Program Booklet

24th International Nondestructive Testing and Evaluation of Wood Symposium

May 19-22, 2026
Vicksburg, Mississippi, USA

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

MISSISSIPPI STATE UNIVERSITY
DEPARTMENT OF SUSTAINABLE BIOPRODUCTS

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Welcome

On behalf of the International Organizing Committee, I take great pleasure in welcoming you to the 24th International Nondestructive Testing and Evaluation of Wood Symposium!

The International Nondestructive Testing and Evaluation of Wood Symposium Series was initiated over sixty years ago. The first symposium was held at the USDA Forest Products Laboratory in the fall of 1963. At that meeting, nearly 100 scientists, engineers, and industry leaders discussed the possibilities of a wide range of scientific means for testing wood nondestructively.

Twenty-three symposia have been held to-date at sites in Brazil, Canada, China, Germany, Hungary, Switzerland and the United States. Proceedings that capture the technical information presented have been prepared and published for each meeting. These proceedings contain over 10,000 pages of scientific and technical information on nondestructive evaluation of wood prepared by scientists from around the world. Technical presentations covered a range of topics-from the inspection of urban trees and grading of structural products to the assessment of historically significant funerary objects. We recently prepared a compendium of all prior proceedings, which is available on-line (https://doi.org/10.2737/FPL-GTR-309).

Our most recent symposium (2024) was a huge success by any measure! Led by Professor Raquel Gonçalves, it was hosted by State University of Campinas and held in Campinas, Brazil. Ninety-nine (99) scientists, engineers, and students from eighteen (18) countries spanning five continents presented results from their most recent research endeavors. The information presented was captured in an excellent proceeding (Gonçalves, Raquel; Wang, Xiping; Ross, Robert J., eds. 2024. Proceedings: 23rd International Nondestructive Testing and Evaluation of Wood Symposium. Campinas, São Paulo, Brazil. September 17-21, 2024. General Technical Report FPL-GTR-305. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 309 p.) that is available on-line (https://www.fpl.fs.usda.gov/documnts/fplgtr/fpl_gtr305.pdf).

Efficient use of our forest resources is of critical importance. Nondestructive testing and evaluation technologies have contributed greatly to this theme and to ensuring public safety. These technologies are now widely used worldwide to grade wood products and to inspect wood structures. The International Nondestructive Testing and Evaluation of Wood Symposium Series has been and will continue to be at the center of many of these technological advances by providing an international forum for presenting the latest scientific and technical information.

Forest resources continue to play an important role in the world, providing wood for a range of uses- from packaging materials to buildings and transportation structures. Wood has been useful to humans for thousands of years; archeological discoveries have shown wood was used by ancient civilizations as a construction material, as a substrate for ornate decorative objects, and for providing the final resting place for royalty. These discoveries, including artifacts that have survived for thousands of years—highlight the unique, long-lasting characteristics of wood.

The international nondestructive evaluation of wood research community will continue its journey of discovery and public service; working cooperatively in laboratories and with industrial partners around the world, we are discovering information that covers the entire spectrum of nondestructive evaluation—from inspecting wood used by ancient societies to developing new grading and assessment technologies for seedlings and trees. If our forests are managed wisely, and if we continue to build our knowledge base in nondestructive evaluation to meet the challenges of evolving human needs and changing wood characteristics, this amazing material that is wood will serve the public well for years to come.

Welcome!
Robert J. Ross

International Organizing Committee, International Nondestructive Testing and Evaluation of Wood Symposium:

Robert J. Ross, Michigan Technological University, Mississippi State University, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Xiping Wang, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

C. Adam Senalik, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Laurice M. Spinelli Correa, Mississippi State University, USA.

Brunela Pollastrelli Rodrigues, Clemson University, USA.

Raquel Gonçalves, State University of Campinas, Brazil.

Cinthya Bertoldo, State University of Campinas Brazil.

Alexis Achim, Université Laval (UL), Canada.

Houjiang Zhang, Beijing Foresty University, China.

Udo H. Sauter, Forest Research Institute Baden-Württemberg, Germany.

László Bejó, University of Sopron, Hungary.

Francisco Arriaga Martitegui, Universidad Politécnica de Madrid, Spain.

Symposium Chairs:

Robert J. Ross, Michigan Technological University, Mississippi State University, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Xiping Wang, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Laurice M. Spinelli Correa, Mississippi State University, USA.

Organizing Committee Chairs:

William A. (Andy) Martin, PhD., P.E., F. ASCE, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Kevin W. Ragon, PhD., Mississippi State University.

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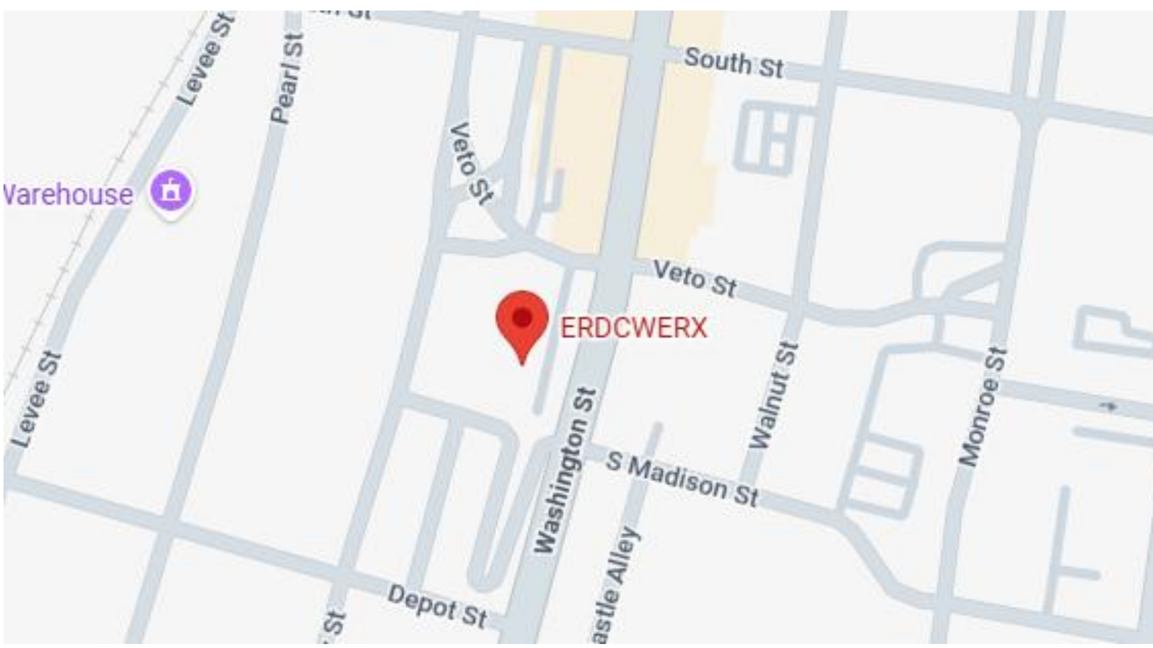
Welcome to Mississippi, mascot Bully's home.

Our venue

We thank you for joining us at the ERDC-WERX convention center located at 1622 Washington St. Suite 300, Vicksburg, MS. If you want to know more about ERDC-WERX, please visit their website at https://www.erdcwerx.org/.



Distinguished Service and Special Recognition Awards

The Nondestructive Testing and Evaluation of Wood Symposium Series has been a forum for presenting scientific and technical information on the science and use of nondestructive testing and evaluation technologies with wood-based materials and structures since 1964. Many internationally recognized wood scientists and engineers have contributed significantly to the field and the Symposium Series. Notable early contributors were George Marra (Washington State University-WSU), Bob Youngs (USDA Forest Products Laboratory-FPL), Helmuth Resch (University of California Berkley), and Bill Galligan (WSU and FPL).

In 1996, we began to formally recognize individuals who contributed significantly to the field through their research and those who were instrumental in moving the Symposium Series moving forward. At that time, Roy Pellerin and Kent McDonald were recognized for their research efforts and their leadership of the Symposium Series (co-chairs of Fifth Nondestructive Testing of Wood Symposium-1985 through Fourteenth International Symposium on Nondestructive Testing of Wood-2005). Below is a list of all scientists who have received the award.

Roy F. Pellerin (1996)
Kent McDonald (1996)
Dr. Voichita Bucur (2007)
John R. Erickson (2007)
Thomas M. Maloney (2007)
Dr. Peter Niemz (2009)
Dr. Robert J. Ross (2009)
Zhitong Wang (2009)
Bozhang Shi (2009)
Dr. Ferenc Divos (2011)
Dr. Helmuth Resch (2013)
Bill and Pat Galligan (2013)
Roy and Patti Pellerin (2013)
Dr. Raquel Goncalves (2019)
Peter Carter (2019)
Dr. R. Bruce Allison (2022)
Frank Rinn (2022)
Dr. Houjiang Zhang (2024)
Dr. Xiping Wang (2024)
Dr. Rubin Shmulsky (2026)

On the 24th International Nondestructive Testing and Evaluation of Wood Symposium, we are recognizing Dr. Rubin Shmulsky, Warren S. Thompson Professor of Wood Science and Technology, from Mississippi State University, MS, U.S.A.

Dr. Shmulsky has built a worldwide reputation as a leader in the wood science field, with significant contributions to nondestructive testing and evaluation of wood. He has mentored many graduate students and supported the development of faculty in the field of nondestructive evaluation of wood. His students and staff have gone on to distinguish themselves in industry and academic institutions. He secured approximately $15 million in support for his staff and students from the USDA Forest Products Laboratory, the majority of which was used to address industry prioritized research needs using nondestructive evaluation methods. He is the Warren S. Thompson Professor of Wood Science and Technology at MSU and was elected an International Academy of Wood Science (IAWS) Fellow in 2022.

Rubin' s research leadership in the field is exceptional. He was head of MSU's Department of Sustainable Bioproducts and has led extensive collaborative research efforts with international colleagues and NDE experts from around the world. He built a strong NDE research team and completed a range of research projects for grading and quality control of timber and wood products including trees, poles, piles, ties, and composite materials. NDE is now integrated into the MSU research and teaching program and is migrating into the industry because of his leadership. He has led condition assessments of timber structures across the United States, including historic wooden ships. He and his staff authored several widely used reference documents on nondestructive evaluation related topics—Wood and Timber Condition Assessment Manual, Third Edition; Machine Grading of Lumber—Practical Concerns for Lumber Producers; Development of Accepted Practices for Field Inspection of Wooden Electrical Utility Structures in Fire-Prone Lands Using State-of-the-Art Wood Condition Assessment Techniques; and Assessment of Condition and Decay of Wooden Mats used in the Construction Industry: With a Review of State-of-the-Art Wood Condition Assessment Techniques.

Dr. Shmulsky has been a very strong supporter of many of our efforts and has been the "behind the scenes" force for building the nondestructive evaluation program at Mississippi State University. He has provided the financial support for many of his MSU colleagues to attend our Symposia.

We thank him for his contribution and wish him nothing but success in his future endeavors,

International Organizing Committee, 24th International Nondestructive Testing and Evaluation of Wood Symposium.

Program Schedule
Tuesday, May 19, 2026

Pre-Symposium Technical Workshop
Nondestructive Evaluation Technologies for Wood Structures: Introduction, Demonstration, & Case Study
(Workshop participants only)

USS Cairo / VNMP Tour
08:45 AM – Gather at the USS Cairo
09:00 AM – Start the tour and split the group into two. One group will stay in the USS Cairo museum and the other will go downstairs and see artifacts and go under the USS Cairo (45 minutes for each group to see each space)
10:30 AM – Meet Park Tour guide(s) for 90–120 minutes tour of the park
12:30 PM – Lunch (*Included with workshop registration*)

Lecture and Demonstration *(Auditorium)*
13:30 PM – Wood and Timber Condition Assessment Introduction (*Laurice Spinelli Correa, Ph.D. – Mississippi State University*)
02:00 PM – Equipment Demonstration
03:00 PM – Case Study: USS Cairo (*Adam Senalik, Ph.D. – USDA-Forest Products Laboratory*)
03:30 PM – Case Study: Chinese Historical Structures (*Robert J. Ross, Michigan Technological University, U.S.A.*)
04:00 PM – Case Study: Brazilian Structures (*Raquel Gonçalves, Ph.D. – State University of Campinas, UNICAMP*)
04:30 PM – End of the workshop

06:00 PM – Welcome Reception (*all symposium participants*)

Wednesday, May 20, 2026

08:00 AM – On-Site Registration

08:30 AM – Welcome/Introduction *(Auditorium)*

09:00 AM – Concurrent Technical Sessions

Session 1A - NDT for Log & Timber Grading *(Auditorium)*
Moderator: Christopher Adam Senalik, Ph.D.
09:00 AM – A Multimodal Deep Learning Method for Estimating Mechanical Properties of Tree Logs – Tilak Neupane, Mississippi State University, U.S.A.
09:30 AM – Nondestructive Evaluation of Railroad Tie Strength Through Resonant Acoustic Method (RAM) – Umesh Lamichhane, Mississippi State University, U.S.A.

Session 2A - Urban Tree Inspection & Risk Assessment *(2nd floor)*
Moderator: Brunela Pollastrelli Rodrigues, Ph.D.

09:00 AM – Accuracy of ultrasonic tomography: A comparative study between standing trees and wood discs in different moisture conditions – Raquel Gonçalves, UNICAMP, Brazil
09:30 AM – Effect of contour geometry simplification and measurement direction on ultrasonic tomography accuracy in standing trees – Raquel Gonçalves, UNICAMP, Brazil

10:00 AM – Coffee break

10:30 AM – Technical Session

Session 3A - NDT for Mass Timber & Engineered Wood Products *(Auditorium)*
Moderator: Randi Dodgson

10:30 AM – Nondestructive Lumber and CLT from Downed Loblolly Pine – Sona Azad, Mississippi State University, U.S.A.
11:00 AM – Photogrammetry as a nondestructive technique for accurate geometry acquisition on reclaimed timber – Guillermo Íñiguez González, Universidad Politécnica de Madrid, Spain
11:30 AM – Stress-Wave Time-of-Flight (ToF) Response for Delamination Detection in Glulam Beams – Manal Bouchlouch, Mississippi State University, U.S.A.

12:00 PM – Lunch (*Included with registration*)

01:00 PM – Concurrent Technical Sessions

Session 2B - Urban Tree Inspection & Risk Assessment *(Auditorium)*
Moderator: Ana Paula Coelho-Duarte, Ph.D.

01:00 PM – Biomechanical assessment of urban trees: a comparative study between 3D and simplified computational models validated by non-destructive field test - Raquel Gonçalves, UNICAMP, Brazil
01:30 PM – Ultrasound-based soil characterization surrounding urban trees: methodological challenges and solutions – Cinthya Bertoldo Pedroso, UNICAMP, Brazil
02:00 PM – Computational simulation of a 3D tree model using different forms of root representation – Raquel Gonçalves, UNICAMP, Brazil

Session 3B - NDT for Mass Timber & Engineered Wood Products *(2nd floor)*
Moderator: Francisco Arriaga Martitegui, Ph.D.

01:00 PM – From red maple veneer to LVL: Nondestructive classification and bending performance - Dalila Belaidi, Mississippi State University, U.S.A.
01:30 PM – Specific Features and Outcomes of Nondestructive Assessment for Extending the Structural Service Life of Reclaimed Timber - Guillermo Íñiguez González, Universidad Politécnica de Madrid, Spain
02:00 PM – Non-Destructive Methods for Field Assessment of Wood Biodeterioration in Hardwood Trailer Decks Exposed to Tropical Rainforest Environments – Xiping Wang, USDA Forest Service, Forest Products Laboratory, U.S.A.

02:30 PM – Coffee Break

03:00 PM – Technical Session

Session 1B - NDT for Log & Timber Grading *(Auditorium)*
Moderator: Umesh Lamichhane

03:00 PM – Non-destructive estimation of the dynamic modulus of elasticity in *Pinus pseudostrobus* wood by longitudinal vibrations and impact waves – Guadalupe Olvera Licona, Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias, Mexico
03:30 PM – Virtual strength grading of Green Spruce Logs with CT Imaging and Finite Element Simulation – Franka Brüchert, Forest Research Institute of Baden-Württemberg, Germany
04:00 PM – NDE of Northern Maple Low-Grade Lumber Across Green, Frozen, and Kiln Dried Conditions – Randi Dodgson, Michigan Technological University, U.S.A.
04:30 PM – End of Technical Sessions for the day
*Dinner on your own

Thursday, May 21, 2026

08:00 AM – On-Site Registration

08:30 AM – Concurrent Technical Sessions

Session 1C - NDT for Log & Timber Grading *(Auditorium)*
Moderator: Fatemeh Rezaei, Ph.D.

08:30 AM – Non-Destructive Timber Pile Evaluation via Machine Learning and Acoustic Response Analysis – Mehdi Shahzamanian, University of South Carolina, U.S.A.
09:00 AM – Modelling Lenga (*Nothofagus pumilio*) Solid Wood Yield via Non-Destructive Testing – Mario Vega, Universidad de Aysen, Chile
09:30 AM – Non-Destructive Evaluation of Mechanical Properties in Corsican Pine Plantation Wood: The Role of Thinning – Andrea De Stefano, Mississippi State University, U.S.A.
10:00 AM – Determining stress wave attenuation coefficient along the longitudinal direction of wood using the pulse echo test – Robert J. Ross, Michigan Technological University, U.S.A.

Session 4 - NDT for Heritage & Historic Wood Structures *(2nd floor)*
Moderator: Franka Brüchert, Ph.D.

08:30 AM – Practical Assessment and Limitations of Portable Nondestructive Methods for Estimating the Mechanical Properties of Existing Timber Structures – Francisco Arriaga, Universidad Politécnica de Madrid, Spain
09:00 AM – Estimation of Modulus of Elasticity of Southern Yellow Pine Timber Pile Segments Using Stress Wave Timer – Brandon Ross, Clemson University, U.S.A.

10:30 AM – Coffee break

11:00 AM – Technical Session

Session 5A - Wood Quality Assessment in Forestry *(Auditorium)*
Moderator: Mehdi Shahzamanian, Ph.D.

11:00 PM – Estimating modulus of elasticity and rupture of wood from *Pinus taeda* and Platanus x hispanica using pulling tests – Ana Paula Coelho-Duarte, Universidad de la República, Uruguay
11:30 PM – Inference of Eucalyptus basic density using increment core samples, nondestructive testing, and machine learning – Cinthya Bertoldo Pedroso, UNICAMP, Brazil

12:00 PM – Lunch (*Included with registration*)

01:00 PM – Concurrent Technical Sessions

Session 3C - NDT for Mass Timber & Engineered Wood Products *(Auditorium)*
Moderator: Guillermo Íñiguez González, Ph.D.

01:00 PM – Leveraging Longitudinal Stress Wave Nondestructive Testing for Quality Control and Performance Prediction of Cross-Laminated Timber – Richard Omotayo, Mississippi State University, U.S.A.
01:30 PM – Mechanical characterization of wooden dowels for use in adhesive-free and metal-free engineered wood products: experimental and numerical analysis – Ana Paula Coelho-Duarte, Universidad de la República, Uruguay

Session 5B - Wood Quality Assessment in Forestry and Session 2C - Urban Tree Inspection & Risk Assessment *(2nd floor)*
Moderator: Umesh Lamichhane

01:00 PM – Comparison of the physical and mechanical properties of wood from branches, stems, and roots of urban trees– Cinthya Bertoldo Pedroso, UNICAMP, Brazil
01:30 PM – Characterizing Annual Ring Structures and Growth Patterns of Fire-Surviving Ponderosa Pines Using Resistance Micro-Drilling – Xiping Wang, USDA Forest Service, Forest Products Laboratory, U.S.A.
02:00 PM – Influence of sap flow and acoustoelastic effects on transverse ultrasonic velocity in standing trees – Raquel Gonçalves, UNICAMP, Brazil

02:30 PM – Coffee Break

03:00 PM – Poster Session *(Auditorium)*
Moderator: Laurice M. Spinelli Correa, Ph.D.

03:00 PM – Meet with moderator
03:05 PM – Condition Assessment of a Wooden Flagpole - Nondestructive Evaluation and Preliminary Laboratory Test Results – Brunela Pollastrelli Rodrigues, Clemson University, U.S.A.
03:10 PM – A new low-force tree pulling test for inclination, bending, and torsion – Steffen Rust, HAWK University of Applied Science and Art, Germany
03:15 PM – Analysis of the dynamic modulus of elasticity in urban trees: a case study in Ulmus pumila L. – Guadalupe Olvera Licona, Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias, Mexico
03:20 PM – Wood Products Stiffness and Strength Prediction by Nondestructive Evaluation Techniques — Energy Loss Parameters with Transverse Vibration and Stress Wave Techniques – Robert J. Ross, Michigan Technological University, U.S.A.
03:25 PM – Nondestructive Prediction of Young's Modulus in Standing Japanese Larch Trees Using Stress-Wave Velocity - Naoya Inaida, Shimizu Corporation, Japan
03:30 PM – Comparative evaluation of ultrasonic wave propagation using direct and semi-direct methods in three thermally modified wood species – Brunela Pollastrelli Rodrigues, Clemson University, U.S.A.
03:35 PM – In situ Moisture Content and Strength of Creosote Treated Southern Pine Timber Bridge Piles in South Carolina – Matthew Gutow, Clemson University, U.S.A.
03:40 PM – Nondestructive Assessment of Stiffness in Thermally Modified U.S. Wood Species – Anjila Lamichhane, Clemson University, U.S.A.
03:45 PM – Evaluating Bending Performance of Fence Posts using Acoustic Non-Destructive Testing Approaches – Ershad Ahmmed, Mississippi State University, U.S.A.

03:50 PM – Tree Risk Assessment in an Urban Avenue: Analysis of Integrated Sonic Tomography and Resistograph Investigations on Monumental Trees – Andrea De Stefano, Mississippi State University, U.S.A.
03:55 PM – Wood grading from a forest stand using ultrasonic techniques at different stages of the production chain – Raquel Gonçalves, UNICAMP, Brazil
04:00 PM – USS Cairo: A Preliminary Assessment of Potential Conservation Solutions through Aesthetic Testing - Kimberly Breyfogle, Texas A&M University, U.S.A.
04:10 PM – Round table: Participants of the poster session will answer questions from the audience.
04:40 PM – End of Technical Sessions for the day

06:00 PM – Banquet at the Carriage House (*Included with registration*)

Friday, May 22, 2026

08:00 AM – On-Site Registration

08:30 AM – Technical Session

Session 5C - Wood Quality Assessment in Forestry *(Auditorium)*
Moderator: Brunela Pollastrelli Rodrigues, Ph.D.

08:30 AM – Classification of Eucalyptus Seedlings Using Ultrasonic Wave Propagation and Machine Learning Models – Cinthya Bertoldo Pedroso, UNICAMP, Brazil
09:00 AM – Estimation of mechanical properties and knotty core in Eucalyptus grandis using acoustic tomography – Ana Paula Coelho-Duarte, Universidad de la República, Uruguay
09:30 AM – Prediction of physical and mechanical properties of Eucalyptus sp. clones using non-destructive tests on standing trees – Cinthya Bertoldo Pedroso, UNICAMP, Brazil
10:00 AM –Wood Properties of Fire-Surviving Ponderosa Pine Trees in the Plumas National Forest – Nkolika B. Omoni, Mississippi State University, U.S.A.

10:30 AM – Coffee break

11:00 AM – Technical Session

Session 3D - NDT for Mass Timber & Engineered Wood Products *(Auditorium)*
Moderator: Fatemeh Rezaei, Ph.D.

11:00 AM – In-situ Non-Destructive Evaluation of Wooden Poles for Residual Mechanical Properties and Service Duration – Jean Luc Sandoz, CBS-CBT, Switzerland
11:30 AM – A High-Quality Wooden Pole Grading Label for X-Large In- Service Duration – Jean Luc Sandoz, CBS-CBT, Switzerland
12:00 AM – Acousto-Ultrasonic Echography for Wood Quality Assessment – Jean Luc Sandoz, CBS-CBT, Switzerland

12:30 PM – Lunch (*Included with registration*)

01:30 PM – Final Remarks
*****Dinner on your own

ABSTRACTS

Session 1 – NDT for Log & Timber Grading

Session 1A - NDT for Log & Timber Grading

A Multimodal Deep Learning Method for Estimating Mechanical Properties of Tree Logs

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Abstract

Tree logs are essential forest products. Log grading is critical for determining their end use. Mechanical properties, particularly the modulus of elasticity (MOE) and modulus of rupture (MOR), are critical parameters for log grading. However, their accurate prediction is laborious and time intensive. This study employs a deep learning approach that integrates images with acoustic velocity to rapidly and reliably predict log mechanical properties. Images were collected from 42 logs, with 756 images generated by extracting patches from the end grain. The model was trained using five-fold cross-validation. Transfer learning was implemented using the Xception network pretrained on the ImageNet dataset. The convolutional features were combined with acoustic velocity to predict MOE and MOR. For MOE, the model achieved an average cross-validation R^2 of 0.67, with a corresponding RMSE value of 1.57 GPa. For MOR, the model achieved a cross-validation R^2 of 0.72 with an RMSE of 4.38 MPa. Future work will focus on expanding the dataset to improve model performance.

Keywords: log grading, mechanical properties, AI, multimodal.

Nondestructive Evaluation of Railroad Tie Strength Through Resonant Acoustic Method (RAM)

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Abstract

Nondestructive testing (NDT) methods enable rapid, repeatable assessment of railroad ties in service without removing or damaging them, providing critical insight into internal deterioration that may not be visually detectable. This study investigates the feasibility of using the Resonant Acoustic Method (RAM), a signal-based NDT technique, to estimate the modulus of rupture (MOR) of railroad ties. Red oak (*Quercus rubra* L.) and mixed hardwood ties representing four condition classes, namely new graded, new ungraded, used, and used degraded, were evaluated. Signals were generated using manual hammer excitation, and responses were recorded using a handheld microphone positioned near the ends and top surfaces of the specimens. The signals were then truncated to focus on the relevant portion, baseline offsets were corrected, and they were converted from the time domain to the frequency domain using Fast Fourier Transforms (FFT) to analyze the energy distribution across frequencies. Frequency bands containing most signal energy were identified. Energy within these bands was used as input features for a predictive model correlating frequency-energy values with MOR measured from destructive third point bending tests. RAM-estimated MOR showed strong agreement with measured values, yielding a coefficient of determination of $r^2 = 0.835$. New ties, both graded and ungraded, exhibited higher MOR values clustered near the upper regression range, while used and degraded ties showed lower MOR consistent with in-service deterioration. These results demonstrate that RAM can effectively distinguish between tie condition classes and offers a reliable, nondestructive approach for estimating in-situ railroad tie strength.

Keywords: Nondestructive Testing, Resonant Acoustic Method, Railroad ties, Modulus of rupture.

Session 1B - NDT for Log & Timber Grading

Non-destructive estimation of the dynamic modulus of elasticity in *Pinus pseudostrobus* wood by longitudinal vibrations and impact waves

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Abstract

Non-destructive methods, including acoustic technologies, provide accurate data on the properties, performance, and condition of materials. The modulus of elasticity (MOE) quantifies the flexibility or stiffness of wood subjected to forces that alter its shape and represents the relationship between the applied load and deformation (deflection) within the yield strength. The dynamic MOE can be determined from the natural vibration frequency of a prismatic sample, based on its dimensions and density. Inducing this vibration is commonly achieved by applying a controlled hit to one end of the specimen. The objective of this study was to analyze the dynamic modulus of elasticity of *Pinus pseudostrobus* Lindl. wood using acoustic methods, specifically vibrations and impact waves. The research included 57 specimens obtained from six trees in Ixtlán de Juárez, Oaxaca, Mexico. Healthy trees with straight trunks and few branches were selected in accordance with ASTM D5536-94. Specimens were extracted from the central part of the first four logs (2.5 m in length) and prepared with final dimensions of 0.05 m × 0.05 m × 0.76 m. The dynamic MOE was measured by longitudinal vibration using FFT Analyser software and by impact waves using the Microsecond Timer (Fakopp Enterprise Bt., Hungary). The longitudinal vibration method yielded a dynamic MOE of 10,613.9 MPa, while the Microsecond Timer produced a value of 12,890.1 MPa.

Keywords: acoustics, density, impact waves, vibrations.

Virtual strength grading of Green Spruce Logs with CT Imaging and Finite Element Simulation

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Abstract

Feeding detailed knot characteristics from CT log scans into finite element (FE) simulations of virtual boards would allow to determine a board's MOR before it was even sawn. Such an approach offers significant advantages, as it would enable sawmills to optimize cutting patterns and log orientation for maximum volume and strength yield. Feature detection in CT scans relies on density contrasts, but localization of knots in the CT scan in wet sapwood of softwoods is often inaccurate due to small differences. Knot location and status were extracted from CT log images of 81 green spruce logs by voxel-wise segmentation with convolutional neural networks. These models were trained with annotated segmentation masks, ground truth data are physical knot measurements (11 features per knot, n=3375 knots) of whorl sections scanned twice (green, dry). Measurements were taken from the dried sections and transferred to the green scans to improve the segmentation in the sapwood zone. Predicted knots are then used to generate finite element models of each virtually cut board. The FE-model includes the information of knot geometry as well as its live/dead situation. Stress distributions from FE-analysis variates in each board, based on the geometry, shape and the position of knots. Concentration of the stresses around knots allows us to predict the mechanical response of the boards. We present the concept of the complete data pipeline from CT log scan to strength prediction of the individual boards. A focus is set on the interfaces of data transfer between the simulation tools.

Keywords: virtual strength grading, knot segmentation, dead/live knot identification, artificial intelligence, finite element simulation.

NDE of Northen Maple Low-Grade Lumber Across Green, Frozen, and Kiln Dried Conditions

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Abstract

This study is a component of the Wood Innovations 2024 project focused on creating structural applications for underutilized northern hardwood species. A barrier to the adoption of hardwoods in structural applications is the lack of hardwood-specific grading data the reflects real-world material conditions present throughout the supply chain. If northern hardwood lumber were to be manufactured for structural purposes, it would likely need to be evaluated in different conditions, including green, frozen, and kiln dried. However, most NDE-based grading relationships have been developed under controlled laboratory conditions and at a single moisture and temperature state, which may not be representative of real-world processing conditions in northern regions. This study focuses on red maple and sugar maple lumber milled from low-grade industrial cants supplied by Northern Hardwoods in Atlantic Mine, MI. The objective is to quantify how NDE-derived stiffness measurements change as the material transitions from green to frozen and ultimately to a typical in-service moisture content. Lumber was evaluated using transverse vibration at an average MC of 60%, following frozen conditioning at subfreezing temperatures, and again after kiln drying. Nondestructive static flatwise bending tests were conducted to determine static MOE and to verify dynamic MOE measurements. Each specimen was assigned an appearance grade in accordance with National Hardwood Lumber Association (NHLA) grading rules and a visual grade following Northeastern Lumber Manufacturers Association (NeLMA) standards. Results will examine the influence and consistency of moisture and temperature on NDE measurements, relationships between appearance grades, visual grades, and tested mechanical performance. The findings intend to support more robust NDE-driven grading, within the modern hardwood manufacturing frameworks, for underutilized hardwood species.

Session 1C - NDT for Log & Timber Grading

Non-Destructive Timber Pile Evaluation via Machine Learning and Acoustic Response Analysis

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Abstract

Treated timber piles are essential to bridge infrastructure in South Carolina but are prone to hidden internal deterioration, underscoring the need for faster and more effective inspection methods than traditional visual techniques. To address this challenge, this study introduces a machine learning (ML)-driven framework designed for continuous, non-destructive assessment of timber pile condition. The proposed approach uses acoustic data from controlled hammer tapping at multiple locations along representative piles. A suite of ML techniques are applied to interpret these acoustic responses and classify the internal health state of the piles. Data analysis begins by converting the audio files of the tapping into amplitude vs. time data extracted from the time-domain waveform data. Next, Mel-Frequency Cepstral Coefficients (MFCCs) are calculated from the amplitude data, which describe the spectral shape of audio similar to the way humans perceive sound, and then summarizing them as mean values. Finally, the three-dimensional (3D) principal component (PCA) projections are derived from the MFCC features and used to categorize the pile condition. The approach is effective at distinguishing piles with large internal cavities. These findings demonstrate the potential of ML methods for predicting the health condition of individual piles.

Keywords: Timber pile; sound tapping test; machine learning (ML).

Modelling Lenga (*Nothofagus pumilio)* Solid Wood Yield via Non-Destructive Testing

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Abstract

Nothofagus pumilio, commonly known as Lenga, is the most economically significant native species in Chile's timber industry, particularly in the Aysén and Magallanes regions, where it sustains local economies through the production of high-value sawn timber for furniture, mouldings, and export markets. Despite its commercial appeal as a premium hardwood substitute for cherry or maple, the industry faces a critical challenge: a high incidence of internal decay in unmanaged stands can reduce usable wood volume to as little as 20%. To address this, the study employed non-destructive acoustic technology to evaluate solid wood quality for structural and appearance purposes, utilising the resonance method with the Hitman tool on logs to measure longitudinal wave frequency and assess the entire log volume, which proved to be the most potent predictor of structural performance variability. Additionally, the time-of-flight method with Fakopp was applied to standing trees for early selection and to logs in parallel and opposite configurations. While the parallel measurement evaluated the outerwood, the opposite configuration traversed the core, becoming crucial for detecting internal white or brown decay that degraded high-value NHLA (National Hardwood Lumber Association)-grade yields. The adjusted models indicated that the proportion of commercial volume in NHLA grades was significantly dependent on the small-end diameter of the log, acoustic velocity, and the presence of knots, providing a precise framework for segregating Lenga logs based on their potential for high-value production while reducing inefficient processing of decay-degraded material.

Keywords: Non-destructive acoustic testing; Nothofagus pumilio (Lenga); decay; NHLA.

Non-Destructive Evaluation of Mechanical Properties in Corsican Pine Plantation Wood: The Role of Thinning

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Abstract

In recent decades, a wide range of non-destructive testing (NDT) instruments has been developed to directly and/or indirectly assess the intrinsic quality of wood in small samples, logs, and standing trees. These approaches enable the rapid and reliable evaluation of physical and mechanical properties, providing valuable information for both forest management and the wood-processing industry. In particular, non-destructive methods support log classification and sorting by modulus of elasticity (MOE) classes, and contribute to optimizing silvicultural practices, including defining appropriate thinning regimes in conifer plantations. Selective thinning is widely recognized as an effective silvicultural practice for improving stand structure, reducing competition among trees, and enhancing growth conditions. However, the effects of thinning on the mechanical properties of wood, especially when assessed at the tree or log level using non-destructive techniques, remain insufficiently documented for many conifer species and site conditions.
This study was conducted in the Sila National Park (Calabria, Southern Italy), a representative area for Corsican pine (*Pinus nigra* subsp. *laricio*) plantations. Two different non-destructive techniques were applied to assess the effects of selective thinning on wood quality. Stress-wave propagation (measured with MicroSecond Timer) and drilling resistance measurements (measured with Resistograph PD400) were used to characterize mechanical-related properties and internal wood features in 56 Corsican pine trees.
The main hypothesis of this study was that selective thinning may significantly influence the dynamic modulus of elasticity (MOE_d) and, consequently, the future mechanical performance of the wood produced. The data obtained highlighted the relevance of non-destructive measurements in detecting variations potentially associated with thinning intensity and stand conditions, confirming the suitability of these tools for in situ wood quality assessment. Overall, the results of this study may contribute to the development of forest plantation management strategies aimed at cultivating trees with improved mechanical properties, while supporting more informed decision-making in sustainable silviculture and wood resource valorization.

Keywords: dynamic MOEs, Pinus nigra Arnold subsp. calabrica; Southern Italy, wood technology.

Determining stress wave attenuation coefficient along the longitudinal direction of wood using the pulse echo test

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Abstract

Attenuation is one of the important characteristics of stress wave propagation. However, a standardized and unified detection method for the attenuation coefficient of stress wave propagating longitudinally in wood has not yet been established. This study focuses on the experimental investigation of the attenuation coefficient and its detection method when stress waves propagate longitudinally in wood. 10 defect-free Scotch pine rods were selected as specimens, and an experimental platform based on the stress wave pulse-echo method was built. The test platform program was compiled by using LabVIEW software to realize signal acquisition, signal preprocessing and parameter calculation of stress wave signals. On the basis of experimentally determining the reasonable impact momentum, a 100 cm long specimen was used to carry out repeatability detection tests, so as to investigate the repeatability and reliability of the detection results of stress wave propagation attenuation coefficient. Finally, the influence of specimen length on the detection results of attenuation coefficient was studied experimentally. It was found that: (1) The attenuation coefficient of stress wave propagation is almost independent of the magnitude of impact momentum, and the reasonable impact momentum value in this study is selected as 0.015 N·s. (2) For a 100 cm specimen, 10 repeated tests were carried out, and the detected attenuation coefficient values showed good repeatability with a standard deviation of 0.00016 and a coefficient of variation of only 0.86%. (3) With the increase of specimen length, the attenuation coefficient decreases, and there is a significant power exponential correlation between them; the longer the specimen, the smaller the dispersion of the attenuation coefficient detection data. It can be seen that the detection of the attenuation coefficient of stress wave propagating longitudinally in wood based on the pulse-echo method is feasible. For the standardized detection test for the evaluation of wood longitudinal stress wave attenuation coefficient, it is suggested that the length of the specimen should be set to 100 cm.

Keywords: stress wave, longitudinal direction of wood, pulse-echo test, attenuation coefficient

Session 2 – Urban Tree Inspection & Risk Assessment

Session 2A - Urban Tree Inspection & Risk Assessment

Accuracy of ultrasonic tomography: A comparative study between standing trees and wood discs in different moisture conditions

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Abstract

Ultrasonic tomography is a key non-destructive technique for assessing internal defects in trees; however, experimental limitations often restrict field inspections of standing trees. Consequently, many studies rely on laboratory tests performed on wood discs obtained after felling, raising questions about the representativeness and accuracy of these laboratory-generated images. This study quantitatively compared the accuracy of ultrasonic tomograms from standing trees with those produced from wood discs under two different moisture conditions. Inspections were conducted on 14 standing trees across three species, followed by laboratory tests on 27 discs extracted from the same specimens. Disc measurements were taken in both saturated and equilibrium moisture content states. Tomographic images were generated using a simplified methodology based on conventional ultrasonic equipment and post-processed via ellipse-based spatial interpolation with velocity compensation. Accuracy was evaluated through a binary confusion matrix, comparing tomograms against photographic records of the disc cross-sections. Results showed that images from standing trees and saturated discs yielded statistically equivalent accuracy. Despite differences in biological activity, stress levels, and moisture between standing trees and discs, adopting reference velocities for each section effectively minimized systematic errors. These findings indicate that laboratory-based studies using wood discs can reliably represent field conditions, provided appropriate calibration criteria are applied.

Keywords: ultrasonic tomography, image accuracy, standing trees, wood discs, nondestructive evaluation.

Effect of contour geometry simplification and measurement direction on ultrasonic tomography accuracy in standing trees

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Abstract

Ultrasonic tomography is an effective nondestructive technique for assessing the internal condition of standing trees; however, the high cost and complexity of commercial systems often limit their widespread application. Simplified methodologies using conventional ultrasonic equipment represent a viable alternative, though such simplifications might compromise image accuracy. This study evaluates the influence of contour geometry simplification and measurement direction on tomographic accuracy. Inspections were performed on 14 standing trees of three species using a sampling grid with eight measurement points. Tomographic images were generated using two contour representations: the exact contour (from photographs) and a simplified elliptical contour (derived from stem diameters). Images were compared through quantitative evaluation using a binary confusion matrix. Although simplifications influenced ultrasonic velocities, these differences did not result in significant variations in image accuracy. Images using exact contours and bidirectional measurements were only ~1% more accurate than simplified versions, a difference that hardly justifies the additional operational effort. For the geometry range evaluated, elliptical approximation and single-direction measurements did not compromise accuracy, supporting the feasibility of these simplified methodologies for practical tree inspection.

Keywords: ultrasonic tomography, simplified methodology, tree decay detection, image reconstruction accuracy, nondestructive testing.

Session 2B - Urban Tree Inspection & Risk Assessment

Computational simulation of a 3D tree model using different forms of root representation.

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Abstract

Critical failure points in urban trees are typically concentrated at the trunk base and within the root system, where stress concentrations and anchorage stability are decisive. In computational simulations, accurately modeling the trunk-root-soil coupling remains a significant challenge. This study evaluates two distinct methods for representing the root-soil interface using the Finite Element Method (FEM). A simplified approach, utilizing a 100-mm thick disk with a diameter equivalent to the tree canopy, was compared against a detailed 3D model. The latter integrated ultrasound tomography and photogrammetry to geometrically represent structural roots as cones. Simulations under two wind loading directions revealed that while both models align with general biomechanical theory, the detailed 3D model was uniquely sensitive to root asymmetry. Specifically, when loading was directed toward the rootless face, the 3D model captured a significant increase in displacement and in compressive stress, revealing a critical loss of global stiffness and a shift in the rotation axis (pivot) that the disk model failed to fully represent. Although based on a single specimen, these findings demonstrate that detailed root modeling could be an important tool for identifying localized structural vulnerabilities in urban trees constrained by infrastructure, providing a more robust framework for failure risk assessment.

Keywords: Tree biomechanics, Finite Element Method (FEM), Root-soil interaction, Tree stability, Root system architecture.

Ultrasound-based soil characterization surrounding urban trees: methodological challenges and solutions

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Abstract

Soil characterization is essential in urban tree stability and risk assessment, as it directly influences the root system's anchorage. However, obtaining properties from undisturbed soil is a complex task. This study aims to evaluate whether ultrasound is a suitable tool for inferring the properties of undisturbed soil surrounding inspected trees. Since undisturbed soil is a highly attenuating material, signal acquisition is often difficult, especially for shear waves (S-waves), which are required to obtain the complete stiffness matrix. This methodological study proposes an ultrasonic testing procedure to characterize soil in its undisturbed state. Results indicated that, with the equipment used, it was not possible to obtain ultrasonic readings from undisturbed specimens within the original dimensions of the sampling ring. Two solutions were proposed: applying a minimum compaction, sufficient for signal reading or reducing the specimen length to shorten the wave path. The results showed that while light compaction allowed signal acquisition, it altered the physical and elastic parameters, failing to reflect the soil's original condition. Reducing the specimen height, provided that the path length to wavelength ratio limits were respected, proved to be the most appropriate approach, as it preserved the soil's original state while allowing clear signal acquisition. Future research will verify the relationships between longitudinal and shear wave velocities to propose a methodology for high-power equipment that may not directly support shear wave readings.

Keywords: undisturbed soil, ultrasonic wave propagation, urban tree stability, acoustic attenuation, shear waves.

Biomechanical assessment of urban trees: a comparative study between 3D and simplified computational models validated by non-destructive field test

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Abstract

In recent years, researchers have developed computational systems to apply tree biomechanics to fall-risk analysis. A major challenge lies in modeling these complex structures, which comprise the root system, trunk, and crown. Currently, the Non-Destructive Testing Research Group (GPEND) employs simplified models for this purpose. Photogrammetry has emerged as a viable technology for remote 3D modeling, representing objects through point clouds or triangulation. This study evaluates whether 3D modeling of the trunk and branches increases numerical simulation accuracy in inferring displacements and normal stresses compared to simplified models. Pulling tests were conducted on four trees to provide empirical data. Dendrometric parameters were collected, and the arboreal specimens were modeled in 3D using photogrammetry. Both 3D and simplified models were used in computational simulations to obtain horizontal displacements and normal stresses under loads identical in magnitude and location to the field tests. Results for normal stresses showed high correlations ($R^2 > 94\%$), acceptable Mean Absolute Error (MAE), and satisfactory residual autocorrelation (Durbin-Watson). The 3D model outperformed the simplified version in inferring normal stresses, yielding lower error rates. Regarding displacements, both models exhibited strong positive autocorrelation in the residuals, indicating that neither fully captured the complexity of the soil-root interaction, resulting in a systematic bias. In conclusion, while 3D modeling significantly improves stress inference, capturing soil-root dynamics remains a challenge for both modeling approaches.

Keywords: biomechanical computer simulation, fall risk analysis, urban trees.

Session 2C - Urban Tree Inspection & Risk Assessment

Influence of sap flow and acoustoelastic effects on transverse ultrasonic velocity in standing trees

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Abstract

Transverse ultrasonic wave velocity is a fundamental parameter in the nondestructive evaluation of standing trees, as it directly supports the generation of tomographic images used to assess internal wood conditions. In living trees, however, this velocity may be influenced not only by wood integrity but also by physiological and mechanical factors such as sap flow dynamics and stem stresses. This study investigates the relationship between sap flow-related environmental conditions, stem stresses and transverse ultrasonic wave velocity in standing trees. Ultrasonic inspections were carried out on three *Spathodea campanulata* trees over twelve consecutive months, with measurements performed at sunrise, solar zenith, and sunset. Climatic variables, dendrometric parameters, and physical properties of the wood were recorded to support data interpretation. Results revealed statistically significant correlations between transverse ultrasonic velocity and environmental parameters affecting sap flow, particularly air temperature and relative humidity. Higher transverse ultrasonic velocities occurred under conditions favoring increased sap flow, whereas reduced transverse velocities were observed during low sap flow periods, especially in early morning measurements. Additionally, variations in crown area showed an inverse correlation with transverse ultrasonic velocity, indicating a possible acoustoelastic effect associated with increased compressive stresses in the stem. Understanding these physiological and mechanical influences is essential to improve the interpretation of transverse ultrasonic measurements. Based on the *Spathodea campanulata* case study, preliminary findings indicate that transverse ultrasonic velocity decreases under low sap flow and high compressive stress conditions. For this species, with very low density, these reductions significantly altered ultrasonic tomography, reducing image accuracy. Research involving species with medium and high densities is needed to confirm the results.

Keywords: ultrasonic tomography, acoustoelasticity, tree physiology, moisture content, *Spathodea campanulata.*

Session 3 – NDT for Mass Timber & Engineered Wood Products

Session 3A - NDT for Mass Timber & Engineered Wood Products

Nondestructive Lumber and CLT from Downed Loblolly Pine

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Abstract

This study investigates the nondestructive evaluation (NDE) cross-laminated timber (CLT) panels manufactured from downed loblolly pine (*Pinus taeda*) timber. Herein, trees were felled to simulate downed pine resulting from storm/high-wind events in the southeastern United States. Trees were in the same plot of the same stand. They were planted at the same time, were 14 to 16 inches diameter at breast height, and were approximately 38 years old at the time of harvesting. Felled trees were left on the forest floor under natural environmental conditions and collected after 0, 6, 9, and 12 months. 2×6 inch of lumber was sawn from the logs, dried, planed, moisture conditioned, and then used to fabricate three-ply CLT panels. Nondestructive evaluation testing was conducted on both lumber and CLT panels using acoustic velocity measurements to determine acoustic velocity (AV) and dynamic modulus of elasticity (D_{MOE}). Results showed minor fluctuations in moisture content and density over specified time; however, AV and D_{MOE} of lumber remained statistically unchanged throughout the one-year time-on-ground period. In addition, CLT panels exhibited consistently higher AV and D_{MOE} values than lumber, with no significant degradation across time-on-ground conditions.
These findings indicate that lumber sawn from and CLT manufactured from downed loblolly pine retains significant mechanical integrity for at least 12 months following felling. Cross-lamination enhances stiffness uniformity and mitigates material variability, reinforcing the potential of salvaged timber for mass timber applications. This study highlights the value of acoustic NDE techniques in assessing storm damaged timber and supporting resilient, sustainable wood-based construction practices.

Keywords: nondestructive evaluation, acoustic velocity, cross-laminated timber, downed timber, sustainability, and loblolly pine.

Photogrammetry as a nondestructive technique for accurate geometry acquisition on reclaimed timber

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Abstract

Increasing global concern on resources circularity has triggered research on the application of NDT to the assessment of reclaimed timber, aiming either its reuse into new structures or its remanufacture and recycle into new products. However, the typically high cross-section variability met in reclaimed-timber specimens remains a big challenge for the determination of its load-bearing capacity. To face this challenge, contactless 3D modelling tools, and specifically structure-from-motion photogrammetry, exhibit significant potential which deserves further research.

In this paper it is therefore proposed a photogrammetry-based methodology which was developed, rehearsed and automated for 3D modelling of over-100-year-old reclaimed oak timber with large cross-section size. After in-lab systematic image acquisition, specific photogrammetry software was employed to align images, build the 3D model point cloud and scale it to real size. Further steps included the use of parametric design tools for automated measurement of cross-section-related values, accompanying its variation all along the specimen.

The results obtained evidence of the usefulness of photogrammetry for the assessment of pieces with significant cross-section variation, outdoing conventional methods (measuring tape, forest caliper) which would instead introduce risky uncertainty. Furthermore, this methodology provides: (1) large control to user over the parameters involved in image acquisition and processing, thus being free to balance accuracy and computational cost; (2) outstanding accuracy in terms of point cloud density, and so geometry and texture; and (3) versatility of applications for the obtained point clouds, affordability of software and equipment engaged, and potential scalability to industrial environment, either in demolition sites or reclamation facilities.

Keywords: cascading, nondestructive testing, reclaimed timber, resources circulation, structural reuse, structure-from-motion photogrammetry (SfM).

Stress-Wave Time-of-Flight (ToF) Response for Delamination Detection in Glulam Beams

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Abstract

Stress-wave time-of-flight (ToF) measurements are widely used in wood products for rapid stiffness screening, but they have rarely been leveraged as a practical tool to detect and localize adhesive delamination in glued-laminated timber (glulam). This study evaluates stress-wave ToF nondestructive testing (NDT) as an approach to detect and localize internal adhesive delamination in glulam manufactured from Southern Yellow Pine (*Pinus taeda L.*) bonded with a one-component polyurethane (PUR) adhesive. Stress-wave ToF measurements were acquired using a Fakopp Microsecond Timer (Fakopp Kft., Sopron, Hungary) and assessed across different wave paths: along the length, across the width, and through the thickness. Thickness-wise ToF proved efficient for identifying delaminated regions and for quantifying delamination severity based on the time response, irrespective of beam and delamination length. Guided by this outcome, discontinuities were introduced at the targeted internal glue line, and a depth-wise testing procedure was applied to pinpoint the specific layer containing the discontinuity. This approach successfully identified the glue-line associated with the defect. By contrast, longitudinal and width-wise measurements were not dependable for detecting delamination, underscoring limitations when wave propagation is primarily parallel to glue interfaces. Finally, dynamic stiffness derived from ToF remained strongly associated with static stiffness from four-point bending ($r = 0.8672–0.9845$) despite the presence of delamination. Overall, the results demonstrate that stress-wave ToF in the thickness-wise and depth-wise testing directions is a rapid, nondestructive, and practical quality-control approach for glulam focused on hidden adhesive integrity.

Keywords: Nondestructive Evaluation (NDE), Wood Engineered Products (EWD), Adhesive Discontinuity, Glue-Laminated Timber, Modulus of Elasticity (MOE), Four-Point Bending.

Session 3B - NDT for Mass Timber & Engineered Wood Products

From red maple veneer to LVL: Nondestructive classification and bending performance

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Abstract

The forest products industry continuously seeks to expand markets and improve resource utilization by developing engineered wood products (EWPs). Laminated veneer lumber (LVL) is a widely used engineered wood product in the building and construction sector, enabling the conversion of variable wood resources into high-performance structural beams. While Southern Pine and Douglas Fir are the primary species used in LVL production, a variety of other wood species, including underutilized hardwoods such as red maple, an abundant and native species in the Northeastern US with favorable mechanical properties, is also suitable for manufacturing LVL. However, the high variability in veneer quality highlights the need for reliable approaches to control and target stiffness in LVL for structural applications.
In this study, stress-wave nondestructive testing was used to evaluate red maple veneers and the resulting LVL. Based on their dynamic modulus of elasticity (MOE_d), veneers were classified into low-, medium-, and high-MOE_d groups. LVL billets were manufactured using veneers from each MOE_d group, as well as a mixed layup configuration with high-MOE_d veneers in the outer layers and medium- and low-MOE_d veneers in the core. Stress-wave testing was also applied to the LVL billets to assess their MOE_d.
To validate the nondestructive measurements, LVL specimens were evaluated in four-point static bending according to ASTM D198 to determine static modulus of elasticity (MOE_s) and modulus of rupture (MOR). A strong correlation was observed between MOE_d and MOEs. LVL manufactured with mixed-stiffness veneers exhibited flexural performance comparable to that of LVL produced with medium-stiffness veneers. These findings show that stress-wave nondestructive testing can accurately classify veneers, improving material utilization, predicting LVL performance, reducing waste, and promoting the structural use of underutilized hardwoods such as red maple in laminated veneer lumber production. This approach also enables stiffness-targeted LVL design by controlling veneer layup, contributing to more sustainable construction practices.

Keywords: Nondestructive testing evaluation (NDT), stress wave, Fakopp, laminated veneer lumber (LVL), red maple, mechanical properties, dynamic and static MOE, engineering wood product (EWP).

Specific Features and Outcomes of Nondestructive Assessment for Extending the Structural Service Life of Reclaimed Timber

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Abstract

The demand for wood as a material increases every year in the construction sector, that continues growing and innovating with reliable engineered wood products and industrialized processes. There are, however, concerns dealing with limits to sustainable use or availability of raw material; for that reason, cascading and extending service life of timber components are key points that must not be overlooked. Reclaimed timber thus represents a valuable potential resource for new constructions and products, where nondestructive techniques play a crucial role in assessing its properties and, therefore, facilitating its reintroduction into the market chain. Despite the extensive research conducted on nondestructive techniques applied to timber and the significant progress made in the development of industrial devices and prediction modelling, several specific aspects still require further analysis. This is particularly relevant for less conventional products such as large cross-section reclaimed timber sourced from demolition or waste facilities. This research examines specific considerations for nondestructive grading applied to reclaimed timber salvaged after more than 100 years in service, presenting results from an extensive testing campaign conducted within a running European project (TiReX). Additionally, it offers a testing methodology and grading models to compare with fresh timber and addresses the issue that current standards mandate strength grading based on criteria difficult to achieve with such products.

Keywords: large cross-section, mechanical properties, nondestructive testing, recovered timber, recycle, remanufacture, reuse, salvaged wood.

Non-Destructive Methods for Field Assessment of Wood Biodeterioration in Hardwood Trailer Decks Exposed to Tropical Rainforest Environments

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Abstract

Apitong (*Dipterocarpus* spp.), an increasingly rare tropical hardwood from the rainforest in Southeast Asia, has long been used as decking materials for open-bed trailers and trucks across North America. As the natural population of Apitong trees steadily declines, there is an urgent need to find sustainable, domestically sourced alternatives for trailer decking. A recent project evaluated the performance of U.S. domestic hardwoods treated with environmentally friendly wood preservatives, in a tropical environment. This paper aims to evaluate the use of non-destructive testing (NDT) methods to assess the condition of hardwood trailer deck materials installed in the tropical regions. Two NDT techniques were applied in the field evaluation of full-size hardwood trailer deck boards: a time-of-flight (TOF) acoustic measurement and the Pilodyn penetration test. The results were compared with visual assessment based on the American Wood Protection Association (AWPA) standard. The results indicate that decay was the main factor contributing to the deterioration of the trailer deck boards at the tropical test site. Visual assessments showed that both treated oak and treated maple boards demonstrated better durability than untreated Apitong. The acoustic and Pilodyn assessments supported the visual findings and highlighted severe deteriorations of the deck boards that were not captured by visual inspection. The results of this study will help develop standardized non-destructive testing protocols for future field monitoring of hardwood trailer decking conditions, supporting the adoption of sustainable domestic hardwood species in the transportation industry.

Keywords: Acoustic testing, biological degradation, condition assessment, decay, hardwood, Pilodyn penetration test, preservative treatment, termite attack, trailer deck.

Session 3C - NDT for Mass Timber & Engineered Wood Products

Leveraging longitudinal stress wave nondestructive testing for quality control and performance prediction of cross-laminated timber

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Abstract

Reliable quality control methods are essential for ensuring the structural integrity of cross-laminated timber (CLT), particularly when low-grade lumber is utilized. This study evaluates the effectiveness of longitudinal stress wave–based nondestructive testing (NDT) techniques for predicting the mechanical performance of CLT. A total of 625 Grade No. 3 Southern Yellow Pine (SYP) 2 × 6 lumber pieces were used to manufacture 3- layer CLT and 64 specimens of dimension 4.5” thick × 1’ wide × 8’ long were obtained. The density of specimen was determined, and nondestructive evaluation was carried out using two independent stress wave systems: Fakopp ArborSonic3D and Hitman HM-200. Longitudinal stress wave velocities obtained from both devices were used to compute dynamic modulus of elasticity (dMOE) and assess consistency across NDT techniques. Following nondestructive testing, specimen were tested under four-point static bending to determine modulus of elasticity (MOE) and modulus of rupture (MOR). Statistical analyses revealed strong correlations between stress wave–derived dMOE and MOE, with R^2 values from 0.61 to 0.89, while moderate correlations were observed for MOR, with values from 0.31 to 0.59. Density and wave velocity exhibited a positive influence on destructive properties. Density showed correlation coefficients of 0.66 for MOE and 0.33 MOR, with velocity ranging from 0.4 to 0.77 for MOE and 0.28 to 0.5 for MOR. The results confirm that stress wave–based NDT provides a reliable framework for performance prediction and quality control in CLT manufacturing using low-grade lumber. This supports improved material utilization and reduced reliance on destructive testing for engineered wood product performance.

Keywords: Mass Timber, low-grade lumber, stress wave velocity, dynamic modulus of elasticity, wood products, quality control.

Mechanical characterization of wooden dowels for use in adhesive-free and metal-free engineered wood products: experimental and numerical analysis

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Abstract

The growing demand for low-impact construction has increased the use of adhesive-free and metal-free engineered wood products (EWPs). Wooden dowels offer a renewable solution for joining mass timber elements, but their mechanical behavior is still not fully characterized for structure design. This study aims to evaluate the mechanical response of wooden dowels made of *Balfourodendron riedelianum* (marfim) with diameters of 10, 12, and 15 mm using ultrasonic testing (NDT), three-point bending tests, and finite element modelling (FEM). Ultrasonic measurements were used to determine the dynamic modulus of elasticity, while bending tests provided the modulus of elasticity and rupture, and failure modes. A strong relationship between the dynamic and static modulus was observed across all series, indicating that nondestructive testing can reliably estimate elastic stiffness. Dowel diameter showed no statistically significant influence on the mechanical properties, suggesting that the behavior is governed by the intrinsic material properties. A linear-elastic finite element model was developed to simulate the bending response and examine internal stress patterns. Numerical predictions aligned closely with the initial stiffness measured experimentally, confirming the model's value as a complementary tool for interpreting the bending response. The findings demonstrate that the combined use of experimental and numerical methods provides a reliable basis for the structural assessment of wooden dowels in such EWPs assembled without adhesives or metal fasteners.

Keywords: bending tests, engineered wood products, finite element modelling, ultrasonic testing, wooden dowels

Session 3D - NDT for Mass Timber & Engineered Wood Products

In-situ Non-Destructive Evaluation of Wooden Poles for Residual Mechanical Properties and Service Duration

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Abstract

Since the 1990s, the CBS-CBT Group, a start-up originating from EPFL (the Swiss Federal Institute of Technology in Lausanne, Switzerland), has been involved in the mechanical characterization of historic timber structures using non-destructive testing (NDT) methods. For wooden poles in service for many years, a new combined non-destructive evaluation (NDE) method has been developed. This method measures the local density at ground-line level, both on the external four-centimeter layer and toward the inner part of the pole, as well as the internal moisture content (MC) beyond the treatment barrier, where the wood has not been exposed to external conditions. The density profile provides an evaluation of the residual bending strength of the pole, while the internal MC is used as an indicator of the remaining service life. Research has demonstrated that for poles with high-quality grain, when the inner (untreated) wood remains sound after 10 years in service, the operational lifetime of the pole can be significantly extended. By combining these parameters, algorithms provide an accurate assessment of the residual mechanical strength in relation to safety requirements prior to pole climbing. In addition, the estimated remaining service life expressed in years offers power companies a key qualitative tool for network assessment and maintenance prioritization. Feedback on millions of tested wooden poles the last 15 years in countries like France, Switzerland, Canada and USA allow to consolidate the decision algorithms.

A High-Quality Wooden Pole Grading Label for X-Large In-Service Duration

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Abstract

Because wood is a natural and heterogeneous material, its mechanical properties show substantial variability. Variations by a factor of seven or eight can be observed between poles of the same species and same origin. Such variability highlights the need for a reliable, non-destructive grading method before to install this support in the network. Based on ultrasonic propagation signal analysis, wooden poles can be graded according to their mechanical performance and expected service lifetime. The evaluation parameters include wave velocity, signal energy attenuation, and frequency changes, principles demonstrated in several scientific works (Sandoz, 1990; Sandoz et al., 2002). It is therefore highly useful to classify poles into three quality categories for each species:

S - short service life, unsuitable for network installation.
L - long service life (30–35 years).
XL - extra-long service life (60–70 years or more).

This classification, validated on full-scale prototypes, is applied to green poles prior to chemical treatment. To better control drying cracks, a longitudinal saw-kerf can be introduced. When made before treatment, the preservative penetrates the crack zone by up to five centimeters, significantly improving protection. As a result, the long-term durability of wooden poles is increased, especially at the ground-line area where bending stresses are highest. This approach improves resistance to water penetration and reduces early-age failures. For the first time, a clear correlation between initial pole quality and in-service lifetime has been demonstrated, resulting in significantly improved reliability of overhead line networks.

Keywords: Wooden poles, non-destructive evaluation (NDE), Ultrasonic testing, Mechanical grading, Service life prediction, EN 338 timber classes.

Acousto-Ultrasonic Echography for Wood Quality Assessment

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Abstract

Timber mechanical grading based on ultrasonic wave velocity has been well established since the PhD work of J.-L. Sandoz (1990), *Timber: Validity of Ultrasonic Grading*. Today, ultrasonic velocity is complemented by additional non-destructive evaluation (NDE) parameters, including signal amplitude, frequency response, and damping behavior. By combining these four NDE variables, multivariate statistical regression models enable a more accurate characterization of the quality of wood and wood-based materials. The modulus of elasticity (MOE) remains strongly correlated with ultrasonic wave velocity and maximum signal amplitude. In contrast, local defects such as knots, cracks, or density variations primarily influence damping behavior and frequency response. Moisture content is also integrated into the analysis.

The following materials were investigated using these NDE parameters:

1. Tropical hardwood
2. European softwood
3. Spruce cross-laminated timber (CLT)
4. Tropical plywood
5. Particleboard
6. Medium-density fiberboard (MDF)
7. OSB panel

These materials were used to establish reference quality profiles represented through a four-axis NDE radar diagram, referred to as an *EchoGraph*. For any type of solid wood or engineered wood product, this four-parameter radar diagram provides a reference positioning of material quality. It allows direct comparison between tested samples and calibrated reference profiles. The resulting EchoGraph delivers both quantitative deviations and qualitative insights into the types of defects affecting performance. This approach opens new perspectives for industrial quality control as well as for assessing the residual quality of existing or aged wooden structures.

Keywords: Non-destructive testing, ultrasonic velocity, timber grading, acousto-ultrasonics, wood quality, EchoGraph, Sylvatest Quattro.

Session 4 – NDT for Heritage & Historic Wood Structures

Practical Assessment and Limitations of Portable Non-destructive Methods for Estimating the Mechanical Properties of Existing Timber Structures

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Abstract

This paper presents the general guidelines for evaluating existing timber structures based on research and applications carried out by our research group over the last 35 years. The experimental work on which it is based was carried out mainly with large cross-section, long pieces of coniferous timber from existing buildings and with highly irregular cross-sections. The first part is dedicated to data collection on site through the differentiation of homogeneous batches, the identification of the species, the assignment of a nominal cross-section, visual grade, and the moisture content of the wood. The second part proposes the use of some non-destructive methods to estimate the main structural properties (modulus of elasticity, strength, and density). The third part includes some considerations on the verification of the structure and the design values of the properties in accordance with the structural design codes. For data collection such as dimension measurement or readings with non-destructive equipment, criteria are included that allow for greater representativeness of the load-bearing capacity of the piece with a minimum number of readings. The higher or lower predictive capacity that is usually achieved with these techniques is also shown, which is equivalent to their limitations.

Keywords: evaluation, existing structures, heritage, large cross-section, load-bearing capacity.

Estimating Modulus of Elasticity of Southern Yellow Pine Timber Pile Segments Using Stress Wave Timer

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Abstract

Timber piles serve as substructure components for many bridges in South Carolina, USA, with approximately 75,000 such piles in the state alone. In recent years, South Carolina has experienced isolated timber pile failures, underscoring the urgent need for cost-effective, reliable, and time-efficient techniques to evaluate pile mechanical properties and condition. This paper is part of a larger study focusing on field-deployable methods for estimating pile mechanical properties and detecting decay. In the current paper, stress wave timing is used as a Non-Destructive Evaluation (NDE) method. As noted in its name, this device measures the time it takes for a stress wave to travel through wood, with slower speeds indicating the presence of voids or areas with low density or stiffness. When measured in the longitudinal direction, the velocity of the stress wave is related to the Modulus of Elasticity (MOE) of the wood parallel to the grain. When the wood density is also known, the MOE can be estimated for in-situ piles. This paper compares MOE values measured from destructive load tests of short timber-pile segments with those estimated from stress wave timing. A method for estimating the effective MOE of piles, based on a weighted average of stress wave test results, is demonstrated. This study will inform a forthcoming program that will test longer pile segments.

Keywords: timber piles, non-destructive evaluation, stress wave timing, stiffness.

Session 5 – Wood Quality Assessment in Forestry

Session 5A – Wood Quality Assessment in Forestry

Estimating modulus of elasticity and rupture of wood from *Pinus taeda* and *Platanus* x *hispanica* using pulling tests

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Abstract

Wind damage, frequent in Uruguay, accounts for substantial economic and ecological impacts in both urban and forested landscapes, underscoring the need for reliable assessment tools. Wood properties such as modulus of elasticity (MOE) and rupture (MOR) have been linked to wind resistance of trees. The aim of this work was to correlate wood properties estimated through pulling test with results of laboratory testing on green wood samples, in order to evaluate the use of pulling test as an estimator of wood stiffness and strength. 11 *Pinus taeda* and 10 *Platanus × hispanica* from a forest plantation in northern Uruguay were tested using the 'TreeQinetic system' with a force meter, 2 inclinometers and 4 strain gauges placed between the tree base and 5 m. Trees were first pulled within a non-destructive range and then until failure. Three logs were extracted from each stem at heights of 1 m, 2 m and 4 m. Thirteen samples were cut from each log for static bending tests. Four samples from the outermost part of each log, with moisture content above the fiber saturation point, were tested according to ASTM D143-94. For pine, the mean values of MOE, MOR, and estimated MOE by pulling test (MOEpt) were 3956 MPa, 28 MPa, and 3510 MPa, respectively; for plane tree, the means were 5041 MPa, 38 MPa, and 5823 MPa. Correlations between MOE and MOR with MOEpt were both 0.77. Further analysis is being conducted to develop MOE and MOR prediction models based on MOEpt values.

Keywords: tree stability, non-destructive assessment, green wood properties, static load test.

Inference of Eucalyptus basic density using increment core samples, nondestructive testing, and machine learning

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Abstract

Forest asset management carried out by companies in the pulp and paper sector, as well as in the sawn timber industry, is based on monitoring key tree properties throughout the production chain. Basic density is one of the most relevant properties monitored and is arguably the one that carries the most information contributing to proper asset management. With the increasing demand for wood-based materials and the growing need for fast and reliable information, the use of nondestructive testing (NDT) has proven to be an efficient tool for inferring properties of forest stands, especially when combined with multivariate analysis methods, commonly referred to as machine learning (ML) techniques. This study evaluated the potential of integrating nondestructive testing with machine learning techniques to infer the basic density of eucalyptus clones. A total of 492 trees, aged between 2 and 6 years, from a pulp and paper company were evaluated using dendrometric data, nondestructive testing, and increment core sampling. Seven machine learning algorithms were tested; each undergoing hyperparameter optimization and performance evaluation using metrics such as the coefficient of determination and mean absolute error. The use of samples obtained through an increment borer as input variables in the machine learning models resulted in algorithms with coefficients of determination 4,3% higher than those obtained from models that did not include increment core samples. The inclusion of additional variables in machine learning models can improve their generalization capacity, and in the case evaluated, this inclusion not only improved the performance metrics but also enhanced the understanding of the relationships among forest properties.

Keywords: drilling resistance, ultrasound, machine learning.

Session 5B – Wood Quality Assessment in Forestry

Comparison of the physical and mechanical properties of wood from branches, stems, and roots of urban trees

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Abstract

Urban trees play an important role in improving the urban environment, contributing to the reduction of urban heat islands, flood mitigation, and the enhancement of the population’s quality of life. However, structural changes over time may compromise their stability, requiring the evaluation of their mechanical properties. Considering that wood exhibits structural variability along the tree, this study aimed to assess whether there are statistically significant differences among the physical and mechanical properties of wood from branches, stems, and roots. For this purpose, samples from these three parts were collected from 15 trees belonging to 11 species used in urban forestry. From the samples, polyhedral specimens were prepared and maintained at a moisture content above the fiber saturation point in order to more closely represent the condition of standing trees. The elastic characterization of the wood was performed using ultrasonic wave propagation tests, allowing the determination of the modulus of elasticity, shear modulus, and Poisson's ratios. Basic density and saturated density were also determined. Based on the results of this study, of the 14 physical and mechanical properties evaluated, 43% were statistically equivalent for the wood of the three parts of the tree (root, stem, and branch); 50% were equivalent for root and stem wood; 71% were equivalent for branch and root wood; and 71% were equivalent for branch and stem wood.

Keywords: wave propagation, elastic constants, wood characterization.

Characterizing Annual Ring Structures and Radial Growth Patterns of Fire-Surviving Ponderosa Pines Using Resistance Micro-Drilling

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Abstract

This study investigates the applicability of resistance micro-drilling as a nondestructive evaluation method to characterize annual ring structures and radial growth patterns of ponderosa pine (*Pinus ponderosa* Dougl.) trees on the Plumas National Forest of the western Sierra Nevada, California. Tree cross-sections were collected from harvested trees at approximately 1 meter above ground level on selected plots having different recent fire frequencies and severities. Resistance micro-drilling tests were then performed to capture wood density variations along the radial profile from bark to pith. We hypothesized that changes in drilling resistance corresponding to known fire years could reveal fire-induced changes in radial growth (e.g. ring width) and serve as a proxy for changes in ring density. This presentation reports our preliminary findings from the analysis of resistance profiles, and thereby, evaluates the effectiveness of this method for assessing fire effects on tree growth and wood density.

Keywords: annual ring, drilling resistance, fire, growth rate, nondestructive evaluation, resistance profile, wood density.

Session 5C – Wood Quality Assessment in Forestry

Classification of Eucalyptus Seedlings Using Ultrasonic Wave Propagation and Machine Learning Models

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Abstract

Proper management of raw materials in the pulp and paper industry directly affects the resources allocated at each stage of the production chain, since edaphoclimatic factors and the inherent characteristics of each clone influence the final quality of the wood produced. Genetic tests used to identify clones in cases of accidental mixing of clonal batches have proven to be time-consuming, labor-intensive, and costly, although they remain the most commonly adopted methods by wood-modification companies. Thus, this study aims to use results obtained from nondestructive tests applied to eucalyptus clone seedlings to evaluate several machine learning algorithms for the classification of eucalyptus clones. In this study, three eucalyptus clones from a pulp and paper company were assessed for total height, basal diameter, age, and ultrasonic velocity using seven machine learning algorithms. All classification algorithms underwent a hyperparameter optimization process, and their performance was evaluated using accuracy, precision, recall (sensitivity), and F1-score metrics. The Gradient Boosting algorithm showed superior performance, with all evaluation metrics exceeding 95%, demonstrating the potential of combining machine learning algorithms with nondestructive testing techniques for the classification of eucalyptus clones at the seedling stage.

Keywords: seedling; ultrasound; machine learning; eucalyptus.

Estimation of mechanical properties and knotty core in *Eucalyptus grandis* using acoustic tomography

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Abstract

Eucalyptus grandis is one of the main species used for solid wood production in Uruguay. The quality of logs destined for the timber industry depends on the wood properties and the proportion of clear wood. The conventional method of determining knotty core (KC) involves destructive testing, and there is insufficient evidence on the effectiveness of non-destructive technologies for characterizing KC in standing trees. This study aimed to estimate the mechanical properties of standing trees and the proportion of KC using acoustic tomography. The study was conducted on three forest properties with 9-, 12- and 15-year-old trees under homogeneous silvicultural management. A total of 75 trees were evaluated using an ArborSonic 3D® sonic tomograph. After felling, discs were obtained at 1.30 m, as well as logs measuring 0.50 m and 2.60 m per tree. The KC was measured in the 2.60 m log through veneer peeling; photographs and radius measurements were taken of the disc; eight samples were also obtained from each 0.50 m log for static bending tests to determine the modulus of elasticity (MOE) and rupture (MOR). The dynamic modulus of elasticity (MOEd) was estimated from the tomograph velocities. A weak correlation was found between transverse velocity and MOE and MOR, with no correlations with KC indicators, while transverse MOEd showed a marginal correlation with KC. Longitudinal velocities and longitudinal MOEd showed a correlation with MOE and MOR and with KN. Models for predicting mechanical properties and KC indicators are currently under development.

Keywords: standing tree assessment, sonic tomography, wood quality, internal defects.

Prediction of physical and mechanical properties of Eucalyptus sp. clones using non-destructive tests on standing trees

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Abstract

Wood property characterization is fundamental for assessing material performance in the forestry sector. Non-destructive evaluation (NDE) techniques provide a practical alternative to destructive testing by enabling rapid, cost-effective measurements in standing trees. This study assessed regression models for predicting the physical-mechanical properties of Eucalyptus sp. wood using non-destructive measurements. Field measurements included ultrasound testing, drilling resistance and penetration resistance assessments, tree height, and diameter at breast height (DBH). 162 trees from two different regions (81 per region) were subsequently felled for bending tests and basic density determination. Pearson's correlation and multiple linear regression analyses were performed to predict modulus of elasticity (E_M), bending strength (f_m), and basic density (D_b) at a 95% confidence level. It was possible to generate predictive models for all variables, but the models for predicting basic density (D_b) showed the best fit indicators, with an R^2 of 85%. The best models were obtained using amplitude (Ampl), ultrasound velocity (V_L and V_R), diameter at breast height (DBH), and stiffness coefficient (C_{LL}) as independent variables. These findings demonstrate the effectiveness of NDE techniques for predicting wood properties and support their application in forest management and operational decision-making.

Keywords: drilling resistance, penetration resistance, ultrasound.

Wood Properties of Fire-Surviving Ponderosa Pine Trees in the Plumas National Forest

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Abstract

Deterioration of wood in fire-killed trees is known to cause mechanical property reductions. However, little is known about the changes in wood physical and mechanical properties for live trees with fire histories varying in fire intensity and frequency. The objective of this study is to investigate the influence of wildfire frequency and severity on the wood properties of ponderosa pine (*Pinus ponderosa* Dougl.) trees in the Plumas National Forest of the western Sierra Nevada, California. Eighteen ponderosa pine trees, with diameters ranging from 26.8 cm to 60.8 cm, were harvested during the summer of 2024. The tree samples were distributed across fire treatments as follows: six from an unburned control plot, six from a one-burn plot, and six from a two-burn plot, representing increasing fire frequency and severity. From each tree, a 61-cm (2-ft) bole section centered at breast height was obtained. Small clear specimens (10 ×10 ×160 mm) were prepared from the center plank of each bole and tested in static bending at 12% equilibrium moisture content. This presentation reports preliminary results on the wood properties of fire-surviving ponderosa pines, with a focus on how fire conditions influence wood density, stiffness, and strength.

Keywords: fire scar, mechanical property, modulus of elasticity, modulus of rupture, live trees, wildfire, wood density

Poster session

Condition Assessment of a Wooden Flagpole - Nondestructive Evaluation and Preliminary Laboratory Test Results

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Abstract

Clemson University, Mississippi State University and USDA Forest Products Laboratory scientists conducted a condition assessment of the timbers from a wooden flagpole that had recently been removed from service. The assessment was conducted on the timbers using commonly used stress wave and resistance drilling nondestructive evaluation techniques. Following the assessment, toughness tests were performed on small specimens obtained from the timbers. Compression testing of sections of the timbers is on-going. The nondestructive assessment indicated extensive deterioration of the timber.

Keywords: Structural condition assessment, visual inspection, decay, moisture, timber, flagpole.

A new low-force tree pulling test for inclination, bending, and torsion

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Abstract

Tree failure has significant economic and safety implications. It is crucial to ensure the stability of trees in urban and managed forests. The static pulling test is a well-established technique for evaluating tree stability. In this test, static forces equivalent to dynamic wind loads are applied, and a tree's mechanical response is quantified by measuring stem strain and stem base inclination. Strain gauges on the trunk measure tree deformation to estimate breaking strength. Inclinometers measure stem-base inclination to evaluate anchorage strength. Although this approach is effective for most trees, it has important limitations. Large, stiff trees require high applied forces to generate measurable signals, which increases operational and safety risks. Similarly, structurally compromised trees, such as standing deadwood (snags), can only withstand low forces. Under these conditions, standard sensors may yield poor signal-to-noise ratios, leading to unreliable extrapolations of failure risk. These limitations reveal a critical gap: the inability to accurately detect small mechanical responses under low loading conditions. Additionally, accelerometers can introduce substantial errors when monitoring trees under natural wind excitation. This study evaluates a novel, high-resolution, low-force pulling test designed to overcome these limitations. This method precisely characterizes stem bending, torsion, and inclination under minimal loads, using either controlled rope pulling or natural wind forcing. It expands the applicability and safety of tree stability assessments, improves risk assessment, and enhances our understanding of tree biomechanics. Data were gathered during experimental activities in Germany and Uruguay using this new test, traditional pulling tests, and storm monitoring.

Keywords: tree risk assessment, static load test, tree stability, biomechanics, laser deflectometer, wind sway motion, wind torsion

Analysis of the dynamic modulus of elasticity in urban trees: a case study in *Ulmus pumila* L.

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Abstract

Mechanical properties define the behavior and capacity of wood to resist external forces. Mechanical strength values are of paramount importance for applications in construction, structural elements, and the manufacture of products subject to mechanical stress, as their dimensions depend on the wood's strength and deformation. The study of wood's mechanical properties is carried out for various purposes, such as proposing potential uses for this material, obtaining data for structural calculations, or, in the case of urban tree assessment, determining fall and fracture rates. The objective of this study was to determine the dynamic modulus of elasticity in *Ulmus pimila* L. wood, a species of great importance as an urban tree in Europe. Measurements were taken on standing trees and on felled logs using a stress wave device (Microsecond Timer, Fakopp Enterprise Bt., Hungary) and an ultrasound devices (USLab, Agrisef, Brazil and Sylvatest Duo, CBS-CBT, France). Indirect measurements were taken at two different heights on three specimens of *Ulmus pumila* from urban trees in the city of Madrid, Spain. Once the trees were felled, direct and indirect measurements were taken on logs obtained at the two different heights. Measurements were taken at eight points around the cross-section of the logs and at one point in the central part (pith). On average, direct velocities of 2578.9 m/s (dynamic MOE = 7247.4 MPa) were obtained with a Microsecond Timer, 2869 m/s with a Syvatest Duo (dynamic MOE = 9032.6 MPa), and 3154 m/s (dynamic MOE = 1084.3 MPa) with a USLab.

Keywords: urban tree, stress wave, ultrasound.

Wood Products Stiffness and Strength Prediction by Nondestructive Evaluation Techniques — Energy Loss Parameters with Transverse Vibration and Stress Wave Techniques

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Abstract

The science of nondestructive evaluation has made major contributions to the forest products sector, particularly in predicting the strength of wood materials. Because wood is a biological substance, it naturally exhibits a level of variability not found in many engineered materials. Using nondestructive methods to estimate wood strength forms the basis of structural lumber grading systems, ultrasonic veneer grading processes, and techniques for assessing the condition of wood already in service. During the 23rd International Nondestructive Testing and Evaluation of Wood Symposium (Brazil) we presented a review of the use of nondestructive evaluation techniques to estimate the strength of wood products. Most of the techniques we reviewed focused on the use of various methods to measure the modulus of elasticity as the principle NDE parameter for grading structural lumber. Subsequently, we received a request to provide a review of the use of energy dissipation techniques for assessing wood strength. This paper presents findings in response to this request. It contains the results from a literature review focusing on the use of energy dissipation techniques for estimating wood strength.

Keywords: lumber, composites, wood products, structural, strength, nondestructive evaluation, energy loss, attenuation, damping

Nondestructive Prediction of Young's Modulus in Standing Japanese Larch Trees Using Stress-Wave Velocity

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Abstract

Nondestructive on-site assessment of stiffness in standing trees is important for log sorting and forest inventories. Young's modulus (E) is often estimated from stress-wave velocity (V) and density (ρ) using $E = \rho \times V^2$; however, ρ is difficult to obtain for standing trees, which reduces confidence in E estimates. This study evaluated whether E can be predicted solely from longitudinal V by fitting a simple linear regression ($E = a \times V + b$) calibrated against static E measured after felling. 10 Japanese larch (*Larix kaempferi*) trees (DBH ≈ 45 cm) were tested. Longitudinal stress-wave velocity (V_L) was measured on standing stems at a height of approximately 1 meter above ground level using a stress-wave timer. After felling, stems were sawn into lumber and static Young's modulus (E_S) was determined by four-point bending. Standing-tree V_L measurements were paired with static E_S obtained from lumber sawn from the same tree. Across all specimens, the V_L–E_S relationship was moderate ($R^2 = 0.43$). Internal decay near the ground level was confirmed in three trees during felling and sawing; when these trees were excluded (n = 7), the relationship improved substantially ($R^2 = 0.72$). These results indicate that longitudinal stress-wave velocity on standing trees can serve as a practical, density-independent indicator of stiffness for sound trees without internal decay. However, on-site implementation requires screening for internal decay before applying a prediction equation. Future work will test simple field indicators and complementary NDT methods for decay detection and will define applicability limits using larger datasets.

Keywords: standing-tree, on-site, linear regression, stress-wave velocity, Young's modulus, internal decay

Comparative evaluation of ultrasonic wave propagation using direct and semi-direct methods in three thermally modified wood species

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Abstract

This study comparatively evaluated ultrasonic wave propagation using direct and semi-direct methods in natural and thermally modified woods of cedar (*Cedrela* sp.), eucalyptus (*Eucalyptus* sp.), and pine (*Pinus* sp.). Thermal modification was performed at 180 °C with a heating rate of 0.3 °C/min. Non-destructive evaluation was conducted using an Ultrasonic Microsecond Timer operating at 90 kHz, with transducers positioned parallel (direct method) and perpendicular (semi-direct method) to the wood fibers. The relationship between dynamic modulus of elasticity (MOEd) and static modulus of elasticity (MOE) was evaluated through simple linear regressions. Results showed strong correlations between MOEd and MOE, with coefficients of determination (R^2) ranging from 74.2% to 82.4% for both control and thermally modified woods. The direct method showed 11% higher R^2 for control wood compared to the semi-direct method, demonstrating that wave propagation parallel to the fibers more accurately reflects mechanical behavior. Thermal treatment altered the MOE-MOEd relationship, with control wood showing lower data dispersion and thermally modified wood exhibiting greater variability. In the direct method, a 46.7% reduction in slope coefficient was observed after thermal treatment, while the semi-direct method showed a 27% increase, indicating higher sensitivity of transverse propagation to thermal modifications. The results confirm that ultrasonic wave propagation is a reliable method for estimating MOE in both natural and thermally modified wood, with the choice of testing method being crucial for estimate reliability.

Keywords: non-destructive testing, modulus of elasticity, wood anisotropy, transverse propagation, dynamic properties

In situ Moisture Content and Strength of Creosote-Treated Southern Yellow Pine Bridge Piles in South Carolina

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Abstract

Timber piles are common substructure components for bridges in South Carolina, and more broadly across the United States. There are approximately 75,000 timber piles supporting bridges in South Carolina, and as they age, environmental factors cause damage, leading to an increased need for repair and replacement. In some cases, engineers perform a 'load rating' analysis of the pile's capacity to inform decisions to retain, repair, or replace the pile. Current load rating procedures make assumptions about pile characteristics that may not accurately represent variations in material properties throughout the length of a timber pile. This study seeks to assess material properties above- and below-grade of in situ creosote-treated southern yellow pine timber piles. Researchers conducted two experimental programs: the first assessed gross density, stress-wave transmission time and the ultimate compressive strength parallel to grain, of piles salvaged from a bridge demolition in South Carolina. A second program assessed moisture content in above- and below-grade timber piles recently removed from service in South Carolina. Differences in density, transverse stress-wave transmission time, and ultimate compressive strength were observed between above- and below-grade pile segments. The reduced below-grade compressive strength found in Program one is consistent with previous studies and was likely a result of several factors, including differences in moisture content, creosote concentration, and intra-pile strength variation. Program two found differences in above- and below-grade moisture content, with elevated moisture content in the pile just below the pile cap and below grade.

Keywords: timber piles, ultimate compressive strength, stress wave transmission time, moisture content, above grade, below grade.

Nondestructive Assessment of Stiffness in Thermally Modified U.S. Wood Species

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Abstract

Thermally modified wood (TMW) is a chemical-free wood with improved dimensional stability, durability, and fungal resistance to decay, offering an environmentally friendly alternative to chemically treated wood. However, the reduction in some mechanical properties of some species after heat treatment restricts the overall TMW use for structural applications. Nondestructive testing method is a rapid and effective approach for assessing the stiffness variations without damaging the wood. Thus, this study will investigate the effects of thermal modification on mechanical properties of three wood species: southern yellow pine (*Pinus* spp.), yellow poplar (*Liriodendron tulipifera* L.), and white ash (*Fraxinus americana*) using nondestructive testing. The dynamic modulus of elasticity will be measured using the transverse vibration method with a Metriguard E-computer. The results from thermally modified samples will be compared with that of control, to determine if thermal modification improves the wood performance. This study will provide information on species-specific changes in stiffness due to thermal modification.

Keywords: thermal modification, dynamic modulus of elasticity, transverse vibration

Evaluating Bending Performance of Fence Posts using Acoustic Non-Destructive Testing Approaches

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Abstract

The reliable assessment of in-service fence posts is critical for ensuring structural safety, minimizing unexpected failures, and enabling sustainable asset management. Conventional static bending tests provide accurate measurements of modulus of elasticity (MOE) and modulus of rupture (MOR) but are destructive, time-consuming, and unsuitable for field inspections. This study investigates the feasibility of using acoustic non-destructive testing (NDT) to evaluate the bending performance of small-diameter round Southern Yellow Pine (SYP) fence post. Forty round SYP poles were tested using an acoustic stress-wave device (Hitman®, New Zealand) to measure longitudinal wave velocity and calculate dynamic modulus of elasticity (MOE_dyn). Static bending tests were subsequently conducted to determine static MOE (MOE_stat) and MOR. In addition, growth ring characteristics were quantified at both butt and top sections. Statistical correlation and regression analyses were performed to evaluate relationships among acoustic velocity, MOE_dyn, MOE_stat, and MOR. The results demonstrate weak correlations between MOE_dyn and MOE_stat, as well as weak correlations with MOR. These findings were influenced by anomalous acoustic velocity data in several specimens, suggesting that measurement protocols require refinement to account for the unique characteristics of small-diameter round poles. Despite these challenges, the study establishes that acoustic NDT holds promise for rapid field assessment when combined with improved testing procedures. Integrating acoustic measurements with static bending performance and growth ring characteristics provides a foundation for the development of rapid, reliable, and non-destructive inspection systems for in-service utility poles.

Tree Risk Assessment in an Urban Avenue: Analysis of Integrated Sonic Tomography and Resistograph Investigations on Monumental Trees

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Abstract

Urban tree risk evaluation in Italy commonly relies on Visual Tree Assessment VTA (VTA) frameworks that culminate in a Statically Integrated Assessment (SIA) “Classe di Propensione al Cedimento” (CPC) (Failure Propensity Class). While effective for screening, visual assessment alone can be subjective, especially in long-lived, repeatedly pruned urban trees where external cues poorly predict internal condition. We report results from a non-destructive testing (NDT) campaign on 100 *Platanus* × *hispanica* along a high-use pedestrian boulevard (Praia a Mare, Calabria region). Each tree was assessed with sonic tomography (ArborSonic 3D Acoustic Tomograph) at multiple stem heights (typically 20–200 cm) and drilling resistance (Resistograph) targeted to primary and secondary scaffold branches flagged during VTA. Sonic tomograms quantified internal section loss and safety factors under standardized load assumptions, while drilling profiles resolved the presence, depth, and continuity of cavities/low-density zones at critical attachment points. We combined these metrics in a transparent decision workflow: (*i*) VTA pre-screen; (*ii*) tomographic grid to qualify stem integrity and trend with height; *(iii*) targeted resistography to confirm or rule out defects in the crown; (*iv)* rule-based mapping to SIA CPC with explicit, minimally invasive prescriptions compatible with monumental-tree stewardship. The integrated approach delivered three main outcomes. First, it reduced classification uncertainty, distinguishing superficial scars from structurally relevant decay and confirming high stem safety where tomograms were intact. Second, it localized actionable defects in the crown (e.g., branch insertions with discontinuous residual rings), allowing minimally invasive, branch-level prescriptions (selective reduction, dynamic support, or removal) instead of conservative whole-tree downgrades. Third, it standardized follow-up, tying CPC to measurable thresholds (e.g., residual wall trends, repeat profiles) and cadence (annual visual vs. biennial instrumented checks). Overall, our data showed~~s~~ that coupling tomography and drilling resistance provides a practical, scalable path to more objective and defensible CPC assignments urban trees, improving public-space safety while preserving heritage avenues through targeted, data-driven maintenance.

Keywords: *Platanus orientalis* L., tree stability; arboriculture, decay detection, risk evaluation

Wood grading from a forest stand using ultrasonic techniques at different stages of the production chain

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Abstract

The wood supply chain involves decision-making processes that depend directly on the intended final use of the material. Several processing steps are costly and may result in significant economic losses if applied to wood that does not meet minimum physical and mechanical performance requirements. In this context, forest-based industries increasingly demand reliable methods for early prediction of wood quality along the production chain.
This study investigates the applicability and effectiveness of ultrasonic nondestructive testing techniques at different stages of wood processing—standing trees, logs, and sawn boards—within a forest stand managed for Glue-Laminated Timber (Glulam) and Cross-Laminated Timber (CLT) production. A total of 20 trees were selected, producing 60 logs and 260 boards. Longitudinal ultrasonic measurements were performed on standing trees and, after felling, on logs. The resulting boards were evaluated using ultrasonic testing in both green (saturated) and kiln-dried (conditioned) states. Conditioned boards were additionally subjected to visual grading and static bending tests in accordance with Brazilian and European standards.
The classifications obtained from static bending tests were compared with grade estimations derived from ultrasonic measurements at each production stage. The results demonstrate that ultrasonic techniques show the highest predictive efficiency when applied to processed wood, followed by logs and, to a lesser extent, standing trees. These findings highlight the potential and current limitations of ultrasonic methods for early-stage wood quality assessment and contribute to optimizing decision-making processes within the industrial timber production chain.

Keywords: nondestructive testing, ultrasound, wood quality, glulam, CLT

USS *Cairo*: A Preliminary Assessment of Potential Conservation Solutions through Aesthetic Testing

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Abstract

The Union gunboat USS *Cairo* was initially raised from the Yazoo River in the 1960s and conserved by amateurs working with the best of intentions. Despite efforts by the National Park Service to stabilize the ship in the 1970s and continued improvements to curation conditions, it now suffers from a wide variety of problems including: extensive checking and peeling, significant material loss, and multiple types of both discoloration and powder generation. Because of the size of the artifact and climate control issues in its curation pavilion, the ship was approached as an architectural feature rather than as an artifact. This allowed a broader and more interventive range of treatments to be considered. Initial testing began by environmental monitoring to gain a better understanding of the variation in ambient humidity and temperature. Once we understood the curation details, we used samples of USS *Cairo*'s wood to determine whether consolidants common in architectural preservation could prevent further deterioration of the ship without dramatically altering the viewing experience. Multiple coating types and thicknesses were investigated using colorimetry, glossmeters, photography, and laser scanning to determine potential aesthetic effects on the wood, an important component of artifact curation. Analysis was completed in preparation for future accelerated aging experiments and abrasion testing to determine the efficacy of potential treatments, allowing us to better understand the full range of conservation options for lengthening the life of large, difficult to curate objects like shipwrecks.

Keywords: archaeology, conservation, aesthetic testing.