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ASSESSMENT OF NOISE LEVELS IN OLD CHURCHES CAUSED BY OUTDOOR SOUND AND PROPOSED IMPROVEMENTS

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Abstract

This study aims to investigate the sound quality inside two churches, both of which are old or somewhat aged, in the city of Manado, Indonesia. The design and age of walls and windows and the distance of the buildings from the road influence the sound comfort within the rooms. Two church buildings served as cases: The Church of Sam Ratulangi University (built-in 1992) and the Bethesda Ranotana Church (built in 1967) in Manado City, Indonesia. A motorcycle was placed outside the room near the fence as the sound source. The level of sound source was varied from about 60 to 100 dB. The received sound level was measured, recorded, and calculated at distance intervals every 2 m outside and inside. Measurement was realized using two Sound Level Meters with data loggers. The result from the measurements showed that the noise level was higher indoor. Calculations were conducted using acoustics theory and I_Simpa software, focusing on the initial design and proposed design improvements. The measurement and calculation results indicate that the interior space experiences excessive noise due to sounds from outside. The calculations were then conducted to provide input for improving the design of the interior space and the building envelope to reduce the noise levels within the room. Based on a proposition of design improvements, the indoor acoustic performance of churches can theoretically be achieved to a higher quality, aiming to meet the maximum indoor noise criteria for churches, which is less than 35 dB.

Keywords: Noise, Outdoor, Indoor, Church.

1. INTRODUCTION

It is challenging to prevent outdoor noise from penetrating indoor spaces of buildings situated along heavily trafficked roads. Noise pollution, a subset of environmental pollution, poses health risks and is frequently encountered (Drew *et al*., 2017; Septiana & Widowati, 2017). Generally, noise pollution from automobile traffic significantly impacts the urban environment (Mavrin *et al*., 2018). Many buildings are designed with natural ventilation concepts employing wide openings for adequate airflow, but this approach also facilitates noise transmission through windows and open doors. This issue requires investigation to develop design solutions aimed at reducing noise infiltration. Initially, it is essential to determine the outdoor sound intensity levels penetrating building openings or facades. Wide-open windows in walls are particularly susceptible to external noise, disrupting room communication (Subagio, 2017).

Additionally, air conditioners, ceiling fans, electrical switches, and even footsteps contribute to indoor noise generation in auditoriums. The noise produced by these appliances can be highly disruptive. Door openings, windows, and furniture movement also contribute to noise within church auditoriums (Ezetu E I and Alibaba H Z, 2015).

This study conducted acoustical research on noise penetration into two old or aged worship buildings: the Church of Sam Ratulangi University buil,t in 1992, and the Bethesda Ranotana Church, which was built in 1967, located in Manado City, Indonesia (FIGURES 1 and 2). These churches were selected due to their proximity

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to roads, which increases the potential for environmental noise within their rooms. Furthermore, the buildings are relatively close to the roadside, approximately 10 meters away, increasing the likelihood of noise transmission. Both churches are designed with natural ventilation concepts, incorporating wide openings to allow fresh outdoor air to enter. Old buildings in tropical climate areas located in urban areas are generally designed relying on natural ventilation, thus employing wide openings. The areas around these two churches were relatively quiet in the past, with minimal air pollution and little traffic. Therefore, the ventilation openings at that time could function optimally as places for fresh air flow and did not become sound transmission holes from traffic noise. However, now the situation has changed; the streets around the churches are busy with traffic, making it a source of noise that enters the room through these window openings. The walls are constructed of masonry plastered with cement and painted white. Some grass, trees, and flower plants are in the yards, though they are relatively dense.

Worship buildings, such as churches, require protection against noise risks, as noise can disrupt the solemnity of the worship process. According to the Indonesian standard SNI 03-6386-2000, the interior rooms of church worship buildings must adhere to a maximum indoor noise standard of 35 dB. Additionally, studies have shown that sound generated from inside the churches may contribute to environmental outdoor noise pollution in the surrounding area (Bojongo, 2020; Gemade & Inja, 2020; Christan & Eberechi, 2019). Increasing indoor sound volume may be necessary in certain situations to counteract external noise."

Apart from the limitation of noise in the church, there is also a requirement for reverberation time (RT) figures (in seconds) for rooms with church functions. Referring to the Indonesian Standard, SNI 03-6386-2000, the value of RT for a prayer room is 1.6 to 2.6 seconds. The larger the RT value, the greater the echo in the room, which will not be comfortable for worship. However, certain echo sounds are still needed for the worship procession. In general, the size of the reverberation time is determined by the material properties of the room interior, which can absorb sound; therefore, there is no excessive reflected sound.

Even though the building has some openings, the configuration of open windows may still reduce outdoor noise. Windows that need to be fully opened are still expected to reduce noise substantially. Mediastika (Mediastika et al., 2018) conducted a laboratory experiment to determine the effectiveness of open windows in reducing noise. The results show that windows with a tilt angle of 10 degrees can still reduce noise by 5 dB. Meanwhile, if the tilt is only 5 degrees, it can reduce noise by 7 dB. A study by Du (Du *et al*., 2019) on noise reduction due to glass ventilation with a permeability of about 20% shows an opportunity for noise reduction of around 8 to 12 dB, depending on the octave applied.

Additionally, the research results by Barbara Locher et al. (Locher B *et al*. 2018) regarding the transmission loss of open windows in apartments show that noise reduction can occur by up to 10 dB in rooms where the interior lacks good sound absorption. A study on the noise reduction of the envelope wall system of hotel rooms equipped with glass windows, which are not too wide (approximately 50% of the associated walls) and located close to the railway, can demonstrate a noise reduction rate of about 12 to 15 dB (Kusuma et al., 2015). Sound-absorbing material has been installed on the inside walls of the hotel room to reduce indoor noise. The sound

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absorption properties of the material in the room contribute to the reduction of indoor noise.

In this study, the architectural configuration of the window openings in both churches comprises approximately 30% of their corresponding walls. Typically, the windows are fully opened during worship activities to facilitate good air ventilation from outdoors. According to the results of the studies mentioned above, this opening configuration hypothetically cannot significantly reduce noise. However, this research aims to determine the magnitude of noise reduction that occurs in both churches. This aims to understand how much noise reduction occurs due to the distance of the building from the sound source on the road, as well as the role of window openings and interior elements.

The results of this study may then lead to the conclusion of whether the rooms in the churches meet the maximum noise standard requirements. Additionally, this study aims to identify the pattern of contour lines of sound propagation from outside to inside to guide practical efforts to improve indoor acoustic quality.

Figure 1: Church of Sam Ratulangi University

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Figure 2: Church of Bethesda Ranotana, Manado

2. METHOD

The study employed a quantitative method, utilizing field measurements, calculations performed using spreadsheets, and the application of a software package.

2.1 Measurement

In the process of measuring sound intensity, researchers used two Sound Level Meters to measure the loudness level in dB(A) for measuring the level of sound source and received sound. The sound of a motorcycle engine was used as the sound source and placed on the road near the fence of the building.

Its sound level was set at 60, 70, 80, 90, and 100 dB, with a tolerance of about 5%. The value of 100 dB was applied as the maximum sound intensity level, which corresponds to the standard of horn sound as referred to in PP No. 55 of 2012 (Indonesian regulation on vehicles).

The regulation mentions that the lowest level of horn sound is 83 dB(A), while the highest is 118 dB(A). The sound source from the motorcycle engine, located on the street, emitted a strong and constant sound. The level of received sound was then measured at every 2 meters distance.

Measurements with a sound level meter were taken from outdoor areas to the center of the room (see Fig. 3 and 4). The Sound Level Meter was positioned at a height of 1.5 meters from the ground or floor. The measurement method also refers to Appendix II of the Decree of the Minister of Environment of Indonesia, KEP-48/MENLH/11/1996.

2.2 Calculation

The calculation of noise reduction due to the distance factor (between the sound source and receiver) was conducted, following the general formula of sound propagation based on a spherical sound distribution pattern.

The general equations of acoustic theory on sound propagation and sound intensity level are as follows (Patel, 2020):

$$I_1 = \frac{P}{4\pi(r_1)^2}\ ;\ I_2 = \frac{P}{4\pi(r_2)^2}\ ;\ I_n = \frac{P}{4\pi(r_n)^2},\ ;\ \text{and}\ IL = 10\ log\ \frac{I}{I_o}\ ; \qquad \textit{(Eq.1)}$$

$$\Delta IL = IL_2 - IL_1 = 10\,log\frac{I_2}{I_o} - 10\ log\ \frac{I_1}{I_o} \qquad \textit{(Eq.2)}$$

Where *I* is the sound intensity, and *r* is the distance between the receiver and the sound source, *P* is the sound power and *IL* is the sound intensity level.

Meanwhile, noise reduction in the building, considering the sound absorption factor of the receiving room and the impact of sound sources in attached rooms, can be estimated through the general formula of Noise Reduction (NR) (Patel, 2020) as follows:

$$NR = IL_1 - IL_2 \qquad \textit{(Eq.3)}$$

$$NR = SRI - 10\,log\frac{A_S}{\sum A_{i(2)}a_{i(2)}} \qquad \textit{(Eq.4)}$$

Where IL_1 is the outside sound intensity level, IL_2 is the indoor sound intensity level; *SRI* is the Sound Reduction Index of the separation wall, and a_i is the coefficient of sound absorption of the surfaces in receiving room, A_i is the area of the wall surface in the receiving room. A_s is the separation wall area.

The measurement results of IL_1 and IL_2 will then be used as inputs in the calculation process to obtain the values of *NR* and *SRI*.

Apart from its role as a factor to counteract noise from outside sounds in the room, the reverberation time (RT, in seconds) must be adequate or in accordance with the function of the room. The formula for calculating the reverberation time is as follows (Szokolay, 2004):

$$RT = \frac{1}{6}x\frac{V}{\sum aA} \qquad \textit{(Eq.5)}$$

Where V is the volume of room (in m^3), A is the sound absorption coefficient of a surface, A is area of the surface (in m^2).

2.3 Simulation with I_Simpa. Program

I_Simpa is a program package for calculating and visualizing the distribution of sound propagation. In this study, it was used to compare the results of calculations (manual) with the results from measurements, as well as to visualize the contour line pattern of the sound spread from outside to the worship room.

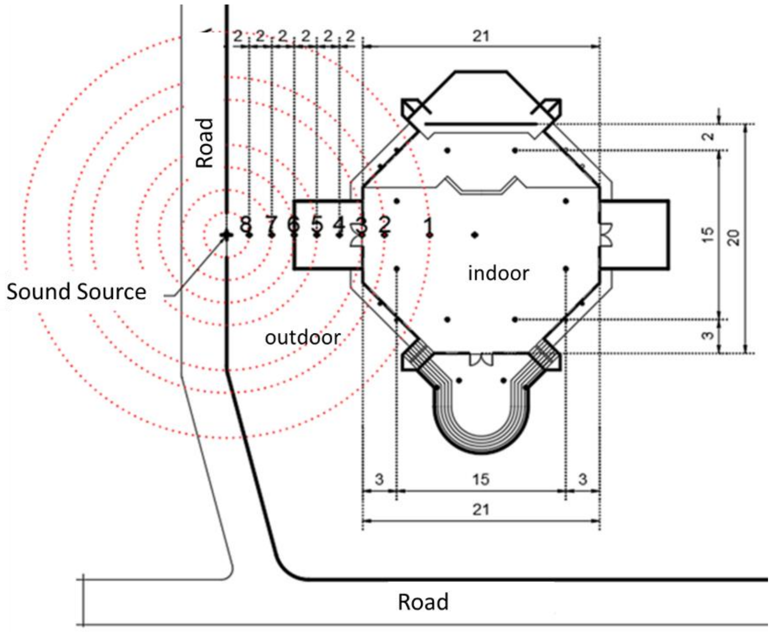

Figure 3: Plan of Church of Sam Ratulangi University, Manado

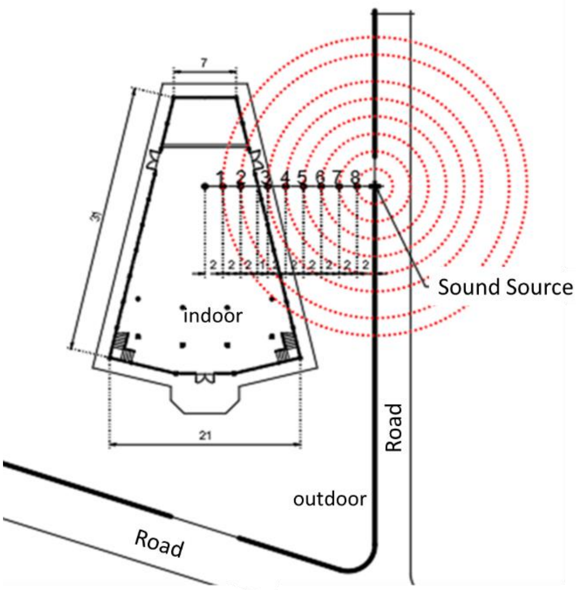

Figure 4: Plan of Bethesda Ranotana Church, Manado

3. RESULTS AND DISCUSSION

3.1 Analysis of Existing Condition

The measurement results show a significant decrease in sound intensity from the sound source outside to the inside. Both church buildings exhibit the same tendency. The results of the measurements at the Church of Sam Ratulangi University are shown in FIGURE 5. By applying a sound source of 100 dBA at the road, a normal graph was observed, where the sound intensity decreased non-linearly along the distance from the source until reaching the indoor area of the church. An anomalous graph was found at distances from 2 to 4 meters when the sound source was changed to 70 and 90 dBA. The sound intensities were recorded very low at distances of 2 and 4 meters

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from the source, and increased at a distance of 6 meters, then decreased normally until indoors. This anomalous sound intensity can occur due to other background noise that cannot be intervened by researchers, such as the sound of wind, birds, people, or cars and other motorcycles passing by the road. The other background sound can either strengthen or weaken the received sound due to the mechanism of sound wave interference. A study by Mama (Mama *et al*., 2018) has found a similar situation regarding the influence of background noises. In this study, when a sound source of 100 dBA from a motorcycle engine on the road was applied, the indoor sound intensity at the center of the worship room was recorded at a level of 67.1 dBA, or equal to 32.9 dB of NR (Noise Reduction). As it is known, the value of Noise Reduction (NR) is equal to the sound source intensity minus the received sound, or NR = IL_1 - IL_2 as mentioned in equation 3. In the next step, when applying a noise source of 90 dBA, the indoor sound intensity level was recorded at 75.6 dBA or NR equal to 14.4 dB. However, by applying a 70 dBA sound source, the Noise Reduction (NR) achieved was only 8.6 dB, meaning a sound intensity of 61.4 dBA was recorded in the center of the worship room. This is the lowest indoor sound intensity found in the measurement at the Sam Ratulangi University Church. For comparison, a study by Mediastika (Mediastika, 2018) shows that an opened window of a building envelope can only produce NR in the range of 5 to 10 dB. The results of the study by Du (Du *et al*., 2019) also show that the NR of a building envelope with a large porosity can only range from 8 to 12 dB. The values of NR found in this study are not much different from the studies of Du and Mediastika. Additionally, the sound intensity heard inside the Church of Sam Ratulangi University did not meet the standard of indoor noise according to SNI 03-6386-2000 (Indonesian Standard), which should be a maximum of 35 dB.

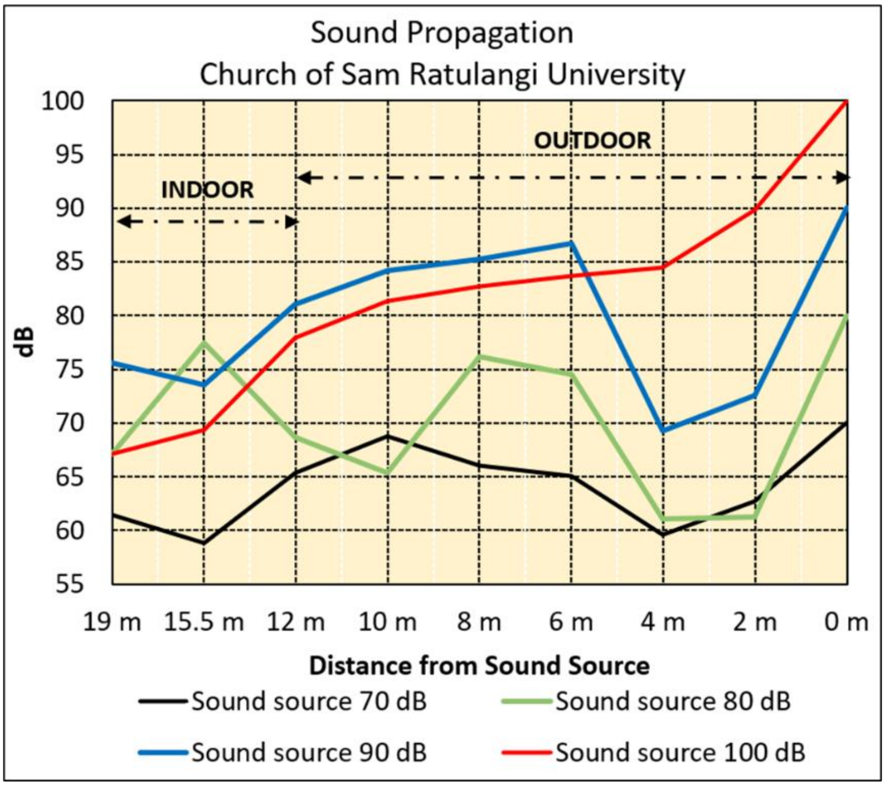

Figure 5: Measurement results of Sam Ratulangi University Church

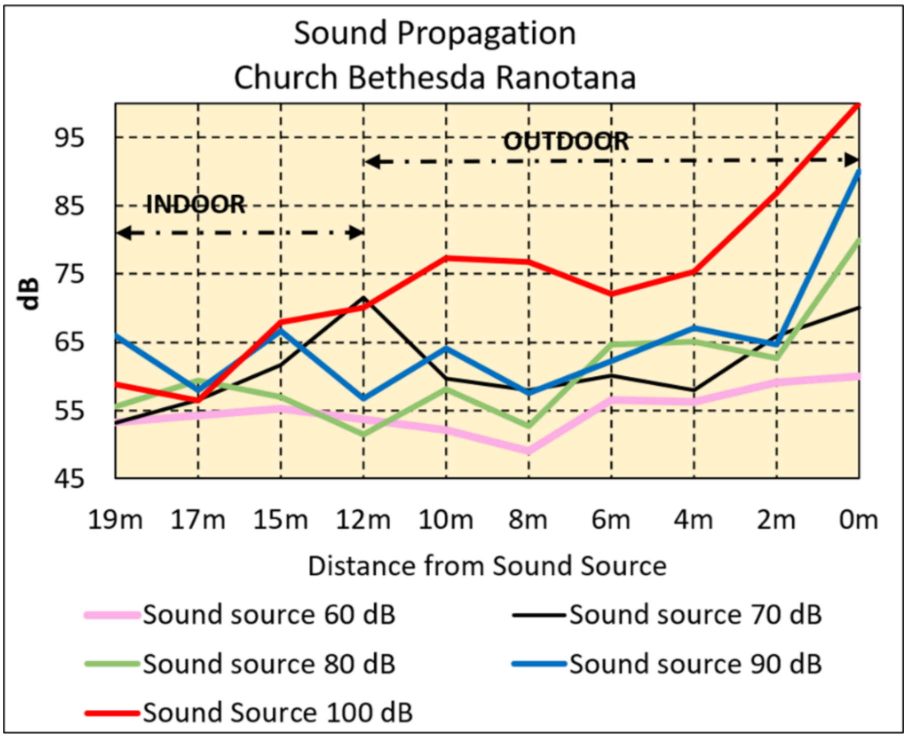

Figure 6: Measurement results of Bethesda Ranotana Church

Similar results and trends of NR were obtained from sound measurements at the Bethesda Ranotana Church (FIGURE 6). By applying a sound source of 100 dBA, an indoor sound intensity of 58.5 dB was found, resulting in an NR of 41.5 dB.

At the measuring points from a distance of 4 to 10 meters, there are indications of anomalies, where the sound level increases slightly. This may be due to unanticipated background noises, such as the sound of birds, wind, vehicles, etc. The graph in Figure 6 generally shows that at a distance of 2 to 6 meters from the sound source, the noise intensity level decreases significantly, and after that, decreases with a gentle slope, which is close to the logarithmic graph pattern as stated in the theory of sound propagation.

The graph in Figure 6 also shows that the sound intensity level in the room did not meet the maximum noise standard of the church's worship room according to the Indonesian Standard (SNI). The indoor sound found in this study was categorized as too loud. Even by applying a sound source with a lower intensity of 60 dB(A), an indoor sound intensity of 53.2 dBA was obtained, resulting in an NR of only 6.8 dB. According to Indonesian standards, the maximum noise level in a church room is 35 dB(A).

Comparisons between measurement and calculation were realized. The calculations were conducted using equations (Eq.1 to Eq.4) from Patel (Patel, 2020) and by using the I_Simpa program. In this calculation, the value of SRI (Eq.4) was set at 8 dB, referring to the study by Du (Du et al., 2019). In this step, the room was considered empty. The sound absorption impact of human bodies is therefore neglected in this calculation step. The results of the comparison are shown in tables 1 and 2.

The level of the sound source 100 dB was chosen in the discussion of the comparison since a loudness of 100 dB is considered to represent the sound of a horn, where the sound of car horns generally ranges between 90 to 102 dB (Supriatna and Kosasih, 2020).

Table 1: Comparison results of sound level (in dB) of Sam Ratulangi Univesity Church

Method	Position of sound reception & distance from the source								
	Indoor		Outdoor						
	1	2	3	4	5	6	7	8	9
	19m	15.5m	12m	10m	8m	6m	4m	2m	0m
Manual NR Calculation	70.7	70.7	78.6	80.1	82.1	84.6	88.1	94.1	100
By Software I_Simpa	71.4	73.3	78.5	79.9	81.9	84.4	87.9	94.1	100
By measurement	67.1	69.3	77.9	81.3	82.7	83.7	84.5	89.8	100

Table 2: Comparison results of sound level (in dB) of Bethesda Ranotana Church

Method	Position of sound reception & distance from the source									
	Indoor			Outdoor						
	1	2	3	4	5	6	7	8	9	10
	19m	17m	15m	12m	10m	8m	6m	4m	2m	0m
Manual NR Calculation	73.9	73.9	73.9	78.6	80.1	82.1	84.6	88.1	94.1	100
By Software I_Simpa	71.6	74.6	74.9	78	80	82.1	84.6	88.1	94.2	100
By measurement	58.8	56.4	67.9	70.1	77.3	76.8	72.1	75.4	86.9	100

The comparison between the measurement results and the calculation of sound intensity is presented in TABLE 1 and 2, specifically discussing the sound source of 100 dB. In Table 1, it is shown that at the Church of Sam Ratulangi University, through manual calculation, the sound intensity level reaches 70.7 dB in the middle of the worship room. This value is 3.6 dB higher than the measurement results. Based on the simulation using I_Simpa, the sound intensity in the center of the room is 71.4 dB, which means it is 4.3 dB greater than the measurement results. The difference between the measurement and calculation results is not more than 7%. By paying attention to the value of the sound intensity level in the middle of the room, it can also be seen that the amount of noise reduction resulting from manual calculations is (100-70.7) dB = 29.3 dB. Meanwhile, by using the I_Simpa software, it can be seen that the amount of Noise Reduction is (100-71.4) dB = 28.6 dB. The measurement results show that the Noise Reduction is (100-67.1) dB = 32.9 dB. The term of Noise Reduction in this case is the value that indicates the total role of the factors of distance from the sound source, courtyard landscape, and interior architecture in reducing noise from the road. To find out the single role of interior architecture in reducing the noise, it can be shown by the difference between the noise on the outside wall position, and against the center of the room (TABLE 3). Based on the results of calculations, interior architecture contributes to noise reduction of (78.6-70.7) dB = 7.9 dB. Meanwhile, based on the measurement results, the contribution of interior architecture to noise reduction is (77.9-67.1) dB = 10.8 dB. From the results with I_Simpa, it can be seen that the contribution of interior architecture to noise reduction is (78.5-71.4) dB = 7.1 dB.

Table 3: Noise Reduction from outdoor sound 100 dB

Method	Noise Reduction from source at road to the center of room		Noise Reduction due to interior performance	
	Sam Ratulangi University Church	Bethesda Ranotana Church	Sam Ratulangi University Church	Bethesda Ranotana Church
NR Calculation	29.3	26.1	7.9	4.7
Software I_Simpa	28.6	28.4	7.1	6.4
Measurement	32.9	41.2	10.8	11.3

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A similar tendency was also found in the case of the Ranotana Bethesda Church, where noise reduction was found to be between 26.1 and 41.2 dB. These values indicate the roles of the building's distance from the road, landscaping, fence, and interior architecture of the church in total noise reduction. Specifically, the contribution of interior architecture to noise reduction ranges from 4.3 to 11.7 dB.

For comparison, the results of measurements at the Puh Sarang Church, an older church in Kediri City, Indonesia, which has openings of 50% in the corresponding wall, showed that the building envelope is only able to reduce outdoor noise by about 11 dB at frequencies from 500 to 1000 Hz (Poetiray, *et al*., 2015).

The results of the visualization of sound propagation through simulation using the software I_Simpa show the role of window openings that contribute to the entry of noise into the room (FIGURES 7 and 8). Figures 7 and 8 also demonstrate that in positions outside the building, sound propagation does not encounter obstacles, as indicated by an even color map. However, behind the walls of the building, a color map appears, showing that some sound is blocked, and only a portion can enter. Nevertheless, the noise that still enters the building remains too loud, especially in cases where the sound source on the street is 100 dB.

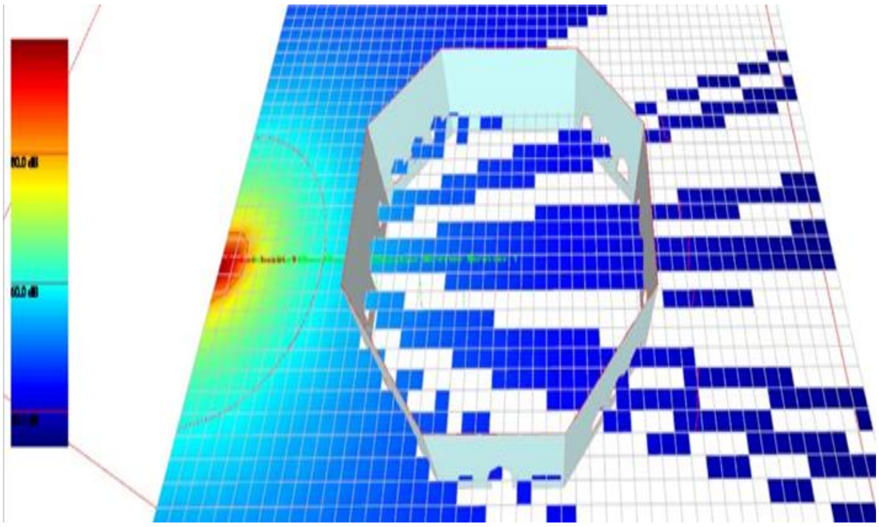

Figure 7: Pattern of sound propagation in Sam Ratulangi University Church

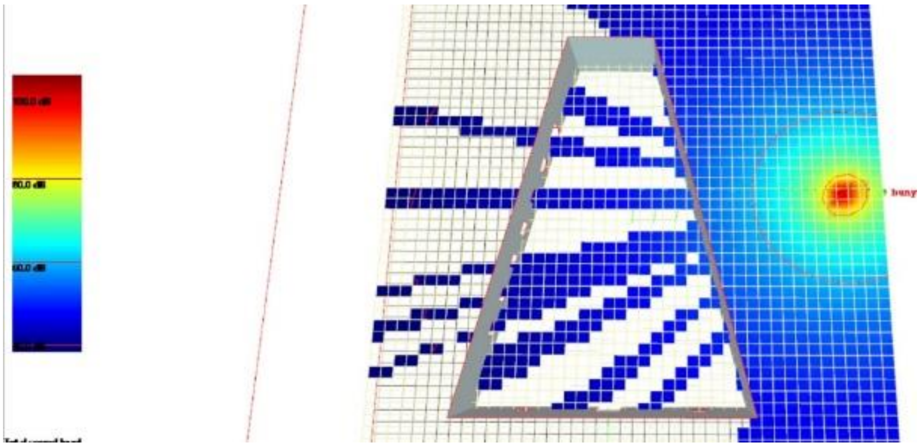

Figure 8: Pattern of sound propagation in Bethesda Ranotana University Church

3.2 Analysis of a proposition to modify interior and wall

The results of measurements, manual calculations, and software simulations show that the existing designs of those two old churches do not produce good acoustical sound quality in the room, and this poses a risk of disrupting worship activities inside. Therefore, in the next stage, it is necessary to propose a design improvement that can produce adequate noise reduction.

In this step, it is a proposition to improve the architectural design of the church building, which consists of enhancements to the wall system and it is interior. The envelope wall is proposed to be a massive soundproof wall with windows and doors tightly closed. It is still possible to have openings only for the need of additional natural lighting, but not for ventilation holes. Therefore, the buildings should be equipped with an air-conditioning system.

Noise reduction from a wall system, as described in equation 4, consists of two parts: the role of the Sound Reduction Index (SRI) of the wall adjacent to the outdoor space, and the role of the acoustic properties of the interior. To achieve a higher SRI, it is necessary to apply a wall system with specific material and thickness so that sound from outside experiences a significant sound transmission loss. Meanwhile, to achieve better acoustic properties in the interior, acoustic materials can be added to the surfaces of the walls, floors, and ceilings. In addition, soft furniture and the human body are also effective as sound absorbers.

The use of window glass may still be applied, provided that the construction or type of glass is capable of significantly isolating noise. The use of glass in walls is still necessary for natural light openings, although they do not need to be excessively wide.

The wall, made of 11 cm thick plastered masonry, can reduce sound by 36 dB (at a frequency of 250 Hz), 40 dB (at a frequency of 500 Hz), and 50 dB (at a frequency of 1000 Hz), as mentioned by Szokolay (Szokolay, 2004). A similar value of sound reduction by brickworks or plastered masonry is also shown by Granzotto (Granzotto, *et al*., 2020).

The frequency range of the sound is to be taken between 250 to 1000 Hz, considering that the average traffic sound, which includes vehicle engine and horn noise, generally falls within that frequency range (Long, 2006). A window pane can be located on the wall to allow natural lighting to enter. The sound insulation due to double glass, with a thickness of 6 mm each, spaced 10 cm apart, can reach 35 to 50 dB at a frequency that around from 250 to 1000 Hz. Meanwhile, a single glass with a thickness of 6 mm is only able to reduce sound by about 25 dB at a frequency of 250 to 1000 Hz (Long, 2006, page 340). In the proposed design improvement, double glazing is used, but only covers 10% of the wall area. Generally, the construction of double-glazed windows is expensive, so the application of double glass is limited.

The amount of sound absorption in the room also plays a significant role in reducing noise. In the practice of indoor acoustics, sound-absorbing materials are used on the inner wall surface. The type of chair also contributes to the sound absorption rate. Generally, soft materials such as carpets, textiles, and rubber have good sound absorption properties, and these materials can be applied in the improvement of church design. Information regarding the sound absorption coefficient of each material can be obtained from various sources, including Szokolay (Szokolay, 2004). Heavy carpet material has a sound absorption coefficient of 0.65, which can be used for floors

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and even attached to wall surfaces. Plywood with a sound absorption rate of 0.15 can be used for the ceiling. Chairs made of soft materials also have sound absorption properties, with an absorption coefficient of 0.15 per seat (Szokolay, 2004).

In the proposal for the improvement of the design, a simulation was conducted where the walls are made from masonry and attached by a heavy carpet at the indoor surface. The floor tiles are also covered with heavy carpet, and the ceiling is made from plywood (TABLES 4 and 5).

Chairs are of soft material, and a double-glazed window covers only 10% of the related wall area. In the room, there are 200 chairs made of soft material. This type of material will be applied to the design of the two old churches. By applying such a building envelope, the Sound Reduction Index (SRI) amounts to 40 dB, considering a frequency value of 500 Hz of the received sound level

The results of calculations for the proposed design improvements are shown in TABLES 4 and 5. The enhancement of acoustic quality through material improvements will increase the Noise Reduction value, thereby producing adequate sound level intensity in the room compared to the initial design.

In the case of the Sam Ratulangi University church, applying a 100 dB sound source on the street with design improvements can result in a sound reduction of 45.9 dB in the room, consequently lowering the indoor sound level intensity to a very low 28 dB. In contrast, using the initial design, the calculated sound intensity level in the room can reach 70.7 dB (TABLE 1). However, the Indonesian standard for noise criteria or sound intensity level in worship rooms is a maximum of 35 dB.

Improvements to the interior acoustics of the church have resulted in a very low reverberation time of 0.5 seconds, whereas the required values are in the range between 1.6 and 2.8 seconds. Design improvements, such as applying a lot of sound-absorbing materials in the room, on the other hand, cause a significant reduction in the number of reverberations.

However, achieving an appropriate reverberation time in indoor space can be accomplished by applying a sound system or electro-acoustic technology (Jeong D, *et al*, 2010). The echo sound can be adjusted using the amplifier device, and the placement of the loudspeaker and microphone in the room can produce an adequate reverberation time. Electro-acoustic simulations can be conducted in future studies to obtain an echo sound in accordance with the function of the church room.

Similarly, for the Bethesda Ranotana Church, using the same design improvement concept can lead to greater noise reduction. Thus, the maximum sound level value in a room that meets the requirements can be obtained, which is less than 35 dB, and in this case, a value of 34.2 dB can be achieved (TABLE 5). If the sound source on the street is less than 100 dB, an indoor room sound level of less than 34.2 dB will be obtained.

The implementation of the improvement design also shows a reduced reverberation time at the Bethesda Ranotana church to only 0.65 seconds, while the standard range value of reverberation time for the church room is 1.6 to 2.8 seconds. In this case, the use of the electro-acoustic concept is also feasible to increase the value of the reverberation time for future research.

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Table 4: Results of Acoustical Calculation of a Proposed Design Improvement of Sam Ratulangi University Church. Sound source at road=100 dB

Surface	Area	unit	a	a x Area = Sabin	Note:
Wall	384	m^2	0.65	249.6	Heavy Carpet
Ceiling	344.5	m^2	0.1	34.4	Plywood
Floor	344.5	m^2	0.65	223.9	Heavy Carpet
Window	38.4	m^2	0.18	6.9	Double Glass
Chair	200	unit	0.15	30.0	Soft Material
Sigma Area			=	1111.3	m^2
Sigma Sabin			=	544.8	Sabin
As			=	139.5	m^2
NR (Indoor)			=	45.9	dB
IL (indoor)			=	28.0	dB
RT (Reverberation Time)			=	0.50	second

Table 5: Results of Acoustical Calculation of a Proposed Design Improvement of Bethesda Ranotana Church

Surface	Area	Unit	a	a x Area = Sabin	Note:
Wall	532.35	m^2	0.65	346.0	Heavy Carpet
Ceiling	446.8	m^2	0.1	44.7	Plywood
Floor	446.8	m^2	0.65	290.4	Heavy Carpet
Window	59.15	m^2	0.18	10.6	Double Glass
Chair	200	unit	0.15	30.0	Soft Material
Sigma Area			=	1485.1	m^2
Sigma Sabin			=	721.8	Sabin
As			=	262.0	m^2
NR (Indoor)			=	44.4	dB
IL (indoor)			=	34.2	dB
RT (Reverberation Time)			=	0.65	second

4. CONCLUSION

From the results and analysis by calculations, measurements, and simulations on the indoor sound quality of Sam Ratulangi University Church and Bethesda Ranotana Church, the following conclusions can be drawn:

a) The sound levels in the rooms of the churches do not meet the sound level standard based on Indonesia's building code. According to the code, the maximum sound level in the room due to outside noise is 35 dB. However, the results of calculations, measurements, and software simulations show that due to outdoor noise of 100 dB at a distance of about 10 m from the building, the sound level in the rooms can exceed 50 dB.

b) The level of noise reduction due to existing walls and their interior sound absorption factors, based on the calculation results, is only slight or not significant, reaching only 2 to 3.4 dB. However, based on measurements, it can reach 16.2 dB at the Bethesda Ranotana Church and 7.5 dB at the Sam Ratulangi University Church.

c) The pattern of sound distribution into the room, based on visualization using software, shows that the intensity of sound propagation is also influenced by the role of openings such as windows, doors, and ventilation holes in the walls.

d) Through design improvements, it will be possible to obtain an indoor sound level that is in accordance with the standard. Simulation calculations are carried out by trying to apply various alternatives of wall properties and sound absorption materials to the interior wall layers. However, excessive sound absorption material can cause a decrease in the reverberation time below the standard. Therefore, the role of the electro-acoustic system is needed to increase the reverberation time through further studies.

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