A MULTI-MATERIAL BALUSTRADE FOR ESCALATOR & MOVING WALK

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1. ABSTRACT

The development of transparent wood as a structural material presents a sustainable and high-performance alternative to conventional glass in escalator balustrades. This study details the design, fabrication, and installation of a novel assembly system for integrating transparent wood into escalator structures. The transparent wood is produced by selectively removing lignin from natural wood and impregnating the porous framework with a polymer, resulting in a material with high optical transmitttance, superior impact resistance, and enhanced thermal insulation.

To ensure structural integrity and ease of implementation, we have designed a dedicated assembly mechanism tailored for transparent wood balustrades. Furthermore, we have successfully installed the material using a layered approach, enhancing its mechanical strength and durability. This layering technique optimizes load distribution and impact resistance, reducing the risk of breakage while maintaining transparency and light diffusion properties. Compared to traditional glass, transparent wood offers superior toughness, lowering the likelihood of shattering and improving passenger safety in high-traffic environments such as shopping malls, airports, and public transit hubs. Additionally, its ability to diffuse light minimizes glare, enhancing visual comfort while preserving aesthetic appeal.

From an environmental perspective, transparent wood is a bio-based material with a significantly lower carbon footprint than conventional glass, which requires energy-intensive manufacturing processes. Its thermal insulation properties contribute to energy efficiency, potentially reducing climate control costs in enclosed spaces. Functional coatings and nanomaterial integration can further enhance fire resistance, UV stability, and long-term performance, making it a viable architectural alternative.

2. INTRODUCTION

In urban infrastructure, the safe and efficient movement of people within high-rise and high-density buildings is of paramount importance. Escalators and moving walkways are integral to modern architectural design, enabling vertical and horizontal transportation, respectively. Each of these systems typically includes balustrades on either side, which not only enhance user safety but also support the movement of handrails.

Traditionally, these balustrades are made of transparent glass, chosen for its ability to propagate ambient light. This feature enhances the visibility of step treads or pallets and contributes to a safer user experience. However, glass is expensive and heavy, increasing the overall cost and complexity of manufacturing and installation. Reduce these costs, alternatives involving multi-material or opaque panels have been explored. While these materials offer economic benefits, they often sacrifice visibility, leading to potential safety risks.

Moreover, current multi-panel balustrade designs involve complex assembly techniques using specialized tools, fixtures, and attachment methods. This not only raises the cost but also increases the time and labour needed for assembly and maintenance.

This research proposes a multi-material balustrade system that addresses the limitations of existing designs. The proposed system uses a combination of cost-effective materials such as transparent wood, acrylic, or polymethyl methacrylate (PMMA) which allow the transmission of ambient light while keeping structural integrity. (Céline Montanari, 2021). The modular design ensures simplified assembly without specialized tools, making it workable for rapid installation and easy replacement of damaged panels. This innovation aims to enhance user safety, reduce manufacturing costs, and improve efficiency in escalator and moving walkway systems.

3. TRANSPERENT WOOD

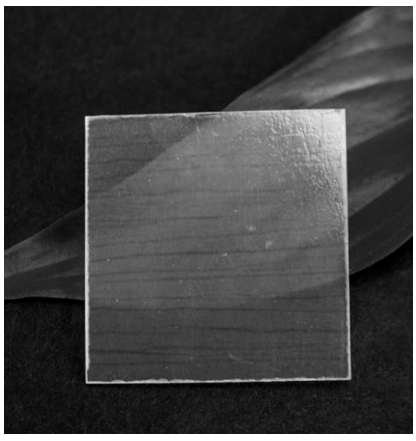

Figure 1 *Transparent Wood Sample* (Coleman, 2023)

Figure 2 *Transparent Wood Sample* (Portillo, 2025)

Transparent wood is an innovative, bio-based composite material engineered to combine the structural benefits of natural wood with optical transparency approaching that of glass.

The fabrication process involves a critical chemical treatment to selectively remove the light-absorbing lignin part – the polymer responsible for wood's brown colour and rigidity – from the cellular structure of a wood substrate, typically thin veneers. This delignification leaves behind a porous, white cellulose scaffold. Subsequently, this scaffold impregnated with a polymer resin (commonly epoxy, PMMA, or bio-based alternatives) having a refractive index closely matched to that of cellulose.

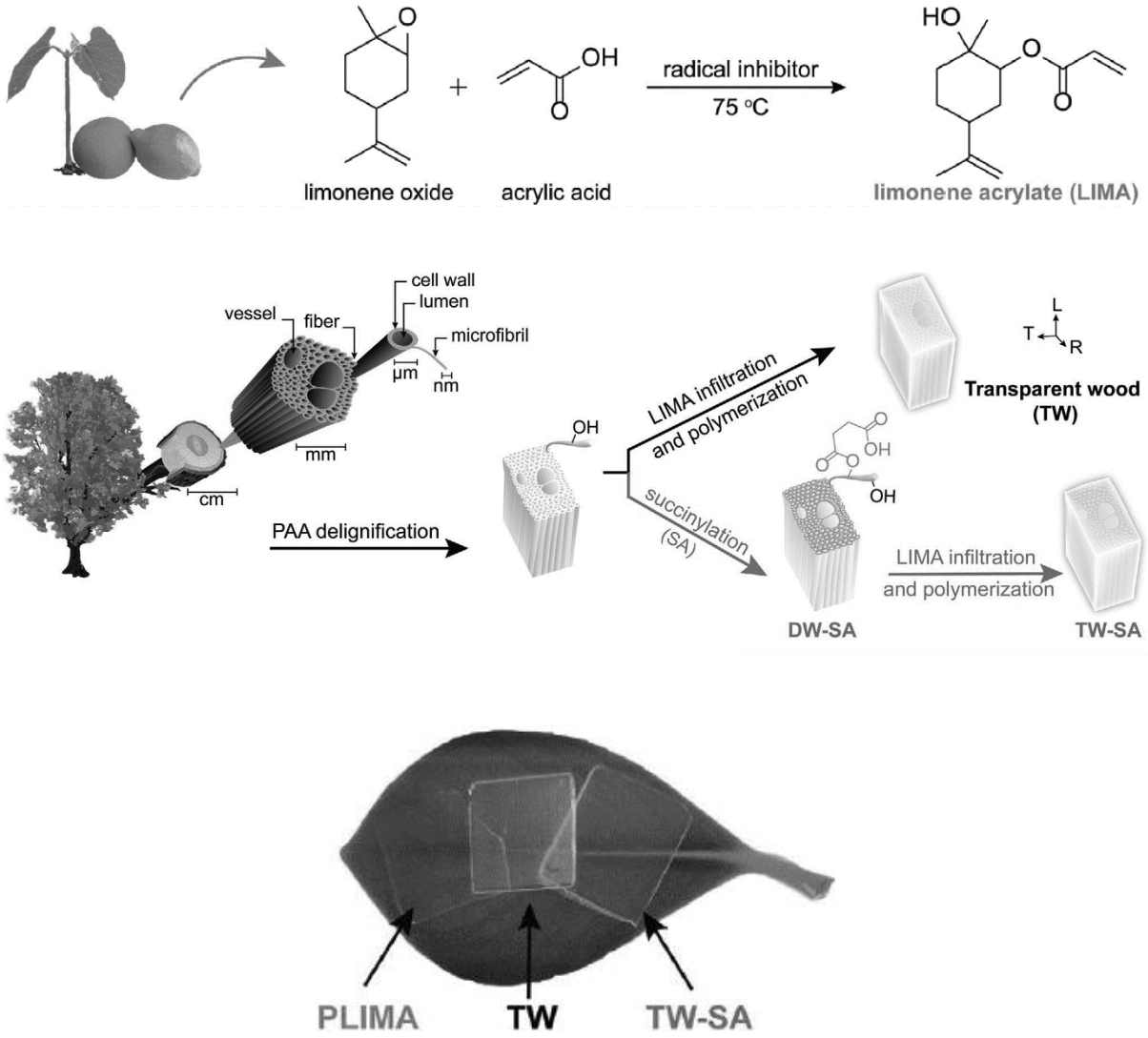

Figure 3 *Schematic illustration depicting natural wood structure and the fabrication sequence for bio-based transparent wood (TW) and TW-SA. Initial green peracetic acid (PAA) delignification removes lignin. Subsequent solvent-free succinylation with bio-based succinic anhydride (SA) enables succinylation-enhanced LIMA impregnation. Finally, LIMA monomer infiltrates the wood scaffold and polymerizes in situ.* (Céline Montanari, 2021)

The resin fills the voids and lumens within the wood structure, significantly reducing light scattering at the interfaces between cell walls and air. The resulting composite material shows remarkable optical clarity or translucency while keeping the inherent mechanical strength, toughness, anisotropy, and low thermal conductivity of the original wood. Its unique microstructure contributes to exceptional fracture resistance compared to brittle glass.

Furthermore, transparent wood leverages wood as a renewable resource and offers a potentially lower carbon footprint compared to conventional transparent materials. (Portillo, 2025)

4. SIGNIFICANCE OF TRANSPERENT WOOD OVER GLASS

4.1 Superior Safety and Structural Performance

Transparent wood fundamentally enhances safety in public infrastructure like escalators due to its distinct fracture behavior. Unlike annealed glass, which fails catastrophically into hazardous shards, transparent wood undergoes cohesive fracture, retaining structural integrity upon impact in a manner analogous to engineered safety laminates. This intrinsic property, stemming from its cellulose-reinforced polymer composite structure, significantly mitigates laceration risks. Furthermore, this composite architecture confers exceptional resistance to surface abrasion and edge chipping, ensuring superior retention of optical clarity and reduced maintenance under sustained mechanical stress in high-traffic environments. (Yuanyuan Li Q. F., 2016)

4.2 Enhanced Thermodynamic Efficiency and Weight Optimization:

The material exhibits demonstrably lower thermal conductivity (κ-values) compared to conventional float glass, providing superior thermal insulation for escalator enclosures within climate-controlled buildings. This inherent property directly reduces undesirable heat transfer, contributing to measurable energy efficiency improvements in HVAC systems. (Hongy Lin, 1992). Concurrently, transparent wood achieves comparable light transmission at a significantly lower areal density than glass. This weight reduction decreases dead loads on escalator trusses and supporting structures, offering potential for structural optimization, and facilitating retrofitting projects where weight constraints are critical.

4.3 Sustainable Life Cycle and Environmental Profile

Transparent wood, synthesized from renewable biomass sources, is gaining attention as a sustainable alternative to conventional mineral glass in architectural and industrial applications. (Portillo, 2025). Unlike traditional glass, which depends on finite silica sand and involves high-temperature, energy-intensive manufacturing processes, transparent wood offers a significantly lower environmental burden. Life Cycle Assessment (LCA) studies suggest that its embodied energy and carbon emissions can minimize, especially when bio-based polymer resins used in fabrication. This innovative material supports circular economy principles by promoting resource efficiency, reducing waste, and utilizing biodegradable inputs. Its adoption in escalator balustrades and building construction presents an opportunity to minimize environmental impact while enhancing sustainability and design flexibility in modern infrastructure.

4.4 Distinct Aesthetics and Fabrication Advantages

Transparent wood surpasses mineral glass aesthetically and functionally. It inherently keeps natural wood grain and textures, offering a warm, organic look ideal for biophilic design. Crucially, its optical properties are highly tuneable; haze, light diffusion, and spectral transmission (including tint or UV resistance) can be precisely engineered during production. This gives architects unprecedented control over light quality and visibility, enabling diverse applications from privacy screens to clear panels. Furthermore, it proves superior machinability compared to tempered safety glass. Processes like CNC milling, drilling, and profiling carry a significantly lower risk of spontaneous catastrophic failure (shattering), a major limitation of glass. This enhanced fabrication tolerance allows for greater design complexity, simpler installation, and previously impractical bespoke geometries. (Erik Jungstedt, 2020)

5. ESCALATOR WITH TRANSPERENT WOOD BALUSTRADE

Driven by diverse customer requirements, the solution architecture offers two distinct configurable design variants. Configuration 1 prioritizes Horizontal assembly approach, while Configuration 2 emphasizes Vertical assembly approach. These divergent configurations enable tailored deployment, optimizing performance for specific functional objectives and operational constraints identified through client demand analysis.

5.1 Configuration 1

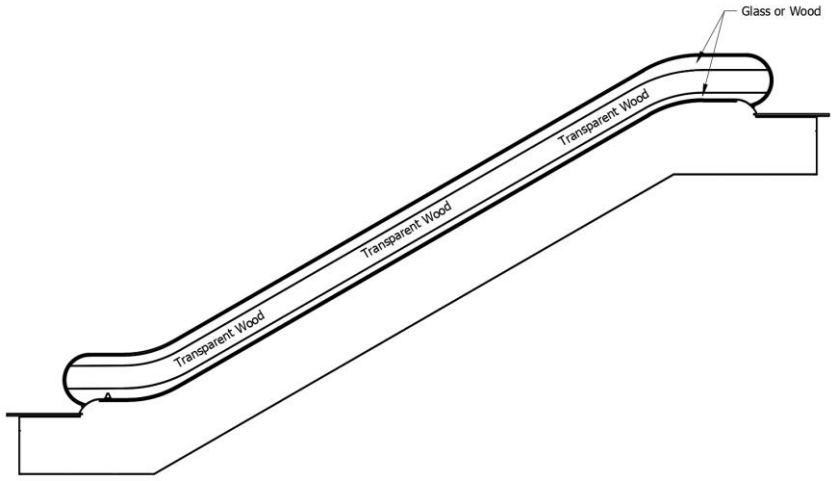

Figure 4 *Escalator with transparent wood balustrade*

The assembly of transparent balustrade systems employs a horizontal sandwich configuration. Within this arrangement, the primary transparent panel is positioned as an intermediate layer between structural elements, typically solid glass or wooden top and bottom rails. This methodology serves a dual purpose: enhancing aesthetic appeal by maximizing visual permeability and perceived lightness, while concurrently augmenting structural robustness by distributing loads through the composite section.

Assembly involves precisely fitting the edges of the transparent panels into pre-formed slots within the adjoining rails or support posts. This interlocking joint system ensures precise alignment and contributes to overall stability. To address potential

lateral forces and vibration, supplementary reinforcement is integrated. This often entails discrete metal brackets, specialized clamping systems, or structural adhesives applied at critical connection points, thereby enhancing the system's rigidity and load-bearing capacity without significantly compromising the desired transparent aesthetic. The combined approach yields a balustrade solution optimizing both visual delicacy and functional integrity.

5.2 Configuration 2

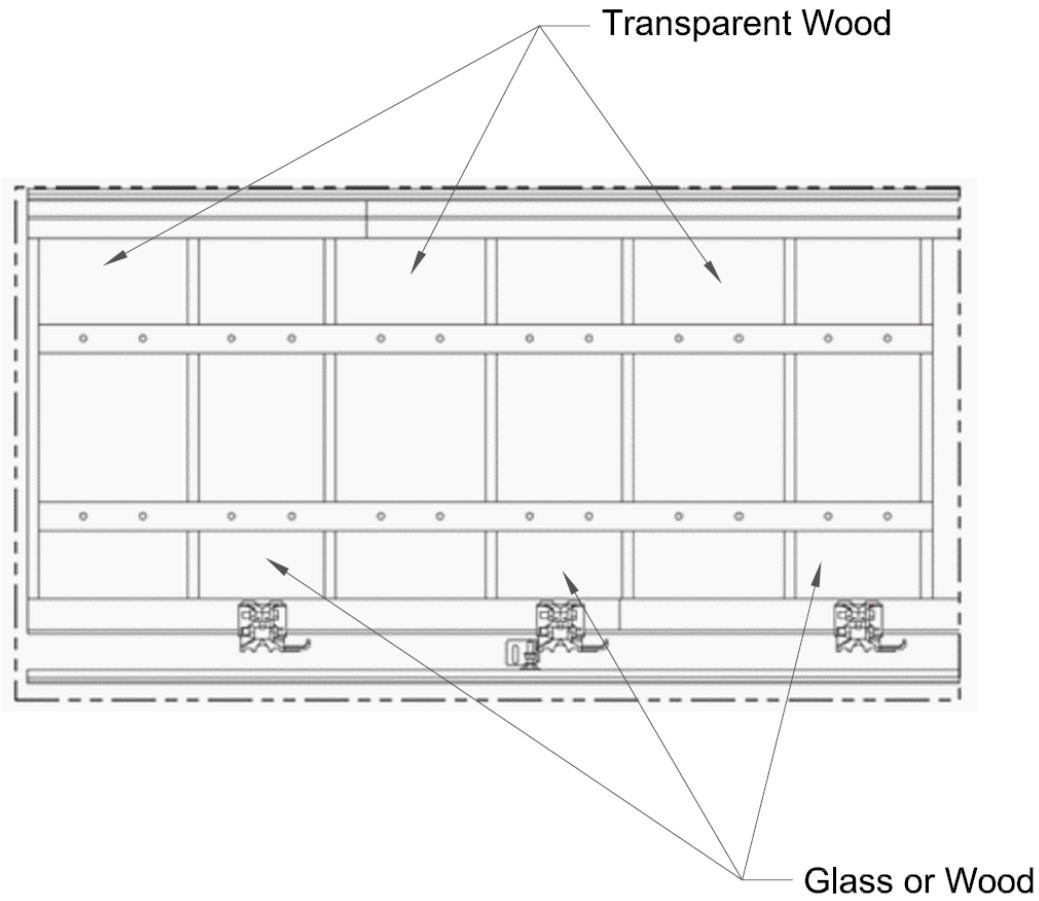

Figure 5 *Escalator with transparent wood balustrade*

The proposed balustrade system incorporates multiple vertical panels arranged in a modular configuration using transparent wood, glass, and conventional wood. These panels are supported at three critical points—top, middle, and bottom—to ensure structural integrity and effective load distribution. Transparent wood, used independently or in combination with other materials, offers a unique balance of mechanical strength, lightweight characteristics, and optical transparency. Unlike conventional glass, transparent wood provides enhanced impact resistance and thermal insulation, making it a practical alternative in architectural applications. The vertical alignment of these panels not only improves safety but also simplifies maintenance and enables efficient panel replacement when needed.

This configuration is particularly suitable for public transportation environments such as escalators, moving walkways, and transit terminals, where safety, visibility, and aesthetics are essential. The successive panel arrangement creates a continuous and visually appealing barrier that enhances the overall architectural appeal of the space. Moreover, the use of transparent wood supports sustainable construction practices by reducing dependence on non-renewable materials and lowering energy consumption through improved natural light transmission. Its renewable origin and biodegradable nature contribute positively to green building standards. The integration of transparent wood in public infrastructure shows its potential as an eco-friendly and structurally efficient alternative to traditional balustrade materials.

6. CONCLUSION

This research successfully proves the feasibility and significant advantages of using transparent wood within a novel multi-material balustrade system for escalators and moving walks. Transparent wood appears as a superior alternative to conventional glass, offering a compelling combination of enhanced safety, improved sustainability, and superior functional properties. Its unique fracture behaviour, characterized by cohesive failure rather than catastrophic shattering, significantly mitigates laceration risks in high-traffic environments. Furthermore, the material's inherent thermal insulation properties contribute to energy efficiency in climate-controlled buildings, while its lower weight reduces structural loads and simplifies handling. Crucially, as a bio-based composite derived from renewable resources and processed with potentially lower embodied energy than glass, transparent wood presents a substantially more sustainable material pathway for the vertical transportation industry.

The dedicated modular assembly system developed alongside the transparent wood panels addresses critical limitations of existing balustrade designs. By enabling rapid installation and replacement without specialized tools or complex fixtures, this system significantly reduces manufacturing complexity, labour costs, and downtime during maintenance. The layered approach employed further improves the material's inherent properties, enhancing impact resistance and load distribution while keeping essential light transmission and diffusion capabilities. This diffusion minimizes glare, improving passenger comfort and visibility without sacrificing the aesthetic transparency required for safety. The result is a robust, user-friendly solution that enhances both operational efficiency and passenger safety.

In conclusion, this multi-material balustrade, cantered on transparent wood and a purpose-built modular assembly, is a transformative advancement for escalator and moving walk design. It effectively overcomes the cost, safety, environmental, and maintenance challenges associated with traditional glass and complex multi-panel systems. The integration of superior material science with innovative mechanical design offers a commercially practical and sustainable solution poised for adoption in modern infrastructure projects seeking enhanced performance and reduced environmental impact.

A patent has been filed on the above research work of using a multi-material balustrade using transparent wood and its dedicated assembly mechanism.

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