International Journal of Sustainable Development & Future Society, 2 (2), November 2024, pp.84-98.

e-ISSN: 3026-247X
p-ISSN: 3025-9797

Content lists available at Indonesia Academia Research Society

International Journal of Sustainable Development & Future Society

Journal homepage: ejournals.indoacademia-society.com

Original Article

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Assessment of Indoor Acoustic Performance: Impact of Interior Materials on Classrooms in Higher Education Buildings

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Article History
Received 20 August 2024
Revised 17 October 2024
Accepted 5 November 2024
Available Online 30 November 2024

Keywords:
Classroom acoustics
Acoustic performance
Interior materials
Higher education buildings
Sound quality assessment

Abstract

The acoustic quality of classrooms in higher education institutions is very important to support effective and efficient teaching and learning processes. Poor classroom acoustic conditions can cause communication disorders, such as difficulty hearing instructions and misunderstandings, thus disrupting the learning process. This study investigates how interior element materials (floors, walls, and ceilings) can affect the acoustic performance of classrooms. The case study took classrooms from six higher education institutions, namely Petra Christian University, Ciputra University, Wilwatikta College of the Arts, and 17 August 1945 University in Surabaya, as well as Satya Wacana Christian University in Salatiga and the Indonesian Institute of the Arts in Yogyakarta. This study used a quantitative method using I-Simpa (Integrated System for Indoor Acoustic Performance Assessment) software. I-Simpa can identify deficiencies in sound quality by measuring RT_{30} (reverberation time), C_{50} (clarity), and D_{50} (definition) of each existing classroom. Data were collected through acoustic measurements and students' perceptions regarding their experiences with classroom acoustics. The findings can reveal the use of inappropriate interior element materials, which can significantly reduce the clarity of sound in the teaching and learning process in the classroom. The results of the study are expected to provide optimal acoustic material solutions and the most strategic layout to improve sound distribution in the classroom. This study provides suggestions for acoustic material management based on innovation and technology, which will be useful for designing classroom interiors in higher education buildings in the future.

1. Introduction

Classrooms in higher education institutions are the primary places where knowledge is imparted and acquired. The acoustic environment within these spaces can significantly impact the quality of the learning experience (Rizk et al., 2018). Regardless matter where they are in the enclosed space, the audience, who are the most significant component of the space, must be in a state of aural contentment (Pillai et al., 2022). Noise can impede cognitive tasks, which may not be evident when productivity is measured in controlled laboratory settings with predefined tasks. This suggests that real work situations, where tasks are more varied and dynamic, might be more affected by acoustic conditions (Antikainen et al., 2008). Because speech intelligibility is directly impacted by acoustic quality, it is critical in classrooms for teachers and students to communicate effectively. By guaranteeing that students can comprehend spoken instructions and discussions, good acoustics help students perform better academically (Sarlati et al., 2014). Exposure to poor acoustic environments can lead to mental and physical

DOI : 10.62157/ijsdfs.v2i2.76

discomfort, including feelings of annoyance, headaches, and increased aggressiveness. This can reduce students' overall well-being, attention, and motivation to learn (Minelli et al., 2022). Noise can impede cognitive tasks, which may not be evident when productivity is measured in controlled laboratory settings with predefined tasks. This suggests that real work situations, where tasks are more varied and dynamic, might be more affected by acoustic conditions

Speech intelligibility is an important determinant of effective acoustic performance, and it is influenced by a variety of factors within the classroom. (Rizk et al., 2018). Expert studies have shown that up to one-third of students may miss as much as 33% of the speech delivered in educational spaces due to poor acoustics. (Rizk et al., 2018). Therefore, it is important to understand now how much acoustics affect students' learning focus in the classroom. Poor acoustics in classrooms can result from several factors, including high levels of background noise, excessive reverberation, and inadequate sound insulation. These conditions can degrade speech clarity and make communication difficult, leading to increased cognitive load for both teachers and students. Environmental factors such as noise from outside the classroom, poor architectural design, and lack of acoustic treatment can contribute to these issues (Recalde et al., 2021). A room with comfortable acoustic conditions will create a tendency for a better learning atmosphere and from this atmosphere, students will tend to be more actively involved in discussions in class (Ulvariandani et al., 2018).

Looking at the previous data study, it is time to realize how important it is to understand how to handle it properly to create a comfortable classroom. Many factors can affect acoustic comfort in a classroom and on this occasion the researchers will show how influential interior materials are in classroom acoustics. Poor furniture arrangement too can lead to sound reflections causing echoes, which disrupts audial comfort and can hinder the learning process (Gharata et al., 2023). The materials used on the ceiling, walls and floors will have a major impact on the acoustics in the room where the material can be reflective or absorptive which will determine how sound is reflected or absorbed in the classroom (Kho, 2014). Materials have a significant impact on indoor sound.

Materials can reflect, absorb, and transmit sound, all of which affect interior acoustics. Selecting the right material can improve acoustic comfort by reducing unwanted echoes and reverberations (Kho, 2014). The choice of material has a big impact on interior rooms' acoustic performance since it affects sound diffusion, absorption, and reflection. Different materials interact with sound waves differently due to their unique properties. For example, porous materials, such as carpets and acoustic panels, are good at absorbing sound, cutting down on echoes, and reverberation time. On the other hand, hard, smooth surfaces like concrete and glass can reflect sound, which can make a room noisier and more reverberant (Mohamed et al., 2024). The interior material itself can have a major impact on classroom acoustics because all interior elements will be wrapped in material which will influence the material on the sound in the classroom.

The researchers used a quantitative method to find out the most optimal classroom material with the help of I-Simpa software. I-Simpa software was developed by Université Gustave Eiffel through the Environmental Acoustic Research Unit (UMRAE). I-Simpa is a graphical user interface (GUI) developed to host three-dimensional numerical codes for the modelling of sound propagation in complex geometrical domains. The focus of the research this time is to evaluate RT_{30}, D_{50} and C_{50} in the classroom using I-Simpa. The three parameters can be explained as follows:

- RT_{30} (reverberation time): the time it takes for the sound pressure level to decrease by 60 dB, extrapolated from the initial 30 dB decay of the sound.
- D_{50} (density): measures the clarity of speech by quantifying the ratio of early sound energy (first 50 ms) to the total sound energy received.
- C_{50} (clarity): quantifies the balance between early-arriving sound energy (first 50 ms) and late-arriving energy (after 50 ms), providing an indicator of speech clarity.

Table 1. Acoustic Parameters and Their Impact on Classroom Performance

Parameter	Optimal Value	Source	Impact on Classroom
RT_{30}	0.5–0.6 s	SNI-03-6386-2000	Reduces speech blur, enhancing intelligibility.
D_{50}	>50%	ISO 3382-1	Improves clarity of speech, reducing listening effort.
C_{50}	>3 DB	ISO 3382-1	Ensures dominance of direct sound over reverberation.

Table 1 shows three acoustic parameters discussed previously can change their results depending on how the material absorption coefficient is to the sound in the classroom, where in general the acoustic absorption coefficient is a value that indicates the ability of a material to absorb sound energy when sound waves hit its surface. This value is expressed in a number between 0 and 1. With all the data above, researchers can simulate indoor acoustics using I-Simpa software to find the most optimal results for implementing classroom learning spaces and suggestions for building classrooms in higher education in the future. However, it should be noted that the results in I-Simpa can be wrong if there are errors in the process of inputting coefficient data and the like, as well as model simplification, which in some cases will affect the shape of the simulated room.

Extra care is needed and attention to every detail of the existing tools to find accurate results, such as real field conditions. The results of this study are expected to be a reference for a good classroom in acoustic standards and an opportunity for interior designers to optimize the use of I-Simpa in the future as a useful acoustic calculation simulation. The three acoustic parameters discussed previously can change their results depending on how the material absorption coefficient is to the sound in the classroom, where in general the acoustic absorption coefficient is a value that indicates the ability of a material to absorb sound energy when sound waves hit its surface. This value is expressed in a number between 0 and 1.

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2. Materials and Methods

The main objective of this study is to provide the most optimal material suggestions for improving or designing classrooms, concluding through simulation results. For this purpose, the main materials needed are 3D modelling software SketchUp, I-Simpa, and absorption coefficient material data. The researchers then conducted observation, measurement, documentation, and simulation for this method.

2.1. Materials

The material in this study is mostly software and the results of this software can be changed through the calculation of the entered material value data. For the use of software, it is calculated by the researchers, but the absorption coefficient value uses data from previous similar research results.

2.1.1. Case Studies and Interior Characteristics

Six classrooms from various schools in the City/Region served as the study's locations. A thorough grasp of acoustic behaviour across multiple learning environments is provided by the classrooms that were chosen to represent a range of architectural styles, building materials, and environmental conditions.

1. Location 1: Petra Christian University (coded as A)
    - Address: Siwalankerto Street No.121-131, Siwalankerto, Wonocolo District, Surabaya, East Java 60236
    - Classroom dimensions: 12.7 m (length) x 7.6 m (width) x 3.8 m (height)
    - Interior materials:

    - Ceiling: Concrete roof

    - Walls: Wood partition, bricks and glass

    - Floor: Tiles
2. Location 2: Ciputra University (coded as B)
    - Address: CitraLand CBD Boulevard, Made, Sambikerep District, Surabaya, East Java 60219
    - Classroom dimensions: 12.1 m (length) x 7.1 m (width) x 3.5 m (height)
    - Interior materials:

    - Ceiling: Concrete roof

    - Walls: Bricks and glass

    - Floor: Tiles
3. Location 3: Wilwatikta College of the Arts (coded as C)
    - Address: Wisma Mukti Housing, Klampis Anom II Street, Klampis Ngasem, Sukolilo District, Surabaya, East Java 60117
    - Classroom dimensions: 8.9 m (length) x 7.9 m (width) x 4.6 m (height)
    - Interior materials:

    - Ceiling: Gypsum board

    - Walls: Wood partition and bricks

    - Floor: Tiles
4. Location 4: 17 August 1945 University in Surabaya (coded as D)
    - Address: Semolowaru Street No.45, Menur Pumpungan, Sukolilo District, Surabaya, East Java 60118
    - Classroom dimensions: 13 m (length) x 6.5 m (width) x 3.5 m (height)
    - Interior materials:

    - Ceiling: Gypsum board

    - Walls: Bricks, glass and wood partition

    - Floor: Tiles
5. Location 5: Satya Wacana Christian University (coded as E)

- Address: Diponegoro Street No.52-60, Salatiga, Sidorejo District, Salatiga City, Central Java 50711
- Classroom dimensions: 11.1 m (length) x 5.8 m (width) x 3.5 m (height)
- Interior materials:

- Ceiling: Gypsum board

- Walls: Bricks and glass

- Floor: Tiles

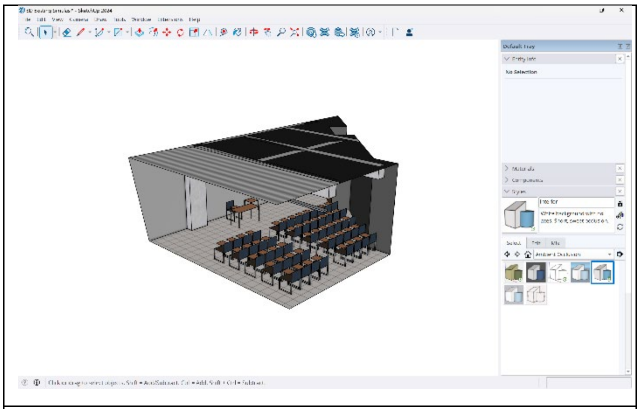
6. Location 6: Indonesian Institute of The Arts Yogyakarta (coded as F)

- Address: Parangtritis Street Km. 6.5, Glondong, Panggungharjo, Sewon District, Bantul Regency, Special Region of Yogyakarta 55188
- Classroom dimensions: 11.4 m (length) x 7.8 m (width) x 3.8 m (height)
- Interior materials:

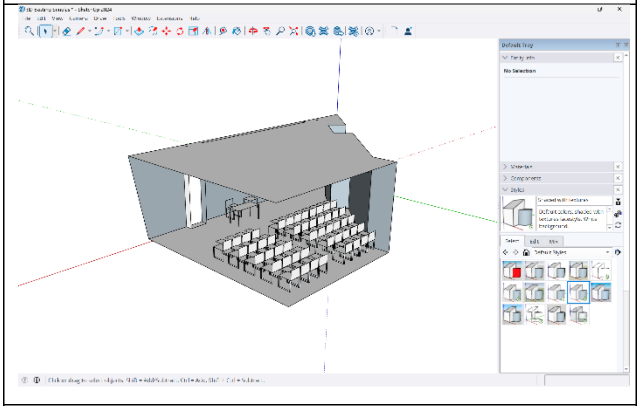
- Ceiling: Concrete roof

- Walls: Bricks

- **Floor: Tiles**



a) SketchUp Software Overview



b) Simplified SketchUp File

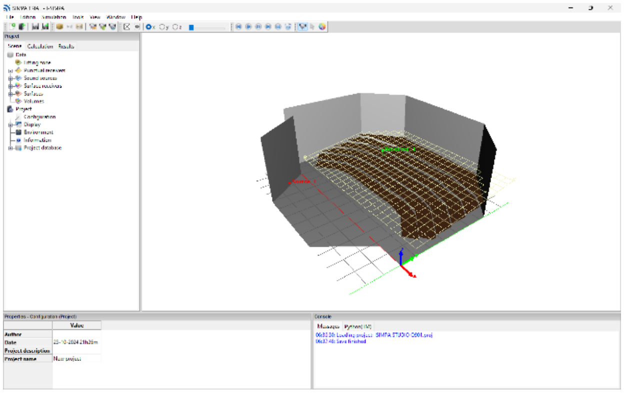
Figure 1. SketchUp Software Overview and Simplified SketchUp File

2.1.2. I-Simpa

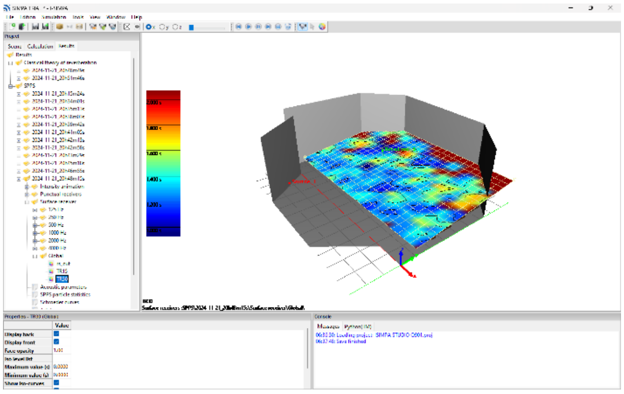
I-Simpa is a software designed for acoustic modelling, particularly focused on sound propagation in complex 3D environments. It provides a graphical user interface (GUI) to support various numerical models used in acoustics (*I-Simpa*. (n.d.)). I-Simpa is not a stand-alone calculation tool but serves as a pre-and post-processor for acoustic codes, integrating with models such as the TCR (Theory of Reverberation) and SPPS (Sound Particle Tracing System). Its primary applications include room acoustics, environmental and industrial noise, and other sound-related studies in three-dimensional spaces.

Developed by the Environmental Acoustics Research Unit (UMRAE) at Université Gustave Eiffel, I-Simpa is open-source software under the GNU General Public License, allowing users to contribute to its development. Its flexible design allows users to incorporate custom acoustic codes and develop additional functionalities through Python scripts. I-Simpa is a versatile acoustic simulation software that offers powerful tools for modelling sound behaviour in complex environments. Some of its key capabilities include:

1. 3D Acoustic Modeling: It allows users to simulate sound propagation in detailed 3D spaces. This is useful for evaluating room acoustics, environmental noise, and other sound-related phenomena in large, complex environments.
2. Integration with Acoustic Codes: I-Simpa is designed to serve as both a pre-processor and post-processor for other acoustic models, such as TCR (Theory of Reverberation) and SPPS (Sound Particle Tracing System). This allows users to input data and visualize acoustic properties such as reverberation and sound reflections.
3. Customization and Flexibility: It supports Python scripting, allowing users to write custom scripts for specific needs. This feature enhances the software's versatility, enabling it to adapt to a wide range of acoustic applications.
4. Data Visualization: I-Simpa provides tools for visualizing the results of acoustic simulations, including sound pressure levels, frequency distributions, and reverberation time, making it easier to understand complex acoustic environments.
5. Environmental and Industrial Applications: The software is particularly useful for modelling environmental noise, urban acoustics, and industrial noise environments. It also supports simulations for room acoustics, which is crucial in spaces such as classrooms, concert halls, and offices.



a) Imported 3D Model in I-Simpa



b) Example of Simulated I-Simpa

Figure 2. Imported 3D Model in I-Simpa and Example of Simulated I-Simpa

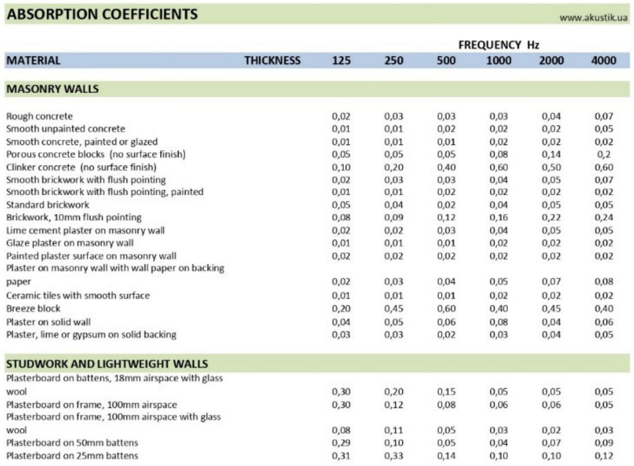
Figure 2 displays I-Simpa is open-source, which allows for broad collaboration and further development by the community. It is primarily developed by the Environmental Acoustics Research Unit (UMRAE) at Université Gustave Eiffel, with contributions from volunteers. In this study, researchers used I-Simpa to obtain the calculation results of RT_{30}, D_{50} and C_{50} by inputting interior materials and their coefficient values and finally inputting them into the simulation.

2.1.3. Absorption Coefficients

The absorption coefficient of a material refers to the amount of sound energy that is absorbed by a material when sound waves strike its surface. This factor is crucial in acoustic applications, as it impacts how sound behaves within space. In physical terms, the absorption coefficient is the ratio of the sound energy absorbed by the material to the total sound energy incident upon it. The value ranges from 0 to 1 which has been explained in ISO 354:2003 as follows:

- 0: The material does not absorb sound at all (all energy is reflected). Examples are hard surfaces such as concrete or glass.
- 0.1-0.3: The material in this range reflects sound more than it absorbs. Examples are wall plaster and glass.
- 0.4-0.6: The material absorbs around 40-60% sound energy. Examples are acoustic ceilings made of gypsum and perforated wood.
- 0.7-0.9: The material is very effective in absorbing sound. Examples are acoustic foam and thick carpet.
- 1: The material absorbs all the sound energy that hits it (no energy is reflected). An ideal example is a perfect absorber, such as a thick acoustic material or a specially designed porous surface.

High absorption coefficient (nearly 1) materials are used in acoustics to minimize sound reflections, manage reverberation time, and produce environments with clearer studios, like concert halls, recording studios, etc. Low-absorption (almost 0) materials are commonly employed in areas where sound reflections are preferred, such as auditoriums, to improve sound projection. In this study, researchers used the absorption coefficient data owned by the Acoustic Project Bureau available on the ACOUSTIC TRAFFIC LLC website, where the Acoustic Project Bureau itself is trusted as a leading acoustic consultant in Russia who has worked on many large projects. Some examples of the following table of data as seen in Figure 3:



ABSORPTION COEFFICIENTS www.akustik.ua

MATERIAL	THICKNESS	FREQUENCY Hz 125	250	500	1000	2000	4000
MASONRY WALLS							
Rough concrete		0,02	0,03	0,03	0,03	0,04	0,07
Smooth unpainted concrete		0,01	0,01	0,02	0,02	0,02	0,05
Smooth concrete, painted or glazed		0,01	0,01	0,01	0,02	0,02	0,02
Porous concrete blocks (no surface finish)		0,05	0,05	0,05	0,08	0,14	0,2
Clinker concrete (no surface finish)		0,10	0,20	0,40	0,60	0,50	0,60
Smooth brickwork with flush pointing		0,02	0,03	0,03	0,04	0,05	0,07
Smooth brickwork with flush pointing, painted		0,01	0,01	0,02	0,02	0,02	0,02
Standard brickwork		0,05	0,04	0,02	0,04	0,05	0,05
Brickwork, 10mm flush pointing		0,08	0,09	0,12	0,16	0,22	0,24
Lime cement plaster on masonry wall		0,02	0,02	0,03	0,04	0,05	0,05
Glaze plaster on masonry wall		0,01	0,01	0,01	0,02	0,02	0,02
Painted plaster surface on masonry wall		0,02	0,02	0,02	0,02	0,02	0,02
Plaster on masonry wall with wall paper on backing paper		0,02	0,03	0,04	0,05	0,07	0,08
Ceramic tiles with smooth surface		0,01	0,01	0,01	0,02	0,02	0,02
Breeze block		0,20	0,45	0,60	0,40	0,45	0,40
Plaster on solid wall		0,04	0,05	0,06	0,08	0,04	0,06
Plaster, lime or gypsum on solid backing		0,03	0,03	0,02	0,03	0,04	0,05
STUDWORK AND LIGHTWEIGHT WALLS							
Plasterboard on battens, 18mm airspace with glass wool		0,30	0,20	0,15	0,05	0,05	0,05
Plasterboard on frame, 100mm airspace		0,30	0,12	0,08	0,06	0,06	0,05
Plasterboard on frame, 100mm airspace with glass wool		0,08	0,11	0,05	0,03	0,02	0,03
Plasterboard on 50mm battens		0,29	0,10	0,05	0,04	0,07	0,09
Plasterboard on 25mm battens		0,31	0,33	0,14	0,10	0,10	0,12

Figure 3. example of absorption coefficient value table

2.2. *Methods*

In this study, the researchers have gone through the stages of observation, measurement, documentation and simulation, where each stage of the method has tools that support these activities.

2.2.1. Observation Method

To see the initial picture of the room and the extent to which the estimated material can affect the sound in the room, it is necessary to observe the classroom that will be used. The classroom used has also been sorted so that it can be apple to apple through observation.

2.2.2. Physical Measurement Methods

In this method, the tools used to measure physical space are manual and digital meter-measuring tools. In general, researchers use digital meters because they facilitate mobility and save time but still use manual meters for some angles that cannot be calculated by digital meters. From this stage, researchers get a product in the form of a room layout.

2.2.3. Documentation Methods

Using a digital camera to document the physical condition of the space, especially documentation related to the condition of the surface area and the area of interior elements (floors, walls and ceilings) and their influence on sound in the space. From this observation, researchers obtained products in the form of documents and photos of the actual conditions/atmosphere of the research location.

2.2.4. Simulation Methods

In this simulation stage, researchers can find out how much RT30, D50 and C50 sound in the classroom where this data will be a reference for the results between several classrooms. In this simulation stage, researchers will enter a 3D file from SketchUp that has been created previously and then inserted into I-Simpa to be given material that matches the existing one. The absorption coefficient value is given at this stage where researchers enter the value on each side of the interior element plane (floor, wall and ceiling). After inputting the material, researchers enter the sound source with the value of a normal person speaking and finally enter the sound receiver (receiver and plane). After everything has been set, researchers simulate sound with 2 methods, namely SPPS and Classical Theory of Reverberation, which according to Université Gustave Eiffel as I-Simpa developer is explained as follows:

- SPPS: The SPPS code (from the French "Simulation de la Propagation de Particules Sonores") uses a 3D domain to track sound particles that are emitted from a sound source and carry a certain amount of energy (ε). Until it collides with an object, each particle travels in a straight line between two-time steps Δt (the entire trajectory may be curved). Depending on the nature of the object, sound waves may be absorbed, reflected, scattered, diffused, or transmitted at each collision. There are two algorithms to contemplate:
  - The energetic approach, which is the first method, assumes that the particle's energy is constant. The particle may vanish from the domain or follow its propagation, depending on the phenomenon: as time passes, the number of sound particles decreases.
  - In the second method (Random), the particle energy fluctuates following the physical phenomena that take place throughout the propagation. In this instance, the quantity of particles within the domain ought to remain consistent over time.
- Classical Theory of Reverberation: The simulation program TCR (which stands for "Théorie Classique de la Réverbération" in French) is a numerical implementation of Sabine's Classical Theory of Reverberation. Based on Sabine's relations for the reverberation time and the sound level of the reverberated field, it enables the evaluation of the diffuse sound field in a single room.

Researchers use SPPS more because in SPPS simulations they can find RT_{30}, C_{50} and D_{50} by tracking sound particles that collide with an object (systematic SPPS).

2.3. Overview of Materials and Methods

The results of the study are expected to provide optimal acoustic material solutions and the most strategic layout to improve sound distribution in the classroom. The research followed a quantitative approach, combining in-site measurements with numerical simulations to ensure a comprehensive analysis of the acoustic conditions. Where this will be achieved with several materials and methods, namely:

1. Study Location: using 6 classrooms in 6 different colleges to find optimal results.
2. SketchUp 2024: using SketchUp 2024 software to create basic 3d files to be simulated in Isimpa.
3. I-Simpa: using I-Simpa as the main software to see how interior materials can affect the sound in the 6 classrooms discussed previously
4. Absorption Coefficients: using the absorption coefficient data table to provide material for each room area in I-Simpa
5. Observation: conduct field observations to get an idea of the room that will be used and understand the interior materials available in the field.
6. Physical Measurement: calculate the size of the classroom to find out the exact size of each classroom to be taken to the sound simulation
7. Documentation: save images related to the classroom used so that they can be used as data that will be useful in the future.

Simulation: simulate 3D data of existing classrooms to analyze how existing interior materials affect sound in the classroom and find gaps in acoustic defects.

3. Results and Discussions

The primary acoustic parameters analyzed include Reverberation Time (RT_{30}), Clarity Index (C_{50}) and Definition (D_{50}). There will be main tables where the first contains pictures of existing classrooms, then the second will be the results of indoor sound simulations using existing interior materials to see how the results of each classroom have different characteristics there are simulation results with the most optimal interior material renovation to be drawn into conclusions regarding indoor acoustic classrooms.

3.1. Existing Condition Simulation

Researchers have collected data related to the condition of existing classrooms, including room size, interior materials in each existing area, and estimated listening areas. From all the available data, researchers conducted research to find sound results in a room with conditions without any changes and by tolerating simplification of the room model.

Table 2. Existing Classroom Data

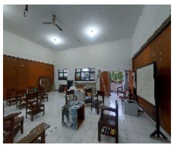
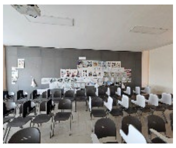
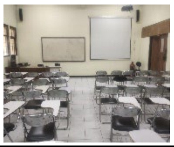
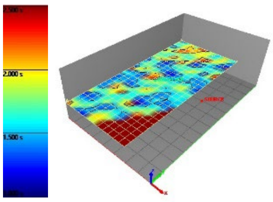
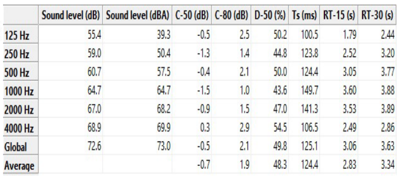
Class Code	Existing Pictures		Room Size in Meters (L x W x H)	Interior Material Descriptions
A			12.7 x 7.6 x 3.8	- Wall: wood partition, glass and brick - Ceiling: concrete roof - Floor: tiles
B			12.1 x 7.1 x 3.5	- Wall: brick and glass - Ceiling: concrete roof - Floor: tiles
C			8.9 x 7.9 x 4.6	- Wall: wood partition and brick - Ceiling: gypsum board - Floor: tiles
D			13 x 6.5 x 3.5	- Wall: brick, glass and wood partition - Ceiling: gypsum board - Floor: tiles
E			11.1 x 5.8 x 3.5	- Wall: brick and glass - Ceiling: gypsum board - Floor: tiles
F			11.4 x 7.8 x 3.8	- Wall: brick - Ceiling: cocncrete roof - Floor: tiles

Table 2 shows all the main data needed by researchers to calculate the sound in the room where the data is divided into 2 main parts, namely the dimensions of the room and the interior materials in the main area of the room. The 6 rooms listed in the table have similarities and differences in interior materials and have their own characteristics where if the main use of the class is described, then classes with codes A, B, D and F are only used for theory classes but for classes C and E can be used as drawing classes and theory classes in general. From this data, the researcher conducted a simulation whose results will be presented in the next Table 2 chart.

Table 3. Existing classroom simulation results with I-Simpa

<table>
<tr><th>Class Code</th><th>Simulation Results</th><th>RT$_{30}$, C$_{50}$ and D$_{50}$ Results</th></tr>
<tr><td>A</td><td>


<table>
<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>55.4</td><td>39.3</td><td>-0.5</td><td>2.5</td><td>50.2</td><td>100.5</td><td>1.79</td><td>2.44</td></tr>
<tr><td>250 Hz</td><td>59.0</td><td>50.4</td><td>-1.3</td><td>1.4</td><td>44.8</td><td>123.8</td><td>2.52</td><td>3.20</td></tr>
<tr><td>500 Hz</td><td>60.7</td><td>57.5</td><td>-0.4</td><td>2.1</td><td>50.0</td><td>124.4</td><td>3.05</td><td>3.77</td></tr>
<tr><td>1000 Hz</td><td>64.7</td><td>64.7</td><td>-1.5</td><td>1.0</td><td>43.6</td><td>149.7</td><td>3.60</td><td>3.88</td></tr>
<tr><td>2000 Hz</td><td>67.0</td><td>68.2</td><td>-0.9</td><td>1.5</td><td>47.0</td><td>141.3</td><td>3.53</td><td>3.89</td></tr>
<tr><td>4000 Hz</td><td>68.9</td><td>69.9</td><td>0.3</td><td>2.9</td><td>54.5</td><td>106.5</td><td>2.49</td><td>2.86</td></tr>
<tr><td>Global</td><td>72.6</td><td>73.0</td><td>-0.5</td><td>2.1</td><td>49.8</td><td>125.1</td><td>3.06</td><td>3.63</td></tr>
<tr><td>Average</td><td></td><td></td><td>-0.7</td><td>1.9</td><td>48.3</td><td>124.4</td><td>2.83</td><td>3.34</td></tr>
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</td><td>RT$_{30}$: 3.34 s (not up to standard)
C$_{50}$: -0.7 dB (not up to standard)
D$_{50}$: 48.3 % (not up to standard)</td></tr>
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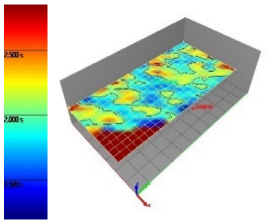
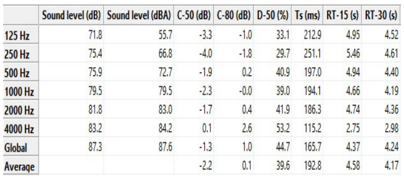
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<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>71.8</td><td>55.7</td><td>-3.3</td><td>-1.0</td><td>33.1</td><td>212.9</td><td>4.95</td><td>4.52</td></tr>
<tr><td>250 Hz</td><td>75.4</td><td>66.8</td><td>-4.0</td><td>-1.8</td><td>29.7</td><td>251.1</td><td>5.46</td><td>4.61</td></tr>
<tr><td>500 Hz</td><td>75.9</td><td>72.7</td><td>-1.9</td><td>0.2</td><td>40.9</td><td>197.0</td><td>4.94</td><td>4.40</td></tr>
<tr><td>1000 Hz</td><td>79.5</td><td>79.5</td><td>-2.3</td><td>-0.0</td><td>39.0</td><td>194.1</td><td>4.66</td><td>4.19</td></tr>
<tr><td>2000 Hz</td><td>81.8</td><td>83.0</td><td>-1.7</td><td>0.4</td><td>41.9</td><td>186.3</td><td>4.74</td><td>4.36</td></tr>
<tr><td>4000 Hz</td><td>83.2</td><td>84.2</td><td>0.1</td><td>2.6</td><td>53.2</td><td>115.2</td><td>2.75</td><td>2.98</td></tr>
<tr><td>Global</td><td>87.3</td><td>87.6</td><td>-1.3</td><td>1.0</td><td>44.7</td><td>165.7</td><td>4.37</td><td>4.24</td></tr>
<tr><td>Average</td><td></td><td></td><td>-2.2</td><td>0.1</td><td>39.6</td><td>192.8</td><td>4.58</td><td>4.17</td></tr>
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C$_{50}$: -2.2 dB (not up to standard)
D$_{50}$: 39.6 % (not up to standard)</td></tr>
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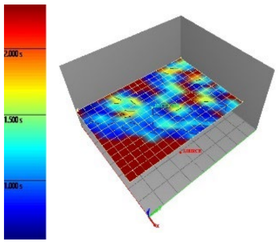
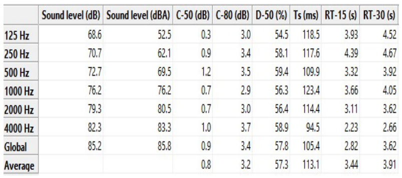
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<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>68.6</td><td>52.5</td><td>0.3</td><td>3.0</td><td>54.5</td><td>118.5</td><td>3.93</td><td>4.52</td></tr>
<tr><td>250 Hz</td><td>70.7</td><td>62.1</td><td>0.9</td><td>3.4</td><td>58.1</td><td>117.6</td><td>4.39</td><td>4.67</td></tr>
<tr><td>500 Hz</td><td>72.7</td><td>69.5</td><td>1.2</td><td>3.5</td><td>59.4</td><td>109.9</td><td>3.32</td><td>3.92</td></tr>
<tr><td>1000 Hz</td><td>76.2</td><td>76.2</td><td>0.7</td><td>2.9</td><td>56.3</td><td>123.4</td><td>3.66</td><td>4.05</td></tr>
<tr><td>2000 Hz</td><td>79.3</td><td>80.5</td><td>0.7</td><td>3.0</td><td>56.4</td><td>114.4</td><td>3.11</td><td>3.62</td></tr>
<tr><td>4000 Hz</td><td>82.3</td><td>83.3</td><td>1.0</td><td>3.7</td><td>58.9</td><td>94.5</td><td>2.23</td><td>2.66</td></tr>
<tr><td>Global</td><td>85.2</td><td>85.8</td><td>0.9</td><td>3.4</td><td>57.8</td><td>105.4</td><td>2.82</td><td>3.62</td></tr>
<tr><td>Average</td><td></td><td></td><td>0.8</td><td>3.2</td><td>57.3</td><td>113.1</td><td>3.44</td><td>3.91</td></tr>
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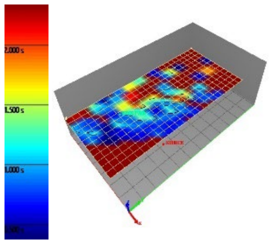
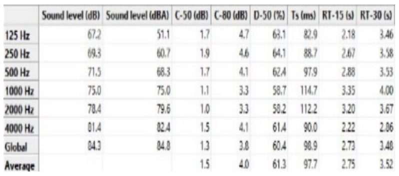
</td><td>RT$_{30}$: 3.91 (not up to standard)
C$_{50}$: 0.8 dB (not up to standard)
D$_{50}$: 57.3% (already meets the standard)</td></tr>
<tr><td>D</td><td>


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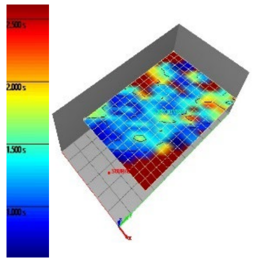
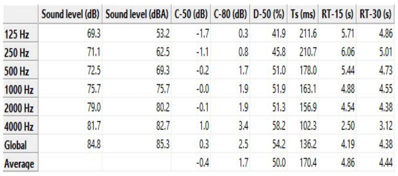
<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>67.2</td><td>51.1</td><td>1.7</td><td>4.7</td><td>63.1</td><td>82.9</td><td>2.18</td><td>3.46</td></tr>
<tr><td>250 Hz</td><td>69.3</td><td>60.7</td><td>1.9</td><td>4.6</td><td>64.1</td><td>88.7</td><td>2.67</td><td>3.58</td></tr>
<tr><td>500 Hz</td><td>71.5</td><td>68.3</td><td>1.7</td><td>4.1</td><td>62.4</td><td>97.9</td><td>2.88</td><td>3.53</td></tr>
<tr><td>1000 Hz</td><td>75.0</td><td>75.0</td><td>1.1</td><td>3.3</td><td>58.7</td><td>114.7</td><td>3.35</td><td>4.00</td></tr>
<tr><td>2000 Hz</td><td>78.4</td><td>79.6</td><td>1.0</td><td>3.3</td><td>58.2</td><td>112.2</td><td>3.20</td><td>3.67</td></tr>
<tr><td>4000 Hz</td><td>81.4</td><td>82.4</td><td>1.5</td><td>4.1</td><td>61.4</td><td>90.0</td><td>2.22</td><td>2.86</td></tr>
<tr><td>Global</td><td>84.3</td><td>84.8</td><td>1.3</td><td>3.8</td><td>60.4</td><td>98.9</td><td>2.73</td><td>3.48</td></tr>
<tr><td>Average</td><td></td><td></td><td>1.5</td><td>4.0</td><td>61.3</td><td>97.7</td><td>2.75</td><td>3.52</td></tr>
</table>
</td><td>RT$_{30}$: 3.52 (not up to standard)
C$_{50}$: 1.5 dB (not up to standard)
D$_{50}$: 61.3 % (already meets the standard)</td></tr>
<tr><td>E</td><td>


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<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>69.3</td><td>53.2</td><td>-1.7</td><td>0.3</td><td>41.9</td><td>211.6</td><td>5.71</td><td>4.86</td></tr>
<tr><td>250 Hz</td><td>71.1</td><td>62.5</td><td>-1.1</td><td>0.8</td><td>45.8</td><td>210.7</td><td>6.06</td><td>5.01</td></tr>
<tr><td>500 Hz</td><td>72.5</td><td>69.3</td><td>-0.2</td><td>1.7</td><td>51.0</td><td>178.0</td><td>5.44</td><td>4.73</td></tr>
<tr><td>1000 Hz</td><td>75.7</td><td>75.7</td><td>-0.0</td><td>1.9</td><td>51.9</td><td>163.1</td><td>4.88</td><td>4.55</td></tr>
<tr><td>2000 Hz</td><td>79.0</td><td>80.2</td><td>-0.1</td><td>1.9</td><td>51.3</td><td>156.9</td><td>4.54</td><td>4.38</td></tr>
<tr><td>4000 Hz</td><td>81.7</td><td>82.7</td><td>1.0</td><td>3.4</td><td>58.2</td><td>102.3</td><td>2.50</td><td>3.12</td></tr>
<tr><td>Global</td><td>84.8</td><td>85.3</td><td>0.3</td><td>2.5</td><td>54.2</td><td>136.2</td><td>4.19</td><td>4.38</td></tr>
<tr><td>Average</td><td></td><td></td><td>-0.4</td><td>1.7</td><td>50.0</td><td>170.4</td><td>4.86</td><td>4.44</td></tr>
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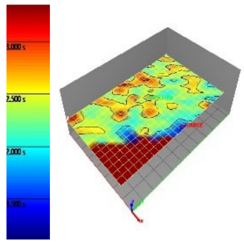
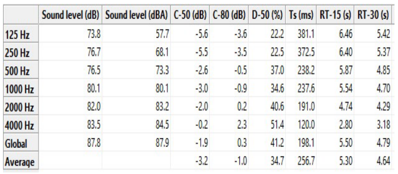
</td><td>RT$_{30}$: 4.44 (not up to standard)
C$_{50}$: -0.4 dB (not up to standard)
D$_{50}$: 50 % (already meets the standard)</td></tr>
<tr><td>F</td><td>


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<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>73.8</td><td>57.7</td><td>-5.6</td><td>-3.6</td><td>22.2</td><td>381.1</td><td>6.46</td><td>5.42</td></tr>
<tr><td>250 Hz</td><td>76.7</td><td>68.1</td><td>-5.5</td><td>-3.5</td><td>22.5</td><td>372.5</td><td>6.40</td><td>5.37</td></tr>
<tr><td>500 Hz</td><td>76.5</td><td>73.3</td><td>-2.6</td><td>-0.5</td><td>37.0</td><td>238.2</td><td>5.87</td><td>4.85</td></tr>
<tr><td>1000 Hz</td><td>80.1</td><td>80.1</td><td>-3.0</td><td>-0.9</td><td>34.6</td><td>237.6</td><td>5.54</td><td>4.70</td></tr>
<tr><td>2000 Hz</td><td>82.0</td><td>83.2</td><td>-2.0</td><td>0.2</td><td>40.6</td><td>191.0</td><td>4.74</td><td>4.29</td></tr>
<tr><td>4000 Hz</td><td>83.5</td><td>84.5</td><td>-0.2</td><td>2.3</td><td>51.4</td><td>120.0</td><td>2.80</td><td>3.18</td></tr>
<tr><td>Global</td><td>87.8</td><td>87.9</td><td>-1.9</td><td>0.3</td><td>41.2</td><td>198.1</td><td>5.50</td><td>4.79</td></tr>
<tr><td>Average</td><td></td><td></td><td>-3.2</td><td>-1.0</td><td>34.7</td><td>256.7</td><td>5.30</td><td>4.64</td></tr>
</table>
</td><td>RT$_{30}$: 4.64 (not up to standard)
C$_{50}$: -3.2 dB (not up to standard)
D$_{50}$: 34.7 % (not up to standard)</td></tr>
</table>

Tables 2 and 3 above are interrelated because the existing field conditions as in Table 1 will be entered into the I-Simpa simulation using the absorption coefficient value data that has been summarized in Table 2 to obtain accurate simulation results. This research uses a sound source of 75 dB as an example of a lecturer teaching without a loudspeaker, even though he does not use a loudspeaker, the sound is still quite loud. Then for the listener himself, the researcher has generalized according to the existing bench model with a plane receiver height of 1.3 meters (sitting position). From the results of Table 2, several points can be made as follows:

1. RT$_{30}$: all classes have the same acoustic defects in the reverberation time 30 parameter where the lowest reverberation time is at 3.34 s and the highest is at 4.64 s. It can be seen that there are still many classrooms that do not meet the standard

which should be around 0.4-0.6 s and this is what can cause student concentration to be disturbed because of the high sound echoing in the classroom.

2. C_{50}: all classes have the same acoustic defects in the clarity 50 parameter where the lowest clarity is at -3.2 dB and the highest is 1.5 dB. It can be seen that all classrooms are still not up to the standard which should be above 3 dB (> 3 dB) and this is what can cause the clarity of the sound to be less clear and mixed with dominant reflections, some words will not be well defined by students in the classroom.
3. (D_{50}): the result of definition 50 in the classroom simulation with existing interior material this time there is a difference because there are 3 classes that meet the standard where the lowest is 50% and the highest is 61.3%. This indicates that in 3 classes (C, D, and E) having adequate space creates a fairly good perception of word clarity with a fairly dominant direct sound arriving quickly at the listener. For the other 3 classes that do not meet the standard, the lowest results are 34.7% and the highest is 48.3% which is almost reaching the standard. The figure of 48.3% itself is still tolerable for listeners, but the conditions of RT_{30} and C_{50} which previously did not meet the standard, ultimately caused acoustic defects that could disturb listeners.

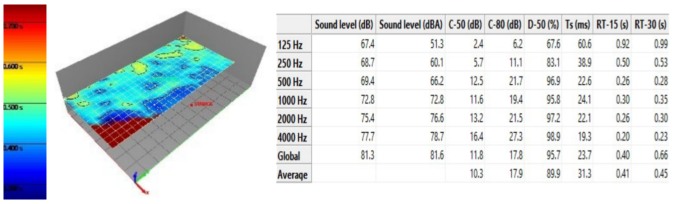
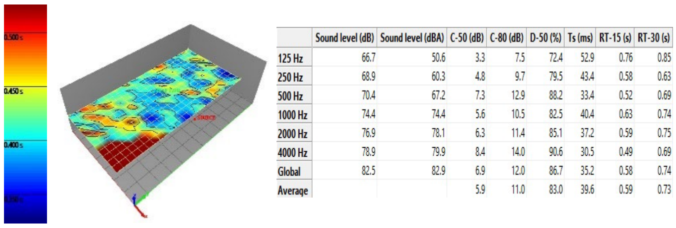
Table 4. Absorption coefficient value of existing interior materials

Interior Materials	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Wood Partition	0.30	0.25	0.15	0.10	0.10	0.07
Glass 6mm	0.10	0.06	0.04	0.04	0.02	0.02
Brick	0.01	0.01	0.02	0.02	0.02	0.02
Tiles	0.27	0.26	0.52	0.43	0.51	0.58
Gypsum Board	0.45	0.70	0.80	0.80	0.65	0.45
Concrete Roof	0.02	0.03	0.03	0.03	0.04	0.07

2.2. Renovation Simulation

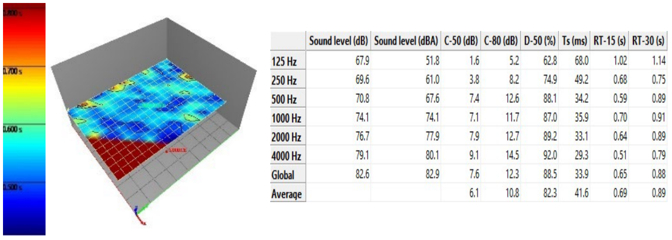
In this section, researchers try to replace the existing interior material with several other materials to simulate and find the best answer regarding the interior material that can be used in the classroom. Finally, after trying many simulations and tinkering with the interior material, researchers found that the materials that could help the most were Rockwool and cotton curtains. These 2 materials have a very good impact on the classroom, creating a classroom atmosphere with comfortable acoustics for teachers and listeners.

Table 5. Classroom simulation results with I-Simpa after replacing interior materials (renovation)

Class Code	Simulation Results after Renovation	RT_{30}, C_{50} and D_{50} Results
A		RT_{30}: 0.45 s (almost meets the standard) C_{50}: 10.3 dB (already meets the standard) D_{50}: 89.9% (already meets the standard)
B		RT_{30}: 0.73 s (almost meets the standard) C_{50}: 5.9 dB (already meets the standard) D_{50}: 83% (already meets the standard)

	Sound level (dB)	Sound level (dBA)	C-50 (dB)	C-80 (dB)	D-50 (%)	Ts (ms)	RT-15 (s)	RT-30 (s)
125 Hz	67.4	51.3	2.4	6.2	67.6	60.6	0.92	0.99
250 Hz	68.7	60.1	5.7	11.1	83.1	38.9	0.50	0.53
500 Hz	69.4	66.2	12.5	21.7	96.9	22.6	0.26	0.28
1000 Hz	72.8	72.8	11.6	19.4	95.8	24.1	0.30	0.35
2000 Hz	75.4	76.6	13.2	21.5	97.2	22.1	0.26	0.30
4000 Hz	77.7	78.7	16.4	27.3	98.9	19.3	0.20	0.23
Global	81.3	81.6	11.8	17.8	95.7	23.7	0.40	0.66
Average			10.3	17.9	89.9	31.3	0.41	0.45

	Sound level (dB)	Sound level (dBA)	C-50 (dB)	C-80 (dB)	D-50 (%)	Ts (ms)	RT-15 (s)	RT-30 (s)
125 Hz	66.7	50.6	3.3	7.5	72.4	52.9	0.76	0.85
250 Hz	68.9	60.3	4.8	9.7	79.5	43.4	0.58	0.63
500 Hz	70.4	67.2	7.3	12.9	88.2	33.4	0.52	0.69
1000 Hz	74.4	74.4	5.6	10.5	82.5	40.4	0.63	0.74
2000 Hz	76.9	78.1	6.3	11.4	85.1	37.2	0.59	0.75
4000 Hz	78.9	79.9	8.4	14.0	90.6	30.5	0.49	0.69
Global	82.5	82.9	6.9	12.0	86.7	35.2	0.58	0.74
Average			5.9	11.0	83.0	39.6	0.59	0.73

<table>
<tr><th>Class Code</th><th>Simulation Results after Renovation</th><th>RT_{30}, C_{50} and D_{50} Results</th></tr>
<tr><td>C</td><td>
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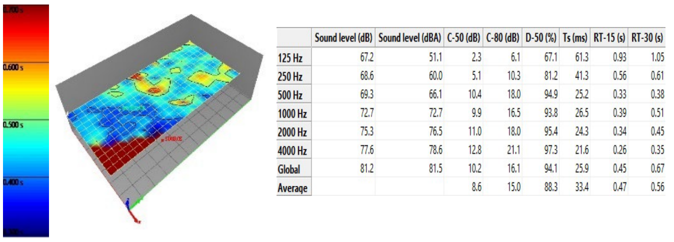
<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>67.9</td><td>51.8</td><td>1.6</td><td>5.2</td><td>62.8</td><td>68.0</td><td>1.02</td><td>1.14</td></tr>
<tr><td>250 Hz</td><td>69.6</td><td>61.0</td><td>3.8</td><td>8.2</td><td>74.9</td><td>49.2</td><td>0.68</td><td>0.75</td></tr>
<tr><td>500 Hz</td><td>70.8</td><td>67.6</td><td>7.4</td><td>12.6</td><td>88.1</td><td>34.2</td><td>0.59</td><td>0.89</td></tr>
<tr><td>1000 Hz</td><td>74.1</td><td>74.1</td><td>7.1</td><td>11.7</td><td>87.0</td><td>35.9</td><td>0.70</td><td>0.91</td></tr>
<tr><td>2000 Hz</td><td>76.7</td><td>77.9</td><td>7.9</td><td>12.7</td><td>89.2</td><td>33.1</td><td>0.64</td><td>0.89</td></tr>
<tr><td>4000 Hz</td><td>79.1</td><td>80.1</td><td>9.1</td><td>14.5</td><td>92.0</td><td>29.3</td><td>0.51</td><td>0.79</td></tr>
<tr><td>Global</td><td>82.6</td><td>82.9</td><td>7.6</td><td>12.3</td><td>88.5</td><td>33.9</td><td>0.65</td><td>0.88</td></tr>
<tr><td>Average</td><td></td><td></td><td>6.1</td><td>10.8</td><td>82.3</td><td>41.6</td><td>0.69</td><td>0.89</td></tr>
</table></td><td>RT_{30}: 0.89 s (almost meets the standard)
C_{50}: 6.1 dB (already meets the standard)
D_{50}: 82.3% (already meets the standard)</td></tr>
<tr><td>D</td><td>
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<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>67.2</td><td>51.1</td><td>2.3</td><td>6.1</td><td>67.1</td><td>61.3</td><td>0.93</td><td>1.05</td></tr>
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<tr><td>500 Hz</td><td>69.3</td><td>66.1</td><td>10.4</td><td>18.0</td><td>94.9</td><td>25.2</td><td>0.33</td><td>0.38</td></tr>
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<tr><td>Average</td><td></td><td></td><td>8.6</td><td>15.0</td><td>88.3</td><td>33.4</td><td>0.47</td><td>0.56</td></tr>
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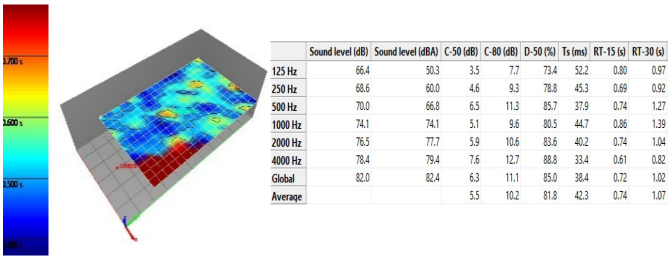
C_{50}: 8.6 dB (already meets the standard)
D_{50}: 88.3% (already meets the standard)</td></tr>
<tr><td>E</td><td>
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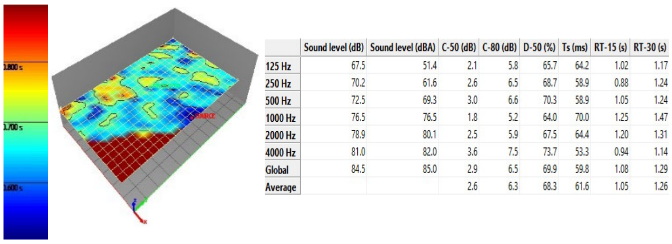
C_{50}: 5.5 dB (already meets the standard)
D_{50}: 81.8% (already meets the standard)</td></tr>
<tr><td>F</td><td>
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<tr><th></th><th>Sound level (dB)</th><th>Sound level (dBA)</th><th>C-50 (dB)</th><th>C-80 (dB)</th><th>D-50 (%)</th><th>Ts (ms)</th><th>RT-15 (s)</th><th>RT-30 (s)</th></tr>
<tr><td>125 Hz</td><td>67.5</td><td>51.4</td><td>2.1</td><td>5.8</td><td>65.7</td><td>64.2</td><td>1.02</td><td>1.17</td></tr>
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<tr><td>1000 Hz</td><td>76.5</td><td>76.5</td><td>1.8</td><td>5.2</td><td>64.0</td><td>70.0</td><td>1.25</td><td>1.47</td></tr>
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<tr><td>4000 Hz</td><td>81.0</td><td>82.0</td><td>3.6</td><td>7.5</td><td>73.7</td><td>53.3</td><td>0.94</td><td>1.14</td></tr>
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<tr><td>Average</td><td></td><td></td><td>2.6</td><td>6.3</td><td>68.3</td><td>61.6</td><td>1.05</td><td>1.26</td></tr>
</table></td><td>RT_{30}: 1.26 s (almost meets the standard)
C_{50}: 2.6 dB (almost meets the standard)
D_{50}: 68.3% (already meets the standard)</td></tr>
</table>

Table 5 shows the results of the classroom acoustic simulation with I-Simpa that has gone through the process of replacing interior materials, researchers found maximum results with materials that are relatively easy to find, cheap and have been used frequently in many rooms that use acoustic treatment. It must be admitted that some of the reverberation time results do not touch the standard value but are very close so that the outline can be taken as tolerable and considered to have entered a fairly good value for the suitability of the classroom for teachers and listeners. Table 2 shows the absorption coefficient values of the materials used to renovate the classroom, and if you pay close attention, you can see that all 3 existing materials have the same high absorption value in several Hz parts, where with the right combination they can create a good design that complements each other. The research results from the 6 existing classes can be described as follows:

1. Class A (Added rockwool panel, cotton curtain, and Rockwool in wood partition)

- RT_{30}: almost meets the standard where the result is 0.45s, just 0.05s short of reaching the minimum standard.
- C_{50}: already meets the standard as the result is 10.3 dB.
- D_{50}: already meets the standard as the result is 89.9%.
- Overall: Class A can be said to be a good class in indoor sound standards.

2. Class B (Added rockwool panel and cotton curtain)

- RT_{30}: almost meets the standard where the result is 0.73s, this result is 0.13s excess of the existing standard.
- C_{50}: already meets the standard as the result is 5.9 dB.
- D_{50}: already meets the standard as the result is 83%.
- Overall: Class B can be said to be a good class in indoor sound standards.

3. Class C (Added rockwool panel and rockwool in wood partition)

- RT_{30}: almost meets the standard where the result is 0.89s, this result is 0.29s excess of the existing standard.
- C_{50}: already meets the standard as the result is 6.1 dB.
- D_{50}: already meets the standard as the result is 82.3%.
- Overall: Class C can be said to be a good class in indoor sound standards.

4. Class D (Added rockwool panel, cotton curtain, and rockwool in wood partition)

- RT_{30}: almost meets the standard where the result is 0.56s, this result was the best result shown in this simulation.
- C_{50}: already meets the standard as the result is 8.6 dB.
- D_{50}: already meets the standard as the result is 88.3%.
- Overall: Class D can be said to be a good class in indoor sound standards, yet it was the best result that researchers got.

5. Class E (Added rockwool panel and cotton curtain)

- RT_{30}: almost meets the standard where the result is 1.07s, this result is 0.47s excess of the existing standart.
- C_{50}: already meets the standard as the result is 5.5 dB.
- D_{50}: already meets the standard as the result is 81.8%.
- Overall: Class D can be said to be a good class in indoor sound standards.

6. Class F (Added rockwool panel)

- RT_{30}: almost meets the standard where the result is 1.26s, this result is 0.62s excess of the existing standart.
- C_{50}: already meets the standard as the result is 2.6 dB, this result is 0.04 dB excess of the existing standard.
- D_{50}: already meets the standard as the result is 68.3%.
- Overall: Class D can be said to be a good class in indoor sound standards but the result of this simulation are the least compared to the other 5 simulations

The researcher took 1 example of the best simulation results, namely the results of class D, where the influence of interior materials on indoor sound is very influential. By adding rockwool panelled material, then the windows are given cotton curtains and the addition of Rockwool in the wooden partition can help to produce RT_{30}, C_{50} and D_{50} which were previously far from the standard are now at the standard number. From here it can also be seen that the existing classroom can be improved if you want to create comfortable room conditions by trying to simulate it with I-Simpa.

Table 6. Absorption coefficient value of replacement interior materials (renovation).

Interior Materials	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Rockwool Panel	0.20	0.22	0.18	0.15	0.15	0.16
Rockwool	0.12	0.45	0.87	0.98	1.00	1.00
Cotton Curtains	0.30	0.45	0.65	0.56	0.59	0.71

4. Discussion

The results above have explained that the influence of interior materials greatly affects the sound in the classroom. By changing the existing interior materials of the room, it produces results that meet standards, if the sound in the room is following with the standards, then it should be both from the teacher's side and the students in the class who are the listeners will be able to carry out their respective activities well. Several things can be highlighted from the existing data, the researcher will describe them in several points as follows:

4.1. The influence of the shape, size of the room, and the placement of the sound source-listener:

From the simulation results that have been carried out, researchers found that each different room size and the placement of different sound sources and listeners will create different results. The simulation results are greatly influenced by the size of the room, namely because size can create reflections of sound energy that collide with solid objects around it. However, a small room does not necessarily guarantee good results because from the results of the trial above the smallest room (C) could be less good compared to class (D) which is known to have a much longer room size. The size of the large classroom must also be responded to with the right room layout to create good indoor sound according to standards. Consideration of the layout of the student's desk and chair and the placement of the sound source will also be very influential.

4.2. The influence of interior materials

Here the most changes in the results of RT_{30}, C_{50} and D_{50} are interior materials. Researchers found that changing interior materials cannot be done carelessly because based on their trials, researchers have tried many materials but not all that seem "good" can create good results. In testing, we must be careful and imagine realistically how interior materials can be installed and how to make existing materials correlate with each other to create a pleasant atmosphere. Simulation processing cannot be done carelessly because if it is done haphazardly, the results can be errors or unnatural results. Accuracy is needed to try interior materials in this study so that the input absorption coefficient value can match its Hz so that the simulation results can be similar to reality.

4.3. Material prices and field conditions:

Classes cannot always be repaired because they must be calculated carefully about the right installation and price. Interior materials related to acoustics themselves are not cheap, and the possibility of total renovation as in the study above is not 100% possible if funds are limited. However, this is where I-Simpa can also be useful because we can see from the distribution of existing sound that even if we do not renovate the interior materials, we can change the layout of the study tables and chairs or the position of the existing sound sources so that the use of existing technology can be maximized.

4.4. Potential arising from acoustic defects:

The researcher found that almost all students and even the researcher himself had been in a classroom that had acoustic defects, even RT_{30} that penetrated 3s, but the researcher, other students and teachers did not feel it. From this, the researcher thought that several hypotheses arose.

- First, students who are accustomed to classes with poor voice grades may be accustomed to the classroom, so it has become a habit for students to adapt to be able to listen to the teacher speak. This made it a habit for students to always be adaptive with their classrooms because not every class will be as good as indoor acoustic standards.
- Having a reverberation time itself can help increase the volume naturally because the reflected sound will be heard throughout the room without the additional devices. This can help a teacher who teaches where if the classroom is a little large then the sound reflection will help reach the back of the listener, but the intonation and pronunciation must be clear so that the reflection is still clearly audible.
- Researchers also realize that the presence of sound reflections can actually create a more lively and crowded atmosphere and impression in the room, for example when there is a group discussion in the classroom, the sound from the crowd and its reflections will create a dynamic sound in the classroom and a perception arises that because of the crowd, many students will dare to talk to their group members.
- Researchers also realize that there is a habit in one of the universities where there is an innovative class response to the existing acoustic defects. In the classroom, both teachers and listeners must be able to create a comfortable atmosphere, but if the sound in the room does not fully support it, here the teacher can make his class more innovative, such as by using visual aids and the like, as well as utilizing small group discussions or forming a chair layout such as a circle and the teacher in the middle so that they can focus more. From here, a positive impact arises, namely how creativity can respond to the existing classroom to create fun teaching and learning activities together. This proves that the layout placement will have a big influence on the sound results in the classroom. Arrange seating and teaching areas to minimize the distance between the teacher and students, reducing the impact of background noise and reverberation (Recalde et al., 2021).
- Researchers also realized that the type of sound produced from the lecturer's lecture tends to be a continuous sound that is continuous where this sound tends not to be heard echoing in the student's hearing perception. If seen from the previous calculations, it could be that the RT_{30} sound that penetrates 3 seconds, or more is an impulsive sound such as applause or loud musical instruments.

From the results of this study, researchers can also provide recommendations for designing classrooms in the future, where the results prove that two-based materials can help create comfortable sound in the classroom. Adding cotton curtains to the existing window glass has proven to be very effective in helping to reduce echo in the room (Nunes et al., 2018). The most recommended interior material from the results of this study is rockwool, because the effectiveness of rockwool as an acoustic material is well-documented, particularly due to its high sound absorption capabilities (Bhatia &

Zaman, 2021). Its structure, made up of open, porous fibres, allows it to trap sound waves effectively (Rao & Kumar, 2017). Rockwool typically achieves high Noise Reduction Coefficient (NRC) ratings, ranging from 0.85 to 1.00, meaning it can absorb a broad spectrum of sound frequencies, especially from 250Hz to 4000Hz (Jin et al., 2019). This makes it an excellent material for controlling reverberation and ensuring speech intelligibility in spaces like classrooms (Meyer et al., 2016). Moreover, rockwool's sound absorption performance can be optimized by adjusting its thickness. For example, slabs with a thickness of 75mm to 100mm can achieve an NRC rating of up to 1.00, indicating near-perfect sound absorption (He et al., 2018). This makes rockwool an ideal choice for applications where high levels of acoustic control are required (Bhatia & Zaman, 2021).

One of the key advantages of using Rockwool in acoustic applications is its installation flexibility, even after a wall has been constructed. This is particularly useful in renovations or when adding soundproofing to existing spaces (He et al., 2018). The material can be easily added to existing walls by creating a secondary frame or racking system in which the Rockwool is installed, allowing it to absorb sound effectively without the need to tear down or rebuild the wall structure (Bhatia & Zaman, 2021; Meyer et al., 2016).

The open-porous structure of Rockwool allows it to absorb sound across a wide range of frequencies. This makes it ideal for spaces like classrooms, where both high- and low-frequency sounds need to be controlled for improved speech intelligibility. By adding Rockwool behind a newly created framework in an existing wall, you don't compromise the structural integrity of the room but still enhance its acoustic properties. Moreover, Rockwool is lightweight compared to other acoustic treatments, which makes it easier to handle and install in retrofit situations. Its high density and thermal insulation properties also make it a cost-effective solution for acoustic control in various settings.

The material can be tailored in thickness and density to meet specific acoustic needs without requiring extensive alterations to the space. In summary, Rockwool offers both high performance in sound absorption and ease of installation, even in pre-existing structures, making it an optimal choice for acoustic treatments in classrooms and other noise-sensitive environments.

5. Conclusions

This research analyzes how interior materials affect three important acoustic parameters that are RT_{30}, C_{50}, and D_{50} yet how these factors relate to classroom acoustic performance. The results show that classrooms with reflective surfaces, like glass and concrete, have less than ideal acoustic performance, with RT_{30} exceeding 1 second and C_{50} below 3 dB, which impairs learning outcomes and speech intelligibility. The addition of absorptive materials like cotton curtains, and 25mm rockwool panels, resulted in significant improvements:

- RT_{30} decreased from an average of 4 seconds to between 0.45-1.26, which refers to the SNI-03-6386-2000 standard recommended for educational spaces is 0.5-0.6s. The excess of 0.60s is still tolerable for listeners
- D_{50} is consistently above 50% and even reaches an average of 80% where the standard itself according to ISO 3382-1 is above 50%, this result ensures that increased speech transmission in various frequency ranges will help create a comfortable classroom.
- C_{50} increased by an average of 5 dB, which refers to ISO 3382-1 has exceeded the minimum threshold of above 3 dB for effective speech clarity, which ensures that the teacher's voice can be clearly received by the listener.

Educational institutions can implement several efficient ways to improve learning outcomes and classroom acoustics. Using high-density absorptive materials on walls, ceilings, and floors like Rockwool, is one important strategy. Because these materials absorb sound waves, especially in the mid-to-high frequency region, they greatly improve C_{50}, D_{50} and reduce RT_{30}. Both of which are important for speech intelligibility in educational contexts. Students can hear and comprehend instructions more clearly due to this reduction in reverberation, which improves the learning environment.

Furthermore, using acoustic simulation software such as I-Simpa provides a proactive way to maximize room acoustics. Before implementation, I-Simpa lets architects and facility managers forecast the acoustic performance of alternative design options by enabling them to simulate different acoustic configurations. This feature reduces the need for expensive physical changes during construction or restoration by empowering institutions to make data-driven decisions that balance cost-effectiveness and acoustic efficiency. Educational venues can be converted into acoustically optimal settings that facilitate efficient teaching and learning by implementing these techniques.

Future studies and technical advancements should concentrate on a few crucial areas to further develop the field of acoustic design in educational settings. Integrating I-Simpa with smart technologies, including Internet of Things-based sensors, to allow for adaptive correction and real-time acoustic monitoring is one exciting avenue. With this integration, classrooms could become dynamic learning spaces that adapt to shifting acoustic conditions on their own, guaranteeing constant sound quality during various instructional activities. Future studies could look into the impact of various ceiling shapes on classroom sound, as this study did not cover this topic.

Examining the long-term effects of an ideal acoustic environment on teachers' voice health and students' cognitive performance is also crucial. Students' attention span, comprehension, and general academic performance may all be enhanced by better acoustics. Concurrently, better acoustics may lessen teachers' vocal strain, which would enhance their ability to communicate and decrease vocal fatigue two factors that are critical for sustaining long-term, successful teaching methods. Finally, one crucial area of research is the creation of sustainable hybrid materials that combine excellent acoustic performance with environmental sustainability. These materials need to be affordable, eco-friendly, and capable of resolving the many acoustic issues in a range of learning environments. In keeping with contemporary architectural regulations and practices, institutions can enhance acoustic performance and support more general environmental objectives by placing a high priority on sustainability.

This study highlights I-Simpa's revolutionary potential as a simulation tool for acoustic environment prediction and optimization in learning environments. Architects and designers can test several design options with I-Simpa's economical and effective solution, which eliminates the need for expensive physical changes and guarantees the best acoustic performance from the very beginning of the design process. This proactive approach makes it possible to make exact alterations that strike a balance between practical and aesthetic acoustic needs, which eventually leads to more sustainable and efficient building practices. The results also emphasize how important interior materials and modelling tools are to designing acoustically optimal classrooms.

Educational institutions can greatly improve speech intelligibility, lessen auditory distractions, and create a more favourable learning environment by implementing these measures. Incorporating cutting-edge acoustic solutions not only improves communication and concentration but also helps the larger objectives of intelligent and sustainable building design, opening the door for further advancements in educational infrastructure.

Author Contributions: Conceptualization, C.J.A.H. and H.C.I.; methodology, C.J.A.H.; software, C.J.A.H.; validation, M.J. and H.C.I.; formal analysis, C.J.A.H.; investigation, C.J.A.H.; resources, C.J.A.H.; data curation, M.J. and H.C.I.; writing—original draft preparation, C.J.A.H. and H.C.I.; writing—review and editing, M.J. and H.C.I.; visualization, C.J.A.H..; supervision, H.C.I.; project administration, H.C.I.; funding acquisition, H.C.I. All authors have read and agreed to the published version of the manuscript.

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Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Inform Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Petra Cristian University, Indonesia, for supporting this research and publication. We also thank the reviewers for their constructive comments and suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

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