Wood–Science–Economy

BOOK OF ABSTRACTS

5th International Scientific Conference
WOOD-SCIENCE-ECONOMY

Sustainable Solutions and Digitalization in Forest-Wood Sector

Poznań, 3-5 December 2025

Łukasiewicz
Poznań Institute of Technology

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UNIVERSITY
OF LIFE SCIENCES

Industry
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Ministry of Science and Higher Education
Republic of Poland

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Sustainable Solutions and Digitalization in Forest-Wood Sector

5th International Scientific Conference

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GENERAL AGENDA

DAY ONE – 3.12.2025

8.00–9.00 Registration, refreshments & networking

9.00–9.15 Welcome (Chair of the Scientific Committee: Dr. Zbigniew Karaszewski, Łukasiewicz – PIT, Deputy Director for Research, Łukasiewicz – PIT: Dr. Dariusz Garbiec, PULS: Prof. Bartłomiej Mazela, Chair of the Organizing Committee: Dr. Dominika Janiszewska-Latterini, Łukasiewicz – PIT)

9.15–9.45 **Keynote speaker's lecture – Thomas Purfürst**: Digital Transformation in the Forestry and Wood Sector – Challenges and Possibilities

9.45–10.05 **Invited Speaker's lecture – Addo Koranteng**: The African Forestry-Wood Sector: Challenges, Opportunities, Barriers, and Strengths

SESSION I: DIGITALIZATION AND SMART TOOLS IN FORESTRY

Chair: Dr. Rachele Venanzi

10.05–10.15 **Petros Tsioras, Zbigniew Karaszewski, Evangelia Siafali**: Bridging Technology and Forestry: Multi-sensor Approaches for Sustainable Forest Utilization

10.15–10.25 **Zoltán Pásztory, Tibor Horváth**: Photo Optical Measurement Technology at the Forest

10.25–10.35 **Karol Tomczak, Felipe de Miguel-Diez, Martin Jankovský, Ondřej Nuhlíček, Lukas Moik, Christoph Gollob, Bartosz Habkowski, Marek Szychta, Arkadiusz Tomczak**: Choosing the Right Tool: Insights from Accuracy Analyses of Four Wood Stack Measurement Method

10.35–10.45 **Gunta Grube, Stefano Grigolato, Bruce Talbot**: How Much Data Is Enough? Evaluating Terrain Complexity from Multi-Sensor Remote Sensing in Mountain Forests

10.45–10.55 **Marek Szychta, Marek Danielak, Marcin Szczepaniak, Włodzimierz Woźniak, Karol Tomczak**: From Forest Data to Smart Decisions – Testing AI and Robotic Innovations in agrifoodTEF

10.55–11.05 **Salvatore F. Papandrea, Maria F. Cataldo, Andrea R. Proto**: Blockchain Technology as a Traceability Tool in the Wood Supply Chain

11.05–11.15 **Vincenzo M. Ascione, Giovanni Aminti, Michele Brunetti, Giovanni Fontani, Graziano Gagliarde, Bijender Kumar, Michela Nocetti, Luigi Saulino**: End-to-End Digital Timber Tracking from Forest to Sawmill: Data Traceability Platform System (DTPS)

11.15–11.25 **Michela Nocetti, Giovanni Aminti, Michele Brunetti, Giovanni Fontani, Simo Kivimaki, Timo Rouvinen, Luigi Saulino**: Digitalizing the Forest-Wood Chain: Implementation of the TRESTIMA App for Douglas Fir in Italy

11.25–11.40 **Q&A and discussion**

11.40–12.00 **Group photo**

12.00–13.00 **Lunch**

13.00–14.00 Horizon Europe networking session (**Agnieszka Możejko**: Networking for Innovation: From Ideas to Horizon Europe projects)

SESSION II: BIOMASS VALORIZATION

Chair: Prof. Henrik Heräjärvi

14.00–14.15 **Zdzisław Kwidziński, Tomasz Rogoziński, Marta Pędzik**: PortaFRAME – Intelligent Technology for the Automated Production of Customized Wood-Based Technical Door Frames

14.15–14.25 **Ferréol Berendt, Florian Wilms, Jennifer Kowalska, Tobias Cremer**: Bark Biomass and Bark Carbon Stock in Scots Pine Stands

14.25–14.35 **Přemysl Šedivka**: The Potential of Second-Generation Oak Wood for Structural Glued Laminated Timber

14.35–14.45 **Tomasz Kurek, Agnieszka Ramion-Harkawik, Mariusz Kowalczyk, Mateusz Modrzejewski**: The Dynamics of Spruce Stands Decomposition in the 2020–2024 Years and the Timber Quality in the Regional Directorate of State Forests in Szczecinek

14.45–14.55 **Ayyoob Arpanaei, Florian Pion, Hayden Thomas, Diahanna O'Callahan, Stefan Hill, Daniel van de Pas**: Stepped Solubilisation of Kraft Lignin from Radiata Pine for Tailored Nanolignin Formation and Functional Property Enhancement

14.55–15.10 Q&A and discussion

15.10–15.30 Coffee break

SESSION III: SUSTAINABLE WOOD PRODUCTS IN INDUSTRIAL APPLICATIONS

Chair: Dr. Mateusz Sydow

15.30–15.40 **Dominika Janiszewska-Latterini, Tiago Lopes, Julia Gościańska-Łowińska, Dobrochna Augustyniak-Wysocka, Ewa Leszczyszyn, Catarina Nobre**: From Research to Adoption: Understanding the Stakeholders Perception on Biochar and Wood Vinegar – Insights from the Horizon Europe PYRAGRAF Project

15.40–15.50 **Henrik Heräjärvi, Veikko Möttönen, Martti Venäläinen, Nguyen Bao Ngoc, Bui Duy Ngoc, Ha Tien Manh, Vu T Hong Tham, Nguyen Thanh Tung, Le Xuan Phuong**: Pathways for Wood Product Industry Development in Vietnam

15.50–16.00 **Bartłomiej Mazela**: Sustainable 3D Packaging from Recovered MDF Fibres

16.00–16.10 **Tobias Weberhofer, Wolfgang Grenzfurtner, Maria Anna Gartner, Manfred Gronalt**: Boosting the Assembly Lines Output in Industrial Housebuilding

16.10–16.20 **Peter Meinlschmidt, Nina Ritter, Julia Belda**: Development of Flexible Beech Fiber Insulation Materials for the Building Industry

16.20–16.35 Q&A and Discussion

16.35–17.30 Poster session

17.30–17.35 Closure

19.30–22.00 **Conference dinner – Pałac Działyńskich, Stary Rynek 78/79, 61-772 Poznań**

DAY TWO – 4.12.2025

FIELD TRIP

8.30 Departure from Poznań (**meeting point: Estkowskiego 6 street**)

9.30–11.30 Visit in Brzechwa – Wooden houses manufacturer
https://brzechwa.com.pl/en/home-english/

12.00–15.00 Visit in Oborniki Forest District, State Forests
https://oborniki.poznan.lasy.gov.pl/

15.00–16.00 Return to Poznań

DAY THREE – 5.12.2025

8.30–09.00 Registration, refreshments & networking

9.00–09.10 Welcome

SESSION IV: SUSTAINABLE FOREST MANAGEMENT

Chair: Dr. Petros Tsioras

9.10–9.20 **Tobias Cremer, Ferréol Berendt**: An Interdisciplinary Strategy for Sustainable Scots Pine Forest Management

9.20–9.30 **Aleš Zeidler, Vlastimil Borůvka, Zdeněk Vacek, Jan Cukor**: Non-Native Spruces as a Potential Substitute for Norway Spruce

9.30–9.40 **Radosław Jagiełło**: Impact of Aphid Infestation on Sap Flow and Needle Morphology in Young Stands of Silver Fir

9.40–9.50 **Rachele Venanzi, Rodolfo Picchio, Angela Lo Monaco, Linda Ruggiero, Luca Cozzolino**: Soil Impact Assessment Due to Forest Operations in an Oak Coppice in Italy

9.50–10.00 **Zdeněk Vacek, Veronika Hamerová, Jan Cukor, Stanislav Vacek, Josef Gallo, Václav Trojan**: Mixed Forests versus Monocultures: Structural and Functional Benefits of Beech–Spruce Mixtures under Climate Change

10.00–10.10 **Aurora Bonaudo, Rachele Venanzi, Rodolfo Picchio, Pierluca Gagliioppa, Angela Lo Monaco**: Development of a Decision Support System (DSS) for Forest Operation Planning in Environmentally Sensitive Areas

10.10–10.20 **Nicolò Di Marzio, Davide Imperiali, Luca Marchi, Stefano Grigolato**: Multi-Criteria Mapping of Mechanized Harvesting Potential for Sustainable Forest Management

10.20–10.30 **Erkki Verkasalo, Markus Mennala, Jukka Malinen**: Bucking-to-Demand Simulation with External Stem Dimensions and Quality

10.30–10.45 **Tomasz Majerowski, Bernard Deus, Lech Radowski, Rafał Selwakowski**: The Optimal Rate of a Forest Worker (PLN/h) in the Forest Services Sector Based on the Example of PGL LP Calculations

10.45–11.00 Q&A and discussion

11.00–11.15 Coffee break

SESSION V: ADVANCEMENTS IN WOOD-BASED MATERIALS

Chair: Dr. Patrycja Hochmańska-Kaniewska

11.15–11.25 **Wojciech Grześkowiak, Bartłomiej Mazela, Waldemar Perdoch, Izabela Siemińska, Anna Szulc**: Non-Halogenated Char-Forming Fire Retardant Additives for Wood Coatings

11.25–11.35 **Tomasz Krystofiak, Dimitar Angelski, Dobrian Dobriyanov, Barbara Lis**: Investigations of the Aesthetic-Decorative Features of Coatings in Printing Technologies

11.35–11.45 **Mateusz Sydow, Emilia Wysocka, Magdalena Komorowicz, Aleksandra Kropacz, Anna Stangierska, Patrycja Kwaśniewska-Sip, Wojciech Cichy, Marta Woźniak-Karczewska, Wojciech Czekała**: CREOSOLVE Project – Innovative Biological Methods for Managing Used Railways Sleepers and Other Creosote-Treated Wooden Components

11.45–11.55 **Marta Pędzik, Dominika Janiszewska-Latterini, Asma Sohail, Apri Heri Iswanto, Widya Fatriasari, Tomasz Rogoziński**: Sustainable Particle-Board Manufacturing Based on Valorization and Efficient Utilization of Alternative Lignocellulosic Raw Materials

11.55–12.05 **Arthur Thirion, Jukka Vaari, Stefan Scheiner, Markus Königsberger, Royson Dsouza, Antti Puisto, Tuukka Verho, Christian Hellmich, Josef Füssl, Stefania Fortino**: Multiscale Models Predicting Wood Structure Infiltration

12.05–12.15 **Łukasz Ignasiak, Tomasz Kiczek, Maksymilian Galiński, Agata Bieńczak, Paweł Woźniak**: A Wood-Based Material Approach to an Intelligent Beehive Mechatronic System

12.15–12.30 Q&A and discussion

12.30–13.30 Lunch

SESSION VI: WOOD AND WOOD-BASED MATERIALS QUALITY ASSESSMENT

Chair: Prof. Magdalena Zborowska

13.30–13.40 **Michele Brunetti, Giovanni Aminti, Michela Nocetti**: Non-Destructive Wood Quality Assessment Along the Forest-Wood Chain – A Case Study on Sessile Oak from Northern Italy

13.40–13.50 **Maciej Niemir**: Artificial Intelligence for Automated Wood Quality Assessment – A Review of Methods, Data, and Emerging Generative Approaches

13.50–14.00 **Tibor Horváth, Zoltán Pásztory**: MobileArborist™ – Revolutionizing Urban Tree Assessment

14.00–14.10 **Grzegorz Pajchrowski, Andrzej Noskowiak**: Selected Mechanical Properties of Beech and Birch Wood in the Context of Use in Construction

14.10–14.20 **Adam Olszewski, Magdalena Rudzińska, Ryszard Gąsiorowski, Łukasz Piszczyk**: Tailoring Mechanical and Functional Properties of Polyurethane-Wood Composites via Isocyanate Index Control

14.20–14.35 **Q&A and discussion**

14.35–15.00 Closure

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SESSION VI: WOOD AND WOOD-BASED MATERIALS QUALITY ASSESSMENT

POSTER SESSION

ORAL PRESENTATIONS

SESSION I

DIGITALIZATION AND SMART TOOLS IN FORESTRY

Bridging Technology and Forestry: Multi-sensor Approaches for Sustainable Forest Utilization

Petros Tsioras[1], Zbigniew Karaszewski[2, 3], Evangelia Siafali[4]

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ABSTRACT

Accurate and cost-efficient mapping of forest road infrastructure is vital for sustainable forest management, particularly following timber harvesting operations. This study evaluated the fusion of three LiDAR-based technologies – Airborne Laser Scanning (ALS) via UAV, handheld SLAM-based laser scanning (HPLS), and iPhone 13 Pro Max LiDAR – for assessing forest road conditions under varying terrain. The objective was to enhance monitoring effectiveness while balancing mapping precision, cost-efficiency, and field applicability.

wResults indicated that ALS data alone yielded the highest accuracy (RMSE = 0.029 m), followed closely by the ALS + HPLS fusion dataset (RMSE = 0.032 m). The combination of ALS + iPhone also performed well (RMSE = 0.108 m), showing the smallest deviation from ALS data (MAE = 0.011 m). In contrast, HPLS alone exhibited the highest error (RMSE = 0.179 m). Sensor performance varied depending on terrain slope, with increased error and variability observed on steeper gradients. The iPhone LiDAR performed consistently in flat areas but was less reliable in uneven terrain. While HPLS provided dense point clouds, its precision decreased under complex terrain when not fused with other data.

The study concludes that ALS remains the most accurate and robust method for mapping forest roads, especially in diverse topographic conditions. However, the integration of consumer-grade sensors like the iPhone 13 Pro Max offers a promising, low-cost alternative for routine assessments in accessible areas. Data fusion improved DEM consistency and reduced elevation discrepancies, demonstrating the value of combining different platforms to enhance spatial resolution and coverage.

These findings support a multi-sensor approach for forest road monitoring, allowing for technology selection based on terrain complexity and operational constraints. Combining professional and consumer-grade sensors can improve monitoring efficiency, helping to support sustainable forest road maintenance and utilization planning.

KEYWORDS: LiDAR technology, sensor fusion, sustainable forest management, terrain analysis

Photo Optical Measurement Technology at the Forest

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ABSTRACT

The recent global situation forces us to take into account the natural resources, protect and manage them with the highest attention. This means to collect up to date information in photo optical digital platform with the highest precision. Forest and forest products are the one of the most important natural resources produced in enormous quantity. The digital technology provides the opportunity to develop new methods which help to serve the sustainable forest management.

The topic of this development paper is the universal integrated, revolutionary new device called MobileForester® which merged the digital technology with the ground level forest management including the precise optical stack and stem volume determination. A new methodology was developed to determine two important group of data concerning forest stocks and the wood raw materials.

The first one needs current data about forest stand to have information about the state of the forest including the quantity and quality. The second group of data relates to the raw material forwarded from the forest. These are the materials the wood production chain uses as raw materials. The goal of development of MobileForester® technology was to combine these measurement techniques and manifest it in an intelligent device.

Photo optical analysis makes the data processing significantly faster and more effective. According to the test measurements the forest stock estimation technologies can perform three to five times faster than that of the traditional methods. Determination of basal area is much more precise because of the built-in digital zoom and the real-time analytics. The accuracy of stock measurement is better than three percent, the determination of the log volume is less than 0.5 %.

The measurements are recorded by digital techniques, which can be easily downloaded and opened in any database software e.g. MS Excel. The device also records the GPS coordinates and time stamp at the moment of surveys.

The new equipment provides a very user-friendly interface and creates the digital data opened the way for digital forestry management. Using MobileForester® can make the work of foresters much easier and faster. There is no need for post-processing of paper-based data, as the measured values are immediately available in digital form even transferred to the company database. In the near future, the digital technology will replace the

traditional methods due to its accuracy and efficiency, providing data that can be processed in digital platforms and helps to create the digital twins.

KEYWORDS: forestry measurement, digital relascope, basal area, MobileForester®, forest stock, stack solid volume

Choosing the Right Tool: Insights from Accuracy Analyses of Four Wood Stack Measurement Methods

Karol Tomczak[1,2], Felipe de Miguel-Diez[3], Martin Jankovský[4], Ondřej Nuhlíček[4], Lukas Moik[5], Christoph Gollob[5], Bartosz Habkowski[1], Marek Szychta[2], Arkadiusz Tomczak[1]

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ABSTRACT

The roundwood trade is fundamental to forest management, affording fiscal resources for the remaining aspects of forest administration. Therefore, the accurate estimation of harvested wood volume is one of the most crucial processes for billing purposes. In many European and American countries, this is conducted applying the traditional volumetric sectional method using analog tools, i.e., forest tape and levelling staff. Although currently digital methods, such as the photo-optical methods supported by smartphones or *ad-hoc* designed devices, and other systems, i.e. LiDAR or data collected by harvesters, are considered as the fast and accurate alternative of roundwood measurement.

The main aim of this study consisted of analysing and comparing the results of roundwood measurements obtained applying the analog (traditional)volumetric sectional method and using digital methods such as the Timbeter app, LogStackLidar app and harvester data from John Deere TimberMatic™ system of measuring stacked wood in forest conditions. In total, the gross volume of 40 stacks of pinewood were estimated. The total estimated volume was over 2000 m^3. Subsequently, each stack was classified according to volume ranges, i.e., stack sizes, to compare the accuracy of the selected measurement methods depending on the stack size. For this purpose, four volume classes were adopted: I – smaller than 30 m^3 (st), II – from 31 to 60 m^3 (st) III – from 61 to 90 m^3 (st), and IV – larger than 90 m^3. For each analysis, analog measurement was considered the reference value to evaluate the accuracy of the digital methods.

The accuracy was then deduced from the deviation of the average volumes estimated with the apps from the average volume obtained by applying the manual traditional method. i.e., $\bar{x}$ – 60.9 m^3 (st). Thus, the highest accuracy was obtained by using LogStackLidar app

which was 62.2 m^3 (st), followed by harvester measurement, which was 64.4 m^3 (st). In this study, Timbeter app resulted in the highest deviation from the reference value, 76.7 m^3 (st). Considering the classified stack sizes, the lowest accuracy of all measurement methods was obtained in the class I. The highest accuracy was obtained in class II for LogStackLidar and Timbeter, class III for harvester head.

To summarize, a detailed analysis of the results of the initial phase of testing shows that both LogStackLidar and harvester measurement have high measurement accuracy with respect to manual measurement. In addition, the average deviation between these methods was also very low. At this stage of the research, measurements obtained with the Timbeter application show a consistent tendency to overestimate the results, with the magnitude of this overestimation increasing proportionally to the stack volume.

KEYWORDS: LogStackLIDAR, Timbeter, harvester, LiDAR, roundwood measurement, photo-optical measurements, forestry digitalisation, wood logistics

How Much Data Is Enough? Evaluating Terrain Complexity from Multi-Sensor Remote Sensing in Mountain Forests

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ABSTRACT

Forest operations in mountainous regions face significant challenges due to steep slopes, dense vegetation, and complex surface conditions. Decisions on whether and how to deploy forest machines depend on accurate information about terrain accessibility and surface roughness. While remote sensing technologies offer promising tools for terrain characterization, they differ in resolution, cost, and usability. This study aims to evaluate how well different remote sensing methods support terrain analysis for operational planning, particularly in terms of identifying zones that may restrict or allow machine movement.

Four remote sensing datasets were analyzed in a complex mountain forest in Cesuna, Italy: airborne laser scanning (ALS, ~1-4 pt/m^2), UAV LiDAR (~2057 pt/m^2), UAV photogrammetry, and high-resolution handheld LiDAR collected over four 20×20 m plots. Each dataset was assessed for acquisition effort, processing time, data size, and capacity to deliver relevant terrain metrics, such as slope, roughness, and terrain ruggedness index (TRI). Additionally, a combined terrain complexity layer based on point cloud geometric features was created to highlight surface irregularities that could hinder machine access. The handheld LiDAR served as a local reference for validating surface structure, helping assess how much detail and point density are needed to represent terrain complexity reliably.

Preliminary observations suggest significant trade-offs between data richness and practicality. ALS may lack the resolution needed to characterize under-canopy terrain or surface obstacles, especially in steep forested areas. UAV photogrammetry offers high visual resolution but limited ground visibility. UAV LiDAR provides dense terrain data with moderate processing effort, while handheld LiDAR offers exceptional accuracy at the cost of area coverage and heavy post-processing. Ultimately, the study aims to support more informed decisions in forest operation planning by identifying what type and amount of data are truly needed in complex terrain.

KEYWORDS: remote sensing, terrain accessibility, mountain forest; data feasibility, sensor comparison

From Forest Data to Smart Decisions – Testing AI and Robotic Innovations in agrifoodTEF

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ABSTRACT

The digital transformation of the forest-wood sector is increasingly based on the use of artificial intelligence and robotics. These applications include both process automation and the creation of new tools to support sustainable forest resource management. In order to fully implement innovations in practice, independent centres capable of objectively testing and validating them under conditions close to real-life are necessary. The European agrifoodTEF (Testing and Experimentation Facility) project is developing a network of such centres that combine research infrastructure, methodologies and experienced experts to support technology developers in moving from prototypes to market deployments.

The primary method of operation for TEF projects is to provide pilot services for testing and validating AI and robotic solutions in realistic usage scenarios. These centres provide both field and laboratory infrastructure, as well as a range of indirect services. These services include, among others, the provision and annotation of data sets for algorithm training, the provision of real-time data streams, the provision of computing power and data space, and the retraining of AI models based on partner data within the European data space that is being created. At the end of each service, the client receives a set of conclusions and recommendations that support the development of the tested solution, while also providing input for further improvement of testing methodologies and standards harmonized among different TEF centres.

One example that clearly illustrates the potential of TEF is the testing of a measurement system using GNSS in a forest environment. The research involved comparing different hardware configurations and analyzing their suitability for creating training data sets for artificial intelligence algorithms. The tests were conducted in two rounds – in summer and autumn. Measurements were taken for five scenarios each time, including static and dynamic measurements. This approach makes it possible not only to objectively assess the performance of technologies, but also to identify directions for further development and opportunities for practical application. Other examples include the validation of

autonomous guidance systems using robotic platforms or the use of satellite observations to assess environmental parameters.

AgrifoodTEF is making an important contribution to the development of independent standards for testing digital technologies in the agri-food and forest-wood sectors. The practice of providing pilot services shows that it is possible not only to support innovation developers, but also to build trust among end users and regulators. The results of the project are published as open results, which promotes harmonization of methods and the creation of a common foundation for digital transformation and safe implementation of AI and robotics in forest and economic ecosystems.

KEYWORDS: artificial intelligence, robotics, digital forestry, technology testing, independent validation, agrifoodTEF

Blockchain Technology as a Traceability Tool in the Wood Supply Chain

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ABSTRACT

In a global context where the issues of illegal timber procurement and the lack of information on the logistical dynamics of wood movement and marketing are increasingly being addressed, this study focuses on the electronic traceability system using blockchain technology to ensure the transparency and safety of processes and products along the production and transformation chain. In fact, by creating a decentralized and distributed register, accessible to all participants in the chain through a digital platform, it allows to consult and add reliable and verifiable data on the origin and movements that wood undergoes during the supply chain. The traceability protocol proposed in this study aims to add to this information also some knowledge regarding the qualitative characteristics of wood through advanced technological approaches used to evaluate the intrinsic properties of wood without damaging it (NDT), such as the accurate evaluation of mechanical properties such as wood density and dynamic modulus of elasticity (MOEd), which are key indicators of the structural integrity of wood and its suitability for different applications. These data will also be accompanied by dendrometric parameters, such as diameter and volume, which provide a more detailed context on the origin and characteristics of the wood. The combination of these data improves the reliability of the traceability system, offering a more complete profile of each log and supporting more informed decisions along the supply chain. This type of technology can improve the qualitative and quantitative traceability system of the marketed wood assortments that reach the end user, reducing the risk of fraud and related document tampering, and support forest sustainability by providing a useful tool to control bodies in the traceability of wood movement.

KEYWORDS: Forest Operations, Digital Technologies, Certification, Wood quality

End-to-End Digital Timber Tracking from Forest to Sawmill: Data Traceability Platform System (DTPS)

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ABSTRACT

Sustainable management of Mediterranean forest resources requires robust traceability and regulatory compliance across the entire timber supply chain, a challenge amplified by dual economic and environmental pressures and by the stringent requirements of new legislation like the EUDR. The Data Traceability Platform System (DTPS) directly addresses this need by enabling verifiable, end-to-end tracking of wood products, from standing trees to sawn timber, through a fully integrated digital solution designed to create an unimpeachable 'digital passport' for every asset.

This paper presents the initial implementation of the DTPS, analyzed through a qualitative case study framework to evaluate its architecture, data workflows, and operational processes. Developed within the Horizon Project *DigiMedFor*, the system integrates three core components: a central web-based Gateway that serves as the primary interface for data management and blockchain synchronization; an Android mobile application for in-field data capture, including RFID tagging and wood log measurements; and an innovative, drone-mounted Traceability Box.

The methods for data collection are founded on a hybrid technological approach, utilizing UHF RFID for unique wood identification, a private blockchain for creating secure and immutable transactional records, and, critically, authenticated drone surveys via a Galileo OSNMA-enabled receiver to certify no-deforestation practices with tamper-proof geospatial evidence.

The results of the implementation confirm a highly functional platform capable of serving a wide range of users, such as forest managers, logging companies, sawmills, and auditors, and of managing both single-operator and complex multi-actor supply chains. The system's collection of highly descriptive data, such as time stamps, geolocation, and qualitative and quantitative information, forms a comprehensive digital thread between the forest and the wooden product.

The platform's capability to provide detailed traceability reports is one of its main outcomes. These reports provide auditable, verifiable evidence of legal origin and sustainable harvesting procedures, directly meeting the EUDR's due diligence criteria. They integrate all gathered data, including the certified drone positions, and provide access to blockchain record via unique QR codes.

In conclusion, the DTPS is capable of accurately showing that a hybrid-technology, integrated system can transform the field of forestry into a digitalized environment. The combination of RFID authenticated GNSS and blockchain into one solution enables the platform to address the gaps between the complex requirements at the high level and the operational environment of the timber industry. The framework strengthens transparency and legal and provable sustainability, thus making it less risky for operators and more accessible to the market for compliant products. The model is not just a method of regulatory compliance, but it also puts in place a scalable and robust framework for the timber value chain.

KEYWORDS: Timber Traceability, RFID, Blockchain, Sustainable Forest Management, Supply Chain Management, No-deforestation, Galileo OSNMA, Data Integrity.

Abbreviations:

DTPS: Data Traceability Platform System

EUDR: European Union Deforestation-Free Regulation

GNSS: Global Navigation Satellite System

OSNMA: Open Service Navigation Message Authentication

RFID: Radio Frequency Identification

UHF: Ultra High Frequency

Digitalizing the Forest-Wood Chain: Implementation of the TRESTIMA App for Douglas Fir in Italy

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ABSTRACT

Collecting qualitative and quantitative forest data is essential for effective and sustainable forest management and planning. Information on species composition, tree density, basal area, and wood volume per hectare, as well as data describing stand wood quality, is crucial to help forest owners and managers define clear planning objectives and develop efficient strategies to achieve them. However, traditional data collection is often costly and time-consuming. To accelerate the process, without compromising reliability, modernizing the technological landscape of the forest-wood supply chain is essential for the whole forest-wood supply chain.

In this context, the Horizon Project *DigiMedFor* aims to enhance competitiveness and promote the sustainable management of Mediterranean forests by, among other initiatives, implementing quick and easy-to-use tools for forest inventory and tree quality assessment.

TRESTIMA is a mobile application that analyzes pictures taken with a smartphone while walking through the forest. Using image analysis techniques, tree stems are segmented, wooden species are identified, and stem diameters are measured. The application generates reports on basal area, diameter distribution, tree height, and volumes. Initially developed in the Nordic countries, TRESTIMA was adapted for use in the Mediterranean environments as part of the *DigiMedFor* project. Four key implementations were done: improved species detection; algorithm corrections to account for steep terrain; adjustments for high basal area stands (exceeding 50 m^2/ha), and trees with a diameter at breast height over 40 cm; and the development and implementation of a stem quality index for standing trees.

In central Italy, 31 Douglas fir forest compartments were sampled, with an average of 15 pictures taken per compartment using the mobile application. A visually assessed stem quality index (ranging from 1 to 3, with 1 being the highest quality) was developed and assigned to each compartment by expert evaluators. Applying machine learning and computer vision techniques, the collected images were used to train the app for species detection and assessment of stem quality.

Additionally, 20 of these compartments were surveyed using traditional forest inventory methods (diameter and height measurements via caliper and hypsometer) in circular sample plots, serving as reference data for algorithm calibration.

As a result, the species detection rate reached 83%, and an accuracy of 71% was achieved for stem quality index classification. Forest inventory metrics showed consistent accuracy, with a correlation of r = 0.88 between app estimates and reference data for stand basal area. These enhancements make the application an efficient and reliable digital tool for forest surveys and inventory, with further improvements expected as more data become available through continued use.

KEYWORDS: forest inventory, image analysis, machine learning, Mediterranean forests

SESSION II

BIOMASS VALORIZATION

PortaFRAME – Intelligent Technology for the Automated Production of Customized Wood-Based Technical Door Frames

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ABSTRACT

PORTA KMI Poland S.A. initiated the PortaFRAME project to ensure the company's continued dynamic growth in door joinery design and manufacturing. The main objective was to strengthen competitive advantage through the development of proprietary, innovative technological solutions. The project emerged from the need to combine high production efficiency with full product customization, while also reducing energy consumption and unit manufacturing costs. The result is an advanced, automated technology for producing wood-based technical door frames, fully aligned with the principles of Industry 4.0 and sustainable manufacturing.

The developed PortaFRAME technology integrates advanced automation, intelligent process control, and the use of modern engineered wood materials with a density above 640 kg/m^3, optimally around 800 kg/m^3. These materials provide a durable and efficient alternative to conventional water-resistant plywood, ensuring high dimensional stability and performance. A key element of the system is the proprietary Translator control unit, which transfers machining parameters directly to the production modules. This eliminates the need for trial runs or verification on substitute materials, preventing waste generation and reducing setup times.

The system architecture combines ERP software, Siemens NX®, and TeamCenter® with a pilot production line through the ProductionBase API, creating an integrated, intelligent environment for real-time data exchange and control. During the pre-implementation phase, a parametric database was developed to describe customizable door frame features as 3D BIM models, enabling complete digital representation and configuration of each product variant.

Implementation of the technology led to a significant increase in production efficiency and flexibility, while maintaining the ability to manufacture fully customized products. The new approach reduced energy use, lowered production costs, and improved process repeatability and product quality. Door frames manufactured with the PortaFRAME technology were tested and certified according to European standards, confirming their compliance with technical and aesthetic requirements.

The PortaFRAME project represents a breakthrough in the automation of door frame manufacturing. It demonstrates how digitalization, parametric modeling, and intelligent control systems can transform traditional woodworking into a smart, adaptive, and waste-free process. This technology improves productivity, flexibility, and product quality while supporting sustainable development and environmental responsibility. PortaFRAME provides a model for how intelligent production methods can increase competitiveness and efficiency across the furniture and construction industries.

KEYWORDS: Industry 4.0, parametric modelling, sustainable production, digital integration, rebated door frame, non-rebated door frame

Bark Biomass and Bark Carbon Stock in Scots Pine Stands

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ABSTRACT

In the scope of the recent discussions about climate change mitigation, researchers have increasingly gathered interest in accurately estimating carbon stocks in forests as forests have a major function in global carbon cycles and carbon sequestration. As bark represents a significant proportion of the total aboveground biomass of trees, with literature values varying between 10 and 20%, the accurate determination of the carbon content of bark is a highly valuable information for estimating carbon stocks in forests. Many studies base their forest carbon stock analyses on two assumptions regarding bark: 1) bark volume models are based on bark thickness data and, thus, bark volumes seem to be overestimated as gaps and cracks are not included, and 2) tree bark is assumed to consist of 50% of carbon, thereby neglecting variations among tree species and tissue types for simplicity. Although Scots pine (*Pinus sylvestris*, L.) is the most common tree species in Poland and Germany, few studies have focused on bark characteristic of this tree species.

This study aims to model the volume and to assess the carbon fraction of Scots pine bark in order to improve the accuracy of carbon content estimations.

We precisely determined the cross-sectional bark area profile of log slices scanned with an X-Ray CT. The resulting bark fissure index [% of actual / geometric cross-sectional area] increased from 92 to 98 % in the lower third and stayed constant in the upper 2/3 of tree. The bark volume of an 88-tree taper dataset was then corrected for bark fissure along the relative position along the stem. Bark fractions were analyzed on 33 bark samples from 11 height zones along the tree stems using C/N-analyzes.

Due to the characteristic change in bark structure along the stem in Scots pine, the bark area and taper models (nonlinear mixed effects models) are based as functions of relative tree height. We found stem bark carbon [% of dry mass] to decrease from 55% at the tree bottom to 49% at the tree top. Finally, the average single-stem bark proportion was estimated to be 8.5% of stem volume with 4.7 kg of carbon stocked.

Our study shows that tree species characteristics such as structural changes of bark along the tree stem should be included to improve bark volume and carbon content estimations.

KEYWORDS: taper function, bark volume, biomass, carbon sequestration

The Potential of Second-Generation Oak Wood for Structural Glued Laminated Timber

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ABSTRACT

Climate change is reducing the availability of softwood and the potential for more climate-friendly oak wood for structural applications. A possible solution is to change the approach to wood production, by switching from traditional first-generation growing systems to second-generation, or sapling, systems. In the Czech Republic, around 4.76% of the area of forest stands is young coppice forests stands, and there is a lack of effective methods for processing of coppice wood from these areas into the products with high added value. Moreover, the potential of these coppice second-generation forests within the EU is considerable. This can make the production function of oak wood more efficient with the potential for achieving structural quality while reducing cultivation costs. The subject of this study is the determination of the quality of coppice wood for structural applications.

Test specimens for determining mechanical properties were made from logs cut from first-generation high-stemmed and second-generation low to medium-stemmed oak forest stands near the village of Neveklov, Czech Republic. The age structure of the stands is from 35 to 65 years. From the cut logs, prismatic lumber was produced, qualitatively graded to strength class D32 according to EN 338. Prisms with a thickness of 5 cm were formatted into lamella blanks cut in the radial direction with a thickness of 2 cm with an allowance for thickness milling, while mechanical defects such as knots and cracks were cut out. The lamellas were technologically conditioned for seven days in a climate chamber, i.e. in our case at a temperature of 20 ± 2 °C and a relative humidity of 65 ± 5% so that the wood moisture content was stabilized and maintained at 12 ± 1%. The subject of this study is the determination of the mechanical characteristics of oak wood with potential for structural applications of glued laminated timber based on the determination and comparison of the wood density according to EN 384+A2, the bending strength by three-point bending strength according to ČSN 49 0115 and the static flexural modulus of elasticity according to ČSN 49 0116 between oak wood from first-generation high-stemmed and second-generation low to medium-stemmed forest stands. For the static three-point bending test, a universal tensile testing machine type TIRA test 2850 with a feed was used. Furthermore, the fire resistance according to EN 1365-3 of the load-bearing elements of glued laminated timber from oak wood from first-generation high-stemmed and second-generation low to medium-stemmed forest stands was determined.

The aim of the present study was to compare selected mechanical properties of oak wood from normal and young growth stands of low to medium forest to determine the potential of its use for non-structural and structural applications. The characteristics of the bending strength limit perpendicular to the fibers in the radial or tangential direction were compared, for which a difference was demonstrated. However, this difference was only within the statistical error. When comparing the characteristics of the wood density, a statistical difference was demonstrated and the results correspond to the bending strength limit perpendicular to the fibers. The study demonstrated that, according to the selected characteristics monitored, oak wood from young growth stands of low to medium forest has similar properties to those from normal stands. The study shows the possibilities of using oak wood from young coppice stands of low to medium forest for structural applications in the interior and exterior, in the same way as oak wood from first-generation high stands.

KEYWORDS: coppice wood, glued laminated timber, oak

The Dynamics of Spruce Stands Decomposition in the 2020–2024 Years and the Timber Quality in the Regional Directorate of State Forests in Szczecinek

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ABSTRACT

In the years 2020-2024, a dynamic spruce stand decline was observed in the Regional Directorate of State Forest in Szczecinek. In that period, the spruce stand log volume in the Regional Directorate of State Forest in Szczecinek decreased by over 25%, from 10.6 million m^3 of gross merchantable timber volume at the beginning of 2020 to 7.8 million m^3 as of January 1, 2025. This phenomenon was related to the increase in the dynamics of the decay of said stands as a result of cleaning up damage caused by, among others, gusty winds that occurred at the turn of January and February 2022, and then sanitary cleaning related to the development of a gradation of secondary pests (mainly the European spruce bark beetle). These phenomena evidently caused an increase in the spruce timber harvesting, from approximately 540 thousand m^3 in the years 2020-2021 to over 1.337 million m^3 in 2023. Simultaneously, in the years 2022-2025 there was an increase in the harvesting of damaged wood (snags, broken or uprooted trees). Over the period 2020-2021 approximately 260 thousand m^3 of damaged wood were harvested. This number increased over threefold between the years 2022-2024, reaching its maximum value in 2023 (1.245 million m^3). Interestingly, in most of the sites, cross-sectional analyses of the trees also revealed internal decay, which reduced the quality of the timber. This required considerable involvement of the Forest Service to ensure the proper classification of the wood material.

Since 2024, a decrease in the intensity of forest stand decline and a reduction in the harvesting of damaged spruce wood have been observed, which can be interpreted as a stabilization of this phenomenon. Nevertheless, this does not change the fact that there has been a sharp decrease in the volume of spruce stands, as well as a shift in their role within forest management. Additionally, the cleaning of large areas of spruce stands was related to the use of clear-cutting, often over extensive multi-hectare plots. This contributed to dynamic landscape changes, which were frequently met with criticism and opposition from the public. Observers, seeing large areas of clear-cuts, accused foresters of the deliberate application of the clear-cutting method and of mismanagement. This created

the need, among other measures, for public information campaigns explaining the primary reasons for such actions, as well as the possible consequences, including impacts on public safety. It became evident that groups of old-growth trees left to natural decay, including spruce, often formed an unstable forest composition, which, due to the sudden dieback of spruce trees, posed a real threat to public safety.

This and many other threats had to be addressed. A particularly difficult challenge during this period of time was the issue of steady timber sales, ensuring the forest's sanitary condition while also selling the lumber at a satisfactory price. The large supply of spruce timber temporarily disrupted the steadiness of timber sales, as sawmills also offered spruce imported from Germany and Czechia, among other countries.

This has demonstrated how climate change triggers a cascade of factors that ultimately reshape the functioning of our forests.

KEYWORDS: spruce stands, bark beetle, wood quality

Stepped Solubilisation of Kraft Lignin from Radiata Pine for Tailored Nanolignin Formation and Functional Property Enhancement

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ABSTRACT

The valorisation of lignin, a major by-product of the pulping industry, is central to advancing the wood-based bioeconomy and unlocking new value streams from forest-derived materials. Lignin, which accounts for up to 30% of wood biomass, remains underutilised despite its rich aromatic structure and potential for conversion into high-value products. In this study, we present a fractionation strategy for Kraft lignin derived from *Pinus radiata*, using a stepped solubilisation approach with increasing concentrations of acetone. This method enables controlled precipitation and the formation of nanolignin particles with tunable physicochemical properties, offering new opportunities for lignin upgrading and application in advanced materials.

Our preliminary solubility tests revealed that Kraft lignin begins to dissolve in acetone at concentrations around 35%. Based on this, we designed a three-step solubilisation process starting at 40% acetone, followed by 50% and 70%. In each step, the insoluble fraction was collected and subjected to further solubilisation in the next higher concentration. This approach allowed us to isolate lignin fractions with distinct molecular characteristics and solubility profiles. In each step, the isolated fraction was subsequently subjected to solubilisation using 70% acetone, followed by lignin nanoparticle formation through a solvent exchange method involving the addition of water.

Comprehensive characterisation was performed using nuclear magnetic resonance (NMR), Fourier-transform infrared spectroscopy (FTIR), size exclusion chromatography (SEC), scanning electron microscopy (SEM), dynamic light scattering (DLS), and zeta potential analysis. SEC results showed that fractions obtained with higher acetone concentrations contained lignin molecules with broader and higher molecular weight distributions. Interestingly, nanoparticles formed from these fractions were smaller in size and less charged but exhibited greater dispersity in particle size distribution. ^{31}P NMR Spectroscopy analysis revealed that the aliphatic hydroxyl group content was higher in larger molecules, while phenolic hydroxyl and carboxylic group contents were lower.

The nanolignin particles demonstrated promising antioxidant and antimicrobial activities in preliminary tests, suggesting potential applications in bioactive coatings, packaging, and functional biomaterials. These properties are being further investigated in relation to particle size, chemical structure, and surface characteristics. Understanding these correlations is key to tailoring lignin-based nanomaterials for specific functional roles.

This work contributes to the development of high-value lignin-derived products and supports the integration of lignin valorisation into sustainable biorefinery models. By transforming a low-value by-product into functional nanomaterials, this research aligns with the goals of the circular wood economy and promotes the efficient use of forest resources in New Zealand and beyond.

KEYWORDS: lignin nanoparticles, solubilisation, molecular structure, antimicrobial properties, antioxidant activity

SESSION III

SUSTAINABLE WOOD PRODUCTS IN INDUSTRIAL APPLICATIONS

From Research to Adoption: Understanding the Stakeholders Perception on Biochar and Wood Vinegar – Insights from the Horizon Europe PYRAGRAF Project

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ABSTRACT

Fighting climate change, fostering circular economy and protecting the agriculture and forest soils are among the most pressing needs which European Union has been facing in the last decades.

Increasing urgency to address the above issues by fostering sustainable land management practices, has led to a growing interest in sustainable tools for carbon sequestration, soil fertility enhancement, chemical inputs reduction and ecosystem resilience.

Pyrolysis, as the process of lignocellulosic biomass thermal conversion at limited presence of oxygen, has been identified as a promising solution for the valorization of agriculture and forestry residues. Among the main products of pyrolysis it is possible to list two that have been showing an enormous potential for sustainable agriculture and forestry: biochar and wood vinegar.

While scientific research on biochar and wood vinegar applications in agriculture and forestry has advanced considerably in recent years, the social awareness, perceptions, and

readiness of practitioners to adopt these products remain less recognized. Addressing this gap is essential for ensuring that research innovations are aligned with the expectations, needs, and realities of stakeholders in the field.

Within the Horizon Europe project PYRAGRAF, we explore the intersection of scientific knowledge and stakeholder perspectives on biochar and wood vinegar deployment in agriculture and forestry. After providing a brief overview of the current state of research, covering recent insights into its agronomic, environmental, and socio-economic impacts, we present results from a survey conducted among farmers and foresters in Poland. The survey was designed to assess levels of awareness on sustainability and the circular economy in agriculture, pyrolysis products, perceived benefits and risks, barriers to adoption, and the role of policy and market drivers in influencing stakeholders' attitudes.

Over 50 answers were gathered in Poland and the replication of the pilot study is planned to take place in Turkey, Germany and Portugal. The questionnaire was provided online, and the sample was selected using a non-random, snowball sampling method. Participants were recruited during conferences, industry and trade events as well as through local farmer and forest associations, advisory centers and other contacts. After the project's dissemination campaign, the study is scheduled to be repeated along with the acceptance assessment.

The preliminary analysis highlights both promising opportunities and key challenges for mainstreaming biochar and wood vinegar in land-based sectors. While levels of awareness vary across regions and stakeholder groups, the surveys reveal important insights into how biochar and wood vinegar are perceived in relation to broader sustainability and climate goals. These findings are critical for effective stakeholder engagement and for the development of future recommendations for the policy makers in order to fasten the transition from the research stage to practical implementation.

KEYWORDS: biochar, wood vinegar, circular bioeconomy, pyrolysis, social awareness, residual biomass

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Pathways for Wood Product Industry Development in Vietnam

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ABSTRACT

One third of Vietnam's forest area of ca. 15 million hectares consists of plantations. Commercial timber is produced in acacia and rubber wood plantations, and logging is prohibited in natural forests. There are ca. two million forest owners, and the average area of privately owned forest stands is less than two hectares. Private owners and communities own 40% of the plantation forests, too. Conflicts over forest land tenure are common in many regions. Plantation forests are commonly managed with the aim in pulpwood production. Poorly mechanized logging and timber transportation systems decrease the efficiency and increase the harvesting costs. Sawmills suffer from log quality variations and inappropriate log dimensions, which results in poor sawn timber yield as well as challenges in productivity and profitability. Problems are reflected to drying and further processing of lumber. These overall conditions decrease willingness to invest in modern wood processing capacity, yet forest resources and lumber demand of the Vietnamese furniture sector suggest doing so. Simultaneously, most of the harvested roundwood (>30 mill. m^3/a) is chipped and exported to foreign pulp mills, while the extensive domestic furniture sector relies on imported wood. Sawn timber made of domestic roundwood mostly ends up in low value applications such as pallets, which decreases the value added in forest sector. Vietnam, however, aims at developing the use of domestic timber. Here we map the pathways for Vietnamese forest and woodworking sectors towards a higher degree of self-sufficiency. We carried out a SWOT analysis, *i.e.*, systematic mapping of strengths, weaknesses, opportunities, and threats in the respective sectors, followed by analytical discussion. The results indicate that the opportunities in the forest-based livelihoods and industry value chains should be more clearly highlighted and communicated to citizens and decision makers to make the sector's opportunities understood, visible, desirable, and finally, reality. The plantation forests, yet located far from the current woodworking factories, allow a significant increase in sawlog production. Risks, such as a higher probability of windfalls, are associated with prolonging the rotation times of plantation forests to increase the saw log yield. Vietnamese woodworking industries and public sector are committed to develop the forest

management and industrial, value adding processing of domestic timber. The production philosophy should be shifted from the current production push to domestic market pull. That calls for organisational innovations, such as better management and networking of the numerous micro scale producers and integration of the large industrial producers more tightly in forestry-wood product value chain development.

KEYWORDS: forestry, SWOT, value chain development, Vietnam, wood products

Sustainable 3D Packaging from Recovered MDF Fibres

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ABSTRACT

The XyloMatrix project presents an innovative solution to the growing challenge of managing post-consumer MDF waste. With the global increase in production and disposal of MDF-based products, current recycling methods remain limited and environmentally problematic. Meanwhile, regulatory pressure on plastic packaging and the search for sustainable alternatives have created an opportunity for fibre-based, biodegradable materials.

While molded pulp packaging is not new, most current solutions rely on virgin fibres or require chemical treatments that generate additional waste or emissions. The XyloMatrix process addresses these gaps by utilizing a hydrothermal and chemical refining method that recovers fibres from MDF waste while simultaneously hydrolyzing and detoxifying synthetic resins, particularly urea-formaldehyde and phenol-formaldehyde adhesives.

This research contributes a clean, compostable, and industrially scalable packaging alternative that mimics the natural microstructure of wood for superior mechanical and barrier performance, without the use of PFAS or other harmful additives.

Three experiments were conducted to evaluate the viability of MDF waste as raw material:

Experiment 1 (lab-scale pulping): MDF production waste was chipped and subjected to pulping process with sodium hydroxide. The process yielded ~46% pulp with reduced formaldehyde content from 2.7 to 0.2 mg/100g. Parameters such as freeness (45°SR), WRV (175.1% after AKD), and fibre length (1.53 mm) were assessed.

Experiment 2 (paper sheet formation): Pulp was formed into lab-scale sheets and tested for strength (tensile index: 45.8 N·m/g), air permeability (251 ml/min), Cobb60 (20.2 g/m^2), and PDA water resistance (max: 5.6 s, t95: 12.2 s), demonstrating high functionality and barrier properties.

Experiment 3 (industrial-scale thermoforming): A 50:50 MDF and BCTMP pulp mix was processed on a full-scale thermoforming line. The resulting 3D packaging prototypes confirmed the pulp's formability and strength.

The results confirm that MDF waste, when properly refined, can serve as a viable feedstock for bio-based packaging. Key observations include:

1. Environmental safety: Formaldehyde content fell well below E1 standards. COD values for the MDF pulp were lower than those of recycled paper pulp, indicating a cleaner process effluent.
2. Material properties: Paper sheets displayed excellent tensile strength, stiffness, and tear resistance, even when blended with recycled pulp.
3. Barrier performance: The addition of AKD improved water resistance significantly, and PDA testing showed promising wetting delay and surface protection.
4. Industrial relevance: Full-scale production trials showed successful molding of clamshells, trays, and plates with commercial-grade quality.

Recovered MDF fibres, processed via the XyloMatrix technology, offer a sustainable, scalable, and high-performance alternative to plastic packaging. This method not only diverts wood waste from landfills and incineration but also enables the production of biodegradable products without harmful additives. Ongoing work focuses on assessing compostability and broader life cycle impacts, positioning this technology as a cornerstone of future circular material systems.

KEYWORDS: molded pulp, MDF recycling, bio-based packaging, lignocellulosic fibres, circular economy

Boosting the Assembly Lines Output in Industrial Housebuilding

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ABSTRACT

The construction industry is undergoing a profound transformation, driven by the increased use of renewable raw materials, prefabrication in weather-independent production halls, and rapid on-site assembly. A promising approach is the use of prefabricated houses in timber frame construction. These houses are built using unique wall elements of varying sizes and shapes, assembled on one or more mixed-model assembly lines (MMAL). Currently, most assembly tasks and production planning are performed manually. To remain competitive, transitioning to a digitalized, data-driven production planning system for an automated production line is essential.

This work presents a three-step approach to improve an existing production facility:

1. Data Acquisition and Data Preparation: The first step involves gathering all necessary data of the production process. To achieve this, an RFID system and Hybrid Forms (HF) were implemented to collect process times on the assembly line. With multiple linear regression (MLR) the most significant properties of the wall elements (e.g., socket type or length) should be identified.
2. Assembly Line Balancing (ALB): In the second step, an ALB algorithm was developed to optimize the task distribution along the assembly line and propose new task configurations, in order to figure out the best line configuration.
3. Discrete Event simulation (DES): Finally, the results from (I) were used to validate the model to enable real-world feasibility. The results from (II) are then tested with the real distribution of wall elements and it can show relevant tail distribution for processing times.

The results of this work demonstrate the effectiveness of the proposed approach:

1. The combination of RFID and HF successfully established a reliable database of process times. Using MLR, three key properties were identified as having the greatest influence on production performance.
2. The ALB produced three optimized task configurations with improved cycle times. One of these configurations also revealed the potential to eliminate one workstation compared to the current layout.

3. The DES highlighted the importance of simulation in testing the new task configurations of the ALB. While the optimized configurations achieved a 20% reduction in time in the system, queuing effects limited the increase in the number of produced wall elements to just 1.8%.

These findings underscore the value of combining data-driven analysis, optimization algorithms, and simulation techniques to enhance production efficiency and address real-world challenges.

To enable a transformation towards a more data-driven approach, several steps must be integrated to enhance the performance of an existing industrialized housebuilding assembly line. Effective data acquisition enables the development of a reliable DES, which can be used to evaluate the system and calculate theoretical improvements through ALB. However, to fully realize this potential, further efforts are required, including the implementation of optimized sequencing strategies and improved order release rules.

KEYWORDS: mixed model assembly lines, industrialized housebuilding, off-site construction, discrete event simulation, optimization, digital twin, wood products

Development of Flexible Beech Fiber Insulation Materials for the Building Industry

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ABSTRACT

With climate change, building insulation is becoming increasingly important for heat and cold protection. To this end, it would be desirable to increasingly replace the petrochemically produced insulation materials currently used with renewable ones.

To produce flexible beech fiber insulation materials, the beech fibers must first be fiberized in a refiner. Because beech fibers are relatively fine, the distance between the grinding discs must be significantly greater than for typical softwoods.

In a second process step, bicomponent fibers are blended into the beech fibers at a concentration of between 2 and 10%. Ideally, polymer fibers are selected that are biobased, degradable, and have a low melting point.

A new machine was developed to mix the polymer fibers with the wood fibers. A spike roller mixes both fibers together at high speeds (~2000U/min), so that good mats can be produced even with only 2% bicomponent fibers.

This fiber mixture is deposited on a sieve carrier in another newly developed system, so that the fibers are aligned essentially horizontally within the mat. This leads to optimized lambda values and thus to excellent insulating materials.

In a final step, the fleece is baked into the finished mat using either hot steam or hot air. The temperature must be selected so that the polymer of the outer fiber melts while the core fiber remains intact. The molten polymer bonds the wood fibers together, while the core fibers form a flexible network.

In order to produce 3D insulation mats, another project is ensuring that the outer shell of the bicomponent fibers can also be melted using high or radio frequency. For this technique, a 3D mold is filled with the fiber mixture, closed, and exposed to high frequency for a few minutes. A carrier material or fabric can also be inserted into this mold and bonded in a single step.

All mats are tested for their mechanical strength, such as compressive strength and shear strength.

But most importantly, their thermal conductivity (lambda values) must be comparable to those of conventional insulation materials used in the petrochemical industry.

In summary, it can be stated that the developed technologies can also produce excellent insulation mats from beech fiber. These can also be produced in 3D molds.

Studies on the recyclability and natural degradation of the polymer fibers to avoid microplastics have also been conducted.

KEYWORDS: insulation boards, beech wood, moulding machine, radio frequency, bicomponent fiber binders

SESSION IV

SUSTAINABLE FOREST MANAGEMENT

An Interdisciplinary Strategy for Sustainable Scots Pine Forest Management

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ABSTRACT

In Germany and Poland, Scots pine (*Pinus sylvestris*) is the dominant tree species, particularly in Brandenburg, Northeastern Germany, where pine forests constitute over 70% of the forest cover. These forests are increasingly at risk due to climate change and extreme weather conditions experienced over recent decades. To mitigate these risks and enhance climate protection, there is a pressing need to increase carbon sequestration by prolonging the material use of wood. Consequently, forest management strategies in Germany aim to increase the proportion of broadleaved tree species. However, the concurrent rise in demand for timber, particularly from coniferous species, necessitates a close integration of adaptive forest management and efficient timber utilization.

The ADAPT-Wald-Holz project addresses these challenges by developing an adaptive forest-wood management system focused on creating an integrative, efficient, and regional value chain. Central to this project is the establishment of a forest real-world laboratory, designed to analyze the effects of various pine forest management scenarios on critical ecosystem services. These services include wood production, carbon binding for climate protection, groundwater management for water balance, and the preservation of microhabitats for biodiversity. Additionally, the project examines the impact of changing climatic conditions and different management practices on timber harvesting and the mechanical properties of pine wood, with the goal of developing standards for timber construction using pine.

The project features an intensive monitoring area divided into three distinct management scenarios: conventional management, dynamic structuring, and a control area with no intervention. Each scenario is equipped with sensors that continuously measure key environmental parameters such as soil moisture, temperature, and precipitation. This setup enables the long-term observation and analysis of ecosystem services, including biomass

production, carbon sequestration, water balance, and biodiversity. Moreover, advanced technologies, including Personal Laser Scanning Systems, have been integrated to create a digital twin of the forest. This digital representation allows for detailed structural analysis and monitoring of forest dynamics over time. Espacially the changes of forest structure and growth conditions after timber harvesting are adressed. Furthermore, the mechanical and microstructural properties of wood have been analyzed to understand how different management practices affect timber quality.

A significant innovation of the project is the development of a platform demonstrator that utilizes a Large Language Model (LLM). This tool provides insights and answers queries related to forest and wood management, enhancing the accessibility and applicability of research findings for both academic and practical forestry purposes.

Overall, the ADAPT-Wald-Holz project exemplifies a comprehensive approach to adaptive forest management. By combining scientific research, technological innovation, and practical application, the project addresses the pressing challenges faced by pine forests in a changing climate.

KEYWORDS: living lab, supply chain, timber harvesting, wood utilization

Non-native Spruces as a Potential Substitute for Norway Spruce Wood

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ABSTRACT

Norway spruce (*Picea abies*) represents the most important commercial tree species in the Czech Republic. It is also the most important source of timber for the domestic processing industry. Ongoing climate change poses a major challenge for forestry sector. Spruce dieback is not only a matter of finding other suitable tolerant tree species, but also an issue of providing material of adequate quality for applications. Very little attention has so far been paid to other spruce species that are not native to Central Europe and may be more drought tolerant. In this work, we present the results of a pilot study from the Czech Republic on the wood properties of introduced spruce species. Serbian spruce (*Picea omorika*) and blue spruce (*Picea pungens*), as the representatives of non-native spruces, were compared with Norway spruce wood.

Serbian spruce is native to Balkan Peninsula. It was introduced to the Central Europe, but mostly for gardening purposes. It is used as an ornamental tree with high resistance to air-pollution. Information on wood properties is rare, limited to areas of its native distribution. Reliable comparison of wood quality with Norway spruce is not available. Blue spruce is native to North America. In Europe it is used as an ornamental tree or as a Christmas tree. In the Czech Republic, this spruce was widely used for afforestation of areas affected by air pollution. Although this spruce kind is more frequent in the Czech Republic, compared to Serbian spruce, data on wood quality are missing. The comparison to the native spruce wood is not sufficient. Density was used as the basic comparative criterion for wood quality evaluation, as it is the property with the broadest predictive value for all applications. Wood density is an important parameter from a view of paper making perspective, and its value also correlates significantly with material strength and stiffness. It thus provides information on wood suitability for constructional purposes.

Sample trees were collected in the Krušné hory mountains. All trees were growing at the same location to ensure the identical growth conditions. A central plank from the stem basal part was the source material for the testing samples production, allowing the assessment of density radial variability within a stem. Oven-dry density was determined using Czech standards.

Serbian spruce reached the highest density value, followed by Norway spruce. The lowest value was achieved by blue spruce. Based on our results, the most promising substitute for the native spruce is the European spruce species from Balkan Peninsula. In contrast, the North American spruce does not reach the native spruce qualities, and it is not a sufficient source of usable raw material.

KEYWORDS: *Picea omorika*, *Picea pungens*, wood properties, density

Impact of Aphid Infestation on Sap Flow and Needle Morphology in Young Stands of Silver Fir

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ABSTRACT

Silver fir (*Abies alba* Mill.) is an important component of stable forest ecosystems in the Sudety Mountains. However, high historical demand for wood led to forest exploitation based on clear-cuts. Subsequent regeneration, carried out mainly with Norway spruce (*Picea abies* (L.) H. Karst.) seedlings, resulted in the destabilisation of species composition and the establishment of extensive Norway spruce monocultures. The current restitution program aims to increase the share of silver fir in the species composition from 0.4% to 20%. Climate warming has contributed to changes in the impact of two biological factors: *Viscum album* ssp. *abietis* in older stands and *Dreyfusia* sp. in younger ones. This study was conducted to assess the impact of aphid infestation on sap flow and needle morphology in silver fir stands. I hypothesised that infested trees possess a reduced assimilative apparatus and exhibit lower sap flow due to the smaller water demand of their thinner crowns. Sap flow was measured using the Granier-type Thermal Dissipation Probe technique in the following design: three stands × two experimental treatments (infested and healthy) × three trees, using an ex post facto approach. The silver fir stands of the second age class were located in the Zdroje Forest District at three elevations: 400, 600, and 800 m a.s.l. Infested trees were identified based on the presence of adult insects on trunks and nymphs on twigs. Measurements were conducted over 21 days in July 2025. After the sap flow measurements, needles from three crown sections – upper, middle, and lower – were collected to determine their length, projection area, and specific leaf area. As expected, feeding by phytoliquivores resulted in shorter needles and smaller projection areas, while the specific leaf area remained similar to that of healthy trees. Counterintuitively, aphid-infested trees exhibited much higher sap flow. Linear model explaining the transformed sum of flown water as a function of experimental treatment and tree basal area accounted for 75% of observed variability, including 22% from the random effect of site location. Taken together, these findings suggest that under ongoing climatic change, *D. nordmannianae* may cause substantial water losses, similarly to the effects of mistletoe infestation. The results highlight that predictions of future tree species distributions should not focus solely on climatic factors, but also consider how entire ecosystems will respond to dynamic climatic shifts.

KEYWORDS: insect-plant interaction, silver fir restitution, Sudety mountains, thermal-dissipation method, xylem water flow

Soil Impact Assessment Due to Forest Operations in an Oak Coppice in Italy

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ABSTRACT

Forest management produces impacts on forest soil, but these can be of different intensity in relation to the machinery used, stationary and climatic conditions.

In recent years, increasing attention has been paid on minimizing these impacts through the adoption of low-impact forest operations and sustainable planning approaches according to the principles of Sustainable Forest Management (SFM).

This study aims to assess soil damages resulting from two different logging methods within a productive silvicultural system. The research was carried out in a 20-year-old stand managed as coppice with standards, located in the municipality of Avigliano Umbro, Umbria Region, in Italy. Two extraction systems were compared: an intermediate mechanisation level based on the use of farm tractor equipped by forest winch, and an advanced mechanisation system using the forwarder.

In order to assess the effects of both forest operations and silvicultural treatment, three different sampling plots were selected and analysed: "disturbed soil" represented by the soil affected by the passage of loads and vehicles, "undisturbed soil" represented by the soil affected by only the silvicultural activity, canopy uncovering and "control site", doesn't affected by logging and selvicoltural activities in the recent management history.

Soil disturbance was evaluated using a set of physical, chemical and biological indices and indicators, combining field measurements with laboratory analyses. Preliminary findings indicate that both extraction methods produced measurable but generally limited alterations to soil conditions, with slightly more pronounced effects observed in the winching treatment.

Slight disturbances were also highlighted regarding the uncovering and referable to the silvicultural system applied.

However, the severity of disturbance can be considered light, and recovery is expected within two to three years, according to other studies conducted in Mediterranean forest ecosystems.

These results contribute to the knowledge on sustainable forest operations and show that both harvesting methods can be further improved by the use of modern technologies, in order to minimize the soil compacted areas. This is possible with an integrated sylvicultural and operational design, especially in coppice forests, where high ecological sensitivity must be balanced with production goals.

KEYWORDS: oak coppice, Sustainable Forest Management, winching, forwarding, soil impact

ACKNOWLEDGMENTS

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Mixed Forests versus Monocultures: Structural and Functional Benefits of Beech-Spruce Mixtures under Climate Change

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ABSTRACT

Global climate change (GCC) brings more frequent disturbances such as droughts, windthrows, and insect outbreaks, which threaten the long-term functioning of forests. In this context, mixed-species stands are viewed as more resilient because they combine species with different ecological traits. Promoting mixtures is therefore seen as a crucial management approach to safeguard both timber production and the broader ecological functions of forests under GCC.

The study was conducted in the Ore Mountains (542–603 m a.s.l.) on 20 permanent research plots in 86–102-year-old stands of European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* [L.] Karst) on acid sites. The main objective was to assess how different proportions of both tree species influence stand diversity and production potential, thereby providing insights into the ecological and silvicultural advantages of species mixtures. For this purpose, five distinct stand variants were established, representing admixture levels of 0, 25, 50, 75, and 100%, which enabled a direct comparison between monocultures and various degrees of mixture.

The results demonstrated significant differences ($p < 0.001$) among admixture variants for most of the studied parameters. Mixed stands exhibited 32.5% higher tree density, 47.4% higher basal area, and 54.1% higher carbon sequestration in biomass compared to monocultures. Stand volume ranged from 354 m^3 ha^{-1} in pure beech stands to 614 m^3 ha^{-1} in the 50% spruce–50% beech variant. The highest mean stem volume was observed in the variant with 25% spruce and 75% beech. In terms of production, species evenness (rather than species richness) proved to be the most influential factor. Stand diversity indices revealed a clear advantage of mixtures, particularly in stands with a balanced proportion of both species, which also reached the highest overall diversity values (B = 5.64), whereas spruce monocultures showed the lowest values (B = 3.21).

Mixed stands achieve higher production potential, carbon sequestration, and structural diversity compared to monospecific stands. The promotion of mixed beech–spruce stands can therefore be recommended as a suitable silvicultural strategy to enhance stability, resilience, and multifunctionality of forests under GCC in similar site conditions. However, it is crucial that the positive effects of mixtures are not diminished by inappropriate management interventions, such as reducing stand density to levels typical of monocultures or the disproportionate removal of shade-tolerant species from the understory.

KEYWORDS: Norway spruce, European beech, production potential, stand structure, biodiversity

Development of a Decision Support System (DSS) for Forest Operation Planning in Environmentally Sensitive Area

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ABSTRACT

In Mediterranean forests, the selection of harvesting systems is often left to the experience of local forest managers or, in some cases, to the preferences of contractors. In the increasing focus on compliance with the principles of Sustainable Forest Management (SFM), increasing the objectivity of these decisions is therefore essential to harmonize operational efficiency with environmental safeguards. A promising tool in this context is the implementation of the Analytic Hierarchy Process (AHP) within a Geographic Information System (GIS), which allows the spatially evaluation of multiple criteria relevant to forest operations. However, the reliability of the GIS-AHP approach in effectively identifying the most appropriate harvesting system for each compartment remains uncertain, as the baseline data typically available from local management plans and open-source datasets often lack the necessary precision. To address this issue, this study evaluated the performance of a GIS-AHP-based Decision Support System (DSS) applied to the development of the forest operations design for a forest estate located in the Selva del Lamone Nature Reserve (Central Italy). The model was first run using only the baseline data typically obtainable from the forest management plan and open-source geodatabases. It was then recalculated for 10 selected forest parcels where detailed field surveys were carried out to acquire high-resolution information on variables such as soil bearing capacity, terrain roughness, and accessibility. The considered alternatives for timber extraction were forwarder, cable skidder and all-terrain cable yarder. The results allowed a direct comparison between model outputs generated from standard management plan data and those derived from field-verified datasets. The results of the comparison showed that the model is effective in highlighting general suitability systems, but discrepancies were observed at a finer scale, particularly in compartments with complex topography or variable soil conditions. In three out of the ten forest parcels examined, the recommended harvesting system changed after field validation. Statistically significant differences were found between the suitability values derived from the forest management plan data and those obtained from field surveys for forwarders and cable skidders, but not for all-terrain cable yarders. These findings indicate that the GIS-AHP model can be a valuable tool for preliminary planning

at the decadal scale, but for executive planning the analysis must be recalculated and validated through updated sample plots and field data to avoid errors caused by possible changes in vegetation or environmental conditions. This work underlines how precision forest harvesting will increasingly represent a key decision-making approach for future forest management plans.

KEYWORDS: Precision Forestry, Decision Support System, Sustainable Forest Operations, low impact logging, GIS-AHP

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Multi-Criteria Mapping of Mechanized Harvesting Potential for Sustainable Forest Management

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ABSTRACT

Forest disturbances under climate change are increasingly shaping landscape patterns and ecosystem dynamics, with significant effects on forest operations and management objectives at multiple scales, affecting local economies and societal well-being. In recent years, this trend has become particularly evident across the Italian Alps, following the large-scale windthrow caused by storm Vaia, and the subsequent outbreak of secondary biotic and abiotic stressors. This study emerges from the need to address the challenges and opportunities posed by these dynamics through new operational strategies. In the aftermath of the massive timber volume available for salvage logging, along with the emergency context and the short time frame for detailed planning, many forest enterprises have adopted highly mechanized harvesting technologies, such as harvesters and forwarders, that offer high productivity and improved worker safety. These systems have enabled interventions beyond many traditional timber forests, often extending into previously marginal areas, or where forest operations were historically oriented toward quality timber under close-to-nature silviculture and shelterwood systems. However, the suitability and long-term sustainability of mechanized harvesting vary widely across different local contexts, resulting in a range of site- and species-related factors to exploit for optimizing strategies at a broader level. In this framework, forest contractors need to determine if equipment in the harvest systems they operate is suitable for the management demands. Therefore, to address this issue and guide future investments, this study proposes a spatial analysis structure for evaluating the operational feasibility across multiple scales. Starting from a provincial case study, the methodology is designed to be scalable at the national level.

The proposed approach combines different datasets and variables to better delineate forest areas that can be effectively operated, with a particular focus on highly mechanized ground-based systems. A set of key parameters was selected to guide the classification and support the decision-making process. These parameters were implemented through cost functions that account for operational and morphological constraints. The analysis included slope classes, extraction distance, and accessibility through forest roads and skid trails derived from open-source datasets or regional inventories. The application of the

Depth-to-Water index allowed further characterization of the terrain in terms of vulnerability to soil compaction and erosion, identifying safe-operating zones from areas that require more caution. The model was then refined by integrating forest type classification and, where available, timber productivity models developed for similar environments. The resulting maps classify suitable forest areas according to the type of machinery that can be deployed, considering both technical feasibility and ecological limitations, therefore estimating the potential of mechanized operations. Linking forest planning with available technologies can support informed decisions and promote adaptive forest management in the face of increasing disturbance pressure.

KEYWORDS: forest mechanization, precision forestry, MCDA, cost-function modeling

Bucking-to-Demand Simulation with External Stem Dimensions and Quality

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ABSTRACT

Stem bucking, that is cross-cutting the stem into timber assortments suitable for different end-uses, is the first irreversible processing decision in the wood utilization. Due to the heterogeneous nature of roundwood as a raw material, the fit between demanded log length-diameter distribution, including timber quality requirements, and actual output is seldom perfect. The need for maximization of the fit, or minimization of unwanted logs is crucial, and further growing along with the complexity of wood products and customer specifications. In bucking-to-demand (BtoD), the fit between demanded and harvested log length-diameter distribution is aimed to maximize. In cut-to-length harvesting (CTL) it is executed using two different methods: adaptive price list method and close-to-optimal method. The overarching aim of this study was to develop and test bucking simulator based on BtoD that utilizes close-to-optimal method and stand and stem data which include external quality of the stems, and to demonstrate the performance of different bucking objectives in different stand classes of Scots pine and Norway spruce when the method is applied. The data was generated from the database of ARVO-software which was developed in the Finnish Forest Research Institute METLA (now a part of Luke) in early 2010's. ARVO stem quality database included a total of 12 568 trees of pine and spruce, and it was expanded by utilizing non-parametric k-MSN and MSN methods. A representative sample of 80 Scots pine and 47 Norway spruce stands was extracted from the ARVO stand database. The bucking simulator of METLA/Luke was applied, incorporating i) dimensions and tapering of the stems based on taper curve models, ii) stem quality information described above, iii) price and demand for each timber assortment by log top-end diameters and lengths, and iv) BtoD approach using close-to-optimal approach. Totals of 11 and 9 bucking alternatives were defined for pine and spruce, respectively, based on different combinations of timber assortments. Bucking simulations were compared by using apportionment index, which is a key figure depicting the fit between demanded and actual log length-diameter distributions. Bucking simulation without quality information leads to unrealistically high saw log recovery and can be considered impractical. BtoD approach with quality information increased notably the fit, demonstrated by higher apportionment index, and was capable to steer log length-diameter distribution while retaining the saw log recovery almost the same as bucking-to-value approach (BtoV) with even price matrix. When long log lengths

or individual lengths are weighted, the fit between demand and actual output is weaker. Traditional habit to add higher price for minimum diameter classes in the simulation did not increase meaningfully the saw log recovery but decreased the apportionment index. In addition to close-to-optimal approach, the performance of adaptive price list should be examined further.

KEYWORDS: bucking, stem quality, simulation, optimization, recovery, *Pinus sylvestris*, *Picea abies*

The Optimal Rate of a Forest Worker (PLN/H) in the Forest Services Sector Based on the Example of PGL LP Calculations

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ABSTRACT

The basis for all business activities should be an economic analysis based on cost calculations. Such calculations are essential for both sides of each party to a commercial transaction: the service provider and the service requester. On the service provider's side, the calculation is necessary to calculate the revenues to provide the service and, if necessary, to propose a value for the task that is the subject of the service. On the service requester's side, the calculation is necessary to determine the cost of providing the requested service. In the absence of such a calculation, the requester is deprived of an important tool for verifying the (economic) feasibility of providing the service. There is no point of reference for determining whether a service priced in this way, in the given economic, technical, and organizational conditions, is feasible or not. Nor can it verify the value of an excessively high service. Such a calculation is all the more difficult the more variable factors have a decisive impact on the cost.

Cost drivers can be various factors, depending on the nature of the work. For service work, the cost driver is working time. During the planning phase, State Forests' organizational units use working time standards developed by the Center for Development and Implementation of the State Forests in Bedoń (ORWLP) between 2009 and 2021. These standards allow to estimate how much time a given activity will take a worker under given conditions. One working hour in our time standard corresponds to one actual clock hour. The planned cost of performing a service is the sum of the products of the hourly rate in PLN and the calculated hourly standard or the assumed workload expressed in hours.

To calculate the hourly cost, a variety of data must be collected. This data comes from, among other things, sales offers for machines, tractors, and equipment, information gathered from websites, consultations with sellers and forestry entrepreneurs, and based on applicable and assumed indicators regarding tax, social security, and other regulations.

Market price analysis published on websites was used to calculate new and used multi-functional machines and tractors, allowing us to determine the impact of the period and intensity of use on purchase prices and residual values. The calculations do not include the

financial costs of purchasing or leasing the machines, meaning they are prepared as if the entire purchase were financed by service providers. The financial indicators used in the calculations, such as taxes, surcharges, and unit costs, are derived from data published on government websites.

The proprietary and verified calculation algorithm for the PLN/hour rate, developed by ORWLP, allows for annual updates to the value of forestry work performed. Currently, it is used in forestry planning as one of the cost calculation elements. However, its application can be much broader. When using PLN/hour billing, it allows the active inclusion of any market changes in the billing rate: changes in fuel prices, labor costs, etc.

KEYWORDS: economical calculations, cost, working time, hourly rate, working time standard

SESSION V

ADVANCEMENTS IN WOOD-BASED MATERIALS

Non-Halogenated Char-Forming Fire Retardant Additives for Wood Coatings

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ABSTRACT

Intumescent coatings are divided into those with a chemical and physical mechanism of intumescence. The most common chemical intumescent agent consists of ammonium polyphosphate (acid source), pentaerythritol (carbon source), melamine (foaming agent), and a film former. Expandable graphite (EG) flake is a radically different intumescent additive used in many flame-retardant applications. It can expand up to 100 times its original thickness. As a result, the graphite flake generates a more significant isolative layer than many intumescents. One of the promising nanomaterials as a source of carbon is carbon nanotubes (CNTs). CNTs can be used in polymer composites to enhance their mechanical, thermal, and electrical properties. CNTs are a popular addition to polymer composites, enhancing their mechanical properties and fire resistance. During combustion, CNTs form a cross-linked protective layer in the condensed phase that protects the polymer matrix from external thermal radiation.

The aim of the study was to use intumescent and char-forming carbon-based materials (CNT and EG) as fire retardants incorporated into protective coatings for wood and wood-based materials.

CNT, EG or CNT/EG additives were dispersed in the synthetic resins: polyurethane varnish (PUR), nitrocellulose varnish (NC), water-dilutable acrylic emulsion (WAE). The following sample variants were tested: control, WAE; NC/PUR; CNT/WAE, EG/WAE; CNT/EG/WAE; CNT/NC/PUR; NC/PUR/EG; CNT/NC/PUR/EG.

Scots pine were coated (300-400g/m2), conditioned, and their fire protection properties were evaluated using the following methods: Mini Fire Tube (MFT) and Mass Loss Calorimeter (MLC) tests.

The MFT test was employed to determine the mass loss (ML) of the samples and the temperature of the exhaust gases over a 120-second exposure period. In the Mass Loss Calorimetry (MLC) method, samples were subjected to incident heat fluxes (HF) of 30 and 50 kW/m^2. The following parameters were recorded during testing: time to ignition (Tign), time to flameout (Tf), effective heat of combustion (EHOC), mass loss (ML), and heat release rate (HRR).

MFT tests revealed that Scots pine wood coated with the WAE formulation containing carbon-based additives (EG and CNT) exhibited reduced mass loss and lower combustion temperature compared to the other tested variants and uncoated wood. The results of the tests conducted using the MLC method showed that wood protected with PUR/NC exhibited the shortest time to ignition. The highest heat release rate (HRR) values were recorded for the control samples and WAE. The addition of EG and CNT significantly reduced the HRR values for coated wood (EG/WAE and CNT/NC/PUR/EG).

The application of intumescent and char-forming additives (EG and CNT) in the coating demonstrated significant potential to enhance the fire resistance of wood. Moreover, the conducted analyses revealed synergistic effects between CNT and EG in reducing the effective heat of combustion.

KEYWORDS: carbon nanotubes, expandable graphite, coatings, fire-retardant, wood-fire protection

Investigations of the Aesthetic-Decorative Features of Coatings in Printing Technologies

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ABSTRACT

The finishing of wood and wood-based materials gives them a beautiful final appearance. Therefore, it is important to choose the appropriate coating system for a given application so that furniture surfaces have the best possible aesthetic and decorative features and the longest possible durability. Tests are conducted to determine the stability of the gloss, color and reflectance of the coatings.

The lacquer coating reflectance is its ability to reflect incident light or radiant energy. The specific material properties and structure of the coating determine its reflective characteristics, which can be engineered for a wide range of applications.

The aim of this work was to determine selected aesthetic and decorative properties of the surface of HDF boards refined with varnish systems in analogue and digital printing technologies. Samples for testing in birch, oak, ash and white versions finished in matt and high gloss were prepared in analogue printing, using Hg-Ga radiators. On the other hand, samples in the "white-black" version were obtained in both analogue and digital printing using Hg-LED lamps. The research material was prepared in industrial conditions.

The gloss was determined by the photoelectric method using the photoelectronic method at three angles of 20, 60 and 85°. For evaluation of color with the use of CIELab system was made. Reflectance analysed with the use of digital reflectance meter.

All tested coatings made in analog printing technology were characterized by high aesthetic-decorative features. The best high gloss was obtained by white high gloss sample, white Mat was followed by ash, birch and oak coatings.

Both analogue and digital printing methods provide a repeatable gloss level of coatings. The gloss depends on curing/hardening.

The lamp power did not show a significant impact on coating gloss level, whereas the use of additional UV LED lamps improved the aesthetic and decorative features of the coatings and slightly increased their gloss values.

Black coatings showed significantly lower reflectance values compared to white coatings, which is related to the greater amount of absorbed light. The RW and RB values depend on the value of the coatings.

KEYWORDS: UV lacquer system, printing, coating, gloss, color, reflectance

Creosolve Project – Innovative Biological Methods for Managing Used Railway Sleepers and Other Creosote-Treated Wooden Components

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ABSTRACT

Forecasts indicate significant challenges regarding the management of hazardous wooden waste generated by modernization efforts within railway infrastructure across Poland and Europe. Specifically, the replacement of wooden railway sleepers impregnated with creosote oil - a carcinogenic substance containing high concentrations (50-90%) of polycyclic aromatic hydrocarbons (PAHs), including the highly toxic benzo(a)pyrene – is anticipated to yield approximately 1.1 to 1.5 million tonnes of waste in Poland, and as much as 12 to 16 million tonnes at the European level over the next two decades. Given the environmental and health risks posed by these contaminants, traditional disposal methods, predominantly thermal and physico-chemical treatments, are increasingly viewed as inadequate and unsustainable. Consequently, innovative strategies aligning with circular bioeconomy principles and sustainability objectives are critically needed.

This research aims to develop and evaluate three innovative utilization methods specifically tailored for creosote-impregnated wooden waste, including railway sleepers, telecommunication poles, and similar structures:

1. A hybrid pyrolytic-biological method combining thermal pyrolysis to initially degrade creosote oil and subsequent microbiological treatment for further decomposition of resultant pyrolytic compounds.
2. Bioremediation techniques utilizing carefully selected microorganisms and plant species capable of metabolizing PAHs, thereby minimizing environmental contamination risks.
3. A composting approach intended to convert creosote-impregnated wooden waste into high-quality compost suitable for use as fertilizer, thus transforming hazardous waste into a valuable resource.

Each method undergoes rigorous laboratory-scale experimentation followed by pilot-scale testing. Analyses include assessments of PAH degradation efficiency, technological

feasibility, scalability, and economic viability. Additionally, detailed Life Cycle Assessments (LCA) is conducted for each method to quantify and comparatively evaluate their potential environmental impacts comprehensively.

The proposed methodologies are expected to provide innovative, sustainable, and efficient solutions to the challenges posed by creosote-impregnated wooden waste. It is anticipated that the hybrid pyrolytic-biological method will demonstrate substantial initial breakdown of contaminants followed by effective microbial remediation. The bioremediation method is expected to show a significant potential for PAH reduction through the metabolic activity of selected microorganisms. The composting approach is anticipated to yield compost with favorable physicochemical properties. The LCA studies will offer robust comparative insights regarding the ecological advantages and possible limitations of each method.

This research addresses a critical need for sustainable management strategies for hazardous wooden waste, particularly creosote-impregnated railway sleepers. The outcomes of this project will contribute significantly toward developing practical, scalable, and environmentally responsible methods, aligned with the European Union's circular economy and sustainability strategies.

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KEYWORDS: creosote oil, railway sleepers, environmental biotechnology, microorganisms, wood, PAH

Sustainable Particleboard Manufacturing Based on Valorization and Efficient Utilization of Alternative Lignocellulosic Raw Materials

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ABSTRACT

The sustainable development of the wood-based panels industry requires not only laboratory research, but also a practical approach to the processing of alternative lignocellulosic material in a way that enables their stable and repeatable use in the manufacturing of particleboard. Increasing restrictions on the availability of primary wood and the need to reduce environmental emissions make the implementation of solutions based on renewable raw materials one of the key technological challenges.

The research and analysis aim to develop a practical approach to assessing the technological suitability of alternative raw materials and to determine whether and what changes in the process and selection of adhesives are necessary to obtain boards that meet quality requirements. Raw materials of plant, agricultural, or waste origin differ in density, particle structure, and chemical composition, which affects their susceptibility to shredding, adhesive bonding, and stability during pressing. This requires the development of not only evaluation procedures, but also new strategies for the selection of bio-based binders and additives that improve the compatibility and durability of bonds while reducing formaldehyde emissions and the environmental footprint of the process.

As part of laboratory tests, processes for grinding and fractionating raw materials and the production of particleboard with different pressing parameters were developed and tested. The boards produced were evaluated in terms of their physical and mechanical property in accordance with the requirements of EN 312, including bending strength, tensile strength, and formaldehyde emissions. Parameters such as the energy consumption of drilling holes and screw withdrawal resistance were also tested. The results show that alternative raw materials can provide comparable mechanical properties, and their use promotes the development of more flexible and low-emission material solutions. The use

of alternative components allows for the partial replacement of primary wood while maintaining the required quality of the boards and having a positive impact on the raw material balance and sustainable development goals.

The analysis confirms that the effective production of particleboard from alternative raw materials requires the simultaneous optimization of material characteristics, the binding system, and the pressing process parameters. This approach makes it possible to decrease the environmental footprint and develop low-emission products with the idea of a circular economy.

KEYWORDS: mechanical properties, bio-based adhesive, technological indicators, circular economy, formaldehyde emissions

Multiscale Models Predicting Wood Structure Infiltration

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ABSTRACT

Transparent Wood (TW) is an innovative composite material distinguished by its lightweight nature, optical transparency in the visible spectrum, and environmental sustainability. Through a series of treatments, including delignification, resin infiltration, and optional functionalisation, TW emerges as a promising alternative to glass and plastics across various industrial sectors, such as construction, automotive, electronics, and furniture. The AI-TranspWood project, supported by the European Commission, aims to develop AI-driven multiscale modelling approaches for TW composites (https://www.ai-transp-wood-project.eu/). Within this framework, simulating resin infiltration into delignified wood is a key step toward understanding and optimising the manufacturing process of TW-based products. This presentation describes a computational framework for predicting infiltration kinetics in delignified wood structures during transparent wood fabrication. The integrated modeling approach comprises three components: (1) molecular dynamics simulations to determine infiltrant viscosity and transport properties under selected conditions, (2) a hierarchical multiscale modeling framework based on micromechanical principles to predict the effective permeability of delignified wood microstructures, and (3) finite element analysis employing modified Darcy flow equations to investigate the effects of processing parameters and boundary conditions on infiltration time scales.

We generate the molecular structures for an infiltrant liquid starting from the SMILES description of the infiltrant molecule. We use open source tools (ACPYPE, Veloxchem) to generate Gromacs topologies for the GAFF force field, and to obtain the atomic partial charges. Gromacs itself is used to initialize and equilibrate the molecular liquid, and to perform the non-equilibrium shear flow simulations, using the box deformation method, for accurate computation of viscosity while maintaining system homogeneity. The workflow has been automated in the AiiDA environment, facilitating the screening of several infiltrants. The micromechanical framework captures essential qualitative trends in structural and fluid transport transformations during lignin removal and subsequent polymer infiltration, revealing that delignification substantially increases pore volume and permeability while poly(methyl methacrylate) (PMMA) infiltration alters fluid pathways and preserves certain permeable domains. The analysis demonstrates strong sensitivity of longitudinal and transverse permeability components to microstructural features

including lumen aspect ratio, lumen volume fraction, and pore shape anisotropy. The modified Darcy approach extends classical Darcy's law to account for permeability variations in different directions, and incorporates surface tension effects, contact angle dependencies, and external pressure gradients in the boundary conditions. This enhanced model is implemented using the FEniCSx finite element framework to solve the coupled flow equations in complex three-dimensional wood geometries. A comprehensive parametric analysis was conducted to evaluate the sensitivity of infiltration kinetics to key processing variables, including infiltrant properties, wood microstructure characteristics, and boundary condition configurations. As a toolchain, the different levels of methodologies enable quantitative prediction of mass transport phenomena in the complex porous network of delignified wood, providing insights for optimizing transparent wood processing conditions.

KEYWORDS: transparent wood, manufacturing, process modelling, infiltration

A Wood-Based Material Approach to an Intelligent Beehive Mechatronic System

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ABSTRACT

In the face of global challenges related to bee protection, modern beekeeping increasingly turns to advanced technologies to improve care for these critically important insects. A key aspect of this effort is the development of solutions that enable continuous monitoring of bee health without the need to interfere with hive life. One of the innovative directions in this field is the integration of mechatronic systems with traditional wooden hive structures.

The aim of this paper is to present the design of the Beehive Control System, which exemplifies the effective combination of traditional material – wood – with modern electronic solutions, creating a system that allows for comprehensive hive supervision. The implementation of this system was based on natural materials.

The developed system was constructed using wood as the main structural material due to its availability, ecological properties, ease of processing, and excellent thermal insulation characteristics. In the system, wood serves not only as a structural component but also as an integrated housing for electronic components.

The mechatronic model includes a set of sensors monitoring temperature, humidity, and carbon dioxide levels inside the hive. Data is collected in real-time and transmitted to a computer or a smartphone, while system control is managed through a dedicated application.

The construction of the research models involved creating a wooden load-bearing body that facilitates easy integration of the system with existing hives, as well as manufacturing other functional components.

Prototype tests conducted under real-world conditions demonstrated the system's high effectiveness in detecting changes in environmental parameters inside the hive and in combating varroa mite infestations. The system successfully identified alarming signals such as sudden temperature drops or increased humidity, which may indicate diseases, parasite presence, or other threats to bee colonies.

Thanks to the use of wood as the base material for the Beehive Control System, no disruptions in the operation of the mechatronic components were observed.

The integration of mechatronic technologies with a traditional, natural material such as wood offers an effective and eco-friendly approach to monitoring bee health.

The developed Beehive Control System confirms the possibility of harmoniously combining tradition with modernity, providing a solution that can support beekeepers in their daily work and contribute to increasing the survival rate of bee colonies.

This project opens new perspectives for the development of smart hives based on the principles of sustainable development and environmental respect.

KEYWORDS: Beehive Control System, wood in mechatronics, bees

SESSION VI

WOOD AND WOOD-BASED MATERIALS QUALITY ASSESSMENT

Non-Destructive Wood Quality Assessment Along the Forest-Wood Chain: A Case Study on Sessile Oak from Northern Italy

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ABSTRACT

Assessing wood quality is an expensive and time-intensive process, typically conducted only when economically advantageous, such as when higher product quality commands better prices, or when mandated by legislation, as in the case of structural timber, where qualification is required by law. As a result, such evaluations are typically carried out downstream in the production chain, once the material has been processed.

However, extending quality assessment upstream – at the standing tree or roundwood stage – can offer significant benefits to forest managers, processors, and end users. Early evaluation of stem quality can inform silvicultural strategies that promote value, not just volume. In the roundwood phase, material selection based on quality attributes enables better alignment with market demands, improving product allocation and pricing. It also enhances customer satisfaction by delivering material more suited to specific needs and with greater consistency.

This study explores the use of various non-destructive tools applied to standing trees, logs, and sawn timber, comparing their performance and predictive reliability. The case study focused on sessile oak (*Quercus petraea*) from northern Italy, a species with high potential but limited market development due to the absence of an organized supply chain.

Standing stems were assessed through dimensional and qualitative metrics, including sonic and ultrasonic wave propagation along the stem. After felling, logs were tested using the same tools, with additional resonance frequency analysis. Photogrammetric surveys were also conducted to evaluate the potential for remote visual classification using 3D point clouds. Logs were subsequently sawn, and boards were classified using grading machines

that measured dynamic modulus of elasticity and scanners equipped with RGB cameras and laser sensors.

The measurements obtained from standing trees showed moderate to high correlation with those taken from the logs (R^2 = 0.68 for sonic measures and 0.44 for ultrasound). Better correlation was observed between tree data and but logs measures (R^2 = 0.71). Lower, yet still significant, correlations were found for the second and third logs cut from the same trees.

Visual evaluation of logs through point cloud data proved to be effective for both dimensional measurements and qualitative classification, showing good agreement with instrument-based assessments.

Further down the value chain, correlations between measurements on sawn timber and those obtained from logs or standing trees decreased. Nevertheless, the physical and mechanical properties of the sawn wood were effectively estimated using non-destructive methods.

While the precision of wood property estimation improves as the material progresses along the value chain, early-stage quality assessment on standing trees or logs offers strategic advantages. It enables more informed forest management, optimizes material sorting for specific applications, and lays the groundwork for a more efficient, high-value, and sustainable forest-wood supply chain. Investing in non-destructive evaluation technologies and integrating them across production stages can promote underutilized resources.

KEYWORDS: non-destructive testing, wood quality assessment, stem evaluation, roundwood classification

Artificial Intelligence for Automated Wood Quality Assessment: A Review of Methods, Data, and Emerging Generative Approaches

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ABSTRACT

Visual inspection of wood quality is time-consuming and subjective. Recent advances in artificial intelligence (AI) – including deep learning and computer vision – enable automated identification of species, detection of defects (knots, cracks, insect damage), and assignment of quality grades. This review synthesizes current methodological trends, datasets, and performance levels across laboratory and industrial settings, and examines the emerging role of generative AI (GenAI) for data augmentation and annotation.

We conducted a structured literature survey of peer-reviewed studies and selected preprints on AI for wood assessment. Inclusion criteria covered: (i) imaging modalities (RGB, microscopy, hyperspectral/NIR, X-ray CT), (ii) tasks (species classification, defect detection/segmentation, grading, biological damage), and (iii) learning paradigms (CNNs, transformers, one-/few-shot, classical ML) plus GenAI (GANs, diffusion). We extracted model families, input data, experimental settings, evaluation metrics, and reported accuracies, prioritizing studies with test protocols reflecting real-world variability.

Convolutional backbones (ResNet, Inception, EfficientNet) and detectors (YOLO, Faster/Mask R-CNN) dominate image-based pipelines, achieving high accuracy for species recognition and defect detection on curated datasets. X-ray CT supports non-destructive internal defect assessment, while hyperspectral/NIR adds chemical specificity for species and property prediction. Transformers and attention modules are gaining traction for fine-grained textures and multi-view inputs. Industrial deployments emphasize latency, robustness to illumination and surface variability, and explainability (e.g., Grad-CAM) to support quality decisions. GenAI shows promise in two roles: (i) semi-automatic pre-labeling (pre-masks, synthetic exemplars of rare defects) to reduce annotation cost; and (ii) targeted augmentation to rebalance classes (e.g., rare biological damage), improving downstream detectors under data scarcity. Reported gains are most consistent in few-shot regimes and when synthetic-to-real ratios are constrained and validated on held-out real data.

AI already surpasses manual inspection in speed and, in controlled settings, in accuracy. Remaining gaps include domain shift (species, mills, finishes), limited public benchmarks

with standardized protocols, and scarce labels for subjective grading. Priority directions are: multimodal fusion (RGB+CT+NIR), robust evaluation under distribution shift, explainable decision support, lightweight edge inference for in-line operation, and principled use of GenAI with realism checks and expert validation. Addressing these will accelerate reliable, scalable, and transparent wood-quality automation.

KEYWORDS: wood quality assessment, computer vision, deep learning, hyperspectral/NIR, X-ray CT, generative AI, defect detection

MobileArborist™: Revolutionizing Urban Tree Assessment

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ABSTRACT

Urban green spaces are essential for creating sustainable cities, significantly improving air quality, mitigating urban heat island effects, and supporting biodiversity. Therefore, effective management of urban trees is crucial. However, traditional assessment methods are often slow, labor-intensive, and prone to inconsistencies, presenting considerable challenges for arborists. There is a clear and growing need for precise digital tools to support modern urban forest management and facilitate the development of digital twins for urban ecosystems.

This presentation introduces MobileArborist™ , an innovative device specifically designed for urban tree assessment. Building upon the foundation of our MobileForester® technology, MobileArborist™ offers a new and highly accurate approach to assessing public and other trees. Its ergonomic design and straightforward operation greatly simplify the surveyor's work, whether for detailed tree inspection or comprehensive tree cadastre data collection. The MobileArborist™ application includes six distinct measurement modules, from which Tree Assessment and Tree Cadastre provide the core functionalities for arborists, utilizing a sophisticated photoanalytical algorithm for determining multiple measurement data like trunk and crown diameter, ensuring high precision. All data collected from the Tree Assessment and Tree Cadastre modules are saved digitally, effectively eliminating the issues associated with paper-based data recording.

MobileArborist™ significantly accelerates and improves data processing through its advanced photo-optical analysis capabilities. Users can create projects to survey trees within specific urban areas like a street. All collected data is saved digitally, without the need to be online during fieldwork. The device offers flexibility, allowing for both actual measurements using the MobileArborist™ hardware and convenient manual data entry. All recorded data can be easily modified and updated as needed. The Tree Assessment module provides detailed fields for documenting a tree's health, potential risk factors, and suggested treatments, with the option to add voice notes for comprehensive documentation. Users can take and select multiple photographs of the surveyed tree, which can then be seamlessly embedded into exportable tree assessment reports. GPS coordinates are automatically recorded for the main measurement functions, with manual input options available for situations requiring higher precision. This comprehensive solution enhances

efficiency and accuracy, empowering professionals to make more informed decisions regarding the health and longevity of urban trees.

MobileArborist™ offers a user-friendly interface that generates digital data directly during the measurement process, making the work of arborists considerably faster and simpler. The immediate availability of digital data removes the need for time-consuming post-processing of paper records. This advanced digital technology presents a highly effective solution for modern urban tree management. By integrating data into digital platforms, MobileArborist™ is a key tool for sustainable urban forest management and for creating accurate digital twins of urban green infrastructure, contributing to the development of more resilient and intelligent cities.

KEYWORDS: MobileArborist™, tree assessment, tree cadastre, urban forest management, digital technology, sustainable cities

Selected Mechanical Properties of Beech and Birch Wood in the Context of Use in Construction

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ABSTRACT

Wooden construction is becoming an increasingly important element of sustainable development and climate neutrality strategies, especially in Europe. As a building material, wood stands out for its favourable carbon balance, renewable sourcing, and lower energy consumption in production processes compared to traditional materials such as steel or concrete.

In construction, hardwood is still less popular than softwood, especially in structural applications. In this context, hardwood has been studied to a lesser extent, which is why expanding the database of its mechanical properties is desirable.

Hardwood resources in Europe still have great potential for construction sector, and products made of hardwood can achieve higher strengths, both, as solid wood components as well as engineered wood products.

Beech and birch, alongside oak, are the most common deciduous species in Poland.

As a part of the CRESTIMB project, strength tests are carried out on small specimens, which include both short-term and long-term tests. The tests are carried out in accordance with the series of ISO 13061 standards. Specimens of clear wood without defects are prepared from dried sawn timber for particular tests: compression along and across the grain, tension along and across the grain, shear and bending in three point bending scheme. The specimens are conditioned in standard climate (65%/20°C) to constant mass before the tests. Total amount of 32 specimens are to be tested for each species and each characteristic.

As preliminary results the values of bending strength have been obtained. Bending strength for beech wood is at the level of 120 N/mm^2 on average with density of 711 kg/m^3 and moisture content of 10.1%, while 94 N/mm^2 for birch with density of 630 kg/m^3 and moisture content of 11.8%.

Further tests of other mechanical properties will help in obtaining experimental creep and mechano-sorptive parameters that will serve as input data for novel rheological model developed by consortium partners within the CRESTIMB project.

KEYWORDS: hardwood, beech, birch, construction, mechanical properties

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Tailoring Mechanical and Functional Properties of Polyurethane-Wood Composites via Isocyanate Index Control

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ABSTRACT

The major drawback of traditional wood panels is the use of formaldehyde-based adhesives, which are harmful to human health and the environment due to their emissions. Recently, the European Union reduced formaldehyde emission levels in consumer products, which showed the necessity of developing formaldehyde-free materials. Polyurethane–wood composites (PU-WCs) are a promising substitute, as they do not contain formaldehyde. Moreover, its properties may be controlled by structure design, especially through modification of the isocyanate index (ratio of NCO:OH groups, NCO index). Proper adjustment may enhance crosslinking density, leading to stronger interfacial adhesion and improved material performance.

In this study, PU–WC were manufactured using a one-step method based on a two-component system. Component A consisted of a mixture of petrochemical polyols (Rokopol® M6000, Rokopol® RF551 supplied by PCC Rokita S.A) with a surfactant (Tegostab B 8465 supplied by Evonik). As a component, B polymeric diphenylmethane diisocyanate (pMDI, Ongronat 2100 supplied by Borsodchem) was used. The mixture of both components was combined with the pre-dried pine (Pinus sylvestris) wood sawdust in a planetary mixer for 10 min. After homogenization, the mixtures were hot-pressed at 100 °C for 15 min, followed by 5 min of cold pressing. No chemical catalyst was used during the process. The NCO index varied from 1:1 to 3:1.

Customisation of the NCO index allowed for improvement of the mechanical performance of the PU-WCs. The increase of the NCO index to 2:1 improved the flexural strength by up to 15% and Young's modulus by up to 21%. Increase in both parameters could be attributed to the crosslinking process realised by dimerisation and trimerisation reactions of isocyanate excess, and improved interfacial adhesion. Thermogravimetric analysis (TGA) proved a two-step degradation of materials with four overlapping degradation processes. Increased NCO indexes slightly improved $T_{5\%}$ (up to 10 °C). The dynamic mechanical analysis (DMA) proved an increase in crosslinking density and allowed for the description of

viscoelastic phenomena occurring in the materials. It was also demonstrated that the NCO index had a significant influence on $T_{g\alpha}$. These result confirms the critical role of the NCO index in governing PU-WCs properties.

This study provides significant advancements to the development of sustainable PU-WCs, which expand the range of achievable properties and applications. The results demonstrate that increasing the NCO index increased adhesion between the composite phases by the reaction between NCO and OH groups of wood. This was reflected by enhanced mechanical strength, stiffness, and thermal stability. Manufactured composites with optimised NCO index outperform conventional wood-based materials. For this reason, developed PU-WCs may be an useful, sustainable, formaldehyde-free alternative to classic materials.

KEYWORDS: polyurethane, wood, composites, sustainability

ACKNOWLEDGMENTS

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POSTER SESSION

A Virtual Tour Approach for Forest Management, Education, and Stakeholder Engagement

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ABSTRACT

Communicating complex forest management concepts and future adaptation options to stakeholders, researchers, students, and the public is, in most cases, challenging, as visiting the site may not be possible for several reasons, including time, distance, and environmental limitations. New technologies for visualisations can comprehensively increase and support communication and knowledge transfer by making sites and scenarios understandable without the need for travel. Therefore, the main objective of the present work was to create an interactive virtual forest tour (VFT) using some practical tools to test whether cloud-hosted 360° tours can support stakeholder engagement, education, and explanation of the primary aims of the ADAPT-Wald-Holz project. Images were taken using an Insta 360 One X camera, which is equipped with two fisheye lenses on the front and back, from the forest site (52.9663, 13.6432) in Brandenburg, Germany. The 360° panorama was transferred to the VR-Easy (vr-easy.com) online cloud-based platform, and various elements, including videos, audio, images, a map, and other information, were added to this panorama. The development workflow emphasized reproducibility and low but standard technical barriers. The prepared panorama presented an overview of the forest site, the workflow, sample scenes, and important information (hotspots, navigation, accessibility options) about different aspects of the project in a virtual situation. The results of the VFT creation successfully demonstrated that 360° visualisations can represent complex forest structures and management concepts in an easy, accessible, and attractive manner. Users were able to explore the site in a self-guided way thanks to the integrated multimedia elements, including short videos, images, and a georeferenced map. Feedback from students, researchers, and project partners revealed that the combination of visualization and forest-based information can improve the understanding of the key ADAPT-Wald-Holz project characteristics, such as its transdisciplinary approach, which involves practices ranging from forest management to material science. The method was very beneficial for visualizing the concepts that cannot be transferred through only text or two-dimensional images. From a technical dimension, content can be efficiently changed, updated, and

maintained using a cloud-based platform. This feature is crucial for tracking changes in the forest over time. The created tour was responsive and online. Therefore, it can be used in various activities, such as workshops, teaching, remote stakeholder consultations, etc. This VFT also highlighted the potential role of cloud-hosted platforms as a valuable tool in forest-related research and management. Overall, this work suggested that digital tools can offer a practical solution for increasing awareness, understanding, and engagement around forest adaptation and sustainable management.

KEYWORDS: 360° visualisation, knowledge transfer, forestry, cloud-based platform

Validation of a Precision Forestry-Based Approach for Geometric or Mixed Thinning in Conifer Plantations

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ABSTRACT

Knowing the exact location of the strip road network created during forest operations is essential to assess soil disturbance, check whether activities matched the plan and gather valuable information for future management decisions. Identifying rapid and effective ways to capture this information can significantly improve the way forest operations are monitored and planned. This study explored the use of Unmanned Aerial Vehicle (UAV) remote sensing as a rapid and scalable solution to address this need. A black pine (*Pinus nigra*) plantation on Mount Amiata, Central Italy, managed with boom-corridor thinning, was used as a test site. Four approaches were tested: RGB imagery method, Hillshading (Hill), Local Relief Model (LRM) and Relative Density Model (RDM). The RGB method relied on the interpretation of UAV orthophotos, while the other three are LiDAR-based approaches that use digital elevation models and point cloud analysis to highlight microtopographical variations caused by machine traffic. The resulting maps were validated against a ground reference map using nine accuracy metrics: overall accuracy, precision, recall, Cohen's kappa, Intersection over Union (IoU), Dice Similarity Coefficient (DSC), true positive rate (TPR), false positive rate (FPR) and specificity. The RDM technique consistently outperformed the other approaches, achieving the highest accuracy and producing estimates of impacted surface areas that closely matched ground measurements. The RGB-based approach also provided solid results and remains an appealing solution when operational constraints or budgets limit the deployment of LiDAR sensors. Hillshading performed the least effectively in terms of recall, whereas the LRM represented a balanced option, combining reasonable accuracy with methodological simplicity. These results show that UAV remote sensing can offer forest managers a reliable way to monitor post-harvest operations, moving beyond traditional ground surveys. By combining RGB and LiDAR-based methods, it is possible to improve the precision and completeness of road network detection, and acquiring this information through rapid and effective approaches can significantly enhance the

monitoring and planning of forest operations, support better decision-making and help reduce the environmental footprint of harvesting activities.

KEYWORDS: precision forestry, UAV, remote sensing, *Pinus nigra*, LiDAR

ACKNOWLEDGMENTS

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This study was carried out within the project RERUM "Resilience and Resistance of Flora and Fauna to Climate Change in Northern Lazio Nature Reserves", Funded by the European Union – Next Generation EU, Mission 4, Component 1, CUPF63D24000010001. under the Italian National Recovery and Resilience Plan (PNRR), Investment Line 1.4, and supported by the European Union – NextGenerationEU (Grant number CN00000033).

Where Color Matters-Utilization of Lightened Lignin in Conservation of Waterlogged Wood

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ABSTRACT

Lignin, the second most abundant biopolymer, is increasingly targeted for value-added applications from coatings and cosmetics to consolidation of waterlogged wood. However, lignin's distinct brown color often limits its use in color-sensitive applications. In the conservation of waterlogged archaeological wood, the color of treated surfaces should remain as close as possible to the natural appearance. To address this constraint, we first chemically modified kraft lignin by acetylation and then generated an encapsulated form via a solvent self-assembly route. The two materials were introduced to waterlogged wood using different carriers: acetylated lignin was dissolved in ethyl acetate, whereas encapsulated lignin was dispersed in water. The resulting solutions/dispersion were used to impregnate waterlogged archaeological pine (*Pinus* sp.) specimens (2 × 2 × 1 cm), immersed for two weeks and subsequently dried under controlled laboratory conditions.

Color was quantified in the CIELAB system (L*, a*, b*) with total color difference (ΔE) calculated against the respective controls. The formulations themselves differed visibly: the acetylated-lignin solution appeared darker/brownish, while the encapsulated-lignin dispersion was lighter and translucent, consistent with reduced perceived chromophore intensity via colloidal light scattering. These formulation differences were transferred on wood appearance. Relative to the ethyl acetate control (ET0), acetylated lignin (ET) produced progressive darkening with increased concentration, lowering lightness from 39.11 (ET0) to 19.65 (ET30) and reducing chroma (e.g., 6.78 in ET30), yielding a duller, browner tone. The total color differences were 6.39, 12.46, 21.30 for ET10, ET20, and ET30, respectively, well above the commonly accepted perceptibility threshold (ΔE > 3–5). In contrast, relative to the water control (W0), encapsulated lignin (W) caused brightening: L* increased to 43.42 (W10) and 57.23 (W20), with ΔE = 10.63 and 24.57. The modest increases in b* and C* for W10–W20 indicate lighter, slightly yellowish yet more saturated surfaces that remain visually favourable.

To sum up, the colorimetric results underline a clear trade-off. Acetylation improves compatibility and penetration but risks surface darkening (ΔE-positive changes toward lower L*), whereas encapsulation acts primarily as a surface-level optical modifier that

masks lignin's intrinsic brownness and elevates L*. For conservation practice, where maintaining or enhancing a natural-looking tone is important, the encapsulated route offers a pragmatic pathway to use lignin in color-sensitive applications while retaining the sustainability benefits of a bio-based consolidant.

KEYWORDS: lightened lignin, acetylation, encapsulation, waterlogged wood conservation

Enhancing Hygroscopic and Mechanical Properties of Scots Pine Using Capric acid/Tallow through Heat and Oil Heat Treatments

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ABSTRACT

Improving the moisture resistance and mechanical performance of wood materials is crucial for extending their service life and promoting sustainable construction applications. In this study, Scots pine (*Pinus sylvestris* L.) specimens were modified using three different methods heat treatment (HT), impregnation with bio-based materials (IW), and oil heat treatment (OHT). For IW and OHT processes, a bio-based mixture composed of 23.08% capric acid (CA) and 76.92% beef tallow (TW) was used.

The modified samples were characterized using FTIR, XRD, and TGA analyses. XRD results indicated a decrease in crystallinity after modification, while FTIR analysis confirmed the presence of characteristic chemical bonds of CA and TW in IW and OHT samples. The contact angle measurements showed an increase in hydrophobicity after treatment, with the highest angle of 94° observed in OHT samples.

Regarding hygroscopic properties, the OHT-treated specimens showed 20% anti-swelling efficiency (ASE) after a 2-week water immersion test. In mechanical tests, both IW and OHT samples exhibited improved modulus of rupture (MOR), with OHT specimens achieving the highest MOR value of 135 N/mm^2.

These results demonstrate that modifications using bio-based PCMs significantly enhance the physical and mechanical properties of wood, highlighting their potential for advanced wood protection and energy-efficient applications.

KEYWORDS: Scots pine, Capric acid, Tallow, oil heat treatment, hygroscopic properties, Instrumental Methods

The Role of European Hare in Forestry: Evaluation of the Damage to Forest Regeneration

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ABSTRACT

European forests are increasingly affected by a variety of both large and small scale disturbances, driven by biotic and abiotic factors. These disturbances have significant consequences for forest biodiversity, structural integrity, ecosystem stability, and species composition. Among these, damage caused by wildlife plays a major role in shaping forest dynamics and influencing forest regeneration success. While the impact of wild ungulates – such as deer species and wild boar – on forest stands is well-recognized and widely studied, the potential negative influence of European hare (*Lepus europaeus*), has remained largely underexplored in forest ecology and management practices.

To address this knowledge gap, our study evaluated the extent of browsing damage caused by the European hare in comparison to wild ungulates. We assessed 209 calamity clearcuts in the eastern part of the Czech Republic, examining a total of 75,912 planted seedlings. The study compared damage intensity in forest stands both with and without standard forest protection measures, including fencing or repellents.

Our findings demonstrate a notable level of browsing damage caused by the European hare, accounting for 10.12% of all observed damage, surpassing the 7.11% attributed to wild ungulates. Species-specific browsing preferences were evident: hares most frequently browsed birch (Betula spp.), with a damage rate of 37%, while ungulates showed a preference for Scots pine (Pinus sylvestris) at 29%. Seasonal variation in hare browsing was also significant – damage peaked in autumn at nearly 14%, while dropping to under 2% in spring when alternative food sources were more readily available. Importantly, common protection strategies, such as coatings and standard fencing, proved largely ineffective against hare browsing. Notably, species like Acer pseudoplatanus and Fagus sylvatica exhibited greater browsing damage even when treated with coating protection.

The study highlights the underestimated impact of the European hare on forest regeneration, particularly in post-calamity reforestation scenarios. These results call for a revision of current protection strategies and suggest a need to develop more effective measures – such as dense wire-mesh fencing and population control – to mitigate browsing damage by hares and ensure successful establishment of young forest stands.

KEYWORDS: browsing, forest regeneration, tree species attractiveness, wildlife damage, climate change

Air Exchange and Its Effect on Indoor Environmental Quality

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ABSTRACT

The emissions of harmful organic compounds from office, room and upholstered furniture were tested in the course of the study. Tests for the emission of formaldehyde and volatile organic compounds (VOC) were performed using the chamber method in climate conditions set forth in PN-EN 717-1:2006 standard. Furniture was tested in large chambers of the volume of 23.6 m^3 and 41 m^3, simulating residential rooms. The following load ratios were used: 1.5 m2/m3 (room furniture); 1.6 m^2/m^3 (office furniture); 0.45 m^2/m^3 (upholstered furniture). The author determined the effect of the number of air exchanges on the concentration of organic compounds in the air of chamber loaded with furniture in an amount that is typical for residential and office rooms.

In the case of office furniture, the gradual reduction of the number of air exchanges from 0.8 to 0.4 h^{-1} resulted in a slight increase in formaldehyde concentration, which was within the range of 0.031 to 0.039 mg/m^3. Only the reduction of the air exchange rate to 0.05 h^{-1} caused a fourfold increase in the equilibrium concentration of formaldehyde in the tested air (0.080 mg/m^3). The situation was similar in the case of room furniture, where, at the chamber load of 1.6 m^2/m^3 and the air exchange rate of 1.6 h^{-1}, the determined equilibrium concentration of formaldehyde in the chamber air equalled 0.045 mg/m^3, thus it was within the limits of permissible concentration of this compound (0.05 mg/m^3). Further reduction of the air exchange rate (twofold and fourfold) caused formaldehyde to exceed its permissible concentration by 30% and 100%, and by as much as 500% at the lowest air exchange rate of 0.05 h^{-1}. A similar dynamics of decrease in VOC emission from office and room furniture was observed when the number of air exchanges in the chamber was reduced.

The tests revealed an increase in the concentration of formaldehyde and VOCs in the air of a model room when the air exchange rate in the chamber was reduced. Given the common practice of limiting air exchanges in residential spaces for economic reasons, it would be advisable to set the air exchange rate in the chamber at 0.05 $m^3/m^2 \times h$ when conducting tests to assess the hygienic quality of furniture.

There is a clear need to establish standards for testing furniture under conditions that reflect actual use, rather than relying on those currently applied to wood-based panels. The latter do not ensure adequate indoor air quality in accordance with the Regulation

of the Minister of Health and Social Care on the permissible concentrations and intensities of substances harmful to health emitted by building materials, appliances, and furnishings in spaces intended for human occupancy.

KEYWORDS: furniture, formaldehyde emission, VOC emission

Enhancing Tree Sapling Growth under Drought Stress Conditions Using Biostimulants and Mulching

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ABSTRACT

Drought frequency and water scarcity are intensifying with ongoing climate change, creating a mounting risk for European forests and nursery production. Early life stages are especially vulnerable, and practical mitigation measures are needed that can be deployed at operational scale. Mulching can conserve soil moisture and buffer temperature, while biostimulants may enhance physiological stress tolerance. However, evidence for their individual and combined effects in nursery grown forest tree saplings under drought remains limited.

We conducted a pot experiment in the Sosny forest nursery (Bogdaniec Forest District, Szczecin RDLP) using one year old saplings of Scots pine Pinus sylvestris and sessile oak Quercus petraea. Saplings were grown in 7.5 L black plastic pots filled with a peat and sand substrate and were subjected to controlled drought. Four treatments were applied: a commercial biostimulant Kaishi, Scots pine wood chip mulching, their combination, and an untreated control. Growth responses were monitored through the growing season, including survival, height, root collar diameter, and biomass allocation, and analysed to detect treatment effects.

All P. sylvestris saplings survived; in Q. petraea one sapling died and several defoliated, indicating greater sensitivity to experimental drought. Treatment responses were species specific. In P. sylvestris, effects were limited overall; the combined Biostimulant plus Mulching treatment produced a significant increase in root collar diameter relative to Control and Mulching alone. In Q. petraea, the combined treatment generated the largest gains, significantly increasing root mass and root collar diameter, whereas biostimulant alone did not improve growth compared to Control. Mulching alone yielded modest but favorable effects, particularly for root collar diameter. These patterns support a moisture conservation benefit from mulching and a complementary effect of the biostimulant when both are applied together.

The synergistic application of mulching with a biostimulant enhanced sapling performance under drought, most clearly in sessile oak and to a lesser extent in Scots pine. The results support pairing organic mulches that conserve soil water with targeted biostimulants to improve drought resilience and early growth in nursery stock. Given the projected increase in drought frequency and severity, integrating these low cost, scalable practices could help

maintain planting quality and improve establishment in restoration and reforestation programs. Further work should test dosage, timing, and mulch types across soil conditions and longer timeframes to optimize outcomes.

KEYWORDS: drought stress, biostimulant, mulching, *Pinus sylvestris*, *Quercus petraea*

Evaluation of Changes in Physical Properties of Spruce Wood Due to High Temperatures

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ABSTRACT

Physicochemical tests using a Shimadzu machine were carried out on approx.

60-year-old spruce wood from a fire-damaged area (Kielce Forest District Kielce). Charred spruce logs (approx. 1 m) from the root collar area were analysed, and samples were prepared for bending strength (20x20x300 mm) and compression and density (20x20x30 mm) tests.

The aim of the study was to determine the suitability of post-fire wood for construction applications. Healthy spruce wood has an average longitudinal compressive strength of approx. 43 MPa and a static bending strength of 66 MPa. Samples of wood obtained from fires showed that the compressive strength along the grain was 39.4% higher and the static bending strength was 10% higher compared to data from the literature. The hardness of the tested wood was 18% lower. Laboratory analyses showed that spruce wood obtained from post-fire areas has suitable physical and mechanical properties, which allows it to be used as a construction material. The strength parameters meet the standards for construction timber ISO PN-EN 338:2016-06. The density of the tested raw material ranged from 348 to 451 kg/m^3, which corresponds to the characteristic density of structural timber in strength class C24. All strength parameters meet the requirements of the standards, including bending (class C40 and higher) and compression (for all classes).

Therefore, this wood can be reused in the construction industry.

KEYWORDS: forest fire, spruce wood, mechanical properties of wood

Assessment of Changes in Selected Mechanical Properties of Ash (*Fraxinus excelsior* L.) and Oak (*Quercus robur* L.) Wood in response to Groundwater level fluctuations

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ABSTRACT

The aim of this study was to assess the impact of elevated groundwater levels – caused by periodic flooding—on selected physical and mechanical properties of heartwood from ash (*Fraxinus excelsior* L.) and oak (*Quercus robur* L.). The research material was harvested from periodically inundated and reference (non-flooded) forest sites within the Gołębowiec Forest District (Strzelce Forest Division, eastern Poland). After seasoning and laboratory processing, samples were subjected to density and moisture content analysis, as well as strength testing in static bending, compression parallel to the grain, and Brinell hardness. Oak wood from inundated areas demonstrated superior mechanical performance, reaching average values of 142.1 MPa in bending strength, 70.5 MPa in compressive strength, and 70.7 HB in hardness, with a bulk density of 700 kg/m^3. In contrast, oak from the reference sites recorded lower values: 99.7 MPa, 60.9 MPa, 57.7 HB, and 680 kg/m^3, respectively. In the case of ash wood, the influence of site hydrology was less pronounced; bending strength remained similar (142.2 MPa for flooded sites vs. 135.2 MPa for reference), while density was slightly higher in flooded-origin samples (740 vs. 700 kg/m^3). These findings suggest that fluctuating water regimes may affect the structural quality of oak more significantly than ash.

KEYWORDS: forest flooding , wood hardness, compressive and bending strength of wood

Biomass from Sorghum Leaves and Stems as PLA-Composites Filler

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ABSTRACT

In response to increasing environmental concerns and the urgent need for sustainable materials, this study explores the application of lignocellulosic fillers derived from sorghum (Sorghum bicolor L. Moench) biomass (divided into stems and leaves) as reinforcements in biodegradable polylactic acid (PLA) composites. The primary objective was to evaluate how the type of filler and its content (5, 10, and 15 wt.%) influence the physicochemical properties of the developed composites. The sorghum biomass was manually harvested in the Greater Poland region, after which it was separated into stems and leaves, dried (at 22 °C in a ventilated room to simulate ambient storage, minimize production costs, and assess real-world impacts on drying time, degradation, and product quality), milled, and fractionated. For composite preparation, only particles smaller than 0.25 mm were used to ensure proper mixing and homogeneity od samples.

The composites were prepared using a combination of extrusion and injection moulding techniques. Characterization of prepared samples involved thermogravimetric analysis (TGA), tensile and impact strength testing, optical microscopy, and scanning electron microscopy (SEM) to analyze microstructure and interfacial behavior.

The results demonstrated that composites reinforced with sorghum stem fillers achieved a more favorable balance between stiffness and ductility compared to those with leaf fillers. Stem-based composites also exhibited better particle dispersion and improved interfacial adhesion with the PLA matrix, which contributed to enhanced mechanical performance. In contrast, leaf-based fillers resulted in composites with higher stiffness but also increased brittleness and a tendency to form agglomerates, likely due to their morphology and chemical composition.

All of the prepared composites variants showed reduced impact strength and thermal stability relative to neat PLA. However, the degree of reduction varied depending on both the type and amount of filler used. These findings underline the importance of optimizing filler characteristics to maintain desirable material properties.

Overall, the study highlights the potential of using sorghum stems as a cost-effective, renewable, and biodegradable reinforcement in PLA composites. This aligns well with current goals in circular economy and bioeconomy frameworks, emphasizing resource efficiency, waste minimization, and the development of environmentally friendly materials.

KEYWORDS: composites, sorghum, polylactide

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Automated Terrain Roughness Assessment Using Remotely Sensed Data

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ABSTRACT

In forestry operations, understanding terrain conditions is essential for improving operational planning, minimizing environmental impact, and managing costs. Terrain trafficability, the capacity of the land to support machinery movement, depends not only on the soil's bearing capacity but also on terrain roughness, defined by the presence of obstacles such as rocks, stumps, and depressions. Traditionally, roughness classification in forest Terrain Classification Systems (TCS) has relied on manual visual assessments, which are labor-intensive, subjective, and limited in spatial resolution. This study presents an automated, high-resolution approach to terrain roughness estimation using UAV (drone) imagery and deep learning techniques.

The method was tested in a post-fire area of the Jonkershoek timber plantation in South Africa, characterized by sparse vegetation and varied surface features. High-resolution drone images were processed to generate dense point clouds and orthomosaics. A deep learning segmentation model (SAM with ViT_H architecture) was fine-tuned to detect and segment terrain obstacles with 95.6% accuracy. These segmented features were used to classify point cloud data and estimate obstacle height and distribution. Manual field measurements (n = 90) were used to validate segmentation outputs, resulting in a height estimation RMSE of 2.62 cm and MRE of 11.4%.

The terrain was divided into 3 × 3 m grid cells, with roughness classes assigned based on obstacle frequency and height following modified TCS classification rules. The resulting roughness maps captured fine-scale heterogeneity and responded sensitively to artificial changes in obstacle density and size. Comparative analysis using traditional terrain metrics – Terrain Roughness Index (TRI), Area Ratio (AR), and Vector Roughness Measure (VRM) – showed moderate correlations with TRI ($\rho = 0.63$) and AR ($\rho = 0.67$), while VRM had a weaker relationship ($\rho = 0.24$), indicating that our method aligns well with established descriptors of surface complexity.

This approach enhances terrain classification accuracy and efficiency, offering a cost-effective alternative to LiDAR in open or post-disturbance areas. However, while promising, the method was tested in a clear, post-fire site. Applying it in complex, forested environments will require further development and integration of additional data sources like LiDAR.

KEYWORDS: terrain roughness, trafficability, UAV, aerial survey

Influence of Adhesives on Bonding Strength and Surface Morphology in PCM-Treated Beech Plywood for Thermal Energy Storage

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ABSTRACT

In the European Union, heating and cooling demands in buildings account for approximately 50% of the total final energy consumption, driving policy and research toward energy-efficient materials and solutions. Integrating phase-change materials (PCMs) into wood-based panels offers a promising approach for thermal energy storage (TES), thereby for example shifting energy demand from peak loads to off-peak times, reducing temperature fluctuations in buildings. Beech wood veneers provide a porous scaffold for PCM incorporation. This study investigates how different adhesives affect PCM-treated veneers, with focus on bonding quality, thermal storage capacity, and leakage resistance.

Five-layer crosswise beech plywood panels were manufactured using three adhesive types: polyurethane (PUR), polyvinyl acetate (PVAc), and a tannin-based adhesive. Veneers were impregnated with a capric acid–stearic acid eutectic PCM mixture (melting point around 28 °C), applied either to only the middle layer, to three layers, or not at all (untreated reference). Thermal characterization, leakage behavior, mechanical properties, surface morphology, and water contact angles with roughness were assessed to better understand the influence of PCM on the adhesion of each wood adhesive.

Panels with three PCM-impregnated layers achieved the highest latent heat capacity (~45 J/g), corresponding to ~190 Wh/m^2 of energy storage, while reference panels reached ~78 Wh/m^2. Thermal cycling tests further demonstrated that PCM integration delayed both heating and cooling phases, confirming the effective utilization of latent heat. For example, cooling times increased from ~3 h for reference panels to over 6 h for panels with three PCM layers

Mechanical performance was strongly influenced by adhesive type. PUR consistently exhibited the highest bending strength values (up to ~96 N/mm^2) and stable behavior across temperature ranges, while PVAc showed a reduction in strength when combined with PCM, dropping to as low as ~18 N/mm^2 for three impregnated layers.

PCM-impregnated plywood can substantially increase thermal energy storage, presenting a viable route for reducing building heating and cooling energy needs. PUR and PVAc adhesives provided stronger bonding performance compared to tannin-based adhesive; however, the tannin-based adhesive exhibited more consistent performance under both room temperature conditions and at temperatures above the PCM melting point. Despite these advantages, none of the adhesives were able to fully prevent PCM leakage, Future research should therefore focus on developing improved barrier strategies or advanced adhesive formulations to balance leakage resistance, mechanical durability, and thermal performance.

KEYWORDS: adhesion**,** bio-based composites, building materials, latent heat storage, surface analysis, thermal regulation

Beyond Traditional Coatings: Toward Engineered Living Materials for Architecture

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ABSTRACT

Architectural coatings enhance the functional and aesthetic durability of building materials by protecting surfaces from heat, UV radiation, and moisture. Increasing environmental concerns are driving the development of sustainable alternatives to conventional surface treatments, which often rely on environmentally harmful components. A promising strategy involves the biomimetic design of coatings that imitate the protective mechanisms observed in nature.

The ARCHI-SKIN project follows this bioinspired approach to develop engineered living materials (ELMs) for architectural applications. ELMs incorporate living cells (e.g., microorganisms) as active components, either embedded within a matrix or forming part of a living scaffold, to provide self-sustaining functionality. In this project, we explore coatings based on living fungal biofilms as active protective systems for various substrates, including wood, concrete, brick, stone, metal, and plastics. Fungi, particularly *Aureobasidium pullulans*, are well suited for this purpose due to their ability to grow on surfaces, secrete extracellular enzymes, and form robust biofilms.

The project aims to create a prototype microbial coating featuring controlled and optimized fungal biofilm formation to protect surfaces, extend service life, and introduce advanced functions such as self-healing and bioremediation. By integrating living systems into coating technologies, ARCHI-SKIN seeks to expand the concept of traditional materials toward adaptive, responsive, and environmentally integrated living architectural coatings. This contribution presents the project's objectives, challenges, and first results.

KEYWORDS: Engineered Living Materials, bioinspired coatings, fungal biofilm, sustainable building materials, alternative materials protection

ACKNOWLEDGMENTS

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Comparative Life Cycle Assessment for Winching Timber with Mini Forestry Crawler and Cable Tractor

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ABSTRACT

In logging operations, pre-winching is an important work step in semi-mechanized timber harvesting methods. Due to the increasing proportion of hardwood and the growing importance of soil protection such methods will be used more frequently in the future, often in combination with extended skid trail distances. In order to meet climate protection targets, it is also important to determine and, where possible, reduce greenhouse gas emissions in harvesting operations and especially during pre-winching. For this purpose, a life cycle assessment was conducted using the Umberto software, to compare pre-winching with a Suffel Smart Skidder mini forestry crawler and the conventional forwarding operations using a Welte W130 cable tractor. In addition to fuel consumption when operating the machine, the emissions for maintenance and the manufacture and delivery of the machine were also taken into account.

For the mini forestry crawler, the life cycle inventory results in a GWP_{100} of 6.857 kg CO_2-eq per machine working hour, of which 13.83% is attributable to the manufacturing of the machine and 86.17% to the operation of the machine. For the cable tractor, the life cycle inventory results in a GWP_{100} of 33.290 kg CO_2-eq per machine working hour, of which 8.46% is attributable to the manufacturing of the machine and 91.54% to the operation of the machine.

In a second step, the emissions per machine working hour were transformed to emissions per solid cubic meter (m^3s) using three different practical examples as scenarios, assuming different productivities, travel distances and felling volumes. The resulting GWP_{100} varies between 0.876 and 3.921 kg CO_2-eq/m^3s for the mini forestry crawler and between 3.365 and 10.998 kg CO_2-eq/m^3s for the cable tractor. It can be shown that the GWP_{100} is especially influenced by the respective productivity, fuel consumption, travel distance and the felling volume.

In total, the emissions per machine working hour as well as the GWP_{100} per m^3s are higher for the cable tractor compared to the mini forestry crawler.

In order to reduce greenhouse gas emissions, long travels to areas with low felling volumes should be avoided, e.g. by forming felling blocks.

KEYWORDS: GHG-emissions, semi-mechanized timber harvesting, life cycle assessment, carbon footprint, productivity

Lignin-Based, Formaldehyde-Free Plywood Adhesives

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ABSTRACT

Phenol–formaldehyde (PF) resins are among the oldest synthetic thermosetting polymers. Due to their outstanding chemical and mechanical performance, such as high water resistance, dimensional and thermal stability, chemical resistance, and electrical insulating properties, they have been widely employed as acid-resistant coatings, fiber-reinforced composites, electrical laminates, and binders in the industrial manufacture of exterior plywood, oriented strand board (OSB), and particleboard. However, the toxicity of formaldehyde (classified as a Group 1 carcinogen by the International Agency for Research on Cancer, IARC) and the dependence on phenol derived from non-renewable petrochemical resources have stimulated extensive research into human- and environmentally benign alternatives to petroleum-based materials in PF resins. The substitution of phenol and formaldehyde with lignin and glyoxal – two renewable and significantly less toxic compounds, represents a promising approach toward the development of more sustainable wood adhesives and a reduction in the overall carbon footprint of wood-based materials.

The present study focuses on the synthesis and optimization of a formaldehyde-free resole resin designed as a base for adhesive formulations for plywood production. The process parameters were optimized to the lower reactivity of lignin relative to phenol. As a result, a lignin–glyoxal resin was successfully developed, exhibiting physicochemical properties comparable to those of conventional phenol–formaldehyde resins. The synthesized resins showed free glyoxal content below 0.05% and demonstrated significantly enhanced stability of key parameters during storage.

The lignin-glyoxal resins were subsequently employed in the preparation of adhesive formulations for the production of wood-based materials, such as plywood. The resulting adhesives exhibited excellent mechanical and bonding performance, comparable to or exceeding that of conventional phenolic adhesives, while offering a considerably lower environmental impact and improved sustainability profile.

KEYWORDS: lignin, plywood, formaldehyde-free adhesives

Forest Loss Ramifications in the Ashanti Region – Ghana

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ABSTRACT

Forest Loss (Degradation and Deforestation) in the Ashanti Region of Ghana has become a significant environmental concern, with far-reaching implications for biodiversity, climate stability, and local livelihoods. This study explores the extent, causes, and consequences of forest loss in the region, highlighting both natural and human-induced factors such as agricultural expansion, illegal logging, mining activities, and urbanization. The Ashanti Region, known for its rich forest reserves and ecological diversity, is experiencing rapid forest degradation, leading to soil erosion, loss of wildlife habitats, and changes in micro-climatic conditions. Through the analysis of satellite imagery (1986 – 2025), field observations, and stakeholder interviews, this research identifies critical hotspots of deforestation and evaluates current mitigation efforts by governmental and non-governmental organizations. The study concludes that despite existing policies and conservation initiatives, enforcement remains weak, and community participation is limited. It recommends integrated forest management strategies that involve local communities, stricter regulation of logging practices, and promotion of sustainable land use practices to curb deforestation and promote environmental sustainability in the Ashanti Region.

KEYWORDS: forest degradation, deforestation, urbanization, anthropogenic factors, satellite imagery

Non-Timber Forest Products (NTFPS) as a Sustainable Alternative to Timber Extraction to Mitigate Deforestation in Ghana

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ABSTRACT

Non-Timber Forest Products (NTFPs) offer a sustainable alternative to timber extraction and have emerged as a promising strategy to mitigate deforestation in Ghana. This study examines how the harvesting and commercialization of NTFPs – such as fruits, nuts, medicinal plants, honey, rattan, and mushrooms – can reduce pressure on forest ecosystems while enhancing rural livelihoods. In Ghana, particularly in forest-dependent regions such as Ashanti, Western, and Brong-Ahafo, NTFPs provide economic incentives for communities to preserve rather than destroy forests. The research analyzes data from community-based forest management programs, case studies, and interviews with local stakeholders to assess the socio-economic benefits and conservation outcomes of NTFP initiatives. Findings reveal that when communities are granted access rights and supported through training, markets, and policy frameworks, NTFPs can promote forest conservation, biodiversity protection, and poverty reduction. However, challenges such as overharvesting, limited market access, and inadequate policy enforcement hinder the full potential of NTFPs. The study concludes by recommending an integrated approach that combines NTFP promotion with forest governance reform, capacity building, and investment in value chains to strengthen NTFPs as a viable tool for mitigating deforestation in Ghana.

KEYWORDS: sustainable forest management, timber extraction, deforestation mitigation, urbanization

Illegal Small-Scale Mining (Galamsey), a Major Driver of Deforestation and Environmental Degradation in the Ashanti Region of Ghana

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ABSTRACT

Galamsey, or illegal small-scale mining, has become a major driver of deforestation and environmental degradation in the Ashanti Region of Ghana. This study explores the direct and indirect impacts of galamsey activities on forest ecosystems, land cover, and biodiversity in the region. The Ashanti Region, once characterized by dense tropical forests, is witnessing significant forest loss due to unregulated mining operations that involve the clearing of vegetation, excavation of forest lands, and pollution of water bodies. Using satellite imagery analysis, field surveys, and interviews with local residents and officials, the research identifies key galamsey hotspots and quantifies forest loss over the past two decades. The findings indicate that beyond tree loss, galamsey contributes to soil erosion, habitat destruction, and contamination of natural resources, thereby undermining both environmental sustainability and community livelihoods. The study also reveals gaps in law enforcement, weak institutional coordination, and limited community involvement in forest protection. It concludes that addressing galamsey-related deforestation requires a multifaceted approach, including stricter enforcement of mining laws, alternative livelihood programs, public education, and community-based forest monitoring systems. Without urgent and sustained intervention, the long-term ecological and socio-economic consequences of galamsey could be irreversible for the Ashanti Region and beyond.

KEYWORDS: forest degradation, deforestation, urbanization, anthropogenic factors, satellite imagery

Scots Pine in Timber Grading: Disadvantage and Need for Adjustment

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ABSTRACT

Scots pine (*Pinus sylvestris*) is the dominant coniferous species in Brandenburg and is also widespread in Poland, representing an important regional raw material for structural timber. The currently applicable grading procedures according to DIN and EN standards were historically developed with a focus on spruce (*Picea abies*). Pine is integrated into this spruce-based system without sufficiently considering its species-specific properties. This results in a disadvantage: although pine generally achieves higher strength values, the application of criteria calibrated for spruce leads to a classification that does not adequately reflect its structural potential.

Consequently, pine is underrepresented in the strength classes, which limits its use in timber construction – particularly in higher-value applications.

The investigation was based on the relevant standards for visual and machine strength grading, in particular DIN 4074 for visual grading, DIN EN 1912 for the assignment of grading classes to European strength classes, and DIN EN 338 and DIN EN 384 for the definition and derivation of characteristic strength values. The analysis examined how the current procedures classify pine and identified where discrepancies arise between the actual strength properties and the normatively assigned classes. The focus was on detecting potential systematic disadvantages for pine and identifying opportunities for a more differentiated treatment of this species.

The evaluation indicates that the current grading and assignment system, oriented towards spruce, can systematically disadvantage pine. Although pine shows higher strength values, this advantage is often not reflected in the normative classification; the resulting strength classes frequently remain at the level of spruce. As a result, a significant part of the structural potential of pine, which is abundantly available in Brandenburg and Poland, is not fully exploited. The findings suggest that the current implementation of the standards does not sufficiently capture species-specific performance profiles.

This discrepancy becomes particularly evident when looking at strength data obtained for Scots pine from the Silesian Forestry Region (Poland). Visual grading according to PN-D-94021 combined with testing and evaluation according to EN 408 and EN 384 resulted in the characteristic values and strength class assignments. These results demonstrate that

pine, depending on the visual grade, can reach strength classes up to C35, which substantially exceeds the levels typically assigned in practice (e.g. C24).

Against this background, it is proposed to develop a species-specific grading or strength class approach for pine – for example, through a supplementary assignment anchored in DIN EN 1912 for defined provenances (Brandenburg, Poland) as well as an appropriate calibration of the relevant parameters in DIN 4074-1, EN 384, and EN 338. The data underline that Scots pine can achieve strength classes well above the standard assignment (C24), reaching up to C35 under defined conditions. Such findings demonstrate the untapped structural potential of pine and highlight the importance of adapting the normative framework accordingly. This could increase resource efficiency, strengthen regional value creation, and substantially enhance the attractiveness of pine in modern timber construction.

KEYWORDS: pine, spruce, strength grading, structural timber

Impact of Bark Thickness on Timber Volume Calculation in Harvester Software

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ABSTRACT

Accuracy of volume calculation provided by a harvester's computer depends on the calibration. However, bark thickness is a crucial factor when obtaining log volume under bark. For that reason, proper bark thickness is a basic parameter when volume calculation is provided, but it is not natural bark thickness due to harvester knives shavings. Therefore, it is important to apply for volume formula bark deduction, which is not natural bark thickness, but remaining bark thickness, after shaving by harvester head knives.

The aim of this study was to find out how thick is remained bark on 4.0 m long logs after processing, to know how many cm must be deducted to obtain log volume under bark without errors. The study was carried out on Scots Pine (*Pinus Sylvestris* L.), 4.0 m long logs, from bottom and middle tree parts. The range of mid diameters of measured logs was ca. 24-28 cm for bottom logs and 21-23 cm for middle logs.

Calculation of log volume by harvester computer (Timbermatic H16) was based on diameter measurements over bark (harvester John Deere 1270G, harvester head John Deere H415) every one cm, and finally mean diameter was used for volume calculation. Bark deduction was based on data installed in the computer, which was bark thickness related to diameter size, but natural thickness of bark without shavings due to harvester knives.

After processing, diameters and bark thickness on logs were measured every 20 cm along three strips where bark was shaved and along three strips where bark was not shaved. After measurements, difference in bark thickness was calculated as well as log volume under bark using Huber formula. Finally, volume from harvester computer was taken and compared with volume obtained from manual measurements.

Bark thickness after shavings was smaller by 40.30% in average on bottom logs and smaller by 35.83% on middle logs. Log volume from harvester computer was smaller by 9.04% in average for bottom logs, and lower by 2.53% from middle logs. The conclusion is that to obtain more accurate volume of logs under bark, reduction of natural bark thickness should be used due to fact, that harvester head knives reduce bark on logs during processing.

KEYWORDS: harvester, Scots Pine, log volume calculation, bark thickness, bark reduction

Spatial Convergence of Timber Prices in the RDSF Katowice: An Assessment of Timber Market Integration Processes

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ABSTRACT

Price convergence in wood raw material markets is a key aspect of assessing market functioning under conditions of highly centralized supply and regionally differentiated demand. In Poland, this issue is shaped by the specific structure of the timber market, where the State Forests act as the dominant supplier, creating a regulated system sensitive to institutional and organizational arrangements.

The aim of this study is to evaluate the presence of β- and σ-convergence for major timber assortments sold by forest districts of the Regional Directorate of the State Forests in Katowice (RDSF Katowice) over the period 2005–2024, and to interpret the findings in the context of the sales policies implemented by the State Forests. The analysis is based on quarterly data for four assortments: oak W0, pine W0, oak S2A, and pine S2A. β-convergence was assessed through the relationship between the initial price level and subsequent price dynamics, while σ-convergence was examined by tracking changes in price dispersion across units over time. All models were estimated in R 4.5.2.

The β-convergence results indicate a clear and statistically significant tendency toward the equalization of price dynamics across all assortments. The strongest convergence was identified for oak W0 ($\beta = -0.951$; $R^2 = 0.859$), whereas the weakest occurred for pine S2A ($\beta = -0.677$; $R^2 = 0.710$). Forest districts with lower initial prices exhibited faster price growth, resulting in a gradual alignment of price dynamics at the regional level. These outcomes can be interpreted as evidence of standardized sales rules, stable auction procedures, and periodically updated allocation policies that contribute to stabilizing market behavior.

In contrast, σ-convergence analysis did not reveal any statistically significant decline in price dispersion. The persistence of regional differences is likely driven by structural factors such as variation in harvesting and extraction costs, the local availability of industrial buyers, differences in timber quality, and site-specific production conditions. These factors remain resistant to full equalization through centrally managed sales policies.

The combined interpretation of both approaches suggests that the State Forests reinforce β-convergence by stabilizing the rate of price change, yet do not eliminate persistent local determinants affecting absolute price levels, which limits the occurrence of σ-convergence.

Consequently, the timber market within RDSF Katowice appears only partially integrated: while price dynamics converge, regional diversity in absolute price levels persists.

KEYWORDS: timber prices, forest sector economics, market regulation

The Influence of Liquid Wood on the Aesthetic Properties of Acrylic Lacquer Coatings Subjected to UV+IR Aging

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ABSTRACT

In response to the growing demand for sustainable and innovative surface finishing materials, as well as increasingly stringent regulations on volatile organic compound (VOC) emissions, ecological surface treatment technologies are gaining importance in the wood and furniture industries. Waterborne lacquer products represent an attractive alternative to traditional solvent-based systems. However, their limited resistance to mechanical and environmental factors remains a significant challenge. To improve these properties, interest is increasing in renewable additives such as nanocellulose and liquid wood, which exhibit beneficial functional characteristics. Liquid wood is a promising, though still not very popular, component of lacquer products. Therefore, further research in this area is necessary.

The aim of this study was to evaluate the influence of two variants of liquid wood, added at concentrations of 1, 3 and 5% (based on the dry mass of the coating), on the aesthetic and decorative features of acrylic lacquer coatings. The lacquer was applied in three layers, each 100 µm thick, onto birch- and pine-veneered plywood. The analyses focused on assessing appearance, gloss (using a photoelectric method, PICO GLOSS 503), and color (using a DT 145 colorimeter). Measurements were taken before aging and after exposure to UV + IR radiation.

The results showed that all tested coatings showed high decorative features without visible defects and had a semi-matt gloss. Although gloss values changed under the influence of aging, this did not affect the verbal assessment, which remained consistent (semi-matt). Color stability depended on the type of liquid wood additive used, its concentration, and the substrate. The results confirm the potential use of liquid wood as an ecological modifier of lacquer product properties.

KEYWORDS: liquid wood, acrylic coatings, birch, pine, aging resistance, gloss, color

Consequences of Repeated Soaking-Drying Cycles on Swelling of Ayous Wood Termotreated

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ABSTRACT

Wood is an interesting material from a sustainability perspective. It is aesthetically pleasing and, from a structural point of view, it is lightweight yet strong. It is widely acknowledged that the material is prone to degradation, particularly when exposed to outdoor conditions. The enhancement of the durability of wood through thermal modification has gained significant popularity, particularly in scenarios where the utilisation of preservatives is discouraged. The main effect of the modification cycle pertains to the partial degradation of the cell wall compounds, and the degradation intensity depends on the modification temperatura cycle and exposure duration. Furthermore, high-temperature treatment induces a colour change throughout the entire thickness of the material, a quality that is highly regarded. After treatment, the wood exhibits reduced hygroscopicity due to a decrease in the number of bonding sites available for water within the cell wall. This also implies greater dimensional stability in response to changes in moisture content than is observed in non-heat-treated wood. The study presented here aims to evaluate the long-term stability of this valuable property, which is particularly useful in outdoor environments. This study examines some properties of both untreated (UT) and thermally modified ayous (*Triplochiton scleroxylon* K. Schum) wood. The thermal modification of the planks was performed using an industrial system with a mild initial vacuum in an autoclave Maspell WDE Model TVS 6000, applying treatment temperatures of 190°C and 215°C (TM 190 and TM215) for three hours respectively. This research explores the behaviour of untreated (UT) and thermally modified ayous wood (TM190 and TM215) when subjected to repeated soaking-drying cycles. The investigation focused on the determination of some physical properties at each soaking-drying cycle, including radial, tangential, volumetric swelling. To collect the data, the ISO reference standards were adopted. Thermal modification resulted in a reduction in swelling for both TM190 and TM215 compared to the untreated samples. However, after repeated application of soaking and drying cycles, the control samples demonstrated a decrease in swelling, while the thermally modified samples exhibited an increase. The findings acquired provide a more profound comprehension of the effects of thermal modification on wood and its behaviour under repeated soaking-drying cycles, which is of significant importance for its utilisation in exterior façades and flooring.

KEYWORDS: *Triplochiton scleroxylon* K. Schum, heat treatment, hygroscopicity, dimensional stability, wetting-drying cycles

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Detection of Wood Preservatives and Cleaning of the Wood Surfaces for Further Use

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ABSTRACT

In Europe, a large amount of waste wood is thermally recycled because it is suspected of being contaminated with old, now-banned wood preservatives. However, rapid detection could determine whether the wood can be reused because it is uncontaminated or has been cleaned after surface cleaning.

In various national and European projects, roof beams from old buildings are being mechanically and chemically examined for their suitability for reuse. The hope is to reuse untreated, thick wooden beams from roof demolitions as beams. Surface-contaminated beams (painted or dipped) must also be identified using rapid, on-site detection techniques. These beams, too, are to be reused after surface decontamination.

From various buildings dating from 1900 to 1980, numerous beams were removed, each as long as possible. The length and quantity of the beams are important because they are also subjected to mechanical testing for strength. More important, however, is the use of rapid detection methods that make it possible to detect many of the organic and inorganic wood preservatives, as well as heavy metals, for surface decontamination.

Currently, the beams are being scanned on-site using X-ray fluorescence (XRF) analysis for numerous elements that indicate the presence of various wood preservatives. Further tests are being conducted in the laboratory using near-infrared spectroscopy (NIR) and the environmental scanning electron microscope (ESEM).

However, Schumann-Analytics has developed a detection system that can detect, particularly organic wood preservatives, very sensitively in just a few minutes.

This drift-tube ion mobility spectrometer (DTIMS) is so sensitive that even a few ppm of various wood preservatives can be detected.

With the combination of XRF, which can primarily detect heavy metal elements and many inorganic wood preservatives, and the newly developed Schumann system (DTIMS), which is very sensitive at detecting organic substances, many beams can already be sorted on-site.

One focus is on the detection of lindane, pentachlorophenol, polycyclic aromatic hydrocarbons, lead, and cadmium.

After identifying wood preservatives, various projects also test dry and wet cleaning methods for reuse of the wooden beams. Dry cleaning focuses on nail removal, while wet cleaning primarily deals with wastewater and the residues that need to be cleaned.

KEYWORDS: wood preservatives, Lindane, PCP, PAH, decontamination

Analysis of Working Time Utilization in Selected Upholstery Processes

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ABSTRACT

The decline in competitiveness of Polish furniture companies on global markets requires immediate action. Rising production costs and a shortage of skilled labor make rational resource management, investment, and modernization crucial.

The upholstered furniture industry in Poland still relies heavily on manual labor, and the level of automation remains far from Industry 4.0 standards. Consequently, maintaining productivity and competitiveness depends on the organization and efficiency of human work.

In order for investments to bring expected results, it is necessary to collect and analyze data indicating critical areas, bottlenecks, and factors slowing production. One important tool is the working time utilization index, which measures the ratio of execution time to working time. This index allows assessing the degree of work efficiency at individual workstations. It is particularly important in operations with a high share of manual tasks, helping to identify areas requiring reorganization or mechanization.

The aim of this study was to determine the value of the working time utilization index for selected upholstery workstations. The analysis of the results obtained provides a basis for planning investment activities.

The research was conducted in a Polish company specializing in the production of upholstered furniture. Two workstations related to the preparation of the frame were selected from the entire technological process: the workstation for assembling structural components and the workstation for covering them with wadding and foam. They were chosen due to the low degree of mechanization.

Working time measurements were carried out during the manufacture of standard products. The working times of three employees with comparable experience were recorded and the results were then averaged. The collected data was used to calculate the efficiency indicators for the positions under review.

An analysis showed that the actual use of working time by employees is relatively low. This is mainly due to the need to organize the workstation and prepare the elements and components necessary for further work. Particularly in the gluing position, as much as

25% of working time is spent on auxiliary activities, such as transporting racks or moving foam packages, which significantly reduces efficiency.

The values obtained indicate that the production process requires investment. The results indicate significant opportunities to improve workplace organization. First and foremost, it is worth considering improving working conditions by using additional equipment. In terms of production growth, it will be crucial to implement computerization in process management and control, as well as automation of selected production stations.

The identified problems and potential improvements are the starting point for further research planned in the sewing department.

KEYWORDS: efficiency, upholstered furniture, working time, furniture industry, production time

Reusing Timber from Dismantled Building Structures: A Case Study

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ABSTRACT

Construction and building use in Poland, as in the EU as a whole, accounts for approximately half of all extracted raw materials and approximately half of the primary energy consumed. It is also responsible for over one-third of the waste generated at various stages of the life cycle of buildings. Modern society increasingly understands that reusing materials and entire products at the end of their original life is crucial to meeting the major challenges facing the modern world, such as: an economically viable circular economy, human- and environmentally friendly construction, zero CO2 emissions, and slowing global warming. Thanks to financial support from the Łukasiewicz Research Network Center, a research project, MATRECBUD, was implemented, aimed at finding optimal ways to reuse post-consumer wood and textile materials and products.

From the demolition of an early 20th-century wooden roof structure and ceiling of an old brickyard, support beams with cross-sections ranging from 130x130mm to 240x200mm and 25mm-thick roof decking boards were recovered. The recovered material, 18.9 m^3, was characterized in terms of basic qualitative and dimensional characteristics, mechanical and chemical impurities, and its strength potential was assessed by measuring the dynamic modulus of elasticity using a SYLVATEST TRIO instrument. In subsequent design steps, the following components were produced from the recovered beams with visually determined best quality characteristics: structural elements with a nominal cross-section of 100x50mm, planks with a nominal thickness of 7mm, and slats with a nominal cross-section of about 4x8mm. From the beams with visually determined poor quality characteristics, cut-outs were prepared, which, after being water-soaked using a vacuum-pressure method, were then used for chip cutting. The structural elements were tested for strength and modulus of elasticity using the method in accordance with EN 408:2010+A1:2012. After this test, small samples (without defects) were made from the material and tested for strength and modulus of elasticity using the method in accordance with ISO 13061-3:2014, and for compressive strength along the grain using the method in accordance with ISO 13061-17:2017.

The recovered beams were characterized by a large number of sockets, holes, and tenons from carpentry joints, as well as mechanical damage incurred both during the building's use and demolition. Numerous, often deeply embedded, metal fasteners, difficult to spot and remove, made sawing the beams and planks difficult. A total of 2.5 kg of nails and other

metal foreign bodies were removed from the 7.9 m^3 beams, and 1.9 kg of nails and 200 g of roofing felt remnants from just 0.6 m^3 of roofing boards. The number and size of traces of fungal decay and/or insect feeding (biological corrosion) were assessed as relatively small, indicating the good quality of the building's construction and the care taken by its users. Chemical tests did not indicate significant contamination with any wood preservative residues. For example, no traces of arsenic were detected, and the chromium content in any sample did not exceed 1 mg/kg. No PCP or lindane residues were detected. Dynamic modulus of elasticity values varied widely, with a mean value of 3952 N/mm^2 and a standard deviation of 1086 N/mm^2, and only 18% of the tested beams were confirmed as potentially having strength class C16 or higher. The average bending strength of the manufactured structural elements with a cross-section of 50x100 mm was 37.1 N/mm^2, and their modulus of elasticity was 10.4 GPa, indicating the possibility of producing structural timber of class C24 or even higher from demolition wood. The average bending strength of small samples (samples without defects) was 76.4 N/mm^2 with a coefficient of variation of 23.7%.

A large-scale study of the suitability of wood from the demolition of a century-old wooden structure for further use confirmed the validity of this approach, but also the need to consider a number of technically demanding and labor-intensive activities that could significantly reduce the economic efficiency of such operations. The technical condition of most of the recovered beams and planks allowed for direct use in structures, after cleaning and possibly preventative heat treatment, where retaining the original characteristics of the post-consumer wood provides added visual value. It is also possible to produce high-quality structural elements with at least good strength parameters, and with further processing, a range of other useful products, such as solid wood sandwich panels, slatted beams, and structural and insulating wood-based panels.

Keywords: structural timber, post-consumer timber management, wood strength

Systematic Literature Review on Forest Exposure to Wind Damage

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ABSTRACT

Over the last two decades, there has been an increased interest in establishing indices that expose forest trees to wind damage among forestry practitioners working and operating across various disciplines. This study aims to provide a comprehensive state-of-the-art review of forest exposure to wind damage. Although numerous researchers have conducted extensive research on wind damage, knowledge of the predictors that expose forest trees to wind damage remains insufficiently explored. A systematic review [PRISMA] focusing on scientific journals published in English in fields such as engineering, agriculture, computer science, meteorology, forestry, environment, and geography was utilised. Grey literature included theses, conference abstracts, and dissertations, while eligible publications were published from selected territories between January 2008 and March 2024. Exclusion criteria barred grey literature, including retracted publications, pre-print reports, unpublished manuscripts, and reports from non-governmental organizations. Search strategies with terms such as wind damage, wind disturbance, windthrow, and machine learning were used across all electronic databases, including Google Scholar, Web of Science, ProQuest Central, Scopus, and Springer Nature. With 80 studies identified, 67 papers met the inclusion criteria for review. Findings identified wind speed, precipitation, climate change, topography, tree species composition, soil, stand structures, gaps and thinning, spacing, and competition as significant predictors of forest exposure to wind damage. Additionally, machine learning models emerged as suitable tools for modelling and forecasting wind damage. The review's implications indicate the need to embrace adaptive forest management practices to enhance forest sustainability, minimise wind damage, and proliferate post-disturbance restorations.

KEYWORDS: wind damage, windthrow, forest exposure, machine learning, forest management

Micro- and Nanostructure as a Determinant of Bio-Based Polyurethane–Wood Composite Performance

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ABSTRACT

Interactions between phases of composites on the micro- and nanoscale are a key parameter which determines the final properties of materials. It is especially important for polyurethane–wood composites (PU-WCs), whose structure can be easily modified with the addition of bio-based components, especially bio-polyols (BP). To this date, a detailed understanding of interfacial interactions in PU-WCs is still limited and needs further expansion. A thorough analysis of the structure-property relationships will allow for a complete understanding of the interactions within the material and enable more accurate design of the structure and properties of the PU-WCs.

In this study, PU–WC were manufactured using a one-step method based on a two-component system and modified by the addition of BPs synthesised via biomass liquefaction. The mechanical properties of bio-based PU-WCs were tested by a three-point bending test, Shore D hardness and Charpy impact tests. Furthermore, thermal properties were examined by dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA). The structure of PU-WCs was determined using atomic force microscopy (AFM) and scanning electron microscopy (SEM). Additionally, PeakForce Quantitative Nanomechanical Property Mapping (PeakForce QNM) was conducted to investigate the nanomechanical properties of PU-WCs. The results of these studies were compiled to determine the influence of the supramolecular structure on PU-WC performance.

An addition of BPs to PU-WCs reduces environmental impact but modifies interaction mechanisms on the nano- and micro-scale. Indicated interactions have a significant impact on the final material properties. Interphase adhesion strongly depends on the amount of BP. The interphase thickness, which defines the intensity of interactions, decreases from 441 ± 25 nm to 94 ± 16 nm for PU-WC80%/BP. PeakForce QNM indicated phase separation between existing domains. Indicated the presence of two regions characterised by different adhesion forces. The brighter domains are composed of isocyanate-rich areas of higher rigidity, while the darker ones are polyol-rich phases. At the same time, the flexural modulus decreases from 1750 MPa to 780 MPa for PU-WC 80%/Bio. Moreover, the flexural

strength decreased from 25 MPa to only 9.8 MPa for PU-WC 80% Bio. The observed reduction of indicated parameters is caused by a decrease in crosslinking density caused by the limited reactivity of BP and a corresponding decrease in glass transition temperature (T_g).

Conducted research proved that PU-WCs' performance strongly depends on the designed micro- and nanostructure, which can be easily modified by the addition of bio-based components. BP use allows for the reduction of PU-WCs' environmental impact, but at the same time decreases the most important properties which condition future application of this material. For this reason, the suggested addition of BP is 40% BP, which provides PU-WCs whose properties are comparable to commercially available wood-like materials.

KEYWORDS: microstructure, wood, polyurethane, bio-based polyols

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From Residue to Functional Binder: Advancing the Circularity by Lignin Utilization in Lignocellulosic Panels

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ABSTRACT

Growing environmental awareness and stricter European Union (EU) regulations on harmful formaldehyde emissions have intensified the search for sustainable alternatives to petrochemical-based adhesives in wood-based panel production. Use of conventional resins containing formaldehyde is associated with significant environmental emissions and is potentially harmful to humans. One of the potential solutions to this problem may be the use of lignin, which is a common natural aromatic polymer. Lignin is a by-product of the pulp and paper industry, which has not yet been optimised. Lignin used as a nature-inspired binder can reduce dependence on fossil resources while reducing the global warming potential (GWP) of lignocellulosic panels. The development of lignin valorisation pathways aligns with circular bioeconomy strategies, leading to greener, safer, and more sustainable construction materials in indoor and outdoor applications.

A systematic literature review was performed using Scopus, Springer, ACS, and Wiley databases. To fully explore the topic, the keywords included but were not limited to *lignin, adhesive, binder, formaldehyde, formaldehyde-free, grafting, binderless, wood, particleboard,* and *sustainabl**. Additionally, experimental trials were conducted using hybrid binders composed of lignin and citric acid in lignocellulosic composites. Materials were manufactured by hot pressing at 160–200 °C, for 10–30 min and at a pressure of 3–6 MPa.

The conducted literature review confirmed the significant potential of lignin as a sustainable binder and enabled the identification of various utilisation strategies. Among them, hybrid systems combining lignin with other bio-based compounds, such as organic acids, natural oils, or polysaccharides, appear particularly promising due to their ability to exploit complementary bonding mechanisms. Experimental tests demonstrated the possibility of lignocellulosic composites manufacturing using lignin-based adhesives. The manufactured samples were characterised by flexural strength in the range of 5.70 – 6.39 MPa and maximum deformation of approximately 2%. Materials manufactured using hybrid binders showed slightly higher mechanical parameters than samples containing pure lignin

or citric acid. However, the obtained results remain below the minimal requirements for structural panels, indicating the necessity of further optimisation to improve material homogeneity and strength.

Lignin and lignin-based binders have a significant potential as a substitute for conventional adhesives for lignocellulosic panels. However, current technologies require further improvement to meet the minimal requirements of standards. Future research should focus on combining lignin with other environmentally benign compounds to create synergistic interactions, enhancing mechanical and functional properties. This will allow for the use of lignin bio-binders in commonly used applications in furniture, construction and automotive industries. Additionally, the development of those technologies will support global sustainability goals and strengthen the role of lignin in the bio-based economy.

KEYWORDS: lignin, lignocellulosic panels, binders, adhesives

Cable Yarding Extraction Systems, Some Aspects Related to Environmental Disturbance in Beech Forests

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ABSTRACT

In the context of mountain forests, where ecosystems are often included within protected areas and characterized by high naturalness, low impact extraction techniques are essential for aligning forest operations with the Sustainable Forest Management (SFM) pillars. This study evaluates the long-term effects on soil and regeneration due to the forest operations of high stand even-aged beech forests in Central Italy using cable yarding systems. Two forest parcels of the Leonessa municipality's management plan were considered. Both parcels were used in the same year and underwent the same form of management and sylvicultural treatment, and were monitored ten years after the intervention to assess the residual impacts due to the forest operations. Data were collected through a combination of physical, chemical, and biological soil analyses, alongside regeneration surveys and biodiversity indices. Special attention was paid to the assessment of biodiversity through the analysis of natural regeneration, using indicators such as the Specific Importance Value (SIV), Shannon-Wiener index, and Evenness. While both sites employed also the same extraction system (cable yarding), their post-harvest dynamics diverged, revealing structural and ecological differences. One stand maintained a mature and homogeneous structure with stable regeneration, while the other showed signs of irregular layering and a more diverse species composition in undisturbed areas. Results showed differences between the two sites, also in terms of soil damage. In one case, soil disturbance was concentrated along the cable line corridor, while in the other, unexpected compaction was observed in adjacent areas, due to lateral dragging during log bunching. Edaphic indicators confirmed that the most impacted zones were able to recover key functional parameters within a decade, although variations in QBS-ar suggest that soil biological quality remained sensitive to spatial disturbance patterns. From a silvicultural perspective, regeneration was generally successful, though dominated by *Fagus sylvatica*, with limited representation of associated broadleaves. However, the absence of a final renovation felling affected the vertical development of young trees, delaying the structural transition of the stands. Overall, the observed impacts were mild and spatially heterogeneous, with a recovery of soil functionality within ten years. These

findings confirm the suitability of cable yarding systems for steep-slope harvesting. Further improvements should focus on tailoring interventions to stand-specific conditions and completing silvicultural cycles to ensure long-term sustainability.

KEYWORDS: Sustainable Forest Management, cable yarding, beech, high forest, even-aged

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Cable Yarding Extraction Systems, Logistic and Assessment in a Case Study

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ABSTRACT

In steep-slope forests, aerial extraction systems such as cable yarders offer a good opportunity to balance operational efficiency with reduced soil disturbance. However, their application in Italy remains limited outside Northern regions, partly due to the perception of high costs and the need for dedicated skills. This study presents an Alpine case study where a heavy cable yarder was employed for timber extraction in a Alpine forest dominated by *Picea abies* and *Larix decidua*. The aim was to provide a detailed assessment of productivity, time consumption, and costs, to identify opportunities for improving the efficiency of this harvesting system, and, more broadly, to contribute to provide evidence that could help overcome the skepticism that still limits the use of cable yarders in Central and Southern Italy. A preliminary site surveys were carried out to collect data required for operational planning and design, including terrain morphology, stand structure, and accessibility. Multiple cable lines were installed to adapt the extraction layout to the site's characteristics. The harvesting system adopted followed a Full Tree System (FTS) approach, with motor-manual felling using chainsaws, bunching and extraction via cable yarder, and final processing at the landing site with a processor. Time-motion studies were carried out during the entire harvesting operation to evaluate gross and net productivity, identify bottlenecks in the production cycle, and determine cost structures associated with machinery and labor. The results highlighted that the analyzed operation achieved high productivity levels and competitive hourly costs, confirming the technical and economic viability of heavy cable yarding in Alpine forests. However, the study also revealed opportunities for further optimization, especially by reducing downtime during line changes and improving work coordination. Beyond quantifying performance, this analysis illustrates the relevance of thorough pre-operational planning when applying aerial extraction technologies in challenging terrain. The comparison with similar harvesting systems carried out under different environmental conditions suggests that site-adapted cable yarding logistics are crucial for achieving cost-effective outcomes. These findings contribute to the broader effort to expand the adoption of cable yarders in Italy and other mountainous regions, where they could play a strategic role in sustainable forest operations by enhancing productivity while maintaining environmental safeguards.

KEYWORDS: cable yarder, extraction, work productivity, cost analysis, softwood

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Specific Cutting Work of Reclaimed Wood Beam during Drilling

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ABSTRACT

The escalating demand for sustainable resources within the furniture industry has given rise to a renewed interest in the reuse of wood from dismantled buildings. The utilisation of reclaimed timber has been demonstrated to extend the life cycle of wood, reduce pressure on forests, and support the objectives of a circular economy. The present study examined an 80-year-old pine beam that had been retrieved from a rural cottage. Pine beams of comparable age have previously been shown to retain sufficient mechanical properties often, suggesting potential for reuse. It has been demonstrated that reclaimed pine retains 80–90% of its bending and compressive strength, proving structural viability. However, it was noted that local variations in density could be attributed to environmental factors, including humidity and temperature fluctuations.

The energy consumption of the drilling process was tested using a PQ-box 150 energy quality analyser. The analyser was connected to the Felder Creator 950 CNC machine for which programs were written. This research was carried out in two stages. In the first stage, energy consumption was determined during the operation of the machine performing the assumed machining cycle without contact with the material (this was to determine the energy consumption of the machine without considering the energy for actual cutting), marked as E0max. In the second stage, full processing of the tested materials was carried out, during which the energy consumption was determined as Emax. The results obtained using the energy analyser in the first and second stages were used to calculate the energy used to make one hole in each plate-speed variant. The energy consumption during wood material cutting was directly measured. The specific cutting work [J/mm^3] (SCW), where Ep is the energy per joint [Wh] and V is the drilled hole volume [mm^3] was calculated from Equation:

$$\mathrm{SCW} = \frac{E_p}{V}$$

The reclaimed pine demonstrated stable machining efficiency. For dowel joints, V = 1658.77 [mm^3], Ep = 1.0555 [Wh], SCW was 2.29 [J/mm^3]. For confirmat screws, V = 1742.59 [mm^3], Ep = 1.571 [Wh], SCW reached 3.25 [J/mm^3]. Local variations in density and hardness were noted, which aligns with previous findings that environmental exposure influences the behaviour of aged timber. The results indicate that reclaimed pine beams can be processed with moderate energy demand and machining stability. Together with evidence of mechanical strength from earlier studies, this supports their reuse as a valuable raw material. Reclaimed beams provide both environmental and technical benefits, offering a practical solution for eco-design and sustainable furniture production while reducing reliance on virgin resources.

KEYWORDS: specific cutting word, drilling, reclaimed wood beam

From Log to Lumber: Yield Efficiency in Hardwood Sawmills

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ABSTRACT

In the context of the international wood supply chain, the implementation of rigorous quantitative analyses of production results is crucial for a precise assessment of both the operational efficiency and the economic profitability of wood processing activities. Among the critical factors influencing the performance and sustainability of the sawmill sector, two parameters emerge as particularly relevant: timber yield – defined as the ratio between the volume of sawn timber and the volume of incoming roundwood – and log quality, which includes a series of anatomical and geometrical characteristics, as well as the presence of defects.

In this study, the aim was to conduct a detailed assessment of both the wood quality and the cutting yield of a selection of hardwood logs from Southern Italy. A total of over 200 logs were subjected to dimensional and qualitative analysis prior to sawing. The experimental protocol included the measurement of log characteristics and the classification of four visible defects (taper, ovality, sweep, and fluting), with the aim of quantifying their influence on the conversion efficiency of the sawing process of three different wood species – olive (*Olea europaea* L.), black locust (*Robinia pseudoacacia* L.) and chestnut (*Castanea sativa* Mill.). Their incidence was also correlated to log diameter classes.

Although these species are not traditionally considered priorities in major industrial logging operations and are underrepresented in the international literature, the data obtained indicate that they possess competitive cutting yields, comparable to those of the most commonly exploited hardwoods.

These results contribute to the growing body of evidence supporting the sustainable and economically viable use of alternative native hardwood species in regional and international timber markets. Furthermore, the study highlights the importance of pre-selection and quality assessment in optimizing sawmill processes, especially in contexts where resource efficiency and environmental impact mitigation are strategic priorities.

KEYWORDS: forest resources, wood defects, sawn timber, wood technology, sustainability

A Methodology to Increase the Service Life in Innovative Timber Buildings – The CRESTIMB Project

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ABSTRACT

The CRESTIMB project focuses on the development of a modular timber construction system intended for multi-storey buildings with open-plan layouts. The system comprises glued-laminated timber (glulam) frames made of both softwood and hardwood, combined with dowel-type cross-laminated timber (CLT) floor panels. Innovative beam-to-column connections are designed to allow easy disassembly and reassembly of structural components.

The primary objective of the project is to significantly extend the service life of the structural system, targeting up to 100 years under indoor conditions, while enabling repeated reuse of its elements. To support this goal, experimental investigations are conducted in parallel with the development of advanced numerical models describing the rheological behaviour of timber. These models account for creep deformation and moisture-induced stresses under variable indoor climates. They are calibrated and validated using data from laboratory testing and full-scale component experiments.

The project also aims to establish scientifically grounded assessment methods for the durability of glued and dowelled joints. In addition, dedicated databases and predictive tools are being developed to support the structural design process with a focus on long-term performance. In parallel, life cycle assessment (LCA) methods are applied to optimise the material and environmental performance of the system.

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KEYWORDS: glued-laminated timber, moment-resisting connections, dowel cross laminated floors, threaded rods, creep modelling, service life

Antifungal Activity of Aspen and Spruce Ethanol Extracts against Wood-Decay Fungi

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ABSTRACT

Growing concerns about the toxicity and environmental impact of wood preservatives have increased interest in bio-based alternatives. Natural compounds such as bark extracts derived from industrial side-streams present a promising solution, combining renewability with inherent bioactivity and contributing to valorisation of these underused natural resources. This study evaluates the antifungal efficacy of ethanol–water extracts (70:30 v/v) from European aspen (*Populus tremula*) and Norway spruce (*Picea abies*) bark against two common wood-decay fungi: *Trametes versicolor* (BAM 116) and *Rhodonia placenta* (BAM 113). Bark of trees was ground and extracted at room temperature using a 1:20 solid-to-liquid ratio for 24 hours at 250 rpm constant mixing. After filtration and vacuum concentration, the phenolic-rich extracts were stored at 5 °C. Antifungal activity was assessed in vitro using potato dextrose agar (2%) plates, where each extract was applied in two concentrations (100 µl and 1000 µl). After ethanol evaporation, fungal inoculation was performed opposite to the extract site. Growth inhibition was monitored via image-based analysis of colony diameter across 10 replicates prepared for each strain and extract. Photos were taken at specific intervals to measure the growth of the culture until complete colonization was observed. The periodic growth of fungal strains at specific intervals was measured by analysing the diameter of the colony from the recorded photographs using image analysis software to assess the fungitoxic effect of the extracts in inhibiting the fungal growth. Both extracts did not impart any substantial inhibition to fungal growth at the lower concentration of 100 µl. The experiment with 1000 µl and further trials with higher concentrations of both bark extracts are underway in order to optimise the threshold concentration. The present trial was executed with the hypothesis that bark extracts from coniferous and deciduous species may offer effective, natural alternatives for enhancing wood durability. The preliminary findings suggest that while lower concentrations of bark extracts may not be sufficient to inhibit fungal

activity, higher dosages could potentially unlock the bioactive potential of these natural compounds. This research may pave the way for eco-friendly innovations in wood preservation – offering sustainable alternatives to synthetic chemicals.

KEYWORDS: bark valorisation, bio-based preservatives, fungal inhibition, natural preservation, wood durability

Anatomical and Growth Features of Chestnut Wood from Coppice Stands in Northern Greece

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ABSTRACT

Chestnut (*Castanea sativa* Mill.) is a highly valuable tree species in Europe, offering not only edible fruits but also durable and aesthetically pleasing timber. Its wood is appreciated for its natural resistance to biodegradation, ease of processing, and suitability for a variety of uses including furniture, technical applications, and decorative purposes. This study investigates the growth characteristics and anatomical features of chestnut wood, aiming to provide data that enhance the understanding of its structure–properties relationships and support its broader industrial utilization.

The material was collected from five chestnut trees (25–27 years old) growing in coppice stands in Arnaia, Chalkidiki, Greece. Sample discs were extracted every meter along the stem. Tree ring width was measured using precision optical equipment, and microsections were prepared for anatomical analysis with a stereomicroscope and digital imaging system. Additionally, wood samples were macerated for fiber length measurements. Statistical analysis was conducted using SPSS software to examine relationships between growth parameters and anatomical features.

Results indicated that earlywood width remained relatively stable across samples (0.51–1.22 mm), while overall tree ring width varied substantially (1.02–5.94 mm). A negative correlation was found between ring width and earlywood percentage, with wider rings exhibiting proportionally less earlywood. Furthermore, heartwood percentage decreased with tree height, while sapwood increased, demonstrating distinct vertical variation in the stem. Fiber length ranged between 0.95 mm and 1.13 mm, showing a trend of increase with cambial age. The most significant growth in fiber length occurred up to 10–12 years, after which the rate of increase declined, indicating a transition from juvenile to mature wood.

The findings enhance the understanding of how anatomical features of chestnut wood vary with cambial age and radial growth. The observed stability of earlywood width and the age-related increase in fiber length may be relevant for evaluating material properties in wood-based applications. Additionally, the quantitative data on wood anatomy may support future studies in dendrochronology or wood quality assessment when combined with ecological or climatic information.

KEYWORDS: chestnut, fiber length, wood anatomy, growth rings

Carbonization of Residues from the Wood-Based Panel Industry to Produce Biochar as an Additive to Improve the Structure of Agricultural Soils

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ABSTRACT

To combat climate change and build an environmentally strong economy and society, the European Commission has taken action to make Europe a climate-neutral continent by 2050. Achieving carbon neutrality requires action on several fronts, including rigorous reduction of CO2 emissions and effective removal of carbon from the atmosphere. One way to capture CO2 can be biomass-based carbon sinks, including biochar as a material for pyrogenic carbon capture and storage.

Biochar is produced by the carbonisation of biomass materials. It is a material that is easy to produce, environmentally harmless and has a wide range of applications. The use of biocarbon as a soil additive has received much attention in recent years. Publications highlight the many benefits of its sorption properties, among others. The introduction of biochar into soils improves their physical, chemical and biological properties, which contributes to increased crop yields. Guidelines describing the production process and the potential use of biocarbon are included in documents issued by the European Biochar Foundation (Switzerland), the British Biochar Foundation (UK) and the International Biochar Initiative (USA). The guidelines also focus on maximising the use of waste biomass materials, which can become a valuable source for obtaining biochar.

The concept of a closed-loop economy is essential for design at the initial stage of a product's life cycle and for an effective waste management system. In terms of the volume of wood-based panels produced, Polish manufacturers lead in Europe and are among the top in the world. One of the main problems faced by Polish woodworking industry producers is managing the waste generated during the mechanical processing of wood materials. The quantities of waste generated in the processing of wood and wood materials are significant. Therefore, innovative research work was undertaken in the area of management of this type of waste.

The project aimed to develop a product solution that can be used to improve the quality of soils used for agricultural and forestry crops. As part of the research work, carbonization of selected waste materials from the wood-based panels industry was carried out

under established conditions at laboratory and quarter-technical scale. The carbonisates obtained were tested to meet the requirements for biochar to be used as a soil improvement agent. Pot tests were conducted with model plants to assess the effect of bio-char on soil structure and plant development. The obtained biochar had a positive effect on the growth of tomato (*solanum lycopersicum*) seedlings, while not affecting the content of heavy metals in the plant's fruits.

KEYWORDS: biochar, carbonisation, biomass, waste wood, soil

Variability of the Compression Strength Parallel to the Grain of the "Istebna" Norway Spruce (*Picea abies* (L.) H.Karst) Wood

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ABSTRACT

The Istebna Norway spruce is considered to be one of the best-growing ecotypes of this species, what was proven by provenance experiments. However, silviculture aimed only at obtaining as much biomass as possible can result poorer mechanical properties of the wood. There is a lack of empirical data in the literature on the properties of the wood of mature trees of the Istebna ecotype spruce grown in the region of their natural occurrence (Istebna, Wisła). The aim of the presented study was to analyse the variability of the compression strength parallel to the grain (CS) of Istebna spruce wood.

In an 86-year-old spruce stand 3 sample trees were selected with diameter at the breast height (DBH) as close as possible to the average DBH (42 cm). The directions of the world sides were marked on the stems of sample trees, after which they were felled and a roll about 1m long was cut from each stem from its lower part. Wood samples were cut from the rolls and were tested for CS on a testing machine.

A total of 399 beams were tested. The average CS was 37.9 MPa. The coefficient of variation within the study trees ranged from 7.6 to 12.2%, while between trees it was 13.3%.

It was found that the wood of tree No. 3 had a significantly higher CS (about 25%) compared to the other two tested trees. This indicates that trees can be selected for the feature under study even among individuals of the same race, growing in the same stand.

It was found that wood from the southern side of the stems had a significantly higher CS compared to the northern and western sides, and that wood from the eastern side had a significantly higher CS compared to the northern side.

No significant differences in CS were found between samples taken from different levels of the rolls (lower, middle, upper) or from different locations on the radius of cross-section, although in this case there was a visible increase in CS from the pith to the bark. This confirms the common opinion that in most coniferous species, the wood of the near-pith zone, including juvenile wood, has poorer mechanical properties compared to the wood of the rest of the cross-section of the stem, containing mature wood.

The average CS obtained in the study, which is close to the values reported in the literature, indicates that Istebna spruce forms wood with strength parameters which are not inferior to those of spruce from other regions and can therefore be considered as a raw material for the production of advanced wood materials such as cross laminated timber (CLT).

KEYWORDS: Istebna Norway spruce, wood, compression strength

Digital Timber Passport: Conceptual Analysis of Standards and Technologies in the Context of EUDR

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ABSTRACT

The European Union Deforestation Regulation (EUDR) introduces strict obligations for operators and traders of timber and timber-based products, requiring transparent and verifiable due diligence. The regulation mandates collection of geolocation data, legality verification, and evidence that raw material is deforestation-free. However, EUDR does not prescribe a single technical standard for traceability. This creates both opportunities and challenges for the timber sector, where multiple existing standards and emerging technologies can be combined. The aim of this paper is a conceptual comparative analysis of existing standards and technologies as the foundation of a digital timber passport, with an assessment of their relevance and complementarity in relation to EUDR requirements.

The study applies a conceptual review methodology, drawing on desk research and analysis of standards and technological frameworks currently used in supply chain traceability. The scope includes global identification and data exchange standards (e.g. GS1, EPCIS), distributed ledger technologies such as blockchain, and digital product passport initiatives being promoted by the European Commission in various sectors. The analysis focuses on the ability of these frameworks to provide interoperability, verifiability, and long-term accessibility of information. Special attention is given to the potential integration of event-based supply chain data with geospatial datasets required under EUDR.

The review demonstrates that each family of solutions provides distinct strengths and limitations. Global standards such as GS1 and EPCIS offer mature structures for identification, semantics, and interoperability, already widely adopted in trade and logistics. Blockchain provides tamper-evident records and high trust but raises challenges of cost, scalability, and governance. Digital product passports, as a policy-driven initiative, offer a unifying framework but require adaptation to sector-specific conditions. Taken together, these approaches can be complementary: global standards provide harmonized semantics, distributed ledgers enhance data integrity, and product passports deliver policy alignment. A hybrid architecture emerges as a promising pathway, ensuring both compliance with EUDR and efficiency of implementation.

EUDR defines what information must be collected and shared but leaves open the choice of technology. This situation highlights the importance of conceptual frameworks that bridge existing standards with innovative solutions. A digital timber passport based on interoperable standards, reinforced with verifiability mechanisms, can ensure compliance, reduce administrative burdens, and increase stakeholder trust. The conceptual analysis indicates that rather than a single mandated system, an integrated approach combining standards and technologies is most likely to deliver long-term sustainability and competitiveness for the forestry and timber sector.

KEYWORDS: EUDR, digital timber passport, traceability, GS1, EPCIS, blockchain, timber supply chain

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