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Research Article

Acoustic property of interlocking compressed stabilized earth blocks: A sustainable alternative for building materials

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ABSTRACT

This study uses a tested laterite soil composition to investigate the acoustic properties of interlocking compressive stabilized earth blocks (ICSEBs) produced by the Nigerian Building and Road Research Institute (NBRRI). The laterite samples comprised 40.75% fines (silt-clay), 48.65% fine/medium/coarse, and 10.6% fine gravel. The ICSEBs produced from this composition were evaluated for their sound absorption coefficient values at octave bands of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The results demonstrate that the ICSEBs exhibit favorable acoustic insulation properties, with sound absorption coefficients ranging from 0.71 to 0.99 at the tested frequencies. Comparative analysis with commonly used materials, such as fiberglass insulation batts and acoustic plasterboard, highlights the competitive performance of the ICSEBs. This study emphasizes the need for further research to explore the influence of composition, thickness, and installation methods on the acoustic performance of ICSEBs, ensuring their suitability for specific applications. Meanwhile, the findings indicate that ICSEBs made from the laterite soil composition can be a cost-effective and durable solution for acoustic insulation in building construction. Therefore, this study provides valuable insight into the acoustic properties of ICSEB, which could be helpful for architects, engineers, and builders who seek to incorporate sustainable and cost-effective building materials in their projects.

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1. INTRODUCTION

The use of the earth as a building material dates back to the earliest times of human civilization, as evidenced by the histories of ancient Egypt and Mesopotamia [1]. Recent studies by Riza [2] suggest that this traditional building material has regained attention, particularly in developing countries struggling to provide adequate housing for their rapidly expanding populations. As a result, stabilized earth has become a topic of ongoing research and development, emphasizing its structural suitability, socio-economic considerations, and environmental sustainability as a modern construction material.

The 2006 National Building Code [3] stipulates that earth blocks should consist of appropriate soils stabilized by ordinary Portland cement, with a minimum of 5% by weight, and be compressed with a minimal pressure of 3N/mm^2. In line with this building code, the Nigerian Building and Road Research Institute (NBRRI) researchers have been working on developing an ICSEB that does not require mortar for bonding. Instead, lateral, and horizontal interlocking of alternate grooves and tongues joints form a wall. This development was reported by Didel et al. [4].

Interlocking compressed stabilized earth blocks (ICSEBs) have gained popularity in recent years as sustainable and affordable building materials. They are made from

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locally available materials, such as soil, sand, and stabilizers, and can be produced on-site using manual or mechanized methods [5]. The Nigerian Building and Road Research Institute (NBRRI) has developed a range of ICSEBs that have been tested for their structural properties, such as compressive strength and durability, and be comparable to or even better than conventional building material [6].

Using sustainable building materials is increasingly becoming a priority in the construction industry as the negative environmental impact of conventional building materials, such as cement and steel, is becoming more apparent [7]. ICSEBs have the potential to be a more sustainable and eco-friendly alternative to these materials, as they use locally available materials, require less energy for production, and have a lower carbon footprint [8]. Investigating the acoustic properties of ICSEBs can provide valuable insights into their potential for use in building applications. It can contribute to the development of more sustainable and cost-effective building materials. Sound insulation and noise reduction are important considerations in building design, particularly in urban areas where noise pollution can be a significant problem. While various building materials, such as concrete, wood, and gypsum board, are commonly used for sound insulation [9], the acoustic properties of ICSEBs are not investigated.

There are quite a few studies on the acoustic properties of ICSEBs. This particular research is believed to contribute to the existing body of literature on this subject matter. Among the literature consulted, Eires et al. [10] examined a new type of interlocking stabilized compressed earth blocks in Mawali. Using a manually operated compaction machine, they conducted acoustic insulation tests on stabilized and un-stabilized compressed blocks. They found that the sound absorption coefficient of their specimens was poor, measuring 0.5 at 3000 Hz. They concluded that this behavior may be attributed to the lower compaction pressure of the blocks. In another study, Leitao et al. [11] researched the thermal and acoustic performance of ICSEBs cured for 28 days, with an average density of 1800 kg/m^3. They used alkali-activated Class F fly ash, which had no commercial value, in the mixture to produce the ICSEBs. Class F fly ash is classified as such due to its low calcium content, generally less than 10%. The results showed that the acoustic performance of the blocks was good, with the highest sound absorption coefficient of 0.82 at 3600 Hz.

Furthermore, Mansour et al. [12] studied the influence of compaction pressure on the mechanical and acoustic properties of compacted earth blocks: an inverse multi-parameter acoustic problem. Their specimens were created by varying the applied compaction pressure, resulting in different bulk densities. Low bulk density CEBs were stabilized by adding 15% cement. The acoustic absorption coefficients of the various specimens were determined experimentally using data obtained from the Kundt tube. Although the focus was on the acoustic and mechanical behavior of compressed earth blocks (CEBs) rather than ICSEBs, the results demonstrated that the applied compaction pressure, including factors such as specimen bulk density and the use of cement as a stabilizer, strongly influenced the acoustic and mechanical behavior of the CEBs. Both studies suggest that ICSEBs can possess favorable acoustic properties and contribute to thermal and acoustic comfort. The acoustic and mechanical behavior of the blocks can be influenced by factors such as compaction pressure, the type of stabilizer used, and the interlocking properties.

This research is centered on investigating the acoustic properties of NBRRI interlocking compressed stabilized earth blocks, focusing on their potential for sound insulation and noise reduction. The results will be compared with other building materials commonly used for sound insulation, and the factors that affect the acoustic properties of ICSEBs will be identified and analyzed. In addition, the research can contribute to developing building codes and standards for ICSEBs, which can help promote their broader use in the construction industry. The findings can also be helpful for architects and builders in selecting the appropriate building materials for sound insulation and noise reduction and for researchers in developing new and innovative building materials that can provide both structural and acoustic benefits. Overall, this research topic is essential for understanding the potential of NBRRI interlocking compressed stabilized earth blocks as a sustainable and eco-friendly building material that can provide acoustic benefits and advantages and contribute to developing more sustainable and resilient buildings.

2. MATERIALS AND METHOD

2.1. Materials and Equipment

The materials used for this research include Soil (Laterite) which was sourced locally from the Du community of Jos-Nigeria (9°50'16.2"N and 8°54'53.6" E as shown in Figure 1, ordinary Portland cement, and water. The equipment used consists of the NBRRI interlocking compressed stabilized earth block molding machine, file cutting machine, BO SOUND amplifier, Bicourbe oscilloscope (GW-INSTEK GDS-2104), and low-frequency generator (LODESTAR FG-20208).

2.2. Method

2.2.1. Laterite Classification

By the Unified Soil Classification System (USCS) specifications [13], the Atterberg limits and grain size distributions of the soil used were established. The results were analyzed on the standard charts that indicated the fines constituent of the soil was predominantly silty than the clayey constituent. Therefore, the soil was classified to be predominantly silty sand.

2.2.2. Production of the Interlocking Compressed Stabilized Earth Blocks

The NBRRI molding machine is used to produce NBRRI ICSEBs, as shown in Figure 2. Laterite is used to make these blocks with a 5% stabilization rate, consistent with NBRRI's recommendations, and they are compressed to 20Mpa. After the blocks are molded and shaped, as

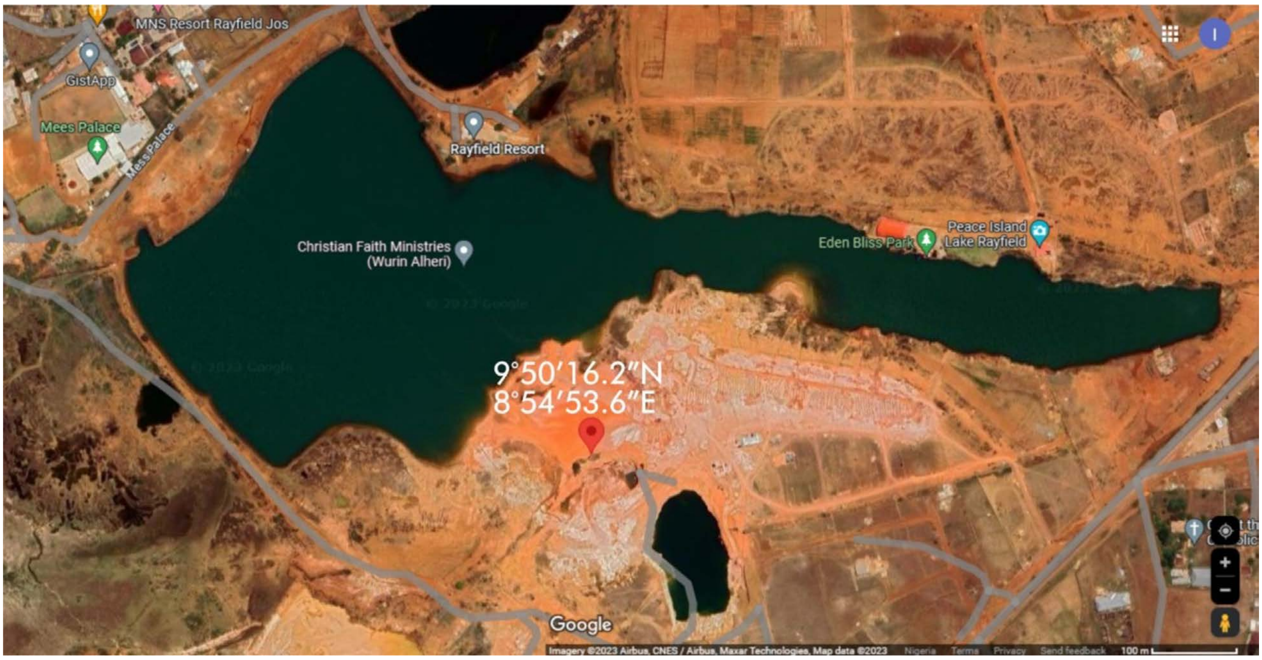

Figure 1. Google Satellite Map of where the Laterite was received.

Figure 2. ICSEB samples produced by NBRRI.

Figure 3. The ongoing building construction using ICSEB.

shown in Figure 2, they are left to cure for 21 days after being covered with polyethylene [6, 14] before putting into use, as depicted in Figure 3.

2.2.3. Measurement of Acoustic Property

Impedance measurement can be performed using any transducers that can measure physical quantities linearly related to pressure or volume. Thus, many systems can be built to measure acoustic impedance. In this study, the set-up of the acoustic impedance tube, as shown in Figure 4, is made up of a tube, microphone, sample holder, amplifier unit, functional generator, an oscilloscope was used by ASTM Standard E1050-98 (1998) [15] and ISO 10534 Part 1 and 2 [16]. The determined sound absorption coefficient of the sample was an index of the amount of sound energy of ICSEB that can absorb noise when used as an infill wall material in construction.

3. RESULTS AND DISCUSSION

3.1. Laterite Property

The composition of a particular laterite and its plasticity index affect its suitability for block production. Onaolapo [17] reported that a suitable laterite soil for block production would comprise 15–20% clay, containing silt of roughly 25–40% by volume and approximately 40–70% by coarse sand. The soil plasticity is said to depend primarily on the function of the clay content. Thus, soil with a plasticity index up to 20–30 is suitable for use in the production of building blocks [18].

Based on the previous study on the thermal conductivity and fire resistance of the same block [19], the laterite used in this investigation showed a high liquid limit (35< LL<75) of 59, a plasticity index of 25.95 and from the grading curve, the laterite consisted of 40.75%

Figure 4. Acoustic apparatus.

Table 1. Acoustic coefficient (α) of 20 mm thick ICSEB

Octave band (Hz)	500	1000	2000	4000
V_1	1.10	0.45	0.6	0.62
V_2	0.19	0.15	0.15	0.15
β	5.79	3.00	4.00	4.13
α	0.50	0.75	0.64	0.63

Table 2. Acoustic coefficient (α) of 20 mm thick ICSEB

Octave band (Hz)	500	1000	2000	4000
V_1	1.10	0.40	0.42	0.60
V_2	0.20	0.20	0.20	0.18
β	5.50	2.00	2.10	3.33
α	0.52	0.89	0.87	0.71

fines (silt-clay), 48.65% fine/medium/coarse sand and 10.6% fine gravel. Therefore, the laterite used is said to be predominantly sand with silt, hence classified as silty sand and considered suitable for producing ICSEB. This can likely be due to the silty sand's fine particle size, good compaction properties, and high plasticity. When stabilized with suitable additives, such as cement, lime, or pozzolanic materials, silty sand can produce durable, strong blocks with good thermal and acoustic properties [14].

3.2. Acoustic Property

Having that frequency is a significant determinant in sound transmission, the acoustic coefficients (α) for the respective octave bands that fall within the critical frequencies for noise control were considered for two sample thicknesses of 15 mm and 20 mm, as shown in Tables 1 and 2, respectively.

$$\beta = \frac{V_1}{V_2} \tag{1}$$

$$\alpha = \frac{4\beta}{(\beta+1)^2} \tag{2}$$

Where:

α = Coefficient of acoustic absorption

V_1 = Maximum wavelength recorded on a particular octave band

V_2 = Minimum wavelength recorded on a particular octave band

β = Amplitude ratio

According to [20, 21], the relationship between the coefficient of acoustic absorption and the thickness of the material is a power function of the form:

$$\alpha = aL^b \tag{3}$$

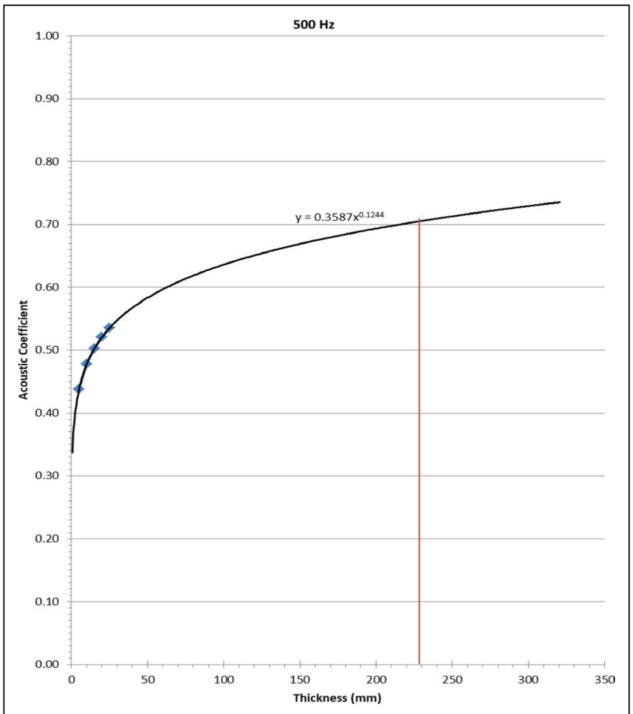

Figure 5. An experimental relationship for acoustic coefficient of ICSEB at 500 Hz.

Where:

α = Coefficient of acoustic absorption

L = Thickness of the material (mm)

a, b = Constants that depend on the material properties and frequency

This means that the coefficient of acoustic absorption (α) increases as the thickness of the material increases but at a decreasing rate. Therefore, the models shown in Figures 1 to 4 were used to determine α for the 230 mm thick ICSEB.

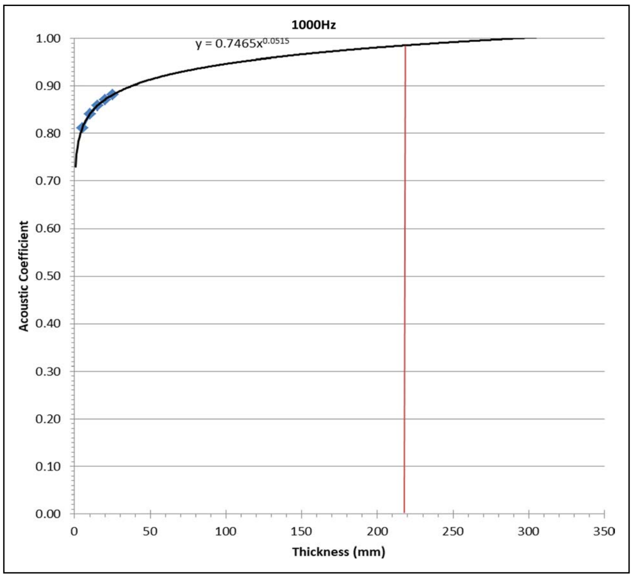

Figure 6. An experimental relationship for acoustic coefficient of ICSEB at 1000 Hz.

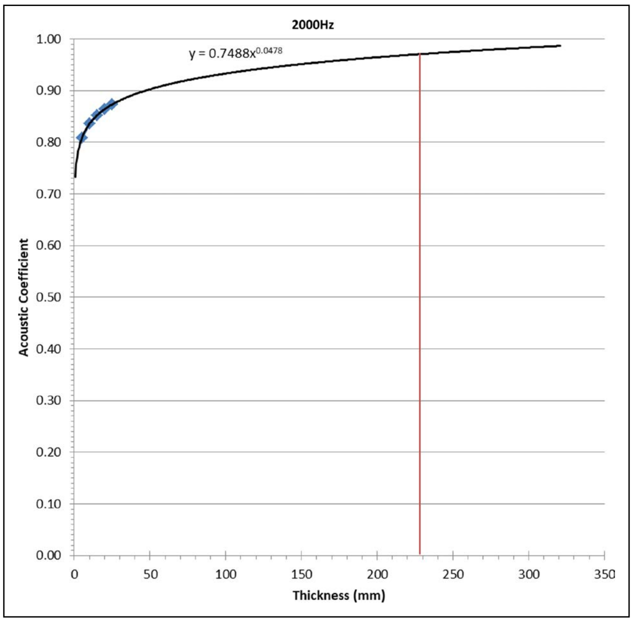

Figure 7. An experimental relationship for acoustic coefficient of ICSEB at 2000 Hz.

Table 3 below shows the R-squared value for the different frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz, and the respective thicknesses of 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm of the ICSEB samples used in this study.

From the results in Figures 5–8, it showed that produced ICSEB with a thickness of 230 mm x 100 mm and cured for 21 days has the acoustic coefficient of 0.71, 0.99, 0.97, and 0.94 at the octave bands of 500 Hz, 1000 Hz, 2000 Hz, and 400 Hz respectively indicates that the material has good acoustic insulation properties. The acoustic coefficient measures the sound absorption of a material, with a higher coefficient indicating a more remarkable ability to absorb sound [22]. The values obtained for the ICSEB suggest that it could effectively reduce sound transmission in buildings,

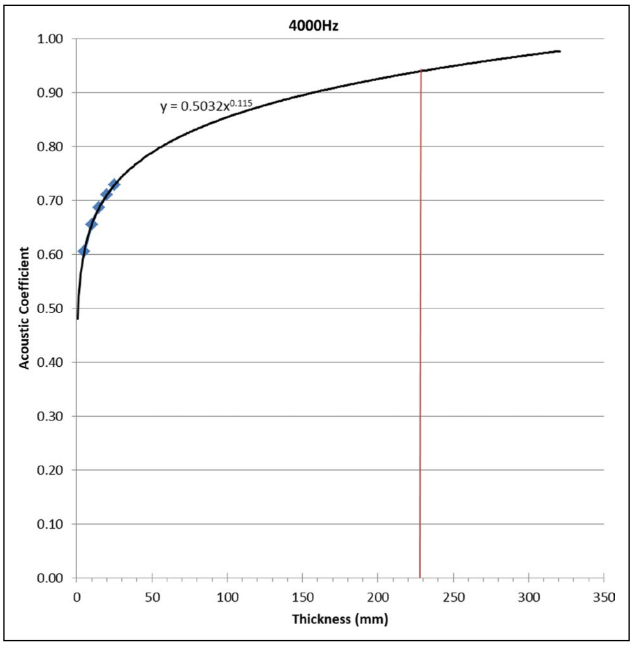

Figure 8. An experimental relationship for acoustic coefficient of ICSEB at 4000 Hz.

Table 3. R-squared value for the different frequencies used

Thickness (mm)	500 Hz	1000 Hz	2000 Hz	4000 Hz
5	0.44	0.81	0.81	0.61
10	0.48	0.84	0.84	0.66
15	0.50	0.86	0.85	0.69
20	0.52	0.87	0.86	0.71
25	0.54	0.88	0.87	0.73
R^2 value	1	0.95	1	1

particularly at higher frequencies where its performance is most notable [23].

A careful look at the results shows that the acoustic coefficient is high at the octave band of 1000 Hz with 0.99, followed by 0.97 at 2000 Hz, 0.94 at 4000 Hz, and 0.71 at 500 Hz. The high coefficient of 0.99 at the octave band 1000 Hz signifies more effective absorption of sound energy at this frequency by the sample. This is because the model absorbs sound energy at higher frequencies less effectively. According to Bhatia's lecture note on M06–026: HVAC systems noise control [24], the decrease in the acoustic coefficient with increasing octave bands beyond 1000 Hz can result from the wavelength of sound, which decreases with increasing frequency. This makes it more difficult for the sample to absorb the sound energy, or the sample thickness becomes less effective at absorbing useful energy at higher frequencies. However, such behavior will be a better subject for further research.

Meanwhile, it is worth noting that the absorption coefficient ranges between 0.00–1.00, one (1.00) meaning no sound energy is reflected and the sound is either absorbed or transmitted. For example, an opened exterior window has an absorption coefficient of one (1.00) because no

Table 4. Coefficient of absorption of different materials

Material	Frequency (Hz)	Coefficient of absorption, α
ICSEB	4000	0.94
Fiberglass	4000	0.90
Plasterboard	4000	0.50–0.70

Source: [29, 30] and Lab work.

sound returns to the room. An effective absorber will have a sound absorption coefficient greater than 0.75 [25].

The thickness of the ICSEB also plays a vital role in its acoustic performance. A thicker block will generally have better sound insulation properties than a thinner block, as it offers more mass and greater impedance to the transmission of sound waves [22]. According to Rivera-Gómez et al. [26] and Silva et al. [27], ICSEBs are influenced by several factors. One of these factors is the applied compaction pressure, which affects the bulk density of the specimen and the added cement used as a stabilizer. Another factor is the type of binder used to stabilize the block. Ouma et al. [28] assessed the potential use of lime and water hyacinth ash (WHA) as binders in producing ICSEBs with good acoustic absorption properties. They found that the transmission coefficient decreased with the compaction pressure and lime addition, while WHA increased the transmission coefficient. Though WHA is not the binder used in producing the ICSEBs in this research, it signified that stabilizers could influence an acoustic property.

Compared to other building materials commonly used for acoustic insulation, the acoustic coefficient values of the ICSEB are competitive and suggest that it could be a viable alternative in certain situations. For example, fiberglass insulation batts, commonly used in walls and ceilings to reduce sound transmission, typically have an acoustic coefficient of around 0.9 at 4000 Hz, as displayed in Table 4, one of the most common frequencies for human speech [29]. This is almost the same as the ICSEB's coefficient of 0.94 at 4000 Hz, as determined in this study. However, it should be noted that the ICSEB's coefficient is still relatively high and competitive, particularly considering its thickness and the fact that it is a solid material rather than a porous one. According to Stani et al. [30], as shown in Table 4, another commonly used material for acoustic insulation is acoustic plasterboard, which typically has a coefficient of around 0.5 to 0.7 at 4000 Hz, depending on its thickness and composition. Again, this is lower than the ICSEB's coefficient, and it should be noted that acoustic plasterboard is typically more expensive and may not be suitable for all applications. This indicates that ICSEB has more capacity to absorb sound energy than commonly used materials such as fiberglass and plasterboard.

4. CONCLUSION

In conclusion, the results of the study indicate that interlocking compressive stabilized earth blocks (ICSEBs) made from the tested laterite soil composition, consisting of 40.75% fines (silt-clay), 48.65% fine/medium/coarse sand, and 10.6% fine gravel, exhibit favorable acoustic insulation properties.

The ICSEBs demonstrated high sound absorption coefficients, with values of 0.71–0.99 at 500 Hz–4000 Hz. These coefficients suggest that the ICSEBs effectively absorb sound energy, and when comparing the acoustic coefficient values to commonly used acoustic insulation materials such as fiberglass insulation batts and acoustic plasterboard.

The ICSEBs are competitive, highlighting their potential as a cost-effective and durable alternative.

However, further research is needed to explore the impact of factors such as composition, thickness, and installation method on the acoustic performance of ICSEBs, ensuring their suitability for specific applications.

ETHICS

There are no ethical issues with the publication of this manuscript.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

PEER-REVIEW

Externally peer-reviewed.

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