayer area, as shown in Figure 3a. Based on information from the Secretary of the Pusdai Mosque Prosperity Board, Faturahman, this mosque can accommodate as many as 4.600 people. The mosque has 2 floors with a height of each floor ±4 m and a four-stacked pyramid roof with a height of 22 m, as shown in Figure 3b.



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

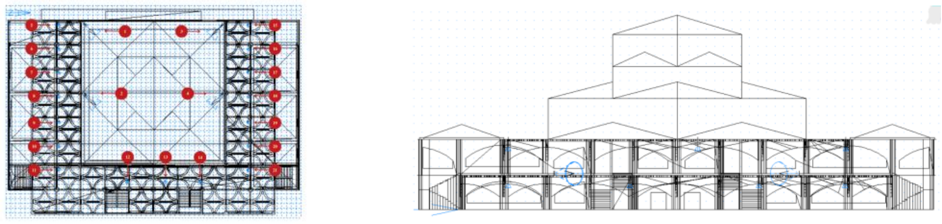
**Figure 3.** (**a**) Floor Plan of Pusdai Mosque; (**b**) East Elevation of Pusdai Mosque. Source: (Pusdai, 2022).

The simulated 3D model has been 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 5 and 6, it can be seen that most of the materials used in the Pusdai Mosque are brick, concrete, and granite.



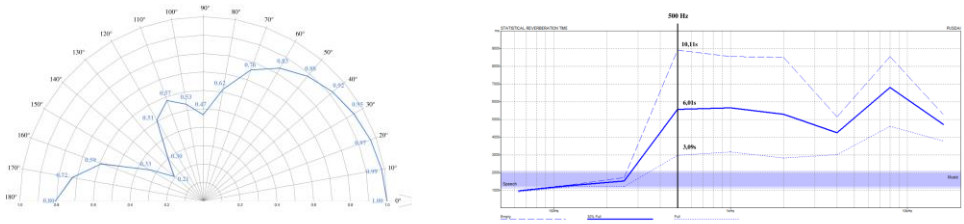

(**a**) (**b**) (**c**)

**Figure 4.** (**a**) Exterior Material Colors; (**b**) Interior Material Colors; (**c**) Description of colors.



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

**Figure 5.** (**a**) Loudspeakers Position Plan; (**b**) Side View Loudspeakers Position.



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

**Figure 6.** (**a**) Loudspeakers Sound Distribution Pattern; (**b**) Reverberation Time Chart.

**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: [15,16].

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 [17]. This can affect the acoustic quality of the Pusdai Mosque.

### *3.3. Reverberation Time*

Ecotect will analyze the reverberation time, after inputting the type of material and the number of speakers used in the room. Pusdai Mosque uses quite a lot of loudspeakers for the prayer area, namely 10 loudspeakers under the ceiling of the first floor corridor, 7 loudspeakers under the ceiling of the second floor, and 4 loudspeakers mounted on the walls around the main prayer area.

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

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 4600 congregations. The simulation was carried out at a percentage of 30% capacity because the Pusdai Mosque is often only filled with about 30% of the congregation from the mosque's capacity (Faturahman, 2020).

Based on the recommendation from Ecotect, this reverberation time calculation uses the Norris-Eyring formula. The optimum value of reverberation time suitable for speech (500 Hz) at the Pusdai Mosque is 1.21 s. Based on the simulation results, it shows that the acoustic quality of the Pusdai Mosque is still not good because the average reverberation time value exceeds the optimum value, especially at the center frequency (500 Hz) which 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 is good for its 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 | 23.132,949 | 1,11 | 1,08 | 1,01 |
| | 125 | 22.736,881 | 1,48 | 1,43 | 1,33 |
| | 250 | 22.186,500 | 1,93 | 1,69 | 1,3 |
| | 500 | 21.645,486 | 10,11 | 6,01 | 3,09 |
| | 1k | 21.132,986 | 9,7 | 6,13 | 3,3 |
| | 2k | 20.383,996 | 9,64 | 5,72 | 2,93 |
| | 4k | 19.293,248 | 5,81 | 4,69 | 3,23 |
| | 8k | 17.524,904 | 9,64 | 7,48 | 4,91 |
| | 16k | 14.331,399 | 5,92 | 5,23 | 4,1 |

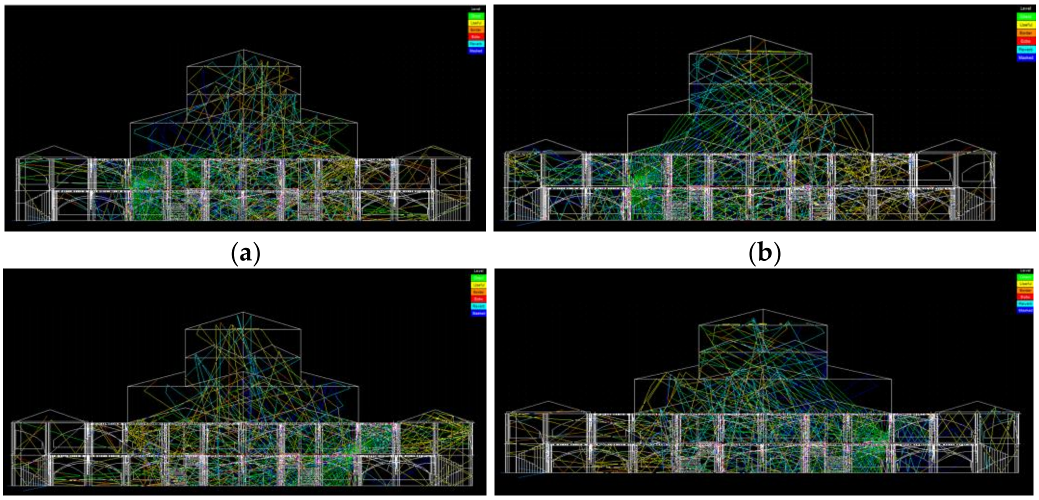
This causes the sound produced from the source to experience a lot of reflection so that the reverberation time will last long. This will reduce the clarity of the voice of the preacher or imam. However, the prayer room at the Pusdai Mosque which has a volume of 22.889,850 $m^3$ also causes the sound to reverberate or buzz if it is 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% (4.600 congregants) is 3.09 s. Meanwhile, when the percentage of congregants is only 30% (1.380 congregants), the reverberation time will increase to 6.01 s. This is because the human body is also a sound absorber [18]. However, in Figure 6b and Table 2, it can be seen that the reverberation time generated at the Pusdai Mosque still exceeds the optimum value even though it is filled with a full capacity of congregants (4.600 congregants). This indicates that the Pusdai Mosque has poor acoustic quality that can cause the voice of the preacher or imam to sound less clear and echoing or reverbing.

### *3.4. Rays and Particles*

This Rays and Particles simulation is useful for seeing the spread or travel of sound produced by each speaker. From this simulation, it can also be seen the effect of the shape of the space and material on sound reflection. In addition, through this simulation, it can be seen that areas that are effective in getting sound or that produce echoes or reverb.

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



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

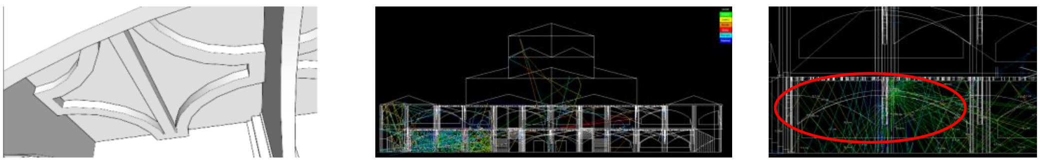
(**c**) (**d**)

Direct Useful Border Echo Reverb Masked

**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 lot of reverb sound in the middle area to the roof which 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 not to 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.



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

**Figure 8.** (**a**) Corridor Ceiling Design; (**b**) Sound Spread of Loudspeaker 11 in the Corridor; (**c**) Speaker 11 Sound Spread Due to Ceiling Design**.**

From Figure 8b, it can be seen that the spread of sound on one of the loudspeakers (loudspeaker 11) that hangs on the ceiling of the corridor causes a lot of 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 lot 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 too much 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 receive the voice of the preacher or imam properly and clearly.

This can lead to reduced solemnity in worship. Therefore, it is necessary to improve the acoustic design of the Pusdai Mosque. Acoustic improvements that can be made are 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 find out 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.

**Author Contributions:** Conceptualization, F.N.L.; methodology, F.N.L.; software, F.N.L. and F.S.; validation, F.N.L. and R.S.P.; formal analysis, F.N.L. and R.S.P.; investigation, F.N.L. and W.H.S.; resources, F.N.L.; data curation, F.N.L.; writing-original draft preparation, F.N.L.; writing—review and editing, F.N.L., B.P. and T.R.; visualization, F.N.L.; supervision, B.P. and T.R.; project administration, B.P. and T.R.; funding acquisition, B.P. and T.R. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are obtained in the article.

**Acknowledgments:** This article was supported by Center of Excellence for Low Emission Building Materials and Energy, and Laboratory of Science, Technology and Building Materials of the Universitas Pendidikan Indonesia. This research funded by BeCool Indonesia.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. De Salvio, D.; D'Orazio, D.; Garai, M. Unsupervised analysis of background noise sources in active offices. *J. Acoust. Soc. Am.* **2021**, *149*, 4049–4060. https://doi.org/10.1121/10.0005129.
2. Eaton, J.; Gaubitch, N.D.; Moore, A.H.; Naylor, P.A. Estimation of Room Acoustic Parameters: The ACE Challenge. *IEEE/ACM Trans. Audio Speech Lang. Process.* **2016**, *24*, 1681–1693. https://doi.org/10.1109/TASLP.2016.2577502.
3. Kusuma, R.B.I.; Suyatno, S.; Prajitno, G. Analisis dan Simulasi Optimasi Parameter Akustik Ruang pada Smart Classroom Departemen Fisika ITS. *J. Sains Dan Seni ITS* **2021**, *10*, B7–B14. https://doi.org/10.12962/j23373520.v10i2.76148.
4. Cahyono, R. Evaluasi akustik ruang dan tata suara pada gedung graha patria kota blitar. 2018.
5. Baikhaqi, M.I. *Desain Akustik Ruang Pada Home Theater Multifungsi Perpustakaan ITS*; Institut Teknologi Sepuluh Nopember: Surabaya, Indonesia, 2015.
6. Sampurna, R. Pengaruh Penampang Asimetris Terhadap Kinerja Akustik Pada Ruang Audio Visual Gedung G Fakultas Teknik Universitas Telkom. 2016. Available online: https://repository.telkomuniversity.ac.id/home/catalog/id/116684/slug/pengaruh-penampang-asimetris-terhadap-kinerja-akustik-pada-ruang-audio-visual-gedung-g-fakultas-teknik-universitas-telkom.html (accessed on 9 January 2023).
7. Fauji, *Evaluasi kinerja akustik ruang pada masjid dengan bentuk plafon tajug*. 2017.
8. Bena, E.F.; Arsitektur, F.T.J.; Sudarmo, B.S.; Ridjal, A.M. Waktu Dengung Ruang Sholat Masjid Desa Berdasarkan Perbedaan Bentuk Plafon. *Rev. Urban. Arch. Stud.* **2014**, *12*, 41–53. https://doi.org/10.21776/ub.ruas.2014.012.02.5.
9. Putra, A.R.; Nazhar, R.D. Peranan Material Interior dalam Pengendalian Akustik Auditorium Bandung Creative Hub. *Waca Cipta Ruang* **2020**, *6*, 71–76. https://doi.org/10.34010/wcr.v6i2.4123.

10. Yani, Y. Penilaian kualitas akustik masjid Raudhaturrahmah Padang Tiji dengan menggunakan simulasi Ecotect. *J. Arsit. Pendapa* **2021**, *4*, 19–27. https://doi.org/10.37631/pendapa.v4i1.234.
11. Kustianingrum, D.; Rozi, A.; Mulyanidya, F.; Firdaus, F. Kajian Tatanan Massa dan Bentuk Bangunan Pusat Dakwah Islam Bandung. *Reka Karsa: J. Arsit.* **2014**, *2*, 1–13.
12. Aldona, N.; Seftyarizki, D.; Prihatiningrum, A.; Ramawangsa, P.A.; Khairunnisa, E.; Refti, S.M.; Kharisma, M.W. Identification of Acoustic Comfort in Classroom of Gedung Kuliah Bersama V of Bengkulu University. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *738*, 012039. https://doi.org/10.1088/1755-1315/738/1/012039.
13. Badan Standardiasi Nasional. *SNI 03-6386-2000 Spesifikasi Tingkat Bunyi Dan Waktu Dengung Dalam Bangunan Gedung Dan Perumahan (Kriteria Desain Yang Direkomendasikan)*; Badan Standarisasi Nasional: Jakarta, Indonesia, 2000; p. 18.
14. Indrani, H.C.; Ekasiwi, S.N.N.; Asmoro, W.A. Aplikasi Model Komputer Dalam Analisis Kinerja Akustik Ruang Auditorium Universitas Kristen Petra Surabaya. *Dimens. Inter.* **2007**, *5*, 109–121. Available online: http://puslit2.petra.ac.id/ejournal/index.php/int/article/view/16882 (accessed on).
15. Sü, Z.; Çalışkan, M. Acoustical Design and Noise Control in Metro Stations: Case Studies of the Ankara Metro System. *Build. Acoust.* **2007**, *14*, 203–221. https://doi.org/10.1260/135101007781998910.
16. Ansay, S.; Zannin, P.H.T. Using the parameters of definition, D50, and reverberation time, RT, to investigate the acoustic quality of classrooms. *Can. Acoust.* **2016**, *44*, 6–11.
17. Dewi, N.U.I.; Syamsiyah, N.R. Kualitas Akustik Ruang Utama Masjid Siti Aisyah Surakarta. *Sinektika: J. Arsit.* **2020**, *16*, 73–79. https://doi.org/10.23917/sinektika.v16i2.10592.
18. Syamsiyah, N.R.; Utami, S.S.; Dharoko, A. Kualitas Akustik Ruang Pada Masjid Berkarakter Opening Wall Design. RAPI XIII Simp. Nas. 2014; pp. 66–74. Available online: http://duniaakustik.wordpress.com/ (accessed on).
19. Ridhatiana, N.S. Tata Akustik Ruang Masjid Raya Al-a'Zhom Kota Tangerang. Ph.D. Thesis, Universitas Brawijaya: Malang, Indonesia, 2021. Available online: http://arsitektur.studentjournal.ub.ac.id/index.php/jma/article/view/1545 (accessed on).
20. Setiawan, D. BAB II Tinjauan Pustaka. 2017; pp. 1–64.