Design and Fabrication of a Tunable Hollow-Core Mass Timber Cassette Floor System

by
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THESIS ABSTRACT

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Master of Science in Architecture

Title: Design and Fabrication of a Tunable Hollow-Core Mass Timber Cassette Floor System

Mass timber floor systems commonly rely on assemblies that achieve structural and acoustic performance through material thickness and secondary acoustical systems rather than geometric efficiency or adaptability. Hollow-core cassette floor panels composed of veneer-based tubular elements are proposed as a fiber efficient and tunable alternative in which structural capacity is derived from geometry and configurable internal cavities. The system is designed to allow internal tubes to remain hollow or be infilled with materials that alter acoustic and vibrational behavior in response to changing building requirements.

The research was developed through iterative physical prototyping, fabrication refinement, and empirical testing of acoustics, vibrational, and structural performance. Five prototype generations were developed, culminating in a full-scale demonstrator deployed at the 2026 International Mass Timber Conference, held March 31- April 2, 2026 in Portland, Oregon. Acoustic testing evaluated multiple infill and surface topping configurations, while vibration and quasi-static load testing assessed dynamic response and preliminary structural behavior.

Initial results demonstrate that substantial material reduction is achievable allowing for flexibility in panel tunability. Final panels weighed approximately one third of an equivalent 5-ply CLT assembly while producing a 16 dB range in Noise Isolation Class values across tested configurations. Vibration testing identified a dominant natural frequency near 19 Hz with rapid decay behavior associated with favorable occupant comfort characteristics.

This research contributes a framework for materially efficient and reprogrammable timber floor systems in which performance is treated as a tunable element rather than a fixed assembly outcome. The work establishes a basis for future development of adaptable mass timber floor systems capable of responding to changing acoustic, structural, and building conditions over time.

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CHAPTER I

INTRODUCTION

1.1 Motivation

Buildings are heavy, in part because the structural systems we use to build them were designed around material abundance, standardization, and the assumption that more material means better performance. The construction industry remains one of the largest contributors to global CO_2 emissions, responsible for approximately 37% of annual global emissions when operational and embodied carbon are combined [1]. Mass timber has emerged as a lower-carbon alternative to steel and concrete because it stores atmospheric carbon, is renewable when sourced responsibly, and can be processed into high-performing structural systems at a fraction of the embodied energy of traditional materials [2]. However, the promise of timber as a climate solution is undermined when those systems replicate the material logic of what they replace as solid, masses, and are optimized for a single design condition. Studies suggest that scaling current mass timber systems to realize the vision of widespread timber cities could require up to 149 million hectares of new forest plantations by 2100 [3]. The problem is not the material; it is how structural systems are designed with it.

The argument for doing more with less has significant precedent. Frei Otto's work at the Institute for Lightweight Structures (ILEK) in Stuttgart, documented across the IL publication series, established that structural performance and minimal material use are not in opposition, and that biological systems had already demonstrated this principle. Otto and his collaborators drew from natural structures such as bird skulls, soap bubbles, and spiders' webs, to ask what an assembly would look like if material appeared only where it was needed [4]. More recently, ILEK extended this thinking into manufactured assemblies through functionally graded concrete research to produce lighter and more material-efficient slabs than their solid equivalents while maintaining structural performance [5,6]. Neri Oxman's research at MIT's Mediated Matter Group pursued a parallel trajectory by proposing that material density in buildings could vary continuously as a function of structural demand, as bones do, by concentrating material where stress is highest and removing it elsewhere [7].

This thesis extends that line of inquiry into mass timber floor systems. Floor plates represent the single largest concentration of timber in any multi-story building, accounting for

roughly 40% of total structural material [8]. If material efficiency is to be meaningfully improved at the building scale, floor systems are the logical starting point. Beyond their initial inefficiency, these systems cannot adapt. When a building's use changes, such as a residential floor becoming commercial space, or a quiet office becoming an active program space, the floor, in turn, can become a constraint. This research proposes that floor systems should instead be fiber efficient, tunable, and reprogrammable over their lifetimes.

1.2 Opportunity

The hollow-core cassette floor panel proposed in this thesis responds directly to these limitations. By organizing material into a grid of veneer-based tubular elements assembled into a cassette with open internal voids, the system achieves structural capacity through geometry rather than solid material volume. This results in an assembly that weighs approximately one third of a comparable 5-ply CLT panel. Internal cavities then become space to adjust for varying design conditions: they can remain empty to minimize weight, be filled with acoustic materials to modify sound transmission, or be packed with mass to address vibrational requirements. Critically, they can be cleared and refilled as building use changes.

We see a history of this design typology in concrete construction. Waffle slabs in reinforced concrete, beginning in the early twentieth century, achieved this by organizing material into a grid of intersecting ribs that concentrate mass in zones of high tension and compression while leaving the interior largely void of material [9]. The resulting geometry improves structural efficiency relative to a solid slab of equivalent depth by using geometry rather than volume to resist bending. This approach has been widely adopted in precast and cast-in-place concrete for its favorable span-to-depth ratios and reduced self-weight, and it offers a well-established formal precedent for the cellular floor geometry proposed in this thesis [10]. The hollow-core cassette panel can be understood as a veneer-based reinterpretation of this same typology. It is like a mass timber waffle slab in which the voids are defined by tubular elements in which those voids remain accessible for reconfiguration after assembly.

1.3 Research Question

Mass timber floor systems commonly achieve performance through material thickness rather than geometric efficiency. With demands for acoustic control, vibration performance, and

service integration in mass timber construction, there is an opportunity to reconsider floor systems as configurable assemblies to address these concerns.

Hollow-core cassette panels are proposed as a fiber efficient alternative in which structural capacity is derived from the arrangement of veneer-based tubular elements and internal cavities that can remain empty, be infilled, or reinforced, making for a floor system whose performance can be tuned through configuration.

This context leads to a primary research question:

How can hollow-core cassette floor systems be designed and fabricated as tunable assemblies that achieve structural performance while enabling controlled acoustic and vibrational behavior?

This leads to the following more specific questions:

1. How can hollow-core cassette panels be efficiently manufactured using veneer-based components, and what fabrication constraints influence their geometry and assembly?
2. How can variations in internal configuration be used to tune acoustic and vibrational performance within the system?

1.4 Organization of Thesis

This thesis is organized into six chapters: (1) Introduction, (2) Background, (3) Scope, (4) Methodology, (5) Results, and (6) Conclusion. Chapter 1 introduces the overall context of the study and outlines the primary motivations behind the research. Chapter 2 provides background on mass timber systems, material efficiency, lightweight structural strategies, and acoustic and vibrational performance in timber floor assemblies. Chapter 3 defines the specific focus of the thesis and expands on its contextual framework. Chapter 4 describes the research methodology, including iterative fabrication development, acoustic testing, vibration testing, and quasi-static load evaluation. Chapter 5 presents the outcomes derived from the methods and analyses outlined in the previous chapter. Finally, Chapter 6 concludes the thesis by summarizing key findings and reflecting on limitations, broader implications, and directions for future work.

CHAPTER II

BACKGROUND

2.1 Mass Timber

The re-emergence of timber as a primary structural material represents a meaningful shift toward renewable, low-carbon construction. The construction sector currently accounts for approximately 37% of global CO_2 emissions and consumes roughly 32% of global energy annually [1], and engineered wood products have been widely positioned as a pathway toward reducing this impact. Timber sequesters atmospheric carbon during its growth, is renewable when responsibly sourced, and can be processed into high-performing structural systems at substantially lower embodied energy than concrete or steel [2]. This has driven rapid adoption of mass timber systems across North America and Europe, alongside proposals for large-scale timber cities designed to function as long-term carbon sinks. However, the land use implications of scaling current systems to meet that vision are significant, with projections estimating the need for up to 149 million hectares of additional forest plantations by 2100 under existing material efficiencies [3]. This raises a question that sits at the center of this thesis: rather than expanding material supply, how might the efficiency of timber systems themselves be improved?

The dominant engineered wood products in modern construction, such as cross-laminated timber (CLT) and glued-laminated timber (glulam), achieve structural performance primarily through mass. Despite their advantages over traditional materials, these systems rely on energy-intensive processing including sawing, drying, pressing, and milling, and produce relatively low fiber yields from raw timber. Studies of wood resource efficiency indicate that lumber-based products such as CLT and glulam retain only approximately 37–39% of the original roundwood volume after milling and processing [11]. Veneer-based alternatives offer a meaningful improvement with rotary-cut veneer peeling averaging approximately 57% usable fiber from roundwood, with final product yields for laminated veneer lumber (LVL) and mass plywood panels (MPP) averaging around 52%, roughly 15% higher than previously mentioned dimensional-lumber-based products [11]. By utilizing thin rotary-cut layers derived from smaller-diameter logs, veneer-based systems also make productive use of wood fiber streams that would otherwise be discarded or burned for energy [12,13].

In mass timber products such as CLT and glulam, raw fiber accounts for the overwhelming share of product cost, meaning that panel price scales closely with material volume [14]. Systems that reduce fiber input per unit therefore may offer a pathway to cost reduction and industry fiber needs. Therefore, fiber efficiency is a practical economic argument for lightweight timber systems as well as an environmental one.

Currently, however, commercially available mass timber products are designed with little concern for fiber efficiency. Floor plates in high-rise construction represent roughly 40% of all material [8], and are almost universally designed as uniform, continuous assemblies. Mass timber cassette panels represent one attempt to address this, acting as a modified sandwich panel, in which face plates and internal webs or ribs replace a solid cross-section. Existing timber cassette systems, most commonly composed of Oriented Strand Board (OSB) face plates and I-joist webs, have remained confined to low-rise residential construction (Figure 1A). Their comparatively low stiffness and mass require greater panel depths to achieve equivalent span performance to CLT (Figure 1B) [15,16], and their reliance on adhesive-intensive components offsets many of the embodied carbon advantages that motivate timber construction in the first place. The gap this thesis seeks to address is not simply whether a cassette geometry can be applied to timber floors, but whether it can be redesigned with a different internal configuration to overcome these limitations.

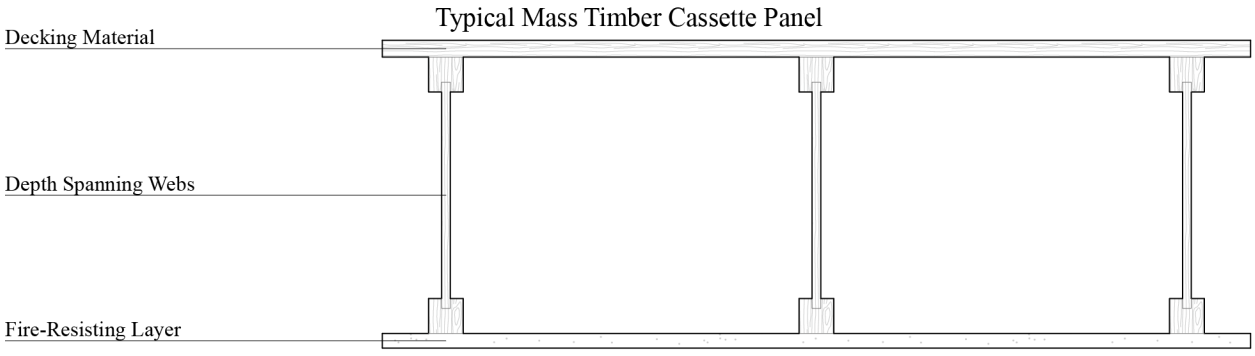


Figure 1. A: Shows the anatomy of a typical mass timber cassette panel common in low-rise residential construction. Decking material and a fire resisting layer sandwich vertical webbing members. B: A typical 5-ply CLT panel is shown with face plies and core plies called out.

2.2 Material Efficiency and Lightweight Structures

Material efficiency in structural design refers to the ability of a system to achieve required performance using the minimum necessary quantity of material. In timber construction this is typically measured through fiber yield, waste reduction, and alignment of material placement with structural demand. While much research has focused on improving fiber efficiency at the manufacturing scale, inefficiency persists at the structural scale, where uniform cross-sections are applied regardless of the actual stress distribution across a floor, column or beam [11].

There is a deep history for rethinking how to treat structures to address this problem. Frei Otto's work at the Institute for Lightweight Structures (ILEK) in Stuttgart, documented across the IL publication series from 1964 to 1991, established that structural performance and minimal material use are fundamentally compatible as shown throughout nature. Otto and his researchers drew from natural structures such as bird skulls, soap bubbles, and spiders' webs, to develop a design philosophy organized around the question of what an assembly would look like if material appeared only where it was structurally needed [4]. This body of work remains foundational to contemporary research in lightweight structural systems.

More recent work from ILEK has extended this thinking into digitally manufactured assemblies through the development of functionally graded concrete. Their approach used water-soluble sand deposits to displace concrete from areas of low structural demand, resulting in slabs that are lighter and more material-efficient than solid equivalents while maintaining their structural performance [6]. The concept of graded material distribution by placing material only where structural demand requires it, is described by ILEK as "meso-gradation," and a principle applicable across structural materials and scales. Neri Oxman's research at MIT's Mediated Matter Group pursued parallel research through Material Ecology and proposed that material density in architectural assemblies could vary continuously as a function of load by concentrating material at zones of high stress and removing it elsewhere [17].

These precedents make a consistent argument that structural performance is most efficiently achieved through strategic material distribution, voids, and hierarchical organization. Historical applications of this thinking in construction include waffle slabs in precast concrete, which remove material from zones of low bending and organize the remainder into a ribbed structure that preserves stiffness. More recent research has explored similar strategies in timber,

including topology-optimized CLT layups [18], zero waste, structurally optimized beams [19] and additive floor plate optimization using MPP remnant [20]. However, the translation of these strategies into prefabricated timber floor assemblies that are not only materially efficient but also configurable and adaptable over time remains largely unexplored.

2.3 Designing for Reuse and Resilience

Material efficiency intersects with a second, related concern: what happens to building materials when a structure is modified or demolished. In the United States alone, construction and demolition activity generated approximately 169 million tons of debris in 2015, over 90% of which came specifically from demolition rather than new construction [21]. Building reuse and adaptive retrofit have been shown to prevent between 50 and 75 percent of the embodied carbon emissions that an equivalent new structure would produce [22,21]. Design for disassembly and material reuse has been an active area of discourse in architecture and preservation for decades, but engineered wood products have been comparatively late to engage in this discussion due to their relatively recent development.

This challenge is particularly relevant for shape-optimized structural systems, whose efficiency is often tied to highly specific geometries and loading conditions. While such systems can minimize material use during initial construction, they are often difficult to adapt, reconfigure, or repurpose when building requirements change. When a structure's program evolves, a shape-optimized system may no longer perform effectively in its new context, limiting opportunities for long-term reuse.

2.4 Acoustic Performance in Timber Floor Systems

Acoustic performance presents challenges for lightweight timber construction. Timber floor assemblies generally exhibit lower airborne and impact sound insulation than equivalent concrete systems due to their reduced mass, lower stiffness, and the flexibility of their connections [23]. This makes acoustic control a persistent concern in multi-story timber buildings. Sound transmission in floor systems is governed primarily by airborne sound transmission, typically evaluated through sound transmission loss, and impact sound transmission, which measures the attenuation of structurally borne sound generated by foot traffic. Both are influenced by the mass, stiffness, and internal damping of the floor assembly, as well as by the presence and properties of surface treatments and decoupling layers [23].

Research on lightweight timber floor acoustics has consistently identified low-frequency sound transmission is the most limited and least well understood. Standard measurement methodologies are designed around frequency ranges that do not fully capture low-frequency behavior, and the acoustic performance of timber assemblies with respect to low frequencies remains an active area of investigation [24]. Composite and hybrid floor systems such as timber-concrete composites and sandwich panel assemblies have demonstrated that layered floor configurations can improve transmission loss relative to single-material systems, with interlayer and topping layers contributing independently to overall acoustic performance [23]. Elastic interlayers and decoupling materials have similarly been shown to reduce structure-borne sound transmission by interrupting the mechanical path between the vibrating floor and the ceiling below [23,18].

The conventional response to acoustic limitations in mass timber floor systems has been to supplement the structural panel with layered topping assemblies. A typical approach combines an acoustic isolation mat placed above the structural panel, and a concrete topping that adds mass to improve low-frequency attenuation [25]. This has significant implications for the system's reuse and adaptability. The concrete topper creates a permanent composite bond between the timber and concrete which prevents future structural changes in the system's floor plates.

2.5 Vibration Performance in Timber Floor Systems

Vibration serviceability is one of the most critical performance criteria for timber floor systems, and one of the most challenging to address through conventional solid panel assemblies. As floor spans increase and mass decreases in lightweight structural systems, floors become more susceptible to human-induced vibration, particularly in the low-frequency range most perceptible to occupants [26]. Unlike concrete systems, lightweight timber floors must achieve acceptable vibration performance through stiffness, damping, and geometric configuration.

Research has established that human-induced vibration is governed primarily by natural frequency, modal mass, and damping ratio [27]. For CLT and other mass timber floor systems, natural frequencies typically fall within the range most sensitive to occupant perception, and the relatively low damping provided in timber connections and assemblies means that vibration can persist longer than in heavier systems [28]. Studies of hollow-core CLT configurations have demonstrated that introducing internal voids into floor panels can meaningfully alter their dynamic response relative to solid equivalents [29].

If the internal configuration of a floor panel can be used to shift dynamic response in a controlled and predictable way, then vibration performance becomes a tunable property to be harnessed. Recent research on hollow mass timber cassette floors has begun to explore this area by demonstrating that long-span hollow timber floor assemblies can be designed for both structural performance and acoustic circularity, with configurable internal conditions playing a role in both [18,30]. This thesis contributes to that emerging body of work through empirical design research by offering a new system geometry.

2.6 Research Position

Across the four areas reviewed above, a consistent pattern emerges. Mass timber has deep environmental and structural understanding, but remains organized around solid, uniform material configurations that prioritize standardization over adaptability. The intellectual and precedent basis for distributing material according to structural demand is well established, from Otto's lightweight structure research to ILEK's graded concrete work to Oxman's material ecology work. Research into hollow and voided timber floor systems has demonstrated that internal configuration can meaningfully shift structural, vibrational, and acoustic performance.

What is missing is a timber floor system that integrates these conditions into a single configurable assembly: materially efficient by virtue of its geometry, tunable in its structural and acoustic performance through internal configuration and designed from the outset for reconfiguration as building use changes over time. Companies such as Strong by Form have signaled industry movement in this direction through fiber-informed structural geometries [31], and recent cassette floor research has begun to address circularity alongside performance [30]. This thesis situates itself at that intersection by proposing a hollow-core cassette floor panel composed of veneer-based tubular elements as a system that addresses fiber efficiency, performance tunability, and architectural adaptability within a single manufacturable assembly.

CHAPTER III

SCOPE

3.1 Focus

Building from the focus areas of the background established in the previous chapter, this thesis focuses specifically on the design, fabrication, and initial acoustical performance of a tunable, hollow-core cassette floor panel. The research proposes a panel which improves fiber efficiency and creates a framework for which floor plates can be more easily adapted to design constraints. Five physical prototypes were developed to understand an initial fabrication workflow, culminating in a full-scale demonstration assembly deployed at the 2026 International Mass Timber Conference in Portland, Oregon. Performance is evaluated across three criteria, initial physical and theoretical constructability, acoustic transition, and vibration response, which were conducted using physical testing.

The scope of this study is to develop and evaluate a tunable floor assembly in which performance is adjusted through an internal framework rather than being a fixed product. The research distinguishes between tuning, which seeks a calibrated response to specific conditions, and optimization, which seeks a single best solution, a distinction that is central to the thesis argument. Many of the performance metrics examined here represent areas outside the primary expertise of the researcher. Structural, acoustic, and vibrational evaluations are therefore approached through empirical prototype testing and collaboration with specialists rather than exhaustive analytical modeling. The goal is not to resolve every challenge within each research area, but to demonstrate that a configurable cassette system can produce meaningfully different performance outcomes through changes in geometry, assembly, and infill, and that this range of outcomes has value for architectural applications.

This research does not address full-scale structural certification, fire resistance, moisture performance, lateral system integration, or lifecycle cost analysis. The long-term durability of infill materials and the performance of the system under cyclic loading are likewise outside the scope of this work.

CHAPTER IV

METHODOLOGY

4.1 General Methodology

This research develops through cycles of physical fabrication, iterative refinement, and performance testing across five prototype generations. Three performance metrics are investigated: fabrication, acoustic transmission, and vibrational response. Each is evaluated through empirical testing rather than computational modeling, with results used collectively to characterize the range of performance achievable through changes in internal panel configuration.

The hollow-core cassette panel system consists of circular veneer-based tubular elements assembled into cassette panels with Mass Plywood Panel top and bottom plates. Three infill conditions are evaluated: tubes left hollow (H series), tubes filled with recycled denim batt insulation (D series), and tubes filled with 6 mm minus gravel (G series), representing minimum weight, acoustic absorption, and maximum added mass respectively.

4.2 Fabrication

Fabrication development proceeded through multiple iterative phases, beginning with early conceptual prototypes and advancing toward refined panel assemblies suitable for both laboratory testing and public demonstration. The veneer-based tubular elements used throughout this research were developed as self-shaping [32,33] structural components in prior work by the author [34]. In that work, thin rotary-cut veneer sheets self-shaped into a cylindrical geometry through moisture differential in veneer bilayers (Figure 2).

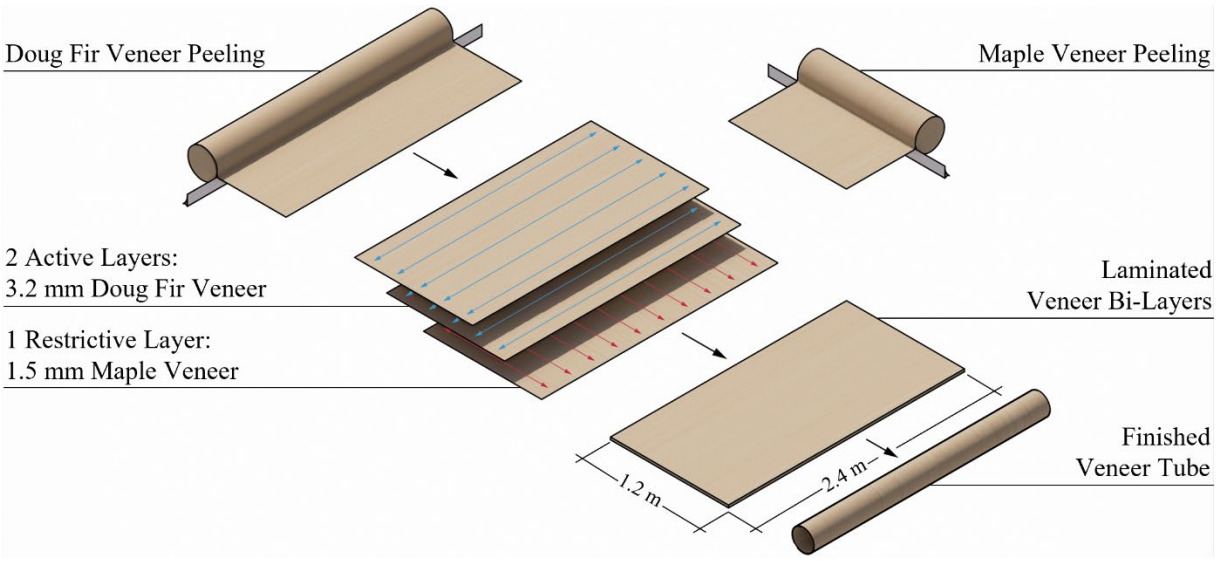
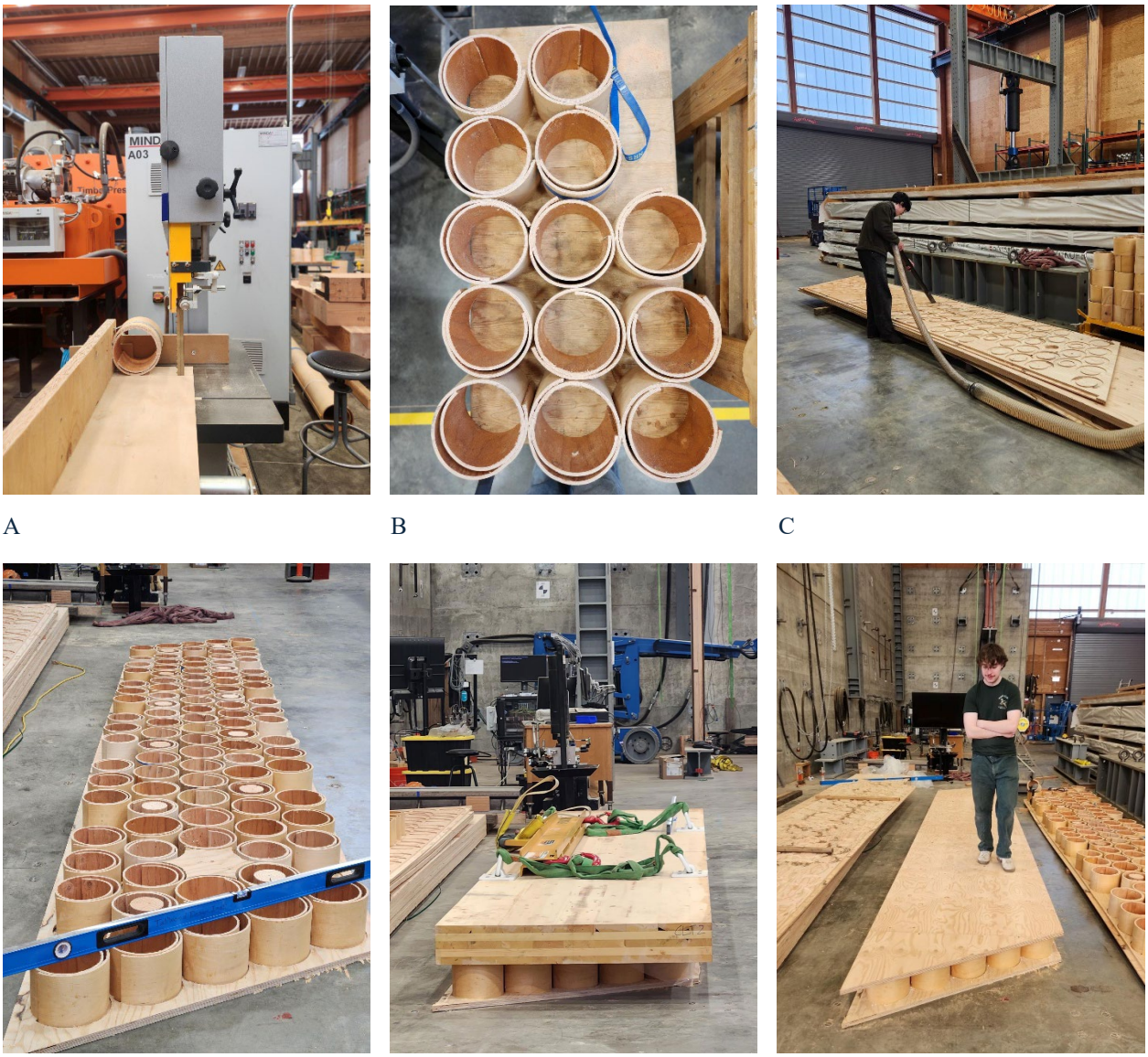


Figure 2. Diagram shows process of cutting veneer, grain orientation in layup and assembly, finalized dimensions, and actuation of a finished veneer-based tube.

This thesis builds directly on that previous research by focusing on their integration into cassette panel assemblies. Panel assembly was developed as a human-operated process in which individual tubes are positioned, aligned, and adhered into cassette configurations manually (Figure 3A-2F).



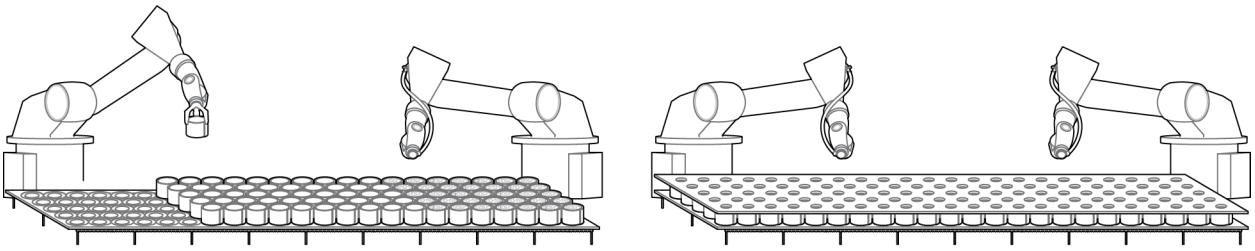
A B C

D E F

Figure 3. Photographs read left to right, top to bottom show overview of assembly process. A: Shows tube cutting setup on a bandsaw. B: Tubes are cut to size at 165.1 mm. C: Panels are milled with 6.3 mm (1/4 in) grooves and vacuumed to remove dust. D: Tubes are adhered into the grooves by hand and leveled. E: A large CLT plate is plated on top to ensure even pressure while adhesive cures. F: The top plate is placed and adhered to the rest of the assembly. Panels remain untouched for 24 hours between gluing stages.

As a secondary and forward-looking consideration, the researchers look to robotic fabrication as a pathway toward more precise and scalable production. Automated systems, such as those using robotic arms, present opportunities for higher consistency in tube placement, controlled infilling, and assembly sequencing that would be difficult to achieve through manual methods alone (Figure 4A). This proposed workflow is documented as a future development direction rather than an evaluated methodology within the current research scope. The system is also conceptually designed for disassembly and re-tuning where tubes can be cleared of infilled

materials and reprogrammed with new contents in response to changing building requirements (Figure 4B).



A B

Figure 4. A: A robotic arm to the left inserts tubes into milled grooves on an MPP base plate while a secondary robotic arm to the right fills tubes with aggregate. B: A robotic arm to the left removes the previous aggregate infill through circular holes in the MPP top plate while a robotic arm to the right replaces it with new rigid insulation.

4.3 Case Study

A full-scale public demonstration was constructed for the 2026 International Mass Timber Conference (IMTC) held March 31- April 2 in Portland, Oregon. IMTC is an annual industry conference that brings together researchers, practitioners, manufacturers, and policymakers engaged in mass timber design, manufacturing, and construction. The demonstration served as a case study in which the cassette panel system was deployed at architectural scale and qualitatively evaluated under real occupancy conditions (Figure 5).

The assembly was designed to be actively engaged by conference participants through walking, running, stomping and jumping. Accelerometers mounted to the underside fed live vibration data to an active readout display which provided participants with dynamic response data under unscripted occupancy loading. Additional panel samples displayed alongside the main floor presented selective infill configurations to communicate the tunable nature of the system.



Figure 5. Rendered diagram shows isometric perspective of the demonstrator assembly for IMTC. The system features four single spanning panels connected laterally into a parallelogram shape. Panel edges were left uncovered to allow attendees to view the internal structure of the panels.

4.4 Acoustics

Acoustic testing was conducted to evaluate the sound transmission and absorption behavior of the cassette panel system across three primary infill conditions. Testing was performed in collaboration with the University of Oregon Institute for Health in the Built Environment, using a micro acoustic test chamber intended for evaluating relative sound transmission loss of iterative panel assemblies during early product development. Acoustic testing procedures for this study were based on ASTM E492 Standard Test Method for Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies Using the Tapping Machine [35] and ASTM E90 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements [36]; however, the lab space is used as the sound source room and an 81.3 cm by 81.3 cm (32 in by 32 in) specimen sealed between the receiving microphone in an acoustically isolated inner 0.54 m^3 chamber. Measurements for both impact and airborne sound transmission tests were taken using a Bruel & Kjaer Sound Level Meter / Analyzer Type 2270 (Bruel & Kjaer, Darmstadt, Germany), which was calibrated using a Bruel & Kjaer Sound Calibrator Type 4231 (Bruel & Kjaer, Darmstadt, Germany). The airborne sound transmission test used a Brüel & Kjaer OmniPower Sound Source Type 4292-L (Bruel & Kjaer, Darmstadt, Germany) within the source room located outside the chamber and a Brüel & Kjær microphone with a preamplifier (Types 4189 and ZC-0032) (Bruel & Kjaer, Darmstadt, Germany) inside the chamber as the receiving room.

The impact sound transmission test used a Bruel & Kjaer Tapping Machine Type 3207 (Bruel & Kjaer, Darmstadt, Germany) placed on top of the assembly sample being tested. Measurements were taken with the tapping machine oriented in the east-west direction, and with the tapping machine oriented in the north-south direction. Finally, background sound control measurements were taken in a quiet room.

The test specimen measured 812.8 mm long by 812.8 mm wide by 203.2 mm deep (32 in by 32 in by 8 in) as dimensioned to fit within the chamber and was evaluated across a matrix of infill and surface topper conditions (Figure 6A and 6B). Three infill conditions were evaluated: hollow, representing minimum panel weight; recycled denim batt insulation; and 6 mm minus gravel, representing a high-mass condition at full cavity capacity (Figure 7). Samples with each infill condition were studied with four topper conditions including no topper, a 76.2 mm concrete topper, the concrete topper with carpet, and finally the concrete topper, with 12.7 mm

polyurethane carpet pad and carpet (Figure 8). For hollow and denim batt conditions, tubes were oriented with 114.3 mm (4.5 in) diameter openings facing downward to evaluate cavity resonance. For 6 mm (1/4 in) minus gravel, all openings were plugged flush prior to testing to close the cavity faces.

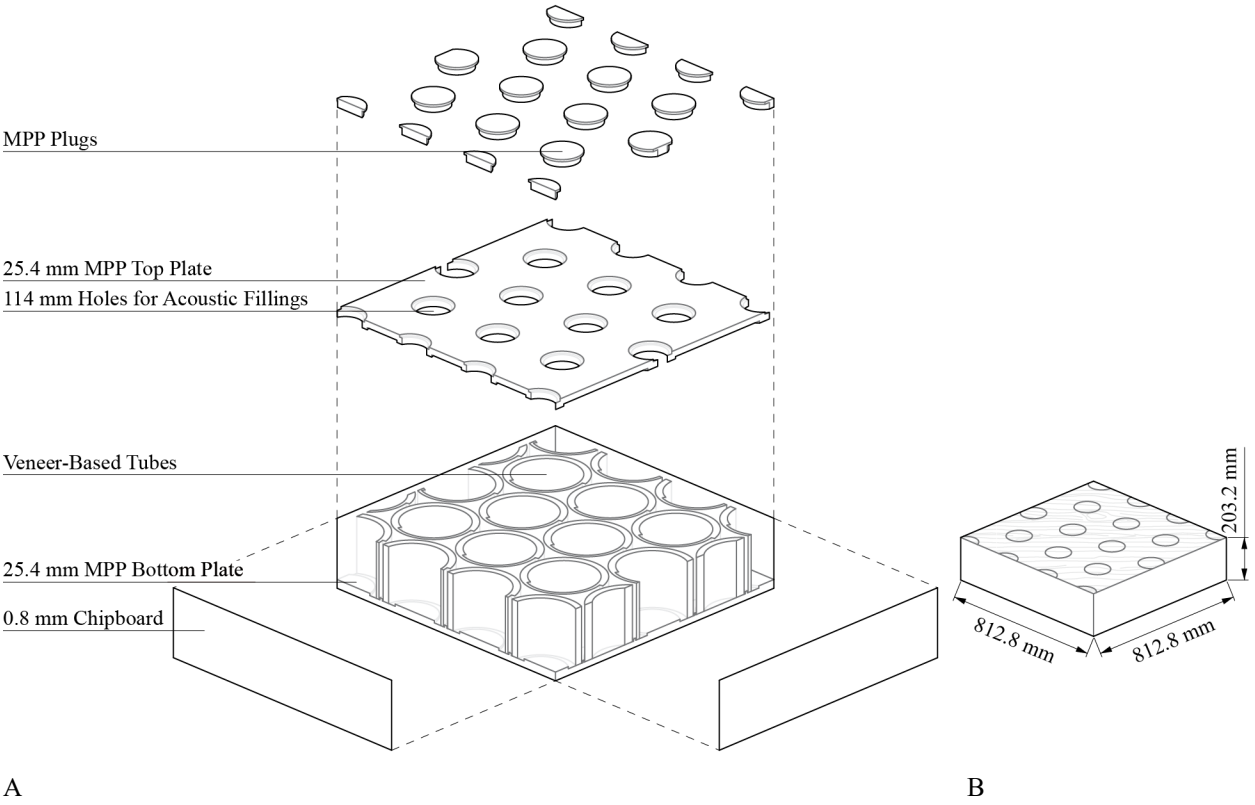


Figure 6. A: Exploded axonometric diagram depicts key elements which make up the finalized acoustic testing sample. 24.5 mm MPP panels sandwich twenty-two veneer-based tubular elements. The top plate has routed holes and plugs which allow for changing infill conditions. Routed MPP plugs fit into holes to allow the sample to be closed. The panel is wrapped in 0.8 mm chipboard to retain infills. B: Shows the closed state of the acoustic sample with final dimensions 812.8 mm wide by 812.8 mm long and 203.2 mm deep.

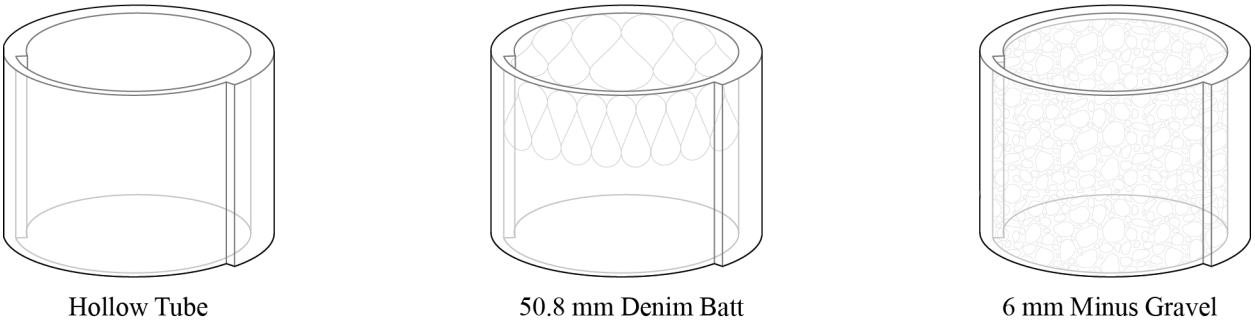


Figure 7. Shows 3 infill conditions explored including a hollow condition, 50.8 mm of denim batt infill pressed to the top of each tube, and a panel filled to capacity with 6 mm minus gravel.

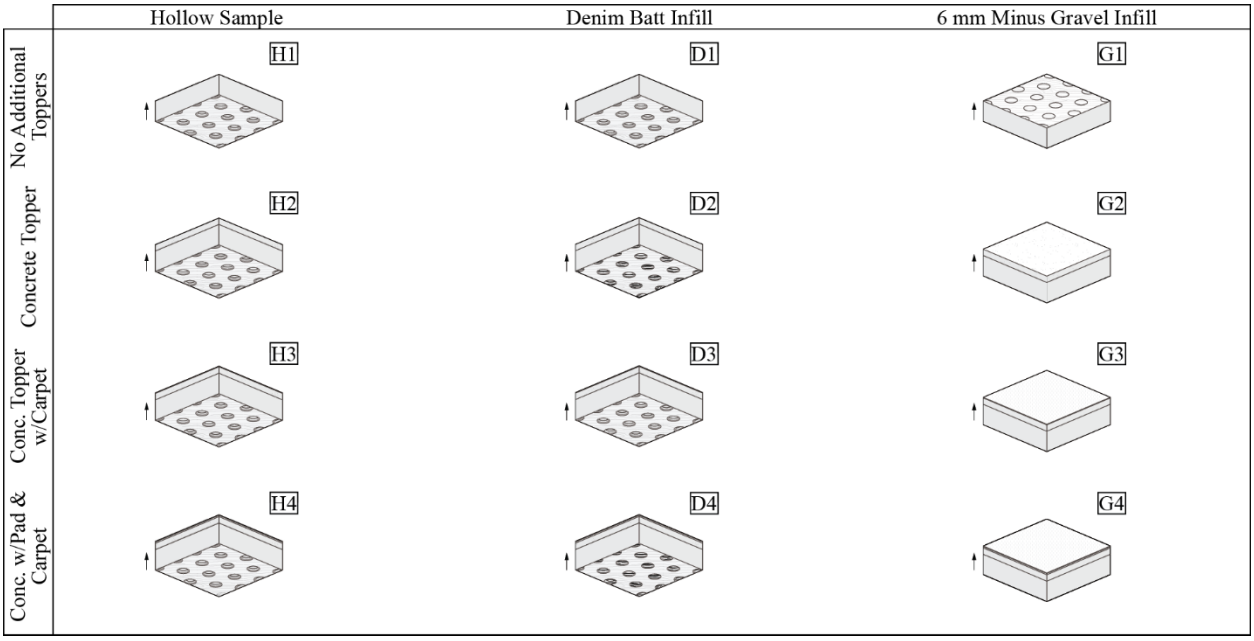


Figure 8. Matrix shows all tested acoustic infill conditions. Columns show infill series as hollow infill, denim batt infill, and 6 mm minus gravel infill. Rows show added toppers: no additional topper, 76.2 mm concrete topper, concrete topper with carpet pad, and concrete topper with 12.7 mm polyurethane carpet pad and carpet. Shorthand names for each configuration are labeled in the top right corner of each diagrammed configuration. The bottom of the matrix shows cross sections of the infill conditions.

Each acoustic sample was filled with a given infill condition and surrounded with sand to seal the perimeter before surface toppers were added as required by the test configuration (Figure 9A and 9B). Edges were then sealed with putty to prevent sound leakage around the specimen prior to measurement (Figure 9C).



A B C

Figure 9. Acoustic testing setup is shown. A: Sample is infilled with 6 mm minus gravel infill inside the micro acoustic test chamber. B: 76.2 mm concrete topper is placed on top of the gravel infill panel. C: The sample is puttied at the edges to prevent sound leakage.

An important limitation of the micro acoustic test chamber is its inability to reliably collect frequency data below 500 Hz, as the physical dimensions of the receiving chamber are insufficient to capture the longer wavelengths. This limitation is particularly relevant to the

evaluation of mass timber floor systems, where low-frequency impact sound transmission is a primary performance concern in occupied buildings. Results are therefore interpreted within the reliable frequency range of 500 Hz and above, which has been calibrated with large chamber test data, and low-frequency performance remains a gap to be addressed through future testing at facilities with larger chamber volumes or alternative measurement methodologies.

4.5 Vibration Testing

Dynamic vibration testing was conducted on a point-supported single-panel specimen across a 4.3 m (14.3 ft) span at the A.A. Red Emmerson Advanced Wood Products Laboratory (Figure 10). A heel drop test was performed by a 160 lb person executing six heel drops at varying cadence to excite the panel's natural vibrational modes. Acceleration data was recorded at a sampling frequency of 1,652.89 Hz and processed using a 4th-order Butterworth bandpass filter across a 0.5–50 Hz range. Dynamic response was characterized through Fourier Amplitude Spectrum and Power Spectral Density (PSD) analysis on a linear scale to identify the dominant natural frequency of the assembly. The tested panel represents one quarter of the full four-panel demonstrator deployed at IMTC. Additional vibration testing of the complete demonstrator was conducted at IMTC and is intended as a basis for future comparison beyond the scope of this thesis.



Figure 10. A point-supported single-cassette panel specimen is shown spanning 4.3 m (14.3 ft) between footings.

4.6 Quasi-Static Load Testing

Prior to the IMTC demonstration, quasi-static load testing was conducted on the same single point-supported panel specimen at the A.A. Red Emmerson Advanced Wood Products Laboratory to establish a safe load threshold for public interaction with the demonstrator and to confirm preliminary analysis. A Linear Variable Differential Transformer (LVDT) was positioned

at mid-span to record vertical displacement under a controlled point load applied incrementally up to 1,000 lbs via a crane-mounted steel beam (Figure 11). This testing was not intended as a comprehensive structural evaluation but as a preliminary measure to inform safe occupancy parameters for the IMTC deployment.

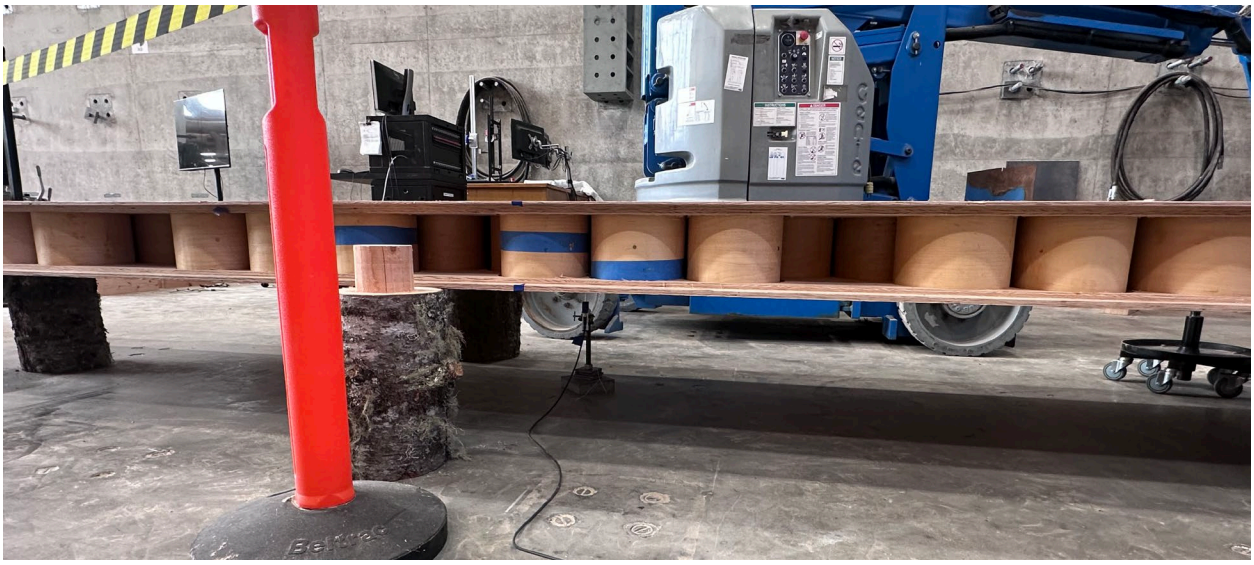


Figure 11. LVDT located on the underside for the quasi-static test is positioned underneath a single panel specimen.

CHAPTER V

RESULTS

5.1 Fabricated Prototypes

Five prototypes were developed across the course of the thesis, each advancing the system's fabrication quality, detailing, and material performance. Iterations varied across MPP plate depth, overall panel depth, tube spacing, adhesive type, and groove geometry (Figure 12A, 12B and 12C). Milling was explored across two platforms: three-axis milling using a Biesse CNC and three-axis robotic milling using a KUKA arm.



A B C

Figure 12. Three key prototypes demonstrate different design metrics being tested. A investigated 9.5 mm (3/8 in) plywood and tube spacing. B tested peeler core integration into panel grooves. C finalized tube groove widths using 25.4 mm (1 in) plate depths.

Early prototypes used Henkel HB X 602, a polyurethane-based adhesive common in CLT production, which performed poorly due to small inconsistencies in tube height. Later prototypes transitioned to Rothoblaas XEPOX G and XEPOX Liquid, two-part epoxy resins selected for their gap-filling properties, which significantly improved bond performance. As a brittle adhesive, however, XEPOX introduced susceptibility to splitting, and additional mechanical supports were incorporated into the final IMTC demonstrator panels to improve structural continuity.

The final prototype established a triangular tube grid with grooves milled 6.35 mm (1/4 in) into 25.4 mm (1 in) MPP top and bottom plates, with tube centers spaced 240 mm (9.4 in) apart (Figure 13A). The groove geometry was designed to accommodate tubes with variable outer diameters, which came from the self-shaping nature of the veneer-based tubes used, by loosely constraining each tube within a consistent outer diameter boundary. Strategically placed peeler core remnants from the veneer rotary-peeling process, were embedded to provide material density sufficient for structural wood screws to be placed (Figure 13B).

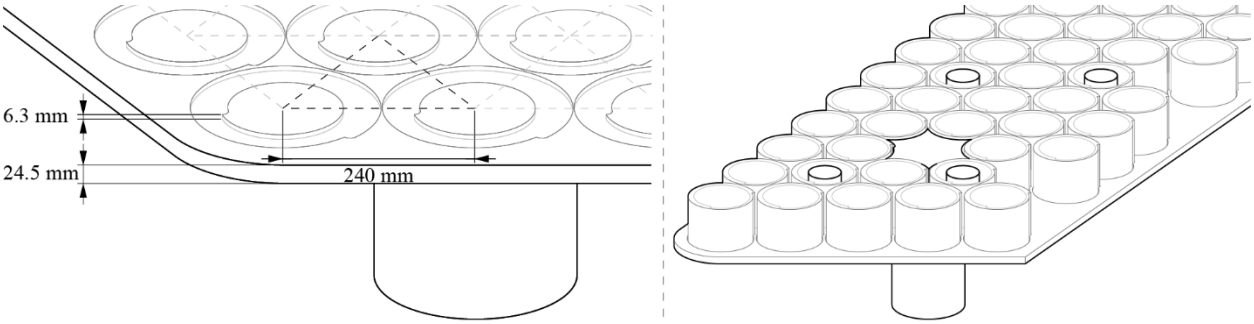


Figure 13. A: Diagram shows finalized geometry of bottom panel plate including grooves and tube spacing. Grooves for tubes are placed in a triangular pattern 240 mm apart into at a depth of 6.3 mm into a panel of 24.5 mm overall thickness. B: Diagram shows evenly spaced peeler cores sitting centered inside hollow tubes within a demonstrator panel layup. Additional gaps in tube placement leave space for lateral attachment to other panels. A 6-pointed star shape is shown made of MPP and sits as a footing insert for the footing below to sit inside as a Mortise and Tenon slotted connection.

Final panels measured 6.2 m (20 ft) long by 1.2 m (4 ft) wide and 203.2 mm (8 in) in depth at approximately 245 kg (540 lbs) which is roughly one third the weight of a 5-ply CLT panel of equivalent area (Figure 14). The final panel depth was determined for the practical goal of maximizing visible panel depth relative to the number of prefabricated tubes available for the IMTC demonstration.



Figure 14. One full-scale demonstrator panel is shown, held up by a gantry crane to find its final weight. The scale read 245 kg (540 lb) for the single panel.

Four cassette panels were connected laterally to create the demonstrator, measuring 7.9 m by 4.8 m (26 ft by 16 ft) in plan, with dimensions guided by transportation constraints and material availability (Figure 15).

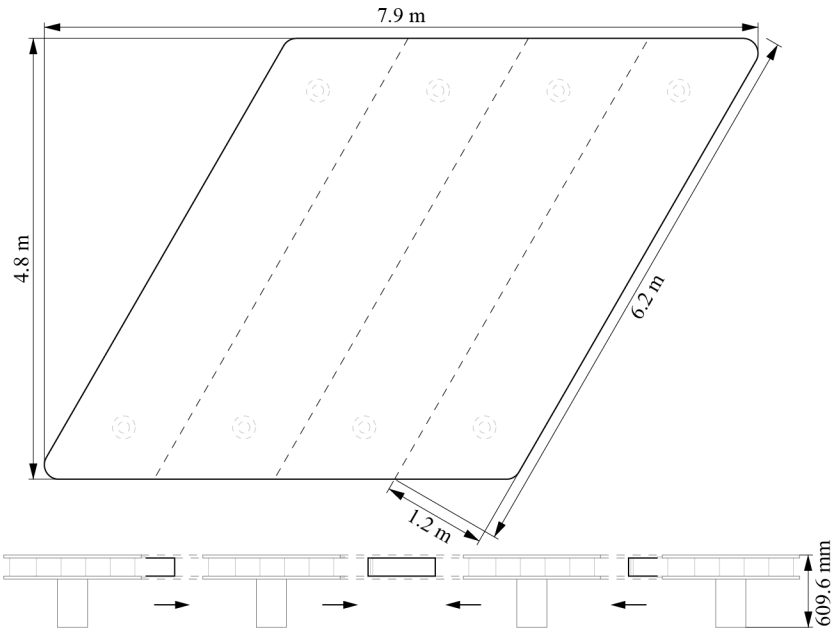


Figure 15. Final panel dimensions are shown both individually and as a four-panel assembly. Panel supports are shown as light grey dashed lines.

5.2 Case Study

The four-panel demonstrator deployed at the 2026 International Mass Timber Conference was publicly accessible throughout the conference. Attendees were invited to walk, stand, jump, dance, and stomp on the surface, with accelerometers mounted to the underside feeding live vibration data to an active readout display (Figure 16).

Qualitative observations indicated strong overall performance under occupancy conditions. The assembly felt solid underfoot with no perceptible instability during normal walking, standing, or jumping. A slight initial deflection was noticeable under load but did not produce sustained bounce or resonance. The floor showed no exceptional echoing under ambient conference conditions and did not vibrate sympathetically in response to amplified music.



Figure 16. IMTC exhibitors jump on the four-panel demonstrator to excite the assembly's natural vibrational modes with active vibration data displayed on a TV to the right.

5.3 Acoustics

Acoustic testing evaluated the hollow-core cassette panel across configurations relative to one another. There were twelve total assembly conditions representing three infill conditions: hollow with open tube faces, denim batt with open tube faces, and 6 mm minus gravel with plugged tube faces. Infills were paired with four surface toppers: no topper, 76.2 mm (3 in) concrete topper, concrete with carpet, and concrete with polyurethane carpet pad and carpet. Only frequencies at 500 Hz and higher were included in the results due to size limitations of the receiving chamber.

Airborne Sound Performance

Noise Isolation Class (NIC) values ranged from 35 dB in the untopped hollow configuration (H1) to 51 dB in the best-performing configurations (Figure 17). This resulted in a 16 dB spread that directly demonstrates the tunable range of the system. Infill alone produced a +8 dB gain over the hollow baseline, with 6 mm minus gravel reaching 43 dB without any surface treatment (G1). This result is notable because a NIC of 43 dB for the gravel-infilled panel with no surface topping exceeds the typical airborne sound isolation performance of a bare 5-ply

CLT panel of equivalent area, which generally falls in the range of 40–41 dB at comparable frequencies (McLain, 2016), while using approximately one third the fiber.

The concrete topper produced the single largest performance jump across all configurations, with hollow (H2), denim batt (D2), and 6 mm minus gravel (G2) conditions reaching 49, 50, and 51 dB respectively. Carpet additions produced marginal further improvement in some configurations.

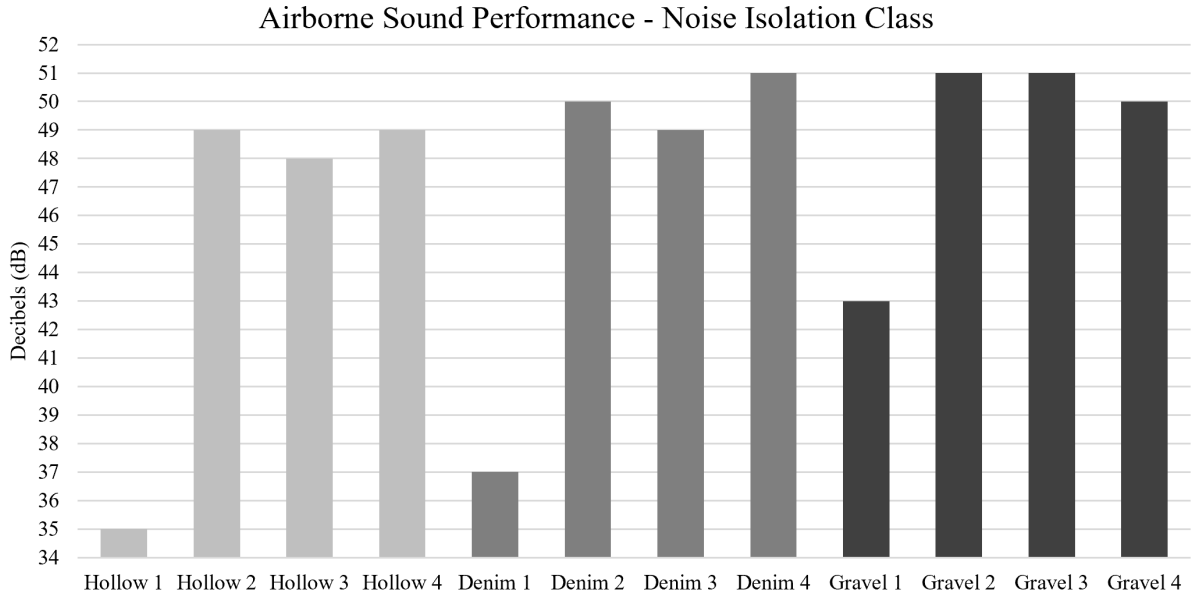


Figure 17. H1-H4 represents the acoustic specimen series with no infill, D1-D4 represents the acoustic specimen series with denim batt insulation, and G1-G4 represents the acoustic sample series with 6 mm minus gravel infill series. Airborne sound performance is expressed as Noise Isolation Class in decibels for all cassette panel configurations. Higher NIC values indicate superior overall airborne sound isolation performance of the assembly. Untopped conditions (H1, D1 and G1) show the lowest airborne sound isolation performance with topped conditions outperforming those without.

Frequency-resolved noise reduction data shows configurations with concrete toppers converging into a tight performance cluster peaking at 75–77 dB between 4 and 5 kHz (Figure 18). Hollow open (H1) and denim batt open (D1) conditions are clear outliers, dropping to approximately 32 dB at 1.6 kHz. Gravel with closed tube faces (G1) rises steeply with frequency, converging with concrete-topped configurations at mid-to-high frequencies. This suggests that closed-cavity gravel infill provides meaningful attenuation without a topper.

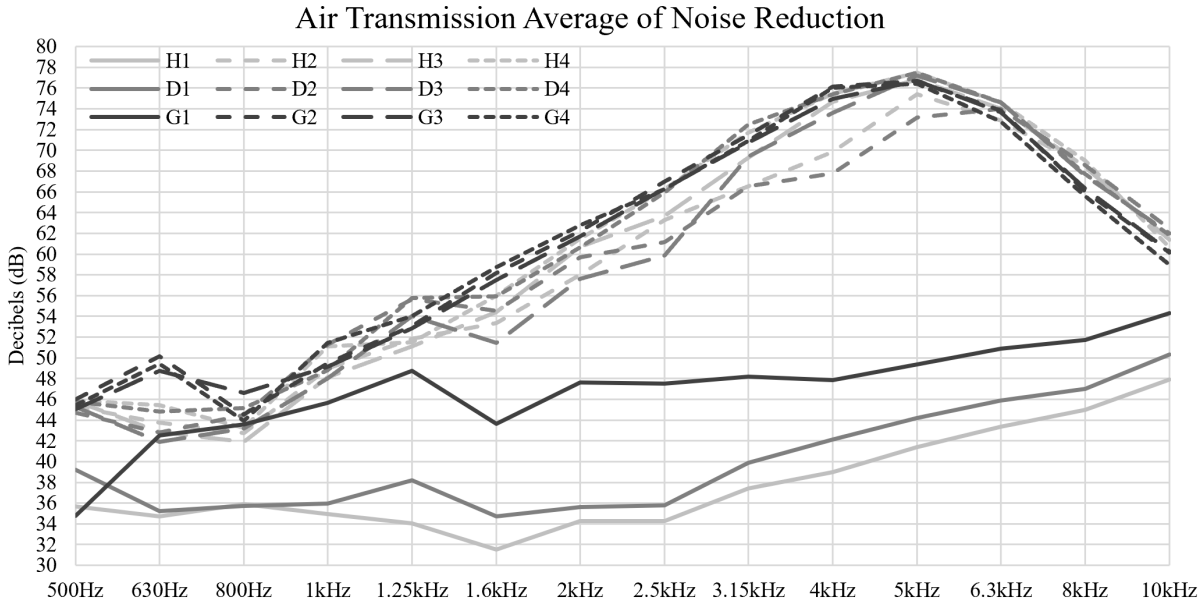


Figure 18. Air transmission average noise reduction in decibels across one-third octave band center frequencies from 500 Hz to 8 kHz for all cassette panel configurations. Higher noise reduction values indicate greater attenuation of airborne sound transmission through the floor-ceiling assembly. Untopped specimen conditions (H1, D1, and G1) show the lowest reduction in air transmitted noise average with topped conditions showing higher noise reduction, peaking around 5kHz.

Impact Sound Performance

Surface topper conditions appeared to exert greater influence on impact sound performance than internal infill (Figure 19). The hollow open condition (H1) performed least well, peaking at approximately 93–95 dB near 1.25 kHz. Concrete topper alone produced moderate reductions across all infill conditions, while carpet pad and carpet produced the most substantial reductions. The specimen with 6 mm minus gravel with the full topper stack (G4) achieved the lowest impact sound levels in the testing matrix, confirmed by Impact Sound Rating (Figure 20). Impact sound performance was not measured for the sample with 6 mm minus gravel and no topper (G1). This was due to the uneven surface created by putty used to close top face seams.

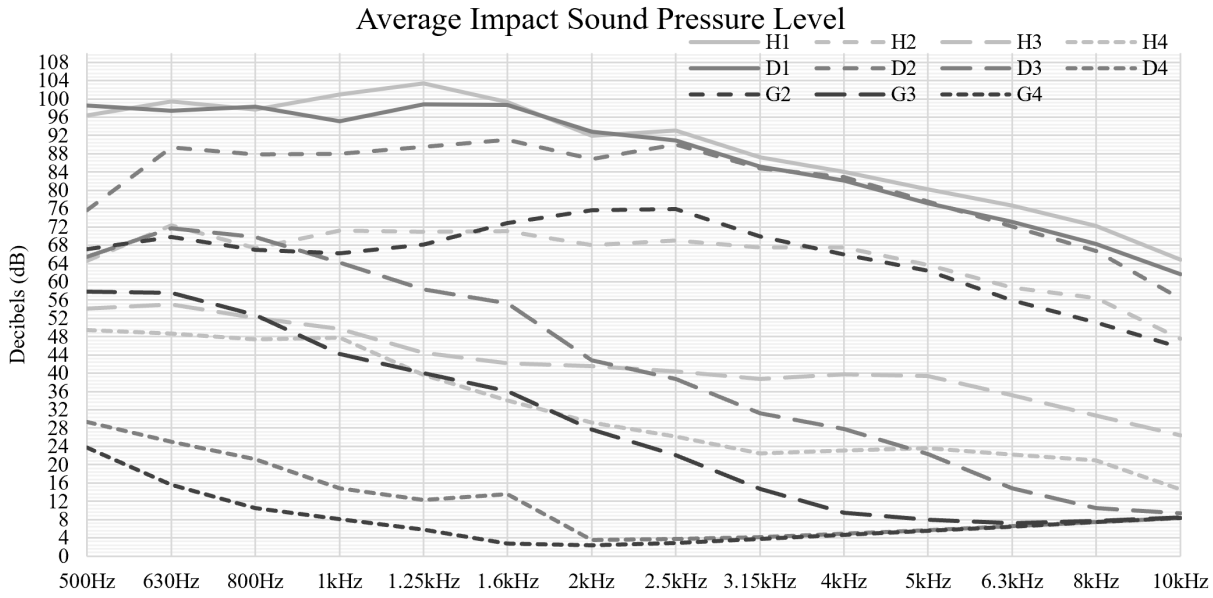


Figure 19. Average impact sound pressure level in decibels measured across one-third octave band center frequencies from 500 Hz to 8 kHz for all cassette panel configurations. Lower values indicate reduced impact sound transmission to the receiving space. A wide range of impact sound pressure levels are shown, with two samples that used a concrete topper, carpet and carpet pad (D4 and G4) showing the highest reduction in average impact sound pressure level being transmitted to the receiving space.

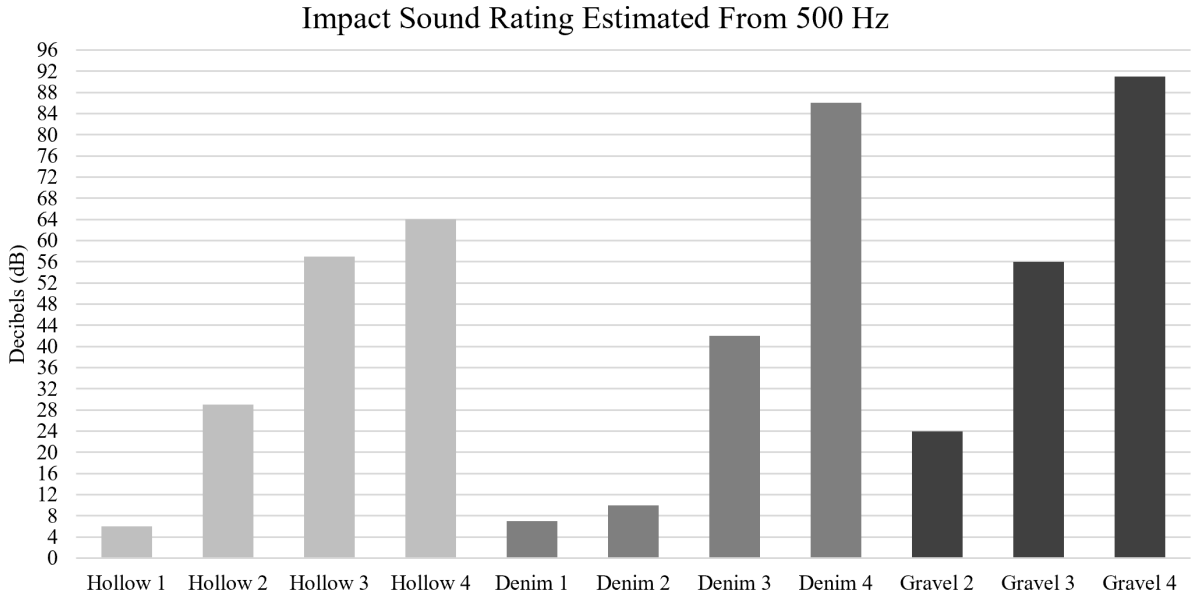


Figure 20. Impact sound rating in decibels estimated from the 500 Hz one-third octave band for all cassette panel configurations. Lower values indicate superior impact sound attenuation performance. A wide range of impact sound ratings are shown, with the highest improvement in rating being from samples that featured a concrete topper, carpet, and carpet pad (D4 and G4).

Untopped configurations (H1, D1 and G1) showed substantially higher impact sound transmission relative to what would be expected of a solid CLT panel of comparable depth [37]. This gap in baseline impact sound performance is a limitation of the panel in its hollow or lightly

infilled state. It is also, however, an argument for the tunable nature of the system. A panel using approximately one third the fiber of a solid CLT assembly will inevitably carry less inherent mass damping. The relevant question is whether that mass can be reintroduced selectively and reconfigured over time.

Summary of Acoustic Findings

Internal infill, concrete topping, and surface carpet were proven to each contribute independently and cumulatively to acoustic performance. The 16 dB NIC range across the testing matrix demonstrates that a single panel assembly can operate at substantially different acoustic performance levels through infill configuration alone.

It is important to note that all results only include frequencies of 500 Hz and above. Low-frequency impact and airborne sound transmission could not be captured within the measurement constraints of the micro acoustic test chamber. It is important to consider that this is the metric in which lightweight timber floors most commonly underperform relative to concrete systems. The degree to which the reported improvements extend into the sub-500 Hz range remains unresolved, and this represents a significant area in which this system should be explored in the future.

5.4 Vibration Testing

Heel drop excitation produced clear and consistent acceleration response across all six drop events (Figure 21). Peak accelerations reached approximately 0.6–0.7 g at impact, with rapid decay between events. This indicates that the panel dissipates excitation energy quickly rather than sustaining prolonged vibration, which is a favorable characteristic for occupant comfort.

Fourier Amplitude Spectrum analysis identified a concentration of spectral energy between 15 and 22 Hz, with a well-defined peak at approximately 18.97 Hz (Figure 22). Power Spectral Density analysis confirmed this dominant natural frequency at approximately 19 Hz (Figure 23). This places the panel's fundamental frequency above the 8 Hz threshold commonly associated with stiff floor behavior under walking excitation, and within a range consistent with acceptable serviceability in lightweight structural floor systems. The sharpness of the PSD peak indicates a well-defined single dominant mode under the tested point-support condition.

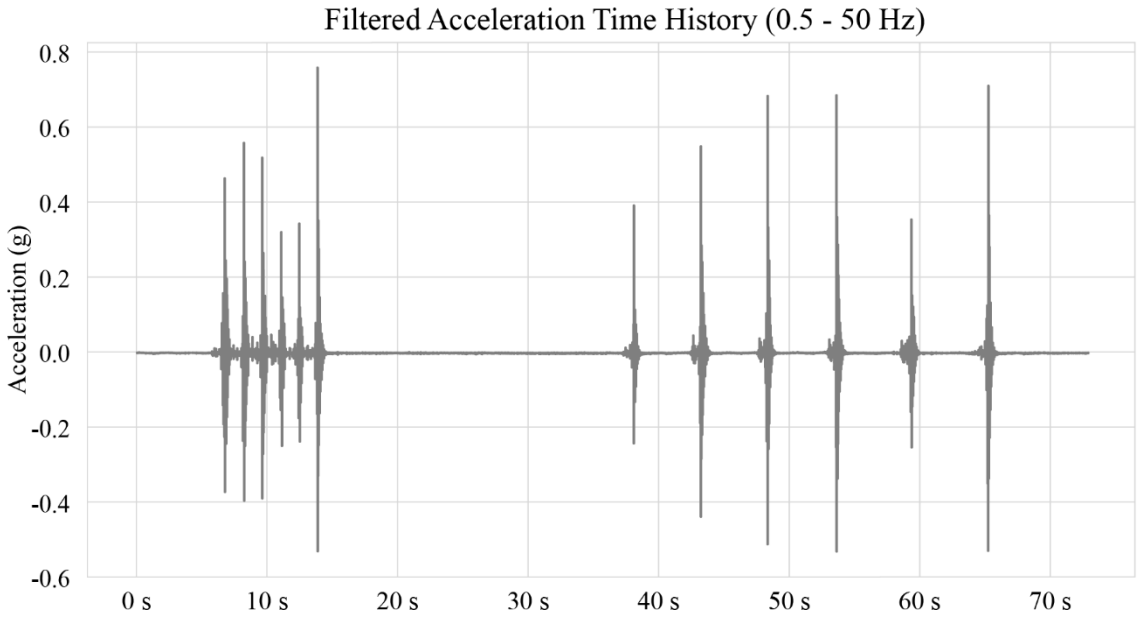


Figure 21. Acceleration time series in g. Heel drop excitation performed by a 160 lb person (6 heel drops) at different cadence to excite the specimen's natural vibrational modes.

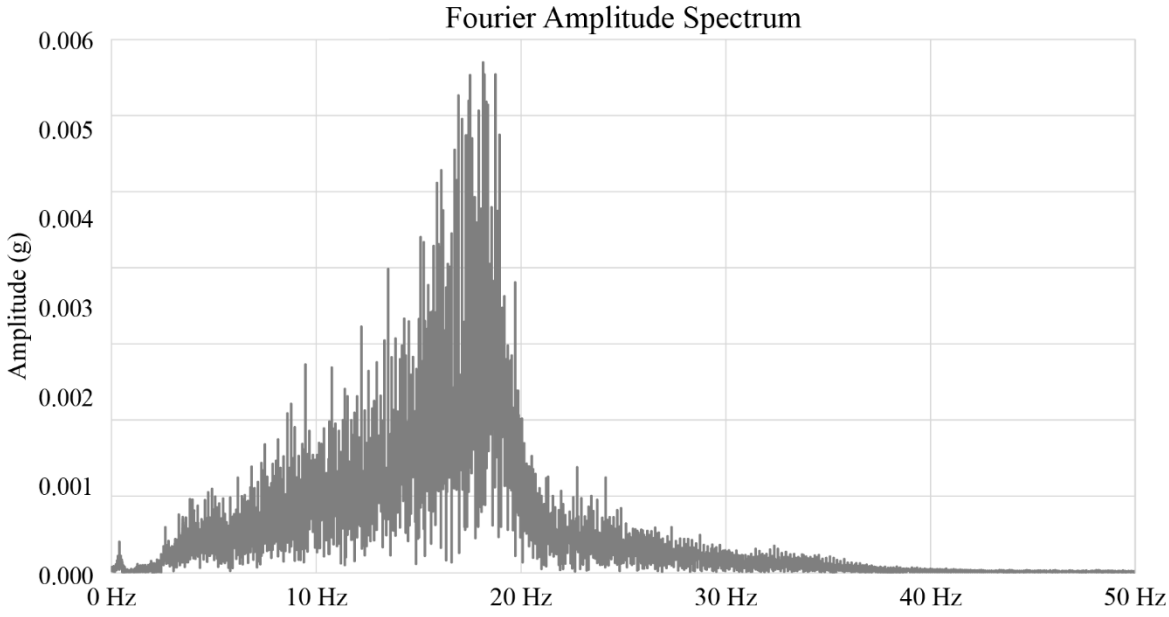


Figure 22. Fourier amplitude spectrum of the acceleration time series shows peaks just before 20 Hz.

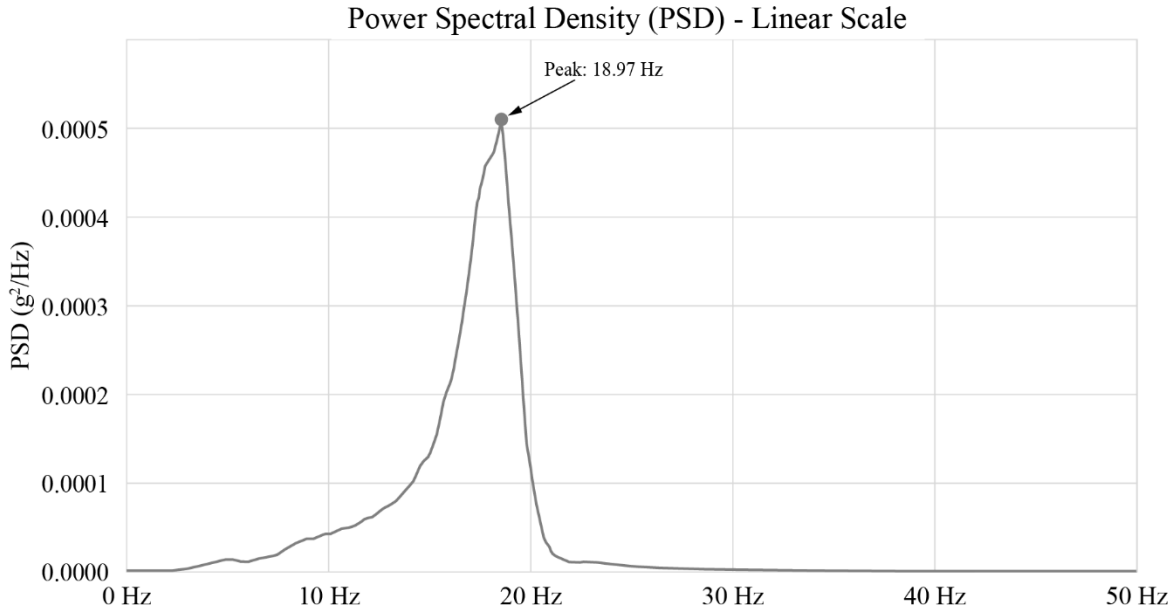


Figure 23. Power spectral density linear scale identified a natural frequency at approximately 19 Hz.

The 19 Hz natural frequency and rapid acceleration decay observed in laboratory testing are consistent with the qualitative occupancy observations made at IMTC, where participants described the floor as solid underfoot with no sustained bounce or resonance. These results establish a baseline dynamic characterization of the hollow-tube panel configuration. Testing across varied infill conditions, such as denim batt and 6 mm minus gravel identified for acoustic testing, would allow direct quantification of how internal configuration shifts natural frequency and damping, and remains a priority for future work. Full-demonstrator testing conducted at IMTC provides a complementary dataset for future analysis and comparison beyond the scope of this thesis.

5.5 Quasi-Static Loading Test

Under incremental point loading up to 453.6 kg (1,000 lbs), the panel recorded a mid-span displacement of 3.68 mm (0.145 in), corresponding to a force-displacement stiffness of 79.49 kg/m (6,900 lb/in) (Figure 24). The panel showed no signs of structural failure through the full load range which provided sufficient confidence to proceed with public deployment at IMTC. Four localized popping sounds were audible between approximately 317.5 and 453.6 kg (700 and 1,000 lbs). These are attributed to minor stress redistribution within the adhesive bonds, consistent with the brittle failure characteristics of the XEPOX two-part epoxy system used in this prototype, which was identified during fabrication as a limitation of the current assembly.

While the panel maintained stiffness and integrity through the test, the popping sounds observed reinforces the belief that the current adhesive system is not ideal for this layup and represents an area for refinement in future iterations.



Figure 24. Load application for the quasi-static test. The steel beam was lowered slowly across the mid-span of the specimen with load measured by a scale attached to the hook of the crane.

5.6 Designing for Adaptability

The acoustic and vibrational results presented in this chapter demonstrate an initial range of tunability across the system. The primary contribution of the hollow-core cassette system is the shift it enables towards performance as a configurable condition that can be set, adjusted, and reset over time.

This configurability operates simultaneously across three scales (Figure 25). At the tube level, individual cavities can receive different infill materials, with potential to be cleared and repacked as acoustic demands change. The plugged tube face condition evaluated in the gravel series of acoustic testing demonstrates that cavities can be sealed and reopened between infill states. At the panel level, performance can vary through infills in specific areas as needed. Tubes near party walls or mechanical equipment could receive high-mass infill while tubes in low-demand zones receive acoustic absorptive materials. This produces a gradient of acoustic performance within a single structural assembly. At the building scale, different floors within the same structure can be configured to address the distinct programmatic requirements of their occupancy without changes to the structural system itself.

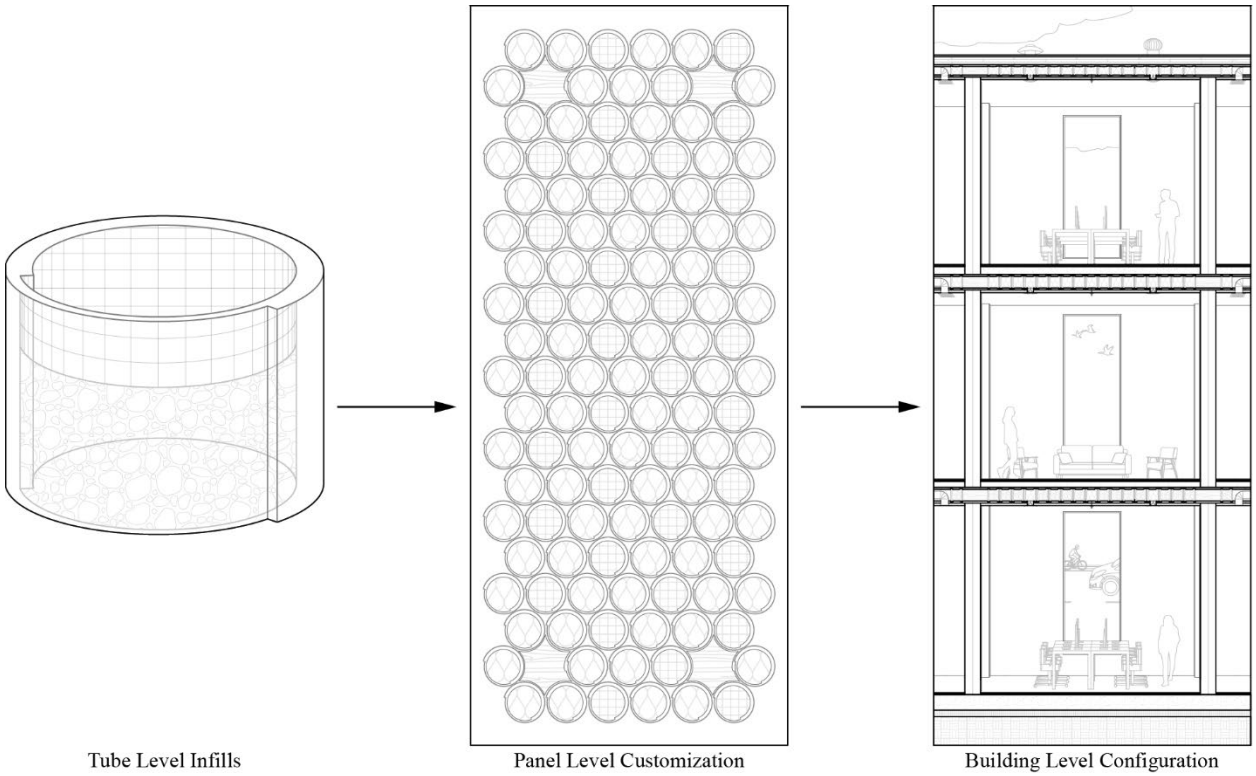


Figure 25. Hierarchy of panel tunability is shown through multi-infill tubes, various infills per panel, and floor plates designed for various occupancy and noise conditions.

The broader implication is that acoustic and vibrational performance can be integrated into the structure rather than layered onto it through surface treatments. This cassette system proposes a hybrid solution between structure and performance in which the floor plate itself is the primary site of acoustic adjustment and in which that adjustment remains accessible throughout the building's life.

CHAPTER VI

CONCLUSION

6.1 Summary

This thesis presents a tunable hollow-core cassette floor panel composed of circular veneer-based tubular elements sandwiched between thin mass timber panels as an alternative approach to conventional mass timber floor systems. Through iterative physical prototyping, a full-scale public demonstration, and empirical performance testing across acoustic and vibrational performance, the study explores new possibilities for improving material efficiency and acoustic adaptability in timber floor assemblies.

The results demonstrate that a single structural assembly can produce meaningfully different acoustic outcomes through geometric and infill configuration. More fundamentally, they provide a path for reimagining structural and acoustic performance as a condition that can be set and adjusted in response to changing building requirements.

Together, these findings address the research questions posed in this thesis. The study demonstrates that a hollow-core cassette panel can be fabricated using veneer-based components through hand assembly and it shows that variations in internal configuration produce meaningfully different acoustic outcomes across a testable range of infill and topper conditions. As a whole, the system presented provides a foundation for more adaptable, fiber efficient, and reprogrammable mass timber floor assemblies.

6.2 Limitations and Future Work

The contributions of this thesis are centered around the development of a tunable cassette panel system and its initial performance evaluation across fabrication, acoustic, and vibration testing iterations. Several limitations exist within these methods which do not negate the results but instead highlight areas where further refinement and validation are needed.

The most significant material limitation is the adhesive used. Rothoblaas XEPOX was an improvement over the initial polyurethane adhesive but is brittle and not ideally suited for tube-to-plate connections as shown with localized popping observed during quasi-static testing. A connection strategy that accommodates the curved endgrain of the tubes while remaining ductile under load is a necessary area of future investigation on this topic.

Acoustic results are constrained to 500 Hz and above by the physical limitations of the micro acoustic test chamber. Low-frequency performance remains entirely uncharacterized and represents the most pressing gap for future acoustic investigation. Vibration testing was similarly limited to a single panel under a hollow infill condition. The effect of denim batt and 6 mm minus gravel infill on natural frequency and damping was not empirically evaluated and remains an unresolved question. The tube-level and panel-level tuning described previously similarly remains conceptual and untested and represents a clear direction for future experimental work.

Structural certification, fire resistance, moisture performance, lateral system integration, and lifecycle cost analysis are all outside the scope of this work and represent necessary areas of future investigation to understand all aspects of this system. Fabrication precision also remains a limitation, where a transition to robotic fabrication is the next logical step for improving manufacturing efficiency, dimensional reliability and scalability across the system.

Overall, this work is conducted as an early-stage design and fabrication study intended to provoke further research and development. Future work will need to address these issues to bring the hollow-core cassette panel toward broader application within practice.

6.3 Impact

The work presented in this thesis offers a contribution to advancing material efficiency and acoustic adaptability in mass timber design research. The research depicts new ways in which mass timber can be made lighter, use fiber more efficiently and address acoustic concerns through a single configurable assembly.

From an architectural standpoint, the cassette panel introduces a new framework for thinking about floor plates in mass timber buildings. The panel configuration types proposed in this research provide a design language that connects material decisions directly to occupancy concerns. From an industry perspective, the fabrication workflow developed through this thesis is grounded in accessible materials and manual assembly processes, making it feasible for near-future prototyping and further development.

As mass timber continues to gain momentum as a low-carbon building material, the need for floor systems that are lighter, more adaptable, and designed for reuse will only grow. The hollow-core cassette panel presented in this thesis provides a conceptual foundation for floor assemblies that treat performance as an ongoing condition rather than a fixed product outcome, and in doing so, contributes to a broader view of buildings as systems designed to change.

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