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Sound Preservation at The Grand Mosque of Yogyakarta in Indonesia : The Acoustic Performance of The Traditional Architecture

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Abstract. The Grand Mosque of Yogyakarta keeps the originality since it was built in 1773, both in the structure and construction of traditional Javanese architectural style. The study needs to be done to determine the quality of the acoustics in the main room of the mosque. A study on the mosque acoustic parameters was conducted by measurements of impulse response and soundscape. The mosque interior setting and surrounding based on Javanese traditional architecture form a good quality acoustics and audial comfort in sufficient loudness, the clarity of speech, evenly distributed clarity of sound and optimum reverberation time that affects the clarity of the conversation. Background noise can be overcome with the gurgling sound of water in the pond in front of the mosque, that it can bring hearts at ease, so that noises from children screaming and motorcycle passing can be minimized. This particular quality provides a very strong reason to preserve it. The acoustic characteristics are intangible cultural heritage as well as local wisdom. With its quietness and audial comfort, the mosque is highly expected to be a coaching center for a better generation and the mosque can be used as reference for planning the other mosque.

INTRODUCTION

The Grand Mosque of Yogyakarta is a traditional mosque that was built on a land area of 16,000 m^2 with building area of 2,578 m^2 to accommodate up to 1,200 worshipers. The mosque keeps it originality since it was built, both in the structure and construction of traditional Javanese architectural style. The Grand Mosque of Yogyakarta is the mosque of an Islamic kingdom in Indonesia, that was built on 29 May 1773. This mosque is a cultural heritage based on the decree of Yogyakarta Special Province (DIY) Governor Number 186/2011. The Mosque is a part of Ngayogyakarta Hadiningrat Palace. The location of the mosque is to the west of the main square, and it is adjacent to the palace as the Governor's cum King's office. This setting makes it easier for the King to attend events at the mosque. The existence of the mosque and the main square is mutually supportive in the socio-cultural and socio-spiritual activities.

Some components of the mosque survive until today, such as construction of its wall and roof. There were changes in some parts of the mosque due to the need of repair and after natural disaster. A major earthquake had undermined the mosque portico. On the initiative of the Sultan VI in 1867, the portico was rebuilt with an area twice larger than the previous one. Another change in 1933 was replacement of the roofing shingles with a zinc *wiron* thick layer, and stone floor of the portico was replaced with floral floor tiles. The other replacement was to the material of main room floor in the mosque in 1936, where the black stone floor was changed for Italian marble. Currently, the floor is covered with a thick carpet installed about two years ago.

The Grand Mosque of Yogyakarta was built with the concept of traditional Javanese architecture. The main characteristics of mosques built in 15-16th centuries are symmetrical layout of the building, rectilinear shape of the main room with 1 : 1 proportion, odd number of *tajug* shaped roof layers, natural building materials (natural wood and stone), moat around the portico, and inexistence of minaret [2]. Javanese traditional architecture has construction rule for buildings, including mosques. Josef Prijotomo said that in this mosque the concept of traditional Javanese architecture known as *'petungan'* is used [3]. It contains measurement and count of the of

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the building parts, especially the length, height and number of rafter pillar. In addition, *petungan* also uses proportions. The building proportion is formed not only by construction space and roof but also by characteristics or *pewatakan* of the building owner, in this case Sultan Hamengku Buwono I as the king and initiator of the Yogyakarta Grand Mosque.

BASIC THEORY

Form of Space and Meaning

Architectural essence exists in the form of space. As a divine space, mosques should bring inner peace for worshipers, humility and insignificance in front of God. Human has been endowed sensitivity in interpreting the divine space because basically humans are intelligent and cultured. Translation and meaning of mosques interior design require an understanding of space-forming factor. Sound is one of the encouraging 'spatial' factor [4]. Acoustic measurements are needed to understand the meaning of space. Acoustic measurements include impulse response and soundscape. The results of acoustic measurements will show us how the building design affects the acoustics quality, so that the meaning of space can be understood. Sugiarto said that when we heard auditory sound, we can also see the space meaning (spatiality) [5].

A quality space will be generated from an understanding of space, that is not only in terms of the limited physical form, but also the relationship between shapes, proportions, effects and usefulness [6]. Javanese traditional architecture ruled the shape of the mosque's space and roof, which allows an easy to understand impression and meaning.

Impulse Response and Soundscape Measurement

There are three important components in an acoustic system. Those are the sound source, the medium or sound energy carrier, and the receiver. They are inseparable as the forming factors of acoustic character [7]. Measurement of impulse response was aimed to determine the acoustic characteristics with several parameters: clarity of sound (speech C_{50} and music C_{80}), intelligibility of speech (D_{50}), reverberation time (T_{30}), and background noise. Another acoustic measurement conducted was soundscape, which was aimed at mapping the noise from the mosque's surrounding environment. There are three aspects in soundscape research: architectural form, objective analysis of the sound source, and a subjective evaluation of the environmental noise [8].

Primary measurement in acoustics is reverberation time, as it relates to the absorption coefficient of the space elements. Measurements were performed in a frequency range of 500 Hz to 1000 Hz [9], because if it exceeds 1000 Hz then it must take into account sound absorption by air. Sabine's formula used for calculating reverberation time is as follows:

$$\mathrm{t} = \frac{0{,}161\ x\ V}{\Sigma A\alpha} \tag{1}$$

Where, t is reverberation time (second), v is volume (m^3), A is surface area of room elements (m^2), α is absorption coefficient of material.

RESEARCH METHOD

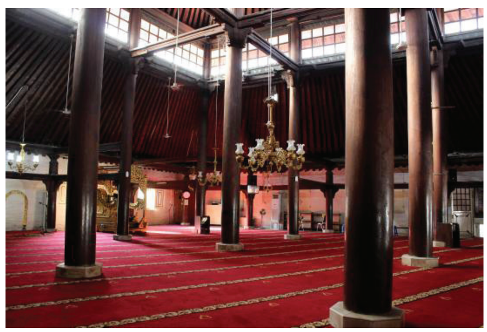
The character of the sound that is non-physical and fills the entire space. Therefore, quantitative or measurable research method is needed to obtain acoustic data. Acoustic measurements include; 1) impulse response measurement in accordance with ISO 3382-2:2008, 2) background noise measurement in accordance with ISO 8253-1, 3) soundscape measurements according to ISO 12931-1-2014. Applied standards includes measurement procedure and analysis methods. Impulse response and background noise measurements employed the following tools: dodecahedron speaker as the sound source, omnidirectional microphone as the receiver, amplifier and sound signal conditioning apparatus, as well as Real-time Analyser Software. Soundscape measurements used H6 Zoom and Adobe Audacity Software. The modelling of measurement results was aided with Surfer 11 geographic information system software that allows easy viewing of noise map. The meaning of quantitative data obtained was then qualitatively interpreted.

RESULT AND DISCUSSION

Acoustic character inside the main hall

There were 25 measuring points (MP) in the main hall of the mosque and 10 measuring points in the portico of the mosque. Measuring points were positioned at a grid so that the value of acoustic parameters could be obtained evenly throughout the room. There were two microphones coded as right and left (mimicking human ears), which were placed sequentially at every measuring point. The sound source was placed at prayer leader's position, at a standing height of 1.55 m. The sound from dodecahedron sound source travels to all directions, and the microphone receives the sound from all directions as well [9]. The results of impulse response measurement are as shown in Table-1. This results were then made into a graphical simulation of acoustic parameters using Surfer 11 software. The existing condition of this research objects can be seen in Figure-1.

The Grand Mosque of Yogyakarta



The main room of mosque

FIGURE 1. The existing condition of research object

TABLE 1. Acoustics Parameters Measurement in Two Different Time

Acoustic Parameters	Mosque (Closed)	Mosque (Open)	Standard
T_{30}	1.55 sec	1.73 sec	1.5-1.8 [10]
C_{50}	0.54 dB	0.75 dB	$C_{50} > 0$ dB [9]
C_{80}	3.26 dB	3.63 dB	$0 < C_{80} < +4$ [11]
D_{50}	51.83%	48.26%	$45 < D_{50} < 70$ [10]
Background Noise	55.51 dB	57.57 dB	25-35 dB [1]

Figure-2 shows the noise mapping pattern of sound pressure level (SPL). The pattern was apparently regular and did not form any of sound wave interference nor sound centralization (sound strengthening or weakening). The sound was distributed evenly, indicated by 3-dimensional gradation pattern that sloped down towards the front direction in a regular manner. The quietest zone was found at the front at 39.25 dB. The SPL value towards the back was higher at 58.72 dB. This finding was supported by the results of questionnaire to 42 respondents aged 20-65 years old. As much as 66.7% of respondents chose to sit at the front of hall, while another 33.3% chose to sit at the middle. The reason for choosing the front seat was because it was quieter (66.7%).

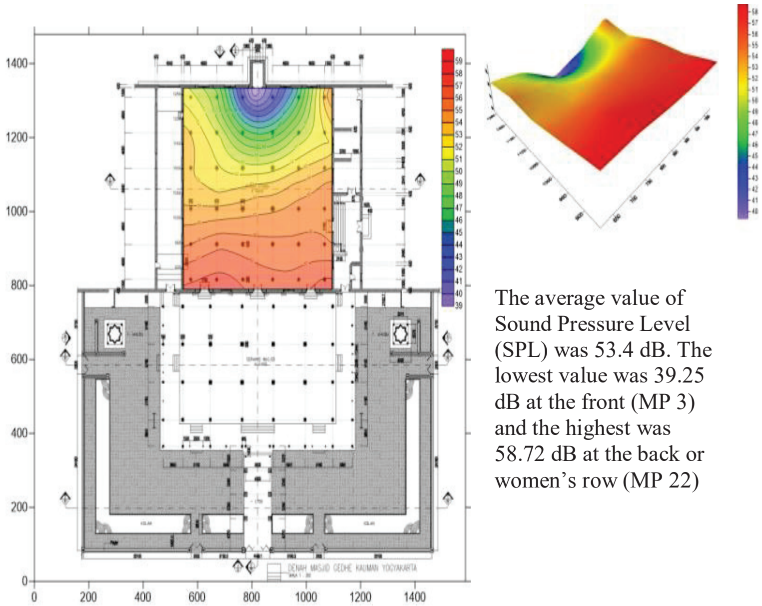


FIGURE 2. SPL noise mapping in main hall by Surfer 11 software

Sarwono said that the acoustics of a mosque will provide audial and aural comfort if one considers the geometrical form of the room, avoids parallel hard surfaces and hard surfaces on the rear wall of the mosque, and uses materials with different acoustic hardnesses to cover the opposing surfaces [7]. Although the mosque geometry is square, it does not produce any flutter echoes because it was built from appropriate materials as an absorber. The surface of room elements adapts to the sound absorption coefficient following standards in Table-2[12].

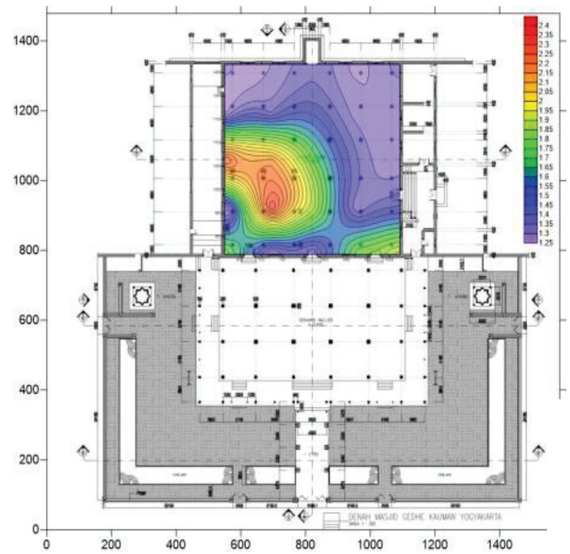
TABLE 2. Sound Absorption Coefficient of Room Elemen Material

Room Elements	Materials	Absorption Coefficient 500 Hz	1000 Hz	2000 Hz
Floor	Carpet t.1,5 cm	0.35	0.40	0.50
Wall	Sandstone without finishing	0.03	0.04	0.05
Pillar and beam	wood	0.10	0.07	0.06
Ceiling	Wooden board	0.17	0.09	0.10

Reflected sound energy was low, as indicated by short reverberation time (T_{30}) and compliance to standard (Table-1). This result indicates that the existing space (especially the covering materials of space element as well as their size and proportions) was able to absorb sound energy early enough before it was reflected.

Ceiling is a room divider element that is not covered by other elements, so it potentially produces sound reflections. This is in contrast with carpeted floors and walls which are obstructed by pillars and beams. Wooden ceiling board of 591.14 m^2 actually has a low level of sound energy absorption. However, due to the high ceiling position at 17 meters from the floor, the initial sound energy decayed in the air before it reached the ceiling. Figure-3 shows a map of sound absorption for reverberation time analysis.

The value of background noise did not comply with standards, which it was higher than standards, but it did not mean that the room was uncomfortable. The voice of prayer leader was still audible, sound clarity was maintained, which values are shown in Table-2. The results of questionnaire also explain that 95% of respondents sensed that the voice of prayer leader was clear. The noise distribution was still within tolerable limits, as proved by regular pattern in noise map formed (see Figure-2). Measurements were made at the time of maximum noise at 07:30 to 11:30 am. Noises around the mosque courtyard came from students' shouting and their teacher's whistle while they were sporting there, motorcycle passing by, trumpet of ice seller, and other noise sources.



The lowest value of T_{30} was at MP 4 (1.28 seconds) at the front of the mosque main hall. The highest value (2.399 seconds) was at MP 17 at women prayer room. A teak wood divider board was the cause of sound reflection.

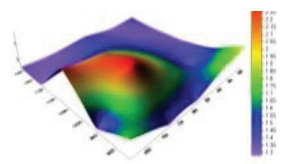
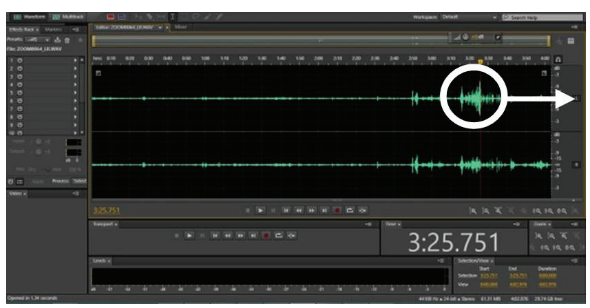


FIGURE 3. The mapping of reverberation time T_{30}

Acoustic character in the mosque portico

The mosque portico is a place for religious and socio-cultural activities, which require audial and aural comfort. The noise around the portico was recorded in WAV format. The signal was then processed in Adobe Audition software to perform frequency analysis of Sound Pressure Level (SPL) in decibel unit. The recorded results in the form of Fast Fourier Transform (FFT) graphs for an easy soundscape analysis of noise identification as shown in Figures-4 and 5.



The maximum noise level of students shouting while running in sport activities was 68.9 dB at 1548 Hz frequency

FIGURE 4. Waveform as a result analysis of Adobe Audition software

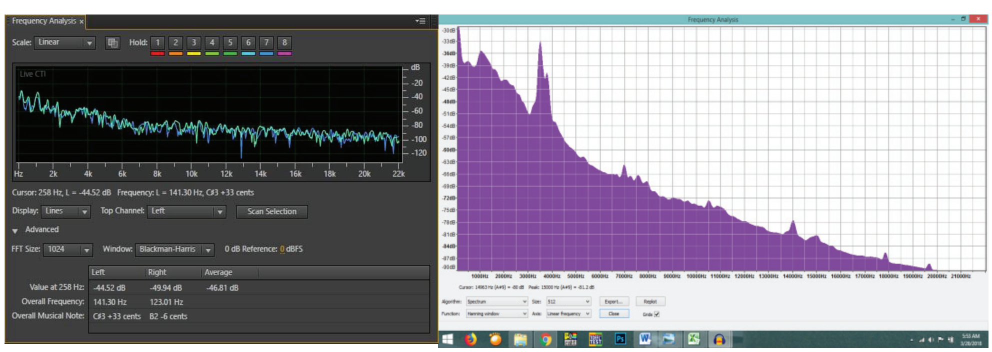


FIGURE 5. Results of audio signal reading by Adobe Audition software (left) and Audacity software (right) for the same waveform signal

The highest SPL based on the software processing results was the sound of children shouting, which reached 68.9 dB. It is also in accordance with the opinion of 64.3% respondents that the most disturbing noises were the shouts of children while only 33% said that interference came from the motorcycles passing across the courtyard. Noises are usually heard when the courtyard is used for sporting activities by students at 7:30 to 09:00 a.m. At that time the mosque is not used for congregational prayer. The congregation is usually between 11:30 a.m. to 19:00 p.m when there is no activity in the courtyard of the mosque so that the worshippers will not be disturbed by any noises. There were several kinds of noises around the mosque and their influence into the mosque inside space which were recorded by H6 Zoom as seen in Figure 6.

Among various noises around the mosque, the percentage of children's shouting was the highest 50.9% (Figure-6). This result is supported by the opinion of questionnaire respondent. The effect of noise was not so influential inside the mosque. Figure-7 shows the values of clarity C_{50} and C_{80}. They were stable on standardized range. The higher the value of C_{50}, the shorter the reverberation time, and vice versa, and the higher the value of C_{80}, the poorer the sound will be. At MP 4 at the front, C_{50} and C_{80} exceeded their standard. At this position, the worshippers can directly hear the voice of prayer leader more clearly than the reflected sound.

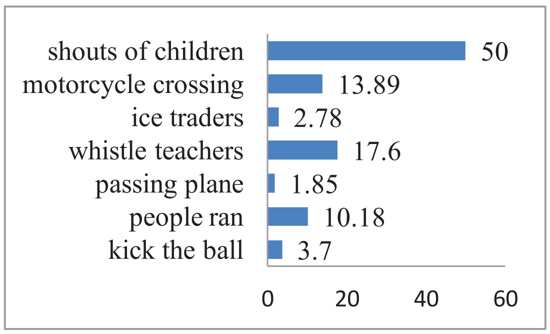


FIGURE 6. Various sources of noise

In Figure-7 SPL value raised and decreased at the front row zone (MP 3-7). SPL was the lowest at MP 3, measured at 39.25 dB, indicating that the front zone has the lowest reverberation time and highest clarity of speech. This means that the surface of absorbing element has a large area and high value of absorbing coefficient.

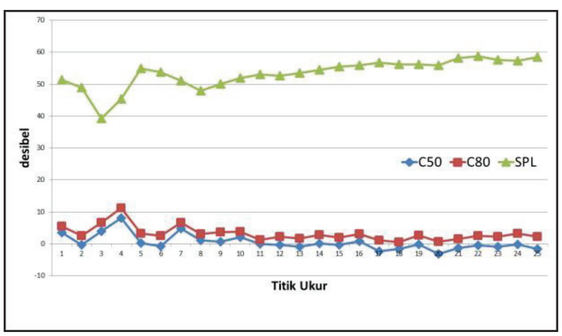
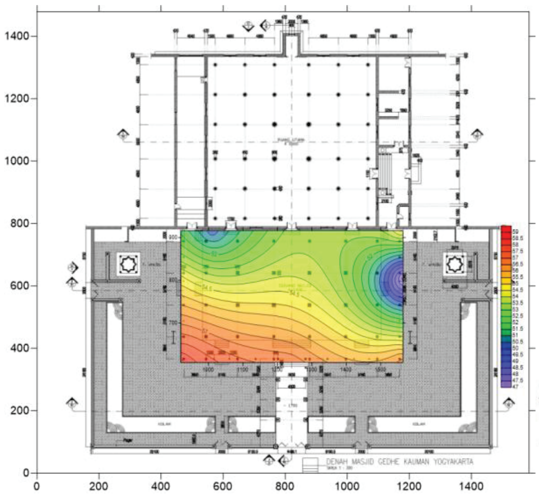
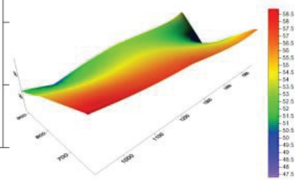


FIGURE 7. The clarity of sound

Effects of noise around mosque portico is reflected in the noise map of Figure-8.

The mosque portico can still provide a comfortable and quiet place to sit and waiting for prayer time, reading Qur'an, discussions, and other religious activities. Based on field observations, before *Zhuhur* time many people had a relax sit and even slept on the north side of the portico. The worshippers were interviewed about the most comfortable place in the portico. They said that the north side of the portico was the best because it was quieter than the others. The sound of water in the pond and fountain around the portico created comfortable and natural atmosphere. Based on the questionnaire results, 66.7% of respondents liked the portico as a place of activities besides the daily prayers, by the reason of quiet atmosphere (59.5%) and conducive aeration (38%).





The lowest average SPL was at the north side at 47.23 dB and the highest was at south east side at 58.85 dB. Measurements were in frequency range of 861 Hz-1464 Hz.

FIGURE 8. SPL noise mapping in portico by Surfer 11 software

CONCLUSIONS

The Grand Mosque of Yogyakarta with Javanese traditional architecture is the building of high historical value. It was proven to have a good acoustics as an intangible cultural heritage. The preservation of good acoustic quality must be done, while maintaining the interior and exterior settings. Measurements of impulse responses identify that the form, size, and type of material affect the quality of acoustics. Measurements of soundscape provide information that the most disturbing sounds were the shouts of children. Interior and exterior simulations show that the most comfortable and quiet place to worship is the front row of the mosque main hall. Meanwhile the northern side of the mosque portico is the most comfortable and quiet place for other activities.

This research has provided knowledge about some things that need to be considered in the planning of mosques, those are the proportions of the building and the main room of worship, room material as an absorber and diffusor, zoning activities must be separated clearly between the activity of prayers and social religious activities, and the last is a need a park around the mosque which include a fountain and vegetation, as a local climate regulator and as a place that can reduce the background noise.

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