Diffuse Material as a Substitute for Indoor Sound Absorber

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ABSTRACT
In sound-conditioning in the room, three factors affect the quantity and quality of sound received by the listener: the sound source, shape, and space-forming material through 3 types of acoustic materials, namely, reflector, absorber, and diffuser. The presence of a diffuser can affect the absorption and crispness of the sound and the breakdown of sound energy. Although the space-forming corner also affects it. A room with space-forming corners elements allows for better sound quality, such as a room with a minimum flat area. This study raises the case of a prayer room with a volume of 3,500 m3. The structural factors of the existing building and the availability of funds require the use of the same material in the ceiling area. Based on these challenges, the problem in this study is to determine the effect of using planes and diffuse materials as a substitute for absorption materials. The methods used are simulation methods and comparative studies. The simulation uses CATT Acoustic to determine the need for acoustic quality in the room and then compares diffuse elements with the absorbent material model. The results showed that to absorb sound in the room could use diffuse material.

Keywords: *Sound-conditioning, Diffuse material, CATT acoustic.*

1. INTRODUCTION

The liturgical room combines the physical acoustics of the worship space and sound quality. A free-field acoustic environment provides more clarity and precision in words in religious ceremonies. However, a diffuse field environment gives the feeling of an otherworldly supernatural being embodied [1].

Acoustic architecture has helped churches achieve their liturgical goals [2,3]. The church is a center for preaching the gospel whose acoustics must meet the community's needs and be able to accommodate the congregation's singing [2,4]. The acoustics of a church must be following its worship program. Three types of activities in the church: 1) Preaching the word from the pulpit by the preacher; 2) Congregational Song; and 3) Musical performance by a church choir, organ, or musical ensemble behind the altar [2].

From a technical and acoustic point of view, there are two categories of church music. There is music that the whole congregation participates in (liturgical hymns) and music for the community (organ and choir). So an ideal acoustic space for church music is an environment that helps all singers and instrumentalists hear each other well to develop a musical ensemble [5]. So that as soon as the sound source emits sound into the air, the church acoustics "process" the sound until the sound goes out [6].

Getting the ideal acoustic space for a church is a challenge because there are often problems with costs in every acoustic room construction—allocating more funds for building construction and interior spaces that are not related to acoustics. Complex materials are also needed to get good acoustical conditioning. It also costs quite a lot. And in an acoustic room, room conditioning is done with an active and passive system, significantly to reduce noise that interferes with acoustical room conditioning.

Exposure to high noise continuously can cause various health problems. Then acoustic absorption is needed to reduce sound pressure, helping achieve acoustic comfort [7]. Many acoustic dampers, such as resonators, porous materials, or combined mufflers, are widely used in acoustical room conditioning [8].

Passive acoustic elements used to control Reverberation Time are silencers and diffusers [9,10]. Furthermore, the positive effect of the sound scatters depends on the position of the source, receiver, and transmitter itself and the degree of spreading properties [11,12]. In addition, switching between the absorptive and reflective zones increases the diffusion of sound, and that the silencer improves the subjectively perceived quality of speech slightly more than the diffuser [13].

Thus, to minimize the cost of passive acoustic elements, a trial was carried out using a diffuser material as a substitute for sound-absorbing materials. The research location is at the Church of Sta. Theresia, Salam - Central Java, by placing diffuser shape and material on the ceiling using the existing design materials (i.e. gypsum board) and part of the wall (except the back wall) to substitute sound-absorbing material to minimize costs and reduce construction burden.

2. METHODS

2.1. Data Collection and Simulation Methods

The data collection method uses the study of object design document (working drawings, visualizations, softcopy of building models), field surveys, interviews, and discussions with the development committee.

They tested the diffuse material on the ceiling using a CATT Acoustic v.8 software simulation. The test uses a model developed from the data of the study object and the application of acoustic materials in the study object's room. The application of acoustic materials in space uses the fundamental theories of room sound conditioning. Then divide the model into two types. The first is a “reference model”, which is a model that utilizes the use of sound-absorbing materials in the ceiling area, and have a good room acoustic quality as standard. Second model is “test model”, use diffuser shape and material on the ceiling of the room. Some limitations and conditions of both models:

- The model is made with simplification to minimize errors in the simulation.
- Both models have the same material conditions on the wall and floor elements.
- Architectural design in existing design that can function in indoor sound conditioning is maintained.
- Make doors and windows open according to the results of interviews about the conditions of use of space by users/owners.
- There are no macro modifications to the basic shape of the room (e.g., not changing the shape of the saddle ceiling to a curved model).
- Design the test model to maximize sound diffusion elements in space.
- Design the test model to maximize the diffusion element on the ceiling, using the material according to the working drawings, namely gypsum board.
- The design of the test model also considers the sacred impression in space.
- The absorption material used in the reference model can absorb sound evenly in the frequency range of human audible sound (e.g., Jayabell).
- Audians are conditioned to attend 60%, one person per 2 square meters of the congregation's area.
- Laying loudspeaker according to the recommendation of sound distribution analysis

2.2. Methods of Analysis and Conclusions

The simulation results analysis method uses a comparative study by comparing the measurement parameters between the reference model, test model, and the acoustic quality standard of the objective room. The room acoustic quality standards used are SPL for sound strength, RT/T30 for reverberation time standards, STI for speech reception, D-50 for speech clarity, C-80 for music clarity, and LF, BR for sound warmth and audial spaced feeling. Then measure the reference value at four sampling points, namely 2 for the front row and 2 for the back row. Next, make observations on the audience area grid graphic. The observation area grid is placed one meter high from the floor to represent the height of an adult human ear when sitting.

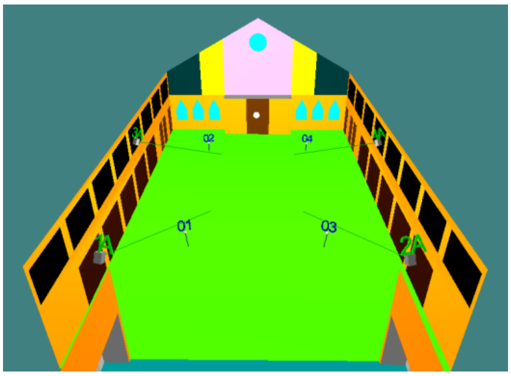

Figure 1 Loudspeaker and sampling node (view from the Altar).

Table 1. Baseline criteria

Criteria	Baseline
SPL	70 – 85 dB
RT/T30 500 & 1000 Hz	± 1.5 second
STI	0.60-0.75 (Good)
D-50	65% minimum
C-80	+3 to +8 (front row) 0 to +5 (back row)
LF	0.1 – 0.35
BR	1 to 1.45 for RT below 1.8s

The method of concluding is to see the achievement of the test model on the measurement parameters and the accomplishment of the reference model. Conduct a review of the difference in achievement between the test model and the measuring parameter with the percentage difference system in the value and the test model on the measuring parameter. Then compare the difference in achievement to see the ability of the test model as an answer to the problem.

3. RESULTS AND DISCUSSION

Data collection has been carried out by field measurements and observing the architectural drawing documents of the building. Then use the data to create a digital model for simulation in both scenarios. Next, test the first scenario (reference model) to be used as comparative study material.

3.1. Existing Design Condition

The space plan of the study object is rectangular, has a central axis, and has the same shape and design elements on the left and right sides of the axis. The community/audience area is 24 meters long and 16 meters wide. The altar area measures 10 x 6 square meters. The roof slope becomes the primary form of the room's ceiling with a sidewall height of 5.5 meters, and the ceiling height on the center axis of the room is 10 meters. The altar area has a sidewall height of 4.9 meters and a ceiling height of 7.7 meters.

Acoustically reflective materials dominate the room's material design. The room floor uses ceramic, while the ceiling uses gypsum board with a metal frame. Each of the left and right walls of the congregation area has a folding door covering an area of 30 m2 and a roster covering an area of 34 m2. The total area of these openings is 48% of the size of each wall, another 52% uses plastered brick walls, and there is a door leading to the confessional. Plastered brick covering an area of 120 m2 dominates the wall on the side of the main entrance. This side has glass windows with an area of 11 m2 and a solid wood entrance of 6 m2.

Table 2. Room materials distribution for eksisting design

No.	Materials Distribution		
	Name	*Area (m2)*	*Acoustic Properties*
1	Ceramics floor	442	Reflector
2	Gypsum ceiling	513	Reflector
3	Brick plaster	343	Reflector
4	Solid doors	26	Reflector
5	Folding door (open when room in use)	60	Absorber
6	Window glass	11	Reflector
7	Vent (Roster/opening)	64	Absorber + Diffuser
8	Brick plaster with slotted wood panel	40	Diffuser + Reflector
9	Brick plaster with rough natural stone	31	Reflector

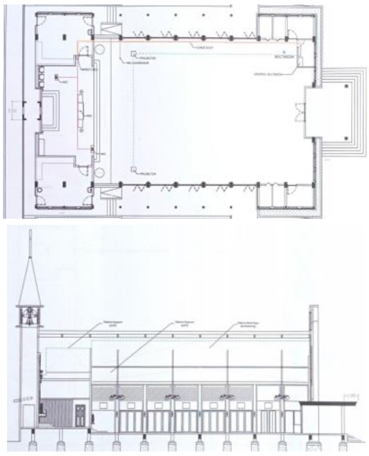

Figure 2 Building plan and section.

3.2. Reference Model

The reference model is a model that uses dominant sound-absorbing material, especially in the ceiling area, and a model with an acoustic material design that provides room acoustic quality close to the measurement parameters. The reference model produces a material composition derived from the experimental results.

Material elements in the initial design that can function acoustically are maintained and maintain the room's shape. The acoustic material's focus is on the back wall and ceiling. The back fence uses sound-absorbing materials, namely absorber panels, and slotted panels, and the ceiling uses a porous absorbent type so that it is lightweight in construction.

In addition to sound absorption, use open doors. The audience area is also a sound absorber because one of the essential elements that make up the interior acoustic parameters in a room is the audience [14]. The audience is the main factor determining the sound absorption area equivalent to a concert hall with a contribution of up to 80% [8,15]. Therefore, when the simulation assumes that the audience is present at 50% of the capacity, if use 100% attendance, the sound quality results at 50% attendance will worsen. Then the use of 50% attendance uses the worst-case scenario.

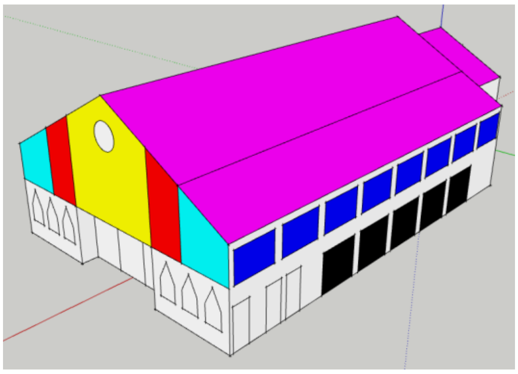

Figure 3 Baseline model perspective.

Table 3. Acoustic materials distribution for baseline model

No.	Acoustic Materials Distribution		
	Name	*Colour code*	*Acoustic coefficient (1st line absorber, 2nd line scattering) as 1/3 octave from 125 Hz*
1	Acoustic Panel (ex. Jayabell)	Purple	52 50 48 42 43 35
2	Slotted panel	Red and Turquois	10 35 55 25 8 2
3	Panel Absorber	Yellow	90 82 56 36 31 22
4	Slotted diffuser	Green	14 10 6 8 10 10 5 5 20 70 80 85
5	Ventilation (Roster)	Blue	20 45 60 40 45 40 5 5 10 90 80 90
6	Open Doors	Black	99 99 99 99 99 99
7	Audien (50% ocupation)	-	12 45 80 90 95 99

3.3. Test Model

The test model is a model that uses the dominant diffuse material as a compromise of reducing the use of absorbent materials. It is said to be prevalent because the room's back wall still uses the same type and proportion of material as the reference model. The focus of processing is on the shape of the ceiling from a flat reference model (flat plane) to an angular shape and minimizing flat areas (purple color in Figure 4). Materials and construction in these areas are the same as the initial design by the architect, namely gypsum board with a metal frame.

Processing the shape of the ceiling of the test model uses the concept of breaking sound energy so that other acoustic materials absorb it more easily. In addition, the use of diffuse material is also able to give the impression of a more spatial sound [16]. According to experts, diffusers are also absorbent, and any use of these surfaces reduces reverberation time [17,18].

The shape of the ceiling uses rectangular protrusions with a greater slope to the axis of the main ceiling shape. Modifying the shape of the ceiling also considers the impression of space and the distribution of sound. It created a ceiling shape with a gradation from the front to the back of the room to give a sacred impression. The front area (altar, the area with green walls in Figure 4) becomes a sacred area by processing a cleaner ceiling, then gradually becomes more crowded by processing the shape of the ceiling towards the back (entrance). The increasingly crowded form processing in the rear area also functions acoustically. The back area of the room is an area with a high potential for acoustic defects due to the buildup of sound energy. Processing the shape of the ceiling still maintains the room's axis to emphasize the focus and impression of the sacred space. In addition to processing the ceiling shape, diffuse material also utilizes the wall area that can still be processed using acoustic materials in the wall area using a sinusoidal diffuser material model.

Table 4. Specific change for acoustic materials in the test model (other material has the same coefficient as in the baseline model as the colour code)

No.	Acoustic Materials Distribution		
	Name	*Colour code*	*Acoustic coefficient (1st line absorber, 2nd line scattering) as 1/3 octave from 125 Hz*
1	Gypsum board with metal furring	Purple	20 15 10 8 4 2
2	Sinusoidal diffuser	Pink	14 10 6 8 10 10 5 5 20 70 80 85

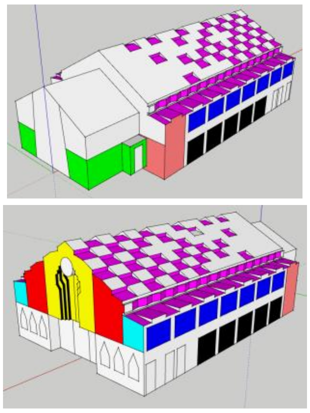

Figure 4 Perspective for the test model.

3.4. Comparison of Results

3.4.1. SPL

The SPL value indicates the loudness of the sound heard. In the function of the worship room, the congregation must be able to hear well the words and sentences spoken by the worship leader. The comparison shows an increase in the scores across all frequencies in the test model. The increase is due to the decrease in the test model's absorbent material, which increases the overall SPL. The increase in SPL is still within the reference value range, but in the test model, there is an improvement in the SPL value at observation points 2 and 4, especially at 2kHz and 4kHz frequencies. Compared with the existing design, there is an improvement in the low-frequency SST by both the reference and test models.

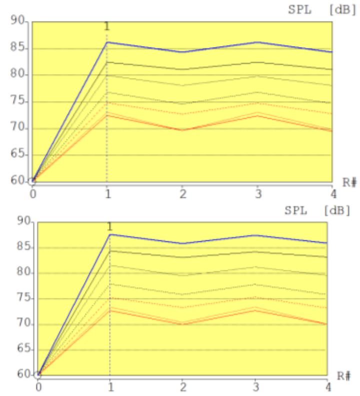

Figure 5 SPL at baseline model (top), test model (bottom).

3.4.2. RT/T30 (500 & 1000 Hz)

The reverberation time of both models at a frequency of 500 Hz shows an increase and decrease of 0.1 to 0.2 seconds at points 2 and 4 (back row). The difference of 0.2 seconds on RT does not significantly impact sound quality. The contrast of 0.3 seconds is at the observation three frequency 1000 Hz. Overall, the use of diffuse material impacts changes in the RT/T30 value. The impact is in the form of an increase and a decrease in value. It is necessary to conduct a more in-depth study regarding the effect of spatial geometry and the sound distribution of each loudspeaker.

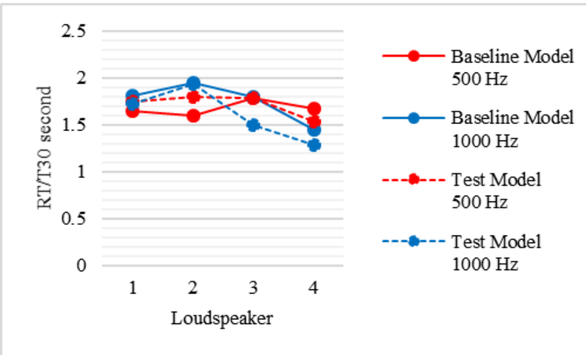

Figure 6 RT/T30 value comparison graph.

3.4.3. STI and D-50

Speech Transmission Index (STI) and Definition at 50 ms (D-50) affect the clarity of human speech (speech). STI shows the percentage of words in a sentence that the audience can hear well. In contrast, D-50 shows an understanding of word pronunciation. Both models show STI values that are in the range of reference values. The results also show improvement compared to the existing design and indicate that the diffuse design in the test model positively impacts the quality of speech sound reception. The D-50 value in the test model shows a significant decrease compared to the baseline model but is still 8 points better at the four observation points compared to the existing design. The

D-50 value at observation points 1 and 3 (front row) is around 60% and is still below the reference value. In the back row, the value of D-50 becomes lower, which indicates that the use of diffuse forms and materials can improve sentence acceptance (STI) and word pronunciation (D-50) but is more significant in enhancing STI scores.

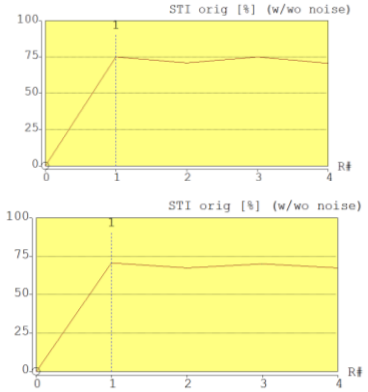

Figure 7 STI at baseline model (top), test model (bottom).

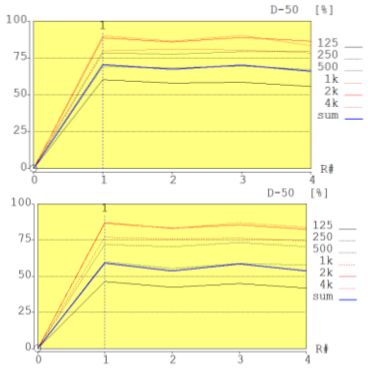

Figure 8 D-50 at baseline model (top), test model (bottom).

3.4.4. C-80

The clarity of sound received by the listener makes the definition of sound and instruments more accurate. The reverberant energy of the sound in the room dramatically affects the clarity of sound. The presence of the diffuser material affects the reverberant energy in the room. The test model shows better performance, especially for measuring points on the back row. The value at each measurement point of the test model is +3.

Meanwhile, the baseline model, especially at the back row measuring point, has reached a value of +6, which is higher than the recommended measuring parameter. The baseline model uses sound-absorbing materials, especially in the back area (walls and ceilings). It means that the use of many sound-absorbing materials will adversely affect the quality of the C-80. There are indications that the combination of absorbent and diffuse materials gives better results for this parameter than using only one type of material. Overall, the test and baseline models provide better results than the existing design models, which use a dominant sound-reflecting material.

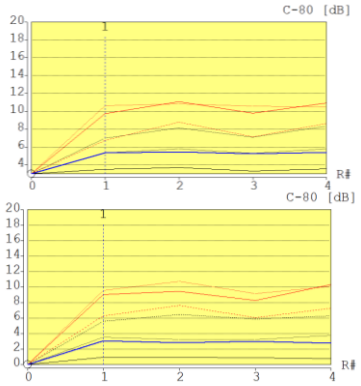

Figure 9 C-80 at baseline model (top), test model (bottom).

3.4.5. LF and BR

Lateral Fraction gives the impression of stereo and space. While the Bass Ratio gives the impression of warmth to the sound. In worship rooms and rooms with music functions, these two parameters play a role in forming the image of space by sound. The LF results show similar values between the test model and the baseline model in total frequency. However, It has seen a difference in the range of values between LF for bass and treble frequencies. The test model has a smaller range of values so that the stereo feeling for all frequencies is more balanced. It means that using the dominant diffuser design positively impacts the quality of the spatial impression.

The recapitulation of the Bass Ratio value shows that the test model gives the impression of a more significant sound warmth than the baseline model. One loudspeaker delivers a higher value but can tolerate it because the function of a room that has a sacred value requires a warmer sound impression than the impression of a sound that tends to be dry. The use of diffuse shapes and materials makes the sound feel warmer. It is possible because the reverberant sound lasts longer in the room due to the lack of sound energy-absorbing materials.

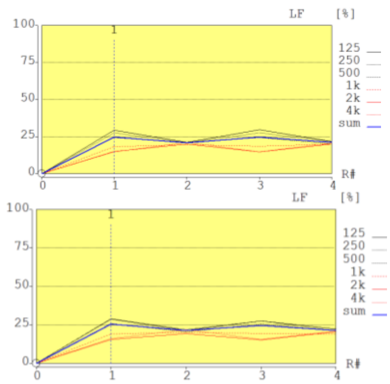

Figure 10 LF at baseline model (top), test model (bottom).

Table 5. BR Comparison

Loudspeaker Number	BR for Baseline Model	BR for Test Model
1	1.31	1.42
2	1.24	1.38
3	1.12	1.41
4	1.28	1.65

4. CONCLUSION

Based on the results of a simulation study, the use of acoustic materials is dominantly sound-absorbing and dominant is sound diffusion, so it has a positive impact on improving sound quality in the room. The use of dominant diffuse forms and materials positively impacts the quality of sentence sound reception, but there is no significant improvement in word pronunciation acceptance. The predominant use of absorbent material harms the sound quality of the music (C-80)—the need for a combination of porous material and diffuser. In addition, the use of the dominant diffuse material positively impacts the impression of space and the warmth of the sound in the room compared to the dominant absorption material. Diffusion materials are needed to strengthen the sacred image in the area. Based on these results, further research can carry to find the right combination for the function of music.

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