

Java's South Beach Sand as a Noise-Absorbing Material Innovation

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Abstract South beach sand, particularly in Central Java, Indonesia, has a smooth texture that distinguishes it from other types of beach sand. The purpose of this study is to identify the properties and sound absorption coefficients of beach sand. Previous studies have found that beach sand in the yard of the Great Mosque of Surakarta is a component of the courtyard that absorbs the high sound. Subsequently, sand performance measurements were performed in the laboratory to assess the material's ability to absorb sound using the metrics of reverberation time (T30), Sound Transmission Class (STC), Outdoor-indoor Transmission Class (OITC), Noise Reduction Criteria (NRC) and sound absorption coefficient. According to the test results, south beach sand has an absorption value of 63%, which is comparable to that of other natural materials, such as wood. The findings of this study can be followed by simulating the use of south beach sand in other mosques to create a calm and quiet atmosphere.

Keywords South Beach Sand, Components of Courtyard, Sound Absorption Coefficient, Environmental Acoustics

1. Introduction

It is commonly accepted that a mosque is a public structure that promotes aural comfort because it is a place of worship. Aural comfort within a mosque is affected by

the shape of the geometric design of the interior space, spatial location, and choice of finishing materials for the spatial elements [1] [2]. The acoustic environment outside the mosque has an impact on the comfort of hearing within. The mosque's location shows the degree of the effect of external noise on the area within the mosque [3].

The auditory environment of worship structures, particularly those beginning outside the place of worship, can produce a religious ambiance that calms visitors' emotions [4]. Sounds that arise in an area create a sonic environment that can affect visitors. The atmospheres surrounding the mosque or mosque areas were highly different. Large mosques, especially on a city or district scale, are typically placed in congested places, making them easier to discover and enter. The region surrounding the large mosque may be a trade area or a tourist/cultural attraction. The auditory environment in an area is a compound sound with different sound intensities.

This study was preceded by prior research on two royal mosques in Surakarta that differed in physical condition. Surakarta Grand Mosque is in a congested and noisy region. Surakarta's Great Mosque is part of a single chess gatra or spatial notion of the kingdom's capital at the time, which featured four parts: the palace, mosque, market, and square. Markets and squares are frequently the epicenters of noise [5]. This is not the case in the Surakarta Grand Mosque setting. Despite being close to the market and square, the quality of the aural environment is calmer. This is very different from the character of the sonic environment at the other great mosque in Surakarta, which is Al Wustho

Mosque in the Education area. In general, the Education Area has the characteristic of a quiet sonic environment, but what appears in the case of this mosque is the high noise.

The existence of a landscape component that supports noise attenuation contributes to the claim that the Great Mosque has a tranquil sound quality. The landscape component is sand from the island of Java's south shore, particularly Central Java, which is extensively spread in the mosque's courtyard [6] [7]. Sound pressure level measurements yielded an average value of 56.19 dB for sonic characteristics in the Great Mosque [8]. This is a low-key category. Meanwhile, the Al Wustho Mosque features a landscape component that reflects sound, namely paving block cement with an average sound pressure level of 73.1 decibel (dB). This study produced a phenomenal sound environment.

Therefore, the aim of this research was to determine the sound absorption value of the south beach sand material, as well as its capacity to transfer and keep sound from one room to another. The value gained will be used to provide an overview of construction material developments using sand as the basic material for the south shore of Java. The study concluded with a simulation of the South Beach sand in the courtyard of the Al Wustho Mosque. The simulation results demonstrate the ability of sand to absorb sound by displaying the achieved Sound Pressure Level (SPL) value.

2. Materials and Methods

This study employed laboratory measurement methods as well as computer analysis. The following software was used:

- a) Real-time analyzer (RTA) for calculating the acoustic parameter reverberation time (T30) and Sound Pressure Level (SPL). T30 assesses the sound absorption ability of sand materials in seconds unit.
- b) The values sought are the STC, OITC, NRC, and the value of alpha (α), or the sound absorption coefficient, which is simply the capability of a material to absorb sound in dB decibel units over a surface area of 1 square meter.
- c) Modelling software for visually mapping the sound pressure level values.

The value of the sound transmission and reduction (sound absorption coefficient), which is the dependent variable, is the study variable. The sand of the south shore as a component of the environment and layout of the Al Wustho Mosque was the independent variable. A trial of the components of the south beach sand landscape was conducted at the Al Wustho Mosque, which currently employs asphalt as a ground cover. Figure 1 depicts a schematic process for the research.

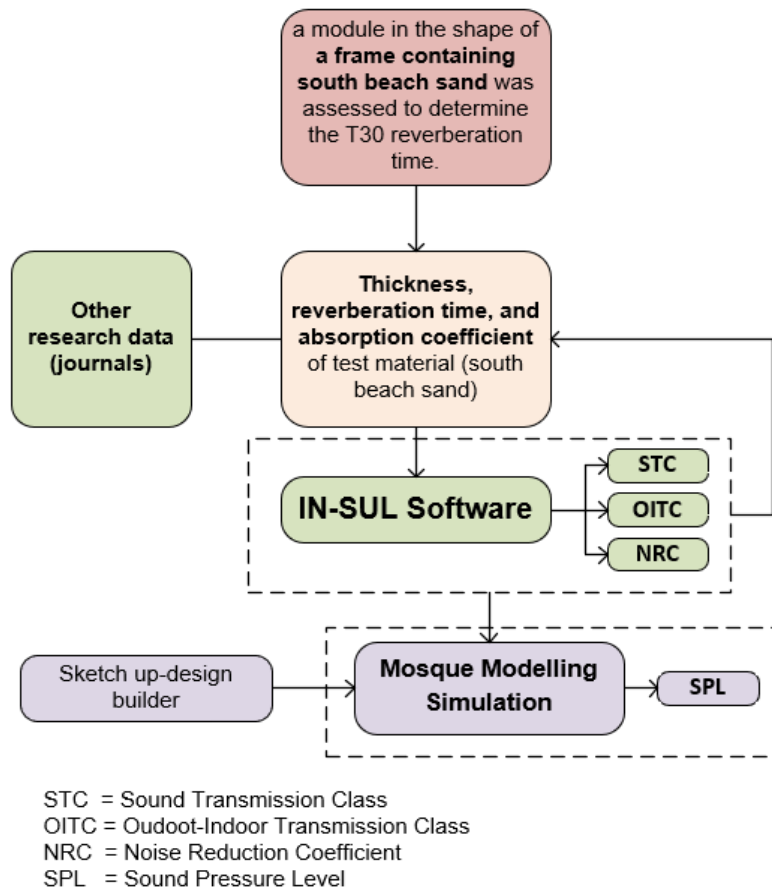


Figure 1. The Research Process

The independent variable was the size of the south beach sand, which was prepared according to the Sabine standard of 1 square meter. The horizontal sand must be made vertical to be measured. Changes in the location of the test material did not affect the measurement findings. Another factor to think is the vertical measurement, as the following use is for vertically installed interior or exterior materials. The procedure for preparing the test material is depicted in the following image, which is separated into two stages:

2.1. Preparation of Sand

The test material preparation process began with the creation of a module of the test material in the shape of a frame measuring 100 cm × 100 cm × 10 cm. On the sides, the frame was covered with fabric to prevent sand out of the frame. The top of the test material module, which was in the shape of a frame, was perforated. The next stage is to prepare sand, which is gathered directly from the courtyard of the Surakarta Grand Mosque. Sand was injected through the preset holes into the test material module frame (Figure 2). The sand must fill the entire test material module frame.



Figure 2. (a) The test material module is a wooden frame; (b) sand is inserted into the test material module frame; and (c) the test material sand is obtained from the courtyard of the Great Mosque of Surakarta

2.2. Room Setup and Testing Equipment

The material testing chamber was 3.00m x 3.00m and 2.40m tall. A domed ceiling with a diameter of 2.00m was in the center of the chamber. This chamber meets the specifications for the material test chamber because the surface material is more sound-absorbing. Multiplex wall substance covers the brick wall.



Figure 3. Test material placement in the testing room

General testing technique according to ISO 354 (2003): Acoustics-Measurement of Sound Absorption in a Reverberation Room, which includes:

- Room preparation: ensuring that the testing room has non-reflective material features.
- Testing equipment: the measuring equipment has been calibrated in accordance with the applicable calibration standards.
- Microphone Positioning: the measuring microphone is in the standard position, with a working plane height of 1.00 m from the floor and a distance of 1.00 m from the test item.
- Sound Source Positioning: place the sound transmitting device (speaker) in the centre of the test material at a distance of 1.50 m with the sound source in the form of gunshots.

The measuring device includes a set of sound source tools and speakers (2 pieces), omnidirectional microphones (2 pieces), a Sound Level Meter (2 pieces), a signal conditioning BSWA MC3022 for sound signal processing (1 piece), a connecting cable unit between the microphone and soundcard, and four tripod units to mount the Sound Level Meter and Microphone measuring devices (see Figure 4). Connecting wires between electro-acoustic devices are critical to the research's success. Prior to measurement, all tools were externally calibrated. The tool preparation technique is following BS EN ISO 3382-1:2009 [9].

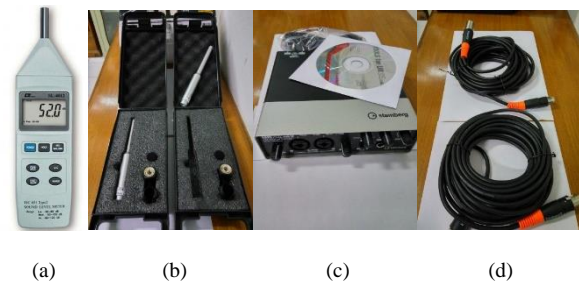
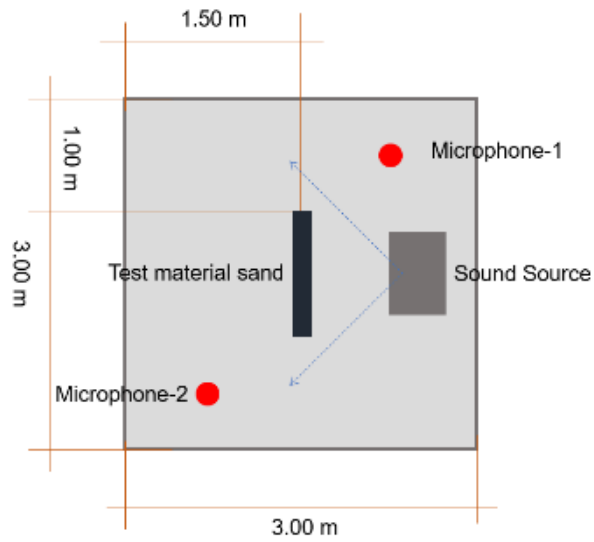


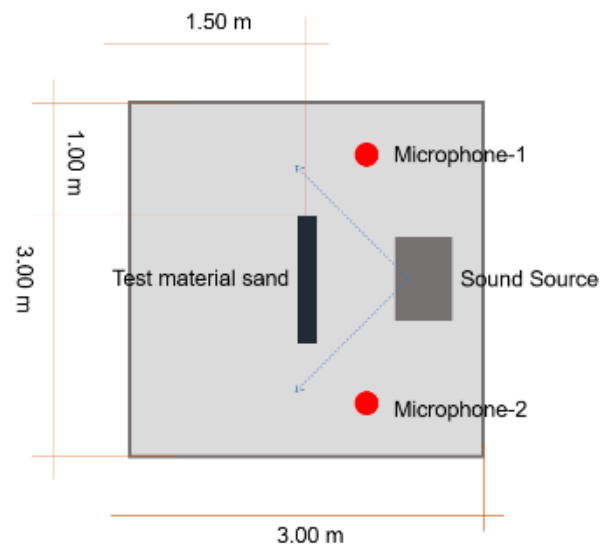
Figure 4. Research measuring instruments: (a) Sound Level Meter, (b) Microphone, (c) Soundcard, (d) Cable connecting the microphone and soundcard

2.3. Measurement of Sand Module

Background noise measurement results meet the ISO 8253-1 standards (procedure, requirements, and measurement of hearing threshold level). Figure 5 illustrates an existing sand material test with two conditions: parallel microphones and crossing microphones. The goal of measuring with two circumstances is to get more data from all angles. Furthermore, measurements were taken when the chamber was empty and when it was filled with sand as the main test materials; these two conditions were set to allow the comparison of the test result. ISO 3382-1:2009 standard was used for monitoring acoustic impulse response characteristics with a Realtime analyzer (measurement of reverberation time in enclosed spaces, measurement procedures, required power and required amount, measurement positions, data evaluation methods and presentation of test reports).



(a)



(b)

Figure 5. (a) Microphones aligned with a height of 1.20 m and (b) Microphones in a crossed position

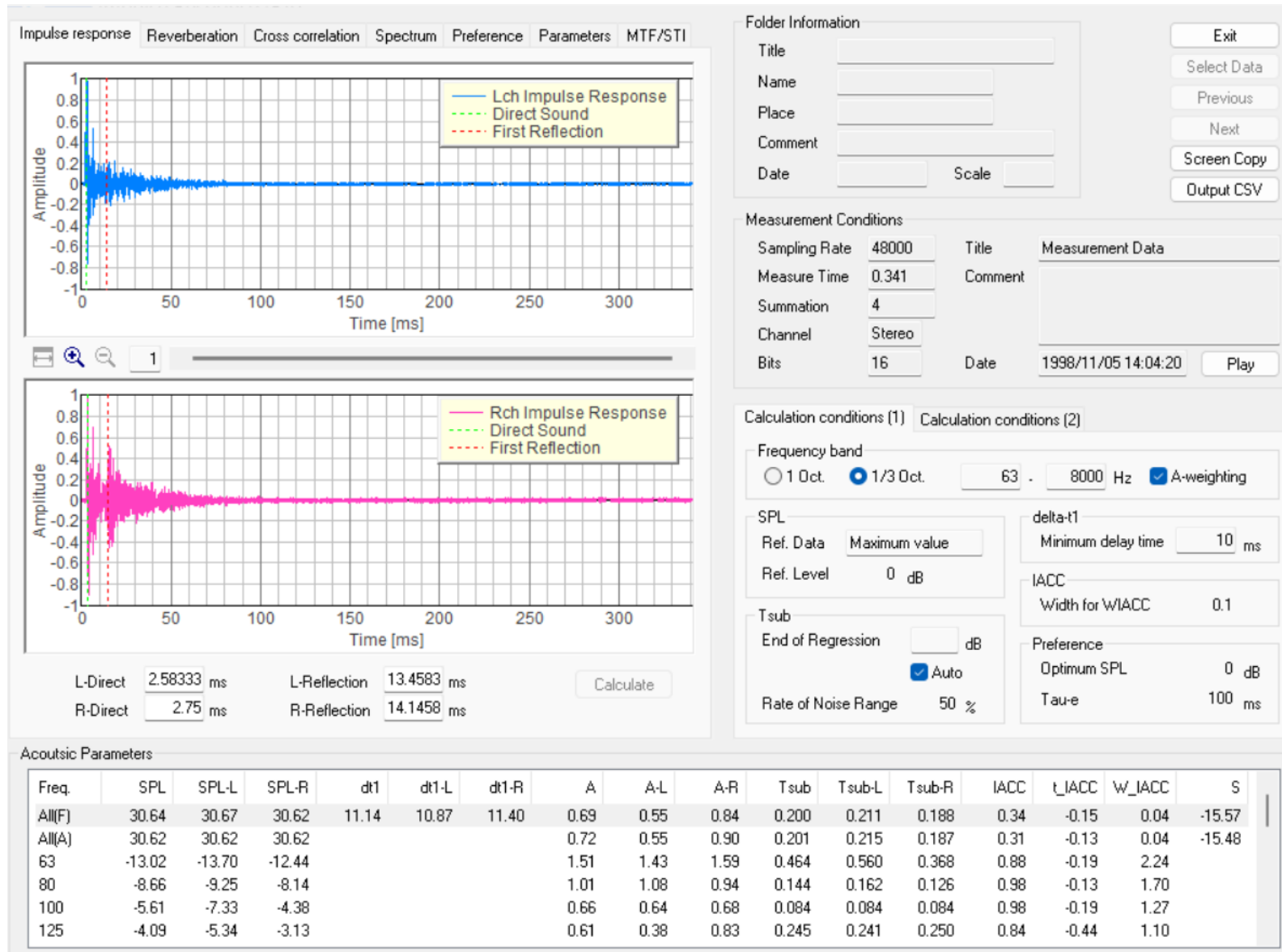


Figure 6. T30 and SPL values are obtained by displaying the impulse response in RTA software

The testing tool is Realtime Analyzer (RTA) software, which measures the impulse response and calculates the T_{30} and SPL reverberation durations. Figure 6 represents the impulse response measuring screen.

T_{30} and SPL readings were further analyzed using INSUL Software to provide an analysis of numerous parameters:

- a) Sound Transmission Class (STC) is a parameter used to calculate the effectiveness of soundproof materials in reducing sound transmission between rooms or reducing decibels (dB) in noise that materials/partitions can provide.
- b) Outdoor-Indoor Transmission Class (OITC) is a standard used to indicate the rate of sound transmission from outdoor noise sources into buildings.
- c) Noise Reduction Criteria (NRC) is an average rating of an acoustic product's ability to absorb sound. The NRC is measured on a scale of 0 to 1.

3. Results and Discussion

The acoustic parameter values of T_{30} 's reverberation time were assessed both when the chamber was empty and when it was filled with sand test materials. Tables 1 and 2 demonstrate the measurement findings obtained using the RTA program and followed up by INSUL in two conditions: parallel and crossing microphone settings.

The results are summarized in Tables 1 and 2 as follows: First, the crossed position of the microphones generates a more stable frequency and T_{30} value than the parallel position of the microphones. Second, the stable condition will serve as the premise for further acoustic performance calculations. Figure 7 shows the sand absorption

coefficient based on Table 2.

Table 1. T_{30} Acoustic Parameter Values and Absorption Coefficient (Microphone parallel)

Frequency (Hz)	T_{30} (empty room) second	T_{30} (with sand) second	Volume m^3	Absorption Coefficient
125	1.89	1.87	21.6	0.01
250	4.48	3.69	21.6	0.17
500	2.76	2.54	21.6	0.11
1000	3.28	3.2	21.6	0.03
2000	2.19	2.17	21.6	0.02
4000	1.93	1.98	21.6	-0.04
8000	1.49	1.42	21.6	0.12

Table 2. T_{30} Acoustic Parameter Values and Absorption Coefficient (Microphone crossed)

Frequency (Hz)	T_{30} (empty room) second	T_{30} (with sand) second	Volume m^3	Absorption Coefficient
125	6.02	3.63	21.6	0.01
250	4.09	2.45	21.6	0.25
500	2.15	2.12	21.6	0.48
1000	2.06	1.94	21.6	0.63
2000	2.13	2.13	21.6	0.47
4000	2.09	1.98	21.6	0.59
8000	2	2.01	21.6	0.56

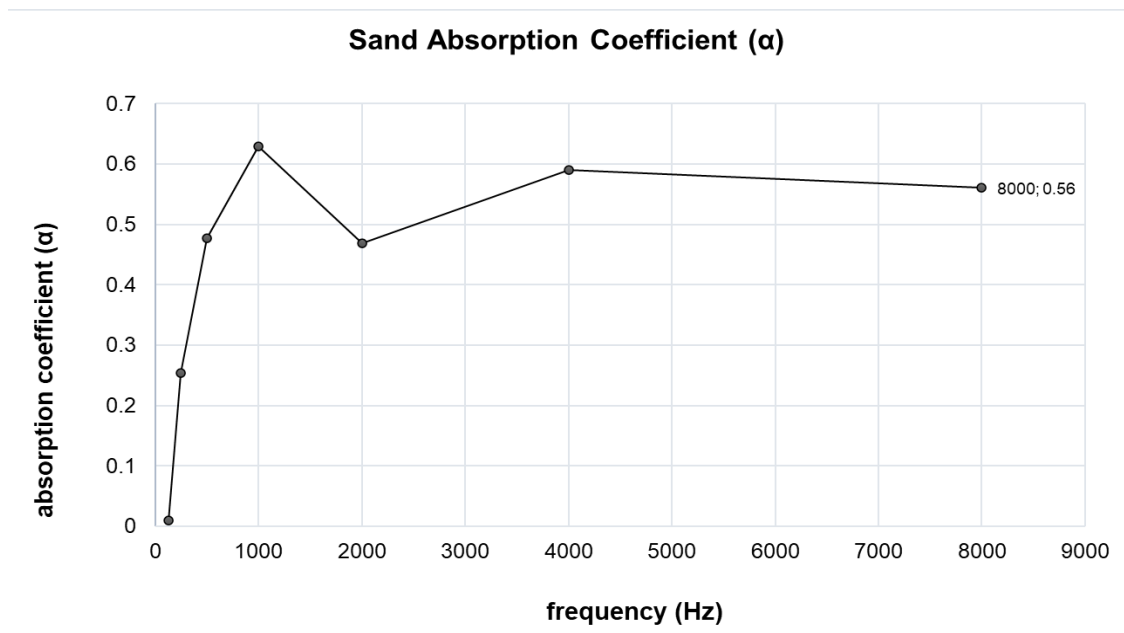


Figure 7. The Sand Absorption Coefficient (α).

According to Figure 7, the absorption of sand is greatest at 1000 Hz, with a value of 0.63. This suggests that sand performance is highly effective at a frequency of 1000 Hz, which is the standard frequency utilized in all sound measurements.

3.1. Sound Transmission Class (STC)

The Sound Transmission Class (STC) grade indicates a material's capacity in the process of sound insulation or sound reduction. STC is calculated by categorizing the sound reduction index/sound transmission loss (TL) values at each frequency. The greater a material's STC rating, the better the insulation level or isolated decibel value [1]. The STC value is 52 based on RTA impulse response measurement data and INSUL analysis (Figure 8).

Table 3. Classification of STC Values

STC	What can be heard
20-25	Normal speech can be understood
25-30	Loud speech can be understood
30-35	Loud speech audible but not intelligible
35-40	Loud speech audible as a murmur
40-45	Loud speech heard but not audible
45-50	Loud sounds faintly heard
50-60+	Good soundproofing; most sounds do not disturb neighboring resident

The ASTM (American Society for Testing and Materials) standard states that the number 52 falls into the category of powerful sounds that are barely audible or nonexistent (see Table 3) [10]. In other words, sand does a superb job of

absorbing sound.

When converted to sand materials, the projected weight-to-wall thickness ratio of STC 52 construction materials is at least 8 inches, or 20 cm (Table 4). Whereas the thickness of this research is just 10 cm, showing a high sand absorption value [11].

Table 4. STC Category Estimates for Wall Materials

Wall Thickness, inches	Hollow Unite		Grout Filled		Sand Filled	
	Weight	STC	Weight	STC	Weight	STC
4	20	44	38	47	32	46
6	32	46	63	51	50	49
8	42	48	86	55	68	52
10	52	50	109	60	86	55

3.2. Outdoor-Indoor Transmission Class

OITC was adopted because it is more reliable than STC [12]. The performance of the exterior façade is more evident due to OITC. The OITC value was sought in this study to establish how far the performance of sand is when used as a building material in the facade. The OITC value is 45, as shown in Figure 8. This result indicates that the STC falls into the group defined by Egan (see Figure 7) [12]. These findings are consistent with prior research, which discovered that weight and material density had a significant impact on sound insulation [13].

Furthermore, the measurements reveal that the Transmission Lost (TL) value is consistent with the STC and OITC values. TL is measured at 57 dB at 1000 Hz.

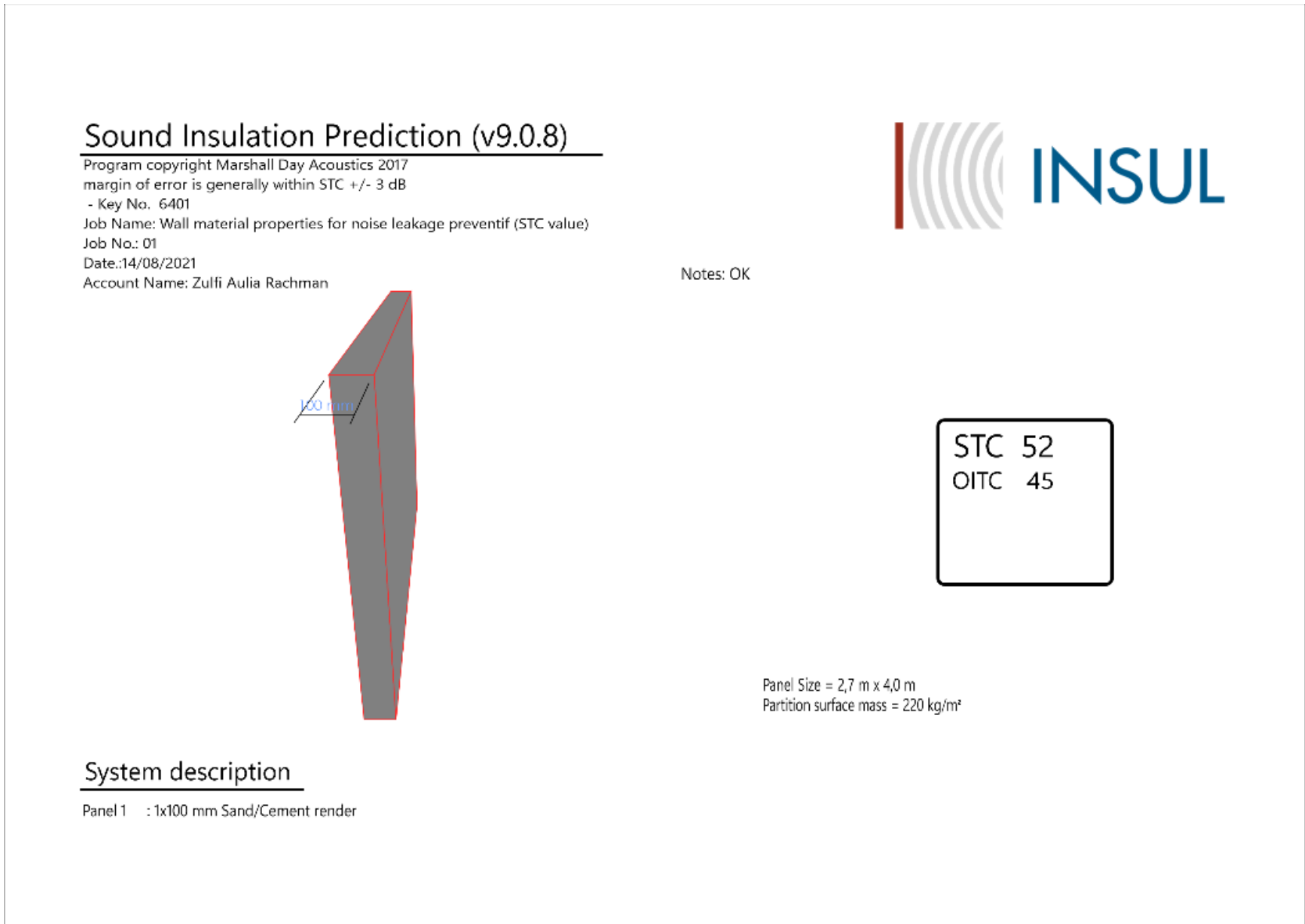


Figure 8. Wall material properties for noise leakage prevent if (STC value) provided by Sound Insulation Predictor

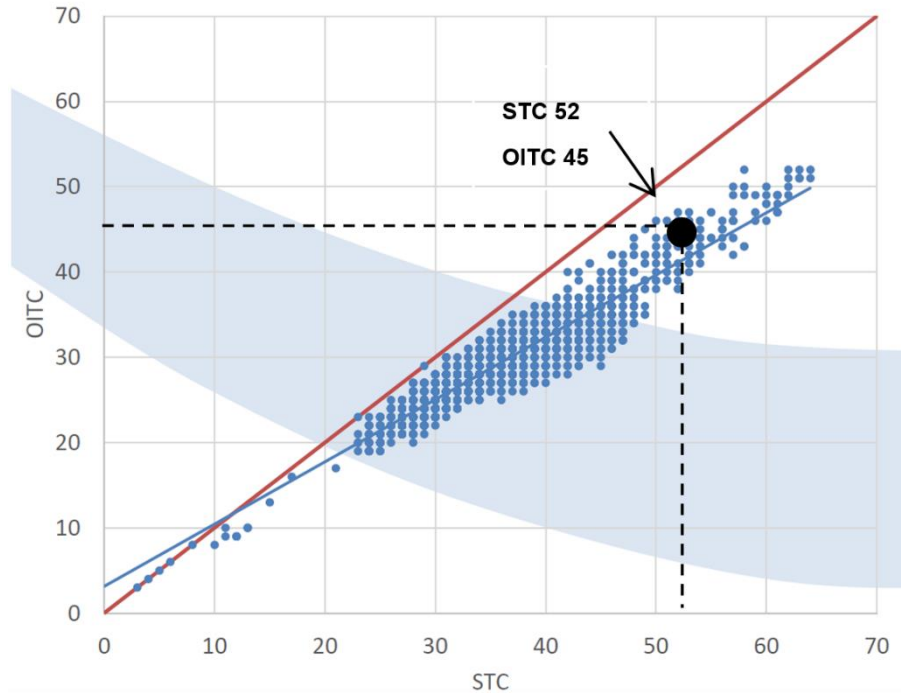


Figure 9. STC-OITC comparison curve according to ASTM E-1332 Standard for Outdoor-Indoor Sound Attenuation Rating

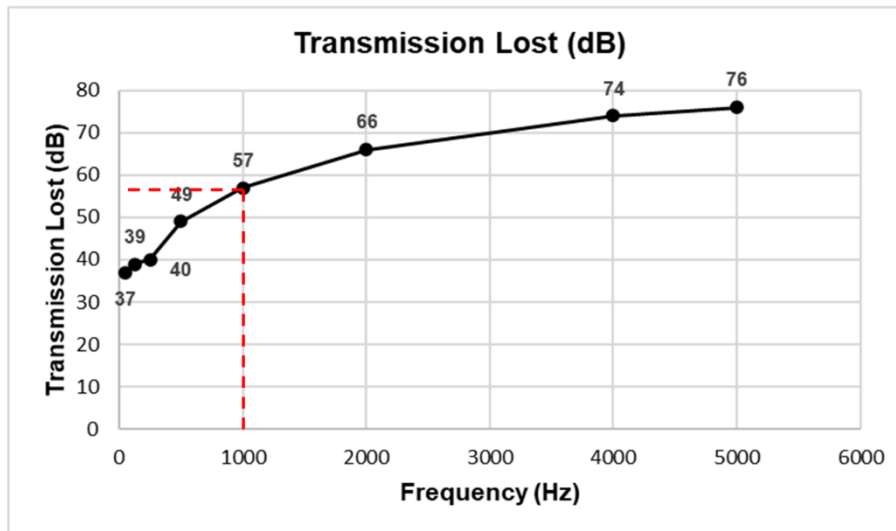


Figure 10. Sound Transmission loss value curve against frequency

3.3. Noise Reduction Coefficient (NRC)

The NRC value is calculated by multiplying the total surface area of the room by the absorption coefficient of the surface material of the space elements when the space is empty and when it is filled with sand. Sabine's formula for multiplication is as follows:

$$T_{60} = 0.16 V / \Sigma A\alpha \tag{1}$$

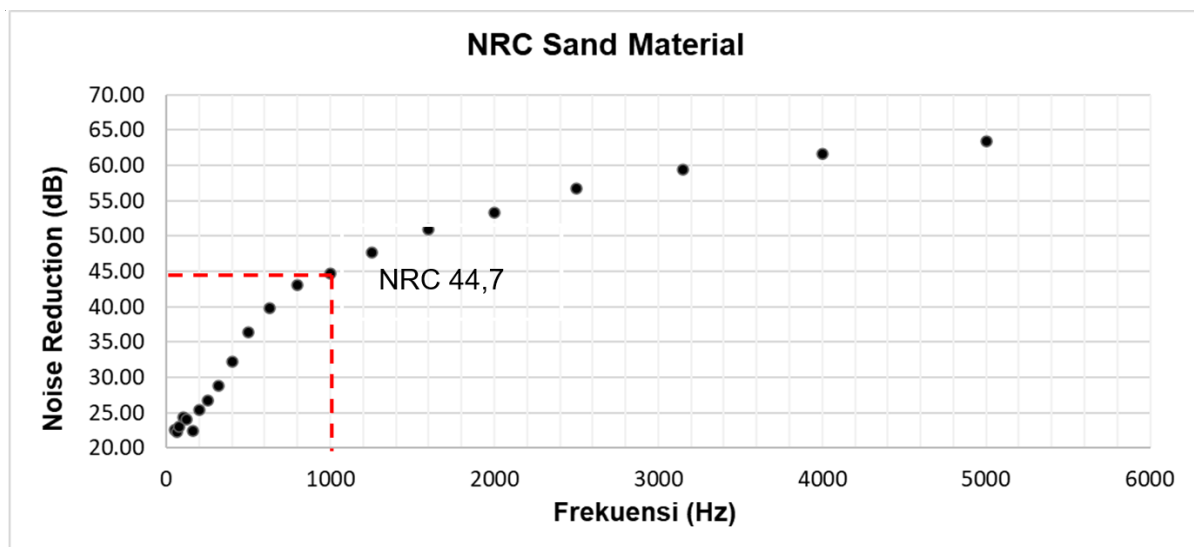
V = volume

A = total surface area
 α = absorption coefficient of the surface covering material

Table 5 shows the NRC values based on the previously obtained acoustic parameters. Figure 11 shows the NRC value in the frequency range 125-5000 Hz, with the NRC value at 1000 Hz being 44.7. The NRC value of 44.7 is a high figure, indicating that the sand material may absorb up to 44.7% of the initial sound heard. The NRC standard, based on numerous sources, is shown in table 6 [14][15].

Table 5. Analysis to get the NRC value

Freq (Hz)	TL (dB)	Area (m ²)	T ₃₀ empty (s)	T ₃₀ sand (s)	V (m ³)	A _α empty	A _α sand	NRC
125	39	29.8	6.02	3.63	21.6	0.57	0.95	24
250	40	29.8	4.09	2.45	21.6	0.84	1.4	26.7
500	49	29.8	2.15	2.12	21.6	1.6	1.62	36.3
1000	57	29.8	2.06	1.94	21.6	1.67	1.78	44.7
2000	66	29.8	2.13	2.13	21.6	1.62	1.62	53.3
4000	74	29.8	2.09	1.98	21.6	1.65	1.74	61.6

**Figure 11.** NRC Sand Material**Table 6.** Audible Effect by Change in NRC

Difference in Coefficient	Effect for Most Situations
0.05 – 0.10	Little/Low
0.10 – 0.20	Significant
0.20 – 0.50	Considerable
0.50 – 0.80	High
0.80 – 1.00	Very High

3.4. Al Wustho Mosque Model Simulation

The results of the tests and analyses demonstrate that the sand material, particularly sand from the south coast of Central Java, has a high sound absorption capacity (NRC value) as well as an excellent sound insulation ability (STC value). In addition, OITC values are produced, showing that the sound (dB) absorbed by the material or lost from the initial sound occurs relatively rapidly.

The sand used in the Great Mosque courtyard was utilised to assess changes to the acoustic environment of Al Wustho mosque. Previous research found an average SPL

value of 73.1 dB at Al Wustho mosque [8]. Following simulations using acoustic modelling software, the average decline in SPL value was 66.9 dB. The whole sand-shaped surface of the page effectively absorbs sound. Figure 12 illustrates the courtyard of the Al Wustho mosque as a material/model for the simulation. Figure 13 shows the results of mapping in the courtyard of the mosque. The average sound level is low on the north and south sides of the mosque's terrace, as seen in Figure 13. Meanwhile, the noise level on the east side near the mosque's fence remained raised but within normal norms. The highway's noise may still be heard in this zone. The overall average page got a high sound before being filled with sand, and the noise is no longer felt after being filled with sand.

The measurement point is in the middle of the mosque's courtyard, with a total of 11 points. The sound source from the mosque's entrance is 82.6 dB, 10 meters from the sixth measuring point (central part). Unlike studies on other types of materials, which allow for sound leakage, the simulation results appear to require field measurements to identify all faults in the current mosque and assure there is no sound leakage [16].

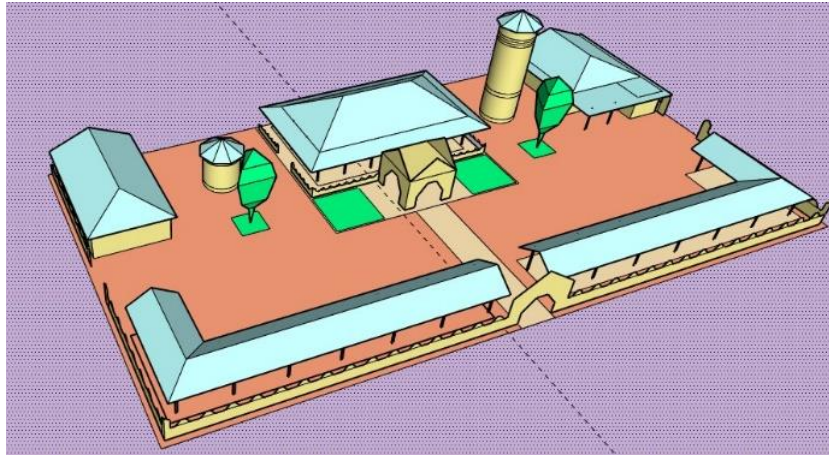


Figure 12. Al Wustho mosque courtyard as simulation material with sketch up

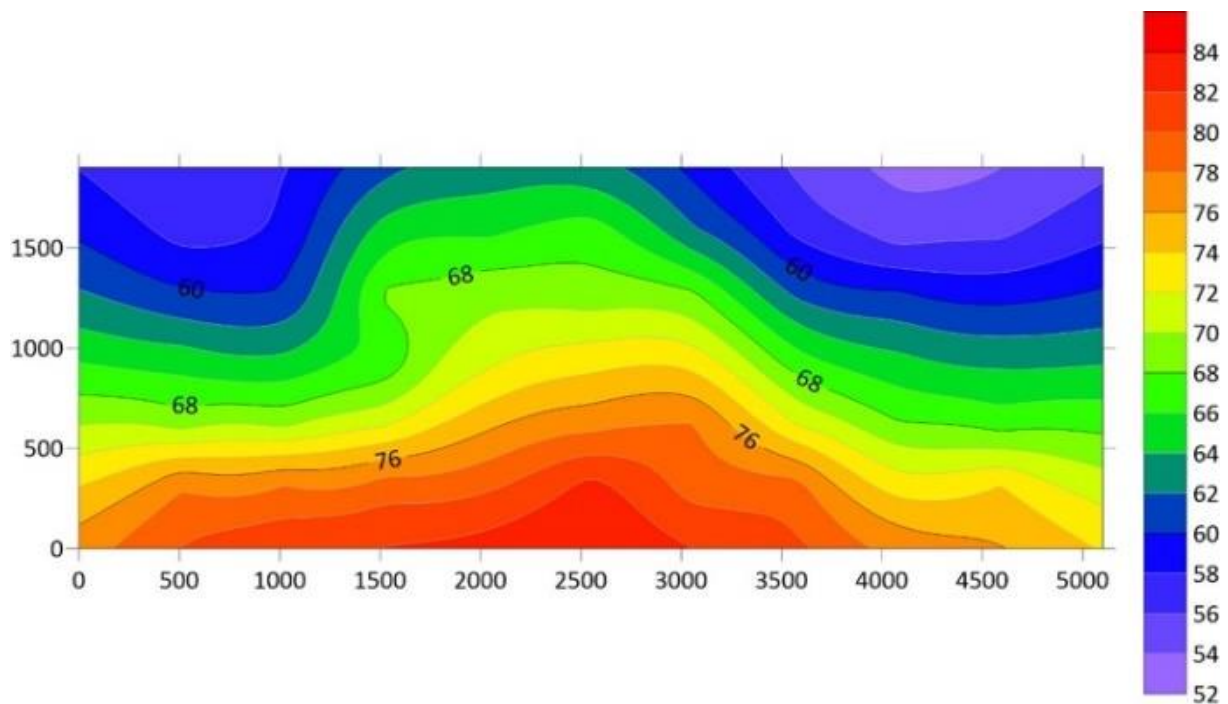


Figure 13. Mapping SPL in the mosque's courtyard

This research's findings support the existing royal mosques in Java. Similar to the study on the acoustics of the Kauman mosque in Yogyakarta, the environment around the mosque affects the sound that is produced by sound measuring devices. From entering the mosque's courtyard to entering the mosque, the congregation's activities form an activity pattern that correlates to the sound pattern. The volume of the sound will progressively decrease as it passes from the mosque's outer courtyard to its inner courtyard and terrace. Even the presence of landscape elements such as ground cover helps to absorb noise in the mosque courtyard [17] [18]. It is recognized that vegetation is a landscape component that contributes significantly to noise absorption in addition to acting as a local climate regulator [19].

4. Conclusions

The sand on the south coast, especially on the beaches of Central Java, is of great quality, which is why it is used to fill the whole courtyard of the Surakarta Grand Mosque. The sand's fine texture distinguishes it from other varieties of sand. The ability of this sand to absorb noises gives it a local edge. The ability of the sand to absorb sound insulation is represented by the STC value of 52 determined using testing and analysis methods. The OITC score was 44, the TL score was 57, and the NRC score was 44.7. The sand material's sound absorption coefficient of 0.63 is the easiest to use for measuring reverberation duration as an application for interior or exterior design in the Sabine formula calculation.

All of these statistics suggest that the sand has the ability to absorb and store sound, preventing it from being heard in other locations. The courtyard of the Al Wustho Mosque, which has a high SPL value, is reproduced using The Great Mosque's sand. The resulting acoustic parameters of SPL were lower than previously, dropping from 73.1 dB to 66.9 dB. It is possible to continue employing sand as an inventive building material or for other more inventive applications now that the material's advantages have been demonstrated.

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REFERENCES

- [1] M. D. J. D. Zhang, "Soundscape evaluation in Han Chinese Buddhist temples," *Applied Acoustics* Vol. 111, pp. 188-197, 2016.
- [2] N. Z. Rusmayanti, "Noise Level Analysis in the Old Market Area, Ketapang Regency, West Kalimantan", *PRISMA FISIKA Journal*, vol. Vol. 9, no. No. 3, pp. 253-257, 2021.
- [3] H. Kuttruff, *Room Acoustics*, London: Taylor & Francis e-Library, Spon Press, 2001.
- [4] J. Lang, *Creating Architecture Theory*, New York: Van Nostrand Reinhold Con. Inc., 1987.
- [5] M. Fowler, "Soundscape as a Design Strategy for Landscape Architecture Praxis," *Design Studies Elsevier*, vol. 34, no. 1, pp. 111-129, 2013.
- [6] N. R. Syamsiyah, R. Hidayati, D. Mutiari and D. Setiawan, "Sonic Environment Characteristics of the Royal Mosque Area in Surakarta," *Journal of Langkau Betang*, vol. 7, no. 2, pp. 175-184, 2020.
- [7] A. Lusiyana, M. Toifur and F. Rohman, "The Magnetic Properties Test of Beach Sand by Determining Relative Permeability Using Logger Pro," *Journal of Fisika* Vo. 4 No. 2, pp. 78-82, 2014.
- [8] F. Kurniawan and I. Isranuri, "Investigation of Tensile Mechanical Characteristics of Aluminium Magnesium (Al-Mg) Alloys Using Conventional Casting Methods," *Journal of Inotera* Vol. 1 No. 1, pp. 1-4, 2016.
- [9] ASTM Standard: Classification for Rating Sound Insulation - ASTM E413-22 DOI: 10.1520/E0413-22, West Conshohocken, PA: ASTM International, 2022.
- [10] S. M. Levy, *Construction Calculation Manual* ISBN 978-0-12-382243-7, Oxford (UK) and Waltham, Massachusetts (United States): Butterworth-Heinemann, Elsevier Inc., 2012.
- [11] J. Loverde and W. Dong, "Comparison of Sound Transmission Class and Outdoor-Indoor Transmission Class for Specification of Exterior Facade Assemblies," *The Journal of the Acoustical Society of America* DOI: 10.1121/1.4987477, vol. 141, no. 5, pp. 3539-3549, 2017.
- [12] D. Egan, *Architectural Acoustics* ISBN 0-07-019053-4, New York: Mc. Graw Hill Book Company, 1988.
- [13] L. Beranek, *Noise Reduction*, New York: Mc Graw Hill Company, 1960.
- [14] F. B. Utomo, B. D. Setyo and M. R. Palupi, "The Analysis Of Sound Transmission Loss On Laminated Glass," *SPEKTRA Journal of Physic and Aplications* doi.org/10.21009/SPEKTRA, vol. 7, no. 1, pp. 51-58, 2022.
- [15] A. S. f. T. Materials, *Form and Style for ASTM Standard*, West Conshohocken, Pennsylvania: Philadelphia, 2022.
- [16] C. Mediastika, L. Kristanto, J. Anggono, F. Suhedi and H. Purwaningsih, "Frame Effects on Outdoor-Indoor Transmission Class of Fixed and Open Glass Windows," *Journal of Computational and Theoretical Nanoscience* DOI: 10.1166/asl.2017.9229, vol. 23, no. 7, pp. 6168-6172, 2017.
- [17] N. R. Syamsiyah and A. Muslim, "Comparative Study of Architectural Style and Spatial Patterns of the Surakarta Grand Mosque and the Yogyakarta Grand Kauman Mosque," *Journal of SINEKTIKA*: <http://dx.doi.org/10.23917/sinektika.v15i1.8989>, vol. 15, no. 1, pp. 1-6, 2018.
- [18] N. R. Syamsiyah, A. Dharoko and S. S. Utami, "Sound Preservation At The Grand Mosque Of Yogyakarta In Indonesia: The Acoustic Performance Of The Traditional Architecture," *AIP Conference Proceedings Journal* DOI 10.1063/1.5043002, vol. 1977, no. 1, 2018.
- [19] M. Syahrul and S. Suharyani, "Evaluation of the Noise Level of Green Open Space in Tirtonadi Park, Surakarta," *Journal of SINEKTIKA* <http://dx.doi.org/10.23917/sinektika.v17i2.11625>, vol. 17, no. 2, pp. 178-182, 2020.