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GRAND HOTEL BERNARDIN

PORTOROŹ, SLOVENIA

Ilona Peszlen, President-Elect

Angela Haney, Executive Director

Edited by Jeffrey Morrell

On behalf of the Society, I would like to thank all of those who attended the meeting and presented their research. I'd especially like to thank all of the students who attended and hope that they join us at future meetings.

Finally, I'd like to thank our Executive Director, Angela Haney, for organizing an excellent meeting and Jeff Morrell for assembling these proceedings. We hope you find them useful and look forward to seeing you all June 15-20, 2025, in Fort Collins, Colorado for our 68th Annual meeting.

Ilona Peszlen, SWST President

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Potentials of wood products in construction to mitigate environmental effects - An Austrian case study

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ABSTRACT

As a renewable raw material, wood offers great potential for reducing climate damaging carbon emissions in the atmosphere. This positive effect is further enhanced by the reuse and cascadic recycling of wood as a secondary raw material in the sense of a circular economy. Due to the development of sophisticated engineered wood products, wood is nowadays used in the construction of multi-story buildings. By that, wood serves as alternative bio-based construction material that is substituting cement-based building elements, which are the third largest source of anthropogenic carbon emissions (Andrew, 2018). This releases pressure from the environment and helps to tackle challenges in the course of human-induced climate change.

As long as wood is used in a material phase, carbon is stored in buildings and is not released into the atmosphere. If we think about this storage effect on a long run – let's say 100,000 years - of course, this storage effect is not eternal, as after some time, a certain kind of down-cycling is inevitable and decay or energetic use by combustion will take place. However, even for the combustion, there might be solutions in future to capture carbon before it gets emitted into the atmosphere. Until then, it is crucial to catch up with using bio-based materials instead of fossil-based resources – there is still plenty room for improvement. Nowadays, engineered wood-hybrid elements can compete with conventional fossil-based construction materials and show high potential for substitution. However, especially for hybrid elements, their re-use concepts are crucial. Materials should be easily reusable. If reuse is not possible anymore, the individual materials should be able to be detached and used separately. In an Austrian case study led by Wood K plus, wood products are specially designed to be re-used as long as possible in wooden buildings. After reuse is not possible anymore, construction elements are modified to generate different construction elements that can be used again in the building sector. Another current project is promoting wood on a policy level - the European Wood Policy Platform ("woodPoP"), initiated by the Austrian government - that aims at encouraging dialog, develop policies and show benefits of using wood. This complements sub-regional initiatives such as the European Green Deal or the related New European Bauhaus. The present study highlights potentials, limitations and trade-offs to use wood for a prospering bio-economy. Best practices are screened and their transferability to other countries is estimated. The study is carried out in the project "Wood for Globe - Towards a Global Wood Policy Platform: Sustainable Wood for a Carbon-neutral Bioeconomy", led by IUFRO and funded through the Forest Fund of the Republic of Austria.

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Acoustic tomography for standing trees

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ABSTRACT

Acoustic tomography is an important tool when evaluating the health status of trees. Based on the detection of speed of elastic stress waves initiated by sound, it presents a nondestructive method to detect internal decay of trees. However, there is a lack of tomogram reconstruction method description for commercially available acoustic tomographs. For this reason, a Python library has been developed to process sound speed data and reconstruct tomogram for detection of decayed wood and sound wood. The results of the data processing have been compared with other available methods and with the actual wood quality detected after felling the tree and exploring the wood in the cut.

Key words: acoustic tomography, wood decay, noninvasive tree assessment, Python, image reconstruction

Introduction

Noninvasive and lightly invasive methods are important tools to inspect trees and wood. These methods allow us to estimate the health of the object with minimal disturbance. Among these methods, acoustic tomography is popular as a fast and cheap method.

Despite the significant progress in tomography in general, acoustic tomography of trees suffers from several limitations which do not allow the use of well elaborated methods for processing the measured data. One of the important issues is that the object is examined using few rays only and the reconstruction of the image based on sparse information does not give satisfactory results. Another issue which makes reconstruction of material properties from acoustic tomography difficult is that the wave propagation mechanism for standing trees is not fully understood yet (Du et al, 2018).

The method used to reconstruct the tomogram in commercial devices is the filtered back projection or unknown (Arciniegas et al., 2014, Perlin et al., 2019). However, the filtered back projection produces good results only if the object is examined from sufficiently many directions and with sufficiently many rays. These conditions cannot be met if 12 sound sources and receivers are used in a typical measurement. For this reason, some refinement such as SIRT method is necessary (Arciniegas et al., 2014). Alternative methods to filtered back projection have been examined as well. Zheng et al. (2013)

introduced an idea of elliptic ray neighborhood which defines the ellipse of influence of each ray. This method has been elaborated by Du et al. (2015) to ellipse based spatial interpolation method (EBSI) and by Du et al. (2018) to ray segmentation by elliptical neighborhood (RSEI) and spatial interpolation by segmented ellipse (SISE).

Li et al. (2014) used Taylor series expansion to obtain quadratic law for the speed of the elastic ray as a function of the angle between the ray and the radial direction. The graph of the velocity as a function of the declination from the radial direction is a parabola with vertex up. This property can be used to examine the health status of the tree (Li et al., 2014) as well as the tool to fix anisotropic wood behavior (Du et al., 2015).

The acoustic tomography is known to overestimate the defect size (Du et al., 2018). Therefore, cracks appear as large areas of degraded wood. A new method which allows detecting these cracks is proposed. The method is based on the fact that if a crack divides two areas of sound wood, then it separates the nodes into two groups. These groups can be identified using clustering algorithms in a net from the nodes where the distance between the nodes is a decreasing function of the sound speed between the nodes. Several algorithms are capable of solving this task in the Python library scikit-learn.

The aim of this paper is to explore the possibility of processing tomograph data using noncommercial tools and open methods. Python has been chosen as a main tool and a Python library TomoTree for processing of tomographic data has been created.

Materials & Methods

The TomoTree library based on selected known methods for image reconstruction and their modifications has been created and tested. It is known that the wave propagation in standing trees and in stem sections with artificial cavities differs (Strobel et al., 2017). For this reason, data collection and library testing have been performed on standing trees. Six *Tillia cordata Mill* trees previously intended for felling have been selected in Valdštejnova alej (Linden alley) in Jičín, Czech Republic (50.4465947N, 15.3724022E). These mature trees have been historically damaged by severe pruning (topping), with varying extents of internal defects in the trunk. Individuals were selected from the row adjacent to the road. Their habitat conditions in terms of stress load are therefore comparable. Dendrometric parameters differed significantly, especially in trunk diameter, with height varying around 8 m for all individuals. Vitality was another parameter that differed significantly between individuals.

Fakopp ArborSonic 3D acoustic tomograph with 12 sensors has been used. Each time of flight (TOF) has been established as the mean value of five measurements for each ray.

The node positions and speed data have been exported from the ArborSonic software. The obtained data have been processed using the TomoTree library to get the tomograms and to get the graphs of the dependence of the speed on the angle between the ray and the

radial direction. The method used for the tomogram reconstruction is based on the RSEN and SISE methods. A combination of these methods is well documented, simple to implement numerically and produces good results in tomogram reconstruction (Du et al., 2018). However, several modifications of these methods have been used to refine the output, make computations faster and gain better harmony between the results and the input data. Namely, the following modifications have been used.

- Wood anisotropy has been handled using the methods described in Maurer et al. (2006) and Du et al. (2015).
- The segmentation process in RSEN method has been adjusted and rather than bisecting segments up to required level we used segments of comparable length. This improves the homogeneity of the resulting tomogram.
- The final data have been postprocessed to match the original TOF again. This is motivated by the fact that the evaluation of averages included in both RSEN and SISE yield speeds with artificially small variation and these speeds do not match the TOF anymore. A linear transformation of the cell speeds has been used to make the travel times in the tomogram as close as possible to the actual travel times. More precisely, the speed of all tomogram cells is transformed by a linear transformation and the parameters of this transformation are such that the difference between the TOF from the tomogram and the measured TOF is as small as possible.

The above-mentioned modification of RSEN+SISE methods is referred to as enhanced ray segmentation method (ERSM). The Python language has been chosen as the main tool for implementation. The Pyhton library NumPy has been utilized for numerical computations. This library allows vectorized operations and thus can be fast when processing a large amount of data, such as grid of cells and their coordinates and properties. The graphic library Matplotlib has been chosen as a backend for results visualization.

The knowledge of the pith position is required for precise evaluation of the dependence of the ray speed on the angle between the ray and the radial direction (Perlin et al., 2019). Since this value is in general unknown and for central cavities even impossible to obtain, the center of mass of all nodes has been used instead.

The DBSCAN algorithm of the scikit-learn Python library has been used to explore the possibility of clusters formation where the sound wood is separated by a crack. The metric between nodes has been defined as reciprocal value of the speed (slowness).
(Insert Figures and Tables within text)

Results and Discussion

The data collection took place on February 20, 2024. All datasets have been collected during a single day. The interval between consecutive measurements was about 40 minutes. The temperature was above freezing point during the measurement and also for a long period before. Thus, the measurements have not been affected by frozen parts in the stems.

The data have been processed by the utility software for the tomograph (ArborSonic 3D v 5.3.162), by the TomoTree library (ERSM method) and by scikit-learn toolkit (scikit-learn 1.4.2, Python 3.12.2, DBSCAN). The outputs have been compared with the photos documenting the actual state of the trees.

A long crack has been observed in tree No. 8 and large central cavities have been observed in trees No. 14 and 15, see Figure 1.

Figure 1. Stem cuts for trees No. 8, 14 and 15.

Two tomograms of tree No. 8 produced by ArborSonic 3D software and by TomoTree library are in Figure 2. Both outputs reveal similar velocity distribution and thus similar degree of degradation across the cross section. The area with the slowest wave propagation reaches from the center to nodes 4 and 6. However, this is not in harmony with the fact that a fast ray is located in this area. Really, the ray between nodes 1 and 4 has been identified as the 8-th fastest ray in the tomogram. This contradicts the fact that this ray is to a considerable extent outside the green area and thus the ray should be slow. This together with physical inspection of the stem suggested a closer investigation and looking for signs of a crack.

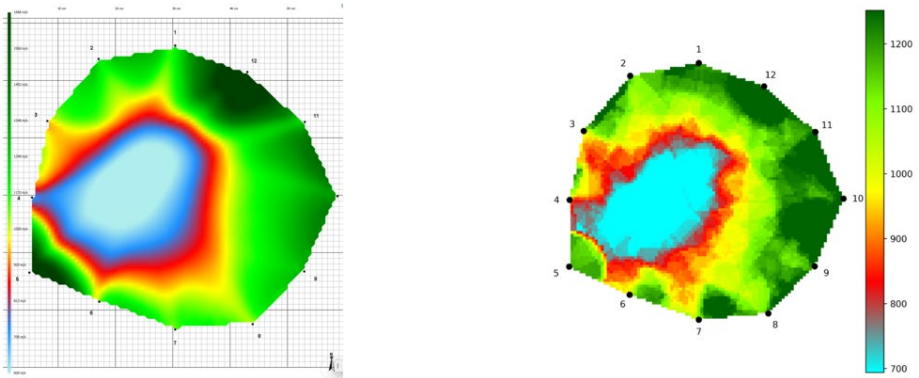

Figure 2. The tomograms for tree No. 8. ArborSonic 3D on the left, TomoTree on the right

The charts presenting the ray speed as a function of the angle between the rays and the radial direction are presented in Figure 3. There is a clear difference between tree No. 8 and trees No. 14 and 15. The shape of the curves in the diagram for the latter trees is a parabola-like function with vertex down and with sharp vertex. The curves in the former tree do not reveal sharp minimum. (Note that for sound wood we expect parabola with vertex up (Li et al., 2014).)

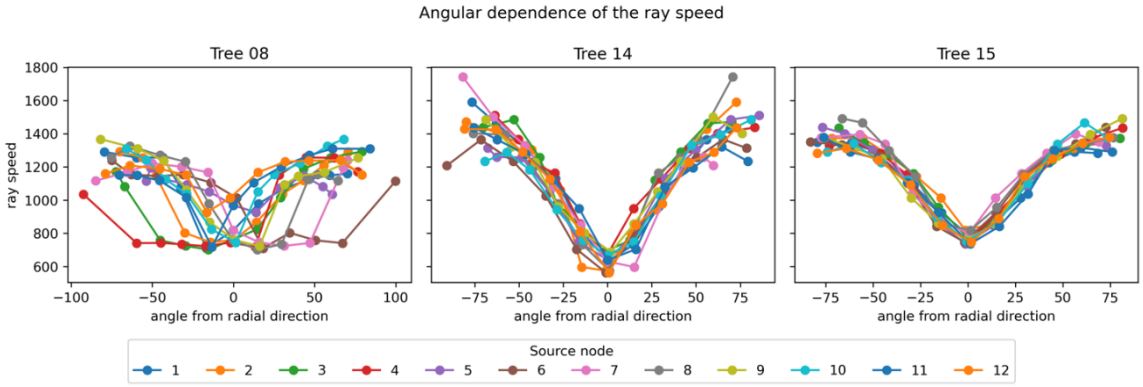

Figure 3. Speed as a function of the angle between the ray and the radial direction.

The results of the DBSCAN algorithm with fastest and slowest rays are presented in Figure 4. The picture shows that the DBSCAN algorithm separates nodes into three groups. The presence of a fast ray between groups 2 and 3 suggests to consider groups 2 and 3 as one group. Now we have two groups (nodes 1 to 4 and nodes 6 to 12) with fast rays inside each group and slow rays from one group to another.

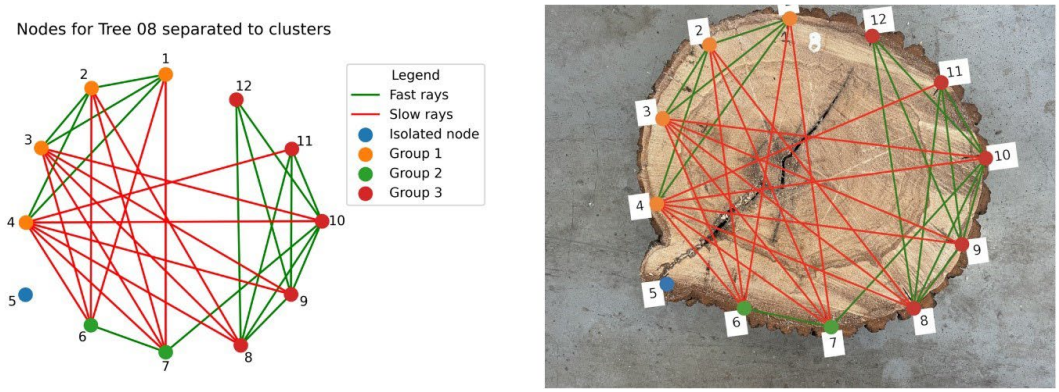

Figure 4. The separation of nodes of tree No. 8 into groups and superposition of the nodes and the stem cut.

The current status of the TomoTree library is alpha release, and the library will be published under GNU license in beta stage. Until the code will be published, the TomoTree library can be accessed via the web interface published as a streamlit application (Mařík, Cristini, 2024).

Summary and Conclusions

It has been shown that it is possible to obtain tomograms comparable to commercial devices using public and documented methods. These methods allow further development by the community, parameter tuning, and allow analyses not included in the software shipped with the device, such as anisotropy compensation, the angle-velocity relationship and clustering according to the slowness of the rays.
Note that several methods should be combined to get reliable data related to the health status of the tree. For example, the above-mentioned separation of nodes to clusters for Tree No. 8 could be caused also by the area of degraded wood in eccentric position. However, the presence of fast ray 1-4 and further measurements with Resistograph suggest that this is not the case.

Acknowledgements

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Historical overview of themes at the SWST's conventions

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ABSTRACT

In 1966, the convention focused on the present and future supply and demand for wood scientists and technologies. It seems that already 58 years ago the sector was exposed to changes and needs for adopting new ….?. In a way, also today, we are discussing the need for certain knowledge and skills in the sector, e.g. digitalisation and circular economy. The 1968 convention focused on continuing education, an important theme of discussions today when we, at least in Europe, are discussing micro-credentials and organized long-life learning programs. In 1972, the convention covered needed skills and suggested that wood science and technology may be facing a crisis. It looks like today's discussions are not new and we should look back, what were the challenges and how they were overcome in the past. It could be seen that 1980 brought a new horizon. The convention title was "Wood structures for permanence". In the 90s we would have used "durability", with today we would use "sustainability." The concept of sustainability was already receiving attention 44 years ago. In 1985, the SWST convention focused on the future of public research, showing an imperative to engage with society, while today we are emphasizing citizen science. Further analysis shows that the term biotechnology was first emphasized in 1987 and in 1988 the awareness of chemical hazards associate with wood processing was discussed, while in 1990 the efficient resource use was emphasized. In 1991, a clear worry regarding the interest of society in wood science was emphasized. In that year, the convention title was "Wood scientists – and endangered species". It seems the history is repeating as we are again discussing how to increase interest in wood science. We should analyse what was done back in the nineties and learn from it. Also in the late nineties, the environmental movement and fiscal influences on wood products research were discussed, a topic receiving increasing attention in today's discussions of the sector.

Looking at past SWST conventions, it can be also seen when certain topics become important for the sector. In 2003 the term biobased economy was used, in 2005 nanotechnologies and wood modification found its place at the SWST convention. In 2006 an important topic of moisture in wood related to timber construction was discussed. Furthermore, Cross Laminated Timber (CLT) first gained attention in 2008. In the following years other innovative products have been discussed, e.g. bamboo and the need to connect with cultural sector. In 2016 a word "lignocelluloic materials" enters the SWST convention and in 2017 recycled wood. 2016 is the first time the connection between wood and human health was emphasized. In the following years, clearly the wood-based products used in construction has been discussed at each SWST convention, while in the SWST Convention 2024 the themes "Regenerative Sustainability" and "Envisioning a future of engineered living materials" indicate a future development of the sector.

The presentation delivers an overview of past SWST conventions and reflects on the current challenges of the sector.

STATE OF THE ART OF WOOD SCIENCE

Ilona Peszlen/Ruppert Wimmer, Co-Chairs

Fire resistance of floor framing members: Development of an intermediate scale test

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ABSTRACT

Engineered wood floor framing members, such as I-joists, must pass full-scale fire endurance tests to demonstrate equivalency to unprotected 2x10 dimension lumber if used in fire-rated assemblies. The full-scale test is performed on a 10.5 m2 floor assembly loaded to 50% of the allowable design stress and then exposed to the standard fire curve. The acceptance criteria of 15 minutes, 31 seconds is determined from the equivalence to the calculated fire resistance of solid wood 2x10 assuming a 3-sided fire exposure and a char rate of 1.5 in hr-1. Because the full-scale test is expensive and cumbersome, it can be difficult to screen new potential technologies. The purpose of this study is to examine the suitability of an intermediate-scale test method for floor framing members. The intermediate-scale test uses two joists spaced 406 mm (16 in.) on center and 3 m (120 in.) long with a 1.8 (72 in.) heated length. Two hydraulic actuators load the assembly so that the maximum bending stress is equal to 50% of the Allowable Stress Design bending design load. Solid wood 2x10 dimension lumber was used to evaluate the suitability of this intermediate scale method. The floor assemblies lasted between 585 and 1070 seconds (9.75 to 17.83 minutes). The method may be useful for screening new fire protective technologies for engineered wood.

Investigation on two types of cell wall water and their effects on dimensional changes of wood

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ABSTRACT

Hygroexpansion is an important property that occurs as a result of changes in the cell wall structure of wood caused by water. Recent research has shown that water in the cell wall of wood can be classified into two different states, further intriguing the evaluation on the investigation of how water in the cell wall influences dimensional changes. In this work, beech (*Fagus sylvatica*) and pine (*Pinus taeda* L.) wood were conditioned at different relative humidities (RH) over saturated salt solutions. The moisture content and sample dimensions were evaluated under various adsorption equilibrium states, along with the relaxation properties of cell wall water by application of 2D time-domain nuclear magnetic resonance with saturation recovery Carr-Purcell-Meiboom-Gill pulse sequence. Two pools of cell wall water were identified: water molecules in the disordered surface of cellulose microfibrils and their surrounding hemicellulose (Peak B), and those in the domain of matrix including lignin and surrounding hemicellulose (Peak C). B-water and C-water exhibited different relaxation properties with different moisture contents. The mobility of both cell wall water types increased with increased RH, with more mobility gained by B-water. Calculations based on cluster theory syuggest that the formation of water clusters in the high RH region may exist in the reservoir of B-water. Specifically, B-water exerted a predominant influence on the dimensional changes of wood in comparison to C-water. Revealing the specific impact of cell wall water on wood dimensional changes is not only crucial for validating the mechanisms underlying dimensional stability of wood, but also essential for ensuring the durability and safety of timber applications.

Deep eutectic solvent assisted thermally-modified wood for enhanced autonomous indoor humidity regulation

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ABSTRACT

The crucial development of materials that automatically adjust indoor humidity, a significant factor in human health and daily life, has gained importance due to the emphasis on energy conservation. Wood, with its natural hygroscopic properties, is effective in this regard but faces challenges of deformation and cracking due to moisture content changes. Herein, we introduced an innovative in-situ wood modification strategy, which integrated deep eutectic solvent (DES) impregnation with heat treatment, producing dimensionally super-stable modified wood for enhanced autonomous indoor humidity regulation. This modification process focused on creating more robust cross-linking structures within the amorphous regions of the wood cell wall. As a result, water-induced deformation of natural wood was significantly reduced, as evidenced by an anti-swelling efficiency exceeding 80%, ensuring the long-term reliability of DES-modified wood in varying humidity environments. Additionally, the introduction of additional pores and hygroscopic sites in the cell wall enhanced the natural wood's moisture buffering value by 2.5 times, showcasing the superior ability of DES-modified wood to control indoor humidity effectively. Moreover, the DES-modified wood also exhibited commendable flame retardancy and antibacterial properties. Consequently, this novel modified wood emerges as a reliable material for indoor humidity regulation, promoting healthier indoor conditions and offering a sustainable alternative for energy-efficient construction practices.

Keywords: wood, dimensional stability, autonomous humidity regulation, in-situ modification, deep eutectic solvent (DES)

Impact of soy protein solubility and particle size on adhesive performance

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ABSTRACT

Soy is considered one of the most promising natural materials for manufacturing wood adhesives due to its low cost, high protein content, and ready availability. However, more cost effective ways of improving its wet shear strength are needed to achieve wider market acceptance. Protein adhesive wet strength depends on the use of (typically expensive) crosslinking additives as well as the processing/denaturation of the protein. Soy protein isolates (SPI) are the most concentrated form of commercially available soy protein (~90+% protein). They are useful for studying protein bonding mechanisms but are too expensive for most wood bonding applications.

Pure soy protein isolates, when used as plywood adhesives, can give commercially viable wet strength or no wet strength, depending on the processing of the protein. Therefore, we are very interested in understanding how the protein aggregation/denaturation state influences bonding performance. We have discovered that while many isolates had commercially relevant wet strength, samples made with the soluble fraction of these isolates usually fell apart during the water soak when determining wet strength using the Automated Bond Evaluation System (ABES) method according to ASTM D7998.

In this work six different SPIs were obtained, five commercial and one native state, laboratory-made isolate. The aim of the study was to investigate the source of the difference in bond strength between the soluble and insoluble fractions. Characterization of the soluble and insoluble fractions included protein, sugar, and salt content, particle size, fraction of native state by DSC, and extent of protein hydrolysis. Both wet strength and dry strength of the SPIs were tested in ABES. Adding the crosslinker PAE (polyamidoamine epichlorohydrin) improved all strength values, but the soluble fractions were still inferior. Initial data indicates that there were no differences between molecular weights of soluble and insoluble fractions, which is significant because we have seen that hydrolysis can result in strength reduction. Initial tests clearly show the particle size of the soluble fraction is smaller than insoluble fraction. A variety of potential causes for the difference in performance will be discussed in light of the data presented.

Crack propagation on some central African tropical woods: Experimental approach and numerical simulation

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ABSTRACT

The use of wood for structural purposes in mechanical engineering, in the form of solid wood, presupposes a good knowledge of the properties of the elementary wood components used. Without this, woods remain excluded from the modern world of mechanical design. In Cameroon, Bilinga (*Diderrichii nauclea*), Dabema (*Piptadeniasmetrum africanum*) and Padouk (*Pterocarpus soyauxii* Taub) are the main forest resources used in construction. Adding value to these resources is a major challenge for the timber industry. The aim of this study is to investigate the fracture behavior of this resource both experimentally and numerically. This study focuses on the process of different primer lengths, different species, different basal density rates for tissue loading direction (longitudinal-tangential) and different loading modes and three-dimensional effects are also taken into account. In this case, the mixed-mode crack growth specimen is considered in order to investigate the effect of scale and its impact on wood fracture. The impact of moisture variation on the cracking parameters, like stress intensity factor or energy release rate, of this type of wood is shown. This knowledge will represent an important step towards the optimal use of these species for structural applications. Indeed, the design of such structures requires detailed knowledge of the mechanical behavior of the constituent material, particularly with regard to cracking. The results show that Dabema and Bilinga have more ductile behavior, i.e., the rate of energy restitution is much higher than Padouk's. However, Padouk and Bilinga have a higher stress intensity factor than Dabema for this reason, Dabema and Bilinga are more resistant to crack propagation than Padouk.

Strategic future of forest biomaterials education, innovation, and engagement at North Carolina State University

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ABSTRACT

The Department of Forest Biomaterials at North Carolina State University is the leader in education, research, and development in forest biomaterials, specifically in paper science and engineering. The Department currently has 20 faculty members, 11 staff members, 10 post docs, 50 graduate students, and 240 undergraduate students. While offering world-class education to our students, we are proud to host multi-million dollar fundamental and applied research initiatives, generously sponsored by NSF, DOE, USDA, and industries, including wood and biomass for biofuels, energy efficiency and decarbonization, waste utilization and recycling, sustainable materials and valued-added products. The Department also plays a key role in fulfilling NC State University's land-grant mission by working to promote economic prosperity, environmental stewardship, and engagement for our stakeholders. We are striving to sustain the excellence of education, innovation, and engagement focusing on strategic future growth.

NOVEL APPLICATIONS OF WOOD IN THE BUILT ENVIRONMENT

Bohumil Kasal and Levente Denes, Co-Chairs

Downscale testing as an alternative to full-scale non-destructive testing of laminated timber

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[1]The University of Queensland, Brisbane, Australia

ABSTRACT

The growing interest in constructing larger and taller timber buildings requires extensive laboratory testing, especially when talking of engineered wood products (EWP). When it comes to small-sized samples, testing is generally straightforward, both in terms of capacity and labour, and requires a lesser amount of material. However, as the scale of testing increases, there is an increased need for meticulous planning, larger spaces, increased capacity, and higher costs. These factors can potentially discourage testing or lead researchers to rely on data available, which may not accurately represent full-size results.

Unlike other materials such as steel and concrete structures, where testing downscaled samples is a more common practice, the timber industry faces unique challenges. The so-called "size effect" significantly impacts the properties of timber, particularly strength, which tends to decrease as the dimensions of the elements increase, which doesn't help to the widespread adoption of downscaled testing in timber engineering.

For longer spans, design considerations are often driven not solely by strength but by serviceability factors, such as stiffness, damping, and natural frequencies. Addressing these serviceability parameters is crucial for ensuring the structural integrity and performance of timber elements in larger and taller constructions.

This research specifically studies the feasibility of downscaled testing for engineered wood products, with a focus on glulam and cross-laminated timber (CLT). The study involves a comparative analysis of six full-scale glulam beams and their downscaled counterparts, as well as nine full-scale CLT panels and their downscaled versions. The evaluation encompasses static and dynamic serviceability parameters, shedding light on the effectiveness and reliability of downscaled testing methodologies for these essential components of modern timber construction.

The design of timber structures for fire, and the importance of holistic design

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ABSTRACT

Traditional fire-safety methodologies such as fire resistance were developed in the early 1900s, long before engineered-timber buildings were being constructed, and are based on the premise that structural elements do not markedly contribute to the fuel load. However, due to its combustible nature, the use of mass timber in the context of an engineered timber building has the potential to overcome the building's fire safety strategy due to the increased fuel load, burnout duration, and external fire spread, the consequences of which could include increased heat exposure to the structure and increased risk to occupant evacuating and to fire brigade intervention. Hence, the risks associated with engineered timber invite a holistic design approach to the fire safety strategy which considers the contribution of the structure to the fire.

A building's fire safety strategy must at the very least: enable the safe evacuation of occupants; enable fire brigade intervention; maintain structural integrity for the duration of the fire; and mitigate the spread of fire within the building and between buildings. However, current design methodologies for the design of engineered timber structures for fire (i.e. reduced cross-section method, classifications of material flammability) only assess their specific performance objectives in isolation, and do not account for their interactions with other aspects of the fire safety strategy, which is critical to develop a holistic fire-safety strategy.

An example of this is the structural design of timber. This is currently achieved by assuming a constant char rate based on a standard fire furnace test to determine the residual cross-section required to remain load-bearing for a specified fire resistance duration. However, this does not consider the impact the combustible structure may have on the fire dynamics in a real building fire. This has the potential for inadequate fire design of engineered timber if combustible elements extend the fire duration beyond the benchmark of the specified fire resistance.

Recently, we undertook a comparative study exposing CLT to a range of incident heat fluxes at both a normal horizontal and an inverted surface (i.e. ceiling) to determine the impact orientation has on the spontaneous ignition and burning rate of the sample.

Preliminary results show that, whilst the critical heat flux is higher for unpiloted ignition in an inverted orientation, the peak and average burning rates were higher than that of a normal horizontal orientation. This simple bench scale study highlights that a change in orientation alone has a significant impact on the fire dynamics in a mass timber compartment with potential consequences for the structure as explained above. This change in orientation cannot be addressed through design methods that were conceived to test singular performance objectives (i.e. fire resistance, flammability).

This presentation will highlight gaps in current design methodologies and showcase the results from the bench-scale test illustrating how fire dynamics can change with orientation, and the consequences for holistic design.

Electrical and mechanical characterisation of adhesive functionalised with electrically conductive fillers

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ABSTRACT

The durability of timber structures is highly reliant on wood moisture, and undetected moisture ingress can lead to performance losses. Monitoring moisture of wooden buildings is therefore necessary to ensure structures' safety. Nowadays, such monitoring is frequently omitted or carried out using many local sensors which can alter the integrity of the structures and only detect local damages. In this regard, wood adhesives can be modified with electrically conductive fillers to detect humidity in situ without adverse impact on the structure.

However, the quality of the electrically conductive network for a specific polymer-filler combination depends on different parameters that need to be assessed. Here we show the effect of different carbon fillers dispersed in melamine-urea formaldehyde resin on the electrical and mechanical properties of the adhesive bondline. Using direct-current (DC) electrical measurements, the electrical resistance of spruce (Picea Abies) bondlines was determined for different filler amounts, and electrical percolation curves for each filler combination were established. The influence of the different fillers on the mechanical strength of the adhesive was evaluated using lap-shear tests.

The findings generally support the understanding of the influence of carbon fillers on wood adhesives and provide insights on how to optimize their electrical and mechanical properties.

Keywords: conductive adhesives, engineered wood, carbon black, graphene nanoplatelets, electrical resistance, percolation threshold, lap-shear testing

Pioneering fully bio-based material solutions of 3D-printed recyclable wall structures for houses

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ABSTRACT

The 3DP Biowalls project represents a groundbreaking approach in employing additive manufacturing (3D printing) techniques alongside renewable raw materials to create fully recyclable wall structures. This initiative addresses four pivotal challenges: the worldwide shortage of raw materials, the dominant reliance on non-renewable construction materials like concrete and steel, the suboptimal utilization and recycling of renewable resources, and the notably low productivity within the construction sector.

Our research focuses on formulating entirely bio-based material compositions that are viable for large-scale 3D printing applications. The selected raw materials capitalize on industrial by-products sourced from the pulp and paper sector, alongside contributions from the wood industry, and starch derived from the food industry. Preliminary data reveal the promising performance of several developed materials, showcasing their potential compatibility with robotic-assisted additive manufacturing techniques.

Anticipated results from this project include the introduction of innovative methodologies that considerably enhance both the conceptual framework and the tangible implementation of circular economy concepts within the construction arena. This paves the way for establishing new standards in sustainable building practices, heralding a new era of environmentally responsible construction methodologies.

Key words: 3DP Biowalls, Additive manufacturing, 3D printing, Renewable raw materials, Recyclable wall structures

A 3D-scanning method to assess deformation of densified beech dowel

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ABSTRACT

Assembling timber by hardwood dowels has been applied in furniture making and timber construction since ancient time. However, wood is a viscoelastic material, showing reduction in strength and change in dimensions over time which may lead to the loose and imperfect dowel connection, especially under the changing temperature and relative humidity (RH). The set-recovery behaviour of thermo-hydro-mechanical (THM) densified wood can counteract the reduced performance of a dowel connection by providing additional frictional force along the dowel-hole interface over time. The set-recovery of densified wood allows for the use of dowels with a dowel diameter less than the pre-drilled hole diameter, thereby facilitating the insertion of the dowel, e.g. in robotic fabrication. Therefore, the objective of this study was to investigate the moisture-induced set-recovery deformation of dowels made of densified wood.

The densified beech wood panels with 30% compression ratio were prepared by carrying out the THM densification in an open-system hydraulic hot press. Then densified panels were manufactured into 11.9 mm diameter cylindrical dowel by PROFILES d.o.o company. The dowels were conditioned under (1) climate chamber at 20 °C and 65 % RH, (2) climate chamber at 20 °C and 95 % RH, and (3) in liquid water bath until achieve equilibrium moisture content. After conditioning, the dowels were dried at 103 °C in an oven. To accurately determine the complex shape of the deformation, the 3D optical scanner (Artec Space Spider, city, country) was used for the measurement during the desorption and absorption. The deformational changes of dowels after described exposures will be presented.

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Bending performance of cross-wise adhered unidirectional pine strand panels

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ABSTRACT

The growing need for building materials caused by increasing global population and standard of living and the opposed natural boundaries of resources lead to the imperative to increase material-efficiency in construction and foster high-rise multi-storey buildings. At present, engineered wood products used for that purpose in Europe (e.g. Cross Laminated Timber) are primarily based on sawn softwood. Yet, the processes involved require sawable logs of suitable quality and diameter and have poor material efficiencies from log to product of 40-60%. Climate change additionally leads to a shift in forest composition towards a greater portion of deciduous trees, which may result in wood qualities that are less suited for sawing. However, the manufacturing process of strand-based wood composites, such as Oriented Strand Board (OSB) or Laminated Strand Lumber (LSL), allows for the incorporation of logs of different qualities and diameters, including thinnings. This results in a comparably high material efficiency of 60-75% from log to product. The application of highly oriented LSL panels, currently used primarily edgewise as beams, as flat layers for a CLT-like cross-lamination could create a new generation of wood composites with sufficient material efficiency. The crosswise layering provides the necessary thickness, strength and dimensional stability to use this material as panels & plates in multi-storey wood construction. Moreover, it should be possible to produce layers with tailored density and strand orientation, which can be optimised to meet specific requirements in various load cases. The homogenisation of the material is thought to reduce the scatter of mechanical properties and increase characteristic strength values. This, in turn, should enable more efficient structural design. To evaluate the key mechanical properties of single-layer (tensile, compression and shear) and cross-laminated multi-layer components (bending), pMDI-bonded unidirectional panels of industrial pine strands measuring of 2.6m x 1.4m x 28mm were produced on a semi-industrial laboratory scale. Focusing on a bending load case of a three-layered CLT-like structure, the main properties of unidirectional strand composites were determined. This provides a basis for further research aimed at optimising the composite structure and verifying the processibility of different wood species for this purpose.

Keywords: strand based composites, maximum orientation, cross-wise lamination, mechanical properties, bending application

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Dynamic moisture content of CLT wall elements from manufacture through construction

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ABSTRACT

Wood construction has been increasing globally and Engineered Wood Products (EWPs), such as Cross Laminated Timber (CLT), have had a major part in it. Increasing wood construction could help decrease the carbon footprint of the construction sector, since wood can be sustainably sourced and wood products store carbon. To use wood in construction in a more extensive way, its properties and behavior as a construction material must be known. Wood has many properties of which moisture has a great impact on other properties, such as strength. Too high moisture can also cause problems, such as fungal growth, on its own. Therefore, it is important to monitor the moisture levels and understand the factors affecting them.

In this study, the wood moisture content (MC) of CLT wall elements was monitored with resistance-based moisture meters from the manufacturing plant, through transportation and construction of a building at the Hyytiälä forest station of the University of Helsinki, in southern Finland. There were sensors in five locations around the building and they all measured MC in three different depths inside the wall. The objective was to see how, where and when did the MC change within the CLT elements. The data was analysed with statistical tests and presented through various types of graphs.

The results showed that variation within the data was large, approximately from 8% to 16%. On average, the MC was at its highest near the surface of the CLT elements, after the protective canopy was removed. Two measuring locations on the opposite sides of the building had consistently higher MC than in the other measuring locations. The MC stayed below FSP (Fibre Saturation Point) throughout the monitoring period and, therefore, the risk for moisture induced damage is very low.

In the future studies, the dynamic variation in MC will be analyzed from the CLT layers of more locations of the building, and the indoor and outdoor temperatures monitored along.

POSITIVE ENVIRONMENTAL CONTRIBUTIONS

Ben Nyses and Mariapaola Riggio, Co-Chairs

Wood and municipal solid wastes for value-added bioproducts

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ABSTRACT

Traditional disposals of municipal solid wastes (MSWs), such as landfilling and incineration in open-air burn pits, pose serious environmental and health risks, especially on the U.S. oversea military camps. Burn pits, which are often used in military operations and other settings, involve the combustion of various materials, including wood, paper, fuel, plastics, and rubber. The smoke and fumes released from these pits can cause air pollution and health issues. The Department of Veterans Affairs has noted that the burn pit emissions can affect health differently, based on the specific mix of chemicals and toxins present. To address waste management and energy generation challenges, converting MSW into solid biofuel pellets or value-added bioproducts has been considered. Research on mixed pellets from plexiglass, rubber, and wood at different ratios has been conducted, including pure wood pellets and plexiglass:rubber:wood mixtures at 5:5:90, 10:10:80, 20:20:60, and 25:25:50 ratios. The moisture content of these pellets is maintained at approximately 13±1%. Each sample undergoes ultimate and proximate analysis, higher heating value assessment, physical, and thermalgravimetric analysis. Furthermore, the technology and mechanisms, such as co-pyrolysis, for producing value-added bioproducts from a mixture of wood and plastics are discussed. Our processed pellet samples and results will be further evaluated on impacts of human health from toxicological perspective.

CO_2 curing and sequestration in wood-sodium silicate composites

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ABSTRACT

In this study, green wood-sodium silicate (SS) composites were prepared and cured with carbon dioxide (CO_2) and the carbon sequestered within the composite. The effect of CO_2 treatment pressure, treatment time, wood fiber particle size and post curing temperature on the mechanical, thermal, morphological and physical properties of wood-SS composites were investigated. A mixture of 50% wood (40 and 200-mesh) and 50% SS were blended and cold pressed into discs for CO_2 curing studies. The rheological behavior of the blends during isothermal curing was determined in the presence of air and CO_2, and a higher complex viscosity was observed for CO_2 treated samples. X-ray microcomputed tomography (micro-CT) was used to determine the depth of CO_2 penetration in the composite and showed that penetration depth was dependent on carbonation time and pressure. Also, % CO_2 uptake increased with CO_2 treatment time and pressure. Curing kinetics of neat SS and wood-SS composites of different wood contents (50 – 70%) were also examined using differential scanning calorimetry (DSC). The flexural properties of the 200-mesh wood-SS composites were higher than the 40-mesh wood-SS composites, with flexural modulus between 0.8 GPa to 11.2 GPa and flexural strength between 3.5 MPa to 59.2 MPa. Generally, the thermal stability of CO_2 cured wood-SS composites was influenced by particle size and post-curing temperature. Statistical response surface modeling showed that CO_2 pressure, and treatment time had significant effects on the mechanical properties of the composites. This study clearly shows that CO_2 curing of wood-SS composites can sequester carbon. It is envisaged that 3D printed wood-SS composites can be cured in the presence of CO_2 and possibly used as green additive construction materials.

Usability of hydrolysable tannin for the production of tannin-furanic foams compared to condensed tannin

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ABSTRACT

Tannin-furanic foams are a lightweight, highly porous material which sparked the interest of science and industry for some time now. Such material is obtained by co-polymerization of a condensed type of tannin and furfuryl alcohol under acid conditions, both being produced from renewable resources. Though these foams show interesting insulating and fire-resistant properties, several drawbacks hinder their commercialisation as insulation material. Regarding the European market, one major concern is the source of raw material, which is mostly condensed tannin obtained from black wattle, a tree typically grown in the southern hemisphere. With the knowledge gained from the foam synthesis with condensed tannins, this study has focused on the application of chestnut tannin, a hydrolysable tannin sourced in Italy, though being known to have a lower reactivity compared to condensed tannins. Therefore, the study compared the usability of chestnut tannin (hydrolysable) with mimosa tannin (condensed) for tannin-furanic foam production using a mechanical foaming approach. Produced materials were further assessed for their physical and mechanical properties. The results show that co-polymerization of a hydrolysable tannin with furfuryl alcohol is possible but requires the use of a stronger acid to prevent foam collapse before hardening. Using the mechanical foaming method with similar experimental parameters, yields chestnut foams with a density of 260 kg/m³, while mimosa-based foams resulted in significant lower densities of around 145 kg/m³. At similar densities (290-300 kg/m³) chestnut-tannin foams showed improved thermal insulation properties compared to mimosa-tannin foams (λ-value: 50 mW/m*K and 55 mW/m*K). Regarding compression resistance at comparable densities, chestnut foams registered only about half the strength of the mimosa-based ones (1.02 MPa instead of 2.25 MPa). In summary, foamability was less for chestnut tannin, resulting in lower densities for the mimosa tannin foams. At similar density, chestnut foams show slightly lower thermal conductivity, whereas mimosa foams have significantly higher compression resistance. Overall, it was demonstrated that hydrolysable tannins have potential for the usage in tannin-furanic foam production, despite being less favourable compared to condensed tannins in terms of their processing and mechanical strength.

Key words: bio-polymer, chestnut tannin, hydrolysable tannin, insulating foam, natural extracts

Replacement of fossil-based phenol by bio-based lignin: Phenol-lignin blends as basis for wood adhesive synthesis

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ABSTRACT

One of the main adhesive types used by today's wood industry are phenol-formaldehyde resins (PF resins). These adhesives are produced in enormous amounts and used at high throughputs. Phenol as main component of this system is toxic and fossil-based. Its cost and availability depend heavily on petroleum prices. Furthermore, growing socio-environmental-economic concerns about the scarcity of fossil feedstock have been encouraging the search for petroleum replacements. A bio-based replacement of phenol is therefore of high importance and could lead to potentially big environmental impacts. One possible replacement for phenol in PF resins is lignin.

Lignin is a major component of all plants and it is the only abundantly available aromatic polymer from nature. It is produced in large quantities as side-stream product of the pulp & paper industry and is mainly treated as a side product formed during the extraction of the targeted valuable product, cellulose. Today, lignin is still mainly burned to generate energy. Its price is quite low, therefore the utilization of lignin in any value-added application would result in considerable economical gain. Different types of lignin are available, not only depending on the source material (plant or tree species), but also on the pulping process applied in the production of cellulose pulp.

Technical lignin is mostly available as a lignin powder, which can lead to problems during industrial utilization, as powders are more difficult to handle than liquids. Issues like electrostatic behavior of the powder, insufficient or very slow powder dissolution during adhesive production, the formation of clumps, clogging of valves and the contamination of equipment all occur. These difficulties are already cumbersome on laboratory scale and are expected to exacerbate when applied on large industrial scale. The difficulties of handling a powder on large scale are therefore large hurdles for industrial application and could be avoided, if the lignin would be supplied in form of a pumpable liquid blend.

This study presents the production and utilization of such blends for lignin-phenol-formaldehyde (LPF) resin synthesis and the utilization of these resins in the production of birch plywood boards and other materials. Special focus is put on water resistance and the achievement of threshold values from European standards. A high substitution rate of phenol with lignin is another focus of this work.

How can the use of wood in construction contribute to the development of a carbon neutral bioeconomy in Africa?

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ABSTRACT

The construction sector is responsible for a significant share of global CO2 emissions and energy demand. Due to the expected demographic explosion in Africa in the coming years and housing deficit, especially in cities, the adoption of low-energy and low-carbon practices throughout the construction life cycle is an urgent matter. Instead of relying on traditional materials such as concrete and steel, which contribute significantly to carbon emissions, this paper explores sustainable practices, emphasizing wood construction as a pivotal component of the emerging bioeconomy. Prefabricated mass timber construction, utilizing materials like Cross-Laminated Timber (CLT), offers eco-friendly benefits such as reduced waste, lighter weight, and lower carbon emissions. While three CLT industries have been identified in South and East Africa, their production is still at a relatively small scale. Noteworthy projects, like the Burj Zanzibar, showcase Africa's potential in hybrid wood technology, marking a transformative shift toward a more sustainable bioeconomy. On the other hand, the bamboo, characterized by its rapid growth and versatile applications, emerges as a promising bio-sourced alternative. Engineered bamboo, integrated with steel and concrete, not only enhances durability but also aligns with the principles of the bioeconomy. Reclaimed wood use, considered within the context of a circular bioeconomy, gains prominence for its role in reducing carbon footprint. To ensure the widespread adoption of bio-based materials and practices, the paper suggests measures like reducing deforestation, promoting reforestation, enhancing bamboo farming, sustainable forest management, wood traceability and technological decentralization. Overcoming negative perceptions of bio-sourced materials, establishing regulations, and fostering research and development are crucial for successfully integrating wood construction into the bioeconomy across African countries. Moreover, promoting the use of raw materials produced locally is crucial to reduce carbon dioxide emissions associated with the energy expended during material transportation. Addressing these factors can transform the construction sector, aligning it with the principles of a sustainable and thriving bioeconomy while mitigating environmental impact.

Acknowledgments: This paper contributes to the "Wood for Globe - Towards a Global Wood Policy Platform: Sustainable Wood for a Carbon-neutral Bioeconomy" initiative led by IUFRO and funded through the Forest Fund of the Republic of Austria.

Creating a carbon sink through innovative wood-hybrid elements and re-use concepts in the wood construction - A life cycle assessment perspective

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ABSTRACT

The building sector is an energy and resource intensive (e.g. cement, steel, glass, insulation material production) sector contributing to a substantial amount of the global carbon emissions. Using wood in the building construction is considered as a renewable and climate friendly solution compared to fossil-based raw materials. Expectations are raised in the utilisation of wood for long-term applications as wood is perceived as CO2-neutral regarding its capability of storing CO2 emissions. To maximize this ability, circular strategies are required to keep the material utilised as long as possible to relieve pressure on the atmosphere.

The research project SINK.CARBON aims at the development of innovative wood-hybrid construction elements as a building material. The established concept is specifically designed for multiple reuse and recycling purposes to reduce the environmental impacts. To quantify the CO2 emissions and the carbon sequestration potential of the construction elements, the project is accompanied with Life Cycle Assessment (LCA). A cradle-to-cradle approach is considered to compare reuse and cascading cycles of the hybrid construction compared to conventional buildings. The wood construction convinces through lower CO_2 emissions throughout the construction phase as well as by a significantly higher storage capacity of several hundred tons of CO_2 within the analysed buildings due to the utilised wood components. Additionally, the reuse concept and the extension of the life cycle contributes to a longer retention of the storage effect and reduces emissions by saving resources. By the identification of the environmental hotspots through implementing LCA in the development stage of wood-hybrid construction elements, the developers are enabled to focus on energy and resource efficient low-carbon building materials, construction techniques, transportation, and end-of-life strategies.

Integrating timber circularity: A holistic strategy for sustainable wood resource management in Australia

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and Mel Harris[1]

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ABSTRACT

Implementing timber circularity is crucial in Australia, where forestry and wood products industry plays a significant role. By addressing the challenges and leveraging opportunities through policy reform, infrastructure development, innovation, and education, Australia can enhance its timber circularity practices, contributing to both, environmental sustainability and economic resilience.

The National Centre for Timber Durability and Design Life (NCTDDL) at the University of the Sunshine Coast (USC) is leading a cooperative project with Forest and Wood Products Australia (FWPA) and a consortium of timber producers, chemical suppliers, and timber users to identify circular pathways for preservative treated timber and engineered wood products (EWP) in Australia. This presentation will update on progress made on the seven project tasks aimed at improving the understanding of preservative-treated timber and engineered wood products within a circular economy framework.

Key Words: Circular Economy, Re-use,

A novel self-wrinkled polyurethane-acrylate wood coating with self-matting, anti-fingerprint performance and skin-tactile feeling via excimer lamp/UV curing

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ABSTRACT

Wrinkled surfaces exist widely in nature and organic living world, such as plants, insects, and skin. The optical, wettability and mechanical properties of materials can be enhanced by artificially preparing regular microstructure on the surface of materials. In this study, a novel self-wrinkled polyurethane-acrylate (PUA) wood coating with self-matting, anti-fingerprint performance and skin-tactile feeling curing by excimer lamp (EX)and ultraviolet (UV) was prepared. The wrinkles were formed on the surface of PUA coating at microscopic level after excimer and UV mercury lamp irradiation. The width and height of the wrinkles on the coating surface can be controlled to adjust the coating performance by changing the curing energy. When the PUA coating samples were cured by excimer lamp and UV mercury lamp with curing energy of 25-40 mJ/cm2 and 250-350 mJ/cm2, the excellent coating performances were observed. The gloss value of self-wrinkled PUA coating at 20° and 60° were less than 3 GU, while at 85° was 6.5 GU, which satisfied the demanding of matting coating. Besides, the fingerprints on the coating samples could disappear in 30s and could still have anti-fingerprint performance after 150 times of anti-fingerprint tests. Furthermore, the pencil hardness, abrasion quantity and adhesion of self-wrinkled PUA coating were 3H, 0.045g and 0 grade respectively. Finally, the self-wrinkled PUA coating has excellent skin-tactile feeling for touching. The coating can be applied to wood substrates and has potential application in the field of wood-based panels, furniture and leather.

Tuesday, July 2

STATE OF THE ART WOOD SCIENCE

Ilona Peszlen/Ruppert Wimmer (Co-Chairs)

Influence of particle size on thermal flow behavior of wood powder with sucrose and citric acid

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ABSTRACT

To optimize the wood particle size in a molding process, the influence of the particle size on the thermal flow behavior of wood powder with a natural binder was investigated by a capillary flow test. In addition, the strength of the material, which was extruded from the capillary, was evaluated by the shear test. The wood particle size was changed from 0.15 to 4.8 mm, and the capillary diameters were set to 1, 2, and 4 mm. The mixture of sucrose and citric acid was used as the natural binder. As a result, the powder successfully flowed under the condition that the particle size was 0.75 mm or larger when the capillary diameter was 2 and 4 mm, and the powder with the particle size of 2.4 mm had the lowest flow pressure. In the case that the particle size was 0.4 mm or smaller, the powder flowed slightly, but the flow pressure reached the limit of 200 MPa during the flow test due to low fluidity. In the case that the capillary diameter was 1 mm, the powder was difficult to flow. The shear strength of the material extruded from the capillary slightly decreased when the particle size was 2.4 mm of which the flow pressure was the lowest, while the influence of the capillary diameter was small. Based on these results, the appropriate particle size for the molding of the wood powder with the natural binder was considered.

Key words: Molding, Thermal flow, Natural binder, Powder, Particle size

Introduction

Development for naturally derived material processing technology has been demanded to prevent the mass disposal of petroleum-derived plastics. Wood is a naturally derived material, and the effective use of wood contributes to sustainable development. However, there are some problems with using wood as an industrial material. One problem is the poor processability of wood due to poor deformability and anisotropy. Therefore, it is difficult to form products of various shapes from wood. Wood is conventionally processed by cutting and bonding (Umemura 2020, Yang et al. 2023), but productivity and yield ratio are not good compared to those for plastics and metals. Wood plastic composite (WPC), which is processed by conventional plastic molding methods, has been developed (Wocott 2001, Eder and Carus 2013), but wood products without petroleum-derived plastic are desired for environmental protection. The use of bioplastic for the binder of WPC has been proposed (Csikós et al. 2015), but a large amount of energy is needed to produce bioplastic.

Authors propose molding wood powder with a natural binder, which is sucrose and citric acid, as an alternative to petroleum-derived plastics (Kajikawa et al. 2020, Goto et al. 2022). The wood powder with sucrose and citric acid fluidizes by heating and solidifies by cooling with the particles bonding together. Therefore, products with various shapes can be molded from wood powder by conventional plastic molding methods, such as injection molding and extrusion. In addition, the molded product has high strength and water resistance. The thermal fluidity of the material is important in molding because molding defects easily occur if the fluidity is too low. The influence of parameters, which are heating temperature, time, and mixing ratio of sucrose and citric acid, on the fluidity was investigated, and the appropriate conditions were clarified in our previous study.

On the other hand, no detailed investigation of the influence of wood particle size has been carried out. To reduce the energy for milling wood bulk into powder, particle size should be large. In addition, the strength of the molded product could be improved by using wood powder with large particles because the longer wood fibers remain. However, large particles could have a negative effect on the fluidity. In this study, the influence of the wood particle size on the fluidity of wood powder with the natural binder, which is composed of sucrose and citric acid, was investigated by the flow test using capillaries with various diameters. In addition, the strength of the extruded material from the capillary was evaluated by the shear test. From these results, appropriate wood particle size was considered.

Materials & Methods

Wood Powder and Binder

Wood powder with a natural binder was used in this experiment. The wood powder was obtained by milling Japanese cedar chips with a crusher (D3V-10, Osaka Chemical Co., Ltd., Osaka, Japan). The wood powder was sieved into various particle sizes as shown in Table 1. Seven sieves were stacked on top of each other when the wood powder was sieved. The particle size d_w was defined as the following equation.

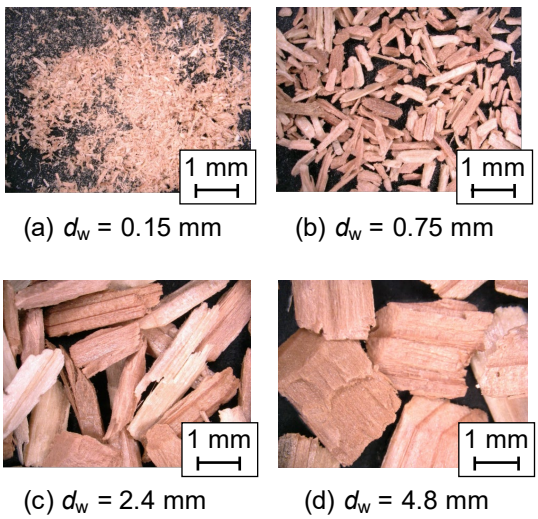
$$d_w = \frac{d_{w1} + d_{w2}}{2} \quad (1)$$

d_{w1} and d_{w2} are the size of the sieve openings through which the powder did not pass and the sieve openings through which it passed. A mixture of sucrose and citric acid, both of which were obtained from Nacalai Tesque, Inc. (Kyoto, Japan), was used as the natural binder. The mixture ratio of the sucrose and the citric acid was 75:25.

The wood powder and the binder were dehydrated in a drying oven (DK340S, Yamato Scientific Co., Ltd., Tokyo, Japan) at 80 °C for 24 h before combining the wood powder with the binder. The wood powder was combined with the natural binder by stirring it into an aqueous binder solution. The binder content *B*, which is the binder weight ratio in the mixture of the wood powder and the binder, was set at 30 wt%. The dried mixture of the wood powder and the binder, called WB powder in this paper, was obtained by dehydration in the drying oven at 80 °C for 48 h.

Table 1: Particle size

Particle size d_w / mm	Sieve opening	
	Mesh on d_{w1} / mm	Mesh pass d_{w2} / mm
0.15	0 (None)	0.3
0.4	0.3	0.5
0.75	0.5	1.0
1.5	1.0	2.0
2.4	2.0	2.8
3.4	2.8	4.0
4.8	4.0	5.6



(a) d_w = 0.15 mm (b) d_w = 0.75 mm

(c) d_w = 2.4 mm (d) d_w = 4.8 mm

Figure 1: Appearance of wood powder with various particle sizes d_w

Thermal Flow Test with Capillary

Figure 2 shows a schematic diagram of the flow test of the WB powder. In this test, a punch was pressed to flow the WB powder into the capillary, and the pressing load was measured during the punch pressing. The punch pressing was stopped when the punch position z_p, which is the distance between the punch and the capillary, was about 5 mm, or the punch surface pressure P reached 200 MPa, which was calculated from the load. Table 2 shows the conditions for the flow test. The capillary diameter was changed to 1, 2, and 4 mm.

The fluidity of the WB powder was evaluated from the possibility of the powder flow or the punch surface pressure P during the powder flow. The flow test was conducted three times for each condition, and the conditions of which the WB powder flowed three times were evaluated as "flowable". In the case that the WB powder flowed, the average punch surface pressure P_a at a steady-state range was calculated. The steady-state range was defined as the range of punch strokes from 5 to 15 mm from the start of the flow. The fluidity of the WB powder is high when P_a is low.

Shear Test of Material Extruded from Capillary

Figure 3 shows a schematic diagram of the shear test of the material extruded from the capillary. The extruded materials were conditioned at 60 %RH and 20 °C before the shear test. In this conditioning, the humidity was adjusted by the saturated salt method using sodium bromide and distilled water. In the shear test, the material, which was constrained by a jig, was sheared by punch pressing. The punch velocity was set at 10 mm/min. Shear strength τ was calculated by the following equation.

$$\tau = \frac{2F}{d_e^2 \pi} \tag{2}$$

F is the maximum load, and d_e is the diameter of the extruded material.

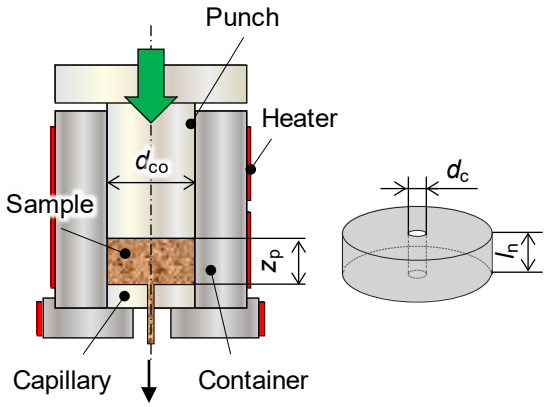


Figure 2. Schematic of flow test of wood powder

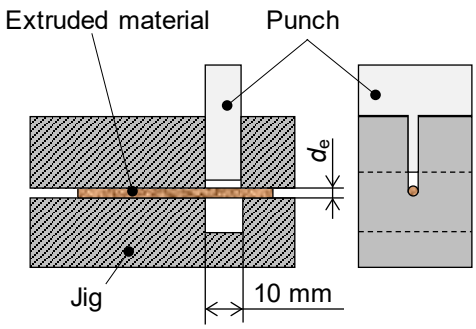


Figure 3. Schematic of shear test

Table 2: Flow test conditions

Inner diameter of container d_{co} / mm	10
Capillary diameter d_c / mm	1, 2, 4
Capillary length l_c / mm	10
Press velocity v_p / mm·s^{-1}	0.1
Temperature T / °C	160
Quantity of WB powder m / g	15
Mixture ratio of sucrose and citric acid S : C / wt%	75:25
Binder content B / wt %	30

Results and Discussion

Influence of Wood Particle Size on Fluidity

Figure 4 shows the typical appearance of the material extruded from the capillary and residual material in the container. In the case that the WB powder flowed, strand-like material was extruded from the capillary. In the case that WB powder did not flow, the material was not extruded from the capillary, and the residual compact remained in the container. Figure 5 shows the example of the change in the punch surface pressure P during the flow test in the case that the wood particle size d_w was 0.5 mm. P was small and constant at the beginning of the pressing, and then P increased drastically when the punch position z_p was around 40 mm for each capillary diameter d_c. P was small at the beginning of the pressing because the air in the powder was ejected, and P increased when the density of the powder became large. In the case that the WB powder was flowable, the powder started to flow during the increase in P, and then P was almost constant during the powder flow. However, in the case that

the fluidity of the WB powder was low, *P* reached the limit pressure of 200 MPa during the powder flow. This case was defined as “slightly flow”. In the case that the WB powder did not flow, *P* reached the limit pressure without flow.

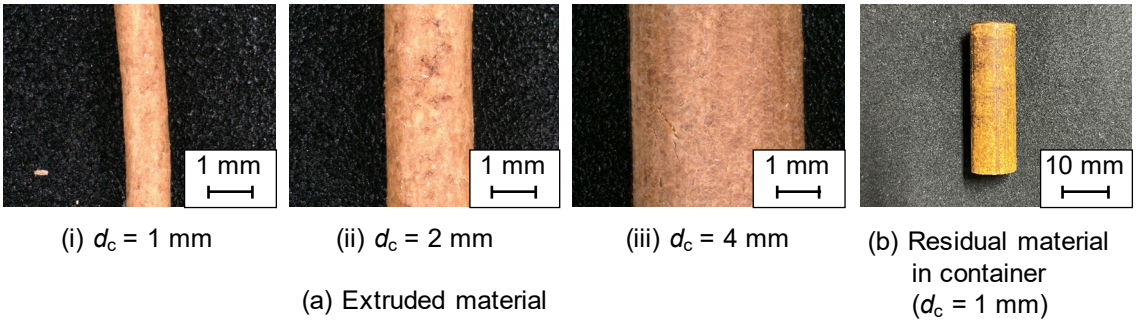


Figure 4. Appearance of extruded and residual material for each capillary diameter d_c (Wood particle size d_w = 0.4 mm)

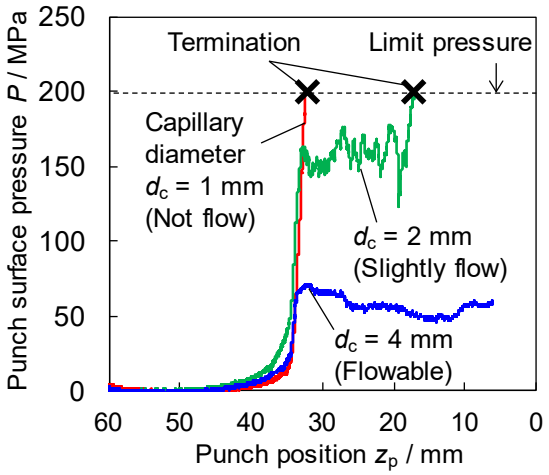


Figure 5. Punch surface pressure variations (Wood particle size d_w = 0.4 mm)

Figure 6 shows the influence of the particle size d_w and the capillary diameter d_c on the flowability. It was possible to flow under the conditions of large d_w and d_c. In the case of d_c = 2 and 4 mm, the WB powder flowed when d_w was 0.75 mm or larger, while the WB powder flowed slightly when d_w was 0.4 mm or smaller. On the other hand, in the case of d_c = 1 mm, the WB powder slightly flow when d_w was 0.15 mm, but the WB powder was difficult to flow when d_w was 0.4 mm or larger. Figure 7 shows the influence of the particle size d_w and the capillary diameter d_c on the average punch surface pressure P_a during flow to evaluate the fluidity for the condition of flowable.

P_a decreased with the increase in d_w, and then P_a was the smallest under the condition of d_w = 2.4 mm for each d_c. Therefore, the fluidity of the WB powder of d_w = 2.4 mm was the highest.

Based on the result of Figure 6 and 7, the influence of the particle size d_w on the fluidity was discussed. In the case that the capillary size d_c was 2 and 4 mm, the fluidity was low when d_w was small. This is because friction between the particles increased with the decrease in d_w as the contact area between the particles increased. The fluidity increased with the increase in d_w, but the fluidity slightly decreased with the increase in d_w when d_w was larger than 2.4 mm. This might be due to that particles need to be fractured in order to flow into the capillary when d_w is large. However, the result in d_c = 1 mm was different from that in d_c = 2 and 4 mm. In the case of d_c = 1 mm, the WB powder did not flow when d_w was 0.4 mm or larger. In these conditions, it could be difficult to fracture the particles because d_c was too small. The size of the wood tissue does not change with the size of the particles, which makes it difficult for the particles to fracture and flow into small capillaries. From these results, in the actual molding such as injection molding or extrusion, the particle size should be about 2.4 mm for improving the fluidity, while the particle size should be small if the mold size is very small.

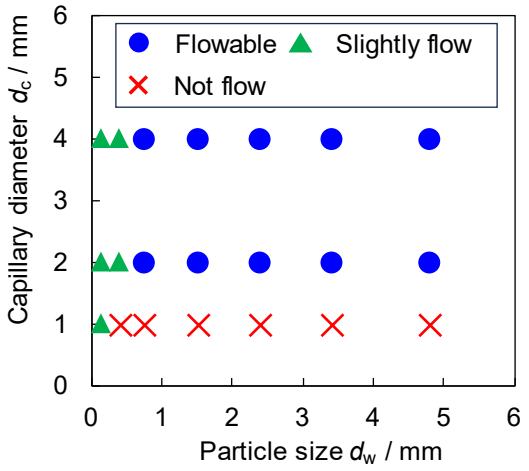


Figure 6. Influence of particle size d_w and capillary diameter d_c on flowability.

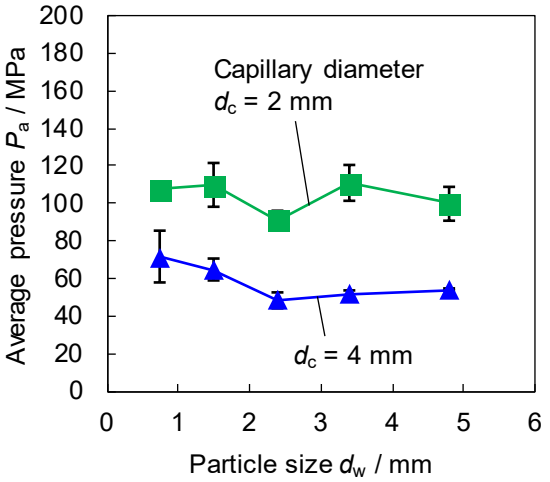


Figure 7. Influence of wood particle size d_w and capillary diameter d_c on average punch surface pressure P_a.

Influence of Wood Particle Size on Strength

Figure 8 shows the distribution of the shear strength τ of the extruded material. τ fluctuated, but the influence of the position l_w was small. Figure 9 shows the influence of the particle size d_w and the capillary diameter d_c on average shear strength τ_a. The influence of d_c was small. On the other hand, τ was the lowest when d_w was 2.4 mm for each d_c. The average punch surface pressure P_a in the flow test was also the lowest when d_w was 2.4 mm as shown in Figure 7. Therefore, P_a might affect τ. τ could be large when P_a was large because the WB powder was compacted under high pressure. To increase the strength of the product in extrusion molding, the pressure should be high by controlling any parameters such as the particle size or the mold temperature.

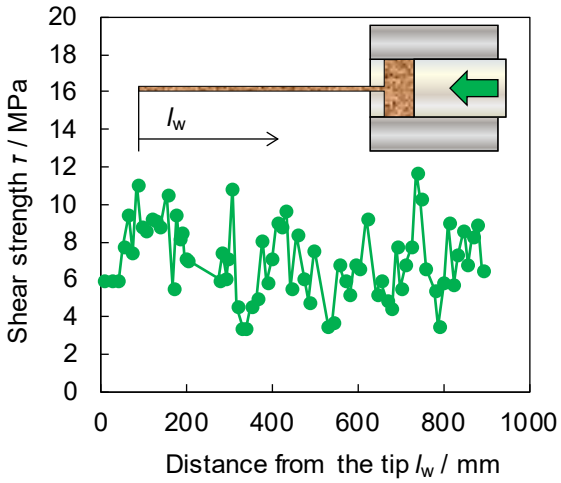


Figure 8. Distribution of shear strength τ in extruded material (Wood particle size d_w = 2.4 mm, capillary diameter d_c = 2 mm)

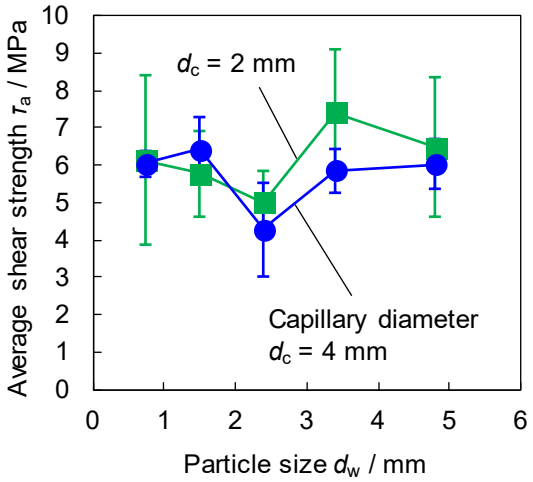


Figure 9. Influence of particle size d_w and capillary diameter d_c on shear strength τ.

Conclusions

The influence of the wood particle size on the fluidity of the wood powder with the sucrose and the citric acid, which was called WB powder in this study, was investigated by the capillary flow test. The wood powders with seven different particle sizes d_w, which were 0.15, 0.4, 0.75, 1.5, 2.4, 3.4, and 4.8 mm, were used. The capillary diameters d_c were 1, 2, and 4 mm. As a result, the fluidity of the WB powder was the highest under the condition of d_w = 2.4 mm in the case that d_c was 2 and 4 mm. The WB powder became more difficult to flow when d_w was too small due to the increase in the friction between the particles, while the flow pressure increased to crash the particles when d_w was too large. The WB powder was difficult to flow in the

case of d_c = 1 mm. The shear strength τ of the material extruded from the capillary slightly decreased under the condition of d_w = 2.4 mm of which the flow pressure was the smallest. These results suggest that d_w of 2.4 mm is recommended to improve fluidity, while higher pressure loading is important to improve strength.

Acknowledgements

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Fungal competition in thermally modified Scots pine wood as related to chemical composition changes

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ABSTRACT

After thermal modification, the chemical composition of wood undergoes significant changes, thus affecting the competitive environment for decay fungi and ultimately the decay resistance of the thermally-modified wood (TMW). This study focused on untreated, 180°C, and 210°C steam protected heat treated Scots pine (*Pinus sylvestris*) sapwood. The wood specimens were subjected to laboratory decay tests according to the standard method described in AWPA E10-12, with the white rot fungus *Trametes versicolor* (Tv) and the brown rot fungus *Gloeophyllum trabeum* (Gt) as test fungi. The study compared the mass loss, chemical composition, and microstructure changes of wood under single-fungus colonization (Tv, Gt) and dual-fungus colonization (Tv-Gt, Gt-Tv). The total duration of fungal colonization is 12 weeks, including 4 weeks of precolonization followed by 8 weeks of fungal incubation. Additionally, ground wood powder from TMW was mixed into the PDA culture medium for both single- and dual-fungal cultures to monitor the time-dependent changes in laccase enzyme activity. The results showed that on untreated wood control, Tv and Gt exhibited a deadlock state or Gt domination, on 180°C TMW Gt mostly replaced Tv, while on 210°C TMW Tv replaced Gt in adverse. This was attributed to the extensive degradation of holocellulose (especially hemicelluloses) and subsequent re-aggregation into pseudo lignin in the wood heat-treated at 210°C. Pseudo lignin had a significant inhibitory effect on Gt, while its inhibitory effect on Tv was relatively weak. The changes in the chemical composition of TMW also induced different fungal competition mechanisms. Under dual-fungus conditions, the laccase activity secreted by Tv was higher than that of Tv under single-fungus conditions. For untreated wood, laccase activity peaked in the early stage of colonization and then rapidly decreased, while in TMW, the peak appeared more delayed and remained relatively high in the later stages. This study fully demonstrates that the changes in the chemical composition of TMW, particularly the generation of pseudo-lignin, play a decisive role in the competition mechanism and ultimate results of fungal decay.

KEYWORDS: wood, thermal modification, chemical component, fungal competition, pseudo lignin

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Dimensional stability and wettability of Samama wood after boron and citric acid impregnation, and heat treatment

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ABSTRACT

This research aims to address the leaching phenomenon of boron preservatives in wood after exposure to high humidity. The subsequent investigation focuses on the dimensional stabilization and surface wettability of wood after a two-stage impregnation process. Samama wood (*Anthocephallus macrophyllus*) is impregnated with boron (boric acid, borax, and a combination of both) at a pressure of 7 atm for 4 hours, with each preservative's concentration set at 5%. After oven drying at 60 °C until achieving a 15% moisture content, the next step involves a second-stage impregnation with citric acid (at a 5% concentration) under the same pressure and duration. The final step includes heat treatment at temperatures of 80 °C and 160 °C for 4 hours. Tests are conducted for density, water absorption, volume expansion, anti-swelling efficiency, shrinkage (tangential and radial), wettability, surface roughness, and the leaching of boron compounds. The research results indicate that boron compounds and citric acid tend to enhance the density and dimensional stabilization of Samama wood. Heating at 160° C exhibits a similar phenomenon regarding the dimensional stabilization of Samama wood. The treatment yielding the best dimensional stabilization is ABS 160 (a combination of boric acid, borax, citric acid, and HT 160 °C). This study confirms that citric acid improves the dimensional stabilization of Samama wood, whether used with boron or not. The two-stage impregnation reduces boron leaching by up to 30% compared to treatments without citric acid and heating. The research also recommends that all treatments exhibit good finishing properties based on indicators of wettability and surface roughness changes.

Keywords: Boron, Citric Acid, Impregnation, Samama, Dimension Stabilization, Leaching, wettability

Numerical modal analysis of CLT with imperfections in the adhesive bondline

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ABSTRACT

The vibration behavior of CLT panel also depends on the quality and amount of bondlines between boards within the layer and between layers. Imperfections in bonding in CLT panel may occur during manufacturing or in service due to mechanical or environmental loads. The goal of the paper was to examine the effect of missing bondlines on modal characteristics of a CLT panel (approx. 80 x 80 cm). Modal characteristics consisted of natural frequencies at which the CLT panel would resonating and the analysis showed the change or shift of those frequencies due to imperfections. The most important natural frequencies will be revealed using a participation factor perspective. There will be various imperfections defined in numerical model of CLT – missing glue in the center and at the edges of the panel. The boards will be glued edgewise within the layer. The CLT panel is to be modeled as a solid volume with orthotropic elastic material. Adhesive bondlines will be infinitely thin and modeled as a perfect connection between the bonded elements. Imperfection will be modeled by a not merging mesh nodes of the same coordinates in adjacent layers. The analysis is carried out using the finite element method in the software Ansys v22R2. Last, comparison with an experimental modal analysis will be carried out for preliminary validation of FE model.

Macroarray for genetic wood identification of trade-relevant tropical CITES timber species

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ABSTRACT

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regulates the trade in vulnerable animals and plants. Endangered species also comprise important commercial timbers which are protected according to CITES guidelines. For the implementation of the conservation regulations, a reliable species identification is essential. However, the control authorities of timber trade lack quick and easy methods to verify the legality of the traded product. This includes the clear identification of the timber species.

In this study, a simple genetic method, the macroarray technique, was modified and optimised for the identification of CITES protected commercial tree species originated in the tropics and their look-alikes. This methodical approach is intended to complement the existing genetic methods and thus improve the effectiveness of controls. In detail, the following six commercial assortments of CITES-protected timber species and their look-alikes were selected and investigated: True Mahogany, Cedro, Bubinga, *Pterocarpus* species, Ramin and Guaiacum Wood. The ITS (internal transcribed spacer) was used as barcode region. Specific probes were designed and tested using this barcode. The results reveal that 61 of these probes are suitable for identification purposes. Hence, 32 of the 50 investigated species can be clearly identified using the developed macroarray. Additional 15 species are represented by probes in groups of two to three species, which enables a delimitation of the species present.

The advantages of the studied macroarray approach offers, (i) parallel analysis of several species, (ii) omission of a DNA sequencing and (iii) application of the technique without prior knowledge of the taxa. Furthermore, the developed test provides a potential of time and cost savings compared to current established methods. In summary, the results reveal that the developed rapid test can contribute to combat illegal timber trade due to its efficient and practical applicability.

Sensory characterization and identification of odorants in birch wood (*Betula pendula* Roth)

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ABSTRACT

As one of the most common tree species, birch wood (*Betula pendula* Roth) is widely used as a material for furniture and decoration indoors for its many excellent characteristics. Whereas there are some studies on the volatile composition of the essential oil from the leaves of *Betula pendula* Roth, only limited information is available on the odor-active constituents of birch wood. To close this gap, the odorants of birch wood were investigated by means of instrumental and sensory analyses, including techniques such as gas chromatography-flame ionization detection/olfactometry, high-resolution gas chromatography-mass spectrometry, and heart-cut two-dimensional high-resolution gas chromatography-mass spectrometry/olfactometry. Overall, a total of 20 odorants were (tentatively) identified on the basis of their respective odor qualities and retention indices and mass spectra by comparison with reference compounds. Birch wood odor was dominated by a series of terpenes, terpenoids and phenyl compounds originating from the degradation of lignin and aldehydes, ketones and acids originating from fatty acid degradation. Sensory evaluation of the birch wood determine that the predominant odor attributes were earthy, pencil-like, corky/mouldy, grassy, fatty, fruity, green tea-like, herb-like, vanilla-like, and vinegar-like.

Long term performance of external barriers for minimising preservative migration and limiting fungal attack

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ABSTRACT

Wood is among our durable lignocellulosic materials but is susceptible to biodegradation under the proper environmental conditions. Durability can be enhanced by supplemental biocide treatments or by modifying the wood chemistry to render it less susceptible to enzymatic degradation. Some users object to the use of preservatives because of the risk of post-treatment migration into the surrounding environment. Barriers have the potential to reduce this risk while possibly prolonging service life. An effective barrier should reduce moisture uptake, minimise preservative migration, and minimise contact with degrading organisms in the surrounding soil. Barriers have long been used with mixed results. For example, concrete has often been used to as a remedial treatment for repairing marine pilings. The concrete effectively prevents renewed attack while simultaneously depriving any marine borers already in the wood of the oxygen required to survive. This process is cumbersome and rarely used. However, there are several potential barriers that could help improve performance including plastic wraps and flexible polymers. Assessing the ability of these systems to prolong the service life of preservative treated wood requires extremely long-term testing since an effective preservative alone should provide 30 or more years of service under most exposures. However, it is possible to assess some attributes of barriers through shorter term tests that evaluate the ability of the systems to minimise preservative migration or alter the wood moisture content of timbers below ground.

The potential benefits of using barriers were assessed in a series of tests including long-term field tests and short-term leaching exposures.

Chromated copper arsenate (CCA) treated and untreated spruce/pine/fir posts (~100 mm in diameter) treated to a ground contact retention of 4 kg/m 3 were installed near Corvallis, Oregon with or without plastic barriers and assessed periodically for condition. Untreated, wrapped posts failed at the top of the barrier within 5 years of installation, while none of the CCA treated posts have failed in the 15 years after installation.

Douglas-fir crossarms with or without pentachlorophenol (penta) treatment were exposed above ground at a site near Hilo, Hawaii with or without a polyurea spray coating. Untreated sections without coatings rapidly decayed, while non-coated penta-treated samples were weathered but sound. Coated penta-treated samples were also sound, while the coatings on untreated sections were heavily degraded by ultra-violet light and suffered considerable internal decay after 152 months of exposure. The oils used to deliver penta treatment appeared to provide UV protection for the coatings. The results highlighted the need for some supplemental preservative treatment when barriers were used.

Immersion of polyurea coated ammoniacal copper zinc arsenate (ACZA) treated Douglas-fir piling in salt water showed that the barriers completely inhibited metal migration. The presence of small areas of damage to the same piling resulted in metal migration illustrating the need for coating maintenance. Preservative loss to seawater increased in proportion to the amount of damage to the pilings.

Measurement and simulation of moisture transport in wood during isothermal drying

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ABSTRACT

Moisture control strategies for wood-based building materials are key to extend their service life, minimize their environmental impact, and maximize their carbon benefit. Hygrothermal simulations—emerging design tools for analyzing heat and moisture transfer in building envelopes—were developed for brick and stone based materials where water does not chemically interact with the material or change its structure. They are therefore relatively unreliable for predicting liquid and vapor transport in wood. We have recently developed an improved engineering model for water absorption in softwoods, which we extend in this work to model moisture transport during drying. Vacuum-saturated southern yellow pine specimens in each of the three anatomical directions (longitudinal, radial, and tangential) are placed in a custom, relative humidity-controlled chamber where their moisture change is continuously measured as a function of time. Simulations with default database inputs for liquid transport significantly underpredict the rate of drying when compared with experimental observations. Optimizing liquid diffusivity using our physics-based model for water absorption, however, results in a good agreement between the measured and model-predicted average moisture content of the drying specimens. Through discussions on the critical role material property inputs and model assumptions play in simulations of moisture transport in wood, we also demonstrate how wood science improves the accuracy of hygrothermal simulations and has the potential to inform building science in general.

NOVEL APPLICATIONS OF WOOD IN THE BUILT ENVIRONMENT

Bohumil Kasal/Levente Denes (Co-Chairs)

Preparation of strong and thermally conductive spider-silk-inspired soybean-protein-based adhesive for thermally conductive wood-based composites

Qiang Gao[1]

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ABSTRACT

The development of formaldehyde-free functional wood composite materials through the preparation of strong and multifunctional soybean protein adhesives to replace formaldehyde-based resins is an important research area. However, ensuring the bonding performance of soybean protein adhesive while simultaneously developing thermally conductive adhesive and its corresponding wood composites is challenging. Taking inspiration from the microphase separation structure of spider silk, boron nitride (BN) and soy protein isolate (SPI) were mixed by ball milling to obtain a BN@SPI matrix, combined with the self-synthesized hyperbranched reactive substrates as amorphous region reinforcer, and crosslinker triglycidylamine to prepare strong and thermal conductivity soybean protein adhesive with crosslinked microphase separation structure. These findings indicated that mechanical ball milling can be employed to strip BN followed by combination with SPI, resulting in a tight bonded interface connection. Subsequently, the adhesive's dry and wet shear strengths increased by 14.3% and 90.5% to 1.83 and 1.05 MPa, respectively. The resultant adhesive also possessed good thermal conductivity (0.363 W/mK). Impressively, because hot-pressing helps the resultant adhesive to establish a thermal conduction pathway, the thermal conductivity of the resulting wood-based composite was 10 times higher than that of the SPI adhesive, which showed a thermal conductivity similar to that of ceramic tile and had excellent potential for developing biothermal conductivity materials, geothermal floors, and energy storage materials. Moreover, the adhesive possessed effective flame retardancy (limit oxygen index= 36.5%) and mildew resistance (> 50 days). This bionic design represents an efficient technique for developing multifunctional biomass adhesives and composites.

Keywords: Soybean protein adhesive, boron nitride, bionic structure, wood-based composites, thermal conductivity.

Experimental evaluation of phase change material-impregnated wood for thermal management in lightweight building structures

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ABSTRACT

The integration of phase change materials (PCMs) into lightweight construction is a promising way to improve energy efficiency and sustainability. PCMs undergo transitions between solid and liquid states, thereby absorbing and releasing heat energy within specific temperature ranges without undergoing substantial temperature changes. Utilising their high specific heat capacity with minimal additional mass and volume, PCMs offer potential solutions to mitigate temperature fluctuations that are often present in lightweight timber structures. This research investigates the efficiency of incorporating PCMs into wood to reduce winter heating demand and overcome summer overheating, providing valuable insights for both new construction and retrofitting applications to achieve energy efficient buildings.

Two experimental houses were constructed for comparative analysis: one as a reference and the other featuring interior walls and floors clad with wood impregnated with bio-based PCMs. The impregnated wood particle composite was used for the walls and a three-layer parquet floor with a PCM impregnated middle layer. These houses, equipped with temperature sensors, controllable ventilation systems and heating units, were exposed to the outdoor environment of a four-season humid continental climate zone in Kuchl, Austria, for one year. Each test house, with an internal volume of 1 m^3, was constructed of wood-based materials and double-glazed window. Electric heater regulated internal temperatures during colder months, while natural ventilation was used to remove heat at night during warmer periods.

The study focused on selected weeks representing winter and summer conditions to reflect the impact of PCM integration on indoor temperature management. The results suggest that incorporating PCMs into wood has the potential to reduce summer overheating and decrease electricity consumption for heating. Furthermore, the study highlights the importance of PCM melting point in determining performance outcomes. This research contributes to the refinement of building design strategies and highlights the challenges associated with the efficient use of PCM-impregnated wood for energy storage in building applications.

Hybrid GLULAM made of beech and spruce wood bonded with MUF and PUR adhesives

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ABSTRACT

Most adhesive systems for the production of glued laminated timber (GLULAM) are designed for softwoods (conifers), which can make them unsuitable for bonding hardwoods (deciduous). Most problems occur in delamination tests due to the high modulus of elasticity of wood and unfavourable shrinking and swelling. The aim of this study was to determine the bonding performance of commonly used MUF and PUR adhesives in the production of spruce GLULAM when applied to GLULAM made of beech or hybrid GLULAM made of beech and spruce. The experimental part was divided into two sections. In the first part, beech lamellas were bonded with MUF, PUR and PUR in combination with a primer to form a GLULAM. In the second part, hybrid GLULAMs made of beech and spruce were bonded using the same adhesives. To test the adhesives, small beams with five 20 mm thick lamellas were produced. The two outer lamellas were made of beech wood, while the three inner ones were made of spruce wood. For beech GLULAM only, all adhesive bonds were found to have a much higher shear strength (about 14 MPa) than required by the EN 14080:2013 standard. All adhesive bonds in a hybrid GLULAM made of beech and spruce also met the requirements, but the shear strength was lower (about 10 MPa). Adhesive bonds between spruce and beech achieved slightly higher average strength values than adhesive bonds between spruce only. The highest shear strengths were achieved with PUR adhesives in combination with a primer, followed by MUF and PUR adhesives without primer. The results show that beech and spruce wood can be successfully bonded to form a hybrid beam using MUF and PUR adhesives. The adhesive bonds between beech and spruce wood show effective adhesive performance and fulfil the standard requirements.

Key Words: Adhesives, Beech, Glulam, MUF, PUR, Shear Strength, Spruce, Wood

A bio-based solution to glue solid wood: Starch-tannin adhesives

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ABSTRACT

Bio-based solutions for solid timber gluing have always been a very sensitive topic in wood technology. In the past, their limited performance forced carpenters to prefer mechanic binders such nails and screws, but in the XXI century many synthetic resins were discovered and then massively used in the whole timber industry compartment.

The goal of our century is to find ecologic alternatives to the synthetic adhesives using more sustainable natural products. Attractive solutions were proposed for pressed composites such as particle- or fiberboards in the last decades, but less fortune was registered in solid-wood gluing.

In this work we adapted a starch-tannin formulation from the literature and optimized the gluing conditions allowing high performance in dry conditions and also resistance to 3 hours water dipping thereby achieving the requirements for D2 classification according to the EN204.

Diluted starch-tannin formulations enhanced their performance by increasing the heating temperature as well as the heating time, obtaining satisfactory results at 140°C for 13 minutes. The proportions of condensed and hydrolysable tannins in the mixture enhanced the water resistance but was effective only up to 20-30%. Although the presence of contained amounts of hexamine did not markedly modify the performance, this small improvement was important for reaching the commercial standard D2, while formulations with condensed tannins without hardeners were sufficient in dry environment formulations.

Thermomechanical and chemical analyses were performed on the more successful resins to understand the mechanism of crosslinking. The presence of tannin enhanced the curing rate in particular when condensed tannin were applied, while the solid state 13C-NMR was used to understand the chemical interactions between the two bioresources.

This study highlights the importance of the equilibrium between starch denaturation and polyphenol crosslinking and sheds light on the synergy between starch and polyphenols. Despite the encouraging results obtained, several further analyses should be done in order to reduce the variability and to obtaining homogeneous formulations for commercialization.

Key Words: Starch-based adhesives, tannin resins, solid wood gluing, bio-polymers, water-resisting formulations

Sustainable bus shelter

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ABSTRACT

Using cross-laminated timber (CLT) for bus shelters is a sustainable and innovative approach to architecture in the transportation industry. This modern design uses engineered wood products, offering economic and environmental benefits, structural integrity, and a unique look. CLT in transportation stations can give a modern and distinctive look while promoting sustainable building practices and reducing our carbon footprint. The shift towards reintroducing engineered wood products in the built environment is significant because steel and concrete have dominated the construction industry for over a century. Steel and glass shelters were popular in the 90s and early 2000s, but today's focus on sustainability and environmental consciousness has changed the ideal city's perception.

The Raleigh transit system plans to establish a new bus shelter made of CLT, pending approval. This shelter will be the first of its kind, and we want to encourage its adoption. We will provide workshops, webinars, and a project website with information on sustainability, materials, and expansion to other towns and cities to achieve this. The shelter may also cover bicycles, public bench areas, and cluster box unit (CBU) mailboxes. The shelter meets the requirements for new construction and offers a long-term opportunity to replace steel structures with wood.

The modular design of the proposed shelter is an innovative solution that can be easily assembled from its readily available components. Moreover, the shelter's highly adaptable design can be customized for various public-covered needs. Bus shelters can improve access to transportation, providing a safe and comfortable place to wait for buses and increasing the chances of reaching destinations even during adverse weather conditions. By modernizing public infrastructure, we can enhance the overall quality of life in the area, bringing much-needed relief to people who have long been underserved.

This flexibility makes it a perfect stimulus for the growth of regional wood products businesses. Engineered wood products are the ideal materials for such projects. Building the shelter, however, comes with various challenges and difficulties. Fortunately, the interest and commitment of stakeholders have shown that a market exists. Our challenge now is to expand that market, ensuring that all communities can benefit from the latest advancements in transportation infrastructure. This project chronicles the endeavors of three university professors who, through their joint expertise, conceptualized and designed a simple yet practical bus shelter. The team worked closely with diverse stakeholders to ensure the vision reflected the initial conception. The shelter's development involved an iterative process, with the team refining their design to incorporate feedback from stakeholders and industry experts. This project highlights the significance of collaboration, innovation, and stakeholder engagement in achieving a successful outcome.

Natural Fiber-based prepregs for thermoforming composite laminates

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ABSTRACT

The advancement in bio-degradable and renewable prepregs for various thermoforming applications is critical to reduce the excessive amount of carbon footprint generated by the commonly used synthetic fibers. Based on experience from fabricating wood-strand based prepreg and thermoforming them into laminates and structures with large curvatures, a non-woven sisal fiber mat was similarly utilized to fabricate prepregs using vacuum assisted resin transfer molding. A low-viscosity liquid thermoplastic resin was utilized for the infusion process. The acquired non-woven mats were partially consolidated to make a porous media for resin infusion. The SEM analysis showed excellent resin encapsulation and some penetration in the fibers, providing an excellent mechanical interlock and good fiber-matrix interaction. The individual prepregs were tested for their tensile strengths and moduli according to ASTM D1037 Standard, to compare the results with that of the wood-strand based prepregs.

Subsequently, flat laminates were produced via thermoforming the prepregs at previously established conditions of 180°C and 830 kPa, for 25 minutes. A stable layup with 5-ply was thermoformed into the desired laminates. The preforms being non-woven, the fiber orientation was random, therefore, the prepregs were assumed to be isotropic in nature resulting in isotropic laminates. The Young's modulus and tensile strength of the laminates were further tested and compared to established natural fiber-based composite panels from the literature and to those laminates thermoformed from wood-strand based natural fiber prepregs developed previously by the group. Preliminary work on thermoforming profiled composite laminates demonstrated that the sisal fiber prepregs have the potential to be a substitute for synthetic fiber prepregs while being able to be thermoformed to complex shapes.

This presentation will outline the process of manufacturing the prepregs and the composite laminates and discuss the results of their mechanical and physical properties. Results of this study further emphasize the argument to use renewable fibers to manufacture bio-based composite products in nontraditional markets.

Keywords: Natural Fiber Composite, Sisal Fiber, Liquid thermoplastic resin, Vacuum assisted resin transfer molding, Thermoforming, Natural fiber panels, Sustainable structures, Recyclable materials

Estimating grain angle of thin beech veneer by means of sound transmission speed

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ABSTRACT

Wood, with its good specific mechanical properties and low environmental impact offers a high potential for environmentally friendly lightweight constructions in fields such as mechanical and automotive engineering. Load-optimized components can be manufactured by stacking several layers of differently orientated sheets of thin wood veneer. If the properties of each veneer layer are known, parts can be manufactured with reproducible mechanical behaviour. Therefore, the need for reliable, non-destructive, and efficient ways to characterise these veneers arises. Of special interest is the measurement of the fibre angle, as it has a very strong influence on the mechanical properties of the veneer.

Measuring the sound transmission speed is a well-studied method to non-destructively characterise wood and is known to be strongly influenced by its fibre angle relative to the direction of the wave propagation. This enables the opportunity to use the sound transmission speed to predict the fibre angle of wood fast and non-destructively.

This study aims to answer the question whether it is feasible to predict the fibre deviation angle of thin beech veneer by measuring the transmission speed of an impact induced sound wave.

Therefore, 327 samples of conventionally sliced 0,9 mm thick beech veneer from a total of 12 different trees with varying fibre angle were prepared and investigated. The fibre orientation of the veneer surface was determined using an incident light microscope, resulting in obtained values between 0 and 32,4 degrees.

The sound transmission speed of each specimen was then measured with a portable stress wave timer (Metriguard 239A) by a pendulum induced pulse.

A strong correlation between the sound transmission speed and the measured fibre angle was observed. This relationship can be described well with Hankinson's equation.

Based on Hankinson's equation, a model was derived to predict the fibre angle. This model was then validated with 22 independent samples from different trees that were measured in the same manner. The results show a well performing model and demonstrate the feasibility of using the sound transmission speed to predict the fibre deviation angle of thin beech veneer.

Connection performance of new mass timber panels fabricated from low-quality small diameter trees

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ABSTRACT

One of the drivers for mass timber innovation in the United States is fuel reduction programs to limit wildfire intensity. Low-quality small diameter trees (SDTs) form an abundant resource in all the forests of the country, which needs a proven technique that can help develop a market for their use. SDTs were widely used in paper mills, but with a struggling paper industry, there is an urgent need to find innovative uses for them that can help make value-added products from low-quality feedstock. An innovative approach is to strand the SDTs, allowing for high fiber recovery. This fiber can then be used to create thin wood-strand composite panels or strand veneers, that can be further processed to produce laminated strand veneer lumber (LSVL). The wood strand composites use both primary (creating LSVLs) and secondary (creating cross laminated strand veneer lumbers) lay-up processes to create large-scale panels that are comparable to oriented strand lumber (OSL) and cross laminated timber (CLT). This expands the possibilities for strand-based products from SDTs to compete with lumber and veneer-based mass timber panels, such as OSLs, CLTs, and mass ply panels.

Connection design in mass timber panels is very important due to the panels' large size and stiffness. As such, it is vital to understand the connection performance of these LSVLs and cross laminated strand veneer lumbers (CLSVLs) to allow designers and practitioners to utilize them. An experimental investigation was done to characterize the connection performance of the LSVLs and CLSVLS produced at WSU, looking primarily at four different characteristics: nail withdrawal, screw withdrawal, dowel bearing strength, and single-dowel lateral resistance. All four characteristics were evaluated for different panel configurations, which also included LSVLs and CLSVLs made from thermally modified strands. The results are compared both between configurations and with existing empirical models to allow comparison with existing mass timber and wood-based structural panels.

This presentation will outline the basic process of manufacturing the mass timber panels, along with the results, comparisons, and recommendations based on the detailed connection study. The results of this study further emphasize the argument for producing value-added products from the abundant bio-mass in the form of low-quality small diameter timbers for structural applications.

Keywords: Cross-laminated timber (CLT), small-diameter trees (SDT), wood strand composite panels, thermal modification, wood strands, mass timber panels, nail withdrawal, screw withdrawal, dowel bearing, lateral resistance

THE SIGNIFICANCE OF BASIC WOOD SCIENCE IN A SUSTAINABLE WORLD

Special Session: International Academy of Wood Science, Rupert Wimmer, Chair

Academy Lecture

Wood materials - potentials and limitations. Ingo Burgert, ETH, Zurich, Switzerland

Wood anatomy and dendrochronology - a long tradition and current challenges. Katarina Ćufar, University of Ljubljana, Ljubljana, Slovenia

Materials from renewable resources- great future or just modern trend? Are they really sustainable? Bohumil Kasal, Fraunhofer WKI, Braunschweig, Germany

The dimensional instability of wood- a new look at an old problem. Markus Rűggeberg, Technical University of Munich, Munich Germany

Swelling of wood cell wall-in 3D at high resolution. Andreas Krause, Thünen Institute, Braunschweig, Germany

Aging of wood as a construction material measured by atomic force microscopy. Juan Li, Fraunhofer WKI, Braunschweig, Germany

Abstracts Not Available

POSTER SESSION AND STUDENT POSTER COMPETITION

Levente Denes, Chair

Anna Sandak, Matthew Schwarzkopf (Judges)

Quantifying olive leaf pruning waste

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ABSTRACT

Precision agriculture benefits current agrarian activities and opens the door to novel opportunities. In this context, olive leaves have proven to be an excellent feedstock for biorefining and the production of valuable extractives (Romero et al., 2014; Clodoveo et al., 2022). Waste olive leaves are produced in large quantities during the harvesting and pruning seasons. However, estimating the available quantities of foliage for downstream conversion is challenging. Assessing the biomass quantity produced during the pruning operations of olive trees is crucial for efficient agricultural management and sustainability practices. Although conventional methods of biomass quantification are effective, they often require labor-intensive procedures. This study aims to evaluate alternative solutions for estimating the mass of pruned leaves by testing dendrometry, photogrammetry, LIDAR scanning, direct branch mass weighing, and iPhone 3D scanning. These are combined with custom-made 3D modeling software tools for point cloud analysis.

Dendrometry, photogrammetry, and laser scanning technologies enhance biomass assessments by generating digital representations of olive trees. These methods can capture intricate details of branch and foliage density, crucial for accurate biomass estimation. Weighing the pruned branch mass and measuring the branch diameter are direct methods that provide excellent accuracy. Nevertheless, the scalability of these methods is limited due to their labor-intensive nature. Laser scanning, photogrammetry, and iPhone 3D scanners are the proposed solutions for overcoming this limitation. These techniques utilize advanced sensors and offer a practical solution for farmers to capture 3D models. The modeling software integrates point cloud data, providing a comprehensive digital representation of the tree or biomass form. This approach offers realistic insights into the spatial distribution of leaves and enables precise volume assessments. It is necessary to define the foliage density ratios to link biomass volumes with leaf mass. As all the presented technologies become more accessible, the potential for their adoption in agricultural contexts presents a promising opportunity for enhancing productivity and sustainability in olive cultivation.

Early identification of moisture changes in building envelopes through time-series anomaly detection

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ABSTRACT

The InnoRenew CoE building in Izola, Slovenia is outfitted with temperature, relative humidity, and wood moisture content sensors throughout the building's envelop and in areas that are at high risk of moisture-related damage (i.e., around bathrooms, sinks). The data collected from these sensors is helpful in assessing the performance moisture prevention measures in the envelop. The data can also be used to identify wet spots for potential remediation efforts and to assess the efficacy of those efforts. However, without a way to identify problematic moisture events before they reach a threshold, interventions are reactionary rather than preventative. Time-series anomaly detection methods allow us to identify problematic trends in the data before conventional thresholds are crossed, providing an early warning system that allows for preventative measures. Time-series data differ from other data in that must have a time element that is presented in chronological order, which would introduce an autocorrelation problem in analysing the data using non-specialised methods. Anomaly detection in time-series data generally takes one of three approaches: outlier identification, change-point identification, and anomalous time-series, which may be implemented in univariate or multivariate domains. Multiple methods for implementing these approaches were compared to identify the most suitable approach for the building envelope moisture monitoring use case.

Key words: wood moisture content, building performance, façades, prevention, maintenance

Revolutionizing sustainable construction: The 3DP Biowalls project approach to resource efficiency and circular economy

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ABSTRACT

Various strategies exist to achieve resource-efficient construction: selecting suitable materials, optimizing structural designs, and enhancing production processes. Building structures are notorious for consuming vast quantities of raw materials and generating significant amounts of solid waste. Consequently, enhancing material efficiency and recycling practices has become a critical challenge. Sustainable construction is attainable using bio-based, carbon-storing materials like wood. However, the often-scarce availability of wood resources, coupled with inefficient processing, leads to suboptimal raw material utilization.

The 3DP Biowalls project innovatively employs additive manufacturing (3D printing) with renewable raw materials to fabricate fully recyclable wall structures. It tackles four critical issues: the global scarcity of raw materials, the prevalent dependence on inorganic construction materials such as concrete and steel, the inefficient use and recycling of renewable resources, and the construction industry's low productivity levels.

The presented research is on the development of material recipes suitable for big-scale 3D printing. The used raw materials are fully bio-based, ideally utilizing industrial by-products. Data show the suitability for robotic-assisted additive manufacturing, optimized for building wall components. These innovations aim to drastically improve the use of raw wood in construction materials, targeting a utilization rate of over 90%, a significant leap from the traditional 40-60%.

Expected outcomes from the project include innovative approaches that significantly advance both the theoretical understanding and practical application of circular economy principles in construction, setting new benchmarks for sustainable building practices.

Key words: resource efficiency, sustainable construction, additive manufacturing, circular economy, raw materials

Near infrared spectroscopy can be an effective tool to control logging and trade of Malagasy rosewood, palisander and ebony woods

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ABSTRACT

Madagascar is among the countries that are source of ebony (*Diospyros*), rosewood and palisanders (*Dalbergia*) wood resources, which largely supply the international timber market. Of the 83 *Dalbergia* and 285 *Diospyros* species found in Madagascar, 55 and 88 respectively are large trees, most are threatened by illegal logging. Establishing sustainable management of these resources requires accurate species identification throughout the supply chain. This poses a significant challenge in tropical countries such as Madagascar. Identifying felled logs as well as processed timber is very difficult due to the similar wood anatomy of several species within both genera. Therefore, this study aimed to assess the potential of near-infrared (NIR) spectroscopy associated with core sampling, which is an easy-to-use and non-destructive method, to discriminate 38 Malagasy *Dalbergia* and 12 *Diospyros* species from heartwood spectral signature. A total of 761 wood core samples were collected from 761 trees spread across several regions of Madagascar. The cores were first conditioned in the lab at 12% moisture in a climatic chamber. Six spectra were then measured along the heartwood of each core using the Bruker MPA II spectrometer. Species discrimination models for each genus, based on partial least squares linear discriminant regression (PLSLDA) were calibrated for both genera using ¾ of the samples. The optimal number of discriminant variables, and the best spectra preprocessing, associated with minimal classification errors, were then chosen through a 4-block cross-validation repeated 20 times. The performance of the fitted models was evaluated by the classification results of the validation ¼ remaining sample by using accuracy, recall and precision metrics. The results show that the models effectively identify the majority of the samples, with a notably higher accuracy for *Diospyros* (91.4%) compared to *Dalbergia* (74.1%). For both genera, the identification performance varies among species, with 14 *Dalbergia* and 8 *Diospyros* species exhibiting recall and precision rates above 70% and 90%, respectively. The originality of this study lies in the efficacy of NIR spectroscopy in identifying a large number of species belonging to the same genus. Utilizing the Bruker MPA II holds promise for contributing effectively to the control of logging and trade of Malagasy precious woods listed in the CITES appendix. Furthermore. this research establishes a NIR spectral reference database for Malagasy *Dalbergia* and *Diospyros* woods, which did not exist previously. The models established in this study were used for the identification of seized wood stockpiles in Morondava and illegal *Dalbergia* species traded in the market of Antananarivo, in collaboration with the Ministry of Environment and Sustainable Development.

Key words: Wood identification, CITES, *Dalbergia*, *Diospyros*, Madagascar, Wood, Near Infrared Spectroscopy, forest control
Acknowledgments: This study was funded by the Gestion Durable des bois précieux Dalbergia et Diospyros de Madagascar project, funded by the European Union [2018-2022]. This paper also contributes to the "Wood for Globe - Towards a Global Wood Policy Platform: Sustainable Wood for a Carbon-neutral Bioeconomy" initiative led by IUFRO and funded through the Forest Fund of the Republic of Austria.

Improving the thermal performance of fired clay bricks produced in the far west of DR Congo

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ABSTRACT

The use of alternative materials for sustainable construction is one of the alternatives advocated for reducing the carbon footprint in building. Fired clay bricks, for example, can significantly reduce the cooling load in a hot city like Kinshasa, under identical operating conditions. And in clay-rich areas, the use of fired clay bricks proves not only more economical but also more eco-responsible.

However, given rich mineralogical and forestry resources of DR Congo, we propose to only use fired clay bricks as a substitute material. Moreover, these bricks are often manufactured by hand and have thus unknown physical and mechanical characteristics.

In the case of clay bricks, improved mechanical (particularly compressive and bending strengths) and thermal properties can be obtained by incorporating sawdust and other locally produced additives. It therefore appears that certain resources which could contribute to a more environmentally-friendly building industry can be neglected, and furthermore the potential of known materials is not fully utilized to date.

This research project therefore proposes a more in-depth analysis of these materials, such as those produced by Kwilu-Briques based in Kwilu-Ngongo, western DR Congo, with the goal to improve their current characteristics to propose products which feature increased mechanical and thermal properties.

The aim of our research project is to define the optimal formulation for fired bricks and to characterize them in terms of mechanical and thermal properties. On the one hand, these properties will have to comply with the standard, but on the other, we expect them to outperform current products of Kwilu-Briques. The tests to characterize the raw materials and additives are currently being carried out in the various workshops of the Institute Pascal research institute (France). On the basis of the results observed and taking into account the expected improvements, the respective compositions of the various samples and the quantities of the mixtures will be determined. Specific fired bricks will be produced and characterized according to their compressive and bending strengths but also their thermal properties. This preliminary study will make it possible to draw relevant conclusions on the positive spin-offs that would result from the use of these bricks as structural materials, as well as for the thermal insulation of buildings, in substitution of the conventional materials generally used in the building construction sector in DR Congo.

Key Words: Improvement, Performance, Thermal, Brick, Clay, Fired

Physico-chemical and morphological properties of *Phyllostachys edulis* Culms produced by pilot-scale heat treatment: Impact of temperature conditions

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ABSTRACT

Bamboo is found throughout the world, mainly in tropical, subtropical, and temperate southern regions including China, Japan, Taiwan, India, and Southeast Asia. Its annual production is estimated at be around 150,000 to 200,000 tons. In South Korea, 19 bamboo species from 5 genera are distributed in the southern region, covering a reported total bamboo forest area of 24,111ha. Although traditionally used for household items and handcrafts due to its ease of processing, bamboo has faced challenges in producing consistent products due to variables such as thickness and drying conditions. As a result, bamboo has gradually been replaced by synthetic materials such as plastic, leading to a decline in bamboo use and an increase in abandoned bamboo forest areas.

When bamboo is used in its natural state (green material), it is divided into two parts (epidermis, inner part), each of which is affected differently by external factors. Defects due to moisture loss and surface discoloration also occur differently as well. To address these issues with bamboo resources, various treatment technologies are applied to bamboo, with heat treatment being a prominent example of modification technology. This method is classified according to heat transfer media such as steam, vacuum, nitrogen, oil etc. The effects of heat treatment include dimensional stability, color stabilization, and resistance to biological attack. The treatment causes changes in the physical and chemical properties of the cell wall.

The main objective of this study was to achieve mass production of heat-treated bamboo (culm) with improved durability. We used a pilot-scale (dimensions: 1.8 meters in width, 1.8 meters in height, and 8 m in length) heat treatment technology developed by our research team using Korean Phyllostachys edulis. Heat treatment temperatures were set at 120, 140, 160, and 180°C. To assess the viability of the heat-treated P. edulis material, we measured the basic physical (density, specific gravity) and chemical properties of the two parts (epidermis, inner part) of both untreated and heat-treated *P. edulis* Culms. In addition, we compared the data on cell microstructure and carried out a comprehensive analysis before and after the heat treatment process.

Characterization of bondlines in cross-laminated timber made with preservative-treated lumber

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ABSTRACT

The number of mass timber construction projects is rapidly increasing in North America but this technology encounters durability issues where termites are present. One method to combat this issue is incorporating termiticidal treatments into mass timber elements. This study measured the impact of pre and post layup treatment of cross laminated timber (CLT) on bond line integrity. Douglas-fir 2 x 6-inch lumber or CLT panel sections were pressure treated with borates, pressure treated with an all-organics preservative system (PTIP) or dip treated with propiconazole, tebuconazole and imidacloprid + borate (PTI). CLT panels were manufactured using melamine formaldehyde (MF) or polyurethane (PUR). Planing treated lumber prior to use in CLT panel assembly reduced the concentration of preservative compounds by over 60% compared to unplaned lumber containing the same treatment. Panels made with borate treated lumber were more easily delaminated than panels composed of PTIP treated wood. Microscopic evaluation of CLT bondlines showed somewhat greater resin penetration in panels made with PTIP-treated wood; however, penetration was highly variable across specimens. All treatments increased surface wettability which may have contributed to reduced treated panel performance. This work helps define some of the challenges associated with incorporating biocidal treatments into and identifies some mechanisms by which they reduce panel performance.

Key Words: Polyurethane, Melamine Formaldehyde, Adhesive, Durability, Cross Laminated Timber

Production of transparent wood with UV assisted lignin modification using beech and oak wood

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Abstract

Transparent wood composites have received lot of attention in recent years due to their favourable optical, thermal insulation and mechanical properties. This new type of composite material has a wide range of applications, including building materials such as windows, furniture and solar panels. In this study, the lignin-modification time of beech and oak wood was investigated. The samples were modified with hydrogen peroxide. The modified process was accelerated by UV-A light. Experiments were carried out to produce transparent wood composites using polylactic acid and epoxy resin.
The process achieved complete bleaching in just 3 hours, which is faster than other lignin modification methods. The average mass loss for oak samples during the process was 19.67 %, while for beech samples it was 21.37 %. The in situ polymerization of polylactic acid caused the samples to turn dark brown or black. Further research is necessary in this area to prevent discoloration. The production of transparent wood yielded the best results through impregnation with epoxy resin. The lumens were completely filled with the resin, resulting in increased light transmission and reduced light scattering. These findings suggest that higher density hardwoods can be effectively utilized to produce transparent wood while preserving the natural texture of the wood.

Key words: lignin modification, brushing method, transparent wood, polylactic acid, in situ polymerisation

Introduction

The growing demand for sustainable and energy-efficient building materials has drawn attention to transparent wood as a possible solution. Transparent wood is particularly attractive because of its thermal insulation and optical properties, which make it ideal for buildings, solar panels and other optical applications. Traditionally, the removal of the lignin needed to produce transparent wood has required large amounts of chemicals and energy, which has created an environmental burden. In addition, the complete removal of lignin weakens the mechanical properties of wood and requires long processing times (Xia et al. 2021a).
To address these problems, researchers have recently focused on modifying the lignin structure and removing chromophore groups without completely removing lignin from the wood structure (Xia et al. 2021b). Such methods of modifying lignin allow for improving the optical properties of wood without compromising mechanical integrity. Innovations in the production of this type of transparent wood, such as solar-assisted chemical brushing, are particularly promising as they reduce the use of chemicals and energy while significantly shortening processing time and increasing production efficiency (Xia et al. 2021a).

The importance of our work in the present study lies in further optimising the transparent wood production process by applying a novel method of lignin modification using UV light. The UV-assisted bleaching method offers a faster and more environmentally friendly alternative, allowing for the production of transparent wood on a larger scale while improving the optical and mechanical properties of the product. The results presented here could open up new opportunities for transparent wood applications and contribute to the sustainable development of building materials.

Materials & Methods

Materials and Chemicals

Beech and oak veneers (40 mm x 40 mm x 0.6 mm) were used in this study. Hydrogen peroxide (H_2O_2 30% solution) and sodium hydroxide (NaOH 10% solution) were used to modify lignin. Lactic acid and epoxy resin were used to prepare the transparent wood. During the polymerization of lactic acid, tin (II) choliride dihydrate ($SnCl_2$) and p-toluenesulfonic acid (TSA) were used as catalysts.

Lignin Modification

The lignin modification process was carried out using two chemical reagents (NaOH and H_2O_2). These solutions were applied on the surface of the prepared wood samples by brushing method. The samples were treated following a two-phase protocol, with the first step being the application of the NaOH solution, followed by the application of the H_2O_2 solution. NaOH was applied by brush every hour while H_2O_2 was applied every half hour. After brushing, the samples were exposed to UV-A light sources (3 pcs UV-A light tubes, 30 W). The samples were placed 5 cm from the light source. After lignin modification, the samples were washed several times in distilled water. The samples were then washed in ethanol and stored in ethanol until further use.

Transparent Wood Production

The lactic acid monomer solution was first oligomerized in 3 cycles. In the first cycle, the melt was dehydrated at 75°C under 150 mbar for 75 min with continuous stirring. In the second cycle at the same pressure at 100°C for 100 min. In the third cycle, lactic acid was oligomerised at 130°C for 160 min. Before saturation of the lignin modified samples, 0.2 w/w% $SnCl_2$ and 0.2 w/w% TSA were added to the lactic acid oligomer. The samples were impregnated at 90°C by placing them in the oligomer. The saturated samples were polymerized between 2 glass plates at 120°C for 360 min and then at 103°C for 2 days to obtain the lactic acid oligomers.
In the case of samples prepared with epoxy resin, the resin and hardener were mixed at a ratio of 100:45 immediately before saturation. Saturated samples were placed between glass plates until the epoxy resin was fully cured.

Results and Discussion

Lignin Modification

When examining the effectiveness of lignin modification in oak and beech, it is worth observing the extent and time course of the response of each species to the treatment.
In the case of oak, the effect of the modification was more rapid. Significant fading of the samples was observed from the early stages. Uniform brightening also occurred more rapidly (120-150 min) and by the end of the process the colour had become almost uniformly light (Fig. 1 A). This suggests that oak responds rapidly to bleaching treatment, which may be advantageous in applications where minimizing treatment time is key.
Beech also started to lighten quickly (Fig. 1 B), but bleaching occurred in patches and took longer to achieve a uniform light colour (180 min). The bleaching of beech in patches and slower fading indicates that beech may be more resistant to certain treatments. Comparing the results from a

technological point of view and in order to reduce the colour deviation of the treated wood, it is appropriate to set the treatment time at 180 min.
In the study, the mass changes of oak and beech woods after the bleaching process were measured. The results showed an average mass loss of oak wood of 19.67 %, while beech wood, on average, suffered a mass loss of 21.37 %. Both woods showed significant mass loss, confirming that the bleaching process is effective in removing organic matter from the wood structure. These results provide important insights into the bleaching reactions of different wood species and may help in the development of further application-specific bleaching protocols.

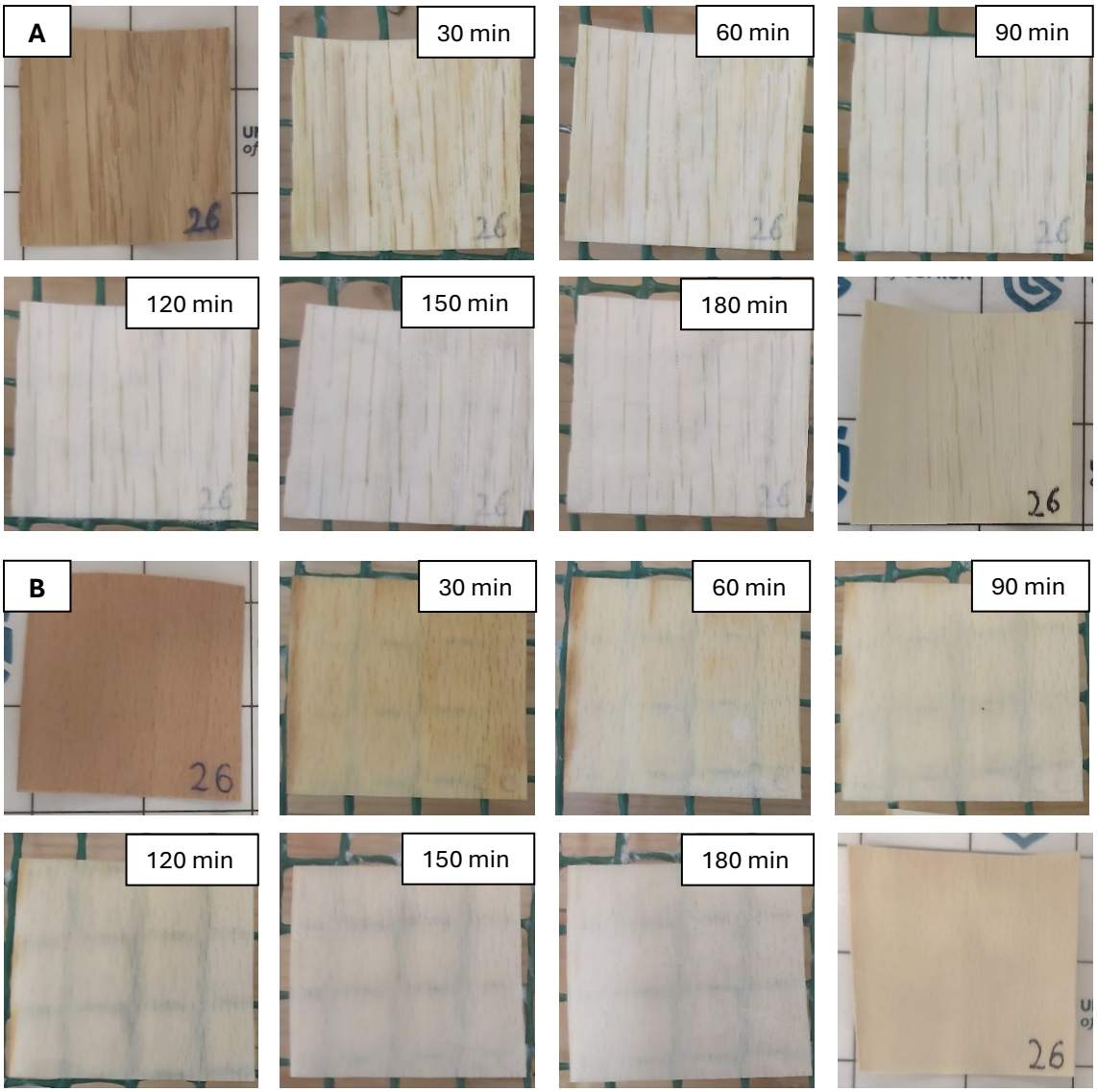

Figure 1. A sequence of images shows the effects of the lignin-modification process on oak (A) and beech (B) over time.

Transparent Wood Production

Samples of beech and oak wood samples were coloured dark brown or black during in situ polymerisation of lactic acid. During saturation, discolouration had already occurred on the samples. At first, only a faint browning started along the edge of the samples. After polymerisation at 120°C for 360 minutes, our samples were completely browned. After treatment at 103°C for 2 days, they were completely blackened (Fig. 2 A), but samples were cured. The

SEM images shown in Figure 2 B, that lactic acid penetrated the gaps between the wood cell walls and the vessels and filled them completely or mostly with polymer.
The beech and oak wood samples saturated with epoxy resin did not show the same discolouration as the previous samples (Fig. 2 C). The yellowish discolouration is due to residual ethanol and the omission of the toluene wash. Xia et al. (2021) report no discolouration. Saturation with epoxy resin is a simple and rapid procedure.
In Figure 2 D, it can be observed that the epoxy resin completely filled the cavities between the cell walls and the vessels. The two glass plates allowed the epoxy resin to be evenly applied to the surface of our samples. The average epoxy coverage was 41.5 µm for beech and 79 µm for oak.

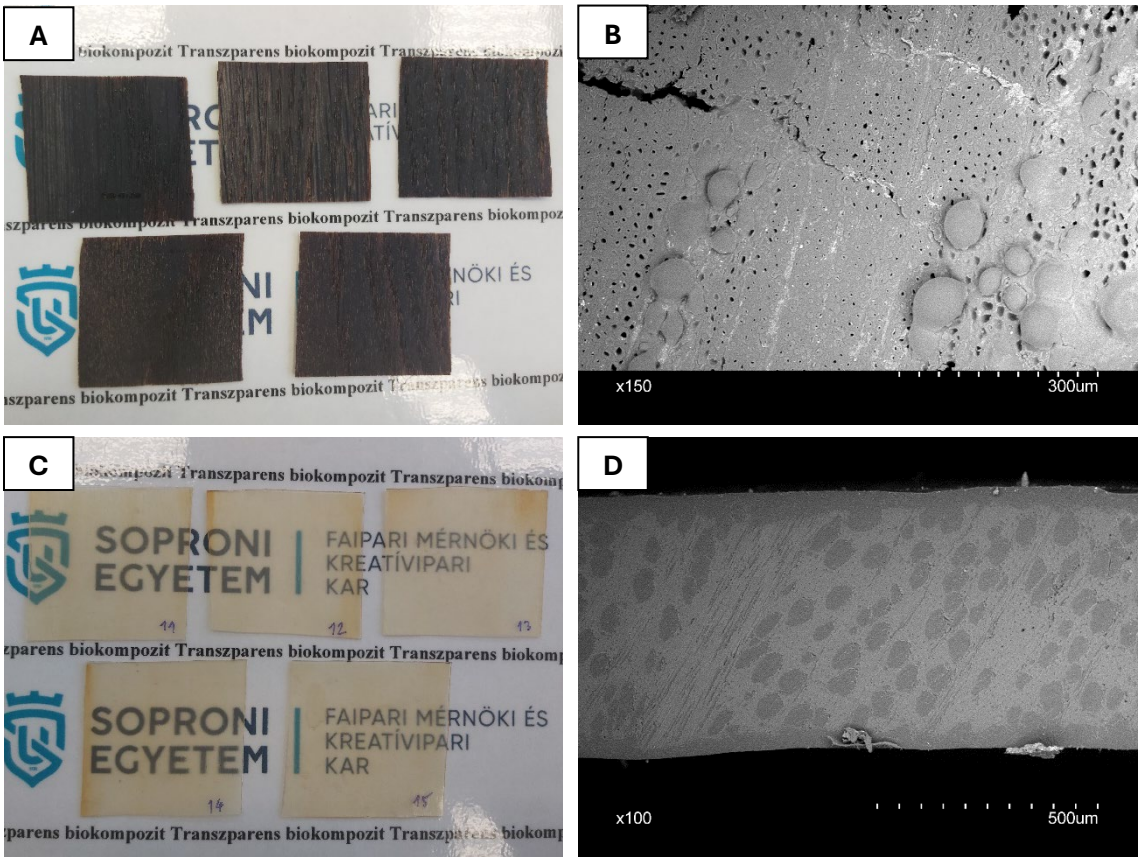

Figure 2. Samples of browned lactic acid lignin-modified oak (A), and saturation of these samples in SEM image (B). Samples of transparent wood beech prepared with epoxy resin (C), and saturation of these samples in SEM image (D).

Summary and Conclusions

In our research we have been working on the production of transparent wood composites. The results of the research showed that lignin modification was faster and more uniform for oak, while beech wood treatment required more time and resulted in patchy bleaching. In order to reduce the discolouration of the treated wood, it is advisable to set the treatment time at 180 minutes. Both woods suffered significant mass loss, confirming the effectiveness of the bleaching process in removing organic matter from the wood structure.
In the production of transparent wood, lactic acid in situ polymerisation caused dark discolouration, whereas no such problems were encountered when using epoxy resin. Samples impregnated with epoxy resin were found to be adequate as control samples.

Our research suggests that higher density hardwoods, such as oak and beech, can be used effectively to produce transparent wood while preserving the natural texture of the wood. The results also highlight the need for further research to focus on optimising polymerisation processes and preventing discolouration in order to make transparent wood composites more widely applicable in construction and other fields.

Acknowledgements

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Using a collaborative robot to automate the determination of wood sorption isotherms

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ABSTRACT

In laboratory research, routine work involving the determination of sorption isotherms is essential for understanding the moisture properties of wood. However, to ensure efficient sample transfer and reliable results, it is essential to continuously look for ways to improve and optimise laboratory procedures. This drive for improvement stems from the need to minimise human time spent on routine work, thereby reducing errors due to mistakes made by operators. The aim of this research was to address these challenges by designing, building, testing and validating a solution to support laboratory personnel in their daily activities related to routine sorption isothermal determination. A key aspect of the project is to reduce the time technicians spend on manual tasks, allowing them to allocate their efforts more efficiently. In this work, a collaborative robot was selected to achieve these goals. The chosen robot is the ABB YuMi where two seven axis of freedom robotic arms are integrated into a single system. A complex but coordinated system was successfully built around the robot to perform the selected measurement tasks. Both robotic arms were fully synchronised with add-on measurement components including laboratory balance, metrological video camera and portable near infrared spectrometer. Both YuMi robotic arms have a physically common basis, even though they are technically two separate robots. These can transport samples between pre-defined workstations while coordinating measurement sequence by communicating with the external PC computer supervising all the hardware components. The presented system is a prototype and may require further adjustments to become a daily solution for routine laboratory work. However, the successful preliminary tests validated the objectives defined for this research.

Water resistant biodegradable composite films fabricated by hemicellulose and lignin derived from lignocellulosic biomass

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ABSTRACT

The majority of packaging and coating materials currently in use are manufactured from synthetic polymers derived from petroleum resources. The accumulation of non-biodegradable plastic waste contributes to severe environmental issues, such as the accumulation of microplastics. As a result, there is a growing demand for packaging materials derived from biological sources that are capable of biodegradation. Consequently, there is an increasing need for renewable materials such as cellulose, hemicellulose, and lignin, derived from lignocellulosic biomass, to replace petroleum-based polymers and mitigate pollution and environmental damage caused by petrochemical plastics. These materials offer several advantages, including their light weight, water resistance, ease of processing, and low production costs. However, petroleum-based packaging materials are chemically stable, making them difficult to decompose.

This study demonstrates the fabrication of composite films utilizing hemicellulose and lignin from lignocellulosic biomass, which possess water resistance and UV protection functionalities, thereby realizing the high-value utilization of lignocellulosic resources. The alkaline extraction method is employed to extract hemicellulose and lignin within the wood. Alkaline extraction allows for the extraction of not only hemicellulose but also lignin from biomass. Xylan, the main polysaccharide in hardwood hemicelluloses, contains linear molecular chains of xylose units and has received considerable attention due to its wide range of applicability as a functional material. However, the abundance of hydroxyl groups in the xylan chain can lead to the absorption of water molecules, potentially reducing its mechanical properties and moisture barrier characteristics. To counteract this, sodium periodate was used to substitute the hydroxyl groups in xylan with dialdehyde groups. We evaluated the optimal properties based on the content of dialdehyde groups to maximize the physical properties of the film. Hemicellulose-lignin composite films were fabricated using chemically modified hemicellulose-lignin dialdehyde, and its characteristics were evaluated.

Keywords: Hemicellulose, Lignin, Biodegradable, Water resistant, Composite Films

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Preparation of alkylated graphene-coated melamine foam using lignin as an effective binding agent for application in oil-water separation process

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ABSTRACT

Currently, over 1 million tons of oil leak into the marine environment annually, often due to ship accidents or wastewater. Because these oil spills have a negative impact on the marine ecosystem, research continues on methods and materials aimed at addressing water pollution caused by oil spills. As a solution, the use of hydrophobic materials to adsorb and separate oil from water is proposed. Graphene is widely utilized to convert the surface of hydrophilic polymer materials into hydrophobic ones, enabling easy oil adsorption. In this study, in order to utilize these characteristics of graphene, hydrophobic alkylated graphene oxide was prepared. An oil-water separation material was prepared by modifying the surface of hydrophilic melamine foam using alkylated graphene oxide (AGO) obtained in this way. In this process, to coat AGO on the surface of melamine foam, lignin was first coated on the foam as a cross-linking agent. Lignin, the second most abundant biopolymer in nature, frequently emerges as a byproduct in the pulp and paper industry. This organic substance is often underutilized, commonly being burned for energy recovery rather than being harnessed for its potential value in various applications. The physical and chemical properties of the prepared AGO-lignin-melamine foam (AGO-L-MF) were analyzed, and the adsorption performance for various types of organic solvents was also evaluated. Hydrophobic melamine foam coated with AGO using lignin facilitated easy oil adsorption due to its three-dimensional porous structure. Additionally, its excellent compressibility enabled easy oil desorption by simply squeezing the foam. By coating melamine foam with lignin and AGO, we prepared an oil-water separation material effective in removing oil spills in aquatic environments, and it is also reusable. This approach presents a practical solution for water pollution control and demonstrates the potential of combining natural and polymeric materials for environmental protection.

Key Words: Lignin, Melamine foam, Graphene, Alkylation, Oil/water separation

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2021M3H4A3A02086904).

Tree-ring characteristics and climate-growth relationship for Quercus cerris (L.) in West Hungary.

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ABSTRACT

Turkey oak (*Quercus cerris* [L.]) is classified as drought-tolerant species. However, there is inadequate scientific knowledge to inform stakeholders about how the hardwood timber species is performing in the present changing climate. The study examined the effect of stand composition and soil quality on radial growth of *Quercus cerris* (L.) grown in Vas County in Hungary. In addition, the study chronologically correlated the prevailed precipitation and maximum temperature for the period of 1961 to 2021 against corresponding tree ring widths. A total of twelve Turkey oak trees were randomly harvested from four different sites, and the sampled wood pieces were extracted from the breast-height portion. Wood strips were machine-sanded, scanned with flatbed scanner into ImageJ compactible files for data extraction. The climate data were obtained from a database of the Hungarian National Metrological Service. The mean tree ring width was larger for trees harvested from mixed species planting site. Overall, tree ring sizes for trees harvested from pure species stand that thrive on poor soils exhibited wider variation (62%). The same plot of trees had a latewood width variation of 82%. Precipitation correlated positively with tree ring size with weak to moderate co-efficient (0.13 – 0.32), whereas maximum temperature negatively correlated with tree ring size on moderate co-efficient (-0.42). Among the growth characteristics, tree ring size decreased from the 1980s to present. However, the yearly pattern of climate variables considered in this study had not visibly changed from the irregular pattern that supported growth before the 1980s. The study findings suggest that much attention should be given to planting Turkey oak among other broad-leaf hardwood species.

Keywords: Earlywood, Latewood, Dendroclimatology, Drought-tolerant, Mixed-species

Assessment of operational carbon emissions for cross-laminated timber buildings according to in-situ measured U-values

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ABSTRACT

In recent years, the construction industry has emitted significant amounts of greenhouse gases (GHGs) while consuming large amounts of natural resources worldwide. To reduce the GHG emissions of the construction industry, timber has been paid attention as a biomass building material with significant carbon reduction potential. Among the many timber building materials, cross-laminated timber (CLT) has been widely used in many countries due to its prefabrication advantages. CLT has lower carbon emissions during the material production stage than conventional building materials, such as clay bricks and concrete. However, there is no consistency in whether CLT buildings have lower carbon emissions during the operational stage. During the operational stage of a building, the thermal performance of the walls can affect the operational carbon emissions. The U-values of walls represent the thermal performance of walls in a real environment. Thus, the measurements of the U-values of walls play an important role in calculating the operational carbon emissions. In this study, in-situ U-value measurements of both the CLT and the conventional wall were conducted in the UK and China. The construction of the conventional wall was the cavity wall which was made of concrete block and clay brick. The heat flow method was applied to obtain measured U-values of both CLT and cavity walls. The measured U-values were inputted into the building energy simulation software to predict the operational energy consumption. The operational carbon emissions were calculated based on the operational energy consumption. The results show that the operational carbon emissions of the CLT building are lower than the operational carbon emissions of the conventional building. This indicates that the CLT building has a lower environmental impact during the operation stage.

Keywords: In-situ U-value measurements; building operational stage; operational carbon emissions; cross-laminated timber wall; cavity wall; operational energy simulation

Efficient synthesis of succinic acid from biomass via chemical oxidation

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ABSTRACT

Lignocellulosic biomass, comprising cellulose, hemicellulose, and lignin, stands out as one of the most abundant and renewable resources available globally. Various chemicals, including levulinic acid, 2,5-furandicarboxylic acid (FDCA), and adipic acid, are derived from biomass, with succinic acid being a notable example. Succinic acid, a C4-dicarboxylic acid, holds promise as a fundamental chemical compound and finds application across diverse sectors such as the food and cosmetics industries, etc. While conventional succinic acid production involves the utilization of petroleum-based maleic anhydride, recent concerns regarding fossil fuel depletion and environmental pollution have spurred interest in biomass-based alternatives.

Microbial fermentation represents one avenue for the production of biomass-derived succinic acid, with microorganisms such as *Actinobacillus succinogenes* and *Anaerobiospirullum succiniciproducens* being commonly employed. Nonetheless, microbial fermentation processes often entail prolonged reaction times and present challenges in maintaining optimal conditions for bacterial growth. Alternatively, the chemical oxidation method presents a viable and efficient approach to succinic acid synthesis from biomass. This method involves the oxidative conversion of sugars present in biomass feedstocks using acid catalysts and oxidizing agents to yield the desired product.

In this study, the chemical oxidation method was employed for the production of biomass-based succinic acid. Prior to succinic acid synthesis, furfural, a precursor, was generated from biomass. Sweet sorghum liquid hydrolysate, rich in xylose, served as the biomass feedstock. Sulfuric acid was employed as the acid catalyst for furfural production, and a biphasic system facilitated the efficient separation of products. Xylene, an organic solvent utilized within the biphasic system, functioned to dissolve the produced furfural. Subsequently, hydrogen peroxide, serving as an oxidizing agent and sulfuric acid as an acid catalyst, was introduced to the furfural to yield biomass-based succinic acid. The overarching objective of this investigation was to achieve the efficient production and refinement of succinic acid from biomass, thereby enhancing yield while reducing reliance on fossil fuels and mitigating associated environmental challenges.

Key Words: Lignocellulosic Biomass, Succinic Acid, Furfural, Xylose, Biphasic system, Chemical Oxidation

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The potential of integrating life cycle assessment into the design phase of wood products

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ABSTRACT

Wood is increasingly recognised as a promising and sustainable raw material that can replace many fossil-based materials. Nevertheless, the impact of manufacturing on the environment should continue to be monitored. The key to environmentally friendly products lies in the ability to assess the sustainability of a product at the design stage rather than after it has been manufactured. LCA analysis has proven to be a good method to assess the environmental impact throughout the life cycle of a product. However, carrying out a full LCA analysis is very time-consuming and requires specialised knowledge. This is why many manufacturers have introduced sustainability assessment at the design stage by using CAD software that has some form of environmental impact assessment built in. It is important for the timber industry to follow this trend and carry out the environmental impact assessment at the design stage. Due to the special characteristics of wood and the production of wood products, we want to evaluate the possibilities of environmental impact assessment in CAD software and find out to what extent sustainability assessment is even possible in CAD programmes such as SOLIDWORKS, NX, Rhinoceros, Autodesk Inventor, Fusion, etc.

Key Words: sustainable design, LCA, environmental impacts, Solidworks, NX, Fusion

The hygrothermal performance and durability assessment of a wood-fiber insulation and cross-laminated timber wall envelope.

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ABSTRACT

Decarbonization of building stock is of global importance. Due to increasing efforts to improve energy and thermal efficiency, thicker wall assembly is being designed and utilized, directly translating to increased volumes of insulation being used during construction. Since the dawn of the industrial revolution inorganic and synthetic materials have become widespread. Recent environmental and climatic concerns have seen shifts leading to the development of new organic materials that exhibit comparable performance to synthetics. Wood-fiber insulation (WFI) is one of these materials, being comprised of defibrillated softwood chips it boasts many benefits. Due to its hygroscopic nature, WFI allows moisture migration due to interior and exterior climactic conditions with lesser risk of accumulation of water, it possesses the ability of moisture buffering and has a high heat storage capacity. However, there is little research assessing the long-term mold and fungal risk associated with WFI utilization in US climates.

The objective of this study was to perform hygrothermal analysis on a building envelope that uses WFI as its thermal insulation. A one-story school building, located in Belfast, Maine, US, was instrumented with temperature (°F), relative humidity (%), and moisture content (%) at north- and south-facing wall and roof assemblies. The data, collected over two years, was used to validate a one-dimensional hygrothermal WUFI® model and assess long-term durability. Results show that the model sufficiently predicts the temperature and moisture conditions within the wall assemblies, and the analysis provides an understanding of how the envelope responds to real interior and exterior climactic conditions.

Different strategies for utilization of inner part of oil palm trunk waste

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ABSTRACT

Oil palm trunk (OPT), which arises in substantial quantities as a by-product of the palm oil industry, is a suitable raw material due to its relatively high content in cellulosic fibers and low cost. The present study focuses on the inner part of OPT, which is light and low in mechanical performance and therefore lacks suitable applications other than fuel wood. Aiming for full utilization of the raw material, three different options were explored. 1) cellulose nanofibers: a combination of alkali pre-treatment and fibrillation by disc-grinding and subsequent high-pressure homogenization was applied, which resulted in fibrils with properties similar to those of cellulose nanofibers from fully delignified OPT. The facile pre-treatment process applied herein requires far fewer chemicals and energy than conventional pulping and is thus also beneficial from both the economic and ecological perspectives. 2) Thermal insulation panels: light-weight panels with densities of roughly 50 – 100 kg/m^3 and thermal conductivity of 40 – 45 mW m-1 K-1 were prepared from OPT fibers by mechanical foaming. With these values, OPT foam panels are well within reach of current non-biobased thermal insulation materials and perform equally well or even better than other biobased thermal insulation materials. 3) Packaging materials: OPT fibers were prepared from delignified material, and, alternatively, from hemicellulose-extracted material, and lightweight cardboard was produced. In conclusion, OPT can be an alternative resource for a range of materials. The approaches studied here boost the productivity/efficiency of the palm oil economy, lead to more sustainability, and encourage the creation of new products/markets benefiting oil palm farmers and communities.

Compost from post-production MDF waste – value-added approach towards circularity and cascading utilization of wood

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ABSTRACT

Medium-density fiberboard (MDF) is a type of wood-based panel produced by combining of wood fibres and resins, and found in a variety of applications, including interior design, flooring, building, and furniture (ASTM, 2016). Despite the fact that the major component of MDF is wood, the presence of formaldehyde-based resins, polyvinyl chloride and melamine makes landfill disposal possibly harmful for the environment, as a consequence of leach that can lead to polluted soil and groundwater. Also energy use at the end of the life cycle is not suggested, considering the pollutant emissions that characterize the mentioned above substances when exposed to high temperatures (Zimmer and Bachmann, 2023). On the other hand, closing the loop in the economy and fostering the cascading utilization of wood are the most important paradigms fostered by the European Union in reference to the wood industry. Therefore, finding suitable recycling pathways for MDF boards is highly recommended and represents a fundamental step towards the implementation of the EU recommendations in the wood sector (European Commission, 2012; European Commission et al. 2016).

In this research, we proposed a closed-loop economy approach based on producing compost for the cultivation of ornamental plants starting from wood waste from the production of door joinery, containing fractions of MDF board. The obtained composts were successfully used for growing ornamental plants, which also contributed to reducing the share of peat in gardening substrates. This research put the base for an innovative valorization pathway for MDF wastes, that supports the concept of cascading utilization of wood raw materials recovered from fibreboards, thus promoting a sustainable use of natural resources and closing the loop of the European fibreboard industry.

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Key Words: Wood Waste, MDF Waste, Composting Process, Compost, Peat Substitution, Circular Economy

Effect of the percentage coverage of MUF adhesive on the shear strength for bonding different wood species

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ABSTRACT

Nowadays, in the production of composite materials, great emphasis is placed on the use of materials from sustainable sources. Sustainable resources include wood particles. In the past and at present, wood particles made from spruce wood have the largest presence in Europe. As a result of excessive harvesting associated with rapidly changing climatic conditions, it is necessary to focus on the use of lesser-known wood species in the production of wood-based composites. The durability of the composite material is limited mainly by the type and amount of adhesive used. The correct determination of the amount of adhesive is key to reducing the price of the resulting composite, reducing VOCs during the production and the use of the composite and subsequent storage and re-recycling, or reducing the carbon footprint during disposal. This work deals with the determination of the shear strength of bonded veneers (eight European wood species: spruce, larch, pine, beech, oak, poplar, birch, and alder) with Silekol® 311 melamine-urea-formaldehyde adhesive (MUF) under variable adhesive coverage of the samples: 10, 15, 20, 25, 30, 50, 75, and 100%. The Automated Bonding Evaluation System (ABES) was used to evaluate and compare adhesive bond strengths. Larch, beech, and oak samples exhibited higher single-lap shear strength than control samples from spruce. There was no statistically significant difference in shear strength regarding the adhesive coverage from 100% to 20% on the surface of the samples, for almost all wood species. The results of the project provide basic information about the bonding strengths with different coverage in the adhesive layer, comparing non-commonly used wood species in wood-based composites such as oriented strand board and particleboard.

Predicting compression strength perpendicular to grain in hardwoods

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ABSTRACT

The share of broadleaved forest in European is growing, but most of the harvested hardwood is burned for energy production. Long-lasting uses, such as building construction, could offer benefits regarding carbon-storage and efficient, circular material use, but a barrier to using more hardwood in structures remains the comparatively low yield in sawn timber and consequently high price. Many hardwood species might, however, offer a competitive edge over softwoods due to their higher mechanical properties, including compression strength perpendicular to grain. Having an accurate description of this property for temperate hardwood species is therefore paramount. However, under the European standards framework, compression strength is not a property that has to be measured as part of a strength grading assignment for structural timber. Instead, it is usually calculated from characteristic density according to EN 384 (European Committee for Standardization & British Standards Institution, 2018). It is unsure how well the given equations predict the compression strength of an ever-growing array of temperate hardwood species coming to market now and in the future. Potentially, other predictors such as side hardness, as suggested by literature, might be better predictors for compression strength. Hardness data for certain resources might already exist, or hardness could be measured with little cost and effort as part of a strength grading assignment. The study assessed the suitability of density and side hardness as a predictor for compression strength. Seventy-five full-size compression tests were performed on a sample of UK-grown sycamore (*Acer pseudoplatanus*) and characteristic (5th-percentile) values for density and compression strength were calculated according to EN 14358 (European Committee for Standardization & British Standards Institution, 2016). Janka hardness tests were performed on specimens cut from the same battens, and characteristic compression strength was predicted from side hardness using an equation given by Lavers (Lavers, 1983). In the sycamore sample, both density and side hardness underestimate the actual characteristic compression strength, density more so than side hardness. Compression strength and hardness were also tested on small clear specimens of seven hardwood species, to investigate if the relationships given by EN 384 and Lavers are consistent over a wide range of species. The tested hardwoods included paulownia, poplar, sweet chestnut, sycamore, ash, oak and beech. The findings suggest that the currently used equations for calculating compression strength from density might give very conservative results, and that side hardness might have a more consistent relationship with compression strength than density. For a more accurate description of the properties of full-size members, equations for both predictor variables should be adapted.

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Looking for the sweet spot: the elements of logistics in the global mass timber panels industry

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ABSTRACT

In 2024, the mass timber panel (MTP) industry, exemplified by Cross-Laminated Timber (CLT), does not feel all that new anymore. Not even in the US. And yet the industry must still be recognized as a radically new concept challenging both commodity-oriented forest products, industry models, and the linear models of construction project development. It is much smaller and more diverse than the volume of information and noise around it would suggest. Organic development of the global mass timber industry since the first commercial applications in the late 1990s has produced substantial diversity in manufacturing processes, levels of automation, scales of operation, and products and services options, as well as in market strategies and modes of interaction with its extensive supply chain. The principal distinction of the MTP industry compared to the rest of engineered wood products sectors, is high level of integration of the elements of architectural and engineering design process, manufacturing technologies, and construction.

One of the less discussed aspects of the MTP industry is its peculiar logistic calculus. While projects are being routinely shipped on intercontinental routes, it is still not clear what would be a sweet spot for a manufacturing operation along its complicated supply and value chains. We believe that a thing or two on that topic may be inferred from the analysis of the existing global mass timber operations, which taken together, make a living laboratory that can be used for better understanding of both the current state of the industry and its future development.

Possibilities of hyperspectral imaging for sorting of recovered wood

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ABSTRACT

Wood is one of the most important construction materials. All the environmental benefits of the wood can be diminished if wood is disposed and degraded in anaerobic conditions. Construction wood, like other building materials, enters the waste streams at the end of the service life. Most of the classification schemes for sorting recovered wood are primarily based on the presence of contaminants, namely biocides, synthetic polymers, mineral residues… In addition, sometimes, even the presence of particleboard must be avoided. Therefore, there is a need to develop robust methods for continuous detection. X-ray fluorescence spectroscopy is suitable for detecting inorganic elements, like Cu, Cr and As, but proved ineffective in detecting organic components. Hyperspectral imaging is a promising technique already introduced to sort recycled polymers. Hyperspectral imaging can differentiate between different types of synthetic polymers. Therefore, the possibility of hyperspectral imaging for wood sorting was tested. Beech wood veneer was used as a substrate, as the beech wood does not contain extractives, that could interfere with spectra. Beechwood was treated with frequently used active ingredients used for wood protection in the EU, namely copper hydroxide, quaternary ammonium compounds, IPBC, arsenic oxide, propiconazole, boric acid, creosote, polymeric betaine … The concentration of the active ingredients corresponds to the retention of active ingredients in the analytical zone of treated wood as defined by specifiers. In addition, some lower retention was applied to check the method's sensitivity. Hyperspectral analysis was performed with a high-resolution ClydeHSI Hyperion A3 Scanner, using visible and near-infrared (VNIR; 400–1000 nm, $\Delta\lambda = 3$ nm) or short-wavelength infrared (SWIR; 900–2500 nm, $\Delta\lambda = 10$ nm) hyperspectral cameras. Subsequently, data analysis was made using Principal Components Analysis (PCA) to determine the presence of contaminants. Hyperspectral imaging proved to be effective in detecting some organic biocides that are invisible by naked light and have the potential to be implemented in sorting recovered wood from construction sites. In addition, the presence of polymers, particleboards, and concrete can be identified as well.

Influence of the layer composition of the spruce and larch strands for manufacturing laminated strand lumber

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ABSTRACT

This study has the main objective for the production of laminated strand lumber (LSL) from underutilized wood species. This topic came out from the forest species composition in the forests of central Europe. The main aim is to focus on the actual problems with the spruce monocultures as a bark beetle calamity and drought in the last decades. These problems can cause changes in the forest composition from the dominant spruce monocultures to the deciduous mixed forests. These factors could have a significant impact on the wood-based composite industry. Another reason for LSL is an opportunity to use low-quality and low-diameter logs for the production of wood-construction materials with very good properties.

For this study, it was selected larch as a potential replacement for spruce in the forest, because it is species with better drought resistance and endurance against bark beetle. This choice was the first step in using underutilized wood species in LSL composite. Four types of LSL panels were made from strands with lengths around 300 mm. The first two types of panels were references, these were made only from one type of strand. Another two panels were made from a mixture of spruce and larch strands. The third panels were made from 50 % larch and 50 % spruce strands and the mixture was blended in the laboratory drum blender. The last type was a larch and spruce mixture with a percentage ratio of 50:50 %, but in this case, panels were made from three layers. The middle one was made from spruce strands and the surface layers were made from larch strands. These LSL panels were tested by European standards on chosen properties. Testing of the physical properties was focused on density, density profile (DP), thickness swelling (TS), and water absorption (WA); mechanical properties such as compression strength, modulus of elasticity (MOE), and modulus of rupture (MOR) were tested. Bending properties were tested in two options on edgewise and flatwise test. The goal of the work was the comparison of the suitability of larch wood for LSL manufacturing.

Keywords: Laminated strand lumber (LSL), wood-based composites, pMDI adhesive, bending properties, Internal bonding (IB)

DCSBD plasma treatment as an alternative to commercial surface degreasing agents before applying clear water-based wood coatings

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ABSTRACT

Plasma science was first established in the late 19th century and is referred to as a fully or partly ionized gas consisting of atoms, electrons, radicals, photons and reactive species. In recent years, atmospheric non-thermal plasma (ANTP) treatment of different lignocellulose materials has become widely used as an alternative to conventional pre-treatment methods, such as chemical and mechanical modifications. Furthermore, ANTP is also used in medicine, water-waste treatment, decomposition of volatile organic compounds, and microorganism treatment. Wood can be modified to improve its mechanical and physical properties, aesthetics, and suitability for further processing. After modification, wood is usually coated to maintain its appearance and properties, as well as protect it from weathering, which extends its lifespan. Prior research has demonstrated that treating wood with plasma can enhance its surface-free energy, leading to reduced contact angles for water-based coatings and improved wettability. This was regularly found to also improve the adhesion of different coatings on wooden substrates through the functional groups created on the surface by the plasma treatment. Moreover, certain wood species have exhibited increased coating penetration after plasma pretreatment. Our research aimed to test the effectiveness of diffuse coplanar surface barrier discharge (DCSBD) plasma treatment as a substitute for traditional surface degreasing methods such as turpentine and other organic solvents. We conducted experiments to test our hypothesis that DCSBD pretreatment could replace solvent-based degreasing of wood surfaces prior to the application of epoxy and alkyd lacquers while providing an equal or better performance. We also tested whether DCSBD pretreatment prior to coating application enhances the coating's adhesion, improves its water resistance, reduces the impact of accelerated weathering and natural outdoor weathering on the coating, and is more cost-effective and environmentally friendly than solvent-based degreasing. We set our experiment to test turpentine and nitro solvent against DCSBD plasma treatment, following surface degreasing procedures according to the requirements prescribed by the lacquer manufacturer. Two different coating systems were applied on European beech (Fagus sylvatica), European red pine (Pinus sylvestris), and Norway spruce (Picea abies) specimens, comparing chemically degreased with plasma-pretreated specimens. An epoxy-based coating system was applied in two variations, that is, one set of specimens with the application of both primer and topcoat according to the manufacturer's instructions, whereas a second set excluded the primer layer to test the possibility of whether plasma pretreatments through the enhanced wetting and adhesion are able to replace the priming of the substrates' surfaces. In comparison to the epoxy-based coating, a single-formulation alkyd-based commercial coating system was tested, that did not necessarily require the application of a primer.

Key Words: DCSBD plasma, wood, turpentine, degreasing, boat coatings, wood weathering

Comparative analysis of wood decay in different European climates: an experimental approach using flawed playhouse structures

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ABSTRACT

The use of wood in the built environment is increasing steadily. However, the dynamic nature of the performance of wood under varying climatic conditions raises questions about the effective service life of wood. Therefore, there is a growing interest among wood construction stakeholders (including building designers, users and owners), to forecast the durability and service life performance of wood exposed to external climatic conditions. This poster presents an ongoing research study that aims to investigate the impact of varying climatic conditions on the functional and aesthetical service life performance of wood. Data collected from this experiment will be used to validate a Building Information Modelling (BIM) tool for identifying wood construction related design flaws that could potentially reduce the functional service life of wood exposed outdoors. Four identical playhouse structures are used as experiment in this research. The playhouse structures are intentionally designed to replicate common construction design flaws that could potentially lead to moisture build-up and accelerate fungal wood decay. The experimental setups are exposed in Izola (Slovenia), Göttingen (Germany), Lund (Sweden), and Vienna (Austria). Each structure is equipped with an array of sensors including climate sensors, wood surface temperature sensors and wood moisture content sensors. These sensors enable continuous monitoring of moisture levels, surface temperature fluctuations and decay progression over time. In addition, regular images of the structure are taken to investigate how the appearance of the test house changes over time. Preliminary results from the ongoing experiment reveal notable variations in the rate of moisture accumulation at the identified design details. The preliminary results also highlight early signs of changes in the appearance on the surface of the playhouse structure. The data collected from the sensors thus far highlights the influence of climate exposure on service life of wood and how improper design detailing could potentially speed up the rate of fungal wood decay.This study is a step towards understanding the complex relationships between climatic conditions, design flaws and fungal wood decay. While the study is still in progress, the insights gained will contribute to the development of more sustainable and resilient wood-based construction methods.

Keywords: Wood durability, Climatic conditions, Design flaws, Moisture accumulation, Decay, Building Information Modelling (BIM), Sustainable construction.

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Lignocellulosic biomass-based hydrogel for efficient microplastic removal

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ABSTRACT

Plastics play a significant role across various industries due to their favorable attributes such as excellent processability, durability, cost-effectiveness, lightweight nature, versatility, and oxygen barrier properties. However, approximately 79% of used plastics end up being incinerated or landfilled, and their exceptional mechanical durability renders them resistant to natural decomposition. Through weathering processes like photodegradation from UV exposure or mechanical abrasion, accumulated plastics degrade into microplastics (MPs). These MPs are emerging as new toxic pollutants due to their unique physical and chemical properties, stability, and resistance to degradation. To ensure the safe utilization of water resources, the removal of MPs from water sources is imperative. Among various methods, adsorption stands out as a promising approach for removing MPs. Lignin, derived from lignocellulosic biomass, is known for its three-dimensional network structure containing phenol and various functional groups, making it suitable as an adsorbent for water purification. Lignin primarily adsorbs organic pollutants via electrostatic attraction, hydrogen bonding and hydrophobic interactions, which aligns with the main adsorption mechanisms observed in reported MP adsorbents. Considering its adsorption mechanism, lignin shows potential as an MP adsorbent. In this study, a lignin-based hydrogel derived from lignocellulosic biomass was successfully prepared for MP adsorption. Spherical polystyrene (PS) microparticle, synthesized through emulsion polymerization, was chosen as a model MP. Physicochemical analysis, including assessment of morphology, surface potential, mechanical properties, and chemical characteristics, was conducted on the prepared hydrogel to assess its suitability for MP removal. Subsequently, the adsorption capacity of the hydrogel was examined under various conditions such as pH, contact time, initial dose, and temperature to evaluate its MP adsorption behavior. Afterwards, the adsorption mechanism and reusability were investigated to evaluate the driving force of MP adsorption and the durability of the hydrogel as an MP adsorbent, respectively. This research explores new avenues for employing lignin in water treatment applications, presenting promising possibilities for addressing the challenge of microplastic pollution in aquatic environments.

Keywords: Biomass, Lignin, Microplastic, Adsorption

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Structural control and chemical modification of lignin for application as biopolyol in polyurethane production

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ABSTRACT

Polyurethane is a petrochemical-based material that is a polymer made through the reaction of hydroxyl and isocyanate groups. It can be used in a wide variety of applications, but its impact on the environment, such as resource depletion and carbon dioxide emissions, has led to a growing interest in eco-friendly polyurethane manufacturing. Lignin is the second abundant natural biomass polymer on Earth, and it has a variety of properties, such as thermal stability, stiffness, UV protection, and hydrophobicity. Especially, its abundance of hydroxyl groups makes it a promising replacement for polyols in petrochemical-based polyurethane. However, its low reactivity and complex structure make it difficult to be used in industry immediately, and chemical modifications are needed to improve its dispersibility and reactivity. In this study, a chemical modification method for the preparation of lignin-based bio-polyurethanes was described. To prepare lignin-based bio-PU, fractionation was performed with eco-solvents to increase dispersibility, and demethylation was performed to increase hydroxyl group content to improve reactivity. The molecular weight of lignin was determined by GPC, and the hydroxyl group content of lignin was quantified by 31P-NMR. Fractionation with eco-solvents resulted in a decrease in molecular weight and polydispersity and an increase in hydroxyl content without significant structural and thermal property changes. When the fractionated lignin (ESL) was subjected to a demethylation reaction, the molecular weight increased slightly, but the polydispersity (PDI) was well maintained low and the hydroxyl group content increased significantly. The molecular weight of lignin decreased in order of KL, ESL_D, and ESL, and polydispersity was highest for KL, while ESL and ESL_D showed similar values. Also, FT-IR analysis indicated changes in hydroxyl groups and C-O-C bonds in ESL_D. Lignin-based polyurethane foams were successfully manufactured and showed improved thermal properties and mechanical strength compared to basic petrochemical-based polyurethanes. This allowed us to evaluate the potential of chemical modification of lignin as a bio-polyol to successfully replace petrochemical-based polyols.

Key Words: Lignin, Bio-polyurethane, Eco-friendly, Fractionation, Chemical modification, Thermal stability

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Breaking barriers in wood science education: a deep dive into the multicultural scholars program at Oregon State University

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ABSTRACT

This presentation aims to explore the educational dimensions of Wood Science and Technology, as it pertains to the future generation of industry professionals. The Multicultural Scholars Program (MSP) scholarship (USDA) is an opportunity offered through the Wood Innovation for Sustainability degree (WINS), Department of Wood Science & Engineering, at Oregon State University. The program first ran in 2022 and a second cohort is currently in the program. This second iteration of the MSP program provides 100% tuition coverage for seven underserved students for their final year at an Oregon community college, and 80% coverage for their final two years at Oregon State University. It also provides direct mentorship with research faculty, industry mentors, funding for study abroad/internships, and funding for conference travel. At its core, this project is intended to shed light on the educational achievements that MSP program has had on the success of underserved community college students pursuing an education within the Wood Science and Technology arena, specifically the impact that this scholarship has on their academic success.

The MSP program originated as a means to support a diverse population of students, whose barriers towards education competed with their ability to complete their education, post community college. As a response to this observation, the MSP program was proposed, and has since lowered some of the major barriers that students were facing, thus increasing the amount of students pursuing a degree in a wood science related field.

By diving into the specific aspects of the scholarship program, such as mentorship, research initiatives, and industry exposure, this project will underscore the invaluable role that the MSP program plays in shaping the next generation of leaders in the field of wood science and technology. Additionally, this project aims to highlight the evolution of the MSP-WINS program. The major focus of this area is to exhibit the progression in curriculum, travel opportunities, and overall program enhancements which impact the success of students.

Ultimately, this project serves as an exploration of the educational aspects of wood science and technology, emphasizing the instrumental role of the Multicultural Scholars Program at Oregon State University in empowering students and fostering innovation.

Keywords: Wood Science and Technology education, educational barriers, higher education, future industry professionals, academic success, industry exposure

Innovation and sources of knowledge in the western North American hardwood sector

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ABSTRACT

The native hardwoods species of Oregon and Washington encompass 10% of the forested land base, and contribute a wealth of cultural, economic, and ecological value to the landscape. However, forest management paradigms have, until recently, sought to significantly reduce their presence on the land base to reduce competition for softwood species at the same time as shifts in consumer values and wood supply have underscored the need for innovative management and production processes. A group of western hardwood product manufacturers has emerged in this region to provide quality wood products from this underutilized stream of local resources. Since innovation can be described as a process of using information in a novel way, a key precursor to successful innovation is information accessibility, and the transition of new information into organizational capability. Research describing modes of innovation in the wood products industry has largely occurred in softwood manufacturing, where it has connected successful innovation to several desirable outcomes. However, little work in this vein has looked at the western hardwood industry, or access to information in that sector. This study applies mixed-method social network analysis, a method uniquely qualified to address the interdependent nature of the industry, to the questions of information sourcing and organizational innovation in western hardwood producers. The work will be conducted in two phases. In the first phase, interviews with high-level managers within most of the hardwood producing firms in Oregon and Washington will be conducted. Thematic qualitative data analysis will be used on interviews including questions such as:

- How are your operations impacted by the background or experience of the people that work here?
- How do you get information from outside the company?
- What types of relationships are most relevant to your company for gathering new information?

Following these findings, a quantitative survey will be employed with the same population. These data will be used to develop a multilayered social network representation and an exponential random graph model examining the inter-organizational dynamics involved in information sharing relationships. Data collection is planned for February – April of 2024 and preliminary results will be presented in Slovenia. As a small, highly interconnected sector related to an emerging discussion in North American forest management, the microcosm of the western hardwood industry presents a unique opportunity to assess the dynamics of information flows and organizational learning in wood products manufacturers. Greater insight in this realm may reveal opportunities for increasing efficiency and innovation that could be applicable to the larger sector moving forward.

Key Words: Hardwoods, Deciduous, Hardwood Manufacturing, Innovation, Information Transmission, Organizational Learning, Social Network Analysis

Development of biodegradable composite material based on PLA via ring opening polymerization of lignocellulosic biomass components

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ABSTRACT

As the use of plastic has significantly increased since its initial development, plastic waste has become a major problem. Specifically, petroleum-based plastics exhibit recalcitrance to natural degradation processes, contributing to the accumulation of microplastics in marine ecosystems. Moreover, these microplastics accumulate in marine life, causing problems by entering the human body when humans consume them. To address these issues, reuse and recycling methods for plastics have been implemented. However, their effect is limited, and the generation of plastic waste is expected to steadily increase in the future.

For these reasons, research has been conducted on bioplastics that are biodegradable or manufactured from the biomass. Among them, Poly (lactic acid) (PLA) is a representative bioplastic made from the polymerization of lactic acid, which has biocompatibility, high tensile strength, and environmental friendliness. Despite these advantages, its use is limited due to its high brittleness and the specific conditions required for biodegradation. Therefore, additives are needed to improve mechanical properties and biodegradability.

Xylan is the most abundant hemicellulose in deciduous woods existing in the form of glucuronoxylan. The main backbone of xylan is composed of 1,4-linked β-D-xylopyranose units, and, unlike cellulose, it has an amorphous structure. Xylan is a renewable and biodegradable resource. Additionally, lignin, one of the main components of lignocellulosic biomass, possesses a rigid structure, antioxidant properties, and high thermal stability. Therefore, xylan and lignin have the potential to be used as additives or precursors for bioplastics. However, their low compatibility with PLA, due to the presence of many hydroxyl groups, is an obstacle for use as an additive for PLA. To overcome these drawbacks, various chemical modifications are necessary.

In this study, xylan and lignin were chemically modified via ring opening polymerization (ROP) with ε-caprolactone to increase the compatibility of xylan and lignin with PLA. The chemical modification result was confirmed using 1H NMR and FT-IR analysis. The thermal properties of products were analyzed using TGA and DSC. After the chemical modification, we made neat PLA film, xylan-g-PCL/PLA film and xylan-g-PCL, lignin-g-PCL/PLA film via solvent casting method.

The tensile strength and elongation of films were analyzed using universal testing machine (UTM) and UV protection properties were analyzed using UV/Vis spectrophotometer. In the meantime, the biodegradability of the film was confirmed in accordance with ISO 14855-2.

Keywords: Hemicellulose, Lignin, PLA, ROP, Film

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Creep behavior of packaging boxes reinforced with columns

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ABSTRACT

The package may loss its strength capacity, resulting in failure, and consequently leading to damage of the content over time when subjected to constant compression load during handling, storage, and transportation. This time-dependent phenomenon is known as creep. This study was aimed at evaluating the creep behaviors of two distinctive corrugated package designs with or without the presence of column reinforcements at 23°C and 70% relative humidity (RH) under 50% and 80% of ultimate compressive load. Two distinct groups of corrugated cardboard boxes in dimension of 610 mm in height, length, and width were fabricated with or without columns that were made of pulp paper. The deflection of each boxes was the average of two measurements using two LVDTs that were mounted at top of the boxes at two corners. It was found that the Bailey-Norton creep law and Power law models showed a good correlation with the experimental creep strain, which was calculated by creep deformation over time. Load and presence of reinforcements affected the creep behaviors of the packages. High load resulted in an increased creep rate. The creep strain was developed in a more stable way for reinforced boxes in comparison with the plain boxes, i.e., non-reinforcement boxes. This research underscored the importance of structural reinforcements in corrugated cardboard boxes to mitigate the effects of creep, especially under conditions of prolonged stress. By providing a deeper understanding of how design variations could influence the long-term performance of packaging, this study contributed valuable insights into the development of more reliable and durable packaging solutions.

Fracture behaviour of solid and adhesive-bonded wood

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ABSTRACT

Lumber-based mass timber products, such as glue-laminated timber (GLT) and cross-laminated timber (CLT), are widely used in the construction industry. The fracture behavior in these products, where new surfaces are formed, significantly impacts the structural integrity of these wood products, and furthermore influences the safety and durability of a timber structure. It is important to note that bond joints are typically subjected to mixed-mode loading conditions, necessitating a comprehensive understanding of the fracture behavior of adhesively bonded joints under various loads, particularly in mixed-mode loading scenarios. This research was aimed at comprehending the fracture behavior of adhesive bond-lines in GLT and CLT under three loading modes (namely, Mode I, Mode II, and Mixed-Mode). Two adhesions used in this study was white spruce (*Picea glauca*) as the major material and sugar maple (*Acer saccharum*) as a control. The adhesives used included phenol resorcinol formaldehyde (PRF), polyurethanes (PUR), and emulsion polymer isocyanates (EPI). Testing involved a modified Arcan test to assess the fracture behavior of solid wood, bond-lines, and glue-lines, incorporating varying loading modes by adjusting the tensile loading angle. A digital image correlation (DIC) system was employed to capture whole field displacements and strains near crack tips. A novel analytical technique combining J-integral theory and the DIC method was introduced to study the fracture behavior of wooden materials. Fracture properties of solid wood, bond-lines, and glue-lines, including energy release rate and stress intensity factor, were therefore calculated. The study compared the critical energy release rate (Gc) and critical stress intensity factor (Kc) of different adhesive bond-lines with those of solid wood and glue-lines. Moreover, an analysis of fracture criteria for solid wood and adhesive bond-lines at various tensile angles was conducted, aiming to provide a theoretical framework for structural design and fracture simulation by investigating the fracture performance of adhesive joints in GLT and CLT. It was found that the proposed method enables the direct calculation of the fracture toughness of wood-based materials by utilizing displacement and stress fields acquired from DIC through the application of the J-integral formula. Furthermore, it allows for the assessment of the impact of material plasticity on fracture performance.

Life cycle assessment (LCA) of sawn veneer wall covering

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ABSTRACT

Rising environmental issues such as climate change, loss of biodiversity, pollution, and resource depletion require urgent attention and careful planning of our future. These issues pose significant threats to ecosystems, human health, and the stability of our planet. Urgent actions are implying much needed mitigation of climate change, reduction of carbon emissions, accelerated transition to renewable energy sources, conservation of natural habitats, and promotion of sustainable practices in various sectors. One of the most valuable natural and sustainable resource we can use in industry is wood. More efficient and frequent utilization of wood, in combination with sustainable wood practices, can decrease negative effect of ever-growing market demands. Scientists and practitioners must constantly develop and discover new approaches that will lead to optimization of product design, production processes and services. Analyzing studies and papers, regarding sustainable production and construction, it is evident that practitioners have recognized Life Cycle Assessment as beneficial tool when analyzing impacts on the environment but also identifying problematic manufacturing hotspots. The purpose of this study is to analyze the amount of Cumulative Energy Demand (CED) during the material extraction and production of decorative wooden wall covering. Cumulative Energy Demand is a LCA method that sums up all energy inputs required in Life Cycle of a product and helps assess its environmental impact in terms of energy consumption. CED analysis can be also used to compare different products or technologies and serve as basis for identification of opportunities for energy efficiency improvements. CED can be important tool for informing decision-making processes aimed at reducing energy consumption and environmental impacts. This assessment was done with the *SimPro*, the leading software for LCA analyses, taking into concern the ISO 14040 and 14044 standards. The results of this study are shown in characterization chart calculated for 1 kg of our product. The processes and materials with the highest impact on the environment are displayed in a Network chart that gives more detailed insight into production process hotspots. LCA analysis entails the gathering of large amount of data, which can be highly beneficial for product designers. Availability of data in the early stages of product design can support optimization of manufacturing process. It's important to note that while CED provides valuable insights into the energy requirements of a product or process, it is just one aspect of a comprehensive LCA. Integrating CED with other environmental impact categories, such as greenhouse gas emissions, resource depletion, and ecosystem impacts, allows a more holistic assessment of the environmental sustainability of products, processes, and

services. Although the LCA is not a new concept it is important to be included in the wood sector education and practice.

Key words: Life Cycle Assessment, LCA, Sawn Veneer, Wooden Wall Coverings, Cumulative Energy Demand, CED, Wooden products

INTRODUCTION

Rising environmental issues such as climate change, loss of biodiversity, pollution, and resource depletion require urgent attention and careful planning of our future. These issues pose significant threats to ecosystems, human health, and the stability of our planet. We must establish a life on our planet in balance with nature (Attenborough, 2020). Urgent actions are implying much needed mitigation of climate change, reduction of carbon emissions, accelerated transition to renewable energy sources, conservation of natural habitats, and promotion of sustainable practices in various sectors. One of the most valuable natural and sustainable resources we can use in industry is wood. More efficient and frequent utilization of wood, in combination with sustainable wood practices, can decrease the negative effect of ever-growing market demands. Over the past decade, in the course of current global challenges with respect to carbon dioxide emissions and climate change, the concept of green building has become more mainstream, and the public is becoming aware of the potential environmental benefits of alternatives to conventional construction (Popescu, 2017). Scientists and practitioners must constantly develop and discover new approaches that will lead to optimization of product design, production processes and services. Wood constructions show great potential when looking for possible ways to push forward a more sustainable building mentality (Kromoser et al 2022).

Analyzing studies and papers, regarding sustainable production and construction, it is evident that practitioners have recognized Life Cycle Assessment as beneficial tool when analyzing impacts on the environment but also identifying problematic manufacturing hotspots. The purpose of this study is to analyze the amount of Cumulative Energy Demand (CED) during the material extraction and production of decorative wooden wall covering. Wood-based panels are products used in various applications with the potential to replace energy-intensive materials while promoting carbon sequestration (Costa et al. 2024). Cumulative Energy Demand is a LCA method that sums up all energy inputs required in Life Cycle of a product and helps assess its environmental impact in terms of energy consumption. CED analysis can be also used to compare different products or technologies and serve as basis for identification of opportunities for energy efficiency improvements. CED can be an important tool for informing decision-making processes aimed at reducing energy consumption and environmental impacts. The trick is to raise the standard of living around the world without increasing our impact on the world (Attenborough, 2020).

MATERIALS & METHODS

Life Cycle Assessment (LCA) is a comprehensive method used to evaluate the environmental impacts of a product (process or service) from cradle (raw material extraction) to grave (final disposal) or even partial or complete reuse of given components. In the wood industry, LCA is particularly significant as it helps to understand the sustainability and ecological footprint of wood-based products. The environmental

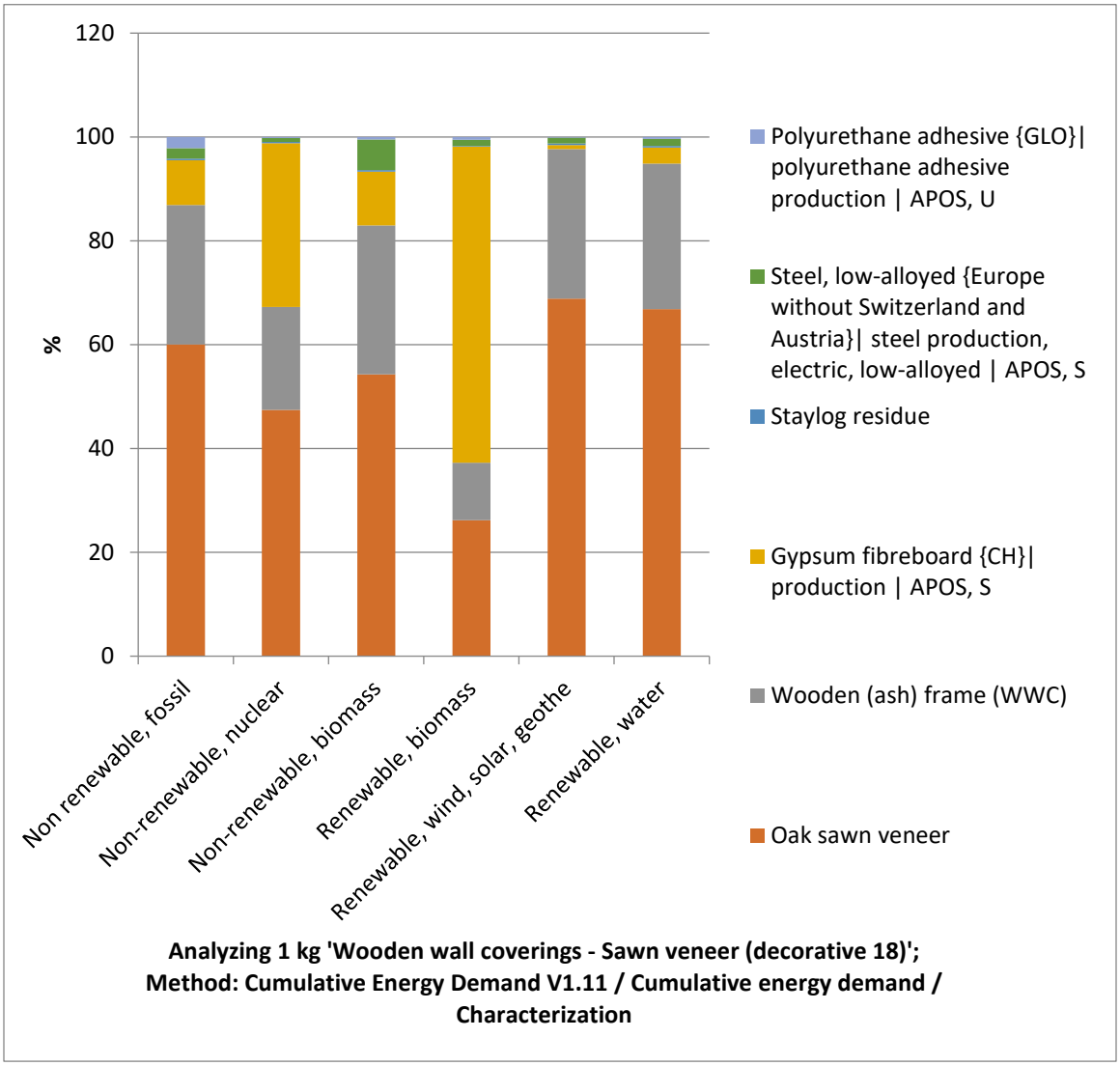
performance of wood-based panels has been widely evaluated in the existing scientific literature using life cycle thinking tools such as life cycle assessment (LCA) and carbon footprint (CF) (Costa et al. 2024). LCA studies require understanding material and energetic inputs and outputs in order to create comprehensive model (Zakuciová et al. 2018). CED is an essential metric in LCA that quantifies the total amount of energy required throughout the life cycle of a (in this case wooden) product. For wooden products, CED includes all energy inputs from the extraction of raw materials to manufacturing, transportation, use, end-of-life, and reuse stages. The system boundaries considered for this study are raw materials extraction and manufacturing stages (including the transportation of elements between the stages). This study was carried out with the *SimaPro* (9.3.0.3), one of the leading LCA software, developed by the *Pré Sustainability* company. CED focus on energy makes it particularly useful in contexts where energy efficiency and conservation are priorities. The results presented in this analysis are displayed within Characterization and Network charts for a 1 kg of Sawn Veneer Wall Covering (which refers to functional unit). *Characterization* in the context of the CED method refers to the process of translating inventory data into a common unit of energy, allowing for the aggregation and comparison of energy inputs from various sources. Characterization factors for the energy resources are divided into the following categories: fossil (non-renewable), nuclear (non-renewable), biomass (renewable), wind, solar, geothermal (renewable) and water (renewable). In *SimaPro*, displaying results as a *Network* is a convenient way to visualize and understand the relationships and flows within a product system. The network view allows users to see how different processes and materials are interconnected, providing insights into the structure and dependencies of the system being analyzed. ISO 14040 considers the principles and framework for an LCA, while ISO 14044 specifies the requirements and guidelines for carrying out an LCA study (Goedkoop et al. 2016). LCA analysis entails the gathering of large amount of data, which can be highly beneficial for product designers. Availability of data in the early stages of product design can support optimization of manufacturing process. Accurate and comprehensive data collection ensures the reliability and validity of the LCA results. The data gathered for this study includes primary data (production processes of wooden elements) form the manufacturers, secondary data (materials for auxiliary elements, energy and transportation) from the *ecoinvent* database, and experts regarding the extraction of raw material (wood) from the forest. Wood-based panels are bio-based materials broadly used in various construction and furniture applications (Costa et al. 2024). While wooden wall coverings are relatively simple in construction, they can have significant functional, aesthetic, and ecological importance in designing our interior and exterior spaces.

RESULTS AND DISCUSSION

CHARACTERIZATION RESULTS OF CED ANALYSIS

Interpreting Characterization results of Wooden wall covering (Table 1), regarding the cumulative energy demand it is evident that the most problematic is the production of sawn veneer elements, which are the main decorative component of the product. The following identified hotspots are the production of wooden ash frame and gypsum fiberboard, which are the main construction components of the covering.

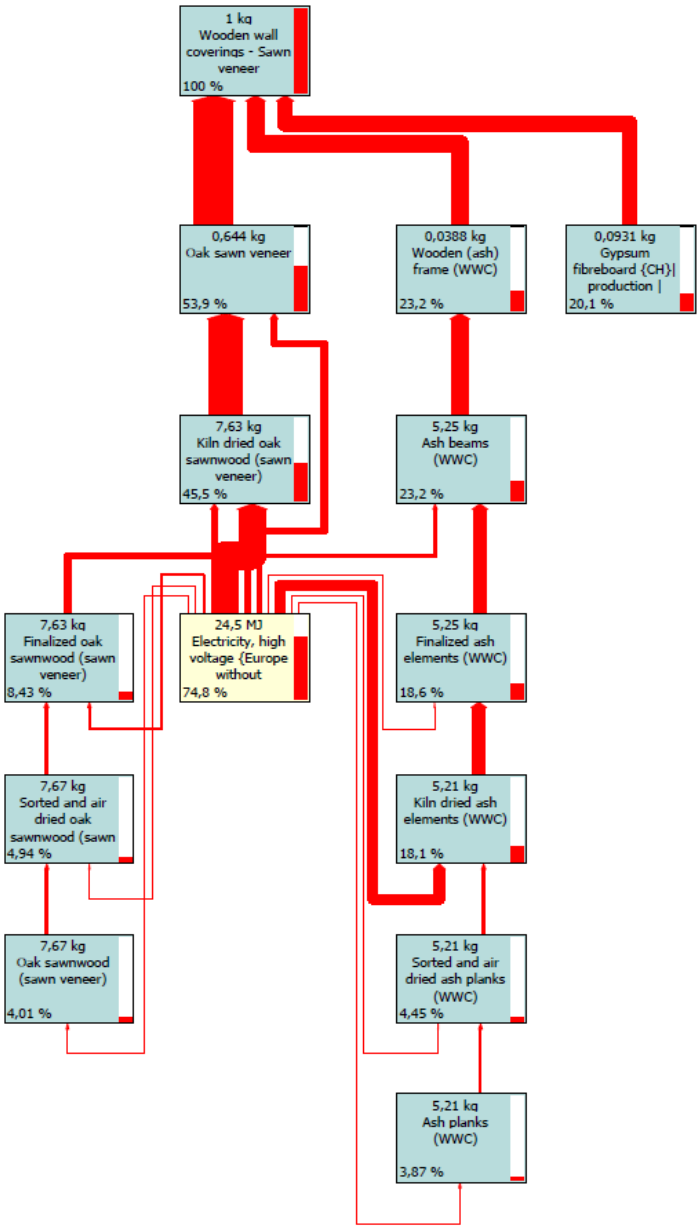
Table 1 Impact assessment chart of characterized results with Analyzing 1 kg 'Wooden wall coverings - Sawn veneer'.



OVERVIEW OF THE CED RESULTS PRESENTED AS NETWORK

By using the network view (Table 2), we gain deeper insights into the structure and impacts of the product system, where we identify critical areas for improvement, and have a chance to communicate findings more effectively. The red bars on the right side of the processes (boxes) are showing the contribution to the environmental load. The thickness of the red lines (arrows) also indicates the total environmental load flowing between processes.

Table 2 Network display of cumulative energy results of 1 kg 'Wooden wall coverings - Sawn veneer'



SUMMARY AND CONCLUSIONS

By implementing LCA, the wood industry can enhance its environmental performance, support sustainable practices, and contribute to the global effort in reducing the carbon footprint of its products. *SimaPro* software provides a reliable platform for analyzing complex life cycles and generating detailed environmental impact reports.

This study gives initial understanding and chance for optimizing the cumulative energy demand of wooden product, in this case decorative wall covering, which enables company that can enhance its sustainability profile, reduce environmental impacts, and promote the use of wood as a sustainable material in various applications.

It's important to note that while CED provides valuable insights into the energy requirements of a product or process, it is just one aspect of a comprehensive LCA. Integrating CED with other environmental impact categories, such as greenhouse gas emissions, resource depletion, and ecosystem impacts, allows a more holistic assessment of the environmental sustainability of products, processes, and services.

ACKNOWLEDGEMENTS

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Effects of chemical denaturation and mechanical homogenization of plant proteins

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ABSTRACT

Wood adhesives derived from plant proteins offer a sustainable alternative to fossil-based adhesives. Plant proteins belong to a group of renewable biopolymers regarded as environmentally friendly and sustainable, especially when obtained from regional sources. In this study, we explore the potential of European plant protein for adhesive applications, focusing on the effects of high pressure homogenization (HPH) in combination with denaturation processes on adhesive properties. The aim is to improve adhesive strength and water stability of these protein-based adhesives. Therefore, maize protein was subjected to HPH treatment with denaturants such as urea, sodium dodecyl sulfate (SDS) and ethylene glycol. The combination of HPH with denaturation agents aimed to expose functional groups to the protein surface, enhancing hydrophobicity and therefore water resistance. Evaluation of adhesive properties included measuring dry substance content, dry and wet tensile shear strength. HPH treatment of plant protein increases final dry substance content and the resulting dry and wet strength according to Malik (to be published 2024). Resulting tensile shear strengths indicated that denaturation agents, particularly SDS, further improved both dry and wet tensile shear strength. Urea exhibited an increase in dry substance content, but did not enhance wet strength. Ethylene glycol improved dry strength but reduced wet strength. Overall, this study demonstrates that the combination of HPH with denaturation agents can enhance the adhesive properties of European plant protein-based adhesives. While promising, further research is necessary to fully comprehend the interactions between denaturation agents and HPH, to possibly further improve the wet strength.

Reconstruction of tree structure in mechanical analysis

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ABSTRACT

Trees provide a wide range of benefits and play a crucial role in the green infrastructure of cities. From a different perspective, they also serve as sustainable and renewable storage of standing wood. Planting and maintaining mechanically stable trees is therefore one of the actual issues, which leads to the study of their mechanical response to load. The mechanical response of any structure is influenced by load, material and geometry, with all three aspects being particularly complex in the case of trees. The fast progress of new technologies has introduced scanning as a valuable tool for obtaining accurate information about tree shapes. This advanced tool, coupled with finite element analysis, provides insight into the mechanical response of trees. However, scanning itself is the first step in a chain of processes and each step can impact the accuracy of the results.

The completed geometry of twelve trees was scanned using Terrestrial Laser Scan (TLS) in both the leaf-on and leaf-off stage. Acquired data, in the form of point cloud, was separated and pre-cleaned in the Cloud Compare software. Subsequently, beam models of trees were created using Tree QSM (Quantitative Structure Model) and employed for finite element analysis (FEA) to assess their static and dynamic mechanical responses. Each step of the process was tested to find their influence on the result. Sensitivity analysis was conducted on the input parameters of Tree QSM, including length and radius of build cylinders, patch size and ball radius of covers, and the influence of element size in FEA. At the end the leaf-on and leaf-off stage was compared. The results showed a high influence of the cylinder length to diameter ratio for model reconstruction. The optimal setting of input parameters was recommended for effective and accurate tree shape reconstruction in FEA and further mechanical analysis.

Influence of internal moisture transfer direction and surface moisturization on drying defect occurrence in red pine round timber

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ABSTRACT

In palace and temple construction and cultural heritage restoration projects, large-cross-section timber is air dried by exposing it to the outside air for up to 3 years before being utilized as building material. In this case, the internal moisture content of the wood was not accurately measured, and large-section lumber that did not reach the usable moisture content was used, causing many problems due to drying defects during the restoration and repair of wooden buildings. Therefore, in order to develop drying process control technology that can dry wood without drying defects, a wood moisturizing method that can reduce the moisture gradient between the surface and inner layers was developed and applied by considering the speed and direction of internal moisture movement of large cross-section timber.

In this study, two large cross-sectional timbers with a length of 1650 mm cut from a pine column with a diameter of 450 mm and a length of 3.6 m were prepared as target trees. The total weight of the raw material was estimated through the average value of the wood density of the disk collected from the raw material and the volume of the raw material, and the moisture content during drying was calculated. In addition, after applying cross-sectional end coating and silica gel cover pre-treatment, the effect of these pre-treatments on the occurrence of drying defects was investigated. It took 840 hours (approximately 28 days) for materials to be dried with an initial moisture content of more than 100% to reach the target moisture content of 19% at an average temperature of 75°C and relative humidity of 90%. Thermocouples, iButton (Hygrochron), HMP60, and LogEt8 THE temperature and humidity sensors were inserted into the target tree at a depth of about 80 mm to measure and record changes in temperature and humidity during the drying period.

Although cross-section end coating could not suppress the occurrence of surface splitting, surface silica gel cover treatment was effective in reducing the occurrence of surface splitting. It is expected that through various and repetitive heat drying experiments, it will be possible to create an optimal drying schedule for extra-large materials for each pre-treatment method.

Keywords: large cross-section, kiln drying, wood density, moisture content, lateral moisturizing, red pine

Analyzing moisture content in natural wood biomass and sweet sorghum mixed with soil using NIR spectra

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ABSTRACT

In the process of storing biomass, problems such as raw material deterioration due to microbial growth and fire due to heat generation often occur. Since these problems are mainly due to failures in moisture management, appropriate moisture management of raw materials and storage environments is necessary. In the case of sweet sorghum and biomass, when measuring moisture content using Near-Infrared (NIR) spectroscopic analysis, higher measurement accuracy was shown compared to commercial electric resistance meters and wood moisture meters. However, research on the analysis of the near-infrared spectroscopic characteristics of unused forest biomass in a natural state mixed with soil and various organic matter is very lacking. Therefore, to measure the water content of lignocellulosic biomass, which undergoes density changes in its natural state, experiments analyzing soil content and water content were conducted using NIR spectroscopy.

In this study, sweet sorghum in its natural state and unused forest biomass were washed to remove foreign substances. They were then divided into 24 specimens, each weighing 1 grams and oven dried. Subsequently, the specimens were conditioned to reach equilibrium moisture content at temperatures of 10°C, 20°C, 30°C, and 40°C, under relative humidity conditions of 30%, 60%, and 80%. Soil collected from Gwanak Mountain in Seoul was prepared in two granularities: fine soil, with particle sizes ranging from 75 μm to less than 150 μm, and coarse soil, with sizes between 150 μm and less than 2,000 μm. These were mixed with the biomass specimens in proportions of 1%, 5%, 10%, 20%, and 30% by weight. The NIR spectrum of each specimen was measured three times at a density of approximately 0.315 g/cm2, after adding the respective amounts of soil.

The predictability of the NIR spectroscopic numerical model, constructed for detecting moisture content and soil content mixed with wood biomass and sweet sorghum was confirmed.

Keywords: NIR spectroscopy, moisture content, soil content, density, unused wood biomass, sweet sorghum

3D volume data of logs from sparse 2D x-ray scans with a combined data- and model-driven machine learning approach

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ABSTRACT

Despite being one of the most advanced countries in terms of sawmilling technology, only 20% of the annually harvested forest in Sweden is transformed into products with a long lifetime and a high rank in the material cascade (e.g., sawn timber). The main cause for this low resource efficiency is the fact that – in contrast to many other industries – the quality of the final product is only known after it is already produced. With the help of X-ray computed tomography (CT) it is possible to observe the internal features of a log in 3D (especially knots), which enables the prediction of the product quality before making the first irreversible processing decision. Unfortunately, such equipment is expensive and at this point only used by very few sawmills. 2D discrete X-ray devices, however, are ubiquitous in medium- to large-size sawmills.

Hence, the objective of this study was the development of a machine learning algorithm to obtain 3D volume data of the interior of a log from only a few discrete 2D X-ray scans, and to evaluate how well knots can be detected from those reconstructions.

From a dataset of 50 CT-scanned Scots pine logs, we simulated the raw data of 2D X-ray scans from 5, 7, 9, 11, 13, and 15 scanning directions, and applied the novel 2.5D Learned Primal-Dual (LPD) algorithm to reconstruct 3D volume data that could otherwise only be obtained by full CT scanning. The LPD algorithm has a deep learning architecture that also takes into account physical constraints of the X-ray scanning procedure. The novel 2.5D aspect refers to the fact for the sequential reconstruction of each target region of a log some part of the surrounding region is also taken into account. To detect knots, 3D U-Net segmentation models were trained on the reconstructed 3D volumes and compared against the full 3D CT volumes of the original log dataset.

Naturally, the reconstruction performance improved with more X-ray directions, but even with only 5 directions, the 2.5D LPD algorithm could reconstruct usable volume data. Especially for such few directions, the 2.5D LPD provided more detailed images than the previous 2D version of the LPD architecture. For 9 and more X-ray directions, the knot detection performance was only marginally lower than full CT scans, and even the industrially much more relevant 5 X-ray directions only had a performance drop of 15% compared to full CT scans.

The next iteration of our approach will be to introduce log rotation – as could be done by a conveyor system – to increase the richness of the data and thereby decrease the number of required X-ray directions, which would make this technology very attractive for the wood industry. On a research level, the resulting data will be the input for the deep learning-based prior-to-sawing prediction of the strength and stiffness or visual grade of sawn timber.

Major wood products monitoring tools in Korea market

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ABSTRACT

Each country is establishing a forest sector promotion strategy as part of its carbon neutral policy. In the case of Korea, the domestic wood production target was set from ('20) 4 million ㎥ in 2020 to 8 million ㎥ in 2050 through the "Forestry Sector Promotion Strategy to Achieve Carbon Neutrality in 2050" (December 2021). presented as. As the supply of domestic wood increases, it is necessary to establish a system to observe changes in our country's wood industry.

The structure of Domestic wood industry, which has recently become highly dependent on foreign imports, including imported wood, is greatly influenced by the import volume and price of wood products. Accordingly, it is necessary to establish an wood products early warning system that can recognize market risk factors in advance in relation to the stable supply of raw materials and the distribution of wood products. In this study, we developed a wood product distribution analysis tool, which is a major component of the wood products early warning system.

Factors were derived through analysis of procurement routes and supply and demand structures of wood products, including logs, lumber, fiberboard, and particleboard. The main factors were classified by the production area of the logs. The main factors for domestically produced wood products were set as supply, demand, and price, and for imported wood products, they were set as demand, price, etc. Exogenous variables include exchange rates, sea freight index, construction economy index, and overseas local prices.

Based on this, a model was developed that takes into account supply and demand in the raw material market and wood product market, including the supply relationship of domestic logs. For logs and wood products, actual and estimated values were verified at a 95% confidence level using supply, demand, and prices from 2010 to 2021. The model was developed based on Excel, and can make rapid predictions using 27 variables, including domestic lumber supply and demand functions, and can also be used for short-term predictions depending on the internal and external variables of the industry.

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High hardwood protection from subterranean termites in tropical zones with new generation biobased/vegetal extracts in water-borne solutions

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ABSTRACT

Treated wood is worldwide a key element in the decarbonization process as this provides related long-lived harvested forest-based materials and products. Therefore, it is necessary to respond to the need to develop suitable, cost-effective, and environmentally friendly wood preservatives for permanent wood protection.

SYNERKEM® technology is the result of scientific development and research into the degree of synergy between plant antioxidants (plant extracts), which have no insecticidal or fungicidal properties on their own, and conventional biocides. Synergistic mechanisms are generated in combination with common insecticides, which can increase the toxic potential of the formulation, thus enabling the concentration of insecticides in the final formulation to be reduced. In this way, it is possible to obtain wood preservatives that will have the same efficacy as conventional treating products, while being less damaging to the environment and human health.

In this respect, equatorial tropical termite field tests were conducted on Malaysian hardwood kempas (*Koompassia malaccensis*) test blocks treated by different modes of surface application. The test blocks were envelope-treated by brushed-on with either a proprietary formulation containing cypermethrin boostered with vegetal extracts (SYNERKEM® technology), or dip-treated for 3 minutes with either a permethrin-based micro-emulsion proprietary formulation or cypermethrin-based micro-emulsion formulation.

Conditioned enveloped treated woods were then artificially weathered to simulate aboveground indoor exposure conditions (H2 hazard class: lab evaporative ageing of treated wood) or aboveground outdoor conditions (H3: lab leaching plus evaporative ageing of treated wood) before subjected to a unique (Wong 2005) Malaysian/Australian H2-hazard class (aboveground and not exposed to wetting) field termite test against natural populations of *Coptotermes curvignathus* at a humid near peatswamp forest site in Kota Samarahan, Malaysia.

After 6 months test, untreated kempas was clearly termite-susceptible (both high percent and absolute (=milligram) wood mass losses, poor termite visual ratings) unlike those treated with the SYNERKEM® technology biocide and 2 pyrethroid-biobased micro-emulsion solutions, reference permethrin-based LOSP (3 minutes dipping) and reference CCA-treated radiata pine, all these displaying total hardwood protection (negligible mass losses, highest termite rating).

These three novel wood preservatives are clearly suitable for “permanent” protection of up to H3-weathered envelope-treated hardwood against *Coptotermes* termites under both aboveground indoor (H2-hazard class) and aboveground outdoor (H3-hazard class) situations for constructed wood in service where only minimal quantities and adequate dosages of biobased preservatives are desired within an increasingly environmentally conscious society in favour of green building constructions.

Synthesis of greener phenol-formaldehyde resins from pyrolytic lignin of forest biomass

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ABSTRACT

In this work, a partial replacement of phenol and formaldehyde (petrol-linked compounds) with pyrolytic lignin from wood origin in phenol-formaldehyde resins was carried out. The pyrolytic lignin used was obtained from the bio-oil produced in a biorefinery fed by wood coming from sustainable management of Mediterranean forests. Three different forest species were used: *Pinus halepensis*, *Quercus ilex* and *Castanea sativa,* which were pyrolysed in an auger reactor at 450 ºC. The separation of the pyrolytic lignin was carried out by cold-water extraction, and further separation of the water-insoluble fraction with a mix of water and methanol. The lignin fraction obtained was characterized by FTIR-spectroscopy and compared with commercial organosolv lignin. For the adhesive production, different degrees of substitution were investigated (ratio pyrolytic lignin:phenol wt/wt 0:100, 30:70, 40:60, 50:50 and 60:40). In this investigation a novel reduction of not only phenol but formaldehyde was carried out, with reductions (compared to the control resin 0:100) of 14% for the 30:70 formula, 20% for the 40:60 formula, 22% for the 50:50 formula and 36% for the maximum substitution formula 60:40. These high substitutions boost the innovative production of an alternative greener adhesive partly made by renewable value-added chemicals from the biorefinery, helping the commercialization of the lignin-phenol-formaldehyde adhesives, commonly used in the manufacture of wood-based panels such as plywood, particle board and fiberboard. The resins were compared according to the most relevant physicochemical properties: pH, solid content, specific gravity, hardening time and free-formaldehyde content. The results showed that lignin-phenol-formaldehyde resins with a 50:50 and 60:40 of pyrolytic lignin:phenol from *Pinus halepensis* offers the best curing performances, lowest levels of free-formaldehyde and the higher hazardous chemicals replacement.

Mapping the value chain of wood products

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ABSTRACT

While wood plays an increasingly important role as a renewable resource, the wood products industry globally navigates complex challenges. Fostering innovation and collaboration across all wood product sectors is vital. A comprehensive map of the wood products industry offers a clearer picture of material flow and is an essential tool for industry advancement, education, and research. This study seeks to unlock new economic possibilities while advocating sustainable resource management. A "Generic Wood Products Industry Map" provides a comprehensive overview. At the same time, detailed "Chain Maps" delve into the four major production sectors: Sawmill, Veneer Mill, Reconstituted Wood Production, and Pulp and Paper Manufacturing. A "Waste Management Wheel Diagram" also charts existing and potential waste management strategies across all processes. This holistic approach emphasizes efficient material use and management, pinpointing areas ready for innovation and value-added product development. It empowers informed decision-making on product end-of-life options and proposes strategies to minimize waste. Ultimately, this research aims to deepen understanding and showcase the potential for circularity and sustainability within the wood products industry. These maps are designed to serve a diverse audience, including industry professionals, architects, designers, builders, and the general public, fostering a shared understanding of this vital sector.

Strong and CO_2 consuming living wood for buildings

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ABSTRACT

The exploration of eco-friendly building materials has proclaimed wood as a significant contender in diminishing carbon emissions within the construction industry. Traditionally, living trees play a crucial role in carbon sequestration, absorbing CO_2 from the atmosphere. However, wood's ability to capture carbon could be compromised when transformed into building materials. Natural wood may suffer from altered structural integrity and be vulnerable to microbial decomposition and weathering. Conversely, the advent of engineered wood products offers enhanced and uniform mechanical properties, indicating a sustainable pathway for construction that prolongs carbon storage in both newly constructed and renovated structures. This research introduces an innovative "living" material, capitalizing on microbial activities within wood matrices to convert traditional wood into a sustainable and biodegradable composite. This composite not only improved mechanical strength but also has superior carbon-fixing capabilities. By integrating microbes during the wood processing phase, this strategy seeks to transcend the boundaries of traditional wood engineering techniques. It presents a renewable substitute for finite construction materials such as steel and concrete, offering an innovative resolution to the sustainable construction challenge. Utilizing the symbiotic relationship between microbes and wood, this innovative approach marks a pivotal advancement toward crafting eco-conscious building materials that facilitate carbon storage and mitigate climate change effects in the construction sector.

Hardwood cross laminated timber (CLT) product development and joinery evaluation

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ABSTRACT

The concentration of carbon in the atmosphere is drawing the attention of scientists, policymakers, and the general public. In the realm of forest products, Cross Laminated Timber (CLT) has emerged as a significant innovation in large-scale engineered wood products, offering a promising means of effectively sequestering carbon within its structural material. This research focuses on scaling down the thickness of conventional large-scale CLT for interior applications and furniture manufacturing purposes. This initiative aims to meet the demand from individuals, designers, and others seeking solid wood rather than composite materials. Additionally, given the global shortage of wood, particularly softwood species, we are shifting our attention towards hardwoods. Previous studies have indicated that yellow poplar exhibits comparable or superior mechanical strength when manufacturing CLT. Hence, we have chosen Yellow Poplar, along with black walnut, to produce hardwood CLT (HCLT). This study aims to use thin Hardwood CLT panels to produce selected joinery to evaluate the structural integrity of material connections. This evaluation seeks to determine whether the joinery techniques employed are sufficient to meet design strength requirements. Utilizing solid wood for furniture and wood-based structures would sequester carbon and help to substitute materials with high carbon emissions. Therefore, hardwood CLT would contribute to resource sustainability and environmental protection.

Ultrasound-assisted impregnation of wood

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ABSTRACT

The wood industry and research institutes are constantly developing new protective agents to protect wood products from biotic and abiotic factors. It is crucial that the active biocides are evenly distributed in a liquid medium, especially when impregnating solid wood objects. Since some compounds with wood preservative potential are poorly soluble in organic solvents or water, their use in impregnation processes causes serious problems and may even become impossible. To impregnate wood with insoluble or low soluble compounds in a liquid medium, suspensions such as the colloidal type are produced. However, the production of such solid-liquid mixtures under laboratory conditions is costly and impractical, and precipitation of the active ingredients over time is also a problem. There are similar problems in the use of low-solubility nano-sized compounds in the field of wood preservation. In particular, the very low solubility of some nanocompounds synthesized in scientific studies limits their use with impregnation methods. An impregnation method is needed to rapidly demonstrate the evaluation of the potential use of such poorly soluble chemical substances in the field of wood preservation. In order to meet this need, the idea of combining the traditional impregnation system with ultrasonic technology was emphasized. The scope of the study, the prototype of an ultrasound-assisted impregnation vessel was created to increase the usability of nanoscale but poorly soluble substances in the field of wood preservation. In this study, the basic principles of the ultrasound-assisted impregnation method are explained. For this purpose, solid wood material is impregnated with a copper-based nano-compound, with or without ultrasound application. The retention level, the penetration depth and the homogeneity of the copper distribution in the treated wood are then investigated. The effectiveness of the ultrasound-assisted impregnation method has been evaluated and criticized.

Key Words: Wood Protection, Ultrasound-Assisted Impregnation, Treated Wood, Nano-Compound, Impregnation Methods

A novel vibration sensing device for measuring flanking transmission in mass timber buildings

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ABSTRACT

Whole-body vibrations, which are known to be relevant for the perception of low-frequency sound, can be perceived especially in lightweight constructions. Basically, the contribution of vibrations to impact sound annoyance is still unknown and could be the reason for the contradictory results in recently conducted research. To investigate this aspect, we recorded vibrations on different types of floors under laboratory conditions and in situ. The aim was to reproduce the recordings in a laboratory, developing a vibration exposure device, which is an integrated part of the ambisonics reproduction system, consisting of a large number of loudspeakers in a spherical configuration. For this purpose, a vibration-sensing device was developed to record vibrations more cost-effectively and independently of commercial recording instruments. The vibrations of predefined impact sequences, like walking with or without shoes and with different velocities, were recorded together with the sound field using a higher-order ambisonics microphone. In addition, this vibration exposure device is considered as a low-cost opportunity for the measurement of the vibration reduction index (Kij) used for determining the flanking transmission of noise in junctions of mass timber buildings. The contribution presents the development and the achieved performance using the vibration sensing unit, tested in a mass timber building acoustic test suite. Results are compared to commercial vibration recording instruments and the potential application of the developed vibration sensing device to measure the acoustic performance of junctions in mass timber buildings, as a basis for prediction of sound insulation performance according to EN ISO 12354, is reviewed.

Key Words: mass timber buildings, vibration sensing device, flanking transmission, junctions, vibration reduction index

Evaluation of the effect of biogenic carbon in wooden building products on climate change by dynamic modelling

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ABSTRACT

In the course of its growth, a tree absorbs CO_2 from the atmosphere and stores it in form of carbon. This leads to a reduction of greenhouse gas concentration in the atmosphere and represents an important contribution to mitigating the climate crisis, especially if CO_2 remains stored in the wood for a very long time. This long-term storage is mainly fulfilled by durable wood products (mostly used in primary construction) in the construction sector. Even if this process is a temporary CO_2 storage, it still avoids direct emissions and thus facilitates medium- to long-term CO_2 reduction targets. However, this is precisely what cannot be mapped with the current method of life cycle assessment of construction products and buildings, provided by EN 15804+A2 and EN 16485. This issue has already been encountered and led to the inclusion of dynamic life cycle assessment in the 2024 annual Union work programme for European standardization.

A first goal is the development of a comprehensible model for mapping the temporary CO_2 storage of durable wood products. Essential parameters for quantifying the effect of temporary carbon storage are the degradation rate of greenhouse gases in the atmosphere and the net carbon uptake in the forest during the lifetime of the construction product. The latter, amongst others, depends on the rotation times of the relevant tree species and their predicted variations due to climate change. In the project's approach, these are determined as input parameters for the dynamic wood product model by means of a dynamic forest model. The adequate consideration of reuse or recycling as well as innovative approaches to End of Life treatment of timber products are also included in this model as input parameters.

The combination of several different modelling approaches with different outputs – forest growth model, LCA wood product model, greenhouse gas decay model and End of Life model – is just one of the challenging aspects.

The result is a holistic quantification of the CO_2 sink of timber, taking into account all relevant input parameters that are variable over time up to the year 2300 in various scenarios. So, amongst others, a minimum storage time of carbon in building products could be identified to ensure a positive climate effect as well as the impact of different harvesting methods with related implications on carbon stock in the forest. Another important contribution comes from End of Life decisions, which seem to be crucial for a positive climate mitigation effect of building products made of wood, implicating the need for intensifying research on this aspect.

The findings gained from the dynamic models are integrated into a simplified model that addresses new, regulatory, economic and societal challenges that require reliable and well-founded methods for determining avoided emissions and their actual effects on the climate crisis.

Key Words: life cycle assessment, dynamic LCA, temporary carbon storage, greehouse gas, carbon sequestration, carbon removal

Thermal modification and steam bending for exterior applications

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ABSTRACT

The use of wood in the modern built environment comes with challenges related to aesthetics and durability. Aesthetically, it can be difficult to make wood follow the shapes of arches and curves. From a durability point of view, not all wood species can be used in exterior applications if chemicals were to be limited. By applying steam bending and thermal modification to wood, the appeal and durability of wood can be increased for use in aesthetically demanding exterior applications. Steam Bending is a century-old process used to fabricate round, curved wood elements. The process uses steam to heat up and soften the wood structure. Upon bending the wood, fracture at the cellular level is minimized. After letting the wood cool down it will retain its shape. Thermal Modification increases the durability of wood products by changing the wood's chemical structure. As a result, the wood is more dimensionally stable and much less degradable by microorganisms. Wood species with an initially low durability designation can be used in exterior applications after thermal modification. The goal of this project is to combine these two techniques to produce an aesthetically attractive material for outdoor uses. Different properties, such as strength and springback are measured to assess the combination of both methods. Eventually, the results will be used in the context of designing wood-based EV (Electric Vehicle) charging stations.

Research on the preparation of wood-based bio-composites with low formaldehyde emissions

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ABSTRACT

Formaldehyde is harmful to human health, and maximum emission limits in interiors are set by national and international standards, e.g., E0, E0.5, E1, ENF, CARB NAF, F****, etc. The aim of the study was to reduce the release of formaldehyde from wood-based materials by developing and testing new, more effective environmental modifiers that bind formaldehyde. In this study, the biopolymers collagen and keratin were prepared and tested as potential agents for reducing formaldehyde emissions from wood-based materials bonded by urea-formaldehyde adhesives (UF).

The experiments with UF resin modified by collagen and keratin confirmed the possibility of altering the properties of adhesive mixtures with a significant decrease in formaldehyde content in condensed UF resin and emission from wood-based panels. The MALDI-TOF spectra of both keratin and collagen samples showed a wide distribution of molecular weights while showing great importance to the type and length of applied hydrolysis. The ATR-FTIR spectra of collagen and keratin samples showed similarity with respect to the bands typical for protein materials. The XPS spectrum of keratin samples depends on the method of modification and the thermal degradation temperature. In the case of sulphur, its total amount in the sample increases from 3.8% to 5.9%, which is caused by the modification of keratin by sulphur at a temperature of 120 °C. The amount of sulphur in the reduced form expressed as sulphide also increases slightly in the sample, from 44.4% to 58.4%. The antioxidant activity of the keratin hydrolysate was studied by DSC and determined in a suspension of polyethylene glycol. The substance has a protective effect, i.e., behaves as an antioxidant if the PF value is > 1. This condition is met by the studied keratin hydrolysate above approx. 60 °C, and below this temperature it behaves as a pro-oxidant. Formaldehyde emission was assessed from five-layer plywood by the desiccator method according to EN ISO 12460-4, and a 38% reduction was achieved compared to the reference sample. The quality of gluing was tested according to standards EN 314-1 and EN 314-2. The tested plywood fulfils the requirements of the standard for gluing class 1 – they are suitable for application in a normal interior environment.

Key Words: formaldehyde emission, wood-based composite, urea-formaldehyde resin, collagen, keratin

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Properties of steamed birch wood treated by discharge plasma

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ABSTRACT

The treatment with warm steam represents a hydrothermal method of modification; steam alters the chemical and physical properties of wood. This method can improve the dimensional stability of wood as well as the colour of wood. The heat and water steam modification of wood results in chemical changes influencing its hydrophobicity. Hydrophilization and/or hydrophobization of wood by water steam were studied by authors who reported the properties of wood after steam treatment, and FTIR spectroscopy was used for analysis. The effect and mechanisms of the water-steam degradation process regarding changes in the chemical structure have not been understood in detail. The hydrophobicity of birch wood (*Betula pubescens* Ehrh.) after steam modification was found to increase. A decrease in the absorption rate of water drops was confirmed on the steam-treated birch wood surface. FTIR as well as XPS measurements of steam-treated birch wood confirmed a decrease in oxygenic functional group content as well as an increase in carbon content on the birch wood surface. SEM measurements confirmed minor changes in the morphology of birch wood structures after modification with water steam. The radio-frequency discharge plasma was used to increase the hydrophilicity of the steam-modified wood due to the formation of various polar groups (e.g., hydroxyl, carbonyl, carboxyl, etc.). The plasma treatment proved its efficiency; plasma-treated samples reached significantly lower contact angle values in comparison with plasma-non-treated samples. Better hydrophilicity was confirmed by the higher tensile strength properties of lap adhesive joints after different conditioning sequences.

Key words: birch wood, steam treatment, plasma treatment, surface properties, adhesion, FTIR, XPS

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Technological feasibility of plasma assisted modification of glued joints for cross-laminated timber

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ABSTRACT

Today, wooden structures are mostly built using glued massive materials of cross-laminated timber (CLT) and glued-laminated timber (GLT). During the life of the structure, the glued joints undergo many unavoidable physical and chemical stresses, which often lead to their degradation and sometimes even delamination. Therefore, it is important to have a high-quality glued joint to increase the life of the building. In the presented work, we shall inform on our assessment of the effect of improving the quality of a joint glued with melamine-urea-formaldehyde and polyurethane adhesives using plasma-assisted pretreatment, specifically the activation of the wooden boards surface (beech, spruce, and larch) with plasma shortly before the actual gluing. The key issue is the identification of an effective and technologically robust solution for plasma surface activation for large, relatively thick (>10 mm) wooden boards. On the basis of the current state of knowledge, a cold plasma based on dielectric barrier discharge (DBD) was used for plasma activation, which works at atmospheric pressure, and has short plasma treatment times (max. tens of seconds per wooden board) and a low temperature of the discharge gas (approx. 60-80°C) that does not damage the wood. The efficiency of the well-known, laboratory-proven DBD system with a coplanar electrode geometry will be compared with two new variations of the DBD arrangement, designed specifically for CLT-intended wood panel activation, with the ambition of offering a more energy- and time-efficient surface treatment. The characterization of the level of surface treatment achieved is realized by measuring the surface energy using the sessile droplet method, or the rate of absorption of an aliquot volume of the test liquid. The actual determination of the achieved improvement in the adhesion properties of the surface is determined by lap shear tests of the bonded samples. The main tool for the analysis of chemical changes in the activated surface will be FTIR in the reflection configuration. The morphology of the applied adhesive as well as the unglued joints are also examined microscopically.

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Mass flow analysis of Korean wood products

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ABSTRACT

As international interest in the contribution of wood products to climate change as a carbon storage is increasing, carbon accounting through wood use at the national level is being attempted. Research on national wood resource material flow analysis methods to present the IPCC basic approach has been actively conducted since the 2000s. And in order to increase the carbon storage effect of wood, which is a key element in achieving carbon neutrality, a plan to expand demand is being proposed to promote the use of wood. The need to perform Life Cycle Assessment (LCA) is gradually increasing in order to quantitatively prove the environmental properties of wooden structures using domestic wood and to scientifically calculate various environmental information such as global warming, acidification, and eutrophication of domestic wood products. It is increasing. As a method of systematically evaluating the flow and accumulation of resources, the principle of mass balance is applied to calculate input, output, and accumulation throughout the entire process from production to disposal of resources. The entire process of wood resources was subdivided into six stages to establish clear flow connectivity, and a mass balance-based material flow diagram was derived for efficient use of wood resources. It is easy to utilize statistical data on the amount inputted from resources to raw materials, production, and industry during the entire process of wood resources. To date, the flow of the path calculated in the process has been identified, and data on the number of by-products, or losses, generated during product production have also been secured based on field data. Based on data on the use flow of lumber by-products, the rate of re-injection into boards is applied at approximately 30%. It was confirmed that the amount of waste wood generated by source at the disposal stage of wood resources was highest in industrial waste, and about 87% was recycled. It can be seen that 100% of discarded household waste is recycled, and more than 97% of construction waste is reused, showing that wood resources play a role as an excellent material in resource circulation. However, the mass balance can be achieved by calculating the accumulated amount of the quantity re-introduced from the recycling stage to the industrial stage. A life cycle assessment was conducted on the structural materials of wooden buildings based on the material flow of domestic wood resources. Through case studies, mid-to-large reinforced concrete buildings were designed to be converted to wooden structures. As a result of conducting a life cycle assessment using the quantity of structural members calculated through design, it was confirmed that the greenhouse gas emission reduction effect of converting to a wooden structure compared to the existing building was confirmed. Through this process, detailed and precise material flow analysis of wood products is expected to play a pivotal role in establishing the carbon neutral contribution of wood construction.

Advancing the woodworking industry through integration of artificial intelligence

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ABSTRACT

The recent emergence of artificial intelligence (AI), epitomized by systems like ChatGPT, has sparked widespread interest across numerous sectors. This technology offers transformative potential across various domains, including woodworking industry. AI-driven design software expedites idea generation and streamlines 3D modeling. During construction, AI optimizes details through techniques like topology optimization and generative design. In production, AI automates CNC machining programs, enhances quality control via advanced image analysis, and predicts production needs. AI aids in market analysis, informing strategic marketing decisions and facilitating customer engagement. While AI promises efficiency gains and innovation, ethical considerations and regulatory frameworks are crucial to ensure equitable treatment and mitigate concerns of job displacement. An exploration of current AI solutions in woodworking industry highlights its crucial role in ongoing digital transformation efforts. AI can support various processes and be an important part of the digitalization of wood processing companies in line with New European Bauhaus values.

Flexible and aesthetic wood veneers

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ABSTRACT

Wood and wood veneers are used in a variety of interior applications. On the one hand, this can be the case for conventional furniture or flooring, due to the abundance of aesthetic design options, but it can also go far beyond that. Refined wood surfaces can thus be found in the highest quality luxury furnishings. Here, new design options and smart features are intended to realize areas of application far beyond the state of the art. Special attention was paid to the highest possible deformability of the veneers used to achieve previously unthinkable elasticity of the materials used. Naturally, the challenge here was to make the veneers more flexible without destroying their aesthetics, but still to maintain a certain strength to ensure processability or applicability on substrates. Based on the state of the art, several modifications and adaptations were necessary to meet the technical as well as the aesthetic requirements. Fact is that this question could not be implemented exclusively with already known methods. It becomes clear that approaches can work in terms of flexibility, but the aesthetic impression of the wood veneer is lost due to massive colour changes and staining, up to complete fraying.

At the end of a series of modifications and adaptations, both in the flexibilization method itself and in the individual processing steps, the desired aesthetic impression could be achieved in combination with the highest possible deformability. In an additional step, the flexible veneers can be provided with a coating with functional properties. This research question is the subject of ongoing development work. In addition to the accompanying analysis and data evaluation, Wood K plus also contributed know-how in sample production on a laboratory scale to prepare the construction of the demonstrator at the company partner. The company partner researches natural, high-quality and flexible materials to create shape-changing interiors that combine functional customer benefits with unsurpassed aesthetics to create more space in the cabin. One example is a flat real wood veneer tray that transforms into a tray for contactless charging of the phone when a mobile phone approaches. The fact that wood does not have to be a conservative material, but rather creates the transformation towards a highly functional and at the same time aesthetic material, was shown with this implementation.

Specialized data crawlers for forest products

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ABSTRACT

The Internet is composed of 50 billion websites and grows larger every day. As the number of links and specialty subject areas increases, it becomes more difficult to find pertinent information. Special purpose data crawlers continually search the Internet for specific information on, for example, real estate, air travel, auto sales, and others. Such single-purpose crawlers can search for hundreds of keywords and use machine learning to determine whether what is found is relevant. The use of such special purpose data crawlers and associated knowledge databases also allows the collection and analysis of agricultural and forestry data. In this presentation, we discuss the development, architecture, functioning, and applications of such specialty knowledge database and crawler system to find information related to two growing forest products sectors: Mass Timber and Urban & Reclaimed Wood Utilization. Our search engine uses intelligent software to locate and update pertinent references related to urban wood as well as to categorize information with respect to common application and interest areas. At the time of this publication, the mass timber and urban wood knowledge databases have catalogued more than 4,500 and over 700 references regarding various aspects of these two topics, respectively.

Some properties of plywood panels manufactured by combining veneers of different wood species in one structure

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ABSTRACT

The research aimed to develop plywood panels by combining birch veneer with alternative wood species in one panel and to evaluate the influences of different lay-up schemes on the properties of the plywood. Five-layer plywood panels were formed with 19 different lay-up schemes using birch (*Betula verrucosa* Ehrh.), black alder (*Alnus glutinosa* L.) and aspen (*Populus tremula*) veneers. The different lay-up schemes were to identify opportunities to improve the mechanical and physical properties of the plywood by replacing high-grade birch veneer in the plywood structure with alternative low-grade alder and aspen veneers with different thicknesses. For comparison, single-species plywood panels were also manufactured. The thickness, density, compression ratio and bonding strength of plywood panels manufactured using urea-formaldehyde (UF) adhesive were determined. It was found that plywood panels manufactured from a mixture of birch and aspen species offered higher bonding quality when compared to panels manufactured from birch or aspen veneers only. The bonding strength values of all panels met the European Standard EN 314-2 for Class 1 plywood. It was shown that alder and aspen veneers, despite somewhat lower strength properties than birch veneer, could be successfully used with proper lay-up schemes in the veneer-based products industry.

Keywords: plywood; lay-up scheme; birch; black alder; aspen; density; bonding strength; adhesives

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Surface and chemical properties of beech wood after treatment with saturated steam and cold plasma

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ABSTRACT

The high-temperature steaming of wood represents a hygrothermal method with more effective heat transfer than conventional heat treatment and is aimed at decreasing hygroscopicity and improving the dimensional stability and durability of the wood. In this process, steam is applied to alter chemically and physically the constituents of the wood. The water-steam modification of wood results in chemical changes influencing its hydrophobicity. The steam degradation of wood alters its chemical and physical properties. Imaging FTIR microscopy has proved to be a valuable tool for the *in-situ* characterization of variations in wood chemical structure. The water-steam modification of the beech wood (*Fagus sylvatica*) changes the chemical composition and influences its hydrophilicity. Hydrophilization and/or hydrophilization of wood treated by water steam have not been studied yet, but further, more detailed experimental research is necessary. The aim of this study was to investigate the effects of the water-steam-treatment process on the chemical changes in the wood components. A further aim was to identify whether these changes are correlated with surface properties and microscopic alterations in the selected wood. The hydrophobicity of beech wood after steam modification was found to increase. A decrease in the absorption rate of water drops was confirmed on the steam-treated beech wood surface. FTIR as well as XPS measurements of steam-treated beech wood confirmed a decrease in oxygenic functional group content as well as an increase in carbon content on the beech wood surface. Subsequent application and surface treatment with cold plasma treatment, the surface-free energy of beech wood is increased as a result of the introduction of polar functional groups on the treated surface, thus making the surface of the wood more hydrophilic. The increase in polarity of plasma-treated wood was observed in all cases. The water contact angles on the investigated beech wood surfaces markedly decreased with the time of plasma modification. The FTIR investigation confirmed the increase in wood hydrophilicity/polarity in all cases due to irradiation by plasma. The content of COOH, C–O and C=O on the surface of wood groups after cold plasma treatment significantly increased. The enhancement of wood wettability as a necessary condition to promote better adhesion confirmed the increase in shear strength of the adhesive joint. Environmentally friendly gluing allows the raw material to retain all of its good natural properties and also makes it more stable and durable.

Key words: beech wood, saturated steam, surface properties, cold plasma, water contact angle, surface chemistry, shear strength, adhesion, FTIR, XPS.

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Lessons from a worldwide interlaboratory study on water vapor sorption

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ABSTRACT

Over the past eight years, we have shown that commonly used protocols for using automated sorption balances (often called dynamic vapor sorption or DVS analyzers) for collecting water vapor sorption isotherms in wood lead to unacceptably high errors and uncertainties in the data. These commonly used protocols stop the absorption prior to equilibrium resulting in an under prediction of up to 1% moisture content in the equilibrium moisture content (10% relative error). However, our suggested protocols for acquiring high quality DVS data are still often not used because they require a long hold time at each relative humidity step. Previous work has shown that a systematic correction factor can be applied to data collected with the commonly used short hold times, although this was only tested on a small amount of data from one laboratory. In 2021 we began a worldwide interlaboratory investigation in automated sorption measurements. The goal of this study was to gather data on matched wood samples from many different types of sorption balances and many different laboratories to develop a systematic correction factor that could be applied to sorption data collected with short hold times. However, along the way, we have learned many lessons about the temperature, mass, and relative humidity stability of these instruments. This paper shares lessons learned on how to identify potential problems with DVS instruments and how to obtain high quality sorption data.

In situ SAXS analysis for tracking the change in multiscale structure of wood under flexural deformation

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ABSTRACT

The material properties are determined by the structure in general. In case of wood, due to its hierarchical structure, multiscale structural analysis is required to understand which structural level affects the observed material properties. In this study, we attempted to visualize how the distribution of cellulose microfibrils as well as the distribution of cell cavities in wood, changes under bending deformation using in situ measurements with small-angle X-ray scattering (SAXS). The microscope observation of bending deformation was also attempted to evaluate the change in cellular structure. We report the findings of these attempts.

Wood specimens with the dimension of 3 mm(L), 2 mm(R), and 50mm(T) was cut from the earlywood region in the heartwood of Japanese cedar (*Cryptomeria japonica*). The specimens were dried at 105°C to reach to the oven-dry condition (oven-dry density: 0.2 g/cm3). The moisture content of the specimens was conditioned to predetermined levels.

In the simultaneous SAXS measurements during three-point bending tests, the specimens were loaded in L direction with a span length of 38 mm. The X-ray beam was irradiated along R direction to the point at which the bending moment was maximum. To prevent irradiated point from shifting during bending deformation, the indenter was fixed, and the supports was displaced in L direction. The displacement was increased stepwise by 1 or 2mm until the specimens were fractured. At each displacement increment, the sample stage was vertically adjusted so that the X-ray beam was irradiated to approximately five points on both the compression and tension sides across the neutral axis.

SAXS measurements were performed at the BL40B2 beamline of SPring-8, the synchrotron radiation facility in Japan. Three-point bending test machine into the experimental hutch and recorded two-dimensional patterns using X-ray wavelength of 1 Å, camera length of 1.5 m, and a photon-counting detector (Pilatus3 S 2M, DECTRIS Inc.). Data reduction was carried out using the python package pyFAI (G. Ashiotis, et al. Journal of Applied Crystallography (2015), 10.1107/S1600576715004306).From the anisotropic scattering patterns, the relationship between the scattering vector and scattering intensity (q-I plot) in equatorial direction was extracted, and quantitative structural analysis was attempted using the WoodSAS model (P. A. Penttila, et al. Journal of Applied Crystallography (2019), 10.1107/s1600576719002012).

The scattering pattern from wood exhibited higher scattering intensity in the equatorial direction. In normal wood, it is believed that the low microfibril tilt angle in the secondary wall middle layer primarily accounts for the scattering pattern in the equatorial direction. In the WoodSAS model, the equatorial scattering from wood is represented as the sum of scattering from three

hierarchical structures: (1) arrangement within the matrix of cellulose microfibrils (diameter of microfibril and space between microfibril), (2) larger assemblies than cellulose microfibrils, and (3) surfaces of cell cavities.

In presentation, we will report on the quantification of changes in the multiscale structure of wood cell walls along the neutral axis, tension side, and compression side with increasing bending displacement.

Mycelium-based composites from recycled wood: Heat insulation materials with low VOC emissions

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ABSTRACT

Mycelium-based composites (MBC) are promising sustainable materials that are created by connecting lignocellulosic (LC) particles as the substrate with the mycelium of wood-decaying fungi. Unlike conventional composites, no additional adhesives are used since LC particles are bonded by single fungal hyphae. For MBC production, the substrate design is crucial since it substantially affects the MBC properties. In this study, recycled wood (RW) was as the substrate for growing MBC. Several substrate variants based on RW were tested. Filamentous fungi belonging to the phylum of Basidiomycota, i.e. *Ganoderma* spp., *Trametes versicolor* and *Pleurotus ostreatus*, were used to connect the substrate particles by the mycelium. Selected physical and mechanical properties of the produced MBC were measured. Results indicated that the developed MBC from RW are very suitable to be used as a heat insulation material. Mycoremediation was also investigated, which is a decontamination method to degrade or isolate environmental contamination. RW are from wooden products originating widely from the previous century, which often show considerable contamination that is coming, e.g. from adhesives and wood preservation treatments. We have found that such contaminated LC material can be remediated by exposing the material to fungal growth; the reduction of contaminants emitted from the substrate was monitored using gas chromatography. Specifically, the influence of fungal treatment on volatile organic compounds (VOC) was studied by using gas chromatography – time of flight mass spectrometry (GC-TOF-MS). The results indicate that the production process of MBC significantly reduces VOC from RW.

Key Words: Recycled Wood, Mycoremediation; Mycelium-Based Composite, Hyphae, Fungus, Wood-Decay

Functionalization of wood veneers using additive manufacturing techniques

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ABSTRACT

Wood and wood composites are important building blocks in the European industrial landscape for traditional areas of application and use. Current research activities aim to enable a wide application of wood as a sustainable, smart material, while at the same time preserving the visual elegance of the surface in the best possible way. Therefore, in the present work, advanced electronics and sensors that are invisible for the user were integrated on wooden surfaces. In the interests of sustainability, the integration of electronic components is realized using additive manufacturing techniques to minimize the use of resources and materials.

The focus is on the development of transparent touch sensors on wood veneer surfaces. In order to prepare the surface of the wood veneers for functionalization, several modifications, such as the application of coatings, were necessary. An evaluation of printing inks was done investigating not only the achieved sheet resistance but also the ink transmittance to light in the VIS range. The sensors were seamlessly integrated on the modified veneer surface using screen-printing technology. The printed sensors showed a high sensitivity to the touch of a human finger and a high cyclic stability. After the application of a protective coating, the printed sensor was no longer visible for the human eye. The results of the present work showed that wood can make the transition to a highly functional and at the same time aesthetic material.

Healing interiors: in search of yet non-quantitative dimensions of social sustainability in building with wood concepts

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ABSTRACT

Buildings and built environment affect human wellbeing in many ways, creating an opportunity to develop sustainable, restorative buildings and materials. This ongoing research project studies human behavior and chosen psychophysiological parameters to create a holistic view on humans' wellbeing related to different living environments.

The aim is to use a multidisciplinary approach to create better understanding on how novel material choices in built environments and interiors affect human's stress levels in longer term, and how psychophysiological load can be relieved by introducing different novel engineered wood and other nature-based materials into housing.

The study utilizes the LivingLab of Wood Construction at the University of Helsinki – a unique test bed for holistic wellbeing research. The research applies ambulatory health metrics technologies to obtain anonymous data from the voluntary study subjects randomized into cross-over trial. The study subjects live in both wooden and non-wooden housing for several weeks, and their heart rate, heart rate variability, and sleep metrics are monitored together with the self-assessments and targeted focus group interviews of perceived wellbeing.

The study provides new knowledge on longer-term impacts of interior materials in built environments for human wellbeing. Suitability of selected wellbeing assessment methods and biomarker measurement technologies are evaluated as part of a more comprehensive assessment of sustainability in the building with wood concepts.

The results help design building materials that may enhance individual's psychophysiological resilience and coping mechanisms, provide stress-relieving experiences and bring new knowledge on coping mechanisms in healthy and restorative environments. This research will focus on finding new bio-based solutions to improve home or work environments. Moreover, the study aims to connect principles of sustainability assessment as part of the assessment of human psychophysiological wellbeing and resilience.

Comparative whole building life cycle assessment of the Baker's Place mass timber project using TallyLCA Tool

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ABSTRACT

The urgent need to mitigate the climate change caused by intensive greenhouse gas (GHG) emissions has increased the focus on embodied carbon and energy reduction, especially within the construction sector. Globally, buildings account for 42% of annual carbon dioxide emissions, with 42% originating from structural materials. Utilizing sustainably sourced mass timber products offer low embodied carbon alternatives to traditional concrete and steel structural systems in buildings. Such carbon impact can be quantified using the Whole Building Life Cycle Assessments (WBLCA), which is a systematic tool to evaluate the total environmental impacts of whole building from all components from material extraction to products manufacturing, building construction, operation and the end of building demolition.

The Baker's Place as an ongoing project, located in Madison, WI, serves as a real-life case study for sustainable building in North America. This 14-story structure includes a 3-story concrete podium and 11 stories of mass timber-steel hybrid construction. The goal of this study is to compare the baseline scheme with full Mass Timber, full steel, and post-tensioned concrete as alternative structural framing materials. For this purpose, the pre-designed structural models, created with Revit, were subjected to WBLCA using TallyLCA tool. Tally serves as a plug-in application for Autodesk Revit, empowering users to define Environmental Product Declarations (EPD) and Life Cycle Inventory (LCI) data for Building Information Modeling (BIM) elements. Through this comprehensive analysis, the study will provide insights of mass timber project's contribution to achieving zero-emission goal and climate positive built environment, as well as contributing valuable information to the public domain and offering practical lessons for the construction industry.

The results will compare the Global Warming Potentials (GWPs), expressed as kilograms of carbon dioxide equivalent per square meter (kgCO2e/m2), of the four structural designs with functional equivalency. The comparative analysis is expected to reveal that concrete in buildings constitutes a significant portion of the global warming potential. This study substantiates and demonstrates the potential of incorporating Mass Timber materials into the construction industry will significantly reduce embodied carbon in building sector and encapsulate the biogenic carbon sequestered by trees in the building for long-term storing benefits.

Keywords: Whole Building Life Cycle Assessment; Mass Timber; TallyLCA Tool, Environmental Impact

From static to dynamic mechanical models of trees

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ABSTRACT

The stability of trees plays a key role in determining the quality of forest plantation and urban forestry, particularly in light of the increasing frequency of wind gust events over the past few decades. Existing mechanical models, such as GALES or HWIND, address tree responses to wind using a simplified static approach. However, trees are a very complex structure living in a dynamic environment, its failure is dynamic too. Description of relationships between parameters describing trees and its response to dynamic loading can help to develop methods of tree stability assessment considering dynamics. Describing such a structure with heterogeneous material properties, complex geometry, and loading conditions requires a series of systematic tasks. The sub-tasks included: a) conducting extensive laboratory testing on green wood, leading to the development of relevant material models; b) observing the effect of simplification in geometry and load conditions on stems and branches to outputs of numerical mechanical analysis; c) experimental testing of trees with different conditions (with or without defects, pruning etc.); d) conducting numerical analysis of simplified models of trees, treating them as beams with representation of crown by mass elements; e) performing numerical analysis of more complex tree structures with realistic crown description; f) running simulations of "what-if" scenarios to observe the effect of internal defects to frequency response and damping. The results revealed trends in the change of frequency spectra and time domain response, based on the changes in mass, geometry, and material parameters. These trends were then compared with tree behavior in the static domain, allowing for a comprehensive evaluation of static and dynamic approaches. The outcomes of this extensive research provided valuable insights and conclusions that should be considered in future work on tree biomechanics.

Value chain analysis of utilizing by-products from wood processing in South Korea

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ABSTRACT

This study aimed to analyze the optimal utilization system for maximizing the economic added value of domestic larch (*Larix kaempferi*) logs by the value chain to expand the use of wood resources and by-products. First, we visited sawmills that produce products using domestic larch and investigated the size and quality of lumber by usage step, as well as by-product collection and sales status. In addition, we looked at alternatives that could be introduced in terms of wood processing or by-product use to transition to a bio-economy system. Next, a simulation analysis of the sawing process was used to determine the types and amounts of wood products that can be produced from larch of various sizes and to assess the economic and environmental benefits of different usage scenarios that would arise if these were used as new alternative resources. Lastly, based on the results derived from the study, future improvements in the domestic wood distribution process and by-product use system were proposed in terms of application of the forest-based bioeconomy. As a result of identifying the production and usage status of domestic wood resources and by-products, the following obstacles to using South Korea's wood resources in a more valuable manner were identified. Supply entities in the wood market, such as log producers, sawmills, and other cooperatives, only focus on individual interests and have relatively little interest in social values or public interests and are unable to adjust conflicting interests or present common goals and directions. And the results showed that producing general-purpose sawnwood increased the total economic value by 6 times, and structural lumber by up to 8 times, compared to producing only temporary construction materials such as scaffold, formwork etc.. Additionally, it was found that larch stands with a diameter at DBH of 26 cm or greater are suitable for structural lumber, although the range of producible wood products varies with the size of the logs. Therefore, in addition to efforts to increase the price competitiveness of domestic goods and find ways to utilize high value-added by-products, it is necessary to put a more effort into improving the distribution structure to utilize domestic goods more efficiently.

Buildings and education in wood ecosystem for the new European Bauhaus – BE-WoodEN

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ABSTRACT

LIFE BE-WoodEN project aims to promote the decarbonisation of buildings and improve circularity in the building sector overcoming barriers that prevent the widespread use of wood and bio-based materials. These obstacles depend on cultural, technical and economic reasons and invest the entire production, design and installation process, including facility management and dismantling. For these reasons, and thanks to a solid European partnership, the project is aimed at a very diverse target of users with an approach geared towards increasing knowledge and skills, testing innovative training methodologies, also of a demonstrative nature. A special focus will be on social housing, matching the need of elderly and fragile people. LIFE BE-WoodEN is based on NEB values and the implementation follows the principles expressed by the NEB Compass. A new NEB Pioneer Hub was created, to contribute to European learning ecosystem in sustainable construction and to guarantee the results dissemination afterwards. The new Hub cooperates with NEBAP Hub of University of Primorska. A strong capacity building activity aimed at professionals, technicians, building managers, companies and policy makers will be carried, concerning NEB and place making, green and circular buildings, use of wood for the building sector. Then, Innovation labs for co-development will be carried out, involving different stakeholders (professionals, public officers, companies, experts, artists) to find together solutions for a reliable use of wood in buildings. Two pilot actions, concerning social housing, will be developed through a participatory and transdisciplinary approach. Activities will regard the design phase and the valorisation of local wood supply chain. The ambition is to prepare professional figures corresponding to market needs and to overcome the fragmentation of the local supply chain, valorising environmental benefits due to the adoption of wood and bio-based materials in the construction.

Stereoscopic vision as AI tree logging enhancement

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ABSTRACT

The Sintetic Project aims to revolutionise the timber industry by introducing a comprehensive traceability system from forest to final products, ensuring reliability, precision, and cost-effectiveness. An important task of the project is to ensure optimal cross-cutting of logs to be identified on the basis of objective multisensory data collected during the harvesting operation.

In this context, we propose the integration of stereoscopic vision and AI data-driven techniques into a tree-harvesting processor to optimise the overall efficiency of this process. By equipping the harvester with 3D cameras positioned above the processor head, we enable the capture of detailed visual and shape data of fallen trees. These cameras generate point clouds, providing rich in-depth information, crucial for assessing tree characteristics such as branch distribution, position, and quantity, as well as log taper and curvature. Leveraging AI algorithms, the system identifies branches and evaluates wood quality based on the presence of defects such as knots, enabling precise decision-making regarding crosscut positions and downstream log utilisation. This integration enhances logging processes by optimising the balance between maximising log length and wood quality while simultaneously minimising processing time and costs associated with inefficiencies.

Furthermore, in line with the project's iterative development approach, these systems will be continuously updated based on field demonstrations and feedback. By integrating stereoscopic vision and AI logging enhancements, the logging and tracking system are expected to achieve unprecedented levels of precision and efficiency. When focusing on the future, the proposed enhancements will be pivotal in achieving the Sintetic Project's overarching goal of establishing a robust traceability system that links every step of the timber supply chain, from forest inventory to final sawn wood products.

Through collaborative effort and technological innovations, the project aims to transform the timber industry, setting new standards for sustainability, transparency, and efficiency.

Wednesday 3 July

EARLY-STAGE RESEARCHER

Lea Pimozic, Chair

Super-strong biomimetic bulk bamboo-based composites by a neural network interfacial design strategy

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ABSTRACT

As a sustainable ecological material, bamboo has become a popular modern green building material because of its rich yield, lightweight, high strength and rich cultural heritage. However, due to the limitation of bamboo tube thickness, multiple thickness-direction laminations are usually required to achieve large-sized materials, which leads to a significant decrease in strength. Therefore, it is urgent to find a way produce high-strength bamboo engineering composites on a large scale. Herein, a neural network interface design strategy was proposed, and a mechanical dissociation and partial matrix removal pretreatment method was used to open the weak intercellular layer and bamboo cell wall layer to increase the resin permeation channels. This allowed the resin to form a multi-scale bonding interface between multiple dense bamboo layers, achieving the preparation of a bulk bamboo-based composite with adjustable dimensions and properties. The neural network-like bonding interface could firmly fix the compressed bamboo cells and enhance the mechanical properties of the bamboo cell wall and intercellular layer of bamboo, resulting in a tensile strength of 853 MPa for the composite, which was nearly three times that of natural bamboo and significantly superior to many structural materials such as alloys and other bamboo-based composites. In addition, this material showed good mildew resistance, flame retardancy and dimensional stability. These large-size bamboo composites are easy to scale production, which can be used in

fields such as wind turbine blades, building structures, and outdoor walkways in the future.

FEM analysis of static and dynamic mechanical response of branches

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ABSTRACT

Assessment of green wood using vibroacoustic methods faces some limits, especially the estimation of vibration modes can be inaccurate in the case of complex geometries such as branches or logs. An experimentally validated physical model with use of finite element method (FEM) on realistic geometry can help clarify this problem.

The samples of linden (*Tilia cordata* Mill.) and beech (*Fagus sylvatica* L.) branches without visible defects were studied. The research consists of two phases. Non-destructive and destructive bending tests take place first. The second phase was the development of a validated FEM model. The laser scanning of the branches was used to improve the FEM model by involving of realistic complex geometry.

The non-destructive testing involved the application of the frequency-resonant method to get the dynamic response and determine the moduli of elasticity in longitudinal and bending modes. Subsequently, three-point bending tests were carried out until sample crack initiation. The complex three-dimensional FEM model was used for modal analysis and three-point bending simulations. Analysis of the degree of simplification of this precise geometry without affecting the results was also part of the simulation.

The relationships of parameters derived from the non-destructive and destructive tests can increase the reliability of quality assessment in-situ methods. The laser-scan-based FEM simulations of the dynamic response of branches bring conclusions for improvement of the frequency-resonant method. The validated simulations of the mechanical response of branches move forward the knowledge of tree biomechanics.

Evaluation of dynamic and static moduli of elasticity of hybrid eucalyptus wood from different locations in Ghana

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ABSTRACT

Understanding both dynamic and static modulus of elasticity (MOE) values in the context of Eucalyptus wood is critical for maximizing its performance in various applications. This study explores the mechanical properties of hybrid eucalyptus wood, which with a focus on dynamic and static moduli of elasticity (MOE), is crucial for understanding the stiffness behaviour of wood. The research employs acoustic and static measurements on samples prepared from six trees sourced from Winneba and Amantia in Ghana. The results reveal significant variations in static and dynamic MOEs, with higher static MOE observed in both Amantia and Winneba samples. However, Winneba and Amantia samples at the tree level were found to be insignificant statistically. The densities of the samples from the two locations, Winneba and Amantia, were found to be significantly different. Correlation studies revealed strong relationships between wood density and static MOE, as well as static and dynamic MOEs, providing valuable insights for comprehensive wood characterization. The findings inform decision-making in the construction and engineering industries, contributing to the sustainable management of Eucalyptus wood resources in Ghana.

KEYWORDS: Eucalyptus wood, dynamic modulus of elasticity, static modulus of elasticity, acoustic evaluation.

Radial variation in the anatomical structure of *Robinia pseudoacacia* L. wood and its correlation with the environment factors

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ABSTRACT

The rapidly expanding tree species known as black locust (*Robinia pseudoacacia* L.) was brought to Europe and has subsequently been accepted in various countries. Environmental factors such as climate, light, water, and soil can influence the wood composition of black locust. This study investigated the impact of environmental variables, specifically temperature, and precipitation, on the microstructural characteristics (fiber length, fiber width, cell wall thickness, lumen diameter, and ring width), such as fiber traits of *R. pseudoacacia* wood. Black locust trees aged 35–38 years were collected from the Hungarian county of Bács-Kiskun. The result revealed that the radial variation did not exhibit a progressive transition from the center to the outside bark. The analysis results indicated that there were positive correlation coefficients for temperature and precipitation with fiber properties, except the ring width showed a negative correlation with temperature. The regression coefficients for the positive and negative correlation were considered.

DENDRO-SPEC project: Spectroscopic methods for rapid phenotyping of trees reflecting their ecological resilience

Edit Földvári-Nagy[1], Jakub Sandak[1], Ondrej Dvoracek[1], René Alexander Herrera Díaz[1], Anna Sandak[1], Elena Cvetanoska[2], Witold Wachowiak[3], Agnieszka Jankowska[4], Włodzimierz Buraczyk[4], and Paweł Kozakiewicz[5]

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ABSTRACT

The DENDRO-SPEC project endeavours to explore the genetic factors shaping the characteristics of Scots pine trees and their wood, particularly focusing on adaptability in response to changing climates. The primary objectives include investigating the impact of genetic variations on tree properties, utilizing near-infrared spectroscopy (NIR) for wood analysis, and understanding the genetic, morphological, and anatomical features associated with tree resilience to drought and elevated temperatures. This information could be crucial for pinpointing populations or individual trees with heightened resilience to climate stressors while preserving favourable wood properties.

In understanding the genetic factors, the project utilizes microsatellite DNA markers (SSR) and genetic association analysis, including a vast database of single nucleotide site polymorphisms (SNP). This approach aims to unravel neutral genetic variations within and between different populations of Scots pine, fostering insights into the genetic basis for ecotype differences and establishing connections between observable traits and genetic variations.

For wood characterization, the project proposes using NIR spectroscopy to indirectly assess technical characteristics and phenotypes. This approach integrates genetic insights with NIR spectroscopy, striking a balance between refined data quality and data acquisition simplicity. The study capitalizes on a unique set of wood samples from 50-year-old trees representing various national Scots pine populations, all cultivated under identical conditions. The project seeks to establish a measurement protocol for wood samples using NIR spectrometers, exploring the feasibility of using NIR spectroscopy for determining wood properties.

The ambition of the DENDRO-SPEC project is to pioneer a new methodology for swiftly, accurately, and non-destructively predicting wood quality properties. By integrating genetic studies with advanced spectroscopic techniques, the project seeks to enhance our understanding of how trees adapt to climate change. The outcomes may hold significant implications for sustainable forest resource management and effective tree breeding programs in response to evolving environmental conditions.

Cellulose nanocrystals to coat and colour wood surfaces

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ABSTRACT

Conventional wood coatings often contain synthetic and hazardous compounds, emitting volatile organic compounds (VOCs) into indoor spaces, posing risks to human health. Moreover, these synthetic coatings often contain non-biodegradable substances (plastics, metals, dyes or pigments), releasing persistent contaminants into the environment when disposed. The complex composition of coated wood boards complicates the recycling process. Hence, there is a pressing need to develop bio-based, non-toxic and biodegradable alternative coating materials.

A promising approach lies in mimicking nature, particularly the vibrant hues found in certain fruits like that of *Pollia condensata*, a herbaceous plant native to Africa. These fruits showcase a brilliant blue colour without relying on pigments. Instead, the colour results from the reflection of light at the highly organized cellulosic network within the fruit's cell wall. Unlike with conventional dyes and pigments, the colour does not results from the absorption of light by chemical bonds but from the light reflection of specific micro- or nanostructures. This phenomenon is commonly referred to as structural colouration.

Cellulose nanocrystals (CNCs) are highly crystalline, rod-like nanomaterials known to self-organize into chiral nematic phases in water. In these helical phases, CNCs feature a twist perpendicular to their longitudinal axis. Since the chiral pitch, i.e. the transverse distance at which the CNCs undergo a full 360° twist, is in the order of the wavelength of visible light, these phases interfere with visible light and exhibit structural coloration. Changing the pitch of the CNC structure will affect the reflected wavelength, thus allowing to specifically tune the colour of the surface.

The present study aims at exploiting the unique optical properties of CNCs for the development of novel wood coatings allowing to apply the concept of structural coating to wood surfaces. The effect of different starting materials, CNC preparation approaches, and drying conditions on the optical properties of coated wood surfaces are reported.

Key Words: Cellulose nanocrystals, Structural colours, Liquid crystals, Wood surface, Coatings

The role of goal-discrepancy in restorative experiences in built environment: a post-occupancy survey study

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ABSTRACT

This study explores empirically the influence of goal-discrepancy on restorative experiences in accommodation buildings using post-occupancy evaluation. The study investigates perceptions of well-being effects (e.g., quality of sleep, restoration, comfort) experienced by occupants of novel wooden accommodation buildings at the Hyytiälä Forest Research Station in Finland. The questionnaire addresses psychophysiological self-evaluation together with subjective evaluation of the building (e.g. ambiance, indoor air quality) and its surrounding natural environment (e.g., milieu, social interaction). Drawing upon the goal-discrepancy theory, the research examines how mismatches between individuals' current goals and their accommodation environment influence on their personal perception of stress level (reduction), mood enhancement, and cognitive restoration. The empirical data consists of two visitor groups (researchers and education professionals) accommodating overnight in the buildings with target sample size of approximately 40-60 respondents in the pilot phase. This data also provides a basis to assess the option for continuous data collection using the designed research framework and serves in validating the survey instrument for further research. This study and its results contribute in a built environment and sustainable wood construction research by examining the applicability of goal discrepancy theory and post-occupancy evaluation methods regarding the impacts of built environment on human wellbeing. In particular, results on associations between goal-discrepancy and residents' experiences of restoration grant feedback for the development of the accommodation spaces, while also providing implications for design practices in general and incorporation of wellbeing consideration in novel wooden buildings in particular.

How wood species influence the curing speed of adhesives used in panel production

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ABSTRACT

To fulfil the expected high demand for timber constructions, an efficient use of resources is necessary. It is also essential to consider alternative wood species, as Central European forests are shifting from predominant monocultures of spruce to mixed forests. Strand-based materials might be the key to fulfilling this increasing demand. In this regard, we are developing a panel-shaped material for construction applications that will consist of strands from different wood species and will have a high yield of raw material.

To enable quick industrial implementation, we are using established adhesive systems such as pMDI, modified MDI and MUF. Achieving optimal results requires a thorough understanding of the bonding properties of different adhesive-wood combinations. When a new wood species is introduced into the production process, the speed of adhesive curing is important as it has an impact on production costs. The common method for assessing cohesive strength development of adhesives is by using the Automated Bonding Evaluation System (ABES). However, utilizing ABES with pMDI adhesives typically results in unreliable results due to differences from traditional polycondensation adhesives in penetration, wetting, viscosity, influence of moisture etc. Consequently, we needed to adapt the method to the specific curing requirements of pMDI and modified MDI adhesives.

Following this adaptation, we conducted preliminary measurements on different wood species, including softwoods and hardwoods. The adhesives used were pMDI, modified MDI and MUF adhesive. The results showed different curing rates of the adhesives between species. The differences were greatest for the pMDI adhesive and could not be explained by the density of the wood.

Experimental modal analysis for the evaluation of the bond line in glued structural elements

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ABSTRACT

The preferred structural elements for taller timber buildings include cross-laminated timber (CLT), glued laminated timber (GLT), and similar composites, typically held together by glue. The structural performance of these elements depends significantly on the bonding properties. Manufacturing defects and environmental factors can lead to bond degradation, potentially leading to serious structural failures. Therefore, ensuring the quality control of adhesive joints in wooden structural elements is crucial. This quality control is suitable before the component's installation and remains desired throughout the wooden element's lifespan. The study presents the application of non-destructive vibro-acoustic methods, specifically experimental modal analysis, as a tool to assess the bond quality and its influence on the general stiffness of the CLT panel under various boundary conditions.

Structural performance evaluation of timber-concrete composite slabs connected with plywood notched connections

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ABSTRACT

In this study, the hollow-core timber-concrete composite was developed. Since the main objective of project was to get a long-span design, so it was necessary to apply a high-performance shear connection. Out of shear connections, the notched connection has been evaluated as the best option, but there were difficulties to use typical notches in terms of productivity and workability. To solve those problems, the novel shear connection using plywood units with specific shape was developed. The composite behavior was derived by interlocking with concrete member and fastening with lumbers by using nails. The structural performance was verified through the comparison of the test results and predictions from an analytical model called the γ-method. After verification, the allowable spans for non-residential building uses were calculated. The hollow-core slab system has a long-span capability up to 8.9 m under 12 kN/m^2 which corresponds to the live load levels of warehouse or factory uses.

Simulating the costs and benefits of implementing design for disassembly in wood-based construction

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ABSTRACT

The construction sector contributes substantially to global CO2 emissions, with a significant portion of the material used in buildings ending up at landfills post-demolition. Design for Deconstruction (DfD) is a concept for building design that includes disassembly and reuse of components at the end of the buildings service life. Wide-spread adoption of the DfD concepts could enable a shift towards circularity through the increased reuse and recycling rates of demolition materials, contributing to a more sustainable urban development. However, while the environmental impact of the deconstruction of individual buildings can be assessed for different design concepts, measuring the global impact of such a shift in design for a multitude of construction and demolition sites over the timespan of several decades is a significantly more complex task. Wood has a high degree of potential in design for disassembly concepts because of the ease of off-site manufacturing and the potential for modularity.

We introduce a discrete event simulation framework to model various scenarios for material use and reuse in constructions and demolitions. The framework will act as an abstraction of the outlined problem, considering buildings as material banks throughout the discrete (annual) time-steps of a system where new construction appears and buildings reach the end of their service life over time and must be renovated or demolished. The system will examine decisions connected to building material acquired through demolition and concentrate on the costs and benefits (both financially and environmentally) of their storage and reuse in future construction projects versus their immediate disposal either through burning or landfilling. Various simulation scenarios will be explored to see how parameters like recovery rate, changing storage costs or penalties on CO2 emission change the behaviour of the system.

Key words: modelling, simulation, deconstruction, circularity, optimisation

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SWST Student Chapters: The Australian Experience

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ABSTRACT

The International Society of Wood Science and Technology (SWST) Student Chapters at partner institutions help to broaden the student experiences and perspectives in the area. SWST Student Chapters are active through the organization of various initiatives such as site visits, meetings with professionals, and practical experiences. This is crucial for the students to develop connections with members of industry and develop networks that are useful for their professional development (Negro et al., 2022).

But the benefit is not only for students. Industry partners can also benefit from this interaction by engaging with the next generation workforce, and, of course, promoting the brand. Academics may also be benefited by expanding their network and meaningful collaborations.

With this context, in 2023, Negro et al. (2023), encouraged the establishment of new chapters by presenting an overview of the chapter's activities and benefits at the 2023 World Wood Day Symposium (At the same time, the first SWST Australasian Student Chapter was being created). Its constitution was approved by the SWST Board in March 2023, and the chapter started activities.

The aim of this work is to present an overview of what the SWST Australian Student Chapter has reached so far, making emphasis on the benefits for the participants as well as on the challenges and issues encountered during its creation and management. We expect that this information can serve for the future creation of SWST Student Chapters.

Keywords: SWST; Student Chapter; Australia; Students; Wood Science

References:

Negro, F., Tamara, F. A. F., & Eric, H. (2022). SWST student chapters: a valuable means of broadening student perspectives in wood science and technology. Wood and Fiber Science, 54(2), 75-80.

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CHANGING THE PARADIGM- THERE IS ONLY HIGH VALUE WOOD

Jan Tippner/Lech Muszynski (CoChairs)

Key factors influencing the formability of beech veneer

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ABSTRACT

The automotive industry is actively seeking sustainable alternatives to petroleum-derived materials in order to reduce environmental impact without compromising performance. Beech wood, with its formability, mechanical behaviour, and inherent wood characteristics, emerges as a compelling candidate for material substitution in automotive applications.

This study investigated the formability of sliced beech veneers considering critical parameters such as pre-damage, density, moisture content and the fibre orientation. Understanding these properties is essential for optimizing the manufacturing process towards a defect-free reshaping of engineered wood. Furthermore, proper process control allows to cope with the natural variability of the anisotropic resource wood and, thus, enhances the efficiency of material input.

In light of the lack of systematic understanding within the scientific literature on the formation of beech veneer, this study aims to elucidate the essential factors required to maximize forming potential. The forming tool for the experimental test features a two-dimensional V-shape, consisting of a matrix and a patrix. This tool is designed to assess the minimum bending radius of wood veneers.

Overall, the tool offers a controlled environment for conducting experimental tests on the formability of wood veneers. Its design parameters, include the 2D V-shape, multiple radii (three different shapes), and precise clearance adjustments, facilitate accurate evaluations of the veneer's behaviour under pressure, enabling insights into its formability characteristics and potential applications in various industries.

The sample preparation included beech veneer with a thickness of 0,9 mm. The fibre orientation was lengthwise with a deviation of 0 – 3°. The experimental tests were conducted at room temperature and a moisture content of 10 – 12 %. During forming a stress – strain curve was recorded. The curves were analysed, and the failure modes were examined using visual observations and microscopic analyses.

The results show that the knowledge of wood moisture, density and fibre orientation is a good indicator to describe the formability of beech veneer for most of the samples. But to describe decisive influences for the forming process of beech veneer and its limits additional factors such as the fibre orientation out of the veneer plane and the wood ray orientation are required.

Innovation and sources of knowledge in the western North American hardwood sector

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ABSTRACT

The native hardwoods species of Oregon and Washington encompass 10% of the forested land base, and contribute a wealth of cultural, economic, and ecological value to the landscape. However, forest management paradigms have, until recently, sought to significantly reduce their presence on the land base to reduce competition for softwood species at the same time as shifts in consumer values and wood supply have underscored the need for innovative management and production processes. A group of western hardwood product manufacturers has emerged in this region to provide quality wood products from this underutilized stream of local resources. Since innovation can be described as a process of using information in a novel way, a key precursor to successful innovation is information accessibility, and the transition of new information into organizational capability. Research describing modes of innovation in the wood products industry has largely occurred in softwood manufacturing, where it has connected successful innovation to several desirable outcomes. However, little work in this vein has looked at the western hardwood industry, or access to information in that sector. This study applies mixed-method social network analysis, a method uniquely qualified to address the interdependent nature of the industry, to the questions of information sourcing and organizational innovation in western hardwood producers. The work will be conducted in two phases. In the first phase, interviews with high-level managers within most of the hardwood producing firms in Oregon and Washington will be conducted. Thematic qualitative data analysis will be used on interviews including questions such as:

- How are your operations impacted by the background or experience of the people that work here?
- How do you get information from outside the company?
- What types of relationships are most relevant to your company for gathering new information?

Following these findings, a quantitative survey will be employed with the same population. These data will be used to develop a multilayered social network representation and an exponential random graph model examining the inter-organizational dynamics involved in information sharing relationships. Data collection is planned for February – April of 2024 and preliminary results will be presented in Slovenia. As a small, highly interconnected sector related to an emerging discussion in North American forest management, the microcosm of the western hardwood industry presents a unique opportunity to assess the dynamics of information flows and organizational learning in wood products manufacturers. Greater insight in this realm may reveal opportunities for increasing efficiency and innovation that could be applicable to the larger sector moving forward.

Key Words: Hardwoods, Deciduous, Hardwood Manufacturing, Innovation, Information Transmission, Organizational Learning, Social Network Analysis

Wheat straw: An untapped resource for high-performance materials

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ABSTRACT

Innovative strategies to utilize available biomaterials are essential in the transition from our currently fossil-based to a modern bio-based economy. The exploration of underutilized agricultural by-products such as wheat straw is very promising in this context. Nature has optimized the structure of straw so that it can efficiently carry the load of the grain and resist external forces such as wind. The abundant availability of straw as a raw material and its excellent strength properties, which result from its fibrous composition, make wheat straw an attractive candidate for the production of structural materials. However, during implementation, straw-specific challenges such as the small size of the individual straws, their hollow nature and low density as well as the presence of a wax layer must be overcome. In our research, we demonstrate methods for processing straw into high-performance structural materials, thus potentially opening up another raw material for the wood sector. Therefore, straw was split along the fiber direction and processed into strands. These strands were then exposed to a mild alkaline pre-treatment, generating a well-malleable material with increased relative cellulose content. Thereafter, the straw stands were densified to maximize mechanical properties material achieving strands with high density, homogeneous structure and optimized fiber orientation. Here tensile strength of the straws could be increased to an impressive 450 MPa. Furthermore, it was found that through the accompanying change in the straw surface, the bondability of the straw significantly increased. This knowledge could be used to produce an engineered material. Therefore, straw strands were bonded to small beams using established adhesives from the wood industry. These exhibited flexural strengths of up to 200 MPa, which is in the range of other non-bio-based high-strength materials like glass fiber reinforced plastic and illustrates the potential of straw as a feedstock for high-performance materials.

Wood beyond the stem: towards a new material concept for underutilized branch wood from deciduous trees

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ABSTRACT

The urgent need to adapt to climate change requires a shift in forestry practices towards potentially more resilient hardwood and mixed forest stands. This transition represents a major challenge for the wood processing industry due to the inherent differences in properties between hardwoods and the softwoods that dominate in Europe and requires innovative approaches to improve the utilisation of hardwoods. In fact, the volume of branches and stem tops in deciduous trees accounts for 20-50% of their total above-ground biomass. Our research addresses this challenge by deepening the knowledge of basic branch wood material characteristics and proposing a new way to produce structural wood products from non-sawmill grade assortments. Our methodology involves several key steps aimed at maximising the material efficiency of hardwood resources. First, we conducted extensive material characterisation studies to understand the physical and mechanical properties of branch wood from prominent broadleaved species such as *Fagus sylvatica*, *Quercus petraea* and *Populus alba*. Our results showed that branch wood does indeed have a significantly different technological profile compared to stem wood, particularly in terms of density and tensile strength. Using personal laser scanning technology, we created digital twins of entire trees, which facilitated the correlation of mechanical material properties with the positional data of individual branches. Our findings revealed that branch slope in particular, but also branch top side and diameter, have a significant effect on elastic properties and bending strength, although variances exist among different species. In the case of oak, it was possible to predict the bending properties of defect-free samples from branch wood by factoring in density and position parameters. At the ultrastructural level, we are currently investigating wood density, microfibril orientation and crystallinity from pith to bark samples of selected branches using wide-angle X-ray scattering. We consider such radial trends to be crucial, as they correspond to the temporal progression of growth and, conversely, could be key for efficient disintegration processes. For radial splitting along the grain, we are using a laboratory-scale branch-splitting technique to produce elongated macro strands to enable the production of structural elements such as panels and beams. Our research represents a pioneering effort to bridge the forestry, wood processing and construction sectors to unlock the potential of hardwood for structural applications. Through these collaborative efforts, we envision a future where hardwood resources, often under-utilised, play a central role in driving innovation and contributing to the wider transition towards a more resilient and resource-efficient society.

THE USE OF LOW-QUALITY AND RECYCLED WOOD PARTICLEBOARDS IN FURNITURE STRUCTURES

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ABSTRACT

The objective is to verify the suitability of the application of particleboards (PB) manufactured using recycled wood-base materials and low-quality wood as a sustainable material for use in furniture structures. This objective is achieved through the assessment of the mechanical properties of furniture joints.

The laboratory-produced control PB with particle content of 100% sound spruce wood (*Picea abies Karst. L.*) and commercial PBs were used for comparison of the results. The load capacity and stiffness of corner joints with the confirmat 5 × 50 mm and wooden dowel ø 6 × 30 mm and the withdrawal resistance and stiffness of the screw 3.5 × 30 mm were tested. The corner joints were loaded under compression by bending moment in the angular plane. In terms of load-carrying capacity, control PB was the most suitable in achieving a load-carrying capacity of 7827.61 N·mm for the confirmat and PB from recycled blockboard 4072.71 N·mm when using the wooden dowel. As for joint stiffness, the best values achieved were 1316.00 N·mm/° and 808.58 N·mm/° for the PB from recycled blockboard using the confirmat and dowel, respectively. PB from recycled blockboard again showed the highest values of screw withdrawal resistance - for the edge withdrawal 416.61 N and for the surface withdrawal 556.44 N. Considering the values found for the investigated mechanical properties the tested materials can be used as non-load-bearing elements in furniture construction.

Keywords: wooden recyclate; particleboard; furniture joints; joint mechanical properties.

INTRODUCTION

Today, a large variety of different materials are used in furniture construction types of screws that are suitable not only for joining wood but also other structural materials or combinations. Metal pin-type fasteners used in the furniture industry include screws, nails and staples. They are mainly used for fixing fittings or parts stressed by pulling or shearing.

Furniture is an apparatus needed in human daily life. The design and construction of furniture is an applied art. The requirements for furniture design are not only appealing appearance and current fashion but also sound functionality and structural safety (Wang and Lee, 2014). Furniture quality is determined by its form, aesthetics, functionality, ergonomy, rigidity, strength, and durability. The strength and durability of furniture are some of the most essential factors determining furniture value (Smardzewski and Majewski, 2013).

Joints fulfil necessary strength, technological, and operational-aesthetic functions in furniture construction. In general, joints are the weakest parts of a given piece of furniture, and furniture durability depends, first and foremost, on their quality (Podskarbi *et al.*, 2016).

In terms of determining the mechanical properties of joints, it is important to know the strain that occur as a result of load transfer. In furniture structures joints are stressed by three generalized forces - two shear forces and one tensile force, and three moments of force - two bending moments and one torque. The most dangerous stress case of the connections is their loading by bending moment in the angular plane.

The pull-out resistance of screws embedded in wood-based materials depends on the type of the materials used and on the direction of the axes of the fasteners with respect to the plane of the board. Factors affecting the screw withdrawal resistance are testing method, screw diameter, pre-drilled hole diameter and accuracy, preparation of the test specimens, etc.

In furniture manufacturing various materials, such as wood and wood-based panels are used. Wood-based panels such as medium-density fibreboard and PBs are widely used in manufacturing case-type furniture because the mechanical, physical, and surface qualities of the engineered panels are comparable to those of solid woods (Kasal *et al*., 2011). PB is widely used in furniture manufacturing because PB is much cheaper than wood, fibreboards, and plywood (Bardak, 2018). In the past, various sources of wood are used for their production, mainly forest assortments, and secondary sources (edges, cuttings and sawdust). Today, the effort is to use old or recycled wood, or various lignocellulosic materials (Guler *et al.*, 2004; Kwon *et al.*, 2013; Kord *et al.*, 2015; Wronka and Kowaluk, 2019; Iždinský *et al.*, 2020; Iždinský *et al.*, 2021; Wronka and Kowaluk, 2022; Vilkovský *et al.*, 2022; Pelc and Kowaluk, 2023). There is still a need to look for other alternative sources of wood replacement in the production of PBs, such as agricultural residues (*e.g.,* poppy husks, walnut, kiwi prunings, cotton seed hulls, rice straw-wood, vine prunings, pinecone, almond shells, wood flour) and non-wood plant fibers (Kucuktuvek *et al*., 2017).

Sustainable product initiatives aim to ensure that by 2030, a significant proportion of products available to consumers in the European Union are designed to be durable, energy and resource-efficient, more environmentally friendly, repairable, and recyclable, and preferably use recycled materials in their production. Eco-design, sometimes referred to as Design for the Environment, is an umbrella term describing techniques used to incorporate an environmental component into products and services before they enter the production phase (Directive 2009/125/EC, Act No. 529/2010 Coll. on Environmental Design and Use of Products) It can be performed by adopting various tools and methods, such as those based on the life cycle thinking principle (ISO 14006: 2020). The design of ecomaterials is changing from the single criterion of environmental consciousness to total life-cycle considerations in the production and use of products. Life-cycle considerations demand checkpoints at three stages of product life: (1) processing stage: from the extraction of resources to the delivery of products; (2) utilization stage:

the period during which products are used as intended; and (3) end-of-life stage: recycling or disposal after use (Halada and Yamamoto, 2001). Life cycle thinking is based on core principles of the Life Cycle Assessment (LCA) methodology according to ISO 14044:2020. The LCA techniques showed that particleboards (PBs) have a minimal impact on the environment, except for global warming if they were not landfilled after use (Rivela *et al*., 2006; Mohd Azman *et al.*,2021; Santos *et al.*, 2021). According to the results of the study of Çınar (2005), standard PB had an environmental impact lower than standard fiberboard (72% improvement). For surface and edge finishes, a low-density laminate is preferred to a high-density laminate (36% improvement). Silva *et al.* (2021) investigated the potential of recycled wood and bio-resins to make the PBs. The iterative testing and LCA of PB resulted in the fact that the developed PBs were environmentally benign alternatives to conventional PB made of synthetic polymers and wood particles, reducing up to 95% of the environmental impacts of human toxicity, abiotic depletion, and other impacts compared to conventional practices.

It is very important that the newly created materials are suitable and compatible with the conditions of the furniture use. The aim of the study by Antov *et al.* (2020) was to evaluate the potential of using new eco-friendly recycled wood fibreboard bonded with magnesium lignosulfonate in furniture construction. For this purpose, the bending strength of L-shaped corner joints with mechanical fasteners was determined.

The L-type corner joints made from the developed composites demonstrated significantly lower bending capacity (from 2.5 to 6.5 times) compared to the same joints made from MDF panels. Nevertheless, the new eco-friendly composites can be efficiently utilised as a structural material in non-load-bearing applications.

The withdrawal capacity is based on the composite action between the screw thread of the wood and hence is defined by the wood properties and geometric parameters of the thread (Hoelz *et al*., 2022). For board materials, the position of the fastener relative to the plane of the plate plays a role. The effect of the thread pitch of confirmats in pine wood was evaluated by Sydor *et al.* (2015); they determined little effect on loading capacity for confirmats placed perpendicular to the tangential plane. The load-bearing capacity of confirmats in the tangential plane was 15% higher than in the radial plane. Chen *et al.* (2016) investigated the pullout resistance of bamboo wood screws with higher resistance compared to that of MDF and PB.

In the work of Taj *et al.* (2009), the axial screw withdrawal resistance of a 4.8 mm diameter screw for beech is 2690 N, hornbeam 3000 N and poplar 1750 N. The pullout force value for a 6 mm diameter bolt for beech is 6111 N, oak 5307 N and pine 2975 N (Efe *et al.*, 2004). The materials often used in furniture are not only commercial materials such as MDF and HDF, but sandwich materials giving the opportunity to improve the properties of the structures or to reduce the price can be used. For example, the three-layer board is made as a combination of PB, as the core, and layers of HDF or MDF as outer layers.

Jivkov *et al.* (2017) investigated 10 wood-based sandwich materials and two types of screw, 4 × 40 mm universal screw, and 7 × 50 mm, concluding that the type of wood-based materials (especially the effect of density) has a significant impact on the axial screw withdrawal resistance investigated; there is no correlation between the density of materials and screw withdrawal resistance; the highest withdrawal resistance for both types of screws was in beech plywood (4066 N), OSB, cherry veneered MDF and birch plywood. The lowest values were obtained in PB, a

three-layer board with a core of PB sheathed with laminated HDF with a total thickness of 18 mm and MDF. According to this work, the lowest load capacity of the universal screw was in PB (920 N).

Although brown and white rot reduce the mechanical properties of wood, it is still a material that can be used in the production of composite materials. These materials are environmentally friendly and pose no health risk to humans. Since we want to verify the suitability of using PB made of recycled PB and lower quality wood in furniture construction, the aim of this paper is to verify and compare the mechanical properties of the corner joints and the screw withdrawal resistance. The quality of the joints is also evaluated through the type and extent of damage to the joint.

MATERIALS AND METHODS

Manufacturing of PB

In the laboratory conditions at the Technical University in Zvolen, three-layer PB type P2 was produced for interior use. Four variants of PBs and one variant of control PB were produced (Tab. 1). The PBs contained particles from (a) old laminated PB furniture, (b) old veneered blockboard furniture, (c) lower-quality timber spruce wood (*Picea abies*, Kart. L.) with inactive brown rot (*Famitopisi pinicola* /Sw./ P. Karst.), or (d) lower-quality timber spruce wood (*Picea abies*, Kart. L.) with inactive white rot (*Armillaria ostoyae* /Romang. /Herink). The quantity of brown and white rot in timer is analyzed in Satinová *et al.* (2022). Only particles from sound spruce wood species (*Picea abies*, Kart. L.) were used for manufacturing the control PB.

The particles were bonded with urea-formaldehyde (UF) adhesive with hardener and paraffin from KRONOSPAN s.r.o. The adhesive mixture was applied to the particles in a rotary mixing machine. The layered particles were cold-pressed in a low-temperature machine at a pressure of 1 MPa. The pressing was carried out in a CBJ 100-11 press (TOS, Rakovník, Czech Republic) according to a three-stage pressing diagram – maximum pressing plate temperature 240 ºC, maximum specific pressing pressure 5.23 MPa and with a pressing factor of 8 $s \cdot mm^{-1}$.

PBs were subsequently conditioned in an environment with a temperature of 20±2 ºC and a relative humidity of 65±5%. The manufactured boards were 400 × 300 × 16 mm in size. A total of 6 pieces of board-were manufactured for each type. The specimens were cut from the parts prepared this way. The control specimen was made to compare the production technology in the laboratory and commercial conditions. The commercial PB was supplied by JAF Holz Slovakia, s.r.o. The raw PB FunderMax E1E05 Homogen was type P2 with a density of 719 $kg \cdot m^{-3}$ (Tab. 1), which is suitable for the interior. An overview of the density of the PB used in the experiment is given in Tab. 1. The density was determined following the requirements of the standard STN EN 323.

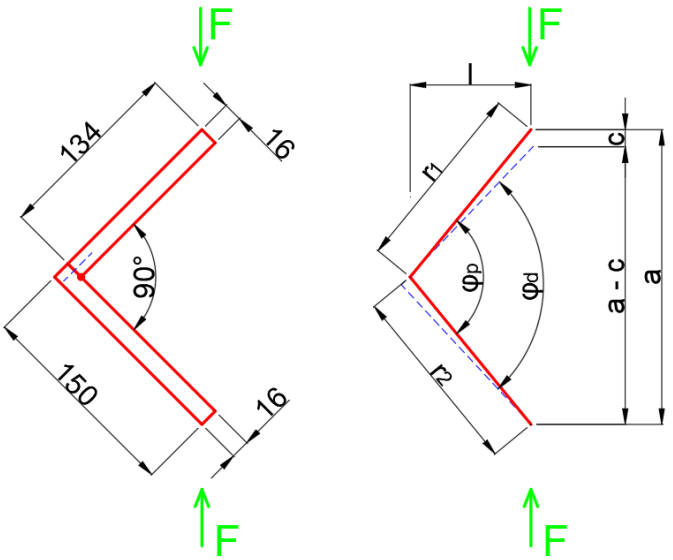
The test specimens of 50 × 150 × 16 mm were stored in an air-conditioned room at a temperature of 20±2 °C and relative humidity of 60±5% for one month. The moisture content of the specimens was determined following the requirements of standard STN EN 322.

Tab. 1 Density of commercial and laboratory manufactured PB used in the experiment.

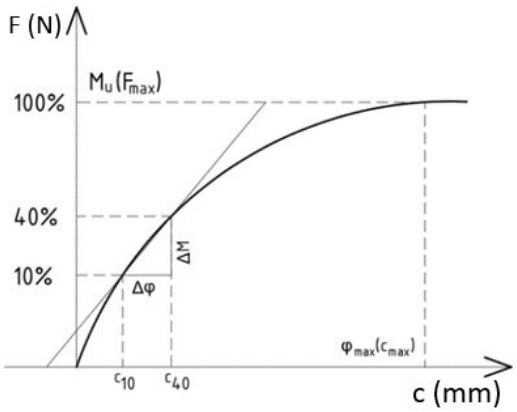
PB types:	Commercial	Control	Recycled PB	Recycled blockboard	Brown rot	White rot
Density ($kg \cdot m^{-3}$)	719 (1.60)	656 (3.46)	643 (3.21)	649 (3.27)	636 (3.60)	640 (3.82)
Moisture content (%)	5.13 (0.21)	6.27 (2.37)	4.96 (0.14)	5.68 (0.34)	5.65 (0.15)	5.89 (0.17)

Determination of the mechanical properties of the corner joints

When determining the load capacity and stiffness of the corner joint, the following scheme (Fig. 1a) for loading the corner joint subjected to bending moment in the angular plane by compression is used. All geometric parameters for determining the mechanical properties of the corner joints can be derived from loading diagram (Figs. 1a and 2b). The load progression of the corner joints was executed according to force deformation diagram (Fig. 1d). Two types of furniture fasteners were tested: a) confirmat with the dimension of ø5 × 50 mm and b) wooden dowel with the dimension of ø6 × 30 mm. The dowels were glued with Technobond polyvinyl acetate adhesive of resistance class D3. It is a one-component copolymer adhesive with good moisture resistance and is suitable for furniture from PB.



(c)



(d)

Fig. 1 Specimen for stiffness and load capacity (a) dimensions of the specimens, (b) loading scheme with geometrical characteristics (c) execution of the test and (d) force deformation diagram.

r_1, r_2 – arms of the joint, the distance of the center of loading force from the pivot point (mm); l – force arm (mm); F – compression loading force (N); a – arm span (mm); c – displacement of the joint arms under load (mm); φ_p – joint angle before loading (°); φ_d – joint angle after loading (°).

The strength characteristics were investigated in the range from 10% to 40% of the maximum load of the joint. Based on the recorded forces and their associated displacements, the deformation, stiffness and load capacity were calculated using the following equations:

(a) Joint load capacity:

$$M_u = F_{max} \cdot l \quad \text{(N·mm)} \qquad (1)$$

(b) Joint stiffness:

$$t = \frac{\Delta M}{\Delta \varphi} \quad \text{(N·mm/°)} \qquad (2)$$

$$\Delta M = 0{,}3 \cdot M_u \ \text{(N·mm)} \qquad (3)$$

$$\Delta \varphi = \varphi_{d10} - \varphi_{d40} \quad (°) \qquad (4)$$

where: M_u – load capacity (N·mm)

F_{max} – maximum loading force (N)

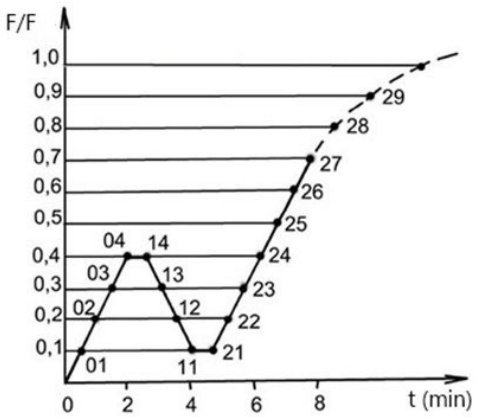
l – arm of the force (mm)

t – joint stiffness (N·mm/°)

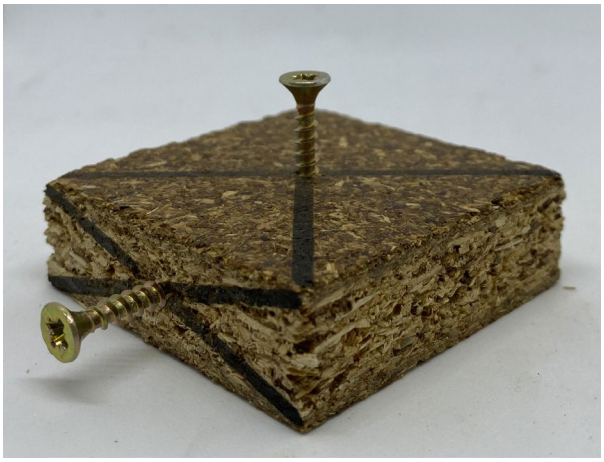
Δφ – angular deformation at load from 10% to 40% F_{max} (°).

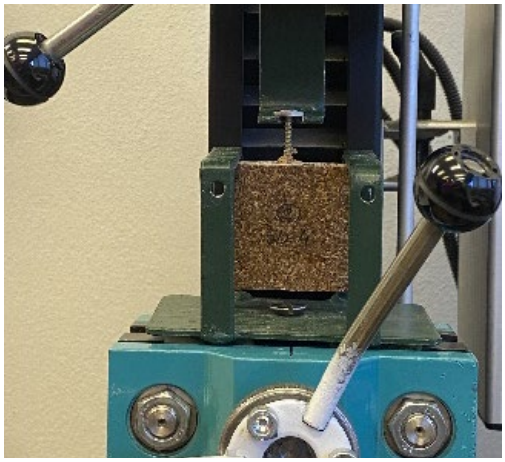
Determination of the withdrawal capacity and stiffness for the screw

When determining the axial screw withdrawal capacity, the methodology of STN EN 26891:1995 was followed. The test procedure requires estimating the maximum F_{est} load to be determined by experience, calculation, or preliminary tests. The procedure for loading the test body is shown in Fig. 2a. The dimensions of the test specimen for determining the screw withdrawal resistance are w x h x d (mm). The fasteners used in this test were ø3.5 × 30 mm screws. Pre-drilled holes of ø2.5 mm to a depth of 16 mm were drilled at the screw location. The size of the specimens was 50 × 50 mm. The screws were mounted in two directions on the surface and on the edge of the plate as shown in Fig. 2b.



(a)





(b) **(c)**

Fig. 2 Test procedure for determining the axial withdrawal capacity of the screw, F_{est}, F – loading force, t – duration of the loading (a), screw placement in test body (b), positioning of the specimen in the testing machine (c).

The determined strength characteristics are:

Screw withdrawal capacity: $F_u = F_{max}$ (N)

Deformation at maximum withdrawal capacity: $u = u_{max}$ (mm)

Withdrawal stiffness (modulus of displacement) of the screws in the material (when it is pulled out) expresses the amount of force required to induce a unit length deformation (displacement). It is expressed by the steepness of the force-deflection curve. The withdrawal stiffness of the screw is determined by following equation:

$$T = \frac{\Delta F}{\Delta u} \quad (\text{N·mm}^{-1}) \tag{5}$$

where: T – withdrawal stiffness (N·mm^{-1}),

ΔF – load capacity difference at 40% and 10% of maximum load (N),

Δu – displacement difference at 40% and 10% of maximum load (mm).

RESULTS AND DISCUSSION

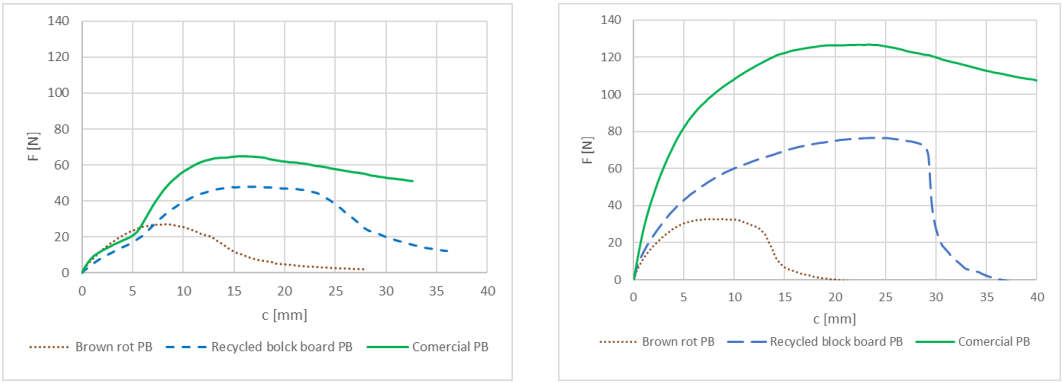
Mechanical properties of the corner joints

The average values of the mechanical properties for corner joints loaded by compressive bending moment for the individual materials and connector types tested, are given in Tab. 2 and 3. The load-carrying capacity M_u (N·mm) and stiffness of corner joints t (N·mm/°) were evaluated. Based on the preliminary tests, it was found that for all materials and dimensions of the confirmat tested, the bending moment stress in the angular plane in tension exhibits a higher load-carrying capacity than the bending moment stress in the angular plane. Both the stiffness and the load capacity of the confirmats reach higher values of mechanical properties compared to pin joints, when stressed in the angular plane by compression. The highest values of these mechanical properties were achieved by the joints for PB with recycled block boards. The load capacity of the pin joint is 33% lower compared to the confirmat. The stiffness of the pin joint is 39% lower compared to the confirmat. Comparing the joints for PB with recycled block board with commercial PB, the commercial PB achieves higher values. The values of mechanical properties for the glued pin joint are smaller by 57% and for the confirmat by 35%.

Tab. 2 Mechanical properties of of the corner joint using wooden dowel and confirmat for tested PBs.

	Mechanical properties of corner joint			
	Wooden dowel		Confirmat	
PBs type:	Load-carrying capacity (N·mm)	Stiffness (N·mm/°)	Load-carrying capacity (N·mm)	Stiffness (N·mm/°)
Commercial	5727.46 (13.06)	605.29 (18.52)	10410.06 (8.82)	3105.18 (4.69)
Control	3720.68 (7.01)	711.56 (15.39)	7827.61 (7.45)	2129.81 (14.54)
Recycled PB	2716.44 (11.93)	766.25 (11.41)	3312.32 (20.85)	939.04 (33.43)
Recycled blockboard	4072.71 (11.79)	808.58 (12.43)	6113.94 (9.88)	1316.00 (16.97)
Brown rot	2199.29 (8.19)	795.30 (10.15)	2709.88 (11.42)	568.54 (7.55)
White rot	2992.55 (12.10)	604.36 (12.99)	5422.54 (13.50)	922.84 (14.98)

Note: Value at parenthesis is coefficient of variance.



(a) **(b)**

Fig. 3 Force-displacement diagram of stress loading in the angular plane – average value (a) wooden dowel joint, (b) confirmat joint.

Tab. 3 One-way analysis of variance for the load-carrying capacity under compression bending and joint stiffness.

Effect	DOF	Stiffness ($N \cdot mm^{-1}$)	Maximum load (N)	Stiffness ($N \cdot mm^{-1}$)	Maximum load (N)
		F	p	F	p
Intercept	1	5158	0.0000	8657.61	0.0000
Material	5	142.75	0.0000	263.37	0.0000
Direction	1	644.13	0.0000	545.71	0.0000
Material * Direction	5	178.05	0.0000	47.84	0.0000

Note: DOF – degree of freedom, F – test value, p – probability.

Tab. 3 shows that at the significance level of 0.05, all investigated factors, *i.e.,* type of fastener (p=0.000) and type of material or density (p=0.000), as well as their interaction (p=0.000), were significant for both the load capacity and stiffness of corner joints. It means that a change in any of the investigated factors will result in a change in the load capacity or the stiffness of the corner joint, respectively.

Withdrawal resistance and stiffness of the screw

The average values of the mechanical properties, the withdrawal resistance F (N) and withdrawal stiffness T ($N \cdot mm^{-1}$) for screws ø3.5 × 30 mm loaded by axial force embedded in the tested materials at their surface and edge are given in Tab. 4.

Tab. 4 Mechanical properties of axially loaded screws ø3.5 × 30 mm embedded in the tested materials.

	Withdrawal from the surface		Withdrawal from the edge	
PBs type:	Withdrawal resistance (N)	Withdrawal stiffness ($N \cdot mm^{-1}$)	Withdrawal resistance (N)	Withdrawal stiffness ($N \cdot mm^{-1}$)
Commercial	863.59 (8.22)	349.64 (10.75)	625.06 (14.52)	381.66 (12.94)
Control	595.22 (7.40)	352.95 (13.40)	403.15 (4.39)	250.75 (18.01)
Recycled PB	379.17 (14.41)	210.23 (17.26)	273.02 (18.12)	214.09 (19.47)
Recycled blockboard	556.44 (9.45)	309.77 (21.40)	416.61 (8.13)	246.89 (11.36)
Brown rot	339.43 (11.28)	225.59 (14.41)	219.47 (17.87)	153.09 (40.41)
White rot	505.62 (6.96)	245.41 (13.54)	338.10 (19.42)	216.15 (27.42)

Note: Value at parenthesis is coefficient of variance.

Tab. 5 One-way analysis of variance for withdrawal stiffness and resistance of ø3.5 × 30 mm screws.

Effect	DOF	Sigma-restricted parameterization Effective hypothesis decomposition			
		Withdrawal stiffness ($N \cdot mm^{-1}$)		Withdrawal resistance (N)	
		F	p	F	P
Intercept	1	3834.86	0.0000	9096.13	0.0000
Material	5	38.41	0.0000	193.90	0.0000
Load Direction	1	16.29	0.0001	277.97	0.0000
Material * Load Direction	5	4.62	0.0007	4.36	0.0012

Note: DOF – degree of freedom, F – test value, p – probability.

Following the one-way analysis of variance (Tab. 5), the effect of selected factors on the withdrawal resistance of the screw ø3.5 × 30 mm was determined. The effect of all factors, density of materials and load direction acting simultaneously was statistically significant at the 5% significance level (p=0.007) when evaluating withdrawal stiffness. The effect of all factors, density of materials and load direction acting simultaneously, was statistically significant at the 5% significance level (p=0.001) when evaluating withdrawal resistance.

Higher withdrawal resistance and withdrawal stiffness was achieved when the screw was embedded in the surface of the specimen (perpendicular to the plane of the plate). The highest values of withdrawal resistance were achieved by the screw embedded in the surface of PB from recycled blockboard at the level of 556.44 N, which is 25.13% higher than for edge embedding with a capacity of 416.61 N. Compared to commercial PB (863.59 N), the withdrawal resistance for PB from recycled blockboard is 35.56% lower for surface embedding and 33.34% lower for edge embedding. The smallest withdrawal resistance values were performed by the brown rot specimen. Compared to the commercial PB, the values for the surface were lower by 60.69% and for the edge were lower by 64.88%. The screw withdrawal stiffness was also the highest for the PB from recycled blockboard compared to other tested materials. Compared to commercial PB, the withdrawal stiffness of PB from recycled blockboard withdrawal resistance for this material was lower, with a difference of 11.40% for surface embedding and 35.31% for edge embedding.

Fig. 4 shows characteristic damage of a glued wooden dowel joint and Fig. 5 shows damage of a confirmat joint.

(a) **(b)**

Fig. 4 Failure modes in some of the studied cases – wooden dowel at: (a) commercial PB and (b) PB with recycled particle board.

(a) **(b)**

Fig. 5 Failure modes in some of the studied cases – confirmat at:

(a) commercial PB and (b) PB with recycled blockboard.

The lower quality of the recycled PB and lower-quality timber was also reflected in the extent of damage around the fastener. According to the work (Langová and Jočšák, 2018), the extent of the damage for ø5 × 50 mm confirmat for spruce and beech joints was 10 mm in diameter around the fastener header. This damage was up to 30 mm in diameter for commercial PB and MDF materials. In the case of the materials tested in this study, the damage was manifested through the entire width of the specimen (50 mm). For a glued ø6 × 30 mm wooden dowel, the material was visible to be torn out at a distance of 18 mm from the centre of the dowel. Although the difference in densities between commercial PB and boards made of recyclate or using lower quality timber was negligible, there was a visible difference in damage at the glued joints. In commercial PB, the dowel breaks, while in the tested specimens the material around the glued joint was torn out. For the confirmat designed for bonding PB when joining commercial PB, there was a bending of the confirmat, which was typical damage to the joint, in our tested specimens there was a breakage of a part of the structural board. This type of damage is related to the quality of bonding in the production of PB.

DISCUSSION

The density values of the control PB were lower, which may be due to the production technology in laboratory conditions.

The measured and calculated load capacity values of corner joints PB made from recycled material and lower quality timber with commercial PB and solid timber can be compared. According to the work of Langová and Jočšák (2018), the assumption that the mechanical properties are influenced by the density of the material and the bolt dimension but also by the thickness of the material was confirmed. For comparison, the values of the strength properties of ø5 × 50 mm compression-loaded corner screwed joints were presented.

The highest load capacity values were achieved by the PB made from recycled blockboard 6113.94 N·mm, which is comparable to the load capacity of commercial MDF with 12 mm

thickness, ρ = 680 kg·m^{-3} (6890.00 N·mm). In the case of our recycled PB, the loading capacity was 3312.32 N·mm, which is comparable to that of commercial PB with 12 mm thickness (3600.00 N·mm) or to that of a joint made from spruce lumber with 12 mm thickness, ρ = 392 kg·m^{-3} (4580 N·mm). According to the work of Antov *et al.* (2020), corner joint with ø7 × 50 mm confirmat made from eco-friendly boards, produced in the laboratory with a density of 720 kg·m^{-3} and 15% magnesium lignosulfonate gluing content, based on the dry fibres, achieved a loading capacity value of 6950 N·mm.

The effect of the diameter of the fastener and the density of the material to be bonded was also confirmed in the case of bonded joints. In our case, a joint of PB made from recycled blockboard (ρ = 649 kg·m^{-3}) with a glued wooden dowel ø6 × 30 mm achieved a loading capacity of 4072.71 N·mm. In the work of Antov *et al.* (2020) a joint made of eco-friendly boards (ρ = 726.5 kg·m^{-3}) with a glued wooden dowel ø 8 × 30 mm achieved a two times more loading capacity of 8020.00 N·mm. The highest stiffness values were achieved in the case of the PB made from recycled blockboard 1316.00 N·mm/°, which is comparable to the stiffness of commercial PB with 12 mm thickness (1279.50 N·mm/°) and 12 mm thick commercial MDF, ρ = 680 kg·m^{-3} (1805.01 N·mm/°). For both commercial materials, with 18 mm thickness, the joint stiffness was almost three times higher compared to the PB made from blockboard recyclate, which showed the best strength properties for both types of fasteners among the tested materials.

The axial screw withdrawal resistance is influenced by the density of the material. Higher values were achieved for screws stressed to pull perpendicularly from the surface of the specimen, which is also suitable from a practical point of view when attaching furniture fittings. In terms of the axial screw withdrawal resistance of ø3.5 × 30 mm screw, the best results were achieved by the PB made from recycled blockboard (556.44 N), which is almost 1.5 times less compared to commercial PB. Compared to spruce parallel to the grain in the tangential and radial directions (1117.00 N) and perpendicular to the grain (1034.00 N), it is 2 times less.

In the work of Pereira *et al.* (2018), panels reinforced fibers reached about 74% of the maximum strength achieved by MDF samples. Panels reinforced with pejibaye showed the worst mechanical performance. However, hybridization between pejibaye and fibers resulted in a performance improvement of approximately 50% in the maximum withdrawal load comparing with panels reinforced only with pejibaye fibers. The results of Yorur *et al.* (2020) indicated that the average direct screw withdrawal resistance ranged from 695 N to 2076 N for frontal test blocks, while for lateral in MDF it ranged from 79 N to 1634 N. For PB frontal test blocks, the average direct screw withdrawal resistance ranged from 474 N to 1646 N, while for lateral it ranged from 190 N to 1313 N. The results of Sackey *et al.* (2008) studies indicate that not only the content of fine particles, but also the ratio of all fractions with particle size strongly influences the efficiency and strength of the bond. In three-ply particleboards with a low target density, replacing 20% of the fines content of the total slurry with coarse particles increased the internal joint strength by 40% and the screw adhesion by 18%. Wronka and Kowaluk (2022) reported that the screw withdrawal resistance decreases with subsequent re-milling of the PB to produce the PB out of recovered particles. The progressive milling of the PB leads to achieving a fraction of the fine-size particles of growing bulk density, which influences the density profile of the panels produced, especially of the face zone. This local densification allows the surface soundness to be kept high, irrespective of the decrease in other mechanical parameters, such as internal bond and screw withdrawal resistance.

In the event of a decrease in forest resources, it is possible to produce PB from various raw lignocellulosic materials. Several studies have dealt with this area. Based on the findings of these studies, we can conclude that sources of agricultural raw materials such as cane stalk (Kord *et al.*, 2015) and lignocellulosic particles of raspberry Rubus idaeus L. (Kowaluk *et al.*, 2019) or rice husks (Kwon *et al*. 2013) meet the standard and in some cases PB had improved physical and mechanical properties, therefore, they are a suitable material for the production of PB.

CONCLUSION

- From a practical point of view, the above results of the strength properties of joints, determined based on experimental tests and subsequent calculations, can be used for dimensioning of bolted joints in furniture constructions when dimensioning according to the first limit condition.
- The results for stiffness of the joint can be used for stress calculations and deformation of entire furniture structures. The resulting strain values provide the basis for an appropriate selection of the joint in terms of safety and reliability.
- The values obtained from experimental measurements also serve as input data for defining the conditions of action of the structure in calculation programs.
- Comparing results for tested mechanical properties of this study with other works carried out under the same loading conditions and dimensions of the test bodies, it can be concluded that particleboard made from recycled materials and lower-quality timber achieves significantly lower strength properties compared to commercial PBs. These properties are evaluated through the mechanical resistance of the joints. Therefore, these materials find application in non-load-bearing elements of furniture structures. In the case of brown rot, the boards can be used as part of decorative interior elements.
- The influence of the proportion of recycled or reduced quality timber is reflected in the density of the material and subsequently in the strength properties of the joints, with the highest values achieved by the PB made from recycled blockboard. Based on the determined strength characteristics of the joints, producing structural boards by adding recyclate and not by adding timber of lower quality is recommended. When using a proportion of timber with brown and white rot, the strength properties of the joints show the lowest values.
- As the material is recommended for non-load-bearing or decorative interior elements, examining the adhesion of decorative veneers or foils is advisable.

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SOCIO-ECONOMIC IMPACTS OF SUSTAINABLE WOOD PRACTICES

Frederik Laleicke (Chair)

Wood vinegar from four tropical woods through slow pyrolysis under different temperatures: Yields, chemical composition and biological effects on crops and pests

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ABSTRACT

Costa Rica produces an extensive amount of forest residues, which can be pyrolyzed slowly to produce by-products like charcoal, wood vinegar, bio-oil, and non-condensable that can be effectively used in agricultural crops, providing a comprehensive approach to leveraging forest resources for finding renewable sources for agriculture production. However, there is a lack of information about the processes and products obtained with slow pyrolysis of forest residues in Costa Rica. Hence, this study presents the results yields, chemical composition and biological effects on crops and pests of wood vinegar obtained in a small pilot reactor for slow pyrolysis of four tropical woods at five varying temperatures (300, 350, 400, 450, and 500 °C). The results showed that charcoal yields ranged from 28.2 to 56.6%, bio-oil from 2.8% to 8.1%, whereas yields of non-condensable varied from 14.0% to 33%, and wood vinegar yields ranged between 25.6 to 40.8%. Another significant finding indicated that due to incomplete pyrolysis of parentwood, the temperatures of 300-350 °C were deemed suboptimal and are thus not recommended. But, the slow pyrolysis between 400-500 °C, the condensable products yields (wood vinegar and bio-oil) were at their maximum at 500 °C. The four tropical wood species exhibited divergent performances, as *Gmelina arborea* and *Dipteryx panamensis* performed differently than *Hieronyma alchornoides* and *Tectona grandis*. Though *G. arborea* produced a higher percentage of non-condensable gases, challenges were encountered in the separation of wood vinegar and bio-oil. While *D. panamensis* produced a low charcoal yield, it benefitted from the highest percentage of condensable gases. In relation to biological effects on crops and pests, wood vinegar from *Gmelina arborea* was tested its effects inhibition against *Ceratocystis fimbriata* (fungus attack plantation trees) under different concentrations and the fertilization effects of this vinegar on the production and quality of *Eruca vesicaria* (rucola). The results showed that the median effective concentration (EC50) of wood vinegar inhibited the fungus.

Paving the way for the sustainable use of wood in construction - a governance-orientated and socio-economic approach in Switzerland

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Abstract

Due to its ecological benefits, wood is playing an increasingly important role as a sustainable resource in areas such as construction and energy. Switzerland's strict forestry laws prioritize the sustainable use of wood. However, the finite nature of wood requires careful management. Three Swiss case studies demonstrate the potential of wood in construction and its ability to extend the life cycle of buildings. The successful integration of wood in construction requires the consideration of the local value chain and the involvement of stakeholders. These findings emphasize the importance of vertical integration of decision-makers and stakeholders, supported by government advocacy. Integrative approaches that involve stakeholders across the wood value chain promote ecosystem services and a carbon-neutral bioeconomy.

Introduction

Legal and political mandate

Switzerland upholds one of the most stringent forest conservation laws globally, ensuring the prevention of overexploitation and safeguarding the integrity of its forests (ForA 1991). The Climate and Innovation Act, which was approved by voters in June 2023, stipulates that Switzerland must have net zero greenhouse gas emissions by 2050. The forestry and timber industry has great potential to contribute to the Federal Council's 2050 net-zero climate target (DETEC 2023).

Socio-political and socio-economic challenges

Figure 1 shows the challenges in achieving the climate protection targets as well as the socio-political and socio-economic challenges. These are:

- An increasing demand for housing, especially affordable living spaces
- Considering climate protection goals
- Achieving climate protection targets

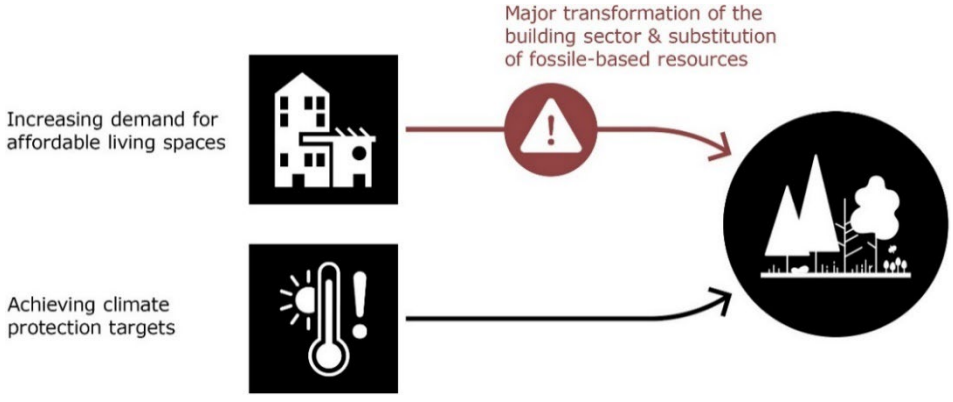

Figure 2: Socio-political challenges and climate protection targets. © CCTP

Need for action from the perspective of the forest and wood value system

In order to ensure that economic, protective and recreational functions of forests are safeguarded even under changing climate conditions, adaptation of forests is essential in many places. The rapid pace of climate change is overtaxing the natural adaptability of forests. This leads to consequential costs for securing ecosystem services.

Rising demands and conflicts of use, increasing cases of damage due to storm damage and pests or diseases, volatile timber prices, rising costs (due to clearing damage, forest conversion, etc.) and weak points in the wood value chain are putting increasing pressure on the economic concept of the forest. Forest owners and actors in forest planning are challenged.

Methodology

The methodological for this paper is based on the analysis of three best practices against the background of the national (Swiss) framework conditions and the identification of findings for transferability.

Best Practices

INNOwood

The INNOwood project (2021-23) was launched as an initiative of a large number of actors in the wood value chain in Central Switzerland to contribute to achieving the Swiss Federal Council's net-zero greenhouse gas emissions by 2050.

So far, system approaches of the forest-wood value chain (and thus also the understanding of it) have focused on the linear flow from the supply of the raw material wood through the products of the further sales stages to the finished building or supplied wood energy. The forest is only depicted as the "producer" and thus raw material supplier without further differentiation in terms of its forest services in a regional, ecological and climate policy context (Geier et al. 2023, p. 7). This leads to the marginalization of the decision at the end of the value chain as to whether local wood or wood from sustainable forest management is used for buildings.

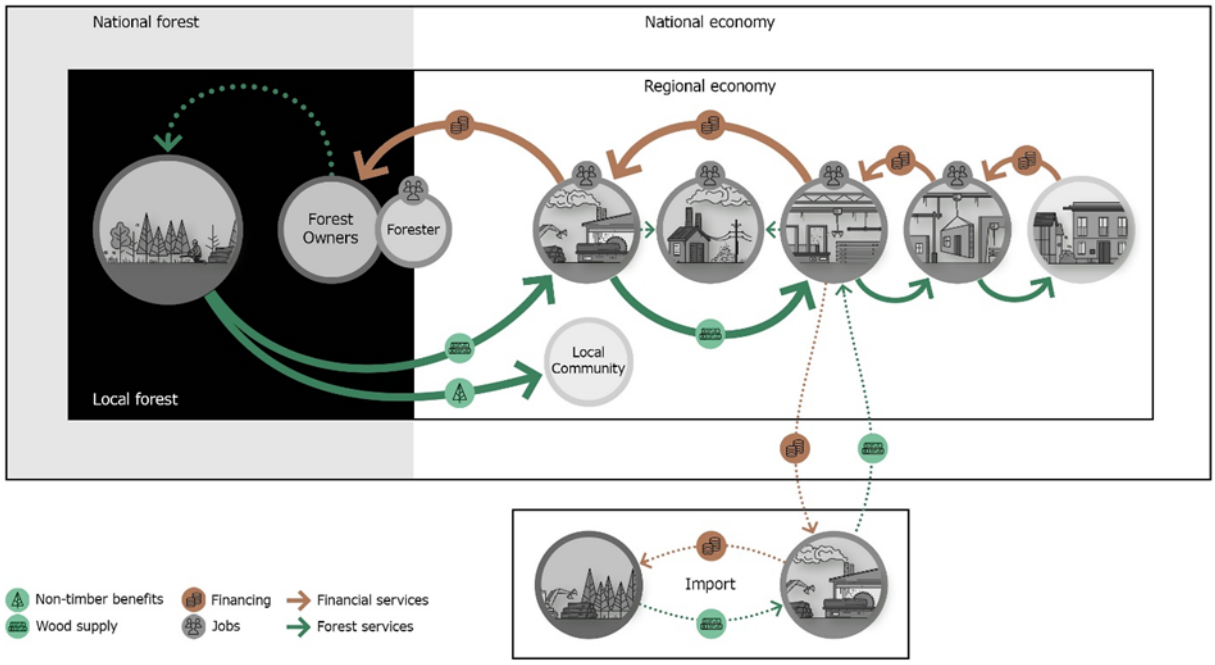

Figure 3: Impact network of the forest and the wood value system.
Source: © INNOwood, scientifically adapted and translated.

The INNOwood project addressed this issue and aimed to raise awareness among decision-makers and the civil society at the end of the forest and timber value chain. Within the project connections and effects as well as interdependencies between forest management and the use of regional wood (impact network) were identified and recorded in a system map (Geier et al. 2023, p. 7-8). Understanding interdependencies can ensure added value throughout the network. Regional wood usage is crucial, integrating forests into the local economic system and directly compensating for forest services. This supports forestry industry sustainability and regional forest management.

Figure 2 shows the graphical representation of the generalized impact structure forest-timber-society. The different benefits provided by donors and recipients are identified on the basis of impact structures in six specific case studies in INNOwood. The main questions were: Who benefits from services, who pays for services?

The abstract character of the interdependencies hinders necessary awareness raising to clients, planners and civil society as they are most often laymen in terms of forestry. Therefore, the INNOwood project carried out communication tests with laymen and multipliers. The results of these tests were sobering, interviewees felt overwhelmed when it came to describing and naming individual dependencies. For this reason, a simplified effect structure was developed and connected to target-group oriented user stories of the local case studies.

Finally, the value of the cognitions of INNOwood led to the launch of a new website, named www.waldnutzen.ch, on which six shining examples of buildings made of wood from local forests tell their stories as explained above. The stories of these shining examples are connected with relevant background information. Low-threshold access to information via a website and user guidance geared towards the desire to discover make abstract content accessible to laypeople and semi-experts.

INNOwood is a best practice example that refers to the primary raw material source for the sustainable use of wood in construction. In future, the sustainable use of wood in construction must take into account resource-oriented use in a global but also in a local context. The demand side at the end of the value chain is able to influence by a pull-effect the supply chain. Informed decisions at the end of the value chain require ordering skills that respect the material and value loops that finally support sustainable forest management. Thus, clients and planners are responsible, but they are experts in the construction sector and are certainly rarely familiar with forest management issues and impacts across sectors. Awareness-raising for semi-experts and laypeople therefore plays an important role.

Through the integrative approach of the INNOwood project cooperation, the diverse dimensions and meanings of the forest and the economic processes of the timber industry could be brought into a mutually enriching relationship.

Holzkreislauf Uri [Wood Circus Uri]

The Holzkreislauf Uri initiative was launched in parallel with the INNOwood project in 2021 and is still ongoing. It aims to empower local actors to implement a political objective. The launch was based on several political drivers. One requirement was adopted by the "Strategy and Government Program 2020-2024^{+}" that describes the specific legislative goals of the Canton of Uri for the period 2020-2024. Within the chapter "O. CO_2 removal from the atmosphere" the relevant objective is formulated: "[...] Increase the use of wood from local forests and increase the use of local wood as a building material and energy source". The realization of this goal should go hand in hand with concrete measures in business and civil society. The following analysis is based on the implementation strategy described in Geier S. and Rupli H. (2023) and the findings from the scientific monitoring of the initiative.

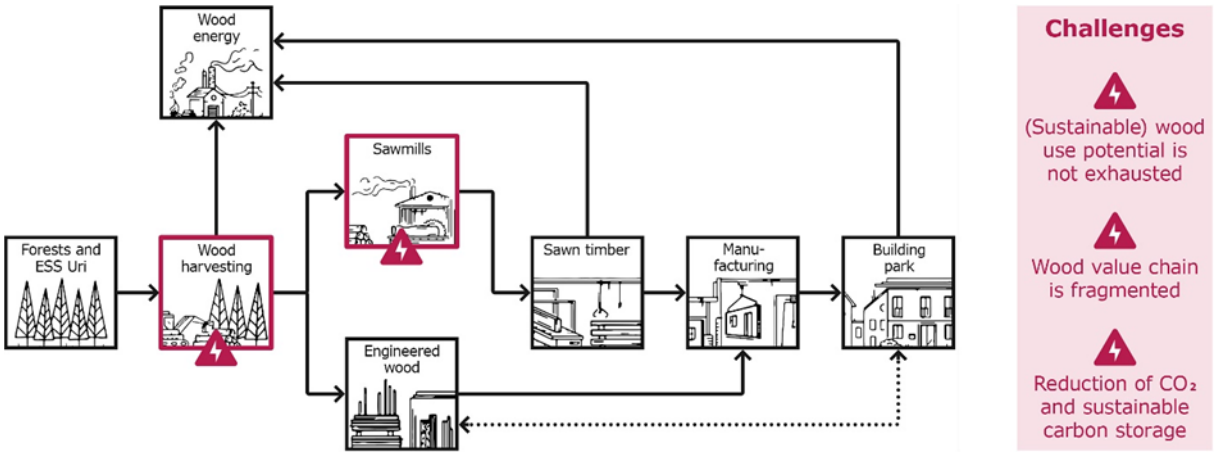

Figure 4: Analysis status quo wood value chain in the canton of Uri. © CCTP

In a first step, the identification of the existing situation in the value chain (Figure 3) showed on the one hand that there is no pull effect at the end of the value chain - the demand for local wood is lagging behind. Clients are not aware of the possibilities of using local wood, and architects are not familiar with suitable technologies and processes to integrate local wood with its specific properties into their planning. Both are unaware of the resulting benefits for local value creation and eco system services. On the other hand, there is the fragmented regional timber processing chain, which cannot supply the necessary capacities or products even if there is a demand for wood from Uri. The analysis of this status quo was discussed and confirmed with forest representatives and players in the wood processing chain. Increased use of local wood in the future therefore requires know-how on the utilization of the range of local timber assortments, an establishment of communication structures between demand side and forestry sector to coordinate harvesting and targeted investments in the processing chain.

For the implementation strategy, the mapping of the value chain was expanded to include possible options for action. In view of the need to use scarce resources sparingly, the concept of value creation cycles (instead of "chains") was coined. The systemic mapping (Figure 4) provided an overview of the entirety of value creation and material cycles and thus the necessary starting points for the implementation strategy and the allocation of specific measures. The measures marked in magenta in Figure 4 show necessary fields of actions.

Transferring the initiative Holzkreislauf Uri beyond the 2020-2024 period and beyond individual projects and pilot actions into a long-term political framework for sustainable action is a task for the future that is currently being planned.

The climate protection targets at national level with the Federal Council's net-zero target by 2050 were the starting point for the initiation of the Holzkreislauf Uri. However, this would not have triggered any direct action at the level of the players in the forestry and timber industry in the canton of Uri. It was only the specification of the 2020-2024 government program and the link to the potential of the forestry and timber industry, which could generate a win-win situation, that provided the impetus for launching the initiative.

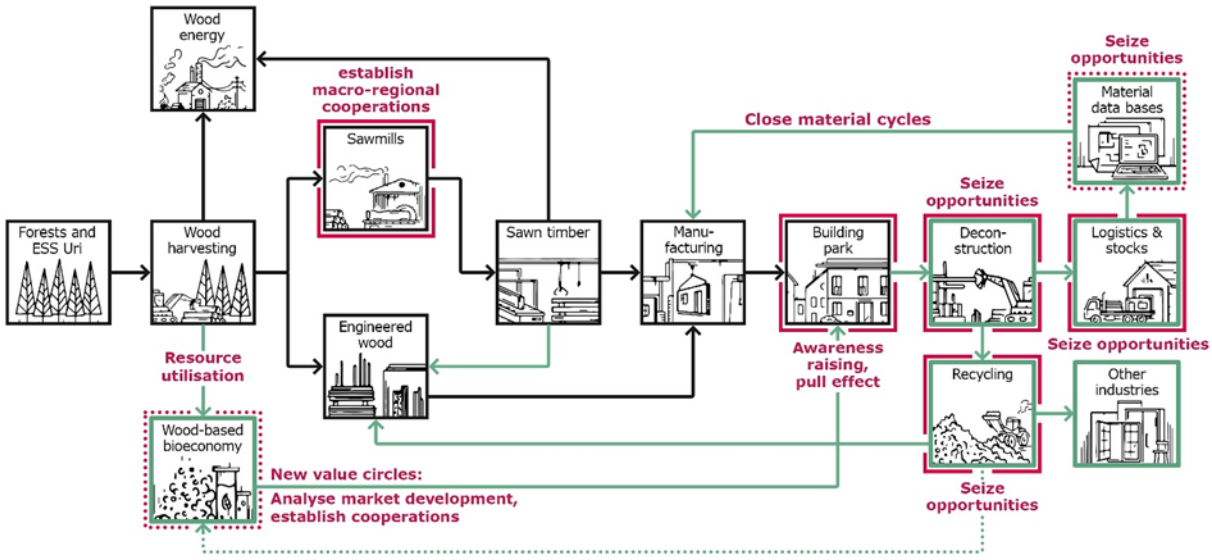

Figure 5: Development of a roadmap towards a new approach of value creation loops in the canton Uri. © CCTP

However, the real key to success was the dialogue-based approach and the alignment of the framework for action to the respective stakeholder level (politics-administration-business-education) and the active linking of these stakeholder levels with each other. The support from Lucerne University of Applied Sciences and Arts made it possible to methodically develop the framework for action from a neutral position, to accompany the dialogue process methodically and professionally and to evaluate the interim results from an overarching perspective.

Modul 17

With the liberalization of fire protection regulations in Switzerland in 2015, the height limit for timber buildings was lifted and became possible to build the same height as with other materials (Keikut and Geier 2019, p.7)

With increasing urbanization and the need to create living space, the pressure for urban densification is growing. However, the extent to which high-rise buildings can contribute to high-quality densification is controversial. From the perspective of timber construction, too, the question arises as to what role timber can play in this development. This is where the project “Timber Hybrid High-Rise Building” came in and investigated the characteristics of a new high-rise typology in timber hybrid construction and what contribution this typology can make to high-quality densification in urban areas. The result of the project is a modular construction concept that utilizes the systemic approaches of timber construction as well as its construction principles and potential for urban redensification through high degrees of prefabrication while reducing disturbance for neighbours.

The basic module, the so-called "Modul17" (Figure 5), consists of almost 90 percent wood and, with a horizontal dimension of 17 by 17 meters - hence the name - and a height of around 14.5 meters, offers a high degree of flexibility in use both vertically and horizontally. Each individual module is held in the corners by four "mega columns", which transfer the vertical loads and conceal the building technology within a cavity. Directly under the ceiling of the module, a "mega ceiling" made of room-high truss girders transfers the vertical loads to the "mega columns" (Keikut and Geier 2019, p.46-47)

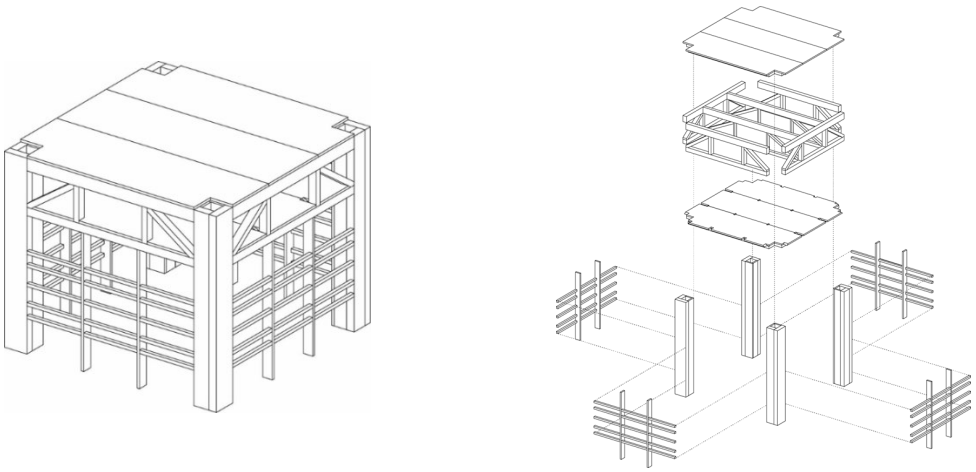

Figure 6: Modul17 – Axonometry. © CCTP

This means that the entire floor plan is column-free and can be freely designed as "free space". The "mega ceiling" in wood-concrete composite construction separates the modules from one another and, together with reinforced concrete stairs outside the module, provides horizontal bracing (Keikut and Geier 2019, p.41)

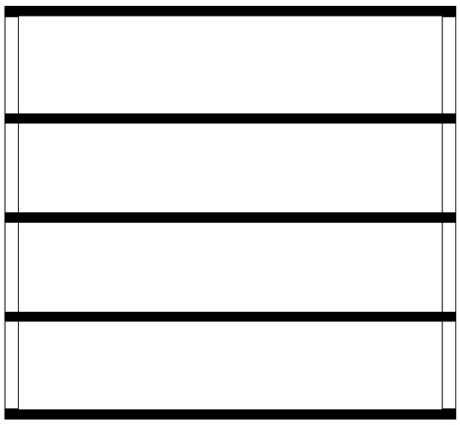

Figure 7: "Cream-slices" in traditional high-rise-buildings. © CCTP

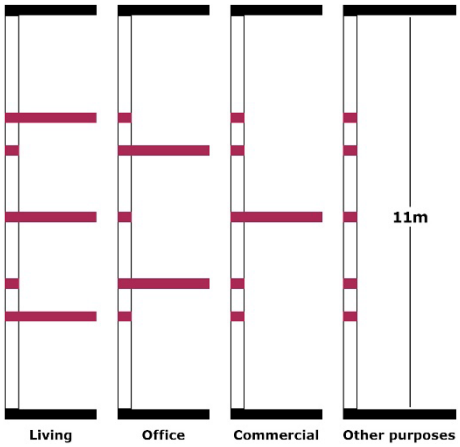

Figure 8: Modul17 vertical free space. © CCTP

The big advantage, however, is the vertical and horizontal flexibility. Instead of a stiffening core, the center of the module is left free ("free space"). Vertically, the usual principle of "cream slices" (Figure 6), which massively restrict flexibility of use due to fixed room heights, has been abandoned. The 11-metre-high free space area allows polyvalent uses with different scenarios (Figure 7), such as four residential floors, three commercial floors or an extra-high room for special uses (Keikut and Geier 2019, p.81). As each module forms an independent unit, it is easy to respond to the dynamics of use.

The developments for Modul17 resulted from current questions about a difficult building typology and its role in urban development. The results provided a good insight into the role of a high-rise building and the possibilities and limitations of modular construction methods in the urban environment. In view of the rapidly growing debate on resource conservation and the circular economy, the work and findings from the project make a valuable contribution. In the context of wood in construction, the Modul17 approach shows a strategic utilization of wood, leveraging its

inherent strengths in conjunction with other materials in a judicious manner, rather than adhering dogmatically to a sole reliance on wood.

Conclusions

Local value creation loops

Both INNOwood and Holzkreislauf Uri succeed in triggering concern through regionality as well as the focus on regional lighthouses, resources and actors and thus derive impulses for action. The preservation and/or creation of jobs and regional value creation at a local level generate income and contribute to the quality of life and the preservation of cultural identity.

In a globally operating timber market, the focus on local resources has to be discussed. The vast offering of a global market is offset by limited local products and technologies. However, local supply chains can prove to be more resilient in the event of a crisis. On the other hand, self-sufficiency in the supply of resources can also lead to more effort and resource consumption than the development of supra-regional cooperation or supply chains. The fact that planners are not always aware of local availability was discussed in the Holzkreislauf Uri. First proposals on how to overcome this lack of know-how had been discussed but not yet realized. In the long term, sustainable development will also require an appropriate balance to be struck with regard to local or global value creation loops, taking into account ecological, social and regional economic objectives.

Inter- and transdisciplinary

In each of the three best practices, the adoption of an interdisciplinary and transdisciplinary methodology emerged as pivotal for success. In an increasingly interconnected environment, challenges cannot be tackled isolated and within the confines of a discipline. The increasing demand for living space cannot be viewed separated from climate protection targets. While disciplinary expertise serves as a fundamental prerequisite for addressing these challenges, a nuanced comprehension of complex issues necessitates transcending the temptation to oversimplify systems and compartmentalize concerns. Instead, fostering an understanding of system dynamics and cultivating iterative, interdisciplinary approaches to problem-solving becomes paramount.

Balance between regulation & participation

Another key is the interplay between the legal and political framework and the involvement of society through actors in a dialogical or participatory process. Only committed players who push the boundaries of what is legally possible enable the implementation of lighthouse projects and, as a logical consequence, the establishment of new technologies and standards. Both projects emphasized the incorporation of stakeholders spanning various levels and societal segments. Notably, the pivotal factor contributing to their success was the integration within political agendas, exemplified by initiatives like the "Strategy and Government Program 2020-2024+". Ultimately, this raises the question of how much legislation is necessary or is it enough to rely on voluntary, committed pioneers in order to achieve sustainable development in the construction sector in the long term?

Acemoglu & Robinson (2012) delineate that for sustainable development mechanism of pluralistic political institutions that allow wide sections of society to participate in governing the country are necessary to achieve prosperity, wealth and higher living standards on a long term. To master the balance between participation and ruling framework is thereby a key to success. This balance can be observed above all in the Holzkreislauf Uri. Without the legal requirements from the government program ("state"), which also brings together two subject areas (forestry and timber industry & climate policy), the process would not have been set into action. Nevertheless, the involvement of the relevant stakeholders ("society") is necessary in order to initiate implementation and to strive thereby for innovations.

A participatory process devoid of delineated structures governing role allocation and delineating the actionable competencies of participants would not have yielded the current outcome.

Target group-oriented awareness-raising at the end of the value chain

The INNOwood project refers to the primary sector (forest) in order to achieve a sustainable use of wood in the construction industry. The use of wood per se can only be considered sustainable in the context of sustainable forest management and the establishment of (local) value-added loops. The decisive factor here is to strengthen the (client's) ordering competence on the demand side at the end of the value chain. The Holzkreislauf Uri focusses on strengthening the local processing chain, among other things. At the same time, the project team is aware that strengthening also depends on the pull effect at the end of the value chain. With the increased demand, it is also possible to initiate the necessary investments in the processing chain. The INNOwood approach of not operating with purely factual, academic information, but rather using an emotional approach geared towards the discovery experience to appeal to laypeople and semi-experts has proven successful in the communication tests.

Wood in the construction sector

With the increasing demand for circularity, timber construction is pushing itself thanks to the ease of processing, advantages in logistics due to low weight and its traditional easy to be dismantled construction principles. Nevertheless, neither circular construction principles nor cascading use has yet been established in timber construction. Dismantling does not take place; during demolition, timber components are sent for thermal recycling.

The approach from Module17 breaks this vicious circle or at least drastically slows it down. Even if the typology was developed for the challenge typology of high-rise buildings, it can be transferred to others, less demanding building typologies. This new typology of adaptable building support structures enables the basic design structure of a building to be retained. The current dynamics in usage can be accommodated with minimal invasiveness in the horizontal, but now also in the vertical alignment. According to the implementation strategies for a sustainable circular economy by Geissdorfer et al. 2017, the "slow" aspect, i.e. extending the life cycle of products or buildings, comes to the fore here and the ability to dismantle the supporting structure becomes less important.

Recommendations

Transferability of conclusions

The situation in Switzerland exhibits a notable emphasis on the use of wood from local forests, which less prevalent in neighboring countries. However, the focus on the use of "wood from local forests" can also be linked to the use of wood from sustainable forestry in a broader sense.

Further on the best practices concerning the inter- and transdisciplinary approaches, the balance between and regulation and participation, improving ordering skills at the end of the value chain with target-group oriented awareness raising and adaptable building structures are transferable to other countries as described in the following chapters.

Integrated resource policy

Even if the legal framework for the mobilization of wood in the construction industry is based on different foundations, an integrative approach of the material (wood) with the primary sector (forest) is essential for the goal of a sustainable bioeconomy. Forest management and adaptation and their contributions to carbon neutrality depend on the integrative approach of actors in the forest sector, the wood value-chain, and the ordering skills at the end of the value chain. Finally, the society benefits from this integrated approach by the provision of ecosystem services and goods supported by the local forests. A sustainable integrated resource policy considers local and global value creation cycles depending on the specific framework conditions.

Mastering the balance between participation and the regulatory framework is a key to success. On the one hand, the legal requirements set by the state must define the framework conditions for the subject areas (forestry and timber industry & climate policy). On the other hand, the commitment of actors and companies in the sector is crucial in order to create pilot projects and thus provide performance indicators and role models. Both are important prerequisites for achieving progress within the specified limits.

Awareness-raising ordering competences

To promote greater use of locally produced and sustainably harvested wood in construction, it is crucial to improve the ordering skills of planners, builders and clients. This requires raising awareness among these decision-makers at the end of the value chain of the commonly known benefits of timber buildings, but also of the added value of the ecosystem services provided by forests to, build local people and society in general. In addition, planners and builders need to weigh up information on regional availability in order to optimize the balance between global and local value cycles. For this awareness-raising, it is of utmost importance to tailor the information to the respective audience.

Enhancing adaptability of wood construction

Growing demand for residential and commercial space and increasing dynamics in the use of buildings require new building typologies that can accommodate this demand and these dynamics without undermining climate and resource policy objectives. The separation of load-bearing structure and fit-out has long been demanded as a system separation but has not yet been implemented in reality. In the future, solutions for the horizontal adaptability and vertical adaptability of structures must be realized. Adaptability is an important aspect of resource conservation. Adaptable building structures extend the life cycle of buildings and reduce necessary dismantling measures and the resulting material cycles to a minimum.

Key Messages

Forest management and adaptation and their contributions to carbon neutrality depend on the integrative approach of actors in the forest sector, the wood value-chain, and the decision-makers at the end of the value chain. Finally, the society benefits from this integrated approach by the provision of ecosystem services and goods.

The amalgamation of the findings of three different best practices underscores the potential for vertical integration among decision-makers, planners, and stakeholders within the value chain, accompanied by participation processes. The findings also emphasize the significance of governmental efforts in actively advocating for wood utilization within local civil society spheres. Ultimately, an inclusive approach that engages stakeholders throughout the forest sector and wood value chain, alongside decision-makers, facilitates the delivery of ecosystem services and goods, creating benefits for the society comprehensively over time.

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Systematic literature review on diversity, equity, and inclusion (DEI) aspects of forest and wood products workforce

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ABSTRACT

The forest sector in general has exhibited significant gaps in diversity and representation, particularly with regards to gender and race. These disparities are present in various categories such as industries, occupations, and business ownership arrangements. As an effort to address the obstacles regarding diversity, equity, and inclusion (DEI) in the sector, the U.S. Forest and Wood Products (FWP) Inclusion Council was formed. This study is a part of the research project supporting the Council's strategic work for outlining a National Action Plan. The aim is to understand DEI-challenges from the perspective of current FWP workforce. Utilizing a concept-driven systematic literature review approach proposed by Webster and Watson, we identified 1,047 potential articles from Web of Science database by Thomson Reuters. Employing inclusion and exclusion criteria such as three search strings (Diversity OR equity OR equality OR inclusion OR justice OR accessibility OR "affirmative action" (Topic) AND forest OR "wood product" (Topic) AND workforce or workplace or employment OR labor OR labour (Topic)), scientific contribution (i.e., having research methods to meet their objectives), and location (only covers United States and/or global perspectives), we identified 28 articles as our population. We then examined both citations and references of each 28 article. Using the same criteria, the first author repeated the inclusion steps. These combined steps resulted in a final selection of 80 articles. We followed a qualitative content analysis approach and highlighted important insights about current FWP sector challenges. We then conclude with a summary of key aspects related to successful and unsuccessful DEI practices in FWP sector and suggest a path forward.

Sustainable wood-based value chains in Finland: three examples and take-home messages for the Global South countries

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ABSTRACT

Many Global South countries possess great economic potential in their current or foreseen timber growing stock, particularly the plantation forests. Further increment and utilization of these resources can be accomplished in line with regenerative sustainability, yet there are unfortunate opposite examples, too. Unlike most other sectors exploiting natural resources, forest-based circular bioeconomy can be established on sustainable and cascading use of renewable raw materials and zero waste. Finland is, by many measures, the most forest dependent country in the World, a fact that is broadly acknowledged in the Finnish policy making, as well. Therefore, it is not surprising that Finland was the first nation to publish a national Bioeconomy Strategy already in 2014. The current, renewed Bioeconomy Strategy 2022-2035 sets its main objective in supporting production of more value per raw material unit used while not forgetting ecological sustainability and social justice. To inspire the Global South countries in their pursuit towards sustainable forest-based bioeconomy, the objective of this article is to describe selected wood-based value chains in Finland. We aim at generating ideas, which are based on existing good practices, and facilitating fact-based discussion on sustainable forest-based bioeconomy opportunities in Africa, Asia, and Latin America. Three distinct wood-based value chains were chosen for the analysis: 1) construction, 2) packaging, and 3) textiles. The maturity of these lines of business varies greatly in terms of the product maturity curve (Introduction-Growth-Maturity-Decline) while wood-based construction value chains locate are predominantly in Mature phase, whereas packaging and textiles are mostly in Growth and Introduction phases, respectively. However, there is quite unanimous expectation that all three value chains have strong global market growth and great innovation potential in the longer term. For each value chain, we present the current state of production followed by estimates on market development in the next decade. We review the raw material requirements, technical-economic limitations, and other relevant preconditions for the use of domestic wood supply in these value chains in the Global South. Finally, we deliver key take-home messages, learnings, and best practices for the Global South countries. The work is part of a project Wood for Globe - Towards a Global Wood Policy Platform: Sustainable Wood for a Carbon-Neutral Bioeconomy", led by IUFRO and funded through the Forest Fund of the Republic of Austria.

Key words: bioeconomy, construction, Global South, packaging, textiles, wood, sustainability

Forest-based bioeconomy in Finland

The forest sector, including forestry and forest industries, has been the backbone of Finnish national economy for centuries. Recent developments in bioeconomy are re-highlighting the importance of forests for Finland and its economy. The National Forest Strategy 2035 (Ministry of Agriculture and Forestry, 2023) and the updated Finnish Bioeconomy Strategy (Finnish Government, 2022) guide the use of forest resources. In these strategies, forests are expected to continue generating economic prosperity and wellbeing for Finnish society while also offering ecological benefits as carbon sinks and biodiversity conservers. The strategies point out wood construction, as well as new wood-based textiles and packaging products important in creating value and climate benefits, as they substitute for fossil-based or energy or resource-intensive materials.

The forestry land area in Finland is 26.3 million hectares, 86% of the land area. The annual increment of growing stock is 103 million m^3 and annual roundwood removal varies between 60 and 90 million m^3. Annual increment has exceeded the removal every year since 1970, and the growing stock volume has simultaneously increased from 1.5 to 2.5 billion m^3. Ca. 13% of the Finns get income from forests annually. In 2021, the value added of the forest sector was 9.3 billion €. Nearly all forest industry products are exported. Forest sector is the most important bioeconomy sector accounting for 30% of the total value added of the Finnish bioeconomy (Natural Resources Institute Finland, 2024). More information on Finland's forests and bioeconomy in the Finnish Statistical Yearbook of Forestry (2023).

Finnish forests are managed by tens of silvicultural regimes based on forest owner's preferences, site type, tree species, growing stock structure, biodiversity conservation needs, etc. The minimum levels of sustainable forest management and biodiversity conservation are set by forest and environment protection laws, yet the voluntary practices go beyond these levels. The commercial forests are managed according to the 'Best Practices for Sustainable Forest Management' published, regularly updated, and implemented via forest owner advising organizations. Approx. 90% of commercial forests are PEFC certified and 10% FSC certified, the two certificates mostly overlapping in the same forests.

The National Forest Strategy 2035 (Ministry of Agriculture and Forestry, 2023) has the purpose of guiding Finnish forest policy. The updated *Finnish Bioeconomy Strategy* has a vision of 'Sustainably towards higher value added' and an aim to create economic growth and jobs with sustainable and highest possible value-added products and services (Finnish Government, 2022). Both strategies recognize the use of wood in construction applications, textiles, and packaging value chains important in fulfilling their aims. They also consider collaboration and stakeholder perspectives as part of social sustainability and responsibility. Both strategies aim at increasing wellbeing and value added from forests through, *e.g.*, rural development, job opportunities, and increasing the knowledge and competence of forest experts.

Wood construction sector

Even minor improvements in the sustainability of construction activities make a big environmental difference. Wood contributes to this development, since it is the only renewable construction material available in industrial volumes, and features many other indisputable sustainability arguments, too. In Finland, the Land Use and Building Act (1999), which is currently under renewal, will make the carbon footprint calculation of new buildings mandatory since 1.1.2025.

With its long history of wood as a construction and interior decoration material, Finland features scientific, educational, and practical expertise related to using wood in construction value chains. Lately, multi-floor wooden buildings and engineered wood-products (particularly LVL and CLT) have gained a lot of research and development interest, and the expertise has progressed accordingly. Sawn timber is the most important solid wood product produced in Finland, both in terms of volume and value. Engineered wood products (EWPs), such as glulam beams, LVL, and CLT, have had an elemental role in the revolution of wood as a construction material for larger buildings characteristic for urban areas. Prefabricated volume elements are now commonly applied in multi-floor buildings. Their low weight allows building extra floors on top of old houses without compromising their load bearing capacity. Low material weight enables a high degree of industrial prefabrication because the light elements can be transported to the building site by trucks, and a crane lifts ready-to-live-in elements to their final assembly position within a matter of hours. Wooden volume elements have, thus, transformed the construction site into an assembly site, which cuts the on-site activity time by half, subsequently resulting in considerable financial savings to the developer.

Wood's property variation has been largely overcome by applying intensive sorting, but also engineering and physical and chemical modifications (*e.g*., Heräjärvi *et al*. 2020). Building regulations for wood-based production in Finland are imposed to ensure the safety and efficiency of wooden buildings, aiming to improve material neutrality and reduce the cost of construction. Three crucial building codes are dealing with fire safety, energy efficiency, and building acoustics.

We identified several knowledge transfer and education export opportunities for applying Finnish wood construction expertise in the Global South. A crucial question is how to integrate these practices in the local regimes and ways of operating within the society so that they support sustainable and just transformation. Mutual learning and collaboration with and between the local actors are essential. Sufficient resources secure the forest-to-building supply chains and enable industrial offerings to the market demand. Wood products industries, yet small in volumetric comparison to concrete industries, can provide products with significantly smaller environmental effects. This is an opportunity for the construction sector to reduce its huge environmental impact just by applying existing technologies. If there is access to a sufficient supply of sustainably managed raw materials and financing for modern technologies, wood construction is an opportunity to improve local employment and broaden the sources of income. Simultaneously, poorly developed supply chains or issues regarding legality or sustainability are a clear barrier to wood construction, operational efficiency, and market development. Political and societal instability, such as regulatory, trade, and economic issues, may expose the wood-based value chain development under threat. Table 1 presents SWOT data collected for this report. The role of societal questions (red font) is emphasized in all SWOT categories. This highlights the fact that social sustainability issues are relevant in value chains based on timber utilization in Global South countries. There are questions related to, *e.g*., land ownership structure, supply chain legality, ethics and just transformation, and political instability that relate to overseas investments and funding opportunities. Technical questions, such as wood durability in moist conditions and fire regulations must be carefully considered.

Table 1. SWOT table for wood construction value chains in Global South countries from the Finnish perspective. Green font stands for environmental, red for societal, and blue for economic issues.

Strengths	**Weaknesses**
Wood use has a low environmental load in comparison to concrete and steel. Substitute for fossil-based or fossil-energy-intensive materials. Timber from plantations => Almost completely certified wood. Excellent earthquake safety of wood due to low weight and elasticity. Climate reasons to use wood are obvious and politically sound. Use of wood enhances resident's well-being. New wood-based value chains create jobs. Abundant, proper-quality, and local raw material supply. Economic growth supports new materials and solutions. Labor availability. Low technical threshold of processing and using of wood – possibility to apply appropriate technologies.	Problems in FLEGT (Forest Law Enforcement, Governance and Trade) control. The use of natural forests has a bad reputation. Lack of skilled labor for modern production. Regulatory barriers (e.g., fire safety). Prejudices: 'poor people live in wooden houses'. Insufficient public awareness on wood's sustainability. Pulp intended plantation species => Poor quality for wood products. Illegal logging / availability of legal timber. Slow growth of timber compared to agriculture crops => Slow Return on Investment. Technical and financial restrictions (expensive and skills-intensive modern processing machinery). Poor availability of proper timber, underdeveloped supply chains. Raw material competition by pulping sector. Fire safety, weathering, biodegradation, and termite resistance in tropical or temperate climate.
Opportunities	**Threats**
Turning the built environment into a carbon sink. Decreasing the ecological footprint of the built environment. Consumers demand greener materials. International politicarrl support. Economic aid supporting SDGs in the Global South countries. Collaboration with Global North countries. Large unused areas for timber production. Regulations towards renewable and low-carbon construction. Cascade use of wood and wood wastes. Extra lightweight structures on top of existing urban buildings. Quicker building processes. Affordable industry establishment costs.	Deforestation and illegal logging. Climate change-related issues, *e.g.*, insect or pathogen outbreaks. More land deployed to timber production => Biodiversity loss. Plantation wood turns into GHG source by, *e.g.*, political decision. Political and societal instability. Prejudices against wooden buildings remain (cultural reasons, technical misunderstandings). Forest ownership structure and indigenous people's rights are not accepted. Governmental restrictions to utilize forest resources. Poor technical skills & education. Alternative materials gain further technical, economic, or environmental benefit.

Key messages and recommendations, wood construction

1. The use of wood in construction value chains is a considerable business and job creation opportunity that is not conditional to huge investments in the Global South countries.
2. As a solar energy empowered construction material, wood is an instantly available opportunity to improve the construction sector's environmental profile.
3. As a global forerunner, Finland can contribute to the evolution of sustainable wood construction expertise in Global South countries through knowledge transfer, education, training, and business partnerships.
4. Questions related to legality, transparency, equality, and sustainability of the supply chains and businesses cannot be overemphasized anywhere in the World.

Production and use of materials for the construction sector are responsible for huge environmental impacts, which are expected to further increase due to population and wealth growth. Wood is generally understood to cause less environmental impact than other major construction materials, which is largely because the primary energy supply for wood is solar, whereas fossil fuels are the primary energy source for concrete, steel, and plastics. The perspectives of different stakeholders should be considered when creating wellbeing with natural ecosystems and the resources they provide. This calls for a systemic change in the current views and paradigms on how people and societies consume and how companies produce products and services.

Finnish expertise related to wood-based textiles and packaging

The textile sector is one of the largest sectors worldwide, and one with the greatest environmental problems, too. Wood-based textile fibres represent less than 10% of the consumption, while cotton and oil-based synthetic fibres (polyester, polyamide, polyacrylate, etc.) cover the rest (*e.g.*, Kataja and Kääriäinen, 2018). Finland features strong scientific and practical expertise related to the sustainable use of wood fibres in different fibre-based processes and product applications. Finland has been a global forerunner in chemical and mechanical pulping, as well as paper and paperboard production technologies, quality control system, and environmental impact reduction since the 1950s.

Scientific and applied research on wood-based textiles and packaging applications is conducted in several academic universities, universities of applied sciences, and governmental or private research organizations in Finland. The development activities of packaging papers and paperboards, which are a major business in Finland, are mostly, yet not completely, performed by the large companies themselves. In the case of rapidly developing new textile processes, on the other hand, public or semi-public research and development, as well as private-public partnership projects are common approaches. Certain textile fibre technologies are developed by spin-off innovation companies of large forest industry corporations, such as Kuura® fibre by Metsä Spring Ltd, a spin-off of Metsä Group.

Half a dozen novel wood-based textile technologies are under development in Finland, whereas the production of conventional dissolving pulp ended in 2021. Some processes, such as Ioncell® and Kuura®, are based on application of ionic liquids in fibre dissolving, whereas Infinna® is based on the carbamate process and BioCelSol relies on enzymes. Spinnova® process does not dissolve the pulp at all. Each process represents different technology readiness levels. The idea in all modern, wood-based textile production processes is to produce textile fibres with reduced environmental footprint and risks compared to those associated with traditional viscose process or production of synthetic fibres.

Depending on the product application and property requirements, the textile fibres can be made of agricultural fibres, used textiles, or wood fibres of virgin or recycled origin. Wood is globally the most common source of fibres in paper, paperboard, and cardboard. Global demand for papers and paperboards started growing steadily in the 1960s (Kärkkäinen, 2005). Due to the 2000s decline in magazine, newspaper, and some other paper markets, Finnish printing paper factories have been one by one upgraded and transformed into packaging paperboard production. Unlike many paper grades, the global paperboard demand has been steadily increasing, and it is predicted to continue doing so. This development is explained by two megatrends. The first one is e-commerce which is based on packing and shipping single items – instead of large retail customer deliveries – from the manufacturer or retailer to the consumer (and often back, too). Independently of its material, the package is expected to offer technical protection to the product against moisture, hits, vibrations, sunlight, chemicals, etc. during its logistics chain. Secondly, there is a need to decrease the environmental footprint of packages and product deliveries (*e.g.*, Leinonen *et al.*, 2022). The appearance of the box, including its shape and print quality, may be critical sales factors, and pronouncedly so in the e-trade. Packages for foodstuff and drinks are highly regulated concerning hygiene, liquid and air tightness, grease barriers, UV light transmission, and recyclability. Wood-based products can compete with non-renewable packages (mostly plastics) in most of these features. In total, 4.2 million tons of paperboards were produced in Finland in 2021, of which 4.1 million tons were exported (Finnish Statistical Yearbook of Forestry, 2023).

Wood-based textile and packaging value chains are an interesting opportunity in the Global South countries. Particularly, countries with large unused, certified, and sustainably managed forest resources should consider these lines of bioeconomy development, bearing in mind the foreseen growth in global demand for more sustainable textiles and renewable packaging. Potential Finnish contributions extend to all levels of research, development, education, training, and businesses along the value chains. One of the most important questions to address with these opportunities is to understand how these practices are integrated into the specific circumstances, *i.e.*, local regimes, of each country and region.

Finnish forest cluster is an example of the triple-helix collaboration between academia, government, and industrial actors. Finland introduced the concept of industrial ecosystems and bioproduct mills, in which the collaboration in production and RDI is built into the system. This model was already taken into practice in pulp-based biorefineries. Metsä Group's bioproduct mill in Äänekoski has been running since 2017 and the industrial ecosystem around the mill has generated collaborations in, *e.g.*, wood-based textiles (Kuura® fibre) and 3D fibre product for packaging (Muoto® product).

Table 2 presents SWOT data for wood-based textile value chains. Production of wood biomass and wood-based textiles have environmental strengths (indicated in green font) related to lower usage of, *e.g.*, water, pesticides, and other environmentally harmful chemicals. In addition, naturally decomposable wood-based textiles can be produced without increasing microplastic pollution. However, there are several economic challenges (indicated in blue font) related especially to production technologies and the availability of proper quality raw materials. Social (indicated in red font) opportunities support the development of wood-based textile value chains. Despite the possible technological developments in production technologies, the technical performance and features of other natural and artificial raw materials may outweigh wood-based textiles, *e.g.*, in features like mechanical strength or consumer preferences. These may appear as threats and decrease the competitiveness of wood-based textiles. Moreover, the loss of biodiversity caused by the expansion of land dedicated to wood-based raw material production is a serious threat. It is therefore essential to maintain reasonable relations between sustainable resource management and industrial growth to ensure the stability of the textile industry in these regions in the long run.

Table 2. SWOT table for wood-based textile value chains in Global South countries from Finnish perspective. Green font stands for environmental, red for societal, and blue for economic issues.

Strengths	**Weaknesses**
Wood biomass production is highly efficient in water consumption and pesticide use compared to agrobiomass feedstock (*e.g.*, cotton). Final products are biodegradable (less landfill waste) and do not break into microplastics. Production needs less harmful chemicals. Several techniques can separate and recycle cellulose and even upcycle materials. Substitute for fossil-, cotton- and animal-based textiles. Wood is less susceptible to disturbances compared to annual plant crops, allowing a stable raw material supply.	Environmental challenges in some techniques, *e.g.*, traditional viscose process. Non-existing textile recycling systems. Consumer preferences stick to traditional textiles. Few applicable industrial-level production technologies. Technical performance of other biomasses or synthetic fibres is better in terms of, *e.g.*, strength and abrasion resistance. Production costs: technology-intensive production, technologies are still developing. Energy-intensive production technologies. Availability of uniform fibre quality in large volumes. Competitiveness against other plant-based biomasses.
Opportunities	**Threats**
Environmental regulations improve the competitiveness of wood-based textiles. Global shortage of clean water causing a decrease in agrofibre production. Major brands and/or role models advertise wood-based textiles (luxury markets). Market pull (environmental awareness of consumers, retailers, and brands). International policy support. Collaboration and mutual learning via RDI with Global North. New jobs substitute current low-salary jobs. Production costs decrease along with industrial upscaling of novel techniques. Agricultural fields are prioritized for food production.	Plantation wood turns into GHG source by political decision. Biodiversity loss, if more land is used to timber production, resulting in image problems and consumer distrust. More competitive agrofibres via breeding. Single-use fashion continues supporting cheap, short-lifecycle products. Mainstream consumer awareness is still low. Slow development of technical or economic competitiveness of wood-based products. Availability of wood raw material: other plant-based biomasses are more accessible in large volumes. Confidence lack among investors results in reduced funding Fluctuations in roundwood prices.

Table 3 presents the SWOT data related to wood-based packaging value chains. The environmental strengths (indicated in green font) of wood-based packaging are similar with wood-based textiles, as the raw materials of packaging products are recyclable and biodegradable, and act as substitutes for fossil-based materials and products. However, there are weaknesses related to the technical properties (blue font) and recyclability of wood-based packaging, which can be considered as economic issues.

Promoting the environmental and climate benefits of wood-based packaging materials can diminish societal and market obstacles. Similarly, constant development in packaging technologies and solutions brings opportunities. Serious threats to the expansion of wood-based packaging are

related to social (red font) and economic (blue font) issues. Major threats are the consumers' lack of willingness to replace current ways of packaging and the global political risks and unstable trade conditions. These political risks and market preferences may lead to progress in using non-renewable but recyclable packaging materials, especially if the climate and environmental impacts of fossil-based packaging are lower than the wood-based ones. These need to be resolved to strengthen the wood-based packaging value chains and remove the threats shadowing the expansion of the industry.

Table 3. SWOT table for wood-based packaging value chains in Global South countries from Finnish perspective. Green font stands for environmental, red for societal, and blue for economic issues.

Strengths	**Weaknesses**
Renewability, recyclability, and biodegradability of the raw material and the product. Substitute for fossil-based plastics and packaging materials. Fast-growing plantations are a CO_2 sink. Responses to consumers sustainability and eco-friendliness values. Hardwood fibres particularly applicable to liquid packaging paperboards. High food compatibility. Flexibility of design. Broad property range.	Limited number of recycling cycles due to degrading fibre properties. Bulkier than plastics. Production requires water. Consumer preferences stick in traditional packages (plastics and metals). Production is expensive due to high technology and expertise. Some properties (*e.g.*, moisture sensitivity) behind plastics. Extra barrier layers are needed for food packaging to have sufficient UV light and oxygen protection. Non-wood fibres may be more easily accessible than wood-based resources in some regions. Challenges in recycling logistics (costs, quality).
Opportunities	**Threats**
Increasing climate and environmental benefits. Regulative support at national and international level. Collaboration and mutual learning in RDI with Global North countries in both technical and economic aspects. Hygiene and health can be improved in food packaging. Constant development of new packaging solutions. Unexploited material properties. Increasing demand for sustainable packaging. Good branding value (need to avoid greenwashing). Technological advances over traditional techniques.	Plantation wood turns into GHG sources by political decisions. Biodiversity loss, if more land is shifted to timber production, results in image loss and consumer distrust. Inproper solutions for wastewater management in production processes. Political risks in global economy: large plantations and production units require stable politics and trade conditions. Consumers are unwilling to replace current ways of packaging. Plastics retain their advantages in for stored product quality. High investment costs of new manufacturing facilities. Progress in non-renewable but recyclable packaging materials. Net climate impact of fossil-based packaging turns to be lower than that of wood-based (*e.g.*, shown through LCA or similar method).

Key messages and recommendations, woos-based textiles and packaging value chains

1. The use of wood in textile and packaging products is a significant business opportunity, which is, however, conditional to a stable and sufficient supply of proper-quality raw materials and extensive investments in the Global South countries.
2. Global markets are growing and miss producers of resource-efficient wood-based textiles.
3. Despite existing global production, the expected demand for wood-based packaging materials opens space for new cost-competitive producers.
4. Finland can contribute to the evolution of sustainable wood-based textiles and packaging expertise in Global South countries by, *e.g*., knowledge transfer, education, training, and business partnerships.
5. Questions of legality, transparency, equality, and sustainability of the supply chains and businesses cannot be overemphasized anywhere in the World.

Production of cotton consumes over ten times more fresh water than production of wood for textile fibres. Therefore, wood-based textiles stand for a great and societally sustainable opportunity particularly in water-scarce regions, to substitute cotton and to utilize the fields for grain production or grazing. The rapid increase of e-commerce has raised the demand for packaging products with a low environmental footprint. Increasing consumption has changed the materials' use tremendously during just one generation, and overconsumption causes most of the environmental mega-problems. Material sustainability and transparency, circularity, and social responsibility, are turning into predominant regimes. This, along with the greening of production processes of non-renewable materials, creates hope for a more sustainable future, in which renewable biomasses play an increasingly important role.

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Assessing total building embodied carbon and embodied energy using the life cycle assessment method for US Government constructions.

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ABSTRACT

Reducing embodied carbons and energy consumption associated with building constructions has spurred innovation in building materials and systems as well as design practices. The life cycle assessment (LCA) method is widely used for assessing the total embodied carbon and embodied energy of buildings. US government agencies are coordinating to develop an LCA that are transparent and useful to the type of facilities managed by its instructions. US Departments of Agriculture, Defense, and Energy, as well as university and industry partners, are collaborating to develop a Whole Building LCA (WBLCA) Model Program to quantify critical sustainability metrics and develop strategies to decarbonize government building constructions and practices to achieve net-carbon-zero goal by mid-century.

The WBLCA model will be built in one of the world's leading LCA software to provide a secure and transparent calculation of the building embodied carbon (EC) and embodied energy (EE), thereby avoiding the undefined or black-box process that commercial building LCA tools are currently using and limitations on user-defined scenario analysis. Furthermore, this WBLCA model will enhance operational readiness by providing research engineers and LCA experts an expanded material database that will include innovative building materials and special construction/deconstruction processes that are not available in current life cycle inventory databases or published environmental product declarations.

An outline of the collaboration to develop this model will be presented. A preliminary model will be tested with a case study on a 14-story Mass Timber building structure to compare to several commercial WBLCA tools.

Wooden flooring in Slovenian bedrooms: Are consumers able to distinguish between natural wood synthetic materials?

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While natural wood has traditionally been a prevalent material in furnishing Slovenian households, the contemporary trend is the shift towards cost-effective alternatives. In the case of flooring, these alternatives often include laminate, vinyl, and ceramics that imitate the look of wood. However, there is no official data regarding the actual frequencies of different materials in floorings and furniture in Slovenian homes. Therefore, we included a question about bedroom flooring material in a quantitative survey conducted in August 2023, involving 1009 members of a Slovenian online market research panel.

Respondents may not always be able to identify the type of flooring material, as they are not necessarily homeowners, and may not have furnished the dwelling themselves. Consequently, we also asked them how confident they were in their answer. In addition, we ran a second survey where respondents were first asked to upload a photo of their bedroom floor and then to report the material again.

In this contribution we present the results of the comparison of respondent answers and evaluations of two experts. We found that in several cases, respondents are not able to distinguish between natural wood and materials that imitate it. Based on the results, we estimate the prevalence of different flooring materials in Slovenian homes and critically evaluate the potential of respondent photos to enhance web data collection. This includes addressing key methodological challenges and laying out recommendations for future research on this topic.

Key words: wooden floors, natural wood, imitation of wood, Slovenian households, bedroom flooring

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Introduction

The use of mobile devices has enabled social science researchers to embrace a range of new active and passive measurement tools to complement traditional survey data collection. In recent years, survey researchers have started to study how to enhance web survey data with metered, geolocation, visual and voice data and found mixed results on its benefits and limitations (Revilla 2022). In this contribution, we focus on visual data, where asking respondent to share a photo of their

environment might provide researchers with more accurate information than asking them to respond to a closed or open-ended question.

For instance, survey researchers have asked respondents for pictures of heating systems (Ilic et al. 2022), books (Iglesias et al. 2023), vacations, dishes, locations and feeling (Bosch et al. 2022). Others have only focused on respondent skills, availability and willingness, and have confirmed that most would be ready to capture and share visual data (Iglesias and Revilla 2023). However, the compliance varies between different tasks and some participants exhibit privacy concerns (Ilic et al. 2021, Struminskaya et al. 2021). Moreover, answering with images increases competition times (Bosch et al. 2022) and can lead to nonresponse (Ilic et al. 2021). Finally, there are also issues related to the analysis of visual data as available software is far from the level that a human coder can achieve, and human verification of outcomes is still needed (Bosch et al. 2018, Iglesias et al. 2024).

In this paper we present results of research that focused on the material of flooring as a case study for visual data in web surveys. Flooring and other materials used in buildings have distinct properties that affect the comfort and well-being of residents (Burnard and Kutnar 2015). Notably, natural materials like wood can contribute to better indoor air quality (Pohleven et al. 2019) and have lower carbon footprint in production and disposal compared to their synthetic counterparts (Quintana-Gallardo et al. 2021).

As official data often lacks specific information regarding the materials used in flooring and other household furnishing, we included questions about specific materials in a survey on residential renovation and furnishing in Slovenia (Slavec et al. 2023). A follow-up survey to the first survey included a question that asked participants to upload a photo complement their response regarding the material of bedroom flooring. Based on the results we compare the responses to the multiple choice and visual question format and discuss the quality of the collected data and potential of using visual questions in future research.

Method

The questionnaire for the first survey included 60 questions on various topics (dwelling characteristics, renovation, furniture, climate change, demographics) and took about 15 minutes to complete on median. In the third section, respondents were asked, among other questions, what material is predominantly used in the flooring of the sleeping area of their apartment. They were given 11 options plus an open-ended "Other", followed by a question about how sure they were of their response.

The second questionnaire was only 8-questions long and the median response time was 3 minutes. It first asked a photo upload survey question which was worded as "*Please take a photo of the floor covering in the sleeping area of the apartment in which you live. Try to cover as much of the floor as possible with the best possible light (if necessary, open the blinds or draw the curtains or turn on the light).”* The question was followed by a request to indicate with material they thought it was, offering the same multiple choice closed-ended options as in the first questionnaire.

Both surveys were conducted using the JazVem online marketing panel owned by the company Valicon Ltd. For the first survey 3765 panelists were invited to participate in August 2023 and there were 1029 fully completed questionnaires by September 1st, but some had to be removed due to data quality issues, leaving the final database to 1009 units. About a week later, 1024 panelists from the 1st survey were invited to the 2nd and 380 started responding but only 331 completed it and 320 provided a photo but only 204 (92%) were valid images showing (bedroom) flooring.

Data for both surveys was collected with the OneClick Survey data tool and downloaded into .sav format. In addition, photo data was downloaded and manually reviewed and coded by the authors using MS Excel. Image metadata was extracted using ExifTool 12.73, and merged with survey data and analysed using IBM SPSS Statistics 29. Finally, a selection of photos was reviewed by two experts on biomaterials that are employed at the InnoRenew CoE.

Results

About 44% of the respondents in the first survey sleep in a bedroom that has flooring predominantly made from wooden material, followed by 37% respondents that have laminate, while other materials (vinyl, ceramics, linoleum, concrete, textile fibres, cork, bamboo and stone) are less frequent (Figure 1). Moreover, about 93% of respondents are very confident in the response they provided, while only 7% are medium confident and 1% are not at all confident (Figure 2).

Figure 9: Responses to question on the flooring material used in the bedroom area (Q22, 1st survey)

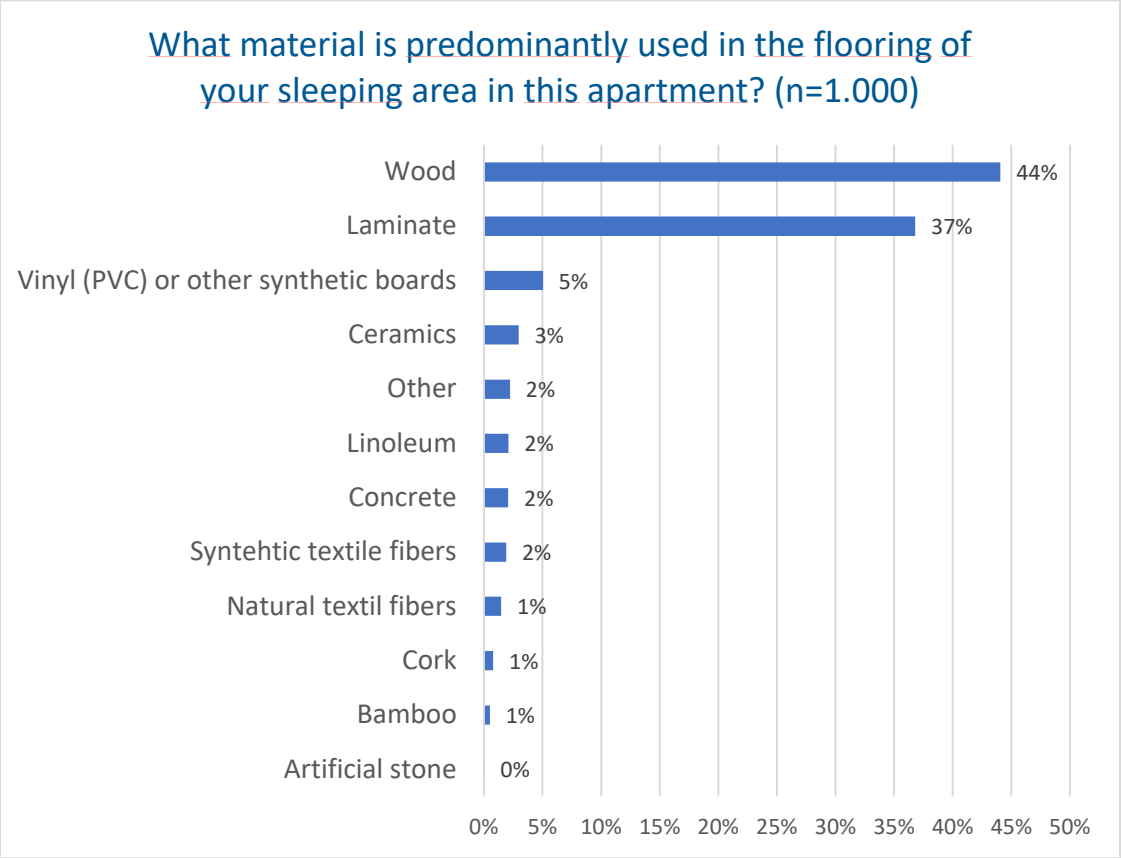
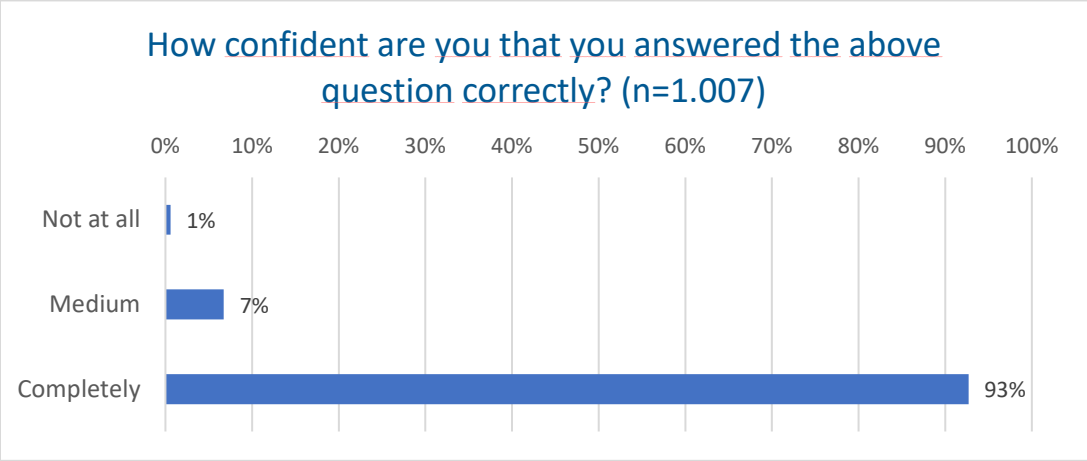
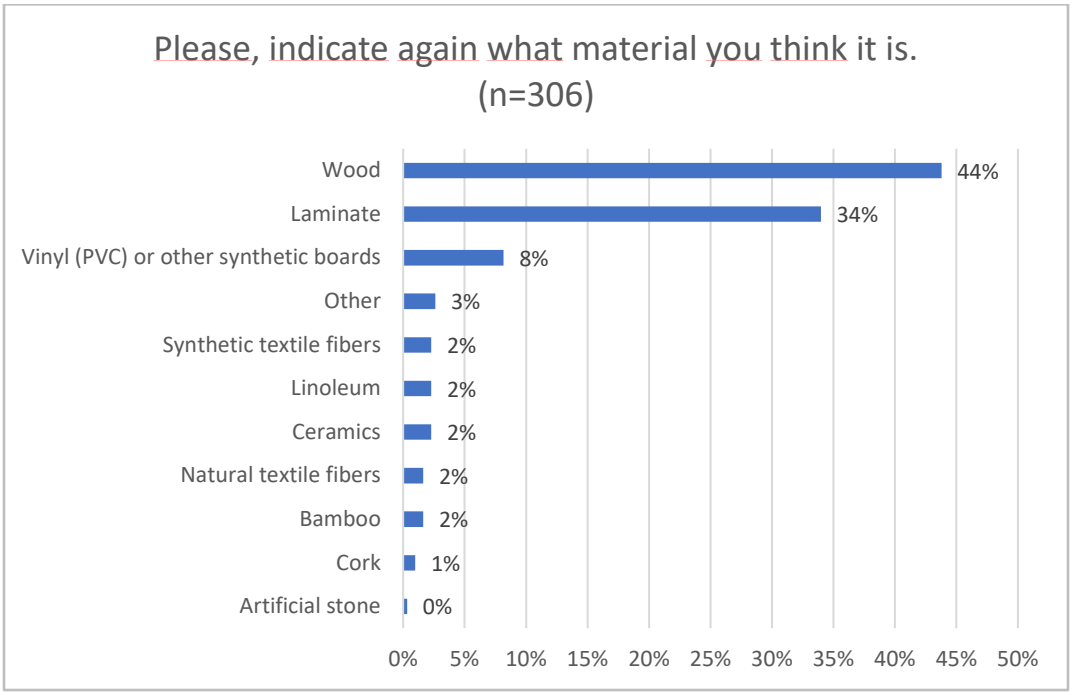


Figure 10: Confidence in the response on the question on the flooring material used in the bedroom area (Q23, 1st survey)



The 320 respondents that provided a photo were asked to indicate what material they think it is. The percentage of respondents responding wood is the same as in the first survey (44%), while for laminate it is a bit lower (34%) and there is slightly more reporting the material is vinyl or other synthetic boards (8%) (Figure 3).

Figure 11: Responses to question on the flooring material displayed on the provided photo (Q2, 2nd survey)



Next, we made a crosstabulation to compare the changes in response between the two surveys (Table 1). As we see, only 112 out of the 144 respondents (78%) that replied wood in the first survey, while 14 changed to laminate, 13 to other and 5 did not answer. Among the 99 respondents that responded laminate to the first, only 75 selected the option laminate in the second (76%), while 8 selected wood, 11 other and 5 did not respond. In total, only 71% provided the same response to the multiple-choice question in both surveys, which is an indication that the responses are not very reliable.

Table 3: Comparison of responses to Q22 in 1st survey and Q2 in the 2nd survey

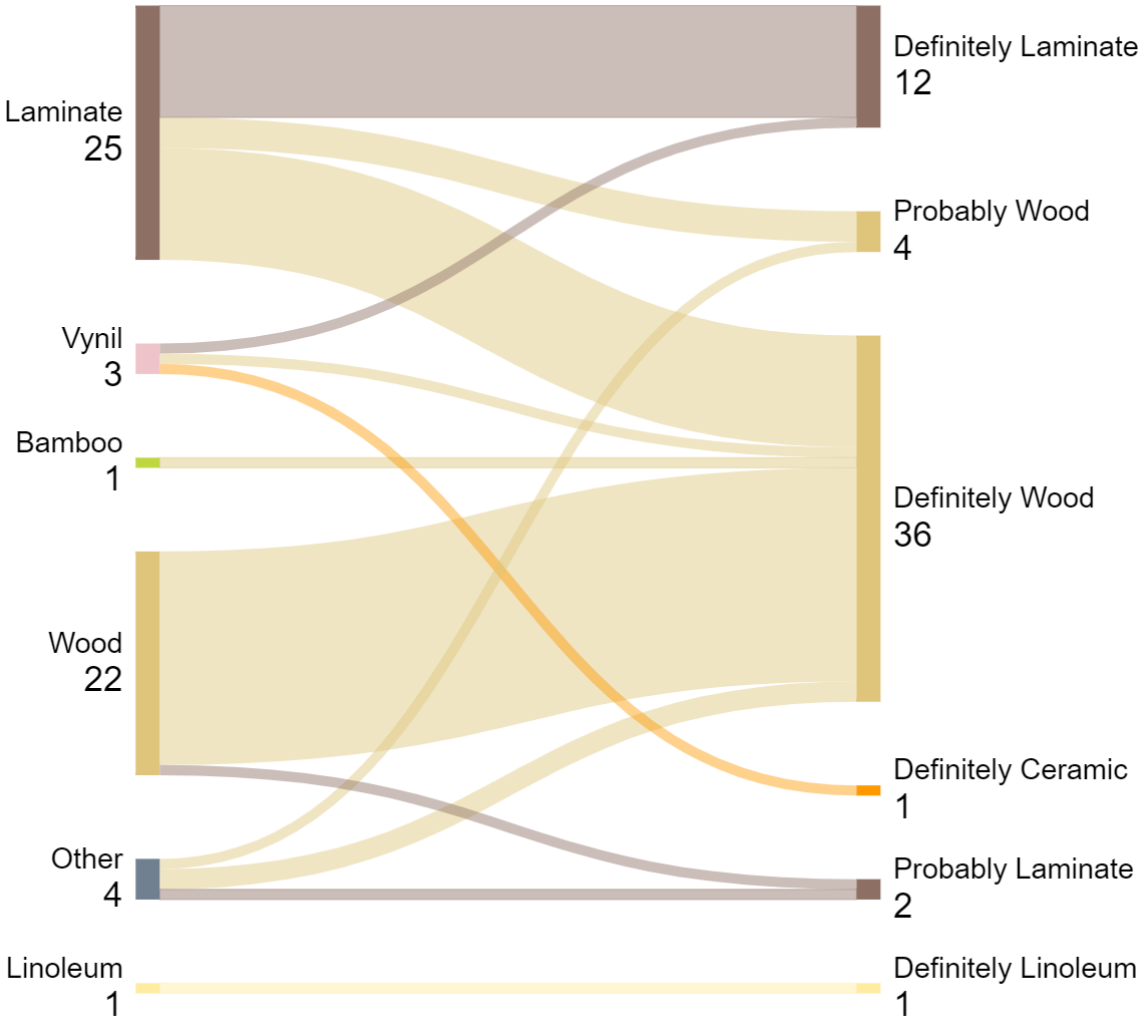
		Response in 2nd survey				
		Wood	**Laminate**	**Other**	**NA**	**Sum**
Response in 1st survey	**Wood**	**112**	**14**	**13**	**5**	**144**
	Laminate	**8**	**75**	**11**	**5**	**99**
	Other	**6**	**8**	**39**	**2**	**55**
	NA	**8**	**7**	**5**	**2**	**22**
	Sum	**134**	**104**	**68**	**14**	**320**

Finally, we coded and analysed the photos, limiting only on those 279 out of the 304 that show a material that is (or is imitating) wood. Firstly, it was decided that expert evaluation is needed for

16 photos where the respondent was not completely sure about the response, while for the remaining 263 photos the authors coded what type of flooring the image reveals and compared the estimate to the actual responses of study participants. In the process, 12 photos were removed due to being fake and 8 because of insufficient quality. Among the remaining 243, 49 (20%) did not match our estimate and 194 did. Moreover, 9 were eliminated due to the material not being wood according to either response or estimate. Thus, 56 photos were selected for expert evaluation in total.

Figure 4 shows the results of the expert evaluation. For 34 (61%) of the photos the two experts confirmed the answer selected by the respondent in the second survey (21 wood, 12 laminate and 1 linoleum), while for 22 (39%) of the photos the experts provided a different answer. Specifically, of the 25 photos reported as laminate, 14 were identified differently by the experts: 3 were probably wood, and 11 were definitely wood. One photo reported as bamboo was definitely wood. One photo marked as "other" was probably laminate, and 2 were probably (1) or definitely (1) wood. One vinyl photo was definitely ceramic, another was definitely laminate, and another definitely wood. Finally, one flooring reported as wood was probably laminate.

Figure 12: Responses given in the 2nd survey (left) compared to expert evaluations (right)



Finally, we attempted to use Microsoft Copilot to code flooring images. However, after a few trials, we realised that artificial intelligence is not capable of distinguishing between natural and synthetic wood, providing the same description regardless of the material.

Discussion and conclusions

The results indicate a substantial measurement error in respondents' reports on flooring materials. Although 93% of participants expressed complete confidence in their responses regarding bedroom flooring material, some of them changed their answers in the second survey. There are at least two possible explanations. First, some respondents were intentionally not paying enough attention when answering survey questions. Second, some respondents might have realised that they provided a wrong answer in the previous survey and corrected it.

Furthermore, for 39% of the images showing a material that is (or is imitating wood), the answer provided by survey respondents did not match the expert evaluation. This indicates that a non-negligible number of participants do not distinguish between different flooring materials. However, even experts were not completely sure about some of their assessments.

Researchers attempting to use online surveys to collect data on materials of flooring or other, should be aware that responses reported by participants are not to be blindly trusted. Perhaps using the face-to-face approach when the interviewer can visit the respondent's household and provide information about the flooring materials. Of course, the interviewers would need to be trained to distinguish between different materials through tactile evaluation.

The study has certain limitations. First, less than a third of respondents from the first survey participated in the second and provided an image which might be due to privacy concerns (Ilic et al. 2021) or other reasons that might lead to some biases. Second, we cannot truly confirm the authenticity of photos provided by respondents. For some we were able to determine that they are fake based on their metadata but there might be more falsifications that we were not able to detect. Third, there might be some partiality due to the human coding and expert evaluations. However, computer vision technologies and artificial intelligence are not yet developed enough to help with such tasks, as confirmed also by previous research (Bosche et al. 2018, Iglesias et al. 2024). Moreover, for some photos even the experts could not provide a definite evaluation of the material. Future research should investigate different case studies and use a more extensive coding of images.

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Can wood elements in retirement homes improve the wellbeing of residents?

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ABSTRACT

Europe's largest group of vulnerable people are older adults, age 65 and over. This demographic is also growing rapidly and is expected to grow from 21 % in 2023 to 29 % in 2070. As they age, older adults face physiological, behavioral, psychosocial, and environmental changes that require adaptation to maintain active and healthy lifestyles. Older adults also spend a significant amount of time indoors, making the built environment a key factor in healthy ageing. In this study, a combined approach of assessing the wellbeing of older adults across physical and psychosocial domains along with subjective and objective building assessment provided insights into which elements of retirement homes may improve the overall wellbeing of residents. The psychosocial assessment focused on human needs, applying both Maslow's Hierarchy of Needs and the Social Production Theory of Successful Ageing as frameworks for constructing the survey instrument and analysing the results. Where gaps have been identified in needs satisfaction, we identified design interventions that may improve the overall wellbeing of retirement home residents. Many of those interventions provide opportunities to increase the quantity of wood used in buildings, providing an often-overlooked connection to nature and potentially improving the sustainability of retirements homes.

POSITIVE ENVIRONMENTAL CONTRIBUTIONS

Ben Nyses/Mariapaola Riggio (Co-Chairs)

Deconstruction and reuse as a circular approach for mass timber buildings at the end-of-life: mitigating uncertainty in cost-benefit analysis

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ABSTRACT

In transitioning towards a low-carbon society, the construction industry aims to maximize resource efficiency and reduce waste and associated carbon dioxide (CO2) emissions. One of the promising ways to achieve this is to recycle and even reuse materials used in buildings after deconstructing them at the end of their service lives, which is a circular approach. However, such a promise can only be measured based on a cost-benefit analysis with solid evidence for a specific construction material and method.

Panelized mass timber building, which uses engineered wood composite, is often proposed as a relatively new construction type with substantially lower cradle-to-gate carbon impact for its massive use of wood compared to other carbon-intensive construction materials such as concrete and steel. This lower carbon impact is enabled as wood products can store carbon as a form of building, creating a buffer to global warming by CO2 emission. This carbon benefit by capturing can be extended if wood products are secured at the End-of-Life (EoL) stage. Mass timber panels are prefabricated off-site with connectors as kit-of-parts and then delivered on-site for rapid assembly, expecting the rapid assembly to enable easy disassembly for reuse. Research and practice demonstrated that light-frame wood building deconstruction and reuse can be a competitive option compared to demolition because there are cases where materials salvage value from deconstruction offset the additional cost due to the extra time needed for deconstruction. However, such a building type is relatively new, and most buildings have not even reached the mid-point of their service lives, limiting data collection for cost-benefit analysis of the EoL options to rough assumptions with wide margins of uncertainty. A recent study comparing the carbon impact of several reuses and other EoL options for a mass timber building showed that landfilling may have the least carbon impact. A lack of a standardized approach to estimating the quantity and quality of reusable mass timber panels makes the resolution of such a cost-benefit balance challenging. Therefore, there is a need for empirical data as a baseline for any carbon- and cost-related disclosures claiming deconstruction of mass timber buildings.

This study addresses the shortage of data and standards by developing a circularity assessment framework for mass timber panels and analyzing the deconstruction process of a medium-scale mass timber test structure. The goal is to mitigate the uncertainty margins in the existing cost-benefit analysis models for informed decisions from project stakeholders regarding the circular

approach for mass timber buildings. This goal is to be achieved by following works in progress: 1) identification of the knowledge gap and pressing research needs in the circular economy for mass timber construction through state-of-the-art review, 2) evaluation of the perception of the circular economy scheme among mass timber building proponents through survey, 3) methodological framework development assessing circularity of mass timber panels after deconstruction, and 4) evaluation of mass timber building deconstruction process through observation.

Use of green tax policies for enhanced use of wood and other natural materials from renewable sources for faster climate neutrality transition

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ABSTRACT

European Union (EU) makes intensive efforts to adapt to the effects of the climate crisis and to mitigate it. That is why several legislative packages and strategies at the global and EU level were adopted, and the member states have taken on rather demanding commitments to reduce greenhouse gas (GHG) emissions. One of the simplest and at the same time least cost-demanding ways to achieve the Green Transition can be the increased use of products made from natural lignocellulosic materials from renewable sources, instead of products made from other materials. Slovenia is especially well-suited for such transition, as we have many forests with a large stock of wood and a large annual increase. We manage the forests in a sustainable way, so we have sufficient quantities of raw materials available for a significant increase in the production of such products. Many times, however, wooden products are more expensive than products made of other materials, or at least users think they are more expensive. With Green Taxation, the state can create favourable market conditions for the purchase and use of wood products, and at the same time stimulate the development of wood processing companies, if it wants to achieve a more significant reduction of GHG emissions in the manner described above. We investigated the possibilities and prepared proposals for: VAT reductions for products made of (mainly) wood; classification of these products into categories for reducing the tax base of companies (purchased as investment); increasing the share of investment's amount in equipment and intangible assets for processing of wood, for which a reduction in the companies' tax base can be claimed. Moreover, options are studied, and proposals prepared for taxation based on product life cycle analysis (LCA). Several scenarios were prepared for the processing of different quantities of wood into products (product groups). Model for allocation of quantities of wood for processing into wood products or groups of products was used to calculate potential revenues of such processing and provide the potential savings in GHG emissions (using the LCA method, comparing the carbon footprints of wood and non-wood products) that would occur if wood products instead of products made from other materials were produced and used. The relationship between GHG emissions that occur during the production of both groups of products were shown, and thus what differences in taxation could be introduced in order to stimulate the purchase of products that have less impact on the environment and do not accelerate the climate crisis. By lowering the VAT rate for wooden products, and supporting investment in wood processing industry, the consumption of these products would not only increase, but also improve the quality of the environment and the efficiency of resource use, and stimulate the local creation of new, greener jobs.

Keywords: Wood Use, GHG Emissions, Substitution and Sequestration Effect, Green Tax Policy

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Enhancing architectural flexibility through mass timber construction: a circular economy perspective

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ABSTRACT

Mass Timber Construction (MTC) epitomizes architectural innovation, seamlessly integrating the pursuit of sustainable solutions with the requirements of contemporary architecture and environmental stewardship. At the core of MTC's circular economy strategies are the principles of deconstruction and reuse, which unlock a closed-loop potential for building materials. This advantage arises from inherent characteristics of mass timber (MT): being typically 40-50% lighter than equivalent-sized concrete structures, making it a more favorable option for transportation; having prefabricated elements with a variety of connections that offer different levels of accessibility and reversibility, enhancing its recyclability and reusability. Moreover, it is crucial to recognize that, beyond strategies merely aimed at closing the material loop, the implementation of measures to slow the material cycle in construction can yield immediate advantages in terms of time and cost savings for new constructions, as well as reducing impacts from demolition and new construction. This approach prioritizes extending the functional and social lifespan of a building, considering that more than half of the existing structures are prematurely demolished before reaching their physical end-of-life.

The foundation of this study lies in the exploration of MT's inherent qualities to support buildings in having longer lifespans in addition to its capacity to achieve a second life post-deconstruction. Among the strategies to prolong building life, designing for "upgradability and adaptability" serves as a cornerstone. This is emphasized by an integrated design approach that promotes collaboration across architects, structural designers, clients, and all stakeholders involved, embedding this strategy into the earliest stages of the design phase. Therefore, the primary objective of this study is to investigate MTC's role in enhancing architectural flexibility in practice, by juxtaposing academic explorations with real-world implementations.

We present a list of criteria aimed at promoting adaptability within the structure layer of buildings. These criteria include three distinct structural scales: system, elements, and connection, which vary across different building materials such as MT, concrete, and steel. Secondly, we collect a diverse range of global case studies—spanning pure MTC to hybrid applications—that has an explicit demonstration of a commitment to a flexible and adaptable design approach by the designers. These projects are analyzed across various dimensions, including geography, time, scale, function, structural adaptability metrics. Our findings evaluate whether the utilization of MT has indeed facilitated flexible design approach at one, some, or all of the structural scales compared to other building materials, or the choice of MT for structural purposes is motivated by factors beyond adaptability approach in their design. This exploration also reveals regional, temporal, dimensional, and functional differences in adopting MT for flexible design, providing insights into the evolving dynamics of sustainable construction.

Ultimately, this investigation highlights the transformative potential of MTC in extending the building lifespans and enabling a more adaptable built environment. By bridging the gap between academic literature and practical application, the study contributes to the broader discourse on sustainable construction practices, advocating for a future where MT plays a central role in creating a more adaptable and environmentally conscious spaces.

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Achieving Circular Economy in Mass Timber Construction Through Adaptable Design

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Abstract

To mitigate the environmental impacts of the construction sector, there is a growing emphasis on sustainable building materials. Mass timber is gaining prominence for its environmental advantages, including carbon sequestration, reduced energy consumption, and recyclability. This study delves into the application of Mass Timber Construction within the circular economy framework, focusing on adaptability and upgradability principles to facilitate future reconfiguration of living spaces and prolong building lifespans. It examines the adaptability of mass timber structures and their impact on the flexibility of architectural design, establishing key criteria for such structures and spaces. Through the analysis of 56 real-world mass timber projects, the study contrasts buildings featuring structural adaptability against those without. Results demonstrate that mass timber buildings designed to have adaptable structures exhibit significantly higher levels of architectural flexibility. This suggests that strategically utilizing inherent characteristics of mass timber elements and connections with an integrated design approach is essential for promoting sustainable and versatile building solutions. This research highlights the potential of mass timber construction's role in fostering a circular economy by enhancing building longevity, minimizing waste from early demolition, and reducing the environmental footprint of new constructions.

Key words: mass timber construction, circular economy, adaptability, architectural flexibility, building lifespan extension, environmental impact

1. INTRODUCTION

The construction industry significantly contributes to global pollution, consuming substantial primary energy, emitting greenhouse gases, extracting non-renewable resources, and generating construction and demolition (C&D) debris. Building operations and the production of construction materials are responsible for 28% and 11% of global carbon emissions, respectively (UNEP 2022). Collectively, the construction industry accounts for 25 to 40% of the world's total carbon emissions (Renz & Solas 2016).

In response to these environmental impacts, there is a growing focus on strategies aimed at reducing the ecological footprint of the built environment. One effective approach is the use of sustainable building materials (Lang et al. 2019). Structural timber stands out for its significant potential within the biological cycle and renewability, offering environmental benefits such as carbon storage, reduced energy consumption for manufacturing, recyclability, lightweight properties, and aesthetic appeal (Campbell 2018). Therefore, Mass Timber Construction (MTC) can effectively integrate the pursuit of sustainable solutions with the requirements of contemporary architecture and environmental stewardship (Akinade et al. 2017).

1.1. BACKGROUND: DESIGN FOR CIRCULARITY

At the core of MTC's circular economy strategies are the principles of deconstruction and reuse, which unlock a closed-loop potential for building materials. This advantage arises from inherent characteristics of mass timber (MT): it is typically 40-50% lighter than equivalent-sized concrete structures (Harte 2017), making it a more favorable option for transportation, assembly and disassembly. Additionally, MT’s prefabricated elements with a variety of connection types offering different levels of accessibility and reversibility (Ottenhaus et al. 2023) enhances its reusability. Moreover, it is crucial to recognize that, beyond strategies merely aimed at closing the material loop, the implementation of measures to slow the material cycle in construction can yield immediate advantages in terms of time and cost savings for new constructions (Mah et al. 2018), as well as reducing impacts from demolition and new construction. This approach prioritizes extending the lifespan of a building, especially considering that more than half of the existing structures are prematurely demolished before reaching their physical end-of-life (The ATHENA Institute 2004 and Ross et al. 2016).

The foundation of this study lies in the exploration of MT’s inherent qualities to support buildings in having longer lifespans in addition to its capacity to achieve a second life post-deconstruction. Among the strategies to prolong building life, designing for "upgradability and adaptability" serves as a cornerstone (Linton & Jayaraman 2005). This study adopts the definition of adaptability by (Schmidt III & Austin 2016), which describes it as a building's capacity to

effectively accommodate the evolving needs of its users and environment, thereby maximizing value throughout its lifespan. Adaptability in this study is classified in two groups: adaptability of structural system and adaptability of architectural design within the building's layout, interior design, or façade integration. This is emphasized by an integrated design approach that promotes collaboration across architects, structural designers, clients, and all stakeholders involved, embedding this strategy into the earliest stages of the design phase.

1.2. OBJECTIVE

The primary objective of this study is to investigate the impact of adaptable MT structures on enhancing architectural flexibility. This investigation juxtaposes academic explorations with real-world implementations to provide an understanding of whether the inherent properties of MT—such as light weight, prefabrication, and ease of deconstruction—contribute to creating more adaptable structures and building designs.

2. MATERIALS & METHODS

2.1. DATA COLLECTION

2.1.1. Criteria for Adaptable Design

For the purpose of this analysis, a framework of design criteria was developed, categorized into two primary dimensions. A detailed exposition of these criteria and their theoretical underpinnings is an ongoing research progress.

- Structure Criteria adopted from (Cellucci & Di Sivo 2015) to focus on the foundational aspects of building design:

    1. Ensuring designs can be easily adjusted in scale and complexity.
    2. Promoting interoperability between various building components and systems.
    3. Facilitating ease of access for maintenance, usage, and adaptation.
    4. Optimizing structural layouts to support large, unobstructed spaces.
    5. Allowing for the temporary assembly and disassembly of components without damage.
    6. Ensuring additional or alternative structural pathways to enhance building safety and durability.

- Architecture Criteria adopted from (De Paris et al. 2022) to address the optimization of interior and operational spaces within the structure:
    1. Efficient use of vertical and horizontal spaces.
    2. Designing spaces that can serve multiple functions over time.

3. Facilitating designs that accommodate the needs of an aging population.
4. Including easily modifiable systems for dividing space.
5. Incorporating wide openings between spaces.
6. Optimizing occupants' circulation within spaces.

2.1.2. Mass Timber Implications

A search was conducted in gray literature to find residential and commercial MT building projects completed between 2000 and 2023 where designers explicitly referred to applying flexibility or adaptability during the design phase. This process identified 56 MT buildings divided into two groups: Group A (43 buildings with adaptable structures meeting at least one structural criterion) and Group B (13 buildings without any structural adaptability criteria).

2.2. DATA ANALYSIS

The data analysis involved two steps:

- Comparing architectural adaptability criteria between two groups:

The number of architectural adaptability criteria between projects with adaptable structures and those without was compared. This comparison aimed to identify if buildings with adaptable structures also showed higher architectural flexibility. The metric used was that an increase in the number of criteria indicates a higher level of adaptability.

- Assessing the relationship between structural and architectural adaptability:

The study assessed whether there is a relationship between the number of structural adaptability criteria and architectural flexibility criteria, considering the building type (residential vs. commercial).

3. RESULTS AND DISCUSSION

3.1. DESCRIPTIVE ANALYSIS

The results indicated that the mean and median for Group A (MT buildings with adaptable structures) were 2.69 and 2, respectively, with a standard deviation of 1.61. These values were higher than those for Group B (MT buildings without adaptable structures), which had a mean of 1.61, a median of 1, and a standard deviation of 1.19. Th results are illustrated in the box plots (Figure 13). The histogram (Figure 14) showed that Group A had architectural flexibility criteria ranging from zero to six, with the majority of buildings (13 out of 43) having two criteria. In

contrast, Group B's architectural flexibility criteria ranged from zero to four, with most buildings (5 out of 13) having only one criterion.

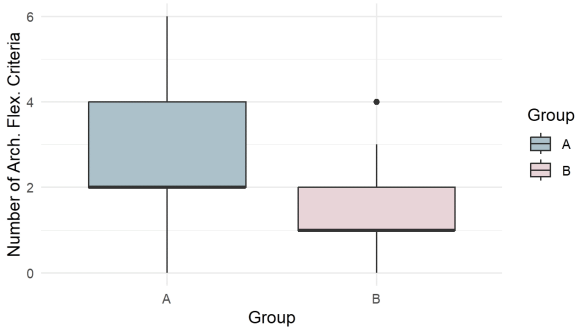

Figure 13 Box plots of the number of architectural flexibility criteria of two groups.

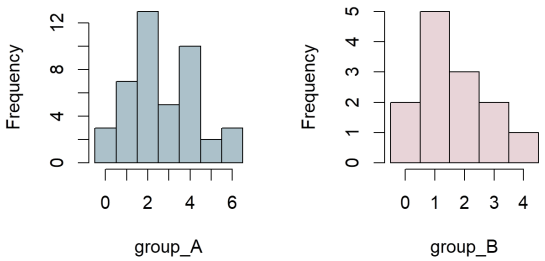

Figure 14 Histogram of the number of architectural flexibility criteria of two groups.

3.2. HYPOTHESIS TESTING

Descriptive analysis suggested that case studies with adaptable structures exhibit higher levels of architectural adaptability. To determine if this difference is statistically significant, a hypothesis test was conducted using the Wilcoxon rank-sum test, suitable for two independent samples with unequal variances and different sample sizes exhibiting non-normality. The test aimed to explore if there is no difference in the level of flexibility between the two groups (null hypothesis). The test results revealed a statistically significant difference at the conventional alpha level of 0.05 (W=390 and p-value of 0.02835). The rank-biserial correlation value was approximately 0.197, indicating a small positive effect size.

3.3. REGRESSION ANALYSIS

Building on the previous results, it was evident that adaptable MT structures positively influenced architectural adaptability. To further explore this, a log-linear model was fitted to determine if increasing the number of structural flexibility criteria affected the number of architectural criteria, while accounting for building type.

The regression analysis showed a significantly positive coefficient for structural flexibility criteria (0.2380, p = 0.00164). Calculating the exponent of this value implies that each one-unit increase in the number of structural flexibility criteria resulted in about a 26.87% increase in the expected count of architectural criteria. Additionally, there was a significant positive coefficient for residential buildings (0.6401, p = 0.00391), indicating that residential buildings had an expected count of architectural criteria about 1.9 times higher than that of commercial buildings.

4. SUMMARY AND CONCLUSIONS

This study investigates the impact of adaptable MT structures on enhancing architectural flexibility, combining theoretical frameworks with current practice. The findings indicate that buildings with adaptable MT structures exhibit higher levels of architectural flexibility compared to those without such structures. Descriptive analysis revealed that MT buildings with adaptable structures have higher mean and median values for architectural flexibility criteria. This was further supported by hypothesis testing, which confirmed a statistically significant difference between the two groups. Moreover, regression analysis demonstrated that increasing the level of structural adaptability criteria significantly boosts the level of architectural flexibility while accounting for building type.

Overall, this research highlights the potential of MT in achieving a circular economy in construction. By leveraging the inherent characteristics of MT elements and connections to create more adaptable structures, we can develop more flexible living spaces that increase the social and functional lifespan of buildings. This adaptability can reduce waste generated by premature demolition, decrease the energy and resources needed for new construction, and store carbon within buildings for longer periods. This underscores the importance of an integrated design approach that prioritizes adaptability from the earliest stages of building design to create more sustainable, resilient, and long-lasting built environments.

Future studies should aim to further explore and refine the criteria for evaluating flexibility. This includes not only creating a comprehensive list of criteria but also conducting studies to weigh the criteria and attribute the level of adaptability to specific attributes of MT structures. This will provide a more nuanced understanding of how to maximize the benefits of MTC to create more adaptable structures.

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Annex: List on mass timber flexible case studies used for analysis

#	**Project name**	#	**Project name**
1	OSU cascade, Bend	29	FNHA Office, Vancouver
2	CIRS, Vancouver	30	Monad, Vancouver
3	District Office, Portland	31	Cooperative Housing, Amsterdam
4	t Centrum, Westerlo	32	Furtwis Housing, Bubikon
5	Adidas Expansion, Portland	33	Zoo Admin Building, Auckland
6	Platte Fifteen, Denver	34	L'échappée, Herblay
7	Clay Creative, Portland	35	iCon Innovation Center, Daventry
8	Olney branch MCPL, Olney	36	Gui'an Innovation Park building, China
9	Wisner-Pilger, Wisner	37	Samuel–Paty Secondary School, Valenton
10	Princeton ECL, Princeton	38	Kindergarten Schönbühl, Seon
11	1 De Haro, San Francisco	39	Showa Gakuin West Wing, Ichikawa
12	The Soto, San Antonio	40	BIB building, Isleworth
13	1030 Music Row, Nashville	41	Feldballe School, Feldballe
14	Mississippi Workshop, Portland	42	c13 residential and office, Berlin
15	Wilson Forest Park Townhomes, Portland	43	Ansbach Residential, Ansbach
16	Rane Science Center, Auburn	44	Terraced houses, Munich
17	Matt's Place Demo, Spokane	45	Brummen Town Hall, Brummen
18	Outpost, Hood River	46	Building D(emountable), Delft
19	77 Wade, Toronto	47	Garden Pavilion, Soest
20	Shrouded House, Melbourne	48	Linq, Ghent
21	OLA Catholic Primary School, Sydney	49	House in Morrillos, Playa Blanca
22	St Andrews Beach House, Melbourne	50	Substrate Factory Ayase, Kanagawa
23	Marie Reay Teaching Centre, Canberra	51	Kindergarten Lugano, Lugano
24	Bayview Elementary School, Vancouver	52	House in Hanekita, Okazaki
25	R-Town Vertical 6, Toronto	53	Te Ara Hihko, Wellington
26	Crawford Bay School, Crawford Bay	54	Wood Innovation and Design Center
27	Cordova Bay School, Victoria	55	Patch 22, Amsterdam
28	The Exchange, Kelowna	56	GIZ academy, Bonn

Solid state fermentation of larch (*Larix decidua*) bark biomass

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ABSTRACT

Larch (*Larix decidua*) bark, often considered as waste material in various industries, is a highly underutilized resource despite its potential for valuable applications, contains an abundance of antioxidants and phytoconstituents, emerges as a valuable resource for bioactive compounds. Solid State Fermentation (SSF) emerges as a promising approach to amplify the value of larch bark biomass, creating avenues for residual utilization. SSF of larch bark biomass with *Aspergillus niger* has demonstrated effectiveness in liberating bioactive compounds, showcasing potential applications in the pharmaceutical and food industries. SSF as a transformative process has the capability to modify essential biomass characteristics, thereby contributing to an enriched and refined raw material. Consequently, SSF not only serves as a means to extract valuable bioactive compounds but also acts as a holistic method to elevate the intrinsic quality of larch bark biomass, unlocking a myriad of possibilities for sustainable applications and value addition. This study aims to identify the specific influence of SSF with *A. niger* on larch bark biomass, focusing on extractive content, lignin content, and other biomass characteristics, aiming to understand the potential improvements in the quality of larch bark biomass and extractives. Aerobic fermentation of larch bark biomass is conducted using *A. niger* to release the bound compounds within the biomass. Subsequently, the liberated compounds are extracted using Soxhlet extraction, and the Klason Lignin content is quantified. Additionally, the carbohydrate content of the biomass will be analyzed to provide a comprehensive understanding of the biochemical composition resulting from the aerobic fermentation process. The results from this research contribute to a comprehensive understanding of how SSF can be utilized to enhance the bioactive potential of larch bark biomass, opening avenues for sustainable and value-added applications in various industries.

Key words: Larch Bark Biomass, Solid State Fermentation (SSF), Aspergillus niger, Extracts, Sustainable Applications

Different strategies for utilization of inner part of oil palm trunk waste

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ABSTRACT

Oil palm trunk (OPT), which arises in substantial quantities as a by-product of the palm oil industry, is a suitable raw material due to its relatively high content in cellulosic fibers and low cost. The present study focuses on the inner part of OPT, which is light and low in mechanical performance and therefore lacks suitable applications other than fuel wood. Aiming for full utilization of the raw material, three different options were explored. 1) cellulose nanofibers: a combination of alkali pre-treatment and fibrillation by disc-grinding and subsequent high-pressure homogenization was applied, which resulted in fibrils with properties similar to those of cellulose nanofibers from fully delignified OPT. The facile pre-treatment process applied herein requires far fewer chemicals and energy than conventional pulping and is thus also beneficial from both the economic and ecological perspectives. 2) Thermal insulation panels: light-weight panels with densities of roughly 50 – 100 kg/m^3 and thermal conductivity of 40 – 45 mW m-1 K-1 were prepared from OPT fibers by mechanical foaming. With these values, OPT foam panels are well within reach of current non-biobased thermal insulation materials and perform equally well or even better than other biobased thermal insulation materials. 3) Packaging materials: OPT fibers were prepared from delignified material, and, alternatively, from hemicellulose-extracted material, and lightweight cardboard was produced. In conclusion, OPT can be an alternative resource for a range of materials. The approaches studied here boost the productivity/efficiency of the palm oil economy, lead to more sustainability, and encourage the creation of new products/markets benefiting oil palm farmers and communities.

Use of low-quality wood species by densification in load bearing veneer-based composites

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ABSTRACT

The escalating demand for renewable raw materials, driven by climate change and the imperative for a sustainable circular economy, necessitates exploring new and underutilized wood species in wood products. Birch (*Betula pendula*) traditionally dominates plywood production in the Nordic countries and the Baltic region. However, studies have shown that alternative species like aspen (*Populus tremula*) and black alder (*Alnus glutinosa*) exhibit lower bending strength than birch plywood, despite their lower cost and density. This study evaluated the impact of different veneer thicknesses, lay-up systems, and veneer densification on the mechanical properties of veneer-based composites from aspen and black alder, aiming to enhance their mechanical properties as an alternative to birch plywood. Three types of veneer-based products were manufactured: a) all non-densified veneers (standard), b) all densified veneers (D), and c) face veneers densified combined with middle layers of non-densified veneers (TB). These plywood configurations were produced with varying thicknesses (9 mm, 12 mm, and 18 mm) and seven veneer layers. Three thickness veneers (1.5 mm, 2.6 mm, and 3 mm) and initial thickness veneers (2.6 mm and 3.0 mm) densified to 1.5 mm were used to enhance mechanical properties. Parameters of the composite production process were consistent with birch plywood standards. Results demonstrated that using densified veneers as face veneers significantly increased the modulus of rupture (MOR) of aspen and black alder plywood by 13% to 38% compared to non-densified plywood. Additionally, the produced composites with densified face veneers from black alder reached the bending strength properties of birch plywood. However, all layers densified plywood (D) exhibited relatively lower strength due to set memory effects and delamination. Eliminating the set memory effect in the future could enable the production of composites with substantially higher mechanical properties.

Key Conclusions:
Densification enhanced bending strength for the same thickness of plywood.

Without dimensional limitations and under bending forces, using veneers without densification is recommended for plywood manufacturing, providing higher load-carrying capacity.

Total veneer usage increased with densified veneers, raising questions about the overall advantage of densification for plywood production.

It is crucial to eliminate the set memory effect for producing composites with higher mechanical properties.

Black alder plywood with densified face veneers demonstrated bending strength not significantly different than birch, with the added benefits of higher modulus of elasticity (MoE) and load-carrying capacity compared to birch plywood.

Consideration of total veneer usage and load-carrying capacity is essential for selecting the optimal veneer-based product configuration.

Keywords: veneer, densification, aspen, birch, black alder, plywood, bending strength.

NOVEL APPLICATIONS OF WOOD IN THE BUILT ENVIRONMENT

Bohumil Kasal/Levente Denes (Co-Chairs)

Moisture protection: an unnoticed but essential basis for sustainable timber construction

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ABSTRACT

Timber construction is gaining popularity in Germany due to its sustainability, versatility, and aesthetic appeal but, as a biological material, it will develop issues if it becomes moist. Wood-destroying fungi can significantly reduce durability and structural stability. Adequate moisture protection during construction is crucial for the longevity and performance of timber structures. This paper examines moisture protection practices on German construction sites and emphasizes the importance of proper on-site moisture management for sustainable timber construction. Visits to sits using timber construction revealed the status of moisture mitigation practices during timber construction in Germany. Qualitative methods included photo documentation and the protocol completion, yielding data for analysis to understand the depth and effectiveness of moisture protection strategies. The findings reveal a gap between problem awareness in the scientific community and practical handling on construction sites. There was no evidence of structural-specific moisture protection practices. Many sites exhibited disorganized structures and deficiencies in moisture protection strategies. While self-adhesive weathering membranes are used in almost 50% of the visited sites, less than one-third of the sites demonstrated sufficient moisture mitigation practices that protected the construction throughout the entire assembly process. This underlines the need to step up efforts in this area in order to ensure durable and high-quality timber construction in the future which will be less reliant on the experience of the designer or craftsmen.

Keywords: Assembly Processes, Moisture, Timber Construction, Standardization, Component Protection Concept, Structural Protection Concept, Rainwater Penetration, Prefabrication\

Aging of polyurethane adhesive bonds in beech composites

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ABSTRACT

Throughout the service life of engineered wood products (EWP) they can be exposed to indoor and outdoor damaging elements resulting in aesthetic changes, fatigue, and even delamination and failure at bond lines. Periodic hygro-thermo-mechanical loads can occur that vary based on season, precipitation rate, wind speed, UV radiation, drying elements such as air-conditioning, etc. These natural and human-caused conditions impact performance and are of great concern when critical structural elements like CLT or GLT used in bridges, towers, tall-timber buildings, etc. are exposed. These impacts do not only affect the wood itself but the adhesive bonds present. To extend the durability of adhesive bonds and to predict their service life performance, an understanding of their behavior with respect to environmental conditions must be provided. To achieve these goals, predictive and diagnostics models would help to lower production costs of adhesively bonded timber structures and provide detailed knowledge of their behavior and response to normal and unavoidable service life impacts. Despite the ever-growing proportion of timber structures in the Central European region, there is a lack of knowledge about the impact that complex loads and service conditions have on the bond performance of beech EWPs.

The DIAMONDS project aims to address this knowledge gap by carrying out research on the impact of ageing on rigid (PUR) and flexible PUR bonds in beech EWPs to be used in timber constructions. This is a bilateral project between Poland and Slovenia that is led by the Cracow University of Technology. The other partners are the AGH University of Science and Technology (Poland), InnoRenew CoE (Slovenia), and the Slovenian National Building and Civil Engineering Institute. This presentation will introduce the overall project and the most up current results of the project.

Effect of biochar impregnation on wood properties

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ABSTRACT

Vacuum modification of wood with biochar affects its properties and represents a new milestone in the development of new impregnation processes. The impregnation of spruce (*Picea abies*), poplar (*Populus nigra*) and fir (*Abies alba*) wood in aqueous solution with 1%, 2.5% and 5% biochar were investigated. The impregnated wood was densified, and the physical and mechanical properties were evaluated for all three ratios of biochar in the water solution and for all three wood species. The results of the study showed that the addition of 2.5 and 5% biochar particles improved the mechanical properties of spruce wood. For the other wood species, the addition of biochar had no effect. For densified samples, the presence of biochar reduced the recovery values. Surface water resistance was improved, especially for spruce.

Recycled wood as a replacement for strand-based composites

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ABSTRACT

The OSB production has recently increased worldwide from 34.8 million m^3 in 2020 to 36.3 million m^3 in 2022, which showed us the potential for the utilization of recycled wood for strand-based composites. The climate change and consequent changes in the forest structure showed a lack of virgin wood material, especially typical wood for wood-based composite production. On the other hand, there is a huge amount of wood incorporated into the building constructions. The demolitions of the buildings can bring valuable material (especially wooden beams, columns, etc.) for the manufacturing of wood-based composites. Most of the manufacturers are using recycled wood for particleboard production because of the particle size, the utilization of the recycled wood for OSB is more complicated- the shape and size of the strands. First, the optimization of the strand cutting process needs to be done.

Strands were made out of the spruce beams after increasing the moisture content for the appropriate cutting process. Shape and the slenderness ratio were compared for the recycled and virgin strands made out on the same machine. The single-layer unoriented strandboards with 10, 30, 50, 70, and 100 % of the recycled wood were bonded with 3 % of pMDI resin. Testing of the physical (density, density profile (DP), thickness swelling (TS), water absorption (WA)) and mechanical (modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength (IB)) properties were carried out. The results from this project will be used for a comprehensive comparison of the physical and mechanical properties of recycled wood for strand boards, which will help to understand the behavior of recycled wood in the strand-based composites as OSB, and LSL.

Mechanical treatments of plant proteins for their utilization as wood adhesives

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ABSTRACT

Adhesion is a key technology needed to produce engineered wood products. Nowadays, the adhesive industry relies on formulations derived from fossil resources. In Europe, despite research efforts, alternative adhesives are still not widely used in industry. Proteins have a long history of being used as adhesives (such as casein from milk and albumin). Protein adhesives exhibit good dry strength with high wood failure; but the product's moisture resistance and inadequate processability (high viscosity despite high water content) restrict their usage. Thus, to provide sufficient cohesive strength to withstand wet conditions, proteins need to be physically or chemically modified or used with a crosslinker. Employing mechanical pre-treatment techniques such as high-pressure homogenization and jet cooking can enhance the protein dispersion's rheological characteristics and solid content. Protein denaturation via mechanical means can help save time and chemicals in comparison to current alkaline treatments. Moreover, we expect the primary structure of the proteins to remain largely unchanged, thus preventing an undesired, excessive reduction of the molecular mass. Furthermore, the use of mechanical techniques has the important benefit of providing flexibility for the cross-linking procedure, which can be completed chemically or solely physically. In this study, we explore various mechanical treatments aimed at improving the rheological and adhesion properties of protein dispersions, to enable the use of plant protein as bio-based adhesives. The results support that mechanical pretreatments can modify plant proteins by improving their rheological and mechanical characteristics.

Keywords: Mechanical Pretreatment, plant protein, adhesives, rheological characteristics, rheological characteristics.

Use of lignin-based adhesive for fibreboard and plywood

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ABSTRACT

Adhesives are expensive and critical components in wood-based composites that can literally make or break them. The chemical precursors used in adhesive synthesis are commonly derived from petrochemical feedstock and are reacted with formaldehyde. As the EU endeavours to transition to a bio-based and climate-neutral continent by 2050, alternatives to imported petrochemicals are needed that are bio-based and that utilise local feedstocks. The BarkBuild project, funded by the Forest Value ERA-NET programme, is tackling this challenge. This project takes the discarded bark from sawmills, processes it, and extracts valuable compounds that can be used in new products. One of these products is a lignin gel-based adhesive (LBA) that is being tested for use in fibreboard and plywood panels.

The LBA with the addition of suberinic acid (used as a bark-derived plasticizer) was used to manufacture fibreboards and five-layer plywood panels for interior use. Glyoxal was used as a bio-based alternative to formaldehyde and the amount of added glyoxal was selected based on workability, reaction temperature, and the resulting strength. Resin curing temperatures were determined through DSC analyses and adopted for manufacture of the boards. Commercially available urea-formaldehyde resin was used for the reference panels. For the fibreboards, dried pine fibres were resinated with 10% LBA (by dry weight) and pressed at 150 °C for 10 min with target density of 300 kg/m3. Three boards of each adhesive type were designated for thermal conductivity (k) and specific heat (c) measurements after being conditioned at 20°C, 65% RH (standard), 20°C, 90% RH (moist), and oven dry. Panels were measured using a heat flow meter by establishing temperature gradient of 20 °C between the two plates. Values measured for k and c were performed on a temperature range from 20 to 45°C. Panels conditioned at standard conditions and measured at 23°C middle temperature had an average thermal conductivity of λ=0.059 W/m K, for LBA and reference panels. Moist panels showed measured at 23°C middle temperature with little higher λ of 0.073 W/m K. Both reference and LBA panels performed with comparable k and c values, while the moist environment had more visible effect on LBA panel dimensional stability. Boards were cut after test for acoustic measurements and will follow determination of sound absorption coefficient and impedance using impedance tubes. Plywood panels have been produced in the laboratory with both UF and LBA and are currently undergoing mechanical testing including flexure, screw withdrawal, and lap-shear tests.

Structural bonding performance of Appalachian hardwoods

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ABSTRACT

The escalating demand for energy-efficient, cost-effective, and sustainable construction practices has propelled unprecedented growth in the mass timber market. Cross-Laminated Timber (CLT), characterized by its layered structural lumber composition, emerges as a competitive alternative to conventional construction materials such as concrete and steel. With favorable physico-mechanical properties, CLTs present an attractive opportunity for utilizing Appalachian low-grade hardwoods. However, integrating hardwoods into CLT manufacturing poses challenges, including structural grading, bonding, performance validation, and certification. This study investigates the relationship between various technological factors and the bonding strength and durability of three Appalachian hardwood species, i.e. Yellow Poplar, Red Oak, and Red Maple. Employing the Taguchi method and regression analyses, an L9-type orthogonal array with four parameters (moisture content, surface preparation, pressure, and resin spread) at three levels was utilized for experimental trials. For specimen preparation, phenol resorcinol and one-component polyurethane adhesives were employed complemented with the utilization of a primer to improve the bonding properties. The performance characteristics analyzed were delamination, shear strength, and wood failure. Based on the statistical analysis and factors' effect determination we can conclude that the bonding properties differ significantly between species and the selected factors affect differently the response characteristics. The bonding performances of the validation panels manufactured with the factors configured at their optimal levels confirm the factors' effect and comply with the Standard for Performance-Rated Cross-Laminated Timber, APA PRG-320. The developed gluing technologies contribute significantly to the introduction of the Appalachian hardwoods in the mass timber construction market.

Unlocking sustainability and economic opportunities through hardwood-centric cross-laminated timber panels

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ABSTRACT

Improving the density of wood has been receiving more attention recently because of its potential to promote sustainability, improve wood performance, reduce costs, and give opportunities for new applications and innovations for wood utilization. Increasing the density of wood can allow the use of lower-grade or fast-growing wood species, which can help reducing the demand for high-quality, slow-growing trees. This can promote sustainable forestry practices and reduce the environmental impact of wood production. The development of new technologies and processes for densifying wood has opened new opportunities for using wood in innovative ways, such in the mass timber panel production. Cross-laminated timber (CLT) for instance has emerged as a revolutionary building material, offering a sustainable alternative to traditional construction methods. As the construction industry seeks environmentally conscious alternatives, the incorporation of hardwoods in CLT provides a promising avenue for enhancing both structural integrity and ecological responsibility.

The overarching objective of the proposed work was to demonstrate the feasibility of using densified yellow poplar (*Liriodendron tulipifera*) to produce cross laminated timber (CLT) panels. Developing new mass timber products using hardwood species will create new markets and jobs in the forest products industry. It will help to revitalize rural communities by creating demand for sustainably managed forests, and in addition, this effort will further increase the economic value of one of the species most commonly available in the Appalachian hardwood forests. Preliminary results demonstrated that, statistically, the factor affecting the most the density of yellow poplar is the compression rate, followed by the temperature in the press, and finally, the time of the wood in contact with saturated steam. Excellent bonding properties were demonstrated gluing densified Yellow poplar with specific adhesives and bonding them with other Appalachian underutilized wood species.

Structural timber products with ETA certification for the construction sector: trends, innovations and research needs

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ABSTRACT

The design of timber structures according to the Eurocode 5 requires harmonised European standards (EN) that define the physical and mechanical properties of the different engineered wood products (EWP) to build safe, efficient buildings and civil structures. To meet the performance and sustainable requirements under the Construction Products Regulation (CPR), EN standards provide the technical specifications to obtain CE marking which allows construction products to be marketed in Europe. Therefore, EWP covered by harmonised EN standards, such as strength-graded structural timber, glued laminated timber, or laminated veneer lumber, can be considered mature products in the wood construction industry. The advantages of wood as a strong but lightweight, sustainable, renewable, and low environmental impact material stimulate an increasing demand for wood in structures, such as multistorey buildings or buildings with complex shapes. These require innovative products and constructive systems, which are however not yet covered by EN standards. Innovative EWP can be commercialized in Europe obtaining the CE marking via the European Technical Assessment (ETA), which is an alternative declaration of product performance based on specifications laid down in European Assessment Documents (EAD). The objective of this research work was to analyse the trends in timber construction through reviews and descriptive statistics of ETAs of innovative EWP and structural systems and identify the further research needs for such innovations to reach wider uptake. Wood products that obtained ETA certification since 2002 were identified in the ETA database of the European Organisation for Technical Assessment (EOTA). About 80% of the ETA certificates corresponded to the product area of structural timber products (PAC13), which showed an increasing trend since 2015, produced both in and outside of Europe. The performance requirements by EADs to manufacture and characterise structural EWP were compared with those of the EN standards for mature structural products. This allowed to identify the challenges and research needs to develop new harmonised EN standards, as required by the recently reviewed CPR. The research has received funding from the EU projects Resonate (No 101000574) and Eufore (101081788).

Keywords: Standardisation, EOTA, CEN, Engineered Wood Products, EWP, timber structures, Eurocodes, ETA, CE marking, Construction Products Regulation, grading, properties

Thursday, July 4

STATE OF THE ART WOOD SCIENCE

Ilona Peszlen/Ruppert Wimmer (Co-Chairs)

Correlation analysis of mass loss and equilibrium moisture content for predicting properties of thermally modified wood

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ABSTRACT

Thermal modification of wood is a process that involves subjecting wood to high temperatures (160-260°C) to alter its chemical composition, thereby changing its physical and mechanical properties. Thermally modified wood has several advantages, including increased hydrophobicity, improved dimensional stability, and enhanced decay resistance against fungi. Due to these benefits, various studies on thermal modification of wood as an environmentally friendly method for wood preservation and insect resistance has been conducted, particularly in Europe since the early 2000's.

The effects of thermal modification on wood vary depending on the treatment temperature and duration. It is well-known that higher treatment temperatures and longer durations result in increased thermal modification effects. However, to find conditions that express the desired properties, subjecting wood to thermal modification under various temperature and time conditions, followed by property evaluations, is necessary. This trial-and-error process consumes a significant amount of time and incurs substantial costs.

In this study, research on correlation analysis was conducted to predict the properties of thermally modified wood based on treatment conditions of temperature and duration. Mass loss (ML) and equilibrium moisture content (EMC) of larch boards treated at various temperatures and durations were evaluated, and the correlation between ML and EMC was analyzed.

Consistent with previous studies, observations revealed that as the treatment temperature and duration increased, the ML of wood also increased, while the EMC decreased. Particularly, there was a tendency for the difference in EMC between untreated wood and thermally modified wood to increase with higher treatment temperatures. Additionally, the difference in EMC between untreated and thermally modified wood was more significant under high relative humidity conditions (above 80% RH). This is considered to be due to the adverse effects of high-temperature treatment on the formation of capillary condensed water. A robust logarithmic correlation between the ML of wood due to thermal modification and the EMC of the thermally modified wood was found, implying that the EMC of thermally modified wood can be predicted through changes in weight of boards before and after thermal modification. Furthermore, applying this study to evaluate other properties of thermally modified wood could enable the prediction of those properties as well.

Time-dependent relaxation of nailed connections in mass timber and solid-sawn timber

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ABSTRACT

One of the key parts of mass timber structures is the connection design and understanding how connections behave is vital to the continued adoption of mass timber. Many of the assumptions for mass timber connections come from previous research on solid-sawn timber. Currently nails are semi-common in mass timber connections, being required for code compliant lateral connections within the United States and being considered for spline connections between floor panels. One current gap, in both mass timber and conventional solid-sawn timber, is the specific effect of viscoelastic relaxation on dowel connections in timber.

Current practice and testing standards include losses in both withdrawal and bending capacity of dowel connections due to relaxation. This is incorporated into ASTM D1761, the testing standard for withdrawal and lateral resistance of dowel connections in timber, with a requirement for all testing to be conducted within one hour of connector installation. This is done to reduce any effects of relaxation, with studies showing losses over time in withdrawal strength. However, much of the data that to support this conclusion did not control for moisture, relative humidity, or temperature when investigating the effect of time. Due to this there is a need, both for solid-sawn timber and mass timber, to quantify the individual and combined effects of these separate variables. To begin filling this knowledge gap, nail withdrawal tests were performed on both solid-sawn timber and Mass Ply Panels (MPP), a veneer-based mass timber material. Both substrates consist of Douglas fir (*Pseudotsuga menziesii*) to allow direct comparison between veneer-based mass and solid-sawn timber. Two nail types and two penetration depths per nail were considered. Conditioned specimens were kept in a climate-controlled chamber with an equilibrium moisture content of 12% after nailing. Nails were withdrawn at one hour, 24 hours, 72 hours, and 168 hours to characterize the effects of time-dependent relaxation on the nailed connection. Experimental data were compared both between the different nails and species with existing equations and as a function of time. The experimental results, analytical and statistical comparisons, and suggestions for connection testing and design will be presented.

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Paraloid B-72 with Nano-CuB additive as consolidant for decayed wood objects

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Abstract

In periods when wooden craftsmanship was important in historical buildings, perishable or non-durable species such as linden, fir and pine were generally preferred because they could be easily processed by hand. As a result, serious biotic and abiotic damages are observed in these wooden objects today. Restoration is required to ensure that damaged wooden works can be delivered to future generations. In the restoration of historical buildings, the originality of the building must be preserved as much as possible. For this reason, consolidation processes are often needed in wood restorations. The aim of this study is to improve the protection properties of Paraloid B-72® monomer, which is a preferred consolidant in protection studies. For this purpose, copper and boron-based nano particals (CuB NPs) produced under laboratory conditions was used as an additive in paraloid B-72.

In our study, in order to simulate damaged wooden artifacts, consolidation process was applied to the specimens that were exposed to *Coniophora puteana* (Brown rot) fungus attack. Pre-decayed specimens were consolidated with CuB NPs added Paraloid B-72. After the consolidation process, the specimens were exposed to *Trametes versicolar* (White rot) fungus for 1 month according to the EN 113 standard test method. The effectiveness of the consolidation process was evaluated depending on the mass losses that will occur in the specimens after the decay test by *Trametes versicolar.*

Key words: Paraloid B-72, Consolidation, Historical Wooden Works, *Coniophora puteana*, *Trametes versicolor*

Introduction

In periods when wooden craftsmanship was important in historical buildings, perishable or non-durable species such as linden, spruce, fir and pine were generally preferred because they could be easily processed by hand. As a result, serious biotic and abiotic damages are observed in these wooden objects today (Irbe et al. 2012; Kisternaya and Kozlov 2012). Finally, restoration is required to ensure that damaged wooden works can be delivered to future generations. Restoration of historical wooden works or building elements is a complex, long and difficult process. Originality of the material must be preserved as much as possible. And, damaged wooden works must be delivered to future generations by using appropriate methods and materials with as little change in the material as possible. For this reason, consolidation processes are often needed in wood restorations.

Conservation experts have been treating different kinds of wooden artifacts with a variety of treatments since the early 19th century. Waxes, linseed oil, alum, sugars, melamine-formaldehyde

resins, Paraloid B-72, and poly(ethylene glycol) (PEG) are the first generation treatments most frequently utilized. For the conservation of timber supports, Paraloid B-72 is an organic soluble copolymer that is often applied as a solution in acetone, ethanol, or toluene. (Traistaru et al. 2011; Walsh-Korb and Avérous 2019, Soytürk et al. 2023)

The aim of this study is to improve the protection properties of Paraloid B-72® monomer, which is a preferred consolidant in protection studies. For this purpose, copper and boron-based nano particals (NPs) produced under laboratory conditions was used as an additive in paraloid B-72. CuB NPs were prepared based on modified in-situ reduction method. In our study, in order to simulate damaged wooden artifacts, consolidation process was applied to the specimens that were exposed to *Coniophora puteana* (Brown rot) fungus attack for 4 months. Pre-decayed specimens were consolidated with CuB NPs added Paraloid B-72. After the consolidation process, the specimens were exposed to *Trametes versicolar* (White rot) fungus for 1 month according to the EN 113 standard test method. The effectiveness of the consolidation process was evaluated depending on the mass losses that occurred in the specimens after the decay test by *Trametes versicolar.*

Materials & Methods

Production of CuB NPs

In the scope of the study, the in-situ reduction method was used for the synthesis of nanoparticles The preparation of functional NPs in powder form consists of an 8-step process flow: (i) Preparation of starting solutions, (ii) NPs synthesis process, (iii) Separation Process, (iv) Washing and Purification Process, (v) Drying Process, (vi) Calcination Process, (vii) Grinding Process, (viii) Screening Process. Cupper chloride ($CuCl_2.6H_2O$, Merck) and sodium borohydride ($NaBH_4$, Merck) was used to prepared the aqueous solutions at rt. Then $NaBH_4$ solution was added into the $CuCl_2$ solution by drop-wise method under ultrasonic treatment (24 kHz, %60 power) at 0 ºC. After the hydrogen gas evolution finished blacked colored solution was filtrated and washed with DW and ethanol for three times. Obtained powders were dried under atm pressure at 105 ºC and then calcined at 450 ºC for 4 hours for stabilization of the structures. The obtained powders were grounded in ball milling and sieved below 200 µm for characterizations. The prepared functional NPs were characterized to ensure the nano-sized formation. Scanning electron microscopy (SEM) was used to study the morphology of the particles and surface features. SEM samples were prepared by coating the powder with a thin layer of gold and then viewing it under a scanning electron microscope (SEM/EDS, Zeiss EVO® LS 10, operated at 7 kV).

Preparation of Pre-decayed Pine Wood Specimens

Wood specimens were cut from sapwood portions of Scots pine wood (*Pinus sylvestris* L.). All wood specimens were conditioned at 35 ± 2 °C and 20 ± 5% relative humidity (RH) for two weeks and their weights were recorded (M_0). The specimens were free of knots and a visible concentration of resins, and showed no visible evidence of infection by mold, stain, or wood-degrading fungi.

Wood specimens (15 mm x 25 mm x 50 mm) were conditioned at 20 ± 2 °C and 65 ± 5% relative humidity (RH) for two weeks and exposed to *Coniophora puteana* (brown rot) (Schum.:Fr.) Karst. (Mad-515) fungus according to the guidelines specified in the EN 113 -1 standard test method (BS EN 2020). *Coniophora puteana* fungus was incubated on 2% malt extract agar (MEA) in glass jars and incubated for 3 weeks at 22 ± 2 °C and 70 ± 5 % RH to allow full colonization of the medium by the mycelium before placement of the specimens into the jars. All specimens were sterilized with steam in an autoclave at 102 °C for 20 minutes and again the next day at the same temperature for 10 minutes. Two specimens were inserted in each glass jar.

Incubation was carried out for 16 weeks at 22 ± 2 °C and 70 ± 5 % RH in a climatic chamber. Once the fungal exposure was completed, the mycelium was removed and the specimens were weighed in order to evaluate their humidity at the end of the fungal exposure. The specimens were then conditioned at 35 ± 2 °C and 20 %RH, and their final weights were recorded. The mass loss of the

specimens was determined according to the EN 113 (BS EN 2020). Mass loss (ML) was expressed as a percentage of the initial weight of the specimens according to Equation (1).

$$ML\ (\%) = 100 \times (M_0 - M_1)/M_0 \qquad \text{Eq. (1)}$$

where, M_1 is the final weight of specimens after fungal exposure and M_0 is the initial weight of specimens which are conditioned at 35 ± 2 °C and 20 ± 5% relative humidity (RH) for two weeks before and after decay period. Then, specimens with 30%±2 mass loss were selected for Paraloid B-72® (PB-72) treatments and stored at 22 ± 2 °C and 70 ± 5 % RH in a climatic chamber for two weeks before Paraloid B-72® treatments.

Paraloid B72® Treatments

Plant based ethanol and Dibasic Ester (DBE, Ataman Chemicals, Turkey) was chosen as green solvents at a ratio of %10 (v/w) (Ethanol and DBE (1:1) / Paraloid B-72®). This concentration level of Paraloid B72® (10%) was chosen due to its extensive use in conservation and restoration practices for wooden artifacts. Paraloid B-72® treatment solution was prepared as a 10% solution in ethanol and DBE (1:1) using the cheesecloth method as stated by Davidson and Brown (2012). CuB NPs were added to the Paraloid B-72® treatment solution at two different concentrations as 0.25% and 0.5% (w/v).

Solid pine wood as control and pre-decayed pine wood blocks were vacuum-treated for 40 min at 100 mm Hg with each treatment according to the AWPA standard E10 method (AWPA 2022). After treatment, the blocks were blotted-dry and re-weighed to determine retention amounts. Retention amounts at the end of the treatment were calculated according to Equation (2)

$$\text{Retention} = G \times C / V \qquad \text{Eq. (2)}$$

where G is $M_w - M_{12}$, i.e. M_{12} is air dry weight before treatment and M_w is wet weight after treatment, C is Concentration, and V is sample volume.

Treated blocks were conditioned at 35 ± 2 °C and 20 ± 5% relative humidity for 2 weeks to ensure that curing was complete, and then weighed again and conditioned for 2 weeks at 22 °C and 65% relative humidity before decay tests.

Fungal Decay Resistance of Consolidated Pre-decayed Specimens

Consolidated pre-decayed and solid pine wood specimens exposed to *Trametes (Corioulus) versicolor* (white rot) (L.: Fr.) Pilat (COV 1030) fungus according to the guidelines specified in the EN 113 -1 standard test method (BS EN 2020). *Trametes (Corioulus) versicolor* fungus was incubated on 2% malt extract agar (MEA) in glass jars and incubated for 3 weeks at 22 ± 2 °C and 70 ± 5 % RH to allow full colonization of the medium by the mycelium before placement of the specimens into the jars. Specimens were wiped with a 70% alcohol wipe and keep under UV light for 40 min. Two specimens were inserted in each glass jar. Untreated pine and beech woods were also used as control specimens.

Incubation was carried out for 4 weeks at 22 ± 2 °C and 70 ± 5 % RH in a climatic chamber. Once the fungal exposure was completed, the mycelium was removed and the specimens were weighed in order to evaluate their humidity at the end of the fungal exposure. The specimens were then conditioned at 35 ± 2 °C and 20 %RH, and their final weights were recorded. The mass loss of the specimens was determined according to the EN 113 (BS EN 2020). Mass loss (ML) was expressed as a percentage of the initial weight of the specimens according to Equation (1) as mentioned before.

Results and Discussion

Characterization of Nanoparticles

The morphological characteristics of the synthesized particles' surfaces were examined using Scanning Electron Microscopy (SEM). Figure 1 presents SEM images of distinct samples at magnifications of 50000x. The analysis revealed that the samples, synthesized with desired elemental compositions within target material, exhibited similar morphological structures. It was observed that the nanoparticles, despite their heterogeneous sizes, formed clusters. Notably, the CuO sample demonstrated a more homogeneous particle distribution with sizes below 50 nm.

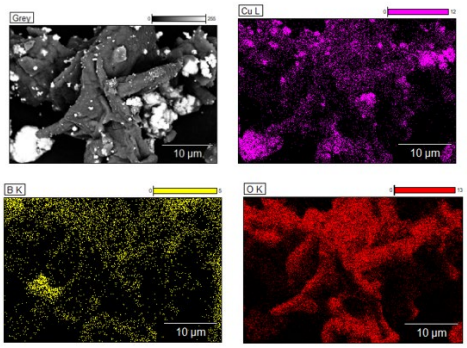

Figure 1. SEM/EDS images of CuB NPs

Retention Levels and Decay Resistance Test Results

Mass losses in the specimens exposed to the white-rot fungus, *T. versicolor*, is presented in Table 1 in comparison with untreated control specimens. Approximately 3.25% less mass loss occurred in pre-decayed specimens treated with Paraloid B-72® with 0.5% CuB NPs, compared to pre-decayed specimens treated with pure Paraloid B-72® solution. Higher mass losses occurred in pre-decayed specimens compared to control wood and Paraloid B-72® treated solid pine wood specimens.

Table 1: Retention levels of the compounds in the specimens after treatments and decay resistance of specimens

Specimens / Treatments	Concentration (%)	*PB-72 Retention (kg/m^3) **CuB Retention (kg/m^3)	Mass Loss After Decay Test (%)
PB-72 Treated pre-decayed pine wood	–	*64,55 (0,94)	23,18 (0,71)
CuB NPs added PB-72 treated pre-decayed pine wood	0,25	**1,56 (0,22)	21,11 (0,20)
CuB NPs added PB-72 treated pre-decayed pine wood	0,5	**3,02 (0,05)	19,93 (0,34)
PB-72 treated solid pine wood	_	*33,76 (10,89)	11,45 (2,43)
Control - solid beech wood	_	_	5,97 (0,38)
Control - solid pine wood			3,73 (0,43)
Values in parentheses are SDs			

Summary and Conclusions

Within the scope of the study, CuB NPs were successfully produced and could be used in adding Paraloid B-72 solutions. A success has been achieved in improving decay resistance in specimens treated with CuB-added Paraloid B-72® solutions. Also, it is thought that higher decay resistances can be obtained at higher inclusion rates due to the decrease in mass loss as the inclusion rate of CuB NPs increases. It is thought that the reason for a higher mass loss in pre-decayed specimens compared to untreated control and PB-72 treated solid pine wood specimens is the presence of a proportionally higher amount of lignin in pre-decayed specimens. *Trametes versicolor*, which was used in decay

tests to determine durability, performs selective biodegradation in softwoods which preferentially convert wood hemicellulose and lignin, but cellulose was retained selectively (Qi et al. 2023). Within the scope of the project, the potential of different nano-metal combinations to increase resistance to decay and fire continues to be investigated.

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How much does the microstructure of wood affect char oxidation?

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ABSTRACT

Smouldering combustion is an understudied hazard in the context of timber construction. Smouldering may occur after flaming extinction and be sustained for extended periods (hours, days). Smouldering combustion has been observed in concealed spaces and gaps between timber boards and at joints due to the limited heat losses in these areas which are conducive to smouldering. Smouldering of timber is a two-step process: heat generated from the heterogeneous oxidation of char is used to drive pyrolysis of virgin wood forming more char which can undergo oxidation. This process consumes the structural timber, potentially resulting in reduced cross-section and collapse.

The wood anatomy affects the heat and mass transfer processes, which control the processes of pyrolysis and char oxidation. Two to three times higher thermal conductivity has been reported parallel to the macroscopic fibre direction than perpendicularly. The longitudinal air permeability is orders of magnitude larger than transverse permeability, i.e. radial and tangential.

This experimental study investigated the char oxidation behaviour of charred pine (*Pinus sylvestris*) to assess the impact of the wood microstructure on smouldering in isolation from flaming and pyrolysis processes. Cylindrical samples (100mm diameter, 20mm thickness) with macroscopic fibre direction parallel to the disk surfaces were cut into two sectors to create a 5mm-wide gap representative of the gaps between boards in commercial cross-laminated timber. Half of the two-sector samples were cut perpendicular, half parallel to the macroscopic fibre orientation. Samples were exposed to heat fluxes of 10kW/m².

Ignition of smouldering combustion occurred predominantly in the gap in both cases due to the reduced heat losses in this location. The measured time to ignition was approximately 50% shorter for the perpendicular fibre orientation compared to the parallel fibre orientation in the gap. Samples with fibres perpendicular to the gap reached their peak reaction (mass loss) rate almost three times faster than samples with parallel fibres. The peak mass loss rate and the carbon monoxide (CO) mass flow rate of perpendicular samples were 23% and 24% higher, respectively while the peak carbon dioxide (CO_2) MFR was on average 6% lower than for parallel samples.

A hypothesis is proposed to explain the different ignition times: perpendicular fibre orientation allows for greater thermal penetration into the sample and enhanced oxidizer availability in the char compared to the parallel case. This may result in faster ignition. This logic is also supported by the higher total reaction rate observed for the perpendicular cases. The change in combustion efficiency (as indicated by a decrease in the CO_2 mass flow rate) may also indicate a change in the reaction dynamics i.e. limited oxygen availability in the perpendicular case.

This work presents a problem at the interface between the wood science and the fire science communities, particularly understanding how the large change in permeability (several orders of magnitude) has a comparatively minor impact (23%) on the smouldering mass loss rate. It is suggested that further investigation of the impact of the wood microstructure and surface reactivity is needed to identify other competing dominating processes.

Enhancing fire safety in plywood: layered treatment for improved flame retardancy

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ABSTRACT

Plywood remains a prominent choice in construction. With climate change already underway, there's a shift in natural forest composition from softwoods to hardwoods like beech or birch. This transition might increase the production of veneer- or strand-based alternatives. However, engineered wood products (EWPs) still face susceptibility to fire incidents. To promote their use in high-rise and public buildings, wood-based materials need to be modified with flame retardants (FR).

While the production of flame-retardant plywood is not a novel concept, as veneers are easily impregnated and drying processes are energy-efficient, flame retardant plywood is currently produced by treating either the entire cross-section of the EWP or applying just a surface finish. Given that fires typically start from the surface and progress into the panel, using the layered structure of plywood presents an opportunity to reduce costs and FR consumption. This can be achieved by treating just the outermost layers before assembling of the veneer layers, thus improving both economic and ecological factors while enhancing the flame-retardant effect, since more FRs are absorbed into the wood compared to a surface finish alone. Another use case for the layered structure could be the application of untreated surface veneers, to preserve the natural appearance of the plywood while improving the fire properties.

In this study heterogeneous 9-layered birch plywood bonded with urea formaldehyde (UF) resin was produced on a lab scale. Plywood with one, two and three layers of veneers impregnated with a commercial, non-halogenated, flame retardant as the surface layers were tested at three different heat fluxes (20, 35, 50 kW m^{-2}) in a cone calorimeter. By applying different heat fluxes the susceptibility of the material towards ignition, the heat release, the mass-loss and the smoke production can be assessed. Additionally, plywood with an untreated surface layer and a treated veneer underneath was produced and tested at the same heat fluxes. Untreated plywood was used for comparison and an estimation of the improvement of the fire properties.

At 20 kW m^{-2} the time to ignition (TTI) can be triplet by just adding one layer of treated veneer. Similar values are measured for two and three layers. At 35 kW m^{-2} the TTI can be tripled by adding one layer and increased sevenfold by adding two and elevenfold by adding three layers. Increasing the heat flux to 50 kW m^{-2} equilibrates TTI for one and two treated layers but for three treated layers it is increased six-fold. Insertion of a layer in the second place under an untreated surface layer has hardly any influence on the time to ignition at the used heat fluxes.

Investigating the role of genotypes in the physical and mechanical properties of *Eucalyptus pellita* and hybrids

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ABSTRACT

Due to the increasing population, there has been increasing pressure to reduce the deforestation rate of natural forests. Over the years, there has been rising interest in many *Eucalyptus* breeding programs around the world. This interest focuses on developing clonal forestry to enhance plantation productivity and wood properties. Genetic improvement efforts have predominantly focused on pulpwood breeding objectives. In the Northern Territory, Australia, the majority of hardwood plantations are located on Aboriginal-owned lands of Tiwi Islands (80 km North of Darwin) which are grown for paper and pulp. Tiwi Plantation Corporation (TPC), Tiwi Islands, has long focused on wood chip production and export. Recently, there has been a shift towards product diversification with a focus on eucalyptus-based products of higher market value. Combining productivity with industrially relevant wood traits remains a challenge. Wood density is an important physical trait for genetic improvement, although the standard for wood quality is not a single index. Compressive strength, stiffness, bending strength, and dimensional stability are all critical for evaluating wood qualities. This research aims to understand the genetic and phenotypic relationship between growth traits and their physical/mechanical properties. Specifically, the research assessed the variations in the physical/mechanical properties of young plantation-grown *Eucalyptus pellita* and hybrids. Correlations between selected phenotypes and the physical/mechanical properties were evaluated. This study attempted to identify desirable and undesirable traits using molecular markers i.e., to link markers to traits and wood qualities. The research focused on two young Eucalyptus pellita plantation sites on Tiwi islands involving three research studies. DNA samples and wood chips were collected from approximately 1500 trees for genotyping and phenotyping (conducted by two other studies under the same research funds). For this study, 59 trees were randomly selected to assess the physical and mechanical properties. Discs were collected at the base of each tree to assess the unit shrinkage and basic density. Samples were collected at the top, middle, and base for mechanical property testing. Variations in the physical and mechanical properties were evaluated. Correlations between physical/mechanical properties and selected phenotypes were analyzed. Association between genotype (SNPs) and physical/mechanical properties was carried out using GAPIT in RStudio. Once the relationship between phenotypes and physical/mechanical properties is understood and associated genes identified, foresters and landowners can use this powerful tool to make decisions and grow the next rotation of trees capable of producing high-value building products. The outcome of this study will help determine the potential for plantation improvement through cutting-edge genomics, molecular markers, and plant breeding technologies. This will have significant implications for the forestry and timber industry, helping to improve sustainability and efficiency in wood product manufacturing. Ultimately, the findings of the project will allow tackling housing timber shortage and alleviate pressure on native forests. The study will also provide significant economic and social benefits to the Aboriginal community in Tiwi Islands.

Keywords: Eucalyptus, Physical properties, Mechanical properties, Genotypes, Phenotypes

Effect of lignin on veneer densification and set-recovery

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ABSTRACT

Wood densification is aimed at reducing wood porosity through compression to improve wood surface hardness and transverse shear strength (Navi & Heger, 2004). This method has generated a lot of interest as it has the potential to improve the properties of low-density wood species, making them suitable for high-end applications such as wooden flooring (Tenorio et al., 2021). However, the hygroscopic nature of wood results in densified wood capable of regaining its original shape when re-moistened, known as set-recovery (Navi & Heger, 2004). To permanently fix wood deformation, chemical treatments have been utilized such as acetylation (Laine et al., 2016), maleic acid glycerol (Yahyaee et al., 2022), ionic liquids (Neyses et al., 2020) or impregnation with unpolymerized low molecular weight resin (phenol-formaldehyde) to cure during densification (Kollmann et al., 1975; Stamm & Seborg R.M., 1941). However, these solutions are costly and can reduce the wood recyclability. Thermal treatment does not use chemicals and can increase wood dimensional stability and its resistance to decay (Hill, 2006). Typical treatment temperatures range from 160°C to 250°C with holding times of several hours (Ding et al., 2011). Although using higher temperatures in treatments can decrease set-recovery, treatments above 160°C–180°C are not advised to avoid decreasing wood mechanical properties, especially under dry heating conditions (Inoue et al., 1993; Kollmann et al., 1975; Navi & Heger, 2004). Higashihara et al. (2000) found that the dominant mechanism for fixation was the release of stresses stored in the cell wall. It is unclear, however, whether semicrystalline cellulose or lignin also impact permanent fixation. By focusing on one variable at a time, such as lignin, we can gain a better understanding of its contribution. Smaller quantities of lignin are hypothesized to have less of a shape memory effect in wood simply because the smaller quantity of lignin is insufficient to store enough of the internal stresses. By partially dissolving lignin from wood structure using acid chlorite treatment and further allowing the matrix and microfibrils to flow with higher moisture content, we are attempting to reduce the accumulation of internal stresses during densification. A greater understanding of the role that lignin plays in the set-recovery can be gained from the present study. For that, the changes in morphological structure, physical properties, and dimensional stability of untreated and treated birch (*Betula pendula* Roth), aspen (*Populus tremula* L.) and grey alder (*Alnus Incana*) were investigated. Results show that by partially dissolving lignin from the wood structure with acid chlorite treatment and allowing the matrix and microfibrils to flow with higher moisture content, the set recovery after water immersion was reduced from total recovery to 70%. This indicates that delignified wood has a lesser shape memory effect in wood due to its reduced capacity to store internal stress.

Using wood colorimetry for the classification of malagasy rosewoods and palisanders

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ABSTRACT

Among the 83 Malagasy *Dalbergia* species, 56 are large trees highly valued in the timber market due to their good technological and aesthetic properties. The wood color, not only an aesthetic attribute, has historically served as a key factor in classifying malagasy *Dalbergia* species as either rosewood or palisander. Palisander is a *Dalbergia* species exhibiting heartwood colors ranging from light yellowish-brown to darker orange, while rosewoods colors range from purple to wine-red. This secondary category known as rosewood is very expensive and highly sought after in the international market. However, this subjective assessment of wood color, lacking objective measurement devices, can lead to variations in perception among operators. Therefore, the aim of this study was to use a desktop color measurement device and wood colorimetry to objectively classify 24 Malagasy *Dalbergia* species. A total of 143 wood blocks each measuring 2 cm3, were sampled from 143 trees distributed across several regions of Madagascar. For each wood sample, six measurements were done on each of the three sanded ligneous plane by using a spectrophotometer CM-5 with the CIELab system. The color table of Camargos and Gonçalez (2001) was used to determine the wood color based on lightness (L*), chromatic coordinates (a* and b*), chromaticity (C*), and hue angle (h). Hierarchical clustering analysis using the Ward method was conducted on the colorimetric variables to perform unsupervised classification of the analyzed species. Results show that the 24 species could be classified into three groups. The first and second groups, characterized by yellowish and brownish wood color respectively, showcased lighter woods. They are characterized by a significant contribution of the colorimetric parameters L*, b*, and C*, particularly pronounced in the first group. In the opposite, the third group exhibited darker woods, with reddish wood color characterized by a lesser contribution of the L*, b*, and C*. Among the five species of Dalbergia described as rosewoods in the literature, three were confirmed in this study as consistently classified as rosewood for the three wood surfaces according to HAC results. Two other rosewood species in the literature were identified as palisanders based on measured wood color. The findings further showed that the remaining 19 analyzed species were palisanders. This study significantly contributes to enriching the wood color properties database of Malagasy *Dalbergia* wood and serves as a scientific argument for reviewing the classification of malagasy rosewood and palisander. Additionnally, the use of portable and less expensive spectrocolorimeters, coupled with visible spectra analysis and multivariate supervised classification, holds a promise for developing tools to support in-field identification of species and the assignment of trade names based on wood color.

Key words: *Dalbergia*, Madagascar, wood colorimetry, Spectrocolorimeter CM-5, CIELab

NEW APPROACHES TO WOOD SECTOR EDUCATION

Ilona Peszlen/Ruppert Wimmer (Co-Chairs)

Wood beyond the stem: towards a new material concept for underutilized branch wood from deciduous trees

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ABSTRACT

The urgent need to adapt to climate change requires a shift in forestry practices towards potentially more resilient hardwood and mixed forest stands. This transition represents a major challenge for the wood processing industry due to the inherent differences in properties between hardwoods and the softwoods that dominate in Europe and requires innovative approaches to improve the utilisation of hardwoods. In fact, the volume of branches and stem tops in deciduous trees accounts for 20-50% of their total above-ground biomass. Our research addresses this challenge by deepening the knowledge of basic branch wood material characteristics and proposing a new way to produce structural wood products from non-sawmill grade assortments. Our methodology involves several key steps aimed at maximising the material efficiency of hardwood resources. First, we conducted extensive material characterisation studies to understand the physical and mechanical properties of branch wood from prominent broadleaved species such as *Fagus sylvatica*, *Quercus petraea* and *Populus alba*. Our results showed that branch wood does indeed have a significantly different technological profile compared to stem wood, particularly in terms of density and tensile strength. Using personal laser scanning technology, we created digital twins of entire trees, which facilitated the correlation of mechanical material properties with the positional data of individual branches. Our findings revealed that branch slope in particular, but also branch top side and diameter, have a significant effect on elastic properties and bending strength, although variances exist among different species. In the case of oak, it was possible to predict the bending properties of defect-free samples from branch wood by factoring in density and position parameters. At the ultrastructural level, we are currently investigating wood density, microfibril orientation and crystallinity from pith to bark samples of selected branches using wide-angle X-ray scattering. We consider such radial trends to be crucial, as they correspond to the temporal progression of growth and, conversely, could be key for efficient disintegration processes. For radial splitting along the grain, we are using a laboratory-scale branch-splitting technique to produce elongated macro strands to enable the production of structural elements such as panels and beams. Our research represents a pioneering effort to bridge the forestry, wood processing and construction sectors to unlock the potential of hardwood for structural applications. Through these collaborative efforts, we envision a future where hardwood resources, often under-utilised, play a central role in driving innovation and contributing to the wider transition towards a more resilient and resource-efficient society.

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Green chemistry method for surface densification of wood

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ABSTRACT

The construction sector is a major contributor to global greenhouse gas emissions, accounting for 40% of the total, with building materials and construction alone responsible for 10% of these emissions. This trend is expected to grow significantly by 2030. To address these environmental concerns, the adoption of green materials, particularly wood products, offers a promising solution to reduce energy consumption and carbon emissions in construction.

Wood, abundant and renewable, offers aesthetics, strength, and durability to construction when used correctly. However, despite its use in residential buildings (71% market share), its low hardness and flammability limit its use in non-residential buildings (4% market share)), such as hospitals and offices. Wood densification, a technique aimed at reducing the void volume of wood, increases density, hardness, and improves properties such as dimensional stability, lifespan, and mechanical strength, while increasing the durability of the wood. This is an essential strategy to improve the use of wood in construction. Current densification methods, however, have limitations in terms of cost and environmental impact. Therefore, the overarching objective of this project is to develop environmentally friendly bio-based densification formulations to enhance surface wood hardness.

This study introduces an approach for surface wood densification involving in-situ polymerization using the Michael-addition as a green chemistry reaction between biobased acrylate and malonate monomers. This reaction, conducted in mild conditions with reducing energy and solvent consumptions, aims to enhance wood densification while minimizing environmental impact. The most promising formulations were identified in terms of reaction rate, conversion rate, and simplicity, and evaluate the efficacy of these formulations in enhancing wood surface density and hardness.

The study consists of two parts: an evaluation of various malonate-acrylate formulations and an investigation of their effects on densified woods. The first part compares various formulations based on their conversion rates obtained from real-time infrared spectroscopy, glass transition temperature (Tg), crosslinking density (CLD) via Dynamic Mechanical Analysis (DMA), and film hardness by using the Konig pendulum hardness test. In the second part, the most efficient formulations were used for surface impregnation of three North American wood species including sugar maple, red oak, and yellow birch. Moreover, the potential of the dual curing system to improve wood properties has been studied which combines the advantages of two reactions to improve the hardness of wood. It was therefore carried out using Michael addition followed by ultraviolet curing to further improve the crosslinking density of the formulation and as a result, wood hardness. The properties of the densified woods were investigated using X-ray densitometry and Brinell hardness, and their results were compared by ANOVA data analysis. The morphology and penetration of the formulation in wood lumens and cell walls were assessed by Confocal Raman spectroscopy and scanning electron microscopy.

By integrating these approaches, this study aims to advance sustainable wood-polymer composites to enhance wood properties, particularly hardness, and potentially reduce greenhouse gas emissions associated with the sector.

How is wood culture addressed in wood science programs?

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ABSTRACT

'Wood heats you up three times: when you cut it, when you split it, and when you burn it'. This old saying, of which variations exist, is just an example of how much this material is linked to human culture and traditions. In fact, wood is included in several entries of the UNESCO intangible cultural heritage list; it is commonly studied in programs in Restoration and conservation of cultural heritage; museums around the world display wood artefacts and their linkages with populations.

Over the ages, humankind has developed a real wood culture, which can be indicatively intended as the ensemble of knowledge, processing, uses, and social aspects related to this material and its products (Spencer-Hoatey 2012; Rosen 2011). This offers a myriad of fascinating stories and anecdotes that can be effectively used for teaching purposes. Actually, telling stories is recognized as a valuable tool to explain scientific concepts, demonstrate their importance, and make them stick in students' minds (Bonds 2016).

This contribution investigates how wood culture is addressed in wood science programs, focusing on its presence in courses or part of courses and in promotional material. To understand this, we consulted the websites of the 185 programs around the world listed in the SWST Wood Science Around the World map.

The search showed that wood culture is rarely mentioned in the description of programs and courses, as well as in promotional material. References, when present, tend to be brief, even if cases of higher valorization were found. Nonetheless, the authors experience is that citations are quite common, with various levels of deepening, during academic lectures.

Formally including wood culture in programs and courses, referring to it in promotional material, addressing it in seminars can be useful strategies to valorize it and to enforce the teaching of wood science. This might also contribute to increase the attractiveness of academic programs in low enrollment situations.

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Virtual laboratory platform for wood material studies

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ABSTRACT

For improving the level of teaching and keeping up with the technological advances in wood material sciences, novel state-of-the-art education environments are needed. However, purchasing laboratory facilities for teaching would require large budget. To provide the students with up-to-date, competitive learning space to indulge in material science education, we are currently building a virtual laboratory that utilizes existing top-science physical laboratories. This will allow the students to get the top-level education with modern and pedagogically high-quality virtual means that are accessible any time and thus ease the completion of the courses.

Virtual Laboratory Platform LabReality for wood and biohybrid material studies will be based on high quality 360°-imaged laboratories with additional virtual hotspots of interactive images, videos, 360/VR & 3D models, and info-boxes of literature combined into an engaging real-world compilation of virtual hands-on laboratory exercises, scaled-up processing practices, and sustainability assessments for wood and other biobased novel materials.

The learning experience will be a self-study module which will be openly available for anyone. The University of Helsinki´s MOOC.fi platform will enable efficient online learning and scalability; after exploring in the virtual lab, students can do related exercise which can be peer reviewed essays or automatically evaluated multiple choice questions, and teacher´s input is not needed for accomplishing the course and getting credits. The lab experience as a MOOC can also be distributed as part of the national Digivisio 2030 platform and be one of the pilot projects for the University of Helsinki. This way the lab experience as an open microlearning opportunity can get wide nationwide audience right away.

Immersive 360-degree images and videos enable learners to see things that would not be possible for the human eye otherwise, such as zooming in and out within an environment. When using these tools, the learners can experience the full location and engage further with the material presented. The users can also decide where they look and when. The immersion with 360-degree videos can connect the viewers with the learning content in a more meaningful and emotional way.

This learning experience will be an ecosystem of media, allowing instructors to use transmedia storytelling to engage students in content using multiple methods, thereby engaging multiple senses, and learning styles. This kind of pedagogy utilizes multiple media platforms where each piece – whether it´s a comic, text, video, 3D graphic, or image – functions as a standalone story experience, but, like a giant puzzle, each piece also contributes to a larger narrative. In the presentation, the current stage of the development work, as well as the existing knowledge on pros and cons of the virtual platforms will be discussed.

The New European Bauhaus (NEB) Academy pioneer hub for sustainable built environments with renewable materials building up NEB Academy Alliance

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ABSTRACT

The urgency of the climate crisis requires accelerating the transfer and adoption of climate change mitigation skills and tools to workers, businesses, policy makers, and the public. Around 40% of GHG emissions come from building operations and an additional 10-20% from embodied emissions, making the construction ecosystem a major contributor to the climate crisis and a necessary sector to transform. One of the main obstacles to transformation is the massive need for skilled workers and educated professionals on all levels. More than three quarters of companies in the EU report difficulties in finding workers with the necessary skills. The twin green and digital transformation of the construction ecosystem is an enormous opportunity to create sustainable employment in urban and rural areas and is central to decarbonising Europe's economy and fighting climate change.

The New European Bauhaus (NEB) Academy Pioneer Hub for Sustainable Built Environments with Renewable Materials established at University of Primorska has evolved and obtained funding to establish an international network, the New European Bauhaus Academy Alliance (NEBA Alliance). This alliance will ensure high quality training for higher education, VET, and life-long learning is available and delivered to as many workers as possible across Europe and the surrounding regions. The NEBA Alliance project began on April 1, 2024, and will establish Hubs that have regional coverage and/or expertise in specific topics and provide a framework for long-lasting collaboration and operations. The project will use a digital platform as a matchmaker between learners and trainers, and provide an open directory and repository for NEBA certified training contents. The critical topics to be covered include bio-based materials (especially wood), as well as circular, regenerative, and long-life processes, concepts, and solutions with microcredentials available. The project will also provide a Skills Agenda and Policy Roadmap, guiding implementation of the Green Deal, Renovation Wave, Circular Bioeconomy, and related policy initiatives. The NEBA Alliance will be the first and most dynamic entry in a massive push for skills/education across all levels of the construction sector and the society.

Navigating the past, present, and future of forestry and wood science education in the United States

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ABSTRACT

The history of forest resources in the United States spans centuries, evolving from the early utilization of vast forested landscapes by Native American populations to the development of sustainable forest management practices in modern times. The exploitation of timber and other forest products played a crucial role in shaping the nation's economy, infrastructure, and cultural identity. But times change and new questions about forest have evolved. Specifically, how is academia ensuring that new generations of foresters are learning the basic sciences behind forest management and wood processing; How prepared are graduates to manage to preserve our natural resources and continue using them for generations to come? Is there still interest by younger students to become involved in Forestry and Wood Science careers? What is academia doing to recruit students to these fields? Do we receive support for these efforts from industry, federal agencies, and local government? Throughout the 20th century and into the 21st century, forest resource management and wood products professionals faced and continued to face new challenges, like invasive species, wildfire management, and population increases. The lack of prepared professionals available to fill the gaps left by professionals who have retired, and those that will continue leaving this important industry, is now a critical concern. Sustainability is now a guiding principle, seeking to balance environmental, economic, and social objectives in forest management. Wood remains a critical world resource, and its applications have expanded across industries, from construction and furniture to packaging and biotechnology. In this presentation I will review current aspects of education in forestry and wood science in the USA, how we plan to face challenges to these professions, and what are we doing to preserve and transfer our knowledge to further generations.

Engaging artificial intelligence content generators in the context of a wood science and engineering graduate course

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ABSTRACT

The artificial intelligence (AI) has arrived, and, whatever the opportunities, threats or shortcomings of the tool, the arrival cannot be ignored. Not by scientific community at large, neither by the academic instructors. There seems to be growing consensus that the use of AI as a tool in any aspect of research activity should be referred to not only by the name of the tool, but with a thorough description of the purpose and approach: reporting initial and refining prompt(s), raw output, the ways the outcome is analyzed and further processed before being used in project, reports, or publications. That consensus has to be promptly communicated to students through thorough class materials and in practical exercises encouraging a curated engagement of AI tools and critical analysis of the outcomes in all aspects of the field related work where students may, rightly or not, perceive their utilities.

The purpose of this presentation is to communicate an attempt of such curated AI Engage exercise in the context of a graduate level hybrid course on foundations of Scientific Methodology for graduate students in Wood Science and Engineering program at Oregon State University. In this course students gradually develop and refine carefully structured summaries of their graduate projects in a format of an extended abstracts (5 pages). Course activities include video lectures, assigned readings, content development assignments, peer reviews facilitated by structured online discussions, timed class presentations and feedback sessions, and anonymous class-responseware polls designed to check comprehension and to stimulate discussions on a variety of related topics.

AI Engage exercise was introduced this winter as the first of its kind assignment at the last week of the classes, when the regular project summaries were already well developed. The assignment was to prompt an AI content generator with a title of the project and a description of the expected structure (250 words reflecting the motivation, goals, hypotheses, objectives, approaches and expected results), which was extensively discussed throughout the class. The students were requested to report the prompts, produce the AI outcome, compare with own summaries, and briefly discuss their observations and impressions, both, the positives, and disappointments.

The exercise was prepared by a series of class discussions on the topic, featuring anonymous class-responseware polls conducted ahead of the planned launch of the exercise and after the outcomes of the assignment were returned.

The polls provide interesting glimpse in students preconceptions and opinions and how they changed following the explanation of the fundamentals of AI content generators, explanation of the AI Engagement exercise and after the curated exposure to AI.

Decision factors of sustainable construction professionals in Slovenia

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ABSTRACT

The built environment and the construction industry account for a significant share of global harmful emissions. Sustainable construction appears to be an effective strategy to achieve a more sustainable society, although it is still not used enough. Therefore, it is crucial to understand what the main decision factors of those deciding about building practices are. We identified professional stakeholders such as architects, engineers, constructors, as the ones advising consumers and deciding about construction. An understanding about their decision factors is needed, in order to increase the implementation of sustainable construction. In this study we provided evidence about key decision factors of professional stakeholders in Slovenia when deciding for sustainable construction practices. Slovenia is among the most forested countries in Europe, is reach with wood – natural and renewable building material, and have a strong forest-based industry and construction sector. By conducting an online survey (questionnaire) we identified and analysed the main drivers and barriers of professionals when making decisions about sustainable construction solutions.

With statistical analysis (mean score method and corelation matrix) we found out that professional stakeholders included in the survey mostly already had previous experiences working with sustainable construction, and they are familiar with sustainable construction concepts, such as LCA, building information modelling or environmental footprint. The most important drivers were connected to the factor of occupant health, and to the energy-efficiency of the buildings, while the biggest barrier in their decision making is related to higher cost of sustainable construction and lack of awareness. Additionally, we discovered that professional stakeholders are concerned about climate change and their attitudes towards climate change are affecting their decision related to sustainable construction. For those who have more experience in the field of sustainable construction this is even more important. Respondent provided many comments, clearly indicating that a simple definition of sustainable construction is needed and more efforts should be done from either researchers, communication practitioners, educators, policy makers, and other important stakeholders, to raise awareness about sustainable construction. Respondents also do not perceive climate change as a thread for the construction sector and for their company which is an additional reason why more efforts to spread the knowledge and raise awareness is needed.

Results are contributing valuable information for professional stakeholders, policy makers and other important stakeholders in the construction sector.

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Key Words: sustainable construction, climate change, decision factors, professional stakeholders, drivers, barriers

Digital Innovation Hub - a game changer for digitalization and education in the traditional European timber industry?

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ABSTRACT

The so called “Third Mission” of Universities has recently been given increased attention in Austria and other countries. Here, the knowledge and technology transfer towards the public, continuing education and lifelong learning as well as social commitment in connection with regional circumstances are defined as objectives.

To foster knowledge transfer between science and companies, the so-called COMpetence centers of Excellent Technologies (COMET) were established in 1998. Wood K plus is one of the more than 20 centers in Austria and is focusing on applied research in the field of wood and wood-related renewable resources. One strategic research aspect at Wood K plus is dealing with evaluating digital technologies for the wood-working sector, which is investigated within the European Digital Innovation Hub (EDIH) INNOVATE. This is a currently running 3-year project funded under the Digital Europe programme by the EU and the Austrian Research Promotion Agency (FFG). Altogether there are 151 EDIHs across Europe.

The goals of the EDIH INNOVATE are to kick start novel digital solutions for the agriculture, timber and energy sector and foster a sustainable circular economy. The EDIH INNOVATE is a network of 10 partners from academia, networking organizations and innovators that offer their service free of charge to SME and Mid-Caps. Based on the three pillars informing, educating and prototyping, the EDIH INNOVATE objectively offers participants workshops, keynotes, webinars, projects for prototyping, digital technologies to be tested and a network to guide them on their digitalization journey. Additionally, funding opportunities for participants are highlighted.

As a predecessor of the EDIH innovate, a nationally funded digital innovation hub (DIH innovate) was successfully finished in 2024. Within this 3-year project, the use of digital technologies such as 3D printing, cobots, sensors or assistance systems for SMEs from the wood sector were evaluated and their digital maturity was assessed. We learned that the wood sector is already right in the middle of a digital transformation of its businesses, and that digital skills and technologies are seen as key factors for the European timber industry to stay competitive.

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ENVISIONING A FUTURE OF BIOBASED, BIOINSPIRED AND ENGINEERED LIVING MATERIALS

Anna Sandak/Francesco Negro

Next generation of sustainability for nature-based materials – functionalization of wood and wood-/bio-based materials by innovative industrially-scaled atmospheric pressure plasma deposition to replace technical, petroleum-based polymers

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ABSTRACT

Expected next decades' mega trend is eco-design in interior architecture, i.e. for private and public facilities and even aircraft interiors, by using sustainable materials, long service life, repairability and previously unknown smart, invisible functionality ("Shy-Tech") while maintaining the high natural aesthetics of wood and natural materials. However, in the woodworking industry, industrially usable high-performance processes for such new materials are lacking so far, e.g. for implementing heating, sensor and switching functions, but also high abrasion resistance and durable antimicrobial protection into wood & nature-based materials.

This gap can be filled by atmospheric pressure plasma deposition (APPD) as a low-temperature, innovative, energy-efficient next-step development for biomaterial surface functionalization beyond vacuum plasma technology (PVD, PACVD), enabling both lateral structured and full-surface economic and ecologic functionalization of even large components, sheets and rolls by eliminating the need for expensive vacuum chambers and very high deposition rates (i.e. process speeds).

Especially by using plasma jets from Inocon Technologie GmbH with uniquely high stability even at low plasma energy and high plasma volumes, APPD is well usable to coat wood, natural materials and bioplastics at low process temperatures without thermal damage, as demonstrated by JOANNEUM RESEARCH's successful basic and applied R&D. R&D on nano to macro scale on material architectures is especially necessary to bridge the very different elasticity of functional, highly conductive, wear-resistant or highly antimicrobial coatings and the sustainable biological soft substrates. Self-healing after overloading ensures e.g. high coating quality and therefore a long product service life even after overstraining, which is seen as main mandatory aspect of the wood working industry.

Successful explained examples include copper conductor tracks on wood with >80% conductivity of bulk copper, low friction & strong abrasion protection through MoS2-graphite-zinc layers with dry friction <<0.14, and previously unknown antimicrobial & flame-retardant protection of ultra-thin veneers & natural surfaces. Of high advantage is the novel use of the same plasma jet technology for plasma spraying of thick layers, plasma polymerisation of nanolayers (plasma-enhanced chemical vapor deposition, PACVD), and the curing of sol gels (even in combination). High importance especially for biobased material and their risk of damage even during coating by thermal load to the surface is further more the developed digital process twin for the plasma jet and its thermal influence on the substrates, which have led to several process patents.

New industrial applications of macro and nanocellulose fibers

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ABSTRACT

Cellulose is the most abundant natural polymer in nature with multiple potential applications beyond traditional manufacturing of paper and cardboard, textile fibers and some resins. In the framework of the project "Wood for Globe – Towards a Global Wood Policy Platform: Sustainable Wood for a Carbon-neutral Bioeconomy", led by IUFRO and funded through the Forest Fund of the Republic of Austria, we are analyzing the contribution of wood fibers. There are strong trends, not only in Europe but worldwide, to replace synthetic materials with renewable cellulose fibers.

In this paper we will present two products developed by the Technological Development Unit (UDT) of the University of Concepción in Chile and licensed to local companies that are currently introduced into the market. There are an insulating material for construction based on eucalyptus bark fibers and a resin reinforcer based on acetylated cellulose nanofibers.

The insulating material will replace mineral wool and expanded polystyrene. Both products have a negative environmental footprint, mainly because they are not biodegradable, their recycling rates are very low, the energy requirement for production is high (in the case of mineral wool) and they release toxic gases in the event of combustion (in the case of expanded polystyrene). The first plant of the new insulating material with a production capacity of 4,000 m3/year is under construction in Tomé, Chile, and will start operating in mid-2024.

Since late 2023, chemically modified nanocellulose, has been applied as a reinforcing additive for urea formaldehyde adhesives in industrial production trials of MDF and particle boards. We demonstrated that low proportions of the additive, less than 1%, allow a reduction of the adhesive dosage by up to 25%, without altering the mechanical properties of the boards or affecting the process productivity. In addition, the curing speed is increased and formaldehyde emissions are reduced. A new production plant of the additive will supply not only the requirements of national companies, but also those of foreign clients, and will start operation in early 2025.

There are other applications of cellulose fibers being developed at UDT, including the replacement of both rigid and flexible plastic materials for food packaging. Along with the physical and mechanical properties required for each specific application, it is essential to endow the material with functional properties, such as water, lipids and oxygen barrier. In this context, the virtuous combination of cellulose macro- and nanofibers in the material and coating can be a solution of high technological, economic, and environmental interest.

Comparative analysis of mycelium and mycelium-based wood composites: properties across fungal species

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ABSTRACT

Wood-based composites represent an innovative material class that often facilitates the upcycling of various low-quality wood sources. These composites are versatile, serving as sustainable alternatives to natural wood in numerous non-structural applications. However, their production typically requires adhesives to bond the individual lignocellulosic particles, potentially leading to significant environmental impacts, including carbon emissions during material production and the potential release of harmful chemicals, posing risks to human health. Consequently, there is an increasing interest in the development of environmentally friendly wood adhesives, such as those derived from lignin, starch, and proteins, which are renewable. Among these natural alternatives, fungal mycelium has gained attention for its ability to naturally bind wood particles into a stable composite through a network of fibre-like elements (hyphae) without the need for synthetic adhesives. This process is unique because the mycelium, a living entity, grows and strengthens the bond between the wood particles by extracting nutrients directly from the substrate. According to the structure of their mycelium (type of hyphae), fungal species can be categorised as monomitric, dimitric, and trimitric, influencing the properties of the produced composite. Focusing on different dimitric and trimitric species, this study compares mycelium growth rates and properties, including tensile strength, to identify candidates for creating mycelium-wood composites under varying production conditions (such as moisture content and particle size). The aim is to assess the mechanical and physical characteristics of these composites and explore the feasibility of using local fungal species for their manufacture, highlighting the potential of mycelium-based materials in sustainable design and construction.

Cross-sector utilization of mushroom cultivation residuals for the production of adhesive free insulation material

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ABSTRACT

Throughout the cultivation of edible and medicinal mushrooms many tons of lignocellulosic mushroom substrate and growing medium accrue daily as residual material, that is normally composted, used for fuel production or disposed of. The commercial mushroom cultivating industry is highly concerned with environmental issues and needs to develop strategies to reduce waste. Value-added solutions for by-products generated from mushroom cultivation are therefore desirable.

Today, research groups and companies around the world are looking at fungal mycelium as a sole binder for lignocellulosic materials. Due to the low production costs and perfect recyclability, such myco-materials are ecologically and economically particularly sustainable.

Research was carried out regarding the production of fungal -bound insulation boards from wheat straw and other lignocellulosic substrates. The aim was to optimize both the yield of high-quality fruiting bodies and the yield and quality of an insulation material, made from the lignocellulosic mycelium infused substrate. – Myco-Insulation.

To estimate its suitability as an insulation material, myco-material was produced on laboratory scale and various material properties were determined for this biogenic substrate with fungal mycelium as the sole binding agent. The study presents the results of mechanical and building physics tests and the optimization steps derived therefrom.

A prospect of engineered living materials in the building sector

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ABSTRACT

Materials have defined civilizations and their development. The relevance of a material today is a combination of its purpose, properties, availability, cost, manufacture, safety, and environmental impact. The new development of material science and the shift toward resilient and active systems requires responsible research and innovation that should guide technology development. The current legislation forces new research and business models that promote circularity, reuse of buildings and materials, whole life cycle thinking, high-performance operations, and ultimately a shift away from fossil fuels. The built environment can reduce emissions by selecting non-toxic building materials and products to support the health of inhabitants and the local ecosystem.

Bio-based materials represent a promising alternative for the building sector. They have the advantage of being renewable, possessing low embodied energy, and CO2 neutral or even negative. However, the future of materials research lies in creative design that allows re-imagining the structure of materials and using their form to serve a certain purpose. Engineered living materials (ELMs) represent the subsequent advancements in materials science and engineering. ELMs use an alternative (living) set of building blocks compared with conventional man-made materials, allowing them to perform tasks associated with living systems such as self-replication, self-healing, or self-regulation.

This talk will present an overview of the prospect of ELMs in the building sector and provide the first results of the ARCHI-SKIN project that develops a living coating system for building facades.

Keywords: engineered living materials, bioinspired design, building sector, material science, multifunctionality

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Bio-innovation in wood bonding: upcycling proteins from byproducts as a renewable polyol substitute

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ABSTRACT

The global construction industry stands as a significant contributor to the planet's carbon footprint, responsible for nearly 40% of annual greenhouse gas (GHG) emissions. The impact of these emissions on climate change is undeniable, yet the adoption of existing strategies presents a viable solution. In particular, harnessing wood as a renewable resource, sustainably harvested in Quebec, offers the potential to temporarily sequester carbon within built structures. One innovative approach to enhance the utilization of wood in construction is the adoption of cross-laminated timber (CLT), renowned for its energy efficiency and minimal waste production. However, it is imperative to acknowledge a critical concern in the production of CLT, namely the synthetic adhesives predominantly used in its manufacture. These adhesives, primarily composed of fossil-origin materials, including substances like formaldehyde, recognized as a carcinogen by the World Health Organization, pose environmental and health risks. Additionally, the non-meltable and non-recyclable nature of petrochemical adhesives significantly impacts the end-of-life cycle of CLT. This issue highlights the urgent need for bio-based adhesives in wood construction. Amid this challenge, polyurethane adhesives emerge as a promising alternative to formaldehyde-emitting counterparts. Comprising at least one prepolymer containing an isocyanate and a polyol, these adhesives emit no formaldehyde and offer exceptional wood panel durability. As part of the ongoing effort to minimize reliance on petrochemical resources, proteins, as biological macromolecules, have gained attention for enhancing wood adhesives in the industry. Abundant, low-toxicity, and environmentally friendly, proteins are also able to improve the adhesion of adhesives to wood. This study endeavors the development of a biobased adhesive specifically tailored for engineered wood products, with a particular focus on cross-laminated timber. Utilizing proteins derived from Quebec industrial co-products, such as soybean meal, microbrewery spent grains, shrimp shells, and skim milk powder, this research aims to partially substitute the petrochemical polyol in polyurethane adhesive formulations. The substitution, executed at various rates, has demonstrated notable improvements in adhesive properties. Irrespective of the substitution rate, the resulting adhesives exhibited superior wood penetration, enhanced mechanical shear strength, and a marginally extended gel time. This study represents a step forward to revolutionize the wood construction industry by developing adhesives that seamlessly combine efficiency and environmental sustainability.

Cross-linking and characterization of kraft lignin for bio-based wood adhesives

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ABSTRACT

This presentation aims to report advances in ways of crosslinking of technical kraft lignin (KL) and its characterization for bio-based wood adhesives. This work focused on the acetone fractionation of KL to obtain acetone soluble KL (AS-KL) fraction and acetone insoluble KL (AI-KL) fraction to reduce the heterogeneity of KL. These fractionated KLs were characterized for their molecular weight, chemical structures, elemental composition, and thermal properties. The AI-KL fractions from softwood and hardwood have greater molecular weight, polydispersity, glass temperature, carbohydrate content, aliphatic hydroxyl groups, and a variety of native wood lignin side chains than those of AS-KL. And then this talk covers ways of cross-linking of technical KL, using epichlorohydrin (ECH), demethylation, and glyoxalation to build thermosetting polymer for lignin-based wood adhesives. The crosslinking of syringaldehyde lignin via cross-coupling reaction is also included for lignin-based wood adhesives. Hardwood KL (HKL) extracted from black liquor of a local pulp mill was also fractionated to prepare acetone-soluble HKL (AS-HKL) and acetone-insoluble HKL (AI-HKL) to improve their low reactivity and high heterogeneity. These fractions were glyoxalated to improve their reactivity, and to build network structure via their self-crosslinking. FTIR, XPS and 13C CP/MAS NMR spectra showed that the cross-linking was successfully done between lignin molecules by forming new peaks for the formation of ether bonds in the glyoxalated lignin. The adhesive strength of lignin-based adhesives was determined by measuring tensile shear strength of plywood. The lignin-phenol-formaldehyde (PF) resins with 20% demethylated softwood KL showed good adhesion of plywood. The self-crosslinked AI-HKL showed the best adhesion performance. And the crosslinking of model syringaldehyde by cross-coupling reaction also showed exothermic reaction for a successful cross-linking of syringaldehyde. These results indicates that ways of cross-linking of KL have good potential of building thermosetting polymers for wood bonding.

In-service performance of untreated and Biofinish coated Scots pine (*Pinus sylvestris* L.)

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ABSTRACT

The service life of timber products exposed to natural weathering is a critical concern for their use in external building elements. Coatings have traditionally served as a protective measure, yet their degradation over time necessitates frequent maintenance or replacement, incurring costs and environmental concerns. Biofinish, an innovative *Aureobasidium pullulans*-based coating, offers protective and self-healing properties inspired by biological processes. By reducing maintenance needs, Biofinish enhances wood's durability and environmental friendliness, unlocking its full potential in construction. This advancement is essential for improving the sustainability and longevity of timber products.

The goal of this study was to investigate the in-service performance of an innovative bioinspired living coating system. The performance of Scots pine (*Pinus sylvestris* L.) wood coated with Biofinish was compared with uncoated references. Samples were exposed to natural weathering for 12 months under the climatic conditions of Izola, Slovenia representing warm temperate climates (Cfa). The colour changes, wettability, glossiness, and surface roughness were measured as indicators of weathering progress. Assessment of fungal diversity on wood surfaces before weathering, after 3, 6, and 12 months of exposure was performed to evaluate the protective properties against wood-infesting fungi and assess the survival of *A. pullulans* within the coating. Results revealed that the total colour changes (ΔE) of Biofinish-coated wood were negligible. However, untreated Scots pine wood revealed colour changes already after one month of exposure. The gloss changes for both types of samples were small. The contact angle measured on Biofinish-coated wood was higher compared to that of uncoated Scots pine. Surface roughness of uncoated wood increased due to the erosion effect caused by the weathering progress. Fungus *A. pullulans* was the dominant species found on both uncoated and Biofinish-coated wood, suggesting its survival and effective antagonistic action against other wood-decaying fungi. These findings highlight the Biofinish coating's superior aesthetic performance against natural weathering and its potential for self-healing properties due to the survival of *A. pullulans*.

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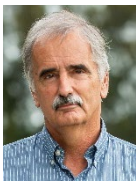

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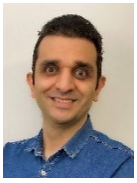

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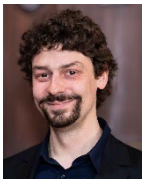

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