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Book of Abstracts

Wood cellulose nanomaterials: diverse and unique structures, morphologies, and characteristics

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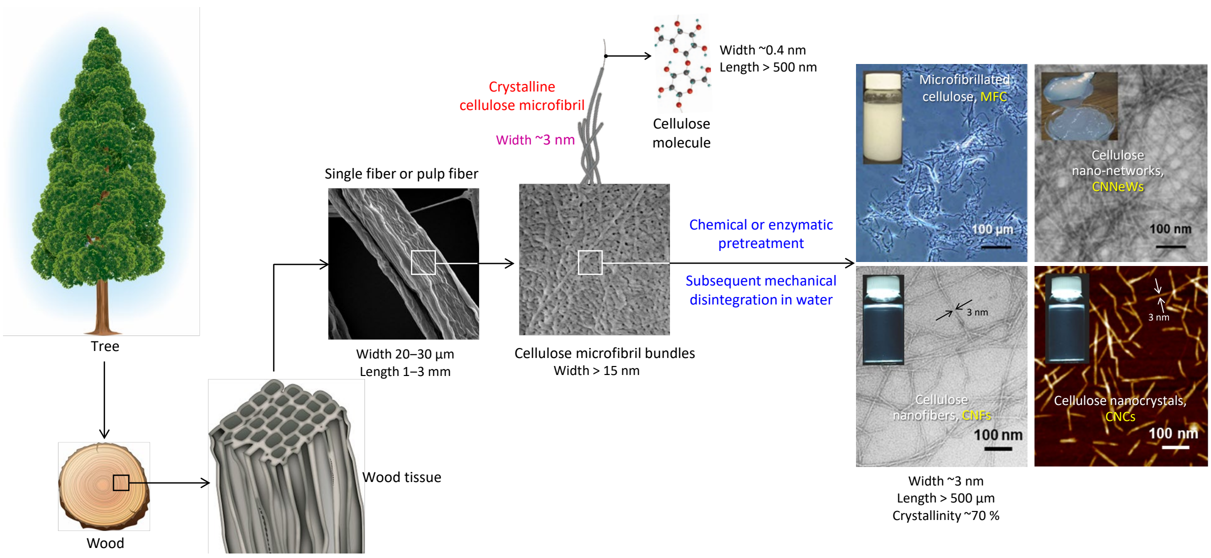
Abstract

Cellulose microfibrils are renewable and crystalline bio-nanofibers most abundantly present in wood as the main component, and annually accumulated in wood from atmospheric CO2 by biosynthesis. Various chemical and enzymatic pretreatments have been developed for efficient conversion from wood cellulose fibers to microfibrillated cellulose (MFC) and diverse nanocellulose materials, such as CNNeWs, CNFs, and CNCs (Fig. 1), depending on the pretreatments and subsequent mechanical fibrillation process in water. CNFs and CNCs with the smallest and homogeneous widths of ~3 nm can be obtained by some chemical pretreatments of wood fibers; their widths are fibrillated from ~30 μm to ~3 nm (or 1/10,000) by downsizing.

As the chemical pretreatments, oxidation, phosphorylation, sulfate esterification, carboxymethylation, and carbamate have been developed, efficiently forming various anionic or nonionic groups, mostly maintaining the original fibrous morphologies and cellulose I crystal structures, i.e., these functional groups are formed position-selectively on all crystalline cellulose microfibril surfaces in each cellulose fiber. These developments of efficient chemical pretreatments to prepare nanocellulose materials have opened new surface chemistry fields in wood cellulose science and engineering.

Although nanocellulose materials have been initially expected to be used for light-weight and strong plastic composites in large quantity for mobilities partly in place of metal or oil-based plastics. However, hydrophilic cellulose nanomaterials, even though they are initially nano-dispersed in water, are prone to formation of aggregates in hydrophobic base plastics, often resulting in inferior properties to those without nanocellulose materials. Furthermore, the production quantity of nanocellulose materials is not so large at present, resulting in high prices, although the resources of nanocellulose materials, i.e., paper pulps, are sufficiently inexpensive. Therefore, more efficient and cost-effective production processes of nanocellulose materials and their suitable applications should be developed for quantitative and qualitative expansion of nanocellulose utilization to commodity goods and industrial materials.



Cellulose microfibrils in trees are bio-based and atmospheric CO_2-accumulated nanomaterials with the largest quantity and annual growth rate on Earth.

Fig. 1: *Conversion from wood cellulose fibers constituting hierarchical structures in wood tissues into micro- and nano-cellulose materials.*

Wood Anatomy and (Ultra)Structure: the need for connecting scales and organs in plant hydraulics

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Abstract

Wood anatomy and ultrastructure play a fundamental role in the functioning and acclimation strategies of woody plants. Indeed, wood traits represent the physics of the plant's structure, which establishes the limits of metabolic and physiological acclimation.

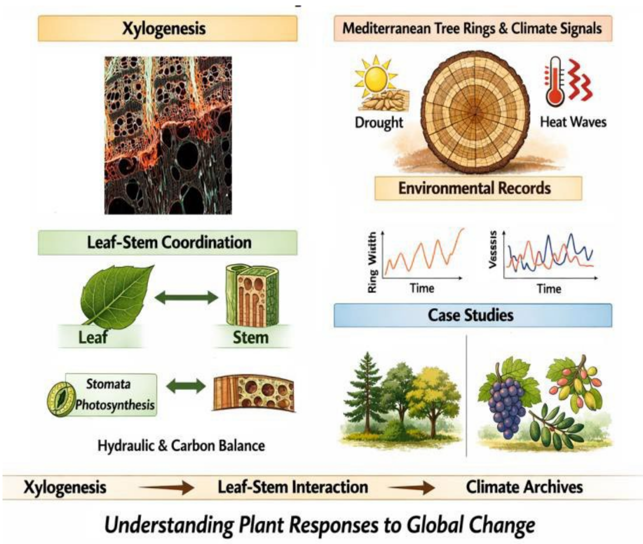
In recent years, quantitative wood anatomy has emerged as a key approach for understanding the acclimation of woody plants. Its relevance extends beyond species-level autoecology, as most of the global vegetation biomass ultimately depends on a very thin layer of cells, namely the vas-cular cambium, whose dynamics shape xylem formation and drive the variability of wood traits. Since xylem structure integrates environmental signals during its formation, wood anatomical traits and growth-rings provide powerful "tools" to investigate plant responses to climate varia-bility. In this framework, linking wood structure with xylogenesis, and further with the coordination between leaf and stem hydraulic traits, opens new perspectives to better understand plant funct-ioning to achieve resilience to climate change in natural ecosystems, as well as in crop systems.

This lecture presents an integrative overview of xylem traits across multiple spatial scales, with particular emphasis on their relevance for plant hydraulics, including efficiency and safety issues along the vascular path through the soil-plant-atmosphere continuum.

A focus will be devoted to study cases conducted on trees and shrubs, including dioecious species, as well as on crops, in the Mediterranean environment, where an increase in the frequency of extreme events, such as severe and prolonged drought periods, is expected. Main findings regarding the processes of xylogenesis will be discussed, highlighting how environmental conditions influence cell production and differentiation, and how they can finally shape anatomical traits observed in tree rings, leaving signals as intra-annual-density-fluctuations.

The lecture will also address the coordination between leaf and stem traits, examining how the study of wood structure needs to be integrated with leaf venation and other anatomical traits, to achieve a comprehensive understanding of the whole-plant hydraulic strategies and carbon–water balance.

Overall, wood is presented as a valuable archive of information on how plants have responded to past environmental changes and cultivation practices. Tools to extract and interpret this information are discussed, with particular emphasis on how understanding wood acclimation potential, and thus plant plasticity, can improve our ability to forecast plants' responses to future climate change, evaluate potential consequences for natural ecosystem dynamics and crop productivity, and support the development of sustainable management strategies under rapidly changing conditions.



X-ray Scattering and Solid-State NMR Reveal Wheat Straw Cell Wall Architecture and Pre-treatment Disruption of Lignin–Carbohydrate Interactions

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Abstract

Plant secondary cell walls constitute the dominant reservoir of renewable biomass, comprising tightly packed cellulose, hemicellulose, and lignin at the nanoscale, yet their extensive lignin–carbohydrate interactions contribute to recalcitrance in biorefinery conversion. Despite recent advanceds in solid-state NMR spectroscopy and the increasing availability of small-angle X-ray scattering for biomass characterization, a unified molecular framework that reconciles spectroscopic and scattering observations and explains how hydrothermal pretreatment disrupts interpolymer interactions has been lacking. Here, using uniformly **13C**-labelled wheat straw as a model system, we integrate X-ray scattering with one- and two-dimensional **13C** solid-state NMR to establish a structural framework consistent with cellulose biosynthesis and native-state cell-wall organization, and to quantify pretreatment-induced interaction changes at atomic resolution. The model features parallel 18-chain cellulose microfibrils that populate the wall cross-section with a largely random arrangement and small interfibril spaces. Arabinose-substituted xylan shows no strong conformational dependence for cellulose binding in wheat; only a minor fraction of two-fold xylan resides in close proximity to cellulose, contrasting with tighter xylan–cellulose association reported in Arabidopsis. While NMR does not unambiguously resolve the internal arrangement of the 18 glucan chains, scattering profiles uniquely constrain fibril size and exclude tight bundling in intact walls, implying that spatial proximity between matrix polymers and cellulose can arise even without strong attractive interactions. Building on this framework, hydration and hydrothermal pretreatments reveal two domain-specific lignin–carbohydrate interaction regimes: labile domains dominated by guaiacyl (G) units with weaker carbohydrate contacts that are readily removed, and stable domains dominated by syringyl (S) units with stronger carbohydrate contacts that resist deconstruction. Hydrothermal treatment further disrupts interactions between unflattened three-fold xylan and lignin, promoting detachment of lignin anchored near cellulose surfaces and concomitantly attenuating cell-wall dynamics and hydration. Together, these findings resolve longstanding discrepancies between scattering and NMR data, redefine matrix–cellulose association in densely packed walls, and provide a molecular basis for efficient lignocellulose deconstruction in next-generation biomass biorefineries.

Processing and Tuning Lignin / Cellulose Multiphase Plastics

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Abstract

Following the pioneering work of Glasser's group in designing multiphase lignin plastics by blending organosolv lignin with liquid crystalline cellulose derivatives1, my research group at the University of Freiburg has expanded on the approach to process liquid crystalline lignin / cellulose blends with 3D printing and shear casting2. Today, this approach enables processing with extrusion and casting-based technologies lignin/cellulosic blends with lignin content as high as 70%. It also delivers multiphase lignin plastics that are highly tunable in mechanical properties.

In this lecture, the main findings from a decade of research at the University of Freiburg on such lignin multiphase plastics will be highlighted. Insights on the molecular mechanisms underlying the tunability of properties in lignin multiphase plastics will be presented. Further, the need for continuing research to enable upscaling and foster technology transfer in lignin multiphased plastics will be discussed.

[1] T.G. Rials, W.G. Glasser, J. Appl. Polym. Sci., 37 (1989), 2399, 10.1002/app.1989.070370827; T.G. Rials, W.G. Glasser, Wood Fiber Sci, 21 (1989), 80.

[2] F. R. Gleuwitz, G. Sivasankarapillai, G. A. de Freitas Siqueira, C. Friedrich, and M-P. Laborie, ACS Appl. Bio. Mat., 3 (2020), 9, 6049 ; M.-P. Laborie, L.S. Billharz, W. Glasser, US Patent App. 18/700,761, 2025; F. R. Gleuwitz, G. Sivasankarapillai, A. Bentaleb, N. Kohlhuber, M.-P. G Laborie, Giant, 21 (2025),100344.

Oversights in the Study of Wooden Cultural Heritages by Wood Anatomists

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Abstract

Wooden Cultural Heritages (WCHs) constitute one of the most information-rich yet persistently underestimated categories of global cultural heritage. While stone, metal, and ceramics have long dominated archaeological and conservation narratives, wooden artefacts—despite their central role in past technologies, economies, and environments—remain marginal in interpretive practice. Paradoxically, this marginalization persists even within wood science itself. Wood anatomical research has contributed indispensably to species identification of WCHs. Yet, in many cases, taxonomy has become not a foundation but a terminus. This presentation argues that the routine reduction of wooden heritage to species names represents a self-imposed limitation that has curtailed the intellectual contribution of wood anatomy to archaeology and conservation. In European and Asian heritage contexts especially, where wooden structures, shipwrecks, and waterlogged remains are abundant, this narrow focus has resulted in substantial analytical loss. Drawing on examples from archaeology, historic architecture, shipbuilding, and traditional repair practices, this study highlights categories of evidence that are frequently overlooked or underexploited: tool marks, woodworking techniques, assembly logic, macro-anatomical traits, and signatures of biological degradation. When examined alongside anatomical data, these features offer insights into timber procurement, environmental conditions, technological decision-making, craft transmission, and material performance over time. Wood anatomists are also uniquely positioned to critically evaluate degradation processes and the efficacy of conservation treatments, particularly in waterlogged contexts. Given that WCHs are finite and sampling is inherently destructive, producing only taxonomic labels from invasive analyses is increasingly difficult to defend. A decisive shift toward an integrated, question-driven framework—bridging wood anatomy, archaeology, anthropology, and conservation science—is no longer optional, but overdue.

Node development and structure in monocots, the multi-layer phloem networks in corn (*Zea mays*) *versus* horizontal circular vascular patterns around the pith in rice (*Oryza sativa*)

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Abstract

Nodes are unique structural and physiological sites along the plant shoot, where vascular tissues initiate, merge, or branch. They are important junctions of vascular pathways from roots to leaves and vice versa, as well as from photosynthesizing leaves to developing young organs above them. The horizontal modifications of the fibers in nodes affect the structural continuity of wood composition, which therefore may affect the physical properties and strength of young trunks and branches.

In this study, we compare node development and vascular organization in two economically important monocotyledonous species: maize (*Zea mays*) and rice (*Oryza sativa*). Our research reveals a previously undescribed novel multi-layer pattern of early phloem networks in maize that is correlated with the number of leaves above the node. This finding contrasts with the horizontally oriented circular vascular arrangement surrounding the pith in rice nodes. In both plant species, horizontal phloem strands are the first to differentiate, followed later during stem development by the formation of wide vessels. The hormonal modifications and ecological significance that induce these patterns will be clarified [1].

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[1] Aloni, Roni. Vascular Differentiation and Plant Hormones. Springer, Cham, 2021

Wood anatomy - from tradition into the digital future. Development of new methodological approaches for the identification of internationally traded timber

Gerald Koch[1], Immo Heinz[1], Volker Haag[1] and Andrea Olbrich[1]

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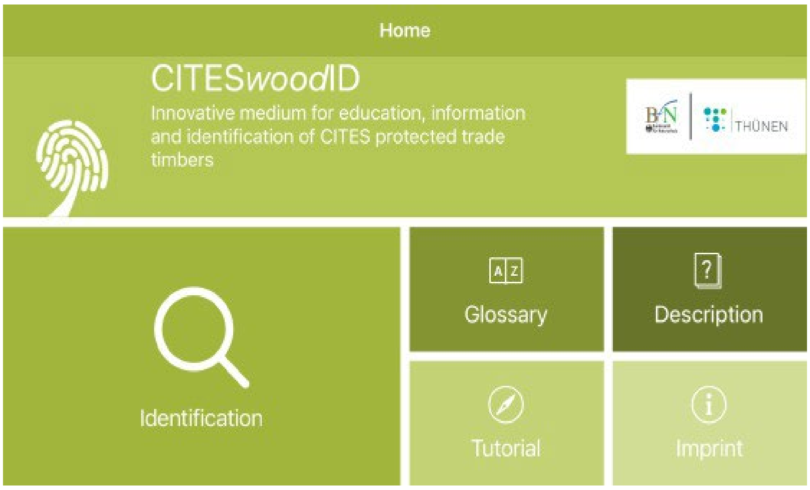
Abstract

Wood anatomy has traditionally constituted the scientific basis for timber identification in international trade, relying on expert knowledge and classical microscopic analysis. However, increasing globalization, complex supply chains, and the rise of illegal logging impose new demands on established identification practices. This contribution addresses the transition of wood anatomical identification from traditional, experience-based methods toward digitally supported and data-driven approaches. These emerging methodologies integrate high-resolution imaging, quantitative extraction of anatomical features, and machine-learning-based classification. By bridging classical wood anatomical expertise with modern digital technologies, these approaches aim to enhance the accuracy of timber identification, thereby strengthening trade control mechanisms, and efforts toward sustainable forest management.

In the context of these important challenges wood anatomy provides the most valuable support for practical wood identification and is routinely applied in the daily control of wood and wood products. Overall, the anatomical descriptions of about 10,000 taxa of hardwoods and softwoods are currently available and documented in several computerized databases, e.g., InsideWood or Commercial timbers, macroHOLZdata and CITESwoodID [1], amongst numerous others.

By using these important references and the development of new digital identification systems and databases, the Thünen Centre of Competence on the Origin of Timber, Germany has processed more than 11,000 official requests for microscopic wood identification since the implementation of the European Timber regulation (EUTR) in Germany in March 2013. The range of test samples comprises solid wood, plywood, and, with a strongly increasing number of requests, fibre-based materials (MDF), in addition to paper and paper products. The submitted presentation provides a comprehensive overview of the work and experience of the Centre of Competence in developing new methodological approaches supporting the enforcement of international timber regulations through anatomical wood identification [2].



Desktop App CITES*woodID*

[1] Koch G, Richter, H-G, Schmitt, U (2011): The database CITESwoodID - Computer-aided identification and description of CITES-protected trade timbers IAWA Journal 32 (2), 213-220.

[2] Nieradzik L, Sieburg-Rockel IJ, Helmling S, Keuper J, Weibel T, Olbrich A, Stephani H (2024) Automating wood species detection and classification in microscopic images of fibrous materials with deep learning. Microsc Microanal 30(3):508-520.

Touch the history through wooden relics in China

Yafang Yin [1,2,3], Juan Guo [1,2,3], Lichao Jiao [1,2,3], Yang Lu [1,2,3], Ren Li [1,2,3], Chang Zheng [1,2,3]

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Abstract

As human societies develop, interactions among biogeography, forests, and human activities have become increasingly prominent, particularly regarding human demands for livelihoods and wood production. The desire to better understand and preserve cultural heritage for future generations has long been a major driver in the exploration of wooden relics in the natural and social sciences. Wood knowledge is critical for uncovering the historical narratives encapsulated within these artifacts, evaluating risks of accelerated degradation, and consolidating them for long-term conservation, yet remains a persistent challenge in archaeological practice due to methodological limitations. In this presentation, investigations of selected important wooden relics in China, including waterlogged water conservancy facilities, marine shipwrecks and historical timber structures are demonstrated how preserved wood materials can bridge with historical information. Challenges for further research are also discussed.

[1] Zheng C, Jiao L, He T, Lu Y, Liu S, Li T, Ye R, Zhou H, Yin Y. Deep learning-based in-situ coniferous wood identification of components in heritage architectures of China, npj Heritage Science, 2025, 546, 1-13.

[2] Li R, Guo J, Macchioni N, Pizzo B, Xi G, Tian X, Chen J, Sun J, Jiang X, Cao J, Zhang Z, Yin Y. Characterisation of waterlogged archaeological wood from Nanhai No.1 shipwreck by multidisciplinary diagnostic methods. Journal of Cultural Heritage, 2022, 56: 25-35.

IAWS Activities and Emerging Trends in Wood Anatomy and Dendrochronology

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Abstract

Recent activities and emerging trends in wood science will be reviewed from the perspective of a recent member of the IAWS Academy Board. The presentation will commemorate recently deceased distinguished Fellows whose sustained efforts significantly improved regional representation and gender balance within the IAWS Fellowship, thus contributing to a more inclusive and diverse Academy. These efforts are now yielding tangible results, with female Fellows serving on the Executive Board, including the election of the first female IAWS Vice-President for the term June 2026–May 2029. Nevertheless, the currently low proportion of women Fellows indicates that further progress is needed.

Current advances in wood science research and development are largely based on innovations ranging from novel wood-based materials with enhanced properties to pioneering preservation techniques, highlighting the potential of wood as a versatile and renewable resource. In this context, the roles of wood anatomy and dendrochronology will be discussed, with examples illustrating their effectiveness in addressing a wide range of wood-related research questions.

Wood anatomy, organised within the International Association of Wood Anatomists (IAWA), has traditionally provided essential knowledge for wood identification, while increasingly fostering an interdisciplinary and globally connected scientific community. A similar evolution has occurred in dendrochronology, organised both informally and through societies such as the Tree-Ring Society (TRS) and the Association for Tree-Ring Research (ATR). Classical wood anatomy, based on advanced microscopy techniques and increasingly complemented by isotope, DNA, and other analytical approaches, remains a fundamental research tool.

One of the prominent emerging fields is the study of wood formation, enabled by the development of less destructive sampling of tissues from living trees, improved preparation of small tissue samples, standardised procedures, and advanced analytical methodologies. These developments have facilitated numerous local studies across diverse environments and species, whose results, integrated into large datasets, have helped to resolve the questions of climatic control of physiological processes on growth phenology, with attention to onset and cessation of growth, biomass production, and carbon dynamics, particularly in temperate and boreal conifers. At the same time, enhanced knowledge of wood formation has contributed to the calibration and use of dendrochronology for environmental and tree physiological studies. Combined with high-resolution climatic data, this has enabled detailed insights into tree functioning in relation to climatic parameters at daily scales and implications for wood structure and quality. Collectively, these advances support improved understanding, management, and sustainable use of wood.

Beyond wood anatomy: a unifying framework for functional, historical, and applied wood science

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[2]*Forest Biometrics Laboratory, Faculty of Forestry, "Stefan cel Mare" University of Suceava, Str. Universitatii 13, 720229 Suceava, Romania.*

Abstract

Wood anatomy has traditionally been regarded as a descriptive discipline, primarily supporting wood identification, taxonomy, and material characterisation. Sixty years after the foundation of the International Academy of Wood Science, however, it is timely to reconsider the role of wood anatomy not as a specialised endpoint, but as a unifying conceptual framework that connects diverse branches of wood science.

Wood anatomy provides a common structural language that links plant development, functional ecology, dendrochronology, materials science, and cultural heritage research. Wood anatomical traits are not static descriptors but dynamic expressions of developmental processes, environmental constraints, and mechanical and physiological functions. When interpreted within this broader perspective, wood anatomy becomes central to understanding structure–property relationships, intra- and inter-individual variability, and long-term wood performance under both natural and anthropogenic influences.

Drawing on examples from modern trees, historical timber, and archaeological wooden objects, this contribution illustrates how anatomical observations gain explanatory power when integrated with ecophysiology, growth dynamics, ageing processes, and conservation science. Particular attention is given to the risks of disciplinary fragmentation, whereby anatomical data are increasingly used without anatomical reasoning, and to the need for explicit reporting of uncertainty and variability in applied contexts such as identification, diagnostics, and modelling.

By reframing wood anatomy as a bridging discipline rather than a subsidiary tool, this contribution aligns with the founding vision of IAWS while addressing contemporary challenges related to sustainability, digitalisation, and interdisciplinarity. It calls for renewed investment in anatomical expertise, integrative training, and conceptual clarity, positioning wood anatomy as a cornerstone for the next generation of wood science.

Diverse wood anatomical responses of beech and oak to climatic variability in Slovenia

Peter Prislan[1], Jernej Jevšenak[1] Domen Arnič[1], Gregor Božič[1], Luka Krajnc[1], Marjana Westergren[1], Hojka Kraigher[1], Polona Hafner[1] and Jožica Gričar[1]

[1]*Slovenian Forestry Institute, Slovenia*

Abstract

Quantitative wood anatomy enables the measurement of morphological characteristics of individual xylem cells (e.g. vessel lumen size and cell wall thickness) within annual growth rings and provides detailed insight into wood formation processes. By linking anatomical traits to environmental drivers, this approach helps elucidate how climatic conditions shape wood structure, thereby influencing the hydraulic and mechanical properties of wood and, ultimately, tree performance and survival. Changes in wood anatomy also affect other functional properties, such as wood density and mechanical strength, making quantitative wood anatomy a valuable tool for assessing tree plasticity and adaptive capacity under changing environmental conditions.

We focused on two ecologically and economically important broadleaved taxa, European beech (Fagus sylvatica) and oaks (Quercus robur, Quercus petraea, Quercus pubescens), growing under contrasting climatic conditions in Slovenia. Ten oak seed stands, including sessile oak, pedunculate oak, and mixed stands included in the study. A similar sampling design was applied to beech, and in addition, intraspecific variability was assessed by comparing provenances grown in two international provenance trials differing in environmental conditions [1]. For each site chronologies of wood anatomical traits and ring-width parameters were established e.g., ring width as well as vessel lumen area, hydraulic diameter, theoretical hydraulic conductivity, and relative conductive area. These data were used to investigate long-term relationships between climatic conditions and anatomical characteristics of tree rings at annual and intra-annual scales [2]. Furthermore, we also evaluated relationships between wood anatomy and the physical properties of wood [3].

Our studies suggest species-specific and provenance-specific growth and anatomical responses to climatic variability, highlighting long-term structural adjustments to local environmental conditions. In both beech and oak, anatomical traits provide complementary information to ring width alone, demonstrating the value of integrating dendrochronology and quantitative wood anatomy to improve the interpretation of climate–growth relationships and climate-driven controls on wood formation under ongoing climate change.

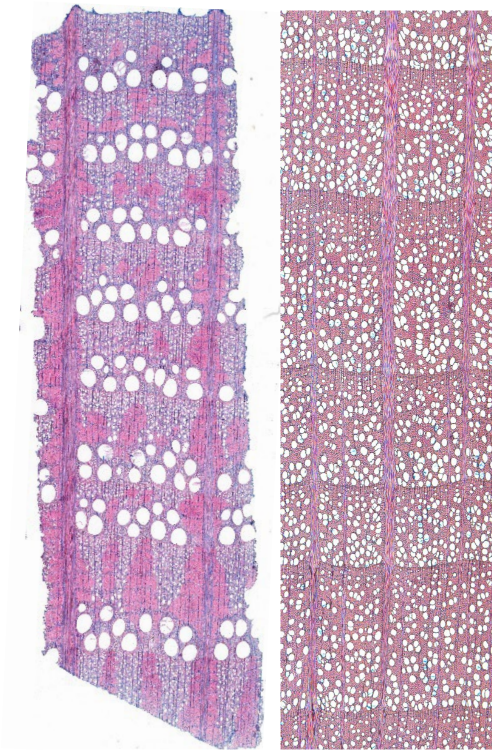

Fig. 1: *Cross-sections of oak and beech cores prepared for analysis of wood anatomical features.*

[1] Gričar J., Arnič D., Krajnc L., Prislan P., Božič G., Westergren M., et al. Different patterns of inter-annual variability in mean vessel area and tree-ring widths of beech from provenance trials in Slovenia and Hungary. Trees 38 (2024).

[2] Arnič D., Gričar J., Jevšenak J., Božič G., von Arx G., Prislan P. Different wood anatomical and growth responses in European beech (Fagus sylvatica L.) at three forest sites in Slovenia, Front Plant Sci. 12 (2021)

[3] Arnič D., Krajnc L., Gričar J., Prislan P. Relationships between wood-anatomical features and resistance drilling density in Norway Spruce and European Beech. Front Plant Sci. 13 (2022)

Insights from 4D Micro-CT: Does density fully govern compressive failure in wood?

Bingrui Chen [1,2,3], Matthieu Boone [2,4], Wim Van Paepegem [3], Joris Van Acker [1,2], and Jan Van den Bulcke [1,2]

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[3] *UGent-MMS, Mechanics of Materials and Structures, Department of Materials, Textiles and Chemical Engineering, Ghent University, Technologiepark-Zwijnaarde 46, 9053, Belgium;*
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Abstract

Wood density is widely used as a primary predictor of mechanical performance. However, whether density alone governs compressive damage evolution remains unclear. In this study, we investigate the role of anatomical topology in compressive failure using time-resolved in-situ 4D micro-CT [1] on eight representative wood species. To decouple density effects from anatomical contributions, we directly compared Pseudotsuga menziesii and Castanea sativa, which exhibit comparable density and radial elastic modulus ($p>0.05$). Despite their similar macroscopic mechanical properties and comparable yield points, the two species displayed fundamentally different post-yield damage evolution and failure localization patterns. Our results indicate that density primarily governs the onset of yielding, whereas anatomical topology controls post-yield damage propagation and structural survival strategy. These findings suggest that compressive failure behaviour in wood cannot be fully predicted by density alone, highlighting the necessarily to incorporate anatomical features into mechanical performance models.

[1] Dierick, M., Van Loo, D., Masschaele, B., Van den Bulcke, J., Van Acker, J., Cnudde, V. and Van Hoorebeke, L., 2014. Recent micro-CT scanner developments at UGCT. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 324, pp.35-40

Automated wood identification on microscopic images of fibrous materials and µCT of solid wood

Stephanie Helmling[1], Jördis Sieburg-Rockel[1], Lars Nieradzik[2], Janis Keuper[2], Linghui Liu[2], Thomas Weibel[2], Petra Gospodnetić[2], Falco Hirschenberger[2], Stephanie Wrage[1], Henrike Stephani[2], Andrea Olbrich[1] Sub-µCT and nano-CT: Jannik Stebani[3,4], Tim Lehne[1], Kilian Dremel[3], Simon Zabler[3,5], Volker Haag[1]

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[4]*Experimental Physics 5, Faculty of Physics, University of Würzburg, Würzburg, Germany*
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Abstract

Anatomical wood species identification is a key tool for verifying timber trade flows and supporting forest protection by assessing the declaration and legality of wood products. However, the limited number of wood anatomy experts and the high volume of globally traded timber products restrict large-scale application. Computer vision and artificial intelligence (AI) therefore offer substantial potential for scaling identification capacity. To date, separate AI models are typically required depending on the degree of material processing and imaging resolution. This presentation introduces two ongoing projects at the Thünen Institute of Wood Research conducted in collaboration with partners.

Firstly, the WoodFiberID project in cooperation with the Fraunhofer Institute for Industrial Mathematics: For the first time, AI models are trained to identify wood genera in fiber materials such as paper and fiberboard [1-4]. Most microscopic features for wood identification are not visible in this dissolved condition, therefore the mixture of genera in a sample must be identified by using information on individual cells. In a guided training process, the vessel elements crucial for hardwood identification are detected and classified in separate steps. Currently, nine classes of hardwood genera can be identified, including two classes each consisting of two very similar genera (Fig 1 left). The development of detection and classification of softwood characteristics is in progress.

Secondly, we would like to present the work carried out in collaboration with the Fraunhofer Development Center for X-ray Technology EZRT and the Faculty of Applied Computer Science at the Deggendorf Institute of Technology. In a series of studies conducted in 2025 [5] [6], it was possible for the first time worldwide to demonstrate the extent to which digital volumetric data sets based on submicro- and nano-CT measurements can be used for wood identification. The major advantages compared to image data based on conventional transmitted light microscopy lie in the much higher resolutions. Additionally, three-dimensional representations can be generated that show far more structural features (Fig 1 right) than samples prepared with classic section techniques for microscopy. In the “proof-of-concept study,” the new technological approach was tested for the first time in a comparison of softwood (pine) and hardwood (maple).

Both studies share the common goal of enabling broader application of wood anatomical analyses in the future through automation of identification.

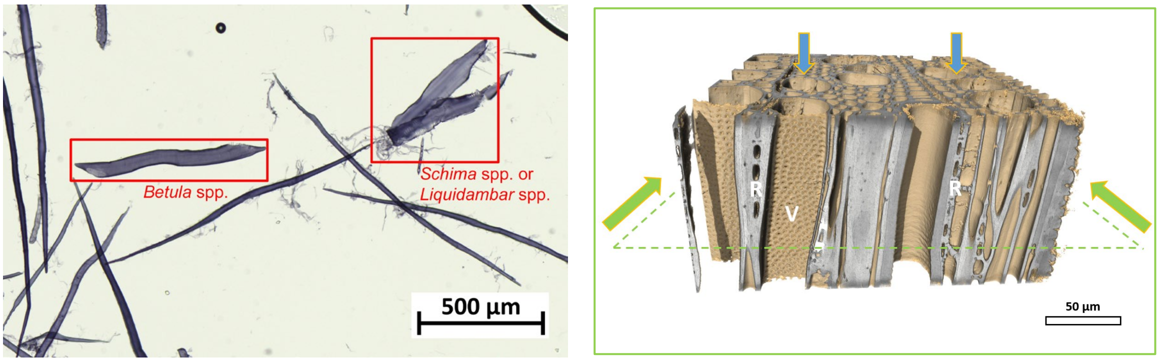

Fig. 1, Left: *Microscopic image of a blind test sample with detected and classified vessel elements.*
Right: *Volumetric 3D representation of a µCT measurement of black alder wood (Alnus glutinosa).*

[1] Nieradzik L, Sieburg-Rockel IJ, Helmling S, Keuper J, Weibel T, Olbrich A, Stephani H (2024) Automating wood species detection and classification in microscopic images of fibrous materials with deep learning. Microsc Microanal 30(3):508-520, DOI:10.1093/mam/ozae038

[2] Nieradzik L, Stephani H, Sieburg-Rockel IJ, Helmling S, Olbrich A, Keuper J (2024) Challenging the black box: A comprehensive evaluation of attribution maps of CNN applications in agriculture and forestry. In: Radeva P, Furnari A, Bouatouch K, Sousa AA (eds) Proceedings of the 19th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2024). Vol. 2. pp 483-492, DOI:10.5220/0012363400003660

[3] Nieradzik L, Stephani H, Sieburg-Rockel IJ, Helmling S, Olbrich A, Wrage S, Keuper J (2024) WoodYOLO: A novel object detector for wood species detection in microscopic images. Forests 15(11):1910, DOI:10.3390/f15111910. https://literatur.thuenen.de/digbib_extern/dn069063.pdf

[4] Sieburg-Rockel IJ, Helmling S, Nieradzik L, Wrage, S, Weibel T, Lehne T, Haag V, Heinz I, Heddier J, Stephani H, Olbrich A (2026), Wood identification in fiber materials: a comparative blind test study of artificial intelligence and human experts Holzforsch (accepted on 2025/12/22)

[5] Stebani J, Lewandrowski TL, Dremel K, Zabler S, Haag V (2025) Technical framework of advanced volumetric sub-µ-CT wood imaging integrated with adaptable deep-learning-based wood species classification: initial evaluation on softwood and hardwood data. IAWA J: Online First, Aug 2025, DOI:10.1163/22941932-bja10196

[6] Stebani J, Lewandrowski TL, Dremel K, Zabler S, Haag V (2025) Evaluation and mitigation of domain shift impact between volumetric submicro-scale and micro-scale computed tomography systems in the context of automated binary wood classification. J Nondestruct Eval 44(4):134, DOI:10.1007/s10921-025-01272-z

Mechanism of LPMOs-mediated Interface Enhancement in Directional Dissociation and In-situ Reassembly of Fruit Wood Cell Walls

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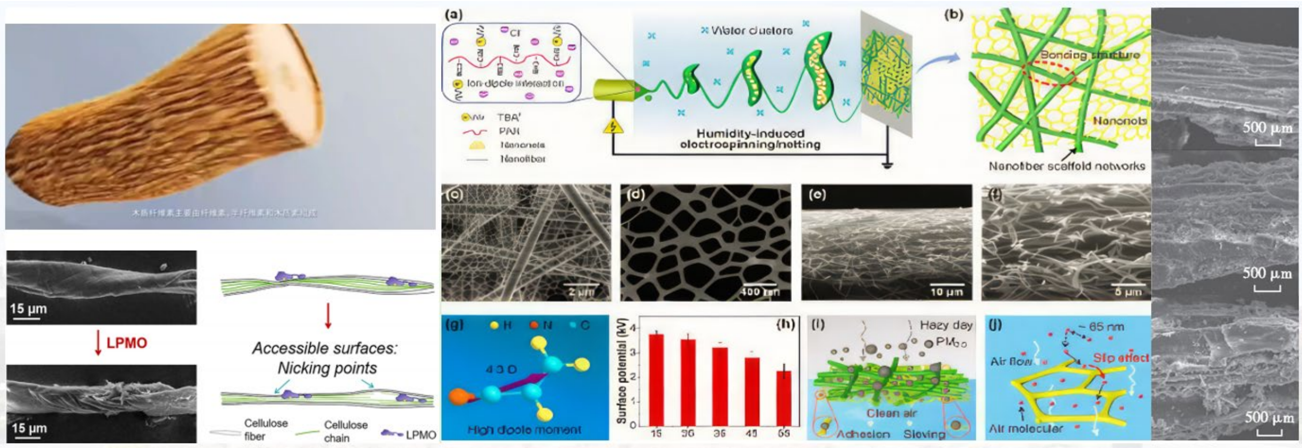
Abstract

The annual consumption of fruit trees in China is less than 1/5 of their growth volume. The rigid and dense structure of fruit tree cell walls, coupled with the unstable interfacial properties of the products, pose challenging issues that hinder the development of the lignin resources industry. Based on the discovery that lyase polysaccharide monooxygenases (LPMOs) can effectively achieve directional dissociation of fruit tree cell walls, this study focuses on the key scientific issues of efficient directional dissociation and interfacial reinforcement of fruit tree cell walls. It aims to investigate the directional dissociation components of LPMOs, multi-scale cellular structure, in-situ activation and interfacial recombination, micro-mechanical properties and reinforcement mechanisms of the recombined interface, and the multi-recombination effect relationship between chemical components/cellular structure/interfacial properties, namely, the four aspects of directional dissociation-in-situ recombination-interface reinforcement-structure-activity synergy. The study proposes a new theory of activated lignin self-gluing "in-situ recombination" and "enzymatic activation-covalent crosslinking", creates a new mode of "bio-physical" synergistic technology, and innovatively adopts methods such as microscopic imaging (AFM) and spectroscopy (Nano-IR) to clarify the controllable dissociation mechanism of LPMOs on fruit tree cells and elucidate the mechanism of directional dissociation and in-situ recombination interface reinforcement of fruit tree cell walls by LPMOs. This study is expected to achieve stable improvement in the mechanical properties of recombinant wood, providing a new path that is both environmentally friendly and efficient for the low-carbon utilization of hardwood.



[1] Yuan J Y, Li Y B, Li S L. et al. Hydrothermal enzyme pretreatment on structure and properties of apple branches. Holzforschung, 2024, 78(6): 352-361.

[2] Guo H B, Chang Z F, Lu Z Y. et al. Enhanced humification of full-scale apple wood and cow manure by promoting lignocellulose degradation via biomass pretreatments. Science of The Total Environment, 2024, 929: 172646.

Mechanical Properties Enhancement of Wood Veneer by Incorporating Cellulose Nanocrystals

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Abstract

Wood properties vary due to differences in species, growth conditions, and moisture content, which can make achieving consistent performance challenging. This study investigated the enhancement of mechanical properties in wood veneers through sequential delignification and cellulose nanocrystal (CNC) impregnation combined with vacuum-assisted treatments. Cherry wood veneer sheets with 175 mm length, 170 mm width, and 0.5 mm thickness were impregnated with glacial acetic acid-treated cellulose nanocrystals (CNC) obtained from popular wood [1,2]. Wood veneers were first delignified using a 2% NaOH solution to remove cell wall extractives and partially degrade hemicellulose, creating a porous structure while minimizing cellulose and lignin degradation. Wood specimens (35 mm × 15 mm × 0.5 mm) were first pre-dried in a vacuum oven at 70 °C under 600 mmHg for 30 minutes. The samples were immersed in the CNC solution (0.5-2%) and subjected to ultrasonication for 25 minutes at 90% amplitude, enhancing CNC penetration via acoustic cavitation. Thereafter sample-containing solution was transferred to a sealed vacuum chamber and subjected to 600 mmHg vacuum for 100 minutes to promote further infusion of CNCs into the wood structure [3]. Oven-dried samples were subjected to mechanical tests. Flexural testing revealed that select formulations significantly outperformed untreated controls, with the highest modulus of elasticity (MOE) increase of approximately 118% and the highest modulus of rupture (MOR) increase of 53% observed in the pre-sonicated 2% CNC solutions and in the vacuum-oven-dried veneer treatment. Atomic force microscopy (AFM) revealed up to a 107% enhancement in the elastic modulus, confirming effective CNC incorporation at the cell wall level. Moreover, AFM results showed negligible variations in modulus from the sample edges to the centre and no signs of CNC agglomeration, indicating uniform dispersion across the veneers. Critical variables impacting performance include the absence of chemical delignification, CNC concentration, and impregnation methods involving ultrasonication and vacuum oven drying. Delignification facilitated cell wall collapse and densification, while CNC impregnation restored and enhanced mechanical strength by forming nanoscale reinforcement networks. Optimal nanoscale stiffness was achieved with 0.5% CNC and 2% CNC loading, attributed to improved dispersion and penetration via ultrasonication.

[1] Agarwal, U. P.; Ralph, S. A.; Reiner, R. S.; Hunt, C. G.; Baez, C.; Ibach, R.; Hirth, K. C. Production of High Lignin-Containing and Lignin-Free Cellulose Nanocrystals from Wood. 2018. Cellulose, 25 (10), 5791–5805, https://link.springer.com/article/10.1007/s10570-018-1984-z

[2] Shojaeiarani, J., D. S. Bajwa, and N. M. Stark. 2018. Green esterification: A new approach to improve thermal and mechanical properties of poly (lactic acid) composites reinforced by cellulose nanocrystals. J. Appl. Polym. Sci. 135(27):46468. https://doi.org/10.1002/app.46468

[3] Bajwa, D. S., Ara, I., Chan, A. O., Bajwa, S. G., & Hartman, K. E. 2024. Transforming Wood into a High-Performance Engineering Material via Cellulose Nanocrystal Impregnation. Forest Products Journal, 74(1), 62-71.

Transforming Wood into Functional Materials via Dissolution-Regeneration Processing with Molten Salt Hydrates

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Abstract

Wood-derived materials are attracting growing interest as renewable, biodegradable, and sustainable alternatives to petroleum-based products. Woody biomass can be transformed into diverse functional materials—including foams, films, hydrogels, and aerogels—with tunable morphology, surface chemistry, and physicochemical properties for emerging applications in energy, packaging, agriculture, and environmental management.

An effective strategy for fabricating these materials involves dissolving or dispersing woody biomass in a solvent, followed by regenerating the materials into a tailorable form. Among the solvents explored, molten salt hydrates (MSHs) have emerged as particularly promising. MSHs are concentrated aqueous salt solutions with water-to-salt molar ratios near the cation coordination number, exhibiting unique properties such as low viscosity, high boiling point, low vapor pressure, and enhanced acidity. In particular, certain MSHs can swell and dissolve cellulose, enabling efficient processing and valorization of lignocellulosic biomass.

This presentation highlights our recent advances in producing functional materials from cellulose, lignin, and whole wood using MSH-based processing. The resulting wood-derived films, foams, hydrogels, and aerogels exhibit outstanding performance in mechanical-energy harvesting, self-powered sensing, moisture harvesting from air, smart and biodegradable packaging, soil-degradable mulch films, and pollutant removal from both air and water. These findings demonstrate a versatile and sustainable platform for converting wood into high-value, multifunctional materials.

[1] Zhang et al. *Polymers*, 2018, 10, 614
[2] Liao et al. *ACS Sustain Chem Eng,* 2019*,* 7, 17723–17736
[3] Zhang et al. *Adv Funct Mater*, 2020, 30, 2001763
[4] Li et al. Green Chem, 2021, 23, 2778–2791
[5] Liao and Pan. *Environ Sci Nano,* 2021, 8, 1283–1295
[6] Yang et al. *Environ Pollut, 2021, 286, 117324*
[7] Lin et al. *Adv Funct Mater*, 2022, 32, 2209262
[8] Pang et al. *Carbohydr Polym Tech*, 2024, 7, 100522
[9] Zhang et al. *Adv Sustain Syst*, 2025, 9, 2400688
[10] Li et al. *Adv Funct Mater*, 2025, 35, 2412324
[11] Xie et al. *Chem Eng J.*, 2025, 168461
[12] Williams et al. *HortScience*, 2025, 60, 7, S385.
[13] Du et al. *Chem. Rev.*, 2025, 125, 11666–11814
[14] Chen et al. *Matter*, 2026, in press.

Regulated Construction of Cellulose Functional Materials and Their Applications in Energy and Light/Thermal Management

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Abstract

Cellulose, as a renewable and structurally designable natural polymer, provides a versatile platform for the development of advanced functional materials in energy conversion and light/thermal management. Our works systematically investigate the regulated construction of cellulose-based functional materials by integrating molecular- and nanoscale structural control with multiscale assembly strategies, and further explore their multifunctional applications across diverse energy-related systems. In hydrovoltaic power generation and solar-driven interfacial water evaporation, rationally designed asymmetric architectures and gradient transport channels enable the synergistic enhancement of coupled electrical, thermal, and mass transfer processes. In triboelectric nanogenerators, the intrinsic differences in molecular structure and surface chemistry between cellulose and its derivatives are effectively exploited to achieve sustainable mechanical energy harvesting and self-powered human–machine interaction. For energy storage devices, particularly separator materials, regulation of the molecular aggregation state and wettability of cellulose homogenizes ion transport behavior, leading to markedly improved electrochemical stability and long-term device durability. Beyond energy-related applications, the tunable optical, thermal, and radiative properties of cellulose-based materials are leveraged to construct multifunctional systems integrating light management, thermal management, phase-change thermal energy storage, radiative cooling, and photothermal conversion. These material systems are further extended to optical applications such as fluorescence and room-temperature phosphorescence, exhibiting excellent environmental adaptability, structural robustness, and processability into diverse forms, including films, fibers, aerogels, and textiles. Overall, our works establish a unified structure–function–application framework for cellulose functional materials, offering new insights into the rational design of sustainable wood-derived materials for next-generation energy and light/thermal management technologies.

[1] Zhang, J.; Dong, H.; Yu, Y.; Yin, S.; Cao, M.; Li, C.; Shen, X.; Li, J.; Xu, Y.; Chen, S.*; Xu, F.* An Eco-Friendly and Multifunctional Textile Integrating Radiative Heating and Cooling for Large-Temperature-Variation Personal Thermal Management. Adv Funct Materials 2025, 35 (24), 2419777.

[2] Wang, X.; Zheng, W.; Zhao, H.; Li, J.; Chen, S.*; Xu, F.* Robust and High-Wettability Cellulose Separators with Molecule-Reassembled Nano-Cracked Structures for High-Performance Supercapacitors. Nano-Micro Lett. 2025, 17 (1), 153.

[3] Li, X.; Li, J.; Yang, Q.*; Feng, J.; Wang, X.; Ye, L.; Liu, Z.; Jiang, N.; Duan, Y.; Tao, Z.; Chen, S.*; Xu, F.*; Qiu, J.* Homogenizing Zn2+ Transport and Deposition by Molecular Aggregation State Regulation of Cellulose Separator for High-Performance Aqueous Zn-Ion Batteries. Adv Funct Materials 2025, e19947.

[4] Li, C.; Miao, G.; Chen, S.*; Xu, F.* Water-Resistant and Multicolor Room Temperature Phosphorescence from Cellulose. Adv Funct Materials 2025, e26407.

[5] Cao, M.; Zhu, J.; Miao, G.; Sha, J.; Li, D.; Li, J.; Wang, C.; Li, C.; Zhang, J.; Xu, Y.; Chen, S.*; Xu, F.* Ambient-Dried Nanocellulose Composite Aerogels for Enhanced Hydrovoltaic Electricity Generation. Adv Funct Materials 2025, 35 (16), 2418823.

[6] Li, C.; He, Y.; Zhang, J.; Mu, J.; Wang, J.; Cao, M.; Nawaz, H.; Chen, S.*; Xu, F.* Cellulose-Based Colorimetric/Ratiometric Fluorescence Sensor for Visual Detecting Amines and Anti-Counterfeiting. Carbohydrate Polymers 2024, 345, 122548.

[7] Nawaz, H.*; Chen, S.*; Zhang, X.; Li, X.; You, T.; Zhang, J.; Xu, F.* Cellulose-Based Fluorescent Material for Extreme pH Sensing and Smart Printing Applications. ACS Nano 2023, 17 (4), 3996–4008.

Lignin reassembly and relocalization in wood: sustainable energy harvesting

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Abstract

Wood, long valued as a construction material, can be re-engineered into a multifunctional platform for sustainable energy applications. In this study, we introduce a strategy to reassemble lignin within the wood structure and relocate it to the surface, producing a superhydrophobic, fully wood-based material. Through pretreatment and in-situ regeneration, lignin migrates, assembles, and redistributes across the hierarchical architecture, enhancing surface hydrophobicity and enabling efficient charge transfer. The surface-localized lignin forms a tribonegative layer, transforming wood into a liquid–solid triboelectric nanogenerator (L–S TENG) capable of harvesting electricity from raindrop impacts. The modified wood achieves a 7.5-fold increase in output voltage and a 6-fold increase in current compared to untreated wood, sufficient to power LEDs and digital timers under simulated rainfall. Additionally, surface-exposed lignin improves light absorbance, inducing a redshift across the solar spectrum and enhancing solar capture. When integrated with phase change materials, the treated wood exhibits thermal regulation, extending its functionality to solar energy management in energy-saving building systems.

This lignin reassembly approach relies solely on intrinsic wood components, eliminating fossil-derived polymers or synthetic additives. By reorganizing natural constituents, we studied dual potential of application and utilization of rainfall and solar energy by wood. The results establish a potential pathway toward wood-based smart building materials that combine renewable energy harvesting, durability, and thermal management, advancing sustainable construction and next-generation green technologies.

Solid-State Adsorption for Wood Surface Functionalization: From Molecular Conformation to Mechanical Energy Generation

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Abstract

Wood is an advanced hierarchical substrate that has attracted considerable attention over the last decade as a platform for functional materials, including optically transparent wood, lightweight aerogels, and energy-generating devices. [1-6] However, for most such applications, the substrate usually first undergoes wet-chemical treatments, e.g., oxidative delignification, to remove lignin and retain only the cellulose-rich vascular scaffold. [1,3,6] Solid-state adsorption proceeds through a molten polymer layer at the surface, forming an irreversibly adsorbed film with a thickness of 1-2 nm. [7-9] This approach offers a generic route to surface modification without prior activation or harsh reaction conditions. We have previously applied solid-state adsorption to soft lignocellulosic substrates, achieving robust hydrophobic to superhydrophobic surfaces. [9]

Recently, we used sum-frequency generation vibrational spectroscopy (SFG-VS) to resolve the molecular conformation of incompatible polystyrene (PS) adsorbed on cellulose as a model interface. The phenyl rings in the irreversibly adsorbed PS adopt an “out-of-plane” orientation (i.e., tilted away from the substrate) in air. They remain highly responsive, such that exposure to water reorients them “in-plane” (i.e., lying down toward the surface). This conformational switching is accompanied by a preferential orientation of cellulose exocyclic hydroxymethyl groups, consistent with CH-π interactions at the confined interface. Furthermore, we extend solid-state adsorption to birch wood veneer without delignification. A conformal, irreversibly adsorbed layer (<10 nm) renders the wood surface hydrophobic. Intriguingly, the modified wood (20 × 20 × ~6 mm^3; longitudinal × tangential × radial) generates an output voltage up to 10 V under mechanical compression and maintains stable performance over >1000 loading cycles at 40% relative humidity. These results open a new avenue for strategic, solvent-minimized surface modification via solid-state adsorption, enabling functional wood-derived materials without extensive wet-chemical preprocessing.

[1] C. Chen, et al., Nat Rev Mater., 2020, 5, 642-666.
[2] J. Garemark, et al., ACS Appl. Mater. Interfaces., 2022, 14, 21, 24697-24707.
[3] J. Sun, et al., ACS Nano., 2020, 14, 14665-14674.
[4] Y. Ding, et al., Chemical Reviews 2023 123 (5), 1843-1888.
[5] J. Garemark, et al., Adv. Funct. Mater. 2025, 35, 2418454.
[6] F. Ram., et al., Compos. Part A Appl. Sci. Manuf., 2022, 160, 107057.
[7] O. Guiselin, Europhys. Lett., 1992, 17, 225.
[8] W. Xu, et al., J. Colloid Interface Sci., 2022, 605: 441-450.
[9] W. Xu, et al., ACS Applied Materials & Interfaces 2024 16 (25), 32874-32885.

Towards Continuous Production of Translucent Wood Films via Calendering

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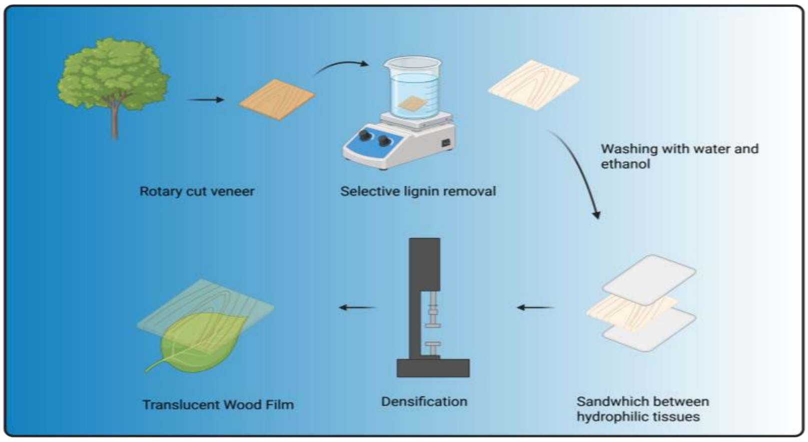
Abstract

Delignified and densified wood veneers offer a promising substrate for the production of transparent films. Several approaches are described in the literature in which epoxy resins [1] or acrylates [2] are impregnated, but there are also polymer-free routes to bio-based optical materials[3][4]. This study examines how moisture content, pressing temperature, pressure, and pressing time influence the optical and mechanical performance of delignified birch veneers, and evaluates how the process can be upscaled toward continuous production. Birch veneers were delignified using an Acetosolv process[5], yielding cellulose-rich scaffolds with strongly reduced lignin content shown by FT-Raman spectroscopy. Subsequent densification was performed under controlled pressure and temperature, with moisture content emerging as the dominant parameter governing light transmittance and haze. Higher moisture (water content 30 %) and elevated temperatures (90°C) enabled improved lumen collapse and reduced light-scattering interfaces with 70 % total transmittance and 95 % haze, whereas pressing time showed no measurable influence and pressure effects were secondary. Mechanical testing demonstrated that densified cellulose scaffolds reached tensile strengths exceeding native birch by more than 100 %, while air permeability decreased by from 1150 ml/min to 33 ml/min. To assess scalability, delignified sheets up to 300 cm × 30 cm were processed through a heated calendering nip. The veneers exhibited sufficient flexibility and wet strength for continuous feed, achieving densification and optical clarity similar to batch-pressed samples. These results demonstrate that delignified birch veneers can be formed into translucent wood films using roll-to-roll calendering, providing a viable pathway toward industrial-scale, polymer-free optical and packaging materials.



[1] Q. Tang, L. Fang, Y. Wang, M. Zou, W. Guo, Nanoscale 2018, 10, 4344.
[2] Q. Tang, M. Zou, L. Chang, W. Guo, Chemical Engineering Journal 2022, 430, 132152.
[3] M. Zou, Y. Chen, L. Chang, X. Cheng, L. Gao, W. Guo, Y. Ren, L. Shupin, Q. Tang, ACS Sustainable Chemistry & Engineering 2022, 10, 2097.
[4] F. Chen, M. Ritter, Y. Xu, K. Tu, S. M. Koch, W. Yan, H. Bian, Y. Ding, J. Sun, I. Burgert, Small 2024.
[5] W. A. Barth, T. Dietrich, M. Freese, S. Fischer, A. Wagenführ, in 10th Hardwood Conference Proceedings

Re-engineering Wood Across Scales: Nanostructural Control of Mechanical, Optical, and Energy Functionalities

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Abstract

Wood is a hierarchically organized nanocomposite whose multiscale architecture enables a unique combination of mechanical resilience, optical tunability, and environmental compatibility. Recent advances in wood nanotechnology demonstrate that its intrinsic structure can be reconfigured, without fossil-based additives, to generate high-performance, multifunctional materials. Room-temperature hydroplasticization enables controlled deformation and energy dissipation through polymer matrix elasticity and interfacial sliding, yielding ultra-strong, self-densified structures with flexural strength approaching 483 MPa [1].

Parallel strategies based on selective delignification, oxidation, densification, and carbonization transform wood into optical platforms with radically different responses [2–4]. Vertically aligned carbon microfibers obtained through controlled delignification and high-temperature carbonization exhibit near-zero reflectance (~0.36%), producing mechanically robust superblack materials that rival microfabricated light absorbers [2]. Alternatively, in situ functionalization of aligned cellulose nanofibrils enables transparent, luminescent veneers combining high tensile strength (up to 422 MPa), optical anisotropy, and UV stability, thus integrating structural performance with photonic functionality [3]. Adhesive-free, self-adhered laminated wood glazes produced via oxidation and densification simultaneously achieve high optical transmittance (~85%), isotropic mechanical strength, water resistance, and low thermal conductivity (0.27 W m-1 K-1), offering sustainable solutions for energy-efficient building envelopes [4].

Across these systems, performance emerges from nanostructural control, modulation of cell wall chemistry, interfacial interactions, densification pathways, and shrinkage-induced alignment [1–4]. The resulting materials integrate mechanical robustness, optical control, and sustainability without reliance on synthetic polymer matrices. These advances position wood not merely as a structural material, but as a tunable nanotechnological platform for next-generation load-bearing, photonic, and energy-efficient applications.

[1] Li S., Wang Y., Wan Z., Du Y., Qi L., Yang R., Li J., Dai H., Rojas O.J., Xia C., Wood Hydroplasticization Toward Ultra-Strong and Self-Densified Complex Structures, Advanced Materials, e18621 (2025). [2] Wood-based superblack

[2] Zhao B., Shi X., Khakalo S., Meng Y., Miettinen A., Turpeinen T., Mi S., Sun Z., Khakalo A., Rojas O.J., Mattos B.D., Wood-based Superblack, Nature Communications, 14, 7875 (2023).

[3] Wang M., Liu H., Feng X., Wang X., Shen K., Qi H., Rojas O.J., State-of-the-art luminescent materials based on wood veneer with superior strength, transparency, and water resistance, Chemical Engineering Journal, 454, 140225 (2023).

[4] Chen C., Zhou T., Wan Z., Xu Z., Jin Y., Li D., Rojas O.J., Insulative biobased glaze from wood laminates obtained by self-adhesion, Small, 2301472 (2023).

Splitting wood fibres –
Targeted liberation of cellulose fibrils from the wood cell wall

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Abstract

The native hierarchical architecture of wood comprises cellulose elementary fibrils bundled into micro- and macrofibrils, embedded within a matrix of hemicelluloses and lignin, presenting both structural complexity and processing challenges. Conventional pulping methods typically disrupt this intricate organization, which results in loss of native cellulose alignment. Our work [1] demonstrates that partial and spatially localized delignification combined with an ionic liquid treatment allows the liberation of cellulose microfibrils preserving their spatial arrangement on the transverse section. The liberated cellulose fibrils remain anchored in the intact wood matrix. This targeted fibril liberation allows access to cellulose structures with retained anisotropy and native morphology, circumventing the need for harsh mechanical fibrillation. Such liberated cellulose fibrils exhibit enhanced potential for development into advanced bio-based materials, including high-performance composites, hydrogels, and functional films. By integrating chemical and structural insights into wood's native organization, this approach advances sustainable strategies for cellulose valorization and broadens the scope of cellulose's functional utility. This work underlines the importance of maintaining cellulose's native microstructure to unlock new possibilities in cellulose chemistry and materials science.

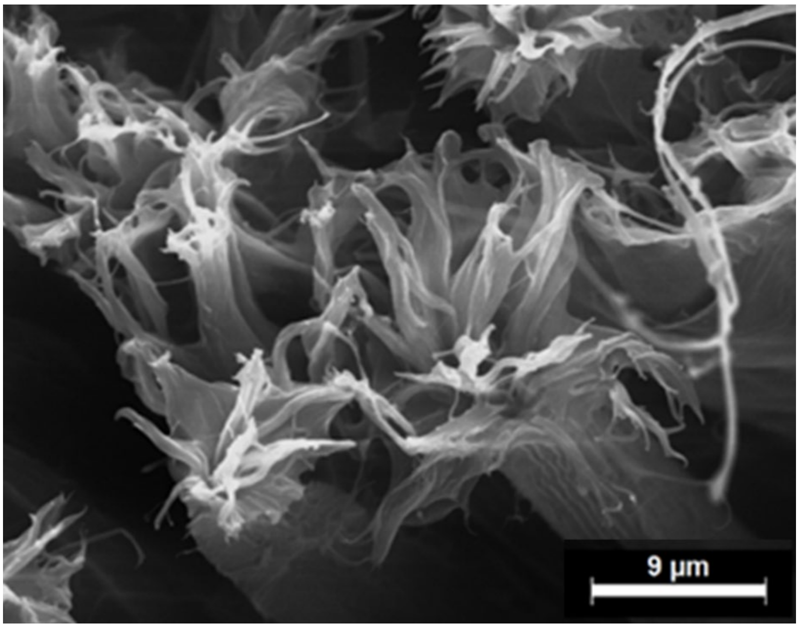

Fig. 1: *SEM image of partly liberated fibrils on the axial surface of libriform fibres of basswood*

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[1] von Usslar F, Günyadin BE, Zollfrank C (2025) Splitting fibres – Liberated cellulose fibrils from hardwoods libriform tissue, under review, Pre-Publication: DOI: 10.26434/chemrxiv-2025-shmvx

Topochemical Control of Lignin for Biomass-Based Energy Materials

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Abstract

Lignin is commonly viewed as a barrier or low-value byproduct in wood and biomass utilization; however, emerging strategies demonstrate that controlled manipulation of lignin content and spatial distribution enables diverse, high-value functionalities in biomass-based energy materials.

By selectively reducing lignin while preserving wood's hierarchical architecture, solid wood can be transformed into anisotropic, elastic, foam-like materials with good thermal insulation performance, demonstrating how controlled lignin removal and surface modification of cellulose unlock mechanical flexibility without structural collapse [1]. Beyond removal, mobilization and relocation of native lignin from the cell wall and middle lamella to fiber interfaces significantly enhance interparticle bonding, enabling the production of durable, high-energy-density biomass pellets with improved heating value and mechanical integrity [2]. At the material surface level, lignin clustering generates superhydrophobic, tribonegative wood layers capable of rain-driven triboelectric energy generation without synthetic fluorinated coatings, while also imparting self-cleaning and antimold functionality [3].

Together, these results position lignin as a tunable functional component rather than a waste fraction, offering integrated pathways for designing sustainable biomass-based materials for energy conversion, storage, and thermal management.

[1] Shi, X.; Bi, R.; Wan, Z.; Jiang, F.; Rojas, O. J. Solid wood modification toward anisotropic elastic and insulative foam-like materials. *ACS Nano* 2024, *18*, 7959–7971.

[2] Guo, T.; Yu, Y.; Wan, Z.; Zargar, S.; Wu, J.; Bi, R.; Sokhansanj, S.; Tu, Q.; Rojas, O. J. Energy pellets from whole-wheat straw processed with a deep eutectic solvent: A comprehensive thermal, molecular and environmental evaluation. *Renewable Energy* 2022, *194*, 902–911.

[3] Shi, X.; Bi, R.; Shu, X.; Wang, P.; Chun, Y.; Chen, Z.; Zhou, C.; Lu, Y.; Rojas, O. J. Native lignin migration and clustering in wood: Superhydrophobic, antimold, and tribonegative layers for rain-driven electrification. *Advanced Functional Materials* 2025, *35*, 2504381.

Suberin in birch bark: from extraction to application

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Abstract

Suberized cell walls form critical plant–environment interfaces by regulating water and nutrient transport and protecting plants against biotic and abiotic stresses. Suberin, an acylglycerol-based heteropolymer composed of polyaliphatic and polyphenolic domains, underpins these functions through a three-dimensional network formed by esterification between glycerol and long-chain fatty- acid derivatives. Beyond its biological role, suberin represents an abundant yet underutilized renewable resource with significant potential for sustainable materials and circular bioeconomy applications.

Here, we introduce an integrated, low-impact strategy to extract and reconstruct suberin from birch bark using reactive eutectic media (REM), enabling its direct conversion into recyclable biopolyester adhesives. This approach preserves the intrinsic chemical functionality of suberin while avoiding harsh alkaline treatments, thereby enhancing processability, thermal responsiveness, and end-of-life reversibility. The resulting materials exhibit strong, substrate-independent adhesion combined with thermally switchable viscoelastic behavior, allowing efficient processing, use, and recycling.

Beyond material performance, this work establishes a holistic birch-bark biorefinery that valorizes all major biomass fractions—suberin, betulin, and lignocellulosic components—into high-value products. Life-cycle assessment demonstrates a substantial reduction in greenhouse gas emissions relative to conventional routes, highlighting the climate-mitigation potential of residue-based materials. Together, these results position suberin not only as a key biological polymer but also as a scalable platform for sustainable materials innovation at the interface of plant biology, green chemistry, and circular systems design.

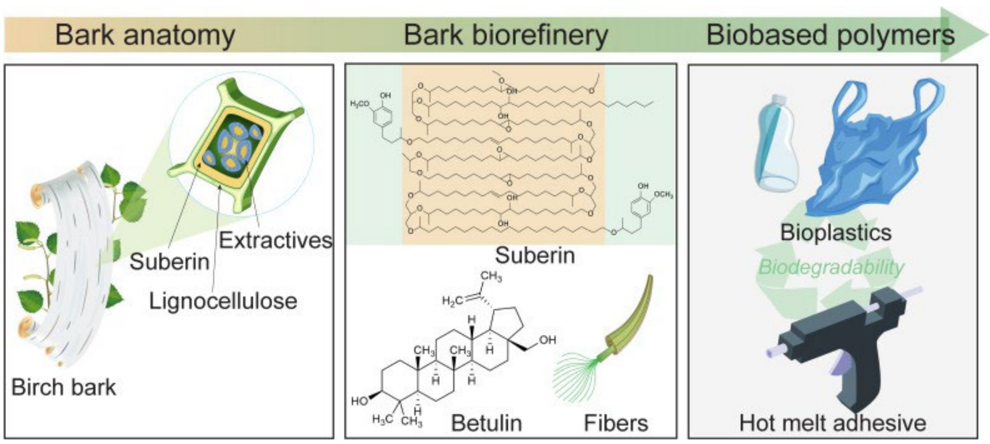

Fig. 1: *Schematic overview of this work, spanning (i) anatomical characterization of birch bark, (ii) integrated biorefinery fractionation to isolate suberin, betulin, and lignocellulosic fibers, and (iii) reconstruction of these biobased components into functional materials, including bioplastics and hot-melt adhesives.*

Reinforcement of wood with partially bio-based fibre materials to improve its property profiles

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Abstract

This contibution is based on a project whose aim was to stabilise the components of double basses. The problem with these large-format stringed instruments is that cracks appear on the sides and top of the instruments due to swelling and shrinking movements of the wood during use and sudden impacts on the instruments themselves during transport. The swelling and shrinking movements generate strong stress peaks throughout the instrument, which ultimately lead to bulging or cracking of the components across the grain of the wood. To compensate for dimensional changes and susceptibility to cracking across the wood grain, fibre matrix applications should be considered. For example, flax fleece (100 g m-2), unidirectional hemp fibre fabric (120 g m-2) and bidirectional basalt fibre fabric (115 g m-2) were used as reinforcement, while a 56% bio-based epoxy resin served as the matrix material. Figure 1 shows the impact bending strength of the unreinforced and reinforced small wooden strips.

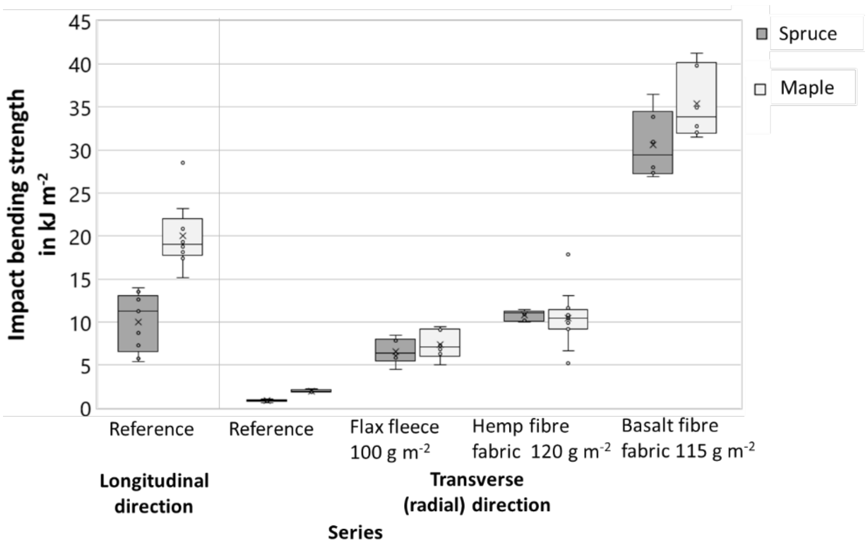

Fig. 1: *Impact bending strength of unreinforced wood in the longitudinal and transverse directions and of fibre-reinforced wood, whereby the wood was loaded transversely to the main anatomical cutting direction.*

It is clear to see that the fibre reinforcements increase the impact bending strength across the anatomical grain of the wood. By reinforcing the wood with basalt fibres perpendicular to the grain, it is possible to achieve even higher characteristic values than those of unreinforced wood when loaded in its longitudinal direction. The reinforcement can also significantly reduce the stresses in the components resulting from the hygroscopic swelling and shrinkage movements, thereby reducing the susceptibility of the wood to cracking across the grain. Furthermore, the sound damping increases as a result of the reinforcement in the longitudinal direction of the reinforced wood. However, acoustic tests carried out on complete instruments did not reveal any negative effects.

Mid- and High-rise Timber Buildings: Benchmarks in Structural Systems and Design Tendency

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Abstract

Timber construction can reduce greenhouse gas emissions significantly because it stores carbon and uses renewable resources. The expansion of mid- and high-rise timber buildings has been accelerated by recent advancements in engineered timber products such as glulam and CLT. Despite their quick growth, a coherent understanding of the structural systems and design principles behind these buildings is still missing. This study examines the structural classifications, core system designs, lateral load-resisting systems, as well as current design tendencies for mid- and high-rise timber buildings in the world. In addition, a brief systematic comparative overview of the world's tallest timber buildings is provided to showcase the benchmarks for future high-rise timber building design [1-3].

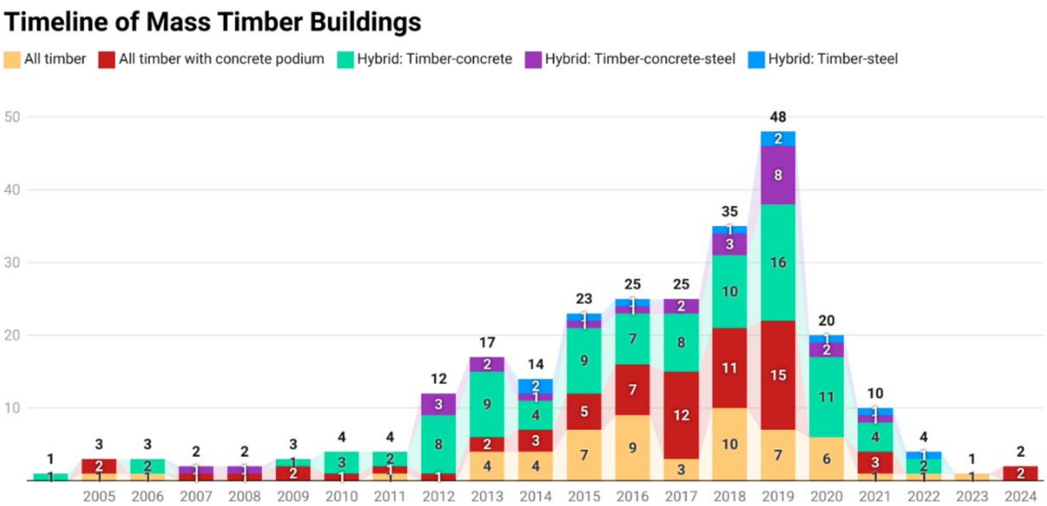

Fig. 1: *Timeline of construction of mid- and high-rise timber buildings in the world*

[1] Chen, H., Yan, L. B., & Dand, J. A. (2026) High-rise timber buildings against wind-induced vibration: A comprehensive study on design criteria, design codes and design cases. Developments in the Built Environment, 25. 100815.

[2] Yan, L. B., Chen, H., & Dand, J. A. (2026). High-rise timber buildings: Benchmarks in structural systems, fire safety, prefabrication efficiency and environmental insights of World's 10 tallest mass timber projects. Frontiers of Architectural Research, https://doi.org/10.1016/j.foar.2025.10.012

[3] Yan, L. B., Klingner, R., Al-Qudsi, A., Chen, H., & Dand, J. A. (2025). Current market landscape and industry voices in key timber construction markets. Buildings, 15(18), Article 3381

Wood substitution with oilseed pomaces as a tool for modulating mould resistance in Wood–Plastic Composites

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Abstract

Growing environmental concerns related to plastic waste and increasing pressure on wood resources have intensified research on wood–plastic composites (WPC) incorporating alternative lignocellulosic fillers. Oilseed pomaces, a by-product of industrial oil production, represent a promising group of fillers that may partially substitute wood particles while contributing to circular bioeconomy strategies [1]. However, incorporating this plant-derived material may influence the biological durability of such composites [2].

This study evaluates the effect of replacing wood particles with oilseed pomaces in WPCs on their resistance to mould growth. Composite panels were produced using post-consumer polyethylene or modified starch as matrices and wood particles partially substituted with oilseed pomaces. The matrix ratio was set at 30 % and 40 %. Wood particles were substituted with oilseed pomace from nigella, rapeseed and evening primrose. The contents of the pomace replacing wood particles were 30 %, 65 % and 100 %. The composites made of a matrix and only wood particles were used as a reference. The pomaces were applied in their raw, industrial form without additional chemical modification. Square specimens (30 × 30 mm) were exposed to cellulolytic fungi (Trichoderma viride and Chaetomium globosum) for 14 days under controlled laboratory conditions. The composite's surface was monitored daily, and the mould growth was quantified using digital image analysis (Image J). Composites containing nigella pomace exhibited an inhibitory trend, particularly against Chaetomium globosum. In modified starch-based variants, this effect was observed at 30% and 65% substitution levels for both fungal species, whereas the 100% substitution variant did not maintain a comparable level of inhibition. Studies from other research areas report antifungal activity of Nigella sativa seed extracts and their bioactive constituents [3]. Our results suggest that this property may also be reflected in composite systems. Notably, evening primrose pomace incorporated into the polyethylene matrix showed an inhibitory effect against Trichoderma viride relative to the remaining variants. The results demonstrate that substituting wood particles with selected oilseed pomaces can affect mould growth. The observed matrix and filler effects suggest that such substitution may serve as a practical strategy for tailoring the biological performance of WPCs, either by enhancing resistance in durable applications or by promoting controlled degradation in short-life products.

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[1] Scaffaro R, La Mantia FP, Lo Re G, Titone V, Citarrella MC. Plant- and Animal-Derived Organic Waste as Fillers in Biodegradable Composites for Advanced Applications: A Comprehensive Overview. Polymers. 2026; 18(1):22. doi.org/10.3390/polym18010022

[2] Mastalygina, E. E., Popov, A. A., & Pantyukhov, P. V. (2017). Effect of biobased fillers nature on biodeterioration of hybrid polyethylene composites by mold fungi. IOP Conference Series: Materials Science and Engineering, 213, 012011. doi.org/10.1088/1757-899x/213/1/012011

[3] Pandey, R., Pandey, B., & Bhargava, A. (2024). The Emergence of N. sativa L. as a Green Antifungal Agent. Mini reviews in medicinal chemistry, 24(16), 1521–1534.doi.org/10.2174/0113895575282914240217060251

Bio-based Adhesives for Particleboard and MDF

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Abstract

The European wood-based panel industry, producing approximately 65 million m3 of particleboards (PB) and fibreboards annually [1], faces a critical challenge as its primary adhesive systems remain dependent on fossil-based raw materials, such as urea-formaldehyde based resins. To address this, the SUSBOARD project is developing a new generation of completely bio-based and formaldehyde-free binders. This research focuses on the synthesis and performance evaluation of adhesives derived from polylysine – a biotechnologically produced amino acid polymer – and carbohydrates enriched with 5- hydroxymethylfurfural (HMF). These components facilitate a rapid chemical cross-linking reaction between the amino-reactive groups of the polylysine and the sugar derivatives. [2]

During first laboratory-scale PB pressings, 16 mm single-layer particleboards were produced using 50% recycled wood chips and a 7% adhesive dosage. Two specific formulations, SUSBOARD 1 and SUSBOARD 3, were evaluated for internal bond (IB) strength according to EN 319. Results demonstrated that both variants significantly exceeded the EN 312 minimum requirement of 0.35 N/mm2, with SUSBOARD 1 achieving approximately 0.6 N/mm2 and SUSBOARD 3 reaching 0.7 N/mm2. These findings confirm that bio-based binders can meet industrial mechanical requirements while remaining compatible with standard manufacturing parameters such as a press time of 8 s/mm.

The SUSBOARD project demonstrates that sustainable raw materials show significant potential as alternatives to fossil-based binders in high-performance wood-based panels. While current IB strength results are highly promising, they remain preliminary; further testing of comprehensive mechanical properties is required to ensure industrial standards are fully met. Whitin the EU-SSbD (Safe and Sustainable by Design) framework, ongoing ecological and toxicological assessment are evaluating the entire value chain. Future project phases will transition these laboratory formulations to pilot-scale testing, a critical step to validate process stability to confirm industrial scalability before conclusions on total fossil-based binder replacement can be drawn.

Funding notice

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CBE JU. Neither the European Union nor the CBE JU can be held responsible for them. Grant agreement ID: 101213812

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[1] Molcean, T. et al. (2023) UNECE/FAO Forest Products Annual Market Review, 2022-2023. United Nations and the Food and Agriculture Organization of the United Nations. https://unece.org/sites/default/files/2023-11/FPAMR23_WEB.pdf.

[2] Rosenfeld, C. et al. (2020) 'Hydroxymethylfurfural and its Derivatives: Potential Key Reactants in Adhesives,' ChemSusChem, 13(20), pp. 5408–5422. https://doi.org/10.1002/cssc.202001539.

Computer Vision-Based Prediction of Quality and Mechanical Properties of Wooden Lamellae

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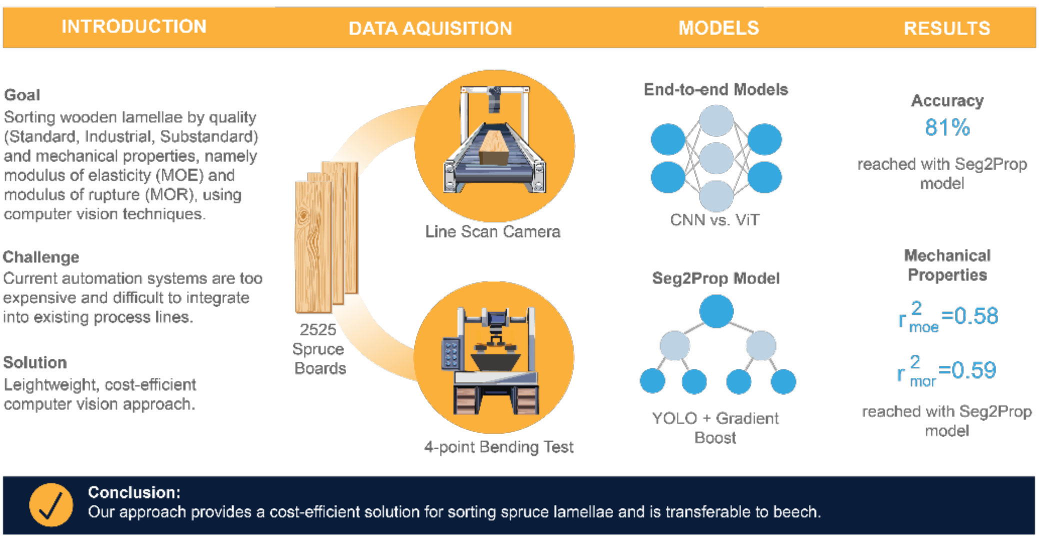
Abstract

Sorting wooden lamellae ensures high product quality, structural safety, and customer satisfaction. Key criteria include both visual features and mechanical properties. This study aims to develop a cost-efficient method for automatically sorting wooden lamellae. We present a dataset of 5050 spruce lamellae images with quality class labels from manual visual inspection. Each lamella undergoes a 4-point bending test to measure its modulus of elasticity (MOE) and modulus of rupture (MOR).

Based on this dataset, two approaches classify lamellae and predict their mechanical properties. The first, the segmentation to properties (Seg2Prop) model, detects critical defects with a segmentation network and infers quality class and mechanical attributes from them. The second end-to-end approach predicts both quality class labels and mechanical properties (MOE, MOR) directly from raw images using either a residual network (ResNet)50-based convolutional neural network (CNN) or a vision transformer (ViT). Training of the models uses either original images or autoencoder-guided (AEG) representations. The autoencoder learns exclusively from defect-free lamellae, and its reconstruction errors highlight defects, guiding the model to the most relevant regions. Training and testing of the end-to-end models on beech lamellae evaluates their applicability to hardwoods.

The Seg2Prop model achieves the highest classification F1-score of 0.81 and predicts MOE and MOR with coefficient of determination (r^2) values of 0.58 and 0.59, respectively. Among the end-to-end models, the ViT with AEG inputs attains the best classification F1-score of 0.74. For hardwood boards, quality prediction reaches an F1-score of 0.54. Our approaches provide a cost-effective, efficient solution for predicting lamella quality and mechanical properties and demonstrate potential for adaptation to other wood species.



Artificial Intelligence for the Discovery of Bio-based Assembled Materials

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Abstract

Multiscale hierarchical materials are widely observed in biological organisms with strong performance across various functionalities including mechanical robustness, signaling, camouflage, and others. However, the limited understanding of hierarchical complexity has hindered the development of man-made hierarchically assembled materials. Additional challenges are posed by the limited processing conditions which the bio-based materials require and the complicated assembly procedures. Recent developments in the field of artificial intelligence enable the analysis of scientific data at unprecedented scales. Multimodal artificial intelligence can extract visual and textual information and supports reasoning towards abstract concepts. This enables understanding of the high complexity of multiscale materials.

In this work we develop an artificial intelligence-based framework to create a library of structural principles for hierarchical materials, and we use these principles to demonstrate new materials. First, through analysis of existing scientific literature, the known structural principles will be collected. These principles will be abstractly represented to form a virtual library of material building blocks, their assemblies, and the corresponding processing methods. Next, novel virtual assembled materials will be designed through simulation and optimization. Finally, using the library of hierarchical structural relationships and based on digitally designed materials, novel hierarchical materials will be proposed and physically developed.

Veneer pultrusion – continuous production of profiles

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[2]TU Dresden, Institute of Lightweight Engineering and Polymer Technology

Abstract

Wood, as a bio-based and renewable raw material, is gaining increasing importance in the development and application of climate-friendly materials. Owing to its outstanding mechanical performance as well as its appealing haptic and optical properties, wood offers considerable potential for both structural and decorative applications. However, solid wood profiles are either comparatively heavy or—particularly in the case of slender, filigree geometries—require complex machining processes and exhibit limited load-bearing capacity perpendicular to the grain.

An alternative approach involves the production of profiles from curved laminated wood (plywood). The layered arrangement of veneers, combined with a targeted orientation of individual veneer sheets, significantly enhances the load-bearing capacity of shell-like structures. At present, such profiles are manufactured using advanced technologies in largely discontinuous processes, often involving a relatively high degree of manual labor.

Veneer profile pultrusion offers a new approach to the continuous production of veneer profiles using a layered construction method, in which – similar to the pultrusion process – several pre-coated veneers are pulled through a shaping tool. The veneers are continuously reshaped and bonded together in several layers, similar to a plywood structure. The focus of development is on continuous shaping, mould design and continuous pressing, as well as the finishing of profiles.

One of the processing issues is the consolidation behaviour in the contact zone with the moulding tool. In addition to the type of wood, other important factors include the contact pressure in the joint zone, the type of adhesive, and the process temperature and time.

This poster presents the process concept and the investigations and results of the process parameters. The results obtained make it possible to design the moulding tool for the entire process in advance.

Recyclable Mineral Binder for Flame-Retardant Sawdust Composites

Ronny Kürsteiner [1], Dan Vivas Glaser [1], Maximilian Ritter [1,2], Annapaola Parrilli [3], Jonas Garemark [1], Lorenza Maddalena [4], Thomas Schnider [1], Christopher H. Dreimol [1,2], Federico Carosio [4], Ingo Burgert [1,2] and Guido Panzarasa [1]

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[3] *Center for X-ray Analytics, Empa, 8600 Dübendorf, Switzerland*
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Abstract

Integrating sawdust into the materials stream through composite formation allows valorising by-products from the wood processing industry, otherwise destined to be burnt as fuel. However, composites formed using traditional, fossil-derived binders are typically non-recyclable and offer moderate flame-retardant properties, limiting their environmental and functional performance. We introduce struvite ($MgNH_4PO_4 \cdot 6H_2O$) as a recyclable mineral binder for the consolidation of sawdust into mechanically robust, highly flame-retardant composites [1]. Struvite is formed via an enzymatically induced, solution-mediated phase transformation from newberyite, using ureolytic protein bodies extracted from watermelon seeds to control urea hydrolysis and crystal growth. This process yields large, well-defined struvite crystals that intimately template the sawdust particles' surface, producing strong mechanical interlocking already at a low binder content. The resulting composites exhibit excellent flame retardance and even fire shielding properties. Moreover, the binder can be recovered from spent composites under mild conditions and reused without significant loss in performance.

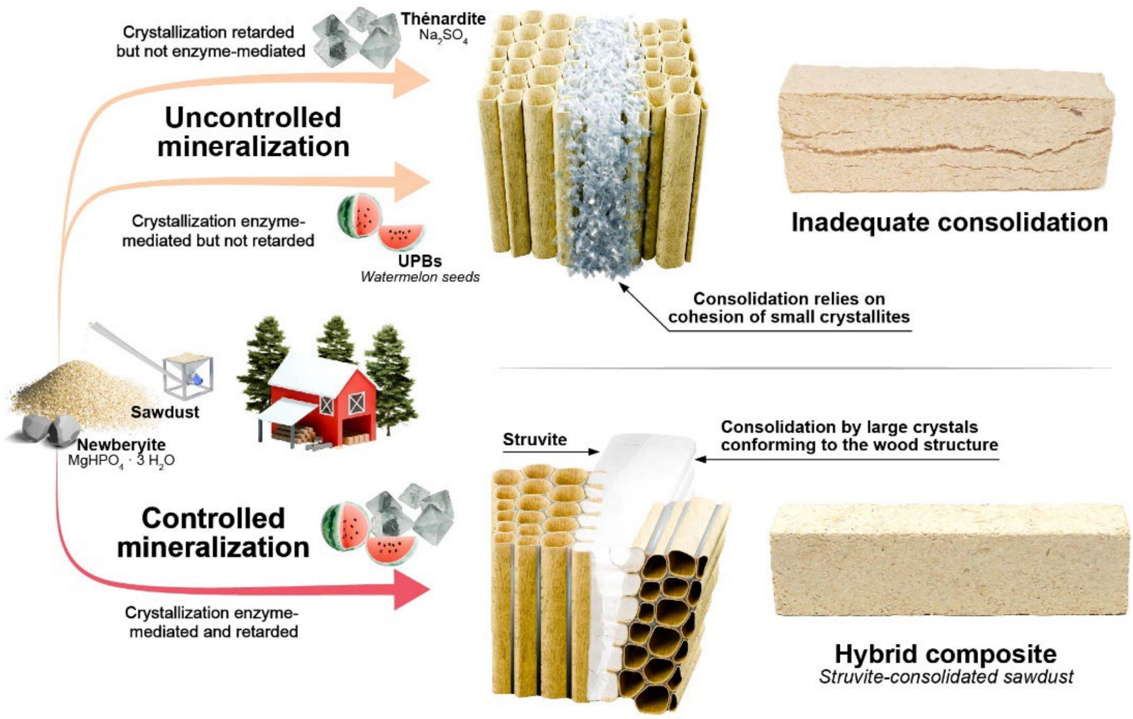

Fig. 1: *Struvite mineralization under confinement is controlled by urease-driven urea hydrolysis and crystallization retardation by Na^+ and SO_4^{2-} ions, yielding large struvite crystallites templated by sawdust. Figure adapted from [1].*

[1] Kürsteiner, R. *et al*. Enzyme-mediated consolidation of lignocellulosic materials with a flame-retardant and fully recyclable mineral binder. Chem Circularity (2026). DOI: https://doi.org:10.1016/j.checir.2025.100004

Norway spruce infested by the bark beetle (*Ips typographus*) and its suitability as coated façade cladding

Tina Künniger[1], Markus Heeb[1]

[1]*Cellulose & Wood Materials, Empa, Dübendorf, Switzerland*

Abstract

The increasing occurrence of bark beetle Ips typographus infestations has led to large quantities of blue stained spruce wood entering the timber market. While blue staining primarily affects the visual appearance of wood, uncertainties remain regarding its material performance, durability and suitability for exterior applications. This project investigated essential material properties of primary blue stained sapwood of Picea abies and evaluated its applicability as coated façade cladding.

19 stems were harvested from Stammerberg forest (Zurich, Switzerland) in three different seasons and after different periods of bark beetle outbreak. In addition, lamellae from industrial production were included to ensure practical relevance. The study was structured into three main work packages: (1) characterization of mechanical, physical and biological properties, (2) evaluation of surface decoloration methods, and (3) assessment of coating performance under laboratory and outdoor exposure conditions.

Results show that blue stained wood harvested and processed shortly after infestation exhibited no relevant deviations in mechanical properties compared to non-infected controls. In contrast, spruce harvested 2 to 3 months after bark beetle attack and stored less than 1 month before processing, showed a minor, but measurable decrease in density, a clear reduction in impact bending strength, linked to increased brittleness caused by early colonization of wood decay. Microscopic analysis confirmed the presence of basidiomycetes in both blue stained and visually unaffected sapwood. The blue stained sapwood showed significantly increased liquid water uptake, while the shrinkage, swelling and hygroscopic moisture behavior remained comparable to non-infected controls. Biological laboratory tests indicated that specimens, already infested by bark beetles, were more susceptible to surface mold growth under humid conditions and degraded to a greater extent by wood degrading fungi such as Gloeophyllum trabeum.

Coating application, film formation, drying behavior, layer thickness, penetration depth and the coating adhesion showed no practical differences on blue stained or non-infected sapwood. However, blue stained lamellae exhibited higher water uptake coefficients and up to 4 % higher wood moisture content during one-year outdoor exposure. Despite this, no significant differences in durability of the tested coating systems were found, whether they were applied on infected or non-infected wooden substrate. Only one white pigmented mineral paint, which reacted problematically to moisture, discolored noticeably on the more humid blue stained areas.

The poster summarizes the main findings of the study and provides practical recommendations.

Polyphenolic plant extracts and their potential in the bioprotection of wood materials against xylophagous organisms

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[2] *Groupe BERKEM – Laboratoires R&D, France*

Abstract

Due to its remarkable mechanical characteristics, wood is a fundamental material for building construction in both indoor and outdoor environments, as well as for the furniture industry. The durability and aesthetic appearance of wood materials are affected by environmental degradation processes caused by decay fungi and wood-feeding insects, which result in considerable economic losses worldwide. Protecting wood from biodegradation is therefore of prime importance.

Because of the negative impact of conventional chemical treatments on the environment and on human health, more eco-friendly solutions are needed. In this context, polyphenolic plant extracts have been developed for several years at Groupe BERKEM (France). Polyphenol-rich formulations with Synerkem® technology or with Plant polyphenolic extracts from Berkem Biosolutions® have demonstrated effectiveness against several species of subterranean termites, as well as against wood-decaying basidiomycetes.

A discussion of the mechanisms of action of polyphenols is presented in order to explain their potential to counteract the attack of xylophagous organisms on wood materials, based on the biochemical modes of action of wood-feeding fungi and insects.

Polyphenolic plant extracts may thus represent a truly sustainable alternative for the long-term protection of wood.

Wood Luminescent Solar Concentrator

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Abstract

Beyond its traditional roles in construction and bioenergy, the hierarchical architecture of wood offers a unique template for advanced photonic applications. This work demonstrates the development of an energy-harvesting Translucent Wood Luminescent Solar Concentrator (TW-LSCs). By functionalizing delignified balsa scaffolds with a Rhodamine 6G, and impregnating with a PMMA matrix, a highly anisotropic material in scattering and photoluminescent properties was achieved. The cellulose scaffold showed to enhance photoluminescence parallel to fiber direction, but due to a grid effect, scatter light preferentially perpendicular to the fiber axis. Thus, contrary to initially hypothesized, the TW-LSC showed an increased efficiency of 1.2% in the perpendicular to fiber axis orientation. Finally, a life cycle assessment (LCA) of the composite highlighted the high impact of the PMMA fossile-based matrix. This work proves the viability of generating energy from sunlight using wood-based materials, and highlights the path forward to achieve sustainable and efficient TW-LSCs.

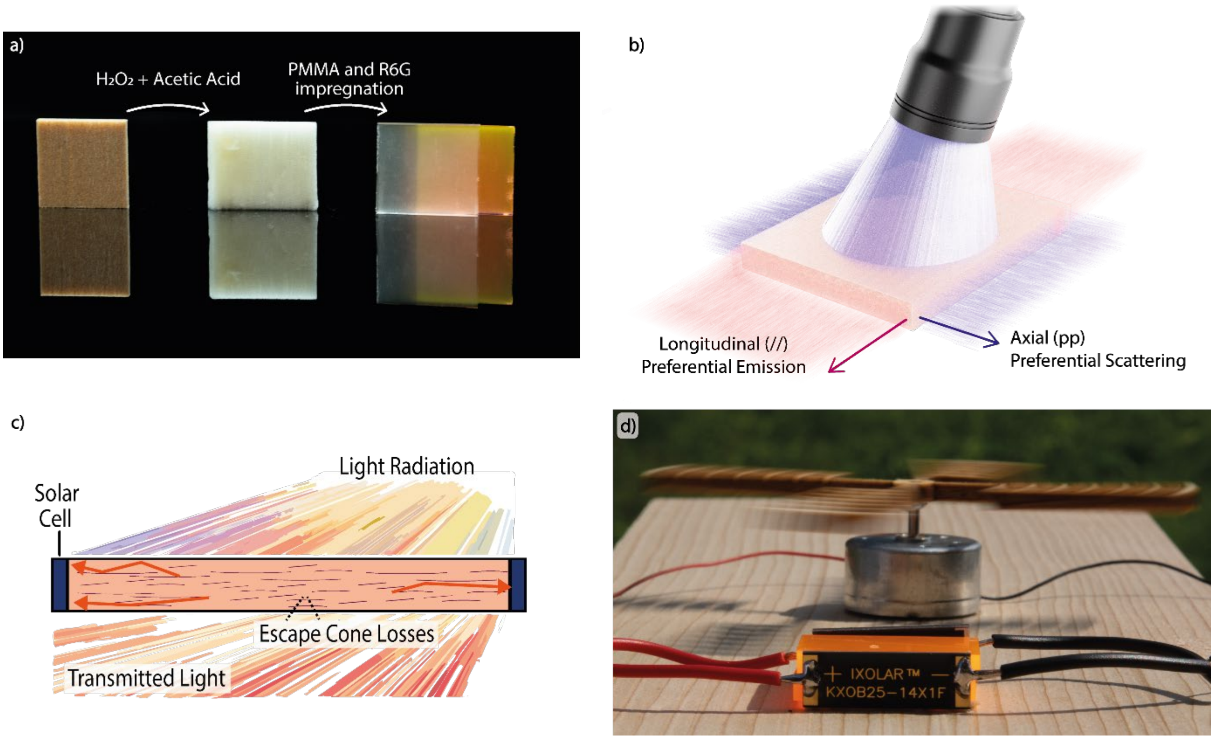

Fig. 1: *Fabrication, concept, and application of anisotropic functionalized transparent wood (TW) luminescent solar concentrators (LSC).* **a)** *Fabrication process showing the steps from wood to a delignified cellulose scaffold to R6G-functionalized TW.* **b)** *illustration of the R6G-TW highlighting the preferential emission parallel to the fiber axis (//) and the preferential scattering perpendicular to it (⊥).* **c)** *Schematic of the working principle of the TW-LSC: incident solar light is absorbed and transmitted towards the edge-mounted PV cells.* **d)** *Demonstrator with a windmill being spun by a TW-LSC under solar illumination.*

Alternative High-Temperature Techniques for Wood Surface Charring: Comparative Evaluation

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Abstract

The pyrolytic formation of a carbonized layer on wood surfaces—commonly known as charring—offers an environmentally friendly strategy for enhancing the durability of wooden elements exposed to outdoor weathering. Conventional charring techniques, such as exposure to a naked flame or the use of a contact hot plate, can provide satisfactory protection but often suffer from limited process control, surface inconsistency, or reductions in mechanical performance. In response, we focus on developing innovative and more controllable high-temperature treatments capable of producing carbonized layers with tailored structural and functional characteristics.

This contribution presents a comparative study of five high-temperature wood-surface carbonization methods. Two conventional approaches—(i) flame-based charring using a propane–butane torch and (ii) hot-plate contact charring—are evaluated alongside three unconventional, technologically more advanced methods: (iii) CO_2-laser engraving, (iv) a highly non-thermal atmospheric-pressure arc-discharge plasma, and (v) rapid 2.45 GHz microwave surface heating. The latter two methods were developed by our team specifically for this study. European beech (Fagus sylvatica) specimens were treated using each technique.

The resulting carbonized layers were characterized with respect to surface morphology (SEM), structural integrity and micro-mechanical properties (nanoindentation), and physicochemical transformations (FTIR). In addition, the long-term stability and weathering resistance of the treated surfaces were examined using accelerated UV exposure in a Q-Lab Xenon Test Chamber. Over a two-month period, changes in wettability, color, gloss, and roughness were quantified and interpreted in relation to the distinct heating mechanisms characteristic of each method.

The combined dataset highlights substantial differences in carbon-layer homogeneity, penetration depth, micro-mechanical performance, and photodegradation resistance among the five techniques. Overall, the results demonstrate the strong potential of arc-plasma and microwave-based approaches to serve as controllable and tunable alternatives to traditional flame or hot-plate charring.

Acknowledgement

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In-situ Laser-induced Chemical Formation of Hexagonal Boron Nitride Coatings on Wood

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Abstract

Hexagonal boron nitride (h-BN) is a promising candidate for advanced fire protection due to its exceptional thermal stability, chemical inertness, and unique layered microstructure. Despite its potential, the integration of h-BN into heat-sensitive substrates like wood remains a significant challenge. Conventional synthesis methods require controlled environment, extreme temperatures and lengthy procedures, limiting the direct synthesis on wood.

We report a scalable and rapid approach to synthesize h-BN coatings directly on wood surfaces using laser-induced chemical transformation. By utilizing a CO2-laser as a localized energy source, we achieve the precise spatiotemporal control required to trigger the chemical reaction of a precursor mixture. This process generates localized high-temperature zones that facilitate the formation of h-BN, while it ensures that the structural integrity of the wood substrate remains perfectly preserved.

Transmission electron microscopy (TEM) and Raman spectroscopy confirm the formation of h-BN. Detailed TEM analysis reveals the presence of nanocrystalline domains with a random orientation, where the calculated interatomic spacing confirms high-quality hexagonal stacking. The functionalized wood exhibits outstanding fire-resistance properties, as demonstrated by single-flame exposure tests. Remarkably, the wood substrate remained structurally unchanged and showed no signs of combustion after 30s of direct flame contact, highlighting the effectiveness of the ceramic coating. This process offers a transformative route for functionalizing timber, facilitating the direct synthesis of high-performance, fire-retardant coatings for the modern construction industry.

The Role of Moisture Gradients and Time Scales in Wood Mechanosorption

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Abstract

Mechanosorptive strains arise when hygroresponsive materials, such as wood and wood-based materials, are mechanically loaded under varying moisture conditions—a situation inherent to many structural applications. Moisture changes simultaneously alter elastic and viscoelastic compliances and induce hygroexpansion; however, the resulting deformation cannot be described by a simple superposition of these individual effects. Although mechanosorption is commonly attributed to hydrogen-bond rearrangement and slippage, key aspects remain only partially understood. In particular, the interplay between moisture transport, viscoelasticity, and the time scales of moisture variation, as well as the role of internal moisture gradients, continues to generate contradictory interpretations.

We address this problem using a Diffusion-Dependent Stick–Slip Fiber Bundle Model that explicitly couples moisture transport with a moisture-dependent mechanical model that can reproduce the main aspects of mechanosorption [1]. Dimensionless numbers are proposed to relate cyclic moisture periods to intrinsic viscoelastic and diffusive time scales, enabling a systematic exploration of time-scale competition. Simulations with and without explicit moisture gradients assess their influence on the mechanosorptive response. A strain decomposition into elastic, viscoelastic, hygroexpansive, plastic, and mechanosorptive contributions enables direct comparison with recent experimental observations.

We show that longer moisture cycles increase cyclic strain amplitudes and, therefore, enhance mechanosorptive deformation. Diffusivity emerges as the dominant internal time scale, governing moisture equilibration and the associated compliance variations, including the viscoelastic contribution. In contrast, internal moisture gradients have only a minor influence on global strain despite locally elevated hygromechanical stresses, as tensile and compressive regions partly compensate each other. More generally, the magnitude of mechanosorptive deformation is controlled by the balance between elastic stiffness and moisture-dependent deformation mechanisms. When viscoelastic and hygroexpansive contributions are large relative to the instantaneous elastic response, mechanosorptive strains are amplified; conversely, elastic-dominated systems exhibit a reduced relative effect. In wood, this general principle manifests as pronounced mechanosorption in the transverse plane and a comparatively weaker response in the longitudinal direction due to its high axial stiffness.

[1] Amando de Barros, J. O., & Wittel, F. K. (2024). *Physical Review E*, 109, 044139. https://doi.org/10.1103/PhysRevE.109.044139

Water-Resistant Structural Colour Coatings from Cellulose Nanocrystals on Wood Surfaces

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Abstract

Visible structural colours are often iridescent, non-pigmented colours that are selectively reflected from the physical interaction of light with periodically ordered helical microscopic structures (helical pitch ca. 100 – 750 nm) in the chiral-nematic liquid crystals [1]. In nature, Pollia condensata and Margaritaria nobilis fruits feature helically oriented cellulose microfibrils, which produce a bright metallic blue colour through reflection [2]. Artificially mimicking these structures is possible through the evaporation-induced self-assembly of wood-derived cellulose nanocrystals (CNCs) dispersed in water. These structures are preserved upon drying as chiral-nematic films and have found applications in anti-counterfeiting labels, environmental sensors, and aesthetic coatings [3]. However, exploiting these exceptional optical properties in the wood coating industry is challenging due to high water- sensitivity, as they swell and delaminate in contact with water and moisture. This phenomenon is primarily attributed to interfacial adhesion made of weak secondary hydrogen bonds between CNC coatings and wood. Furthermore, wood swelling and shrinkage cause it to warp over time, affecting the structural integrity of the CNC coatings.

In this work, the physical properties of CNCs, such as pH, viscosity, and surface charge density, were optimized for electrostatic stabilization and to promote uniform self-assembly for producing homogeneous structural colour coatings on warp-resistant 3-layer oak wood panels (Figure 1). The water hydrophobicity of CNC coatings was improved through high-temperature heat treatments (>100 ˚C), while preserving the structural colouration. Furthermore, surface functionalization of coatings with acetal groups was developed to enhance their hydrophobicity further. Microscopic and spectroscopic characterizations were performed to evaluate optical properties, oriented microscopic structure sizes, and the degree of surface modification. These primary findings establish a strong foundation for any further approaches required to develop a robust water resistance of structural coatings on wood surfaces.

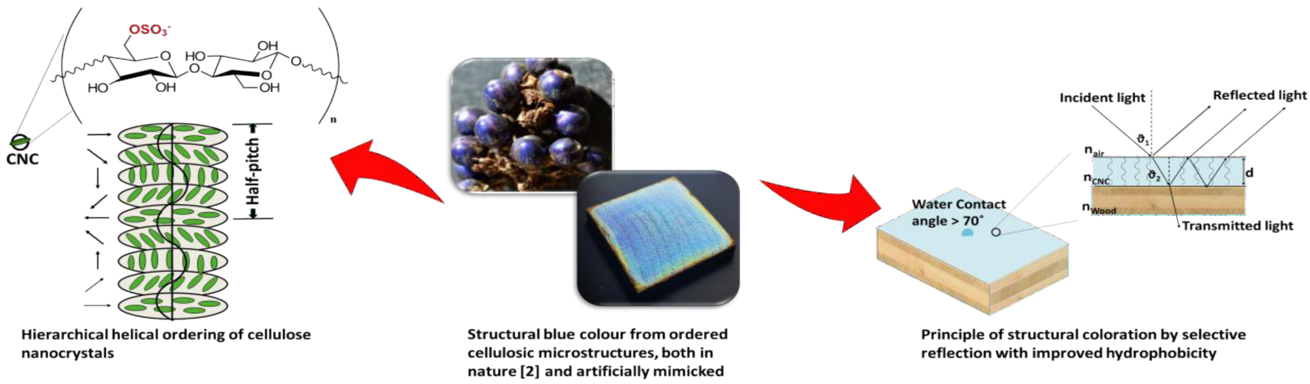

Fig. 1*: Structural colour coatings from water-resistant cellulose nanocrystals*

[1] De France, K.J., Chiral nematic cellulose nanocrystal composites: An organized review. The Canadian Journal of Chemical Engineering, 2024. 102(8): p. 2695–2713.

[2] Middleton, R. and M. Sinnott-Armstrong, Structural color in fruits: Biomaterials to inspire physical optics. APL Photonics, 2024. 9(8).

[3] Parker, R.M., et al., The Self-Assembly of Cellulose Nanocrystals: Hierarchical Design of Visual *Appearance.* Advanced Materials, 2018. **30**(19): p. 1704477.

Species-Dependent Super-Black Wood Formation Following CF_4 and O_2 Plasma Etching

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Abstract

Super-black materials achieve extremely low reflectivity in part through the effects of surface microstructure on light reflection and absorption. They are attracting substantial scientific and industrial interest in fields as diverse as astronomy and art [1], [2]. We developed a super-black wood by oxygen (O_2) plasma etching the transverse surface of basswood (Tilia americana L.) [1], [2]. In this study we examined whether a carbon tetrafluoride (CF_4) plasma could also create super-black wood by comparing the colour of six different wood species after etching with CF_4 or O_2 plasmas. The following species were subjected to CF_4 and O_2 plasma etching: basswood, Ohio buckeye (Aesculus glabra Willd.), New Zealand white pine (Dacrycarpus dacrydioides (A.Rich.) de Laub.), lime (Tilia vulgaris Hayne Mill.), jelutong (Dyera costulata (Miq.) Hook.f.), and balsa (Ochroma pyramidale (Cav. ex Lam.) Urb.). Our results clearly show that CF_4 plasma is capable of creating super-black wood surfaces; however, we found an interaction of wood species and plasma type (CF_4 v. O_2) on the black colour of the woods. This interaction occurred because the black colour of lime etched with a CF_4 plasma was significantly lighter than that of lime etched with an O_2 plasma. The other wood species showed no such effect of gas type on blackness following plasma etching. Balsa was more susceptible to plasma etching than the other wood species showing the largest reduction in thickness following O_2 and CF_4 plasma-treatments. Such species-dependent differences in blackness and etching rate might be associated with variations in the basic density of the different woods. Contact angle measurements of O_2 and CF_4 plasma-treated super-black wood indicate that the latter super-black wood exhibits greater hydrophobicity, possibly due to the ability of CF_4 plasma to simultaneously deposit and form a hydrophobic fluorocarbon layer on the surface of wood [3].

[1] L. M. Schmidt et al., "Characterization of the reflectivity of various black and white materials," in Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation IV, R. Geyl and R. Navarro, Eds., Proc. SPIE, vol. 11451, Art. no. 11451-129, 2020. doi: 10.1117/12.2562759.

[2] K. J. Cheng, D. Feng, L. M. Schmidt, M. Turner, and P. D. Evans, "Super-black material created by plasma etching wood," Adv. Sustain. Syst., vol. 8, no. 10, Art. no. 2400184, 2024, doi: 10.1002/adsu.202400184.

[3] B. Poaty, B. Riedl, P. Blanchet, V. Blanchard, and L. Stafford, "Improved water repellency of black spruce wood surfaces after treatment in carbon tetrafluoride plasmas," Wood Sci. Technol., vol. 47, no. 2, pp. 411–422, 2013, doi: 10.1007/s00226-012-0505-8.

Living UV and moisture-protecting coating for wood surfaces

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Abstract

In today's increasing awareness of the environmental impact of building materials, wood stands out as a renewable solution. However, it needs to be treated or coated with environmentally problematic compounds to avoid damage from ultraviolet radiation, water, and organisms. Sustainable solutions, including self-healing technologies, are largely unscalable. In this project, a perspective shift was made by using a living melanin-producing fungus as a natural shield for wood surfaces. The formation and the role of melanin as a UV and water-resistant coating are explored. The living component is evidenced by its potential to enable dynamic environmental responses and self-healing.

A strain of the Ascomycetes K. deusta was cultivated through liquid fermentation and added to a cellulose-based gel. Applied to wood surfaces, it was incubated at 100%RH and RT. Wood colonization and melanin production were monitored on camera. The coatings were characterized using UV-vis spectrometry, contact angle measurements, and thickness measurements.

Uniform colonization and melanin formation on the wood were achieved within 2 weeks. The UV-vis spectrum of the coatings reveals a broad-band absorption. The sample's low thickness of 94 ± 40 µm, confirms light absorption. The average contact angle exceeds 150°, indicating superhydrophobicity.

This ongoing research demonstrates that melanin-producing fungi can protect surfaces against radiation and water. Currently, new challenges are being addressed to improve coating-wood interaction and coating durability at low moisture levels.

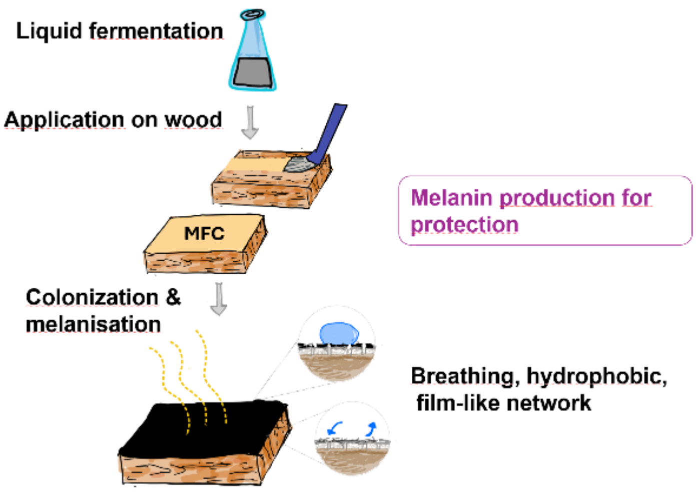

Fig. 1: *Animation illustrating the general approach.*

Acknowledgements
Jonas Garemark, Tina Künniger, and Markus Heeb.

Multifactorial Analysis of Properties Governing Gluability in Hybrid Engineered Wood Products

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Abstract

Increasing pressure on traditional timber resources necessitates the use of various hardwood and softwood species in high-performance engineered wood products [1,2]. A primary challenge in this transition is ensuring reliable adhesive bond performance. As a wide range of wood parameters influence adhesive bonding [3], this research applies machine learning as an analytical tool to systematically investigate wood-adhesive interactions. The objective is to establish a generalizable model capable of predicting gluability based on intrinsic material properties, allowing for extrapolation to wood species outside the training set.

Generating large datasets in wood materials science is inherently restricted by the time-consuming nature of physical testing and sample preparation. Consequently, this investigation is based on a dataset representing a substantial experimental effort, comprising 70 dual-species wood panels manufactured from 14 distinct wood species. To account for the high material variation intrinsic to natural timber, 1260 mechanical specimens were cut and tested. The input features, comprising physical, chemical, and mechanical properties, were determined on a per-board level through multiple measurements. The output parameters, specifically tensile shear and transverse tensile strength, were obtained at the specimen level and averaged to provide a representative value for the entire board.

The methodology utilizes a multi-modal approach integrating two distinct data streams. First, the physical characterization data is analyzed to determine the governing factors of bond strength. Given the limited sample size (n=70 boards), a nested cross-validation strategy is employed to evaluate regression models (SVR, Gradient Boosting, Random Forest). A feature importance analysis is subsequently conducted to identify critical material properties, which informs the development of targeted intervention strategies to improve bonding. Second, high-resolution RGB and hyperspectral imaging data is utilized to correlate spectral signatures with bond performance. This framework aims to combine fundamental materials science with data science techniques to allow for a fast, non-contact, non-destructive, and potentially industrial-process-ready application.

[1] Churkina G, Organschi A, Reyer CPO, et al (2020) Buildings as a global carbon sink. Nat Sustain 3:269–276. https://doi.org/10.1038/s41893-019-0462-4

[2] Huber C, Langmaier M, Stadlmann A, et al (2023) Potential alternatives for Norway spruce wood: a selection based on defect-free wood properties. Ann For Sci 80:41. https://doi.org/10.1186/s13595-023-01206-7

[3] Hunt C, Dunky M, (2022) Analysis of Future Prospects and Opportunities for Wood Adhesives: A Review*. Forest Products Journal 72 (s2): 14–22. https://doi.org/10.13073/FPJ-D-23-00011.

Leaching of Copper-Based Preservative from Traditional Wood Shingle Roofing

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Abstract

Traditional wooden shingle roofs are an important part of Swiss Alpine cultural heritage. However, climate change threatens their durability, particularly by shortening periods of snow cover. This, together with competition from other materials, endangers the continued practice of this savoir-faire. To extend their service life, copper-based wood preservatives (e.g., Korasit KS2) are used; yet, concerns exist regarding the potential environmental impact of runoff in sensitive mountain landscapes. Standardised semi-field leaching test protocols1 as well as copper preservative leaching studies reported in the literature2,3 typically employ larger sawn softwood boards installed vertically. On the other hand, traditional wood shingles have noticeably different characteristics and installation design: they are radially split, have significantly smaller dimensions, are not artificially dried either before or after impregnation, and are usually installed at an inclination of 22 to 32° with overlapping geometry. These differences could significantly impact the leaching behaviour of wood shingles.

To address this gap, this study aims to investigate the leaching of copper preservatives from traditional wooden roofs. Semi-field test protocols were adapted in accordance with the common practices in the shingle sector. After the first 390 mm of rainfall over three months, our preliminary results showed the expected decreasing trend in copper leaching rates, with the highest emissions generated by initial rain events (Figure 1). Vertical control specimens collected only 10% of the runoff volume but exhibited higher copper concentration. Concurrently, a laboratory immersion test investigated whether pre-weathering and re-wetting, a common practice among shingle craftsmen, could reduce initial copper leaching on site. However, our data do not support this assumption.

Both experiments remain ongoing; additional preservative systems are also under investigation. A further challenge lies in translating measured leaching rates into ecotoxicological risk assessments for water and soil, given the complex and site-specific dynamics involved.

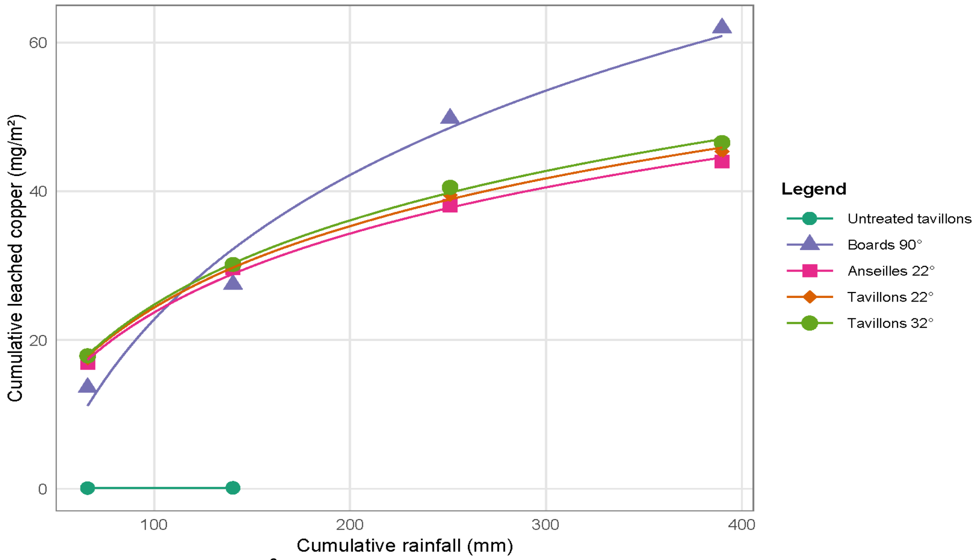

Fig. 1: *Cumulative copper leached (mg/m^2) versus cumulative rainfall (mm) over four leaching periods (390 mm total rainfall) of spruce boards and schingles treated with Korasit KS2. Total test Racks (N) = 8. Untreated tavillons: N=1; Boards 90°: N=2, R^2=0.978; Anseilles 22°: N=2, R^2=0.997; Tavillons 22°: N=2, R^2=0.998; Tavillons 32°: N=2, R^2=0.998.*

[1] Nordtest. (2005). Leaching of active ingredients from preservative-treated timber—Semi-field testing (NT build 509).

[2] Lebow, S., Williams, R. S., & Lebow, P. (2003). Effect of simulated rainfall and weathering on release of preservative elements from CCA treated wood. Environmental Science & Technology.

[3.] Waldron, L., Cooper, P. A., & Ung, T. Y. (2005). Prediction of long-term leaching potential of preservative-treated wood by diffusion modeling. 59(5), 581–588. https://doi.org/10.1515/HF.2005.095

Temporal Dynamics of Wood Life Cycle Assessment: Over a Decade of Retrospective on Inventory Evolution and Impact Prediction Amidst Standard Transitions

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Abstract

The wood industry has long positioned itself as a cornerstone of the bio-based economy, relying on Life Cycle Assessment (LCA) to validate its environmental credentials. Over the past fifteen years, the methodological framework underpinning these assessments has undergone profound transformations, driven largely by the inception and subsequent major revisions of core standards, specifically EN 15804 (Sustainability of construction works) and EN 16485 (Round and sawn timber - EPDs - PCR for wood and wood-based products for use in construction). This paper presents a longitudinal analysis of Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) evolution within the wood sector, examining the consequences of transitioning from initial standard implementations to their current iterations.

By synthesizing over a decade of inventory data, this study identifies a dual trajectory in LCI development. First, a "horizontal" expansion is observed, where system boundaries have widened from simple cradle-to-gate analyses to comprehensive cradle-to-grave scopes, necessitated by the modular approach of EN 15804. Second, a "vertical" deepening of inventory granularity is evident, particularly regarding biogenic carbon accounting and forestry processes (module A1), as mandated by the inclusion of EN 16485:2014, which followed the first EN 15804:2012.

The analysis reveals that the evolution of environmental impact results is not merely a function of industrial efficiency gains but is significantly influenced by standardization artifacts. The transition to EN 15804+A2, for instance, introduced new impact categories and altered characterization factors, resulting in a statistical divergence in reported Global Warming Potential (GWP) for identical wood products when comparing legacy datasets with contemporary calculations. Specifically, the study highlights how impact indicators related to resource use and land use have evolved from qualitative descriptors to quantitative metrics, fundamentally changing the environmental profile of wood products.

Ultimately, this retrospective demonstrates that as inventory transparency improves and standards converge, the environmental impact profile of wood products has shifted from a dominant focus on energy consumption in processing to a nuanced balance of biogenic carbon sequestration, land-use stewardship, and end-of-life circularity perspectives. These findings provide critical insight for the wood science community regarding the interpretation of historical LCA data and underscore the necessity of updating background databases to reflect the methodological rigor of current international standards.

Keywords:
life cycle assessment, life cycle inventory, impact analysis, wood industry, EN 15804, EN 16485, sustainability, environmental impact, circularity.

Wood as an Active Humidity Sensor: Integrated Environmental Monitoring via Iron-Catalyzed Laser-Induced Graphitization

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Abstract

Iron-catalyzed laser-induced graphitization (IC-LIG) has recently emerged as a scalable, eco-efficient approach for converting a tannic acid–iron precursor formulation into conductive carbon architectures on renewable substrates such as wood and cellulose. The IC-LIG process forms multilayered, porous, and phase-tunable iron/iron oxide–graphitic networks with sheet resistances of ~18 Ω sq^{-1} and precise structural control.

Within the COMET Module i^{3}Sense, a collaborative project including scientific and industrial partners, we extend IC-LIG to temperature and humidity sensor structures designed for prospective environmental monitoring applications in buildings. These sensors were directly fabricated on several construction-relevant wood species, including beech and spruce, as well as decorative veneers such as maple, demonstrating excellent material compatibility and high patterning fidelity. IC-LIG-based devices have previously shown outstanding mechanical durability, with strain sensors operating reliably for ~70 000 loading cycles, highlighting the intrinsic robustness of the material system. Here, the novel sensor designs use wood as the active sensing material for humidity detection, and initial humidity sensing experiments show stable, drift-free responses and high reproducibility across repeated humidity stages, confirming the suitability of IC-LIG sensor architectures for integrated and long-term environmental monitoring applications. The sensor structures can be manufactured in < 3.5 s per device, enabling rapid and low-cost production suitable for distributed sensor networks manufacturable on multiple scales.

Curing Kinetics evaluation of Tannin-Carbonate-Based NIPU Wood Adhesives by dynamic mechanical analysis

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Abstract

Developing new polymer materials requires a thorough understanding of their behavior to ensure optimal performance and assess potential chemical emissions during their service life. The updated REACH Annex XVII regulation on formaldehyde emissions, published in 20231, sets a new limit for VOC emissions at ≤ 0.062 mg/m^3 for wood-based products and furniture. This reinforces the urgency to develop more sustainable adhesive systems with lower environmental impact.

In the field of adhesives, particularly polyurethane-based systems, ongoing research is focused on the development of non-isocyanate polyurethanes (NIPUs). One promising approach involves the use of cyclic carbonates2 derived from CO_2 feedstocks to create carbonate-based NIPUs. Another route is based on Carbonated Tannin, which we are developing at University of Freiburg. While this last one is both environmentally safer and industrially viable, further improvements are needed, especially in terms of the modeling of cure, the water resistance, and the formulation optimization. The TANIPU project aims to address these challenges through systematic formulation development and kinetic studies of the curing process.

A kinetic evaluation using Dynamic Mechanical Analysis (DMA) provides key parameters such as activation energy (Ea), reaction order, and rate constants (k) which are essential to understanding the curing and polymerization behavior of TANIPU adhesives. The work to be presented at the International Academy of Wood Science is about the kinetic analysis of two adhesive formulations, differentiated by their amine components.

Keywords:
TANIPU, amine, carbonate, tannin, DMA, kinetic.

Acknowledgments
We would like to thank the German Federal Ministry of Food and Agriculture (BMEL) for funding the TANIPU project, and all associated partners : Fraunhofer-Institut für Chemische Technologie (ICT), Silvateam, Jowat SE, Synthopol Chemie GmbH, nova-Institut für Politische und Ökologische Innovation GmbH and Lignotrend.

[1] Commission Regulation (EU) 2023/1464 of 14 July 2023 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council as regards formaldehyde and formaldehyde releasers (Text with EEA relevance).

[2] Balla, E.; Bikiaris, D. N.; Pardalis, N.; Bikiaris, N. D. Toward Sustainable Polyurethane Alternatives: A Review of the Synthesis, Applications, and Lifecycle of Non-Isocyanate Polyurethanes (NIPUs). Polymers (Basel). 2025, 17 (10), 1364. https://doi.org/10.3390/POLYM17101364.

Condensed Tannin-Derived Non-Isocyanate Polyurethanes for Class A1 Wood Adhesives

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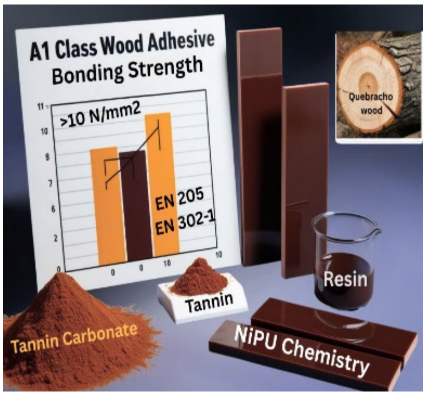
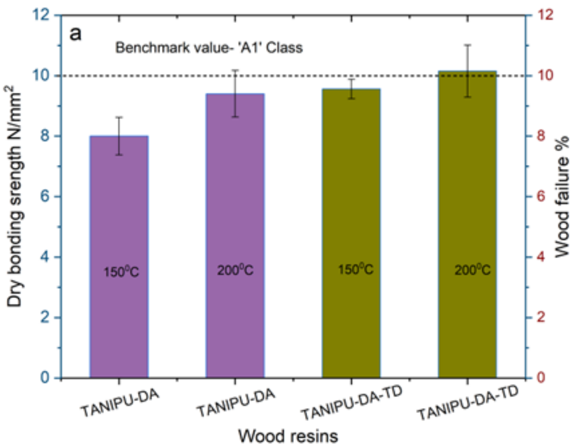
Abstract

Wood adhesives are essential for engineered wood products but still primarily rely on formaldehyde and isocyanate chemistries, raising concerns about emissions, toxicity, and fossil fuel dependence. This has led to the development of sustainable, bio-based alternatives from renewable resources such as lignin and tannins. Among these, non-isocyanate polyurethanes (NIPUs), created by reacting cyclic carbonates with amines, provide a safer alternative by avoiding hazardous isocyanates. Recent efforts focus on incorporating natural polyphenols, such as condensed tannins, to produce low-emission, high-performance wood adhesives.

This study developed nonisocyanate polyurethane (NIPU) wood adhesives from Quebracho condensed tannins via carbonation with dimethyl carbonate, followed by reaction with amines. Two formulations were created: TANIPU-DA (hexamethylene diamine) and TANIPU-DA-TD (including hexamethylenetetramine cross-linker). Urethane formation was confirmed by FTIR. Dynamic mechanical analysis (DMA) revealed gelation at 120–150 °C and vitrification between 160–220 °C. TD addition improved cure kinetics, and TANIPU-DA-TD achieved lap shear strengths over 10 N/mm^2, meeting A1 standards (DIN EN 302–1). Although high curing temperature (~200 °C) and time (~20 min) are needed, these results show tannin-based NIPUs can meet structural wood adhesive standards as a sustainable alternative to formaldehyde- and isocyanate-based systems. Research continues on performance, scaling, and broader use.





[1] Gopakumar Sivasankarapillai, Arsène Bikoro Bi Athomo, Detlef Schmiedl, Antonio Pizzi, Marie-Pierre Laborie, Tuning Polyphenols for Thermosetting Wood Adhesives: Class 'A1' Non-Isocyanate Polyurethanes from Condensed Tannins, J. Agric. Food Chem. 2025, 73, 27, 17057–17068

[2] Marie-Pierre Laborie, Gopakumar Sivasankarapillai, Antonio Pizzi, Tannin-Based Non-Isocyanate Polyurethane Adhesives, US20240392174A1 granted on 2024-11-28

Salt-in-Wood Piezoelectric Power Generators

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Abstract

The nanowatt-scale power output of current bio-based piezoelectric energy harvesters limits their practical use in converting biomechanical energy efficiently. In this work, we present a high-performance, sustainable piezoelectric device based on environmentally benign Rochelle salt, integrated into a laser-patterned wood scaffold to create arrays of crystal pillars. By systematically examining how pillar geometry influences the piezoelectric response, we identify a shear-oriented configuration (pillars aligned at 45°) that delivers voltages up to 30 V and currents of 4 μA, corresponding to an order-of-magnitude increase in power compared to single-crystal Rochelle salt. Furthermore, we introduce a method for direct laser-induced graphitization of the crystal surfaces using a fully renewable precursor, enabling the formation of low-resistance electrodes (36 Ω sq^{-1}). The device is fully designed in accordance with green chemistry principles, following a cradle-to-grave strategy that supports disassembly, recycling, and reuse. Overall, the developed nanogenerator surpasses the performance of existing bio-based systems and approaches that of conventional lead-based materials, while offering a substantially reduced environmental footprint, as confirmed by life-cycle assessment.

[1] J. Garemark et al. Salt-In-Wood Piezoelectric Power Generators with Circular Materials Design for High-Performance Sustainable Energy Harvesting. Adv. Funct. Mater.2025, 35, 2418454

Photocurable Wood-Derived Materials for Additive Manufacturing: Insights from Lignin and Cellulose Systems

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Abstract

Wood-derived polymers such as organosolv lignin (OSL) and liquid crystalline cellulose derivatives (e.g., hydroxypropyl cellulose, HPC) offer promising avenues for extrusion-based additive manufacturing. However, obtaining stable printed objects remains challenging, as structures often collapse post-printing. Photocuring is a well-established strategy to enhance stiffness and stabilize printed constructs, but the photocuring behavior of these bio-based inks presents significant limitations [1]. OSL exhibits very limited photoreactivity due to its strong UV-blocking capability and radical scavenging activity [1]. HPC demonstrates higher intrinsic photoreactivity, undergoing rapid photocrosslinking, but the increase in stiffness is negligible, restricting gel-to-stable-solid transitions in UV-irradiated inks and limiting part stability [2].

To address these limitations, we systematically investigated the effect of UV-reactive chemical group attachment, specifically methacrylation, on the photoreactivity of these materials. Methacrylation of HPC markedly enhances UV-induced crosslinking kinetics and mechanical stiffness in direct ink writing (DIW) printed parts, achieving more than a 1000-fold increase in storage modulus within 30 seconds. However, very high degrees of methacrylic grafting (between 1.8 and 2.6) generate significant cure stresses, resulting in brittle 3D-printed materials and compromised printability, highlighting the need to carefully tune curing kinetics and optimize 3D ink formulations [2]. For lignin, methacrylation enables photocuring, but even at ~80% methacrylation, efficacy remains constrained by intrinsic UV-blocking and radical scavenging, resulting in only a ~100-fold increase in storage modulus over 300–400 seconds [3], which may be too slow for practical UV 3D printing applications.

Overall, these findings demonstrate that functionalization and careful control of grafting levels are critical for modulating photoreactivity in wood-derived systems. Understanding the interplay between polymer chemistry, functionalization, photocuring kinetics, and DIW processing conditions is essential for designing UV-curable inks capable of producing stable, high-fidelity printed objects [2,3].

[1] M.-T. Yapa, J. Lalevée, M.-P. Laborie, Polymers 2024, 16, 2869.
[2] M.-T. Yapa, G. Sivasankarapillai, J. Lalevée, M.-P. Laborie, Polymers 2025, 17, 278.
[3] O. Mhirsi, M. Yapa, M. G. Laborie, Macromolecular Materials and Engineering 2026, 311.

WOODOMICS: Integrative approach for the analysis of sex-specific plant responses to drought in dioecious Mediterranean species

Napolitano F. [1], Amitrano C. [1], De Francesco S. [1], Erbaggio A.[2], Cirillo C.[1], Biagini B [2], Aversano R.[1], Chiaiese P.[1], Rita A[1], De Micco V.[1]

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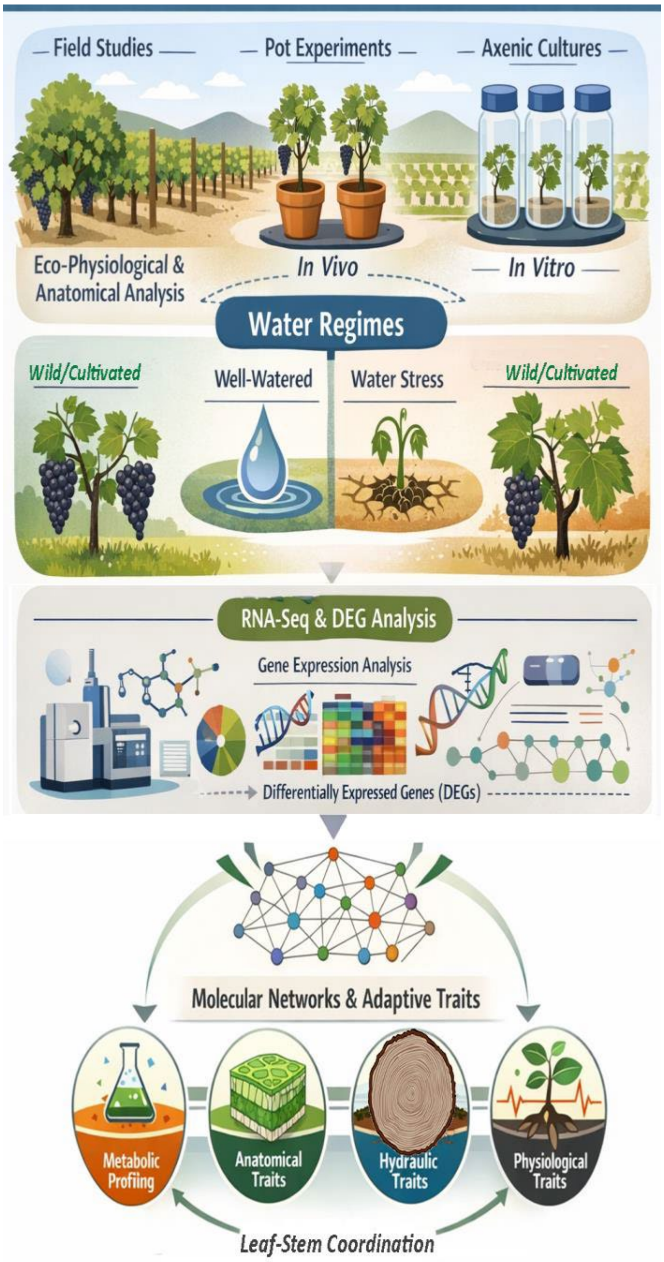
[2]Freelance

Abstract

In the Mediterranean basin, climate change threatens the sustainability of both natural ecosystems and agricultural systems. The increase in the severity, frequency, and duration of drought, strongly influences plant metabolism and growth processes. This study aims to investigate drought responses in dioecious plants coexisting in a Mediterranean ecosystem in Southern Italy, considering potential sex-specific differences. The leaf-stem coordination is evaluated in male and female individuals in three species representing different leaf habits, namely a deciduous vine (Vitis vinifera L. - formerly Vitis vinifera L. subsp. sylvestris Hegi), an evergreen shrub (Pistacia lentiscus L.), and a conifer (Juniperus macrocarpa L.). Leaf functional traits and wood anatomical parameters related to hydraulic efficiency and safety are quantified in juvenile structures. Wood anatomical traits are also analysed in tree-ring series to evaluate responses to past environmental variability. To dissect sex-related mechanisms of acclimation, we further apply an integrative approach in Vitis vinifera, performing experiments under controlled environmental conditions. Experiments will be performed in pots (in vivo) and under axenic culture (in vitro), comparing responses of wild dioecious individuals and cultivated hermaphrodite genotypes. Plants will be exposed to two levels of water availability, and their responses will be analysed through eco-physiological measurements, coupled with the characterization of leaf and xylem traits. In addition, metabolomic and gene expression analyses via RNA-seq, followed by the identification of differentially expressed genes (DEGs), will be conducted on grapevine plants grown under the controlled conditions in vivo and in vitro, to dissect the molecular networks associated with metabolic, anatomical, hydraulic, and physiological traits. This is expected to provide a broader understanding of the different adaptive strategies in the shoot-leaf coordination. The integration of this multidisciplinary approach helps clarify how and to what extent Mediterranean plants may be resilient in a climate change scenario.



Spruce Cross-Sections as Scaffold for Engineered Living Bioreactors

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Abstract

Wood has already emerged as a promising sustainable filter material for water treatment due to its hierarchical porosity, directional flow channels, and large internal surface area, which support the removal of contaminants ranging from dyes to microplastics.1–3 Recent studies have also shown that wood can serve as a natural scaffold for immobilized enzymes in continuous-flow systems.4,5 Building on this concept, our project moves beyond passive filtration and beyond conventional enzyme immobilization by introducing a living catalytic site into the wood structure. Instead of loading purified enzymes onto wood, we immobilize genetically engineered *Escherichia coli* that produce bacterial laccase in situ, creating a porous wood–microbe hybrid material for future wastewater treatment applications. This bio-based route is attractive because it can reduce the need for enzyme purification and repeated reloading, while potentially extending catalyst lifetime through continuous intracellular enzyme production and partial protection of the catalyst within the cell envelope.

In this study, a recombinant *E. coli* BL21(DE3) laccase construct was screened and optimized with respect to induction temperature, induction density, copper supplementation, pH, and ionic strength. The best overall expression conditions were 30 °C for 24 h, induction at $OD_{600} \approx 0.7$, and 1 mM $CuSO_4$. Whole-cell activity was highest at mildly acidic pH, while elevated chloride concentrations reduced activity; among the tested variants, the cytosolic construct showed the greatest salt tolerance.

For immobilization, recombinant cells were introduced into porous spruce cross-sections and evaluated by ABTS oxidation.

These results establish wood not only as a passive filter or enzyme carrier, but as a platform for engineered living biocatalytic reactors. Compared with enzyme-only wood hybrids, this strategy opens a route toward self-renewing, lower-processing, and potentially more durable catalytic materials for continuous treatment of dye- and other pollutant-containing waste streams.

[1] Wang, Y. et al. Flowthrough Capture of Microplastics through Polyphenol-Mediated Interfacial Interactions on Wood Sawdust. Adv. Mater. 35, 2301531 (2023).

[2] Goodman, S. M., Bura, R. & Dichiara, A. B. Facile Impregnation of Graphene into Porous Wood Filters for the Dynamic Removal and Recovery of Dyes from Aqueous Solutions. ACS Appl. Nano Mater. 1, 5682–5690 (2018).

[3] Escolà Casas, M. et al. Use of wood and cork in biofilters for the simultaneous removal of nitrates and pesticides from groundwater. Chemosphere 313, 137502 (2023).

[4] Goldhahn, C., A. Taut, J., Schubert, M., Burgert, I. & Chanana, M. Enzyme immobilization inside the porous wood structure: a natural scaffold for continuous-flow biocatalysis. RSC Adv. 10, 20608–20619 (2020).

[5] Goldhahn, C., Burgert, I. & Chanana, M. Nanoparticle-Mediated Enzyme Immobilization on Cellulose Fibers: Reusable Biocatalytic Systems for Cascade Reactions. Adv. Mater. Interfaces 6, 1900437 (2019).

Biochar-based treatment to increase durability of wood

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Abstract

In order to prevent the worst effects from climate change, prevention of greenhouse gases is not sufficient. It is necessary to implement carbon fixing technologies that help us accelerate the decrease of current greenhouse gases in the atmosphere. This study investigates the feasibility and advantages of combining naturally carbon fixing materials such as wood with renewable carbon obtained from pyrolysis of biomass, also called biochar. Biochar produced using pyrolysis temperatures of around 700℃ is a highly stable type of carbon that lacks flammable volatile gases usually observed in biochars produced at lower temperatures. It has also been observed that introducing biochar particles into biopolymer composites1,2 and concrete-fiber hybrids3 improves overall fire and mechanical performance. It is speculated that introducing biochar within the wood structure improves its resistance to fire and fungal degradation. Carbon processing and wood infiltration methodologies that utilize only sustainable biobased components are explored along with an optimization of parameters aimed at increasing the durability of wood.

Hierarchically Architected Wood-Derived Xerogels: Toward Absorption-Dominant EMI Shielding

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Abstract

Wood-derived nanocellulose offers a versatile foundation for engineering multifunctional materials, as its surface chemistry and hierarchical assembly can be tuned from nanoscale surface chemistry to macroscale porous architectures. Yet, translating nanocellulose from lab-scale gels into device-ready constructs remains constrained by drying routes that distort geometry or require specialized equipment, and limited strategies to program composition and structure-property relationships throughout 3D architectures without complex multi-nozzle systems or post-assembly steps. Here, we implement a unified material design → fabrication design → functionality design strategy to create lightweight, shape-preserving, wood-based xerogels by integrating conductive and magnetic nanomaterials into a nanocellulose framework for absorption-dominant electromagnetic interference (EMI) shielding.

In the material design stage, a printable water-based scaffold is formulated from TEMPO-oxidized cellulose nanofibers and sodium alginate (TOCNF–NaAlg), chosen for its abundant functional groups, interfacial interactions, and network-forming capability. $Ti_3C_2T_x$ MXene nanosheets and Fe_3O_4 nanoparticles are incorporated as conductive/dielectric-loss and magnetic-loss components, enabling complementary dissipation pathways within a renewable biopolymer matrix. In the fabrication design stage, ink rheology is tuned for stable direct ink writing (DIW) of periodic lattices with controlled infill, allowing geometry to act as a design parameter. To further encode multifunctionality without increasing processing complexity, a single-nozzle, sequential in situ DIW strategy is employed to produce compositionally stratified constructs with a defined interface between $Ti_3C_2T_x$-rich and Fe_3O_4-rich domains. Post-printing, ionic crosslinking reinforces filament integrity, while low-surface-tension solvent exchange enables ambient drying with minimized capillary collapse, preserving printed geometry and hierarchical porosity without specialized drying equipment.

In the functionality design stage, the resulting architected xerogels combine hierarchical porosity for impedance matching and multiple scattering with synergistic dielectric and magnetic losses, promoting absorption-dominant EMI attenuation in lightweight porous structures. This work highlights an IAWS-relevant route for transforming wood-derived building blocks into manufacturing-relevant functional components by co-programming chemistry, interfaces, and architecture within a single design framework.

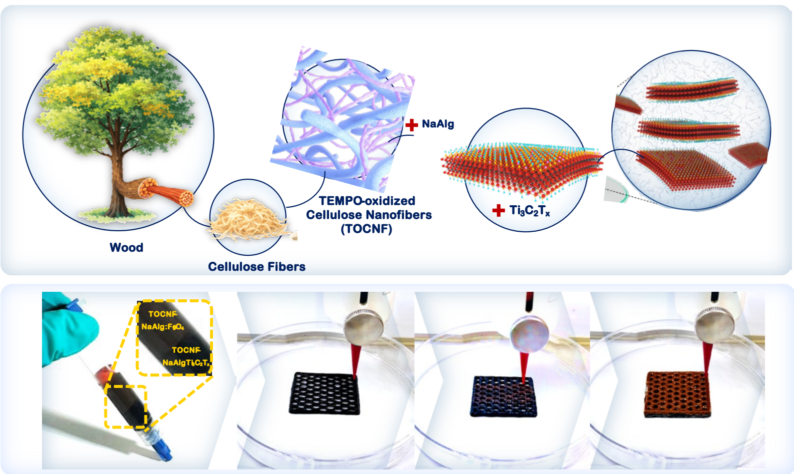

Fig. 1: Schematic illustration of wood-derived TOCNF-based ink formulation and sequential in situ DIW.

Transparent Protection: The Elusive Quest for Durable Exterior Clear Coatings for Wood

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Abstract

Few goals in wood technology have proven as seductive—or as relentlessly elusive—as a truly durable exterior clear finish for wood, despite long-standing desire from architects, builders, and consumers for such a coating. The journey towards this goal initially focused on modifications to coating formulation. Progress was incremental, and coating failure in service within two years remained the norm. A major breakthrough occurred when it was discovered that a clear silicone coating applied to wood pre-treated with chromic acid could meet consumer expectations for durability. This unexpected success reframed the problem: the key was the wood-coating interface in addition to the clear coating. By combining a pre-treatment that effectively photostabilizes lignin with a UV-transparent coating, a practical pathway emerged toward long-lasting clear-coat protection. As a result there was worldwide interest in wood pre-treatments as a way of enhancing the durability of clear coatings. Research initially focused on transition metal compounds as alternatives to chromium VI, but then shifted in the direction of organic and inorganic photostabilizers or even more radical pre-treatments designed to enhance the photostability of wood and the adhesion of clear coatings under outdoor exposure. Even these approaches met with limited success. Today, the most promising route forward appears to be integrated protection: pre-treatments that dimensionally stabilize wood, suppress surface fungal colonization, and photostabilize lignin, when combined with flexible, photostable coatings. My keynote traces this evolving journey, drawing upon my own research and that of other groups who have focused on this elusive goal.

Reflections on wood as a raw and construction material based on selected projects at TU Graz

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Abstract

In the context of this lecture, it is attempted to dedicate oneself to the tension between material|product and construction|building, using selected topics of the Institute of Timber Engineering and Wood Technology. What influence do industrially manufactured and standardized mass-made products have on the evolution of timber engineering, and can the demands of sustainable construction be sufficiently fulfilled? A temporal arch, which can also be seen in context of the professional career time of the lecturer, is established. The first project, the "European Timber Bridge", is presented with a focus on the nearly two-year long planning process, under the motto of "Construction determines durability". The second topic area revolves around the path "From bar to slab" and the possibilities connected to the product Cross-Laminated Timber (CLT), concerning usage in accordance with engineering. As is the case for all materials and products in the field of construction, there are suitable areas of application for CLT and such that are to be avoided. Peeling logs is nothing new in itself. What is new, however, is to increase the peeling capacity from the usual veneer thickness of around 3 mm to a board dimension of 10 mm and more. "Limits are there to be pushed". That is how the project "peeled_boards" or "rethink_LT_processing", the third project to be covered in this lecture, could be summarized. What exactly can be achieved with this, must be explored and put up to discussion. On the other side of our temporal arch is the product "purewood", standing under the motto of "From mass-made product to product of the masses". No small demand is connected to the intention of building entire timber structures, including fasteners and joining technology solely out of timber. Metallic fasteners as well as adhesives are to be avoided and aside from engineering, an important aspect of "purewood" is the promotion of moderate, handcrafted timber structures.

"European Timber Bridge" [larch GLT]

"rethink_LT_processing", peeling process: t = 10 mm

"purewood", fasteners made of wood

Wood Durability and Innovative Wood Protection

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Abstract

Wood species exhibit highly variable natural resistance to biotic (e.g., fungi, insects) and abiotic (e.g., weathering, UV radiation) degradation. In exposed outdoor applications—particularly in vulnerable environments—selecting naturally durable wood species is essential. However, compared to tropical regions, forests in other climatic zones offer only a limited number of naturally durable species, making technical protection against biological and environmental attack necessary. Traditionally, this has been achieved using biocidal wood preservatives, or, more superficially, through coatings such as paints and stains—methods still widely used today. Yet, growing concerns over the toxicity of conventional biocides have caused intensive research into less toxic biocides and, increasingly, biocide-free protection technologies. Some of these innovative approaches have already been implemented industrially, while others remain in development.

Furthermore, fire-retardant treatments are in the focus of research for external applications, especially in façade systems where both fire safety and weather resistance are critical. New formulations include phosphorus-based, intumescent, and mineral-based fire retardants where fixation to the wood matrix is crucial. These treatments aim to reduce flammability, limit smoke emission, and maintain performance under prolonged weathering—without compromising the wood's mechanical properties or environmental profile.

In conclusion, the field of wood protection is undergoing a significant transformation—from reliance on conventional biocides toward a more sustainable, multi-functional approach combining advanced wood modification, low-toxicity biocides, and innovative surface treatments. This presentation will provide an overview of existing and emerging wood protection technologies, critically discussing their durability, environmental impact, scalability, and suitability for modern construction, particularly in demanding external applications. The future of wood protection lies in integrated, science-based solutions that balance performance, safety, and sustainability

[1] Hill, C.: Wood modification. ISBN-13, 978-0-470-02172-9 (2006)

[2] Schultz, T.P., Goodell, B., Nicholas, D.D.: Deterioration and protection of sustainable biomaterials. ACS Symposium Series 1158 (2014)

[3] Goli, G., Negro, F., Cuccui, I., Todaro, L., Jones, D., Militz, H., Cetera, P.: Proceedings of the 11th European Conference on Wood Modification. ISBN 978-3-031-99417-3 (2025)

Wood Material Properties and Mechanics

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Abstract

Wood is re-emerging as a high-performance engineering material at the centre of sustainable construction, yet its mechanical behaviour remains uniquely complex due to its hierarchical structure and strong interaction with moisture. This plenary talk provides an integrated overview of the current scientific understanding of wood material properties and mechanics, from the nanoscale architecture of the cell wall to macroscale performance in engineered wood products. By linking structure to mechanical response, the talk highlights how anisotropy, moisture-dependent behaviour, statistical variability, and interface mechanics govern the reliability and long-term performance of timber structures.

Advances in adhesive bonding, surface modification, and the mechanics of bond-line interfaces are discussed in the context of modern engineered wood products, where manufacturing precision and interface performance determine overall structural behaviour. Contemporary insights into fracture mechanics, damage evolution, creep, and mechano-sorptive effects are presented as key factors influencing durability and service life, particularly under climate-induced stressors.

The talk also explores emerging frontiers, including multi-physics modelling, machine learning for mechanical property prediction, AI-assisted grading and process control, and digital twins for timber structures. These innovations signal a paradigm shift toward data-driven and computationally supported wood mechanics. Finally, the talk connects material behaviour to broader sustainability impacts, showing how mechanical reliability, carbon storage potential, and substitution effects position wood as a critical material for climate-neutral construction.

By combining fundamental science with applied engineering and digital transformation, the plenary will outline the opportunities and challenges in harnessing the full potential of wood as a next-generation structural material and the key research directions needed to advance the field.

Wood-based panels in the bioeconomy transition: Scientific pathways toward circular and fossil-free materials

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Abstract

Wood-based panels represent one of the most successful examples of resource-efficient material use within the forest-based bioeconomy. By converting lignocellulosic biomass into high-performance engineered products, the sector has long demonstrated how wood science can bridge fundamental material understanding with industrial innovation. Today, however, the wood-based panel industry faces a new generation of challenges driven by resource competition, climate change, stricter environmental regulations, and the transition toward circular and fossil-free production systems. This plenary lecture will discuss key scientific challenges that will shape the next decades of development in the sector and highlight how research can support this transformation. One important frontier is the diversification of raw material sources beyond traditional forest fibres. The project FIBSUN [1] explores the use of alternative lignocellulosic feedstocks derived from annual and grass-like plants to broaden the resource base for panel production. Increasing material circularity is another major challenge, addressed in EcoReFibre [2], which investigates technologies and material strategies to recover and reuse fibres from post-consumer fibreboards. Reducing reliance on fossil-derived chemicals is being pursued within the BioGlue Centre [3], where new generations of bio-based adhesive systems are developed for packaging, furniture and construction. Finally, the project WoodTreat [4] addresses the complex issue of secondary raw materials originating from treated or contaminated wood waste streams. Together, these initiatives illustrate how advances in wood science, chemistry, and materials engineering can enable the transformation of wood-based panels toward more resilient raw material supply chains, circular material flows, and fossil-free manufacturing. They also highlight the critical role of interdisciplinary research and collaboration between academia and industry in shaping the future of wood-based materials

[1] https://www.fibsun.eu/

[2] https://ecorefibre.eu/

[3] https://www.slu.se/en/research/research-catalogue/projekt/b/bioglue-centre/

[4] https://www.woodtreat.eu/

A damage accumulation approach to the strength of new, in-situ and recovered wood

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Abstract

The strength of wood can be measured at the various scales: from nanometre level in electron microscopes until macrolevel for structural applications. At every scale, many parameters influence the test outcomes, but in all cases the strength depends on the mixture of the various types of molecules that ´make´ wood what it is. When discussing the strength of wood at the macroscale, there are not only the 3 main constituents, the scatter in strength values is also heavily influenced by what is generally referred to as ´wood quality´, depending on growth area, stand densities, location within the log, to name a few. Then, when applied in structural applications, the ratio between estimated applied stress and characteristic wood strength needs to be addressed by the structural engineer. He generally applies structural design codes, considering specific factors for wood, such as the long-term strength, but also the material ´grade´, which is supposed to provide the engineer with ´safe´ characteristic strength, stiffness and density properties. In this contribution, backgrounds on the scatter and safety factors for wood will be discussed, in relation to some specific tasks that wood engineers may face in practice. This relates to properties and designs made with new wood, the assessment of wood ´in-situ´ and the determination of its residual service life, as well as for the assessment of recovered wood, where the level and type of loading in the previous use phase needs to be addressed.

A common denominator for designing with new, in-situ or recovered wood, is that so-called ´damage accumulation models´ can address many of the challenges when establishing mechanical properties for (re)design. The damage accumulation modelling approach goes back to chemical reaction kinetics theory [1] and applied to wood by researchers in the ´80s and ´90s [2,3], explaining the reaction kinetics background of damage accumulation models developed by p.e. Gerhards [4] and Foschi & Yao [5]. The applicability of this approach will be shown for new, in-situ and recovered wood with respect to test methods, derivation of strength values, adult and juvenile wood, partially deteriorated wood as well as recovered wood. It includes a critical analysis of current design approaches and possible adaptations will be presented.

[1] Krausz, A.S, Eyring, H. Deformation Kinetics, John Wiley and Sons, 1975

[2] Caulfield, D.F. A chemical kinetics approach to the duration of load problem in wood. Wood and Fibre Science 17(4), 504-521, 1985

[3] Van der Put, TACM., A model of deformation and damage processes based on the reaction kinetics of bond exchange. CIB-W18, Paper 19-9-3, Florence, Italy, 1986

[4] Gerhards, C.C., A cumulative damage model to predict load duration characteristics of lumber, Wood and Fibre Science 19(2),147-164, 1987

[5] Foschi RO, Yao RC, Another look at three duration of load models. CIB/W18, Paper 19-9-1, Florence, Italy, 1986

Engineered Bamboo and Timber Structures

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Abstract

This paper reports experimental studies on hybrid structures made of engineered bamboo and timber. Several forms of hybrid systems are presented, including cross laminated bamboo and timber (CLBT) panels, glued laminated bamboo and timber beams and columns. The experimental programs are carried out on materials and structural components, with the results showing adequate mechanical performance. The hybrid usage of bamboo and timber is particularly promising for taking advantages of abundant resources of bamboo and some wood species, which are conventionally not well suitable for structural usage.

The paper also presents examples of practical design and construction of several buildings in which CLBT and hybrid bamboo and timber elements are utilized.

Fig.1. *Hybrid glued laminated bamboo (glubam)*

Fig.2. *Cross laminated bamboo and timber (CLBT)*

Fig.3. *World's first seven story engineered bamboo tall building – the Ninghai Bamboo Tower*

[1] Xiao, Y. (2022). Engineered Bamboo Structures. 1st ed. London: CRC Press.

[2] Ruijia WU; Yubing HOU; Xinlei LI; Peixiang WANG; Xiangfei ZHANG; Ziling XIAO; and Yan XIAO (2005). Design and Construction of the World's First Seven-Story Engineered Mass Bamboo Building: The Ninghai Bamboo Tower. (accepted).

Ductile load redistribution in dowelled steel-to-timber connections under a column removal scenario

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Abstract

As the size and complexity of timber buildings grow, so do the consequences of a collapse, making robustness a key requirement in the structural design. To assess the robustness of a building, it is common to analyse the structural behaviour and damage propagation numerically under a notional column removal. In such damage scenarios, large displacements and combined loading or load redistribution may occur. The structural analysis thus requires better knowledge of the inelastic structural behaviour. In timber buildings, plasticity and the capacity for load redistribution are usually concentrated in the connections.

To investigate the ability of timber post-and-beam buildings to develop alternative load paths in a column removal scenario, a campaign of large-scale quasi-static pushdown experiments was carried out. The investigation focuses on beam-to-column connections with laterally loaded dowels and continuous slotted-in steel plates in beams made of LVL, GL24h, and GL32h. An experimental setup was designed that can simulate a column loss and subject the beam-to-column connection to large rotations and displacements. The horizontal stiffness of the surrounding structure is a key influential parameter in the load redistribution, so the setup enables the implementation of different values of constant horizontal restraint stiffness. The connection was expected to develop alternative load paths by transferring shear loading to bending and, at very large displacements, to axial tension, i.e., catenary action.

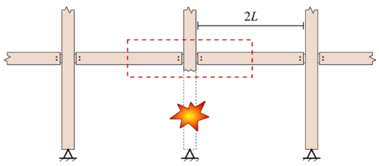

Fig. 1: *Scenario and focus area.*

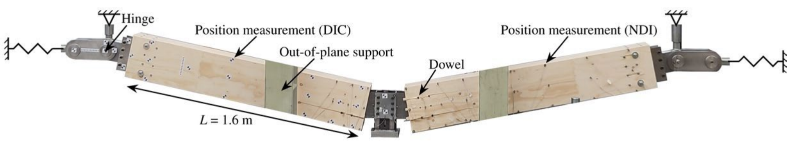

Fig. 2: *Unreinforced specimen after failure (photo by Jonathan Wilp).*

The results show that dowelled beam-to-column connections with continuous steel plates through the damaged column can reach high displacements and rotations and enable load redistribution through bending and catenary action. Ductile connection failure with pronounced plastic hinges in the dowels was achieved. In unreinforced connections, splitting occurred during the bending phase, followed by row shear in the tensile phase. Self-tapping screws as reinforcement perpendicular to the grain were highly effective in delaying these brittle failure modes and increasing the load-carrying capacity. With a stiffer horizontal restraint, catenary action develops at lower rotation and vertical displacements. Further experiments to investigate the dynamic effects in the case of a sudden column loss are ongoing, alongside the validation of a numerical model that captures the nonlinear and dynamic connection response in a column loss scenario.

From Life-Cycle Optimization to Joint Strategy: Adaptive Design of Sustainable Timber Lattice Shells

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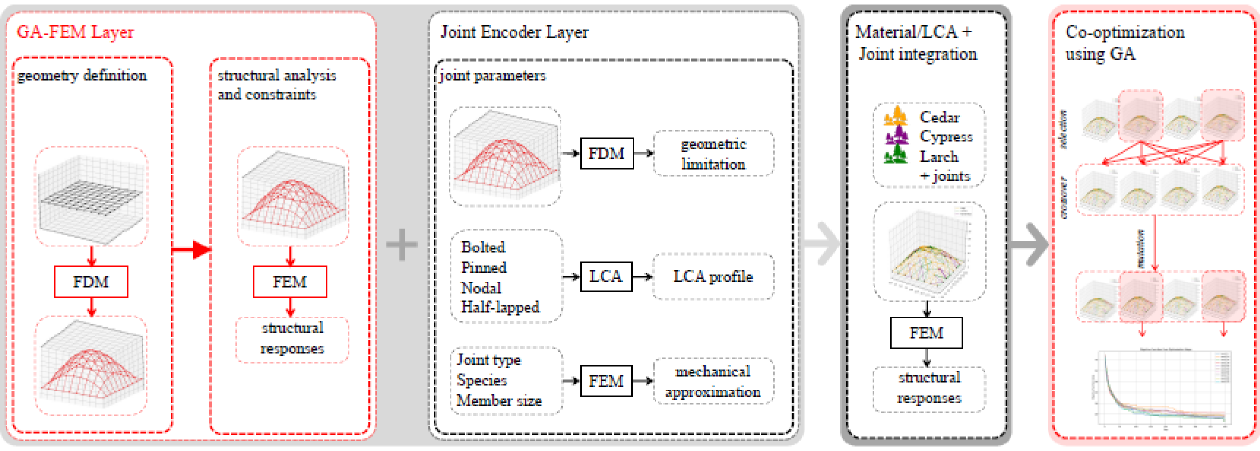
Abstract

Timber lattice shells offer high stiffness-to-weight efficiency and low embodied carbon potential; however, sustainable timber design requires coordinated consideration of structural mechanics, species-level material allocation, and connection strategy. This study presents an integrated framework linking life-cycle-aware optimization and joint rationale in timber lattice shells. A genetic algorithm [1] and finite element method (GA–FEM) formulation embeds species-specific mechanical properties and life-cycle assessment (LCA) [2] data to optimize member sizing and timber allocation under strain energy and greenhouse gas minimization objectives. The results reveal consistent structural zoning patterns: compression-dominant regions favour low-carbon species such as Japanese cedar, while tension-critical zones exhibit geometry-dependent allocation flexibility. A fabrication-oriented joint design layer encodes a compact catalogue of joint archetypes, each with defined mechanical [3], geometric, and life-cycle [4] characteristics. The co-optimization of joint types, node geometry, and mechanical performance with member sizing and species allocation yields constructible, low-carbon, and highly repetitive joints. Together, this integrated approach establishes a transferable framework linking life-cycle assessment and fabrication-oriented joint development for sustainable timber spatial structures.



[1] Holland, J. H. (1992). Genetic algorithms. Scientific American, 267(1), 66-73.
[2] Klöpffer, W., & Grahl, B. (2014). Life cycle assessment (LCA): a guide to best practice. John Wiley & Sons.
[3] Fan, F., Ma, H., Cao, Z., & Shen, S. (2011). A new classification system for the joints used in lattice shells. Thin-Walled Structures, 49(12), 1544-1553. https://doi.org/10.1016/j.tws.2011.08.002
[4] Paris-Viviana, O., & Galeote, E. (2026). A simplified method based on eco-efficiency indicators to estimate and optimize the embodied carbon of gridshell structures. Structures, 84, 111098. https://doi.org/10.1016/j.istruc.2026.111098

Bending performance of dowel-laminated timber made of reclaimed beams

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Abstract

Timber beams recovered from heritage buildings represent a valuable material resource with both significant cultural value and potential for reuse in structural applications. This study evaluated the performance of dowel-laminated timber (DLT) floor elements made from reclaimed softwood beams that were sourced from the recent renovation of a heritage building in Slovenia (Figure 1).

Fig. 1: *Reclaimed timber beams recovered from a former Servite Monastery in Koper, Slovenia.*

The research is conducted within the framework of a broader Horizon Europe project dedicated to advancing high-value reuse pathways for reclaimed timber in construction, with particular emphasis on DLT systems [1]. In this context, the present work investigated whether reclaimed timber can satisfy contemporary performance requirements when it is re-engineered into load-bearing DLT floor elements. The original reclaimed beams were initially 3D-imaged, visually inspected, and then fully processed into structural boards. The recovery rate of usable boards was assessed. The boards were then subjected to non-destructive dynamic modulus of elasticity assessment, followed by non- destructive static bending tests to assess stiffness. The DLT elements were then produced in three different lamellae layups: (i) all-reclaimed lamellae, (ii) hybrid reclaimed and virgin spruce lamellae (strength class C24), (iii) and all-virgin spruce lamellae (reference group with strength class C24). The bending stiffness, bending strength, and failure modes of the DLT elements were evaluated under a four-point bending test setup.

The findings of this study contribute quantitative evidence to support high-value structural reuse pathways for heritage timber within circular construction frameworks.

Acknowledgment
The funding from the European Commission for the EcoDLT project (Grant Agreement No. 101180622) within the ERA Fellowships program is acknowledged. Slovenian Research and Innovation Agency (ARIS) is also acknowledged for funding the infrastructural programme IO-0035 and research program P4-0459.

[1] EcoDLT Project. (2024). Lifecycle extension of salvaged wooden materials through reuse in dowel-laminated timber (EcoDLT) (Grant Agreement No. 101180622). CORDIS, European Commission.

Long-Term Marine Exposure and Durability Assessment of Wooden Piles: Findings from a 10-Year Study

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Abstract

To explore the potential use of wood in marine environments, we have conducted long-term exposure tests on wooden piles. Our previous observations revealed that the service life of untreated materials is approximately 5-6 years for bamboo and 1-2 years for Japanese cedar, Japanese cypress, and hardwood species. We also found that covering the piles with a fine-mesh polyester net can extend their durability by an additional 6-7 years; however, degradation of the net by ultraviolet radiation may contribute to marine pollution. In contrast, heat treatment and phenolic treatment have been shown to provide durability exceeding eight years1). In this report, we present the condition of the piles recovered ten years after the start of exposure and summarize the results of their deterioration assessment.

Wooden specimens of Japanese cedar, Japanese cypress, bamboo, and hardwood species-procured from areas near the test site-were installed in a marine environment with variations in cutting patterns and treatment methods. The site has a maximum tidal range of approximately 400 cm, exposing the piles to the atmosphere up to the ground line during low tide. Each pile was 2.5 m in length, including 1.5 m embedded in the ground, and no tip sharpening was applied. The specimens were installed on June 9, 2015, and retrieved on June 10, 2025. During the exposure period, regular visual inspections were conducted, and after retrieval, both external observations and internal assessments using an X- ray computed tomography system were performed.

Only the specimens subjected to heat treatment or phenolic treatment remained unbroken over the ten-year exposure period. However, external observations and internal imaging revealed numerous traces of marine borer attack in the heat-treated specimens. The damage was particularly pronounced in piles without net covering, suggesting a high likelihood of breakage in the near future. In contrast, the phenolic-treated specimens exhibited no notable external damage, and although internal tunneling by shipworms was detected, the extent of deterioration was not sufficient to cause structural failure at this stage, indicating the potential for even longer service life.

The fourteen piles that remained intact have been reinstalled at the same location in December 2025, and monitoring will continue.

Acknowledgment

This work was supported by JST Grant Number JPMJPF2215.

[1] Ryu Noda, Noboru Fujimoto, Tomoya Murano: Exposure tests of wood in sea area with large tidal range ～Changes up to 101 months after exposure began～, Proceedings of the 74th Annual Meeting of the Japan Wood Research Society, N15-02-1100, 2024

Non-Destructive Detection of Degradation in Urea Formaldehyde Structural Wood Adhesive Bonds by NMR Relaxometry

Philippe Grönquist[1,2], Maximilian Mehl[1,2], Maximilian Henning[2], Sabina Haber-Pohlmeier[2,3], Gerhard Dill-Langer[2], and Jürgen Frick[2]

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Abstract

After the prominent collapse of the Bad Reichenhall ice-arena in 2006, Urea Formaldehyde (UF) adhesives and all adhesives classified as ”type II” according to the European adhesive classification standard EN 301 were removed from lists of adhesives approved for structural bonding in Germany. However, many laminated members of timber structures still in use today are glued with UF. This poses a latent risk of structural integrity, and often, reassessments become necessary. In this study, low-field nuclear magnetic resonance (NMR) relaxometry was examined as a non-destructive method for assessing degradation of urea-formaldehyde (UF) bondlines of laminated timber members. The obtained results show that UF adhesive bondlines result in distinct NMR signals between freshly bonded and harshly artificially aged bondlines (A5 treatment according to EN 302- 1), see Figure 1. Mechanical tensile shear tests showed strength reductions of up to 71%, and a correlation coefficient of r = 0.96 between NMR amplitude ratios and bondline strength was found. This implies that NMR relaxometry would effectively be able to detect UF adhesive degradation in laminated timber joints. As new non- destructive and in-situ testing method options, portable NMR devices could help determine the residual service life of structural glued timber members or support their reuse after service life.

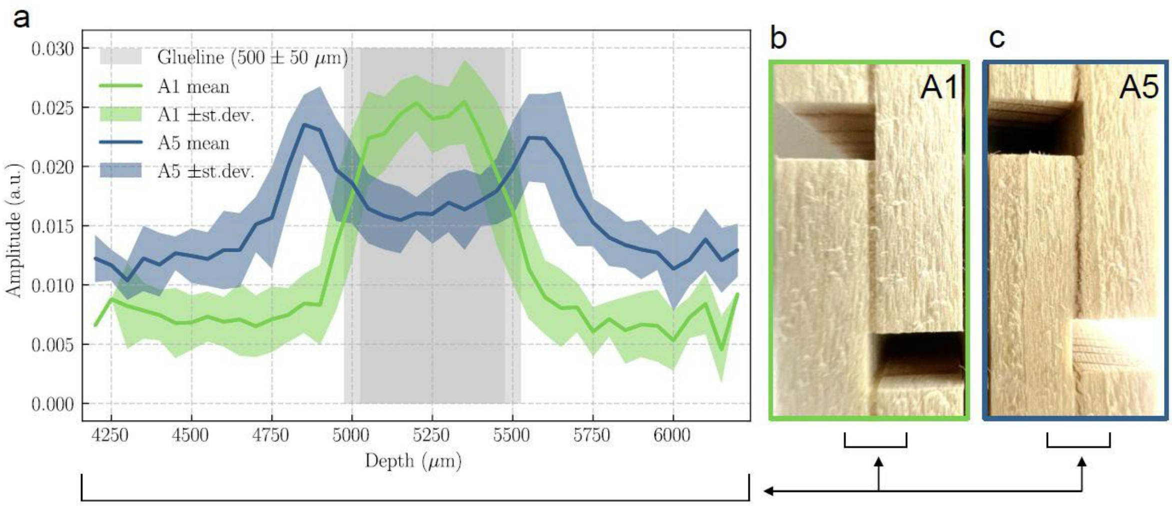

Fig. 1 a: *Measured proton density profiles on initial (A1) and artificially aged (A5) main spruce samples (n = 10).* **b:** *Exemplary photo of bondline close-up of A1 spruce sample before NMR measurement. c: Exemplary photo of bondline close- up of A5 spruce sample after A5 treatment and before NMR measurement.*

Recent advances in assessing the behaviour of wooden bond lines in fire – relating laboratory to full scale testing approaches

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Abstract

So far, in fire design of timber structures according to EN 1995-1-2:2010 [1] the one-dimensional charring behaviour of structural timber building products is considered as being steady at a constant rate. In the future, however, the newly revised version of the standard [2] will account for the fact that contemporary engineered wood products such as glued laminated timber (GLT) and cross laminated timber (CLT) are made up from numerous single laminations adhesively bonded together – and that the integrity of these bond lines in fire and thus ultimately the charring behaviour of the product can be influenced by the high temperature behaviour of the employed adhesive. The underlying phenomenon of heat-induced delamination, meaning the detachment of single laminations or parts thereof due to premature bond line failure, has been observed in various compartment fire tests of CLT ceilings and appears to be highly adhesive-bound, whereby polyaddition adhesives are affected much more than polycondensation adhesives [3]. To assess the bond line integrity in fire of a specific adhesive, FprEN 1995-1-2 [2] prescribes a fire test on a GLT specimen.

In an effort to provide an alternative route for fast, simple and reproducible classification of structural wood adhesives regarding their high temperature behaviour, a laboratory-based test method and evaluation scheme employing small block shear specimens from spruce wood has been developed [4]. It relates the mean residual shear strength of solid wood specimens to that of bonded specimens after temperature exposure of up to 270 °C, i.e. near wood carbonization, see Fig. 1a-b. An extensive test campaign comprising twelve different adhesives and six different test temperatures was carried out and confirmed not only the anticipated superior behaviour of polycondensation adhesives vs. polyaddition adhesives in the high temperature range but also proved an excellent selectivity of the method with adhesives being characterized by five different failure temperatures [5]. To validate the legitimacy of this method, an attempt was made to correlate the real charring properties of GLT cross-sections manufactured with the above-mentioned twelve adhesives obtained from full scale fire tests (Fig. 1c) with residual strength ratios of small-scale block shear specimens after high temperature exposure [6]. A good correlation between the two was obtained, indicating high predictive power of the small-scale approach even for real fire scenarios.

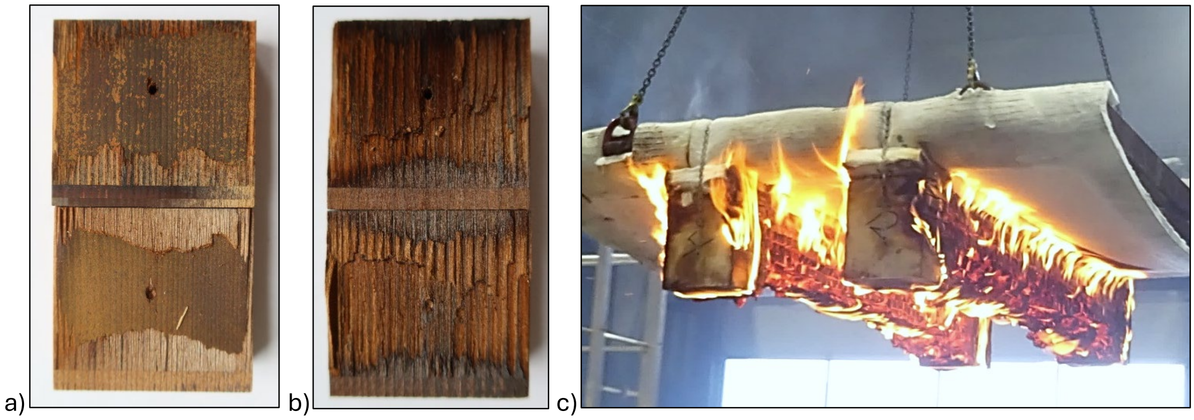

Fig. 1: *Laboratory and full-scale test specimens after temperature/fire exposure a) MUF bond line after 232 °C b) PRF bond line after 270 °C c) GLT beams after 90 min standard fire.*

[1] EN 1995-1-2, 2010. Eurocode 5: Design of timber structures – Part 1-2: Structural fire design.
[2] FprEN 1995-1-2, 2025. Eurocode 5: Design of timber structures – Part 1-2: Structural fire design.
[3] Ali Awadallah A, Hadden RM and Law A, 2024. Meta-analysis of temperature, heat release rate, delamination and auto-extinction of timber compartments. Fire Safety Journal 146. doi: 10.1016/j.firesaf.2024.104164
[4] EN 18070, 2025. Performance of wood adhesives exposed to high temperatures with regard to behavior of load-bearing timber structures in fire – Test method, evaluation and classification.
[5] Aicher S, Henning M and Münzer A, 2024. Bond line shear strength of structural wood adhesives at high temperatures up to wood carbonization – A classification approach. Results in Engineering 23. doi: 10.1016/j.rineng.2024.102762
[6] Aicher S, Münzer A and Just A, 2025. Bond line integrity in fire of glued laminated timber predicted by high temperature block shear tests. Construction and Building Materials 499. doi: 10.1016/j.conbuildmat.2025.144065

Adhesively bonded timber-concrete composite decking system: experimental studies, long-term and fire performance and practice recommendations

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Abstract

Adhesive bonding has been proposed for timber–concrete composites (TCC) system because it provides a rigid connection, unlike mechanical fasteners that allow partial slip and consequently increase deflection while reducing stiffness and load-bearing capacity. However, the long-term behaviour of adhesively bonded TCC systems particularly under outdoor conditions relevant to bridge applications, remains insufficiently understood. This study investigates the 86-week bending behavior and bond integrity of glulam–concrete panels manufactured using wet or dry bonding with ductile polyurethane (PUR) or brittle epoxy adhesives. In addition, the results of first kind of fire tests on adhesively bonded TCC slabs are reported. Furthermore, practical recommendations for adhesively bonded TCC are provided.

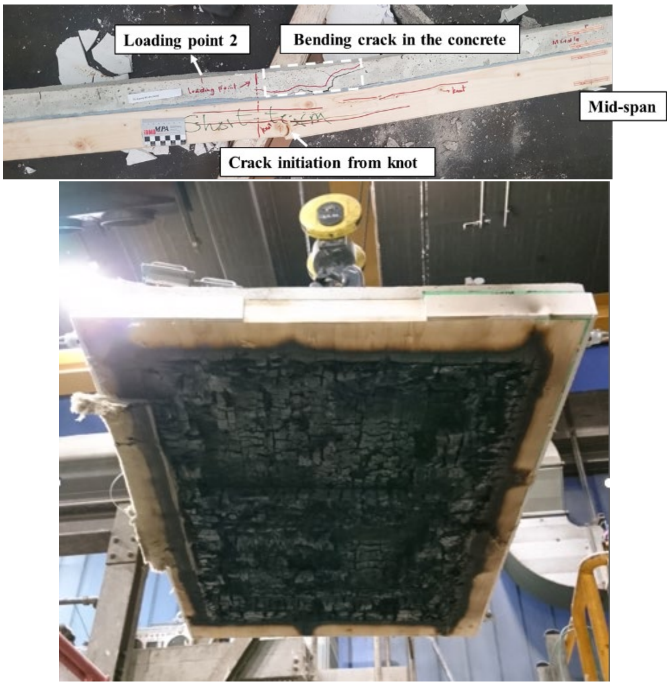

Fig. 1: *Failure mode of epoxy bonded glulam-concrete panel after four-point bending (up) and fire (bottom)*

[1] Fu QN, Chen HZ, Brunkhorst S, Zehfuß J, Kasal B, Yan LB. Thermal behavior of adhesively bonded timber-concrete composite slabs subjected to standard fire exposure. Fire and Materials 2024, 48(8): 824-837

[2] Chen HZ, Ma W, Kasal B, Wei Y, Yan LB. Flexural behavior of adhesively bonded TCC panel with glass-fibre textile mesh as reinforcement in concrete. Engineering Structures 2025; 330: 119916

Intergraded Research and Collaboration on Forest-Wood Value Chain in the S-P-F species in East Canada

Tony Zhang

International Centre for Bamboo and Rattan & FPInnovations

Abstract

This presentation highlights my decade-long multi-institutional research on the forest-wood value chain in the East Canada's S-P-F species at FPInnovations. Following a brief introduction to the concept of the forest-wood value chain and my research program at FPInnovations, the presentation focuses on the development of various models needed to describe tree growth & stand yield, DBH distribution, tree diameter-height relationship, stem taper and deformation, stem knottiness and wood quality, lumber recovery and product quality. These models developed will make it possible to link forest growth & yield with product recovery & value. Such an integrated approach to the forest-wood value chain will help make better-informed decisions to achieve both improved forest management and value-added wood processing & utilization. The Jack Pine Task Force is highlighted to quantify the impacts of major forest management decisions (e.g., initial spacing, PCT, CT, rotation age) on the stem and wood quality and product recovery. Such an integrated approach allows for the development of a product parameter-based decision-support system for stand density management in jack pine and black spruce. Based on these intergraded studies, a multi-year and multi-institutional project funded as an NSERC Strategic Network (called"ForValueNet") is introduced to highlight the nation-wide team efforts and integrated approach to the forest-wood value chain modelling.

Engineered Bamboo for Sustainable Construction: Science, Technology and the Path Forward

Chunping Dai

Department of Wood Science
Faculty of Forestry and Environmental Stewardship
The University of British Columbia

Abstract

Rapid urbanization and the urgent need to reduce greenhouse gas emissions are driving the search for renewable construction materials that can reduce reliance on carbon-intensive materials such as concrete and steel, while alleviating pressure on global timber resources. Bamboo, one of the fastest-growing biomass resources on Earth, offers strong potential as a low-carbon structural material due to its high strength-to-weight ratio, rapid renewability, and widespread availability in many developing regions.

Despite these advantages, the adoption of engineered bamboo in modern construction remains limited by challenges related to feedstock variability, processing efficiency, durability, and the absence of widely accepted engineering standards and building code recognition. This presentation reviews recent progress in understanding bamboo culm structure and its implications for engineered product development, and highlights advances in laminated bamboo and emerging hybrid bamboo–wood composite systems for structural applications.

Looking forward, a roadmap is proposed to accelerate the integration of engineered bamboo into sustainable construction. Key priorities include establishing reliable culm supply chains, improving manufacturing technologies and product consistency, enhancing durability and fire performance, developing standardized testing and certification pathways, and enabling circular end-of-life utilization. With continued innovation and collaboration among researchers, engineers, manufacturers, and policy makers, engineered bamboo can complement timber and contribute to the next generation of sustainable structural materials for the built environment.

[1] Nkeuwa, W. N., Zhang, J., Semple, K. E., Chen, M., Xia, Y., & Dai, C. (2022). Bamboo-based composites: A review on fundamentals and processes of bamboo bonding. Composites Part B: Engineering, 235, 109776.

[2] Chen, M., Weng, Y., Semple, K., Zhang, S., Hu, Y. A., Jiang, X., ... & Dai, C. (2021). Sustainability and innovation of bamboo winding composite pipe products. Renewable and sustainable energy reviews, 144, 110976.

Integrating Biobased Materials into Modern Boat Building: A Sustainable Wood Infusion Approach

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[1]*TUD Dresden University of Technology, Chair of Wood Technology and wood-based Bioeconomy*
[2]*Eberswalde University for Sustainable Development, Department Forest-Wood-Environment*
[3]*Jan Brügge Bootsbau GmbH*

Abstract

Wood, as a renewable and environmentally friendly material, has been central to boat building for millennia. Traditional wooden boat construction has evolved from clinker-built hulls—characterized by overlapping horizontal planks—to carvel construction, where smooth planks are joined edge-to-edge, requiring complex processing and meticulous caulking [1]. While these methods offer craftsmanship and aesthetic appeal, they are labour-intensive, time-consuming, and often result in suboptimal force distribution and water tightness. More recently, molded gluing techniques have emerged, enabling multi-layered hulls with superior structural integrity and sealing performance. However, these processes remain highly complex, demanding extensive manual labour and long production cycles.

In order to enable more efficient construction of wooden boats using form gluing, a new approach was researched, developed, and implemented as part of the BiobasedBoats project [2]. A novel wood infusion method was developed that combines traditional manufacturing methods with modern vacuum technology. The process is close to vacuum infusion for conventional carbon/glass fibre plastic yachts. The individual layers of wood veneer are positioned on a positive mold. These lie on a separating layer and are covered on the outside with a mesh fabric and then with a vacuum film. A vacuum pump sucks the free-flowing epoxy resin-hardener mixture from a container through the materials, while the vacuum film presses the wood layers together. The hull's layered structure consists of four veneer layers made from local larch; each 2.5 millimetres thick. It is essential for the success of wood infusion to create appropriate pathways for even resin distribution between the veneer layers. To this end, various test series were conducted to investigate methods for introducing specific flow paths into the veneers.

The result is a wooden hull saturated with epoxy resin, just like a conventionally molded one. However, a number of intermediate manual steps are eliminated. This means that each layer does not have to be coated individually with resin, positioned, and treated with a vacuum. In addition, the use of resin is more controllable, and emissions can be reduced significantly thanks to the almost completely closed system. The process was used for the first time in the construction of the WOY 26, a new type of daysailer. At the "boot" trade fair in Düsseldorf, it was awarded the European Yacht of the Year 2026 prize.

[1] Klabunde, Bernd (2023) Bootsbau 1 "Geklinkert" oder „Kraweel" –„Karweel". Classic Forum

[2] BioBasedBoats (FKZ: ZF4092215TA9) "Boote aus biobasierten Materialien: Entwicklung neuer Verbundmaterialien und Fertigungstechniken zur Steigerung der Effizienz im biobasierten Boot und Jachtbau"

Laser-drilled wood with improved pore accessibility and dimensional stability as a modification scaffold

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Abstract

The hierarchical porous structure of wood is a remarkable evolutionary achievement. It makes wood strong yet lightweight. Moreover, this porous architecture makes wood an ideal scaffold for incorporating chemical agents and developing hybrid composite materials. Two key challenges when using wood as a modification scaffold are: (i) limited pore accessibility—especially perpendicular to the fibre direction—which restricts mass transport, and (ii) dimensional instability under humidity changes.

This presentation focuses on structural modification of wood via laser incising. During laser incising, well-defined holes are created perpendicular to the fibre direction, yielding a three-dimensionally interconnected scaffold composed of laser-drilled channels and the natural cell lumina. To understand how these modifications influence performance, we employed high-resolution, in situ neutron imaging to visualize moisture distribution and dimensional changes within the wood (Figure 1) 1. The results show that laser drilling effectively accelerates moisture transport and reduces humidity-induced swelling/shrinkage. In addition, laser-drilled wood provides a highly accessible scaffold for subsequent chemical functionalization. We will present examples demonstrating how laser-drilled wood can be further modified to achieve functions such as passive indoor climate regulation 2, actuation 3, and energy generation 4. Overall, this work highlights a promising strategy for developing high-performance wood materials that preserve wood's intrinsic advantages while addressing key limitations.

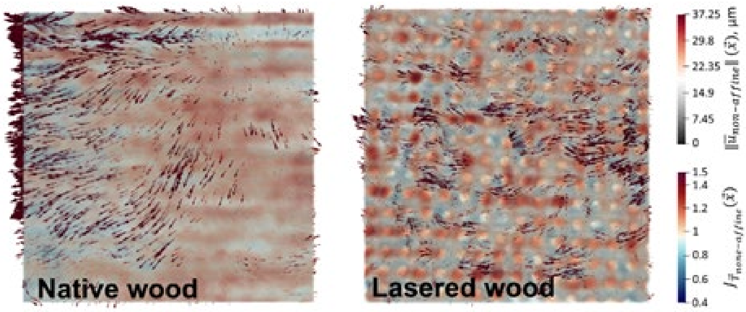

Fig.1*: Water distribution and local dimensional change of native wood and laser-drilled wood from neutron imaging*

[1] Ding Y, Shakoorioskooie M, Mannes D, Zhang Z, Chernyshov D, Burgert I. Laser-drilled functional wood materials show improved dimensional stability upon humidity changes–a neutron imaging analysis. J Mater Chem A. 2025;13(9):6364-75.

[2] Ding Y, Dreimol CH, Zboray R, Tu K, Stucki S, Keplinger T, et al. Passive climate regulation with transpiring wood for buildings with increased energy efficiency. Mater Horiz. 2022.

[3] Ding Y, Panzarasa G, Stucki S, Burgert I, Keplinger T. Thermoresponsive Smart Gating Wood Membranes. Acs Sustainable Chemistry & Engineering. 2022;10(17):5517-25.

[4] Garemark J, Ritter M, Dreimol C, Lopes Laranjeira R, Kürsteiner R, Vivas Glaser D, et al. Salt-In-Wood Piezoelectric Power Generators with Circular Materials Design for High-Performance Sustainable Energy Harvesting. Adv Funct Mater. 2025:2418454.

Carbon Quantum Dots as Multifunctional Nano-Enhancers for Wood Protection and Restoration

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Abstract

Wood is one of the most promising sustainable materials for a low-carbon future. Yet its inherent vulnerability to cracking, fungal decay, and mechanical degradation continues to limit its broader application in construction and heritage preservation. This presentation introduces a coherent, multiscale strategy centered on carbon quantum dots (CQDs) as a versatile nano-platform for wood protection and restoration.

We designed two types of CQDs, nitrogen-doped CQDs (N-CQDs) and ionic CQDs (ICQDs). By regulating the strucutre of N-CQDs, its antifungal properties were optimized, and further the antifungal mechanisms were uncovered [1]. Positively charged N-CQDs adhere to and penetrate fungal cell membranes, inducing metabolic disorder and cell death. They further generate reactive oxygen species under light irradiation and chelate Fe^{3+} to suppress non-enzymatic cellulose degradation, which was confirmed by transcriptome analysis. By coorporating N-CQDs and polyvinyl alcohol (PVA), an antifungal repairing agent for wood and other lignocellulosic materials was prepared. N-CQDs penetrate deeply into wood cell walls, bulking them and acting as a molecular bridge between PVA and the wood substrate. The resulting repair achieves a dry shear strength of 2.8 MPa, while the intrinsic antifungal activity of N-CQDs simultaneously confers decay resistance, with minimum inhibitory concentrations of 120-180 ppm against representative wood-rotting fungi [2]. By introducing tetrafluoroborate into the raw materials for preparing ICQDs, we demonstrate a "molecular compaction" strategy in wood cell wall. At an ultralow loading of 0.25%, ICQDs reorganize the cell wall polymer network through hydrogen bonding with cellulose and hemicellulose and π-π interactions with lignin, achieving a 62% increase in strength and 30% increase in toughness, therefore decoupling density-strength-toughness in wood modification [3].

These findings establish CQDs as a scalable, eco-friendly, and mechanistically grounded solution for next-generation wood protection– from healing surfaces to hardening cell walls.

Acknowledgment
Funding: National Key Research and Development Program of China (2023YFD2200502).

[1] Zhao X., Zhang S., Zhang M., Zhang Z., Zhou M., Cao J. Antifungal performance and mechanisms of carbon quantum dots in cellulosic materials, ACS Nano, 2025, 19 (14) : 14121-14136.

[2] Zhao X., Zhang S., Zhang M., Zhang Z., Lu D., Cao J. A novel strategy to heal cracked wood, Chemical Engineering Journal, 2025, 519: 165438.

[3] Dong Y., Chen X., Lu D., Zhao X., Zhang Z., Cao J. Decoupling density-strength-toughness in wood modification via molecular compaction, Advanced Materials, 2026, 38:e21176.

Efficacy of Arnica-based wood preservatives from Berkem Biosolutions® against subterranean termites and basidiomycete fungi: A comprehensive laboratory and field evaluation

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[2] *Groupe BERKEM – Laboratoires R&D, France*

Abstract

The susceptibility of wood to deterioration by fungi and xylophagous insects is a major concern for construction materials and represents an important socio-economic issue. While conventional synthetic biocides are effective, they also pose potential risks to human health and the environment. Therefore, safe, cost-effective, and environmentally friendly solutions are needed.

Polyphenol-rich plant extracts have been developed for several years at Groupe BERKEM. Recently, formulations containing up to 100% polyphenolic active ingredients from Berkem Biosolutions® - particularly those derived from *Arnica montana* L.—were tested against wood-deteriorating fungi and insects. Their efficacy was evaluated against several species of subterranean termites (e.g., *Reticulitermes flavipes, Coptotermes formosanus, Coptotermes gestroi, Prorhinotermes canalifrons*), against *Hylotrupes bajulus*, and against wood-decaying basidiomycetes. Both laboratory and field studies showed not only high resistance but also a strong lethal effect.

The mechanisms of action of polyphenols that could explain their ability to counteract attacks by xylophagous organisms are discussed in relation to the biochemical pathways involved in fungal lignin degradation and termite wood digestion, as well as the specific biochemical properties of polyphenols. Overall, this work highlights the excellent potential of Arnica extract from Berkem Biosolutions® as a fully natural and sustainable alternative for long-term wood protection.

Assessing natural durability and its variability: the specific case of *Cryptomeria japonica* from Reunion Island

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Abstract

The natural durability of wood is defined as its intrinsic ability to resist biological degradation. This factor is key to the use of wood and wood-based products, but also to determining their service-life, as well as for life-cycle assessment and Environmental Declaration Products. In Europe, the EN 350 [1] framework standard specifies the biological tests to be carried out in order to classify the natural durability of wood.

Cryptomeria japonica is the only plantation wood species that can be used in construction in Reunion Island. However, its variable behaviour against basidiomycete fungi and termites constitutes an obstacle to the deployment of its use in Reunion Island, where climatic conditions are particularly favorable to the degradation of biobased materials by these agents. The study therefore consists of precisely determining the natural durability of this species against two species of ubiquitous fungi (Rhodonia placenta and Coniophora puteana). To carry out a comparative analysis of the results, Scots pine (Pinus sylvestris), known to be poorly durable, and Western Red Cedar (Thuja plicata), durable, were also used. The fungal tests were performed according to EN 113-2 [2] and the classification was done according to EN 350 criteria [1].

The results confirm high the variability of the durability of the Cryptomeria heartwood from Reunion Island. The classification of this species could not be made following the method described in EN 350 [1] due to the discribution of the sample mass loss among the 5 durability classes. However, an aging test (leaching) prior to biological testing is important for use in tropical climates and allows a more relevant durability classification of Cryptomeria.

[1] EN 350 (2016) Durability of wood and wood-based products - Testing and classification of the durability to biological agents of wood and wood-based materials, CEN Brussels

[2] EN 113-2 (2020) Durability of wood and wood-based products - Test method against wood destroying basidiomycetes - Part 2: assessment of inherent or enhanced durability, CEN Brussels

Wood2Wood project: Decontamination and material recovery of post-consumer wood by coupling thermochemical and biological processes.

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[1] *Université de Lorraine, LERMAB, France*

Abstract

Post-consumer wood waste streams are highly heterogeneous, containing adhesives, coatings, and preservatives that significantly limit their recycling potential [1]. This variability highlights the need for efficient and adaptable decontamination strategies. This study evaluates a hybrid thermochemical–biological approach to decontaminate post-consumer wood, subsequently valorised into new bio-based products to reduce carbon impact and limit virgin resource use (Fig.1). The recyclability of the resulting materials was also assessed.

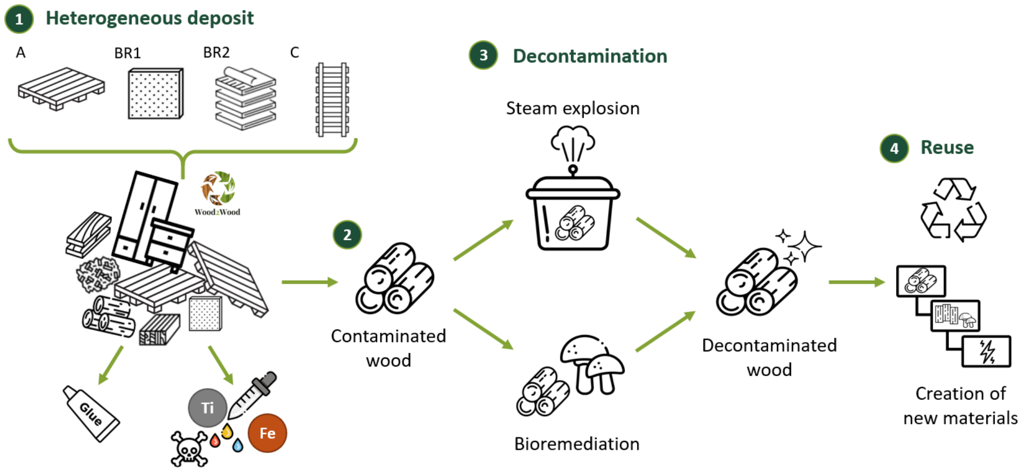

Fig. 1: *Hybrid thermochemical–biological wood decontamination process.*

Formaldehyde, a major adhesives component in particle and fiberboards, is identified as a key contaminant. Post-consumer wood was first simultaneously fragmented and UF-resin removed through steam explosion, transferring formaldehyde into the liquid effluent [2]. Process efficiency was evaluated by SEM-EDS, FTIR, and fluorescence microscopy, focusing on nitrogen as a contamination indicator. A subsequent fungal mediated bioremediation step was implemented ensured complete removal of formaldehyde from aqueous phase. Chemical monitoring confirmed full degradation within three days, alongside molecular profile changes indicating active bioremediation. Treated wood particles were reused to produce particleboards and mycelium-based composites. This integrated strategy highlights the potential of combined thermochemical and biological treatments to enhance circularity in wood waste valorisation.

[1] M. Altgen, K. B. Gedde, L. Ross, et E. Larnøy, « Physical and chemical characterization of post-consumer wood chips for recycling », Waste Management, vol. 200, p. 114762, juin 2025, doi: 10.1016/j.wasman.2025.114762.

[2] S. Troilo, A. Besserer, C. Rose, S. Saker, L. Soufflet, et N. Brosse, « Urea-Formaldehyde Resin Removal in Medium-Density Fiberboards by Steam Explosion: Developing Nondestructive Analytical Tools », ACS Sustainable Chem. Eng., vol. 11, nº 9, p. 3603-3610, mars 2023, doi: 10.1021/acssuschemeng.2c05686.

Fluorescence of mycelium-based composites from the genus *Ganoderma* – chemical origin, biological triggers and use cases

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Abstract

Mycelium-based materials (MBC) are typically used in packaging, construction, insulation, and other material applications. They are made from lignocellulosic plant residues colonized with a wood-rotting fungi such as *Trametes sp*., *Pleurotus sp*. or *Ganoderma sp*..[1] Research on MBCs at Fraunhofer WKI has revealed a multicolored fluorescence of the mycelium and respecting fruiting bodies of several species from the genus *Ganoderma* under UV light (Figure).

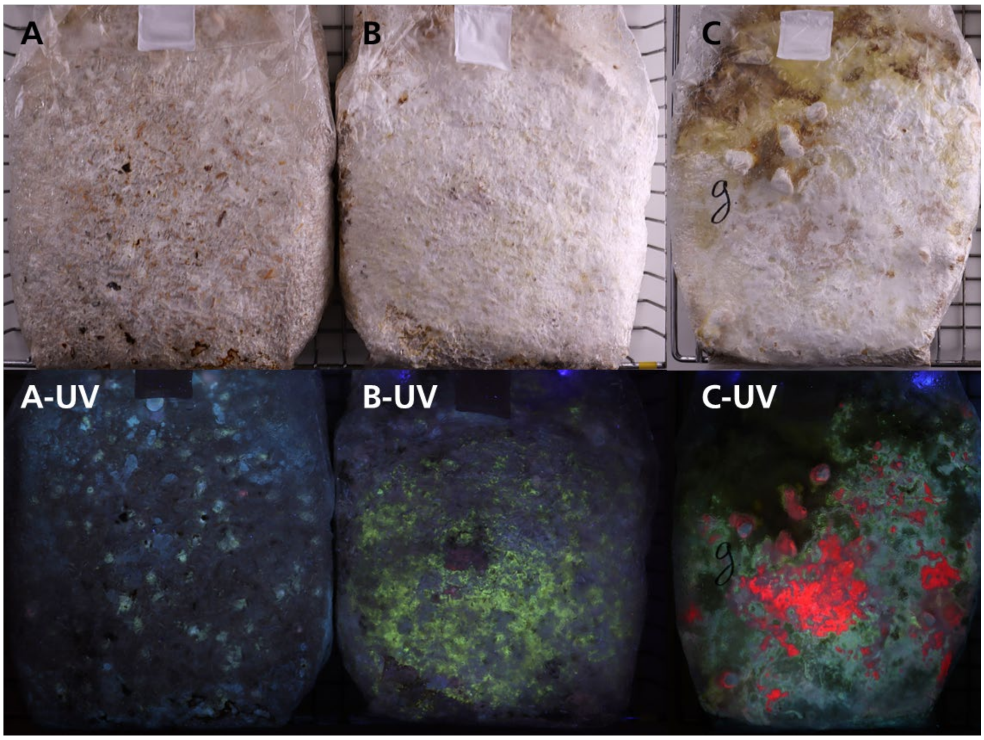

Fig. 1: *Fluorescence of living mycelium-based materials made from hemp shives after 27 days of cultivation with three species from the genus Ganoderma under normal lighting (A, B and C) and UV light (300– 450 nm, A-UV, B-UV and C-UV).*

The spatial change of the fluorescence on the surface of mycelium in solid-state culture on hemp shives depended on the cultivation conditions and fungal strains used. The presentation will discuss the chemical origin, potential biological triggers, and possible technical applications of the fluorescence. Additionally, an overview of the ongoing artistic work of visual artist Malte Taffner with the phenomenon, in collaboration with Fraunhofer WKI, will also be provided.

[1] Z. Parhizi, J. Dearnaley, K. Kauter, D. Mikkelsen, P. Pal, T. Shelley, P. Burey, Journal of Fungi 2025, 11, 549;
[2] V. Meyer, E. Y. Basenko, J. P. Benz, G. H. Braus, M. X. Caddick, M. Csukai, R. P. de Vries, D. Endy, J, C. Frisvad, N. Gunde-Cimerman et al., Fungal Biology and Biotechnology 2020, 7, 5

Mycocomposites for reducing the weight of concrete structures

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Abstract

The production of cement is currently one of the main sources of greenhouse gas emissions associated with the building sector. Reducing its use therefore represents a crucial challenge for sustainable construction. It is in this context that this work was carried out in collaboration with the company Modulatio. The company develops materials whose internal structure— inspired by alveolar and trabecular biological architectures — features density gradients that reduce the quantity of material required while maintaining the mechanical performance needed for structural applications. At present, Modulatio uses polystyrene cores that have been tested under real-world conditions. However, this material is derived from petrochemical resources, which represents a significant limitation. The objective of our study is therefore to replace this core with a fully bio-based material: the mycocomposite.

Mycocomposites are produced from biomass colonized by a fungus that acts as a natural binder [1]. This technology aligns with a circular bioeconomy approach, but scaling it up to industrial production requires overcoming several technical challenges. To optimize the fixation of biogenic carbon while preserving forest resources, the substrate used consists of recycled wood. However, recycled wood contains various contaminants (glues, varnishes, coatings) that require a depollution pretreatment based on steam explosion [2]. Outside the panel industry, recycled wood is still poorly valorized as a material, which further reinforces the interest of this approach. Producing a core intended for a concrete slab requires manufacturing a large-scale mycocomposite. Several parameters must therefore be controlled: mold design, aeration management during mycelium growth, geometry retention during drying, and the influence of density and the intrinsic properties of the fungal material. Interactions between the mycocomposite and the concrete also represent a major challenge. Certain molecules from the biomass can leach into the concrete, leading to a longer setting time or a degradation of mechanical performance. Part of the study is therefore devoted to analyzing these interactions during the implementation of slabs incorporating mycocomposite cores made from recycled wood.

[1] Elsacker, E., Vandelook, S., Brancart, J., Peeters, E., De Laet, L., 2019. Mechanical, physical and chemical characterisation of mycelium-based composites with different types of lignocellulosic substrates. PLoS ONE 14, e0213954. https://doi.org/10.1371/journal.pone.0213954

[2] Troilo, S., Besserer, A., Rose, C., Saker, S., Soufflet, L., Brosse, N., 2023. Urea-Formaldehyde Resin Removal in Medium-Density Fiberboards by Steam Explosion: Developing Nondestructive Analytical Tools. ACS Sustainable Chem. Eng. 11, 3603–3610. https://doi.org/10.1021/acssuschemeng.2c05686

Monitoring the long-term stability of classical guitar necks: evaluating the potential of European-grown wood species in musical instrument manufacturing

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Abstract

We report on the long-term deflection behaviour of 17 tropical and European-grown wood species for classical guitar neck construction. Using both tuning-key and weight-loaded tension setups (Figure 1), deflection was monitored over several months under constant and varying humidity conditions [1]. Mahogany and cedro confirmed their reputation for high stability, while European black walnut and alder demonstrated comparable or superior performance, positioning them as promising sustainable alternatives. Quarter-sawn samples showed slightly more stable behaviour than flat-sawn samples, though species-specific variation remained. No significant differences were found between the two tensioning setups, supporting the practicality of the tuning-key configuration. We will also report on the long-term (multi-year) behavior of the same set-up under constant humidity conditions (analysis ongoing).

These findings provide valuable guidance for material selection in instrument making and highlight the potential of locally sourced woods for reducing reliance on tropical species.

Fig. 1: *Tuning-key (left) and weight-loaded tension set-up (right). From [1].*

[1] Chen, B., Goovaerts, P., Willen, S., Walraet, J., Deklerck, V., Zhan, T., Van Paepegem, W., Van Acker, J. and Van den Bulcke, J., 2025. Monitoring the long-term stability of classical guitar necks: evaluating the potential of European-grown wood species in musical instrument manufacturing. Wood Science and Technology, 59(4), p.71.

How do we look upon moisture sorption

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Abstract

Water is an essential matter for all existing living features and it is thus not surprising that it has a profound influence on the properties of wood and cellulose based materials. Being such a small molecule its interaction with surrounding molecules and substances is surprisingly complex and although the water molecule has been studied for more than a century its interaction with cellulosic materials still poses questions. Generalizing, moisture sorption has been dealt with based on two different approaches; the first associated to the wood material sector viewing moisture sorption as occurring at surfaces and related to the pore structures of the material, the second coming from the polymer sector viewing the sorption as related to molecular phenomena. Looking at the approaches at a nano-scale, the two views approaches each other when considering pores as spaces between the constituent molecules. However, when relating property changes of the cellulose materials undergoing moisture sorption to the different approaches each of the approaches may exhibit different difficulties from a physical point of view. Such relations to the views of moisture sorption will here be further dealt with.

It is a well-known fact that cellulosic materials change their dimensions with moisture sorption, a fact that may be considered as that of expanding pores or the swelling of the polymers encountering sorption. In fact, it has been demonstrated that the dimensional changes are a direct and immediate respons to the adsorption or desorption of water molecules [1], a fact that must be related to. On the molecular arena one has also to consider the influence on the sorption behavior of charged groups and their counter-ions on the property changes encountered. One should also consider the effects of the chemical composition in general of the cellulosic material as well as the amounts of water molecules associated to the sorption at different environmental conditions. Furthermore, the impact on softening phenomena in lowering the glass transition of the different wood constituents must be taken into account. One also has to consider the fact that the absorption of moisture generats surprisingly high forces within the cellulosic wood material. These forces are high enough to substantially deform the cellulose crystals both in the length and transverse directions [2].

[1] Salmén, L., Olsson, A-M, (2016) Physical properties of cellulosic materials related to moisture changes. Wood Science and Technology, 50 (1) :81-89, DOI: 10.1007/s00226-015-0777-x

[2] Salmén, L., Stevanic, J. S., Holmqvist, C., Yu, S., (2021) Moisture induced straining of the cellulose microfibril, Cellulose, 28: 3347-3357, DOI.org/10.1007/s10570-021-03712-1

Long-lasting Pine: Pinosylvin Distribution in a 850 Year old Tree and in Waterlogged Archaeological Shipwrecks

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Abstract

Pine trees are known for their longevity, as evidenced e.g. by 1270–1280-year-old trees in southern Italy as the oldest in Europe [1]. Another specificity of pine species is that they accumulate pinosylvin and pinosylvin monomethyl ether during the transition from sapwood to heartwood. *Pinus nigra* was found to have the highest contents, ranging from 10.9 to 128.2 mg per g dry heartwood weight [2]. To reveal the distribution of pinosylvins within the anatomical wood structure, Raman imaging has shown high potential due to the high Raman scattering intensity of stilbenes [3]. In this study we applied Raman imaging on a core sampled 850 year old pine (*Pinus nigra* J.F. Arnold) tree grown in Austria and on waterlogged archaeological pine wood (*Pinus* sp.) samples from chinese shipwrecks (Chinese Cruiser Chih Yuen, Qing dynasty, 1894 and Nanhai No.1 (Southern Song dynasty, 1127~1279 AD, see [4]). The old pine heartwood was completely loaded with pinosylvins: rays, cell walls and cell corners as well as some tracheid lumens were filled. In the archaeological waterlogged pine wood samples we also found clear indications for pinosylvins based on the Raman marker bands at 1001 and 1637 cm^{-1}. We could verify them in cell corners and cell walls together with lignin, while the carbohydrates were more and more degraded from slight to strong degraded samples. Finding pinosylvin together with lignin, suggests a strong association of the two, that might spatially restrict accessibility of lignin during decay. Besides pinsylvins might directly inhibit fungal hydrolase enzymes and interfere with oxidative wood degradation.

[1] Piovesan, G., Biondi, F., Baliva, M., Saba, E., Calcagnile, L., Quarta, G., D'Elia, M., De Vivo, G., Schettino, A., & Di Filippo, A. (2018). The oldest dated tree of Europe lives in the wild Pollino massif: Italus, a strip- bark Heldreich's pine.. Ecology, 99 7, 1682-1684 . https://doi.org/10.1002/ecy.2231.

[2] Ioannidis, K., Melliou, E., Alizoti, P., & Magiatis, P. (2017). Identification of black pine (Pinus nigra Arn.) heartwood as a rich source of bioactive stilbenes by qNMR. Journal of the Science of Food and Agriculture, 97(6), 1708–1716. https://doi.org/https://doi.org/10.1002/jsfa.8090

[3] Felhofer, M., Prats-Mateu, B., Bock, P., & Gierlinger, N. (2018). Antifungal stilbene impregnation: transport and distribution on the micron-level. Tree Physiology, 38(10), 1526–1537. https://doi.org/10.1093/treephys/tpy073

[4] Jiabao Chen, Shoujia Liu, Lijuan Yin, Huimin Cao, Guanglan Xi, Zhiguo Zhang, Jian'an Liu, Rupeng Luo, Liuyang Han, Yafang Yin, Juan Guo, Non-destructive preservation state estimation of waterlogged archaeological wooden artifacts, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, Volume 285, 2023, 121840, ISSN 1386-1425, https://doi.org/10.1016/j.saa.2022.121840

Synchrotron-Based *In-situ* Analysis of Stress Transfer from Macro to Nano in Native and Delignified Wood at Different Relative Humidities

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Abstract

Wood's hierarchical structure and moisture-dependent polymer interactions govern the stress transfer mechanisms from the macroscopic to the molecular scale. However, the role of the hemicelluloses-lignin matrix remains incompletely understood (1). In this work, we explore the function of this embedding matrix in transferring stress from the macroscopic wood sample to the crystalline phase of the cellulose fibrils by selectively removing the matrix while retaining the wood tissue structure (delignification). Small Douglas fir specimens (native, delignified, and delignified + densified) were studied using in-situ tensile tests at different relative humidities (RH) (35%, 65%, and 90%), while monitoring the structural deformation of the crystalline cellulose in wide-angle X-ray diffraction (WAXD) (Figure 1). Additional ex-situ experiments, including dynamic vapor sorption, small angle x-ray diffraction, and solid-state nuclear magnetic resonance (ss-NMR) were performed to understand underlying material changes caused by delignification and densification. The results show that the hemicelluloses-lignin matrix not only governs stress transfer in fibrillar hygroscopic materials but also dampens their sensitivity to humidity, thereby stabilizing mechanical performance across varying humidity conditions. Relative to native wood, delignified and densified specimens exhibit increased specific stiffness at low humidity but a marked reduction in stress transfer efficiency and mechanical integrity at high humidity. Ss-NMR experiments confirm effective lignin removal and show partial degradation of amorphous cellulose, which may explain the greater variability in mechanical response of delignified specimens. This work emphasizes the importance of the wood cell wall matrix in humidity-dependent stress transfer from macro- to nanoscale.

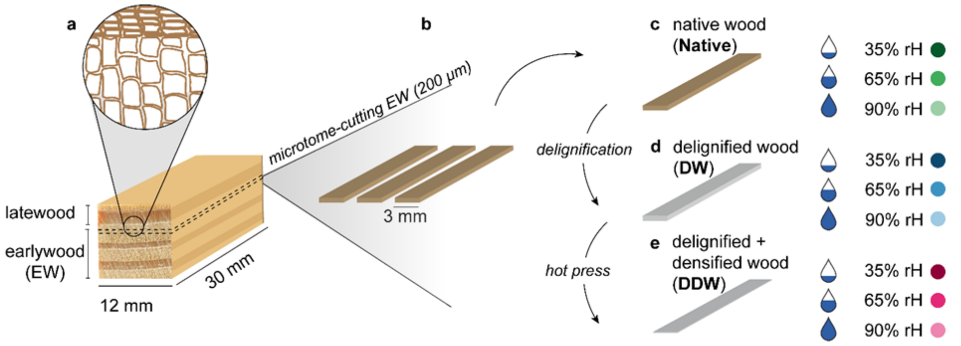

Fig. 1: *Sample preparation and testing parameters.* **(a)** *Earlywood tissue of Douglas fir was microtome-cut to 200 µm thin sections.* **(b)** *The material was cut into 3 mm-wide specimens and subjected to one of three treatments:* **(c)** *no further processing (Native),* **(d)** *delignification (DW), or* **(e)** *delignification followed by densification (DDW). Specimens were subsequently conditioned and tested at three controlled RH levels: 35%, 65%, and 90%.*

[1] Spies P-A, Keplinger T, Horbelt N, Reppe F, Scoppola E, Eder M, et al. Cellulose lattice strains and stress transfer in native and delignified wood. Carbohydrate Polymers. 2022; 296:119922.

New insights on mechanosorptive creep in Norway Spruce across the scales

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Abstract

Mechanosorptive creep strains (MCS) develop when the moisture content of wood changes under load. Considering load-bearing structures and seasonal changes in relative humidity, this combination is omnipresent in timber during the lifespan of timber structures. Surprisingly, MCS can exceed elastic strains by factors of 1 up to 20, depending on the stress state. Unfortunately, MCS are not straightforward to interpret, as changes in moisture simultaneously alter elastic and viscoelastic compliances, lead to hygric deformations, and potentially promote plastic deformation. As a result, the literature on MCS is replete with contradictions, ambiguous observations, and misconceptions in models.

We approach MSC by demonstrating, via a generic uniaxial statistical mechanical model, how MSC emerges from slip-stick dynamics in fibre bundle models and by exploring the roles of moisture gradients and time scales [2]. We demonstrate a strain decomposition procedure to distinguish between elastic, hygric, viscoelastic, and plastic strains, as well as between recoverable and irrecoverable MSC. In the second part of the talk, we confront the theoretical insights with MSC measurements on Norway spruce (*Picea abies*) tissue [1] and bulk samples [3]. While tissue samples are limited to tensile loading perpendicular to the grain, macroscopic samples are loaded under tension and compression in all possible normal and shear configurations to determine the full orthotropic compliance tensor.

We show that moisture changes under stress trigger a complex interaction of moisture-dependent mechanisms and reveal an unexpected scaling behavior, exposing a critical gap in understanding relaxation mechanisms at low scales. Our results at larger scale give a clear indication of the relative importance of orthotropic MCS. We thus challenge long-held assumptions in wood mechanics by proving that MS compliances do not simply scale with elastic or visco-elastic properties.

[1] A. Ferrara and F.K. Wittel: Mechanosorptive Creep of Norway Spruce on the Tissue Scale Perpendicular to Grain, in print by Holzforschung (2/2026) Preprint: https://doi.org/10.31224/5602.

[2] J. Amando de Barros and F.K. Wittel: The Role of Moisture Gradients and Time Scales in Wood Mechanosorption, in preparation for Wood Science and Technology, (2/2026) Preprint: https://doi.org/tbd.

[3] J.M. Maas and F.K. Wittel: Orthotropy of Wood Mechanosorption, in preparation for Mechanics of Materials (2/2026).

Influence of elevation on wood density of trees of different porosity groups

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Abstract

Among other factors, wood-anatomical traits of trees form the basis for mechanical properties [1] and therefore wood density, which depends on the thickness and structure of cell walls in different cell types, the proportion of latewood in wood increment, and structural differences between earlywood and latewood [2]. In general, a higher proportion of thick-walled and narrow latewood cells positively contributes to wood density [3]. In conifers (e.g., Norway spruce), wider growth rings usually indicate lower density because broader rings typically contain more less dense earlywood. In hardwoods, the relationship between growth rate and density is not so straightforward and depends on wood porosity [4]. In diffuse-porous species (e.g., European beech), the wood structure is homogeneous and, consequently, the difference in wood density between earlywood and latewood is less pronounced, while in ring-porous species (e.g., sessile oak), wider growth rings indicate a higher proportion of dense latewood [3].

In addition to wood-anatomical traits, various environmental factors also greatly influence the mechanical properties of wood [5, 6]. Climate and other external environmental factors are presumed to have a much stronger influence on wood growth and structure than internal factors [5]. Because tree growth and wood density are highly correlated, any factor that influences tree growth will indirectly affect wood density.

Considering the combined influence of external and internal variations on wood density, we investigated the effect of elevation on wood density across three distinct porosity groups with certain species: Norway spruce, European beech and sessile oak. We analyzed over 1400 tree increment cores using X-ray Computed Tomography (CT) densitometry and CarDen software [7]. The three species together represent almost two thirds (65,1 %) of total growing stock in Slovenia [8] and systematically cover the whole country. We present two years of data, encompassing different elevations, different forest types, species etc. Contrary to expectations, elevation alone explained surprisingly little variation in wood density, and differences among elevation classes were not significant for any of the three species. The trend for conifers (Norway spruce) was that at higher elevations the wood density is higher, but for ring-porous species (sessile oak) there is no expected trend.

These results suggest that wood density is less directly affected by elevation than assumed, which highlights the importance of taking the wood density as a complex, multifactorial trait. Rather than attributing variation to a single external factor, our results emphasize the importance of considering the interactions among multiple internal and external drivers when interpreting wood density patterns.

[1] Zhang S., Belien E., Ren H., Rossi S., Huang J.-G. 2020. Wood anatomy of boreal species in a warming world: a review. iForest - Biogeosciences and Forestry, 13, 2: 130, https://doi.org/10.3832/ifor3230-013

[2] Krajnc L., Hafner P., Gričar J. 2021. The effect of bedrock and species mixture on wood density and radial wood increment in pubescent oak and black pine. Forest Ecology and Management, 481: 118753, https://doi.org/10.1016/j.foreco.2020.118753

[3] Dinwoodie, J. M. 1981. Timber: its nature and behaviour. New York, Van Nostrand Reinhold Company.

[4] Pretzsch H., Biber P., Schütze G., Kemmerer J., Uhl E. 2018. Wood density reduced while wood volume growth accelerated in Central European forests since 1870. Forest Ecology and Management, 429: 589–616, https://doi.org/10.1016/j.foreco.2018.07.045

[5] Creber G. T., Chaloner W. G. 1984. Influence of environmental factors on the wood structure of living and fossil trees. The Botanical Review, 50, 4: 357–448, https://doi.org/10.1007/BF02862630

[6] Zobel B. J., van Buijtenen J. P. 1989. Wood Variation: its causes and control. Berlin, Heidelberg, Springer, https://doi.org/10.1007/978-3-642-74069-5

[7] Jacquin P., Mothe F., Longuetaud F., Billard A., Kerfriden B., Leban J.-M. 2019. CarDen: A software for fast measurement of wood density on increment cores by CT scanning. Computers and Electronics in Agriculture, 156: 606–617, https://doi.org/10.1016/j.compag.2018.12.008

[8] Pintar A. M., Ferreira A., Krajnc L., Skudnik M. 2024. Pestrost in pojavljanje domačih in tujerodnih drevesnih in grmovnih vrst na ploskvah nacionalne gozdne inventure v Sloveniji. Acta Silvae et Ligni, 134: 11–26, https://doi.org/10.20315/ASetL.134.2

Assessment of various minerals for the reaction-to-fire performance of wood

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Abstract

Wood is a widely used construction material and offers the advantage of being renewable. However, its flammability remains a key drawback. With the increasing use of timber in high-rise buildings and rising wildfire exposure at wildland–urban interfaces due to climate change, durable fire-protection strategies for exterior wood applications are increasingly important. Water-soluble salt-based fire retardants can be highly effective, but they may leach from exposed components (e.g., façades) and impair durability due to hygroscopicity. Mineralization has therefore been proposed to improve leaching resistance by forming sparingly water-soluble minerals *in situ* within the wood structure. Various minerals (e.g., calcium carbonate, calcium phosphate, magnesium phosphate) and precipitation routes have been investigated, including different precursor systems and biologically induced precipitation [1,2]. This study compares several mineralization systems and provides an initial assessment of fire performance and application potential, with a focus on the role of reaction by-products and precursors. Minerals investigated include calcium oxalate, calcium sulfate, calcium sorbate, calcium phosphate, and magnesium phosphate. Precursors/salt constituents include calcium chloride, diammonium hydrogen phosphate, potassium oxalate and calcium acetate. The reaction-to-fire was assessed by calorimetry methods according to ISO 5660-1:2015. Exemplary results (Table 1) show that salt treatments (e.g., diammonium phosphate and calcium chloride) can substantially reduce peak heat release rate (pHRR), whereas mineralized specimens generally achieve smaller pHRR reductions and require comparatively high weight percentage gain (WPG) for relevant improvements. Efficacy depends also on wood species and unleached by-products. Overall, mineralization must be assessed case-by-case with respect to mineral chemistry, process route, by-product formatiotions etc. Furthermore, achieving performance comparable to highly effective salt treatments—while meeting regulatory requirements (e.g., EN 13501)—remains challenging for mineralized wood.

Table 1: *Examples of reduced peak Heat release rate (pHRR) of mineralization agents in dependance of the amount (WPG) and the wood species*

	Minerals (slightly water soluble)				**Salt (water soluble)**		
Mineral/salt	**Magnesium phosphate**	**Magnesium phosphate**	**Calcium phosphate**	**Calcium oxalate**	**Calcium chloride**	**Potassium oxalate**	**Diammonium hydrogen phosphate**
Wood specie	Fir	Fir	Fir	Beech	Beech	Beech	Fir
WPG [%]	37.5	31.2	9	29.2	29.2	25.4	8.8
Reduced PHRR [%]*	24.7	17.3	20.1	57.1	83.4	27.2	36

** ratio between untreated control and treated sample of the same wood species*

[1] Franke, T., Larnøy, E., & Volkmer, T. (2024). Thermal behavior and reaction to fire of European beech (Fagus sylvatica) treated with various salts and mineralization formulations. Fire Safety Journal (144).

[2] Ogorelec, K. B., Gubenšek, A., Sandak, A., & Gubensek, A. (2025). Towards eco-friendly fire retardant of wood-exploring fungal biomineralisation. Proceedings of the 56 Annual Meeting of the International Research Group on Wood Protection.

The Future of Wood Science: Circular Value Creation from Processing to Bio-based Materials

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Abstract

Wood science is increasingly expected to contribute not only to the understanding of wood as a biological and structural material, but also to the development of circular technologies and products that address climate change, resource scarcity, and the transformation of industrial value chains. In this context, the future of wood science lies in connecting material knowledge with processing science, surface and interface engineering, and the design of sustainable value-creation systems.

This keynote highlights how circular value creation can emerge from a deeper understanding of wood processing, particularly in relation to disintegration, machining, and the generation of particles, fibres, and side streams [1] (Fig. 1). These processes are often treated as technical operations or unavoidable sources of residue. However, they also create new surfaces and interfaces that decisively influence reactivity, adhesion, wettability, electrostatic behaviour, material compatibility, and ultimately product performance. Surface-related phenomena, including triboelectric charging, surface activation, and changes in morphology and chemistry, are therefore presented not simply as process effects, but as opportunities for innovation. Given examples are innovative technologies to reduce wood fine dust, or electrostatic primer treatment of wood surfaces prior to coating. one page maximum; figures, tables can be included [2,3]

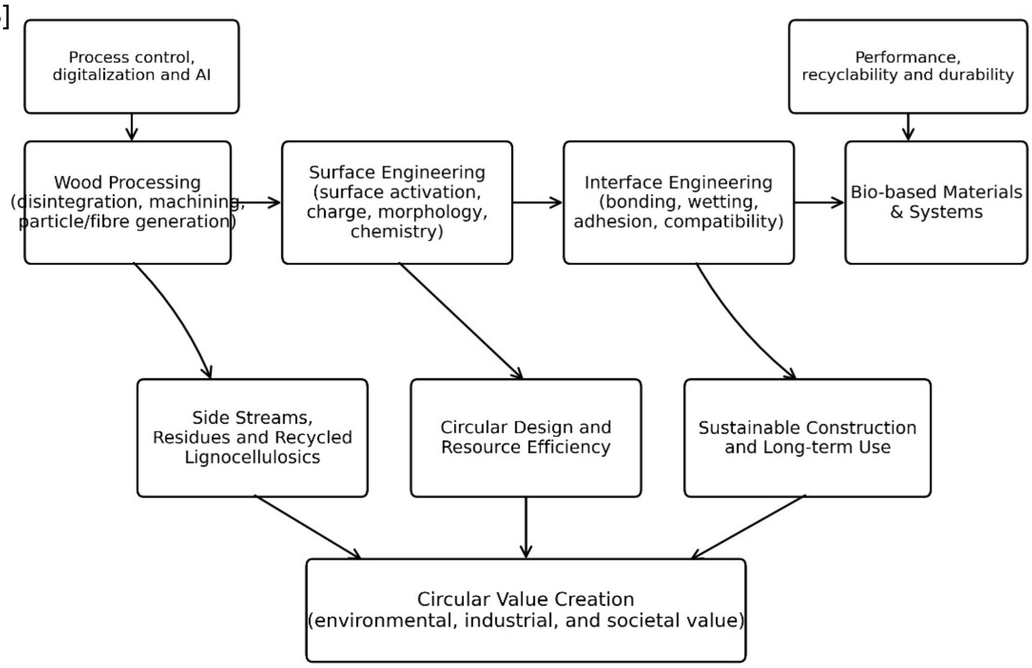

Fig. 1: *Major research themes leading to circular value creation*

The lecture further explores how the targeted engineering of surfaces and interfaces may support the conversion of underutilized lignocellulosic resources, residues, and recycled fractions, into higher-value bio-based materials and circular material systems [4]. From improved bonding and composite performance to resource-efficient product design and sustainable construction applications, the presented topics illustrate the central role of wood science in bridging scales from microstructural interactions to industrial manufacturing and long-term use [5,6]. By linking processing, surface functionality, interface design, and circular thinking, the keynote presents wood science as a discipline uniquely positioned to generate environmental, technological, and societal value in the decades ahead.

[1] Wimmer, R., Frey, M., Hausmann, M., Keplinger, T., Siqueira, G., & Zimmermann, T. (2023). Plant-fiber and wood-based functional materials. In Springer Handbook of Wood Science and Technology (pp. 1645-1693). Cham: Springer International Publishing.

[2] Leiter, L. M., Wimmer, R., & Cool, J. (2025). Triboelectrification in woodworking: influence of machining parameters on surface charges in planing, shaping, and sanding. Wood Material Science & Engineering, 1-11.

[3] Myna, R., Wimmer, R., Liebner, F., Leiter, L., & Frömel-Frybort, S. (2021). Triboelectric charging of dust particles during hand-held circular sawing of wood and wood-based materials. Wood Material Science & Engineering, 16(1), 64-73.

[4] Kromoser, B., Reichenbach, S., Hellmayr, R., Myna, R., & Wimmer, R. (2022). Circular economy in wood construction–Additive manufacturing of fully recyclable walls made from renewables: Proof of concept and preliminary data. Construction and Building Materials, 344, 128219.

[5] Hýsek, Š., Sahula, L., Němec, M., Żółtowska, S., Kytka, T., & Wimmer, R. (2025). Non-standard adhesives for wood-based composites: powder adhesives and bicomponent fibers. Journal of Adhesion Science and Technology, 39(5), 778-800.

[6] Hellmayr, R., Wimmer, R., Myna, R., & Liebner, F. (2025). Introducing the Circular Lignin-Polysaccharide Board (CLIPboard): Advancing Recycling Options for a Sustainable Circular Economy in the Wood Industry. Circular Economy and Sustainability, 1-18.

Thermal dehydration reactions of cellulose in the context of bio-based carbon fiber production

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Abstract

Pyrolysis and carbonization of biomass was among the first chemical processes conducted in human history. Despite this longstanding interest, the complex chemistry involved in these high temperature transformations is still not sufficiently understood. This also holds true for the thermal reactions of cellulose, the major biomass constituent, which was often chosen as a model compound in fundamental investigations on pyrolysis processes. In our groups' endeavours to utilize regenerated cellulose fibers as precursors to manufacture carbon fibers (CFs), this knowledge gap complicated optimizations of the carbonization process.

To obtain a better understanding of the occurring chemistry a series of mechanistic studies was conducted. Thereby, the focus was set on the initial dehydration reactions below 300 °C. These are generally associated with the initial stages of cellulose charring and responsible for significant increases in the final char yields. In the cellulose CF focused literature, the observed water evolution was often explained by elimination reactions from the glucopyranose backbone. By applying a recently developed solution state NMR protocol this mechanistic view was challenged [1]. Isothermally heat-treated cellulose did not show any signs for elimination reactions at temperatures up-to 250 °C. Instead, only transformations on the reducing end groups (REGs) and associated cross-linked structures were determined [2,3] Additionally, a recalcitrant phase was encountered, which was previously described as "thermostable condensed phase" after treatments at similar temperatures [4].

It was postulated that this phase incorporates a polyfuranic network and represents an important carbonization intermediate. However, the limited reported analytical data left room for scrutiny. By prolonging the heat treatment and applying dehydration catalysts, it was possible to isolate several pure "thermostable condensed phases". A comparative analysis with cellulosic hydrochars confirmed its polyfuranic nature [5]. Overall, the gathered data suggested clear similarities to the more sufficiently understood transformations operative during hydrothermal treatment of cellulose or monosaccharides. There it is postulated that polyfurans are formed through a polycondensation of 5-hydroxymethylfurfural. In cellulose this intermediate mechanistically can only be formed through reactions of the REGs, which is in accordance with their enhanced reactivity observed in the previous studies.

[1] Fliri et al., Nat. Protoc. 18, 2084–2123 (2023); https://doi.org/10.1038/s41596-023-00832-9
[2] Fliri et al., J. Anal. Appl. Pyrol. 175, 106153 (2023); https://doi.org/10.1016/j.jaap.2023.106153
[3] Jang et al., Carbon 218, 118759 (2024); https://doi.org/10.1016/j.carbon.2023.118759
[4] Pastorova et al., Carbohyd. Res. 262 (1), 27-47 (1994); https://doi.org/10.1016/0008-6215(94)84003-2
[5] Fliri et al., Anal. Appl. Pyrol. 181, 106591 (2024); https://doi.org/10.1016/j.jaap.2024.106591

Note: Lukas Fliri was awarded First Place in the IAWS PhD Award Competition (2025) and invited to present at the IAWS 60th Anniversary Conference, Zurich, June, 2026.

Innovative Lignin Nanoparticle Manufacturing and Applications in Sustainable Packaging Solutions

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Abstract

Lignin, the most abundant renewable aromatic biopolymer, holds significant promise for replacing petroleum-derived chemicals in sustainable packaging. However, its broad adoption is limited by challenges in producing functional lignin micro- and nanoparticles (LMNPs) at scale and integrating them into fully biodegradable composites with strong barrier properties. The research addresses these barriers through the development of energy-efficient LMNP manufacturing processes and their application in plant-based, PFAS-free water- and oil-resistant materials.

A temperature-controlled ultrafine friction grinding (UFG) process was developed to produce nanolignin without chemical modification or surfactants. Systematic investigation revealed a tunable tradeoff between grinding temperature and final particle size, with low-temperature grinding (~0 °C) yielding particles near 100 nm. Increasing the solids content to ≥20 wt% reduced energy consumption by approximately 90% compared with traditional dilute processes, providing a scalable and industrially adaptable route for LMNP fabrication.

The LMNPs were subsequently applied to design biodegradable composites with enhanced barrier performance. Hot-pressing LMNP suspensions onto cellulose substrates produced continuous lignin films exhibiting strong water and oil resistance suitable for food-contact applications. To overcome the common issue of surface discoloration associated with lignin coatings, a sandwich-structured composite was developed by embedding LMNPs between cellulose layers. This strategy preserved product aesthetics and mechanical strength while delivering exceptional barrier performance, achieving water retention times exceeding 100 minutes and oil retention over 60 minutes using a fully biobased formulation of 65% LMNP, 25% PVA, and 10% PLA. These materials remained fully biodegradable and compostable.

A dry-forming method was further introduced to create LMNP–fiber composites in which lignin functions as an internal binder by filling inter-fiber cavities and lumens, strengthening the cellulose network without relying on water-intensive processing. The resulting materials demonstrated barrier properties comparable or superior to commercial fluorinated papers, offering a viable route to PFAS - free disposable tableware and packaging.

Overall, this research bridges fundamental lignin chemistry with scalable manufacturing, enabling fully plant-derived paper composites. The developed LMNP processes and composite designs provide practical pathways for industry to transition toward biodegradable, PFAS-free packaging materials aligned with global sustainability goals and the mission of advancing innovative wood-based bioproducts.

[1] Z. Zhou. et al. Industrial Crops and Products, 2023, 198, 116685. (DOI: 10.1016/j.indcrop.2023.116685)

[2] 4. Z. Zhou. et al. Composites Part B: Engineering, 2025. (DOI: 10.1016/j.compositesb.2025.112763)

[3] Z. Zhou. et al. ACS Sustainable Chemistry & Engineering, 2024, 12, 50, 18043-18057. (DOI: 10.1021/acssuschemeng.4c06079)

Note: Zhongjin Zhou was awarded Second Place in the IAWS PhD Award Competition (2025)and invited to present at the IAWS 60th Anniversary Conference, Zurich, June, 2026.

Nanotomography and modeling as complementary tools for assessing the role of anatomy in wood properties

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Abstract

Wood is known to exhibit considerable variability and anisotropy in its properties, both between species and within the same species. The anatomical and ultrastructural organization of wood is an obvious explanation for these characteristics (see for example [1]).
Nowadays, thanks to the spectacular progresses in 3D imaging (laboratory or Synchrotron nanotomography, Fig. 1a) and High-Performance Computing, these effective parameters can be predicted by 3D calculations on real pore morphologies. Upscaling methods, such as homogenization or volume averaging, allowed the macroscopic properties to be predicted from the phase properties and their morphology [2]. The set of examples presented in this work concerns mainly the transfer properties of wood, thermal conductivity and mass diffusivity (Fig. 1b).
Finally, it will be shown how 3D observations during time (the co-called 4-D imaging) can be analysed to further assess the role of anatomy in wood behaviour [3].

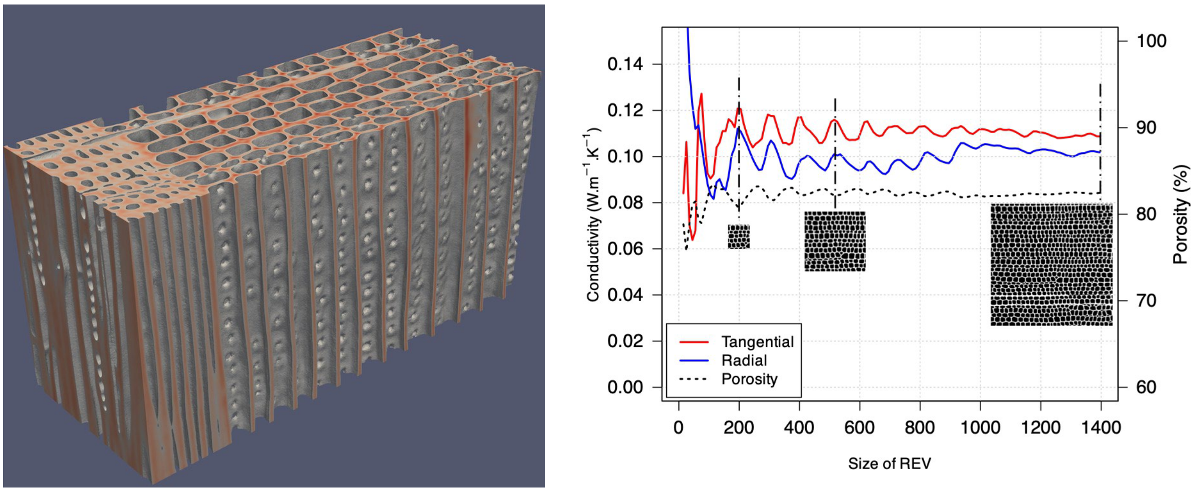

Fig. 1: *Example of thermal conductivity prediction from a nano-tomograph scan a) 3D view of a spruce sample after thresholding and b) Convergence of the conductivity predicted using a FFT method with the size of REV.*

[1] Panshin, A. J., Zeeuw, C. D., 1981 - Textbook of wood technology, 722 p., McGraw-Hill, New York.

[2] Turner I.W., Perré P., 2025 - The use of implicit evolution equations with generalized Mittag-Leffler kernels to elucidate a connection between distributed microstructure models in porous media and fractional calculus. Multiscale Modeling & Simulation, 23(3):1089–1144.

[3] Perré P., Nguyen D. M., Almeida G., 2022 - Mechanisms of liquid imbibition in wood: a macroscopic Washburn approach derived from X-ray tomography observations, Scientific reports, 12, 1750.

Assessment of Spiral Grain on Wood Quality of Black Spruce Grown in Labrador, Canada

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Abstract

Black spruce (*Picea mariana*) is a key resource for the forest industry in Newfoundland and Labrador, Canada. However, frequent spiral grain occurrence in this species has been reported to adversely affect wood quality, lumber grades, and construction applications [1-3]. This study examined spiral grain patterns in black spruce from Labrador and their impact on wood shrinkage and mechanical properties. Two forest blocks along the Churchill River in Labrador (on its south and north sides) were selected for sampling black spruce trees. Three trees were randomly sampled from each block. From each tree, three 0.6-meter-long log segments were cut at 3.6-meter intervals from the bottom to the top. Small, clear wood specimens were then prepared from these segments. The key testing instruments employed were a laser-based fiber angle tester, an X-ray densitometer scanner, and a universal testing machine. The analysis included spiral grain angle, growth ring width, specific gravity (SG), shrinkage, density profile, tensile modulus, and tensile strength.

It was found that: (1) Spiral grain angle generally decreased from bark toward pith, with a reversal observed near the pith. Maximum spiral grain angle also decreased with tree height, from approximately 12° at the bottom, to 10° in the middle, and 8° at the top. (2) The average growth ring width and oven-dry specific gravity were 0.65 mm and 0.485, respectively, reflecting the slow-growing nature of the black spruce trees in Labrador. (3) The average linear shrinkages from green to oven-dry were 0.61% (longitudinal), 4.42% (radial), and 7.67% (tangential). Spiral grain contributed to the larger longitudinal shrinkage. (4) The bottom and middle specimens exhibited relatively uniform density distributions from bark to pith, with more compact growth rings near the bark and smaller density differences between earlywood and latewood. (5) The average tensile modulus and tensile strength of the specimens were 10,656 MPa and 66.02 MPa, respectively. As spiral grain angle increased, both tensile modulus and tensile strength tended to decrease.

[1] Department of Natural Resources. (2006). Strategic plan to develop Labrador secondary manufacturing and value-added wood products industry. Labrador Wood Products Report, Department of Natural Resources, Department of Natural Resources Government of Newfoundland and Labrador, St. John's, NL, Canada.

[2] Forward, G., (1988) Lumber test cape caribou river goose bay, Labrador, Forest Product and Development Division, Government of Newfoundland and Labrador, St. John's, NL, Canada.

[3] Milley, P. (2006), Strategic plan to develop Labrador secondary manufacturing and value-added wood products industry. Halifax Global Inc., Halifax, NS. Canada.

Structure-activity relationship of multi-functional POMs in the oxidative depolymerization of lignin

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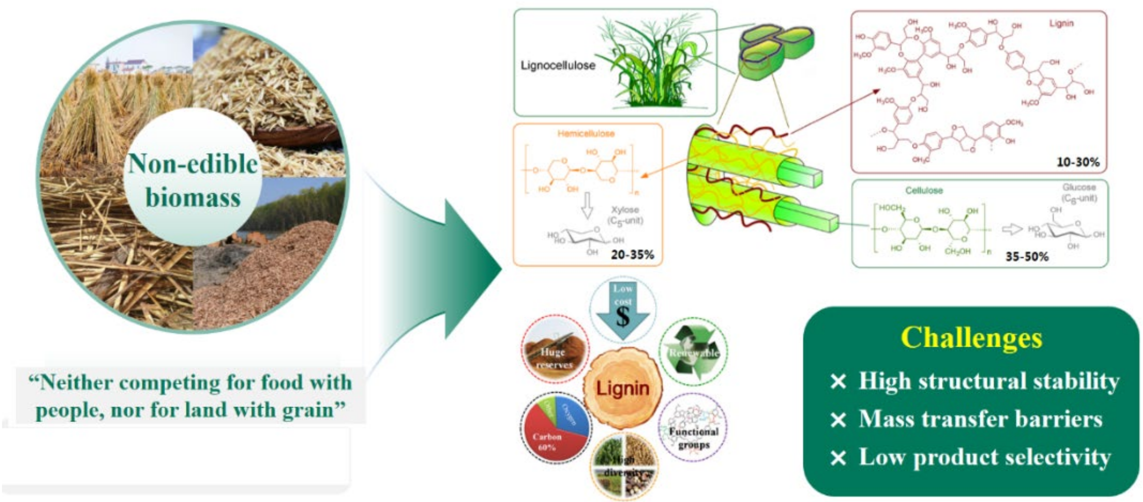
Abstract

To support China's "Dual Carbon" goals and address the low utilization rate and environmental pollution caused by open burning of agricultural and forestry waste, this study focuses on lignin, an abundant but structurally stable component in lignocellulose. Based on the discovery that polyoxometalates (POMs) can effectively achieve controllable oxidative depolymerization of lignin, this study focuses on the key scientific issues of efficient cleavage of lignin macromolecules and high-value conversion of lignocellulose. It aims to investigate the structure–activity relationship of multi-functional POM catalysts, multi-scale lignin structure evolution, in-situ activation and oxidative depolymerization, micro-mechanism of bond cleavage and product selectivity, and the multi-recombination effect relationship between catalyst structure/lignin structure/conversion efficiency, namely, the four aspects of catalyst design–selective depolymerization–structure–activity synergy–full-component utilization. The study proposes a new theory of "redox-acidity synchronous tuning" and "amphiphilic assembly-induced enzyme-like catalysis", creates a new mode of "lignin-first" mild catalytic biorefinery technology, and innovatively adopts characterization methods such as spectroscopy and chromatography to clarify the controllable depolymerization mechanism of multi-functional POMs on lignin and elucidate the structure–activity relationship and catalytic enhancement mechanism of POMs in lignin oxidative depolymerization. This study is expected to achieve full-component high-value conversion of lignocellulose, providing a new path that is both environmentally friendly and efficient for the low-carbon utilization of agricultural and forestry waste and sustainable biorefinery.



[1] Yang G P, Liu Y F, Wei Y G. Application of Polyoxometalates in Biomass Conversion[J]. Coordination Chemistry Reviews, 2024, 521: 216172.

[2] Xue W, Liu Y, Ma X, Ye J, Bai X, Zhao J, Liu B. Tuning the Equilibrium of Excitons and Carriers in The (001) Plane-Exposed Bismuth Oxyhalide Enables Efficient Selective Photocatalytic Oxidation of 5-Hydroxymethylfurfural[J]. ACS Catalysis, 2025, 15: 9621-9632.

Impacts of fire severity on wood quality and biotic degradation in boreal forests: insights from Canada's 2023 wildfire season and beyond

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Abstract

In 2023, Canada experienced an unprecedented wildfire season, with approximately 15 million hectares burned nationwide—over 3.5 times the area of Switzerland. This event heightened concerns about how fire severity affects the quality of salvaged wood for both traditional forest industries (lumber, pulp and paper) and the emerging bioeconomy (biofuels, biomaterials, biochemicals) [1–3]. Understanding changes in wood properties following large, mixed-severity fires in Western Canada is therefore critical for planning effective salvage operations and maximizing the value of fire-damaged timber for multiple industries or cascading processes [1–3].

To address this, a series of studies evaluated the impacts of fire severity on chemical, physical, mechanical, and anatomical properties of three major boreal species: white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), and aspen (*Populus tremuloides*). Both destructive and non-destructive methods were employed, combining standard tests (e.g., wet chemistry, static bending, elemental analysis) with high-throughput techniques (e.g., acoustics, infrared spectroscopy, TGA, GC-MS, microscopy). The influence of fire severity on biotic attacks (insects and fungi) was also investigated.

In 2023, a forest inventory was conducted near Fox Creek, Alberta (54.476°N, 116.783°W) [1–3]. Thirty-six trees per species were sampled across three diameter classes and four fire severity levels (unburned control, low, moderate, high) four months post-fire to assess wood quality under optimal salvage conditions. Successive sampling in 2024 and 2025 examined the shelf life of burned trees. Published studies [1–3] indicate that fire severity significantly alters chemical composition and reduces wood moisture content. For conifers such as white spruce and lodgepole pine, the dynamic modulus of elasticity increased markedly in high-severity stands. Near-infrared spectroscopy (NIRS) successfully differentiated blue-stain and brown-stain fungi during early fungal colonization four months post-fire.

Ongoing and future research will clarify the complex interactions among fire severity, time since fire, biotic degradation, and wood quality, providing critical insights to optimize salvaged-wood utilization and guide post-fire forest management and policy development—ensuring that post-fire interventions align with global sustainability and bioeconomy goals, while supporting science-based decisions for resilient forests.

[1] Boakye, E. A., Mvolo, C. S., & Klutsch, J. Wildfire increases the chemical contents of wood and bark tissues in both conifer and broadleaf trees in northern Alberta, Canada (2025) submitted.

[2] Boakye, E. A., Mvolo, C. S., Klutsch, J., & Koubaa, A. Post-wildfire wood moisture content of boreal tree species in residual stands (2025) submitted.

[3] Boakye, E. A., Klutsch, J., Mvolo, C. S., & Duarte, A. G. (2025). Near-infrared spectral signatures differentiate blue stain and brown rot fungi in conifer and broadleaf trees. Wood and Fiber Science, 57(3), 147-156.

The use of high-throughput Xray tomography, a new paradigm for analysing the relationships between the growth conditions of the trees and their resulting wood properties

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Abstract

Wood is derived from trees—complex woody organisms whose morphology and internal structure exhibit pronounced heterogeneity. Describing and quantifying this heterogeneity represents a major scientific and industrial challenge for two primary reasons. First, it enables identification of the biological and environmental drivers underlying variations in wood properties and supports the adaptation of forest management strategies. Second, it is essential for primary and secondary wood-processing industries, which must produce large volumes of materials with consistent and predictable properties despite the intrinsic variability of the resource.

X-ray computed tomography (CT) has emerged as a non-destructive technology particularly well suited to characterizing wood heterogeneity across multiple spatial scales, from the annual growth ring—including its anatomical elements—to the entire stem.

Two main application domains are distinguished. First, CT enables precise measurement of radial and longitudinal density variations, a parameter closely related to mechanical performance and carbon content. Second, CT facilitates the localization and measurement of internal stem features, including pith, bark, sapwood, heartwood, knots, resin pockets, reaction wood and annual growth rings. These structural descriptors are essential for both biological interpretation and industrial grading.

Recent progress in detector technologies, reconstruction methods, and digital image processing has expanded accessible spatial scales and improved measurement accuracy. However, trade-offs remain among resolution, acquisition speed, sample size, and cost.

Two examples illustrate the current expansion of this technology. The first concerns rapid measurement of density, shrinkage, and moisture content on increment cores, representing a strategic tool for reassessing forest carbon stocks (1,2). The second involves the integration of CT scanners in sawmills (3) for log grading, sawing optimization, and mechanical grading of sawn timber based on radiographic image processing.

Although computed tomography is a well-established technology, recent technological and computational advances have substantially renewed its relevance. These developments enable the generation of large-scale datasets, which, when integrated with artificial intelligence models, open new avenues for data-driven analysis and prediction. As a result, CT has become a strategic tool in wood quality research, strengthening its interaction with industrial performance optimization and supporting more informed high-throughput decision-making processes.

[1] Cuny, H., Leban, et al., (2025). XyloDensMap: a georeferenced dataset for the wood density of 110,000 trees from 156 European species in France. Scientific Data, 12(1), 380. https://doi.org/10.1038/s41597-025-04645-1

[2] Leban, J.-M., Kerfriden, B., Lacarin, M., Taupin, A., & Hervé, J.-C. (2020). La biomasse des forêts méditerranéennes Les premiers résultats du projet XyloDensMap. Forêt Méditerranéenne, XLI(4), 267–274.

[3] Ravoajanahary, T., Rémond, R., et al, (2025). Variability in Wood Quality and Moisture Content Measured by an Industrial X-Ray Scanner Across 700,000 Sawlogs of Picea abies, Abies alba, and Pinus sylvestris. Forests, 16(9), 1457. https://doi.org/10.3390/f16091457

AI-Enabled Wood Technology: Driving Efficiency, Sustainability, and Innovation

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Abstract

The growing demand for the sustainable use of wood as a renewable raw material requires manufacturing processes that can extract maximum information from each individual piece of material, regardless of its geometry, wood species, or processing history. Recent advances in computer vision and machine learning are enabling high-resolution, multimodal characterization that provides unprecedented insights into defects, quality characteristics, mechanical properties, and bondability. These developments point toward a future in which data-driven, resource-efficient decision-making becomes an integral part of the wood value chain.

At Empa and ETH, we are currently building such technologies and integrating them into operational systems. We have already developed deep-learning models based on RGB imaging that reliably identify wood species, detect defects, perform quality classification, and predict mechanical properties [1,2,3]. To extend the information depth beyond what RGB data alone can provide, we are now integrating hyperspectral imaging into the same multimodal platform. By combining spectral and visual information, we aim to enhance material characterization, in particular with respect to adhesive bondability and other properties that benefit from spectral sensitivity. This multimodal approach is paired with advanced deep-learning architectures, including convolutional neural networks and emerging vision transformer models, enabling a comprehensive and scalable foundation for next-generation AI-enabled wood assessment. Our vision is to enable fully automated characterization at the piece level in real production environments and ensure that each piece of wood can be assigned to the application where it achieves the highest performance, sustainability, and resource efficiency. At the same time, this data-driven foundation will support the development of next-generation hybrid and wood-based products, for which a precise understanding of material variability is essential. Building on this foundation, emerging large language models (LLMs) can complement visual models by linking recognized characteristics to relevant standards, documentation, and process knowledge, thereby improving transparency, documentation quality, and decision support across the entire wood value chain.

[1] Achatz, J., Sailer, P., Mayer, S., & Schubert, M. (2025). An explainable segmentation decision tree model for enhanced decision support in roundwood sorting. Knowledge-Based Systems, 324, 113814

[2] Lukovic, M., Ciernik, L., Müller, G., Kluser, D., Pham, T., Burgert, I., & Schubert, M. (2024). Probing the complexity of wood with computer vision: from pixels to properties. Journal of the Royal Society Interface, 21, 20230492

[3] Achatz, J., Speigl, L., Elsener, R., Burgert, I., Rigling, A., & Schubert, M. (2026). Computer Vision-Based Prediction of Quality and Mechanical Properties of Wooden Lamellae. Advanced Engineering Informatics. Accepted

Bio-Crosslinking of Oxidized Hardwood Kraft Lignin for Fully Bio-Based Wood Adhesives

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Abstract

Hardwood kraft lignin (HKL) is being burned or wasted in kraft pulping mills, and it low reactivity and crosslinking challenges limits its valorization as wood adhesives. Various kinds of synthetic crosslinkers used often involve hazardous chemicals, raising environmental concerns. To address this, this presentation focuses successful chitosan bio-crosslinking of HKL with chitosan rather than toxic and environmentally harmful crosslinkers. HKL extracted from black liquor is acetone franctionated to obtain acetone soluble HKL (ASHKL) and acetone insoluble HKL (AIHKL) fraction. These ASHKL and AIHKL are oxidized with sodium periodate at low oxidation (LO) and high oxidation (HO) levels, which improve the reactivity of HKL by introducing aldehyde groups by the formation of imine and amide bonds with chitosan, leading to higher glass transition temperature (*Tg*), higher viscosity, and greater adhesion strength. The crosslinking of ASHKL at LO level with chitosan exhibits excellent dry tensile shear strength (TSS) (1.15 ± 0.2 MPa) of plywood, exceeding the requirment levels of Korean and European standard, and reveals that chitosan is an outstanding polysaccharide-based crosslinker for the bio-crosslinking of HKL owing to its sustainability, biocompatibility, functional properties, and capability to form covalent bonds for fully bio-based wood adhesives. However, the wet TSS of these adhesives need to be addressed in the future.

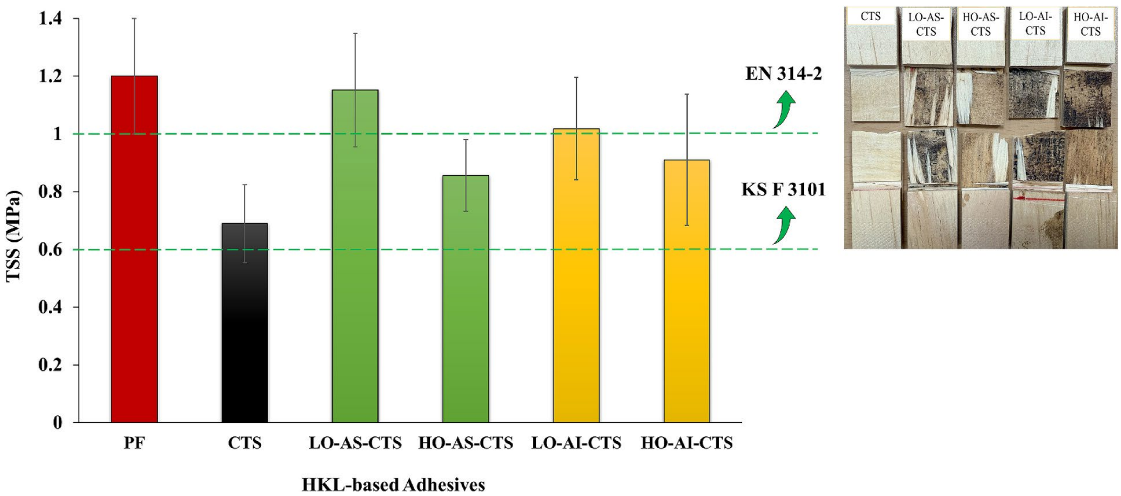

Fig. 1*: Dry tensile shear strength of plywood bonded with bio-crosslinked AS-CTS and AI-CTS at LO and HO levels [1].*

[1] Saman Ghahri, Byung-Dae Park. Int. J. Bio. Macromol. (2025) 309: 142907

Split Wooden Rods for Structural Wood Products: Enhancing Resource Efficiency in Hardwood Utilization

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Abstract

The increasing demand for wood in construction and the expected shifts in the future availability of certain wood species necessitate innovations in the wood processing industry. One aspect of sustainable wood utilization involves transitioning from the predominant use of softwoods in engineered wood products for structural applications towards an increasing use of more drought-resistant hardwood species. To this end, we introduce a new wood separation and processing method that is tailored to the use of hardwoods [1]. Splitting, instead of sawing, the wood along the grain into rectangular rods enables the utilization of lower quality wood grades with enhanced material efficiency and reduced energy consumption. Subsequent bonding of the split rods allows for the fabrication of novel hardwood-based wood products for use in construction. To address the challenge arising from the inherent irregular geometries of the split rods, we employ Machine Learning algorithms trained on images of the split wood rods for geometrical and mechanical characterization. This allows the sorting of the rods prior assembly, aiming for predictable mechanical properties within the final wood product.

Within this project, we demonstrate the workflow from splitting different hardwood species and the adhesive bonding of the characterized rods into structural boards. Mechanical characterization of the boards showed superior strength and comparable stiffness to existing softwood-based products, demonstrating the potential of this material-efficient wood processing method for novel wood-based products that are adaptable to prospective resource availabilities.

[1] Burgert, I., Kegel, S., Schnider, T., Achatz, J., Stucki, S., & Schubert, M. (2024). Split wooden rods for novel wood-based boards in the construction sector. RILEM Technical Letters, 9, 30-35. https://doi.org/10.21809/rilemtechlett.2024.193