22nd International Nondestructive Testing and Evaluation of Wood Symposium

May 24-27, 2022
Quebec City, Quebec, Canada

Conference Guidebook

Forest Products Society

Université Laval

Renewable Materials Research Centre

Forest Products Laboratory
Research Working For You

Forest Service U.S. Department of Agriculture

IUFRO

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FPInnovations MD

Mississippi State University

Welcome

22nd International Nondestructive Testing and Evaluation of Wood Symposium

Co-hosted by the Renewable Materials Research Center (CRMR) of Université Laval, the USDA Forest Products Laboratory (FPL), the Forest Products Society (FPS), and sponsored by the International Union of Forestry Research Organizations (IUFRO) Division 5, Mississippi State University, and FPInnovations

Conference Chairs

- Dr. Robert J. Ross, Project Leader, USDA Forest Products Laboratory, USA
- Dr. Alexis Achim, Professor, Université Laval, Canada

International Organizing Committee

- Dr. Robert J. Ross, Project Leader, USDA Forest Products Laboratory, USA
- Dr. Xiping Wang, Research Forest Products Technologist, USDA Forest Products Laboratory, USA
- Dr. Alexis Achim, Professor, Université Laval (UL)
- Dr. Laszlo Bejo, University of West Hungary, Hungary
- Dr. Raquel Gonçalves, University of Campinas, Brazil
- Dr. Francisco Arriaga Martitegui, Universidad Politécnica de Madrid, Spain
- Dr. Udo H. Sauter, Forest Research Institute Baden-Württemberg, Germany
- Dr. C. Adam Senalik, FPL, USA
- Dr. Houjiang Zhang, Beijing Forestry University, China

Local Organizing Committee

- Dr. Alexis Achim, Professor, Université Laval
- Claude Durocher, Research Associate, Université Laval
- Dr. Rosilei A. Garcia, Research Associate, Université Laval

Student Scholarship Winners

Karen Christina de Freitas

P.h.D., Agricultural Engineering, Concentration in Nondestructive Methods Applied to Materials, Structures and Trees, State University of Campinas, Brazil

Bakare Misirat Bisola

M. Tech., Wood Science and Technology, Federal University of Technology Akure, Nigeria

Isaac Nyarko

Ph.D., Forestry Engineering major Wood Processing and Forest Machinery, Czech University of Life Sciences

Carolina Kravetz

P.h.D., Agricultural Engineering, Concentration in Nondestructive Methods Applied to Materials, Structures and Trees, State University of Campinas, Brazil

Achraf Ammar

M.Sc., Engineering, Concentration of Renewable Materials, Université du Québec en Abitibi-Témiscamingue, Canada

Abel Feyisa

M.Sc., Biodiversity Conservation and Management, 2nd M.Sc., Aquatic Ecosystem and Environmental Management, Faculty of Science, Addis Ababa University, Ethiopia

Thanks for our Scholarship Sponsor!

FPInnovations MD

Content

Program Schedule

	Tuesday, May 24, 2022 **Pre-symposium Technical Workshop** Nondestructive Testing and Evaluation of Wood for Cultural Uses	Wednesday, 25 May, 2022 **Day 1**	Thursday, 26 May, 2022 **Day 2**	Friday, 27 May, 2022 **Day 3**
6:30			30 min Morning run	
8:00		**Registration**	**Registration**	**Registration**
8:30	**Coffee and Pre-Symposium resgistration**	**Opening Ceremony** Alexis Achim, CRMR, Université Laval // Robert Beauregard, Executive Vice Rector of Academic and Student Affairs, Univeristé Laval // Mohammad-Sadegh Mazloomi, FPInnovations	**Technical Session #2A**	**Mixed Session (Online)**
9:00	**Welcome note** **Keynote** Alexis Achim, CRMR, Université Laval	**General Session** **In-Forest Wood Quality Assessments - Where We Are with NDT Technologies?** X. Wang* & R. J. Ross, USA		
9:30	**Nondestructive Evaluation of Historic Artifacts and Structures** R. J. Ross, USDA, Forest Service, USA	**Industrial CT Scanning in Wood Research** J. Couceiro*, L. Hansson, D. Sandberg & E. Ursella, SWEDEN		
10:00	**Coffee Break + Basket Exhibition**	**Coffee / Tea** - 30 min	**Coffee / Tea** - 30 min	**Coffee / Tea** - 15 min
10:30	**Black Ash – A Culturally Important Species** Laurence Boudreault, CRMR // Selection criteria for basketry / Nondestructive method demonstration / Pounding demonstration	**Technical Session #1A**	**Technical Session #2B**	**Mixed Session (Online) // Technical Session 3A**
11:00				
11:30			**Lunch** - 1h30 min	
12:00	**Lunch** - 1h30 min	**Lunch** - 1h30 min		**Lunch** - 1h
12:30				
13:00			**Tour and Banquet** Visit Art Massif Wood Structure // Ras-L'Bock Microbrewery - An Art Massif realization // Banquet to Louis Hébert restaurant	**Technical Sessions #3B and #5A**
13:30	**Dating Historic Buildings** Martin Simard, Centre for Northern Studies, CANADA	**Technical Sessions #1B and #4**		
14:00	**Visit Gene-H.-Kruger Building** Benoit St-Pierre // Alexandre Morin-Bernard, CRMR			
14:30				
15:00	**Visit Université Laval TELUS Stadium** Simon T. Bellavance, Cecobois // Vadim Siegel, ABCP	**Coffee / Tea** - 15 min		**Coffee / Tea** - 15 min
15:30		**Poster Session // Technical Session #6**		**Techinical Session #5B**
16:00				**Closing Remarks**
16:30				
17:00	**Welcome Reception** CRMR, Université Laval			
17:30				
21:00				
22:00				

Venue

Conference room: Gilbert Tardif (GHK-2320-2330), 2nd floor
Renewable Materials Research Center (CRMR), Université Laval • Pavillon Gene-H. Kruger, 2405 Rue de la Terrasse
Québec, QC G1V 0A6 CANADA • Tel.: +1 (418) 656-2131

Contact

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Rosilei A. Garcia: Rosilei.Aparecida-Garcia@sbf.ulaval.ca

Map of Laval University Campus

PAVILIONS AND BUILDINGS

- Centrale d'eau refroidie (CER) 10
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- Complexe des serres de haute performance 14
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- Édifice La Fabrique 2
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- Pavillon des Services (PSA) 18
- Pavillon d'Optique-photonique (COP) 12
- Pavillon Envirotron (EVT) 16
- Pavillon Félix-Antoine-Savard (FAS) 28
- Pavillon Ferdinand-Vandry (VND) 19
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Parking Zones - Categorie -1 -2 -3 - Resident

Exclusive bus lane

Underground lanes

Toll booths (parking permits by the hour)

Electric charging station

Le Point - Service and Information

Detailed Program Schedule

Tuesday, May 24, 2022
Pre-Symposium Technical Workshop
Nondestructive Testing and Evaluation of Wood for Cultural Uses

8:30 **Coffee and Pre-Symposium registration**

9:00 **Welcome Note**
Alexis Achim, Renewable Materials Research Centre, CANADA

Nondestructive Evaluation of Historic Artifacts and Structures
Robert Ross, USDA, Forest Service, USA
This presentation focuses on the condition assessment of historic artifacts and structures. Part one of the presentation will focus on a review of commonly used nondestructive evaluation techniques, and interpretation of results obtained from their use. Part two will provide a review of assessments for a variety of historic materials and structures.

10:00 **Coffee Break + Basket Exhibition**

10:30 **Black Ash – A Culturally Important Species**
Laurence Boudreault, Renewable Materials Research Centre, CANADA
Selection criteria for basketry / Nondestructive method demonstration / Pounding Demonstration
The implications of species loss are particularly difficult when they hold value for ecological and cultural goods and services. Black ash in QC, for example, is a species of great importance to the Waban-Aki Nation's cultural and spiritual practices, yet is known to be highly impacted by the introduction of an exotic insect (*Agrilus planipennis*). Working through dialogue and understanding with the Waban-Aki Nation, Laurence Boudreault (PhD) will document the properties that give black ash its cultural importance and co-construct potential strategies to maintain cultural activities currently depending on it. Through her research she's co-developing tools and strategies to maintain the weaving activities fundamentally important to the Waban-Aki Nation by ensuring access to quality black ash.

12:00 **Lunch**

13:30 **Dating Historic Buildings**
Martin Simard, Centre for Northern Studies, CANADA

14:00 **Visit Gene-H.-Kruger Building**
Guide tour by Benoit St-Pierre / Alexandre Morin-Bernard, Renewable Materials Research Centre, CANADA
The Gene-H.-Kruger building is the hub of teaching, innovation, and development of wood sciences at Université Laval. It provides a showcase for the use of engineered wood products in construction, elements of which are featured in the labs, classrooms, meeting venues and administrative buildings that comprise this 8,000 m² complex. Virtual visit.

15:00 **Visit Université Laval TELUS Stadium**
Guided tour by Simon T. Bellavance, Cecobois consulting firm in wood construction & Vadim Siegel, Architecture ABCP, CANADA
The TELUS stadium is part of a large-scale project, the regional expansion project of the PEPS sports building at Université Laval. The stadium has a magnificent main frame constructed of glued laminated timber, being an example of sustainable construction. This structural choice avoided the emission of around 1,500 tonnes of CO2. See pictures of the TELUS Stadium.

17:00 **Welcome Reception**
Renewable Materials Research Centre, Université Laval

22nd International Nondestructive Testing and Evaluation of Wood Symposium | May 25-27

Wednesday • May 25, 2022 • **Day 1**

8:00 **Registration**

8:30 **Opening Ceremony**

Alexis Achim, Renewable Materials Research Centre, Université Laval, Canada
Robert Beauregard, Executive Vice Rector of Academic and Student Affairs, Université Laval, Canada
Mohammad-Sadegh Mazloomi, FPInnovations, Canada

9:00 **General session**

Moderator: Bruce Allison, USA

In-Forest Wood Quality Assessments - Where Are We with NDT Technologies?
Xiping Wang* & Robert J. Ross, USA

Industrial CT Scanning in Wood Research
José Couceiro*, Lars Hansson, Dick Sandberg & Enrico Ursella, Sweden

Questions and comments

10:00 **Coffee/Tea**

10:30 **Session 1A: Nondestructive Characterization of Wood and Wood-Based Materials**

Moderator: Laszlo Bejo (Hungary) and Udo H. Sauter (Germany)

10:30 – 11:45 ID-09: Effects of Microwave Radar Sensor Distance and Material Thickness on Density and Moisture Content Determination, Laszlo Bejo*, Mihaly Jakocs & Ahmed Altaher Omer, Hungary

10:45 – 11:00 ID-17: Comparison between Static Modulus of Elasticity and NonDestructive Testing Moduli of Elasticity in White Spruce and Lodgepole Pine Wood, Cyriac Mvolo*, James D. Stewart & Ahmed Koubaa, Canada

11:00 – 11:15 ID-18 Evaluation of Elastic Constants of Oil Palm Wood Using Ultrasonic Measurement, Katja Fruehwald-Koenig*, Benedikt Faust, Germany

11:15 – 11:30 ID-21: Estimation of the moisture content in wood by combination of Neutron and X-ray imaging, José Couceiro*, Lars Hansson, Dick Sandberg, David Mannes & Peter Niemz, Sweden

11:30 – 11:45 ID-33: Nondestructive Model for Predicting the Mechanical Properties of Wood in Southwest, Nigeria, Lawrence Aguda*, Misirat Bakare & Ige Oluwagbemiga, Nigeria

11:45 – 12:00 ID-36: Comparative Estimation of Acoustic Velocity and Strength Properties of Down Pine Trees Using Near Infrared Spectroscopy, Munkaila Musah*, Javier Hernandez Diaz, Dana Mitchell, Mathew Smidt, Yucheng Peng, Tom Gallagher, Maria S. Peresin & Brian Via, USA

12:00 **Lunch**

13:30 **Session 1B: Nondestructive Characterization of Wood and Wood-Based Materials**

13:30 – 13:45 ID-40: Nondestructive Determination of the Within-Ring Wood Dynamic Modulus of Elasticity for Black Spruce and Jack Pine, Wassim Kharrat*, Ahmed Koubaa, Mohamed Khlif & Chedly Bradai, Canada

Session 4: NDE of Sawn Logs for Optimal Utilization

Moderator: Ahmed Koubaa (Canada)

13:45 – 14:00 ID-45: Small-Diameter Logs from Oak for Structural Purposes – Determination of Mechanical Properties by NonDestructive and Destructive Testing, Nicolas Hofmann, Franka Brüchert*, Udo H. Sauter, Kay-Uwe Schober & Beate Hörnel-Metzger, Germany

14:00 – 14:15 ID-11: Distribution of Wetwood in Silver Fir (*Abies alba* MILL.) – A Prerequisite for Nondestructive Testing Mechanical Characterisation of Logs, Franka Brüchert*, Guénaël Klotzbücher, Martin Huber & Udo H. Sauter, Germany

14:15 – 14:30 ID-13: Using X-Ray Computed Tomography (CT) Scanning to Optimize Log Primary Breakdown in Plantation-Grown White Spruce (*Picea glauca* (Moench) Voss), Isabelle Duchesne*, Queju Tong & Patrick Lenz, Canada

14:30 – 14:45 ID-27: Nondestructive Testing of Timber Prior to Sawing Using Finite Element Models Based on X-Ray Computed Tomography Data - A Preliminary Study, Johannes A. J. Huber*, Olof Broman, Johan Oja, Lars Hansson & Mats Ekevad, Sweden

14:45 – 15:00 ID-47: Evaluation of Sawmill Log Scanners with Comparison to Forest Harvester Measurements, Kari Hyll* & Maria Nordström, Sweden

15:00 **Coffee/Tea**

15:15 **Poster session**

Moderator: Alexis Achim (Canada)

15:15 – 15:30 ID-64 Approved Method for Efficient Inspection and Documentation of Not Only Historic Timber Structures based on Results Obtained in Hundreds of Successful Projects Since 1988, Frank Rinn*, Germany

15:30 – 15:45 ID-49: Urban Green Spaces and How They Affect Woody Species Diversity and Biomass Carbon Stock in Hawassa, Ethiopia, Abel Woldeyohanis*, Mesele Negash, Yoseph Melka, Ethiopia

Session 6: Condition Assessment of Historic Wood Artifacts and Structures

Moderator: Isabelle Duchesne (Canada)

15:45 – 16:00 ID-35: Mechanical Performance and Nondestructive Test of Demolished Timber Collected from a Wooden Building Several Hundred Years Old, Erina Kojima*, Hideo Kato, Yasutaka Watanabe, Ken Yamamoto & Ichirou Saitou, Japan

16:00 – 16:15 ID-61: Using Dielectric Orthotropy as an Indicator of Internal Decay of Wood Members, C. Adam Senalik*, James P. Wacker, Benjamin Farber & Xiping Wang, USA

* Presenter

Thursday • May 26, 2022 • **Day 2**

8:00 Registration

8:30 **Session 2A: In-Forest Wood Quality Assessments**

Moderator: Xiping Wang (USA) and Franka Brüchert (Germany)

8:30 – 8:45 ID-01: Using Time-of-Flight Acoustic Velocity to Assess the Modulus of Elasticity and Bending Strength Properties of White Spruce from Tree Improvement Experiments, Iman Rashidi-Jouybari*, Alexis Achim, Patrick Lenz, Jean Beaulieu & Jean Bousquet, Canada

8:45 – 9:00 ID-34: Nondestructive Characterization of Sugar Maple Wood Decay and Modulus of Elasticity by Acoustic Tomography, Achraf Ammar, Ahmed Koubaa*, Dorra Gassara, Yves Bergeron, Pierre Grondin & David Voyer, Canada

9:00 - 9:15 ID-15: Effect of Partial Harvesting on Growth, Density, and Dynamic Modulus of Elasticity of White Spruce in a Mixed Boreal Forest, Md Nazrul Islam, Ahmed Koubaa*, Brian Harvey & Suzanne Brais, Canada

9:15 - 9:30 ID-29: Effect of Silvicultural Practices on Basic Wood Density of Sugar Maple in Lake States Region, Chinmoyee Das, Peng Quan, Xinfeng Xie*, Yvette Dickinson, Xiping Wang, Robert J. Ross & Christel C. Kern, USA

9:30 - 9:45 ID-31: Differentiation of Eucalyptus Clone Seedlings by Nondestructive Tests and Machine Learning Methods, Rafael Gustavo Mansini Lorensani*, Cinthya Bertoldo Pedroso, Raquel Gonçalves & Isabela Constantino de Toledo, Brazil

9:45 – 10:00 ID-32: Distinction of Eucalyptus Planting Areas Through Data Mining, Carolina Kravetz*, Cinthya Bertoldo, Rafael Mansini Lorensani & Fernanda Trisltz Perassolo Guedes, Brazil

10:00 **Coffee/Tea**

10:30 **Session 2B: In-Forest Wood Quality Assessments**

10:30 – 10:45 ID-14: Dynamic Modulus of Elasticity in *Calophyllum brasiliense* Cambess Trees from Bajo Calima (Colombia), Julio Bermúdez Escovar*, Roger Hernández, Alexis Achim & Claudia Cáceres, Canada

10:45 – 11:00 ID-37: Field Assessment of Downed Timber Strength Deterioration Rate and Wood Quality Using Acoustic Technologies, Munkaila Musah*, Javier Hernandez Diaz, Dana Mitchell, Mathew Smidt, Tom Gallagher, Maria S. Peresin & Brian Via, USA

11:00 – 11:15 ID-60: Models for Predicting the Within-Tree Variation of Ultrasonic Velocity and Dynamic Modulus of Elasticity for Plantation Loblolly Pine, David Auty*, Joseph Dahlen, Thomas L. Eberhardt, Laurence Schimleck & Nawa Pokhrel, USA

11:15 – 11:30 ID-19 Electric Resistance Tomograph: A Nondestructive Testing Approach to Valuation of High-Value Trees of India, Baragur Divakara*, S. Chaithra & C Balaji, India

* Presenter

11:30 **Lunch**

Tour and Conference Dinner

13:00	**Bus departure from Renewable Materials Research Centre to Saint-Jean-Port-Joli** (duration: 1 h 8 min)
14:10	**Visit Art Massif Wood Structure** Art Massif designs and manufactures original, superior-quality glued-laminated timber structures. They have an extensive portfolio of commercial, cultural, educational, and historical renewal buildings among others that are true works of art in wood.
16:00	**Bus departure from Art Massif to Ras-L'Bock Microbrewery (duration: 6 min)**
16:10	**Visit Ras-L'Bock Microbrewery – An Art Massif Realization** This two-level building houses a restaurant on the ground floor and a bar upstairs. Facing the mighty St. Lawrence River, the wavy glulam structure echoes the river's waves offshore. On the large outside terraces, guests can enjoy the location's beauty during the warmer months.
17:00	**Bus departure from Ras-L'Bock Microbrewery to Laval University or Old-Quebec (duration: 1 h 10 min)**
18:10	Free time
19:10	**Bus departure from Laval University to Old Quebec (duration: 10 min)**
19:30	**Banquet at Louis Hébert Restaurant** French cuisine restaurant located on Grande-Allée Est in the heart of Old Quebec
22:00	**Bus departure from Old Quebec to Laval University (duration: 10 min)**
	More details: Art Massif Wood Structure // Restaurant Louis Hébert

Friday • May 27, 2022 • **Day 3**

8:00	**Registration**
8:30	**Mixed session (Online)** Moderator: Alexis Achim (Canada) **8:30 – 8:45** ID-59: Relation of Ultrasonic Wave Velocity and Compression Strength of Artificially Decayed Wood, Kana Yamashita*, Hirofumi Ido, Yuko Ota & Toshihiro Yamada, Japan **8:45 – 9:00** ID-08: Combining Nondestructive Testing Technology and Digital Twin for Preventive Conservation of Wooden Cultural Relics, Xueyi Ma, Jian Zhao*, Puxiang Wang, Yuankai Weng, Lihua Fei & Dong Zhao*, China **9:00 – 9:15** ID-42: Influence of Moisture Content on Mechanical Properties and Damage Forms of Ancient Timber Members, Zhenbo Xin*, Houjiang Zhang, Dongfang Ke & Yongzhu Yu, China **9:15 – 9:30** ID-48: Nondestructive Evaluation of the Concealed Wood Columns in Historic Buildings, Houjiang Zhang*, Zhenbo Xin, Yongzhu Yu, Dian Zhang & Hui Wang, China **9:30 – 9:45** ID-51: Flexible Machine Strength Grading: Using Acoustic Nondestructive Testing of Green Sawn Timber to Calculate Grading Settings for Individual Batches of Spruce Sawn Timber, Andreas Weidenhiller* & Andreas Neumüller, Austria **9:45 – 10:00** ID-52: Nondestructive Detection and Three-Dimensional Mapping of the Root System of an Ancient Camphor Tree Based on Ground-Penetrating Radar, Zhang Xiaowei, Wang Zepeng, Xue Fangxiu, Li Haibin, Li Shuang & Wen Jian*, China
10:00	**Coffee/Tea**

10:15 **Mixed Session (Online)**

10:15 – 10:30 ID-39: Nondestructive Timber Testing as a Tool to Detect Depletion of Carbon Storage in Stem of Aspen, Linda Čakša, Laura Ķēniņa, Nauris Siksna, Kristaps Ozoliņš, Ieva Jaunslaviete & Āris Jansons*, Latvia

10:30 – 10:45 ID-46: Loading Resistance of Silver Birch (*Betula pendula* Roth.) and Eurasian Aspen (*Populus tremula* L.) in Urban and Peri-urban Forests, Oskars Krišāns, Linda Čakša, Roberts Matisons, Steffen Rus, Didzis Elferts, Andris Seipulis & Āris Jansons*, Latvia

10:45 – 11:00 ID-12: Near-Infrared Spectroscopy Coupled with Chemometric Analysis as a Valuable Nondestructive Tool for Prediction of Carbon Content in Wood Samples, Iris Beatriz Vega Erramuspe*, Dana Mitchel, Jason Thompson, Thomas Elder & Brian Via, USA

11:00 – 11:15 ID-07: Assessment of Incipient Decay on Wood Using Stress Wave Technique, Tamara Franca*, Brianna Duquette, Adam Senalik & Robert Ross, USA

Session 3A: NDE for Urban Trees

Moderator: C. Adam Senalik (USA) and Raquel Gonçalvez (Brazil)

11:15 – 11:30 ID-23: Tree Risk Assessment: Systemic Approach Involving Nondestructive Techniques and Tree Biomechanics, Raquel Gonçalves*, Gustavo Garcia, Karen Freitas, Mariana Reis, Stella Palma, Camila Linhares & Monica Ruy, Brazil

11:30 –11:45 ID-24: Use of Tomographic Images to Support the Inference of Strength Loss in Trunk Using Equations from Literature, Mariana Nagle dos Reis, Raquel Gonçalves* & Camila Stephanie Fernandes Linhares, Brazil

11:45 – 12:00 ID-25: Influence of the Manner of Obtaining Coordinates of Contour of Irregular Discs in Tomographic Images, Stella Stopa Assis Palma, Mariana Nagle dos Reis & Raquel Gonçalves*, Brazil

12:00 – 12:15 ID-26: Adjustment of Ultrasonic Tomography Velocity Ranges to Represent the Variations within Tree Trunks Using Confusion Matrix Metrics, Stella Stopa Assis Palma, Mariana Nagle dos Reis & Raquel Gonçalves*, Brazil

12:15 **Lunch**

13:15 **Session 3B: NDE for Urban Trees**

13:15 – 13:30 ID-62: Visual Tree Assessment and Static Integrated Assessment Do Not Allow Breaking Safety Evaluation of Defective Stems of Mature Urban Trees, Frank Rinn*, Germany

13:30 – 13:45 ID-63: Biomechanical and Mathematical Basics of “Allometric Self-Referencing” for Evaluating Breaking Safety of Defective Stems of Mature Urban Trees, Frank Rinn*, Germany

13:45 – 14:00 ID-38: Dynamic Tree Stability: Improved Testing Methodology and Indications of Reliability, Laszlo Bejo*, Imre Sumegi & Ferenc Divos, Hungary

14:00 – 14:15 ID-41: Comparing the Stability of the Trees in Different Seasonal and Weather Conditions by Using Nondestructive Method, Ferenc Divos, Laszlo Bejo & Shadabeth Fathi*, Hungary

14:15 – 14:30 ID-20: Identification of Wood Decay and Hollowness in Standing Tress using Electric Resistance Tomograph: A Nondestructive Testing Approach, Baragur Divakara*, S Chaithra & C Balaji, India

Session 5A: Advanced Grading Technologies for Solid Wood and Engineered Wood Products

Moderator: Xinfeng Xie (USA)

14:30 – 14:45 ID-03: Prediction of Tensile Modulus of Elasticity from Longitudinal and Transverse Natural Frequencies in Hardwood Species, Gonzalo Moltini*, Gonzalo Cabrera & Vanesa Baño, Spain

14:45 – 15:00 ID-30: Influence of Board Geometry on the Determination of Dynamic Mechanical Properties of Structural Lumber, Aleš Straže* & Luka Krajnc, Slovenia

15:00 **Coffee/Tea**

15:15 **Session 5B: Advanced Grading Technologies for Solid Wood and Engineered Wood Products**

15:15 – 15:30 ID-43: Strength Grading Softwood Structural Lumber with MoE Low Point, Jon Shanks*, Richard Schaffner, Geoff Boughton & James Szabadics, Australia

15:30 – 15:45 ID-44: Challenges and Opportunities Toward the Use of Northern Hardwood Species in Glued-Laminated Timber in Canada, Alexandre Morin-Bernard*, Alexis Achim & Pierre Blanchet, Canada

15:45 – 16:00 ID-54: Local Modulus of Elasticity by Constrained Optimization, Friend K. Bechtel*, USA

16:00 – 16:15 ID-58 Using Acoustic Tomography Techniques to Estimate Bending Properties of Cross-Laminated Timber, Frederico Jose Nistal França*, Christopher Adam Senalik, R. Daniel Seale, Robert J. Ross & Rubin Shmulsky, USA

16:15 **Closing Remarks**

* Presenter

Post-Symposium Tour

Saturday, May 28, 2022 • Optional tour

Sightseeing Tour of Old Quebec (Optional Tour)
20 participants maximum

Sightseeing tour of Old Quebec from the perspective of wooden heritage guided by a historian and an architect specializing in heritage

9h00	**Visit of the Dufferin Terrace** Presentation of the history of Quebec City and the historical site of the Terrace by D. Mendel (10 min walk to get to the Ursuline grounds)
9h45	**Visit of the Ursuline Chapel** (10 min walk to Holy Trinity)
10h40	**Visit of the Holy Trinity Anglican Cathedral** (10 min walk to the Petit Séminaire de Québec)
11h30	**Interior courtyard of the Petit Séminaire de Québec**
11h35	**Laval University School of Architecture** (10 min to get to Augustine's Monastery)
12h25	**Lunch at the Augustine's Monastery**
13h30	**Visit of the Augustine's Monastery**
14h30	Departure by bus to General Hospital
14h45	**Visit of the General Hospital**
15h30	**End of the visit** Departure by bus to Old Quebec

Heritage and historical tour of Quebec City
Specialists who will lead the tour

Émile Gilbert, architect, obtained his bachelor's degree in architecture from the École d'architecture de l'Université Laval in 1972. Émile Gilbert is one of the contemporary architects responsible for revitalization projects in the central districts of the Quebec capital. His work is rooted in the enhancement of and respect for the heritage sites in which they are located. Émile Gilbert was awarded the Quebec government's Medal of Citizenship in 1991 Biography from the Répertoire du Patrimoine Culturel du Québec.

David Mendel, a historian, studied at York University in Toronto and the Université de Paris-Sorbonne, before moving to Quebec City in 1976. After completing a Master's degree in Art History and undertaking a doctorate at Laval University, he co-founded Visites Mendel in 1984. He is often called upon at international conferences to give lectures on the history of Quebec City. He has also given many guided tours for dignitaries. A resident of the historic district of Quebec City since 1976, he is very involved in heritage preservation issues. He is the President of the Holy Trinity Cathedral Foundation - the first Anglican cathedral to be built outside the British Isles. He is the author of a series of best-selling guidebooks dedicated to Quebec City and its surrounding regions. After 35 successful years in the tourism industry, David Mendel has decided to take early retirement in 2019, to devote himself to the activities he enjoys most: giving lectures and guided tours of Quebec City and writing books.

Conference Chair Bios

Robert J. Ross

Bob Ross has served as Project Leader for several research work units at the USDA Forest Products Laboratory since 1988. His current research focus is the development and use of nondestructive evaluation technologies for various wood products and structures. He has written or co-authored more than 320 technical reports/articles about nondestructive evaluation and jointly holds two dozen U.S. and foreign patents. He served as team leader and editor of Wood Handbook—Wood as an Engineering Material, FPL's flagship publication.

Bob has received numerous awards for his publications and scientific work, and for his community service. He was presented the President's Volunteer Service Award in 2013.

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Alexis Achim

Alexis Achim is a full professor and vice-dean of research at the Faculty of Forestry, Geography, and Geomatics at Université Laval, Canada. He holds a bachelor's degree in Forest Management and Environment and a PhD in Silviculture from the same institution.

He was director of Laval University's Renewable Materials Research Center (CRMR) from 2017 to 2022. He currently leads important research partnerships bringing together members of governments, communities, industries, and universities in Canada. His interdisciplinary expertise at the interface between forestry and wood science has contributed to the training of a large team of highly qualified personnel and the publication of over 100 peer-reviewed scientific papers and reports. He is also an Editor of Forestry: an international journal of forest research for the field of wood quality and leads an international research group on the same subject within the International Union of Forest Research Organizations (IUFRO).

General Session Bios

Xiping Wang, Ph.D.

Dr. Xiping Wang is a Research Forest Products Technologist at the USDA Forest Products Laboratory (FPL), Madison, Wisconsin. His work at FPL focuses on nondestructive testing and evaluation of wood, condition assessment of wood structures, urban tree hazard assessment, and heat sterilization of wood for invasive species mitigation. He has led and conducted fundamental and applied research in the development of new methodologies and procedures for evaluating wood quality of standing trees and logs, and assessing the structure integrity of historic wood structures. He has published more than 200 research papers, been granted eight U.S. and foreign patents. He received the 2018 Forest Service Deputy Chief's Distinguished Science Award and the 2019 Forest Service Chief's Award for Applying Knowledge Globally.

Xiping received his BS and MS degrees in Mechanical Engineering and Forest Engineering, respectively, from Beijing Forestry University, and a PhD in Wood Science from Michigan Technological University. He is an Elected Fellow of the International Academy of Wood Science (IAWS) and the Associate Editor of the Journal of Materials in Civil Engineering (ASCE). He currently serves as the coordinator of IUFRO D5.01 Wood and Fiber Quality Research Group and holds adjunct faculty appointment at Michigan Technological University and Mississippi State University.

Jose Couceiro

José Couceiro is a associate senior lecturer at Luleå University of Technology in Skellefteå, Sweden, and responsible for wood drying research within the CT WOOD research program. Originally from Spain, his background is in Forestry, but soon he specialized in wood technology. After one year as an exchange student at Joensuu University (now the University of Eastern Finland), he moved to Sweden to continue his formation first as a master's student, and then as a Ph.D. candidate. His work has been on the subjects of wood and moisture, timber drying, and computed tomography.

General Session Abstracts

In-Forest Wood Quality Assessments – Where Are We with NDT Technologies?

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Recent research and development on nondestructive testing technologies have brought the in-forest assessments of wood and fiber properties of standing trees into forest management, resource evaluation, harvesting operation, and efficient wood utilization. Significant values are associated with the wood and fiber quality of our forests for the production of structural lumber, engineered wood products (such as glulam, LVL, and CLT), and pulping and paper. Rapid and nondestructive measurements on trees allows this value to be captured through better silvicultural practices, as well as the allocation of resources to highest value users and application of best processing methods. This presentation provides an overview of recent research and development on in-forest wood quality assessments using emerging precision-based nondestructive technologies, with a focus on forest resource evaluation and wood utilization. These technologies include SilviScan™, near infrared, DiscBot, acoustic waves, and resistance drilling. A brief discussion follows on how these technologies and the knowledge obtained from them can support the development of the next generation of forests (e.g., through tree breeding and silviculture).

Keywords: wood and fiber properties, wood quality, trees, forest, forest resources, silviculture, genetic improvement.

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Industrial CT Scanning in Wood Research

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The X-ray computed tomography (CT) lab at Wood Science and Engineering (WSE) has been a cutting-edge facility in wood research: drying, thermal modification, sorting, and machining. Since the mid-1990s, the research at Luleå University of Technology has produced more than 50 doctorate theses and hundreds of projects have supported the improvement of processes in the wood-industry sector. Nowadays, industrial CT scanners and other X-ray technologies are installed in sawmills around the globe. Nevertheless, there has always been a mismatch between the technologies used in industrial environments and in research. In research, CT technology has mostly been based on medical equipment, which comes with quite hindering limitations caused by the low doses of radiation required and by certain characteristics in the visualisation of tissues. For wood research, the objective has to be versatility and freedom. An industrial prototype of a CT scanner developed by Microtec (Bressanone/Brixen, Italy) has been installed in the laboratories of WSE in Skellefteå. The advantages of this equipment are the wider range of acceleration voltages, the unlimited scanning time, and the possibility to obtain raw data instead of non-disclosed ready-processed images, as is the case with medical technology. The new Microtec Mito scanner has shown great capabilities, with voxel volume of 0.3x0.3x0.3 mm3 and the possibility to scan large specimens, such as entire logs, with great accuracy. The laboratory is currently being developed so that wood drying processes and thermal modification can be performed and scanned. The goal is to develop further the cutting-edge research that WSE has been performing during the last 30 years, with more accurate results and great opportunities that this new technology provides in the form of more access to the image generation process. This presentation gives insight into the first year of tests of this equipment, its capabilities, and future projects.

Keywords: X-ray CT, computed tomography, industrial CT, wood drying, thermal modification

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Session 1 • Nondestructive Characterization of Wood and Wood-Based Materials

Effects of Microwave Radar Sensor Distance and Material Thickness on Density and Moisture Content Determination

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Abstract

According to our earlier research, measuring the microwave attenuation and propagation time across the thickness of wood allows the simultaneous determination of wood moisture content and density, using one relatively simple and quick measurement. Results seem to be independent of wood species. On the road to developing a practical measurement system, the next step is to assess various other influencing factors that need to be considered when calibrating the instrument. Small clear specimens of eight different species and different thicknesses ranging from 5 to 50 mm were conditioned to different moisture content levels below the fiber saturation point (FSP) and were measured with a microwave radar. The distance of the sensors, as well as the position of the specimens were varied to assess the sensitivity of the method to these factors.

Keywords: moisture content, density, microwave radar, propagation time, signal attenuation.

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Comparison between Static Modulus of Elasticity and Nondestructive Testing Moduli of Elasticity in White Spruce and Lodgepole Pine Wood

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Abstract

Static bending tests to measure modulus of elasticity (MOE_{ST}) or wood stiffness provide an indicator of the structural performance of a finished product. However, these tests are slow and expensive. Tests to measure MOE using nondestructive testing (NDT) [MOE_{NDT}] provide alternatives to MOE_{ST} tests, but comparisons between the different modes of measurement need to be established. MOE_{NDT} measured by two methods (SilviScan [MOE_{SS}] and time of flight [MOE_{TOF}]) have been compared with MOE_{ST} for lodgepole pine and white spruce. Stress wave speed (SWS) relationships with MOE_{ST} have also been evaluated. Simple linear regression of MOE_{SS}, MOE_{TOP}, and SWS produced coefficients of determination (R^2) with greater explanatory power than did multiple linear regressions including growth rate or other wood fiber attributes. Simple linear regression from MOE_{TOF} and MOE_{SS} on MOE_{ST} had lower R^2 for lodgepole pine than for white spruce; however, the converse was true for SWS. SWS had the highest R^2 (89%) and MOE_{SS} the lowest R^2 (47%) with MOE_{ST} in lodgepole pine. The results were tool and species specific, suggesting that R^2 between MOE_{ST} and MOE_{NDT} values must be validated separately for each commercial tree species and for each measurement technique.

Keywords: modulus of elasticity, stress wave speed, juvenile wood, mature wood.

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Evaluation of Elastic Constants of Oil Palm Wood Using Ultrasonic Measurement

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Abstract

Oil palm trunks are still a “waste by-product” of palm oil production. Almost 200 million m^3 of trunks are harvested per year. For value-added use, material modelling and product optimization, and therefore knowledge of the elastic properties of oil palm wood, are required. For example, the MOE calculation of beams requires the shear modulus. However, until now—apart from Young´s modulus parallel to the vascular bundles—the elastic properties of oil palm wood are not known and the lack of radial-tangential anisotropy is only assumed [Killmann and Lim 1985]. Several authors showed the applicability of ultrasonic methods to determine the full set of elastic constants for common wood species [e.g., Bucur and Archer 1984; Goncalves et al. 2011; Hering et al. 2012; Ozyhar et al. 2013; Bachtiar et al. 2017], but it has not been used for palm wood until now. The anatomic structure of monocotyledonous palms differs remarkably from common trees (palm wood consists of high density vascular bundles embedded in low density parenchymatous ground tissue). Therefore, within a research project, the applicability and preliminary results of ultrasonic testing for the characterization of all 12 elastic constants of oil palm wood with various densities was investigated under the assumption of an orthotropic material behavior by means of time of flight measurement of three longitudinal, six shear, and three quasi-shear wave measurements. For the evaluation, the simplified uncorrected and the full stiffness inversion method according to Bachtiar et al. (2017) were used. The findings of the investigation—the lack of correlation between the bulk density and the speed of sound when using flat probes—raise new research questions about the applicability of this method from the view of the material model. Possible reasons for this will be discussed in the full paper.

Keywords: oil palm wood, elastic constants, ultrasonic measurement, time of flight.

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Estimation of the Moisture Content in Wood by Combination of Neutron and X-Ray Imaging

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Abstract

Recent advances in image processing and computed tomography (CT) have allowed substantial development in the field of nondestructive moisture content (MC) estimation in wood, but a real-time technique is not yet available. The use of dual-energy CT has been proposed, but not yet proven, due to the similarities in the X-ray attenuation in wood and water. Neutron imaging (NI) opens an opportunity, as the large difference in the interactions of neutrons with hydrogen and carbon could allow the estimation of MC. The equipment available at Paul Scherrer Institute (Switzerland) allows simultaneous scanning of wood with both neutron and X-rays in a climate chamber, so that the evolution of moisture distribution in time can be studied through both methods. The aim of these studies was to build the basic knowledge of how the use of neutrons and X-rays, and the combination of those, can be applied to studying wood-moisture interactions and moisture flow in wood and wood-based products. Experiments have been performed in which wood specimens conditioned to different MCs are exposed to varying conditions and scanned with both techniques in the three main anatomical directions. The results are processed by an advanced image-processing algorithm for MC calculation, both for X-ray and NI data. The preliminary analysis of the results suggests the possibility that the NI technique may be used to estimate MC with an accuracy equivalent to that of CT-based techniques. Results also show a clear difference in X-ray attenuation in wood at different acceleration voltages that may be used to estimate MC with an accuracy equivalent to that of NI. Nevertheless, further analysis and statistical studies are needed at this point.

Keywords: neutron imaging, X-ray computed tomography, moisture content, dual energy, wood drying.

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Nondestructive Model for Predicting the Mechanical Properties of Wood in Southwest, Nigeria

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Abstract

Destructive methods of testing have been popular for determining the mechanical properties of wood in most parts of West Africa as a result of nonavailability of equipment for nondestructive testing (NDT). Data for this study were collected from a series of four ages of teak (*Tectona grandis*) plantations (10, 15, 20, and 25 years old) using destructive testing methods. Samples were collected from teak plantations at Onigambari Forest Reserve, Ibadan, Oyo State, Nigeria. A stand was harvested from each age, and samples were taken at the base, middle, and top and were further partitioned into inner wood, center wood, and outer wood. Investigations were carried out to determine the strength properties using a computer control electronic universal testing machine. Data collected were subjected to regression analysis at $_{0.05}$ to predict the mechanical properties for the age-series of 30, 35, 40, and 45 years old. The result revealed that the nonlinear regression model (Power) was adjudged the best for the prediction following least root mean square error and highest adjusted coefficient of determination. This implied that the NDT-Power model can be used to determine mechanical properties of teak in southwest Nigeria.

Keywords: nondestructive, destructive, mechanical properties, *Tectona grandis*, prediction, model.

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Comparative Estimation of Acoustic Velocity and Strength Properties of Down Pine Trees Using Near Infrared Spectroscopy

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Abstract

Near infrared reflectance (NIR) spectroscopy was used to determine the acoustic velocity and strength properties of down pine trees in the southern coastal plains of the United States. Three different acoustic measurements (longitudinal, transverse, and offset or opposite-face method) from the acoustics velocity determined by Time-of-Flight (TOF) measurement and the increment core samples obtained from the thirty down loblolly pine trees were used in the study. NIR spectra were obtained using a fiber probe on the radial surface of each core to rapidly predict the speed of sound and strength properties of the down trees from the Time-of-Flight acoustic estimations. The NIR prediction was moderately good for the transverse and offset methods. The predictability was 0.67 for offset measurement and 0.65 for transverse. The longitudinal measurement recorded the least prediction (R^2 = 0.42) with the standard error of prediction (SEP) of 0.305 degrees and mean property value of 3.498. The dry density from the increment cores had a moderate variance percentage (60%), whiles the green density recorded a low variance percentage (42%) from the multiple linear regression (MLR) of the reduced model of the density properties. The results of the acoustic model indicated that NIR spectroscopy has a potentially useful role in the measurement of the acoustic velocity and strength properties of down trees; however, further development of the method is still necessary to reach acceptable accuracy.

Keywords: near infrared spectroscopy, down trees, acoustic velocity, strength properties.

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Nondestructive Determination of the Within-Ring Wood Dynamic Modulus of Elasticity for Black Spruce and Jack Pine

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Abstract

Ultrasonic measurement is a widely used approach for nondestructive determination of wood elastic properties, including the dynamic modulus of elasticity (DMOE). The latter is calculated from wood density and ultrasonic wave propagation velocity. Using the average wood density to estimate the DMOE introduces significant imprecision considering the important variation of this property. For accurate DMOE evaluation, we developed a device to measure the ultrasonic wave velocity in wood with the same resolution as the X-ray densitometer for density measurement. Data from the X-ray densitometry and the ultrasonic device determined the radial and the within-ring wood density and DMOE variations. High-order polynomials modeled the within-ring wood density and DMOE variations for black spruce and jack pine. Predicted and measured wood density and DMOE data were highly correlated. The earlywood (EW) to latewood (LW) transition, defined as the inflection point, was determined to compute EW and LW width, density, and DMOE data. High correlations between ring, EW, and LW densities and DMOE are found. The practical implications of the results are discussed, namely the ease of determination of the EW and LW elastic properties, the evaluation of the impact of several forest management practices on the wood mechanical properties, and a better understanding of their variations.

Keywords: ultrasonic wave velocity measurement, nondestructive assessment, wood density, dynamic modulus of elasticity, within-ring variation.

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Session 2 • In-Forest Wood Quality Assessments

Using Time-of-Flight Acoustic Velocity to Assess Modulus of Elasticity and Bending Strength Properties of White Spruce from Tree Improvement Experiments

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Abstract

Although acoustic tools are commonly used to estimate wood stiffness (MOE) in standing trees, the derived relationships are often not very accurate. In this study, we aimed to investigate the efficiency of acoustic velocity to predict the mean individual and family-level MOE of white spruce (*Picea glauca* [Moench] Voss) from a 21-year-old tree improvement trial. A total of 190 white spruce trees were targeted from two different genetic improvement plantations established in Quebec, Canada. Standing tree acoustic velocity was assessed using the ST300 tool, which measures the time-of-flight of a longitudinal stress wave between two probes inserted in the stem. Dynamic stiffness (MOE_d) was calculated using two different estimates of density (i.e., a constant for green wood density (MOE_{dGD}) and a measured density at 8% relative humidity (MOE_{dRH}). From each tree, two samples of 2.5*2.5*40.60 cm were collected at breast height (1.3 m) to measure static bending stiffness (MOE_s). In site Normandin, compared with site Valcartier, moderate levels of correlation (R^2 = 0.34 to 0.42) between MOE_{dGD}, MOE_{dRH}, and MOE_s were obtained at the individual tree level plantation, whereas stronger levels of correlation (R^2 = 0.57 to 0.60) were obtained at the family level. Results showed that MOE_d calculated based on density at 8% relative humidity (RH) allowed a better prediction of stiffness at both sites. Further, the Pearson correlation matrix also revealed strong correlations between MOE_s and MOE_{dRH} of r = 0.65 and r = 0.77 at the individual tree and family levels, respectively. Values of MOE_d estimated at 8% RH were in good agreement with static MOE values measured on solid wood samples and had lower bias compared with MOE_d estimates based on a constant green wood density. Results also show that predicting bending strength properties at the family level is more accurate that making predictions at the individual level. This method confirms that MOE_{dRH} corresponds 57% to 60% to the static MOE. Also, it is easily obtainable at very low cost and can potentially be used in tree improvement programs in which MOE is a trait of interest.

Keywords: modulus of elasticity, nondestructive evaluation, prediction, standing tree measurement, green wood density.

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Nondestructive Characterization of Sugar Maple Wood Decay and Modulus of Elasticity by Acoustic Tomography

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Abstract

Sugar maple wood is highly prized for appearance and structural applications. However, the presence of decay in maple causes considerable decreases in its stem value and wood properties. Thus, the general objective of this study was to evaluate the potential of acoustic tomography to detect decay in sugar maple trees and evaluate its impact on wood mechanical properties. Specific objectives were to (1) characterize the proportion of decay by acoustic tomography, (2) evaluate the impact of decay on the static modulus of elasticity (MOE) and dynamic MOE (DMOE), and (3) evaluate the potential of acoustic tomography to predict the impact of decay on the mechanical properties of sugar maple wood. In this study, 54 trees were sampled from two sites in La Tuque, Quebec. The sound propagation speed in wood and its density determined the DMOE. Also, 18 sugar maple trees were sampled and felled from two sites in Abitibi-Témiscamingue, Quebec. Their parallel compression and flexural properties were measured on clear wood samples (ASTM D143). The DMOE was also measured by acoustic tomography and ultrasound methods to investigate the relationship between the wood MOE measured by destructive and nondestructive methods. Acoustic tomography accurately predicted the proportion of decay in sugar maple trees. The DMOE measured on standing trees correlated well with the static MOE and DMOE measured on destructive samples. Decay has a significant negative impact on the mechanical properties of sugar maple wood. Properties can be reduced by up to 60% depending on the decay stage. Practical implications of acoustic tomography include effectiveness in predicting the wood quality and economic value of sugar maple stands.

Keywords: sugar maple, wood decay, nondestructive characterization, acoustic tomography, dynamic modulus of elasticity.

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Effect of Partial Harvesting on Growth, Density, and Dynamic Modulus of Elasticity of White Spruce in a Mixed Boreal Forest

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Abstract

Several forest harvesting practices that are alternatives to clear-cutting are being tested for their ability to accelerate stem growth in boreal and temperate forests. Partial harvesting removes the oldest and largest shade-intolerant broadleaf trees, which improves the ecological perspective of the forest by enhancing the survivability and proper growth of shade-tolerant conifers while preserving the economic value of the operation. This study aimed to determine the effect of partial harvesting intensity in mixed forests on the radial growth, density, and dynamic modulus of elasticity (DMOE) of white spruce (*Picea glauca* (Moench) Voss) wood of different social classes, i.e., suppressed, co-dominant, and dominant. X-ray densitometry served to measure ring width (RW), earlywood width (EWW), latewood width (LWW), latewood percentage (LWP), ring density (RD), earlywood density (EWD), and latewood density (LWD) on radial increment cores. An ultrasonic wave propagation method assessed the DMOE. RW, EWW, LWW, and LWP increased, while RD decreased significantly with partial harvesting intensity. However, the effects were less prominent on LWD and EWD. The impact of harvesting intensity on RD was higher in co-dominant trees than in other social classes. Moreover, RD varied significantly without affecting the DMOE. The results suggest that partial harvesting increased the radial growth of remaining stems and reduced the wood density without negative effects on the DMOE.

Keywords: white spruce, partial harvesting, ring density, wood density, dynamic modulus of elasticity, ultrasonic wave propagation, X-ray densitometry.

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Effect of Silvicultural Practices on Basic Wood Density of Sugar Maple in Lake States Region

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Abstract

The quality of wood in a tree is a critical factor in determining its engineering applications. Silvicultural practices and growing environment are known important factors influencing wood quality. While much research has been done on softwood species on that regard, there is a knowledge gap for hardwoods between silvicultural practices and wood properties. The goal of this study was to elucidate the effects of silvicultural treatments on the basic density of hardwoods grown in Lake States region. We investigated the basic wood density of sugar maple in an existing long-term silvicultural trial at the Dukes Experimental Forest in northern Michigan, USA. The silvicultural treatments included clear-cut, 30cm diameter limit cut, 55cm diameter limit cut, group selection, 70% stocking cut with 17cm diameter limit, single tree selection cut, and an old-growth as the control. A total of 105 increment cores were extracted from the sampled trees and studied using SilviScan. The data of each growth ring were averaged for each core sample based on the ring area (ring area weighted average). The results showed that the clear cut (CC) and diameter limit 12 inch treatment could be relatively effective approaches to affecting the basic density of annual rings in sugar maple wood.

Keywords: increment cores, northern hardwood, nondestructive testing, silvicultural treatment, SilviScan, specific gravity.

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Differentiation of Eucalyptus Clone Seedlings by Nondestructive Tests and Machine Learning Methods

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Abstract

The correct management of raw materials in the pulp and paper industry impacts the resources to be used at each stage of the production chain, since edaphoclimatic factors and the inherent characteristics of each clone interact in the final quality of the wood produced. Genetic tests to identify clones in cases of accidental mixing of clonal batches has been shown to be time-consuming, laborious, and costly, but they are the means most used by wood modification companies today. Therefore, this research seeks to use results obtained from nondestructive tests applied to eucalyptus clone seedlings in the evaluation of several machine learning algorithms in order to act in the classification of eucalyptus clones. For this research, 28 eucalyptus clones, from a pulp and paper company, were evaluated according to their total height, base diameter, age, and ultrasonic pulse propagation velocity using 7 machine learning algorithms (K-Nearest Neighbor, Decision Tree, Random Forest, Gradient Boosting, Xtreme Gradient Boosting, Superior Vector Machine, and Neural Networks). All classification algorithms went through the hyperparameter optimization process, and the classification resulting from each one of them was evaluated using the accuracy, precision, sensitivity, and f1-score metrics. The Decision Tree algorithm was the one that presented all metrics above 79%, demonstrating the potential of using machine learning algorithms together with nondestructive tests in the classification of eucalyptus clones still in the seedling stage.

Keywords: machine learning, seedling, ultrasound.

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Distinction of Eucalyptus Planting Areas Through Data Mining

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Abstract

Wood, the main raw material for industries in the forestry sector, is influenced by the edaphoclimatic characteristics of plantation sites. This interference can cause changes in physical, chemical, mechanical and anatomic characteristics, influencing the final product quality. To anticipate knowledge about the quality of wood, nondestructive tests have been applied to freshly felled logs and even standing trees. One way to evaluate the results of these tests is through data mining, which has different algorithms that elaborate prediction models or data groupings. Thus, from nondestructive tests in three different clones of the genus Eucalyptus, the objective of this work was to identify which variable has the highest degree of importance for the prediction model to differentiate two edaphoclimatic conditions of planting. Among the available algorithms, random forest was used for the elaboration of class prediction models, which provides a rank of the attributes that had the greatest importance in the obtained model. As a result of this work, analyzing the individuals with 1 year, in Clone A, the radial propagation velocity was the attribute that obtained the highest degree of importance in the prediction model, in Clone B was the perforation resistance and C the highlighted attribute was the longitudinal propagation velocity. A descriptive statistical analysis collaborated with the knowledge of the data distribution in the two regions, and in this work, it was possible to notice the interference of edaphoclimatic characteristics in the performed tests. Therefore, new field tests and laboratory tests will be carried out to understand the dynamics of the relationship between wood characteristics, nondestructive tests and edaphoclimatic characteristics.

Keywords: nondestructive tests, bagging, random forest.

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Dynamic Modulus of Elasticity in *Calophyllum brasiliense* Cambess Trees from Bajo Calima (Colombia)

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Abstract

The aceite maría tree (*Calophyllum brasiliense* Cambess) is a versatile species with good physical and mechanical wood properties, which places it in a privileged place for marketing in Colombia. Aceite maría is currently replacing other high-priced woods in the Colombian market, but there are only two reported studies of this species from Colombia. This study compares the dynamic modulus of elasticity (MOE) between aceite maria trees grown in natural environments and those grown in plantation forests using nondestructive methods such as ultrasound to find the stress wave time. The research was carried out on an experimental plot of 0.29 ha with trees planted 34 years ago. A total of 90 trees, 30 trees from the natural forest (estimated age 26 years) and 60 trees from planted forests (with spacings of 4 by 4 m and 5 by 5 m), were sampled. The results showed that there were no differences in MOE according to the position in which transducers were located in the tree for measurements (N and E). Significant differences in MOE were found between natural environment trees and plantation trees. The diameter at breast height (DBH) had a negative influence on the MOE in the longitudinal direction of the fiber, showing highly significant differences between the natural and planted forests. Between the forests planted at 4 by 4 m and 5 by 5 m, the significant differences were moderate. Predicting MOE from DHB in the three types of forests is possible. The stress wave speed (SWS) technique in standing trees can be successfully used for nondestructive evaluation (NDE). These results allow the promotion of aceite maria plantations to market high-value products and contribute to the sustainable management of Colombian tropical forests.

Keywords: *Calophyllum brasiliense*, natural and planted forests, MOE, DHB, SWS, NDE.

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Field Assessment of Downed Timber Strength Deterioration Rate and Wood Quality Using Acoustic Technologies

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Abstract

Hurricane and tornado events cause significant damage to high-value timber in the United States each year. Forest managers and landowners are keenly interested in finding solutions to salvage and repurpose these downed timbers before they cause pest infestations and fire outbreaks, losing their value completely or increasing processing costs. To better understand the wood quality of downed timber, we used acoustic wave techniques as a nondestructive testing approach to assess the wood degradation rate of downed trees and determine the extent of fracture and voids in the damage regions. We monitored the acoustic velocity of the downed trees periodically for 12 consecutive months using a time-of-flight (TOF) acoustic method. Acoustic measurements were conducted in three different approaches, longitudinal, transverse, and offset method. Wood density, age and the diameter at breast height (dbh) class measurement for the South (Chip-n-saw for dbh 8–11 in. and Sawtimber with dbh 12 in. and up) were used as predictive parameters of the downed trees.The results indicated positive relationships between tree dbh class, stand age, and all acoustic velocity measurement (R^2 > 65%), except the longitudinal measuring technique (R^2 = 45%). The regression coefficient from the repeated measures indicated that both age and diameter class have strong impact on the acoustic properties of the downed trees (P-value < 0.000). The Sawtimber dbh class recorded higher acoustic velocity compared to the chip-n-saw class. Generally, the acoustic measurements were able to detect fracture, voids, and massive decay in downed trees beyond the visible inspection; however, they showed a weak response in picking up subtle incremental deterioration as changes in certain environmental factors (rain, humidity, moisture) affect acoustic readings. The results of this study showed that acoustic wave methods have potential for use as a field evaluation tool for assesing the quality of downed trees.

Keywords: acoustic velocity, dbh class, down timber, non-destructive evaluation, wood properties

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Models for Predicting the Within-Tree Variation of Ultrasonic Velocity and Dynamic Modulus of Elasticity for Plantation Loblolly Pine

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Abstract

Approximately 90 percent of conifer wood is comprised of longitudinal tracheids, which are responsible for water transportation and mechanical support of the standing tree. The anatomical and mechanical properties of tracheids vary within the tree, which ultimately impacts the utilization of the wood. Young trees contain a high proportion of low-stiffness corewood that can be attributed to high microfibril angle values in tracheid cell walls. As an alternative to expensive microfibril angle measurements using X-ray diffraction techniques, related properties such as dynamic modulus of elasticity (MOE_{dyn}) can be determined using a combination of wood specific gravity (SG) and ultrasonic velocity (USV), the latter measured at frequencies greater than 20 kHz. The objective of this study was to examine the within-tree variation in wood stiffness for loblolly pine grown in southeastern Georgia through assessment of SG, USV, and MOE_{dyn}. In total, 419 pith-to-bark radial strips collected from multiple height levels in 92 trees were processed to obtain matching SG (2-mm tall) and USV (8.2-mm tall) samples. Ring-by-ring SG was measured using X-ray densitometry and time-of-flight USV was measured at a 10-mm radial resolution from pith to bark. A subset of samples was sent to SilviScan to determine microfibril angle using X-ray diffraction. The relationship between microfibril angle and USV was strong (R^2 = 0.91, RMSE = 2.6°). Nonlinear mixed-effects models were developed to predict radial variation in SG, USV, and MOE_{dyn}. Fixed effects for the models, which included cambial age and height of disk within tree, had R^2 (pseudo) of 0.67 for SG (RMSE = 0.051), R^2 of 0.71 for USV (316 m/s), and R^2 of 0.69 for MOE_{dyn} (1.9 GPa). When combined with SG measurements from X-ray densitometry, acoustic velocity measurements from pith to bark are a powerful tool for assessing variability in wood stiffness.

Keywords: acoustic velocity, nondestructive testing, *Pinus taeda*, SilviScan, southern pine, wood and fiber quality, wood stiffness

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Electric Resistance Tomograph: A Nondestructive Testing Approach to Valuation of High-Value Trees of India

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Abstract

Electric resistance tomograph (ERT) is a promising nondestructive technique to noninvasively study the stems of standing trees. It allows insights into xylem properties based on the cross-sectional distribution of electrical resistivity that is governed by the wood's electrical conductance. ERT as a nondestructive tool can capture the complete assembly of the internal structure of the standing tree without harming the perpetual health of the tree. This multisensor channel system passes the required current to the tree based on its wood moisture and electrolyte content to sense the status of wood internally. By generating an electrical field to conduct the tests at different tree heights starting from ground level to clear bole height, a three-dimensional structure of any tree can be obtained and thereby the valuation of that tree can be analyzed with subsequent measurement of the electrical conductivity. The value of a tree, with certain years of a fixed financial rotation period especially for highly valued trees such as *Santalum album* and *Pterocarpus santalinus* within a tropical community, provides significant ecological, economic, and social benefits. Economic value may be defined as the monetary worth of a tree at a given time with the expectation of benefit, and the valuation of the tree can be estimated using ERT three-dimensional technology by deciphering the internal formation of the wood and its health. Therefore, ERT can be a nondestructive approach to estimating the value of highly valued trees in India.

Keywords: electric resistance tomograph, nondestructive testing, *Santalum album*, *Pterocarpus santalinus.*

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Session 3 • NDE for Urban Trees

Tree Risk Assessment: Systemic Approach Involving Nondestructive Techniques and Tree Biomechanics

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Abstract

Analyzing the risk of falling trees is complex, involving many different aspects of knowledge, such as the physical and mechanical properties of the different parts of the tree (root, trunk, and branches), both in clean and deteriorated conditions; the forces acting on the standing tree, which trigger different types of effects on roots, trunks, and branches; the influence of aspects related to the surroundings and planting conditions; and the expected behavior of this tree subjected to such efforts. This complexity made the research group on nondestructive testing at the School of Agricultural Engineering of the University of Campinas, Brazil, work for years on research at different levels (scientific initiation, master's, doctoral, and postdoctorate) with a common focus. This paper aims to briefly address the main results of this group involving the nondestructive characterization of wood from different parts of the tree and in different health conditions; the association of physical and mechanical parameters with those inferred using nondestructive field inspection techniques; the development of methodologies for the inference of wind loads on trees, involving the simplified calculation of the drag coefficient, the wind speed trunk profile, and the crown geometry and area; and the development of a methodology for analyzing aspects of the surroundings that impact the stability of the tree; and finally, incorporating all these aspects into a proposal for a simplified simulation of the tree's behavior, using numerical methods, with a focus on the analysis of the risk assessment. It is expected that this systemic approach will lead to the introduction of a methodological proposal that allows us to obtain results closer to the specific condition of trees and thus treatments or interventions that are also more specific, reducing, as far as possible given the inherent complexities of this approach, accidents or unnecessary tree suppression.

Keywords: tree inspection, ultrasound tomography, characterization of wood from root, branch, and trunk.

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Use of Tomographic Images to Support the Inference of Strength Loss in Trunk Using Equations from Literature

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Abstract

The importance of the urban forest is undeniable when considering its associated benefits to achieve sustainable urban development. However, trees in urban environments are subject to failures that can cause human and material losses. Knowledge of the phytosanitary status of trees helps to prevent accidents and is particularly important in an urban context. Some equations are proposed in the literature to infer the strength loss. These equations are based on cavity and trunk diameter relation or based on the remaining stem wall dimension. However, these formulas have limitations, such as assuming only cavities, always centered, and not including the wood decay. Ultrasonic tomography has been considered a suitable tool for tree inspection. It is expected that tomographic images represent, with relative accuracy, the dimension and the position of biodeterioration inside the trunk. Therefore, the objective of this study was to quantitatively evaluate whether the use of ultrasonic tomography could allow improvement of the accuracy of the equations used to infer the strength loss of tree trunks with the presence of cavities and biodeteriorations. The results showed that ultrasonic tomographic images allowed the equations to be closer to real conditions of the tree trunk, such as the inclusion of wood strength reduction from decay and the displacement of internal cavities in calculating the reduction of the moment of inertia.

Keywords: biodeterioration, mechanical stress, tree hazard, tree risk assessment.

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Influence of the Manner of Obtaining Coordinates of Contour of Irregular Discs in Tomographic Images

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Abstract

Ultrasonic tomography has been widely used in tree inspections because it makes it possible to obtain internal images of the stem relatively easily and without causing damage to the inspected material. For the application of the technique using measuring mesh, it is necessary to obtain coordinates of the contour of the stem. However, the morphology of the stem of many species, especially tropical leafy ones, can make it difficult to obtain contour coordinates, generating the need for the application of more complex technology. An alternative to overcome this difficulty is the use of approximate techniques, such as those that simplify the outline of the trunk, making approximations to fewer complex shapes and with better known geometric relationships. However, when promoting such approximations, there are changes in the wave propagation routes that, even if small, could cause interferences in the resulting image, since the calculation of velocities depends on the path lengths and wave propagation times, measured in microseconds. Thus, this research aimed to quantify, through the metrics of the confusion matrix, the interference of the method that approximates the irregular outline of the stem to an ellipse, in the image produced by the tomography. For this, tomographic images were obtained from 12 disks with irregular shape of Cenostigma pluviosum DC. Gagnon & G.P.Lewis, produced with the real and the approximate contour. The difference between the metrics obtained in the images using the two contours indicated small differences, allowing us to conclude that the ease in applying the simplified method is rewarding.

Keywords: contour of trees, ultrasonic tomographic, urban trees.

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Adjustment of Ultrasonic Tomography Velocity Ranges to Represent the Variations within Tree Trunks Using Confusion Matrix Metrics

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Abstract

There are numerous benefits related to the practice of urban forestry. However, attacks by biotic agents, such as xylophagous insects and fungi can modify wood properties. To ensure preservation and risk reduction to the public, one must invest in research to evaluate the accuracy of the technological tools used in tree inspection. The objective of this research was to define a methodology to adjust velocity range to best represent the different regions (deterioration and cavities) inside the trunk generated by ultrasonic tomography images using metrics of the confusion matrix. Discs of *Cenostigma pluviosum* DC. Gagnon & G.P.Lewis with different types of biodeterioration were analyzed so that it was possible to create representative masks of these different regions so they could be compared to the tomographic images. The tomographic images were created using different ranges and median filter setting to narrow the best velocity range for each of the different regions using the confusion matrix methods. The results showed that the best velocity ranges to infer the position and size of the cavities were from 0% to 40% of the maximum velocity and from 40% to 45% of the maximum velocity to detect deteriorated zones. We conclude that the methodology using metrics from confusion matrix is very reliable to propose fine adjustments in parameter associations to be inferred through tomographic images.

Keywords: ultrasonic tomographic, urban trees, filters.

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Visual Tree Assessment and Static Integrated Assessment Do Not Allow Breaking Safety Evaluation of Defective Stems of Mature Urban Trees

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Abstract

The well-known visual tree assessment (VTA) method promotes two criteria for evaluating the safety of trees: the ratio of the thickness (*t*) of the intact outer shell-wall divided by the local radius (*R*) should be higher than 1/3 for guaranteeing sufficient breaking safety (*t*/*R* > 1/3!) of decayed trunks. For intact trees, the ratio of total height (*H*) divided by the stem diameter at breast height (*D*) should be below 50 (*H*/*D* < 50!). A biomechanical analysis shows that these two criteria are not relevant and that the *t*/*R* rule is not applicable to defective mature urban trees, which are typically evaluated in terms of safety considering the following factors: (1) the cross-sectional shape is usually not circular; (2) the defects are usually not located in the center; and (3) the "allometric age effect". The widely used static integrated assessment (SIA) concept is not an alternative because it uses formulas that are valid only for thick-walled metal tubes with homogeneous material properties. Biomechanical science shows that SIA calculations deliver results that are inaccurate by factors of 10 or even more. Because of the highly anisotropic material properties of wood, a fundamentally different math has to be used to determine and evaluate the real load carrying capacity of decayed wooden trunks under bending loads. In addition, the SIA windload prediction contains huge estimation errors. In consequence, both methods are fundamentally wrong and/or inappropriate and thus should not be used to evaluate the safety of defective trunks of mature urban trees and should not be recommended by standards.

Keywords: VTA, SIA, shell-wall, tree-safety.

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Biomechanical and Mathematical Basics of "Allometric Self-Referencing" for Evaluating Breaking Safety of Defective Stems of Mature Urban Trees

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Abstract

Tree safety experts evaluate if a damaged mature urban tree has a significantly increased probability of breakage compared with the "normal condition" (intact tree). Only then, a risk reduction is required, by, for example, pruning. Thus, there is no need to determine absolute values of load carrying capacity and wind loads but only to compare the current tree with the same tree in an intact state. For mature urban trees, the total tree height H determines the wind load ($\sim H^3$) just as the trunk diameter D determines its load carrying capacity ($\sim D^3$). Thus, in first order, D^3/H^3 characterizes trunk breaking safety in changes with time. That's why most trees keep H/D approximately constant in the "exploration phase" (after juvenile growth and until maximum tree height is reached). Then, the trunk diameter continues to grow as long as the tree is alive, increasing the "basic safety" each year incrementally (allometric safety effect). Reductions in tree height caused by age and/or previous pruning increase the safety because of lower wind loads. The loss in mechanical load carrying capacity of a trunk cross section caused by defects is determined by wood-specific, anisotropic, and tomographic area integrals (compared with the intact state). Combining all these aspects allows the evaluation of a relative level of breakage safety of a defective trunk compared with the intact state, without the need of measuring or estimating any material properties or wind loads. This enables arborists to keep more mature trees longer with the same budget.

Keywords: allometry, self-referencing, tree safety.

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Dynamic Tree Stability: Improved Testing Methodology and Indications of Reliability

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Abstract

Dynamic tree stability assessment is a relatively new technique that has good potential to replace the more cumbersome and less productive static pulling test as the primary method of tree stability evaluation. The reliability of this new technique was greatly improved in recent years through introducing new statistical tools and approaches in the evaluation of the measurement results. This includes using the maximum rather than the mean value during the statistical evaluation and applying a baseline correction using a median filter to eliminate the slow drift of the inclination sensors. The evaluation algorithm was also simplified by using the first member of the Taylor series for the tangential pressure-inclination function, reducing it to a simple linear approximation. This study provides a detailed explanation concerning these changes. The reliability of dynamic tree stability testing is inherently more difficult to evaluate than that of the static pulling test, in which the ultimate load can be verified by pulling the tree over. However, in recent years, a significant body of experience has accumulated that provides good indications concerning the consistency and accuracy of the dynamic method. Experimental evidence includes comparison of the dynamically measured parameters to static ultimate load testing results, the demonstration of the effect of foliage change through dynamic testing results, tracking the effect of root cutting through measuring dynamic safety, and results of high-wind measurements, which allow the comparison of dynamic safety prediction to actual ultimate load indications found under dynamic conditions. Based on these case studies – described in detail in the paper – dynamic tree stability testing is an accurate and reliable tool for tree stability assessment, albeit the interpretation of the results requires in-depth expertise in the dynamic behavior of trees.

Keywords: tree stability, tree safety, dynamic stability, safety factor, uprooting.

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Comparing the Stability of the Trees in Different Seasonal and Weather Conditions by Using Nondestructive Method

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Abstract

There are many available evaluations and equipment to measure the safety of live trees. In contrast to static loading, dynamic techniques use actual wind loads. The goal of this study is assessing how dynamic tree stability is affected by various factors, including soil moisture content, wind direction, and seasonal foliage changes. Trees are considered natural capital. The biggest motivation to pursue nondestructive testing in the wood and wood product industries was the need to use trees in the best way possible. In this research, the DynaRoot system (Fakopp BT 2018) was used. This system consists of 3 parts: Anemometer (wind measurement), Inclinometer (measuring the inclination of tree movement), and Evaluation software (analyzing the data). A number of tree specimens were chosen in the Botanical Gardens of the Sopron University, Hungary, including both broadleaves and conifers. Data were collected over a 2.5-year period, during which trees were measured in different conditions. With the dynamic method, there is a limitation on how well measurement conditions can be controlled. Measurements can only be taken in windy weather. Wind intensity and direction cannot be controlled, and sometimes there is no wind to measure trees in the chosen conditions. Results show that soil moisture content has a strong positive correlation with the dynamic Safety Factor of coniferous trees. On the other hand, Wind direction variation had less effect on the stability of broadleaved and coniferous trees than expected. It is likely that other factors are more influential on dynamic stability. Also, seasonal foliage loss had a weak positive effect on the stability of broadleaved trees. When trees lose their leaves, there is less crown area for the winds to act upon, which improves stability, but in the meantime, the drag factor also increases, which influences the results, so correlation was relatively weak.

Keywords: tree stability, dynaroot system, safetyfactor, wind direction, foliage.

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Identification of Wood Decay and Hollowness in Standing Tress using Electric Resistance Tomograph: A Nondestructive Testing Approach

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Abstract

The term nondestructive evaluation is well established in wood science research, representing "the process by which selected physical properties of a material is being tested without damage or alteration to its end-use capabilities." Nondestructive testing methods locate and quantify wood decay and defects or hollowness of large physical wooden structures, thereby analyzing the structural soundness of trees to estimate the probability of failure. Nondestructive testing equipment with advanced techniques provides extensive information on the internal integrity of trees. Proper tree health involves regular monitoring and using preventative measures to ensure the tree is free from fungal infections, avoiding tree failure. Visual inspections of fungal conks or open cavities for tree stability evaluation are limited. To measure the internal physical conditions of standing trees to make better decisions, a multisensor electric resistance tomograph (ERT) method can be carried out without disturbing the long-term health of the tree by determining the presence and extent of internal decay. Defects affect the internal energy flow leading to varying resistivity differences. ERT using the specific software PiCus Treetronic can sense the damaged or abnormal tree tissue, such as wood deterioration or hollowness, and identify it based on the measured resistivity patterns.

Keywords: electric resistance tomograph, nondestructive testing, tree decay, hollowness.

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Session 4 • NDE of Sawn Logs for Optimal Utilization

Small-Diameter Logs from Oak for Structural Purposes—Determination of Mechanical Properties by Nondestructive and Destructive Testing

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Abstract

In Germany, only half the annual increment is used in oak stands. Especially small-diameter oaks are currently either not used or only used as firewood. To achieve long-term carbon dioxide storage and higher added value, our research project aims to make small-diameter oak logs available as structural timber members, e.g., for columns, frameworks, and agricultural buildings, such as barns. For this purpose, mechanical properties of the logs and factors influencing them must be determined. In the experimental program, static MOE/MOR (bending tests), dynamic MOE (Viscan), density/moisture content (CT-scanning, wood samples), internal and external wood defects (CT-scanning, visual quality grading), and geometry properties (DiShape) of 70 oak (*Quercus petraea* (Matt.) Liebl.) logs with a length of 5 m and an average mid-diameter of about 25 cm have been investigated and statistically analyzed. First results show that moisture content and wood density in fresh and dry condition are within the range found for oak in the literature. Most logs were graded in quality class C, which represents intermediate quality logs characterized by a larger number of medium- to large-sized knots, presence of curvature, and other features. MOR ranged from 27 to 135 MPa, whereas static MOE ranged from 4,600 to 30,000 MPa (median 9,683 MPa) and the dynamic MOE from 5,480 to 15,907 MPa (median 11,941 MPa). Mean dynamic MOE was about 18% higher than mean static MOE, which is in accordance with other studies comparing nondestructive and destructive methodologies for mechanical characterization of timber. These preliminary results indicate that small-diameter oak logs appear suitable for load-bearing structures. The results will be further discussed to develop strength-grading procedures supported by machine testing for such irregular-shaped small-diameter logs, which should to be used as structural elements.

Acknowledgment: This project (support code 2218WK18C3) was funded by the Federal Ministry of Food and Agriculture (BMEL) through the Agency for Renewable Resources (FNR).

Keywords: CT scanning, bending tests, structural timber, *Quercus petraea.*

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Distribution of Wetwood in Silver Fir (*Abies alba* Mill.) – A Prerequisite for Nondestructive Testing Mechanical Characterization of Logs

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Abstract

Wetwood areas are confined zones with extremely high moisture content (MC) compared with the surrounding stem wood. Such wood abnormalities are a well-known feature in stem wood of the genus *Abies* and can usually be found in the heartwood core of older trees. Their water content greatly exceeds that of the adjacent normal wood, and the MC can be found to be even higher than that of water-saturated sapwood. Presence of wetwood in logs can cause severe problems in wood processing. Not only is timber drying quality greatly affected, but the deviation of MC can also lead to heavy distortions of the boards. Because density and mechanical properties of timber vary with MC, the presence of wetwood also interferes with nondestructive testing (NDT) because NDT is usually based on these material characteristics. Yet, the formation of wetwood is still not fully understood in detail. The size and distribution patterns of wetwood in the stem and logs vary to a large extent. High resolution x-ray based computed tomography (CT) was found to be suitable for detection and analysis of the moisture distribution in trees and logs. Logs of silver fir (4-5 m length, mid-diameter from 39 to 83 cm) were CT scanned at 180 kV and 14 mA, and images were reconstructed to app. 1x1x5-mm voxel resolution. With a new, automated algorithm, which is capable of coping with the irregular distribution of high moisture pockets, the shape and location of the wetwood zones were detected and the volumetric fraction per slice was calculated. The analysis of the logs and their CT scans showed the potential of CT scanning for the further optimization of wood processing based on the overall wetwood level (up to 30% volumetric fraction). The scan showed the location as well as the identified 3D distribution patterns of wetwood within the logs.

Keywords: x-ray, CT, wetwood, *Abies alba.*

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Using X-ray Computed Tomography (CT) Scanning to Optimize Log Primary Breakdown in Plantation-Grown White Spruce (*Picea glauca* (Moench) Voss)

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Abstract

This study examined the effects of incorporating internal knot characteristics into log breakdown decision-making on lumber value for white spruce. Knot characteristic information was extracted from sawlogs using X-Ray computed tomography (CT) imaging to examine the impact of site, genetic provenance and sawing optimization strategy on lumber product recovery. Of the 79 trees sampled for this study, 48 came from two mature genetic trials (Baskatong, Quebec; Petawawa, Ontario), while 31 trees originated from a younger Nelder spacing trial (Woodstock, New Brunswick). The log and stem reconstructions were done using a knot-detection algorithm within the Optitek sawing simulator that applied three optimization strategies: sweep up (traditional), shape optimized, and knot optimized. The results indicated that the knot-optimized strategy consistently generated the highest value recovery, while the sweep-up strategy generated the lowest. The increase in lumber value recovery from sweep up to knot optimized was the highest in the Nelder plantation that had the smallest trees. Increase in lumber value was lowest amongst the largest trees in this study, suggesting that the knot-optimized strategy may provide more benefit for smaller trees than for larger trees. Overall, the results demonstrated that knot-optimized sawing strategies can help to extract more value from every tree, which presents an opportunity for the forest industry to augment its competitiveness in the face of reduced fibre supply.

Keywords: CT scanning, knots, sawing optimization, lumber value recovery.

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Nondestructive Testing of Timber Prior to Sawing Using Finite Element Models Based on X-Ray Computed Tomography Data—A Preliminary Study

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Abstract

X-ray computed tomography (CT) of wood delivers internal density data of a scanned object, from which, depending on the resolution, internal features such as the pith, annual rings, and knots can be identified. Some sawmills use CT scanners in front of the saw line to determine optimal positioning of the log in the saw, to maximise the value yield of the sawn products. We envision that the gathered CT data also could be used for mechanical evaluations of the timber using numerical models of boards prior to sawing. In a recent study by the authors, a method was developed to create 3D and 1D finite element (FE) models based on CT scans of dried sawn timber, which could predict bending stiffness and strength in bending simulations with high accuracy. The objective of the present study is to explore how the method can be adapted to CT scans of logs before sawing. Our preliminary study was based on CT data of green Norway Spruce logs and the corresponding scans of dried sawn timber. The stiffness and strength were evaluated using four-point bending tests. Additionally, the resonance frequency of the logs was recorded. The corresponding volume of each piece of sawn timber was extracted from the log data, and an FE model was created. The model accounted for the pith, the annual rings, the knots, and the local fibre deviations around knots. Various laws for local stiffness and different failure criteria were tested. The study showed how FE models of virtual pieces of sawn timber can be created from CT data and what obstacles need to be overcome for further development of the presented method. The results indicated that more detailed evaluations of the relationship between local stiffness and density may be required, specifically for knots and for wood in green state.

Keywords: strength prediction, virtual grading, numerical modelling, sawmill optimization.

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Evaluation of Sawmill Log Scanners with Comparison to Forest Harvester Measurements

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Abstract

A set of log scanners at Swedish sawmills have been evaluated with respect to random measurement uncertainty when measuring top diameter and length of sawlogs in an operational environment. The impact of some technical and environmental factors on the measurement was also investigated. The log scanner measurements were benchmarked against manual measurements performed by professional quality controllers. The variability in the difference between the log scanner and the manual measurement was used to evaluate the scanners. The results were compared to top diameter and length measurements performed by quality assessed harvesters. The results show the 3D X-ray scanner in the study had significantly lower variability than the other log scanner types. The length variability differed less among different models than top diameter measurement. In general, 1D optical scanners had higher variability than 3D optical scanners but could perform similarly given the right conditions. The harvesters' variability in top diameter and length measurement was generally equal to or lower than that of the log scanners. However, the log scanner with the very lowest variability in the top diameter measurement outperformed all the harvesters in that regard.

Keywords: Log scanner, log scaling, diameter, length, harvester, X-ray, optical, sawlogs, measurement uncertainty.

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Session 5 • Advanced Grading Technologies for Solid Wood and Engineered Wood Products

Prediction of Tensile Modulus of Elasticity from Longitudinal and Transverse Natural Frequencies in Hardwood Species

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Abstract

Currently, most structural timber in Europe is graded with C classes, obtained from bending tests. However, many engineered wood products require grading in T classes, from tensile tests. The increasing demand for wood for structures has led to the need to study new timber species, mainly focused on both high strength capacity and/or fast-grown criteria. Therefore, the objective of this study was to evaluate the stiffness properties of different hardwood species by both nondestructive testing and tensile tests according to EN 408. Three high-, medium- and low-density hardwood species from Spain, namely *Eucalyptus globulus, Fagus sylvatica,* and *Populus x euramericana*, respectively, were studied and compared with a well-known and more commonly used species in structures in Europe (*Pinus sylvestris*). The first step was the measurement of both longitudinal and transverse vibration modes, following the standard ASTM C215-2, in 30 specimens of each species to estimate the dynamic moduli of elasticity obtained from the longitudinal natural frequency and from the first, third, and fifth transverse natural frequencies, using the Timoshenko beam theory. The second step was the comparison between the dynamic moduli of elasticity and the static modulus of elasticity in tension. The results showed different stiffness/density relationships for the four studied species, with poplar and pine grouped in the lower values and Eucalyptus in the higher values. Poplar showed behaviour that would be expected from a coniferous species. The values for dynamic modulus obtained from transverse vibration were higher than those obtained from longitudinal vibration for the medium- and low-density species. However, *Eucalyptus globulus*, being the one with the highest values for both density and stiffness properties, showed a lower value. In addition, the values obtained from transverse vibration showed better correlation with the static tensile modulus than did the values obtained from longitudinal vibration.

Keywords: NDT, hardwood, vibration.

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Influence of Board Geometry on the Determination of Dynamic Mechanical Properties of Structural Lumber

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Abstract

Nondestructive grading of sawn timber is of great importance to the sawmill industry and is often carried out by determining the dynamic modulus of elasticity by means of sonic velocity or ultrasound and by longitudinal and transverse vibration. When using these methods, considerable differences in the measured values have been found, which depend on the frequency range of the method and the geometry of the boards and are also influenced by the phenomena of wave dispersion. To better understand the differences between the dynamic methods, we selected spruce (*Picea abies* Karst.) wood without visible anomalies with cross sections of 42 by 42 mm and 42 by 84 mm and a length of 4.0 m. The dynamic mechanical properties of the wood were determined by analyzing the longitudinal and flexural vibrations of freely supported specimens and the transit time of compression and surface ultrasonic waves. The measurements were performed sequentially in eight steps by cutting the specimens at 0.5-m intervals. The sound velocity and the modulus of elasticity (MOE) determined in longitudinal vibration (v_L, E_L) and by velocity of bulk ultrasonic waves (v_{USB}, E_{USB}) were independent of the length of the test specimens. In contrast, the MOE decreased with the shortening of the specimens when we analyzed the transverse vibration method (E_B) and measured the velocity of the surface ultrasonic waves (v_{USS}, E_{USS}). We confirmed the characteristic differences in the measured velocities ($v_{USB} > v_{USS} > v_L$), the same for the MOE ($E_{USB} > E_{USS} > E_L$), in all the samples studied. The geometry of the samples significantly affected the differences between the measured values of the moduli when the ratio between the sample length (L) and the wavelength ( ) was less than 20 or for samples shorter than 2 m.

Keywords: structural lumber, dynamic testing, modulus of elasticity, sample geometry.

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Strength Grading Softwood Structural Lumber with MoE Low Point

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Abstract

Sawn structural radiata pine lumber commonly used in Australia is stress-graded prior to sale. The stress-grading process uses indicators of strength and measurements of modulus of elasticity (MoE) to assign individual pieces of timber to a stress-grade that most accurately represents its properties. Each stress-grade has a full suite of structural properties including bending MoE. This paper focuses on strength grading of structural softwood lumber using a number of different attributes of the timber and correlates the attributes with the tension strength. The research program used full length tension strength to correlate with various grading parameters. By testing the full graded length of the timber in tension, the region with the lowest strength will initiate failure. Typically, the failure initiates at or near knots where there is some local slope of grain near a corner. Grading parameters from commercial grading machines were used to correlate with tension strength and included knot size estimated by surface scanning and tracheid response; knot area ratio (KAR) from an aggregation of knot data across the cross section; and local MoE on-flat. Correlations between MoE on-flat and bending, compression, and beam shear strength were investigated using data from an in-grade study. The test results indicated that the best correlation was obtained using a mixture of all grading parameters, but it was only marginally higher than the correlation obtained from local MoE on-flat alone for the radiata pine resource processed in this study.

Keywords: strength grading, MoE low point, radiata pine, grading parameters.

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Challenges and Opportunities Toward the Use of Northern Hardwood Species in Glued-Laminated Timber in Canada

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Abstract

The interest toward the use of hardwood species in structural engineered wood products is undeniable. However, some challenges have prevented gaining the momentum required to introduce their use in glued-laminated timber in Canada. Yet, timber from broad-leaved species is largely available and using it in engineered wood products could provide great opportunities for undervalued species. Moreover, the mechanical properties of most hardwood species are superior to those of softwoods, which could allow the manufacture of products with outstanding strength. In the United States, AITC 199-96 provides specifications for the manufacture of glued-laminated timber from hardwood species, with characteristic bending strengths and average modulus of elasticity comparable with products made from softwoods. There is, however, some potential for much higher strength and stiffness, as demonstrated by the impressive properties of glued-laminated timber products made from European hardwood species. This study examined some challenges and opportunities for increasing the use of northern hardwood species in engineered wood products in Canada. Strength grading of hardwood species remains a major challenge, partly because of their complex and variable anatomical structure. Although relationships derived from trials on softwood species are applicable to hardwoods, they lead to a very conservative use of the resource. A test campaign conducted on white ash and yellow birch specimens allowed us to understand how various indicating properties such as knots, grain deviation, density, and dynamic modulus of elasticity influence the tensile strength of these species. Tensile tests conducted on finger-jointed lamellae and preliminary bending tests on full-scale beams also confirmed that finger joint strength remains the factor that limits the strength of the product. Although the distinctive appearance of hardwood species may favor the use of high-quality material, succeeding in exploiting the full strength of this timber remains crucial to justify it economically.

Keywords: engineered wood products, glued-laminated timber, hardwoods, strength grading.

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Local Modulus of Elasticity by Constrained Optimization

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Abstract

Machine stress rating (MSR) is generally accepted as the preferred production-line process in the grading of lumber for structural applications. The most widely used MSR machinery measures bending stiffness, and from stiffness, modulus of elasticity (*E*), on a sequence of bending spans along a wood board. Strength is inferred from its correlation with *E*. The advantages of estimating local modulus of elasticity (local *E*), particularly regarding strength inferences, have been discussed in the literature along with three local *E* estimation methods. Each uses a sequence of *E* measurements as input. The first employs the Fourier transform, the second a Kalman filter, and the third chooses from among an infinite number of solutions for an underdetermined set of linear equations. All three methods yield similar results, but the last may be the easiest to implement. The present work optimizes the choice of solution from among the available solutions with the third method. Lagrange multipliers minimize a measure of local compliance variation (compliance *C* being defined as the reciprocal of *E*, i.e., $C = 1/E$) all while constraining the solution to satisfy the set of linear equations. This method makes much better use of the *E* measurement sequence than does the usual MSR measurement process. Graphs of local *E* from the same piece of lumber with the same sequence of bending *E* measurement data studied in previous work allow the conclusion that constrained optimization is a practical method for estimating local *E*. All indications point toward efficient and beneficial production-line implementation from software modifications in existing MSR equipment. Some related, but unpublished, additional material may be obtained from references in the USDA Forest Service, Forest Products Laboratory report FPL-GTR-280 by opening that document with Adobe Acrobat and selecting the boxes labeled supplemental material at the ends of those references.

Keywords: local *E*, modulus of elasticity, compliance, span function, lumber grading, MSR, constrained optimization, Lagrange multipliers.

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Using Acoustic Tomography Techniques to Estimate Bending Properties of Cross-Laminated Timber

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Abstract

This research is focused on evaluating the bending stiffness and strength of cross-laminated timber (CLT) panels with acoustic tomography techniques. Eleven panels of Southern Pine three-ply CLT were acquired for this study. One test specimen was cut from each panel. Weight and dimensions were measured for each specimen. Each specimen measured approximately 0.11 m thick, 0.46 m wide, and 3.05 m long. The specimens were nondestructively tested (NDT) using multiple sensor tomography techniques comprised of up to 12 sensors. Panel density and wave velocity between sensors were calculated. Each specimen was then tested to failure in flatwise (third-point) static bending. Flatwise bending modulus of elasticity (MOE) and strength (modulus of rupture (MOR)) were determined. To predict the MOE and MOR using NDT variables, stepwise procedure was used for fitting models. It was found that the correlation between the acoustic technique outputs and bending properties varied based on which subset of 12 sensors was used. The highest coefficient of determination (r^2 = 0.62) was from using eight sensors (acoustic technique output) and strength (bending MOR).

Keywords: mechanical properties, mass timber products, modulus of rupture.

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Session 6 • Condition Assessment of Historic Wood Artifacts and Structures

Mechanical Performances and Nondestructive Test of Demolished Timber Collected from a Wooden Building Several Hundred Years Old

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Abstract

The long-term use and reuse of timber as a structural material are important from the viewpoint of the carbon storage effect. However, it is well known that timber often undergoes brittle fracture and decreases strength with long-term use. Although this is a major concern from the perspective of safety and maintenance of wooden buildings, there are no scientifically based criteria for the reuse of timber as a structural material in the renovation of wooden buildings. Therefore, it is worthwhile to accumulate data on the strength of demolished timbers and to develop strength estimation techniques for nondestructive testing. In this study, the dynamic Young's modulus was measured by the longitudinal vibration method and stress waves method using demolished timber (*Pinus densiflora*) collected from a wooden building that was several hundred years old, and the relationship between the dynamic Young's modulus and the bending and compression strength properties of the full-scale wood was investigated. In addition, the effects of defects such as mortise holes and insect bites on the mechanical performance of the specimens were investigated. Specifically, the dynamic Young's modulus was measured by the longitudinal vibration method for the case where the mortise holes were removed and the case where all other damage such as insect bites and nail holes was removed. As a result, the correlation between the actual bending strength and compressive strength and the dynamic Young's modulus by the longitudinal vibration method was the highest. The results show that the longitudinal vibration method has potential as a strength estimation method. It was also shown that the effect of mortise holes and other damage on the dynamic Young's modulus was comparable.

Keywords: demolished timber, dynamic Young's modulus, *Pinus densiflora.*

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Using Dielectric Orthotropy as an Indicator of Internal Decay of Wood Members

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Abstract

Several material properties of wood are directionally dependent. Mechanical properties such as tension, compression, and bending strength vary greatly for the same piece of wood when tested parallel to the grain (longitudinally), perpendicular to the grain, parallel to the annual rings (tangentially), or perpendicular to both the grain and rings (radially). For this reason, wood is often considered to be a cylindrically orthotropic anisotropic material. The orthotropy extends to dielectric properties of wood. However, in the presence of internal decay, the directional dependency of the dielectric qualities diminishes. By identifying and measuring the loss of directional dependency, the presence and extent of internal decay is evaluated. Ground penetrating radar (GPR) is used as the inspection tool. A bowtie, bistatic, dipole antenna with a center frequency of 2 GHz is used for measurement. The specimens are wood members of sizes typically used in bridge construction. The GPR technique has several advantages over existing nondestructive testing (NDT) techniques: it requires access to only one side of the specimen, no special methods are needed to couple the sensor to the specimen, and it uses a commercially available tool already accepted within the NDT industry.

Keywords: Ground penetrating radar, GPR, glulam, bridge timbers, brown rot.

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Mixed Session (Online)

Relation of Ultrasonic Wave Velocity and Compression Strength of Artificially Decayed Wood

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Abstract

Sound velocity is used for detecting decay of trees and wood nondestructively. In order to improve the accuracy of estimating strength decrease from sound velocity, it is important to clarify the relations of decay degree, sound velocity, and wood strength. In this study, artificially decayed specimens were prepared by inoculating *Fomitopsis palustris*. Specimens of *Larix kaempferi* were tested for compression strength in tangential, radial, and longitudinal directions. The relations between mass loss, ultrasonic wave velocity loss, and compression strength were obtained. With increase of the ultrasonic wave velocity loss, mass loss increased linearly and compression strength decreased curvilinealy in the three directions. The ultrasonic wave velocity loss was larger in the radial direction than in the tangential and longitudinal directions, which was suggested to be affected by the difference of decay degree of earlywood and latewood.

Keywords: brown rot, decay, mass loss, ultrasonic velocity, compression strength.

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Combining Nondestructive Testing Technology and Digital Twin for Preventive Conservation of Wooden Cultural Relics

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Abstract

Large movable cultural relics are constantly subject to degradation due in particular to atmospheric and environmental agents. As an advanced protection scheme, preventive strategies have been gradually preferred to curative approaches for the conservation of large movable cultural relics, especially wooden cultural relics, because of their ability to maintain their significance. Nondestructive monitoring methodologies based on image sensors and data analysis methodologies based on digital technologies play a key role for the analysis of cultural relic degradation. This study aims to present a framework for analysis of the state of degradation of cultural relics, exploiting an approach including a combination of monitoring database, inverse dynamics problems, and digital twins. In this regard, a preliminary case-study is presented, based on the stern of the Quanzhou Bay Song wooden shipwreck, China. Such an approach starts with the 3D survey of the stern structure and culminates with the definition of a detailed finite element model that can be exploited to predict future scenarios. In order to reduce uncertainties in analyzing the stern structure models and to obtain a proper digital twin, the scan-based 3D model is imported into the finite element environment and then the material properties are calibrated through monitoring database and inverse dynamics problems, which use material characteristics identified from field displacement data recorded before and after the modification intervention as reference indicators. After evaluating the effectiveness of the reinforcement measures, the digital twin ability of the reconstruction of the past and future damage scenarios of the stern is verified by nonlinear static analysis. The results highlight the great advantages of combining nondestructive testing technology and data analysis methodologies in the field of heritage conservation.

Keywords: nondestructive testing technology, digital twin, the finite element model updating, 3D-DIC, wooden cultural relics.

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Influence of Moisture Content on Mechanical Properties and Damage Forms of Ancient Timber Members

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Abstract

Timber members are the key load-bearing components and indispensable parts of the ancient wooden architecture, and their physical and mechanical properties affect the safety and stability of the structure. Moisture content (MC) is one of the most important factors for mechanical properties and damage forms of timber. Ancient larch (*Larix principis-rupprechtii Mayr*) timber, and ancient nanmu (*Phoebe zhennan S. Lee*) timber, two main species of timbers used for northern China royal wooden architectures, were used to analyze the effect of MC on mechanical properties and damage forms in this paper. The mechanical properties and damage forms of specimens with 3 levels of MC were used in the mechanical tests. A total of 36 small clear specimens were obtained from ancient and current timber of both larch and nanmu timber. First, 3 groups were divided equally from 36 specimens processed, and MC of 3 groups was adjusted to high, medium, and low levels, respectively, by using constant temperature and humidity chamber and drying oven. Then, the load-displacement curves were obtained using a universal material testing machine to analyze the effect of MC on the damage forms. Modulus of rigidity (MOR), modulus of elasticity (MOE), and compressive strength parallel to grain (CSPG) were calculated to analyze the influence of MC on mechanical property parameters. The results indicated that there was a significant influence of MC on the bending damage form of larch timber specimens; however, the damage forms of compressive parallel to grain for both larch and nanmu specimens were less affected by MC. In addition, the MOR, MOE, and CSPG of specimens all decreased with the increase of MC and showed a clear negative correlation.

Keywords: ancient timber members, mechanical properties, damage forms, moisture content.

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Nondestructive Evaluation of the Concealed Wood Columns in Historic Buildings

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Abstract

The supporting wood columns in the ancient buildings in China are normally partially or completely wrapped within the wall systems. Decay can occur on the contact areas between the wood columns and the wall, and there is limited access for physical testing and inspection operation. Through the field inspection of an ancient building complex in Beijing, we investigated the use of nondestructive testing and evaluation methods for assessing the conditions of the concealed or partially concealed wood columns and determined the location and extent of the defects within the wood columns. Sixty-eight concealed or partially wood columns in the Main Hall, East Hall and West Hall of the building complex were used as the investigation objects. First of all, the exposed face, air vent and opening of wood columns were used for field detection, which includes external defect detection, sounding detection, internal defect detection and moisture content determination. Then, the data of wood column sizes, surface defect types and sizes, micro drill resistance curves and so on were collected and analyzed to evaluate the defects status of each wood column tested, and the location and extent of the decay in the wood columns were determined. The main forms of external defects were surface decay and material loss, and the main forms of internal defects were internal rot and cavity. For a single wood column, the decay mainly occurred in the area where the wood columns were in contact with the wall at the cross sections. Decay mainly occurred at the bottom of the wood columns, and the severity of decay decreased with height. The inspection results of this study provides basis for repairing the wood columns in the building complex, and also provides proved nondestructive testing procedures for evaluating the concealed wood columns in similar ancient wood buildings.

Keywords: wood columns, defects, decay, inspection, nondestructive evaluation.

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Flexible Machine Strength Grading: Using Acoustic Nondestructive Testing of Green Sawn Timber to Calculate Grading Settings for Individual Batches of Spruce Sawn Timber

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Abstract

Machine strength grading is an efficient method to achieve sawn timber of homogeneous quality. In the European machine-controlled approach, settings for machine strength grading need to be calculated in advance, based on a representative sample of destructively tested sawn timber, which may need to contain a thousand or more pieces. If an industrially graded batch deviates strongly from the characteristics of the representative sample, the grading becomes less efficient. This study introduces and evaluates a modified approach to settings calculation that adapts the settings to the quality of the batch to be graded. The aim is to thus maintain a high grading efficiency even on deviating batches. To achieve this, the new method adjusts the original representative sample to match the current batch by means of statistical simulation. The quality of the batch is assessed by means of acoustic nondestructive testing of the green sawn timber, which can simultaneously be used to segregate the timber by quality. In contrast to the method currently in use, the new method could maintain a high grading efficiency even for batches with substantially lower quality than the representative sample. This method opens up new and interesting options for machine strength grading, especially in combination with different kinds of pregrading. Further research should be directed toward the potential and the limitations of simulation approaches to machine strength grading.

Keywords: acoustic nondestructive testing, dynamic modulus of elasticity, green sawn timber, machine strength grading, settings for individual batches, spruce (*Picea abies*).

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Nondestructive Detection and Three-Dimensional Mapping of the Root System of an Ancient Camphor Tree Based on Ground-Penetrating Radar

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Abstract

Old trees are a precious heritage left by nature and have very important historical, cultural, ecological, scientific research, and economic values. As one of the important organs of ancient trees, the root system provides important support and material exchange with the soil. But because of the complexity of the soil environment and root spatial distribution, obtaining a three-dimensional map of the structure of the root system can be difficult. The object of this study was to achieve nondestructive and accurate in situ detection and three-dimensioal (3D) mapping of the root system of a 300-year-old camphor tree in Deqing, Huzhou, Zhejiang Province, with ground penetrating radar (GPR), an efficient geophysical detection technique. FK migration and Hilbert transform were used to detect the root on the pre-processed GPR B-scan image of the camphor tree root system. Effectiveness and accuracy of root detection were verified by simulation experiments and fresh grapevine control experiments. With consideration of root system growth characteristics and the impact of root orientation on root detection using GPR, the root system spatial structure of the camphor tree was mapped in 3D space using OpenGL by combining the detected roots in the GPR B-scan images and their circular scanning traces. Then, the spatial discretization method was adopted to obtain and analyze the distribution density map of the root system at different depths. The result showed the effectiveness of the scheme in root detection and its 3D structure mapping. This study demonstrates the future of root nondestructive detection based on GPR and provides important support for ancient tree conservation.

Keywords: nondestructive detection, ground penetrating radar, root detection, 3D structure mapping

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Nondestructive Timber Testing as a Tool to Detect Depletion of Carbon Storage in Stem of Aspen

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Abstract

Carbon sequestration and storage are increasingly important forest ecosystem services, even so much that forests can be established and maintained only for this purpose, which can be easily implemented by using widespread and fast-growing tree species, such as Eurasian Aspen (*Populus tremula* L.). However, aspen is considered to be particularly prone to biotic agents, which can notably reduce the life span of aspen even in stand level. Therefore, determination of the optimal rotation period for this species in terms of carbon sequestration could facilitate evaluation of the role of old aspen stands in climate-change mitigation. The study was carried out in European hemiboreal forests of Latvia, where wood density of stem basal part (determined by a resistograph) was compared with actual wood density and carbon content (after felling) for 1305 trees in aspen-dominated old-growth (104 to 135 years) stands. Most of the tested aspen had stem-rot, leading to 17% lower wood density for moderately decomposed stage, while strongly decayed stems had up to 5 times lower wood density than that of a healthy aspen. For moderately decomposed stems, carbon concentration did not differ from unaffected wood, while for strongly decayed stems it was 4% higher. However, stem rot led to only 2% to 9% reduction of carbon storage on old-growth aspen stands. A resistograph can be used as the identification of stem decay levels in any aspen stand. Further studies shall address the amplitude of presence of stem-rot in mid-aged stands as the old-growth stands may represent an outlier from the average trend due to aging effect.

Keywords: Eurasian aspen, *Populus tremula*, resistograph, Carbon sequestration, stem-rot, hemiboreal forests.

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Loading Resistance of Silver Birch (*Betula pendula Roth.*) and Eurasian Aspen (*Populus tremula L.*) in Urban and Peri-urban Forests

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Abstract

In urbanized areas, wind disturbances can be intensified by anthropogenic stresses under which trees may become hazardous, creating serious threats and damages to near targets. Therefore, species with notably lower wood mechanical properties and compartmentalization, such as pioneers, are considered to have higher wind damage risk if subjected to unfavorable growing conditions. Eurasian aspen (*Populus tremula* L.) and silver birch (*Betula pendula* Roth.) are frequently found in both urban and peri-urban forests in northeastern and central parts of Europe, which strengthens the necessity for the evaluation of mechanical stability of such species. Therefore, static pulling tests were performed to compare the mechanical stability of the studied species in urban and peri-urban forests. The loading resistance of the studied species differed, with birch being more stable than aspen, indicating that aspen is more prone to wind damage. Also, the mechanical stability of birch did not differ between trees growing in urban forests and those growing in peri-urban forests, suggesting that static pulling tests are a suitable method for comparison of trees from completely different growing conditions.

Keywords: Eurasian aspen, *Populus tremula*, silver birch, *Betula pendula* Roth., static tree-pulling test, urban forests, peri-urban forests.

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Near-Infrared Spectroscopy Coupled with Chemometric Analysis as a Valuable Nondestructive Tool for Prediction of Carbon Content in Wood Samples

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Abstract

As interest in wood as one of the primary feedstocks for the materials, energy, and chemicals of the future continues to grow, the need for an accurate estimation of the amount of wood available for consumption becomes more evident. Carbon-Nitrogen-Hydrogen (CHN) elemental analyzers are used in routine analysis to quickly determine the carbon, nitrogen, and hydrogen content in lignocellulosic biomass. Near-infrared (NIR) spectroscopy is widely used to study the chemical composition of these samples also. The chemometric analysis of large and complex data from NIR spectroscopy measurements is a powerful tool for predicting the carbon content in woody biomass samples. This study was carried out with more than one hundred samples from the same tree species. The ground samples were analyzed using a Thermo Scientific Flash2000 Series Elemental Analyzer and a Perkin Elmer Spectrum 400 FT-NIR spectrophotometer equipped with a 10-mm sample spinner accessory in a near-infrared reflectance accessory (NIRA). Partial least square (PLS) and principal components regression (PCR) algorithms were used in the chemometric analysis. The results show the potential of NIR spectroscopy as a quick and nondestructive method to predict the C content of woody biomass. Additionally, the results clearly show the importance of sample collection and preparation.

Keywords: near-infrared reflectance accessory, FT-NIR spectroscopy, chemometrics, template near infrared reflectance accessory.

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Assessment of Incipient Decay on Wood Using Stress Wave Technique

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Abstract

Wood is a biological, sustainable, and renewable material. However, because of its nature, it is susceptible to degradation. To fully achieve the capacity of wood structures, it is important to understand the behavior of the material and to monitor in-service wood, consequently enhancing safety and avoiding unnecessary replacement. The objective of this work was to evaluate the performance of nondestructive testing (NDT) to detect early decay in wood structures. This work is part of a larger study that focuses on improvement of in-service condition assessment of wood structures such as timber bridges and mass timber structures. A total of 320 specimens of untreated southern yellow pine measuring 0.5 by 0.5 by 11.25 in. (tangential by radial by longitudinal directions) were exposed to natural conditions. The NDT method used in this study was stress wave speed. Time of flight (TOF) was also recorded. For this work, the variables presented included mass loss, TOF, and ultimate tension strength (UTS). NDT was the most consistent method in identifying early decay in wood, and it was able to identify decay before any significant changes in mass loss or UTS. The results of this project will help improve on-site assessment of wood structures and increase scientists', builders', and end-users' knowledge of wood used as a building material.

Keywords: early degradation, fungi damage, detection of decay, evaluation, wood structures.

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Poster Session

Approved Method for Efficient Inspection and Documentation of Not Only Historic Timber Structures based on Results Obtained in Hundreds of Successful Projects Since 1988

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Abstract

Caring about historic buildings is not only important for preserving a society's cultural heritage and for attracting tourists, but it also brings other benefits: a 700-year-old roof structure of a church in Germany, for example, not only teaches us how to build stably and sustainably for a long usage time but also what needs to be done to ensure that such a structure survives for centuries without significant damage. A special combination of conventional inspection (visual and tapping) and electronically regulated, high-resolution resistance drilling was shown to be affordable and efficient in reliably examining the condition of old wood in structures. But how the results are presented is critical, so that administrations, architects, engineers, and repairing carpenters quickly and fully understand the condition of the structure. For this, we developed a special concept for mapping the condition (very different from just showing defects) and successfully used it in hundreds of projects (church roofs, multistory half-timbered buildings, timber bridges, timber towers, playground toys, harbor structures, etc.). Compared with previous common procedures, our inspections help preserve more historic integrity and at the same time typically lead to reduced repair costs of about 50% due to various reasons. For example, we find 'hidden' defects and we can examine even invisible beams behind stucco or in ceilings. Based on our condition sketches, the renovation measures can be well planned, organized, and optimized beforehand. In addition, our results help with designing better new timber structures that last longer with less defects.

Keywords: resistance drilling, timber structures, condition mapping.

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Urban Green Spaces and How They Affect Woody Species Diversity and Biomass Carbon Stock in Hawassa, Ethiopia

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Abstract

Urbanization tends to alter the ecosystem. Urban green spaces are established to reduce impacts of urbanization. However, in developing regions, this is often neglected. The city of Hawassa, Ethiopia, has been greatly affected by rapid urbanization. Hence, this study's aim was to assess the role of green infrastructure in woody species diversity and carbon stock in Hawassa. A cluster sampling method was used to classify the existing green infrastructure. In this study, 240 sample plots were used to compile a woody species inventory and for soil sampling. Also, 58 woody species belonging to 44 genera and 28 families were recorded; 67.25% of these were exotics. The highest Shannon–Wiener diversity was in private and public institution compounds (mean 1.35) and the least diversity was in street trees (0.68). The highest mean biomass carbon was recorded in street trees (167.5 t C ha^{-1}) and the lowest was in urban forests (11.4 t C ha^{-1}). Soil organic carbon accounted for 90% of ecosystem carbon stocks for urban forests, 60% for private and public institutions, 57% for urban church forests, and 37% for street trees. Generally, there is lower species diversity and a dominance of exotic species. Planting diverse and indigenous species should be the next priority.

Keywords: carbon stock, Ethiopia, Hawassa, urban green infrastructure, woody species diversity.

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Notes