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## THE AIRBORNE SOUND INSULATION PERFORMANCE OF CROSS-LAMINATED BAMBOO AND TIMBER (CLBT) AND CROSS-LAMINATED TIMBER (CLT) WALL PANELS

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*The growing application of timber and bamboo in construction applications makes it important to investigate their acoustic properties. This study conducted a comparative experimental investigation of the airborne sound insulation performance of Cross-Laminated Timber (CLT) and a novel composite, Cross-Laminated Bamboo and Timber (CLBT), wall panels. A total of 10 full-scale wall specimens, including basic designs and upgrades with lining systems, were tested in accordance with ISO 140-3. The results demonstrate that structural optimization using multi-layer linings is effective for sound insulation performance for both CLT and CLBT walls. The optimal CLT wall achieved an  $R_w$  of 47 dB with consistent spectrum-adjusted values, meeting high acoustic standards. The optimized CLBT wall reached an  $R_w$  of 45 dB, which can meet the acoustic requirements of most conventional buildings, but its low-frequency sound insulation performance is insufficient ( $R_w+C_{tr}=39$  dB). This study demonstrates that using a multi-layer composite structure, integrating porous materials, high-density reflective layers, and elastic flanking transmission control elements, is key to achieving good sound insulation performance across the full frequency range. Furthermore, CLBT walls can achieve comparable sound insulation performance to CLT walls with proper design, meeting the acoustic requirements for many conventional buildings.*

**Keywords:** wall panels, Cross-Laminated Timber panels, Cross-Laminated Bamboo and Timber panels, sound insulation, acoustic properties, sound insulation index.

## ЗВУКОИЗОЛЯЦИОННЫЕ СВОЙСТВА МНОГОСЛОЙНЫХ КЛЕЕНЫХ ПАНЕЛЕЙ ИЗ БАМБУКА И ДРЕВЕСИНЫ (CLBT) И ПАНЕЛЕЙ ИЗ ДРЕВЕСИНЫ (CLT) ДЛЯ СТЕН

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*Возрастающее применение древесины и бамбука в строительстве вызывает необходимость в изучении их акустических свойств. В рамках исследования проведены сравнительные испытания звукоизоляционных свойств многослойных клееных деревянных панелей (CLT) и нового композитного материала – многослойных клееных стеновых панелей из бамбука и древесины (CLBT). В соответствии со стандартом ISO 140-3 протестировано в общей сложности 10 образцов стен в натуральную величину, включая базовые конструкции и усовершенствованные слоистые конструкции панелей. Результаты показывают, что конструкции с использованием многослойных систем эффективны для обеспечения звукоизоляции как стен из CLT панелей, так и из CLBT панелей. Стена из CLT панелей*

обеспечивает  $R_w$  на уровне 47 дБ с постоянными значениями, скорректированными по спектру, что соответствует высоким акустическим требованиям. Конструкция стены из CLBT панелей достигла значения  $R_w$  в 45 дБ, что соответствует акустическим требованиям большинства зданий, но характеристики низкочастотной звукоизоляции опытных образцов недостаточны ( $R_w + C_{tr} = 39$  дБ). Это исследование демонстрирует, что использование многослойной композитной структуры, включающей пористые материалы, отражающие слои высокой плотности и эластичные боковые элементы, влияющие на звукопередачу, являются ключом к достижению хороших звукоизоляционных характеристик во всем диапазоне частот. Кроме того, стены из CLBT панелей при правильном проектировании могут обеспечить звукоизоляцию, сравнимую со стенами из CLT панелей и соответствовать акустическим требованиям, предъявляемым к различным зданиям.

**Ключевые слова:** стеновая панель, многослойные клееные деревянные панели, многослойные клееные панели из бамбука и древесины, звуковая изоляция, акустические свойства, индекс звукоизоляции.

## 1. Introduction

Noise pollution has emerged as a major environmental concern in modern society, with well-documented adverse effects on human health and well-being (Basner et al. 2014; Goines and Hagler 2007; Miedema and Oudshoorn 2001; Muzet 2007; Sørensen et al. 2012; Stansfeld and Matheson 2003). This has heightened the demand for acoustically comfortable built environments, where the sound insulation performance of building envelopes plays a critical role. International building codes, such as the International Building Code (IBC), mandate minimum performance standards for partitions, requiring for instance an airborne Sound Transmission Class (STC) of 50 dB for walls separating dwelling units (ICC 2020). To meet these standards, a variety of solutions, from dense concrete to double-skin partitions, have been employed.

Concurrently, the global emphasis on sustainable development has driven the promotion of carbon-sequestering biomass materials, such as wood and bamboo, in construction (Churkina et al. 2020). Among wood-based products, Cross-Laminated Timber (CLT) has gained widespread application in structural elements like walls and floors due to its excellent mechanical properties, sustainability, and prefabrication potential (Brandner et al. 2016). However, in regions like China, where high-quality timber resources are limited, bamboo presents a strategic alternative. The development of engineered bamboo materials, such as glued laminated bamboo (Glulam), has overcome the limitations of raw bamboo culms, enabling their use in modern structures (Xiao 2022). Inspired by the success of CLT, a novel composite, Cross-Laminated Bamboo and Timber (CLBT), has been recently developed to further expand the possibilities of bamboo in engineering (Xiao et al. 2021).

While preliminary research on the mechanical behavior of CLT and CLBT components, such as beams and floors, has been conducted, their acoustic performance remains a critical yet less explored area (Huang et al. 2022; Wen and Xiao 2023). Systematic experimental data on the sound insulation capacity of wall assemblies, in particular, is relatively scarce. Given their growing structural application and the stringent acoustic requirements of green buildings, a comparative understanding of their airborne sound insulation is imperative. Consequently, this study aims to experimentally investigate and compare the airborne sound insulation performance of CLT and CLBT wall panels, thereby providing essential data to support their informed application in acoustically sensitive sustainable construction.

## 2. Test specimens

Two groups of wall specimens, which are cross-laminated timber (CLT) walls and cross-laminated bamboo–timber (CLBT) walls, were designed in this study to compare their sound insulation performance in terms. Specimen Wall 1 was a 175 mm thick CLT wall composed of five orthogonal layers of spruce–pine–fir (SPF) planks. Specimen Wall 6 was a 161 mm thick CLBT wall,

comprising two surface layers of thin strip glulam on the top and bottom and three orthogonal SPF layers in the middle. Based on Wall 1 and Wall 6, Specimens Wall 2–5 and Wall 7–10 were constructed by adding the following lining systems: stucco, extruded polystyrene (EPS), water proof paper (WPP), gypsum board, glass wool with timber strapping, and glass wool with resilient channels. All specimen details are summarized in Table 1. The values of density for all the materials used in wall specimens are listed in Table 2.

Table 1. – Details of all the specimens of CLT and CLBT walls

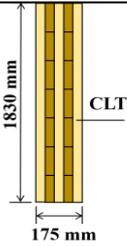
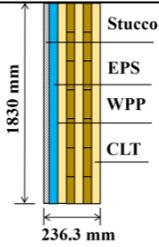
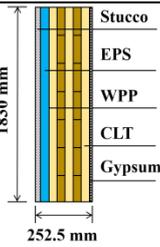
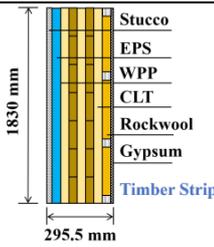
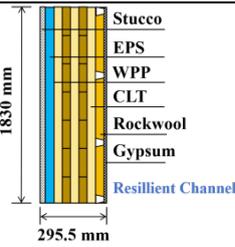
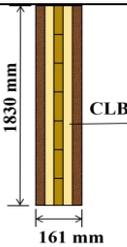
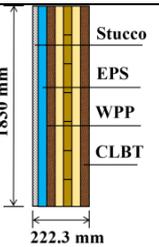
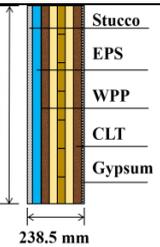
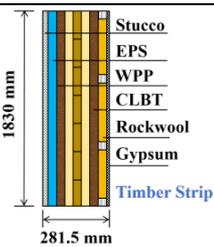
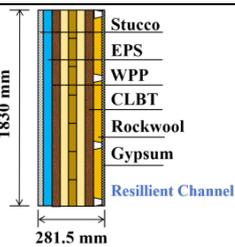
	Wall 1	Wall 2	Wall 3	Wall 4	Wall 5
					
Stucco	0	21 mm	21 mm	21 mm	21 mm
EPS	0	40 mm	40 mm	40 mm	40 mm
CLT	175 mm	175 mm	175 mm	175 mm	175 mm
Gypsum	0	0	16 mm	16 mm	16 mm
Rockwool	0	0	0 mm	40 mm	40 mm
Walls	Wall 6	Wall 7	Wall 8	Wall 9	Wall 10
					
Stucco	0	21 mm	21 mm	21 mm	21 mm
EPS	0	40 mm	40 mm	40 mm	40 mm
CLBT	161 mm	161 mm	161 mm	161 mm	161 mm
Gypsum	0	0	16 mm	16 mm	16 mm
Rock-wool	0	0	0 mm	40 mm	40 mm

Table 2. – Details of all the specimens of CLT and CLBT walls

Materials	Glulam	SPF	Stucco	EPS	Gypsum	Rockwool
Density (kg/m <sup>3</sup> )	839.6 (2.63)	405.633 (5.520)	1929.63 (1.11)	30.12 (0.35)	682.6 (0.10)	63.35 (24.89)

\*Value in parentheses is coefficient of variation (%).

### 3. Experimental measurements

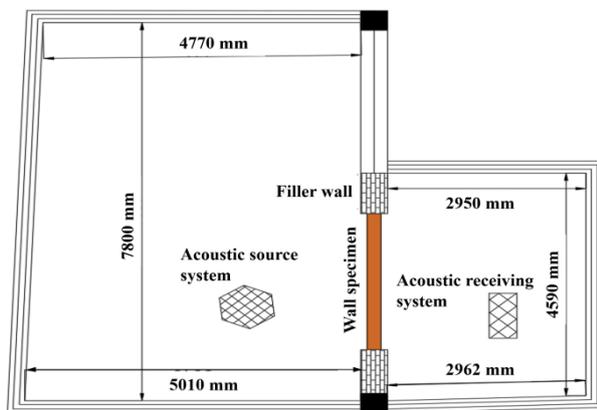
In this study, the sound insulation properties of the materials and wall specimens were measured in accordance with ISO 140-3 using the reverberation room method in the Building Acoustics Laboratory of the Guangdong Provincial Academy of Building Research (Figure 1). The test facility consisted of two adjacent chambers, a sound source room with a volume of approximately 160 m<sup>3</sup> and a receiving room with a volume of about 53 m<sup>3</sup>, both satisfying the volume requirements specified in ISO 140-1 for laboratory measurements. The two reverberation chambers

were constructed with highly reflective surfaces, including walls, floors and ceilings to promote a diffuse sound field.

A wall specimen was installed between two adjacent reverberation rooms. The difference in sound pressure levels between the two rooms is measured ( $L_1$  for the source room and  $L_2$  for the receiving room), and the reverberation time ( $T$ ) in the receiving room is determined to account for the sound insulation performance across frequency bands using

$$R = L_1 - L_2 + 10 \lg \frac{ST}{0.163V}, \quad (1)$$

where  $R$  is the airborne sound insulation index (in dB),  $S$  is the area of the test specimen (in  $m^2$ ),  $V$  is the volume of the receiving room (in  $m^3$ ) and  $T$  is the reverberation time (in s).



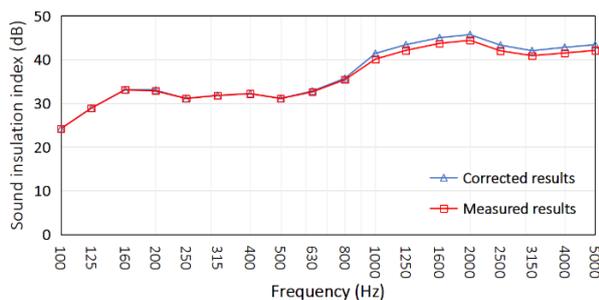
a. Schematic diagram



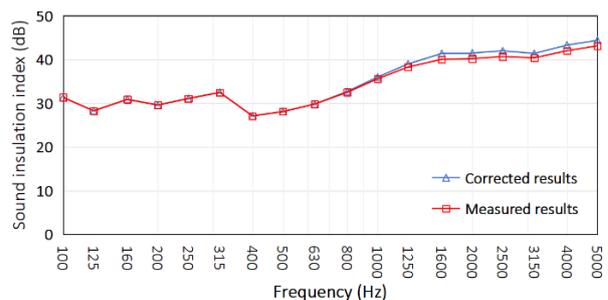
b. Schematic diagram

Figure 6. – Sound insulation test

Since the test specimen was smaller than the test opening, a filler wall was designed to serve as a supporting frame for the specimen. In this case, the measured sound insulation value of a wall specimen needs to be corrected to eliminate the influence of flanking transmission. Flanking transmission occurs when sound waves travel via indirect paths, such as through the infill wall and the surrounding structures of the test opening, rather than passing directly through the specimen itself. ISO 140-3 specifies the details of the correction procedure to ensure that the final results truly reflect the sound insulation performance of the wall specimen itself. Therefore, it is mandatory to correct all results in accordance with this standard. Taking Wall 1 and Wall 6 as examples, the measured and corrected sound insulation values for both specimens are plotted in Figure 2 for comparison. The presence of flanking transmission results in lower measured sound insulation values, leading to an underestimation of the true acoustic performance of a specimen.



a. Wall 1 (CLT)



b. Wall 6 (CLBT)

Figure 7. – Measured and corrected sound insulation values

#### 4. Experimental results and discussion

The sound reduction index results for all CLT and CLBT wall specimens are plotted in Figure 3 across the frequency range of 100-5000 Hz (in one-third octave bands). The data presented in this figure clearly demonstrate that structural optimization is the core factor for improving the sound insulation performance of both CLT and CLBT walls.

##### 4.1 Effect of lining systems

Wall 1, a simple 175 mm CLT panel, exhibits the lowest sound insulation, while Wall 5, with the most complex structure, achieves the highest and most stable sound insulation across all frequency bands. This trend directly demonstrates the positive impact of structural diversity and enhanced flanking transmission control on sound insulation. Due to the low surface density of SPF, it is constrained by the mass law, where its sound insulation in the low-frequency range (<1000 Hz) is only about 25 dB, and although it improves in the mid-to-high frequency range, it still offers no advantage. By adding WPP, EPS, and stucco to the CLT base, Wall 2 achieves an increase of 5–10 dB in low-frequency sound insulation. This improvement is attributed to the porous structure of the EPS, which enhances sound absorption, combined with the high surface density of the stucco, which improves sound reflection. Wall 3 further incorporates a 16 mm gypsum board. Gypsum's high density enhances the reflection of mid-to-high frequency sound waves, while its damping properties help suppress the coincidence dip typical of CLT panels. Consequently, the utilization of gypsum boosts the wall's sound insulation by 3–5 dB in the mid-to-high frequency compared to Wall 2. For Wall 4's sound insulation performance, despite incorporating a 40-mm porous sound-absorbing rockwool layer that effectively absorbs mid-to-high frequency acoustic energy, the rigid timber strip connections introduce new flanking transmission paths, limiting the overall sound insulation improvement. By replacing the timber strips with resilient channels, Wall 5 achieves the optimal and most stable sound insulation performance across all frequency bands. This not only interrupts rigid flanking transmission paths but also combines the sound absorption of rockwool, the high density of gypsum board, and the vibration-damping effect of resilient channels to cover sound insulation needs in low, mid and high frequency.

An analogous trend is clearly evident in the CLBT wall specimens (Figure 3b), confirming the key principle in wall acoustic design: low-frequency sound insulation relies on a combination of surface density and porous materials, whereas the mid to high frequency sound insulation performance requires damping materials to suppress the coincidence effect, along with elastic structural elements to minimize flanking transmission.

The structural upgrade from simple CLT and CLBT walls to walls with multi-layer sound insulation materials achieves a significant improvement in sound insulation performance. This indicates that the sound insulation performance of CLT and CLBT walls cannot depend solely on thickness, but can be effectively improved by using a composite structure that integrates porous sound-absorbing materials, high-density reflective layers, and elastic elements for flanking transmission control.

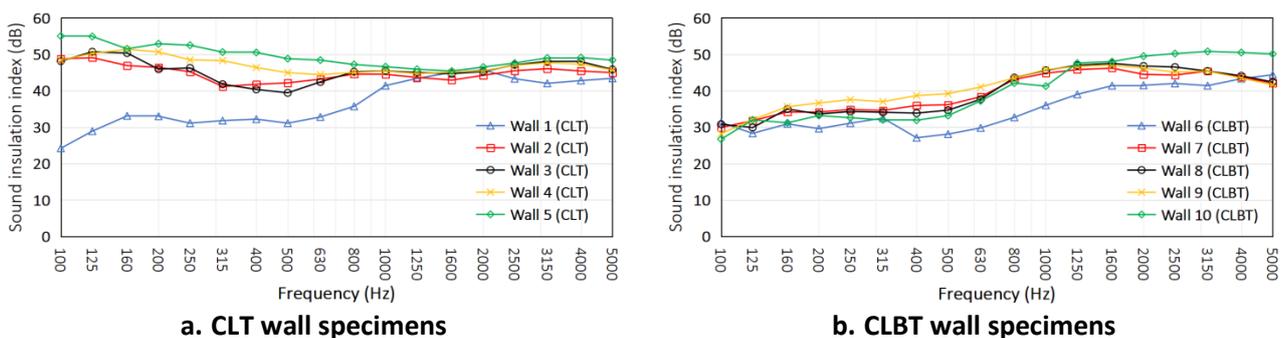


Figure 8. – Sound Reduction Index Results for Wall Specimens

#### 4.2 Evaluation of the sound insulation performance of CLT and CLBT walls

In order to simplify the complex full-band sound insulation curve into a single value, the weighted sound reduction index (Rw) is used as the core single indicator to evaluate the airborne sound insulation performance of walls. Real-world noise varies significantly in frequency distribution. Daily living noise, for example, is predominantly mid to high frequency, typically above 1000 Hz. In contrast, traffic noise falls mainly in the mid to low frequency range, mostly below 500 Hz. To account for these differences, spectral adaptation terms (C and Ctr) are introduced to adjust the weighted value according to different acoustic environments. Accordingly, Rw+C can better reflect walls' sound insulation performance against daily living noise, and Rw+Ctr is more suitable for traffic noise scenarios.

According to the calculation method specified in an international standard (ISO 717-1 2020), the values of Rw, Rw+C and Rw+Ctr for all the CLT and CLBT walls are given in Table 3. A Chinese standard (GB 50118 2010) gives airborne sound insulation requirements for walls in different building areas in China, and all the values are listed in Table 4. As shown in Table 3, the optimized CLT wall (Wall 5) achieves a weighted sound reduction index (Rw) of 47 dB, with both Rw+C and Rw+Ctr maintaining high at approximately 47 dB. The wall can meet all the sound insulation requirements listed in Table 4 for residential, educational, and hotel buildings. In terms of CLBT walls, Wall 10 is adequate for most applications, but it needs to be improved to satisfy high-demand acoustic specifications.

Table 3. – Sound insulation indexes for CLT and CLBT walls

	Wall 1	Wall 2	Wall 3	Wall 4	Wall 5
Rw	39	44	45	46	47
Rw+C	37	44	44	46	47
Rw+Ctr	35	44	44	46	47
	Wall 6	Wall 7	Wall 8	Wall 9	Wall 10
Rw	35	42	42	44	45
Rw+C	34	41	41	43	43
Rw+Ctr	33	39	39	41	39

Table 4. – Standard for sound insulation indexes of walls in different building types

Building type	Wall type	Sound insulation requirements
Residential Buildings	Exterior Wall	Rw+Ctr $\geq 45$ dB
	Partition Walls between bedrooms	Rw+C $\geq 35$ dB
	Partition Walls between other rooms	Rw+C $\geq 30$ dB
Schools	Exterior Wall	Rw+Ctr $\geq 45$ dB
	Partition Walls between classrooms	Rw+C $> 45$ dB
Average hotels	Exterior Wall	Rw+Ctr $> 30$ dB
	Partition Walls between rooms	Rw+C $> 40$ dB

#### 4.3 Comparison between CLT and CLBT walls

The primary objective behind developing the CLBT concept was to use bamboo as a substitute for timber, thereby promoting the engineering application of bamboo resources and alleviating China's dependence on imported high-quality wood. In terms of wall's sound insulation performance, a comparison between CLT and CLBT walls (Figure 4) clearly shows that the latter can achieve a sound insulation level comparable to that of the former.

In the baseline configuration (Figure 4a), the sound insulation index of the pure CLT wall (Wall 1) is slightly higher than that of the pure CLBT wall (Wall 6). As listed in Table 3, their weighted sound reduction indices ( $R_w$ ) are 39 dB and 35 dB, respectively, resulting in a performance gap of 4 dB. This discrepancy is probably due to the difference in material thickness (175 mm for CLT vs. 161 mm for CLBT).

With the use of lining systems, the difference can be reduced. Specifically, the  $R_w$  of the optimal CLT construction (Wall 5) reached 47 dB, while the  $R_w$  of the optimal CLBT construction (Wall 10) increased to 45 dB, narrowing the gap to 2 dB. Also, Figure 4b shows that the sound insulation performance of CLBT Wall 10 at medium and high frequencies is close to that of CLT, but there is a notable deficiency in the low-frequency range. In terms of spectral performance, CLT Wall 5 demonstrates adequate sound insulation across both mid-to-high and mid-to-low frequency ranges. CLBT Wall 10 provides good performance for mid-to-high frequency noise, while it shows limited effectiveness in low-frequency sound isolation, making it less suitable for environments dominated by traffic noise.

In summary, CLT walls exhibit good acoustic performance in a broader frequency range, making them more suitable for different sound insulation scenarios; while CLBT walls, through structural optimization, can not only meet the conventional sound insulation needs of most buildings but also offer space advantages to some extent.

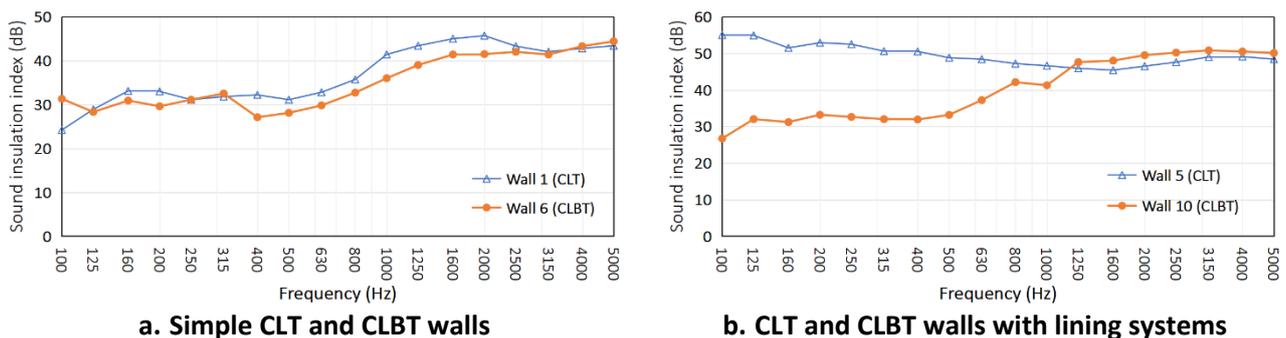


Figure 9. – Sound Reduction Index Results of CLT and CLBT walls for comparison

## 5. Conclusion

This study provides a systematic experimental evaluation of the airborne sound insulation performance of CLT and CLBT wall panels, and the following findings can be concluded:

1. Structural optimization is important in the acoustic design of walls. The sound insulation performance of both CLT and CLBT walls is not only dependent on their base thickness but can be significantly enhanced through multi-layer lining systems.

2. CLT walls exhibit slightly better sound insulation performance. The optimized CLT wall (Wall 5) achieved an outstanding  $R_w$  of 47 dB, with similarly high values for both  $R_w+C$  and  $R_w+C_{tr}$  at approximately 47 dB, enabling it to meet the acoustic requirements for various building types.

3. CLBT walls, which proper design, can be an effective alternative to CLT walls in many acoustic scenarios. CLBT walls with lining systems can fulfill the sound insulation needs of most residential, school, and hotel buildings.

4. The application of CLT or CLBT walls should be guided by specific acoustic conditions, such as the spectrum of the noise source and the required insulation standards. For conventional construction applications, CLBT walls can offer a resource-efficient alternative, promoting the use of fast-growing bamboo with ensuring the sound insulation capability.

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