

Forest Products Society

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Society of Wood Science & Technology

Book of Proceedings



JUNE

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2025

**Fort Collins,
Colorado, USA**



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**SOCIETY OF
WOOD SCIENCE &
TECHNOLOGY**

PROCEEDINGS OF THE

Forest Products Society

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PROCEEDINGS OF THE
2025 FPS/SWST Joint Convention
Wood for a Sustainable Future: Strengthening the
Connection Between Industry and Science
Fort Collins Marriott – Fort Collins, Colorado, USA
June 15-20, 2025

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MONDAY, JUNE 16

10:30 AM – 12:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 1.1 - 21st Century Forest Sector Business & Marketing Practices I

~ Session Organizer - Eric Hansen (Oregon State University)

~ Moderator - Joonas Mullarniemi

Bridging Links of Transformational Wooden Business and Innovation Ecosystems by Encouraging New Actors

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Abstract

Utilization of wood in construction is a viable option for lowering the carbon footprint of the built environment. However, previous research has shown that wood construction faces multiple stumbling blocks, deriving from the prevailing practices and interests of the incumbent construction businesses, and the inability to create profitable business around wood. Despite difficulties, various innovations, ideas, and practices are being brought forth, such as wooden retrofits, circular wood, wood together with nature-based solutions. Understanding the dynamics of the business ecosystem and stakeholder perspectives of these developments is pivotal. Our previous study results have highlighted that low profitability, unclear business logic, inadequate information flows, and even inexplicable unwillingness hinder the acceptance of novel wood construction approaches. We also found a lack of business actors, e.g., product manufacturers and dedicated construction companies, as well as missing collaboration and engagement links between different actor groups, e.g., planners and project people along with novel maintenance and end-users. This suggests that while there are many emerging innovators and keen actors in industrial wood construction, they need further ecosystem connections and engagement to facilitate the uptake of wood and develop new solutions. Between 2021–2024, we collected comprehensive interview and workshop data of the Finnish wood construction business ecosystem in collaboration with stakeholders. In order to find pathways for facilitating stakeholder engagement, we explore the existing ecosystem and analyse the roles, positions, and connections of previously under-represented actors of the business ecosystems. Our thematic data analysis shows that to boost marginalized wood construction businesses and innovation, co-creation, information-sharing, as well as guidance and strengthening the city-business interface for the benefit of end-users is needed.

European Woodworking Sector Outlooks and Main Barriers Against Further Digitalization Development in Small and Medium-sized Enterprises

Jaan Kers^p (Tallinn University of Technology), Loretta Kalju (Tallinn University of Technology), Alar Just (Tallinn University of Technology), Alar Kuusik (Tallinn University of Technology), Oliver Jancke (InnovaWood asb)

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Abstract

There is no doubt that in the current ongoing decade the digital technologies are being continuously adopted into many European industries everyday use. Although the woodworking sector is known to be more conservative towards the implementation of newer technologies related to new EU regulations being entered into force, like the EU Deforestation Regulation or The Green Deal Industrial Plan, the adoption to further digitalization is inevitable. The digitalization raises the woodworking sector's production efficiency and productivity and increases the workers IT skills and safety as well as allowing the European woodworking companies to stay competitive in the global market. The latest statistics done in year 2024 showed that approximately 50% of the woodworking companies in Europe are using 4.0 technologies actively or in the planning state, with countries like Germany, Estonia, Italy, France, Finland and Sweden being in the front with most digitalized companies to exist. The main barriers towards further digitalization in most woodworking companies in Europe are data protection and security, lack of IT skills among employees and high investment costs. In order to bring awareness to these barriers the European Commission has launched a 3-year project called 5G-Timber with the main aim to support and address the further implementation of 4.0 technologies into small and medium-sized enterprises' whole wood value chain. The project focuses on demonstrating many 5G technologies' key innovations for the field of timber - open standards for production and secure change of data; precise indoor localization; material models; Digital Twin (DT); augmented reality (AR); and industrial IoT. During the duration of the project the main use cases were categorized into three different woodworking fields: sawmill and woodworking machine setup; modular wood-house factory; valorization of composite waste and construction and renovation with wooden elements.

Scaling-Up Science-based Forest Sector Innovation

Judith Gisip^p (Universiti Teknologi MARA), Lyndall Bull (FAO), Jigchen Norbu (FAO)

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Abstract

Innovation is vital for unlocking the full potential of forests in achieving the Sustainable Development Goals and the Global Forest Goals. Globally, forest use and demand are on the rise while unsustainable harvesting and deforestation persist in some regions and climate change exacerbates forest stressors. Forest sector innovation can help address these complex and often conflicting trends. Despite advancements in forest sector innovation, challenges persist including a general lack of an innovation culture and partnerships amongst regions, sectors, and stakeholders, and knowledge gaps particularly on innovations beyond the technological realm and in the Global South. A coordinated global effort is essential to advance forest sector innovations that drive environmental, social, and economic progress. The FAO Forestry Innovation Programme, encompassing a Global Forest Sector Innovation Initiative, aims to promote science-based, scalable, inclusive, and responsible innovations in the global forest-sector. It includes enhancing institutional innovation culture, developing demand driven policy guidance, creating transformational partnerships for global knowledge exchange and technology transfer, and strengthening global and regional education and capacities for forest sector innovation. The programme aims to create a Community of Practice (CoP) that brings together expertise across the different innovation types and is diverse in sectoral and geographical representation (enabling two-way Global North and South exchange) and leverages the power of youth in innovation. The CoP anticipates pursuing a suite of activities including a foundational review of education and capacities in forest sector innovation, development of a forest sector innovation education and learning package, a policy brief on forest sector innovation knowledge products and their uptake in policies, and research on innovation in the Global South and under-represented groups. This session delves into the FAO Forestry Innovation Programme, its objectives, and approaches to achieving science-based, scalable, inclusive and responsible forest sector innovation.

Heterogeneity in Stakeholder Expectations on Ecological Responsibility of Finnish Forest Industry

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Abstract

Environmental responsibility has become a central focus of stakeholder expectations across various industries. In the forest industry, a key aspect of this is the impact of forest management practices on ecosystems and biodiversity, which can be referred to as ecological responsibility. This is particularly relevant given the industry's dependence on natural resources and its significant effects on forest ecosystems. Our study examines stakeholder perspectives of ecological responsibility, how effectively forest industry companies address it, and identifies areas for improvement in the case of Finland. In this study, we integrate stakeholder theory and legitimacy theory with the broader institutional theory to examine how forest industry companies justify their practices and respond to external pressures. Using survey data from key stakeholder groups—including research institutions, environmental authorities, NGOs, financial organizations, auditors, subcontractors, and forest owner organizations—we assess how stakeholders perceive the ecological responsibility of industry practices. Our study employs thematic and statistical analysis, providing a new understanding of the gaps between stakeholder expectations and corporate practices. We expect that while regulatory compliance and sustainable forest management certification frameworks have improved ecological sustainability in forestry, they remain insufficient in fully addressing biodiversity concerns. We also expect that stakeholders believe forest industry companies should go beyond regulatory minimums and actively integrate ecological considerations into their operations. Our results will contribute to the understanding of corporate ecological responsibility by highlighting the role of evolving societal values and the need for companies to proactively adapt their sustainability strategies.

Innovative Value Co-creation in the Finnish Forest-based Sector

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Abstract

The forest-based sector can lead the way in developing new renewable resources-based businesses that contribute to the sustainability transition. However, despite high-quality R&D and ambitious goals set by private- and public-sector strategies for sustainable, higher value-added businesses in the circular bioeconomy, progress has been slow. What are the reasons for this stagnation? This presentation shares insights from an ongoing project that is developing a framework, using the Finnish forest-based sector as its empirical basis, which can be used by companies to manage their transition to new sustainable businesses. This framework is also applicable to other societal actors in their transition management. The study challenges the notion that value creation occurs only within organizations. The goal of collaborative business models is to co-create value—including ecological and social value in addition to economic value – through various collaborative mechanisms and the engagement of diverse actors, including companies, consumers, NGOs and politicians. These approaches are seen as crucial for promoting new business models, innovations and sustainability, yet they remain under-studied and under-applied. This project utilizes complimentary approaches such as textual analysis, interviews and future workshops, combining theoretical foundations of sustainable business models, foresight and transition. In Finland, the polarization of views on forest utilization is prominent, and public discourse often fails to equally include diverse societal actors. While many actors in the sector agree on sustainability goals, there exist differing interpretations of how sustainability should be interpreted in practice. Companies, although committed to sustainability goals, continue to primarily focus on creating value for customers and shareholders. Politicians are viewed as having the responsibility and power to provide solutions. However, the forest regime, dominated by large companies and their interest organizations, creates structural power that constrains change. Overall, sustainable value co-creation could facilitate the transition but requires stronger involvement from diverse actors.

Session 1.2 - Monitoring, Maintenance and Protection: Increasing the Durability of Wood to Face the New Environmental Challenges I

~ Session Organizers - Upamanyu Ray (Warner Babcock Institute for Green Chemistry), Qiongyu Chen (University of Maryland College Park), Jan Vcelak (Czech Technical University in Prague)

~ Moderators - Upamanyu Ray and Qiongyu Chen

Structural Health Assessment and Monitoring of Timber Buildings: From Data to Decisions

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Abstract

This contribution explores the technological and methodological advancements in monitoring systems for the assessment of timber buildings, focusing on how data collected from various monitoring techniques can inform actionable decisions regarding their structural integrity and service life performance. It addresses key challenges in the application of monitoring technologies and the interpretation of data, specifically examining how these insights can support proactive decision-making in timber building management. The discussion highlights a range of phenomena influencing timber structures, and reviews the corresponding monitoring techniques. Additionally, the contribution examines the role of modeling approaches in simulating the behavior of timber structures over time, incorporating data-driven methods for predictive analysis and performance forecasting. Despite the promising capabilities of these technologies, the contribution also acknowledges the limitations related to sampling methods, data quality and the complexity of timber's inherent variability. Finally, it discusses the integration of monitoring data with decision-support systems, proposing strategies for enhancing the effectiveness of monitoring systems in guiding maintenance and retrofitting decisions.

Multi-Scale Models for Capturing & Mitigating Fungal Effects on Wood Structures

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Abstract

With the increasing frequency of high intensity rainfall events, hurricanes, and freshwater inland flooding, the likelihood of moisture intrusion events into timber framed structures is increasing. These hazard events provide favorable conditions for fungal degradation. However, few efforts have evaluated the impacts of biodeterioration on wood structural assemblies. This work proposes a multi-scale material model of degraded wood from the polymer-scale to the scale of dimensional lumber to study the effects of degradation on wood framed structures. The model was validated by using an experimental data set tracking brown rot degradation of Southern Yellow Pine. The study found that the material model was able to accurately capture wood decayed wood stiffness. This work provides tools for estimating structural performance under biodegradation, a critical consideration for timber engineering in the future environment, and a test bed for evaluating novel interventions to improve the durability of wood structures.

In-Situ Polymerization of Cardanol Glycidyl Ether and Maleic Anhydride for Enhanced Wood Protection: Bio-Durability and Combustion Properties

Liang Liang^{p*} (University of Idaho), Aynun Nishat Farhabi (University of Idaho), Dylan Willard (University of Idaho), Armando McDonald (University of Idaho), Lili Cai (University of Idaho)

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Abstract

Cardanol glycidyl ether (CGE) is a bio-based epoxy monomer derived from cashew nutshell liquid (CNSL). Maleic anhydride (MA) is a versatile crosslinker that can react with CGE while connecting with hydroxyl groups in wood to form durable crosslinked networks. This study aims to understand the fungal resistance and fire performance of wood treated by CGE and MA to form bio-based epoxy resin (CGE-MA) networks in wood structures. CGE and MA were pre-mixed at different weight ratios (6:1, 3:1 and 2:1; denoted as CGE6MA1, CGE3MA1 and CGE2MA1, respectively) and were vacuum impregnation in the wood structure, followed by heat-induced curing and in-situ polymerization at 105°C. Microscopic observation of CGE-MA treated wood samples found that most wood cell lumens were filled with CGE-MA networks, which were resistant to leaching with over 75% mass gain retained after a 14-day leaching test. The results from soil block tests indicated that CGE-MA networks significantly improved the resistance of wood samples to four common wood-decay fungi (including two brown rot *Gloeophyllum trabeum*, *Rhodonia placenta* (Fr.)), and two white rot fungi, *Trametes versicolor* (Linnaeus: Fries) Lloyd, *Irpex lacteus* (Fr.) Fr), resulting in less than 11% average mass loss after 8-week fungal exposure. The results from thermogravimetric analysis (TGA) found that all the CGE-MA treated wood samples have significantly lower onset temperatures and peak Derivative Thermogravimetry (DTG) values when compared to those of the control. Further, mass loss cone calorimeter testing found that CGE2MA1 treated wood samples have comparable fire performance to the control. However, the lower the ratio of MA in the CGE-MA networks, the higher the fire risks of the CGE-MA treated wood samples. Overall, the in-situ polymerization of CGE and MA in wood can improve its fungal durability performance and thermal stability while not increasing fire risks, in particular at a higher MA ratio.

Bio-oils as Coatings for Mitigating Deterioration of Wood from Artificial Weathering

Dylan Willard^{P*} (University of Idaho), Armando McDonald (University of Idaho), Lili Cai (University of Idaho)

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Abstract

Wood weathering is an abiotic deterioration process influenced by environmental factors, including but not limited to UV radiation, oxidation, and moisture, which significantly impacts wood's structural integrity, dimensional stability, surface quality, and aesthetic value. This study investigates the performance of bio-based oils, including seed oils, pyrolysis oils, and pine tars, as a sustainable renewable solution to mitigate damage to wood caused by weathering. The effects of linseed oil on the weathering performance of pyrolysis oils and pine tars as wood coatings were also investigated. Wood samples treated with various organic coatings were subjected to artificial weathering for eight weeks and incrementally tested for changes in mass, hydrophobicity, color change, and surface chemistry analysis, the latter of which was measured by Fourier transformed infrared spectroscopy (FTIR). Coatings were analyzed by gas chromatography/mass spectrometry (GC/MS) for their composition, which was closely related to their performance as wood coatings. Results indicated that linseed oil significantly improves surface retention and weathering resistance of pyrolysis oils and pine tars when used as an additive for coating formulations. Results from this study provided insights into optimizing bio-based coatings for sustainable wood preservation.

1:30 PM – 3:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 2.1 - 21st Century Forest Sector Business & Marketing Practices II

~ Session Organizer - Eric Hansen (Oregon State University)

~ Moderator - Maria Nystrom

Cross-laminated Timber in the U.S. South: Changes in Sector Influencer Perceptions and Engagement Over the Past 8 Years

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Abstract

Cross-laminated timber (CLT) was first manufactured and used in building construction in Europe in the early 1990s, although product development goes back to 1980s with the first patent from France. CLT was later introduced into North American building markets in the early 2000s. The first CLT manufacturer in North America started production in 2010 in Canada, followed by the U.S. in 2012. North American (CLT) production and use in building has grown significantly in the Pacific Northwest and eastern Canada, while CLT manufacturing and construction in the U.S. South using southern yellow pine (SYP) has been on a slower trajectory. The literature is sparse regarding drivers, perceptions, awareness, and potential involvement in the CLT supply chain in the region. Given this, in 2018, a study was conducted at the Louisiana Forest Products Development Center, Louisiana State University Agricultural Center, to better understand the dynamics of CLT market knowledge, perceptions, and adoption targeting *influencers* - architects, engineers (architectural, civil, and structural), non-residential builders, and CLT *feedstock providers* - sawmills. Regarding *influencers*, overall, the most important characteristic when specifying/using structural construction materials was 'Structural Performance', and the most specified/used wood products were oriented strandboard and structural plywood. Last on the list of wood products was CLT. Only 3% of respondents said they were very familiar with CLT and 7% had used or specified CLT. With regard to softwood lumber manufacturer respondents, 12% said they were very familiar with CLT. We are currently replicating the 2018 study using the same survey instruments being sent to the same respondents. The current study will provide another snapshot of where the CLT sector currently stands. More importantly, this temporal approach, with a 5-year span between studies, will identify quantifiable changes across myriad CLT market-based constructs in the U.S. South.

Global Mass Timber Industry and the Promise of New Jobs

Lech Muszynski^P (Oregon State University)

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Abstract

In 2025, 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 continues throwing surprises and posing baffling puzzles. The industry integrating elements of mass timber design, manufacturing technologies, and construction 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 than the volume of information and noise around it would suggest. It is also surprisingly diverse 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. One of the often expressed expectations is that the rise of the industry will bring new, much needed jobs to rural areas. Jobs that are expected to be "smarter" and better paid than regular "mill jobs". Yet hardly any data is available on the number of people employed in mass timber panel industry and the employment structure. The objective of this study is to examine the structure of the employment in the global mass timber industry and compare differences and similarities between MTP producing regions. The data has been gathered through surveys, interviews and site tours. The preliminary outcomes of this tally will be shared in the presentation.

From Hesitation to Innovation: De-Risking the Mass Timber Value Chain

Alice Palmer^P (Independent Consultant), Zara Rabinovitch (British Columbia Council of Forest Industries), Ian McAuliffe (British Columbia Council of Forest Industries)

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Abstract

North American demand for mass timber has been rising steadily. Seeing the potential for increased forest sector employment and many other benefits, governments in forestry-dependent jurisdictions have enthusiastically encouraged mass timber adoption. Yet, most manufacturers of traditional forest products have been hesitant to add mass timber to their product roster. This industry-initiated study sought to identify the challenges of growing the mass timber value chain. Through a one-day workshop with moderated table discussions, the research team heard from 100 members of British Columbia's wood construction supply chain, including manufacturers, developers, academics, and various levels of government. We heard that BC-based forestry companies' biggest concern is risk, as building new facilities is costly and the return on investment is uncertain. Inspired by Rodgers' diffusion of innovations concept, we identify five characteristics that forest industry companies evaluate when deciding whether to produce a new product: *scalability* of demand, *familiarity* of the business model, *consistency* of raw material supply, *networkability* of the supply chain, and *predictability* of government policy.

Communication about Sustainable Construction – Stakeholder Engagement

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Abstract

Society must drastically change the way of living if we want to achieve climate goals. We need to strive for more sustainable practices in all sectors, including the construction one. Effective communication strategies play a crucial role in promoting sustainable construction, yet current communication efforts often lack targeted messages for key stakeholders. In this study we aimed to develop and test a communication strategy for sustainable construction concepts. We used the restorative environmental and ergonomic design (REED), in which wood plays an important role in designing sustainable built environment with positive impact on the wellbeing of the users. The communication strategy included defining and testing communication messages tailored to professional stakeholders (architects, engineers, and constructors). We relied on Laswell's (1948) model of communication and identified the communicator (the developer of the sustainable construction concept REED), channel (social media) and target audience (professional stakeholders). Communication messages and its effectiveness were tested by using online questionnaires with randomized controlled experiments (AB testing). Eight communication messages were developed in order to test and compare all combinations of three factors – emotional or informational tone, focus on the topic of human health or focus on sustainable construction cost, and scientific or non- scientific type. The statistical analysis of the AB testing results provided insights into which messages are most effective in engaging professional stakeholders and promoting sustainable construction concepts like REED on platforms such as LinkedIn. Findings provide suggestions for improving promotion of new concepts of sustainable construction. Additionally, it raises attention that more education about sustainable construction for professional stakeholders is needed. By enhancing education and engagement among professionals, these findings can contribute to a wider adaptation of sustainable construction, supporting the ambitious climate goals.

Session 2.2 - Monitoring, Maintenance and Protection: Increasing the Durability of Wood to Face the New Environmental Challenges II

~ Session Organizers - Upamanyu Ray (Warner Babcock Institute for Green Chemistry), Qiongyu Chen (University of Maryland College Park), Jan Vcelak (Czech Technical University in Prague)

~ Moderators - Upamanyu Ray and Qiongyu Chen

Preliminary Experiment on Grafting of Phytic Acid on Wood and its Effect on Fungal Resistance and Thermal Stability

Aynun Nishat Farhabi^{P*} (University of Idaho), Lili Cai (University of Idaho)

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Abstract

This study aims to chemically graft phytic acid (PA) onto Loblolly pine (*Pinus taeda* L.) wood using a simple one-step vacuum impregnation process. To understand the factors that affect grafting, various concentrations of PA (2.5, 5, and 10 wt.%) and drying temperature (40 to 140 °C at an interval of 20 °C) of the wood samples after vacuum treatment were assessed. The chemical grafting efficacy of PA in wood was evaluated by recording the mass gain of all the wood samples post-treatment and after an accelerated leaching test. Both the control (deionized water-treated) and the PA-treated wood samples were further characterized using Fourier transform infrared spectroscopy (FTIR) and thermogravimetric analyzer (TGA). It was found that both PA concentrations and post-drying temperatures have significant effects on the grafting of PA onto wood. At the same post-drying temperature, the mass gain of the wood samples before leaching increased as a function of PA concentration. However, after leaching, the mass gain of the wood samples decreases with increasing PA concentration except for the optimal conditions identified, which include a PA concentration of 10 wt% and a post-drying temperature of 140 °C. The increased stability of PA in wood under this condition was further confirmed by the characteristic bands of PA at 1160, 1110, 962, and 853 cm⁻¹, which were associated with P=O and P-O-C stretching. Moreover, TGA results found that PA-treated wood samples under optimal grafting conditions had a lower onset temperature, higher residual mass, and lower peak DTG values, regardless of leaching, indicating the increased thermostability of the treatment. The antifungal efficacy of the treated wood samples against the wood-decaying fungus *Rhodonina placenta* (*R.p.*) was assessed using a soil block test following the American Wood Protection Association E22-16 standard, and results are underway.

The Effect of Guayule Resin as a Natural Wood Preservative on Termite Resistance

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Abstract

Wood materials are susceptible to termite attacks and therefore need effective solutions for enhancing durability. Although traditional chemical treatments provide proven protection, there are environmental and health concerns which creates a need for sustainable alternatives. Guayule resin is an environmentally friendly and sustainable material that contains bioactive compounds such as sesquiterpenes and triterpenoids, known for their insecticidal properties. The goal of this study was to evaluate the efficacy of guayule resin formulations as natural termiticides against *Coptotermes formosanus*. To achieve this goal, yellow poplar and southern pine were treated with guayule resin at 0.5% and 5% concentrations in combination with different carrier systems including acetone and toluene through vacuum impregnation process. The specimens were then subjected to a no-choice termite test followed by AWP Standard E1-23 (2024). Mass loss percentage, termite mortality, and visual termite damage ratings were evaluated and compared to untreated controls. Mass loss percentages were analyzed using a two-way ANOVA. Significant interactive effects between wood species and resin concentrations were observed in termite resistance. The lowest mass loss of termite activities belonged to 5% concentration of guayule resin in toluene in both yellow poplar and southern pine. This result indicates that 5% concentration of guayule resin in toluene as a carrier system provided the highest protection. Visual assessments showed that pine samples had moderate to severe termite damage (ratings of 6.8 - 7.0), while yellow poplar exhibited only moderate to slight attack (ratings of 8.6 - 9.0). Termite mortality was low across all treatments, suggesting that guayule resin primarily acts as an antifeedant rather than a toxicant. These findings suggest that guayule resin, particularly at concentrations of 5% and more, could serve effective bio-based termite treatment.

Using Pre-Treatment Methods to Increase the Accessibility of the Cellulosic Layer of Softwood for Improved Nanoparticle Impregnation

Callisto Beuthe^{P*} (University of Ottawa), M.Reza Foruzanmehr (University of Ottawa)

Student oral presentation competition – First place winner

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Abstract

Over the past two decades, innovative methods of modifying the wood cell structure via the impregnation of various nanoparticles have risen to prominence and represent potential new avenues of creep reduction and wood reinforcement. One promising method involves the impregnation of a cellulose nanocrystal colloid to both reinforce the wood and reduce the accessibility of water through the formation of additional hydrogen bonds in the amorphous region of the cellulosic portion of the wood cell walls. However, previous research has shown that the interconnected layer of hemicellulose and lignin that forms a barrier around cellulose significantly reduces the ability of the colloid to infiltrate this region and impedes its passage through the cell walls. Therefore, various pre-treatment techniques have been proposed to expose and increase the permeability of the cellulosic portion before impregnation. This ongoing research aims to build on existing literature to determine whether alkaline (NaOH) and hydrothermal pre-treatments can sufficiently break down the hemicellulose-lignin barrier and allow cellulose nanocrystals to more effectively infiltrate the cellulosic portion of the wood cell wall. Supercritical CO₂ treatment is also being examined as a potential avenue of improving wood permeability through the dissolution of cell walls and the creation of an interconnected pore network. In theory, the detrimental effects of these pre-treatment methods would be offset by the impregnation of the cellulose nanocrystals, which would reinforce the crystalline structure and ultimately increase the creep resistance of wood.

Enhancing Wood's Fire and Fungal Resistance: Laccase-Mediated Grafting of Lignin Nanoparticles (LNP)

Jovale Vincent Tongco^{o*} (University of Idaho), Aynun Nishat Farhabi (University of Idaho), Lili Cai (University of Idaho)

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Abstract

Lignin, one of the main building blocks of plants, can be valorized to lignin nanoparticles (LNP) as a potential eco-friendly and bio-based flame retardant due to its high specific surface area and porosity, as well as an agent against fungal decay due to its phenolic subunits. This study aims to employ enzymatic grafting of LNP on Southern Yellow Pine (SYP) using laccase to enhance its fire resistance and fungal durability. LNP was prepared through hydroxymethylation of softwood Kraft lignin (KL), followed by solvent shifting method using acetone/water. Control (untreated) SYP and treated (KL-treated and LNP-treated) SYP were characterized using Fourier-transform infrared spectroscopy, resulting in increased band intensities at 3350 cm^{-1} (—OH), and peak intensities at 2850 cm^{-1} and 1290 cm^{-1} ($\text{—CH}_2\text{OH}$) due to hydroxymethylation. The particle size of softwood KL and prepared LNP samples were analyzed using a Dynamic Light Scattering particle size analyzer, with LNP showing a mean particle size of 210 nm, an improvement in size reduction compared to KL with a mean particle size of $137\text{ }\mu\text{m}$. Moreover, the particle size and surface morphology were verified through Scanning Electron Microscopy. Leaching test was performed on the control and treated SYP samples. The thermal properties and flame retardancy of control and treated SYP after leaching were evaluated using thermogravimetric analysis and thermal imaging via a modified UL94 flammability test, respectively. The LNP-treated SYP samples exhibited higher residual mass, lower thermal degradation rate, lower peak temperature during combustion, and shorter flame-out time (self-extinguishing properties). The fungal durability of unleached and leached SYP samples was tested against two brown-rot fungi, *Gloeophyllum trabeum* (G.t.) and *Rhodonía placenta* (R.p.), by using soil-block test.

Oriented Strand Board Treated with Beta-cyclodextrin *trans*-cinnamaldehyde and thymol

Jason Street^p (Mississippi State University), Ethan Turo (Mississippi State University), Hamed Olayiwola (Mississippi State University), Yunsang Kim (Mississippi State University)

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Abstract

Oriented strand board (OSB) is an engineered wood product used for construction and furniture framing as an alternative to plywood. However, a major drawback of OSB is its susceptibility to dimensional instability when exposed to water, weathering, and excessive loads. These vulnerabilities highlight the need for engineered panels with improved resistance to moisture, biological degradation, and mechanical performance. This study investigates the dimensional stability and mechanical properties of OSB panels treated with four different β -cyclodextrin (β CD) compounds, each at a 5% concentration: unmodified β -cyclodextrin (β CD), β -cyclodextrin-*trans*-cinnamaldehyde (β CD-tCN), β CD-thymol (β CD-THY) and β CD-nickel (β CD-Ni) particles. Southern Yellow Pine (*Pinus spp.*) wood flakes of uniform size were dried to approximately 6% moisture content for OSB fabrication. The flakes were then combined with the β CD compounds and a 4% concentration of diphenylmethane diisocyanate (pMDI) adhesive in a drum mixer. The treated strands were oriented and pressed in a Dieffenbacher press to produce 0.5x0.5 m panels with a target thickness of 11.68 mm. After curing, the panels were cut to dimensions specified by ASTM D1037 for internal bond and dimensional stability testing, and ASTM D3043 for bending tests.

3:30 PM – 5:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 3.1 - 21st Century Forest Sector Business & Marketing Practices III

~ Session Organizer - Eric Hansen (Oregon State University)

~ Moderator - Lea Primožic

The Role of Policy Environment and Markets in the Context of Finnish Circular Forest Bioeconomy

Joona Myllarniemi^{p*} (University of Helsinki), Anne Toppinen (University of Helsinki), Anni Tuppuru (Lappeenranta-Lahti University of Technology), Alice Ludvig (BOKU University), Nina Ehrnrooth (University of Helsinki) - Corresponding author:

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Abstract

Global challenges, including climate change, biodiversity loss, and extensive extraction of virgin materials, have accentuated the urgent need for strategies to mitigate the effects of production and consumption on the environment. Policy frameworks at both the European Union (EU) and national levels have endorsed the concept of a circular bioeconomy (CBE) as a viable approach to facilitate a transition towards sustainable production and consumption practices. Within this paradigm, there is an increasing focus on forest-based products as substitutes to fossil-based materials and products, as well as resource-intensive products and manufacturing processes. However, the CBE presents a markedly different value creation model, which may diminish incentives for businesses entrenched in linear models to actively pursue CBE opportunities or invest in enabling initiatives. It is essential to facilitate an enabling environment that supports innovation in forest-based product and process technologies while enhancing the resilience of the system against disturbances and risks. Existing literature has noted the slow progression and market penetration of innovations, revealing a research gap concerning the influence of policy and regulation on enhancing the innovative capacities of organizations within the forest-based product markets. This study aims to fill that gap by analyzing existing literature, EU and national policy documents, and insights from 11 Finnish policy and industry experts specializing in the circular bioeconomy. Findings indicated that policy documents entail trade-offs regarding forest land use and resource availability, revealing conflicting interests among stakeholders regarding environmental and economic facets of forestry. Interviewees expressed concerns about EU-level regulations leading to a high-risk investment landscape and reduced competitiveness of innovative wood-based products. Although interest in CBE within policy strategies has grown, trade-offs and conflicting interests can impede Finland's innovation system capacity. The research suggests that market demand should drive the transition, but policies are needed as catalysts to attract investment and stimulate innovation.

Marketing Hardwoods to a Disconnected Consumer and Ignorant Designers

Dallin Brooks^p (National Hardwood Lumber Association)

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Abstract

The National Hardwood Lumber Association (NHHLA) conducted a focus group with architects and designers talking about wood, sustainability, and carbon sequestration. In that focus group it became clear that they had several misperceptions about forests, trees and wood products. Hardwood Markets have suffered devastating losses of production and have not recovered. Now as we go forward, we need to help people recognize the importance of forest change, help them understand the need for super sustainable products and the importance of carbon. Alerting them to the fact that wood is innovative and will be used forever because trees will grow forever. And thus the future of wood is assured as trees live and die on earth in the future. It is just a question of what do we do with the wood as we work to keep our forests healthy.

Croatian wood-based industry and its markets: Past, Present, and Future

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Abstract

The Croatian wood-based industry has played a crucial role in the country's economic development, representing a blend of tradition and innovation. This sector, deeply rooted in the rich forest resources of Croatia, contributes significantly to GDP, employment, and exports. With approximately 47% of the country's land area covered by forests, the availability of high-quality raw materials—primarily oak, beech, and conifer species—has enabled the development of a diverse range of wood-based products. These include furniture, sawn timber, parquet, and wood-based panels. Historically, the industry focused on the domestic market and traditional woodworking techniques, with limited technological advancements until the late 20th century. In recent decades, however, the sector has experienced a shift towards modernization and export-oriented production. Today, Croatian wood-based products are in demand across the European Union, with exports exceeding €1.5 billion annually, particularly to Germany, Italy, and Austria. Furniture manufacturing and wood flooring production are the fastest-growing segments, driven by increasing consumer demand for high-quality and sustainable products. Despite its success, the industry faces significant challenges. Limited investments in cutting-edge technology, labor shortages, and environmental sustainability concerns have prompted the need for strategic transformation. Looking ahead, the sector's future lies in embracing digitalization, automation, and circular economy principles. Opportunities exist in expanding value-added production, adopting innovative wood-based composites, and strengthening global market presence. Croatia's commitment to sustainable forest management and growing interest in green building materials provide a solid foundation for growth. Overall, the Croatian wood-based industry has evolved from a traditional, domestic-focused sector into a modern, export-driven industry with promising potential. The key to its future success lies in balancing innovation and sustainability while capitalizing on global market trends.

Navigating Timber Sales in Public Land Management

Jaana Korhonen^P (Oak Ridge Institute of Science and Education), Gregory Frey (USDA FS Southern Research Station), Sonia Bruck (USDA FS Southern Research Station)

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Abstract

Public land management organizations face multiple overlapping and sometimes hard-to-measure goals, shaped by societal, cultural, environmental, and economic pressures. Timber sales are one method used by the U.S. Forest Service (USFS) to meet multiple objectives, yet this strategy is challenged when sale offerings receive no bids from prospective buyers. We conducted a survey in 2021 to understand the views of USFS employees involved in timber sales about how timber sale processes could be developed from the institutional perspective. We use qualitative content analysis methods to analyze survey responses. This research aims to evaluate how employees who are involved in the timber sale process perceive the potential to integrate other priorities into practices. This way, we can i) identify ideas to build organizational capacities to reach inter-related forest management objectives, and ii) contribute to the public organizational management literature. This study complements the previous literature on timber sales that have focused into four thematic areas: factors affecting stumpage value of timber from public lands, appraisal methods and accuracy, sales and auction methods, and factors correlated with timber sale success by integrating the organizational change aspects into the mix. The results are aimed to help National Forest Managers to identify potential issues in organizational structure and interactions surrounding timber sale process, including those that are difficult to become aware and are often beneath the surface, and provide more nuanced insights into potential areas for development than the previous recent literature on the topic. Furthermore, this article offers insights into organizational change theory in the context of large public organizations managing natural resources.

Standardization of forest product carbon accounting

Adam Taylor^P (University of Tennessee), Hongmei Gu (USDA FS Forest Products Laboratory)

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Abstract

Forests are often viewed as major components of climate change mitigation. The focus has generally been on in-forest carbon storage, with some acknowledgement of carbon storage in forest products. The avoided fossil carbon emissions resulting from the use of wood products in place of fossil fuel-intensive alternatives - the 'substitution' of 'displacement' effect - has been described in research literature but is not yet a common part of national climate accounting or carbon credits programming. Recent national and international standards development - which include displacement - will enable a more holistic consideration of the roles of forests and their products have in carbon dynamics. This presentation will provide an overview of US Forest Service recently published the guidelines for US Forest Landowners to account the carbon benefits of the Harvested Wood Products generated from their lands, and the international standards - ISO 13391 (soon to be published) for the countries to report and calculate the GHG dynamics of wood and wood-based products.

Session 3.2 - Advanced Characterization in Forest Products Research I

~ Session Organizers - Nayomi Plaza (USDA FS Forest Products Laboratory), Laura Hasburgh (USDA FS Forest Products Laboratory), Katie Ohno (USDA FS Forest Products Laboratory), Nathan Bechle (USDA FS Forest Products Laboratory)

~ Moderators - Nayomi Plaza and Oswaldo Erazo

Roots, Shoots, and Leaves: How Novel Methods and Apparatus Are Applied for Comprehensive Spatial Multiomics at Various Scales and Timepoints

Kevin Zemaitis^p (Pacific Northwest National Laboratory)

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Abstract

Next generation sequencing and transcriptomics has become a common tool within basic research into physiological development, and abiotic or biotic stress tolerance in plants and trees. Most tissues of woody plants including roots, shoots, and leaves can be sequenced at great depth. However, the past decade has revealed many questions which cannot be answered solely through genomics or transcriptomics. This has required unlocking direct measurements of proteins, lipids, and metabolites from these tissues. The objective of this talk is to overview the current state-of-the-art of molecular imaging by desorption electrospray ionization (DESI) and matrix-assisted laser desorption/ionization (MALDI) mass spectrometry imaging (MSI), with several avenues for integrating high-resolution microscopy, spectroscopy, and other analytical measurements. With these tools, we can now trace byproducts of lignocellulose decay in complex environmental samples, just as easily as imaging the host response of microbial pathogens in tissues and cultures. Shifts in lipid production and spatial distributions can now be routinely identified in roots interacting with various microbes, and complex proteomic mechanisms can be detected in-situ. While the field of MSI is almost three-decades old, application of MSI and related workflows to plant tissues has lagged behind biomedical research. To this end, the Environmental Molecular Sciences Laboratory (EMSL), a national user facility provides researchers access to over a hundred instruments, specialized workflows, and supporting data analysis pipelines to solve high-impact scientific problems. Several scientific case studies will be presented using these technologies, exemplifying a path forward to advance basic knowledge of forest products through the combination of MSI methodology with novel apparatus and sampling strategies.

Structural Characterization of Plant Tissues using Scanning X-ray Scattering Tomography

Lin Yang^p (Brookhaven National Laboratory)

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Abstract

Traditional x-ray and neutron scattering methods provide valuable insights into the structural organization on molecular scale in bulk samples. By combining scattering with a small beam spot size, scanning structural mapping can be used as an imaging method for physical thin sections. We have gone one step further, to perform virtual sectioning of intact plant samples based on existing tools for x-ray scattering and tomographic imaging. This reveals the cross-sectional morphology and distributions of material constituents (e.g. starch) with known scattering signatures. More importantly, the local scattering intensity can be recovered for any location in the virtual section. Therefore, traditional methods for scattering data analysis can be applied to enable spatially resolved characterization of quantities such as cellulose crystallinity and microfibril angle. Concurrent data collection for x-ray fluorescence emission has been implemented to provide additional information on elemental distribution. This method has been successfully applied to small branches and stems, conifer leaves, as well as seeds and flowers (pistil). Further developments aim to: (1) help associate scattering data with materials that do not exhibit distinctive scattering signatures, and (2) speed up the measurements to reduce radiation damage to the samples and for in-situ structural characterization during material processing.

Enhancing Hygrothermal Performance of Wood Fiber Insulation using Microencapsulated Phase Change Materials

Jihee Nam^{p*} (Yonsei University), Ji Yong Choi (Yonsei University), Hyeonseong Yuk (Yonsei University), Sumin Kim (Yonsei University)

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Abstract

The global transition toward carbon neutrality in the building sector has increased interest in sustainable material selection. Wood, with its inherent carbon storage capacity, lightweight nature, and well-being benefits, is an ideal material for eco-friendly construction. Among various wood-based materials, wood fiber insulation (WFI) is gaining market traction in Europe due to its excellent thermal properties. However, its susceptibility to moisture can lead to mold growth, posing structural and health risks. To enhance the hygrothermal performance of WFI, this study incorporates microencapsulated phase change materials (MPCM) to regulate thermal and moisture behavior in insulation layers. MPCM, consisting of a PCM core encased in a polymer shell, provides superior latent heat storage, mitigating temperature fluctuations while preventing leakage issues. WFI exhibits varying thermal conductivity depending on its density, influencing its insulation efficiency. Experimental measurements revealed that high-density (160 kg/m^3) WFI panels demonstrated a thermal conductivity of $0.0479 \text{ W/m}\cdot\text{K}$, while low-density (87 kg/m^3) WFI exhibited $0.0380 \text{ W/m}\cdot\text{K}$. To achieve the best thermal storage performance, this study evaluates the optimal MPCM content based on these density variations. Extensive experimental analyses, including thermal conductivity and moisture absorption tests, were conducted to assess the performance improvements of MPCM-enhanced WFI. Additionally, the study examines the effect of MPCM-enhanced WFI on indoor temperature regulation and wall layer moisture control. These findings contribute to the development of energy-efficient insulation materials suitable for both new construction and retrofitting applications, addressing the growing demand for sustainable insulation solutions.

Moisture-dependent Transverse Isotropic Elastic Constants of Wood S2 Secondary Cell Wall Layers Determined using Nanoindentation

Joseph Jakes^o (USDA FS Forest Products Laboratory), Xavier Arzola (University of Wisconsin Madison), Nayomi Plaza (USDA FS Forest Products Laboratory), Nathan Bechle (USDA FS Forest Products Laboratory), Yikai Wang (University of Wisconsin Madison), Don Stone (University of Wisconsin Madison), Rod Lakes (University of Wisconsin Madison)

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Abstract

Moisture- and orientation-dependent mechanical properties of the S2 secondary cell wall layer (S2 layer) are needed to better understand wood mechanical properties and advance wood utilization. In this work, nanoindentation was used to assess the orientation-dependent elastic moduli and Meyer hardness in loblolly pine (*Pinus taeda*) S2 layers under environmental conditions ranging from 0% to 94% relative humidity (RH). The elastic moduli were fit to a theoretical transverse isotropic elasticity model to calculate the longitudinal elastic modulus, transverse elastic modulus, axial shear modulus, and transverse shear modulus for the S2 at 0%, 33%, 75%, and 94% RH and 26°C. The longitudinal elastic modulus was consistently higher than the transverse elastic modulus because of the orientation of the stiff cellulose microfibrils in the S2. The axial shear modulus was consistently higher than the transverse shear modulus. The Meyer hardness had a much smaller orientation dependence than the elastic properties. Moisture generally plasticized the S2 layer. Over the range of RH tested, the longitudinal elastic modulus decreased 30%, the transverse elastic modulus and transverse shear modulus decreased 83%, the axial shear modulus did not have an observable trend with RH, and the Meyer hardness decreased 68% to 82% with the hardness in the longitudinal direction softening less than in the transverse direction.

Tracking the Structural Evolution of Cellulose Nanocrystal Suspensions via Small Angle Light Scattering

Nayomi Plaza^P (USDA FS Forest Products Laboratory), Carl Houtman (USDA FS Forest Products Laboratory), Oswaldo Erazo (USDA FS Forest Products Laboratory), Ronald Sabo (USDA FS Forest Products Laboratory)

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Abstract

Light scattering techniques are powerful tools for studying cellulose nanocrystals (CNC) in aqueous suspension. The formation of ordered domains was observed for suspensions of moderate concentration (1 – 9 wt%) by small angle light scattering (SALS) and polarized microscopy. As has been observed by others, a transition from isotropic to ordered depends on concentration and history. Ultrasonication of these suspensions modifies the rate of structure formation, which was followed over two days. As technology develops for production of CNC films and coatings, the solution structure in this range of concentrations will likely determine the ultimate ordering of CNCs in the final product.

Eco-Friendly Fire Resistance in MDF: Enhancing Fire Safety and Sustainability with Biochar and Expandable Graphite

Ji Yong Choi^{D*} (Yonsei University), Jihee Nam (Yonsei University), Yongjun Choi (Yonsei University), Sumin Kim (Yonsei University)

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Abstract

The increasing focus on sustainable construction materials underscores the need for eco-friendly flame retardants to enhance the fire safety of wood-based products like medium-density fiberboards (MDF). This study investigates biochar (BC) and expandable graphite (EG) as flame retardant additives in a melamine resin coating for MDF. BC, a carbon-rich material derived from biomass, and EG, which expands under high temperatures, were chosen for their potential to enhance fire performance and sustainability. Thermal conductivity analysis revealed reductions of 7.1% and 6.5% for BC- and EG-coated MDF, respectively, compared to uncoated MDF. This improved insulation delays rapid temperature rise, critical for mitigating fire spread. Cone calorimeter tests demonstrated substantial fire resistance improvements, with peak heat release rates (pHRR) decreasing by 14.3% with BC and 69.1% with EG. Additionally, total smoke production was reduced by 81.3% for EG-coated MDF, highlighting its effectiveness in minimizing smoke emissions, a major factor in occupant safety during fires. Enhanced insulation and reduced smoke levels together provide safer conditions for evacuation during emergencies. Morphological analysis showed that BC limits oxygen flow through its porous structure, while EG forms an expanding carbon barrier that blocks heat and oxygen, slowing combustion. These mechanisms improve fire resistance and maintain structural integrity under high temperatures. The study also highlights the importance of integrating eco-friendly fireproofing solutions to address the dual challenges of fire safety and environmental sustainability. This study underscores the potential of BC and EG as sustainable flame retardants for MDF, offering a safer and greener alternative to traditional halogen-based solutions. These findings contribute to the advancement of environmentally conscious fireproofing strategies and support broader applications in sustainable construction.

TUESDAY, JUNE 17

8:30 AM – 10:00 AM | EARLY STAGE RESEARCHER 3-MINUTE TALKS

(^p denotes presenter, * student)

~ Moderator – Francesco Negro

Session ESR – Early Stage Researcher

Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products – Tools for the Sustainable Development

Annika Hyytiä^{p*} (University of Helsinki)

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Abstract

In the sustainability governance, policy is highlighted. There are useful tools in the sustainability where sustainable resources and managing natural resources sustainably are highlighted as well as strengthening the competitiveness. Certification of forests is a voluntary, market driven system and provides valuable information. Bioeconomy highlights the opportunities in sustainability. Bioeconomy is connected to innovation. Circular Economy can advance the CSR. United Nations provide sustainable development goals as drivers in the national and international policy development. Sustainable policy aspects include resources being sustainable and used sustainably. This is a qualitative research based on academic databases and policy literature.

Timber Engineering for Equitable Communities

Garrett Tatum^P (University of Wyoming)

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Abstract

Engineers are to “hold paramount the safety, health, and welfare of the public,” and as such have a big role to play in ensuring the sustainable development of our world for future generations. The design, durability, and resilience of structural systems plays a significant, if unassuming, role in how communities develop and thrive. Timber structural systems in particular provide unique opportunities and challenges for meeting these objectives. This talk will study the role of timber structural systems in community equity through the work of the EnDURES laboratory group at the University of Wyoming. The talk will examine how wood durability issues can impact vulnerable communities following natural hazards and the role of novel timber materials in promoting sustainable community growth. The talk will conclude with a vision for promoting novel timber structural systems utilizing locally available fiber and promoting timber engineering in the Rocky Mountain Region.

Eco-friendly Wood Protection Using Cellulose Nanofiber-based Hydrophobic Coatings: A Sustainable Approach for Enhanced Water Resistance

Junsik Bang^{p*} (Seoul National University), Jungkyu Kim (Seoul National University), Seungoh Jung (Seoul National University), Bonwook Koo (Kyungpook National University), Jungkwon Oh (Seoul National University), Hwanmyeong Yeo (Seoul National University), In-Gyu Choi (Seoul National University), Hyo Won Kwak (Seoul National University)

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Abstract

Wood products require effective protection against water penetration to maintain their durability and service life. While traditional petroleum-based hydrophobic coatings have been widely used, there is an urgent need for sustainable alternatives. Here, we present an environmentally friendly approach using cellulose nanofibers (CNFs), derived from abundant biomass resources, combined with silica nanoparticles to create highly effective water-resistant wood coatings. The CNF-based composite coating demonstrates remarkable hydrophobic properties with water contact angles of 151°, effectively preventing water infiltration into wood structures. The unique properties of CNFs, including their natural compatibility with wood surfaces and ability to form stable dispersions with silica nanoparticles, enable the development of durable and uniform coatings. The coating can be applied through various methods such as spraying, dipping, and brushing, offering practical versatility. Notably, this bio-based coating system addresses the environmental concerns associated with conventional petroleum-based products while providing superior water protection. The strong interfacial interactions between CNFs and wood surfaces enhance coating durability, ensuring long-term protection. Our findings demonstrate that CNF-based hydrophobic coatings represent a promising sustainable solution for wood protection, combining excellent water-resistant properties with environmental stewardship. This approach not only advances the field of eco-friendly wood preservation but also contributes to reducing the environmental footprint of wood protection technologies.

Detection of Defect Bonds in CLT Panels Using Ultrasonic Techniques and Resistance Microdrilling

David Decky^p (Mendel University in Brno), Luděk Praus (Mendel University in Brno), Mojtaba Hassan Vand (Mendel University in Brno), Ema Kovačević (Mendel University in Brno), Václav Sebera (Mendel University in Brno)

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Abstract

The number of timber structures made of cross-laminated timber (CLT) has been increasing in an atlantic space for more than 30 years. The CLT panel is held together by an adhesive bond that is prone to degradation by mechanical, environmental and biotic factors that intensify their effects in time. Therefore, it is necessary to know whether a debonded adhesive bondline occurs in the construction. The paper aims on defectoscopic analysis of CLT panels (80x80 cm²) of spruce and beech with designed imperfections in adhesive bonding with help of non-destructive and semi-destructive techniques (NDT and SDT). There are 4 scenarios of CLT panel produced: reference, panel with 10% imperfection in one layer in the centre, panel with 40% imperfection in one layer in the centre and the panel with 40% imperfection in one layer at the side. The panels were examined using ultrasound wave propagation across the panel thickness using both standard point-to-point and tomographic approach. Furthermore, the CLT panels were examined using the micro-resistance drilling. The ultrasonic techniques detect impaired bondline very well and the greater the imperfection, the better the location and size of imperfection is identified. The acoustic tomography also shows difficulties in data interpretation since missing gluing bonds within a lamina are also identified. The micro-resistance drilling shows the missing peaks where adhesive is not present, but interpretation of data has to be done carefully due to early and late wood showing peaks and valleys in resistance.

Introduction of Cellulose Nanofibril (CNF), and Plasma Treatment for Robust Biodegradable Natural Fiber–reinforced Plastics

Seungoh Jung^{p*} (Seoul National University), Junsik Bang (Seoul National University), Jungkyu Kim (Seoul National University), Bonwook Koo (Kyungpook National University), Jungkwon Oh (Seoul National University), Hwanmyeong Yeo (Seoul National University), In-Gyu Choi (Seoul National University), Hyo Won Kwak (Seoul National University)

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Abstract

Natural fiber–reinforced plastics (NFRPs) are an attractive option for industries due to rising concerns about environmental pollution and energy efficiency. However, their application is limited by low dimensional stability resulting from the high water absorption of natural fibers and weak interfacial bonding between the fibers and the polymer matrix. To overcome these challenges, this study incorporated two strategies: introduction of nano/micro hierarchical structures in natural fiber preform and surface plasma treatment of polymer matrix for enhanced interfacial compatibility. A nano/micro hierarchical fibrous preform was fabricated using lyocell fiber (LF) and cellulose nanofibril (CNF), where CNF contributed to enhanced mechanical strength and moisture resistance. The preform was hot-pressed with biodegradable polybutylene succinate (PBS) to fabricate layer-by-layer (LbL)-structured PBS-LF/CNF NFRPs. Hydrophilic plasma treatment on the PBS surface improved interfacial compatibility with the fibrous preforms, leading to enhanced moisture stability and tensile properties. The resulting NFRP, featuring the CNF binder and plasma treatment, exhibited significantly improved mechanical properties, with a modulus increase of 980%, tensile strength increase of 430%, and toughness improvement of 270% compared to neat PBS. Additionally, PBS-LF/CNF NFRP demonstrated biodegradability in a composting environment. Moreover, this method is simpler, faster, and more environmentally friendly than previous methods that used chemical treatments. These findings indicate that hierarchical structure and plasma treatment can be promising strategies for improving high-performance NFRP manufacturing process.

10:30 AM – 12:00 PM | CONCURRENT SESSIONS (*denotes student)

Session 4.1 - Talk of the Town in your Area or Region: From Stakeholder Initiatives to Cooperative Extension Efforts in Wood/Forest Products I

~ Session Organizers - Brian Bond (Virginia Tech), Scott Leavengood (Oregon State University), Frederik Laleicke (North Carolina State University)

~ Moderator - Scott Leavengood

Driving Innovation Through Extension in Engineering

Vikram Yadama^P (Washington State University)

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Abstract

Innovative approaches are crucial for sustainable resource utilization and advanced material development. Engineered wood-based composites, such as strand-based wood composites and wood-plastic composites (WPC), enhance wood resource efficiency and create new opportunities from manufacturing byproducts. The increasing availability of small-diameter and genetically improved trees presents opportunities for innovation. Public perception and sustainability considerations drive technological advancements and market acceptance. Consumers favor environmentally responsible products, encouraging the development of high-performance composites from sustainable sources like fire hazard forests and plantation-grown trees. This presentation explores research-based extension initiatives advancing next-generation composite technologies for structural and exterior applications. By integrating engineering practices and education with industry outreach, these innovations can expand market opportunities while addressing technical challenges, fostering resilient and responsible material innovation.

NC Wood Products Extension: Working with Businesses Across the Country

Frederik Laleicke^p (North Carolina State University)

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Abstract

“Extension is for the people” is a common phrase that captures the role of extension services. Who are these people and where can I find them? At the center of Wood Products Extension’s mission are the people and the industry of North Carolina, but reaching them can be challenging at times. Using my programs in urban wood utilization and drying as an example, I will highlight my engagement with locals at the state level and the steps that expanded my work across state lines. Working with different associations and groups, such as the NC Urban Wood Group and the Urban Wood Network, has helped broaden and capture the desired impact. Workshops and webinars have played an important role in building the program and progressively growing the audience. However, continuous engagement beyond that is essential to fostering trust and strengthening relationships.

Hardwood University - Technical Education for Primary and Secondary Hardwood Industries

Rado Gazo^p (Purdue University), Eva Haviarova (Purdue University)

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Abstract

The hardwood processing industry, like many others, is experiencing a lack of qualified employees ready to fill the open job positions. With the demise of wood science education at US universities, other ways have to be developed to provide basic technical knowledge to employees new to the hardwood industry, those that are cross-training for other jobs, or those that are ready to take on more responsibility in their current positions. Purdue University in cooperation with Indiana Hardwood Lumbermen's Association has developed *Hardwood University*, a program that consists of a year-long curriculum that is being offered in two tracks, primary and secondary, to the industry in the Midwest of the US. The industry's acceptance and experience teaching this program will be discussed in the presentation. Hardwood University is now in its 5th year and we will share our experiences conducting this program.

Alternative Structural Lumber Grading at the State Level

Adam Taylor^p (University of Tennessee)

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Abstract

A number of states have passed laws that enable its citizens to grade structural lumber on their own. These laws, and their rules of implementation, do not comply with the federal-level program (under DOC PS 20, the American Softwood Lumber Standard), require relatively little training, do not include third-party verification, but still provide compliance with the building code requirements for 'grade-stamped' lumber. The most active state-level programs are Wisconsin, Tennessee and Alaska. Dozens of training programs have been conducted, and hundreds of individuals have been certified to grade structural lumber. Programs vary by state, and attendees in the programs appear to be motivated by different considerations, e.g. the opportunity for landowners to use their own logs and for sawmiller to produce lumber on a relatively small scale and using local species. The attendees at the training programs have generally been very satisfied with the laws and the subsequent training programs. It is unknown whether the use of lumber graded under these unusual circumstances has been widespread, or caused problems with code approval, structural performance and safety, or resource use efficiency.

Near-Peer Mentoring to Attract and Recruit Young Rural Women and Minorities in Forest Sector

Pipiet Larasatie^P (Virginia Tech), Ana Gutierrez (University of Arkansas Monticello), Elena Rubino (University of Arkansas at Monticello), Kamana Chamlagain (University of Arkansas at Monticello), Jolene Hammock (University of Arkansas at Monticello)

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Abstract

With substantial concern regarding labor shortages in forest industries, it is crucial to make efforts to attract a broader pool to diversify and increase the forest workforce. This project, funded by USDA, will better prepare high school women and minorities (W&M) students in rural areas for Forestry STEM studies in college, leading to successful degree completion and hiring into STEM industries post-college. Each year, K10-K14 W&M students in rural Arkansas will be paired with current W&M college students. The pairs will work on their preferred science projects and compete in competitions such as 4-H, FFA, or Science Fair from summer to spring (approximately nine months). They will begin to build their relationship with in-person meetings during a summer camp on campus and work together toward their chosen science competition. Participation over a nine-month period will enable the students to make significant progress on their project and see it through to completion. This presentation will focus on the experience of the first cohort of mentorship, where W&M students spent a week on campus during Summer 2024 learning about the forestry supply chain. We conducted pre- and post-summer camp interviews to gain a deeper understanding of their learning journey. One K10-14 student who is a homeschool student and a pilot trainee shows a tremendous interest and will compete in a science competition with her study on pilot perception of carbon footprint.

Wood Product Extension Training and Wood Recovery Programming in Kentucky

Chad Niman^P (University of Kentucky)

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Abstract

The forest products industry is one of the largest sectors in Kentucky contributing over \$18.6 billion annually while providing White oak barrels for the \$9 billion Bourbon industry. Statewide, nearly half the land surface is in forest cover with some counties exceeding 70%. Formal training to support the forest products industry is limited with no technical 2-year or 4-year wood or biomaterials programs available. With over 57,000 people employed in Kentucky because of the forest sector there is a continual need for targeted training to address the needs of the current and future workforce. To address these needs the University of Kentucky Forestry and Natural Resource Extension has developed programming working directly with industry facility stakeholders and partners. Foundational programming in wood grading systems, sawing and edging of lumber, railway tie product manufacturing, wood drying, proper material handling are a few examples of volume and value recovery necessary to maintain a thriving circular bio-economy. Adaption to and adoption of new technology is critical for industries to recover volume and value. Working with stakeholders to develop new markets for underutilized material helps the forest sector to accomplish forest management at the landscape level while providing income to private landowners. Extension support provided to industry facilities and employee trainings in yield, grading training, wood drying and quality control saved/earned \$81 million throughout the region. To expand the reach of forestry and wood products manufacturing education, ForestryWorks of Kentucky was developed. The high school curriculum is approved through the Kentucky Department of Education for use in all 120 counties to train and certify high school teachers. Extension programming can address many training workforce needs but the creation of the ForestryWorks Kentucky curriculum has reinforced the need for wood product technical and college training.

Session 4.2 - Advanced Characterization in Forest Products Research II

~ Session Organizers - Nayomi Plaza (USDA FS Forest Products Laboratory), Laura Hasburgh (USDA FS Forest Products Laboratory), Katie Ohno (USDA FS Forest Products Laboratory), Nathan Bechle (USDA FS Forest Products Laboratory)

~ Moderators - Nayomi Plaza and Oswaldo Erazo

Virtual Reality of Wood Anatomy and Protection

Dengcheng Feng^{p*} (University of British Columbia), Yan Liu (Carleton University), Michael Turner (Australian National University), Ajay Limaye (Australian National University), Philip Evans (University of British Columbia)

Student oral presentation competition – Second place winner

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Abstract

Virtual reality (VR) is a technology that allows people to explore and interact with computer generated environments using devices that stimulate different senses (sight, sound and touch). VR is mainly used for education, training and entertainment, but it also has the potential to provide new insights into scientific phenomena. In this paper we describe the evolution of VR and its many uses, focussing on those that are most relevant to wood protection. We describe our work on the use of VR as a learning tool for students taking a course in wood protection. Students taking this course used a fully immersive VR device to explore and interact with realistic computer-generated X-ray micro-computed tomography animations of the micro-structure of the following timbers: (a) The silica-containing, marine-borer resistant wood, satinay (*Syncarpia hillii* F.M. Bailey); (b) Southern pine (*Pinus* spp.) treated with either a micronized water-borne wood preservative or an ionic alkaline copper quaternary preservative. Students were surveyed to assess their views on the system as a learning tool. The results showed that students were very positive about the VR system, and they frequently commented that the system was better than traditional methods at aiding understanding of wood protection. We discuss the limitations and future potential of our VR system as a learning tool for wood protection.

Color Modification of Appalachian Hardwoods by Thermal Treatment Methods

Levente Denes^p (West Virginia University)

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Abstract

This study aims to analyze the effect of thermal and hydro-thermal treatments on four Appalachian hardwoods, i.e. Yellow Poplar, Red Oak, American Beech and Red Maple. The selected species were steamed, pressure steamed, and heat treated for various durations and the color modification was recorded at certain intervals. Thermal treatment consisted of placing the specimens in an oven set at 200 C and atmospheric conditions. The treatment time started after the specimens' temperature reached the set value. For steaming and pressure steaming a conventional autoclave was used, the steaming temperature was 110 C and for pressure steaming the treatment occurred at 180 Kpa. A portable spectrophotometer set for the CIELAB color space was used for color components measurements. Each specimen was marked at two places and the lightness (L^*), the red-green opponent (a^*), and the yellow-blue opponent (b^*) were measured at the predetermined treatment intervals. After the treatments the color coordinates and the color differences (DE) were analyzed and compared with the color of other domestic hardwood species. Based on the interval measurements a regression model was fit to the data, therefore the dynamics of the color change was determined. The models allow optimization of the treatment procedures and set the treatment parameters in function of the desired color.

Characterization and Pyrolysis of Slash Biomass from Douglas Fir and Red Alder in Oregon

Alhassan Ibrahim^P (Oregon State University), Gerald Presley (Oregon State University), Islam Hafez (Oregon State University)

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Abstract

The increasing demand for sustainable biofuels has intensified research into the thermochemical conversion of lignocellulosic biomass. This study evaluates the physicochemical properties and pyrolytic behavior of Douglas Fir (DF) and Red Alder (RA) slash, two abundant forest residues in the Pacific Northwest, to determine their suitability for biofuel production. Proximate and ultimate analyses were conducted to characterize their chemical composition, while fast pyrolysis experiments optimized bio-oil yield. Proximate analysis revealed that DF exhibited higher volatile matter content (81.62%) compared to RA (79.33%), whereas RA had greater fixed carbon (19.41%) and ash content (1.26%) than DF (17.63% and 0.75%, respectively). Ultimate analysis indicated similar carbon (DF: 48.25%, RA: 48.32%) and hydrogen (DF: 5.98%, RA: 5.93%) compositions, with oxygen levels slightly higher in DF (44.21%) than RA (43.66%). Both biomass types demonstrated comparable higher heating values (HHV) of approximately 19.24–19.25 MJ/kg, highlighting their potential as energy feedstocks. Fast pyrolysis was conducted at 500°C in a fixed-bed reactor, with particle sizes of 0.5 mm and 2 mm to assess bio-oil yield variations. The highest bio-oil yields were observed at the 0.5 mm particle size, with DF producing 56.03% and RA achieving 58%, while the larger 2 mm particles resulted in lower yields (47% for both species). Mixed samples showed slightly improved yields, particularly at 0.5 mm (57–60%). Bio-oil characterization identified key fractions, including gasoline-range hydrocarbons, sustainable aviation fuel (SAF), and industrial solvents, underscoring the economic feasibility of pyrolysis-derived biofuels. This study compares DF and RA slash as feedstocks for thermochemical conversion, offering insights into optimizing pyrolysis conditions to maximize biofuel yields and improve fuel quality. The findings contribute to the advancement of sustainable biomass utilization strategies in the Pacific Northwest, promoting the viability of forest residues as a renewable energy source.

Mycelium/Paper-Based Composite Materials for Insulation Applications

Emmanuel Osei-Bonsu^{p*} (University of Idaho), Lili Cai (University of Idaho), Armando McDonald (University of Idaho), Damon Woods (University of Idaho)

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Abstract

This study investigates the feasibility of producing mycelium/paper-based composites (MPCs) using two types of paper substrates, including printing paper and kraft paper. Each of the substrates was mixed with an actively growing mycelium from an Ecovative GIY kit at a mass ratio of 8:2. The samples were incubated in an environmental chamber at 25°C and relative humidity of 75% for 4 weeks. The composites were sterilized in an oven at 105°C and their water absorption, compressive resistance, fire resistance, and thermal conductivity were assessed. Half the samples were also hot-pressed to ascertain the effects of pressing on the tested properties. Results showed that the MPCs have limited water absorption by up to 65% compared to commercial hemp insulation (after 24 hours of immersion) and maintain a compact structure even after longer periods of water immersion (7 days). Mass loss cone calorimetry showed mycelium composites had lower peak heat release rates compared to their specific substrate-only controls, took a longer time to ignite and showed higher mass residues after the test. While hot-pressing of the composites significantly improved their water resistance, compressive resistance, time to ignition and total heat release, it had no significant effect on peak heat release rates and mass retention after fire tests. The thermal conductivity of the MPCs (0.054 - 0.059 W/m·K) places them among moderate insulators, and they compare favorably to conventional insulation materials such as hempcrete, straw insulation and polyester insulation. These findings show the promise of mycelium to bind paper wastes as an eco-friendly insulation alternative.

Using Notch Delamination to Study Moisture Adhesive Interaction

Samuel Ayeni^{P*} (Oregon State University)

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Abstract

This study explores moisture-adhesive interactions in solid laminated panels, emphasizing how moisture influences delamination, crack propagation, and overall structural performance. The hypothesis driving this research is that layer thickness profoundly impacts the durability and performance of laminated panels under seasonal environmental stresses. The objective of this study is to determine methods for maximizing the durability of layered panel products, focusing on drying methods, allowable layer thickness, role of resin, and panel design features such as notches. Key methods involve static moisture treatment of laminated veneer panels configurations followed by mechanical tests including three-point bending for notch delamination and four-point bending for crack propagation and are closely monitored using Digital Image Correlation (DIC) technology to provide precise measurements of crack initiation and propagation under stress. A fracture mechanics approach is employed to quantify key parameters to deepen understanding of failure mechanisms. The anticipated findings include identifying the effects of layer thickness, resin properties, and moisture treatment on delamination and crack propagation. Robust modeling will be developed to simulate these interactions and extend the results to new panel products and structures, enabling predictive analysis for future designs.

Effect of Thickness Variations on Clamping Pressure Redistribution Transfer in Cross-Laminated Layups with Uneven Thicknesses in the Adjacent Laminations

Samson Idoghor^{P*} (Oregon State University), Lech Muszynski (Oregon State University), Fatemeh Rezaei (Mississippi State University), John Nairn (Oregon State University)

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Abstract

The integrity of the adhesive bond is an imperative criterion for qualifying layered engineered wood-based composites (EWP) for structural use. The failure in adhesive bond in EWP manufactured by laminating lumber with an industrial adhesive that is oriented perpendicular to the adjacent layers is mostly attributed to several factors like the lack of adhesive and wood compatibility, clamping pressure, duration, and wood species while omitting the possibilities of other silent factors. In cross-laminated timber (CLT) even moderate variations in lamination thickness within the same layer can significantly affect the distribution of clamping pressure at the intersections of laminations. This study aims to address the strict criteria adopted by the North American product performance standard ANSI/APA PRG320 on the performance of adhesive bond in CLT, which seems not yet supported by theoretical or experimental data. The project aims to determine the effect of thickness variation in adjacent laminations on the clamping pressure redistribution and transfer in CLT on adequate bonding and integrity between layers. The project specific objective is to determine the effect of thickness differences in adjacent lamination on clamping pressure redistribution in cross-laminated layers with controlled thicknesses at the middle layer. Measurements were conducted on scaled-down models of 3-ply and 5-ply layup sections covering three intersections of laminations with uneven thicknesses in the middle layer. The test layups were subjected to clamping pressure in a simulated pressing condition but with no adhesive. The redistribution of pressure between laminations and layers was evaluated from the cross sections of the model layups using optical measured system. The output of this study will aid the refinement of the analytical model of the actual clamping pressure redistribution between layers of controlled thickness while also highlighting the critical thresholds of thickness tolerance needed to maintain consistent pressure transfer and better integrity of bonds.

1:30 – 3:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 5.1 - Talk of the Town in your Area or Region: From Stakeholder Initiatives to Cooperative Extension Efforts in Wood/Forest Products II

~ Session Organizers - Brian Bond (Virginia Tech), Scott Leavengood (Oregon State University), Frederik Laleicke (North Carolina State University)

~ Moderators - Brian Bond and Frederik Laleicke

Dealing with Change: A Look into the Past and into the Future for Wood Products Extension

Brian Bond^p (Virginia Tech), Marshall White (Virginia Tech)

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Abstract

University extension programs have a long history of supporting the forest and wood products industries through education, technical assistance, and applied research. Wood products programs at major land grant universities after World War II focused on sawmill efficiency, wood preservation, drying techniques, and market development for timber products. There were many agencies that supported these outreach efforts. Many of these outreach efforts were developed and led by the U.S. Forest Service, Forest Products Lab such as the Sawmill Improvement Program (SIP). The SIP program involved strong partnerships between the Forest Service, state forestry agencies, industry associations and university associated extension programs. There were also strong collaborations between university extension programs, for example in the southern dry kiln program that involved faculty from Virginia Tech, North Carolina University, and the University of Tennessee. Since the mid 1990's there has been a reduction in both university extension programs, state forestry positions, and Forest Service emphasis on wood/forest products. Collaborations between agencies and universities exist but on a smaller scale. The industry's needs have also changed as they have adopted the proposed practices, market changes, technology changes and significant industry conglomeration has occurred. Industry associations have increased their emphasis on education and outreach programs often overlapping with traditional extension programming as the number of individual industry members has reduced. Given these changes, what is the need for wood products extension programming efforts moving forward and what should it look like? In this presentation, we will use the case study of wood products extension at Virginia Tech to illustrate these changes and provide a vision for future wood products extension. We will address how did extension programming come about, what was its initial focus, how has it changed, how have the industry changes impacted programming and where should it go in the future.

Wood Products Extension at Oregon State University – Reflections on the Past 5 Decades

Scott Leavengood^P (Oregon State University)

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Abstract

The Wood Products Extension program at Oregon State University formally began in the late 1970s with the hire of Dr. Terry Brown. Terry soon established himself as an expert on sawmilling and in particular, lumber QC/lumber size control. In 1994, the program grew significantly as four new 'value-added forest products Extension' faculty were hired. Two of the new faculty were located off-campus and served as County Agents and the other two faculty were on-campus Extension Specialists. The program evolved again in 2006 with the formation of the Oregon Wood Innovation Center (OWIC). This presentation will recap the history of wood products Extension at OSU, the specific areas of focus, and how the methods used and focus areas have changed over the past nearly 50 years. The presentation will conclude with a discussion of what the future may hold.

Session 5.2 - Sustainable Advanced Manufacturing of Value-added Wood Products through Innovative Pathways I

~ Session Organizers - Daniel Saloni (North Carolina State University), Frederik Laleicke (North Carolina State University)

~ Moderator - Daniel Saloni

Structural Properties of Lumber from Small Logs Generated in Forest Thinning Operations: Bending Properties

Michelle Jayawickrama^{P*} (Oregon State University), Lech Muszynski (Oregon State University), Dessie Tibebe (Oregon State University), Elijah Olawumi (Oregon State University)

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Abstract

Restoration forest thinning is an important strategy for mitigating risks of catastrophic wildfires in forestlands of the Western US. This process is costly and yields a significant percentage of younger, smaller diameter trees containing a high proportion of juvenile wood, which differs from mature wood in many characteristics, including strength properties. Utilization of lumber from small diameter logs in structural applications, including cross laminated timber (CLT) panels, would add market value to the material generated as a byproduct of the thinning operations. Given the abundance of ponderosa pine growing in major restoration thinning regions, increasing the market value associated with this species is of particular interest. Unfortunately, most sawmills consider processing small logs unprofitable and the resulting lumber less qualified for structural uses. A recent study, based on elastic moduli measured on a limited sample, suggested that lumber from small diameter logs may not meet the National Design Specifications (NDS) benchmarks for their visual grades, established on lumber from logs harvested in commercial operations with substantially larger proportions of large diameter trees. The objective of this project is to experimentally verify these earlier findings by comparing structural properties determined on a representative sample of lumber (sawn from forest restoration ponderosa pine logs across the growing range) with reference values listed in NDS for the same size, grade, and species. The testing procedure (including four-point bending and tension parallel to the grain) of full-sized lumber specimens follows respective ASTM standard methods for structural lumber. The resulting data will be used to obtain estimates of elastic modulus as well as bending and tensile strength. These estimates will be compared with the current NDS values for the purpose of determining whether or not the lumber meets established structural requirements.

Reevaluation of Mechanical Characteristics of Lumber from Small-Diameter Logs: Small Clear Specimens

Elijah Olawumi^{P*} (Oregon State University), Lech Muszynski (Oregon State University), Michelle Jayawickrama (Oregon State University), Dessie Tibebe (Oregon State University)

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Abstract

Forests that grow too densely increase the risks of catastrophic wildfires. Thinning these forests, which typically involve the removal of small-diameter logs, can mitigate this risk. These logs are currently considered low value because they contain more juvenile wood than logs from commercial harvests and are more costly to process into lumber due to their smaller size and higher taper that reduces the yield. Utilization of this material in structural applications would add market value to small diameter logs. However, high juvenile wood content in this lumber makes it less suitable for construction. Currently, National Design Specification (NDS) values are based on lumber from commercial harvests with much higher proportions of mature wood. There is limited evidence that lumber with high juvenile wood content does not meet the NDS benchmarks for its visual grade. The goal of this project is to verify the findings from earlier studies with elastic and strength data determined on a representative sample of lumber and small clear specimens from small-diameter logs. In case the earlier findings are confirmed, new design values will be generated. The specific objective of this study is to determine the mechanical characteristics of small clear specimens harvested from the same material. This data will complement the strength and stiffness data obtained from tests performed on structural lumber performed in parallel projects. The test procedures follow the ASTM D143 methods to determine strengths (and elastic modulus) in compression parallel to grain, compression perpendicular to grain, shear parallel to grain and static bending on small clear specimens of ponderosa pine which is considered the weakest of Western Wood species. The outcome of this study will be used to verify the correlation between properties determined for structural sized lumber and small clear specimens of the same material with lumber from commercial harvests.

Soy Flour-Modified pMDI Resin Improves Wood Composite Properties by Suppressing Steam Generation

Brian Via^P (Auburn University)

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Abstract

Soy flour (SF) exhibits high water retention, and its incorporation into polymeric methyl diphenyl diisocyanate (pMDI) resin alters water absorption within the furnish. This effect raises the boiling point of water and inhibits steam formation in the mat. The steam inhibition mechanism was validated using sodium polyacrylate, a highly absorbent polymer capable of retaining several hundred times its weight in water. Reduced steam generation minimizes steam escape during pressing and increases internal board pressure. Early-stage pressing measurements of partially bonded panels reveal that SF enhances bond strength—reducing press time—mitigates press blows, and decreases springback. Furthermore, vertical density profiles of fully cured boards can be dialed into a specific profile. When bonded with pMDI, thin wood pieces exhibit reduced warp under humid conditions when SF is included in pMDI. We also found fire resistance benefits in soy modified pMDI panels.

Non-destructive Evaluation to Sort and Evaluate Red Maple Veneers and Associated Laminated Veneer Lumber (LVL)

Dalila Belaidi^{P*} (Mississippi State University), Mostafa Mohammadabadi (Mississippi State University), Rubin Shmulsky (Mississippi State University), wang xiping (USDA FS Forest Products Laboratory)

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Abstract

Laminated Veneer Lumber (LVL) is usually manufactured using softwood species like Douglas fir and southern pine due to their availability and cost-effectiveness. However, the growing abundance of red maple (*Acer rubrum* L.) in northeastern U.S. forests provides a cost-competitive alternative. As an underutilized native hardwood species, red maple offers promising mechanical properties for engineered wood products. Expanding its market can help reduce pressure on more widely harvested hardwood species. This study evaluates the effect of sorting and assessing red-maple veneers using non-destructive testing methods on the structural performance of LVL. A total of 553 specimens, measured 3.5 mm (0.14 in) in thickness, 304 mm (12 in) in width, and 2.44 m (8 ft) in length were subjected to a non-destructive test using the stress waves method to measure the dynamic modulus of elasticity (MOE_d). To assess the reliability of this method, a tensile test was also conducted on 2.44 m (8 ft)-long specimens. Additionally, the effect of density, velocity and grading was investigated on dynamic modulus of elasticity. Based on the MOE_d values, the veneers were categorized into four groups: low-grade, medium-grade, high-grade, and a combination of all grades. LVL billets were then manufactured from each group, using 12 layers of veneer bonded with polyurethane (PUR) adhesive. The LVL billets were evaluated using two different non-destructive testing (NDT) methods—using Hitman and FAKOPP Microsecond Timer—with both methods providing very close results. From each LVL billet, three edgewise and three flatwise specimens were cut and submitted to bending test to understand the effect of sorting veneer using NDT methods on both MOE and MOR of LVL.

Evaluating the Adhesive Properties of a Novel Biobased Cement for the Manufacture of Particleboards

Courage Alorbu^{P*} (University of Idaho), Dylan Willard (University of Idaho), Armando McDonald (University of Idaho), Lili Cai (University of Idaho)

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Abstract

Most industrial particleboard manufacturing relies on urea-formaldehyde (UF) resin as the primary adhesive due to its cost-effectiveness and strong bonding performance. However, formaldehyde, a key component of UF resin, is a known toxic compound linked to long-term health risks, including respiratory diseases and carcinogenic effects. This study introduces a novel nanoparticle-essential oil adhesive system as a less toxic and more environmentally sustainable alternative for particleboard production. The adhesive system was developed using two model compounds, magnesium oxide nanoparticles (nanoMgO) and trans-cinnamaldehyde (CN) solution, which were mixed at a ratio of 1:1.25, forming a Magnesium-trans-cinnamaldehyde (nanoMgO-CN) cementitious slurry. The slurry was then mixed with wood sawdust (8% moisture content) and molded under a preheated press at a 1008 psi pressure and 140 °C temperature for 10 minutes to produce nanoMgO-CN bonded particleboards with 10% and 20% adhesive loading. The fabricated particleboards upon cooling and conditioning will be trimmed and sectioned into standardized sample sizes and subjected to extensive property evaluations, including fungal decay resistance classification based on the AWWA E10 standard. This assessment will involve exposure of 10 and 20% MgO-CN contained board samples to two brown-rot fungi, *Gloeophyllum trabeum* and *Rhodonia placenta*, as well as two white-rot fungi, *Trametes versicolor* and *Ipex lacteus*. Additional tests will be conducted to evaluate internal bonding (IB) strength, flexural properties, fire resistance characteristics and water-resistant tests. We hypothesize that particleboards manufactured using the novel MgO-CN cement resin will demonstrate enhanced properties comparable to those produced with conventional formaldehyde-based resins, offering a safer and more environmentally friendly alternative for particleboard production.

3:30 – 5:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 6.1 - Formulating Sustainability in the Forest Products Industry I

~ Session Organizers - Hyo Won Kwak (Seoul National University), Bonwook Koo (Kyungpook National University), Glenn Larkin (LarChem LLC)

~ Moderators - Hyo Won Kwak, Bonwook Koo, and Glenn Larkin

Strategic Approaches to the Cascading use of Wood Resources in Korea

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Abstract

In Korea, as of 2022, 28.68 million tons of wood are used annually, of which domestic timber supply is only about 15%, at 4.31 million tons. In addition, the wood is mainly used for pulp (32.5%) and biomass (26.4%), so it is considered that strategic and innovative changes are needed considering the cascading use of wood. Korean government is attempting seven key strategic approaches to achieve the cascading use of wood resources and carbon neutrality goals. The first is to gradually increase the supply of domestic timber. In 2030, the government plans to supply an additional 8 million tons to the market. The second is the promotion of a project that dramatically drives the demand for wood by expanding the public-led wood construction market, such as the timber-friendly city development project and the domestic wood construction demonstration project. The third is to promote the policy of consolidating the timber industry by region and raising the competitiveness of producers by establishing specialized timber industrial complexes and establishing clusters. The fourth is to improve public awareness of the use of wood and to provide campaigns and services to reduce the burden on wooden buildings that are not yet universal and to improve quality. The fifth is to establish and implement the 'Act on the Activation of Wood Constructions for Carbon Neutral Practice' jointly by the Ministry of Land and Transport Affairs and the Korea Forest Services, which is to provide an institutional basis for the smooth dissemination of wood constructions. The sixth is the operation of the 'Wood Information Service Platform' for integrated history management over the entire period of wood resources. Finally, the seventh is the robust operation of a system that uses 'unused biomass', which can not be used for other purposes among domestic wood resources, as an energy source.

Analysis of the Governance Systems of the Forestry Sector in Ghana: A Multidimensional and Sustainability-Based Approaches

Bernard Effah^P (Akenten-Appiah Menka University of Skills Training & Entrepreneurial Development), Peter Kessels Dadzie (Kumasi Technical University)

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Abstract

Effective governance systems are critical for the sustainable management of forest resources, especially in regions with complex socio-ecological dynamics such as Ghana. However, governance challenges, including weak institutional frameworks, illegal logging, deforestation, and conflicts over land tenure, have significantly hampered the sustainable management of forest resources in Ghana. This study aims at evaluating the governance systems of the forestry sector in Ghana using a multidimensional analysis framework and sustainability-based approaches. The study employs both qualitative and quantitative research methods, including stakeholder interviews, policy analysis, and statistical data assessment. Primary data was collected from forestry officials, local communities, timber companies, and environmental organizations, while secondary data was sourced from government reports, research publications, and international forestry governance frameworks. The study applied a sustainability-based governance model, including the principles of transparency, participation, accountability, and equity, to evaluate the current governance structures. The study shows that Ghana continues to lose approximately 2% of its forest cover annually due to illegal logging and mining as well as bad agricultural practices. The study further shows that governance in Ghana's forestry sector involves multiple stakeholders like civil society, local communities, traditional authorities, and government agencies with divergent interests. It was observed that local communities often get into conflict with private logging companies over resource access, while civil society advocates for stricter conservation measures. Economic incentives, such as benefit-sharing mechanisms, have been introduced to promote sustainable practices. However, these mechanisms are often unequal, with local communities receiving minimal benefits compared to the private companies. Based on the findings, the research recommends a more integrated governance approach that strengthens law enforcement, enhances community participation, and promotes sustainable economic incentives for forest conservation.

Analyse the Size and Location of Timber Deterioration by Non-Destructive Test

KugBo Shim^P (Chungbuk National University), HyungJoon Han (Chungbuk National University), KyoungHyun Ryu (Chungbuk National University)

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Abstract

Timber is a widely used structural material known for its strength, renewability, and environmental benefits. However, timber structures deteriorate over time due to factors such as moisture, fungal decay, insect infestation, and mechanical stress. Accurate assessment of deterioration is essential for ensuring structural safety, extending service life, and promoting sustainable construction. Non-destructive testing (NDT) methods enable early detection of deterioration, allowing for targeted removal of damaged sections and reinforcement of the remaining timber, thereby minimizing material waste and supporting sustainable restoration practices. This study applies ultrasonic, stress wave, drill resistance, and X-ray imaging NDT techniques to evaluate the deterioration of *Pinus densiflora*. The primary objective is to accurately determine the size and location of defects so that deteriorated portions can be efficiently removed, and the remaining structure can be reinforced. Ultrasonic and stress wave velocity measurements are analyzed using Hankinson's formula to assess wave propagation based on grain angle. A predictive model is developed to simulate wave paths and detect deteriorated areas. Drill resistance testing measures localized density variations, complementing wave-based evaluations, while X-ray imaging provides a detailed internal view of defects. By integrating multiple NDT techniques, this study enhances the accuracy of timber assessment while minimizing unnecessary material loss. From a sustainability perspective, selective removal and reinforcement reduce greenhouse gas emissions by extending timber durability and reducing reliance on carbon-intensive materials such as steel and concrete. This research contributes to the advancement of non-invasive diagnostic methods, supporting the efficient rehabilitation of deteriorated timber structures while promoting sustainable conservation and resource utilization.

Environmental Performance of Hardwood Product Production Over Time

Richard Bergman (USDA FS Forest Products Laboratory), Scott Bowe (University of Wisconsin), Poonam Khatri (USDA FS Forest Products Laboratory), Matthew Bumgardner (USDA FS Forest Products Laboratory), Hongmei GU^p (USDA FS Forest Products Laboratory)

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Abstract

In recent years, life cycle assessment (LCA) has become one of the most effective tools available for assessing and reducing the life-cycle environmental impacts of products. This study used LCA to track the environmental performance of hardwood products produced in the U.S. The hardwood product sector in the United States has undergone major changes in the last two decades. These changes have negatively and positively affected the utilization of hardwoods. U.S. hardwood production has declined substantially because of both imported finished wood and nonwood products along with the cost competitiveness of domestic softwood species as replacement for industrial products like pallets. Contrarily, technology changes for hardwood product manufacturing have generally improved the environmental footprint of these products. These environmental improvements have been quantified and tracked for two hardwood products (plane dried lumber and industry average pallets) using LCA. For cradle-to-gate production of planed dry hardwood lumber in the northeastern/north central and southeastern U.S., thermal energy consumption decreased from 5,800 to 3,876 and from 4,678 to 2,733 MJ/m³, respectively while global warming (GW) impact decreased from 187 to 166 but unexpectedly increased from 134 to 209 kg CO₂e/m³, respectively. For wood pallets, cradle-to-grave GW impact for new pallet production was 4.88 kg CO₂e per industry-average pallet compared to the value of 0.355 kg CO₂e for an industry-average repaired/remanufactured pallet. The reduction of GW impact for repairing wood pallets underlies a huge reduction of embodied carbon emissions for the sector which in part comes from lower requirements of raw materials such as roundwood while keeping current wood in circulation to the best extent possible.

Optimizing Biomass Utilization and Sustainability Through Multi-Feedstock and Multi-Product Pathways in the MASBio Project

Jayendra Ahire^P (USDA FS Forest Products Laboratory), Richard Bergman (USDA FS Forest Products Laboratory), Troy Runge (University of Wisconsin), Debangsu Bhattacharyya (West Virginia University), Tristian Brown (SUNY), John Hu (West Virginia University), Nate Anderson (USDA FS Rocky Mountain Research Station), Jingxin Wang (North Carolina State University)

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Abstract

The Mid-Atlantic Sustainable Biomass for Biofuels and Bioproducts Consortium (MASBio) project explores sustainable strategies for optimizing biomass utilization in bioenergy and bioproduct production. Our research employs a multi-feedstock, multi-product approach by integrating agricultural residues, woody biomass, and dedicated energy crops to enhance feedstock flexibility and process efficiency. A key initiative involves the development of an integrated biorefinery that will utilize multiple feedstocks to produce sustainable aviation fuel (SAF) and various value-added byproducts such as bioadhesive, intermediate chemicals, and resin for 3D printing. SAF is critical for reducing the aviation sector's 2.5% contribution to global greenhouse gas emissions. This study assessed the techno-economic and life-cycle environmental impacts of producing SAF from forest residues via gasification and Fischer–Tropsch synthesis. Considering co-products, we estimated the minimum selling price (MSP) of FT-SPK-SAF at \$1.44/L with a global warming (GW) impact of 24.6 g CO₂ eq/MJ—significantly lower than other lignocellulosic feedstocks. In addition to SAF, the integrated biorefinery will produce bioproducts such as a lignin-isolate soy protein (LISP) bioadhesive, a more economical and better environmental alternative to formaldehyde-based adhesives. Specifically, our analysis shows that LISP bioadhesive has a MSP of \$1.40/kg and a GW impact of 2.20 kg CO₂ eq/kg using steam as the primary input. Moreover, machine learning models are developed for biomass sustainable indicators to predict residue removal rates and for soil respiration rates to improve the scalability of forest soil carbon management. For the latter, a hybrid Prophet-artificial neural network model was developed to significantly improve forest soil carbon flux predictions. Overall, this integrated biorefinery model development should assist maximizing the environmental and economic performance over the whole supply chain to promote a more sustainable bioeconomy.

Session 6.2 - Sustainable Advanced Manufacturing of Value-added Wood Products through Innovative Pathways II

~ Session Organizers - Daniel Saloni (North Carolina State University), Frederik Laleicke (North Carolina State University)

~ Moderators - Daniel Saloni and Frederik Laleicke

Innovation in the Forest Industry - Past, Present, and Future

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Abstract

How innovative is the forest industry? If you posed that question to people from outside the industry, it's likely most would say - 'not very.' However, the industry has been developing and/or adopting new product and process innovations for decades. The inspiration or 'drivers' of innovation in the industry have included a variety of goals such as improving durability, quality, and performance of products; optimizing yield of finished materials; and enabling the use of byproducts as well as lesser-known species. And of course, innovation in the industry continues to focus on those goals today as well. However, in recent years innovation in the forest industry has increased emphasis on goals related to the environmental performance of products. It seems likely that these drivers will continue into the near future. This presentation will review the past and present of product and process innovations in the forest industry and speculate a bit on where things may go in the future.

Interrelated Factors Governing the Densification of Yellow Poplar

Gloria Oporto^p (West Virginia University), Balazs Bencsik (West Virginia University), Levente Denes (West Virginia University), Joseph McNeel (West Virginia University), Luke Chaddock (West Virginia University)

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Abstract

The densification of yellow poplar (*Liriodendron tulipifera*) has emerged as a critical area of research, driven by its desirable properties and broad potential applications. This study investigated the effects of four densification parameters using a 24 full factorial design to evaluate their impact on physical and mechanical properties. Analysis of Variance (ANOVA) and Pareto analyses identified the compression ratio as the most influential factor, significantly affecting bending strength, compression strength, hardness, and spring-back behavior. Pressing temperature was the second most significant factor, with higher levels positively impacting mechanical properties. However, increasing the pre-steaming treatment duration from 30 to 60 minutes at 130 °C had a detrimental effect on strength and spring-back performance, particularly at a 50% compression ratio. Pressing time showed no significant effect on strength properties but contributed positively to hardness and spring-back behavior at higher levels. Several significant factor interactions were observed, further influencing the outcomes. Differences in density profiles were notable across compression ratios, with higher ratios producing more uniform distributions. Under optimal parameters, densification increased compression strength by 117%, bending strength by 60%, and hardness by 154% compared to undensified control samples, demonstrating the potential of densified yellow poplar for high-performance applications.

Sustainable Bonding of Engineered Wood Panels Using Sodium Hydroxide: An Eco-Friendly Alternative to Petroleum-Based Adhesives

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Abstract

Strand-based composite panels are engineered wood products used in construction and furniture for their strength, stability, and affordability. Traditional manufacturing relies on petroleum-based adhesives like phenol-formaldehyde (PF), raising environmental and health concerns due to VOC emissions. This study explores using sodium hydroxide (NaOH) to improve bond strength without synthetic adhesives. Wood chips were treated with NaOH under various conditions, with results showing enhanced bonding due to lignin modification. This adhesive-free method reduces environmental impact, offering a sustainable alternative for strand-based composite panel production. In this research, wood strands were soaked in NaOH solutions at different concentrations, temperatures, and time durations to assess the optimal conditions for effective bonding. The chemical treatment altered the lignin structure, making the surface more reactive and improving the natural adhesion between wood fibers. Mechanical tests, such as lap shear strength measurements, are conducted to evaluate the bonding performance. Fourier-transform infrared spectroscopy (FTIR) analysis confirmed changes in the chemical structure, particularly the reduction of lignin peaks, indicating successful modification. The results demonstrated that NaOH treatment not only improves mechanical strength but also reduces dependency on synthetic adhesives. Additionally, this method reduces production costs by eliminating expensive chemical adhesives. This environmentally friendly approach supports sustainable manufacturing practices, minimizes the release of harmful VOCs, and promotes healthier indoor environments.

Thermally treated wood: insights and perspectives from the industrial experience of the ThermoVacuum process

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Abstract

Several technologies are currently used for the thermal treatment of wood. Although they have the same purpose, there are differences in the properties of the resulting products. The aim of this contribution is to share the experience gained over many years in the production and commercialization of wood thermally treated by the ThermoVacuum process. In short, this is performed in vacuum environment at approx. 300-350 mBar; treatment temperatures range from 170 to 220 °C and are usually maintained for 2-4 hours, while the entire cycle (pre-heating, drying, treatment, cooling) typically lasts 30-40 hours". Some of the main applications are presented, including in building, furniture and urban furniture, playgrounds, outdoor flooring, decking of boats and piers, etc. The marketplace is also outlined, to highlight the main geographical and market aspects. Finally, a special focus is given to sustainability. ThermoVacuum wood can in fact be considered an eco-friendly material for several reasons, both at the process and product level. To mention some: the power can be supplied from renewable energy sources; the closed-system plant avoids energy dispersion; the process does not involve chemicals; the gases are condensed and stored for disposal as non-hazardous liquid industrial waste; treated wood is easy to recycle at the end of life stage; the amount of Volatile Organic Compounds is very low, which makes ThermoVacuum wood also suitable for indoor use. Overall, being based on real and extensive experience in the field, this overview can be a useful tool for evaluating the main perspectives of thermally treated wood.

Wood Chip Moisture Content Prediction Through Transfer Learning-enhanced Regression Analysis

Tilak Neupane^{P*} (Mississippi State University), Jason Street (Mississippi State University), Abdur Rahman (Mississippi State University), Haifeng Wang (Mississippi State University), Mohammad Marufuzzaman (Mississippi State University)

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Abstract

Wood chips are important renewable energy raw materials for the biofuel and paper industries, but higher moisture content decreases its calorific value. The traditional oven-drying method for measuring wood chip moisture content is time-consuming and labor-intensive. RGB imaging combined with various machine learning models offers a more time- and labor- efficient method. This study aims to develop a transfer learning model to predict moisture content levels of wood chips (10%, 20%, 30%, 40%, 50% and 60%). The moisture levels were achieved by adding water to wood chips and measured using the oven-drying method. Images were captured inside a closed box with a top-mounted uniform light source. The dataset included 1802 training and 318 test images. The Convolutional Neural Network (CNN) model achieved a coefficient of determination (R^2) of 0.90 on training sets and 0.86 on test sets. Among pretrained CNN models, ResNet101 obtained a R^2 of 0.85 and 0.82, while DenseNet101 had R^2 values of 0.86 and 0.84 and InceptionV3 achieved R^2 of 0.90 and 0.88 on training and test sets respectively. The Xception model outperformed all the models, with an R^2 of 0.94 on the training set and 0.90 on the test set. While previous image-based approaches considered the characterization of wood chip moisture content as a classification task and could only predict moisture as a range, this study approached it as a regression task. These image-based machine learning models, enhanced with transfer learning, provide an efficient approach for rapidly predicting wood chip moisture content, enabling real-time monitoring of the production process.

WEDNESDAY, JUNE 18

8:30 – 10:00 AM | CONCURRENT SESSIONS (P denotes presenter, * student)

Session 7.1 - Formulating Sustainability in the Forest Products Industry II

~ Session Organizers - Hyo Won Kwak (Seoul National University), Bonwook Koo (Kyungpook National University), Glenn Larkin (LarChem LLC)

~ Moderators - Hyo Won Kwak, Bonwook Koo, and Glenn Larkin

Timber-Concrete Composite Slab for Carbon-Neutrality and the Cascaded Use of Wood Resource

Jungkwon Oh^P (Seoul National University)- Corresponding author: jungoh@snu.ac.kr

Abstract

Timber-concrete composite (TCC) slabs have emerged as a promising structural solution in mass timber buildings, offering significant advantages through the combination of timber and concrete materials. This composite system effectively utilizes high compressive strength of concrete and tensile properties of timber, resulting in enhanced structural performance compared to timber-only system. The composite action achieved through mechanical connections between timber and concrete layers significantly reduces deflection and vibration issues while improving acoustic performance and fire resistance. These structural benefits have led to increasing adoption of TCC systems in mid-rise timber buildings. From an environmental perspective, TCC slabs present compelling advantages in the context of carbon neutrality goals. The timber component serves as a long-term carbon storage medium, sequestering atmospheric CO₂ throughout the building's lifetime. Additionally, the hybrid nature of TCC systems reduces the overall concrete usage compared to conventional concrete slabs, thereby decreasing the carbon emissions associated with cement production. This reduction in concrete volume also translates to lower overall building weight, potentially leading to reduced foundation requirements and associated environmental impacts. Furthermore, TCC systems align well with the principles of cascaded use. The design of mechanical connections between timber and concrete layers facilitates future deconstruction and material separation. This design approach enables multiple life cycles for the timber components: after the building's primary service life, the timber elements can be recovered and repurposed for lower-grade construction applications, manufactured into engineered wood products, or ultimately utilized as biomass fuel for energy generation. This cascaded use strategy maximizes the value extraction from wood resources while extending their service life across multiple applications, contributing to more sustainable resource management in the construction sector.

Shifting Formaldehyde-Based Wood Adhesives to Lignin-Based Adhesives for Sustainability in Wood Bonding

Byung-Dae Park^p (Kyungpook National University), Saman Ghahri (Kyungpook National University), Ega Cyntia Watumlawar (Kyungpook National University), Eko Setio Wobowo (National Research and Innovation Agency)

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Abstract

Formaldehyde-based resins such as urea-formaldehyde (UF) resins, melamine-urea-formaldehyde (MUF) resins, phenol-formaldehyde (PF) resins, and phenol-resorcinol-formaldehyde (PRF) resins had been dominantly used as adhesives for wood-based products. These adhesives use synthetic raw materials from petrochemicals, and are toxic owing to the formaldehyde emission from the glued wood products. The formaldehyde emission issue became a critical health problem, particularly for amino resins including UF resins and MUF resins. As a response to these problems and climate change, bio-based adhesives are increasingly receiving greater attention for wood bonding. This presentation aims to provide an overview on the transition from formaldehyde-based wood adhesives to bio-based lignin adhesives for sustainability in wood bonding. The formaldehyde issue and UF resin adhesives will be covered. Lignin-based wood adhesives as an example of bio-based adhesives will be covered for lignin fractionation, characteristics of lignin, crosslinking of lignin, and their adhesion in wood bonding. In particular, the crosslinking of kraft lignin with various methods such as cross-linkers, cross-coupling glyoxalation, and amination is covered. These results suggest that bio-based adhesives offer low toxicity, lower greenhouse gas emissions, and increased sustainability with circular economy by promoting renewable and degradable sources, which generates a driving force for the transition.

Assessing Mill Residue and Roundwood Equivalent Factors

Edward Seabright^p (University of Tennessee), Consuelo Brandeis (USDA Forest Service), Adam Taylor (University of Tennessee)

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Abstract

The United States is a world leader in the production of roundwood and primary wood products. Assessing the level of roundwood resources needed to meet known production of primary products requires updated information on industrial roundwood utilization rates. Two such rates include roundwood equivalents, which calculates the amount of roundwood that goes into producing a specified amount of wood product; and mill residue factors, which calculates quantity of mill residue production by unit of roundwood processed for a given primary product (e.g., amount of sawdust generated per unit of sawlogs processed). These factors are not static in time or across regions and are expected to change due to new technologies, different tree species, log characteristics, etc. Applying outdated factors could significantly affect estimated amounts of total roundwood used and mill residues availability, leading to incorrect assessments and decision making. To evaluate factors currently used by the USDA Forest Service Timber Products Output (TPO) program, we compared log allocations to primary product and residues using TPO factors along with factors found in the literature and estimated from private industry studies. Additionally, we ran non-parametric pair-test analyses comparing calculated mill residue production versus mill reported data using a subset of TPO data. We found significant differences between mill provided and calculated residue for all residue types except bark. While more research is needed given the small dataset available, preliminary results suggest the need to update these factors to better represent residue amounts.

Analysis of Energy Savings in Kiln-Drying Systems Utilizing Solar Energy as an Auxiliary Heat Source

Yonggun Park^P (National Institute of Forest Science), Wonho Jin (National Institute of Forest Science), Min Lee (National Institute of Forest Science), Hyoung Woo Lee (Chonnam National University)

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Abstract

The wood drying process is known to be the most energy intensive of all wood processing processes. Therefore, in order to increase the added value of wood products, efforts are needed to reduce the energy required to dry wood. Especially, to reduce carbon emissions and achieve carbon neutrality, it is urgent to discover alternative energy sources to fossil fuels that can be applied to wood drying. Solar energy is an infinitely renewable natural energy source that does not emit greenhouse gases or other pollutants, and has been used as an energy source for drying wood since the past. However, solar energy has some limitations in being widely used commercially because it is greatly affected by environmental conditions, such as not being able to be used at night and on cloudy, rainy, or snowy days, and its effectiveness is insufficient in winter. In this study, a system that used solar heat as an auxiliary heat source for a kiln-dryer using an electric heater was designed. This system can reduce the amount of electric energy used by not using an electric heater when the temperature of the air inside the kiln-dryer can be sufficiently heated by solar heat. The energy saving effect of the auxiliary heat source was evaluated by drying 50 mm thick pine boards and 25 mm thick oak boards in a drying device to which this drying system was applied. In the pine drying experiment, the electric energy usage actually increased below the fiber saturation point, resulting in approximately 50% more electric energy being used (energy saving effect of -48.6%). In the oak drying experiment, almost no electric energy was used overall, resulting in a final energy saving effect of 93.5%.

Session 7.2 - Sustainable Advanced Manufacturing of Value-added Wood Products through Innovative Pathways III

~ Session Organizers - Daniel Saloni (North Carolina State University), Frederik Laleicke (North Carolina State University)

~ Moderators - Daniel Saloni and Frederik Laleicke

Closing the Loop: Recycling PLA 3D Printing Waste for a Sustainable Campus Makerspace

Daniel Saloni^P (North Carolina State University), Catherine Kirch (North Carolina State University)

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Abstract

This project aims to tackle an overlooked campus waste stream: PLA 3D printing material. NC State's Makerspaces, which provide students free access to 3D printers, generate significant waste. Common sources of waste include failed prints, material overflows, support structures, and scraps from design errors. This is often only a limited amount of waste each individual produces, so it may not seem like an issue. However, this rapidly accumulates with so many individuals using 3D printers at all our on-campus Makerspaces. This PLA waste goes directly to landfills, contributing to campus plastic waste. Our solution is to intercept and repurpose this waste into recycled 3D printing filament, creating a closed-loop recycling system. PLA (polylactic acid) is an ideal candidate for recycling due to its thermoplastic properties, allowing it to be melted and re-extruded into new filaments. The project began as a collaboration between Hodges Lab and the D.H. Hill Makerspace, where PLA scraps are collected in designated bins and sent via campus mail to Hodges Lab. Here, we process them using a tabletop grinder, extruder, and spooler to produce usable recycled filament. Our vision of this program is rooted in long-term viability and sustainability. This program is intended to serve as a long-term recycling system for our on-campus PLA 3D printing waste stream, which provides a usable product for NCSU students. It is designed as a closed-loop system to improve long-term on-campus sustainability by keeping this waste stream out of landfills, processing it, and using it in-house to be used again in our on-campus maker spaces.

Wood Plastic Composite Feedstock Options for Extrusion-based Large Scale Additive Manufacturing

Douglas Gardner^P (University of Maine)

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Abstract

The production of wood-based composite parts from extrusion-based large scale additive manufacturing (LSAM) typically requires relatively expensive pre-compounded wood plastic pellet (WPC) feedstocks. Sourcing of LSAM feedstocks from local sources is challenging because wood flour manufacturing is not widespread in wood product producing areas and wood flour is expensive to transport. Densification of wood flour into pellets offers a way to reduce transportation costs, but the processing of densified wood pellets and plastic pellets to form WPC feedstocks requires research to understand the resulting material properties of LSAM parts produced from such an approach. The overall goal of the current work is to produce and characterize WPC LSAM parts on the pilot-scale manufactured from densified wood flour- plastic pellets. The specific objectives were: 1. collect wood residues from local forest products manufacturers and prepare and characterize both neat and densified wood flour, 2. Manufacture LSAM WPC parts from both neat and densified wood flour WPC pellets on the pilot-scale, and 3. Characterize the material properties of WPC LSAM parts via mechanical testing. The results indicate that LSAM WPC feedstock pellets from densified wood flour offer potential to produce parts with similar mechanical properties to WPC pellets manufactured from conventional wood flour.

Novel Green Chemistry Strategies for Enhancing Wood Surface Hardness

Vahideh Akbari^{P*} (Laval University), Véronic Landry (Laval University)

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Abstract

The construction sector accounts for 40% of global greenhouse gas emissions, with building materials and construction alone responsible for 10%. As this trend is expected to rise by 2030, adopting green materials, particularly wood, offers a sustainable solution. While wood is renewable and widely used in residential buildings (71% market share), its low hardness and flammability limit its application in non-residential structures (4%). Wood densification enhances density, hardness, and durability of wood, improving its suitability for broader construction use. 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 for interior applications. This study develops bio-based densification formulations to enhance surface wood hardness using two approaches: a single-cure system via in-situ polymerization through Michael-addition and a dual-cure strategy combining Michael-addition and photopolymerization. Both reactions are green chemistry reactions, conducted in mild conditions with minimizing solvent consumptions, aimed to enhance wood densification. To facilitate industrialization of the final products, the proposed methods are simple with high reaction rate and low energy usage toward reducing cost and environmental impacts. The research comprises two phases: formulation evaluation and application on wood samples. Various formulations were assessed based on conversion rates (real-time infrared spectroscopy), glass transition temperature and crosslinking density (dynamic mechanical analysis), and film hardness (pendulum test). The most effective formulations were then used to impregnate sugar maple, and their densification performance based on chemical retention, density profile, surface hardness, morphology and formulation penetration were examined. Moreover, statistical comparisons were conducted using ANOVA data analysis to verify results. 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.

10:30 AM – 12:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 8.1 - Trends in Education and Workforce Development Practices in Forest Products-related Disciplines I

~ Session Organizers - Gloria Oporto (West Virginia University), Nayomi Plaza (USDA FS Forest Products Laboratory)

~ Moderators - Nayomi Plaza and Gloria Oporto

SWST Accreditation: Shaping the Future of Wood Science and Technology Education and its Role in the Forest Products Industry

Judith Gisip^p (Universiti Teknologi MARA), Eric Hansen (Oregon State University)

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Abstract

The Society of Wood Science and Technology (SWST) accreditation is crucial in ensuring wood science and technology programs remain relevant, industry-aligned, and future-ready. As the forest sector evolves with shifting global markets and growing sustainability demands, the need for highly skilled professionals is more pressing than ever. SWST accreditation establishes rigorous standards, equipping graduates with the knowledge and skills necessary to thrive in the industry. However, awareness of accreditation's benefits remains limited, and many programs could better leverage it to enhance curriculum, strengthen industry connections, and boost global recognition. This presentation provides an overview of SWST accreditation and its role in shaping the future of wood science and technology education through maintaining program quality, fostering interdisciplinary approaches, and supporting the long-term success of the forest products industry.

Developing a Standardized Wood Education Framework to Promote Sustainable Wood Utilization

Jiyeon Yang^p (National Institute of Forest Science), Keon-Ho Kim (National Institute of Forest Science), Chang-Deuk Eom (National Institute of Forest Science), Su-Yeon Lee (National Institute of Forest Science), Joo-saeng Park (National Institute of Forest Science)

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Abstract

As climate change and environmental issues gain increasing public attention, there is a growing need for education that fosters sustainability awareness. Although many individuals recognize the importance of addressing environmental challenges, they often lack sufficient information on practical solutions. Wood, a renewable and carbon-storing material, is crucial for sustainable development. However, current public education systems provide limited information on wood and its benefits. This study aims to develop a standardized wood education framework to address this gap by integrating wood-related content into formal education. Based on an analysis of public perceptions and educational needs, the framework establishes clear educational goals and directions tailored to different developmental stages. It aligns with national curricula and provides structured programs for preschool, elementary, middle, and high school levels. We developed five programs tailored to each school level and incorporated hands-on woodworking activities to enhance experiential learning. This framework aims to improve students' understanding of wood's environmental, social, and economic value by systematically introducing wood education at various educational stages. The study also highlights the importance of equipping educators with comprehensive resources to implement wood education effectively in classrooms. This research contributes to the promotion of sustainable wood utilization by bridging the gap between public interest in environmental issues and the lack of available educational content. The proposed framework serves as a foundation for integrating wood education into formal curricula, fostering a generation that values and utilizes wood sustainably.

Sustainable Design Education: A Path Towards Sustainable Design Education

Rico Ruffino^P (North Carolina State University)

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Abstract

Sustainable design education in materials and wood programs typically covers wood structure, anatomy, mechanics, chemistry, processing, and composites but often neglects design. As a sustainable designer, I encounter unique challenges that lead to different perspectives from traditional ones. Key factors shaping the course direction and my educational path include the number of classes, the most relevant topics, interpretations of sustainability in design, and new technologies that foster sustainable outcomes while engaging students. A practical educational approach emphasizes interactivity and hands-on learning. It utilizes technology to its fullest potential through engaging learning practices and tools. My toolkit for achieving these learning methods includes various CAD programs, virtual reality (VR), AI tools, CAD tables, CNC machines, and 3D printing technology. The primary methods of instruction used are standard lectures and lab-based learning. While preserving this basic formatting, I incorporate diverse strategies within my classroom, including personalized learning, blended learning, project-based learning, student-centered learning, and design thinking. This procedure ensures that the students' various educational needs are addressed, accommodating their learning styles. What impact does sustainable design have on student learning? A quantitative method to gauge the impact of sustainable design courses on student comprehension over time is what I refer to as a "sustainable design folio chronicle." This visual representation showcases student achievements over time in courses related to sustainable design. It represents how they learn and progress with the knowledge received. Prospective steps for the sustainable design course involve starting with reality-based experiences that identify issues and then creatively working toward solutions by reverse engineering the classroom. For example, students may visit landfills to witness the waste problem firsthand. These experiences will be paired with interactive lectures and challenges, focusing on finding and implementing practical solutions.

Mass Timber & Circular Economy: Preparing the Next Generation of Wood Industry Leaders

Allison Culver^P (Oregon State University), Mariapaola Riggio (Oregon State University), Eric Hansen (Oregon State University)

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Abstract

The Department of Wood Science and Engineering at Oregon State University (OSU) is launching an online, non-thesis Master's degree in Wood Innovation for Sustainability (WINS), with tracks in Mass Timber and Timber Circular Economy. As a leader in wood science education, OSU's College of Forestry, in collaboration with the TallWood Design Institute, is well-positioned to deliver this program, expanding access to transformative education for professionals in the wood products industry and beyond. Currently, most wood science & engineering degrees are only available on campus, which is limiting access for industry professionals. The WINS program is especially designed for place-bound employees, enhancing their career advancement and economic mobility while equipping them with unique skills in two highly competitive and sought-after fields. The curriculum integrates five core areas: (1) wood science fundamentals; (2) specialized knowledge in mass timber or circular economy; (3) engineering and business technical skills; (4) communication and management expertise; and (5) professional responsibility and ethics. Additionally, students complete a comprehensive internship, applying knowledge to real-world challenges. Graduates of the Mass Timber track will be equipped to drive innovation across various sectors of the industry's supply chain, including advanced manufacturing, digital fabrication, engineering, and construction management. Graduates of the Circular Economy track will advance sustainable industry practices, enhancing resource efficiency in wood-product manufacturing and the wood construction sector. They will develop solutions to reduce environmental impact through improved processes, bio-based materials, and waste reduction strategies, aligning with society's commitment to lowering its carbon footprint. By expanding access to industry-focused, high-impact education, the WINS program will help shape the future of sustainable wood innovation.

Session 8.2 - Sustainable Advanced Manufacturing of Value-added Wood Products through Innovative Pathways IV

~ Session Organizers - Daniel Saloni (North Carolina State University), Frederik Laleicke (North Carolina State University)

~ Moderators - Daniel Saloni and Frederik Laleicke

PFAS-free Molded Pulp Trays: Effects of Pulp Type, Refining Level, and Cellulose Nanofibrils or Biowax Addition on Tray Performance

Jinwu Wang^p (USDA FS Forest Products Laboratory), Seongkyung Park (University of Maine), Colleen Walker (University of Maine)

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Abstract

Polyfluoroalkyl substances (PFAS) are commonly used in food packaging for thermal and liquid resistance but pose significant risks to human health and the environment. This study investigates PFAS-free molded pulp trays, focusing on the effects of pulp type, refining level (freeness), cellulose nanofibril (CNF), or biowax addition on tray performance. Trays were produced using a pilot-scale wet molding machine with four pulp types: Northern Bleached Hardwood Kraft (NBHK), Northern Bleached Softwood Kraft (NBSK), Southern Bleached Softwood Kraft (SBSK), and Northern Unbleached Softwood Kraft, refined to varying freeness levels. Refining significantly influenced physical, mechanical, and barrier properties. Lower freeness (finer pulps) generally produced denser trays with lower bulk and thickness, better tensile properties, and higher oil resistance. NBHK pulps were highly sensitive to freeness, showing strong performance at low freeness but significant deterioration at higher levels. NBSK pulps maintained a good balance of strength and stability, while SBSK exhibited intermediate performance. Northern Unbleached Softwood Kraft provided the most consistent performance across all freeness levels, excelling in compression and tensile strength. Barrier properties, such as porosity (Gurley seconds) and oil absorption, correlated strongly with freeness. Refining reduced porosity, increasing resistance to air and oil permeability. CNF addition to NBHK pulp improved oil resistance while maintaining higher absorption than softwood pulps, but unbleached softwoods were more effective for enhancing barrier properties. Results highlight optimizing suction times, refining levels, and material selection to achieve desired tray properties. Low freeness enhances strength, while medium freeness offers a balance of properties. Unbleached softwood pulp shows promise for applications requiring consistent performance and robust barrier properties, whereas bleached pulps perform well in high-strength applications. These findings inform strategies for developing sustainable, PFAS-free molded pulp packaging.

Design, Development, and Evaluation of Cellular Beams as Lightweight Alternatives to Glulam

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Abstract

With rapid population growth, the demand for sustainable and high-performance mass timber construction has increased significantly. To enhance the resilience and health of our forests, sustainable forest management practices, such as mechanical thinning, are crucial. However, this process produces large quantities of underutilized small-diameter trees (SDT). Converting low-value SDT into high-performance engineered wood products offers a valuable opportunity to maximize resource efficiency while promoting sustainable forestry. This study focuses on developing a novel cellular beam using wood strands from underutilized small-diameter trees. To identify the most effective configuration, different orientations of corrugated panels for the development of the cellular core were evaluated through four-point bending tests. Experimental results revealed that one of the configurations achieved a specific bending stiffness 18% higher than that of glulam beams, while its specific maximum bending load was nearly competitive, being only 2% lower. These findings highlight the potential of cellular beams as lightweight, high-performance alternatives to conventional glue-laminated timber, while also underscoring the need for further optimization of core geometry. A linear finite element (FE) model was developed in the virtual environment of Abaqus FE software to further improve the structural performance of cellular beams by designing new corrugated geometry. Therefore, a parametric study was conducted to understand the influence of core geometry on the flexural stiffness of the cellular beam. Based on the insights gained from parametric study, a new corrugated core geometry was selected and designed, resulting in a 9% increase in bending stiffness compared to the initial design. Using an aluminum matched-die mold, the new corrugated geometry and associated cellular beams were fabricated. The bending results of this beam exceeded our design expectations. By transforming SDT into high-value structural products, this research provides a sustainable alternative to conventional mass timber while promoting efficient forest resource utilization.

Valorization of Mixed Municipal Solid Waste to Biochar

Harrison Appiah^{P*} (University of Idaho), Armando McDonald (University of Idaho), Ezra Bar-Ziv (Michigan Technological University), Jordan Klinger (Idaho National Laboratory)

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Abstract

Municipal Solid Waste (MSW) management has become increasingly critical due to rapid urbanization and population growth. The significant biomass content in MSW presents an opportunity for value-added product development. This study investigated (i) Xylene extraction of plastics from Utah and Michigan MSW to afford an MSW-biogenic fraction and (ii) characteristics of raw MSW and biochar derived from MSW's biogenic fractions, pyrolyzed between 400-500°C. FTIR compositional analysis of MSW samples was shown to contain polyethylene, polypropylene, polystyrene, and polyethylene-terephthalate. Solvent extraction of the MSW yielded plastic fractions of 26% and 32%. Chemical analysis of the biogenic fraction revealed carbohydrates (52-60%), lignin (32-34%), and ash (11-14%). The biogenic MSW was subjected to pyrolysis using an Auger reactor under nitrogen flow and residence time of 6.4s. Product yields showed temperature dependence, with optimal biochar yield (69.1%) achieved at 450°C for Utah samples. Bio-oil yields decreased with an increase in temperature, reaching 9.1% at 500°C. The biochar exhibited a range of calorific values (13-27 kJ/g), with Michigan-biogenic biochar at 500°C achieving 27 kJ/g. DSC analysis revealed that some of the biochar still contained plastic. GC-MS and FTIR analysis of the pyrolysis oil showed the presence of alkenes, alkanes, lignin-degraded compounds, and carbonyl groups. Biochar characterization included chlorine content (Utah: 47 ppm, Michigan: 40 ppm), ash content, volatile matter, fixed carbon, BET surface area, Raman spectroscopy, and thermogravimetric analysis. The results demonstrate potential applications for upcycled MSW biochar in wastewater treatment, soil remediation, and composite materials, advancing circular economy principles.

Pine Bark Tannins as a Viable Alternative to PRF for use in Printed Biocomposites

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Abstract

Embracing sustainable and bio-based alternatives within the construction industry could substantially mitigate the burgeoning environmental impact. One promising option is pine bark tannin, a natural polyphenolic compound derived from pine trees, which serves as a renewable and eco-friendly substitute for adhesives in additive construction. The objective of this study is to develop a pine bark tannin-based resin specifically designed for 3D printing of wood composites, as an alternative to synthetic resins such as phenol-resorcinol-formaldehyde (PRF). Tannin was extracted from the bark of ponderosa and radiata pine using a hot water extraction method, and its chemical structure, quality, and molar mass were characterized through FTIR, NMR, and ESI/MS spectral analyses. Subsequently, the tannin extract was either used neat or blended with commercial PRF resin in a 1:1 ratio, followed by the addition of a hardener. The performance of the tannin-based resins was compared to that of commercial PRF resins in terms of rheology and lap shear adhesion tests and demonstrated competitive performance relative to PRF resin. Wood composites (50% wood particles and 50% resin (tannin, PRF-tannin, and PRF) were prepared by compression molding (10 min at 150°C) and flexural and water soak properties determined. In addition, the wood composites (50/50 wood-resin) blends were extruded into rods and evaluated for their rheological and flexural properties and the results will be further discussed in detail. Overall, this research offers an approach for producing sustainable adhesives for use in construction applications within the built environment.

1:30 – 3:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 9.1 - Trends in Education and Workforce Development Practices in Forest Products-related Disciplines II

~ Session Organizers - Gloria Oporto (West Virginia University), Nayomi Plaza (USDA FS Forest Products Laboratory)

~ Moderators - Gloria Oporto and Nayomi Plaza

Outcomes of Woodisbest Promotion and Recruiting Activities

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Abstract

At the 2021 SWST Annual Convention, Bob Smith of Virginia Tech led a conversation about how wood-focused programs might cooperate to collectively promote our programs. This initial conversation led to a series of virtual conversations and a commitment by a consortium of 10 universities to jointly develop a promotion and communications campaign. The consortium is made up of: Auburn, Idaho, Maine, Michigan Tech, Mississippi State, North Carolina State, Oregon State, Purdue, West Virginia, and Virginia Tech. Each university made an initial investment to engage with a professional marketing firm, Monte. Extensive background information was gathered by Monte and a conceptual approach developed. The first conceptual approach was presented in the 2023 Annual Convention. Reaction and feedback from that meeting resulted in a major change in the imagery used in the campaign. This presentation will provide an overview of the two cycles (23/24 & 24/25) of promotion conducted through the Woodisbest.com site and associated social media campaigns.

Promotion of Sustainable Materials & Technology Undergraduate Program at the University of Maine

Ling Li^p (University of Maine), Mehdi Tajvidi (University of Maine), Xuefeng Zhang (University of Maine)

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Abstract

This presentation will highlight the efforts made by the faculty members at the School of Forest Resources of the University of Maine in the past three years to promote the sustainable materials and technology (SMT) undergraduate program and increase student enrollment. Some examples include 1) developing a double major in SMT and Construction Engineering Technology, 2) developing a research learning experience (RLE) course during the bridge week for the incoming first-year students to establish research interest in SMT, 3) securing federal grants to support outreach activities, like running a summer camp for high schoolers. Through making these efforts, the UMaine SMT program has been growing.

Women in the Woods: A New Forestry Education and Outreach Program at Louisiana Tech University

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Abstract

The ***Women in the Woods*** program at Louisiana Tech University was developed to increase female participation in the forestry profession via mentorship, community outreach, and experiential learning. Forestry has long been a male-dominated field. Recent studies have shown young women may not consider forestry as a possible profession because they do not see other women who are educated and/or work in this area of STEM. Thus, experiential learning from female foresters, as well as developing of professional relationships with these women, may encourage future generations of women to pursue education in forestry-related disciplines, and even become foresters. This innovative education program has three components. First, we are developing forestry-related teaching resources K-12 teachers in Louisiana may access online. These teaching resources will include activities, worksheets, and instructions for in-class experiments related to forestry. Second, we seek opportunities to educate children, especially young girls, about forestry and all associated areas of this profession. Such opportunities include local farmers' markets, federal agency community events, state agency community events, and student youth organizations. At these events, we have experiential learning opportunities in forestry to introduce young people to career possibilities in the field. Last but not least is a well-designed annual workshop for high school girls, where female forestry professionals are invited to give presentations and share their work and life experiences to help train young women in forestry, build their self-confidence, teach them to balance their personal and professional lives and develop leadership and problem-solving skills.

Innovative European Master's Program in Forestry, Wood Technology, Economics, and Sustainability: The Virtual Wood University Initiative

Jaan Kers^p (Tallinn University of Technology), Guenter Berger (Salzburg University of Applied Sciences), Ilkka Tarvainen (LAB University of Applied Sciences), Hubert Speth (Baden-Wuerttemberg Cooperative State University), Erika Olofsson (Linnaeus University), Andrea Stuebner (Weihenstephan-Triesdorf University of Applied Sciences), Arnaud Besserer (Université de Lorraine), Bartłomiej Mazela (Poznań University of Life Sciences), Vjekoslav Živković (University of Zagreb)

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Abstract

The *Virtual Wood University Master Program* (VWU_MASTER) is a pioneering initiative aimed at developing a joint European blended or online master's program in forestry, wood technology, economics and sustainability. Led by Salzburg University of Applied Science in partnership with eight distinguished universities from across Europe. This project seeks to equip future industry leaders with cutting-edge, interdisciplinary knowledge while fostering cross-border academic cooperation. The curriculum will be collaboratively designed to integrate sustainable management principles of natural resources, processing technologies, digital transformation, and innovative teaching methodologies. By aligning with the *European Approach for Quality Assurance of Joint Programmes*, the initiative aspires to establish a seamless accreditation framework that will set a precedent for future international programs. The project focuses on ensuring inclusivity and accessibility by providing digital and flexible learning pathways including industry professionals and individuals from geographically remote areas. The implementation strategy includes four key pillars: (1) the collaborative development of a comprehensive master's curriculum, (2) the preparation and execution of the European accreditation process, (3) the establishment of operational frameworks for institutional collaboration, and (4) a robust communication and dissemination strategy to engage stakeholders and maximize impact. The methodology involves an iterative approach, incorporating stakeholder feedback, SWOT analysis of existing programs, and scenario planning to ensure adaptability. Expected outcomes include an accredited master's program recognized across Europe, a structured framework for university cooperation, and a digital learning environment enriched with industry engagement. The long-term vision is to create a sustainable and scalable educational model that can be replicated for future European joint degrees. This project will contribute significantly to higher education internationalization, the digitalization of learning, and the sustainable management of natural resources.

Extended Reality-Assisted Equipment Setup & Safety Learning Tool

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Abstract

This project explores how Extended Reality (XR) can enhance students' training with complex machinery at the University of British Columbia's Centre for Advanced Wood Processing. By utilizing high-definition XR headsets, we are developing interactive guides for equipment setup, maintenance, safety, and troubleshooting. Through XR, students receive step-by-step visual instructions overlaid directly onto the machine, enabling safe and immersive "learning by doing." Currently, we are focusing on non-operational tasks, such as initializing equipment, changing tools, setting up safety systems, and troubleshooting – primarily to ensure safety and because the integration of XR into technical training is still in its early stages. By practicing in a controlled, self-paced environment, students build confidence and technical understanding before transitioning to live machinery operations. The ultimate goal is to develop a reusable teaching tool that enhances safety and engagement while helping students master essential technical skills. The broader ambition of this project is to establish a framework for AR-assisted technical training, potentially benefiting hands-on applications in various disciplines.

Experiences in Teaching and Developing Models for Mass Timber (Design and Construction) Curricula in Institutions of Higher Education

Carlos Lee^p (University of Puerto Rico Mayagüez), Ingrid Arocho (Oregon State University), Francisco Maldonado (University of Puerto Rico Mayagüez), Christopher Papadopoulos (University of Puerto Rico Mayagüez)

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Abstract

Substituting traditional materials used in the built-environment such as reinforced concrete and structural steel with forest-based building products can help reduce greenhouse gas (GHG) emissions from the construction sector. In the USA, the demand for buildings constructed with Mass Timber (MT) products, including cross laminated and glue laminated timber, has grown exponentially during the last 15 years. Academia must meet the growing demand for professionals with skills needed for designing and constructing with MT. The supply of newly trained teaching faculty in MT architecture, civil/structural and construction engineering is extremely limited. The University of Puerto Rico - Mayagüez began addressing the lack of guidance and roadmaps on how to build faculty capacity in 2022. This presentation will include the experiences in teaching about MT design and construction at an institution of higher education (IHE): 1) in civil/construction engineering undergraduate and graduate level courses; and, 2) in a course open to the entire undergraduate community. Current literature and research on developing models for introducing MT curricula at an IHE will also be presented.

Session 9.2 - Sustainable Advanced Manufacturing of Value-added Wood Products through Innovative Pathways V

~ Session Organizers - Daniel Saloni (North Carolina State University), Frederik Laleicke (North Carolina State University)

~ Moderators - Daniel Saloni and Frederik Laleicke

Evaluation of Polybutylene Succinate Composites Reinforced with Lignin and Milled Hemp Stalks Nnaemeka Ewurum and Armando McDonald Department of Forest and Fire Sciences, University of Idaho, Moscow, ID 83844-1132, USA

Nnaemeka Ewurum^{P*} (University of Idaho), Armando McDonald (University of Idaho)

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Abstract

This study examines the effects of kraft lignin, milled hemp stalks, and dicumyl peroxide (DCP) crosslinking on polybutylene succinate (PBS) composites, focusing on rheological, mechanical, thermal, and weathering properties. Two composite series were produced via twin-screw extrusion: (a) simple blends (B-series) and (b) DCP-crosslinked formulations (R-series), with emphasis on hybrid lignin-hemp composites (B-PLH and R-PLH).

Rheological analysis showed that hemp fiber increased viscosity, while lignin reduced it, and DCP further enhanced shear-thinning behavior. Mechanical testing confirmed that R-PLH exhibited a 16% increase in flexural strength (42.6 MPa) and a 2.4-fold increase in flexural modulus (1785 MPa) over neat PBS. Thermal analysis revealed a 14–26% reduction in mass loss rate and increased char formation (up to 16.3% in R-PLH), indicating improved thermal stability. Water absorption tests showed that hemp fibers increased hydrophilicity, further exacerbated by DCP. Accelerated weathering led to significant color change and surface degradation, particularly in R-PLH. Overall, B-PLH and R-PLH offer a balance of stiffness, thermal stability, and controlled hydrophilicity, though trade-offs in tensile strength and weathering resistance should be considered for sustainable applications.

Enhancement of Thin Aspen Veneer Quality in Rotary Peeling

Heikko Kallakas^p (Tallinn University of Technology), Catherine Kilumets (Tallinn University of Technology), Kaur Tootsi (Tallinn University of Technology), Jaan Kers (Tallinn University of Technology)

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Abstract

European aspen (*Populus tremula*) is a fast-growing hardwood species, reaching about 30 meters in height. It is diffuse-porous and frost hardy, resisting deformation under low temperatures during preconditioning of the peeler block. Aspen is used in the pulp and paper industry, transportation boxes, wooden handles, and sauna interiors due to its low thermal conductivity. To diversify aspen products, further research into processing techniques like rotary peeling is needed. However, aspen tends to create rough surfaces and breaks when veneer thickness is below 1 mm, and there is no available data on aspen veneer peeling parameters. This study aims to identify optimal parameters for peeling thin aspen veneer, targeting a green veneer thickness of 0.3 mm. Conventional high-temperature soaking methods for peeler blocks proved counterproductive, as aspen's high cellulose content and loose fibers become too soft, resulting in poor-quality veneers. Therefore, an alternative preconditioning method was necessary. Our hypothesis is that reducing preconditioning temperature helps maintain cellulose fiber integrity during rotary peeling, enabling thin veneer production. We experimented with different conditioning and soaking times, testing peeler block temperatures from -30°C to 10°C, with and without water soaking. The goal was to determine which conditions result in more successful peeling tests. Preliminary results showed that peeler block temperatures below freezing yielded good results, while higher temperatures did not produce acceptable veneer quality. Although high-quality veneer was obtained at very low temperatures, further testing is needed to expand the range of parameters for evaluating veneer yield and surface properties.

Enhancing the Mechanical Properties of Wood through Cellulose Nanocrystal Impregnation: A Sustainable Approach for Engineering Wood Quality

Dilpreet Bajwa (Montana State University), Ismat Ara^P (Montana State University), Nicole Stark (USDA FS Forest Products Laboratory), Joseph Jakes (USDA FS Forest Products Laboratory)

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Abstract

Wood modification through the impregnation of cellulose nanocrystals (CNC) presents a transformative approach to enhancing its mechanical properties while maintaining environmental sustainability. This study investigates the effect of CNC impregnation on fast-growing southern yellow pine (SYP) wood and commonly used hardwood beech veneer, focusing on the role of delignification in optimizing CNC penetration and performance. Results indicate that sodium hydroxide treatment alone did not significantly alter the SYP wood's modulus of rupture (MOR) and modulus of elasticity (MOE), suggesting insufficient delignification. However, beech veneer samples treated with 2% sodium hydroxide for 2.5 hours exhibited a reduction in lignin content from 19.5% to 16.5%, facilitating CNC uptake. CNC impregnation in beech veneer increased cellulose content from 35.4% to 38.9%, leading to significant improvements in MOR (39%), MOE (48%), and Janka ball hardness (20%). Further experiments explored ultrasonication and pressure-assisted impregnation, revealing that higher ultrasonication time and pressure enhanced mechanical performance, albeit inconsistently. Microstructural analyses using atomic force microscopy, scanning electron microscopy with energy-dispersive X-ray spectroscopy, micro-computed tomography (microCT) and nanoindentation confirmed CNC integration within the wood matrix, with treated beech veneer samples displaying increased elastic modulus and hardness. The findings demonstrate the potential of CNC-modified wood for high-performance applications in construction, naval engineering, and advanced composites, contributing to sustainable material development and economic growth as well as offering an eco-friendly alternative to conventional wood treatments.

Optimizing Key Parameters: Temperature, Equilibrium Moisture Content, and Pressure for Effective Wood Densification

Tolgay Akkurt^{a*} (Tallinn University of Technology), Anti Rohumaa (South Eastern Finland University of Applied Science), Jaan Kers (Tallinn University of Technology)

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Abstract

Due to increasing environmental concerns and sustainability demands, enhancing wood properties has become essential, especially for veneer-based products. The scarcity of high-quality wood necessitates improving properties such as strength, surface smoothness, and impact resistance. Densification has emerged as a key method for achieving these improvements, with various approaches including mechanical, thermo-mechanical, and hygrothermal-mechanical densification. While many studies have explored the effects of densification parameters—temperature, equilibrium moisture content (EMC), pressure, and pressing duration—most have varied only one parameter at a time. This study adopts a holistic approach by systematically investigating all key parameters simultaneously to determine optimal conditions for birch veneer densification. Birch veneers were densified in the radial direction using four temperatures (90 °C, 130 °C, 170 °C, and 210 °C), three pressures (1.8 MPa, 3.6 MPa, and 5.4 MPa), three EMC levels (5%, 12%, and 20%), and two pressing durations (8 and 16 minutes), resulting in 72 unique parameter combinations. Results showed that higher pressure and higher initial EMC led to greater densification. Optimal densification was achieved under two conditions: (1) 90 °C with high EMC and high pressure, and (2) 210 °C with high EMC and high pressure. Intermediate temperatures did not produce expected improvements in densification, despite being higher than 90 °C. Temperatures above 200 °C were critical as lignin transitions past its glass transition temperature at this point. These findings provide new insights into the combined effects of densification parameters and offer improved guidance for industrial applications to enhance the properties of veneer-based wood products.

In Situ Delignification of Lumber Through Self-Flow Process B

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Abstract

Wood has complex composition and structure, which make it difficult to achieve consistent and controllable treatment. A self-flowing process presented for the chemical treatment of wood is inspired by liquid transportation in trees during photosynthesis and tree growth, whereby liquid in the soil is brought through the natural vessels and/or fiber tracheids. In this process, wood lumbers are placed in a tank containing treatment chemicals such as preservatives, fire retardants, or reactive agents. Through an absorbent sheet bridging the untreated lumber to an overflow tank, the chemicals are drawn into the lumber under capillary force and pressure difference, so that continuous treatment occurs inside the wood. Effectiveness of the self-flowing process is evaluated and compared to conventional immersion and vacuum wood treatment methods. The self-flowing method is very effective for wood delignification, which is six and four times more effective than that from immersion and vacuum pressure treatment methods, respectively. The self-flowing process allows a more uniform wood treatment compared to that from the immersion and vacuum pressure methods. A mathematical model was developed to describe the self-flowing process. This model can accurately predict the treatment time required for achieving desired results under various conditions.

3:30 – 5:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 10.1 - Trends in Education and Workforce Development Practices in Forest Products-related Disciplines III

~ Session Organizers - Gloria Oporto (West Virginia University), Nayomi Plaza (USDA FS Forest Products Laboratory)

~ Moderators - Nayomi Plaza and Gloria Oporto

Understanding How Wildfire Hazard Reduction Treatments Across the Western US Will Affect Labor Markets

Jaana Korhonen^p (Oak Ridge Institute of Science and Education), Jeffrey Prestemon (USDA FS Southern Research Station)

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Abstract

Achieving forest management goals of reducing wildfire impacts in the forest lands, managed by the Forest Service, depends in part on the availability of a workforce to plan and manage the treatments (typically federal employees); complete the treatments and transport materials to a production facility (typically private logging and forestry employees) as well as production workers to process timber into saleable products (typically primary wood processing mill workers). In this presentation, we delve into the implications of anticipated wildfire reduction treatments on labor needs and production capacities within Wildfire Crisis Strategy landscapes, as an empirical example of labor market interactions in the interphase of public-private sectors. We quantify the employment impacts in the logging and related forest product sectors using a negative binomial regression model. The initial results indicate regional and temporal variation in the effects of these treatments. Furthermore, the findings suggest that employment supply in the logging sector is quite inelastic, raising concerns about the capacity to increase treatment quantities on the ground and discuss potential implications further in the value chain.

Wood Science Education in the United States: A Comprehensive Review of Challenges, Strategies, and Future Directions

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Abstract

Wood science education in the United States has reached a critical stage, facing significant challenges that threaten academic programs' sustainability and relevance. This review examines the historical context, current state, and future of wood science education in the United States, focusing on identifying the factors contributing to declining undergraduate enrollment and evaluating the effectiveness of strategies used or discussed by universities to address these challenges. Despite the initial growth of wood science programs through the 1970s, enrollment has been steadily declining since the 1980s. This review identifies factors contributing to this decline, including poor perceptions of the discipline, assumptions about limited career opportunities, shifting industry needs, and competition from emerging interdisciplinary fields. Universities at different times have tried to deal with the enrollment challenges with strategies, such as curriculum changes, rebranding efforts, adding new majors, merging with other departments, offering online programs, and increasing recruitment efforts. However, these strategies have not yielded the expected results, suggesting a need for a more comprehensive and coordinated approach to revitalizing wood science education. The review argues that ensuring the long-term sustainability and relevance of wood science education requires a critical re-evaluation of program structures, curricula, and recruitment strategies. Recommendations include establishing consistent program nomenclature, updating and ensuring uniformity of curricula that meet industry needs and challenges, and developing targeted recruitment approaches in collaboration with forestry schools and industry partners. Collective efforts from the wood science education community are urgently needed given the growing demand for sustainable materials and wood-based solutions to global environmental challenges. Improving wood science education is crucial to train undergraduates with the right skills to advance the wood industry and ensure sustainability. This review aims to stimulate debate and action among wood science academics, educators, and industrial stakeholders for a thoughtful analysis, recommendations, and futuristic ideas.

Session 10.2 - Mass Timber Research and Innovation I

~ Session Organizers - Hongmei Gu (USDA FS Forest Products Laboratory), Daniel Hindman (Virginia Tech)

~ Moderators - Hongmei Gu and Nan Nan

Flexural Properties of Homogeneous and Hybrid Cross-Laminated Timber

Levente Denes^P (West Virginia University), Balazs Bencsik (West Virginia University), Eduardo Sosa (West Virginia University), Curt Hassler (West Virginia University), Gloria Oporto (West Virginia University), Jonathan Norris (West Virginia University), Joseph McNeel (West Virginia University)

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Abstract

In this study, the flexural properties of homogeneous and hybrid hardwood CLT were investigated using non-destructive (NDT) and destructive testing methods.

Phenol-resorcinol-formaldehyde (PRF) and one-component polyurethane (1C-PUR) adhesives were used to fabricate CLT panels of homogeneous red oak, red maple, and hybrid red oak – yellow poplar, red maple - yellow poplar panels. NDT measurements on the CLT beams were performed using transverse vibration (TV) and longitudinal stress wave timing (SWT) techniques. Using yellow poplar for the transverse layer did not significantly affect the modulus of elasticity (MOE) and modulus of rupture (MOR) of the CLT specimens but resulted in a density reduction of 9% to 12%. Using PRF adhesive resulted in a higher average MOR than PUR, but the difference was significant only in the case of the red maple species. A strong linear regression was observed between the dynamic MOE and the static mechanical properties, especially between $MOE_{d,SWT}$ and MOR of the homogeneous CLT samples. Non-destructive testing methods (TV, SWT) allow the prediction of static mechanical properties for hybrid hardwood CLT with nearly the same level of accuracy as for homogeneous hardwood CLT. From a utilization perspective, hybrid CLT made from hardwood species can be an excellent choice when high mechanical performance is required along with moderate product density.

Shear and Bending Properties of Homogeneous and Hybrid CLT Panels Fabricated from Low-value North American Hardwood Species

Oral Bencsik^p (West Virginia University), Levente Denes (West Virginia University), Joseph McNeel (West Virginia University), Curt Hassler (West Virginia University), Eduardo Sosa (West Virginia University), Gloria Oporto (West Virginia University), Jonathan Norris (West Virginia University)

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Abstract

This study examines the mechanical properties of the homogeneous and hybrid lay-up cross-laminated timber (CLT) made from red oak, red maple, and yellow poplar. For the three-layer CLT manufacturing phenol-resorcinol-formaldehyde and polyurethane adhesives were used. A variable-span regression model was used to assess the effective bending stiffness and shear properties of CLT panels. The results showed that the span-to-depth ratio significantly affects the effective and apparent bending modulus ratios and varies slightly by lay-up configuration. A strong linear correlation ($r^2 = 0.735$) was found between the apparent and effective modulus of elasticity, allowing the prediction of effective modulus from apparent values. The effect of the applied adhesive was insignificant on the performances tested. The lay-up configuration significantly affected the shear strength performance. While hybrid CLTs had approximately 30% lower shear strength than homogeneous ones, their performance still exceeded softwood CLTs, with shear strengths ranging from 2.38 N/mm² to 2.52 N/mm². On average, the shear analogy model underestimated the effective bending stiffness by 8.9% and the shear stiffness by 74.8% across different CLT configurations. The numerical simulation results for the stiffness properties of each CLT panel type show a reasonable agreement with the experimental test data. These findings highlight the potential of hardwood CLT to improve structural performance, especially in bending, although shear limitations in hybrid configurations should be considered.

Quasi-static and Cyclic Testing of Half-Lap Cross-Laminated Timber Pegged Joints

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Abstract

Typical attachment methods of CLT floor panels rely upon the use of various CLT profiles (butt, half lap, spline) and the use of metal fasteners to generate shear strength and stiffness between the panels. With growing concerns over the carbon emission output and the global warming potential (GWP) of erected structures, it is important to understand the impact material choices have on the structure as a whole. In a traditional GWP analysis, fasteners are commonly ignored as insignificant relative to the building as a whole. However, for CLT structural systems, the carbon footprint associated with steel fasteners may become significant. As such, there may be a need for connection methods maintaining a lower carbon footprint of the entire floor system. One possible solution is the use of hardwood dowels (pegs) from traditional timber joinery techniques. The purpose of this study was to measure the quasi-static and cyclic connection performance of CLT half lap joints using hardwood dowels. Two different size of dowels were used, and both softwood (Austrian pine) and hardwood (yellow-poplar) CLT specimens were tested. Comparisons of test data with current metal connections were made. By determining the capacities of dowel connections, dowel spacings required to resist forces in the connection will be available for use in design. This research may allow for some aesthetic benefits to the CLT floor and ceiling as the dowels are more natural looking and may provide a unique aesthetic, and this work hopes to further inspire research into more traditional methods for joining mass timber buildings that are more structurally and carbon efficient.

Dimensional Stability of Green Assembled Dowel Laminated Timber

Paul Mayencourt^p (University of California Berkeley), Maximilian Pramreiter (BOKU University), Johannes Konnerth (BOKU University)

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Abstract

Proper wood drying and adhesive application are considered key factors in the manufacture of modern Mass Timber products like Glue Laminated Timber (GLT) and Cross Laminated Timber (CLT). Both process steps contribute significantly to the environmental impact of these products, as they require high amounts of energy and, in the case of adhesives, fossil-based raw materials. Adhesive-free products such as Dowel Laminated Timber (DLT) offer a fully bio-based alternative, while also being easier to recycle and reuse. In order to further increase the environmental potential of these products, the dimensional stability of green assembled DLT beams was investigated. This could further decrease the energy demand and storage costs and improve their overall environmental impact. Therefore, five undried dimensional lumber boards were joined together using hardwood dowels. Subsequently, six assemblies each were stored outdoors and in a solar kiln, while individual boards (ten each) were used as a reference for shape retention. Two different dowel patterns were chosen to investigate the influence of the dowel position on the dimensional stability of the assembly. The total width and the gaps between the boards at each dowel location were measured in order to evaluate the dimensional stability. Over the course of four weeks a significant decrease of moisture content was observed for the outdoor as well as solar kiln samples. The overall shape of the beams was retained compared to the reference boards and only few cracks were observed. A slight increase in gaps between the boards was recorded, which is in line with initial assumptions. In conclusion, the suitability of green dimensional lumber for the production of DLT was successfully demonstrated. These results support an easy up-scaling of value-added production in less-developed Mass Timber markets with the added benefit of lower investment costs for solar kilns compared to conventional kilns.

A Wood-science-based Approach to Evaluate the Moisture Performance and Long-term Durability of Mass Timber

Natalia Farkas^p (USDA FS Forest Products Laboratory), Samuel Glass (USDA FS Forest Products Laboratory), Samuel Zelinka (USDA FS Forest Products Laboratory)

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Abstract

Mass timber is gaining popularity for its low carbon footprint, construction efficiency, aesthetics and economic competitiveness. High levels of moisture content in mass timber however may lead to practical difficulties, such as dimensional instability, mold growth and fastener corrosion. Additionally, moisture gradients that can arise during use, especially during commissioning can cause checking and cracking, leading to undesirable aesthetics for exposed mass timber. So, for mass timber to become what it could be in terms of sustainability, not only do we need to understand moisture transport in wood, but we must also be able to predict moisture performance and long-term durability of mass timber in different building applications. Here, we propose improvements to a simulation tool for assessing spatial and temporal moisture variations in cross-laminated timber (CLT) for different levels of built-in moisture and humidity conditions. Our approach is informed by wood-science, utilizes the interplay between measurement and simulation, and intends to fill critical knowledge gaps that hinder wider adoption of CLT. First, we improve the deterministic outcome of hygrothermal simulations through small-scale laboratory characterization and modeling efforts of wood species the CLT panel is composed of. Next, validation of the simulations is accomplished by large-scale water absorption and drying measurements of CLT panels. This validation step is a key prerequisite for reliable moisture performance assessments and preemptive design decisions. We use the validated simulation tool then to evaluate the response of CLT wall assemblies to different transient moisture conditions, such as inward moisture diffusion from solar exposure of absorptive claddings after rain. We also study the relation between the formation of drying cracks and large moisture gradients that occur after construction wetting followed by fast drying of CLT. The results overall offer optimization strategies for design and construction practices in identifying and mitigating moisture risks in mass timber buildings.

Detection of Impaired Adhesive Bondline in CLT Panel Using Numerical and Experimental Modal Analysis

Vaclav Sebera^p (Mendel University in Brno), Patrik Nop (Mendel University in Brno), Jan Tippner (Mendel University in Brno)

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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. The imperfection in bonding in CLT panel may occur from its manufacture or during its service life due to mechanical or environmental loads. The goal of the paper is to examine the effect of missing bondlines on modal characteristics of CLT panel with model size (approx. 80 x 80 cm).

Experimentally, there are 4 scenarios of CLT panel produced: reference, panel with 10% imperfection in one layer in the centre, panel with 40% imperfection in one layer in the centre and the panel with 40% imperfection in one layer at the side. The modal analysis are carried out numerically using finite elements. The FE model of CLT is solid 3D model with an orthotropic elastic material. The experimental modal analysis used forced vibration assisted by laser vibrometer mounted to automatic system to obtain modal shapes across the panel surface. The FE modal analysis reveal shifts in frequencies and modal shapes due to impaired adhesive bondline. The numerical bending modal shapes were successfully used to locate impaired gluing using modal shape damage index (MSDI). The imperfection in gluing cause an origin of new natural frequencies where a vibration is mostly occurring in freed boards where glue bondline is missing. The experimental modal analysis showed similar patterns as numerical one which gives promising results for future development of non-destructive assessment of CLT panels inbuilt in structures.

THURSDAY, JUNE 19

8:30 – 10:00 AM | CONCURRENT SESSIONS (^P denotes presenter, * student)

Session 11.1 - Addressing Environmental and Social Challenges with Engineered Renewable Materials I

~ Session Organizers - Maria Soledad Peresin (Auburn University), Gloria Oporto (West Virginia University), Yucheng Peng (Auburn University), Lu Wang (University of Tennessee)

~ Moderator - Maria Soledad Peresin

Prediction of Strength and Stiffness of Glued Laminated Bamboo Beams Based on Constituent Properties

Daniel Hindman^P (Virginia Tech), Jonas Hauptman (Virginia Tech), Sushant Dahal (Virginia Tech)

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Abstract

Recent research efforts have focused on the creation of composite bamboo panels and beams which focus on minimizing materials removal and processing to improve the overall carbon footprint of the product. Known collectively as mass bamboo, or MassBu, the building system focused on the use of lightly modified bamboo (LMB) elements, which are bamboo poles that have been faced on two or four sides to provide standard attachment and gluing surfaces. MassBu is a building system designed with appropriate technology in mind to help manufacture and use these building materials in developing countries where bamboo is plentiful. While panel development with MassBu has been studied more extensively, less testing and analysis has been applied to beam elements. Also, the design principles of MassBu beams are still evolving and questions about the composite action of the beams themselves exist. The purpose of this project was to predict the bending performance of composite LMB beams based upon the stiffness of individual bamboo layers. Individual LMB layers were proof-loaded to determined stiffness, then used to create a series of composite beams. Composite beams of 2-, 3- and 6-layers were connected using glued, bolted, and a combination of glued and bolted connections. Comparisons of connection performance showed much greater composite action in the glued and glued and bolted compared to the bolted connections. Methods to calculate the composite action and estimate the percentage of composite action for the different connections are presented. Understanding the composite action can help lead to methods for designing MassBu beams.

Biocarbon from Forest Feedstocks for Lead ion Adsorption in Aqueous Solutions

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Abstract

Over the recent past, biochar has emerged as a promising material for its carbon sequestration properties, use as a soil amendment and potential for removing heavy metals from wastewater. Among other sources, heavy metals from mining operations are present in soil and wastewater, posing environmental and health threats. In the current work, biocarbon collected from commercial and demonstration facilities manufactured using various processes have been evaluated for their ability to adsorb lead ions (Pb^{2+}) and characterized with respect to chemical and physical properties. Based on laboratory results, biocarbon will be identified for field applications. Results to date indicated significant differences in lead ion adsorption depending on the feedstock and carbonization process used for biocarbon production. In general, more alkaline biocarbon obtained from lignocellulosic materials are more effective at adsorbing lead ions. Softwood and hardwood also demonstrated significant capability differences in adsorbing lead ions with the superior performance of hardwood.

Woody Biochar for PFAS Adsorption in Agricultural Lands to Reduce their Bioaccumulation in Vegetable Crops

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Abstract

Per- and polyfluoroalkyl substances (PFAS) contamination in agricultural lands has attracted increasing concern due to the movement of PFAS at successive trophic levels, which can contaminate crops and livestock, and consequently risk human health. Among about 5000 PFAS, PFOA and PFOS are the top two concerns for their risk of environmental pollution, and risk to agricultural production and human health. The Environmental Protection Agency (EPA) is proposing to amend its regulation under the Resource Conservation and Recovery Act (RCRA) by adding 9 specific PFAS, their salt, and their structural isomers (PFOA, PFOS, PFBA, PFBS, PFDA, PFNA, PFHxA, PFHxS, and HFPO-DA or GenX). To date, more than 50 farms in the state of Maine have been impacted by PFAS. The application of PFAS-laden biosolids in agricultural lands dates back to the 1960s and has caused a halt in farming activities in the farms that tested positive for unsafe levels of PFAS. Thus, there is an urgent need to find a solution for farmers. We conducted a study to investigate the effectiveness of biochar to reduce PFAS uptake by lettuce and tomato in a greenhouse study at UMaine and a field study on Hunter Farm in 2023. Our results are promising, proving the reduction in PFAS bioaccumulation in lettuce leaves and tomato fruits at various degrees. This presentation will introduce this work and provide insights on future work.

Effect of the Properties of the Hybrid Molded Fiber Substrate on the Effectiveness of CNF Coatings

Nabanita Das^{o*} (University of Maine), Islam Hafez (Oregon State University), Douglas Bousfield (University of Maine), Mehdi Tajvidi (University of Maine)

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Abstract

Molded fiber food containers offer a viable solution to plastic pollution. However, pulp production requires considerable time and energy, and therefore, replacing part of the pulp stock with a low-cost lignocellulosic material makes economic sense. In addition, the recent ban on per- or poly-fluoroalkyl substances (PFAS) traditionally used for oil and grease barrier properties enhancement has motivated the industry and the academia to develop alternative solutions to replace PFAS. The goal of this study was to improve the oil and grease barrier performance of a newly developed hybrid molded fiber container that integrates cellulose nanofibrils (CNFs), bleached kraft pulp (BKP), and wood flour, thereby allowing for the partial substitution of traditional pulp components. CNFs were used both as a binder and coating material in this work. The objectives were to investigate the fundamental principles of CNF film formation during filtration related to oil barrier properties and reduce the CNF coat weight while maintaining excellent barrier performance. Various coat weights of CNF were applied to hybrid molded fiber substrates to determine the minimum coat weight necessary to provide oil and grease resistance, minimizing CNF coating costs. The study demonstrated that a coating as low as 3 g/m² applied at 0.05 wt.% CNF reduced the oil absorption by the samples by approximately 72-78% compared to their uncoated counterparts. The samples coated with 5 g/m² of CNF demonstrated the most favorable performance, notably improving oil and grease resistance, Cobb values, and microwave compatibility. For the 5 g/m² CNF-coated samples, a kit value ranging from 9 to 11 was achieved, alongside a remarkable 90% reduction in oil absorption depending on the drying methods of the samples. Additionally, no oil stains were observed during the microwave compatibility tests.

Eliminating Oil and Plastic Pollution in Marine Bearings: Assessing Lignum Vitae's Environmental Impact – Part 1: Availability, Material Properties, and Pollution Reduction

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Abstract

Lignum vitae has long been used as a journal bearing material in marine and industrial applications due to its excellent wear resistance, low friction, and high load-bearing capacity. Although overharvesting in the mid-20th century necessitated usage restrictions, modern sustainable forest management now permits commercial harvesting. This study evaluates newly harvested lignum vitae by comparing its material properties with historical data to verify its suitability for contemporary applications. Mechanical properties—including specific gravity, compressive strength, friction coefficient, and water resistance—were systematically analyzed. Preliminary results indicate that lignum vitae has a significantly lower wear rate than plastics, promising an extended operational lifespan under similar conditions. In high-load environments, it outperforms synthetic alternatives. The average specific gravity is 1.20, and compressive strength reaches up to 121.3 MPa along the end grain. The static coefficient of friction ranges from 0.158 to 0.33, making it well suited for bearing applications. Water absorption and swelling behavior were also investigated. Lignum vitae exhibited less than 3% volumetric swelling up to 140°F, aligning with the performance of synthetic bearing materials. Beyond 140°F, resin extraction and structural denaturation were observed. Swelling varied with grain orientation, and constrained samples demonstrated compensatory expansion in unconstrained directions. Sustainable harvesting practices allow for an average harvest of 400 tons per year over the next 30 years. This supply could support bearings for approximately 25,000 ships (about 20% of the merchant fleet), thereby reducing greenhouse gas emissions, improving fuel efficiency, and eliminating PFAS contamination. Estimations show this technology can remove 3.88 million tons of green house gas emissions annually and prevent up to 29.7 million liters of oil contamination to oceans annually. Additionally, lignum vitae bearings extend service life, and lower maintenance costs. These findings confirm that newly harvested lignum vitae meets or exceeds historical performance standards as a sustainable, high-performance journal bearing material.

Session 11.2 - Mass Timber Research and Innovation II

~ Session Organizers - Hongmei Gu (USDA FS Forest Products Laboratory), Daniel Hindman (Virginia Tech)

~ Moderators - Hongmei Gu and Nan Nan

Hygrothermal Analysis of Hybrid Cross-Laminated Timber Made of Thermally Modified and Unmodified Wood

Abasali Masoumi^{P*} (Virginia Tech), Brian Bond (Virginia Tech), Daniel Hindman (Virginia Tech), Georg Reichard (Virginia Tech), Joseph Loferski (Virginia Tech)

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Abstract

The use of cross-laminated timber (CLT) panels is increasing and there is a corresponding need to ensure an adequate supply of raw materials and enhance its durability. Building codes currently limit the use of CLT in environments prone to moisture exposure because of potential durability concerns. Thermally modified wood (TMW) presents a sustainable and effective alternative for improving CLT's resistance to moisture. Incorporating TMW into CLT expands its potential applications for exterior use. The hygrothermal model is a widely used method to analyze the moisture performance of CLT. However, current models heavily rely on Fick's law of diffusion, which is primarily designed for solid materials and not for wood or layered composites like CLT. Swelling stress in wood is another significant factor driving moisture diffusion, yet it is not accounted for in current hygrothermal models. Additionally, these models often exclude the effects of adhesive layers and cross-lamination in their calculations, instead incorporating these factors as calibration parameters between experimental and simulation data. This approach can obscure simulation results and lead to overestimation by software such as WUFI or DELPHIN. Specimens used in this study included one- and two-layer boards, as well as three- and five-layer (12×12-inch) CLT blocks made from 1-inch-thick layers of Yellow Poplar and TMW. Moisture vapor transmission through the thickness of the specimens was measured using in-situ gravimetric methods in accordance with ASTM E96 standards to evaluate water vapor permeability. The experimental data served as input for simulations in the WUFI software. Finally, the data of diffusion and strain were used to develop an integrated machine learning-driven multiphysics model. This model addresses overprediction issues and provides a more accurate representation of the correlation between moisture diffusion and strain. Results from experimental, simulation and modeling phases will be presented.

From Small-Diameter Trees to Arched Corrugated Panels and Engineered Beams

Arun Kuttoor Vasudevan^{P*} (Mississippi State University), Mostafa Mohammadabadi (Mississippi State University)

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Abstract

Wildfires and disease outbreaks in forests can arise from various causes, yet controlling and containing them is challenging in overstocked stands. Implementing sustainable forest management practices is essential for enhancing the health and resilience of forests. To offset the associated costs, the market must be expanded for small-diameter trees (SDT), which are often the primary byproduct, and removing them is not economically viable. In addition to established commercial products such as OSB, particleboard, fiberboard, and paper and pulp products that are utilizing SDT, even though corrugated panels represent an emerging and promising market for these underutilized materials. Beams made from these panels at their core have higher specific stiffness and strength than flat panels due to their corrugated shape and increased depth. As mass timber construction grows in North America, questions remain about whether SDT and corrugated geometry can be merged. In this study, a curved corrugated panel, the first of its kind, was designed and fabricated to develop a novel engineered beam that competes with mass timber products such as glulam. Parametric research was undertaken in Abaqus finite element software to determine how the geometrical parameters of curved corrugated panels affect engineered beam bending performance. Utilizing parametric studies and manufacturing constraints, an optimal curved corrugated geometry and a corresponding aluminum mold were created. Commercial wood strands sourced from an OSB plant were hot-pressed between the mold halves, forming them into the desired geometry. Curved corrugated panels were assembled for the core, which was then sandwiched between dimensional lumber to produce a structural beam. The beam was tested for its structural performance using a four-point bending test, and results were compared to a glulam beam. A finite element model was created to predict beam performance and comprehend deformation.

Thin Hardwood CLT – Product Development and Joinery Evaluation

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Abstract

Cross-laminated timber (CLT) has emerged quickly as an innovative large-scale engineered wood product, offering a promising means to effectively sequester carbon in building construction. With the abrupt popularity of mass timber in North America, the utilization of softwood has grown exponentially, and there is a global concern about its shortage. At the same time, the wood products industry and architectural community in the US hardwood and Great Lakes regions expressed interest in being involved in the mass timber movement. Additionally, architects and designers are increasingly interested in using solid wood in their innovative work. The shift towards utilizing hardwood species in CLT construction could contribute positively to building construction. Our research focuses on reducing the thickness of conventional large-scale CLTs. We also consider using hardwood species to make thin CLTs for interior applications. Several studies indicate that hardwood CLTs made of yellow poplar exhibit comparable or superior mechanical properties to softwood CLTs. Hence, yellow poplar was selected to produce thin HCLTs. Black Walnut was also chosen because of its appearance and popularity among architects. After making and testing HCLT panels, structurally sound portions of the material were used to produce joinery samples. The two types of joints were tested to determine whether employed joinery techniques were sufficient to meet design strength requirements and ensure user safety. The aim is to expand the utilization of solid wood in building construction and consider using thin HCLTs for interior applications such as interior walls, partitions, or furniture.

Life Cycle Assessment of Hardwood Cross-Laminated Timber Production in the Eastern United States

Jinghan Zhao^{o*} (North Carolina State University), Jingxin Wang (North Carolina State University), Levente Denes (West Virginia University), Zhichao Liu (West Virginia University), Nate Anderson (USDA Forest Service Rocky Mountain Research Station), Richard Bergman (USDA Forest Products Laboratory), Kai Lan (North Carolina State University)

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Abstract

Cross-laminated timber (CLT) is an emerging sustainable construction material with the potential to replace concrete. Life cycle assessment (LCA) has been widely applied to quantify the environmental impact of CLT materials and buildings. However, current research on CLT LCA mainly focuses on softwoods, lacking reports on hardwood CLT. Despite the less frequent utilization of hardwood by CLT manufacturers, hardwood CLT is technically feasible and provides value-added uses for low-quality timber. This study developed a cradle-to-gate life cycle modeling framework to produce hardwood CLT in the eastern United States to address this research gap. The framework integrates process-based modeling of log production, lumber production, and CLT production and explores the influences of hardwood species, supply chain network, and energy sources through sensitivity analysis. The global warming impact of producing 1 cubic meter (m³) of hardwood CLT ranged from 141.9 to 377.4 kilograms (kg) of carbon dioxide equivalent (CO₂ eq). The results showed that to satisfy the manufacturing requirements of CLT, lumber production caused more energy consumption and emissions than CLT production. Compared to selecting low-density hardwood species and minimizing transportation distance, increasing the use of biomass energy can more effectively reduce the overall environmental impact. Furthermore, the amount of carbon stored in hardwood CLT exceeded the carbon emitted during its production, with net carbon storage of 430.2 to 988.3 kg CO₂ eq per m³. This study provides valuable insights for the development of environmental product declarations for hardwood CLT and proposes improvement strategies to enhance the sustainability and market competitiveness of hardwood CLT.

Effect of Water Repellents on Water Intrusion in Cross-Laminated Timber

Diego Ramirez^{p*} (Oregon State University), Arijit Sinha (Oregon State University), Jeffrey Morrell (Oregon State University)

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Abstract

Mass timber products, such as Cross-Laminated Timber (CLT) and Mass Plywood Panels (MPP), are gaining popularity in sustainable construction due to their environmental benefits and strong structural performance. These products use dry timber; however, water intrusion after manufacturing until installation remains a critical concern, as prolonged moisture can lead to swelling, delamination, and degradation of mechanical properties. Previous studies using computer-aided tomography scanning (CT-Scans) showed that water intrusion was concentrated around non-edge-glued joints, but the scans could not quantify moisture levels. This study quantified the effects of water exposure on three-ply Douglas-fir and southern pine CLT and evaluated the ability of a water-repellent to mitigate water absorption. Sections of three-ply Douglas-fir and southern pine CLT were cut into 100 by 150 mm sections and conditioned to stable mass at 65% relative humidity and 23°C. The edges were sealed with elastomeric caulking applied around the upper edge. A 25 mm wide closed-cell foam weather strip was applied around the upper edge of each block to create a well to retain water. The assembly was weighed, and water was added to the top. The samples were incubated for 4 to 30 days before being cut into sections, weighed, oven-dried, and reweighed to determine moisture distribution. Moisture levels were elevated in the upper 15 mm of the pieces and along non-edge-glued zones, reaching levels above those required for fungal decay. Moisture levels in southern yellow pine CLT samples exposed to water for two weeks were highest at the surface (58.7%) and decreased with depth, stabilizing around 14.5% below 45 mm. Application of a water repellent reduced moisture uptake by almost 25%, illustrating the benefits of these treatments while highlighting their limitations.

10:30 AM – 12:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 12.1 - Addressing Environmental and Social Challenges with Engineered Renewable Materials II

~ Session Organizers - Maria Soledad Peresin (Auburn University), Gloria Oporto (West Virginia University), Yucheng Peng (Auburn University), Lu Wang (University of Tennessee)

~ Moderator - Maria Soledad Peresin

Role Of Protein Mobility In Bond Formation

Christopher G. Hunt^p (USDA FS Forest Products Laboratory), Linda Lorenz (USDA FS Forest Products Laboratory)

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Abstract

Most North American interior plywood has been bonded with a soy flour +crosslinking agent adhesive since 2006. Despite significant research effort, plant protein-based systems have made little progress in penetrating the larger markets for particleboard (PB) and fiberboard (FB). The lack of commercial success in PB and FB comes to cost/performance: the additional crosslinker needed to achieve the required performance results in uncompetitive pricing. Here we consider the protein-protein interactions contributing to bond strength, as improving these interactions could improve overall bond performance or lower the amount of crosslinking chemical needed. At low temperature, proteins are coiled up like balls because of their large hydrophobic content. Heat **and** moisture are necessary, both to make a protein mobile and to form a water-resistant protein bond. This suggests that protein molecular mobility is an essential element in bond formation. In this work we compare the strength development via ABES (ASTM D 7998) to the protein's molecular mobility during bonding assayed through differential scanning calorimetry and rheometry. Through this we hope to better understand the importance of large-scale protein mobility in bond development. This question is important for the general understanding of protein-based adhesives and has special significance for bonding PB and FB. Even in high moisture protein adhesives used for plywood, it is not clear that denaturation conditions are always encountered in the glue line during pressing. In PB and FB where moisture contents are generally much lower, it is unlikely that the proteins have significant mobility, even during hot pressing. Improving the performance of protein adhesives will depend on understanding these fundamental processes that contribute to bond formation.

Nanocellulose Reinforced PRF Resin

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Abstract

This study looked at the effects of nanocellulose addition (1 and 3%) and resin age (new and 3-4 y old) on the properties and performance of phenol resorcinol formaldehyde (PRF) resin. Three types of nanocellulose were evaluated, (i) nanocellulose crystals (CNC), nano-defibrillated bleached fibers (BNF) and nano-defibrillated unbleached fibers (UBNF). The modified resin samples were characterized based on their curing behavior, flow behavior, mechanical and thermal properties. The average width of the BNF and UBNF were 810 nm determined via optical and atomic force microscopy. The BNF and UBNF fibers were freeze-dried, then ball-milled @1000 rpm for 6 h, to disentangle. The nanocelluloses were then added to PRF resin and ball-milled wet for 3 h to obtain a fully dispersed mixture. The curing behavior of the resin was determined by differential scanning calorimetry (DSC). The presence of nanocellulose increased the exothermic peak temperature. Dynamic rheometry was employed to understand the flow characteristics (frequency sweep) of the resin and the onset of gelation and vitrification (temperature ramp) of the modified resin. The gelation point increased with the addition of nanocellulose. The addition of nanocellulose fibers increased the flexural strength due to reinforcement. Also, the new and old resins demonstrated comparable properties showing that these resins have good long-term stability. Adding nanocellulose improved the properties of the resin, ensuring enhanced performance for future applications such as 3D printing with wood-PRF composites.

Impact of Catalyst and Oxidant Levels in a TEMPO Oxidation Process on the Generation of Cellulose Nanofibers

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Abstract

Wood-derived cellulose is commonly pretreated with 2,2,6,6-tetramethyl piperidine-1-oxyl (TEMPO) and NaBr as catalysts, along with NaClO as the oxidants, within the TEMPO/NaBr/NaClO oxidation mechanism. Substantial research has been conducted on cellulose nanofibers (CNFs) produced through standardized TEMPO-mediated oxidation; however, the influence of catalyst and NaClO concentrations and the reaction mechanisms involved remain poorly elucidated. In this study, we optimized the oxidation system for economic CNF production by varying the TEMPO concentrations between 0.05–0.5 mmol/g and NaClO concentrations from 3–15 mmol/g, specifically focusing on the roles of the catalyst and oxidant in the oxidation system. TEMPO-oxidized celluloses were comprehensively characterized via analyses of the carboxylate content, sugar concentration, crystallinity, morphology, and particle size. The results revealed that rapid consumption of NaClO within a defined reaction time is crucial for enhancing the efficiency of TEMPO-mediated oxidation. Additionally, our improved TEMPO oxidation system facilitated the fabrication of highly transparent and uniformly dispersed TEMPO-oxidized cellulose nanofibers (TOCNs). TOCN transmittance results revealed that particle size and the presence of microfibrils in the colloidal suspension can affect TOCN dispersibility. We expect that these findings offer meaningful insights for applications that demand high-purity cellulose nanomaterials, such as displays and polymer films.

Enhancing Sustainability in Additive Manufacturing: Bio-Based Phenol-Resorcinol-Formaldehyde Resins for Construction Applications

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Abstract

The rapid advancement of additive manufacturing, particularly three-dimensional (3D) printing, has revolutionized the construction industry by improving efficiency, minimizing material waste, and reducing costs. However, conventional building materials, such as concrete, contribute significantly to global carbon emissions, highlighting the urgent need for more sustainable alternatives. One promising approach involves replacing petroleum-derived resins with bio-based materials, reducing environmental impact while maintaining structural performance. In this study, we investigate the partial substitution of commercial phenol-resorcinol-formaldehyde (PRF) resin with bio-oil to improve the curing profile and flowability of the material, enhancing processing during extrusion in 3D printing. CascophenTM 4001-8, the base resin, was partially replaced with bio-oil, while CascosetTM 5830 was used as the hardener, maintaining a resin-to-hardener ratio of 2.5:1. The bio-oil was integrated based on dry basis composition and the mixtures were subjected to pre-treatment at temperatures ranging from 50–110°C to enhance mixture homogeneity and promote polymerization. A full factorial experimental design was implemented to evaluate the effects of pretreatment temperature, mixing sequence and percentage of bio-oil on resin curing, assessed through mass loss measurements. The bio-based PRF resin was combined with wood flour in a 50:50 ratio to fabricate particleboards, which were pressed at 180°C for 5 minutes. Characterization included flexural testing (ASTM D1037-12), water absorption, and swelling to assess mechanical and dimensional stability. Additional analyses included solvent resistance to evaluate resin stability, FTIR to identify functional groups, and viscosity and gel time measurements to assess curing kinetics. Preliminary results indicate that incorporating bio-oil enhances resin performance while reducing reliance on fossil-based phenol. These evaluations provide a comprehensive understanding of wood-PRF-bio-oil composite's structural performance and its potential as a viable, sustainable material for additive manufacturing in construction.

High-performance Hempcrete for Building Insulation

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Abstract

Hempcrete is increasingly being recognized as a viable, sustainable alternative in construction. It contributes to greener building practices and reduces the industry's environmental impact. However, the hemp fiber market needs optimization to support better performance in buildings. In this paper, the hemp fibers are modified by using naturally extracted silica coatings through the Sol-gel method and binder optimization to increase performance in fire (ASTM E113), acoustic (ASTM E413), and thermal performance. The results showed higher surface roughness ($> 3\mu\text{m}$) in the coated fibers for better bondability and a 30% increase in thermal performance. The fire and acoustic performance of the modified hemp also showed better improvement (15-25%) compared to the untreated hemp. These findings highlight the potential of pre-treated hemp fiber performance and binder modification as an alternative to create high-performance hempcrete for building insulation.

Utilizing Hemp Hurds Fiber in Extrudable Thermoset Composites

Sodiq Yusuf^{†*} (University of Idaho), Michael Maughan (University of Idaho), Armando McDonald (University of Idaho)

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Abstract

The housing shortage, increase in housing costs and construction worker shortages have necessitated the need for new building practices, such as additive manufacturing (AM). Recent studies have shown that wood-based composites can be printed by AM. Environmental concerns have called for reduced pressure on forest wood resources, therefore exploring non-wood fast growing crops such as hemp. This study focused on utilizing low value hemp hurds (HH) as a reinforcement for use in biocomposite materials. The HH was characterized by particle size, surface area and chemical composition. Mixtures of 30-50% HH and 70-50% phenol-resorcinol-formaldehyde (PRF) resin were blended and subsequently extruded on a single screw extruder. The wet blended were evaluated for their rheological properties and showed pseudoplastic behavior. The extruded biocomposites were cured and their water absorption and flexural properties determined. and the water absorption properties decreased with HH content. The bio composites containing 40% HH had the best flexural properties of 41MPa compared to 34MPa and 37MPa for 50% and 30 % HH respectively. These results show that underutilized HH can be valorized in bio composite materials for use in AM applications in low-cost housing.

Session 12.2 - Mass Timber Research and Innovation III

~ Session Organizers - Hongmei Gu (USDA FS Forest Products Laboratory), Daniel Hindman (Virginia Tech)

~ Moderators - Nan Nan and Hongmei Gu

Nondestructive Evaluation of Treated Southern pine, Douglas–fir, and Mixed Hardwood Glulam

Aleria Story^{p*} (Mississippi State University), Laya KhademiBami (Mississippi State University), Colin McCown (Mississippi State University), Rubin Shmulsky (Mississippi State University)

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Abstract

The sustainability of engineered laminated timber products such as glued laminated timber (glulam) and cross laminated timber have been previously researched. However, the performance of these products when treated with preservatives under heavy load applications such as road planking have not been previously well-investigated. In this study, the use of acoustic technologies on treated and untreated full-size glulam composites was investigated to nondestructively compare the efficacy of different wood preservatives in protecting glulam exposed to biological degradation. To achieve this goal, three types of glulam including southern pine, Douglas–fir, and mixed hardwoods with the size of 2.5 × 5.5 × 37.25 in. (T× W× L) were prepared. All specimens were conditioned to a moisture content of 8–12% and were weighed. The time on flight (TOF) of each specimen was measured with a stress wave timer and recorded. Control specimens were kept at stable environmental conditions and the other glulam specimens were treated with one of three different wood preservatives including DCOI (4,5-Dichloro-2n-Octyl-4-Isothiazolin-3-One), CA-C (Copper Azole type C), and MCA (Micronized Copper Azole). The TOF of each specimen was measured and recorded after treatment. All data has been analyzed using one-way and two-way ANOVA. An increase in TOF after treating glulam specimens with preservatives was observed for all preservatives, showing the successful treatment application of glulam specimens. There was also a significant interactive effect between glulam and preservatives for TOF, in which the lowest TOF was observed in Douglas-fir treated with DCOI preservative.

Nondestructive Evaluation of CLT from Downed Pine Timber

Sona Azad^{P*} (Mississippi State University), Laya KhademiBami (Mississippi State University), Iris Montague (USDA FS Northern Research Station), Kozma Naka (Alabama A&M University), Troy Bowman (Alabama A&M University), Rubin Shmulsky (Mississippi State University)

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Abstract

The southeastern part of the United States frequently experiences severe weather events, such as hurricanes and tornadoes, causing extensive damage to forest lands and resulting in substantial economic losses in timber resources. This study examined the nondestructive (NDE) performance of lumber and CLT from downed loblolly pine (*Pinus taeda*) trees. Approximately 20–25 pine trees from Chapman Mountain, owned by Alabama A&M University, were felled simultaneously and left under natural forest conditions to simulate environmental exposure. Logs were collected and processed into lumber at four-time intervals (0, 6, 9, and 12 months). Lumber moisture content (MC), density, acoustic velocity (AV), and dynamic modulus of elasticity (D_{MOE}) were measured. Cross laminated timber (CLT) panels were made from the lumber and then the panels were evaluated via NDE. Findings aim to determine the optimal or maximum timber salvage timeframe for maintaining mechanical integrity, enhancing sustainable timber utilization, and reducing waste. This research highlights the efficacy of AV for assessing the quality of felled timber for applications such as CLT production. All data were analyzed individually for lumber and CLT panels with One-Way ANOVA. No significant treatment differences were observed for AV and D_{MOE} for both lumber and CLT panels among different time periods. However, higher MC was observed for lumber belonging to 12-month intervals compared to any other time periods. These results showed that although some characteristics of lumber differed across time periods, there was no difference in NDE observed between lumber and CLT panels at the 12-month time. Further investigation is needed to evaluate the final modulus of rupture (MOR) and modulus of elasticity (MOE) of the CLT panels.

Advancing Cross-laminated Timber Connections: Evaluating Glued-in Rod Technology Reyyan Okutan^{p*} (Virginia Tech), Joseph Loferski (Virginia Tech), Daniel Hindman (Virginia Tech)

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Abstract

Over the past two decades, the use of engineered wood products in building construction has increased due to their dimensional flexibility, sustainability, and high strength. Among these, cross-laminated timber (CLT) has made significant advancements, enabling both low-rise and mid-rise construction. However, like other building materials, CLT's structural capacity relies on connections that resist pull-out forces, which increase with building height. This study investigates the application of glued-in rod (GiR) technology in CLT connections. GiR is a connection method which has been widely used in solid and engineered wood products such as glulam due to their high axial load transfer capability, as well as superior aesthetics and fire resistance compared to dowel-type fasteners. However, their application in CLT remains limited. The lack of national and international standardization for GiR connections has led to hesitancy among engineers and the wood industry, despite their cost-effectiveness and ease of application. This absence of standardized guidelines causes quality control challenges related to GiR connection variables such as adhesive type and thickness, anchorage depth, rod diameter, and curing time. Therefore, this study aims to address these challenges by reviewing existing literature to identify best practices for managing these variables and assessing the potential of GiR connections in CLT applications. We aim to provide a comprehensive summary and identify gaps and future directions for applying GiR techniques to CLT, benefiting researchers, industry professionals, and practitioners in timber engineering.

Predicting Size Effect in Veneer-Based Structural Joists Based on Small-Sample Test Results

Samuel Donkor^{D*} (Oregon State University), Lech Muszynski (Oregon State University), John Nairn (Oregon State University)

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Abstract

Structural veneer-based products, such as mass ply panels (MPP) and laminated veneer lumber (LVL), are often used in construction as joists, that is, in edgewise bending. Due to substantial size effects in engineered veneer-based products, current industry standards (ASTM D5456) require product qualification and product quality assurance to be tested on full-scale elements, rather than on small-scale material samples or scaled specimens, which is material-intensive and costly. The uncertainty margins obtained with the standard model are expected to account for the size effect and are deemed unsatisfactory.

The objective of this project is to develop a reliable empirical model to predict the size effect in structural veneer joist elements based on small- to medium-scale tests.

The approach is to correlate the size effect in veneer-based materials, as reported in prior studies, with the known structure of the laminates and the specific distribution of joints within veneer sheets and composite laminations. In addition, strength properties measured on jointed and joint-free material references will be used as input. Experimental validation will be conducted on mass ply panels (MPP) and laminated veneer lumber (LVL) specimens sourced from West Coast manufacturers. The resulting model is expected to support a reliable and cost-effective product qualification and quality assurance procedure option for the structural veneer-based products industry.

Advancing Resilience-Based Design: Insights from Full-Scale Testing of Tall and Midrise Mass Timber Buildings

Prashanna Mishra^{P*} (Colorado State University), John Van de Lindt (Colorado State University), Shiling Pei (Colorado School of Mines), Andre R. Barbosa (Oregon State University), Steve Pryor (Simson Strong-Tie), Jeffery Berman (University of Washington), Barbara Simpson (Stanford University), Keri L Ryan (University of Nevada Reno), Arijit Sinha (Oregon State University), Patricio A. Uarac P. (Oregon State University), Morgan McBain (Stanford University), Steven Kontra (Oregon State University), Tanner Field (Oregon State University)

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Abstract

This presentation discusses the findings from shake table testing of full-scale 10-story and 6-story mass timber building specimens, conducted under the NHERI Tallwood and NHERI Converging Design research projects from 2022-2024. These landmark tests, performed at the world's largest outdoor shake table at UC San Diego, aimed to advance resilience-based seismic design methodologies for tall and mid-rise wood buildings. The growing emphasis on sustainable construction has pushed mass timber into the spotlight as a viable, eco-friendly alternative to traditional construction materials. Advancements in engineered wood products, structural components, and building systems have made the construction of taller mass timber structures not only feasible but also cost-competitive with materials like concrete and steel. Despite these advancements, the industry still relies heavily on conventional lateral force-resisting systems, such as concrete cores or steel bracing, highlighting a gap in code-approved solutions and innovative design approaches for tall mass timber buildings in the US. The NHERI Tallwood and NHERI Converging Design projects addressed this gap by employing a post-tensioned mass timber rocking wall system, complemented by a low-damage gravity framing system and drift-compatible non-structural components. The 10-story structure (34.4 meters) and the 6-story structure (20.7 meters), both with an 84 m² (900 ft²) floor plan, underwent extensive seismic testing. Following the initial tests on the 10-story building, its top four stories were removed to create the 6-story structure for subsequent testing, enabling a comparative analysis of the two configurations under similar seismic loads. This presentation highlights the performance of the lateral force-resisting systems in these two structures, showcasing the potential of innovative design strategies to improve seismic resilience in tall and midrise mass timber buildings. Additionally, it emphasizes the role of mass timber as a sustainable and resilient material, paving the way for its integration into the next generation of seismically resilient construction.

1:30 – 3:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 13.1 - General (other topics) I

~ Session Organizers - Joseph Jakes (USDA FS Forest Products Laboratory), Francesco Negro (University of Torino)

~ Moderators - Francesco Negro and Joseph Jakes

Hemicellulose Influence on Set-Recovery and Densification of Veneer through Hot Water Extraction

Catherine Kilumets^{p*} (Tallinn University of Technology), Heikko Kallakas (Tallinn University of Technology), Junyong Zhu (USDA FS Forest Products Laboratory), Christopher G. Hunt (USDA FS Forest Products Laboratory), Jaan Kers (Tallinn University of Technology)

Student oral presentation competition – Third place winner

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Abstract

Wood density plays a critical role in determining its mechanical properties, making densification a promising technique to improve surface hardness, abrasion resistance, and shear strength. This approach is especially valuable for low-density wood species, broadening their suitability for high-end applications like flooring and composite materials. However, the hygroscopic nature of wood poses a significant challenge, as densified wood is prone to set-recovery upon moisture exposure, which can undermine the benefits of densification. Among the cell wall components, hemicelluloses are the most hydrophilic and contribute significantly to swelling. Thermal modification, whether applied during densification or as a post-treatment, has proven effective in reducing set-recovery. However, it often leads to increased brittleness, creating a trade-off between dimensional stability and mechanical performance. A critical question is whether thermal modification and hemicellulose water extraction operate through similar mechanisms. Water extraction allows for the controlled removal of hemicelluloses, offering a pathway to better understand and optimize wood modification strategies to achieve a balance between mechanical performance and dimensional stability. To explore the role of hemicelluloses in set-recovery, a series of mild water extractions were conducted using rotary-peeled European aspen (*Populus tremula* L.) veneer. The study focused on evaluating dimensional stability after densification to assess the effects of hemicellulose removal. These investigations aim to shed light on the role of hemicelluloses in wood swelling and the potential for enhancing the durability of densified wood through targeted extraction methods.

Hardwood-Based Composites with Flexible Polyurethane Adhesive Joints

Klaudia Śliwa-Wieczorek^p (Cracow University of Technology), Arkadiusz Kwiecień (Cracow University of Technology), Jaka Pečnik (InnoRenew CoE), Paweł Szeptyński (Cracow University of Technology), Matthew Schwarzkopf (InnoRenew CoE)

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Abstract

In recent years, the European civil engineering sector has seen a steady increase in the use of wood and wood-based products due to aspects related to sustainability, positive impact on the user, aesthetic values as well as increased architectural possibilities. Most of them are made from softwood (spruce, pine), but the changing structure of Central European forests opens opportunities for alternative solutions based on hardwood, especially using beech wood (*Fagus sylvatica* L.). Considering its high mechanical performance, it has a large potential to be used in production of glued timber structural products such as the cross laminated timber (CLT) and the glue laminated timber (GLT). Therefore, an international scientific team from Poland (Cracow University of Technology) and Slovenia (INNORENEW) has developed a research project (NCN OPUS LAP “Diamonds”). Its main goal is to fill the knowledge gap related to an impact of complex loads on the performance of bond between beech wood and an adhesive. This project covers also the impact of ageing on adhesive bonds in beech composites. A rigid one-component polyurethane (PUR) adhesive joint and an innovative two-component flexible polyurethane (FPU) adhesive joint (built from three types of commercial polyurethanes FR&PS, FR&PST and FR&PTS) were considered for the construction of samples. Experiments were conducted on micro, medium and large scales. This work presents a part of an extensive research campaign, presenting selected experimental results for the single shear lap test, considering the influence of the adhesive type, natural ageing and the influence of time on the load-bearing capacity of the connection. Furthermore, the experimental results were compared with the analytical and numerical models.

Durability of Plantation Hinoki

Elizabeth Israel^{P*} (Oregon State University), Jeffrey Morrell (Oregon State University), Arijit Sinha (Oregon State University), Patricia Vega (Oregon State University), Jed Cappellazzi (Oregon State University), Sato Yuichi (Japan Lumber Inspection & Research Association)

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Abstract

Hinoki (*Chamaecyparis obtusa* Endl) has historically been valued as a construction material in Japan because of its durable heartwood and mechanical properties. The increasing availability of plantation-grown Hinoki has raised concerns regarding heartwood decay resistance compared to old-growth material. This study assessed the natural durability of second-growth Hinoki heartwood using standardized laboratory decay tests following the American Wood Protection Association Standard AWP A E30-16 to supplement durability assessments previously conducted under Japan Industrial Standards (JIS). Hinoki samples sourced from 120 parent boards across four different stands in Japan were compared with decay-resistant Western redcedar (*Thuja plicata* D Donn) and non-durable southern pine (*Pinus* sp) for resistance to fungal attack and total extractives content. Wood blocks were exposed to *Rhodonia placenta*, *Gloeophyllum trabeum*, and *Trametes versicolor* following AWP A E30-16 with mass losses measured after at least 12 weeks of incubation at 28°C to assess fungal degradation. The results confirmed aggressive fungal attack, with non-durable pine experiencing mass losses exceeding 40%. Western redcedar experienced mass losses of 15.0% for *R. placenta* and 10.7% for *G. trabeum*. Hinoki exhibited high decay resistance, with mass losses ranging from 2.9% to 47.0%, averaging 9.5% for *R. placenta* and 6.3% for *G. trabeum*. Variability across samples suggested the presence of decay-susceptible sapwood, which is difficult to detect in hinoki. Preliminary findings indicate that plantation-grown Hinoki maintains the durability of old-growth material. Extractive levels varied widely among timber sources. Chubu had the highest extractive content (4.7%), and Kyushu the lowest (3.1%). Hexane and ethanol soluble extractives were more abundant than water-soluble compounds. Sesquiterpenes play a key role in Hinoki's durability. Despite minor differences in decay resistance, overall extractive content remained consistent across sources. Future research will investigate specific extractive compounds by tree source.

Session 13.2 - Mass Timber Research and Innovation IV

~ Session Organizers - Hongmei Gu (USDA FS Forest Products Laboratory), Daniel Hindman (Virginia Tech)

~ Moderators - Dan Hindman and Levente Denes

Exploring the Climate Impact of the Building Construction Phase: An LCI-Based Comparison of Mass Timber and Reinforced Concrete Buildings

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Abstract

Global warming is increasingly recognized as a major societal challenge, and the building sector—responsible for one-third of global carbon emissions—must play a pivotal role in advancing decarbonization efforts. Recently, more and more research has identified the potential of mass timber as a sustainable alternative to traditional high-carbon-emission materials. This study proposes a comprehensive Life Cycle Inventory (LCI) analysis framework for the construction installation phase (A5), utilize design drawings and construction logs from two recently completed multi-family commercial buildings located in a cold climate region of North America. In this research, the A5 phase is divided into four construction activities—earthwork, concrete work, mass timber work, and general conditions—with the associated energy consumption systematically quantified and analyzed. This framework helps to address the significant gaps in existing studies, which rely too heavily on assumptions without solid datasets and frequently overlook calculated construction quantities during the A5 phase. Furthermore, a functionally equivalent reinforced concrete (RC) building model was developed for comparative purposes. The results demonstrate that mass timber buildings achieve significant energy savings during the A5 phase, due to the lightweight and prefabrication-oriented characteristics, which lead to a relatively lower construction load and shorter project durations. The results also show that in mass timber construction, the most energy-intensive activities during the A5 phase are vertical material movement (e.g., crane operations) and general conditions (e.g., temporary heating). Moreover, current data indicate that screw connections—the primary method for joining components in mass timber buildings—have not yielded substantial energy savings compared to traditional construction methods. Nevertheless, the analysis of construction logs reveals an increase, suggesting that construction efficiency could improve beyond current recorded as construction teams gain more experience with mass timber. Considering this learning curve, mass timber buildings may demonstrate even greater carbon-saving potential in the future as construction teams gain more experience.

Comparative LCA of Utah's First Large-scale Mass Timber Building, Baltic Pointe, with a Steel Alternative

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Abstract

The construction industry is proactively seeking ways to enhance sustainability in the building sector by developing and implementing new structural materials that reduce environmental footprint and energy consumption while improving design outcomes for timber construction. Mass timber is a construction material group which has grown increasingly popular across the architecture, engineering and construction community and represents a significant shift toward advancing sustainable building practices. This research study uses Tally LCA to conduct a comparative life-cycle assessment (LCA) of Utah's first large-scale mass timber project, Baltic Pointe - a 12,635-m², 5-story commercial office building located in Draper, UT. The structure of the project is constructed of 5,978-m³ of mass timber materials, including Douglas fir glulam and cross laminated timber (CLT) sourced from forest in the West Kootenay region of British Columbia, Canada. For seismic purposes, the project also incorporates steel buckling-restrained bracing (BRB). The structural frame rests on a 2-story concrete parking podium – the design of which was kept the same for both LCA scenarios. Compared to an all-steel alternate design, LCA results for Baltic Pointe's structural frame demonstrate significant reductions in global warming potential (83.5%), ozone depletion potential (71.7%), primary energy demand (65.8%), non-renewable energy demand (108.3%), and acidification potential (29.0%). However, the steel alternative demonstrates lower impact in the categories of eutrophication potential, smog formation potential, and renewable energy demand.

Comparative Whole Building Life Cycle Assessment on the Four Framing Systems of the Bakers Place using Tally LCA Tool

Hongmei Gu^p (University of New Brunswick), Nadia Zahabi (University of New Brunswick), Meng Gong (University of New Brunswick), Janet Blackadar (University of New Brunswick)

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Abstract

The urgent need for climate change mitigation has increased the focus on reducing embodied carbon and energy, particularly in the construction sector. Utilizing sustainably sourced mass timber products provides a low-carbon alternative to traditional concrete and steel structural systems in buildings. These carbon impacts can be quantified by the Whole Building Life Cycle Assessments, a systematic tool that evaluates the total environmental impact of a building, from material extraction and product manufacturing to construction, operation, and demolition. This study was aimed at evaluating potential environmental impacts of the 14-storey mass timber-steel hybrid building, Bakers Place, in Madison, USA, especially global warming potentials (GWP), which were measured as greenhouse gas emissions or CO₂-eq, using a cradle-to-grave life cycle assessment (LCA). The Tally® LCA tool built in Autodesk® Revit® was used. The baseline building was compared to functionally equivalent full mass timber, full steel, and post-tensioned concrete structural designs. The results showed that the full mass timber design had the lowest GWP, with a 16% reduction compared to the concrete design. The hybrid baseline design showed 14% lower GWP than concrete but was 1% higher than the steel structure. Both hybrid and full mass timber designs demonstrated biogenic carbon storage of approximately 1,910,490.5 kg and 2,497,649.5 kg CO₂, respectively. Additionally, the full mass timber and hybrid designs showed about 30% lower non-renewable energy use than concrete and steel designs. While these findings highlighted mass timber's benefits in reducing GHG emissions and energy use, hybrid and full-mass timber designs had higher impacts in acidification, eutrophication, ozone depletion, and smog formation.

Collaboration and Networking in Europe Through the Holistic Design of Taller Timber Buildings — COST Action HELEN

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Abstract

Construction is responsible for forty percent of the world's energy consumption, waste production, and one-third of global carbon dioxide emissions. It is therefore essential to transition towards more sustainable and renewable construction methods. Engineered timber, a leading material in sustainable construction, has advanced to a point where it can now be used not only for family housing but also for the construction of taller buildings, which have traditionally been made from concrete or steel. An integrated, interdisciplinary approach is required to safely design, construct, maintain, and recycle taller timber buildings. The design process should involve close collaboration between the various members of the design team (e.g. architects, structural, fire, and acoustic engineers, etc.). This study focuses on the design of taller timber buildings from a collaborative perspective that considers factors such as static and dynamic forces, fire safety, acoustics, human health, and other relevant aspects in parallel, rather than in isolation. Our aim is to develop comprehensive design guidelines that will ensure the safe construction of taller timber buildings while also prioritising human well-being through interdisciplinary analysis and interaction. COST Action CA20139 "Holistic Design of Taller Timber Buildings – HELEN" is advancing holistic approaches to enhance the performance of taller timber buildings and expand their competitiveness and adoption both within the EU and globally. The Action currently involves 403 members from 52 countries. Networking is an important component to the success of the COST HELEN. Through events such as meetings, training schools, research visits, and conferences, participants are able to exchange knowledge and build strong international networks to achieve our objectives. This presentation will introduce COST Action HELEN, its research goals, results and opportunities for collaboration.

Characterization of Monolithic Vertical Wall Connections for Veneer-Based Mass Timber Walls

Ian Morrell^P (Tennessee Technological University), Arijit Sinha (Oregon State University), Daniel Cheney (Boise Cascade Company), Daniel Way (Boise Cascade Company)

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Abstract

Recent code changes in the United States have simplified the use of mass timber walls into structures, with a prescriptive design methodology in the Special Design Provisions for Wind and Seismic. This methodology includes a limitation on the aspect ratio of the panels, limiting the height of a wall panel to four times its width. One method to allow for a taller panel would be to connect two adjoining panels along their vertical seam to make the two panels act as a single monolithic panel, thereby doubling the width of the panel. To do this requires the connections to have the equal or greater strength and stiffness compared to a single monolithic panel. Three possible connections were identified as candidates to create this connection: a gap filling adhesive along the entire adjoining vertical edge, an aluminium block connector, and threaded rods glued perpendicular to the panel joint. Monotonic and reverse-cyclic testing was conducted with these three connectors at the connection scale, installed in a veneer-based mass timber material. Control tests from single continuous panels were also conducted as a baseline for comparison. The testing suggested that the aluminium wedge and glued in rod connections were neither stiff enough nor strong enough to create a monolithic connection. The continuously glued connection performed comparably with the control test, suggesting an adhesive connection could replicate a monolithic wall panel. Further results and findings will be discussed in the presentation.

Mass Timber Alternatives in Construction with Flexible Adhesives Joints

Arkadiusz Kwiecień^P (FlexAndRobust Systems Sp. z o.o.), Klaudia Śliwa-Wieczorek (Cracow University of Technology), Urša Blumauer (Požarni laboratorij ZAG), Nataša Knez (Požarni laboratorij ZAG)

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Abstract

The last decade has witnessed a global increase in environmental consciousness and in concerns about the effects of construction sector activities on climate and natural resources. Environmental concern has caused companies and researchers to consider the merits of new concepts, such as environmental or green marketing, green building (GB) or healthy nearly Zero Energy Buildings (nZEB). In Europe, the MEZeroE project was developed: Measuring Envelope products and systems contributing to the next generation of healthy nearly Zero Energy Buildings, Horizon 2020 No. 953157. This international project aims to create an EU distributed open innovation ecosystem to: develop nZEB solutions; transfer knowledge; match testing needs with test facilities; provide monitoring in real buildings used as living labs; standardize state-of-the-art solutions from small and medium-sized enterprises and larger industries. One of the proposed innovations is the use of engineered wood products (EWPs) such as cross-laminated timber (CLT) and glued-laminated timber (GLT) manufactured using flexible polyurethane (FPU) adhesive joint that offer many advantages over rigid synthetic adhesives or metal fasteners. This work presents a part of an extensive research campaign conducted in Poland and Slovenia on special Pilot Measurement & Verification Lines, presenting selected experimental results for the materials test as well as for connections (single and double shear glued connections) including static, creep and fire tests. There has been a lot of progress on the fire performance of timber products in Europe, however there is no research on flexible adhesives joints as a mass timber application. For the resistance to fire test two different materials in two different thicknesses (80 mm and 160 mm) were tested in bending and in tension during exposure to standard fire curve. The reaction to fire testing Cone calorimeter and small flame tests were performed on small scale samples, respectively for two different polyurethanes FR&PST and PM.

3:30 – 5:00 PM | CONCURRENT SESSIONS (^p denotes presenter, * student)

Session 14.1 - General (other topics) II

~ Session Organizers - Joseph Jakes (USDA FS Forest Products Laboratory), Francesco Negro (University of Torino)

~ Moderators - Francesco Negro and Joseph Jakes

Retrofit Analysis of an Educational Building in South Korea with CLT Walls for Energy Efficiency and Sustainability

Ji Hun Park^{p*} (Yonsei University), Yujin Kang (Yonsei University), Seong Taek Kang (Yonsei University), Sumin Kim (Yonsei University)

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Abstract

Many buildings constructed before South Korea's reinforced energy efficiency regulations suffer from poor insulation, leading to excessive energy consumption. This study explores the retrofitting of a 2008 educational building in Incheon, which has substandard thermal performance under the energy codes of that time. To enhance energy efficiency and sustainability, this research proposes a passive retrofit strategy incorporating Cross-Laminated Timber (CLT) walls, improving insulation while utilizing an eco-friendly material. Furthermore, high-efficiency mechanical systems will be integrated to align with South Korea's Zero Energy Building (ZEB) certification standards. The study employs WUFI to assess the hygrothermal performance of CLT walls and DesignBuilder for dynamic energy simulations. Initially, the building's existing energy consumption is analyzed, revealing significant heating and cooling loads due to poor insulation. The CLT retrofit scenario is then evaluated, demonstrating a notable reduction in energy demand while mitigating condensation and mold risks. The combination of passive CLT retrofitting and active high-efficiency systems leads to an optimized thermal environment, improved occupant comfort, and substantial energy savings. By transforming an outdated structure into an energy-efficient model, this research highlights the feasibility of CLT-based retrofitting in South Korea's educational sector. The results serve as a reference for future retrofit projects, promoting mass timber applications in energy-conscious building renovations. The findings also support the national goal of achieving carbon neutrality by demonstrating a practical pathway for upgrading existing buildings to meet modern energy standards.

Carbon Mitigation and Energy Efficiency of Hybrid Cross-Laminated Timber Community Center Buildings

Yujin Kang^p (Yonsei University), Ji Hun Park (Yonsei University), Young Uk Kim (Yonsei University), Sumin Kim (Yonsei University)

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Abstract

Achieving carbon neutrality in the building sector requires innovative material solutions to reduce greenhouse gas emissions and enhance energy efficiency. Cross-laminated timber (CLT), as a nature-based solution (NBS), has gained attention for its carbon mitigation potential and energy performance benefits. Several countries, including the Netherlands, France, Japan, and Canada, have implemented policies to promote using wood or eco-friendly materials in construction. However, South Korea lacks sufficient legislation to support widespread timber adoption in its construction sector. CLT has been shown to reduce greenhouse gas emissions and improve energy efficiency, with studies in Brazil and South Korea confirming its benefits in various climates. Mass timber structures, including CLT, have been found to reduce carbon emissions by 80–99% compared to steel designs in mid-rise buildings. This study evaluates the carbon reduction potential of hybrid CLT systems for a regional community center, emphasizing their role in low-carbon, energy-efficient public buildings in South Korea. Life cycle assessment (LCA) results show that the product stage contributes most to carbon mitigation, with concrete-to-CLT substitution resulting in a 9.22% reduction. In the use stage (B4 and B6), operational energy consumption is reduced, particularly in cold climates where heating accounts for 88% of energy savings. Hybrid CLT buildings with higher exterior material substitution ratios (S3-1 and S3-2) demonstrate improved energy efficiency and reduced life cycle emissions. Extending the building lifespan beyond 40 years enhances carbon mitigation, highlighting the long-term benefits of timber construction. As South Korea progresses with its zero-energy building (ZEB) roadmap, integrating timber construction into public buildings can contribute significantly to carbon neutrality and sustainability goals. Further research on optimized timber assemblies and large-scale solutions is essential for advancing sustainable, low-carbon, high-rise timber construction. This study shows hybrid CLT systems can reduce life cycle emissions and mitigate climate change, contributing to sustainable global construction practices.

Investigating Information Sharing Networks in the Western Hardwood Sector

Victoria Diederichs^{p*} (Oregon State University), Mindy Crandall (Oregon State University), Eric Hansen (Oregon State University)

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Abstract

Despite their ecological and cultural presence on the landscape, the native hardwoods of Oregon and Washington are often relegated to harvest waste in wood processing sectors. The dominance of softwood-focused policy and management in this region has led to hardwoods being treated as a byproduct of the forest industry. Still, a small manufacturing sector has emerged to use this resource. These manufacturers utilise species and logs harvested as part of traditional forestry activities or as urban and rural salvage. Little research has focused on this sector and their adaptations to this operating environment. This study uses a mixed methods approach to assess the information needs and sharing dynamics among these manufacturers, since relatively little available market and technical information is specific to western hardwoods. First, 15 semi-structured interviews were conducted followed by a qualitative analysis to gather contextual data. Preliminary findings from the first phase highlight the challenges the western hardwood sector contends with in finding consistent supplies of both material and technical expertise. Manufacturers rely on in-house research and capacity building in conjunction with support from local networks of similar companies, amenable suppliers, and in some cases technical support from manufacturers in hardwood dominant regions. The next phase involves collecting data on information sharing relationships between companies using surveys gathered from a larger sample of the western hardwood sector. This relational data is analyzed using social network analysis to develop a broad view of information sharing networks and assess information resource sharing dynamics at multiple scales. A stronger understanding of information development and use in hardwood manufacturers can provide avenues to incentivize improved hardwood utilisation and stronger management practices for mixed wood forests in this region.

Session 14.2 - Mass Timber Research and Innovation V

~ Session Organizers - Hongmei Gu (USDA FS Forest Products Laboratory), Daniel Hindman (Virginia Tech)

~ Moderators - Dan Hindman and Levente Denes

Reuse Potential of Screw Connections in Southern Pine Cross-Laminated Timber

Ian Morrell^P (Tennessee Technological University), Ellie Cauthen (North Carolina State University), Arijit Sinha (Oregon State University)

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Abstract

There has been growing interest in the concept of circularity in the built environment, which involves, in part, finding ways to reuse or repurpose materials in a structure for future projects. This reduces the need to dispose of materials from a structure at the end of its service life and also reduces the need for new virgin material. Currently, if a structure is deconstructed, most structural members are repurposed into non-structural components, as there is little guidance to determine the damage to the component and if it is still suitable for structural applications. One important area for this is connections. Screwed connections can physically be taken apart and put back together or repurposed with the same geometry. However, there has been little data or investigation into the effect this would have on the connection properties of a rebuilt connection. To begin to fill this gap in knowledge, monotonic lateral resistance testing was conducted using southern pine Cross-Laminated Timber (CLT) with a steel side plate connected with either a conventional wood screw or a self-tapping screw. These connections were loaded to a percentage of their design load and then unloaded. The screw was then replaced, and the connection was tested to failure. These tests suggested that for the conventional wood screws there was little difference in the yield strength or stiffness even as the initial load increased. The self-tapping screw exhibited a lower peak strength, but similar yield strength and stiffness. This suggests that there is capability for reuse with screwed connections, but further study would help to understand these effects across connections, load types, and species. The above results and other discussions and findings will be presented.

Building Colorado's Mass Timber Economy

Will Lepry^p (Colorado Mass Timber Coalition)

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Abstract

As mass timber continues to grow in popularity, regions across the U.S. are developing mass timber supply chains to help meet demand. While the end goals are similar, each area will have their own unique approach based on their natural resources, timber industry, and various policies. This talk will highlight the rapid growth of the Colorado Mass Timber Coalition (CMTTC) including the challenges and successes of building a mass timber economy within the state and region.

Key Insights from Whole Building Life Cycle Assessment (WBLCA) of the World's Tallest Hybrid Concrete and Mass Timber Apartment Building

Hongmei Gu^P (USDA FS Forest Products Laboratory), Marco Lo Ricco (USDA FS Forest Products Laboratory)

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Abstract

When the 25-story Ascent apartment building opened its doors in Milwaukee, Wisconsin, on July 20, 2022, the Council on Tall Buildings and Urban Habitat declared it the “World’s Tallest Timber-Concrete Hybrid Building.” The top 18 stories of Ascent were framed with glulam and decked with cross-laminated timber (CLT) panels. According to whole building lifecycle assessment (WBLCA), mass timber lowered the overall global warming potential of the building by nearly one third in comparison to an entirely concrete benchmark of conventional construction and functional equivalence. As a result of performance-based fire safety design, approximately 60% of glulam beams, 45% of glulam columns, and 40% of CLT ceilings were left architecturally exposed to view, which further enhanced sustainability by conserving gypsum wall board encapsulation that would otherwise be prescribed by the International Building Code. While the WBLCA shows the mass timber hybrid construction of Ascent to be generally advantageous over an entirely concrete structure, this case also identified several areas of potential improvement. First, the sustainability of mass timber could be enhanced in the A4 (transportation) stage with domestic sourcing and production of mass timber materials. Second, WBLCA reports could be more useful in selecting structural systems if specific construction data, distinguishing timber and concrete construction procedures, were available to model the A5 (installation) stage. Third, mass timber buildings could be even more competitive with concrete post-tensioned flat slab construction by achieving shallower floor heights through technological innovation. From WBLCA of the Ascent, the audience will learn how sustainability may be optimized in building design and future research.

Cursory Review of Funded Research Related to Mass Timber

Tahar Messadi^P (University of Arkansas), Mahboobeh Hemmati (University of Arkansas), Moein Hemmati (University of Arkansas), Hongmei Gu (USDA FS Forest Products Laboratory)

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Abstract

This funded program is dedicated to investigating the environmental impacts of cross-laminated timber (CLT) and Glu-lam in the construction and operation of Adohi Hall residential building at the University of Arkansas campus, Fayetteville, AR. The first phase of this research examines transportation impacts, comparing overseas CLT imports (Austria to Fayetteville, AR) with locally supplied timber from two U.S. regional locations, Conway, AR and Seattle, Washington. Results reveal that transportation mode and distance are critical factors influencing GWP, with water transport showing the lowest emissions, followed by rail and road. The second research deals with the moisture monitoring of CLT panels in the same building, because of their long exposure to local weather on the site showing an elevated moisture content close to 20%. The third research compares the embodied carbon (EC) between similar structures of mass timber and steel. Mass timber achieves a 19% reduction in carbon emissions (198 kg CO₂ eq/m² vs. 243 kg CO₂ eq/m² for steel) and stores approximately 2,757 tonnes of CO₂ eq. over the building's life stages A1 to A4. Replacing concrete with lighter CLT slabs also reduces foundation size, resulting in a displacement factor (DF) of 0.28, favoring the utilization of mass timber over steel structures. The fourth research focuses on the carbon emission during the construction-phase, identifying earthwork and mass timber installation as the highest contributors. A detailed greenhouse gas (GHG) emissions database and modeling of the construction process (material transportation to site and equipment operation) are developed, revealing underestimated EC in previous studies. Finally, operational carbon (OC) consists of assessing and quantifying emissions from building energy use. Adohi Hall's mass timber design, when combined with the University-campus applied energy-efficient systems, achieves significant OC reductions. This integrated LCA approach underscores the importance of considering both embodied and operational carbon to address climate change.

TUESDAY, JUNE 17 | 5:30 – 7:30 PM

Poster Session

(*denotes student)

A study on how to promote the use of forest-based bioproducts and develop business models

Yonggun Park (National Institute of Forest Science), Yoon-Seong Chang (National Institute of Forest Science), Soon Gil Kwon (National Institute of Forest Science)

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Abstract

The purpose of this study was to identify factors that hinder the utilization of forest resource bioproducts based on market research and surveys, and to derive action plans to resolve and revitalize them in the future. Examining the case of biochar, bioplastics, and pulp-based packaging at each stage of the value chain from the perspectives of resources, technology, and services, we found that the market for forest-based bioproducts is diverse and that it is essential to analyze demand and target products for each market. At the same time, it is necessary to differentiate from competitors and alternative products, establish a sustainable raw material supply system for stable production, and reduce production costs to secure continuous demand and expand the market. In addition, an online survey was conducted among 1,000 members of the general public to identify key factors necessary for the conversion of domestic forest resource bio-products. The most main factors for activating the use of bio-products were government and public institution support policies and demand creation (35%), followed by improvement of public awareness (23%) and new product development and technological innovation (14%). It is necessary to stabilize the initial market through government-led public procurement and address investment risks and product safety concerns. Forest-based biomaterial products were expected to increase in the future (61%), but the reasons for the inactive use of domestic wood were that it is more expensive compared to imported wood (47%) and difficulty in ensuring continuous supply (27%). The respondents are willing to pay an average of 33% more for bioproducts compared to conventional products. In conclusion, in order to expand the use of forest-based bioproducts, it will be important to comply with certifications such as FSC and PEFC that ensure sustainability and efficiently utilize by-product resources that would otherwise be discarded.

Apple Pomace Fermentation Broth as a Potential Biobased Road Deicer

Listowell Darko* (University of Idaho), Armando McDonald (University of Idaho)

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Abstract

Road salt usage on winter roads poses significant environmental and infrastructural corrosion challenges, prompting the need for greener alternatives. This research aims to develop bio-based de-icer additive from fermented food wastes. This study focuses on the fermentation of apple pomace, a byproduct of cider production, to organic acids and ethanol, as a sustainable, bio-based road deicer. Apple pomace was fermented at 35 °C for 13 days, yielding 3.66 g/L ethanol, 0.36 g/L acetic acid, and 0.27 g/L lactic acid, confirming its suitability as a chemical feedstock. Ice-melting tests conducted between -1 °C and 0 °C revealed that apple pomace achieved a maximum melt volume of 8.21 mL/g at 45 minutes, slightly lower than NaCl's 8.65 mL/g, yet demonstrating competitive deicing performance. However, Differential Scanning Calorimetry (DSC) analysis showed that the freezing point of the apple pomace solution was significantly higher (-0.99 °C) than that of NaCl (-22.66 °C), indicating weaker freezing point depression capability. Corrosion tests on steel coupons over 30 days revealed that apple pomace caused higher metal degradation: 0.193 mm/year at Day 10, decreasing to 0.130 mm/year at Day 20 and 0.098 mm/year at Day 30, while NaCl maintained rates below 0.021 mm/year throughout. These results suggest that fermented apple pomace has promise as a low-toxicity deicer additive, but further formulation enhancements are needed to improve freezing point depression and reduce corrosivity.

Modification of Hemp Shiv Properties Using Novel Functionalized Silica Coatings to Develop Sustainable Thermally Insulated Building Materials

Ukasha Tiibu Mohammed* (University of Massachusetts Amherst)

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Abstract

The Architecture, Engineering, and Construction (AEC) industry reliance on non-renewable, high GHG-emitting materials, such as cement and fossil fuel, significantly contributes to global warming and ozone depletion. Hemp shivs, a sustainable biomaterial has the potential to sequester CO₂ and serves as aggregates in hempcrete, a composite material known for its fire resistance, thermal insulation, mechanical durability, and acoustic properties. This research aims to enhance the durability and performance of hemp shivs by developing a novel silica treatment technology that transitions them from hydrophilic to hydrophobic while retaining their natural moisture buffering capacity. The proposed treatment involves the functionalization of silica nanoparticles through a sol-gel process using silica extracted from rice husk, a sustainable biological material, along with hexadecyltrimethoxysilane (HDTMS) and tetraethyl orthosilicate (TEOS) catalyze with glacial acetic acid. This process will replace surface silanols with hydrophobic groups, reducing water absorption and improving resistance to biodegradation without compromising the material's porosity for vapor permeability. The study will evaluate parameters such as water absorption, moisture buffering capacity, and thermal insulation properties. Target outcomes include reducing water absorption below 250% and achieving a hydrophobic contact angle comparable to 120° observed in similar studies. The findings from this research will inform the development of hempcrete as a renewable and sustainable building material for the AEC industry, addressing critical environmental challenges and advancing sustainable construction practices.

Effect of Particle Size on Wheat Midds Biomass Composition

Ruth Azike* (University of Idaho), Armando McDonald (University of Idaho), Ezra Bar-Ziv (Michigan Technological university)

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Abstract

In this study, wheat midds (byproduct of the wheat milling process) samples that were milled and separated into four distinct particle sizes -<74 μm , 850-74 μm , >850 μm , and unsifted were examined for their chemical composition and thermal characteristics. A range of studies, including dichloromethane extractives, ash, lignin and carbohydrate contents were determined. The extractives were analyzed by GCMS as their fatty acid methyl ester profile. FTIR spectral analysis was performed to determine gross chemical features of the fractions. Thermogravimetric analysis (TGA) was employed to determine the thermal degradation behavior of the fractions. The unsifted fraction exhibited the lowest extract yield (2.1%), while the 850-74 μm fraction showed the highest (3.6%), indicating that particle size influences the extraction potential of wheat. The finer midds fraction (<74 μm) displayed lower ash content (4.7%), suggesting that smaller particles contain more organic material and fewer mineral impurities. The larger midd particles had a higher lignin content and better thermal stability. The smaller midds particles (<74 μm) had more acid-soluble lignin. Carbohydrate analysis showed that the main sugar was glucose. The fines midds fraction had the highest concentrations of glucose and xylose. These results highlight how crucial particle size is in defining wheat's chemical and thermal properties, which have significant importance for the production of bioenergy.

Life Cycle Assessment and Techno-Economic Analysis of Negative Carbon Sustainable Aviation Fuels from Paper Sludge

Jiawei Huang* (North Carolina State University), Yinqiao Wang (North Carolina State University), Kai Lan (North Carolina State University)

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Abstract

Paper sludge, a solid waste from pulp and paper mainly composed of fibers, fines, and fillers. The forest products industry plays a critical role in the transition toward a sustainable and circular bioeconomy, where integrating waste valorization strategies can enhance resource efficiency and build long-term sustainability. There is a growing interest in more sustainable valorization strategies for the advancement of the decarbonization of the pulp and paper industry. One promising option is to convert it into sustainable aviation fuel (SAF), a renewable substitution for fossil-based jet fuel. This study developed a cradle-to-grave life cycle assessment (LCA) model and conducted Techno-economic analysis (TEA) for producing SAF from paper sludge via pretreatment, enzymatic hydrolysis, saccharification and fermentation, dehydration, oligomerization, hydrogenation and purification. The carbon capture and storage (CCS) unit was integrated into the system. The LCA was coupled with a full-scale process model built in Aspen Plus. A total of 16 scenarios were evaluated in terms of feedstock composition, ethanol concentration, dehydration catalyst, and the CCS unit. A sensitivity analysis was performed to identify the hotspots of the system. Our preliminary results showed that, on a 1 MJ basis, without CCS, the global warming potential (GWP) of SAF is lower than fossil jet fuel by 59% across the scenarios. Greenhouse gas (GHG) emissions range from 44.5 to 63.4 g CO₂eq/MJ without CCS, while with CCS, they range from -137.2 to -102.0 g CO₂eq/MJ. The MFSP varies from \$4.2 to \$8.7/GGE across the 16 scenarios. Trade-offs are identified between the various environmental impact categories and economic feasibility for SAF from paper sludge. The deployment of CCS significantly reduces the GWP and results in negative carbon SAF but increases the burdens in other impact categories and the production costs.

Concept of a Strategy for the Development and Sustainability of Wood-processing Family Businesses in the European Union

Mariana Sedliačiková (Technical University in Zvolen), Martin Halasz (Technical University in Zvolen), Denis Pinka (Technical University in Zvolen)

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Abstract

Family businesses play a key role in the EU economy, supporting the stability and development of traditional industries such as the wood-processing industry. These businesses also represent a fundamental pillar of regional economies. The sustainability and strategic development of businesses in the wood-processing sector brings emerging challenges that require the application of intelligent approaches to ensure their continuity. The wood-processing industry, as one of the significant traditional sectors in the EU, is one of the main sectors that faces the increased pressure on sustainability due to ecological and technological sectors. The main goal of the scientific contribution is to propose a comprehensive framework strategy for the development and sustainability of family businesses in the wood-processing industry within the EU, from the point of view of their industrial sustainability, ecology and succession. The research was carried out using the survey method in the form of a questionnaire that was sent to wood-processing businesses operating in the EU. The hypotheses were tested using the Interval Estimation of Relative Frequency and the Relative Frequency Hypothesis Test. The results showed that most of the surveyed enterprises within the EU do not perceive sustainability comprehensively, but mainly focus only on output processes. Sustainability from the perspective of ecology is not sufficiently developed and most enterprises don't address the issue of succession. However, it is clear from the research that enterprises are aware of the importance of this issue, while having a strong interest in its implementation. The results of the research have potential to contribute to the development of family business in the wood-processing industry and ensuring its development in the EU. At the same time, they will contribute not only to practice, but also to the development of theory and scientific research in the field of sustainability of family businesses and their strategic development.

Wooden Origami Unfolding Layered Design: A Singular Sustainable Systematic Chair

Rico Ruffino (North Carolina State University)

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Abstract

Waste is an increasing concern connected with consumerism, emerging from our purchasing practices, how we use products, and how we dispose of them. The focus extends beyond just the companies producing these items; it also involves the design of the products themselves. The outcome for a product at the end of its life is determined during the design phase. Shifting the emphasis during this phase and changing the mindset of manufacturers is crucial for achieving sustainability. A goal of sustainable design is to minimize waste, focusing not only on the materials used but also on the manufacturing processes involved. A design study depicting this concept is a simple folding chair that utilizes a single material, utilizes one machine, and features a straightforward design. This technique results in an aesthetically pleasing and functional folding chair. The chair is made from soy-based, formaldehyde-free plywood provided by Columbia Forest Products, which meets higher environmental standards than traditional formaldehyde-based plywood. The design features a unique, stylized approach reminiscent of origami folded paper. At specific points, the chair incorporates a mechanical mechanism and a pattern of parametric kerf design, allowing the plywood to flex in a way that mimics folding. The focal point of the design is where the legs fold underneath the seat and where the seat back interlocks with the legs. Additionally, a flexible wooden latch stabilizes the folding legs at the bottom. This chair is made from a single sheet of plywood, maximizing material usage while employing only one design pattern, the use of a Computer Numerical Control (CNC) for minimalist manufacturing, emphasizing the flat-pack to maximize shipping efforts and reducing space. with no additional parts or hinges. This approach streamlines the manufacturing process and reduces waste in several capacities.

Enhancing Timber Piles Inspection in SC Bridges Using Non-destructive Methods

Aashish Sapkota* (Clemson University), Brandon Ross (Clemson University), Brunela Pollastreli Rodrigues (Clemson University)

Student poster competition - Third place winner

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Abstract

Timber piles serve as a critical component for bridges and play an essential role in the transportation infrastructure across South Carolina, USA, with approximately 75000 timber piles in use across the state. Wood deterioration is the primary cause of timber pile failures, emphasizing the urgent demand for cost-effective, reliable and time-efficient evaluation methods. This study aims to identify and assess field-deployable methods that effectively detect decay in timber piles, enabling preventive maintenance and repairs. To achieve this, the study employs nondestructive evaluation (NDE) techniques such as resistance micro-drilling and stress wave timing. Resistance micro-drilling detects internal decay and defects by measuring low-density resistance to penetrate the wood. On the other hand, a stress wave timer measures the time it takes for a stress wave to travel through wood, where slower velocity indicates deteriorated areas in wood. The presentation will summarize the preliminary results of the study, such as the correlation between NDE and destructive testing, along with predictive models for improved timber pile inspection. The study will help to refine the timber pile inspection process by understanding timber pile deterioration mechanisms and establishing a comprehensive and cost-effective framework for condition assessment.

Driving Change: Hardwood CLT- Concept to Code Approval

Brian Bond (Virginia Tech), Henry Quesada (Purdue University), Sailesh Adhikari (Virginia Tech), Daniel Hindman (Virginia Tech)

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Abstract

North America adopted cross-laminated-timber utilizing softwoods as an alternative to multi-story steel and concrete structures in 2015. While the United States produces significant softwood lumber, it is a net importer of softwoods. In the Appalachian region, the availability of low-grade hardwood, yellow-poplar in particular, provided a logical alternative to softwood use. Around this timeframe, faculty at several universities investigated opportunities for hardwoods in mass timber. This poster presents one such multi-partner approach, beginning with the concept of yellow-poplar use in CLT to laboratory testing, industrial application, submission to change the standard, to acceptance building code. The authors present the steps from original concept to code approval including the partnerships, funding, and outcomes.

Wood Artifacts Historic Pilot Project

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Abstract

There are an unknown number of significantly important wood artifacts and structures existing under the jurisdiction of various federal agencies. This includes ships, timber bridges, historic landmark buildings, tools, recovered artifacts, and many others. However, the condition of many of these artifacts is unknown, making this research a necessity to ensure their continued protection. The Department of Sustainable Bioproducts at Mississippi State University has an extensive history of evaluation, protection, and archiving of wooden artifacts in the Cully Cobb and Virgil Priester Tool Collections and the David A. Kribs Wood Specimen Collection. One historic item that the Department has been involved in protecting is the ironclad ship, the USS Cairo, located at Vicksburg Military Park in Vicksburg, MS. The ship has been treated in the 1990's with diffusible borate solutions to prevent any acceleration of decay in the wood portion. Inspections were conducted most recently in 2023 and 2024. This project will take the next step of installing an environmental monitoring system to determine moisture and humidity levels throughout the structure, which has a protective roof but is not enclosed within a climate-controlled building. Visual inspections will be carried out to determine pest infiltration, wood decay, metal damage, and other areas of deterioration. Sensors will be installed across the structure and monitored monthly. The environmental data that will be collected will be used to inform the National Park Service of how to best protect this unique and very large piece of history.

Investigation of Guayule Resin as an Oil-based Wood Treatment

Jordan Miller* (Mississippi State University), Elizabeth Stokes (Mississippi State University)

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Abstract

The purpose of this research is to determine if guayule resin (from *Parthenium argentatum*) can be mixed with an oil to create a better wood preservative. Guayule resin has already been tested and proven to have insecticidal and microbial properties which is very important when it comes to protecting wood, but problems exist with its application due to its very thick sludge-like consistency. Guayule resin does not mix with water-based products, but we have recently found that it can successfully mix with oil carriers. During this research, we have blended the guayule resin with three different oils that have antibacterial and antifungal properties to create a novel wood preservative – neem oil, castor oil, and jojoba oil. Neem oil is a natural extract from the seeds of the neem tree, which is native to the Indian subcontinent, and has been used for centuries for its various pesticidal properties. Castor oil comes from the seeds of the castor bean plant, which is native to tropical areas of Africa and Asia. Castor oil's versatility has led to its use as a mold inhibitor, preservative, and in protective packaging, among many others. Jojoba oil is extracted from the seeds of the jojoba plant, is shelf stable and low in triglycerides. It has been reported to have toxicity, antifeedant activity and repellency against many insects including termites. We have applied the blended oils to wood products to determine uptake and treatability, tested water repellency effectiveness, and material swelling.

Empowering Future Leaders in Timber and Digital Manufacturing: The REEU Experience

Allison Culver (Oregon State University), Arijit Sinha (Oregon State University), Eric Hansen (Oregon State University)

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Abstract

The Research and Extension Experiences for Undergraduates (REEU) program at Oregon State University (OSU) provides undergraduates from institutions across the country with hands-on research and extension opportunities to prepare them for the next steps in their careers. Through these experiences, students deepen their understanding, develop critical thinking and problem-solving skills, and enhance their workforce readiness. This project strengthens OSU's capacity to produce graduates who meet industry demands and contribute to the next generation of research scientists in the timber industry. With sustainability concerns driving increased use of wood in tall buildings (mass timber), digital manufacturing plays a crucial role in this evolving sector. This REEU project offers undergraduates immersive experiences in digital manufacturing and wood science, equipping them with specialized knowledge and skills essential to this economically significant field. Each year, students are recruited, matched with mentors, and engaged in projects that provide hands-on research experience, extension and outreach opportunities, and structured mentorship through regular meetings.

Through this program, students:

1. Gain hands-on research and extension experience to enhance their technical skills.
2. Develop strong, lasting professional relationships with mentors.
3. Acquire science-based knowledge, engage with cutting-edge research, and interact with academic and industry leaders.

Students have opportunities to present their work at regional conferences and pursue publication in peer-reviewed journals. Program success is evaluated based on student-centered learning outcomes, measured in both the short and long term.

Determining the Toxic Threshold of Industrial Hemp Seed Oil as a Wood Protectant

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Abstract

The objective of this study is to determine the level of cold-pressed hemp seed oil that would be considered ineffective against fungi and termites, the toxic threshold. This research is expected to give us valuable information on the toxic threshold that it would take for the application of cold-pressed hemp seed oil applied to wood materials to be effective against damaging organisms. The shift away from petroleum oil-based preservatives has been driven by several factors related to health, environmental, and technological advancements. This caused the development of water-based preservatives, generally because they are less toxic to humans and the environment compared to oil-borne preservatives. However, natural oils derived from plants and plant waste products have shown viability as an alternative to petroleum oils in wood protection. The significance of this is that it is a natural preservative based on plant oils would not only be effective but also beneficial for the environment. Testing has included a variety of uses of this oil, such as aiding in weathering and resistance to water intrusion. Determining the toxic threshold, evaluating the water repellency effectiveness, measuring product swelling, and pairing the hemp seed oil treatment with available coatings will give the project sponsor a picture of the limitations of this product. This study will provide adequate data to the sponsoring company that would allow them to get a better idea of the effectiveness of their hemp seed oil product at different concentrations and in different blends.

Correlative Microscopy of Cellulose Nanofibrils

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Abstract

In terms of sample preparation and imaging, every microscopy method has advantages and limitations. Thoughtful combinations of various methods can leverage the strength of each method to provide a better understanding of the material. This is particularly useful in biomass research, where samples are often strongly affected by sample preparation and imaging techniques. Correlative microscopy employs conventional light, fluorescence, cryogenic, and electron microscopy on the same research sample. We present current research at FPL on the morphology of cellulose micro- and nanofibrils (CMFs, and CNFs). Our objective is to exploit the potential of different microscopy methods for the characterization of microfibrillated cellulose (MFC). We include and discuss the following topics:

- Phase-contrast, and fluorescence light microscopy for studying the degree of fibrillation of CMFs, the ratios of micro- and nanofibrils, and the occurrence of lignified and nonlignified fibrils.
- Conventional and environmental scanning electron microscopy (SEM, ESEM) for characterization of the morphology of CMFs. While the resolution of ESEM is lower compared to SEM, hydrated samples can be observed avoiding the artifacts of fibril agglomeration and shrinkage during the sample preparation for SEM.
- Field-emission SEM for characterization and measuring the diameters of individual and entangled nanofibrils.

Life Cycle Assessment and Valorization of Hazelnut Shells into Value-added Products

Proknight (Cheng-Chi) Kao* (Oregon State University), Alhassan Ibrahim (Oregon State University), Islam Hafez (Oregon State University), Gerald Presley (Oregon State University)

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Abstract

According to United States Department of Agriculture (USDA) statistics, Oregon produces 99% of the hazelnuts grown in the United States, and the total volume produced has risen about 2.7-fold since 2014. Hazelnut shells are therefore an increasingly available agricultural waste that will require better utilization to extract the most value from this crop. In this study, the primary goal is to investigate the potential of hazelnut shells for biochar applications and pellets production. The first part of this study focuses on the characterization of hazelnut shells and the conversion to biochar via pyrolysis. The pyrolysis process will be optimized to maximize the biochar yield and quality. Following this, the environmental impacts will be evaluated through a life cycle assessment. Additionally, the production of pellets by mixing hazelnut shells with forest residues will be investigated. Overall, this study demonstrates the potential of a circular economy via the valorization of agricultural and forest residues into value-added products.

Moisture Content Analysis of Soil-Mixed Woody Biomass Using Near-Infrared Spectroscopy for Efficient Resource Utilization

Minjee Kang (Seoul National University), Bat-Uchral Batjargal (Seoul National University), Taekyeong Lee (Seoul National University), Hwanmyeong Yeo (Seoul National University), Youngmin Cho (Seoul National University), Sangwoo Park (Seoul National University), Hyo Won Kwak (Seoul National University), In-Gyu Choi (Seoul National University), Sung-Wook Hwang (Kyungpook National University)

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Abstract

The efficient utilization of residual wood biomass has become increasingly important. Accurate measurement and control on the moisture content of the woody biomass is essential for improving energy production efficiency and cost-effectiveness. Biomass storage presents challenges such as moisture absorption, decay, and heat generation, which can lead to tissue deterioration and performance decline, thereby affecting production and distribution processes. Proper moisture management is crucial to mitigating these issues. Near-infrared (NIR) spectroscopy has emerged as an effective technique for rapidly and non-destructively assessing the moisture content of biomass. This study utilized NIR spectral data in the 870–2500 nm wavelength range to predict the moisture content of soil-mixed biomass and validated the results against the conventional oven-drying method. Standard normal variate (SNV) and Savitzky-Golay (SG) preprocessing techniques were applied to optimize the data. The combination of SNV and SG preprocessing on raw spectral data yielded the highest predictive performance in the partial least squares regression (PLSR) model. The PLSR model achieved a coefficient of determination (R^2) of 0.82 and a root mean square error (RMSE) of 1.41 during calibration, while in the prediction phase, R^2 was 0.74 with an RMSE of 1.89. Furthermore, this study analyzed the effect of soil content on moisture content prediction accuracy and identified key water absorption bands at 1437 nm and 1927 nm. These findings highlight the potential of NIR spectroscopy for quantifying moisture content in complex biomass-soil mixtures, significantly enhancing manufacturing efficiency in biomass applications. This study underscores the importance of efficient moisture management during biomass storage and processing. By enabling real-time analysis and reliable data acquisition in biorefinery processes, it contributes to sustainable development.

In situ Synthesis of Prussian Blue on the Lignin for Ultrafast and Highly Selective Cesium Adsorption

Jungkyu Kim* (Seoul National University), Junsik Bang (Seoul National University), Seungoh Jung (Seoul National University), Bonwook Koo (Kyungpook National University), Jungkwon Oh (Seoul National University), Hwanmyeong Yeo (Seoul National University), In-Gyu Choi (Seoul National University), Hyo Won Kwak (Seoul National University)

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Abstract

The removal of radioactive cesium (Cs^+) from contaminated water sources is a critical environmental challenge, particularly in nuclear energy and radioactive waste management. Developing efficient, selective, and eco-friendly adsorbents is essential for mitigating the environmental impact of nuclear activities. In this study, we introduce a novel lignin-based Prussian blue adsorbent (PB-Lig) synthesized through an in situ approach involving carboxylation and Zr/Zn crosslinking. This method facilitates the robust immobilization of PB nanocubes onto the lignin surface, enhancing its structural stability and Cs^+ adsorption efficiency. PB-Lig exhibited rapid and highly effective Cs^+ adsorption, achieving equilibrium within 480 s and demonstrating a maximum adsorption capacity of 163.3 mg/g. The adsorbent maintained consistent performance across a wide pH range (6–10) and exhibited exceptional selectivity for Cs^+ even in the presence of competing cations. Importantly, PB-Lig remained structurally stable during multiple adsorption-desorption cycles, with no detectable PB leaching, ensuring long-term usability and reducing secondary pollution risks. Various characterization analyses confirmed that Cs^+ removal by PB-Lig occurred through lattice capture within the PB structure and ion exchange with K^+ . Compared to previously reported biomass-based adsorbents, PB-Lig offers a sustainable and practical alternative for radioactive Cs^+ remediation, leveraging the renewable nature of lignin while maintaining superior adsorption performance. This study highlights new opportunities for utilizing biomass in environmental applications and presents the first reported lignin-based Cs^+ adsorbent with exceptional efficiency, selectivity, and stability.

Innovating for Sustainability: A New Online Master's Program in Wood Science

Allison Culver (Oregon State University), Mariapaola Riggio (Oregon State University), Eric Hansen (Oregon State University)

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Abstract

The Department of Wood Science and Engineering at Oregon State University (OSU) is launching an online, non-thesis Master's degree in Wood Innovation for Sustainability (WINS), with tracks in Mass Timber and Timber Circular Economy. As a leader in wood science education, OSU's College of Forestry, in collaboration with the TallWood Design Institute, is well-positioned to deliver this program, expanding access to transformative education for professionals in the wood products industry and beyond. Currently, most wood science & engineering degrees are only available on campus, which is limiting access for industry professionals. The WINS program is especially designed for place-bound employees, enhancing their career advancement and economic mobility while equipping them with unique skills in two highly competitive and sought-after fields. The curriculum integrates five core areas: (1) wood science fundamentals; (2) specialized knowledge in mass timber or circular economy; (3) engineering and business technical skills; (4) communication and management expertise; and (5) professional responsibility and ethics. Additionally, students complete a comprehensive internship, applying knowledge to real-world challenges. Graduates of the Mass Timber track will be equipped to drive innovation across various sectors of the industry's supply chain, including advanced manufacturing, digital fabrication, engineering, and construction management. Graduates of the Circular Economy track will advance sustainable industry practices, enhancing resource efficiency in wood-product manufacturing and in the wood construction sector. They will develop solutions to reduce environmental impact through improved processes, bio-based materials, and waste reduction strategies, aligning with society's commitment to lowering its carbon footprint. By expanding access to industry-focused, high-impact education, the WINS program will help shape the future of sustainable wood innovation.

Biobased Novolac Composites: Flow, Curing and Mechanical Properties

Japneet Kukal* (University of Idaho), Lorena A. Portilla (Auburn University), Brian Via (Auburn University), Lucilla M. Carias (Auburn University), Maria Audad (Auburn University), Manish Sakhakarmy (Auburn University), Sushil Adhikari (Auburn University), Armando McDonald (University of Idaho)

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Abstract

This study looked at the possible applications of a biobased novolac (pyrolysis oil / phenol-formaldehyde) resin and hexamethylenetetramine (HMTA) hardener with either 40 mesh and 100 mesh wood fiber (30%), for additive manufacturing (AM) of wood composites. The materials were characterized by a combination of thermal analysis, rheology, mechanical, and water absorption properties. Wood pyrolysis oil was partially substituted for phenol in the novolac resin preparation to increase its biobased content. The curing behavior of the resin and composites was determined by differential scanning calorimetry (DSC). The presence of wood and pine fibers decreased the curing enthalpies and increased the curing peak temperature. The flow characteristics of the uncured resin and composites were determined by dynamic rheometry. At 25°C, the frequency sweep flow curves of the 40 mesh and 100 mesh wood biobased-novolac composite blends displayed shear thinning behavior, with complex viscosity values (at a shear rate of 1 Hz) of 181 kPa.s and 136 kPa.s, respectively. Extrusion experiments on the biobased-novolac/wood composites were successful in producing a pliable continuous rod and showed promise for use in AM. The extruded biobased novolac-wood composites rods were cured (150°C for 5 min), and the flexural strength and modulus properties determined.

Reevaluation of Mechanical Characteristics of Lumber from Small-Diameter Logs: Small Clear Specimens

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Abstract

Forests that grow too densely increase the risks of catastrophic wildfires. Thinning these forests, which typically involve the removal of small-diameter logs, can mitigate this risk. These logs are currently considered low value because they contain more juvenile wood than logs from commercial harvests and are more costly to process into lumber due to their smaller size and higher taper that reduces the yield. Utilization of this material in structural applications would add market value to small diameter logs. However, high juvenile wood content in this lumber makes it less suitable for construction. Currently, National Design Specification (NDS) values are based on lumber from commercial harvests with much higher proportions of mature wood. There is limited evidence that lumber with high juvenile wood content does not meet the NDS benchmarks for its visual grade. The goal of this project is to verify the findings from earlier studies with elastic and strength data determined on a representative sample of lumber and small clear specimens from small-diameter logs. In case the earlier findings are confirmed, new design values will be generated. The specific objective of this study is to determine the mechanical characteristics of small clear specimens harvested from the same material. This data will complement the strength and stiffness data obtained from tests performed on structural lumber performed in parallel projects. The test procedures follow the ASTM D143 methods to determine strengths (and elastic modulus) in compression parallel to grain, compression perpendicular to grain, shear parallel to grain and static bending on small clear specimens of ponderosa pine which is considered the weakest of Western Wood species. The outcome of this study will be used to verify the correlation between properties determined for structural sized lumber and small clear specimens of the same material with lumber from commercial harvests.

Fabrication and Characterization of COMPOLEs from Lumber of Southern Pine (*Pinus* sp.) Trees

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Abstract

Wood and wood-based utility poles serve as the literal backbone of our national grid. According to Love et al. (2021), an estimated 180 million utility poles are in operation in the United States, supporting more 450,000 miles of line, with 83% made of wood. Currently produced tall wooden poles over 100 feet have been comprised of laminated timbers; COMPOLE research is observing the feasibility of designing with materials from small-diameter trees (SDT). The first phase of this study evaluated the manufacturing feasibility of COMPOLEs with a hollow hexagonal cross-section. Eight-ft-long COMPOLEs with a diameter of 10.35 inches were manufactured using NO. 2 grade 2x6 southern yellow pine lumber and phenol resorcinol formaldehyde (PRF) resin, bonded with 304 stainless steel straps at every foot. To evaluate their deformation, structural performance, and failure modes, these poles were subjected to three-point bending tests. The findings of this study provided valuable insights into the design and fabrication of COMPOLEs, ensuring they meet the structural performance of various classes of existing solid cross-section utility poles. This research opens new avenues for developing hollow, lightweight, high-performance utility poles to replace both glulam and conventional utility poles with solid cross sections.

Utilization of Walnut Plantation Thinnings and Challenges Related to Product Marketing

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Abstract

The utilization of plantation thinnings has been a long-term, persistent challenge for Black Walnut plantation owners, and there are no widely adopted solutions. Wood product manufacturers often perceive these logs as low-quality resources. The cost associated with small-diameter timber processing and various defects limit their market potential. This study presents a roadmap for maximizing the value of plantation thinnings, exploring both high-value and low-value product categories. For high-value applications, we propose highlighting furniture that embraces natural character marks and innovative engineered wood products that optimize yield from small-diameter timber (SDT). Additionally, options for low-value product categories will be explored to ensure full resource utilization. Two case studies will examine economic aspects, including cost analysis, lessons learned, and marketing challenges. This research aims to provide practical insights for improving the financial viability of Black Walnut plantation thinnings, creating new opportunities for sustainable forest management and wood product innovation.

Tailoring the Properties of Biochar for Enhanced Performance of Wood-based Composites

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Abstract

The incorporation of biochar into wood-based composites offers a viable way to improve the physical and mechanical properties and increase sustainability of these composites. However, the effectiveness of biochar as a reinforcing additive is significantly dependent on its physical and chemical properties, which can be influenced by production parameters and pre or post treatment changes. This study investigates the effect of major process parameters, such as pyrolysis temperature, heating rate, and residence time on the properties of biochar made from woody biomass. Furthermore, other activation methods, such as chemical activation, are being explored to impart surface functionality to biochar. The project aims to identify optimal processing conditions using three different chemical compounds to potentially activate and utilize biochar as a functionalized additive in wood-based composites. Characterization techniques, including scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), Raman spectroscopy, Thermogravimetric analysis, and surface area analysis, among others will be employed to evaluate the morphological, chemical, and thermal properties of functionalized biochar. The findings in this study will provide insight into tailoring biochar properties for improved moisture resistance, thermal stability, and fire performance of wood-based composites.

Bioinspiration and Sustainable Product Development: Connecting Theory and Practice in the Global Educational Space

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Abstract

Bioinspiration is becoming an increasingly important tool for sustainability education across scientific and artistic disciplines. Although biomimicry permeates various fields of research and practice, its application in higher education still requires the development of effective methodological frameworks and validated teaching strategies. This study presents selected outcomes of a long-standing collaboration in applying biomimetic principles and biomimicry in teaching at two universities - Purdue University (course *Global Sustainability Issues*) and the Technical University of Zvolen (course *Ecology versus Design*). Through the biomimicry method and biomimetics practices, students were guided step-by-step through the basics of implementing these practices (methodology) in their projects. From 2020 to 2025, students in both courses were provided with identical theoretical foundations, applying the methods from biology to design. The goal was to abstract design principles from biological mechanisms to identify opportunities for their implementation in final conceptual products. The teaching methodology is applicable across disciplines where knowledge needs to be linked. The project also collects student feedback and analyses their experience and creativity through case studies. The results of this study can serve as inspiration for the development of interdisciplinary education and as a basis for building new teaching models that foster innovative thinking, interdisciplinary collaboration, and a deeper understanding of the relationship between natural principles and their application in creative design. In addition, it highlights the importance of international cooperation and the exchange of experiences between universities, which opens the way for new approaches to biomimicry teaching and research as a tool for sustainable innovation in a global context.

Disaster Response Housing Solutions: Insights from an Educational Experience

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Abstract

In 2023, an estimated 2.5 million people in the U.S. were displaced due to natural disasters, including hurricanes, wildfires, floods, and tornadoes, forcing families to seek temporary housing. In 2024 the western United States saw over 10,000 wildfires in increasingly more populated areas, the need for temporary shelter is urgent and growing. Initial research under the College of Forestry's Mentored Employment Program at Oregon State University focused on investigating existing temporary housing options. Working to identify and list features needing improvement. During the "Timber Tectonic in the Digital Age" course, a joint class between Oregon State University and the University of Oregon, students collaborated on problem-solving in the design and construction process. We identified key challenges: access to supplies, construction knowledge, and the need for displaced people to feel connected to the rebuilding process. Our design utilizes a Stressed Skin Panel system that can be flat-packed and assembled with simple tools by a group of five people with limited construction knowledge, using an IKEA-type manual. Panel design focuses on easy creation, replacement, and nationwide availability. To reduce waste and allow for multiple uses of the temporary shelter, our connection system allows for deconstruction and reuse of panels. The build's size and dimensions minimize waste, incorporating often-discarded materials into the connection systems. Recommended future design adjustments based on the system prototype include fastener tolerances to facilitate easier alignment, along with simplified and strengthened connections at the wall-to-floor joints. The primary focus of the course is on the design and prototyping of a construction system; therefore, we were unable to incorporate other critical elements such as the integration of utilities and enhanced outer protective layering. Hands-on practical approaches with theoretical research highlighted the realities of working with wood materials. The project also provided valuable insights into team management and communication strategies.

Reciprocal Structures as a Practical Teaching Methodology for Wood Designs

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Abstract

Reciprocal frames can be defined as linear, flat, or inclined structures that support each other and are arranged to form a closed circuit or unit. Reciprocal frames present opportunities and challenges to realize architectural ideas and innovative wood. These creative designs show new architectural possibilities in applying high-tech analytical techniques to realize low-tech design solutions. We will present different shapes, patterns, and examples of recently realized student projects and their involvement in different design stages. We will also feature examples of educational methods dealing with reciprocal structures and present them as a great teaching concept for product development. Reciprocal structures can lead to complex wood frame structures and be inspiring examples for architects. They can showcase efficient material utilization by forming something big from something small. This concept can engage students in creative group work and develop healthy group competition. It also involves the creation of innovative joinery systems. This concept was applied in two international institutions: a Furniture Strength Design course at Purdue University and a Construction and Design course at the University of Ljubljana. Students' outputs were collected and evaluated.

Effect of Wooden Indoor Environments on the Psychological and Physiological Responses

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Abstract

In industrialized nations, where individuals often spend considerable amounts of time indoors, research indicates that various physical elements within the built environment significantly influence the well-being of residents. Among the various materials available, wood is distinguished by its natural properties and is extensively utilized as both interior and exterior building materials. This study was conducted to understand the impact of wooden buildings on modern individuals who spend a lot of time indoors. Psychological and physiological changes in the human body were specifically observed within a confined wooden indoor environment. The designated experimental site was situated within a wooden structure at the National Institute of Forest Science in Seoul. The experimental space was constructed with walls that exhibited a wood coverage of 100%. In contrast, the control group utilized a space that did not incorporate any wood materials. Participants in the study measured heart rate variability before and after exposure to a wooden environment. We are currently engaged in quantifying the autonomic activity, autonomic balance, stress resistance, stress index, and fatigue index based on the collected data. Through this study, we aim to utilize it as a quantitative indicator to evaluate the human-friendly effects of wood in the future.

Shear Performance Evaluation of Self-Tapping Screw Joints in Larch CLT Under Cyclic Loading

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Abstract

To expand the width of a domestically produced structural orthogonal laminated plate wall, the lateral capacity performance of joints using self-tapping screws was evaluated. The larch CLT joint method used in the lateral strength test was divided into butt joint, half-lap joint, and spline joint, and was manufactured so that back lateral load was applied. The self tapping screw had a diameter of 8 and 10 mm, and the total number of STS used in the one-sided joint was 6. The lateral strength performance test of the STS joint was conducted based on the maximum load measured through simple loading and a lateral strength test for cyclic loading was performed by applying the protocol in accordance with ISO 16670. In the case of the STS joint strength performance to which a simple load was applied, the maximum lateral strength of all joints except the butt joint tended to increase as the diameter increased. As a result of the repeated load test, the half-lap joint showed the best joint performance when STS of the same diameter was applied. There were also differences in joint stiffness depending on the type of joint, and in the case of spline joints, it was confirmed that the spline material affected joint strength performance.

Characterization of Cross-Laminated Timber-Concrete Composite Connections with Insulation

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Abstract

"Sandwich panels" consist of two layers of structural material with a layer of insulation in between, providing a rapidly constructable and energy-efficient building envelope. While sandwich panels are commonly used in precast and tilt-up concrete construction, it is an underutilized technique in mass timber construction. This is partially due to a knowledge gap in panel assembly methods for mass timber. This poster will present ongoing efforts to develop composite sandwich panels consisting of a cross-laminated timber (CLT), 2" natural fiber insulation, and a concrete layer. In this study, two shear connections are evaluated through experimental testing to define their constitutive relationships. This work provides a foundation for new methods of assembling novel CLT sandwich panels, opening new opportunities for mass timber construction.

Potential Application of Sunflower Stalk Particles in the Manufacture of Lightweight Particleboards

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Abstract

This study aimed to evaluate the effectiveness of producing lightweight particleboards using sunflower (*Helianthus annuus* L.) stalk particles. Three-layer particleboards with densities of 350, 450, and 550 kg/m³ were fabricated using varying proportions of wood-to-sunflower stalk particles (100:0%, 75:25%, 50:50%, 25:75%, 0:100%) in the core layer, while the outer layers were composed solely of wood particles. Boards made entirely of wood particles in both the outer and core layers served as reference samples.

Urea-formaldehyde resin was utilised as the bonding agent. The results indicated that substituting wood particles in the core layer with sunflower stalk particles enhanced the physical and mechanical properties of lightweight particleboards. The three-layer boards with the optimal configuration, consisting of 100% wood particles in the outer layers and 100% sunflower stalk particles in the core layer, exhibited slightly higher bending strength (MOR) and modulus of elasticity (MOE) than the reference boards. Additionally, these boards demonstrated significantly improved internal bonding strength (IB), lower water absorption, and reduced thickness swelling at the same board density. For the 550 kg/m³ boards containing 100% sunflower stalk particles in the core layer, the MOR, MOE, and IB values were 16.3%, 16.6%, and 62.7% higher, respectively, compared to the reference boards. Furthermore, the lightweight particleboards with densities of 450 and 550 kg/m³, fully met the requirements outlined in the CEN/TS 16368 standard for both LP1 and LP2 board types. Finally, the most important finding of this study is that sunflower stalks could be successfully used to manufacture lightweight indoor particleboards saving wood raw materials.

Enhancing Standardized Testing Methods for Thermally Fused Laminates and Wood Mouldings: Bridging Laboratory and Real-World Performance

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Abstract

Standardized test methods are the foundation of quality assurance, enabling manufacturers to meet industry standards and demonstrate product reliability to consumers and regulatory bodies. A key challenge in this field is developing test methods that ensure consistency and repeatability while accurately simulating real-world conditions that affect product performance. In this study, the wood products service center partnered with several industries to evaluate the effectiveness and applicability of existing test methods across a range of wood products, namely Thermally Fused Laminates and Wood Mouldings. By identifying gaps, limitations, and areas for improvement, we refined existing methods and consolidated them into a comprehensive set of testing protocols specifically tailored to the products under consideration. This comprehensive analysis helped ensure that the test methods were robust, relevant, and capable of providing accurate insights into product performance across diverse applications. The insights gained will contribute to the evolution of testing protocols that more closely align with real-world usage conditions, ensuring that future products are innovative and reliable. Our service center will continue collaborating with industry associations to refine these methods, facilitate broader adoption, and address emerging challenges in the wood products sector.

Surface and Adhesive Properties of Alder Wood Treated by Steam and Plasma

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Abstract

Saturated water steam treatment generally causes changes in the surface properties of wood. The surface becomes hydrophobic, which can cause serious difficulties when bonding or coating. In this study, the radio-frequency discharge plasma was used to increase the hydrophilicity of the steam-modified alder (*Alnus glutinosa*) wood surface. Discharge plasma in air significantly increases the hydrophilicity of wood because various polar groups are formed, and the wood macromolecules are also cross-linked, which leads to an increase in scratch resistance and an improvement in the barrier properties of the wood material. This research investigates surface, adhesive, and chemical changes in alder wood after water steam treatment at a temperature of 135 ± 2 °C during a period of 9 hours. Hydrophilicity of steam-treated alder wood before/after plasma treatment was evaluated by the determination of contact angle with glycerol as the testing liquid. The FTIR-ATR spectrum of wood was recorded in the mid-infrared region ($4000\text{--}650\text{ cm}^{-1}$). X-ray photoelectron spectroscopy data were recorded using a Thermo Scientific K-Alpha XPS system. Adhesion measurements were carried out with determination of the tensile strength of adhesive lap joints for native and steam-modified alder wood before/after plasma treatment according to EN 204 durability class D4. The plasma-treated samples reached significantly lower contact angles values in comparison with plasma non-treated samples. After plasma treatment, an increase was observed in the intensity of peaks corresponding to carbon-oxygen groups, especially those assigned to C=O and COOH groups. Better hydrophilicity was confirmed by the higher strength of lap adhesive joints after different conditioning sequences.

Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products with Sustainable Policy Development

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Abstract

Sustainable development and stakeholder importance are interlinked. Natural resources of forests with certification and Flegt themes are actively discussed in the policy schemes worldwide. Also scientifically, competitiveness is an up-to-date matter. CSR benefits exist for companies, and stakeholders' sustainable framework is taken into consideration by the sustainable development policy. This is a qualitative research.

Understanding the Fundamental Influence of Wood Extractives on Wood adhesion

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Abstract

Queensland Australia features a variety of attractive, high-density hardwoods that hold value in composite products like glue laminated lumber. Among these, spotted gum (*Corymbia citriodora*) stands out for its strength, durability, and attractive color. However, the broader use of spotted gum in engineered wood products is hindered by two significant challenges. The poor bonding could be associated with the high content of lipids and phenolic compounds present in spotted gum, which migrate to the surface during drying, forming a chemically inert layer that impairs adhesive bonding. Additionally, its dense structure, characterized by vessel cells could be blocked by tyloses, limiting adhesive penetration, further complicating the bonding process. The challenges created by these traits emphasize the need for innovative solutions. This study aims to investigate the correlation between extractive composition and adhesion performance of spotted gum. To address this, we employ a novel approach by conducting weathering-induced delamination testing on solid wood treated with solvents of varying polarities. Despite the complexity of extracting solid wood, this study employs solvents of varying polarities to evaluate how removing extractives and specific compounds affects adhesive bond durability. Untreated and extracted wood specimens were bonded in cross-laminated structures, subjected to cyclic soaking and drying, and assessed using critical crack density measurements to evaluate delamination and bonding performance. Preliminary results indicate significant improvements in adhesion, with reduced delamination and delayed failure in extracted samples, as a function of the polarity of the solvent. These findings could change the utilization of spotted gum and other hardwoods, supporting the growth of the forest industry while enhancing the competitiveness of engineered wood products.

Low Formaldehyde Emission Plywood Bonded with Collagen-modified Urea-formaldehyde Resin

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Abstract

Formaldehyde is a gaseous, toxic matter harmful to human health, and its release, especially from furniture boards, is strictly monitored. The aim of the research is to reduce formaldehyde emissions from wood-based composites with required mechanical and physical parameters by investigating the composition of urea-formaldehyde (UF) adhesive mixtures. Biopolymer collagen marked as Collagen-S and Collagen-ST (modified thermally, with sulfur and with silicate additives) was prepared for testing. After verification of its parameters by XPS and FTIR spectroscopy and study of its antioxidant stability by differential scanning calorimetry (DSC), its effect on the life pot and viscosity of UF adhesive mixtures and formaldehyde emission after their condensation was tested. The measured values show that Collagen ST and Collagen S are suitable for reducing the formaldehyde emission in cured UF adhesive mixtures. Formaldehyde emission from plywood was tested using the desiccator method according to EN ISO 12460-4, with the highest reduction in formaldehyde emissions of up to 42% when applying 3.0% collagen S to the UF adhesive compared to the reference sample. At the same time, a reduction in formaldehyde emission of approximately 35% was recorded compared to the reference board determined by the chamber method according to EN 717-1. The evaluation of the mechanical properties of the manufactured plywood shows that the quality of bonding of the plywood fully complies with the reference sample and requirements of the EN 314-2 standard for Class 1.

Evaluating User-Friendly and Portable Kiln Technologies for Sustainable Biochar Production in Ghana

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Abstract

The demand for biochar and its benefits has necessitated the need to explore its production efficiency and effectiveness especially when climate change is still a global concern. Among other factors, technologies for producing biochar are significant components of its sustainability. In regard, this study explored the potentials of three user-friendly kiln technologies for sustainable biochar production (Oregon kiln – Type - A, Closed Oregon - Type - B, and Modified Dartmoor Dragon Retort – Type - C), especially for small-scale producers or those with less capital. Biochar yield was determined using selected agricultural residues (corn cobs, coconut husks, and coconut shells), and the elemental compositions of the resulting biochar were examined using ultimate analysis. Based on 27 field experiments, the Type - C biochar kiln recorded the highest average biochar efficiencies (20.0% - 62.0%), followed by the Type - B biochar kiln (15.0% - 32.0%), and the Type - A kiln recorded the lowest yield between 10.3% and 30.4%. With feedstock, coconut husk recorded the lowest average biochar yield (10.3%-20.0%), preceded by coconut shell (22.7% - 36.3%) and corn cobs (27.3% - 62.0%). Likewise, percentages of stored carbon of biochar were higher in Type - C kiln (3.2% - 4.8%), followed by Type - B (3.2% – 3.6%) and Type - A (1.2% - 2.8). The most dominant elements identified in all feedstocks were Hydrogen, Carbon, Potassium, Nitrogen, Calcium, and Sulphur, and the least available elements were Magnesium and Phosphorous. In conclusion, restricting air entry into kilns during pyrolysis (Type - C) resulted in high biochar production efficiencies and higher percentages of stored carbon. However, the yield and quality of biochar were significantly affected by the moisture content and sizes of feedstock, and the experience of the producers in using biochar kilns.

The Effect of Beech Wood Modifications on Formaldehyde Emission and the Bonding Quality of Plywood

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Abstract

Modifications of wood cause changes in their surface properties. The surface of wood after treatment with saturated water steam becomes hydrophobic, which can be problematic during bonding or surface finishing. Chemical changes in the surface properties of beech wood samples tested by X-ray photoelectron spectroscopy (XPS) confirmed an increase in the total amount of carbon from 74.4% to 75.8% with a simultaneous decrease in oxygen from 23.8% to 22.5%. The findings explain the deterioration of wettability, increased hydrophobicity, and reduced polarity of the wood surface. The radio-frequency discharge plasma in air was used to increase the hydrophilicity of the surface of wood modified with water steam in order to increase the strength of the glued joint. The samples of veneer were treated on both sides with a plasma power of 200 W for 20, 40, and 60 seconds. The results of FTIR spectral analysis of surfaces show that the concentration of COOH, C–O, and C=O groups increased, and the polarity of surfaces increased as well. Subsequently, the influence of physicochemical changes in beech wood surfaces on the strength of the glued joint and formaldehyde emissions was analyzed. To determine the formaldehyde emission, physical and mechanical properties, samples of plywood were prepared. The most significant decrease in formaldehyde emission of up to 38% and the highest shear strength of 3.5 MPa were achieved in the sample prepared with 40 s modification of the veneer by RF plasma before applying the UF adhesive mixture to its surface. The tested plywood is suitable for bonding class 1 and is appropriate for use in a normal indoor environment.

Evaluation of the Applicability of Fire Resistance Design Method for Glulam using Reduction Factor

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Abstract

As timber buildings grow taller, fire resistance requirements increase, making safety a critical issue. To address structural degradation from charring, FDS and Korea Standard add an outermost layer while removing inner layers. However, safety concerns arise due to layer thickness regulations. In FDS, a nominal 2-inch layer may have an actual thickness of 1.5 inches, smaller than the 1.8-inch char depth, potentially compromising the outermost layer. Additionally, KS lacks layer thickness regulations, raising further safety concerns. This study evaluates the applicability of the reduction factor using the transformed section method in glued laminated timber fire design. A one-hour fire resistance test assessed failure probability. Since NDS adjusts design strength to the average value, the reduction factor is expected to be safely applicable if failure probability remains below the average. Two specimen types were tested: Type 1 (five specimens without an added outermost layer) and Type 2 (five with an added outermost layer). Since Korea lacks layer thickness regulations, Type 2 applied the reduction factor under a relaxed char depth criterion. The proposed criteria require a minimum 25 mm layer thickness (half of the nominal 2-inch or 50 mm) and at least eight plies. The specimens were designed for conditions with the most significant reduction. The fire resistance test followed a three-sided charring condition for one hour under the standard temperature curve. The design strength was calculated based on NDS, incorporating the reduction factor through the transformed section method. The measured average char depth was 38.2 mm, more conservative than the KS standard. Despite a 37% failure probability under normal distribution, no failures occurred, confirming the reduction factor's conservative application. This study improves fire resistance design safety while offering various options to enhance efficiency.

Vibrational and Stress-wave Methods for Rapid and Cost-effective Assessment of Veneer-based Mass Timber Elements

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Abstract

This project will explore the effectiveness of transverse vibrational modal analysis and time-of-flight of mechanical waves in characterizing manufacturing defects in veneer-based mass planer and linear timber elements. Through transmission time-of-flight measurements perpendicular to the laminations in a tight grid will be used to create a velocity map. The locations and magnitudes of anomalous data will then be compared with physical observations of defects in panels once opened along their glue planes. Subsampled sets of the data will also be analyzed to determine if they could have accurately predicted defects. The vibrational analysis will be conducted on simply supported elements with an impacting hammer and a contact accelerometer to characterize the responding waveform, to determine if variations in dynamic MOE predicted using analytical techniques for beam-like and plate-like geometries correlate with the pervasiveness of defects. Of particular interest to this study are manufacturing defects such as delamination and voids. If these techniques prove to be accurate at predicting manufacturing defects in veneer-based mass timber elements, then the methodology used could be built-on by manufacturers to nondestructively detect defects in in-line production of their veneer-based mass timber elements.

Sustainable Cross-Laminated Timber: A Comparative Life Cycle Assessment of Yellow Poplar and Douglas-Fir CLT in the Central United States

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Abstract

This study investigates the environmental impact of manufacturing Cross-Laminated Timber (CLT) from underutilized hardwood species, specifically Yellow Poplar, in the Central U.S., through a cradle-to-gate life cycle assessment (LCA). While softwood-based CLT has been widely studied, the carbon footprint and energy demands of hardwood CLT remain underexplored. We compare the environmental performance of producing 1 m³ of Yellow Poplar (hardwood) CLT with Douglas-fir (softwood) CLT, applying mass and economic allocation approaches. Results reveal that hardwood CLT requires 20–30% more energy and generates higher greenhouse gas emissions, primarily due to energy-intensive kiln drying and processing. However, Yellow Poplar CLT demonstrates a 6.6% greater biogenic carbon storage capacity (1,049 kg CO₂/m³) than softwood CLT (984 kg CO₂/m³), highlighting its potential role in carbon sequestration. Strategic process improvements—such as integrating air drying prior to kiln drying—could reduce energy demand by up to 25% and lower environmental impacts, bridging the sustainability gap between hardwood and softwood CLT. These findings advocate for targeted optimizations in hardwood CLT production to balance carbon benefits with energy efficiency, supporting broader adoption of regionally sourced hardwoods in engineered wood markets. This work advances actionable pathways for sustainable CLT innovation, emphasizing the interplay between material selection, process design, and climate-smart forestry.

Evaluating the Environmental Impact and Carbon Sequestration Potential of Mass Timber Construction

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Abstract

This study presents the Life Cycle Assessment (LCA) results of Adohi Hall, a 200,000-square-foot mass timber residential building located at the University of Arkansas. Conducted using the Tally LCA tool, the assessment follows a cradle-to-grave approach, incorporating biogenic carbon to evaluate the building's environmental performance across its 60-year life span. The analysis covers key environmental impact categories, including Global Warming Potential (GWP), Acidification, Eutrophication, Smog Formation, Ozone Depletion, and Energy Demand. The results indicate that Adohi Hall's total GWP is approximately 4,500,197 kg CO₂eq, with significant contributions from the product stage (A1-A3) and the end-of-life stage (C2-C4). However, the inclusion of biogenic carbon offsets -440,753 kg CO₂eq in Module D, demonstrating the benefits of carbon sequestration in mass timber construction. The study also highlights the role of materials such as cross-laminated timber (CLT) in reducing emissions compared to conventional concrete and steel structures. These findings reinforce the potential of mass timber as a sustainable alternative in the built environment, promoting carbon footprint reduction and enhancing resource efficiency.

BUILD'EM: A Lignin-based Resin to Compete with Phenol-Formaldehyde

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Abstract

In this project, we seek to use a lignin-based, thermo-setting binder in engineered wood products as a substitute for phenol-formaldehyde. This binder, “BUILD’EM,” has shown promise in concrete applications and here, we present its translation into wood products. We primarily focus on MDF (medium-density fiberboard) applications.

Phenol-formaldehyde (PF) is one of the most widely used resins to generate MDF and generates considerably less formaldehyde emissions compared to urea-formaldehyde (UF). However, PF is also significantly more expensive than UF. Bypassing the need for formaldehyde altogether, BUILD’EM crosslinks lignin to generate a truly formaldehyde-free resin with similar properties to traditional MDF. We estimate that, compared to PF resin, BUILD’EM (1) is about 20% cheaper than PF, (2) exhibits similar mechanical properties, (3) can be integrated into existing capital equipment, (4) commands a premium market by reducing resin carbon emissions by about 80%.

Cross-Laminated Strand-Veneer Lumber and the Influence of Thermal Modification on their Structural and Fire Performance

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Abstract

The construction industry, known for its significant carbon footprint, is increasingly turning to eco-conscious solutions, including the rise of mass timber structures like cross-laminated timber (CLT). CLT, capable of transferring loads in two directions, is emerging as a viable alternative to steel and concrete in low-to-mid-rise buildings. In addition to its structural efficiency, CLT offers aesthetic appeal, cost-effectiveness, and acceptable fire performance in case of thicker panels. However, its fabrication requires high-quality dimensional lumber, predominantly sourced from large diameter timber. The current concerns in both fabrication and use of CLT panels include: (a) differential shrinking of adjacent lumber due to growth ring orientations that may result in premature failure, resulting in the use of only high-quality lumber for production; (b) rolling shear failure in CLT panels that has limited their applications; (c) susceptibility of wood to high moisture environments requiring protection and again resulting in limited exterior applications. Interestingly, low-quality small diameter trees (SDTs) are abundantly available in our national forests, which have minimal use in the current mass timber industry due to their reduced yield of high-quality straight lumber suitable for CLT manufacturing. Therefore, there is an interest in developing high-performance composite products such as strand-based mass timber panels with properties comparable to CLT panels. The current presentation focuses on the development of the proposed strand-based mass timber panels from low-quality SDTs, and understanding the influence of thermal modification on their dimensional stability, structural properties, and fire performance.

Performance of Edge-Bonded Cross-laminated Timber from Small-Diameter Tree Generated from Forest Restoration Program

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Abstract

The United States Forest Service is conducting forest restoration programs aimed at reducing the wildfires risks in the Western region. This process is costly and yields a substantial volume of low-value small-diameter logs. Utilization of these materials for cross-laminated timber production (CLT) or glulam has been proposed as a path for offsetting the high cost of forest thinning. However, small logs are unlikely to yield structural lumber in dimensions sought for laminations. The goal of this project is to develop efficient technology to use thin and narrow lumber from small logs in edge-bonded laminations of uniform widths which should be easy to handle and not require major changes to standard CLT or glulam production. Edge-bonded laminations and custom CLT incorporating such laminations are fabricated in pilot-scale line plant at Oregon State University. Characteristic design values of edge-bonded laminations were determined and compared with national design specifications (NDS) design values for structural lumber of the same species and similar dimensions. Structural characteristics of 3- and 5-ply CLT test billets with edge-bonded lamination layers are determined and compared with commercial products.

Hempcrete Modification and Characterization for Sustainable Building Systems

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Student poster competition - Second place winner

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Abstract

Sustainable building materials are essential to reducing environmental impacts in the construction sector by minimizing emissions and resource exploitation. Among these materials, hempcrete, a biocomposite made from hemp hurds, lime-based binders, and water—offers a breathable, insulating, and carbon-negative alternative to conventional building materials. However, its broader adoption is constrained by limitations in mechanical performance, particularly compressive and tensile strength. This study employs a factorial design with independent variables including binder type, density, and curing time to assess performance metrics such as compressive and flexural strength, thermal conductivity, acoustic properties, and carbonation potential. Advanced characterization techniques, including SEM, TG-DTG, XRF, and FTIR, were used to analyze the chemical, physical, and mechanical properties of the material. The thermal conductivity of studied materials ranges from 85 to 180 W/m K) at (23 °C; 50%RH). The preliminary findings showed 15% higher bondability and thermal performance for the modified hempcrete compared to the traditional hempcrete. The compressive strength results show a significant improvement due to the incorporation of the binders. The binder modification of the hempcrete improved the compactness of the material, thus increasing its density, which leads to a greater mechanical strength.

Synthesis of Bio-Based Binder Using Lignin via Vinyl Polymerization Methods

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Abstract

Rechargeable batteries have emerged as a key technology for sustainable energy transition, electric vehicles, and renewable energy storage systems. In particular, lithium-ion batteries are widely utilized across various industries due to their high energy density, long cycle life, and fast charge-discharge rates. However, concerns have been raised regarding the environmental impact of materials and solvents used in battery production. With the acceleration of carbon neutrality policies and eco-friendly technological advancements, research on improving battery performance and reducing costs has been actively conducted. Next-generation battery technologies, such as solid-state batteries and lithium-sulfur batteries, are being explored as promising alternatives. Lignin, a major component of lignocellulosic biomass, has gained attention as an environmentally friendly and sustainable biomaterial with diverse industrial applications. Traditionally regarded as a byproduct of the pulp and paper industry, lignin is now being recognized as a high-value chemical in the chemical, energy, and materials industries. Due to its excellent antioxidative and thermal stability properties, lignin can serve as a raw material for plastic substitutes, adhesives, and coatings. Moreover, lignin-derived carbon materials show great potential as electrode materials and energy storage components. With advancements in biorefinery technologies, lignin-based biofuels and chemicals are being actively researched, contributing to the reduction of fossil fuel dependency. In this study, we aim to explore lignin as an alternative binder for rechargeable batteries. First, lignin will be chemically modified through vinylation to introduce acryl functional groups. The chemical modification results will be analyzed using ¹H-NMR and FT-IR. Subsequently, a polymer will be synthesized via vinyl polymerization by incorporating acrylic acid into the modified lignin. To evaluate the polymer's performance as a binder, thermal and structural properties will be examined through TGA, DSC, FT-IR, and zeta potential measurements.

Evaluating the Mechanical Properties of 3D Printable Earthen Material Reinforced by Forest-Based Products

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Abstract

Additive manufacturing offers innovative solutions to utilize forest-based materials, including wood residues, natural fibers, and bio-based materials in the construction and manufacturing sectors. Due to the increasing demand for clean and sustainable construction, using earthen-based and wood-based materials combined with digital fabrication technology can help to promote sustainable construction practices. Furthermore, this technology also offers various opportunities in design and production. The current study focuses on developing a 3D printable earthen slurry reinforced by wood particles. The mixture formulation consists of clay, xanthan gum as a binding agent, glycerol as a plasticizer, water as a solvent, wood particles as filler, and cellulose nanocrystals. This study examines the shrinkage behavior, compressive strength, shear stiffness, and buildability of the printed slurry. It is observed that xanthan gum helps in enhancing the compressive strength of the mixture whereas wood particles enhance the dimensional stability of the mixture. Challenges associated with the mixture development, printing procedure, and drying process have been discussed and directions for future research are outlined.

Structural Properties of Lumber from Small Logs Generated in Forest Thinning Operations: Bending Properties

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Abstract

Restoration forest thinning is an important strategy for mitigating risks of catastrophic wildfires in forestlands of the Western US. This process is costly and yields a significant percentage of younger, smaller diameter trees containing a high proportion of juvenile wood, which differs from mature wood in many characteristics, including strength properties. Utilization of lumber from small diameter logs in structural applications, including cross laminated timber (CLT) panels, would add market value to the material generated as a byproduct of the thinning operations. Given the abundance of ponderosa pine growing in major restoration thinning regions, increasing the market value associated with this species is of particular interest. Unfortunately, most sawmills consider processing small logs unprofitable and the resulting lumber less qualified for structural uses. A recent study, based on elastic moduli measured on a limited sample, suggested that lumber from small diameter logs may not meet the National Design Specifications (NDS) benchmarks for their visual grades, established on lumber from logs harvested in commercial operations with substantially larger proportions of large diameter trees. The objective of this project is to experimentally verify these earlier findings by comparing structural properties determined on a representative sample of lumber (sawn from forest restoration ponderosa pine logs across the growing range) with reference values listed in NDS for the same size, grade, and species. The testing procedure (including four-point bending and tension parallel to the grain) of full-sized lumber specimens follows respective ASTM standard methods for structural lumber. The resulting data will be used to obtain estimates of elastic modulus as well as bending and tensile strength. These estimates will be compared with the current NDS values for the purpose of determining whether or not the lumber meets established structural requirements.

Predicting Size Effect in Veneer-Based Structural Joists Based on Small-Sample Test Results

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Abstract

Structural veneer-based products, such as mass ply panels (MPP) and laminated veneer lumber (LVL), are often used in construction as joists, that is, in edgewise bending. Due to substantial size effects in engineered veneer-based products, current industry standards (ASTM D5456) require product qualification and product quality assurance to be tested on full-scale elements, rather than on small-scale material samples or scaled specimens, which is material-intensive and costly. The uncertainty margins obtained with the standard model are expected to account for the size effect and are deemed unsatisfactory.

The objective of this project is to develop a reliable empirical model to predict the size effect in structural veneer joist elements based on small- to medium-scale tests.

The approach is to correlate the size effect in veneer-based materials, as reported in prior studies, with the known structure of the laminates and the specific distribution of joints within veneer sheets and composite laminations. In addition, strength properties measured on jointed and joint-free material references will be used as input. Experimental validation will be conducted on mass ply panels (MPP) and laminated veneer lumber (LVL) specimens sourced from West Coast manufacturers. The resulting model is expected to support a reliable and cost-effective product qualification and quality assurance procedure option for the structural veneer-based products industry.

Effect of Thickness Variations on Clamping Pressure Redistribution Transfer in Cross Laminated Layups with Uneven Thicknesses in the Adjacent Laminations

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Abstract

The integrity of the adhesive bond is an imperative criterion for qualifying layered engineered wood-based composites (EWP) for structural use. The failure in adhesive bond in EWP manufactured by laminating lumber with an industrial adhesive that is oriented perpendicular to the adjacent layers is mostly attributed to several factors like the lack of adhesive and wood compatibility, clamping pressure, duration, and wood species while omitting the possibilities of other silent factors. In cross-laminated timber (CLT) even moderate variations in lamination thickness within the same layer can significantly affect the distribution of clamping pressure at the intersections of laminations. This study aims to address the strict criteria adopted by the North American product performance standard ANSI/APA PRG320 on the performance of adhesive bond in CLT, which seems not yet supported by theoretical or experimental data. The project aims to determine the effect of thickness variation in adjacent laminations on the clamping pressure redistribution and transfer in CLT on adequate bonding and integrity between layers. The project specific objective is to determine the effect of thickness differences in adjacent lamination on clamping pressure redistribution in cross-laminated layers with controlled thicknesses at the middle layer. Measurements were conducted on a scaled-down models of 3-ply and 5-ply layup sections covering three intersections of laminations with uneven thicknesses in the middle layer. The test layups were subjected to clamping pressure in a simulated pressing condition but with no adhesive. The redistribution of pressure between laminations and layers was evaluated from the cross sections of the model layups using optical measured system. The output of this study will aid the refinement of the analytical model of the actual clamping pressure redistribution between layers of controlled thickness while also highlighting the critical thresholds of thickness tolerance needed to maintain consistent pressure transfer and better integrity of bonds.

Adhesive Bonding Performance of Cross-Laminated Timber Made of Thermally Modified and Unmodified Wood

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Abstract

Thermally modified wood (TMW) is increasingly considered for outer lamination in cross-laminated timber (CLT), but its adhesive bonding quality under varying manufacturing conditions remains poorly understood, necessitating further investigation. This study evaluates the impact of different pressures (30, 70, 100, 150, and 200 psi) on adhesive bonding quality in TMW-CLT using one-component polyurethane (1C-PUR), assessing shear strength, wood failure percentage (WFP), and microscopic bond integrity to optimize manufacturing processes. Hybrid CLT panels, consisting of TMW and unmodified yellow poplar layers, were prepared and compared with control panels made of unmodified wood. A block shear test was conducted to measure shear strength and WFP, while microscopy assessed bondline quality. Unmodified samples exhibited significantly higher shear strength (approximately 148–199% higher at 100–200 psi) than TMW; however, TMW samples showed predominantly wood failure (90–100% WFP) compared to 60–95% WFP in unmodified wood at 30–200 psi. At pressures from 70 to 200 psi, TMW consistently exhibited 100% WFP, but as pressure increased, shear strength decreased, suggesting that high pressure may crush or affect brittle TMW cells, a phenomenon not observed in light microscopy. Conversely, in unmodified wood, increased pressure enhanced shear strength. Unmodified wood also displayed significantly greater adhesive penetration (approximately 540–560% higher at 100–200 psi) than TMW. As pressure increases, adhesive line thickness decreases while penetration increases; however, with rising pressure, the rate of maximum penetration growth slows, whereas effective penetration continues to rise. A pressure of 100 psi is considered optimal for manufacturing CLT with TMW beyond which penetration does not increase significantly and shear strength, while not statistically different, exhibits a consistent sharp decline.

Mass Timber Building Inspection Using Resistance Drilling

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Abstract

Mass timber, a wood-based material, is vulnerable to decay when exposed to high moisture levels for extended periods. Ensuring the longevity of mass timber buildings depends on durability and early decay detection, both of which are crucial for maintaining structural integrity, fostering public confidence, and advancing its adoption in sustainable construction. Resistance drilling is a non-destructive testing method that measures the torque required to drill through wood. Since higher-density wood requires greater torque, this method indirectly provides information on wood density variations along the drill profile. It is commonly used to assess trees, utility poles, and lumber, typically in a radial direction. However, in mass timber products such as Cross-Laminated Timber (CLT) and Mass Ply Panels (MPP), the lamination of panel layers results in varying growth ring patterns and orientations, making drill signal interpretation more complex. Extensive research is needed to distinguish growth rings, knots, voids, and varying decay levels to effectively apply resistance drilling for mass timber evaluation. This study aims to develop a robust dataset of resistance drilling profiles in mass timber panels with varying decay levels. The hypothesis is that resistance drilling can evaluate the presence and extent of decay pockets in mass timber products with minimal destructive impact. The methodology will compare existing resistance drilling datasets for solid wood with new datasets from mass timber products. Two commercial resistance drilling devices (RINNTECH Resistograph and IML-Resi) will be used to evaluate Douglas-fir and spruce-pine-fir CLT and Douglas-fir MPP panels sourced from manufacturers in the U.S. Pacific Northwest. Preliminary data comparing resistance drill patterns in mass timber and solid wood will be presented. Test samples will be analyzed for fungal decay, with specimens categorized to ensure standardized decay characterization.

Novel Green Chemistry Strategies For Enhancing Wood Surface Hardness

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Student poster competition – First place winner

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Abstract

The construction sector accounts for 40% of global greenhouse gas emissions, with building materials and construction alone responsible for 10%. As this trend is expected to rise by 2030, adopting green materials, particularly wood, offers a sustainable solution. While wood is renewable and widely used in residential buildings (71% market share), its low hardness and flammability limit its application in non-residential structures (4%). Wood densification enhances density, hardness, and durability of wood, improving its suitability for broader construction use. 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 for interior applications. This study develops bio-based densification formulations to enhance surface wood hardness using two approaches: a single-cure system via in-situ polymerization through Michael-addition and a dual-cure strategy combining Michael-addition and photopolymerization. Both reactions are green chemistry reactions, conducted in mild conditions with minimizing solvent consumptions, aimed to enhance wood densification. To facilitate industrialization of the final products, the proposed methods are simple with high reaction rate and low energy usage toward reducing cost and environmental impacts. The research comprises two phases: formulation evaluation and application on wood samples. Various formulations were assessed based on conversion rates (real-time infrared spectroscopy), glass transition temperature and crosslinking density (dynamic mechanical analysis), and film hardness (pendulum test). The most effective formulations were then used to impregnate sugar maple, and their densification performance based on chemical retention, density profile, surface hardness, morphology and formulation penetration were examined. Moreover, statistical comparisons were conducted using ANOVA data analysis to verify results. 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.



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