JOURNAL OF ARCHITECTURAL RESEARCH AND DESIGN STUDIES
DOI: 10.20885/jars.vol7.iss2.art3

Reverberation Time Improvement in the Worship Room of Palihan Javanese Christian Church

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Article History
Received : 15 June 2023
Accepted : 01 November 2023
Published : 21 November 2023

Abstract

Acoustic comfort is one of four types of comforts in a room. Acoustic comfort allows users of worship spaces to be more focused and solemn in worshipping. One indicator that indicates the optimality of acoustic comfort is the level of clarity of sound articulation. The level of sound articulation in the worship space of the Palihan Javanese Christian Church is considered unclear, so it can be concluded if there is excessive reverberation time in the worship room. Therefore, it is necessary to improve the ideal reverberation time in the worship room of the Palihan Javanese Christian Church. The research was conducted using quantitative research methods. The improvement of reverberation time in this research is done by identifying the materials that are used in the worship room of the Palihan Javanese Christian Church at a frequency of 500Hz and 1000Hz using Sabine's reverberation time theory. From this research, it can be concluded that the replacement of some reflector materials with diffuser and absorber materials can reduce the excess reverberation time in the worship room of the Palihan Javanese Christian Church.

Keywords: *acoustic materials; improvement; reverberation time*

Introduction

In designing a house of worship, there are aspects of user comfort that must be considered by an architect. The aforementioned comfort aspects are thermal comfort, visual comfort, acoustical comfort, and comfort in space for movement (Aghniya & Pandelaki, 2020). What will be the main focus of this research is the comfort of a house of worship from the point of view of acoustical comfort.

Palihan Javanese Christian Church is located in Selong, Palihan, Temon, Kulon Progo, D.I. Yogyakarta and it is close to New Yogyakarta International Airport. The church was built in early 2017, just after the New Yogyakarta International Airport construction project was begun. Palihan Javanese Christian Church consists of a worship room and several other supporting rooms such as meeting room, office, warehouse, and toilets. The worship room of Palihan Javanese Christian Church has a capacity up to 280 people for weekly services with a room volume of 2520m³.

According to Imran & Demak (2018), acoustical comfort in a room is at least affected by two main aspects, they are the amount of reverberation time and the amount of noise in a room. Palihan Javanese Christian Church worship room indicates that it has a reverberation time that is improper for the standard of a worship room of a Protestant Church. The indicator that is shown there is a decrease in clarity of voice articulation (Sulistyowati et al., 2018). This indication shows that the existing reverberation time in the worship room of Palihan Javanese Christian Church has exceeded the proper reverberation time.

The excessive reverberation time will have a negative impact on people's solemnity in the worship. People will find it difficult to understand the meaning of the sermon that is delivered by the pastor and also cannot understand the lyrics in each song that is sung properly

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(Soelistyo & Sutanto, 2023). Therefore, the improvement of reverberation time in the worship room of Palihan Javanese Christian Church is necessary to fulfill the comfort of the worshipers in carrying out each worship process.

This study aims to determine the influence of material selection on its impact on the amount of reverberation time in the worship room of the Palihan Javanese Christian Church. If it turns out that the material that is currently used in the worship room of Palihan Javanese Christian Church causes excessive reverberation time, it is necessary to replace the material in the worship room to achieve optimal reverberation time, so that it can achieve the acoustical comfort in the worship room of Palihan Javanese Christian Church (Sutanto et al., 2014).

Literature Review

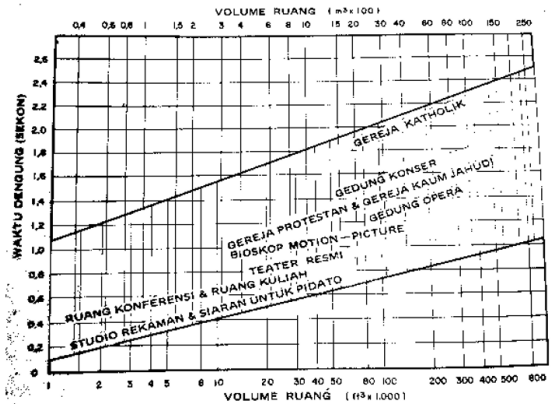
1. Reverberation Time

According to Cavanaugh et al. (1999), reverberation time is defined as the time it takes for a sound to decrease by one millionth of its initial intensity. If this is described in decibels, then reverberation time is the time required for the SPL (Sound Pressure Level) to decrease by 60dB since the sound stops (Latifah, 2015). For example, if the SPL when the sound stops in a room is 100dB and then drops to 40dB within 1.5 seconds, then the reverberation time in the room is 1.5 seconds. Reverberation time can also be described as the reflection of sound that occurs in a room (Mediastika, 2005).

The amount of reverberation time in a room is influenced by several factors; they are the volume of the room, the surface area of the sides of the plane forming the room, the sound absorption coefficient of the material, and the frequency used in the room (Mediastika, 2005). The volume of the room affects the amount of the reverberation time because the larger the volume of a room, it has the potential to produce a higher reverberation time (Howard & Angus, 2001). The surface area of the sides of the plane forming the room and the sound absorption coefficient of the material forming the room serve to determine the total amount of sound absorption that will be produced. The reverberation time that occurs at each frequency will be different, because at different frequencies, the sound absorption coefficient is also different (Everest & Pohlmann, 2012). In general, the higher the frequency, the lower the reverberation time will be. This is because the value of the material absorption coefficient is increasing at higher frequencies (Marikani, 2020).

The ideal reverberation time can be determined if the room volume and room function are known (Doelle, 1993). The bigger the volume of a room, the more reverberation time will be generated in the room. According to Doelle (1993), the correlation between room volume and room function can be described as below:

Figure 1. Ideal reverberation time at frequencies of 500Hz to1000Hz
Source: Doelle (1993)



The reverberation time at various frequencies will be different (Fry, 2013), however, the best reverberation time that can be used as a reference for the optimal reverberation time is when the reverberation time curve above 500Hz is flat. Frequencies between 500Hz and 1000Hz are frequencies that are used to determine the optimal reverberation time in a room. The deviation of reverberation time that is still tolerable is 5% to 10% of the optimal reverberation time which is determined in the reverberation time graph (Doelle, 1993).

Finding out the reverberation time in a room can be done manually or by using acoustic software such as iSimpa, Ecotect, and CATT Acoustics. Manual reverberation time calculation can be done with the following formula proposed by Sabine (Barron, 1993):

$$RT = \frac{0{,}16 \, . \, V}{A}$$

RT is the reverberation time to be known, V is the volume of the room, and A is the value of the total absorption coefficient in a room (Barron, 1993). To know the value of A, the average absorption coefficient (ᾱ) must first be known with the formula below (Setyowati, 2015):

$$\bar{\alpha} = \frac{\Sigma\, S.\, \alpha}{\Sigma\, S}$$

After the average absorption coefficient (ᾱ) value is known, the value of A can be known by the following formula below (Setyowati, 2015):

$$A = S[-2{,}3 \log (1 - \bar{\alpha})]$$

Excessive reverberation time can be reduced by decreasing the volume of the room, increasing the surface area of an absorptive field, and adding materials that have a high coefficient of sound absorption (Hassan, 2009).

2. Acoustic Materials

When designing an acoustic room, it is certainly inseparable from the acoustic materials. Acoustic materials can be defined as materials that have the ability to absorb sound (Doelle, 1993). Acoustic materials are materials that have the ability in conditioning the acoustics of the room, including conditioning the sounds that are expected to be heard (H. Sutanto, 2015). According to Sutanto (2015), acoustic materials can also be used as sound insulation materials.

To elaborate, acoustic materials have the following characteristics (Latifah, 2015):

Reflector

It is self-explanatory that a reflector material has the ability to reflect sound. The original sound that is reflected on this material is reflected directly towards the listener/audience. Reflector material should be placed on the stage area that is facing towards the listener/audience. Reflector materials generally have a sound absorption coefficient less than 0.30 and have a hard and slippery nature.

Some acoustic materials that have the character as a reflector are the plastered brick wall, concrete with smooth surface, solid wood door, and ceramic with smooth surface. All of these materials have a sound absorption coefficient less than 0.30.

Absorber

Absorber is a material that is used to absorb the sound that reflects in the room. Absorber material is also often used to control excessive reverberation time in a room (Mediastika, 2005). The absorber material has a sound absorption coefficient of more than 0.30 and it is generally a porous, soft porous material, and or in the form of a hollow resonator. This material will be very effective at a frequency of 1000Hz. The absorber material will be more effective when placed on the opposite walls, floor, and or walls directly facing the stage.

Several acoustic materials that have the character as an absorber material are the fabric curtain, fiber absorber on perforated sheet metal, and mixed 9mm acoustic gypsum board +10mm coconut fiber.

Diffuser

A diffuser material usually has an uneven surface and an irregular shape, therefore, the characteristic of this material is to spread the reflected sound (Wicaksono et al., 2017). The purpose of using diffuser material is to avoid acoustic defects. Diffuser material is recommended to be applied to the back wall of the room, the wall that faces each other, and the wall that is directly opposite the stage. Diffuser material has a sound scattering coefficient (Vorlander, 2007).

A few materials that are used as diffuser materials are hexagonal interlocked diffusorber porous ceramics, RPG QRD, and even concrete with very rough surfaces.

Methodology

The method incorporated in this study is the quantitative research method. The independent variable in this research is the acoustic material covering the worship room of Palihan Javanese Christian Church, while the dependent variable in this research is the reverberation time in the worship room of Palihan Javanese Christian Church. Research on reverberation time is done manually by using the reverberation time formula proposed by Sabine.

The research was started by calculating the volume of the Palihan Javanese Christian

Church's worship room. The calculation of the room volume is done by making a 3-dimensional model on SketchUp software. The next step is collecting data on the acoustic materials that are used in the worship room in the Palihan Javanese Christian Church along with their absorption coefficient. In addition to collecting data on the types of materials that are used, data collection is also carried out on each material surface area on each side of the wall in the worship room of the Palihan Javanese Christian Church.

After completing the data, the next step is to calculate the reverberation time in the worship hall of Palihan Javanese Christian Church. The calculation of reverberation time is calculated at a frequency of 500Hz and 1000Hz as the middle frequency (Siahaan & Darianto, 2020). If after the calculation is done, and the result of reverberation time that is obtained is not in accordance with the reverberation time required in Doelle (1993), then the calculation of reverberation time improvement is performed. The calculation of reverberation time improvement is conducted by changing the type of acoustic material in the worship room of Palihan Javanese Christian Church (Kho, 2014). The expected reverberation time in the worship space of Palihan Javanese Christian Church is expected to be better after material replacement.

Result and Discussion

To determine the reverberation time in the worship room of Palihan Javanese Christian Church, it is necessary to know the volume of the worship room first (Sabtalistia, 2020). The measurement of the volume of the room is done by making a 3-dimensional model of the worship space based on the existing work drawings that are owned by the Palihan Javanese Christian Church and re-measuring the existing worship space. The floor plan of the worship room of Palihan Javanese Christian Church is as shown in Figure 2 and Figure 3.

Figure 2. Floor plan of the ground floor of the worship room of the Palihan Javanese Christian Church
Source: Author

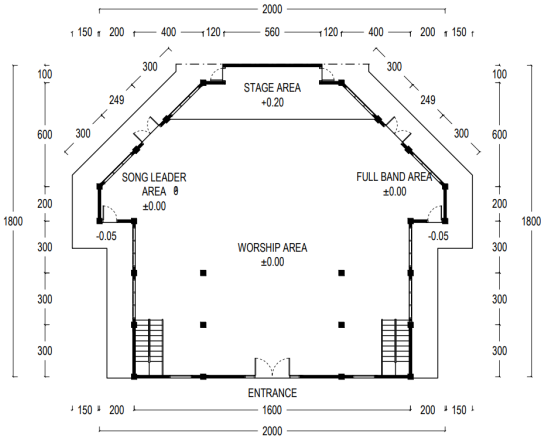
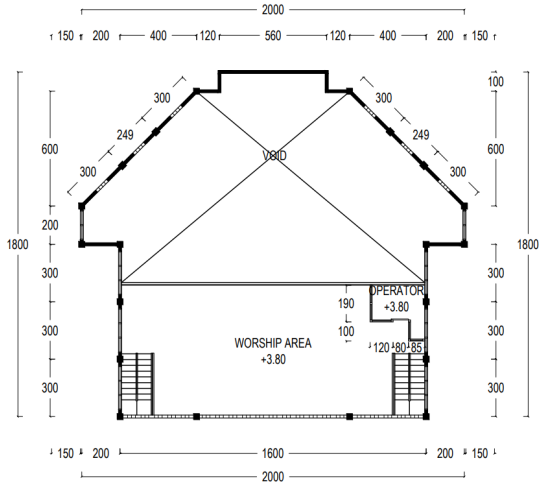


Figure 3. Floor plan of the mezzanine floor of the worship room of the Palihan Javanese Christian Church
Source: Author



The availability of the floor plan makes it easier to make the 3-dimensional modeling of the worship room of Palihan Javanese Christian Church. Through this 3-dimensional modeling, it is found that the volume of the worship room of the Palihan Javanese Christian Church is 2520m3.

1. Existing Reverberation Time

After calculating the volume of the worship room of the Palihan Javanese Christian Church, the next stage is defines the acoustic material that is used in the worship room of the Palihan Javanese Christian Church as shown in Figure 4. The acoustic material data is then complemented by the surface area on each side of the room and the sound absorption coefficient of each material. The data is then entered into the calculation table to simplify

the calculation of the total sound absorption coefficient.

Figure 4. Surrounding materials of worship space of Palihan Javanese Christian Church
Source: Author

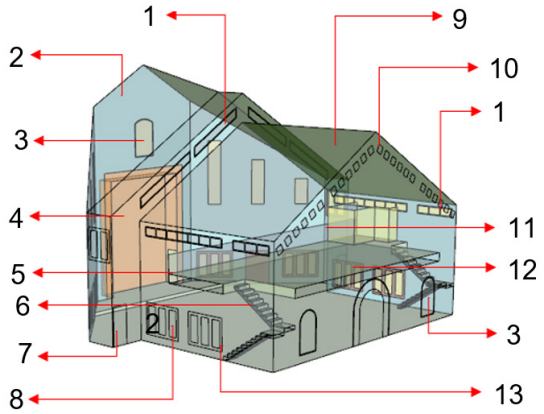


Table 1. Table of the existing acoustic materials in the worship room of Palihan Javanese Christian Church base on Figure 4

No.	Acoustic Materials
1.	3mm thick single glazing
2.	Plastered brick wall
3.	4mm thick glass
4.	Thin plywood panel
5.	Glass door
6.	Concrete with smooth surface
7.	Solid wood door
8.	6mm thick glass
9.	1/2 inch thick gypsum board
10.	Thick glass
11.	Fiberglass
12.	Ceramic with smooth surface
13.	Solid wood

Source: Author

Reverberation Time at 500Hz

The calculation of reverberation time in this research will be calculated at the middle frequency, which is at 500Hz and 1000Hz. The first reverberation time calculation is at a frequency of 500Hz. At a frequency of 500Hz, the sound absorption coefficient and surface area of the material is as follows: (Table 2)

As seen in Table 2, the acoustic material used in the worship room of the Palihan Javanese Christian Church at a frequency of 500 Hz has an absorption coefficient value of less than 0,30. This means that most of the acoustic materials that are used in the worship room of the Palihan Javanese Christian Church are reflector materials (Latifah, 2015). With so many reflector materials used, the reverberation time that is generated is also inevitably bigger (Ramadhan et al., 2017). The reverberation time that occurs in the worship space of the Palihan Javanese Christian Church at a frequency of 500Hz is:

Calculating the average absorption coefficient value ($\bar{\alpha}$)at a frequency of 500Hz:

$$\bar{\alpha} = \frac{\Sigma\, S.\, \alpha}{\Sigma\, S}$$

$$\bar{\alpha} = \frac{84{,}69}{1719{,}43}$$

$$\bar{\alpha} = 0{,}05$$

Calculating the total absorption coefficient (A) of the room at a frequency of 500Hz:

$$A = S[-2{,}3 \log (1 - \bar{\alpha})]$$

$$A = 1719{,}43[-2{,}3 \log (1 - 0{,}05)]$$

$$A = 87{,}00$$

Calculating the reverberation time value of Palihan Javanese Christian Church worship room at a frequency of 500Hz:

$$RT = \frac{0{,}16\,.V}{A}$$

$$RT = \frac{0{,}16\,.2520}{87}$$

$$RT = 4{,}63$$

From the calculation above, it can be seen that the reverberation time in the worship room of Palihan Javanese Christian Church at a frequency of 500Hz is 4,63 seconds.

Reverberation Time at 1000Hz

After knowing the reverberation time at a frequency of 500Hz, then the second reverberation time calculation is at a frequency of 1000Hz. At a frequency of 1000Hz, the sound absorption coefficient and surface area of the material are as follows: (Table 3)

Table 2. Table of acoustic materials in the worship room of Palihan Javanese Christian Church at a frequency of 500Hz

No.	Acoustic Materials	Area (S) in m²	Absorption Coefficient (α)	S.α
	North Side			
1.	Plastered brick wall	153,46	0,03	4,60
2.	Solid wood	2,86	0,06	0,17
3.	Solid wood door	9,11	0,06	0,55
4.	4mm thick glass	8,49	0,10	0,85
5.	Thick glass	3,84	0,04	0,15
6.	3mm thick single glazing	6,27	0,03	0,19
	South Side			
1.	Plastered brick wall	166,76	0,03	5,00
2.	Solid wood	7,45	0,06	0,45
3.	4mm thick glass	2,91	0,10	0,29
4.	Thin plywood panel	64,21	0,10	6,42
5.	Thick glass	13,44	0,04	0,54
6.	Solid wood door	6,30	0,06	0,38
7.	Glass door	3,36	0,11	0,37
8.	6mm thick glass	8,40	0,01	0,34
	East Side			
1.	Plastered brick wall	52,03	0,03	1,56
2.	Solid wood	5,77	0,06	0,35
3.	6mm thick glass	5,60	0,04	0,22
4.	3mm thick single glazing	2,80	0,03	0,08
	West Side			
1.	Plastered brick wall	52,03	0,03	1,56
2.	Solid wood	5,77	0,06	0,35
3.	6mm thick glass	5,60	0,04	0,22
4.	3mm thick single glazing	2,80	0,03	0,08
	Stairs			
1.	Concrete with smooth surface	15,22	0,02	0,30
2.	Ceramic with smooth surface	16,00	0,01	0,16
	Mezzanine			
1.	Concrete with smooth surface	11,81	0,02	0,24
2.	1/2 inch thick gypsum board	99,60	0,05	4,98
3.	Thick glass	17,20	0,04	0,69
4.	Fiberglass	15,85	0,42	6,66
5.	Ceramic with smooth surface	99,60	0,01	1,00
	Others			
1.	Ceramic with smooth surface	269,97	0,01	2,70
2.	1/2 inch thick gypsum board	304,92	0,05	15,25
3.	Wooden chair (unoccupied)	280	0,10	28,00
	Total Amount (∑)	**1719,43**		**84,69**

Source: Author

Table 3. Table of acoustic materials in the worship room of Palihan Javanese Christian Church at a frequency of 1000Hz

No.	Acoustic Materials	Area (S) in m^2	Absorption Coefficient (α)	S.α
	North Side			
1.	Plastered brick wall	153,46	0,03	4,60
2.	Solid wood	2,86	0,08	0,23
3.	Solid wood door	9,11	0,08	0,73
4.	4mm thick glass	8,49	0,07	0,59
5.	Thick glass	3,84	0,03	0,12
6.	3mm thick single glazing	6,27	0,03	0,19
	South Side			
1.	Plastered brick wall	166,76	0,03	5,00
2.	Solid wood	7,45	0,08	0,60
3.	4mm thick glass	2,91	0,07	0,20
4.	Thin plywood panel	64,21	0,08	5,14
5.	Thick glass	13,44	0,03	0,40
6.	Solid wood door	6,30	0,08	0,50
7.	Glass door	3,36	0,11	0,37
8.	6mm thick glass	8,40	0,03	0,25
	East Side			
1.	Plastered brick wall	52,03	0,03	1,56
2.	Solid wood	5,77	0,08	0,46
3.	6mm thick glass	5,60	0,03	0,17
4.	3mm thick single glazing	2,80	0,03	0,08
	West Side			
1.	Plastered brick wall	52,03	0,03	1,56
2.	Solid wood	5,77	0,08	0,46
3.	6mm thick glass	5,60	0,03	0,17
4.	3mm thick single glazing	2,80	0,03	0,08
	Stairs			
1.	Concrete with smooth surface	15,22	0,02	0,30
2.	Ceramic with smooth surface	16,00	0,02	0,32
	Mezzanine			
1.	Concrete with smooth surface	11,81	0,02	0,24
2.	1/2 inch thick gypsum board	99,60	0,04	3,98
3.	Thick glass	17,20	0,03	0,52
4.	Fiberglass	15,85	0,77	12,20
5.	Ceramic with smooth surface	99,60	0,02	1,99
	Others			
1.	Ceramic with smooth surface	269,97	0,02	5,40
2.	1/2 inch thick gypsum board	304,92	0,04	12,20
3.	Wooden chair (unoccupied)	280	0,12	33,60
	Total Amount (∑)	**1719,43**		**94,23**

Source: Author

Similar to the value of the sound absorption coefficient at a frequency of 500Hz, the acoustic material at 1000Hz is dominated by reflector material which has a sound absorption coefficient of less than 0.30. So the calculation of reverberation time in the worship room of Palihan Javanese Christian Church at a frequency of 1000Hz is as follows:

Calculating the average absorption coefficient value ($\bar{\alpha}$) at a frequency of 1000Hz:

$$\bar{\alpha} = \frac{\Sigma\, S.\alpha}{\Sigma\, S}$$

$$\bar{\alpha} = \frac{94{,}23}{1719{,}43}$$

$$\bar{\alpha} = 0{,}05$$

Calculating the total absorption coefficient (A) of the room at a frequency of 1000Hz:

$$A = S[-2{,}3 \log (1 - \bar{\alpha})]$$

$$A = 1719{,}43[-2{,}3 \log (1 - 0{,}05)]$$

$$A = 87{,}00$$

Calculating the reverberation time value of Palihan Javanese Christian Church worship room at a frequency of 1000Hz:

$$RT = \frac{0{,}16\,.V}{A}$$

$$RT = \frac{0{,}16\,.2520}{87}$$

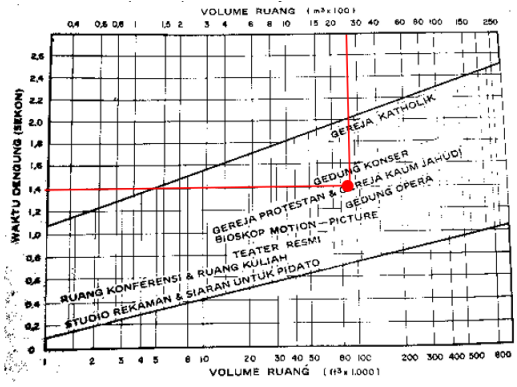
$$RT = 4{,}63$$

From the calculation above, it can be seen that the reverberation time in the worship room of Palihan Javanese Christian Church at a frequency of 1000Hz is 4,63 seconds. Thus, the reverberation time at 1000Hz is the same as the reverberation time at 500Hz.

2. Ideal Reverberation Time in Worship Room

Palihan Javanese Christian Church is a Protestant Church. The acoustic functions of rooms required for a Protestant Church are the acoustic function of speaking and the acoustic function of music (Ola, 2023). To determine the ideal reverberation time of a room using a graph proposed by Doelle (1993) data on the volume of the room and the function of the room are required. The function of the room in this study is as a Protestant Church worship room and the volume of the room is 2520m3, so the ideal reverberation time for the Palihan Javanese Christian Church worship room according to Doelle (1993) is:

Figure 5. Ideal reverberation time in the worship room of the Palihan Javanese Christian Church
Source: Doelle (1993), edited by author



Based on the graph in Figure 5, it can be inferred that the ideal reverberation time for the Protestant Church worship room with a room volume of 2520m3 is 1,4 seconds. When it is compared with the current result of the calculation of reverberation time in the worship room of Palihan Javanese Christian Church, the result shows a significant deviation. The reverberation time of the current worship room is 4,63 seconds, which means that the reverberation time of the Palihan Javanese Christian Church worship room has exceeded the ideal reverberation time for the Protestant Church worship room.

An improvement in the reverberation time needs to be done because the reverberation time found in the worship room of Palihan Javanese Christian Church exceeds the ideal value. The most possible improvement in reverberation time is to apply acoustic material with a sound absorption coefficient value of more than 0.30, which is an absorber acoustic material. But in addition to adding absorber material, it is also necessary to add diffuser material to the improvement of the Palihan Javanese Christian Church worship room so that the acoustic conditions in the worship room are not too quiet and can still reflect sound at an ideal limit for Protestant Churches.

As seen in Figure 4, many reflector materials are facing each other. The reflector material placed on the back wall (directly facing the stage) will make the sound reflect back towards the front and will certainly have an impact on

the high reverberation time that will occur in the room (Latifah, 2015). Thus, the first part of the wall that must be covered with acoustic material is the back wall that is directly facing the stage. The acoustic material that can be applied to the back wall is diffuser acoustic material so that the sound distribution in the worship room remains even (Hawari & Dinastry, 2017).

The west and east walls are two sides of the walls facing each other and have the same design and materials. Both sides of the walls of the Palihan Javanese Christian Church worship room have acoustic materials such as reflectors that will reflect sound repeatedly and cause high reverberation time (Laela, 2015). Therefore, it is necessary to apply acoustic materials such as diffusers and absorbers on the west and east walls.

3. Reverberation Time Improvement

The reverberation time in the worship room of Palihan Javanese Christian Church turns out to be significantly higher than the ideal reverberation time, therefore it is necessary to make an improvement in the reverberation time. The improvement of reverberation time that is very possible to do at this time is by adding some acoustic materials on the sides of the walls, ceiling, and floor (Yani, 2021). Some materials that must be layered with acoustic materials are on the surface of the walls, roof, and floor in the following figure:

Figure 6. Acoustic materials in the worship room of Palihan Javanese Christian Church after improvement
Source: Author

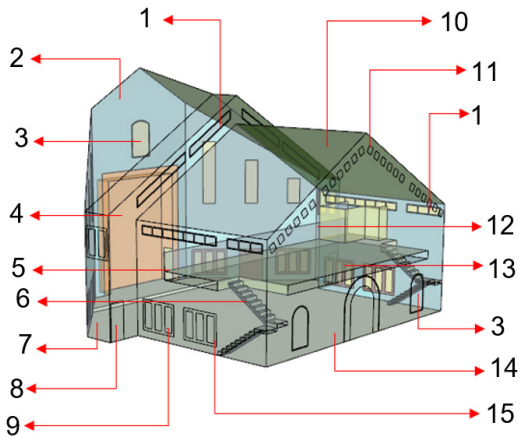


Table 4. Table of acoustic materials in the worship room of Palihan Javanese Christian Church base on Figure 2

No.	Acoustic Materials	Existing / Replacement
1.	Fibre absorber on perforated sheet metal	Replacement
2.	Plastered brick wall	Existing
3.	4mm thick glass	Existing
4.	Thin plywood panel	Existing
5.	Glass door	Existing
6.	Concrete with smooth surface	Existing
7.	PRG QRD diffuser panel	Replacement
8.	Solid wood door	Existing
9.	Fabric curtain, density (0,2kg/m^2), 90mm from the wall	Replacement
10.	Mixed 9mm acoustic gypsum board + 10mm coconut fiber	Replacement
11.	Thick glass	Existing
12.	Fiberglass	Existing
13.	Ceramic with smooth surface	Existing
14.	Hexagonal Interlocked Diffusorber Porous Ceramics	Replacement
15.	Solid wood	Existing

Source: Author

Figure 6 shows the new acoustic materials that are suitable for installation on several sides of the room. The materials that are replaced with new acoustic materials are as follows:

Table 5. Table of acoustic material replacement in the worship space of Palihan Javanese Christian Church

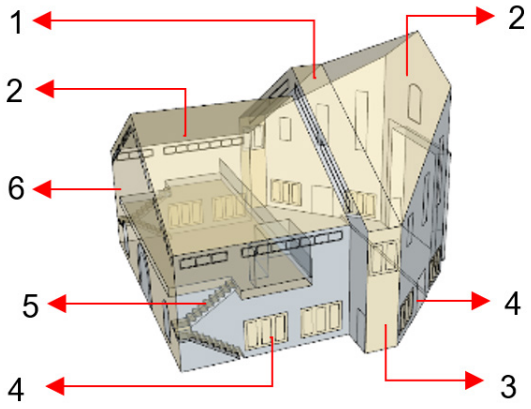
No.	Acoustic Materials	Replacement Materials
1.	1/2 inch thick gypsum board **Reflector Material**	Fibre absorber on perforated sheet metal **Absorber Material**
2.	1/2 inch thick gypsum board **Reflector Material**	Mixed 9mm acoustic gypsum board + 10mm coconut fiber **Absorber Material**
3.	Plastered brick wall **Reflector Material**	RPG QRD diffuser panel **Diffuser Material**
4.	Solid wood + 6mm thick glassl **Reflector Material**	Fabric curtain, density (0,2kg/m^2), 90mm from the wall **Absorber Material**

5.	Ceramic with smooth surface	Heavy carpet on concrete
	Reflector Material	**Absorber Material**
6.	Plastered brick wall	Hexagonal Inter-locked Diffusorber Porous Ceramics
	Reflector Material	**Diffuser Material**

Source: Author

Table 5 shows the replacement of the initial types of acoustic materials that are used in the worship room of the Palihan Javanese Christian Church and the recommended replacement acoustic materials. The position of the acoustic material that needs to be replaced in the worship space of the Palihan Javanese Christian Church is shown in Figure 7.

Figure 7. Position of the acoustic materials that need to be replace in the worship room of Palihan Javanese Christian Church
Source: Author



The acoustic material replacement in the worship room of the Palihan Javanese Christian Church is already known. To ensure that the acoustic material is really a fit acoustic material to replace the original one, the calculation of the reverberation time of the worship room of the Palihan Javanese Christian Church with replacement acoustic materials needs to be done.

The ideal reverberation time for the worship space of the Palihan Javanese Christian Church according to Doelle's graph is 1,4 seconds. However, the calculation of reverberation time is tolerated up to 10% of the ideal reverberation time (Doelle, 1993). So the deviation of the ideal reverberation time of the worship space of Palihan Javanese Christian Church is 1.4 + 0.14 seconds.

Reverberation Time at 500Hz

The first reverberation time calculation with acoustic materials replacement is at a frequency of 500Hz. The sound absorption coefficient and surface area of the material are as follows: (Table 6)

In Table 6, it can be seen that the replacement of acoustic materials at a frequency of 500hz has a sound absorption coefficient value of more than 0,30. The value of the sound absorption coefficient of more than 0,30 allows a material to absorb more sound, so it can reduce the reflection in the room (Latifah, 2015). The amount of reverberation time after improving the design of the material enclosing the room with the addition of new acoustic materials is as follows:

Calculating the average absorption coefficient value ($\bar{\alpha}$) at a frequency of 500Hz:

$$\bar{\alpha} = \frac{\Sigma\, S.\, \alpha}{\Sigma\, S}$$

$$\bar{\alpha} = \frac{256{,}20}{1719{,}43}$$

$$\bar{\alpha} = 0{,}149$$

Calculating the total absorption coefficient (A) of the room at a frequency of 500Hz:

$$A = S[-2{,}3 \log (1 - \bar{\alpha})]$$

$$A = 1719{,}43[-2{,}3 \log (1 - 0{,}149)]$$

$$A = 276{,}828$$

Calculating the reverberation time value of Palihan Javanese Christian Church worship room at a frequency of 500Hz:

$$RT = \frac{0{,}16\,.V}{A}$$

$$RT = \frac{0{,}16\,.2520}{276{,}828}$$

$$RT = 1{,}457$$

From the calculation above, it can be seen that the reverberation time in the worship room of Palihan Javanese Christian Church at a frequency of 500Hz after improvement is 1,457 seconds. This value is still within the ideal reverberation time for the acoustic function of the Protestant Church because, as it is still within the deviation of the ideal reverberation time tolerance for the Protestant Church, which is 1,4 + 0,14 seconds or it can be concluded

Table 6. Table of acoustic materials in the worship room of Palihan Javanese Christian Church at a frequency of 500Hz

No.	Acoustic Materials	Area (S) in m^2	Absorption Coefficient (α)	S.α
	North Side			
1.	Plastered brick wall	42,96	0,03	1,29
2.	Hexagonal Interlocked Diffusorber Porous Ceramics	110,50	0,36	39,78
3.	Solid wood	2,86	0,06	0,17
4.	Solid wood door	9,11	0,06	0,55
5.	4mm thick glass	8,49	0,10	0,85
6.	Thick glass	3,84	0,04	0,15
	3mm thick single glazing	6,27	0,03	0,19
	South Side			
1.	Plastered brick wall	166,76	0,03	5,00
2.	4mm thick glass	2,91	0,10	0,29
3.	Thin plywood panel	64,21	0,10	6,42
4.	Thick glass	13,44	0,04	0,54
5.	Solid wood door	6,30	0,06	0,38
6.	Glass door	3,36	0,11	0,37
7.	Fabric curtain, density (0,2kg/m^2), 90mm from the wall	15,85	0,39	6,18
	East Side			
1.	Plastered brick wall	42,52	0,03	1,28
2.	RPG QRD diffuser panel	9,51	0,45	4,28
3.	Fabric curtain, density (0,2kg/m^2), 90mm from the wall	11,37	0,39	4,43
4.	3mm thick single glazing	2,80	0,03	0,08
	West Side			
1.	Plastered brick wall	42,52	0,03	1,28
2.	RPG QRD diffuser panel	9,51	0,45	4,28
3.	Fabric curtain, density (0,2kg/m^2), 90mm from the wall	11,37	0,39	4,43
4.	3mm thick single glazing	2,80	0,03	0,08
	Stairs			
1.	Concrete with smooth surface	15,22	0,02	0,30
2.	Heavy carpet on concrete	16,00	0,14	2,24
	Mezzanine			
1.	Concrete with smooth surface	11,81	0,02	0,24
2.	Mixed 9mm acoustic gypsum board + 10mm coconut fiber	99,60	0,25	24,90
3.	Thick glass	17,20	0,04	0,69
4.	Fiberglass	15,85	0,42	6,66
5.	Ceramic with smooth surface	99,60	0,01	1,00
	Others			
1.	Ceramic with smooth surface	269,97	0,01	2,70
2.	Fibre absorber on perforated sheet metal	41,26	1,00	41,26
3.	Mixed 9mm acoustic gypsum board + 10mm coconut fiber	263,66	0,25	65,92
4.	Thick glass Wooden chair (unoccupied)	280	0,10	28,00
	Total Amount (∑)	**1719,43**		**256,20**

Source: Author

that the ideal reverberation time limit in the worship room of Palihan Javanese Christian Church is in the range of 1,26 seconds to 1,54 seconds.

Reverberation Time at 1000Hz

The first reverberation time calculation with acoustic materials replacement is at a frequency of 1000Hz. The sound absorption coefficient and surface area of the material are as follows: (Table 7)

Table 7. Table of acoustic materials in the worship room of Palihan Javanese Christian Church at a frequency of 500Hz

No.	Acoustic Materials	Area (S) in m^2	Absorption Coefficient (α)	S.α
	North Side			
1.	Plastered brick wall	42,96	0,03	1,29
2.	Hexagonal Interlocked Diffusorber Porous Ceramics	110,50	0,515	56,91
3.	Solid wood	2,86	0,08	0,23
4.	Solid wood door	9,11	0,08	0,73
5.	4mm thick glass	8,49	0,07	0,59
6.	Thick glass	3,84	0,03	0,12
7.	3mm thick single glazing	6,27	0,03	0,19
	South Side			
1.	Plastered brick wall	166,76	0,03	5,00
2.	4mm thick glass	2,91	0,07	0,20
3.	Thin plywood panel	64,21	0,08	5,14
4.	Thick glass	13,44	0,03	0,40
5.	Solid wood door	6,30	0,08	0,50
6.	Glass door	3,36	0,11	0,37
7.	Fabric curtain, density (0,2kg/m^2), 90mm from the wall	15,85	0,63	9,99
	East Side			
1.	Plastered brick wall	42,52	0,03	1,28
2.	RPG QRD diffuser panel	9,51	0,95	9,03
3.	Fabric curtain, density (0,2kg/m^2), 90mm from the wall	11,37	0,63	7,16
4.	3mm thick single glazing	2,80	0,03	0,08
	West Side			
1.	Plastered brick wall	42,52	0,03	1,28
2.	RPG QRD diffuser panel	9,51	0,95	9,03
3.	Fabric curtain, density (0,2kg/m^2), 90mm from the wall	11,37	0,63	7,16
4.	3mm thick single glazing	2,80	0,03	0,08
	Stairs			
1.	Concrete with smooth surface	15,22	0,02	0,30
2.	Heavy carpet on concrete	16,00	0,37	5,92
	Mezzanine			
1.	Concrete with smooth surface	11,81	0,02	0,24
2.	Mixed 9mm acoustic gypsum board + 10mm coconut fiber	99,60	0,18	17,93
3.	Thick glass	17,20	0,03	0,52
4.	Fiberglass	15,85	0,77	12,20
5.	Ceramic with smooth surface	99,60	0,02	1,99
	Others			
1.	Ceramic with smooth surface	269,97	0,02	5,40
2.	Fibre absorber on perforated sheet metal	41,26	0,97	40,02
3.	Mixed 9mm acoustic gypsum board + 10mm coconut fiber	263,66	0,18	47,46
4.	Wooden chair (unoccupied)	280	0,12	33,60
	Total Amount (∑)	**1719,43**		**282,35**

Source: Author

In Table 7, it can be seen that the replacement of acoustic materials at a frequency of 1000hz also has a sound absorption coefficient value of more than 0,30. The value of the sound absorption coefficient of more than 0,30 allows a material to absorb more sound, so it can reduce the reflection in the room (Latifah, 2015). The amount of reverberation time after improving the design of the material enclosing the room with the addition of new acoustic materials is as follows:

Calculating the average absorption coefficient value ($\bar{\alpha}$) at a frequency of 1000Hz:

$$\bar{\alpha} = \frac{\Sigma\, S.\alpha}{\Sigma\, S}$$

$$\bar{\alpha} = \frac{282{,}35}{1719{,}43}$$

$$\bar{\alpha} = 0{,}164$$

Calculating the total absorption coefficient (A) of the room at a frequency of 500Hz:

$$A = S[-2{,}3 \log (1 - \bar{\alpha})]$$

$$A = 1719{,}43[-2{,}3 \log (1 - 0{,}164)]$$

$$A = 308{,}466$$

Calculating the reverberation time value of Palihan Javanese Christian Church worship room at a frequency of 500Hz:

$$RT = \frac{0{,}16\,.V}{A}$$

$$RT = \frac{0{,}16\,.2520}{308{,}466}$$

$$RT = 1{,}307$$

From the calculation above, it can be seen that the reverberation time in the worship room of Palihan Javanese Christian Church at a frequency of 1000Hz after improvement is 1,307 seconds. This value is still an ideal reverberation time for the acoustic function of the Protestant Church because it is still within the deviation of the ideal reverberation time tolerance for the Protestant Church, which is 1,4 + 0,14 seconds. It can be concluded that the ideal reverberation time limit in the worship room of Palihan Javanese Christian Church is in the range of 1,26 seconds to 1,54 seconds.

Conclusion

From the research on the improvement of reverberation time in the worship room of Palihan Javanese Christian Church, it can be concluded that the suggested ideal reverberation time in the worship room of Palihan Javanese Christian Church is 1,4 seconds with a deviation of 1,4 + 0,14 seconds. However, the current reverberation time in the worship room of Palihan Javanese Christian Church is still improper when compared to the ideal reverberation time because the current reverberation time in the worship room of Palihan Javanese Christian Church is 4,63 seconds.

From the various factors that affect the amount of reverberation time in a room, the most possible improvement of reverberation time to be done in the worship room of Palihan Javanese Christian Church at this time is the improvement of the interior framing material of the worship room. The improvement can be done by replacing the interior framing material of the worship space of Palihan Javanese Christian Church by adding absorbers and diffuser materials on several sides of the room, both on the walls, ceiling, and floor. So that after the improvement, the reverberation time in the worship room of Palihan Church can be reduced to 1,457 seconds at a frequency of 500Hz and 1,30 seconds at a frequency of 1000Hz. The result of the improvement of reverberation time is still acceptable because it is still within the deviation of the ideal reverberation time for the type of Protestant Church.

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