The promise of transparent wood as a multifunctional energy material

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Transparent wood has potential not only as a sustainable substitute for glass, but also as a multifunctional energy material whose value lies in the integration of diffuse light management, thermal insulation, mechanical load bearing and sustainability. Its widespread adoption will require application-driven design, realistic durability assessments and alignment with standards.

[H1] Introduction

Partially or completely removing lignin from wood and then infiltrating it with monomers that are polymerized or cured in situ results in a novel type of composite that combines optical transparency, mechanical strength, and eco-friendly sourcing[1-4]: transparent wood. Its properties make it a potential environmentally friendly alternative to glass in buildings and a reliable base for photonic and optoelectronic devices.

Nonetheless, as studies in this field progress, it is increasingly evident that considering transparent wood just as a substitute for glass is too simplistic. This perspective conceals the features that provide transparent wood with distinct value, such as its diffuse light transmission, direction-dependent optical properties, limited heat conduction, and strength under applied mechanical stresses[5-9]. In this Comment, we argue that transparent wood ought to be redefined as an advanced energy material, emphasizing its remarkable optical, thermal, and mechanical properties and its sustainability rather than just its transparency. For instance, it exhibits even better thermal insulation properties than low-emissivity conventional glasses. In addition, it is generally characterized by high haze, thus allowing for homogenous distribution of the transmitted light, which results in more comfortable ambient illumination, especially for glazing applications.

[H1] Main applications

Transparent wood's defining optical feature is not its absolute transparency, but rather its high optical haze[7,8]. Early research showed that wood treated to remove lignin and add polymers lets plenty of visible light pass through. Still, further findings revealed that its natural cell structure scatters light intensely due to directional grain patterns. Hence, sunlight spreads evenly without harsh brightness. At comparable transmittance, transparent wood panels distribute light more homogeneously than glass, improving indoor visual comfort and potentially reducing the demand for artificial lighting[5]. The directional nature of scattering, arising from the aligned wood microstructure, also enables optical design strategies that integrate load-bearing capacity and light management within a single material. This scattering constitutes a structurally encoded optical function rather than a secondary effect. Since the scattering is anisotropic, light is preferentially redistributed along the fiber axis. This increases the internal optical path length while maintaining high transmittance. This behavior enables applications in passive daylighting, photovoltaic light management, privacy glazing, and optomechanical sensing[7]. Transparent wood emerges as a multifunctional, structurally programmable photonic material that couples mechanical strength with anisotropic light control, rather than merely being a sustainable alternative to glass.

Because of their cellular composition, inherited from natural wood, transparent wood composites typically exhibit lower thermal conductivity than glass[6], which might minimize heat loss through building exteriors (such as windows and other light transmitting glass parts).

The performance of transparent wood is strongly determined by wood species because the anatomical template governs optical, mechanical, and thermal behavior. Low-density species, such as balsa, provide higher transmittance and stronger directional scattering, which favors daylighting and photovoltaic applications. Denser woods, such as birch, enhance mechanical strength for structural applications, and softwoods with pronounced growth rings, such as pine, have advantageous anisotropic thermal properties.

Finally, its optical diffusion, mechanical durability, and suitability for large-area applications make transparent wood suitable for optoelectronic and photonic uses, such as substrates for solid-state lighting, luminescent panels, and hybrid photovoltaic systems[1-4]. Rather than enabling high-precision optoelectronics, transparent wood is suited to roles in which light management and mechanical support are equally important, such as diffusive substrates for devices operating at low temperatures and structurally integrated lighting elements.

[H1] Challenges

Despite its potential for applications, several obstacles restrict the practical utilization of transparent wood. One important challenge is durability. Eliminating lignin raises vulnerability to photodegradation, and infiltrated polymers may discolor, become brittle, or deteriorate at the interface when subjected to ultraviolet radiation, moisture fluctuations, and thermal stresses. While protective coatings and chemical stabilization methods can enhance performance, they introduce complexity and frequently compromise the sustainability of the final material.

Processing and scalability pose equally important challenges. The production of transparent wood requires several chemical processes, such as delignification, thorough washing, monomer infiltration and in situ polymerization or curing[2-4]. These processes are time-consuming and may be difficult to scale up without losing uniformity, especially for thick or large wood specimens.

Also, the limited diffusion and anisotropic transport in wood hinder process control and introduce concerns regarding reproducibility and costs that are mostly overlooked in the academic literature.

While sustainability is frequently mentioned as the primary advantage of transparent wood, this topic is more complex than generally recognized. Although the cellulose scaffold is renewable, delignification requires chemicals – which might be fossil-based and non-biodegradable –, water, and energy. Life-cycle assessments show that transparent wood may be more sustainable than glass in specific impact areas with optimistic assumptions, yet the findings are very dependent on system boundaries and energy inputs[10]. Additionally, the hybrid characteristics of transparent wood make recycling and end-of-life management more complex, leaving circularity largely unaddressed.

Ultimately, important regulatory and standardization obstacles persist. As an example, for use in buildings, transparent wood must satisfy stringent standards concerning fire safety, mechanical integrity, visual uniformity, and enduring durability. These issues can also limit the potential applications in optoelectronics, a sector in which standards for qualification and reliability are strictly enforced. At present, the lack of standardized testing procedures and certification routes constitutes a substantial obstacle to real-world implementation.

[H1] Outlook

The future of transparent wood will hinge not on its ability to substitute glass, but instead on its promise to transform the design opportunities of multifunctional energy materials. To accomplish this goal, we need to redirect our attention from individual-property standards to optimization tailored for specific applications. This means considering diffuse light transmission, thermal behavior, structural performance, and environmental impact together.

Advancement requires improvements in processing chemistry, including the creation of more sustainable delignification methods and bio-derived or recyclable polymer systems. It also relies on design strategies focused on durability, emphasizing long-term functionality in actual service conditions. Integrating transparent wood into hybrid material systems is equally crucial, as its distinct combination of properties enhances established materials rather than competing with them.

Transparent wood exemplifies the potential and limitations of bio-based engineered materials amid the shift in energy sources. Its path highlights the necessity for truthful evaluations of performance, cross-disciplinary cooperation, and proactive involvement with standards and policy structures.

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Acknowledgements

The AI-TRANSPWOOD project, HORIZON-CL4-2023-RESILIENCE-01-23 (Grant Agreement 101138191), is gratefully acknowledged. This project is co-founded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them.

Competing interests

The authors declare no competing interests.