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TECHNICAL PERFORMANCE OF INNOVATIVE DOVETAIL MASSIVE TIMBER BOARD SLABS

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ABSTRACT: Dovetail massive timber board elements (DMWBEs) offer a sustainable alternative to engineered wood products (EWPs), such as cross-laminated timber (CLT). By eliminating the need for adhesives and metal connectors, DMWBEs address critical environmental concerns related to disposal, reuse, and recyclability. This study compiles recent findings on the acoustic, fire, and air permeance properties of DMWBEs, emphasizing their technical superiorities. Experimental results highlighted the superior airborne sound insulation of DMWBEs (Rw = 43 dB) compared to CLT (Rw = 40 dB). Fire performance testing revealed a charring rate of 0.71 mm/min for DMWBEs, which closely aligns with solid timber, and significantly lower than the 0.93 mm/min observed in CLT due to delamination effects. Additionally, DMWBEs effectively prevent flame penetration and char fall-off, maintaining structural integrity under thermal stress. Air permeance tests indicated variability based on moisture content, with q50 values ranging from 1.4 to 9.9 m³/(m²h), demonstrating the material's adaptability under different environmental conditions. Collectively, these results position DMWBEs as a robust and environmentally friendly solution for the construction, offering enhanced acoustic, fire, and air permenace performance while reducing environmental impact. Future research should address scalability and practical implementation to fully integrate DMWBEs into modern building practices in construction industry.

KEYWORDS: timber, dovetail massive timber board slabs, fire performance, airborne sound insulation performance, air permeance performance.

1 – INTRODUCTION

The construction industry is at a crossroads, facing the dual challenge of meeting global infrastructure demands while mitigating its environmental footprint [1]. Traditional building materials, such as concrete and steel, dominate the industry but are associated with significant carbon emissions and energy-intensive production processes [2]. In response, EWPs have emerged as a sustainable alternative, combining renewable resources with advanced engineering techniques to deliver high-performance construction solutions [3,4]. Among EWPs, CLT has gained prominence for its structural versatility, dimensional stability, and ability to support large-scale architectural projects [5-7]. Iconic buildings such as the 24-story HoHo Wien (2020) in Austria [8] and the 14-story Lighthouse Joensuu (2019) in Finland [9] exemplify the innovative potential of CLT in reducing the environmental impact of urban development.

Despite its many advantages, the widespread use of CLT is not without challenges. The reliance on adhesives and metal fasteners in CLT production raises critical concerns [10,11]. Adhesives, primarily petroleum-based, are associated with volatile organic compound (VOC) emissions and formaldehyde release, which pose health and environmental risks throughout the product's lifecycle [12,13]. Similarly, metal fasteners complicate recycling and reuse at the end of the building's life, undermining the sustainability of CLT [14,15]. These challenges highlight the need for alternative construction solutions that combine high performance with ecological responsibility.

DMWBEs (Figure 1) represent a breakthrough in sustainable construction, addressing the limitations of traditional EWPs [16]. Constructed entirely of pure wood and joined using a dovetail technique that eliminates adhesives and metal connectors, DMWBEs offer a holistic approach to sustainability [17]. The dovetail assembly, rooted in ancient carpentry practices, ensures robust mechanical connections while maintaining the integrity of the wood. This approach not only enhances recyclability and end-of-life reuse but also improves the material's overall environmental profile.

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Figure 1. DMWBE

Despite these advantages, the adoption of DMWBEs in the construction industry remains limited, primarily due to a lack of comprehensive studies evaluating their large-scale structural applications [18]. Existing research tends to focus on model-scale assessments, joint detail analyses, or isolated performance metrics, leaving significant gaps in understanding their suitability for multi-story and high-performance buildings [19-23]. This study aims to address these gaps by synthesizing recent findings on the sound insulation [24], fire [25], and air permeance properties [26] of DMWBEs, providing a detailed evaluation of their potential as a sustainable and high-performance building material.

Achieving effective sound insulation is a critical factor in enhancing the commercial viability of building components [27] and directly impacts the acoustic quality of indoor environments. As a result, the performance of CLT and other EWPs in mitigating both airborne and impact noise is a subject of considerable importance. While national regulations establish minimum standards for sound insulation between adjoining spaces, these standards vary significantly across countries, with notable differences in target values and measurement descriptors [28]. For instance, in Europe, regulatory benchmarks for airborne sound insulation between spaces can differ by as much as 7 dB [28], reflecting diverse approaches to defining acceptable acoustic performance. Understanding these variations is essential for the development and application of CLT and EWPs in global markets, as compliance with region-specific acoustic standards is often a prerequisite for their broader adoption in construction projects.

Researchers are actively investigating ways to improve the fire performance of CLT and related materials like bamboo, addressing growing market demands [29-31]. [32] demonstrated that protective claddings, such as Fireline gypsum plasterboard and a plywood-Fireline composite, significantly delayed charring in Irish spruce CLT panels by 30 to 44 minutes. [33] explored fire behavior in large office-like enclosures, revealing that ceiling protrusions like down-stand beams affect heat flux and fire spread rates, influencing flaming combustion and auto-extinguishment. [34] studied the role of exposed CLT surfaces in compartment fires, finding that larger exposed areas amplified heat release rates, burning rates, and fire dynamics, with detached charred layers introducing variability in fire progression. [35] focused on cross-laminated bamboo, showing that fire-resistant treatments like flame retardant coatings and chemical impregnation reduced charring compared to untreated slabs under ISO 834-1 conditions. [36] synthesized data from numerous experiments, including cone calorimeter tests, furnace trials, and fire compartment studies, identifying consistent trends in how material and design parameters influence critical fire performance metrics. These findings collectively advance the understanding of fire resilience in engineered wood products and their applications in modern construction.

Airtightness is a critical factor in the performance and commercial viability of building components, particularly in CLT structures [37]. [38] highlighted that high initial moisture content in CLT panels and water exposure during construction significantly reduce airtightness, while maintaining low moisture levels (around 13%) ensures effective air barrier properties in 5-layer panels. [39] emphasized proactive weather protection, such as tarpaulins and adhesive membranes, to safeguard airtightness during construction. [40] demonstrated through modeling that air leakage increases wall thermal permeability and promotes mold growth when relative humidity (RH) exceeds 40%. [41] found that reduced RH and equilibrium moisture content decrease air permeability in CLT panels, with 5-layer panels showing minimal air leakage compared to 3-layer panels. [42] noted that moisture reduction in CLT connections could amplify air leakage by up to tenfold, stressing the importance of sealed joints. [43] revealed that infiltration at joints fosters moisture accumulation and mold on inner wall surfaces. Field measurements further corroborate that higher initial panel moisture content (25%) leads to substantial air leakage, exceeding thresholds at pressure differences of 25–50 Pa, whereas panels with lower moisture content (13%) consistently meet airtightness standards [44-46]. These findings collectively underscore the importance of moisture control, joint sealing, and protective measures to ensure airtightness in CLT construction.

The transition to environmentally sustainable construction materials is not merely an option but a necessity in the face of global climate and resource challenges. DMWBEs offer a promising path forward, combining ecological integrity with superior performance across multiple criteria. By eliminating the need for harmful adhesives and metal fasteners, they set a new standard for sustainability, recyclability, and health-conscious design. This paper seeks to build upon existing research, bridging the gap between experimental findings and practical applications, to position DMWBEs as a transformative solution for modern construction challenges.

The findings presented here have far-reaching implications for architects, engineers, and policymakers seeking to integrate sustainable practices into the built environment. By emphasizing both technical performance and ecological responsibility, DMWBEs have the potential to redefine the future of construction, offering a viable alternative to conventional EWPs and contributing to the development of resilient, energy-efficient, and environmentally conscious building systems.

2 – MATERIALS AND METHODS

This study evaluates the performance of DMWBEs as a sustainable alternative to CLT, focusing on airborne sound insulation, fire performance, and air permeance. To ensure reliable and comprehensive results, each performance metric was assessed using tailored specimens and standardized testing protocols. This section details the materials, test specimens, preparation processes, and methodologies applied.

DMWBEs were fabricated from Norway spruce (Pinus sylvestris), a widely available timber species in Nordic countries, classified as structural grade C24. These elements were manufactured using a 5-axis CNC machine to ensure high dimensional accuracy and consistency (Figure 2). Offcuts generated during fabrication were repurposed for applications such as thermal insulation, minimizing material waste. On the other hand, CLT served as the benchmark material for comparative analysis. Panels were constructed with five layers of lamellae, each bonded using M1 class polyurethane adhesive. The lamella dimensions were 145 mm × 40 mm, and the layers were oriented perpendicular to each other to maximize structural stability. Both materials underwent strict quality control processes during fabrication to ensure uniformity and adherence to test requirements.

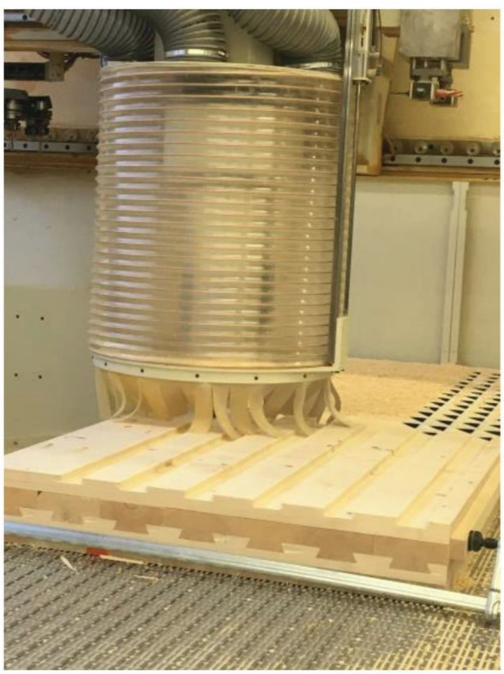

Figure 2. The manufacturing of DMWBEs with a 5-axis CNC machine.

To meet the specific requirements of each performance test, tailored specimens were prepared. The dimensions and configurations varied depending on the test type:

Airborne sound insulation testing specimens (Figure 3):

o Dimensions: 200 mm (thickness) × 1160 mm (width) × 1190 mm (length).

o Both DMWBE and CLT specimens were prepared to identical dimensions to facilitate direct comparison of sound insulation performance. These dimensions reflect practical applications in flooring and wall systems.

Fire performance testing specimens:

o Dimensions: 200 mm (thickness) × 950 mm (width) × 950 mm (length).

o Reduced dimensions were selected to fit the testing furnace, ensuring a balance between representativeness and practicality. The specimens included embedded thermocouples to monitor internal temperature progression during fire exposure.

Air permeance testing specimens:

o Three specimens of varying dimensions were prepared:

o Smallest: 1160 mm × 1160 mm × 200 mm.

o Two larger specimens: ~1300 mm × 1300 mm × 200 mm.

o These variations allowed for an exploration of size-related effects on air permeability performance.

Each specimen was carefully prepared to eliminate variability caused by fabrication inconsistencies. This ensured that differences in test results reflected inherent material properties rather than external factors.

Figure 3. Test specimens: DMWBE (upper) and CLT (lower).

Sound insulation performance testing was conducted in accordance with ISO 10140-2, which specifies laboratory procedures for airborne sound insulation measurements (Figure 4). Specimens were installed between two adjoining reverberation chambers, where sound transmission loss was measured across frequencies ranging from 100 Hz to 5000 Hz. This frequency range captures critical noise levels encountered in residential and commercial applications. Weighted sound reduction index (Rw) values were calculated to quantify the effectiveness of the materials in reducing airborne sound transmission. Furthermore, the Transmission Loss Factors (TLFs) of the installed specimens were determined in accordance with the ISO 10848-1 standard [47]. TLF encompasses the internal losses, coupling losses, and radiation losses of the structure. Given that the specimens were of similar dimensions and geometry

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and were installed under equivalent conditions, it is probable that the observed variations in the TLFs primarily arise from differences in the internal losses of the panels.

Figure 4. Mounting of sound insulation testing specimens.

Fire performance of the specimens was assessed using the EN 1363-1 standard, which defines general requirements for evaluating fire performance (Figure 5). Specimens were subjected to a standard time-temperature curve in a fire furnace to simulate real-world fire exposure. Thermocouples were strategically embedded at multiple depths within the specimens to measure temperature progression and assess structural resilience under thermal stress. Key metrics included charring rate (β) and structural integrity. The DMWBEs exhibited a slower charring rate (0.71 mm/min) compared to CLT (0.93 mm/min), attributed to the absence of adhesives, which accelerate thermal degradation. The dovetail assembly prevented delamination, a common failure mode in CLT during fire exposure. Observations also included the formation of protective char layers, which insulated the inner material and contributed to prolonged structural stability.

Figure 5. Mounting of fire performance testing specimens.

Air permeance tests were performed in accordance with SFS-EN 12114, which measures the airtightness of building components (Figure 6). Specimens were exposed to pressure differentials ranging from 5 Pa to 50 Pa in a controlled chamber. The air permeance coefficient (Ka), expressed in $m^3/(m^2 \cdot s \cdot Pa)$, was recorded for each specimen. The influence of environmental factors, particularly relative humidity (RH) and moisture content, was a focal point of this analysis. Specimens were conditioned in controlled environments to simulate seasonal variations: Low RH (~25%): Representing dry indoor conditions, and High RH (~50%): Representing moist storage conditions. Moisture content varied between 6% and 13%, with higher levels correlating to reduced air permeability. Results demonstrated that DMWBEs achieved acceptable airtightness under both dry and moist conditions, with air permeance values (q50) ranging from 1.4 to 9.9 $m^3/(m^2h)$.

To ensure consistent and reliable results, all specimens underwent environmental conditioning before testing. This involved storing them in chambers with controlled RH levels for predetermined periods, allowing moisture content to stabilize. The oven-dry method was used to verify moisture content, ensuring accuracy. This step replicated real-world conditions, accounting for seasonal fluctuations that could affect material performance.

Figure 6. Air permeance test equipment.

Data from each test were systematically analyzed to compare the performance of DMWBEs and CLT. Key aspects of analysis included:

Acoustic Data: Sound transmission loss was evaluated across frequency bands, and Rw values were compared to identify differences in sound insulation effectiveness.

Fire Data: Charring depth and temperature progression were analyzed to determine fire performance and structural stability.

Air Permeance Data: Relationships between RH, moisture content, and air permeability were explored to understand the environmental adaptability of DMWBEs.

These analyses provide a robust framework for assessing the potential of DMWBEs as a sustainable and high-performance alternative to traditional EWPs.

3 – FINDINGS AND DISCUSSION

The findings of this study are presented across three key performance areas: sound insulation, fire performance, and air permeance. Each set of results is analyzed to compare the performance of the two materials and their implications for construction applications. The findings revealed that DMWBEs are a highly promising alternative to CLT in modern construction. Through rigorous testing of sound insulation, fire performance, and air permeance, DMWBEs have demonstrated significant performance advantages over CLT, while also addressing critical sustainability challenges. This discussion explores the implications of these findings in the context of building materials science, sustainability, and practical applications, while identifying limitations and areas for future research.

The sound insulation tests, conducted in accordance with ISO 10140-2, assessed the ability of DMWBEs and CLT to reduce airborne sound transmission. Measurements included the weighted sound reduction index (Rw), which is a key metric in evaluating the suitability of materials for sound-sensitive environments. DMWBEs demonstrated superior airborne sound insulation performance, achieving an Rw value of 43 dB (Figure 7). The single-number quantities representing the airborne sound insulation properties of the specimens are provided in Table 1. The dovetail assembly technique contributed to this high level of sound insulation by creating a continuous wood mass without adhesives or fasteners, which can introduce weak points for sound transmission. The uniform composition of the DMWBEs likely improved their ability to dampen and absorb sound waves, making them highly effective in noise-sensitive applications such as residential complexes, and offices. On the other hands, CLT panels exhibited a slightly lower Rw value of 40 dB. The layered construction of CLT, combined with adhesive bonds, may have introduced minor discontinuities that allowed greater sound transmission compared to the seamless dovetail assembly of DMWBEs. While still within acceptable airborne sound insulation performance ranges for general construction, CLT was outperformed by DMWBEs in this study. These findings establish DMWBEs as a superior choice for projects requiring stringent acoustic standards, especially in urban and high-density areas where noise control is paramount.

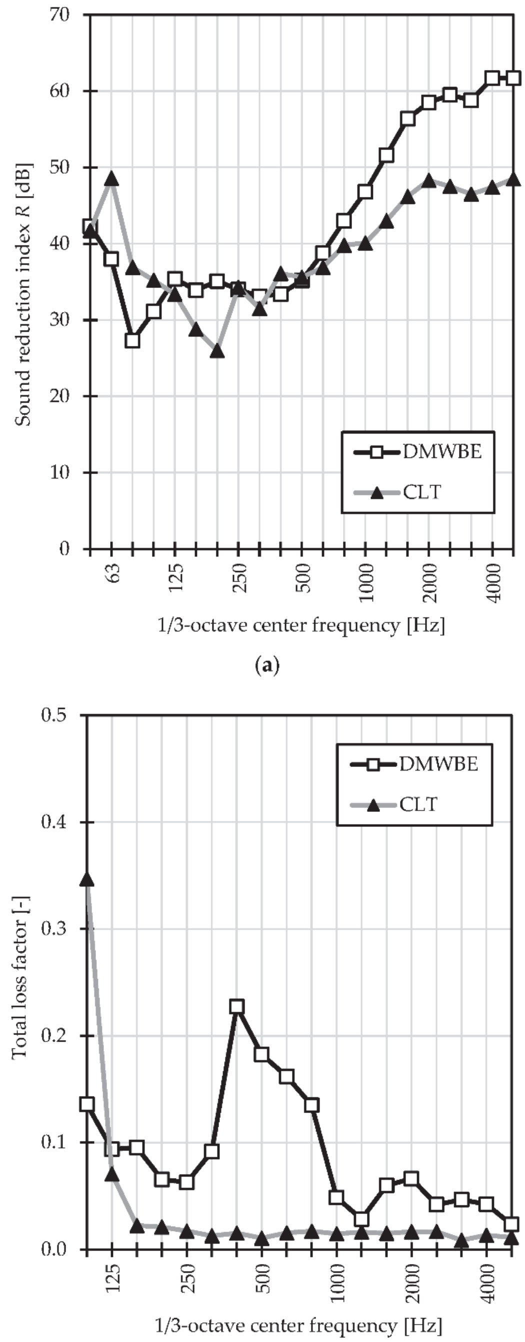

Figure 7. Measured sound reduction indices and loss factors of the 200 mm thick DMWBE (m' = 84 kg/m2) and CLT (m' = 85 kg/m²) specimens. The panels were installed similar to the laboratory opening, and their areas were 1.210 × 1.210 m²: (a) sound reduction index; (b) TLF

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Table 1: Single-number quantities for airborne sound insulation according to ISO 717-1.

Single-number quantity	DMWBE	CLT
R_w	**43 dB**	**40 dB**
$R_w + C$	42 dB	39 dB
$R_w + C_{tr}$	39 dB	37 dB
$R_w + C_{100\text{-}5000}$	43 dB	40 dB
$R_w + C_{50\text{-}3150}$	42 dB	39 dB
$R_w + C_{50\text{-}5000}$	43 dB	40 dB
$R_w + C_{tr,100\text{-}5000}$	39 dB	37 dB
$R_w + C_{tr,50\text{-}3150}$	39 dB	37 dB
$R_w + C_{50\text{-}5000}$	39 dB	37 dB

The superior airborne sound insulation performance of DMWBEs, as evidenced by their higher Rw, underscores the impact of their seamless dovetail construction. Unlike CLT, which relies on adhesive bonding and layered structures, the continuous wood mass in DMWBEs minimizes sound transmission paths. This feature is particularly beneficial in multi-story buildings, where airborne sound insulation is a regulatory requirement and a key factor in occupant comfort. From a scientific perspective, the dovetail technique aligns with principles of wave propagation and damping, where uninterrupted material structures better absorb and dissipate sound energy. This finding supports the hypothesis that adhesive interfaces in CLT introduce weak points that can amplify sound transmission. However, further research is needed to explore how varying wood species, densities, and dovetail geometries influence airborne sound insulation performance. Additionally, field studies in operational environments could validate these laboratory results under real-world conditions.

Fire performance testing, conducted according to EN 1363-1, evaluated the charring rates and structural integrity of the specimens when exposed to standardized fire conditions. Charring rates were calculated to determine the material's degradation over time, and observations were made regarding structural stability during and after fire exposure. DMWBEs showed excellent fire performance, with a charring rate of 0.71 mm/min, closely aligning with the performance of solid timber. The absence of adhesives in the dovetail construction prevented delamination, a critical failure mode often observed in CLT. Delamination occurs when adhesive layers weaken under heat, exposing inner layers to rapid combustion. The interlocking dovetail joints in DMWBEs maintained their integrity, effectively insulating the inner layers and delaying the progression of fire. In contrast, CLT panels demonstrated a higher charring rate of 0.93 mm/min. The degradation of adhesive layers at elevated temperatures led to delamination, compromising the structural stability of the panels. Once delamination occurred, the exposed inner layers burned more quickly, reducing the fire performance of CLT compared to DMWBEs. The findings emphasize the fire safety advantages of DMWBEs, particularly in applications where enhanced fire performance is critical, such as multi-story buildings, schools, and public infrastructure. Figure 8 compares the average charring depths observed for both the DMWBE and CLT panels.

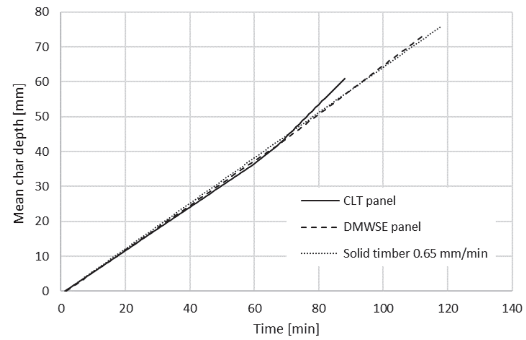

Figure 8. Mean charing depths for DMWBE and CLT panels. For comparison, charring depth development based on the design charring rate of 0,65 mm/min for solid timber is shown.

DMWBEs' fire performance demonstrates their resilience and safety advantages compared to CLT. The slower charring rate and absence of delamination in DMWBEs reflect the robustness of their dovetail assembly, which maintains structural integrity under thermal stress. In contrast, CLT's reliance on adhesives introduces vulnerabilities, as these materials degrade under high temperatures, leading to delamination and accelerated charring. This distinction has significant implications for fire safety in building design, particularly in regions with stringent fire regulations. DMWBEs offer a safer alternative for high-risk structures, including schools, hospitals, and multi-story residential buildings. Furthermore, the dovetail technique's ability to prevent char fall-off suggests enhanced protection for occupants and extended time for evacuation during a fire event. However, while the experimental data highlight the advantages of DMWBEs, additional studies are warranted to evaluate their long-term fire performance under varying environmental conditions. For example, the role of moisture content in charring behavior and the potential for fire retardant treatments to further enhance performance remain open questions. Figure 9 depicts the charred dovetail geometry following the test.

Figure 9. Remaining lamella layers and the dovetail structure of DMWBEs at the end of the test.

Air permeance testing, performed according to SFS-EN 12114, assessed the airtightness of the specimens under varying environmental conditions, including different relative humidity (RH) levels and moisture contents. Airtightness is a critical factor in energy-efficient construction, influencing thermal performance and indoor air quality. The air permeance of DMWBEs varied depending on moisture content and RH. The driest specimen, with a moisture content of approximately 6%, exhibited the highest air permeability, with a q50 value of 9.9 $m^3/(m^2h)$. Conversely, specimens with higher moisture content (~13%) demonstrated significantly lower air permeability, with q50 values as low as 1.4 m³/(m²h). This variability underscores the importance of proper storage and environmental control during installation to optimize performance. The dovetail assembly technique effectively minimized gaps between elements, contributing to acceptable airtightness levels even under less-than-ideal conditions. The results confirm that DMWBEs can meet modern airtightness standards, making them suitable for energy-efficient buildings. While specific air permeance values for CLT were not directly tested in this study, existing literature suggests that CLT panels often exhibit lower airtightness due to potential gaps between adhesive layers and lamellae. These discontinuities can increase air leakage, particularly in structures exposed to fluctuating moisture levels. DMWBEs' performance in this area highlights their adaptability to varying environmental conditions, providing a reliable option for airtight construction in climates with significant seasonal humidity changes.

The surface areas of the respective test pieces during the measurement were as follows: Test piece K had a surface area of 1.4884 m^2, Test piece Y had a surface area of 1.3456 m^2, and Test piece O had a surface area of 1.4280 m^2. During the air permeance measurement of test piece Y, the air flow rate surpassed the measuring capacity of the equipment of 200 dm³ per minute, and this occurred at a pressure difference of 44 Pa. Figure 10 shows the air flow rate that flowed through the test pieces as a function of the pressure difference.

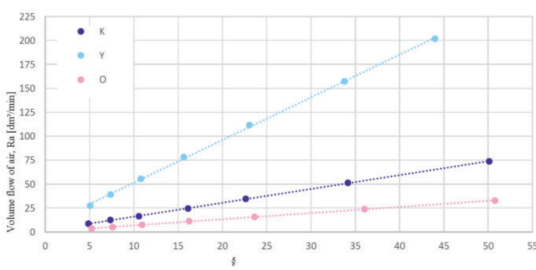

Figure 10. Air flow rate that flowed through the test pieces as a function of the pressure difference.

In Figure 11, the air permeance Ka of the test pieces is graphed against the RH of the storage conditions. The graph demonstrates a noticeable trend: as the RH rises, the air permeance K_a shows a decreasing pattern.

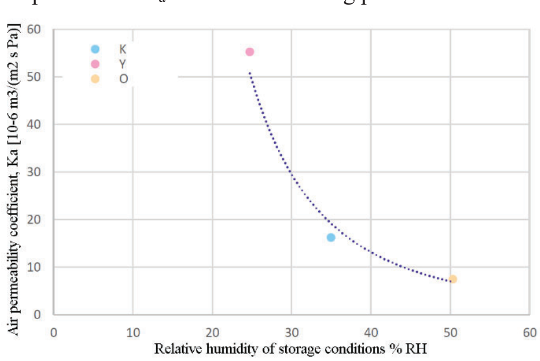

Figure 11. Air permeance as a function of the RH of the storage conditions.

The variability in air permeance results for DMWBEs emphasizes the importance of environmental factors, such as relative humidity (RH) and moisture content, in determining airtightness. While the driest specimens exhibited higher air permeability, even these values were within acceptable thresholds for energy-efficient construction. This adaptability positions DMWBEs as a versatile material for climates with significant seasonal humidity variations. Compared to CLT, DMWBEs' dovetail assembly minimizes the gaps and discontinuities that often compromise airtightness in adhesive-bonded panels. This finding highlights their potential in passive house designs and net-zero energy buildings, where airtightness is critical for thermal efficiency and indoor air quality. Nevertheless, future studies should investigate strategies to further optimize the airtightness of DMWBEs, such as integrating sealing membranes or coatings during construction.

The findings from this study demonstrate that DMWBEs consistently outperform CLT across critical performance metrics:

1. Sound insulation: The seamless dovetail assembly in DMWBEs contributes to superior sound reduction, making them ideal for environments requiring strict noise control.

2. Fire performance: The absence of adhesives and the robustness of the dovetail joints enhance the fire safety of DMWBEs, ensuring slower charring rates and better structural stability under fire conditions.

3. Air permeance: While moisture content influences air permeability, DMWBEs achieve satisfactory airtightness, underscoring their suitability for energy-efficient buildings.

These results position DMWBEs as a transformative material for modern construction, addressing both functional and environmental challenges. Their superior performance across airborne sound insulation, fire, and air permeance properties suggests they could play a key role in advancing sustainable and resilient building practices.

Despite their advantages, DMWBEs face practical challenges that may hinder widespread adoption. The manufacturing process, relying on precision machining, requires advanced equipment and skilled labor, potentially increasing costs compared to CLT. Additionally, the lack of mass production infrastructure for DMWBEs could limit scalability in large projects. Moisture management also presents a critical challenge. As shown in the air permeance tests, environmental conditions significantly impact DMWBEs' performance. Effective storage, transport, and installation practices are essential to maintain optimal moisture content and ensure long-term durability.

While this study provides a strong foundation, several areas require further exploration to fully realize the potential of DMWBEs: (a) Material Optimization: Investigating how different wood species, densities, and finishes affect sound insulation, fire, and air permeance performance. (b) Field Validation: Conducting real-world studies to evaluate performance in operational buildings under diverse environmental conditions. (c) Economic Viability: Assessing the cost-effectiveness of DMWBEs

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in large-scale production and exploring strategies to reduce manufacturing costs. (d) Environmental Impact: Conducting life cycle assessments (LCAs) to quantify the environmental benefits of DMWBEs compared to traditional EWPs and other materials.

The findings of this study contribute to a growing body of knowledge supporting the transition to sustainable building materials. DMWBEs not only offer functional advantages but also address pressing environmental concerns, aligning with global initiatives to reduce carbon emissions in the construction sector. By integrating traditional woodworking techniques with modern precision engineering, DMWBEs exemplify how innovative design can bridge the gap between sustainability and performance. In conclusion, DMWBEs present a compelling case for adoption in the construction industry, particularly for applications requiring high airborne sound insulation, fire, and air permenace performance. While challenges remain, ongoing research and development could position DMWBEs as a transformative material for sustainable, resilient, and efficient building practices.

4 – CONCLUSION

This study establishes DMWBEs as a sustainable and high-performance alternative to CLT in contemporary construction. The results demonstrate that DMWBEs excel in airborne sound insulation, fire performance, and air permeance, addressing critical functional and environmental demands. The unique dovetail assembly technique, which eliminates the need for adhesives and metal fasteners, enhances the recyclability and environmental compatibility of DMWBEs, making them a significant improvement over traditional engineered wood products. The findings underscore their exceptional fire performance, as the absence of adhesives prevents delamination, maintaining structural integrity and ensuring slower charring rates compared to CLT. Similarly, their seamless wood construction enhances acoustic insulation, offering superior sound reduction critical for building applications. The adaptability of DMWBEs to varying environmental conditions, evidenced by their air permeance performance across different moisture levels, further emphasizes their versatility and suitability for energy-efficient construction.

Despite these advantages, there remain areas requiring further exploration to fully realize the potential of DMWBEs. While the findings demonstrate strong performance metrics, future research should focus on optimizing their large-scale production to address economic feasibility and manufacturing scalability. Additionally, long-term studies under real-world environmental conditions are needed to validate the durability and performance of DMWBEs in diverse applications. LCAs could provide a more comprehensive understanding of their environmental benefits compared to other materials, strengthening their case for widespread adoption. With continued development, DMWBEs offer a transformative solution for sustainable and resilient building practices, aligning with global efforts to reduce the environmental impact of the construction industry while meeting the highest standards of performance and safety.

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5 – REFERENCES

[1] S. Barbhuiya, B.B. Das and D. Adak. "Roadmap to a net-zero carbon cement sector: Strategies, innovations and policy imperatives". In: Journal of Environmental Management 359 (2024), pp. 121052.

[2] A. Mastrucci, F. Guo, X. Zhong, F. Maczek and B. van Ruijven. "Circular strategies for building sector decarbonization in China: A scenario analysis". In: Journal of Industrial Ecology 28.5 (2024), pp. 1089-1102.

[3] P. Maithani and K. Mishra. "Sustainability in Structure: Innovations in Engineered Wood Products for Green Building". In Encyclopedia of Green Materials (2024), pp. 1-7. Singapore: Springer Nature Singapore.

[4] J. Tamošaitienė, S. Parham, H. Sarvari, D.W. Chan and D.J. Edwards. "A Review of the Application of Synthetic and Natural Polymers as Construction and Building Materials for Achieving Sustainable Construction". In: Buildings 14.8 (2024), pp. 2569.

[5] M. Tenório, R. Ferreira, V. Belafonte, F. Sousa, C. Meireis, M. Fontes, ... and J.M. Branco. "Contemporary strategies for the structural design of multi-story modular timber buildings: A comprehensive review." In: Applied Sciences 14.8 (2024), pp. 3194.

[6] M. Sutkowska, A. Stefańska, M.D. Vaverkova, S. Dixit and A. Thakur. "Recent Advances in Prefabrication Techniques for Biobased Materials Towards a Low-Carbon Future: From Modules to Sustainability." In: Journal of Building Engineering (2024), pp. 109558.

[7] J.J. Cisneros-Gonzalez, A. Rasool and R. Ahmad. "Digital technologies and robotics in mass-timber manufacturing: a systematic literature review on construction 4.0/5.0." In: Construction Robotics 8.2 (2024), pp. 1-26.
[8] A. Almusaed and A. Almssad. Sustainable wooden skyscrapers for the future cities. In Wood Industry-Past, Present and Future Outlook. IntechOpen. (2022)
[9] M.R. Rahman, I. Wallin, R. Toivonen and A. Toppinen. "Local policy networks in support of wood-based construction: A case study from Joensuu, Finland." In: Forest Policy and Economics 163 (2024), pp.103225.
[10] L. Han, A. Kutnar, J. Sandak, I. Šušteršič and D. Sandberg. "Adhesive-and metal-free assembly techniques for prefabricated multi-layer engineered wood products: A review on wooden connectors." In: Forests, 14.2 (2023), pp. 311.
[11] H. Ren, A. Bahrami, M. Cehlin and M. Wallhagen. "Proposing new adhesive-free timber edge connections for cross-laminated timber panels: A step toward sustainable construction." In: Case Studies in Construction Materials, 20 (2024), pp. e02975.
[12] L. Jia, J. Chu, J. Li, J. Ren, P. Huang and D. Li. "Formaldehyde and VOC emissions from plywood panels bonded with bio-oil phenolic resins." In: Environmental Pollution 264 (2020), pp. 114819.
[13] M.H. Hussin, N.H. Abd Latif, T.S. Hamidon, N.N. Idris, R. Hashim, J.N. Appaturi, ... and J. Sedliačik. "Latest advancements in high-performance bio-based wood adhesives: A critical review." In: Journal of Materials Research and Technology 21 (2022), pp. 3909-3946.
[14] Q. Sun, Q. Huang, Z. Duan and A. Zhang. "Recycling potential comparison of mass timber constructions and concrete buildings: A case study in China." In: Sustainability 14.10 (2022), pp. 6174.
[15] L. Marchi, F. Ferretti, L. Pozza and R. Scotta. "Role of fastenings in modifying the hysteretic response of panel-to-panel joints for CLT structures." In: Construction and Building Materials 364 (2023), pp. 129856.
[16] H.E. Ilgın, M. Karjalainen, O-P. Koponen. Various Geometric Configuration Proposals for Dovetail Wooden Horizontal Structural Members in Multistory Building Construction. In Engineered Wood Products for Construction, InTech Open. (2022).
[17] H.E. Ilgın, M. Karjalainen, O-P. Koponen. Review of the Current State-of-the-Art of Dovetail Massive Wood Elements. In M. Gong (Ed.), Engineered Wood Products for Construction, InTech Open. (2021).
[18] H.E. Ilgın, M. Karjalainen. "Preliminary Design Proposals for Dovetail Wood Board Elements in Multi-Story Building Construction." In: Architecture, 1.1 (2021), 56-68.
[19] W. Hu, M. Luo, Y. Liu, W. Xu and A.C. Konukcu. "Experimental and numerical studies on the mechanical properties and behaviors of a novel wood dowel reinforced dovetail joint." In: Engineering Failure Analysis 152 (2023), pp. 107440.
[20] W. Hu, R. Yu, M. Luo and A.C. Konukcu. "Study on tensile strength of single dovetail joint: experimental, numerical, and analytical analysis." In: Wood Material Science & Engineering, 18.4 (2023), pp. 1478-1486.
[21] Z. Li, X. Wang, M. He, Z. Shu, Y. Huang, A. Wu and Z. Ma. "Mechanical performance of pre-fabricated metal dovetail connections for Cross-Laminated Timber (CLT) structures." In: Construction and Building Materials 303 (2021), pp. 124468.
[22] V. Ouch, P. Heng, Q.H. Nguyen, H. Somja and T. Soquet. "An experimental investigation on the dovetail notched connection for cross-laminated-timber-concrete composite slabs." In: European Journal of Environmental and Civil Engineering 27.15 (2023), pp. 4466-4496.
[23] A. Karolak and J. Jasieńko. "Experimental research on tensile dovetail joint between rafter and collar beam." In: Engineering Structures 307 (2024), pp. 117854.
[24] H.E. Ilgın, J. Lietzén and M. Karjalainen. "An Experimental Comparison of Airborne Sound Insulation Between Dovetail Massive Wooden Board and Cross-Laminated Timber Elements." In: Buildings 13.11 (2023), pp. 2809.
[25] H.E. Ilgın, M. Karjalainen, M. Alanen and M. Malaska. "Evaluating Fire Performance: An Experimental Comparison of Dovetail Massive Wooden Board Elements and Cross-Laminated Timber." In: Fire 6.9 (2023), pp. 352.
[26] H.E. Ilgın, S. Haapaniemi, M. Karjalainen and J. Vinha. "Measurement of Air Permeance in Mass Timber Elements Assembled through the Dovetail Technique." In: Journal of Building Engineering 94 (2024), pp. 110009.
[27] M.S. Andargie, M. Touchie, W. O'Brien and M. Müller-Trapet. "A field study of the relationship between sound insulation and noise annoyance,

https://doi.org/10.52202/080513-0696

activity disturbance and wellbeing in multi-unit residences." In: Appl. Acoust. 206 (2023), pp. 109291.

[28] Rasmussen, B. Sound insulation between dwellings—Comparison of national requirements in Europe and interaction with acoustic classification schemes. In Proceedings of the International Congress on Acoustics, Aachen, Germany, 9–13 September (2019), pp. 5102-5109.

[29] B. Anna-Lisa Östman, J. Schmid, M. Klippel, A. Just, N. Werther and D. Brandon. "Fire design of CLT in Europe". In: Wood Fiber Sci. 50 (2018), pp.68-82.

[30] S. Pei, D. Rammer, M. Popovski, T. Williamson, P. Line and J.W. van de Lindt. An overview of CLT research and implementation in North America. In Proceedings of the World Conference on Timber Engineering (WCTE), Vienna, Austria, 22–25 August (2016). pp. 15–22.

[31] M. Klippel, J. Schmid, and A. Frangi. Fire Design of CLT. In Proceedings of the Joint Conference of COST Actions FP1402 & FP1404 KTH Building Materials, Cross Laminated Timber—A Competitive Wood Product for Visionary and Fire Safe Buildings. (2016), pp. 101–122.

[32] M. Yasir, A. Macilwraith, C. O'Ceallaigh and K. Ruane. "Effect of protective cladding on the fire performance of vertically loaded cross-laminated timber (CLT) wall panels." In: J. Struct. Integr. Maint. 2023 (2023), pp. 1-10.

[33] D. Hopkin, M. Spearpoint, R. Blondeau, T. Sleik, H. Krenn, G. Stapf and W. Węgrzyński. Implications of A Down-Stand Beam on The Ceiling Flame Extension Characteristics in A Large-Scale Clt Enclosure Fire Experiment. In Proceedings of the World Conference of Timber Engineering (WCTE), Oslo, Norway, 19–22 June (2023). pp. 1831–1838.

[34] J. Zhang, Y. Sun, Y. Wang, C. Lu, W. Wang and L. Wu. "Experimental study on fire performance of cross laminated timber structure exposed to compartment fire". In: J. Build. Struct. 43 (2022), pp. 115.

[35] Q. Lv, W. Wang and Y. Liu. "Charring depth and charring rate of cross-laminated bamboo slabs exposed to a one-sided standard fire". In: Fire Saf. J. 125 (2021), pp. 103439.

[36] C. Kontis, C. Tsichlas, D.I. Kolaitis, M.A. Founti. Fire Performance of CLT Members: A Detailed Review of Experimental Studies Across Multiple Scales. In Wood & Fire Safety: Proceedings of the 9th International Conference on Wood & Fire Safety 2020; Springer International Publishing: Cham, Switzerland, 2020; Volume 9, pp. 251–257.

[37] Cpr Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 Laying Down Harmonised Conditions for the Marketing of Construction Products and Repealing Council Directive 89/106/EEC Text with EEA Relevance (2011)

[38] V. Kukk, A. Bella, J. Kers and T. Kalamees. "Airtightness of cross-laminated timber envelopes: influence of moisture content, indoor humidity, orientation, and assembly." In: J. Build. Eng. 44 (2021), pp. 102610.

[39] Herms, J. L. Achieving airtightness and weather protection of CLT buildings. In E3S Web of Conferences (Vol. 172, p. 10011). EDP Sciences. (2020).

[40] U. Martin, P. Blanchet and A. Potvin. "Modeling the impact of assembly tolerances regarding air leaks on the energy efficiency and durability of a cross-laminated timber structure." In: Bioresources 14.1 (2019), pp. 518-536.

[41] V. Kukk, T. Kalamees and J. Kers. "The effects of production technologies on the air permeability and crack development of cross-laminated timber." In: J. Build. Phys. 43.3 (2019), pp. 171-186.

[42] H. Skogstad, L. Gullbrekken and K. Nore. Air Leakages through cross Laminated Timber (CLT) Constructions, 9th Nordic Symposium on Building Physics Tampere University of Technology (2011) Tampere: Tampere

[43] T. Kalamees and J. Kurnitski. "Moisture convection performance of external walls and roofs." In: J. Build. Phys. 33.3 (2010), pp. 225-247.

[44] J. Niklewski, M. Fredriksson and T. Isaksson. "Moisture content prediction of rain- exposed wood: test and evaluation of a simple numerical model for durability applications." In: Build. Environ. 97 (2016), pp. 126-136.

[45] K. Mjörnell and L. Olsson. Moisture safety of wooden buildings - design Construction and Operation, Forum Wood Building Baltic (2019).

[46] E.L. Schmidt, M. Riggio, A.R. Barbosa and I. Mugabo. "Environmental response of a CLT floor panel: Lessons for moisture management and monitoring of mass timber buildings." In: Building and Environment 148 (2019), pp. 609-622.

[47] ISO 10848-1:2017; Acoustics—Laboratory and Field Measurement of Flanking Transmission for Airborne, Impact and Building Service Equipment Sound between Adjoining Rooms—Part 1: Frame Document. ISO: Geneva, Switzerland, 2017.