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Design of Simple Acoustic Materials for High School Hall Using Software CATT

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ABSTRACT

Good acoustic quality is essential to consider in designing a multipurpose room. Unfortunately, school halls usually have poor room acoustics. Lack of funds and lack of knowledge about acoustics cause the acoustic quality of the room to be very poor. The purpose of this research is to design a simple acoustic material application concept for a high school hall based on the Ministry of Education and Culture manual to meet the requirements for speech, music, and sports functions. Simple acoustic materials exist in everyday life, such as corrugated cardboard, cork, multiplex boards, newspapers, egg racks, and cloth. The research applied a simulation method using CATT v8 software. The parameters used to measure room acoustic quality were RT60, C-80, D-50, STI, EDT, and LF The simulation compared the hall's acoustic performance without and with the simple sound absorbers. The absorbers were applied to 39% of the walls and 55% ceilings. The absorbers reduced T-30 (500Hz) from 3.8 seconds to 1.5 seconds with an omni sound source and 1.3 seconds with speakers. The averaged Speech Transmission Index (STI) was improved from 38% to 60% with the omni sound source and from 43% to 65% with speakers.

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1. INTRODUCTION

The principle in interior acoustics is to amplify or direct good sounds and eliminate or weaken sounds that are not useful for human hearing. Thus, designing the interior of a particular room must be adjusted to the acoustic needs of the activities in it; for example, classrooms for teaching and learning activities, music rooms for musical activities, and multipurpose rooms such as auditoriums and stages can accommodate both activities [1].

An auditorium requires special handling for its acoustics [2]. Therefore, it significantly influences the success of an activity accommodated in it [3]. The purpose of visitors attending an event in the multipurpose room is to enjoy and focus on the show. However, if the designer ignores the hall's acoustic quality and aesthetics, he will not achieve the desired goal. Therefore, designing the acoustics of a multipurpose hall is essential to meet the hopes of visitors or guests attending the room [4].

The high school hall, which is the object of research, is the high school hall designed according to the Manual for Standardization of High School Buildings and Furniture published by the Ministry of Education and Culture [5]. The high school hall can perform arts/films, meetings, public lectures, exhibitions, demonstrations, or indoor sports. Three functions can be accommodated in the hall: conversation, music, and sports, which require different acoustic standards.

The shape of the hall, according to the manual, is a rectangle (shoebox) with a total audience area of 180m^2, while the total standard size of the high school hall is 252m^2. In the manual, there are only notes to choose materials that do not reflect sound in the wall and floor area to reduce echoes, and there is no discussion about designing the space in the hall to have good acoustic quality. The diversity of space functions demands different acoustic treatments. It is due to differences in the quality and quantity of sound received by listeners [6], [7]. Speech and music activities have different acoustic requirements, especially the reverberation time [8]. The conversation function usually uses a short reverberation time to ensure that audiences hear the speech clearly. Long reverberation times are generally used for rooms with music functions so that the sound of the music sound alive. The volume of space and the proportion between the absorption plane and the reflected plane determine the reverberation time [9]. The recommended reverberation time for conversations is 0.6 – 1.2 seconds. For music, 1.0 – 1.7 seconds is recommended [10], [11]. As for sports, the recommended reverberation time is a maximum of 1.5 seconds at a frequency of 500Hz to 2000Hz [12]. The acoustic quality requirements for classical music concerts and contemporary music vary. Band concerts usually use a sound amplifier whose loudness can reach 100-120dB. For music concerts using bands, special handling of absorbent material is needed to make the reverberation time as low as 0.6 seconds [9]. One of the factors that significantly affect the comfort of interior acoustics is the material of the interior elements, where the character of the material can reflect, absorb, and spread sound [1].

Table 1 Acoustic parameters used in research

Parameters	Standard	Function
Reverberation time / RT_{60} / T_{30})	Depending on the function of the room and the volume of the room	Echo or reverberation in the room
Clarity Index C80, sound clarity index	Front row: +3dB to +8dB Rear row : 0 dB to +5dB	Music sound clarity
Definition D50, speech clarity	D50 > 65%	Speech sound clarity
Speech Transmission Index (STI)	Good: 0.60 – 0.75 Very good: 0.75 – 1.00	Clarity of word fragments between vowels and consonants
Early Decay Time (EDT)	≤ RT60	Echo or reverberation in the room
Lateral Fraction (LF)	0.1<LF<0.35 or 10%-35%	Space impression

Currently, the common practice to set the hall's acoustic quality is by adjusting the sound system and not selecting the appropriate surface materials. Meanwhile, no matter how sophisticated and expensive the sound system installed in a room is, if the room's acoustics are wrong, it will make the sound quality in the room terrible [9],[7]. Acoustic materials can be in the form of absorbent material, reflected material, or diffuse material. We use absorbing materials that absorb sound energy to avoid echo. To reflect sound, we use reflective materials. Diffuse material breaks up sound and reduces sound energy to distribute sound evenly while maintaining reverberation time [13].

Acoustic materials available in Indonesia are of limited choice. Shops provide only the most popular acoustic materials. They advertise acoustic materials through brochures. It takes a long to import from overseas. Currently, the government recommends using environmentally friendly acoustic materials [9]. Many studies have found simple acoustic materials that can improve the acoustic quality of a room. In the multipurpose room, the most widely used acoustic material is absorbent. The following are some studies that have been carried out regarding the types of simple, porous materials using impedance tubes:

a. Low-frequency absorbent material

   In 2014, Priscilla Gloria and Hedy C. Indrani wrote a journal entitled "The Potential of Newspaper and Cork as an Alternative to Acoustic Materials." This study states that pulp, cork, and multiplex panels absorb up to 96% sound. The composition of the panel layer used is pulp:cork:multiplex board = 3:3:0.6. In comparison, the composition of paper pulp is newspaper:casting = 1:3 [14]. The sound-absorbing panel is made by gluing cork with plywood using wood glue and then placing the pulp. It is then wrapped with chicken wire and then covered with cloth.

Table 2. Absorption coefficient of paper, cork, and multiplex

Frequency (Hz)	Absorption coefficient
125	0.76
250	0.87
500	0.41
1000	0.19
2000	0.09

Source: P. Gloria and H. C. Indrani, 2014 [14]

Figure 1 Example of alternative acoustic panel coating
Source: P. Gloria and H. C. Indrani, 2014 [14]

b. Mid-frequency absorption material
In 2017, Prasasto Satwiko, Verza Dillano Gharata, Herybert Setyabudi, and Fefen Suhedi wrote a journal entitled "Enhancing Egg Cartons' Sound Absorption Coefficient with Recycled Materials." This study states that egg cartons filled with straw and patchwork can absorb more than 50% sound energy at a frequency of 315 – 2500Hz. Patchwork and straw are shaped like eggs and placed in the egg holder, then covered with another egg carton with a hole in the top [15]. The panels are made by nailing egg cartons with plywood then wrapping them with a cloth.

Table 3. Egg carton module absorption coefficient

Frequency (Hz)	Egg Carton Absorption Coefficient
100	0.05
125	0.08
250	0.37
500	0.78
1000	0.72
2000	0.54
4000	0.48
NRC	0.60

Source: P. Satwiko et al., 2017 [15]

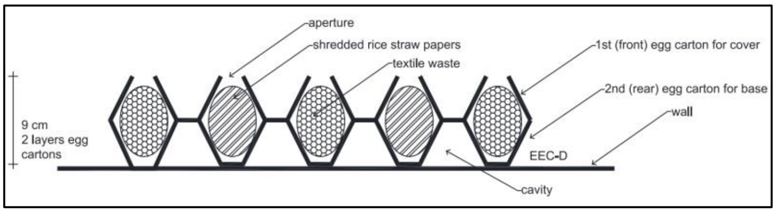

Figure 2 Section of egg carton module
Source: P. Satwiko et al., 2017 [15]

Figure 3 Egg carton module
Source: P. Satwiko et al., 2017 [15]

c. High-frequency absorbent material
In 2015, Oki Kurniawan, Pribadi Widodo, and Andriyanto Wibisono wrote a journal entitled "Experimental Design of Acoustic Panel Absorption Capacity from Corrugated Cardboard Box Waste." This study states that corrugated cardboard boxes of 40mm have a 0.22 absorption coefficient at a frequency of 500Hz and a 0.52 absorption coefficient at a frequency of 1kHz. The

panels are arranged by exposing or displaying the corrugated cardboard cavity as a panel texture [16]. Making this panel is very easy, just by sticking the cut cardboard onto the base cardboard.

Table 4. Panel absorption coefficient 40mm

Frequency (Hz)	Panel Absorption coefficient 40mm
125	0.08
250	0.17
500	0.22
1000	0.52
2000	0.88
4000	0.95
NRC	0.45

Source: O. Kurniawan,et al.,2015 [16]

Figure 4 Samples of corrugated board mounted on an Impedance Tube
Source: O. Kurniawan,et al.,2015 [16]

The use of simple absorbent materials aims to save the budget. All people who need sound conditioning can apply it because they can easily find the materials in the surrounding environment. There are several advantages and disadvantages when using this simple absorbent material, including:

1. Advantages:
   - Low cost
   - Can find the essential ingredients for making materials in the surrounding environment
   - Relatively easy panel creation
2. Disadvantages:
   - Installation that requires high accuracy
   - It takes a long time to make the panel because it is a custom-made acoustic material.

Table 5. Specification of the absorption coefficient

Material	Sound absorption coefficient					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Brick wall	0.01	0.01	0.02	0.02	0.02	0.03
Glass	0.35	0.25	0.18	0.12	0.07	0.04
Plywood (3/8”)	0.28	0.22	0.17	0.09	0.10	0.11
Gypsum celing (1/2”) suspended	0.15	0.10	0.05	0.04	0.07	0.09
Marble/ceramic	0.01	0.01	0.01	0.01	0.02	0.02
Wood	0.15	0.11	0.10	0.07	0.06	0.07
Ventilation holes	0.99	0.99	0.99	0.99	0.99	0.99
Low frequency absorbent materials (paper plup, cork, and multiplex)	0.76	0.87	0.41	0.19	0.09	0.09
Middle frequency absorbent material (egg cartoon)	0.08	0.37	0.78	0.72	0.54	0.48
High frequency absorbent material (corrugated cardboard box)	0.08	0.17	0.22	0.52	0.88	0.95

2. RESEARCH METHOD

2.1. Research Procedure

There are two stages in the research method: literature study and simulation. In the literature study stage, three topics must be looked for, namely: the standard of the high school hall according to the Ministry of Education and Culture's guidebook, the parameters/standard for the acoustics of the multipurpose room/hall, and simple acoustic materials. The next stage is to design the digital model and proceed with the simulation.

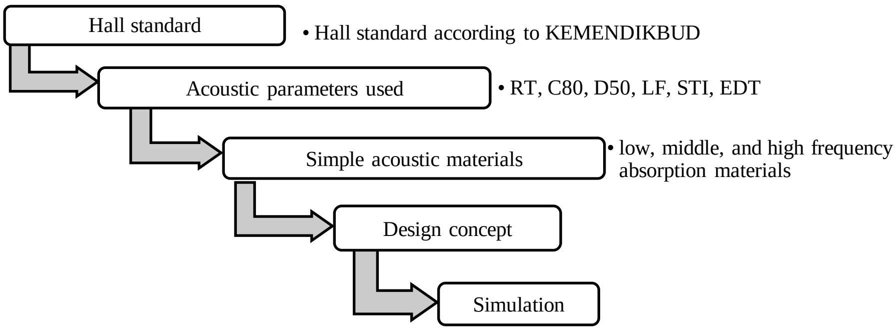

Figure 5 Literature study research flow

According to the manual, the simulation begins with loading the hall room model, performing a simulation using the CATT Acoustic software, and then comparing the simulation results with acoustic quality standards. If the results are not good, it will carry out remodeling, and if the results are good, it will be followed by concluding.

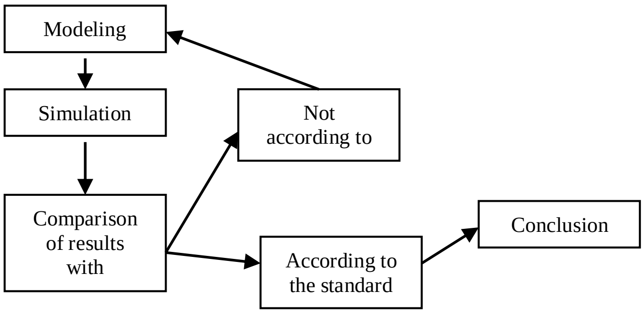

Figure 6 Simulation flow

2.2. Analysis Method

The result analysis method compares simulation results with good room acoustic standards. The parameters are more concerned with the room's reverberation time. If it is not up to standard, it will perform the scheme as shown in the following chart :

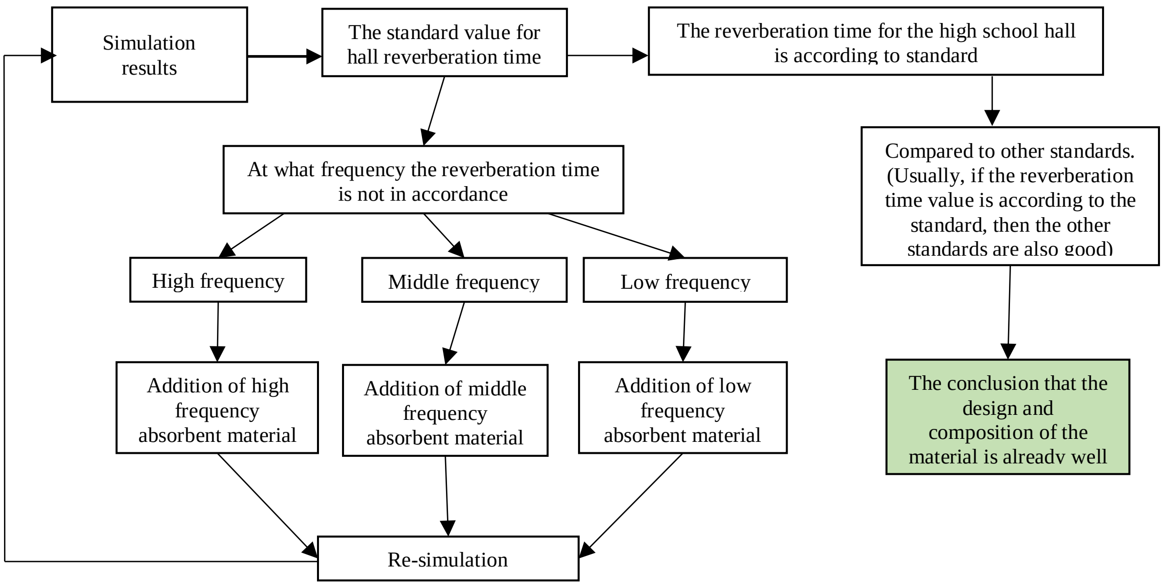

Figure 7 The result analysis flow

2.3. Interior Materials

There were four experiments carried out with different percentages of absorbent material area, with the following comparison:

Table 6. The area of the absorbent material used on the wall

Wall Area	Original	P-13	P-17	P-21
Wall	100%	63%	61%	63%
High frequency	0%	12%	12%	10%
Middle frequency	0%	9%	10%	9%
Low frequency	0%	16%	17%	19%

Source: author,2021

Table 7. The area of the absorbent material used on the ceiling

Ceiling Area	Original	P-13	P-17	P-21
Ceiling	100%	41%	45%	45%
High frequency	0%	24%	21%	20%
Middle frequency	0%	22%	21%	21%
Low frequency	0%	13%	13%	14%

Source: author,2021

The original model was constructed based on the Manual for Standardization of High School Buildings and Furniture published by the Ministry of Education and Culture.

2.4. Room Condition during

The condition of the room at the time of the CATT analysis was set at a temperature of 30°C, 75% humidity, and an air density of 1.20kg/m^3. A 40dBA background noise was evenly distributed at all frequencies according to the allowed noise criteria in a room [9].

3. RESULTS AND DISCUSSION

a. RT60 / T30 and EDT

Using simple absorbent materials at the lower, middle, and upper frequencies can improve the hall's reverberation time and EDT value. For example, in the P-21 modeling, the value of T30 at a frequency of 500Hz at all audience points is 1.5 seconds using an Omni sound source and 1.3 seconds with a speaker sound source (Figure 8). While the EDT value at a frequency of 500Hz is 1.3 seconds for Omni and 1.2 seconds for speaker (Figure 9)

The results of this simulation indicate that the P-21 modeling meets the standards to accommodate activities that can carry out in the SMA hall; function of performing arts/films, meetings, public lectures, exhibitions, demonstrations, or indoor sports. In addition, the more absorbent material can reduce the reverberation time.

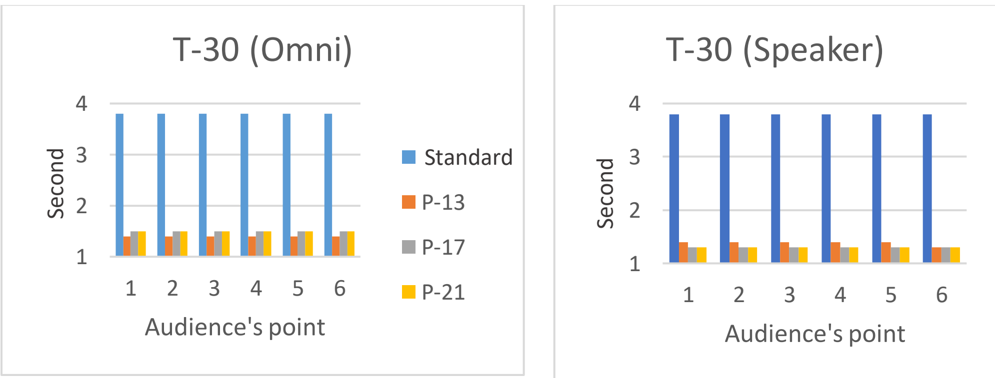

Figure 8. T-30 value using omni and speaker sound source

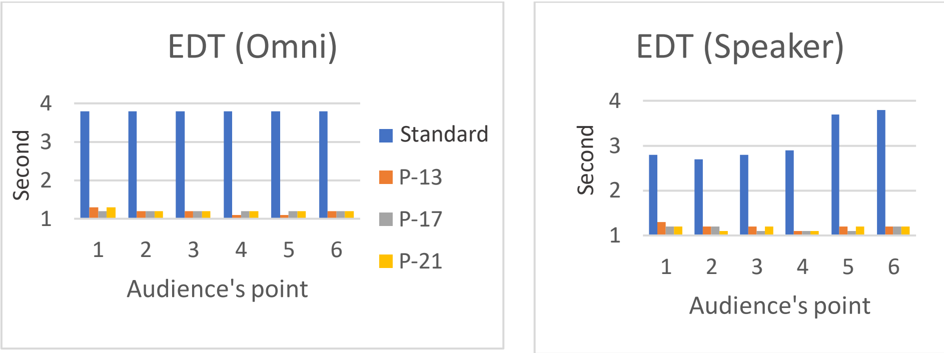

Figure 9. EDT value using omni and speaker sound source

b. C-80 dan STI

The C-80 and STI values have different functions. The value of C-80 is used to assess the clarity of the sound or the vibrancy of the sound. On the contrary, the STI is used to evaluate the clarity of word splitting between vowels and consonants. In addition, the use of absorbent materials in a room determines the live and dead sensation of music or the clarity of word fragments when speaking.

In the P-21 modeling, the C-80 value for the Omni sound source is only the audience point at the back of the room that meets the standard, and the C-80 value is +3.1dB and +3.5dB. However, when the analysis used speakers, each audience point met the bar with a value range of +3.5dB for the back to +4dB for the front of the room (Figure 10).

For the STI value in the P-21 modeling using an omni sound source, only one audience point at the back of the room meets the standard with a value of 60%, while the sound source using speakers all meet the bar with a range of 65% values at the front and 62% at behind (Figure 11)

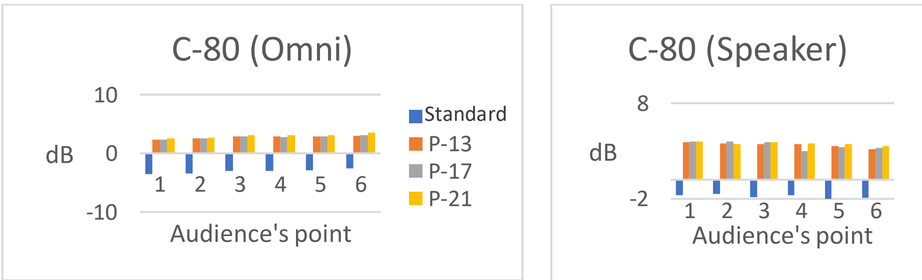

Figure 10. C-80 value using omni and speaker sound source

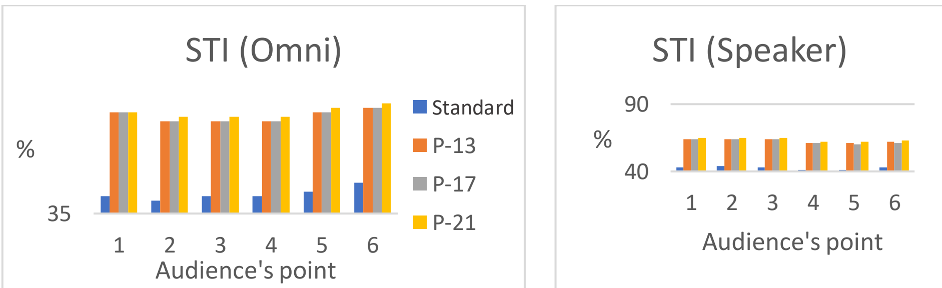

Figure 11. STI value using omni and speaker sound source

c. LF

The LF value is used to assess the impression of a room or the stereo appearance of a room. The addition of absorbent material as a space cover material does not affect the LF value. LF assesses the ratio between the reflected sound energy from the side and the total sound energy coming from all directions, including direct sound (Figure 12). The LF values of all modeling are still included in the standard LF values 10%-35%.

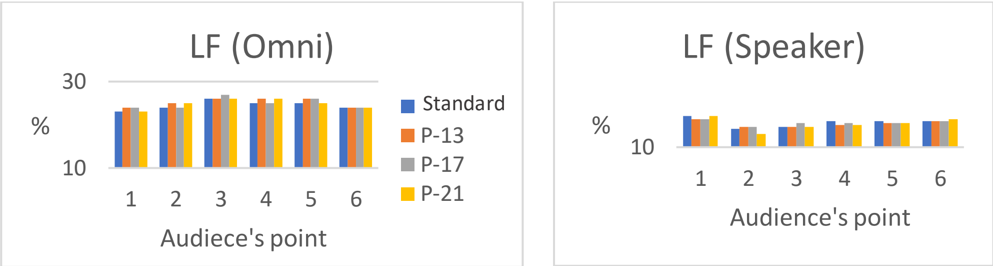

Figure 12. LF value using omni and speaker sound source

3.1. Selected Design

The model that will be the design proposal is the P-21. Not all high school hall materials use unique materials for room acoustics. The only special material used for handling room acoustics is absorbent and for reflected and diffuse materials using existing materials.

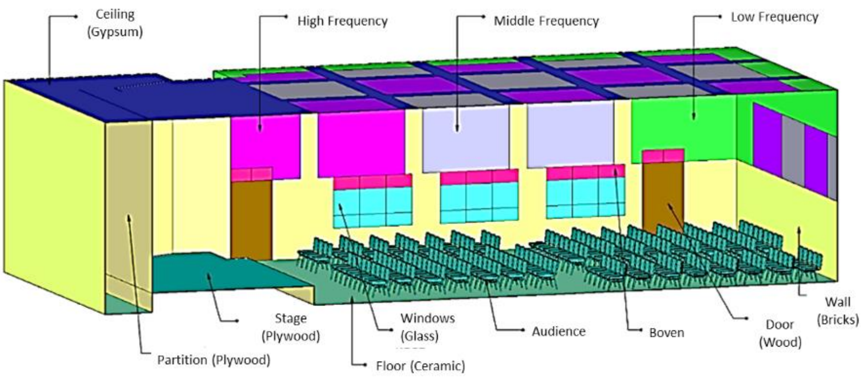

Figure 13. High school hall arrangement

a. Absorbent
Sound absorbing materials use simple acoustic materials, which their raw materials are available around. The material used is the result of research that has been done previously by other researchers using impedance tubes. Low-frequency absorbent materials use the pulp, cork, and multiplex panels, middle frequency uses egg cartons filled with straw and patchwork, and high frequency uses corrugated cardboard boxes.

b. Reflector
The sound-reflecting materials used are all materials that have smooth and hard surfaces such as walls, floors, glass, and multiplex board.

c. Diffusors
Place the diffuser material on the ceiling and walls by arranging the absorbent material at different heights.

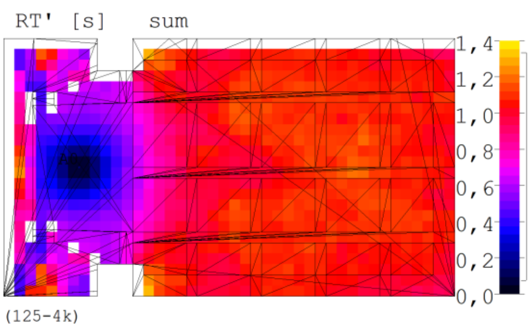

Figure 14. Average T-30 value on the P-21 using an omni sound source

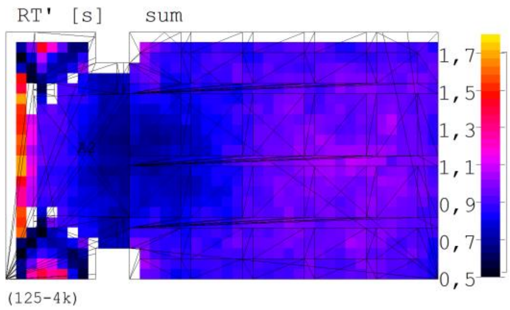

Figure 15. Average T-30 value on the P-21 using a speaker sound source

3.2. Simple Acoustic Panel Installation

The acoustic panel to be used is 50cm x 50cm. The total panels required for the P-21 are as follows:

a. Low-frequency acoustic panel: 424 panels
b. Middle-frequency acoustic panel: 341 panels
c. High-frequency acoustic panel: 349 panels
d. Total panels: 1,114 panels

High school students can do the easy manufacturing process. Eighty students can produce 1,114 panels, with one student expected to make 14 panels within one month from the raw material manufacturing process to the panel assembly process. Thus, the panel installation process is expected to be completed by 40 students within a maximum of one month under the supervision of several teachers. The more students who participate in the manufacturing process up to the panel installation process, the shorter the time needed to complete. The cost of a high school hall acoustic quality improvement package using simple materials and a comparison using ready-made acoustic panels is as follows:

Table 8. Price of one simple acoustic material panel

	Price listed in the journal	Unit area	Sought price	Unit area	Price of one panel	Unit area
Low-frequency absorbent material	Rp13.000,-	/30cm^2	-	-	Rp37.000,-	/50cm^2
Middle-frequency absorbent material	Rp30.000,-	/m^2	-	-	Rp7.500,-	/50cm^2
High-frequency absorbent material	-	-	25.000	/50cm^2	Rp25.000,-	/50cm^2

Source: author,2021

Table 9. Cost of one package using simple materials

	Price of one panel	Unit area	Number of panels needed	Total price
Low frequency absorbent material	Rp37.000,-	/50cm^2	424	Rp15.693.920,-
Middle frequency absorbent material	Rp7.500,-	/50cm^2	341	Rp2.557.500,-
High frequency absorbent material	Rp25.000,-	/50cm^2	349	Rp8.727.000,-
	Cost of one package			**Rp26.978.420,-**

Source: author,2021

Table 10. Cost of one package using jayabell acoustic board
(Jayaboard gyptile bhyhua painted – square 120x60)

	Price of one panel and installation cost	Number of panels needed	**Cost of one package**
Jayabell Acoustic Board	Rp135.000,-	387	**Rp52.245.000,-**

Source: https://www.arsiteki.com/harga-plafon-akustik-per-m2/

Table 11. The difference in the price of one package using simple acoustic materials and using ready-made acoustic panels

Cost of one package using simple acoustic materials	**Rp26.978.420,-**
Cost of one package using Jayabell Acoustic Board	**Rp52.245.000,-**
Price gap	**Rp25.266.580,-**
Percentage price gap	**48%**

Source: author,2021

Note: The prices listed are only estimates, and each city might have a different price. Using simple materials for acoustic panels can be much cheaper when using recycled materials sold in the second-hand market.

4. CONCLUSION

Based on the simulation and analysis results, the use of simple absorbing acoustic materials in the high school hall based on the Ministry of Education and Culture guidelines can improve the acoustic quality of the room. The use of simple absorbent materials in the form of corrugated cardboard boxes, cork, multiplex boards, newsprint, egg racks, and cloth can be an alternative to improve the acoustic quality of the room. However, compared to ready-made acoustic materials, these materials have limited costs and limited access to purchase.

The simulation found that a hall constructed based on the government manual had T-30 (500 Hz) 3.8 seconds, which was poor. The hall's STI was 38% (with an omni sound source) and 43% (with speakers), which was also poor. The use of simple sound absorbent materials in 39% of the walls and 55% of the ceilings reduced the hall's T-30 value (500Hz) as much as 2.3 seconds (from 3.8 sec to 1.5 sec) with an omni sound source and from 3.8 sec to 1.3 sec with speakers. The average STI value also increased by 18.5% for omni sound sources and 21.2% for speakers' sound sources. Thus, the absorbers improved the hall's STI to 60% with an omni sound source and 65% with the speakers. These results have met the hall's acoustic standards for various events. The auralization results can be played from https://bit.ly/Auralisasi. (Note: the name of the files have not been translated to English. Please use this simple translation. Musik = music, Percakapan = speech/conversation)

Further research is needed to test the results of this study by applying design concepts and conducting tests using acoustic tools (e.g., PAA3).

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