WS001: Prediction of Young's Modulus in Three Orthotropic Directions for Some Important Turkish Wood Species Using Ultrasound

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The materials used in the study consisted of 720 small clear specimens of nominal dimensions 20 × 20 × 60 mm, of Turkish Red Pine (Pinus brutia), Lebanon cedar (Cedrus libani), Oriental beech (Fagus oriantalis), and English oak (Quercus robur) from Turkey. The specimens were grouped into four batches of 15 specimens each and were tested in the ETH laboratories in Zurich, Switzerland. The influence of EMC was studied over four batches of 15 specimens each, conditioned for 6–8 weeks before testing at a temperature of 20 ± 2 ºC and at four different relative humidities (50%, 65%, 85%, and 95%). Time of flight value was measured with an ultrasonic commercial device Steinkamp BP-V. Measurements were made end to end directions (L, R, T) on each specimen, with a constant sensor coupling pressure. According to the time results of ultrasound devices, the wave velocities (length/time) and Edyn were calculated. Samples were also tested in uniaxial compression in order to determine E values in three orthotropic directions using a Zwick Z 100 universal testing machine. A load cell with 100-kN maximum capacity was used for compression tests performed in all directions. The feed rate was defined in such a way that the failure of the specimen should be reached in 90 (±30) s. The strains were evaluated using the digital image correlation DIC technique. Wood MC was determined by the oven-drying method. The R2 values between E and Edyn ranged from 0.79 to 0.96 for the species tested. Moisture content seems to be an influencing factor on sound velocities.

WS002: In-Situ Synchrotron Micro-Tomography and Acoustic Emission of Norway Spruce Samples under Tensile Load

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Damage mechanisms occurring in a material during increasing load lead to the emission of acoustic signals. For wood, this is especially true for tension in the longitudinal direction. Although a multitude of experiments have been done for wood, assignment of signals to the initiating mechanisms is not yet possible. For this, knowledge of changes occurring during emission of the acoustic signals is necessary. To monitor changes in the structure, nondestructive in-situ methods are necessary. Of those methods, synchrotron micro-tomography (SRμCT) is best suited because of fast recording times and the 3D images of the complete sample obtained. To realize this combination, an in-situ testing device for in-situ loading at the TOMCAT-beamline (PSI, SLS Villigen) was used in combination with in-situ monitoring of acoustic emissions. With this setup, used for different clear and glued Norway spruce samples, it was possible to record acoustic emissions and the developing changes of the respective samples. The results enable reconstruction of the failure mechanisms (cracks) and their evolution during loading in connection with their original structure. The acoustic emission signals compliment the structural information obtained from the tomography.

WS003: Predicting Plywood Properties with Wood-Based Composite Models

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Previous research showed that stress wave nondestructive testing techniques could be used to evaluate tensile and flexural properties of wood-based composite materials. Regression models were developed that related stress wave speed to flexural strength (modulus of rupture, MOR) and stress wave speed to modulus of elasticity (MOE). The developed regression models accounted for over 94% of the observed elastic properties of these materials and for over 90% of their observed MOR. The original research was developed using data obtained from untreated wood composites. In this study, the previously developed models are used in conjunction with the wave speed of treated plywood to predict both MOE and MOR. The treated plywood has greater variation in property values than that of the untreated wood composites. With the inclusion of the treated plywood data to the previous data set, the model accounts for over 90% of the variation in the material properties. The decrease in correlation caused by including the treated plywood data was found to be less than the decrease caused by known outliers within the original data set.

WS005: Ultrasound Transmission Times in Biologically Deteriorated Wood

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The use of a variety of stress wave transmission techniques for the in-service condition assessment of deteriorated wood is well documented. This paper summarizes results from an extensive study designed to examine the relationship between ultrasound transmission times and deterioration of exposed wood. A total of 275 southern pine lumber specimens were evaluated nondestructively using a through transmission ultrasound technique after field exposure for periods up to 57 months. Ultrasound transmission times increased with exposure time. Several statistical models of the relationship between transmission time and length of exposure were developed and are presented.

WS008: Analysing the Accuracy of Internal Hardwood Log Defect Prediction Equations

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The type, size, and location of internal defects dictate the grade and value of lumber sawn from hardwood logs. Significant correlations have been documented among external log defect indicators and internal defect features. Prediction models for four hardwood species have been developed based on these correlations. A recently developed high-resolution laser log scanner that locates external log defects uses these models to predict internal defect locations and sizes based on detected external defect data. The models are species- and defect-type-specific and allow users to estimate internal defect size, shape, depth, and position. This paper examines the accuracy of the red oak and yellow-poplar prediction models by comparing defect attributes on actual sawn board faces with predicted defect attributes on virtually sawn boards from the laser-scanned logs. In this validation test, 11 red oak and 9 yellow-poplar logs were sawn into a total of 209 boards. The outer face of the boards had a total of 218 observed surface defects, of which the models predicted 68.3%. Overall, the yellow-poplar model performed slightly better than the red oak model. In addition, the models accurately predicted the sawing of 95 of 105 boards with no knot defects, an accuracy rate of 90.5%.

WS010: Assessing Specific Gravity of Young *Eucalyptus* Plantation Trees Using a Resistance Micro-Drilling Technique

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The objective of this study was to evaluate the use of a resistance micro-drilling technique for assessing wood specific gravity (SG) of young *Eucalyptus* plantation trees for pulpwood production. The genetic material used in this study consisted of 50 trees of 34 months old and 50 trees of 62 months old from *Eucalyptus grandis* × *Eucalyptus urophylla* hybrid clonal plantations located in the north of Espirito Santo State, Brazil. Resistance micro-drilling readings (relative resistance profile) were collected from each tree at breast height (BH). Trees were then felled and a 4-cm-thick disc at BH level was removed for laboratory determination of SG and moisture content (MC). For full drill penetration (diameter), the Resistograph readings (average amplitude) showed a moderately good linear relationship with SG (r = 0.73) when two age groups were combined. For half-radius drill penetration, the Resistograph readings showed a relatively weak correlation (r = 0.49 for the first radius, r = 0.62 for the second radius) with SG. At increment drilling depths, the Resistograph readings showed a strong linear correlation (r = 0.87) with SG at 5 to 15 mm depths, but the strength of the correlation decreased as the drilling depth increased.

WS011: Stress Wave Propagation in Larch Plantation Trees—Numerical Simulation

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The use of stress wave technology for standing tree quality assessment has received a lot of attention in recent years. By far, most research has been limited to direct measurement of stress wave velocity in trees. Subsequent wood property prediction was based solely on the measured velocity value. There is still a lack of understanding of how stress waves propagate in standing trees and how tree diameter, species, tree age, and environmental conditions affect wave propagation in a tree. The objective of this study was to investigate the mechanism of stress wave propagation in standing trees through laboratory experiments and two-dimensional (2D) numerical simulations. Laboratory experiments were conducted on small clear specimens cut from larch (*Larix principis-rupprechtii* Mayr) trees to obtain 12 elastic constants of wood. The measured elastic constants satisfied the Maxwell theorem of a composite material. A tree trunk was subsequently modeled as a transverse-orthotropic cylinder. Longitudinal stress wave propagation under this physical model was investigated using finite element analysis software under two dynamic loading scenarios: (1) direct impact at the center of the end and (2) impact on the side of the end with a 45° angle to the surface. The results of numerical simulation indicated that stress wave propagation in the longitudinal-radial midsection of the tree trunk was affected by tree diameter, travel distance, and the elastic properties of wood. The 2D wave fronts observed in numerical simulations were in agreement with those obtained through field stress wave testing on larch tree stems.

WS012: Stress Wave Propagation in Larch Plantation Trees—Experimental Validation

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The objective of this study was to validate stress wave propagation patterns in plantation trees through field experiments. A series of stress wave time-of-flight (TOF) data were obtained from three freshly cut larch (*Larix principis-rupprechtii* Mayr) logs using a two-probe stress wave timer. Two-dimensional (2D) and three-dimensional (3D) stress wave contour maps were constructed from the experimental data using a commercial software (2D) and a Matlab software (3D). These stress wave contour maps represent the wave fronts in a time sequence, illustrating the flow of stress wave energy within a tree trunk. The analysis of TOF data and wave fronts indicated that stress wave propagation in larch plantation trees was affected by tree diameter, travel distance, and internal wood conditions (wood properties and structural defects). When a stress wave was introduced into a tree trunk from a point source, it initially propagated in the impact direction (45° to the longitudinal axis) as a 3D wave. Then the flow of the stress wave energy gradually changed towards the longitudinal direction. As the diameter-to-distance ratio reached 0.1 or below, the wave front became a quasi-plane wave. Our experimental results were found in good agreement with the numerical simulations reported in a separate paper.

WS013: Determining Modulus of Elasticity of Full-Size Wood Composite Panels Using a Vibration Method

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Traditionally, modulus of elasticity (MOE) of full-size wood composite panels is determined by mechanically testing multiple small specimens cut from the panels. The evaluation process is time consuming and destructive in nature. In manufacturing facilities, it is often desired to rapidly and nondestructively assess MOE of full-size composite panels as a quality control procedure. The goal of this study was to develop a vibration-based measurement system that can be used to evaluate MOE of full-size panels in production settings. We first built a laboratory testing apparatus for measuring the fundamental frequency of 2440-mm by 1220-mm composite panels. A free vibration is initiated through a gentle push at the end of the panel away from the pressure sensor and followed by a quick release. Vibration signal was collected through the laser sensor located in the middle of the panel, and the weight of the panel was measured by the pressure sensor located at the 22.4% or the 77.6% in its length direction. A total of 303 pieces of 2440-mm by 1220-mm composite panels were then tested using this vibration apparatus, including 101 pieces of medium-density fiberboard (MDF), 100 pieces of particleboard, and 102 pieces of plywood. Following free vibration testing, six small specimens were cut from each panel and standard static bending test was then performed on each specimen to obtain static MOE. The results indicated the average dynamic MOE of full-size panels by vibration method was slightly higher (6.2%) than the average static MOE of small specimens. A good linear relationship (r = 0.923) was found between dynamic MOE of full-size panels and average static MOE of the small specimens. This study demonstrated that MOE of full-size wood composite panels can be potentially measured in production settings as a quality control procedure.

WS014: Development of a Nondestructive Testing Technique to Quantify Marine Borer Damage—Observations from a Pilot Study with Sitka Spruce and Western Hemlock Logs

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Stress-wave nondestructive evaluation (NDE) techniques are used widely in the forest products industry—from the grading of wood veneer to inspection of timber structures. Inspection professionals frequently use stress-wave NDE techniques to locate internal voids and decayed or deteriorated areas in large timbers. Although these techniques have proven useful, little information exists concerning the relationship between stress-wave parameters and deterioration observed as a consequence of marine borer attack. In this pilot test, we examined the relationship between stress-wave transmission time and the quality of wood in Sitka spruce and western hemlock logs that had various degrees of deterioration as a consequence of attack from marine borers. Stress-wave transmission time, perpendicular to grain, was measured at several locations on each log. The logs were then sawn into lumber, which was then visually evaluated. A relationship was observed between stress-wave transmission time and deterioration of the logs and the yield of lumber from the logs.

WS015: Condition Assessment of a Historic Trout Rearing Station

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The Michigan Technological University (Michigan Tech) School of Forest Resources and Environmental Science maintains a log cabin on the north branch of the Otter River in southern Houghton County (Portage Township), Michigan, USA. The cabin was built in 1934–1935 and measures 150 m^2. The cabin's location is less than 10 m from the river, which when combined with the region's high snowfall (5+ m/year) and subsequent spring melting, results in it being highly susceptible to occasional flooding and subsequent water damage and decay. The history and use of the cabin dates back to the mid-1930s. The Michigan Conservation Department (predecessor of the Michigan Department of Natural Resources) and the Civilian Conservation Corps built the cabin in 1934–1935 to house workers who used the site as a trout hatchery. Grayling (*Thymallus arcticus*), rainbow (*Oncorhynchus mykiss*) and German brown (*Salmo trutta*) trout were propagated at the site. Since 1998, Michigan Tech, in cooperation with the USDA Forest Products Laboratory (FPL), has conducted periodic inspections of the cabin. This poster presentation summarizes results obtained from the inspection we conducted in 2013. It includes a brief summary of the nondestructive testing techniques we utilized, observations, and data from tests conducted on the cabin.

WS016: Determination of the Mechanical Properties of *Castanea sativa* Mill. Using Ultrasonic Wave Propagation and Comparison with Static Compression and Bending Methods

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The goal of this paper was to analyze the mechanical properties of *Castanea sativa* determined using an ultrasonic wave method. The results were compared with those obtained using the traditional static compression and bending methods with the same sample. The results were also compared with expected values for this species, and relationships among properties were determined to verify if there were differences between the results and the expected behavior of the wood. The elastic constants determined using ultrasound did not reveal statistically significant differences compared with the static methods, and the results were generally within the expected range for this species. This result makes ultrasound a powerful method for determining the elastic constants of wood, in addition to its feasibility and low cost. Future studies regarding optimization of the specimen are important to improve the results of the Poisson's ratios.

WS017: Acoustic Evaluation of Thinning and Biosolid Fertilization Effects on Wood Quality of a Douglas-fir Stand

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In this study, we examined the potential of using a time-of-flight (TOF) acoustic wave method to evaluate thinning and bio-solid fertilization effects on modulus of elasticity (MOE) and grade yields of structural lumber from a 76-year-old Douglas-fir (*Pseudotsuga menziesii* Mirb., Franco) experimental stand. The stand consisted of four treatments: control, thinned, biosolid fertilization, and a combined thinned and fertilized treatment, each with three replicates on 0.08-hectare plots. Four trees were selected in each plot using a stratified random sample based on the plot quadratic mean diameter, resulting in a total sample of 48 trees ranging from 14.2 to 53.3 cm diameter at breast height (dbh). The sample trees were first nondestructively tested using a TOF-based acoustic measurement system to obtain acoustic velocity in trees. The sampled trees were then harvested, bucked into merchantable-length stems and then mill-length logs that were sawn into lumber. Acoustic velocities of stems and logs and MOE of lumber were subsequently obtained. Our results indicated that biosolid fertilization had a statistically significant effect on acoustic velocities of trees, stems, and butt logs; thinning did not have a statistically significant effect on acoustic velocities; combining thinning with biosolids did not produce a change in acoustic velocity different from applying biosolids alone. These findings are consistent with the treatment effects that were reported on interannual ring specific gravity. At tree level, treatment had no significant effect on lumber stiffness.

WS019: **Wear Behavior of Drill Bit and Its Blunting Effect on Force Parameters in Drilling Resistance Measurement on Wood**

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The purpose of this research was to investigate wear behavior of the cutting head of a needle drill bit and its blunting effect on force parameters during drilling resistance measurement on wood. An IML-RESI PD 400 tool (IML-Instrumenta Mechanik Labor System GmbH, Wiesloch, Germany) and a standard spade-type needle drill bit were used in this laboratory investigation. A total of 375 drilling measurements were performed along a 2.58-m-long yellow birch (*Betula alleghaniensis*) log (large end diameter of 35 cm; small end diameter of 29 cm). All drilling measurements were conducted at a fixed feeding speed (0.508 m/min) and a fixed rotating speed (2500 rpm). The cutting path length was calculated for the outer point of the cutting edge based on the drilling distance and the speed parameters used. Interaction between other feeding and rotating speeds and cutting path length were also calculated. The wear (loss of metal) characteristics of the cutting head were optically investigated using an Olympus BX 41 microscope (Olympus Corporation, Tokyo, Japan). On the basis of static rectangular coordinate system, wear parameters of the clearance and rake face, edge rounding, diameter of cutting head, and area of cutting edge wear were measured and calculated for initial conditions and incremental cutting path lengths. Drilling resistance and feeding force were continuously recorded during each drilling measurement and their mean values were determined after 17 incremental cutting path lengths. Results are presented as graphical interactions between wear parameters of the cutting head and force characteristics with the cutting path length.

WS020: Characterization of Physical and Mechanical Properties of Pino (*Pinus patula*) and Tornillo (*Cedrelinga cateniformis*) from the Peruvian Forest using Nondestructive Techniques

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The objective of this study was to determine the physical and mechanical properties of two species of wood from Peruvian forest, Pino (*Pinus patula*) and Tornillo (*Cedrelinga cateniformis*) using nondestructive methods. These species are commonly used in the design of wooden structures in Peru. In this study, a Parametric PR 5800 Ultrasound of 1 MHz-frequency equipment was used to characterize these two species. At first, the velocities of propagation of longitudinal and transverse acoustic waves in the main directions were measured and then the respective elastic moduli were calculated, obtaining values comparable to those obtained in traditional mechanical tests. The results indicated that the behavior of velocity are very similar for both species, fulfilling the typical relations V (LL)> V (RR)> V (TT). Other typical relations are related to the symmetry of the cutting speed V (LR) = V (RL), V (LT) = V (TL) and V (RT) = V (TR). In the case of *Cedrelinga cateniformis,* the coefficients of variation for V(TT), V(TL) and V(LT) of the speeds are significantly higher compared with *Pinus patula,* this is possibly because the former was extracted from natural forest. Speed results of longitudinal polarization show similar elastic anisotropy in relation to the three major axes for both species. For *Cedrelinga cateniformis is* 1: 2.3: 3.6 whereas for the *Cedrelinga cateniformis is* 1: 2.4: 3.6. Such anisotropy values are slightly higher than for Chilean softwoods but lower than for hardwoods. The Young's modulus obtained through NDT are very similar for both species but in the radial direction a small difference is observed, where the values are highest for the *Cedrelinga cateniformis* in about 200 MPa, while for the shear modulus the difference between the two species is most significant. In the future, studies measuring Poisson coefficients and the evaluation of *Cedrelinga cateniformis* are recommended.

WS021: Application of Infrared Spectroscopy and Thermogravimetric Analysis in the Screening of Disease Tolerant *Pinus taeda* (Loblolly Pine) Families for Chemistry, Strength, and Bioenergy

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Pinus taeda (loblolly pine) is the most economically important tree species in the United States. With 30 million acres in plantations in the southern United States alone, it provides 110,000 jobs and contributes approximately $30 billion to the economy of this region. Over the past five decades, reduced growth, decline, and mortality have however been associated with loblolly pine trees. As a management strategy for this disease complex, stakeholders are selecting and deploying genetically superior families that have been selectively bred to be disease tolerant. It is vital that we do not compromise other important properties while breeding for disease tolerance. In this study, three novel analytical tools—near-infrared spectroscopy, Fourier transform infrared spectroscopy, and thermogravimetric analysis—will be used together with multivariate data analysis in the development of prediction models for the rapid and nondestructive screening of 15 genetically superior loblolly pine families based on their chemical composition, strength, and thermal reactivity. Whereas the chemical composition determines the optimum utilization pathway to a large extent and any change will impact the yield and quality of

products, it is important that strength is not compromised or else mortality due to reasons other than forest disease, such as wind failure, could occur. Models developed in this study should also be applicable in the rapid screening of other loblolly pine families for tree improvement programs. The long-term goal of this study is to make the right feedstocks available for the conventional forest industry and to support the emerging bioeconomy.

WS022: Nondestructive Prediction of the Chemical and Thermal Reactivity Properties of Forest Biomass Using Vibrational Spectroscopy and Thermogravimetric Analysis

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Forest-derived biomass will play a major role in the necessary shift to a sustainable low-carbon economy. In order to utilize this resource, its properties must be well understood. In this study, three analytical tools were used to rapidly and nondestructively predict chemical and thermal reactivity properties that are important in the utilization of forest biomass as a feedstock in the emerging bioeconomy. Near-infrared (NIR) spectra, Fourier transform infrared (FTIR) spectra, or thermogravimetric analysis (TGA) thermographs were used in conjunction with data collected via conventional methods to develop partial least squares regression (PLSR) models for property prediction. Models developed with first-derivatives-treated spectra used two or three latent variables (LVs) to predict individual properties (i.e., PLS1) for both NIR and FTIR models—with R^2 values ranging from a high of 0.93 for extractives content (FTIR) to a low of 0.57 for higher heat value (NIR). NIR spectroscopy and FTIR spectroscopy were able to predict the chemical and thermal reactivity properties of forest biomass comparably using PLS1. TGA also predicted the cellulose and lignin content satisfactorily, with models performing comparably to NIR and FTIR models. PLS2 models that were developed to predict all properties simultaneously also performed well. Models developed in this study should be able to predict the studied properties of similar biomass types. This will be useful in rapidly allocating feedstocks that optimize biomass conversion technologies.

WS023: Nondestructive Evaluation of Laminated Veneer Lumber Composed with High-Density Polyethylene

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The objective of this paper was to evaluate the feasibility of using stress wave nondestructive technique to determine properties of a new wood veneer composite bonded with high-density polyethylene (LVL-HDPE). Wood veneers from a tropical species were obtained and used to manufacture a laminated veneer lumber (LVL) using expanded high-density polyethylene as binding agent. Three HDPE amounts were tested: 150, 250 and 350 g/m^2. Twelve LVL-HDPE composite boards were produced and samples were cut and nondestructively tested using stress wave method, and stress wave velocity (sw) and dynamic modulus of elasticity were calculated (E_d). Afterwards, the samples were tested up to rupture to assess bending, compression, hardness, and shear strength properties. The sw and E_d data were utilized to generate a simple linear regression model ($y = a + bx$), with these properties entering as independent variables (x) and mechanical properties (f_m, E_M, f_H, $f_{c,0}$, $f_{v,0}$) entering as dependent variables (y). Initially we analyzed the variables in a grouped form, for all treatments as a single group and later we analyzed separately by treatment. The models obtained by treatment were nonsignificant. However, when evaluating all treatments as a single group, only regressions between sw and E_M and between E_d and E_M were significant at 1% level. It was identified that the stress wave velocity (sw) explained 34.35% of the modulus of elasticity variation data (E_M), while the dynamic modulus of elasticity (E_d) explained 44.73%.

WS024: Mechanical and Physical Properties of Wood and Bamboo in Cell Wall Level: Our Recent Progress

Siqun Wang[1*], Xinzhou Wang[1,2], Dong Xing[1,3], Yurong Wang[1,4], Chengjian Huang[1,5], Deliang Xu[1,2], Yujie Meng[1]

[1] Center for renewable carbon, University of Tennessee, 2506 Jacob Dr., TN 37996, USA; [2] College of Materials Science and Engineering, Nanjing Forestry University, Nanjing, China; [3] Material Science and Engineering College, Northeast Forestry University, Harbin, China; [4] Research Institute of Wood Industry, Chinese Academy of forestry, Beijing, China; [5] College of Engineering, Zhejiang Agricultural and Forestry University, Hangzhou, China. As biopolymer composites, both wood and bamboo have been extensively used for homes and other structures, furniture, paper, and decoration. They have good machinability, beautiful appearance, good strength, and light weight. However, they are prone to degrading, warping, and cracking under changing environmental conditions. Therefore, improving the environmental resistance of wood and bamboo, such as mechanical strength, dimensional stability, or resistance to biodegradation, to expand their application fields and to prolong the service life of products is of critical interest. Wood and bamboo consist of different cell types that are oriented in the axial or radial direction. Cell walls of fibers built up of layers of different thickness, spiral microfibril angles (MFA), and chemical components dominate the natural properties of wood and bamboo. To better understand the mechanism of weathering degradation and modification of wood and bamboo, investigating mechanical and physical responses in cell wall level is essential. In this presentation, we overview nano-mechanics of wood and bamboo treated by several modification methods, an improved nanoindentation technique, and potential applications in wood science through our recent developments. First, we discuss nanoindentation approach for measuring static mechanics (modulus, hardness), dynamic mechanics (storage modulus and loss modulus), and creep behaviour. Second, we attempted a combined technique of *in-situ* heating and nanoindentation to measure modulus and hardness of wood fiber cell walls and wood adhesives at elevated temperature. This nondestructive testing method has proven to be an accessible and straightforward approach to analyze temperature-dependent materials like wood, polymers, and solid composites. Third, we discuss how to measure mechanical properties of each layer of cell wall, especially for the thin ones, such as S1 and S3 layers. Fourth, we discuss penetration and diffusion of different types of commercially available polymers in the wood cell wall by using nanoindentation and nanoscale infrared spectroscopy to increase the understanding of formation mechanism of interphase in wood-based composite.

WS027: Revision of Nondestructive Acoustic Measurements on Standing Trees to Predict Timber Stiffness

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This study, which forms part of a PhD, aims to improve the method of predicting sawn, dry, timber stiffness using portable acoustic tools on standing trees. The method commonly used in research and industrial practice measures the time-of-flight of a stress wave between transducers, usually about 1 m apart, to predict the stiffness of timber in that tree. However, the correlation between time of flight measurements made on individual trees and the stiffness of their timbers is often weak. It has previously been suggested that this is because the short measurement distance of only 1 m is not representative of the wood stiffness throughout the log and that a ratio of tree diameter to measurement length should be <0.1. In this study we tested this theory on four tree species grown in plantations in Scotland: *Abies procera, Tsuga heterophylla, Picea abies*, and *Thuja plicata*. We collected multiple time-of-flight measurements on each of the 36 trees (9 per species), with a fixed origin over a measurement distance of 1, 2, and 3 m. Further, we compared arrival times on the opposite side of the tree with vertical distance between the transducers of 1 and 2 m. We then felled the trees and measured resonance acoustic velocity of the logs before processing them into structural sized timbers, on which we measured stiffness by resonance velocity and bending strength and stiffness using destructive tests. We compare the empirical relationships between tree stiffness predicted from multiple acoustic time-of-flight measurement distances to these log and timber assessments and provide a recommendation for best practice in the future based on variation of wood properties within the log and the nature of the propagation of acoustic waves in standing trees.

WS029: Three-Dimensional Knot Models Based On Surface Laser Scanning

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Most machine strength-grading methods are based on statistical relationships between strength and various more or less global measures of modulus of elasticity. These relationships are in general rather weak, resulting in limited grading accuracy and poor yield, particularly in higher strength classes. A new and more accurate grading method based on laser scanning was recently approved for the European market. In this, however, no consideration is taken to the out-of-plane orientation of the fibres. A first important step towards scanning-based three-dimensional (3D) models of fibre orientation is the establishment of 3D knot models developed on the basis of information from scanning. When a surface of a softwood board is illuminated by a dot laser, the light will spread more along the fibres than across due to the tracheid effect, resulting in the dot entering an elliptical shape. In this investigation both the shape of the ellipse and the direction of its major axis are used to estimate the 3D fibre orientation on surfaces. Knot surfaces are identified on longitudinal board surfaces where the angle between the estimated 3D direction of fibres and an approximated direction of the board's pith exceeds a threshold value. By means of algorithms based on polar coordinates, knot surfaces that belong to the same physical knot visible on different sides of the board are identified, and as a result, the orientation and volume of each knot is determined. Further, with the information about the direction of each knot, an improved linear approximation of the position of the board's pith can be calculated. The established 3D knot models show good agreement with the physical knots in boards investigated. In future research, the information obtained will be used to model the 3D fibre orientation that is to be included in the newly developed strength grading method.

WS030: Use of the Attenuation Gamma Radiation Technique for Qualification of Heartwood and Sapwood in *Eucalyptus*

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The presence of heartwood influences the use of wood in different ways[1]. The conceptual bases that allowed precise definition and general physiological aspects involved in heartwood and sapwood formation were consolidated for some time, but some current techniques such as X-ray scans, infrared, and gamma rays can be used for more detailed quantification and characterization of heartwood inside the trunk[2]. In this study we used the nondestructive method of gamma radiation attenuation to determine apparent density at 12% moisture content of wood portions (heartwood and sapwood) of mature trees of four forest species (*Eucalyptus grandis* Hill ex. Maiden, 18 years old; *Eucalyptus saligna*, 60 years old; *Eucalyptus tereticornis*, 35 years old; and *Corymbia citriodora*, 28 years old). Six discs were sampled at breast height of each species, and the heartwood and sapwood were delimited by macroscopic analysis of the vessels (the heartwood was characterized by the presence of tyloses in the vessels, the sapwood, by the absence thereof) in each sample. Apparent density values ranged from 672 to 933 kg/m³ in the heartwood zone and 749 to 899 kg/m³ in the sapwood zone. Averages of apparent density did not differ significantly between wood zones. Despite the different ages of the plantations, the highest values of apparent density of wood, both in the heartwood and in the sapwood zones, were observed in *Corymbia citriodora*.

WS031: Assessing Southern Pine 2 x 4 Lumber Quality Using a Portable Device

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Preliminary studies based on 2x4 lumber sets shows that smartphone accelerometers have the potential for rapidly estimating wood stiffness. Smartphones are devices that are able to make phone calls, but also adds features that you might find on a computer. The objective of this research was to demonstrate the use of smartphone technology in transverse vibration nondestructive testing techniques. A portable device with an adequate oscilloscope app was used to collect data from 25 samples of southern pine No. 2 2x4 lumbers. Simply supported lumber specimens subjected to transverse vibration and the frequencies were collected with Metriguard Model 340 Transverse Vibration E-Computer and with the portable device. In addition, longitudinal stress wave velocities were collected with a Hitman (Director HM-200^{TM}). Strong linear correlations were obtained between the data collected with the smartphone and the dynamic modulus of elasticity (MOE) obtained with the E-Computer (r^2 = 0.996; p < 0.0001) and with the Hitman (r^2 = 0.967; p < 0.0001). The results indicate a potential use of portable devices to determine the MOE of structural pieces of lumber and to expand the access of nondestructive techniques.

WS032: Laser-Based Optical Nondestructive Method for Evaluation of Pine Timber Strength

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Fast and reliable strength classification of timber is becoming more important. The traditional visual methods cannot provide sufficient accuracy, and these are dependent on human factors; the destructive processes are slow and cannot be used on all samples. We developed a complete technology that is capable of determining the bending strength of spruce timber by a nondestructive method. The He-Ne laser-based tool is able to scan the surface of the timber using a camera while feeding and transmitting the data to the computer. Laser spots are projected to the timber surface. The computer software determines knot locations, decays, and grain anomalies based on the change of the laser spots. The final strength of the timber is calculated by analyzing the sets of vectors by statistical method. This method is real time. The big advantage of the method is that the results do not depend on color changes on the surface. The color change deceives the color-based optical systems in most cases. The analysis on the upper and bottom surface results in more accurate 3D representation of the knot size and position inside the timber.

WS033: Strength Grading Based on High-Resolution Laser Scanning—Performance of a Procedure Newly Approved for the European Market

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Strength grading of timber is based on visual inspection or machine grading. Machines based on flatwise bending, dynamic excitation of longitudinal modes of vibration, or X-Rays are frequently used in many countries. Accuracy of strength predictions from current methods is in general limited, which results in poor raw material utilization and lower yield. Therefore, there is a considerable economical potential in improved grading accuracy. Laser scanning of timber gives high-resolution information regarding fibre orientation on the wood surface, and this information can be used to calculate local modulus of elasticity (MOE) in the direction of the board. Within and near knots, MOE is very low. A bending stiffness profile along a board can be established by integration over the board cross section, and the lowest bending stiffness along the board constitutes a very accurate indicating property (IP) of bending strength. An extensive investigation of the performance of the described method has been performed on Norway spruce, including more than 900 boards of various dimensions from Sweden, Norway, and Finland. Results from the study show that the method surpasses the performance reported for other methods available on the market. Using the method, the coefficient of determination between IP and bending strength becomes as high as 0.70 and the yield in high strength classes is approximately twice as high as the yield using dynamic MOE as IP. The laser scanning and data processing involved can be performed in a speed corresponding to production speed of sawmills and the method was recently approved for the European market. The paper will include a detailed description of the method and the material investigated in the study.

WS035: Nondestructive Characterization of African Mahogany Wood with Ultrasound

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Acoustic-based nondestructive testing techniques have been investigated and are used widely for assessing wood products. For example, ultrasound technologies are used to grade wood veneer in manufacturing laminated veneer lumber (LVL) and to inspect wood conditions in timber structures. Although widely used, little information exists on the fundamental relationship between ultrasound transmission and properties of tropical hardwood species. This study was conducted to provide baseline information on the effect that commonly observed defects have on ultrasound transmission properties in two tropical hardwood species, *Khaya ivorensis* and *Khaya senegalensis*. Five 76- x 5- x 5-cm specimens for each species were selected from 19-year-old plantation trees. The specimens selected contained a variety of naturally occurring defects. Ultrasound transmission times were measured in longitudinal, tangential, and radial directions for each specimen. Based on velocity variation in transverse direction, it was possible to identify end split and pin knots in *Khaya ivorensis* and reaction wood in *Khaya senegalensis* wood. Grain angle reduced ultrasound velocities in radial and tangential directions. *Khaya senegalensis* exhibited lower longitudinal velocities due to larger amount of interlocked grain. Beetle galleries could not be detected in *Khaya senegalensis* wood.

WS036: Development of an Automated Portable Tester for Evaluating Dynamic Hardness of Wood

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Hardness is considered a meaningful quality indicator for wood and correlates well with other mechanical properties of the material, such as compressive strengths normal and perpendicular to the grain. In addition to its good correlation to those mechanical properties, the hardness test is easier to perform than any other strength test. In Europe, the most widely used method for determining wood hardness is the Brinell test, whereas in the Americas, the Janka test is predominant. More recently, international studies have reported the use of dynamic hardness for wood, claiming as main advantage the feasibility of tests under field conditions. This paper presents results obtained in the development of the third generation of a portable hardness tester for wood, which uses a displacement transducer and embedded electronic processor in order to automate the dynamic hardness measurement. Functional tests of the equipment were carried out using seven species of *Eucalyptus*. Results already obtained revealed strong correlation to Janka hardness and confirmed the potential of the equipment for wood classification. Furthermore, this paper introduces a new methodology for dynamic hardness calculation, which is based on the ratio between the average impulse force promoted by the indentation and its depth.

WS037: Acoustic Velocity as Predictor of Strength Properties in Softwoods and Hardwoods Grown in Estonia

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The purpose of this study was to evaluate strength properties of timber using acoustical nondestructive methods. This research used ultrasound and stress wave methods to examine timber, combining the results of measurement with the properties of bending strength and stiffness. The timber—*Picea abies*, *Pinus sylvestris*, *Alnus glutinosa*, and *Populus tremula*—used in these experiments was cut from the forests of Estonia. All together, 196 pieces with dimensions of 50 x 50 x 970—1100 mm were sawn from the collected material. The physical-mechanical properties of wood were determined in laboratory conditions according to standard practices. Acoustical measurements were performed in the longitudinal material directions. TICO Ultrasound Instrument fitted with 50 mm 54 kHz compressional wave transducers and Fakopp Microsecond Timer was used to conduct measurements. Longitudinal measurements with alder characterized bending strength with r = 0.59—0.60 and modulus of elasticity with r = 0.81—0.82 and with aspen r = 0.27—0.33 and r = 0.48—0.59, respectively. With softwood, stronger correlations were found; longitudinal measurements with spruce characterized bending strength with r = 0.22—0.52 and modulus of elasticity with r = 0.55—0.86 and with pine r = 0.73—0.74 and r = 0.80—0.81, respectively. In addition, dynamic and static modulus of elasticity values were analyzed. Dynamic modulus of elasticity characterized static among hardwood samples R^2 = 0.28—0.65 and among softwoods R^2 = 0.44—0.79.

WS038: Investigation of Stress Wave Velocity Perpendicular to Grain in Softwoods and Hardwoods Grown in Estonia

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This ongoing study deals with the evaluation of stress wave velocities measured in different grain directions of timber using acoustical nondestructive method. In additional, measurements were conducted at different moisture content levels. Three types of softwood and hardwood species—*Picea abies*, *Pinus sylvestris*, *Larix* ssp., *Alnus glutinosa*, *Populus tremula*, and *Acer platanoide*—used in this experiment were cut from the forests of Estonia. All together 36 pieces were sawn from the collected material. Acoustical measurements were performed in the radial and tangential material directions with using a Fakopp Microsecond Timer. The physical properties of wood were determined in laboratory conditions according to standard practices.

WS039: An Application of 3D Fiber Angles Identified through Laser Scanning Based on Tracheid Effect

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Development of accurate calculation models for analysis of timber are dependent on advanced laboratory measurements. Such calculation models in turn enable production of high-value wood products with well-defined properties, provided that high-speed data sampling and analysis are performed continuously in the industrial process. It is well known that fast dot laser scanning and the tracheid effect can be used for determination of in-plane fiber orientation on timber surfaces. Resent research indicates that the out-of-plane fiber angle can also be determined on the basis of data from scanning. This paper presents a finite element model based on knowledge of 3D fiber orientation obtained from high-resolution scanning. Materials employed for the present study are side boards of Norway spruce of dimensions 24 × 95 × 2000 mm. For assessment of the model, a simulated load case of pure bending and corresponding calculated strain fields in the vicinity of knots are compared with strain fields obtained from 3D displacement measurements based on digital image correlation (DIC) technique applied during laboratory bending tests of the boards. Results from calculations and measurements show good agreement regarding the strain fields in the vicinity of knots in the examined boards. This indicates that the 3D fiber orientation model gives basis for an accurate FE model that can be used for assessment of strains and stresses locally within boards. This in turn offers the potential for very accurate grading and optimized use of each board being produced. Further research should address development of accurate 3D fiber orientation models of scanned boards in general, not only side boards, and utilization of the developed models for adding value to boards being produced for different applications.

WS042: Influence of Moon Phase on Stress Wave Velocity and Structural Timber Properties

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Nondestructive tests are easy and quick to perform, and their ability as predictors of timber properties is obvious, but it is important to note that several factors affect nondestructive variables measured. Traditional knowledge and some research indicate that the date of tree felling (moon phase) has an important influence on wood quality; therefore, it is reasonable to think that nondestructive variables and mechanical properties could also be affected by this issue. The objective of the research was to analyze this potential effect on stress wave velocity (measured with the Microsecond Timer device) and on mechanical properties (density, modulus of elasticity, and modulus of rupture) by testing specimens felled at different moon phases. The material studied involved 360 structural timber pieces of Japanese larch (*Larix kaempferi* (Lamb.) Carr.) and four sizes (from 70 x 150 mm to 200 x2 50 mm) felled on moon`s waxing and waning phase in Basque Country provenance. In addition to the analysis of influence of moon phase on timber properties, linear regression models for estimation of mechanical properties by means of stress wave velocity are presented for this species.

WS044: Influence of Sensor Placement in the In-Situ Measurement of Ultrasonic Wave Velocity

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The best way to measure wave velocity in timber pieces is from end to end (parallel to the grain). However, in practice of in situ inspection of timber structures, this is not possible, and it is necessary to use a different positioning of sensors, placing one of the sensors in one face and the other in the opposite (or in the same) face. The aim of this paper is to analyze the differences in results of these different arrangements. Ultrasound wave velocity was measured on 30 timber pieces of Scots pine (*Pinus sylvestris* L.) from Spain, with 90 x 140 mm cross section and 4 m in length, using five different sensor placement arrangements: end to end (v_0), face to opposite face (v_{cf}), edge to opposite edge (v_{ce}), face to same face (v_{sf}), and edge to same edge (v_{se}). The pieces were successively shortened to 3, 2, and 1 m to obtain these velocities and their ratios with respect to reference value v_0 for different lengths and for several angles with respect to the axis of the piece for the crossed measurements (v_{cf} and v_{ce}). The velocity obtained in crossed measurements is lower than v_0 depending on the angle with respect to the axis of the piece (approximately the angle of the grain). A correction for crossed velocities is proposed depending on the angle to adjust them to the reference v_0. The velocities measured in surface (v_{sf} and v_{se}) also show lower values than v_0, but its ratio with respect to v_0 is not constant with respect to length, mainly for surface measured on the same edge. Practical conclusions are derived for in situ measurements.

WS045: Assessment of Biomass for Energy Industry in Arauco Forest Company

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Biomass from *Pinus radiata* stands with different productivities, sites, seasons, and industry sub-product biomass was assessed to quantify and evaluate quality of the biomass. Biomass extraction activities were classified by slope types. Stands of low and high productivity were selected for sampling, located in the northern and central areas of Arauco land, during summer and winter harvest seasons. The system production biomass in tons was classified in five types: total aboveground biomass (*TAB*), total commercial biomass (*TCB*), potential exploitable biomass (*PEB*), total extracted biomass (*TEB*), and total residual biomass (*TRB*), which are subject to *TAB* = *TCB* + *PEB*, with *PEB* = *TEB* + *TRB*. Biomass models for total aboveground biomass for each tree component (i.e., stem, bark, branches, cones, and needles) were generated by use of simultaneous modeling and macro-nutrients data. It was determined that there was an increase of total biomass in high-productivity stands, with 250 and 177dry tons/ha of total aboveground biomass the central and northern areas, respectively. Also, in those different areas, *PEB* varied within a range of 22%–31% compared to *TAB* per hectare. Average PEB was composed of branches (40%), tree topping (20%), bark (20%), and needles (20%). Bark and needles were the components with higher caloric value, 5300 and 5000 cal/g, respectively, whereas stem and branches averaged 4600 cal/g. Despite these variations in caloric value, moisture content was the main determining factor on quality of biomass extraction activities. Moisture content had a negative proportional effect on caloric value, which occurs in the biomass exported in winter up to 20% of inert material (e.g., mud, rocks, sand). Moisture content of the biomass was determined using a portable measurement MARRARI model M75D because of emphasis on the quality. Preliminary functions for determining moisture content were generated in different types of biomass for seven industries. Calibration functions were generated following two phases: the first considered general functions, only differentiated among products, and the second calibrated local functions, which were set for both product and industry type.The portable equipment showed great potential to be implemented at industrial level as a characterization tool, sampling, raw material census, mainly because of ease of operation and quick measurement time.

WS046: Nondestructive Analysis Reveals Effect of Installation Details on Plywood Siding Performance

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This study evaluated the influence of a variety of construction techniques on the performance of plywood siding and the applied paint. The impact of end-grain sealing, flashing, caulking, water-repellant preservative, back priming, location (Wisconsin vs. Mississippi), and a secondary drainage plane behind the siding to facilitate drainage were tested in a fully replicated experimental design. Test fences were constructed to provide outdoor exposure of three replicates of each permutation. Yellow poplar (*Liriodendron tulipifera*), a decay-prone wood species, was used for the plywood to accelerate the results. After five years of outdoor exposure, mushrooms were observed on the surface of the boards and they were removed for lab evaluation. Extensive water staining was seen on the backs of the boards caused by water travelling upward from the bottom edge. Sound velocities were measured to determine the degree of decay. Herein we will present a detailed analysis of the factors impacting performance, including the poor performance obtained when the bottom of a piece of wood is in contact with another surface, edges are caulked in the typical fillet style, and the unusually poor performance of the secondary drainage plane. The talk will conclude with recommendations for construction practices.

WS047: Ten Years of Experience Using NIR in Arauco: From Model Development to Operational Use in *Eucalyptus* sp. Breeding Program and Commercial Plantations Assessment

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Arauco's forest company has a *Eucalyptus* sp. breeding program focused on the deployment of the best genetic material that will be planted to support the annual demand of 2,900,000 m^3 of solid wood that is required to produce kraft pulp at Nueva Aldea, Arauco, and Valdivia pulp mills. Considering the importance of raw material characteristics on the end pulp productivity, during 2005 Arauco chose the NIR method as a nondestructive evaluation tool. Since 2007, the methodology allowed development of an assessment program to predict basic density (BD), kraft pulp yield (KPY), and specific wood consumption (SWC) of the best *Eucalyptus* sp. genotypes tested in genetic tests and commercial plantations included in the annual harvesting program. Samples of shaves were dried, milled, and conditioned inside the laboratory. Then, two spectra per sample were generated using the spectrophotometer Foss NirSystems 6500. The NIR models were adjusted, calibrated, and validated for predicting values at Bioforest laboratory. The calibrated models included samples of *E. globulus* and *E. nitens* between 4 and 20 years old. Standard errors of predictions were 23.1 kg/m^3, 1.29%, and 0.22m^3/Adt, for BD, KPY, and SWC, respectively. The main results of the operational use of NIR are the pulpability assessment of 34,000 ha of *E. globulus* and 18,000 ha of *E. nitens* plantations and 2,125

and 158 genotypes of *E. globulus* and *E. nitens*, respectively, as part of the breeding program. After 10 years of NIR research at Arauco, it is expected that the main impact in the future will be the reduction of the SWC of the Eucalypts raw material used for kraft pulp production.

WS048: Effect of Moisture Content on Nondestructive Probing Measurements

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In assessing existing timber structures, it is not possible to obtain density as the ratio mass/volume, so nondestructive probing methods are used for prediction of density. As in other nondestructive techniques, moisture content has an influence on measurements. The goal of this paper is to study the influence of timber moisture content on two nondestructive probing techniques. Needle impact penetration depth (using commercial device Pilodyn 6 J Forest) and screw withdrawal strength (using commercial device Screw Withdrawal Resistance Meter) were measured on 25 timber large-cross-section (100 x 150 mm) specimens of laricio pine (*Pinus nigra* Arn. Ssp. S*alzmannii*) from Spanish provenance of 0.5 m length. The ranges of average moisture content were studied from 36.3% to 7.6%. Final moisture content was achieved by oven dry method. Penetration depth decreased and screw withdrawal strength increased when moisture content decreased below fiber saturation point. There are lineal tendencies in both techniques. No moisture content influence was found above fiber saturation point. For both techniques, correction factors are proposed for the measurements depending on timber moisture content below fiber saturation point.

WS049: **Prediction of the Velocity in Logs and Beams from the Velocity in Standing Trees**

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The ultrasound velocity obtained in logs or beams can more accurately predict wood properties than the velocity obtained directly from the standing tree. However, anticipating knowledge of the strength and stiffness properties of the wood from the living tree is important for decision making in the forestry sector. The objective of this research was to develop models to predict the velocity in logs and beams, using the velocity in standing trees combined with other parameters also obtained from the tree. To obtain the models we selected six eucalyptus trees of three different species. For all trees, we performed ultrasound tests and measured the diameter at breast height (DBH). The freshly felled logs were also tested with ultrasound in longitudinal direction. Afterwards, logs were cut into beams and we performed ultrasound tests in these beams in green condition. We removed specimens (with polyhedral geometry) from the beams to determine the Poisson's ratio by ultrasound. With the results, we generated and analyzed models using multiple regression to adjust the velocity in logs (V_{Ladj}) and beams (V_{Badj}) using the ultrasound velocity and the DBH obtained in the tree, and the Poisson's ratio obtained from specimens removed from beams. The models showed very high adjustment (R^2 = 0.99) for both cases (logs and beams).

WS050: Prediction of Strength and Stiffness of Wood in Bending Using Adjusted Ultrasound Velocities in Standing Trees

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The ultrasound velocity obtained from logs or beams can more accurately predict wood properties than the velocity obtained directly from the standing tree. However, anticipating knowledge of the strength and stiffness properties of the wood from the living tree is important for decision making in the forestry sector. The objective of this study was to validate the power of a model to predict the strength and stiffness of wood. This model is based on adjustment of the velocity obtained on live trees, the diameter at breast height (DBH), and the Poisson's ratio. For the tests, we used 20 *Eucalyptus* and *Pinus* trees. We tested the trees using ultrasound with 45 kHz transducers to obtain the velocity of wave propagation. From these trees we cut logs, and from the logs we obtained the beams. We tested the beams in bending at equilibrium moisture content to calculate modulus of elasticity (E_M) and modulus of rupture (fm). The Poisson's ratios of the trees were estimated using a correlation with density. The correlation between the adjusted velocity and the strength or stiffness was statistically significant with coefficients of determination R^2 = 0.905 and R^2 = 0.937, respectively.

WS051: **Ultrasound as a Tool in Defining the Use Potential of Crossarms Manufactured with Recycled Wood**

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The disposal of wooden poles removed from service is a complex problem. Wood treated with potentially toxic chemicals imposes risks to the environment when discarded and/or re-used inappropriately. Wooden poles treated with CCA have potential to be reused and/or recycled, resulting in ecological and economic advantages. The objective of this study was to evaluate the use of ultrasound to sort crossarms made from recycled wooden poles removed from service. *Eucalyptus citriodora* crossarms (2 m long) were used for the tests. The crossarms were measured (size and weight) and tested with ultrasound and in bending. With the velocity results, we calculated the stiffness coefficients in the longitudinal direction (C_{LL}) .These results were correlated with the modulus of rupture (f_m) of the crossarms. Preliminary results show a statistically significant correlation between C_{LL} and f_m, with logarithmic setting model (logarithmic-Ysquared-X) and correlation coefficient r = 0.86. Using the minimum load specified by the Brazilian standard for acceptance of crossarms and the model set by the Standard Error of Estimate (characteristic values), it was possible to propose a C_{LL} value from which the crossarms would be rejected. Using this model there was an 18% error in the classification of the crossarms manufactured from reused poles: 9% of the crossarms were erroneously rejected (economic implications) and 9% were wrongly accepted (security implications).

WS052: Influence of Diameter on Ultrasound Wave Velocity in Round Timber

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The use of logs in their original shape, as round timber, has been considered economically competitive and sustainable, placing importance on the development of techniques that allow their classification. Wave propagation tests can be used in log classification; however, it is necessary to evaluate parameters that can affect the results (outcome) of this classification. The objective of this research was to evaluate the influence of log diameter on ultrasound wave velocity. The ultrasound tests were performed in eucalyptus (*Eucalyptus grandis*, *Eucalyptus cloeziana*, *Eucalyptus resinifera*, *Eucalyptus maculata*) and *Pinus elliottii* round timber. For the statistical analysis, the logs were separated in predetermined diameter ranges. The *Eucalyptus grandis* was tested with different types of transducers (flat and exponential) and different moisture conditions (green and equilibrium moisture) to verify the influence of these parameters on the results. For *Eucalyptus*, we found no statistical differences in velocity among the different diameter ranges. For *Eucalyptus grandis*, moisture conditions and type of transducer did not affect the statistical equivalence among velocities in the different diameter ranges. For *Pinus elliottii*, a statistical difference was detected, indicating different performance between the results for hardwoods and softwoods.

WS053: Variation on Acoustic Properties of Eucalyptus Clones with Age

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For companies that use clones, anticipating knowledge of the quality of wood contributes to reduction of investments in those clones whose characteristics indicate little chance of becoming commercial. One way to anticipate this knowledge is to be able to measure the property on a young tree; but it is necessary to know the evolution of this property with age. Acoustic methods have been studied to monitor the quality of the wood from tests directly in standing trees. The objective of this research is to evaluate the evolution of the velocity of ultrasound wave propagation in eucalyptus clones from seedling to cutting age. We present initial trials in a commercial clone of Eucalyptus from a pulp and paper company; 180 trees of these clones were evaluated in six different ages (1 to 6 years), with 30 trees per age. In all the trees were performed ultrasound tests, with 45 kHz exponential transducers, in the longitudinal and radial directions. The results showed a statistically significant correlation (P-value < 0.05) between speed and age, in both the radial and longitudinal directions. However, due to the short cutting cycle of trees (6 years) in pulp and paper companies, the velocity variation in the period was small (around 1.5% per year for the longitudinal direction and 3% per year for the radial direction). The combination of short cutting cycle and variability of acoustic properties of the trees of the same age (around 8%) could be the reason for the weak correlation with age (r = 0.17 for the longitudinal direction and r = 0.46 for the radial direction).

WS054: Evolution of Properties, from Planting to Cutting Age, Obtained by Nondestructive Testing in Eucalyptus Clones

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In companies that use clones, anticipating the knowledge of wood properties contributes to the reduction of investments in clones whose characteristics indicate little chance of becoming commercial. One way to anticipate this knowledge is to enable property measurements on a young tree; but it is necessary to know the evolution of this property with age. Acoustic methods have been studied to monitor the quality of wood, but when applied isolated, they do not have the required accuracy. The objective of this research is to evaluate parameters that can be obtained nondestructively directly from the tree that, associated with the acoustic measurements (velocity), will allow the prediction of properties in the cutting age. Measured were height of the tree (TH), canopy height (CH), diameter at breast height (DBH), canopy diameter (CD), drilling resistance (DR), and basic specific gravity (BD) of 180 trees of a clone in six different ages (1 to 6 years), with 30 trees of each age. As expected, parameters directly linked to growth (DBH, CD, TH, and CH) showed significant and high correlation coefficients (79%, 73%, 73%, and 95%, respectively) with age. For the DR, it was only possible to obtain statistically significant correlation with age using average values for the 30 trees of each age evaluated (R = 0.89). The BD was not correlated with age, even considering averages. The little variation of this parameter (BD) at different ages (CV = 3.2%) and the large variability within the same age (CV 4% to 10%) are hypotheses to explain this behavior.

WS055: Prediction of Basic Specific Gravity Using Parameters Measured on Trees

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Basic specific gravity is a critical property for the use of wood, especially in pulp and paper companies. Determination of this parameter is laborious and time-consuming as it requires the removal of tree discs for laboratory analysis. Therefore, for these companies, the viability of obtaining the density using tests directly in the standing tree is very important. The objective of this study was to analyze parameters obtained directly in the tree that would allow predicting wood density. The initial tests were conducted using a commercial eucalyptus clone from a pulp and paper company. For this clone, 180 trees were evaluated in six different ages (1 to 6 years old) with 30 trees per age. In all the trees were measured total height, canopy height, stem diameter at breast height (DBH), time of ultrasound waves propagation in the longitudinal and radial directions, and drilling resistance. Basic density was calculated using cylindrical samples taken with an increment borer. Using simple regression, the height of the tree was the parameter that best correlated with basic density (R = –0.41), followed by canopy height (R = –0.33), DHB (R = –0.20), radial velocity (R = 0.19), drilling resistance (R = –0.11), and longitudinal velocity (R = 0.09). With multiple regression the most appropriate model to predict basic specific gravity of the tree is the one involving tree height, drilling resistance, and radial velocity (R^2 = 0.748).

WS056: Monitoring of Wood Degradation Caused by Termites Using Ultrasonic Tomography

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Defects in timber can be detected with the use of ultrasonic tomography. Termites act to form galleries in the latewood, following the grain and causing cracks and irregularities. The objective of this research was to evaluate the viability of ultrasonic tomography, performed with Brazilian technology, in the evolution of degradation on wood attacked by termites. To achieve this goal we used six *Pinnus* sp. discs inoculated with subterranean termite *Coptotermes gestroi*, grown for 11 months. During the period, we visually followed the conditions on the discs and we performed ultrasound measurements with Brazilian equipment and 45 kHz exponential transducers. The images were also generated with a software developed in Brazil. Considering that the attack is still in an incipient stage, we did not identify visual changes; however, the generated images showed early degradation on the disks. Although preliminary, the results indicate that the technology shows sensitivity in detecting changes in wood caused by the termite attack.

WS057: Monitoring of Wood Degradation Caused by Fungi Using Ultrasonic Tomography

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Ultrasonic tomography is used to detect defects in materials and structures. In wood, the decay generated by the action of fungi is one of the most recurring defects causing degradation and making its detection extremely important. The objective of this study was to evaluate the viability to detect the evolution of degradation of wood caused by action of fungi using ultrasonic tomography (equipment and software) performed in Brazil. To achieve this goal we used five *Pinnus* sp. discs inoculated with the fungi from the specie *Lentinula edodes*, which acted on the material for 11 months. During the period, we measured the weight change and performed ultrasound tests on the discs with the Brazilian equipment and 45 kHz exponential transducers. The images were also generated with a software developed in Brazil. The discs were completely degraded at the end of the period. The technology was able to detect and track the degradation of wood, and the detection was consistent with the weight loss of the discs.

WS058: Velocity Variation in Wood as a Function of Defects

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Ultrasonic tomography is based on the velocity of wave propagation, in which we use these variations to detect defects on materials and structures. In wood, these occurrences may be present in different ways; the most frequent are internal holes, degradation by the presence of fungi and termite attack. The detection of such degradations is very important. The objective of this study was to evaluate the variation of ultrasound velocity in different types of defects in wood, using equipment developed in Brazil and 45 kHz exponential transducers. To achieve this goal, we used 41 *Pinnus* sp discs. Five discs were inoculated with fungi *Lentinula*, six infested by termites *Coptotermes gestroi*, and 30 drilled artificially. Using the ultrasonic results, we obtained the velocity variation caused by the action of fungi, the attack of termites, and the drilled parts. The pattern of images generated by degradation and by the artificial holes cannot be distinguished visually. But if we use speed range comparisons, it is possible to differentiate the three situations. In the discs attacked by fungi, the speed drop is much sharper than when compared to the discs with the holes and termite attacks.

WS059: Modulus of Elasticity and Rebound Coefficient Correlated for Tropical Species

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Modulus of elasticity of wood is a mechanical property that relates to the material stiffness and needs to be known to develop engineering designs. Methods to determine this property that require the extraction of specimens shows difficulties in some applications. Research has been done to generate correlations between modulus of elasticity of wood obtained by destructive method (with the use of specimens) and results of nondestructive methods. In this study, we evaluated the correlations between rebound coefficient obtained by sclerometry (a NDT established for applications in concrete structures) and the modulus of elasticity parallel to the grain. We used two species of tropical wood, *Cedrela* ssp. and *Apuleia leiocarpa*, and for each species were extracted 12 prisms (80 mm by 200 mm by 300 mm) of different beams. These prisms with moisture content stabilized were subjected to the sclerometric test. In sequence, one specimen (50 mm by 50 mm by 150 mm) of each prism was obtained to test the compression parallel to the grain, from which we obtained the modulus of elasticity. The evaluation of results for these two species allowed us to conclude that the correlation established between elasticity modulus and rebound coefficient is significant (with coefficients of correlation equal to 0.82), showing that the sclerometric method can be used to estimate this property of the wood.

WS060: Influence of Drying Defects in the Velocity of Ultrasonic Waves and in the Compression Strength of Wood

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Cracks and checks originated from the drying of the wood are more evident in the end**s** of the structural lumber. For this reason, some standards indicate that the characterization of wood must be done with the material extracted out of disposal region. In this research, we evaluated the implications of drying defects in the velocity of ultrasonic waves and on compression strength parallel to the grain. We used structural lumber of the tropical species *Cedrela* ssp., *Apuleia leiocarpa, Goupia glabra,* and *Dipteryx odorata*. From disposal region we extracted two specimens (50 mm x 50 mm x 150 mm), one from each end of the longitudinal direction. To determine the wave propagation velocity of ultrasound we used a 45 kHz frequency longitudinal transducer. Afterwards we subjected the specimens to compression parallel to the grain. The results shown little variation, but it was not possible to distinguish the specimens of both ends of disposal. We conclude that the drying defects do not affect significantly the behavior of wave propagation and parallel compression.

WS063: NDT for Wood Biological Damages Identification

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Nondestructive testing (NDT) is defined as a group of techniques that allow examining materials or its components without affecting their properties, integrity and final utility. The use of these techniques is widespread in assessment of existing timber structures. The models proposed for these methods are usually performed in laboratory using small clear wood specimens. But in real situations, when these techniques are applied in situ, many anomalies, defects, and biological damages are found in wood. In these cases, the existing models only indicate that the values are outside normality without providing any other information.

To solve this problem, a study of current mechanical nondestructive methods for wood was performed, testing the behaviour of different technics (Screw withdrawal, Penetrometer, Resistographm and Wood Extractor) on wood samples with different biological damages simulating an in situ test. The wood samples were obtained from Spanish existing timber structures with biotic damage caused by borer insects, termites, brown rot, and white rot. The study concludes that the information provided by the first two methods (Screw withdrawal and Penetrometer) cannot distinguish between pathologies. On the other hand, with the Resistograph and the Wood Extractor it is possible to differentiate some pathologies and even identify species or damage location. Finally, a comparison of the techniques used was made in order to characterize their advantages and disadvantages.

WS064: Use of Visual and Mechanical Variables for Structural Grading of Pine from Uruguayan Plantations

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Currently Uruguayan pine lumber, mainly of *Pinus elliottii* and *P. taeda*, has no structural classification indicating physical and mechanical features of the material. In Uruguay, forestry plantations of pine are characterized by rapid growth, with high percentages of juvenile wood and low values of bending elasticity modulus. In consequence, there is a need to define a mechanical-visual classification to predict which features should have national pine wood to be used in structural parts. The aim of this paper is to determine the visual variables that predict the bending modulus of elasticity of Uruguayan pine lumber and assign a structural class based on European standards (EN 338: 2009). One hundred commercial pine beams 2800 mm long were used, with a cross section of 50 by 150 mm. The wood was provided from two plantations located in the north of Uruguay; one of *P. taeda* 14 years old with pruning and the other one of *P. elliottii* 27 years old without pruning and thinning. Based on Chilean (NCh1207:2005) and European (EN 56544:2011) standards, a series of visual variables were measured and dynamic modulus of elasticity (E_d) was determined using nondestructive ultrasonic test equipment. The beams were then tested in a universal testing machine, determining bending modulus of elasticity (EI) and flexural strength (*f*). Density (*d*) and moisture content were also determined according to European standard (EN 408). From a primary descriptive analysis and as expected, the limiting variable to classify national pine in structural classes according to European legislation is EI, for both samplings. From the regression trees analysis, for the 14-year-old sampling, any beams were classified in the structural classes of European regulations (EN 338: 2009). However, analysis of the 27-year-old sample defined the visual variables that distinguish groups of structural timber. If E_d is included as a predicting variable, the analyses define this variable and classification in wet condition (PRECLASIF) as the variables with more influence on EI, with an r^2 of 0.88. The classification in wet condition takes into account the presence and position of pith and greats knot near the edge. If E_d is not included in the analysis, three other variables are defined as important: greater diameter edge knot in the thickness (DCANTO), larger diameter flat knot in the width (DCARA), and presence of pith (MED), with an r^2 of 0.64. If the beam has a DCANTO <48%, DCARA <28%, and presence of pith is distinguished as C16 timber class; and classified as C22 if the beam has no pith, in addition to presenting the first two features.

WS066: Surface Roughness Determination in Some Wood Boards using Speckle Interferometry

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Within the timber forest industry, important products exist, such as the different boards, OSB, hardboard, MDF, and particleboards, which are widely used both in the country and in foreign countries. Most of these boards are used in walls, furniture, or other kinds of products, in some cases without treatment and in others with different coatings. In these last cases, many present problems of adhesion due to gaps formed between the board surface and the coating. This problem can be solved if the surface roughness of the board is known with certainty. This would decrease considerably the rejection rate in the product. In this paper a noncontact technique is used to determine the surface roughness of some types of boards using Speckle Interferometry. The results show good consistency with measurements made by mechanical testing. However, it is necessary to adapt the application of this

technique to solve different types of problems in controlling the quality of products in the current timber industry.

WS068: Surface Defect Detection in Solid Wood using Infrared Techniques

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Among major irregularities and defects in solid wood are resin pockets, knots, and freckles, which affect its quality and limit production of export laminated wood. Today, the wood industry requires a diversity and variety of technologies to detect these irregularities as well as to extract relevant information for quality classification. Reflected and absorbed electromagnetic radiation in the near-infrared (NIR) is widely used to identify different characteristics and properties of wood products. This work studies the average of spectral behavior in different spatial grids in the spectral band from 900 to 1700 nm. It was done for three different defects (resin pockets, knots, and freckles) using an optoelectronic sensor. The infrared images were studied through their spectral characteristics.

WS070: Near-Infrared Laser Reflection Based Wood Moisture Content Determination

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The near-infrared (NIR) region of the electromagnetic spectrum extends from 800 to 2000 nm in wave length. The related frequency range is 150–400 THz. This frequency range includes the self-vibration frequencies of various molecules. Thus, NIR spectroscopy is a sensitive tool for identifying certain molecules. The wavelengths belonging to the resonant frequencies of liquid water are 1460 and 970 nm, for symmetric and asymmetric stretch of the hydrogen bond. At these wave lengths, absorption is high and the reflected infrared intensity is low. This phenomenon provides the possibility of noncontact moisture content determination. In the forest products industry, NIR moisture sensors have been available in the past year. Manufacturers of on-line wood moisture meters include JWII (Australia), M.C.TEC (The Netherlands), and NDC Technologies (USA). These instruments use NIR lamps and three to six filters for measuring the reflection at different wave length ranges. Our approach is similar, but instead of filters, we are using very narrow band lasers at 980, 1310, and 1450 nm wave lengths. This way, we can eliminate the rotating filter disk and hopefully the laser provides higher accuracy. We have tested 25 different wood species, measuring the initial and the reflected NIR light intensity at the above-mentioned three wave lengths. We have studied the effect of moisture content changes, the effect of temperature, and NIR light penetration depth in solid wood. Finally, we have characterised the accuracy of the moisture content measurement by near infrared laser reflection.

WS071: Detecting Beech Red Heart by Electrical Resistance Measurement

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Beech (*Fagus sylvatica* L.) red heart is an important problem, and its early detection may help determine the optimal harvest age of trees. Red heart's electric properties differ from those of sound wood. This offers the possibility of red heart detection based on resistance measurement.Live beech trees were examined using simple resistance meters, as well as an impedance tomograph. The number of electrodes varied between 4 and 24. Optimal electrode placement was determined based on the best results (expressed as the ratio of voltage measured in sound and in red heart beech.) The results from the various measurements were compared to the actual extent of red heart (determined after felling.) The results showed high accuracy in case of impedance tomography. Simple resistance measurements also have a reasonably good potential to detect moderate to severe red heart in live beech trees.

WS072: Evaluation of the Root System's Stability Based on Actual Wind Intensity and Inclination Measurements

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Tree root system stability assessment is the most difficult part of tree condition evaluation because visual techniques are not applicable. The only reliable method adopted in today's practice is the pulling test, which simulates a wind storm with wind speeds of 33 m/s and an inclination of 0.2 degrees. This is an extreme wind load situation that typically occurs only once in every two years. Even in strong winds, actual wind speeds usually remain in the 10-15 m/s range, with wind loads approximately 5–10 times lower than those at 33 m/s. The pulling test is also a typical static test, while wind load is dynamic because of the wind gusts. Our investigation was aimed at measuring the wind load and inclination in real-life situations. This requires high sensitivity inclination sensors with a resolution of 0.001 degree. The inclinations of several trees were monitored over several days using such sensors. Inclination data were collected 10 times per second in two directions and compared to wind intensity measurements taken nearby. This allows the evaluation of the root system's stability under dynamic loading. The comparison of inclination and wind intensity values shows a clear positive correlation between these two parameters. Anomalies typically occur after sudden gusts of wind, which cause excessive displacement, showing a loss of balance on behalf of the tree. Such imbalances may be responsible for most of the uprooting that occurs. A detailed analysis of the results is underway to create a suitable evaluation algorithm to predict the safety factor from the actual dynamic load and inclination measurements.

WS073: Glue Laminated Timber Structure Evaluation by Acoustic Tomography

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An approximately 40-year-old wooden watching tower was examined in Budakeszi, Hungary. First we made the visual inspection of the structure. The watching tower structure was made of glue laminated timber. Because of their large cross sections, we have applied acoustic tomography. This way got information about the internal conditions of the pillars, at the critical height. The purpose of the paper is to present the acoustic tomography technique, which can support the work of structural engineers and wood preservation experts. Every evaluation of a structure starts with a visual inspection, detecting fungal and insect attack visible on the surface. The visual inspection is not just what we can see; it is a very difficult method, requiring a lot of practice. A lot of damage can be recognized by visual inspection, but there are some cases when we do not know exactly the extent of the damage due to the large cross section or because of the formation of the structure. Otherwise, some insects and fungi do their damage inside the structural elements. Acoustic tomography is based on sound velocity measurements between several sensors around the structural element. The investigated wooden watching tower, located in Budakeszi, near Budapest, has six large glue laminated timber pillars. From the previous visual inspection, it became apparent that some pillars would need to be measured with acoustic tomography. We made measurements at critical points or sections of the pillars. The data collected by the acoustic tomography helped the wood preservation expert to make a more precise and reliable report.

WS079: Strength Grading of Turkish Black Pine (*Pinus nigra* var. *pallasiana* Arnold.) Structural Timber by Visual Evaluation and Nondestructive Testing

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Strength grading of the timbers according to their exterior appearance by a visual examination is extremely useful and has been widely used all around the world. In addition the predictive capability of nondestructive techniques to evaluate the mechanical properties of timber has been widely studied, based on the relationship between wave velocity and Young's modulus. The objective of this study is to determine the compatibility between visual strength grading and mechanical strength grading performed by using nondestructive and destructive test methods in Turkish black pine (*Pinus nigra* var *pallasiana* Arnold.) structural timbers. Fifty-three structural timbers with the dimension of 6 × 8 cm (width × depth), 6 × 10 cm and 2-m-length were graded by visual inspection in accordance with three different visual strength grading standards; TS 1265, DIN 4074, and BS 4978. Following visual examination, dynamic modulus of elasticity (MOEd) was determined by using a longitudinal vibration nondestructive test method. Then, static modulus of elasticity (MOEs) and modulus of rupture (MOR) were determined on the timbers in structural size in accordance with EN 408. The relationship between visual, nondestructive, and destructive strength grades was determined in order to assess the compatibility between them. Results indicate that the visual strength classes determined using BS 4978 standard showed the best compliance with the MOEd determined by longitudinal vibration and the MOEs and MOR determined by destructive test. The visual strength class was increased by increasing the values of MOEd, MOEs, and MOR. However, the visual strength classes determined in accordance with DIN 4074 and TS 1265 showed weaker correlations with the MOEd, MOEs, and MOR than BS 4978. There were high correlations between MOEd and MOEs (R = 0.92) and MOR (R = 0.79). Mechanical grading was more reliable and more efficient than visual grading. It was also concluded that the best results can be achieved by combining visual evaluation with MOEd determined by longitudinal vibration nondestructive test.

WS080: **Modulus of Elasticity in Transverse Vibration of Some Growing Woods in Chile**

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the main aim of this work was the design and development of a system for determining the modulus of elasticity (MOE) in transverse vibration of samples of native and growing woods in Chile, based on the use of an acoustic sensor and a Pasco 850 interface. Fundamental frequencies of vibration of different growing woods in Chile were measured using the software incorporated in this interface. The samples were made according to DIN standards for static flexion tests of 20 x 20 x 400 mm. This paper describes the theoretical fundaments of this nondestructive technique. Furthermore, the working methodology was focused on determining the physical-mechanical characteristics of materials by vibrating a bar. The results of these preliminary experimental set-ups showed that the values of MOE in vibration for some softwood were higher than those for hardwoods, between 6.2 and 9.9 GPa. The average of fundamental frequencies of species was between 453 and 579 Hz. The results are shown as density graph vs fundamental frequency and MOE vs density for the different species. However, in order to improve the signal acquisition system, the acoustic sensor will be replaced by a contact micro-vibrations sensor and the Fourier transform processing software will be improved as well.

WS081: Ultrasonic Testing with Different Orientations throughout Cross Section of *Eucalyptus grandis*

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Wood, as an orthotropic material, shows different mechanical behavior depending on the analyzed angle with its main axes. Since wood is also hygroscopic, its mechanical properties are also a function of the humidity level. This research investigates the mechanical properties of *Eucalyptus grandis* specimens using ultrasound. Ultrasonic readings through a cross section were performed at different angles with the tangential axis at several humidity levels. The gathered results were compared to the Hankinson equation, allowing to model wood mechanical behavior. Such a behavior is very important when a tomographic process that considers the orthotropic nature of wood is to be used to assess internal homogeneity.

WS082: Measures of Crystallinity as a Nondestructive Indicator of Wood Hardness: Study on Young Fast Grown Plantation Teak Planted in Dry and Wet Sites

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Models for predicting wood hardness based on ultra-structural characteristics have been developed using crystallinity and other quantifiers of the cellulosic nature of wood, including degree of crystallinity, crystallite dimension (width and length), and microfibril angle (MFA). Air-dry wood density was also used in the models as it is known to be related to wood hardness and it can also be measured nondestructively. Five factors, including sites (two levels), ages (two levels), tree diameter classes (three levels), vertical positions within tree (seven levels), and radial positions (three levels) were analyzed using four response (dependent) variables: radial hardness, tangential hardness, side hardness, and end-grain hardness. A study was conducted on 5- and 6-year-old fast grown plantation teak. Variable selection and model development was carried out using stepwise multiple regression and quadratic curve fitting with Matlab®. The results indicated that wet site plantation gave rise to significantly lower wood hardness than that from the dry site. Six-year-old trees produced wood that was harder than that from 5-year old trees. However, only the end-grain hardness was statistically significant. Smaller trees of the same age exhibited significantly higher side hardness than medium-size and large trees. In this case, the end-grain was higher but not statistically significant. Along the tree stem, wood hardness decreased from the bottom to a height of 120–130 cm above ground, and then increased towards the middle and top part of the tree. However, generally wood hardness did not vary significantly at different vertical positions along the tree. At radial positions, the transition zone had significantly higher wood hardness than the sapwood and heartwood zones. Furthermore, the results revealed that wood hardness along different structural directions was influenced by different ultramicroscopic characters of wood crystallinity. It was found that the degree of crystallinity was positively related only to end-grain hardness, while crystallite dimensions, mainly crystallite width and MFA, were negatively correlated to hardness along all structural directions. The proposed models offer intermediate power of prediction with adjusted R^2 values in the range of 0.53 and 0.63 when air-dry density is included among the prediction variables.

WS084: Early Age Evaluation by Stress Wave Speed for Breeding High Young's Modulus Japanese Cedar

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The purpose of this study is to inspect the effectiveness of the wood quality evaluation technique of standing tree by stress wave speed in early age (2–10 years) for the creation of high Young's modulus Japanese cedar. Studying Japanese cedar of selected clone tree among mating families of plus tree, we investigated the standing tree by a stress wave velocity property (Vp) and growth traits from 2 years to 7 years after planting and the log by dynamic Young's modulus (E_{fr}) felled for the early period in two examination forest. The individual tree difference of Vp appeared to be 1.5 to 2.5 km/s, and the high correlation was recognized for Vp for 2 years and 3–6 years. Furthermore, investigating tree Vp in different test forests from 4 years to 7 years, a similar tendency was confirmed. A high correlation was recognized between tree Vp of 2 or 6 years and E_{fr} of log felled at 6 years. In addition, as for most of standing trees, when Vp in 4 years showed more than 2.5 km/s, it was found that E_{fr} in 7 years showed higher than 6 kN/mm^2 that became the index of the high Young's modulus. No significant correlation was found concerning the quantity of change of growth trait (diameter and height) and the quantity of change of Vp during growth period.

WS085: Wood-Based Composite X-Ray Densitometry—Attenuation Effects on Measurements

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In the wood-based composite industry, precise and reliable knowledge about the panel's raw density is inevitable for production and quality control. Nondestructive measurement of vertical raw density profile and in-plane area density distribution is state of the art by means of X- and gamma-rays and also prevalent within related fields of research. Currently employed X-ray measuring devices lack required accuracy and reliability; in particular, the shape of distinct vertical raw density profiles is flattened and in-line area density determination provides relative estimations. Corresponding radiation-physical effects are responsible for these deviations. It was found that optimized X-ray measuring device hardware and improved calibration and data evaluation procedures enable enhanced result accuracy with reliable absolute density values. Subsequent fundamental considerations are still pending. This study considers interaction mechanisms of polychromatic ionizing radiation with inhomogeneous porous media such as wood and wood-based composites. For absolute X-ray material density measurements, both radiation-physical effects (e.g., beam hardening, scattering) and material compositions with their subsequent energy-dependent mass attenuation coefficients are pointed out and discussed on theoretical and experimental bases. To this end, exploratory X-ray measurements and elemental analyses on a practice-oriented variety of sample types (lab and industrial origin) and conditions verify the assumptions quantitatively. The findings help to understand X-ray interactions with wood-based composites and enable development of approaches for enhancement of devices, calibration, and data evaluation, thus, X-ray measuring systems for wood-based composite densitometry in general.

WS086: Nondestructive Evaluation of Coconut Palm Wood by Means of Ultrasonic and Natural Frequency Methods

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The application of nondestructive methods such as ultrasonic and natural frequency to determine elasto-mechanical properties of wood is widespread in cases of dicotyledonous species. The aim of the study was to examine these methods regarding their applicability on coconut palm wood. The different anatomic structure of monocotyledonous coconut wood shows vascular bundles embedded in soft parenchymatous ground tissue. Furthermore, material utilization is not prevalent so far, thus the investigation of potential grading methods is required. To this end, small- and medium-sized specimens were investigated by ultrasonic time-of-flight and natural frequency measurements with subsequent dynamic MOE computation. Static bending tests were carried out accordingly for comparative purposes. It can be observed that the dynamically determined results show significantly higher values

(75% (ultrasonic) and 44% (natural frequency) above) compared to the static results. Thus, compared to European wood species, assumed lower shear modulus has significant influence on the results of static bending tests by a supporting width of 15 × thickness. The higher values of ultrasonic compared to natural frequency measurements are caused by bulk density gradients within a specimen, different sound velocities in parenchymatous ground tissue and vascular bundles, and corresponding higher speed of sound in the area with the highest permeability. Flexural vibration measurements are an appropriate method especially for the investigation of small clear wooden beams under laboratory conditions. Longitudinal vibrations are well suited to determine the MOE of medium-sized specimen.

WS087: Effect of Wood Properties and Production Process on Stiffness of Charcoal Studied by Ultrasonic Technique

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The world steel industry is based on the use of virgin raw materials such as iron ore and coking coal, mainly used in the blast furnace process of iron making. Charcoal has often been compared to coke and can replace it in blast furnaces, avoiding the use of reducing agents derived from fossil fuels. However, the main limitation of charcoal as replacement coke is its lower strength, which is essential for supporting the load in a blast furnace. The physical and structural characteristics of charcoal have been extensively studied, but there is a lack of information on the link between the stiffness of charcoal and production processes coupled with wood properties. The improvement of the mechanical properties requires a study of the variability of these properties in charcoal obtained under different conditions of temperature and pressure, but also with different wood qualities. A total of 73 trees of one hybrid of *Eucalyptus urophylla* ST Blake (6 years old) were harvested and cubic samples (30 mm in R, T, L directions; *N* = 238) were cut at 1.30 m height and at two radial locations. Sample density was measured and then tested with ultrasounds to determine the modulus of elasticity. The cubic samples were pyrolyzed at two different temperatures (500°C and 900°C) and two different pressures (1 bar and 10 bars). The density and modulus of elasticity of the obtained charcoal samples were again tested. The relationship between charcoal properties according to the coupled effects of temperature/pressure/wood properties was then analysed.

WS089: Investigation of Cross Sectional Density Profile of Wood with Portable X-Ray CT System

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A portable X-ray CT system was applied to investigate the inner state of wood. A Korean traditional wooden building column was used as a specimen in this study. Using a self-developed CT gantry for rotating portable X-ray tube (CP120b, ICM, Belgium) and digital detector (NX06, RF system, Japan) with every 2 degrees, 180 radiograph projections were acquired. As it is easy to distinguish sound wood from deterioration and defect by using density difference, CT images were reconstructed with 180 density profiles, which were converted from 180 radiograph projections considering X-ray penetrating depth in wood. There were areas of insect damage in column surface. However, it was hard to confirm the inner deterioration size and location in cross section of wood visually. When portable X-ray CT system was applied to the wooden column, inner deterioration could be successfully detected in cross sectional density profiles. Moreover, inner deteriorations were more clearly detected by two dimensional CT image slices after binary image processing as the result of threshold with 70% of sound wood density. From that results, it was considered that the cross sectional density profiles with portable X-ray CT system could be used for investigating the inner state of wood or making a decision whether insect-damaged historical wooden properties be reused or not.

WS090: Eucalyptus Wood Evaluation by NDT Assessment

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The objective of this study is aimed to predict the modulus of elasticity (MOE) and modulus of rupture (MOR) of the wood of 13-year-old *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid clones using acoustic assessment in longitudinal and transverse directions as a nondestructive test (NDT). A total of 42 trees, 13-year-old *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid clones, were cut from a plantation in Alcobaça, Brazil. The logs were cut into boards and air dried to reach equilibrium moisture content. The specimens were removed from the diametrical board and cut into static bending test dimensions, 50 x 50 x 760 mm (ASTM D 143, 2006). Velocities were measured in longitudinal direction using stress wave timer equipment (Metriguard) and a microphone with a specific computer software to read the longitudinal and transverse vibration frequencies. All three methods were reliable to predict MOE. Results showed a high positive correlation between static MOE and dynamic MOE; however, both of the longitudinal direction techniques resulted in a slightly higher correlation compared to the transverse direction method. Unfortunately, all the techniques used were unreliable to predict MOR, as previously expected.

WS091: Structural Grading of Timber Using the Modulus of Elasticity Obtained by Longitudinal Stress Wave Method

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Wood pieces at structural sizes have growth defects and irregularities, which can reduce their strength and stiffness compared with small clear wood specimens. The visual stress-grading of wood depends on the classifier's experience. In addition to static testing methods may be applied dynamic methods based on measurement of the natural frequencies of the material to determine the modulus of elasticity (MOE) of the wood. The dynamic modulus of elasticity in most tests is restricted to longitudinal or transverse vibrations, which can be used to estimate the wood structural strength class. The objective of this work is to grade visually structural size specimen of wood and evaluate the stiffness values of wood reforestation species of *Pinus* sp. for use in structures by nondestructive testing of longitudinal vibration, using the portable device Brookhuis Micro Timber Grader (MTG), and compare the results with traditional static bending tests to estimate the strength class. This method allows the structural

classification of all the pieces of wood in the output of the sawmill, contributing to the structural strength classes of wood according to the Brazilian Standard ABNT NBR 7190 - Wooden Structures Project.

WS094:Detecting Defects in Standing Trees by an Acoustic Wave Tomography with Pseudorandom Binary Sequence Code: Effect of Frequency

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The acoustic tomography Dr.Woods®, which uses the pseudorandom binary sequence code and accurately controls frequency, is expected to give high accuracy in estimating internal decay area in standing trees. In order to find the optimum measurement condition, this study investigated the effect of frequency. The sound velocities were measured among 16 test points around the trunk. Several tree species with different wood densities were tested at positions with different levels of decay area, or using cross sections in which cavities were artificially chiseled. The sound velocities, two dimensional images of velocity distribution, and estimated decay areas were compared among the frequencies 10 kHz, 15 kHz, 20 kHz, 30 kHz, and 40 kHz. The estimated decay area became larger at the lower frequency. The transmitted pulse could not arrive at the high frequency. The frequency 20–30 kHz was found to be suitable; and the available frequency might be lower for trees with lower wood density but higher for trees with higher wood density.

WS095:Detecting Defects in Standing Trees by an Acoustic Wave Tomography with Pseudorandom Binary Sequence Code: Simulation of Defects Using Artificial Cavity

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This study aimed to evaluate the potential of Dr.Woods® acoustic tomography to detect internal defects in standing trees. Using the pulse of pseudorandom binary sequence code, the sound velocities among 16 test points around the trunk were measured at the frequencies 10 kHz to 40 kHz. In order to simulate different sizes and shapes of decay, different sizes and shapes of cavities were artificially chiseled in the trunk cross sections in green condition: without cavity, a circular hole or a slit at the center, a crescent-shaped hole between the center and bark, and slits at the rim. As the cavity area increased, the velocity frequency shifted to a lower side and the estimated decay area increased. The velocities were different by tree species, which suggested that the threshold velocity for estimating decay area should be set by species depending on their wood density.

WS097: Digital X-ray Images Applied in Characterization Physics and Anatomical of *Pinus caribaea* var. *hondurensis* Wood

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The X-ray densitometry is a classic methodology to analyze tree-rings and obtain the radial wood density profile, as well as the intra- and inter-annual tree-rings density variation. The wood densitometric analysis can be applied to studies related to wood quality of trees and genetics, management practices, etc. This work applied to the analysis of digital X-ray images by means of X-ray Faxitron machine model LX-60 with an intensity of 30 kV for 19 s to evaluate the anatomy and densitometric profile of *Pinus caribaea* var. *hondurensis*. The digital image analysis of macroscopic and microscopic structure of wood by ImageJ software allowed in the transverse plane to rings the preview of growth, formed by early and late wood, and false growth rings, fine lines radial parenchyma, and small points of resin channels. Furthermore, the construction of densitometric profiles allowed the differentiation of growth rings, density differences between early and late wood, and the presence of false growth rings. Standing out as advantages of digital X-ray images, in relation to other methods of anatomical and physical analysis, are the integrity of the samples after analysis, density measurements in micrometer intervals, fast analysis, and ease of interpretation.

WS098: Preservative Treatment Effect on the Propagation Velocity of Ultrasonic and Stress Waves in Three Tropical Hardwoods

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The objective of this study was to evaluate the effect of preservative treatment with CCA-C in three tropical timbers on the speed of sound and ultrasound propagation in longitudinal and transverse directions using two nondestructive evaluation methods. In this study, marupá (*Simarouba loved* Aubl.), tauari (*Couratari* sp.) and cumaru (*Dipteryx odorata* (Aublet.) Willd.) wood were selected and 30 samples of each were produced at the dimensions of 30 x 20 x 500 mm (thickness x width x length). The preservative treatment was carried out under full cell process with chromated copper arsenate (CCA-C). The methods used for the nondestructive evaluation of wood species were the stress wave technique and ultrasonic waves, being performed on the same set of wood samples before and after preservative treatment. The stress wave propagation had superior velocity than ultrasound method on longitudinal and transverse directions. The CCA impregnation on wood presented a significant influence on the behavior of passing waves in both methods, decreasing its propagation. The result of the regression analysis indicated a positive relationship between the propagation speed in longitudinal and transverse direction for the two methods and the specific gravity for the studied wood.

WS099: Nondestructive Evaluation of Wood Using Thermal Conductivity and a Case Study in Kastamonu, Turkey

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Kastamonu Province is one of the provinces of Turkey, in the Black Sea region to the north of the country. Kastamonu is still one of the cities where the examples of architecture of Ottoman period and traditional Turkish House appear intensely. Kastamonu houses are masonry on the basement and timber frame (brick or cob filled) on the upper floors. They are two- or three-story houses with hipped roof or gable roof, and they have wide timber eaves. Foundations of houses are a block stone placed underneath the timber columns. In this study, relationships between the thermal conductivity and the mechanical properties of wood were investigated. For this reason, a device was developed that gives a constant heat into the wood from one surface to the other surface by a heat source and measures temperature values on the opposite surface via a thermal sensor. A case study was conducted using this device in a nearly 135-year-old Kastamonu house. Obtained test values are compared with traditional mechanical test values and significant correlations were found.

WS101: Eucalyptus Wood Phenotyping by Near Infrared Spectroscopy

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More than 3,500 wood samples were collected for different species and hybrids (*E. urophylla*, *E. grandis*, *E. camaldulensis*, *E. urophylla* x *E. grandis*, *E. grandis* x *E. urophylla*, *E. urophylla* x *E. pellita*, *E. robusta*) from different age of plantation (from 5 to 30 years old), and location (Congo, Senegal, Madagascar, and Brazil). Three hundred samples were selected to represent the species and age diversity. They were used to define calibration for NIRS prediction. NIR spectra of grounded samples were measured in diffuse reflectance mode with a Bruker spectrometer (model Vector 22/N-1, Bruker Optik GmbH, Ettlingen, Germany). Spectral analysis was performed within the 12,500 to 3,500 cm^{-1} (800 to 2,850 nm) range at 8 cm^{-1} resolution. The NIR spectra were acquired on samples stabilized at 12% of moisture content. A sub-set of samples was subjected to extraction in a soxhlet apparatus with ethanol-ethanol extractives (EE) and then water-water extractives (WE) in order to eliminate all the extractives—total extractives (TE = WE + EE)—that could interfere with the lignin and cellulose analyses. Klason lignin (KL), holo-cellulose (HCE), and alpha cellulose (ACE) contents were analyzed by Tappi standard method from the dried extractive-free. Partial least square regression calibrations were performed and validation of models was done by test set validation. Based on ratio performance deviation (RPD) criteria and Williams (2014), the NIRS models are classified as very good (application process control) for ethanol extractibles (RPD = 4.4), good (application quality control) for total extractives (RPD = 3.2), fair (application screening) for klason lignin, water extractives, and alphacellulose (RPD = 2.8, 2.6, and 2.5) and poor (application rough screening) for holocellulose (RPD = 2.1).

WS102: Wood Defects Analysis of *Pinus* Boards Using Digital Image Processing and Artificial Neural Networks

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Pinus boards are extensively sawed by the Brazilian industry and can be classified in different quality classes, depending on the presence and severity of defects. Nationally, the Brazilian Association of Technical Standards (ABNT) defines a standard for the visual grading of sawn wood of softwood in general. The main type of visual defect in the *Pinus* wood is the knot. The aim of this study was to develop a classifier of defects in *Pinus* boards using image processing and Artificial Neural Networks (ANN). In the experiment setup we used 220 images, with 64x64 pixels, distributed in five classes of knots variations and one class of clear wood. These images were used for extraction of the main image information through color analysis techniques (percentiles of bands of color) and texture (Gabor wavelet). The information generated was processed to create a classification model of defects in *Pinus* boards using ANN multilayer perceptron (MLP), where each image was classified into the six classes assumed (clear wood and five classes of knots). The best result obtained has generated a classification model with 94% accuracy rate in the classification of the defects in *Pinus* boards, using visual classification of the knots as the theoretical referential. These results demonstrate the feasibility of ANN to generate an automated classifier of defects on *Pinus* boards that can be used as a basis for quality procedure for grading boards.

WS103: Chemistry of Wood in 3D: New Infrared Imaging

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Chemical detection, mapping and imaging in three dimensions will help clarify our understanding of wood properties and durability. We describe here a pioneering infrared method to create visual 2D and 3D images of the chemicals in wood, providing for the first time spatial and architectural information at the cell level without liquid extraction or prior fixation. The analysis utilized high-resolution Fourier transform infrared (FTIR) microspectroscopy that obtains infrared light from a synchrotron beamline facility at the University of Wisconsin Synchrotron Radiation Center that is equipped with a unique design for illuminating samples. An advanced detector allows many spectra to be taken simultaneously. The result is rapid data collection and high spatial resolution with a pixel size of 0.54 × 0.54 µm, enabling analysis of 34 × 204 µm of wood in 0.5 h. Chemical images were generated in 2D and 3D for lignin, hemicellulose, and cellulose in the cell wall layers of *Pinus taeda* and *Populus deltoides* Bartr. We will present 3D visualization and interpretation of the chemical composition of fungal degraded pine wood.

WS108: Nondestructive Classification of Parica Timber for Beams Production in Glulam

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Structural elements in glued laminated timber (GLULAM) consist mostly in exotic wood from planted forests. Studies that evaluate the performance of native species already used in homogeneous stands for use in GLULAM beams are uncommon in Brazil. This study aimed to evaluate a nondestructive method of determining deformation of GLULAM beams made with wood native species *Schizolobium amazonicum* (parica). The modulus of elasticity (MOE) of the blades that form the parica GLULAM beams was estimated by a method that used a constant weight and the values of deformation was read for each blade. To estimate deformation of GLULAM beams, the Homogenization Section Method (HSM) was used, which uses the MOE of the blades to determine the MOE of GLULAM beams. Subsequently, the GLULAM beams were tested destructively by the bending test at four points to determine experimental deformation. At the end, the deformation estimated by the HSM was compared with the experimental test. It is concluded that the nondestructive method is efficient, and promote security, because the analytical deformation was 36.59%, on average, higher than that found by the destructive method.

WS109: Grading of Paricá Wood for Structural Purposes

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The planting of native species has been presented as an excellent alternative for production and marketing of wood in the past 30 years in the Amazon region. Among the various species planted, the parica (*Schizolobium amazonicum* Huber ex. Ducke) is the first species exploited for such purposes. The aim of this study is to determine the modulus of elasticity (MOE) of timber with different ages (6, 10, 19, and 28 years) by destructive and nondestructive testing in order to identify its use in structures. In nondestructive testing, ultrasound equipment was used, according to NBR 15.521/2007; destructive test was performed according to NBR 7.190/1997. The parica wood was graded as structural uses as much by the destructive method as the nondestructive method. It was observed that according the NBR 7190/1997, the wood was graded as species belonging to class strength C-20; in the NBR 15.521/2007 the average was graded as C-30. The suggestion, based on this research, is to replace the constant in the equation of ultrasound velocity determination of NBR 15.521/2007, so the estimated values will be closer to the values of destructive testing. Based on the results obtained, the possibility of using ultrasound as a classification tool and the use of parica as structural timber must be emphasized.

WS110: Development of an Inexpensive Field and Research Tool for Acoustic Testing of Tree Decay

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Advances in electronics and microprocessors, plus significant reductions in costs, create opportunities for developing effective, low-cost tools to measure the presence of decay and defect in standing timber. Single path acoustic testing tools in the hands of many field users combined with recording results in a large data base provide an opportunity for research and better understanding of interpreting measured results.

WS111: Effect of One-Side Thermo-Mechanical Treatment on the Stress Wave Velocity and Dynamic MOE of a Tropical Wood

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The objective of this paper was to evaluate the effect of one-side thermos-mechanical treatment on the stress wave velocity and dynamic MOE of *Simarouba amara*, a tropical hardwood. Thirty wood boards were obtained from market and were thermomechanically treated using a single-opening hot-press. Two temperatures (180ºC and 200ºC) and two pressure levels (50% and 75% of the perpendicular compression strength) were studied. Only one surface of the board was subjected to densification, while the opposite surface was kept under room temperature. Six boards per treatment were subjected to this process, and six were left untreated. Treated and untreated boards were kept at in a conditioned room (20ºC; 65%) until they reached constant mass. Afterwards, samples were cut and nondestructively tested using stress wave method and dynamic modulus of elasticity (E_d) was calculated. The results were analyzed using Dunnett test to compare untreated and treated material means, while 2 x 2 full factorial analysis (ANOVA) was run to identify the source of the variation. The results showed that the thermomechanical treatment significantly affected stress wave velocity (SWV) and E_d in comparison with untreated material. It was found that temperature affected both SWV and E_d, whereas pressure affected only SWV. This way, the utilization of the highest temperature (200ºC) reduced the stress wave velocity and dynamic MOE, but highest pressure (75%) only reduced stress wave velocity, without significant effect on dynamic MOE.

WS114: Determination of Modulus of Elasticity of CLT Panels Made From Pine and Eucalyptus Pith

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The cross laminated timber (CLT) construction system, first developed in Austria and Germany, has recently emerged as an excellent alternative for the construction industry. The region of Telemaco Borba-PR has a sawmill industry that produces a large amount of low-value wood pieces, like pieces of small length of *Pinus* and boards from *Eucalyptus* pith, both materials used in this research. The objective of this work is the analysis of quality and structural performance of CLT panels, using plantation wood boards, *Pinus* spp. and *Eucalyptus grandis*, previously visually and mechanically graded by ultrasound NDT method. After this grading, all the boards were grouped into three levels according to modulus of elasticity (MOE). These pieces were organized into four groups of panels, one exclusively of pine and one exclusively eucalyptus. The other types were developed combining these two species, one type with eucalyptus in the central layer and the pine in longitudinal layers and another type with pine positioned in the central layer and eucalyptus in the outer layers of the panel. A fourth type of panel was produced using ungraded pine and eucalyptus, for the sake of comparison with the classified ones. The adhesive was urea formaldehyde melanin (MUF). The panels were mechanically tested in bending according to ASTM D 198 (2009). Individual stiffness (MOE) of the panels was compared to the lumber MOE, showing the importance of nondestructive grading in the manufacture of the panels. The MOE panel values were also compared to the results found in literature and international standard that regulates CLT (ANSI-APA / PGR 320 (2012)) showing the possibility of using both species successfully in the production CLT.

WS116: Automated Wood Species Identification by CT-Technology

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The introduction of the CT-technology for automated identification of wood structures in logs for optimizing the value output in real industry processes is in full progress. First industry CTs are successfully installed in mills of different wood industries. The latest CT installation is in the most modern softwood sawmill in Europe. Therefore several algorithms have been developed for a wide variety of European softwoods. These algorithms are primarily used for automated identification and detailed description of quality relevant wood structures. At the moment they are used in a softwood sawmill environment for high speed CT up to 120 m/min. The quality parameters covered include dimension, position, and differentiation of green and black knots. The correct match of species-specific algorithms to species-specific product lines in sawmills to the right log species is highly relevant. Due to the fully mechanized harvesting processes, arriving truck loads often include several species at a time. At the entrance point in the sawmill we have to realize high-speed processes. At the moment the focus is directed to softwood species such as Norway spruce, Sitka spruce, Silver fir, Grand fir, Douglas fir, Scots pine, and Black pine.

WS117: NIR Spectroscopy Calibrations for Estimating Carbon Content in Eucalyptus Wood, Roots, and Leaves

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Forestry industries such as producing pulp and paper, steel and timber in general, require fast and accurate methods that could be applied to a large number of samples for characterization of their raw material. Determining the carbon content of lignocellulosic materials by conventional methods is time consuming and costly. Near infrared spectroscopy combined with multivariate statistical analysis is a fast and efficient technique currently used for predicting many wood properties. Thus, the aim of this study was to develop multivariate models for estimating carbon content from near infrared spectra in Eucalyptus wood, roots, and leaves. Vegetal materials were sampled from stem, leaves, and roots of seven genetic materials of Eucalyptus at 12 months. Wood from stem, roots, and leaves were dried and ground. Carbon contents were determined using an elemental analyzer. NIR spectra were recorded from the powders of the air-dried material. Dried biomass was calculated, allowing estimates of carbon stock by plant compartment. Principal component analyses showed the NIR spectra taken from wood and roots presented similar patterns, while NIR spectra from leaves had 90% of their differences evidenced by the first principal component. The second principal component accounted for 6% of variances between types of material. Taking into account the NIR data collected from wood, roots, and leaves together, the predictive model calibrated by partial least square regression method provided good correlation: the coefficient of determination (Rcv^2) of that model in cross-validation test was 0.69, the root mean standard error of prediction was 0.77%, and the ratio of performance to deviation (RPD) was 1.79. This model was developed using raw NIR spectra and the selection of wavelength was carried out using an uncertainty test. The application of mathematical treatments such as first and second derivative on NIR spectra did not improved the adjustment of calibrations. Thus, near infrared spectroscopy can be successfully used for predicting carbon content and stock in Eucalyptus biomass.

WS118: Mobile Unit Forestry for Hazard Assessment of Urban Trees in Bogotá

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The Mobile Unit Forestry operates in a hybrid truck that works with an electric propulsion system integrated into an advanced internal combustion engine, which reduces the impact one the environment; the unit is equipped with measuring devices, such as two Rinntech tomographs and a Resistograph, to establish the physical and health status of trees to identify damage or cracks in the wood. The purpose of using these machines is to determine the most appropriate silvicultural treatments and thus reduce the number of trees felled when this activity is not absolutely necessary and work for the conservation of forest resources in the city. During the activity of this Unit, 507 measurements of different Bogota trees provided important information for decision-making through technical concepts issued by the District Environment Secretariat. Needs have been identified for

specific testing rate for naturalized and native species in Bogotá: data to establish risk levels in trees and avoid impact damage rollovers in Bogotá amount to 240 trees annually, and as the response to remove trees and manage pests and diseases identified in the city. The results will be of significant value in the daily work being carried out within the process to evaluate, control, and monitor the implementation of urban forestry activities in the Capital District and will address short- and medium-term reduction of the risk of falling trees in the city, according to current knowledge on development and behavior of trees in the urban context.

WS119: Experimental Analysis of the Roof System Truss Rafter in Nailed Laminate Wood Using Lumber of *Pinus* spp.

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The roof system of Brazilian social housing generally consists of wood components of native forests of high market value. Taking into account the increasing number of planted forests and the need to develop new products and to add value to this wood, this work deals with the development and structural analysis of a roof system using plantation wood of *Pinus* spp. species, a sustainable material, which has many defects and therefore to use it in structures requires visual and nondestructive mechanical grading. The technology MLP (Laminated Wood Nailed) was chosen as it allows the use of shorter length pieces and cross section, eliminating major defects. Seven samples of the structural trussed rafter in MLP were tested; six with graded lumber and one ungraded in order to verify the impact of wood grading in the structural performance of the model. As the Brazilian standard does not address structural testing, we adopted the procedures described in NBR 7190/97 for bending samples. The results showed that the trussed rafter system lattice in MLP meets the necessary structural condition performance requiring poor conditions of infrastructure for manufacturing process, and that the graded wood samples showed better results with respect to deformation structure than the ungraded one.

WS120: Impact of Wood Grading on the Structural Performance of the Connections of Nailed Laminated Lumber (MLP) Of *Pinus* spp.

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The most common use of wooden structure in Brazil is for roofing. Plantation wood, especially *Pinus* spp., is a good alternative for building structures, considering that is a raw material that is sustainable and highly available in the market. A trussed rafter roofing system with coniferous wood is widely used in other countries. This work deals with the development of the trussed rafter system with *Pinus* spp. as nailed laminated lumber (MLP) to enable the use of pieces of shorter length and cross section. Prior to the truss test, the connections of MLP were tested in tension in models with structural size in order to check the connection performance with the joints 20 cm distant from each other: nine nails distributed in three rows and three columns spaced every 5 cm. Three variations of metal pins were tested: common nail, common nail with bent tip, and ardox nail. Seven specimens of each variation were tested, totaling 21 models. For the manufacturing of the connections, the lumber was both visually and non-destructive mechanically graded through ultrasound. The results were very encouraging and showed the positive impact of grading on the structural behavior of the samples.

WS121: Structural Segregation of Lumber for CLT Panels through Transverse Vibration Testing

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Cross laminated timber (CLT) is a multi-layer wooden panel that has received much attention in the last two years in Chile. Dimensional lumber is the main input material, and it is desirable to use low structural grade for the interior layers and higher grades for the outside. Although this approach is interesting, it suffers from the lack of structurally graded timber in Chile. The aim of this study is to validate the transverse vibration technique as an alternative for preliminary estimation of the structural grading of dimensional lumber for CLT panels. About sixty *Pinus radiata* D.Don lumber (33 x 145 x 4900 mm), with different visual and mechanical grades, were tested through transverse vibration according to ASTM D 6874-12 standard. The results showed a significant positive linear correlation (R^2 = 0.856) between transverse vibration elasticity modulus (MOE_{tv}) and static elasticity modulus (MOE_s). Moreover, there were significant differences ($p < 0.05$) between visual grading classes and MOE_{tv}. The findings of this study suggest that transverse vibration testing can be used to segregate, with good accuracy, the structural lumber for CLT panel manufacturing.

WS124: Wood Colorimetric Characteristics of *Cordia americana, Melia azedarach*, and *Parapiptadenia rigida* by the CIEL*a*b* Method

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The color of wood is not a stable property because it tends to be altered when exposed to the action of weathering. Colorimetry is a nondestructive technique for measuring the color of the wood. This technique is based on the 1976 CIELAB system. This is a quantitative method characterized by three

coordinates (L*, a*, and b*) in the three-dimensional color variation, where L* represents lightness, and a* and b* represent chromaticity. The objective of this study was to evaluate the wood colorimetric characteristics of *Cordia americana*, *Parapiptadenia rigida*, and *Melia azedarach*. Tests were performed in Physical and Mechanical Properties of Wood Laboratory of UFPel, by using the portable colorimeter Konica Minolta CR- 400, with sensor opening of 8 mm, coupled to a computer. For this study were made 20 specimens of each species. For these were determined brightness colorimetric parameters (L*), the red-green axis coordinated (a*), and the blue-yellow axis coordinated (b*). Six readings for each face (radial and tangential) were performed in 20 samples of each species, which resulted in 120 readings per species, totalizing 360 readings in this study. Colorimetry allowed efficient characterization and differentiation of the tones between radial and tangential faces of woods evaluated. The variables analysed showed that the three wood species exhibit differences in colorimetric parameters between anatomical sections. *Parapitadenia rigida* is characterized by red, by increasing a* coordinated; *Melia azedarach* is characterized by yellow color; and *Cordia americana* is characterized by dominance of dark green tone, by the lower value of a* coordinated.

WS126: Effects of Nonlinearity and Variability in the Study of Natural Frequency of *Eucalyptus grandis* Wood Using an Impulse Excitation Nondestructive Technique

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The influence of length of a piece wood on the natural frequency of vibration was evaluated in a study conducted at Laboratory of Materials Properties of São Paulo State University – UNESP – Experimental Campus of Itapeva. The main objective of this study was to determine the natural frequency range to calculate longitudinal modulus of elasticity in bending of 10-year-old *Eucalyptus grandis*. The results of the linear regression analysis rejected the null hypothesis (p = 0.0001). This indicated that longitudinal frequency does not depend on the length of the piece. The high quality of the model fit measured by the adjusted coefficient of determination (R^2) was equal to 0.92 but it was obtained from the average of the frequency data. This approach masked the important effect of natural variability in the phenomenon. Furthermore, graphical analysis of the results might suggest use of nonlinear models as best suited for the explanation of the phenomenon. Simulations were performed with the Monte Carlo Methods in R (programming environment for statistical computing and graphics). Five conditions of variability (coefficients of variation between 5 and 25%) and a nonlinear model in which the logarithm of frequency as a function of length were evaluated. Median R^2 ranged from 0.89 to 0.49 in a simulated variation range. The low value obtained (0.49) for the most tested coefficient of variation (25%) indicates the need to consider the role of variation more appropriately. The median R^2 for the nonlinear model ranged from 0.92 to 0.43 and indicated no substantive gain of quality in relation to the linear model.

WS127: Near Infrared Spectroscopy in Wooden Floor: Application for Wood Discrimination and Air-Dry Density Estimation

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Many times it is required to evaluate applied wood floors. The main complaints are about the timber used. Since there are variations of heartwood colors even in the same timber, many customers mistrust the supplier's wood identification after its installation. Also, problems related to wood physical properties like density and moisture content are also reported. Although moisture can be nondestructively tested by some electrical meters, commonly the only way to assess air-dry density and wood identification are collected samples. This implies undesirable damage to the floor. Near infrared spectroscopy is a potential tool for nondestructive wood inspections when it is required to discriminate between the customers specified timbers from other ones, despite color variation. Also, it could be used to estimate air dry density and so help to detect low grade wooden floor parts. We developed a model to discriminate cumaru (*Dipteryx* sp.) floor samples from sucupira *(Dipteryx* sp. and *Bowdichia* sp.). None of the sucupira samples we tested were classified as cumaru, indicating the model correctly distinguishes the spectral data from these two timbers. Also, with the same spectral data, we made a calibration to estimate wood air density from the samples. The standard error of prediction (SEP) was 32 kg/m^3 and the ratio of the standard error of performance to the standard deviation of the reference data (RPD) was 2.13. This is suitable for an initial screening. We are working to raise the performance to a quality control level.

WS133: Ultrasound Tests for Evaluating Sensitivity in Identifying Cracks in a Piece of *Pinus* spp.

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The ultrasound technique presents several possible applications, and one of them is in the investigation of internal imperfections present, such as cracks and galleries of wood-destroying insects. This paper presents the results of experimental research done in order to evaluate the sensitivity of the ultrasound technique in detecting internal non-homogeneities in a piece of *Pinus* spp. wood with dimensions 7 cm x 11 cm x 300 cm. Some cracks were produced in it with a saw in radial-tangential plane of wood and in the radial-longitudinal plane of the piece. Each one of these cracks presents 2 cm, 4 cm, and 6 cm depth. Wave propagation time through the crack direction was measured using ultrasound equipment and transducers of 200 kHz with flat faces. The spacing between transducers is chosen with different values in order to identify how far from the crack it is possible to detect internal voids in this wood piece.

WS134: Module Evaluation of Dynamic Elasticity, Determined by Ultrasound, in Three Species of Tropical Wood

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The use of ultrasonic propagating waves is an alternative to determine the elastic properties of wood. The correlation between the dynamic modulus of elasticity of the wood and the elastic modulus and rupture in bending can predict the mechanical properties of wood. The objective of this study was to evaluate the use of dynamic modulus of elasticity obtained by ultrasound in the estimation of elasticity and rupture in bending modules of three species of tropical wood (Axixá - *Sterculia pruriens* (Aubl) K. Schum; Amarelinho - *Aspidosperma macrocarpum* Mart and Jatoba - *Hymenaea courbaril* L.).

This study was developed in the Wood Technology Laboratory of the University of Brasilia. Collected were five wooden planks of all species (Axixá, Amarelinho, and Jatoba). Eighteen specimens of each species were made, each measuring 2 x 2 x 30 cm (width, height, length), and packed in the climate chamber to obtain a final moisture content of 12%, before the destructive and nondestructive testing. For nondestructive testing, we used USLab ultrasound equipment, 0.1 µs resolution and longitudinal wave transducers and flat section operating at a frequency of 45 kHz. Dynamic modulus of elasticity (MOEd) was calculated taking into account the speed of propagation and the specific gravity of the timber. The same specimens were subjected to destructive testing of bending, using a universal testing machine EMIC DL model 30 kN, where modulus of elasticity (MOE) and modulus of rupture (MOR) static were determined. The results showed different behaviors between MOEd and MOE and MOR for each species studied. Correlations between these parameters in predicting the mechanical properties by ultrasound method were not always good, showing the influence of the method, besides the viscoelastic characteristics of the timber. The average propagation velocities of wave ultrasonic ranged from 4903 m/s to 5296 m/s, depending on the species. The average MOEd was between 14079.00 MPa to 20163.00 MPa. These were always greater than the static MOE for all species. The interest in this methodology (ultrasound) remains, as it was efficient to evaluate differences between properties of each species, being efficient and fast.

WS136: Methods for Nondestructive Investigation of Heritage Listed Timber Buildings to Support Restoration Projects and Preservation Initiatives

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This paper presents methods and instrumental standards for restoration and preservation studies of heritage listed timber buildings through nondestructive techniques. The constructions analyzed in this paper were built in the beginning of the twentieth century using Araucaria wood at the Murici Colony of polish immigrants in the city of São José dos Pinhais, south of Brazil, and are important examples of building technique development, regional environmental and fauna conditions, and the contribution of immigrants. An anatomical macroscopic wood analysis was performed according to the Italian UNI 11119:2004 regulation, on which the building elements were identified and photographed. Deterioration agents were identified by visual analysis, which were combined with resistograph surveys to determine the condition of the structures. Critical sections of each structural element were determined according to the deterioration levels, and structural analyses were developed considering the Brazilian NBR 9170:1997 regulation to verify the structural safety of the buildings. It is concluded that although insects of Coleoptera and Isoptera order and moist and rotting fungi are actively deteriorating the timber structures, the building stability is not compromised. Maintenance works are recommended. Nondestructive techniques were proven effective and worthwhile to ensure the maintenance and preservation of heritage listed buildings. Further studies concerning the evaluation of historical wood elements are also recommended in order to set standards to support the structural analysis.

WS137: Evaluation of European beech (Fagus sylvatica L.) roundwood for improved production of strength-graded lamellas

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Declining stocks of softwoods in European forests and, simultaneously, increased use of wood in the building sector which is both desired and anticipated will presumably lead to a future gap in wood supply for the production of glued structural timber. At the same time, increasing stocks of hardwoods such as European beech (Fagus sylvatica L.) with its favourable mechanical wood properties make utilisation of this resource for glued structural timber products a possible alternative. In the first part of a study on the suitability of lower-quality beech logs for the production of strength-graded lamellas for glued structural timber, a sample of 29 logs was evaluated for roundwood properties, including visual roundwood grading, measurement of dynamic modulus of elasticity (MOE) and X-ray computed tomography (CT) scanning. The results did not indicate any significant relationships between the measured roundwood properties. In a subsequent investigation, boards with common dimensions for glulam lamellas produced from the sample logs will be analysed including MOE measurements and visual strength grading. The data from the CT scans are planned to be used in sawing simulations for estimating the potential to optimise log breakdown for glulam lamellas**.**

WS138: Assessing the Performance in Service of a Cross Laminated Timber Structure Exposed to Extreme Conditions

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Cross-laminated timber (CLT) panels are widely used across Europe, but their use in extreme environmental conditions is not yet spread. Eurocode's Service Classes enable the design of timber structures taking in account environmental conditions. CLT panels are evaluated for structural applications in Service Classes 1 and 2 conditions (below 20% equilibrium moisture content). Structural applications in Service Class 3 (above 20% equilibrium moisture content) are not allowed, mainly because of (1) the high moisture content expected in timber and (2) some concerns related to the

potential change in panels size when significant moisture changes happen. High moisture contents in CLT panels are not advisable, because it will lead to high level of stresses in glue lines. Several European Technical Approvals (ETA) state the insignificance of the dimensional variations of CLT panels due to moisture content variation; however, according to other technical documents, this kind of variation should be accounted for. This paper will report the assessment of the performance after 3 year in service of one swimming pool build with this technology, taking advantage of a monitoring program started when construction was completed. The monitoring program aims to evaluate the performance of CLT panels in places where high environmental humidity is expected. The major parameters monitored are (1) wood moisture content, to ensure that the CLT panels are in Service Classes 1 and 2 conditions, and (2) the dimensional stability of the panels, to ensure that no unforeseen stresses will develop in the structure. Monitoring techniques used are discussed in the paper as well as its results, in terms of confirmation of the validity of design parameters. The relevance of the results is extremely important also to assess the possibility to use the panels in tropical climates, with similar conditions observed inside the building.

WS140: Mechanical Properties of Structural Wood Used in Coal Mines by Traditional Testing and Nondestructive Testing

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Colombia is the world fourth largest coal exporter, setting a goal of nearly 98 million tons in 2015; of this, 6.5% is extracted by the tunnel system. The tunnel systems of Colombian mines intensively use *Eucalyptus globulus* wood in the support structure, in tunnel entrance-exits and in the operation fronts. To determine the effectiveness of this material and improve the mechanical characterization we performed tests using ASTM D 143 and NSR-10 standards. Additionally we used nondestructive tests by transverse vibration (Beam Identification by Nondestructive Grading -BING) developed by the Center for International Cooperation in Research Agricultural for Development (CIRAD). The pieces to real scale are collected and processed in the mines located in the center of the country. Destructive tests in 100 pieces were performed in the Wood Laboratory in the District University, reporting a elasticity modulus equivalent a 10652.7 (±1582.4) MPa for static bending and 3573.61 (± 498.1) MPa for parallel compression test. The nondestructive testing in 20 pieces reporting a elasticity modulus equal to 14078.02 MPa and a elasticity modulus of 16232.62 MPa for parallel compression test. Finally, the two methodologies are compared and the research recommends a method for using better wood in the mines, plus an internal protocol based on mechanical wood grading BING system in the areas of mining exploitation.

WS141: Evaluation of Moisture Content in Green Solid Wood Using Dual-Energy X-Ray Absorptiometry with Digital Radiograph

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The oven-dry method is one of most accurate way to evaluate moisture content. However it reveals only local moisture content of full size specimens and cannot measure a progressive change in moisture content continuously. To solve those problems, use of a dual-energy X-ray absorptiometry (DXA) method is reported in this paper. Because a digital detector was used to reduce error from the process of developing X-ray films and measure the quantity of transmitted X-rays energies, the accuracy of the DXA method was improved to evaluate moisture content. For calculating the accuracy of the DXA method, estimated moisture contents using the DXA method were compared with actual moisture contents. Actual moisture contents were measured by the oven-dry method. In the 28.68–172.81% moisture content range, root-mean-square error (RMSE), which was the differences between predicted moisture content and actual moisture content, was only 3.15%. Moreover, moisture content distribution in solid wood was gained by using a relationship between the ratio of two reference X-ray energies (45 and 60 kV) and moisture content. It was considered that the DXA method with digital radiograph could be used in solid wood production.

WS142: New Generation of Nondestructive Tool for In-Field Wood Poles Using Combined Parameters for Improved Reliability

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Nondestructive evaluation of in-field wood poles used in telecom and utilities overhead lines remains as a key issue for network managers. If existing tools all have their own approaches to give an estimation of the residual status of individual poles, the goals are usually the same: Security (Keep only safe poles in the networks); Costs (Change the least number of poles possible); Productivity (Inspect as many poles as possible within a short period). For many years, CBT has been working to achieve those goals. If the tool—as called Polux—is considered as the reference on the market, engineers have developed a newer generation taking into account new parameters to strengthen its performances. This paper will present the very first results of this new generation of device born in 2015 using the existing Polux parameters plus new ones such as screw energy, screw power, local density graphics, and "density energy". Specific efforts have been made to improve the ergonomic aspects of the device to give an optimized solution for wood poles management. This presentation will then open the discussion for other applications for this new portative device, especially in the construction domain.

WS143: Nondestructive Testing of String Musical Instruments Made in Solid Wood

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In this article are discussed three groups of nondestructive methods for testing stringed musical instruments from classical music, namely instruments from the violin family—violin, viola, cello, double bass, and guitar. The nondestructive techniques included mechanical methods (modal analysis), optical methods (holographic interferometry, laser Doppler vibrometry, near field acoustic holography), X ray methods (X-ray computed tomography), and synchrotron radiation phase-contrast microtomography. Theoretical parameters of the vibration of musical instruments are given by modal analysis. The influence of physical parameters of materials (density, moduli of elasticity) and geometry (size of plates, thickness distribution, etc.) used for instruments construction on their vibrations can be demonstrated with simulations through modal analysis. Modal testing allows experimental identification of modal parameters of vibrating musical instruments (natural frequencies, modal damping, and mode shapes). From the 1970s, optical non-contact techniques—holographic and scanning laser Doppler vibrometry—have been developed for experimental studies of violins. The advantages of scanning laser Doppler vibrometry include capability of determining velocity of vibration quantitatively; capability to measure vibration mode shapes with high-speed sampling; capability to measure vibration of objects of complex shape; frequency range up to 5000 Hz; measurement uncertainty below 3%. X-ray (CT) computed tomography using clinical scanners can be used for determining geometrical parameters of external and internal shape of instruments. This technique is also used to obtain data on wood density of different structural components and different maps such as map of thickness, map of density variation, map of arching. Images obtained with this technique allowed univocal confirmation of the authenticity of precious historical instruments and identification of repairs, restoration work, damage by insects, etc. Technical limitation of clinical equipment is due to the limited spatial resolution of the scanner which is of 0.4 x 0.4 x 0.6 mm. Synchrotron radiation phase-contrast microtomography is considered an ideal technique for nondestructive 3D analysis of samples of musical instruments and other objects of cultural heritage.

WS144: Wood Density Measurement by Microwave Radar

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Microwave radar is under development for evaluation of wood density. Tests were performed on air dry wood samples with the same size (150 x 300 mm) and thickness (20 mm), with moisture content of 12%. The samples were poplar (*Populus*, 295 kg/m^3), spruce (*Picea*, 371 kg/m^3), linden (*Tilia*, 477 kg/m^3), black walnut (*Juglans nigra*, 561 kg/m^3), black pine (*Pinus nigra*, 637 kg/m^3), ash (*Fraxinus*, 706 kg/m^3), and acacia (*Robinia*, 756 kg/m^3). All conditions were the same for the samples. The distance between microwave transmitter and receiver antenna was 7 cm, and the sample was placed between the antennas. The microwave signal penetrated the samples, and the amplitude and phase signal changed due to the properties. The measured amplitude and phase data are density predictors. We could establish linear relation between phase and density. This is a preliminary study for a more complex density evaluation. The results are encouraging for further measures for developing a fast, nondestructive, and noncontact density measurement.

WS145: Biodeterioration and Hazard Assessment of Tipuana Trees in the Sidewalks of São Paulo, SP

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In the sidewalks of São Paulo city, Brazil, 1109 tipuanas (*Tipuana tipu*) trees were evaluated for biodeterioration process and hazard assessment, using biomechanical concepts. The trees were characterized taking into consideration the surroundings and target analysis, dendrometric variables, and external and internal biodeterioration using nondestructive equipment (penetrograph) for the trunk prospection. The hazard assessment was estimated using a static structural model. The old aged trees did not show any sign of dieback, even though the general aspect of their surroundings was critical by the inadequate places they were planted and inappropriate management and/or occurrence of injuries. The trees had their trunks deteriorated by xylophagous organisms, mainly decaying fungi and subterranean termites, which affected the heartwood. The decaying fungi observed were classified as white rot and soft rot, the white rot being more common in the heartwood of the trees. The infestation of the trees by the subterranean termite *Coptotermes gestroi* was at high levels, however, it was considered as a secondary plague organism because its attack was associated with the previously decayed heartwood by *Ganoderma* sp. fungi. The structural model categorized 177 (16%) tipuanas as hazardous trees and statistical significance was observed with the external presence of fungi and termites, DBH and internal biodeterioration processes; a statistical model with these attributes was validated for predicting falling risk for this species.

WS146: Two-Dimensional Image Construction of Ultrasonic Wave for Detecting Internal Hole Defect in Log Disc

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The ultrasonic propagation parameters in an Amur Linden (*Tilia amurensis* Rupr.) log specimen that was in intact and defective status were measured and obtained. These parameters were then used as training set and test set to classify the hole size in the log based on a support vector machine (SVM). Furthermore, a kind of method to quantitatively determine the location of the defect point on the cross section of the log was proposed and improved. Based on this, the two-dimensional simulation image of the internal hole defect in the log was constructed. The results show that (1) it is feasible to classify the hole size in the log using SVM and the identification accuracy is 84.78%, and (2) the two-dimensional simulation image of the hole defect in the cross section is in good agreement with the actual image of log specimen.

WS148: Efficiency of Acoustic Segregation of *Castanea sativa* Standing Trees and Logs for Structural Timber Production

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Chestnut (*Castanea sativa* Mill.) is one of the most important hardwood species traditionally used in construction in Spain. It has recently been included in the Spanish Standard for structural timber, UNE 56544, assigning the strength class according to European Standard EN 338. From the demonstrated effectiveness of acoustic techniques, this paper proposes classification models for trees and logs based on acoustic velocity to estimate the mechanical properties and improve the yield of structural timber processed. The acoustic velocity (ST300) was measured in a representative sample of 61 standing trees from Galicia region (northwest of Spain). 163 logs from these trees were obtained and resonance method (HM200) was used to measure the acoustic velocity and characterize the logs. The modulus of elasticity (MOE) was measured according to the European Standard EN 408 on 81 pieces of structural lumber milled from the tested logs. The relationship between acoustic velocities and the average lumber MOE was good for both models, $R^2 = 0.78$ for the log model and $R^2 = 0.62$ for the tree model. An acoustic segregation of chestnut logs in three classes according to strength classes defined in EN 338 (D18, D24 and D35) was proposed. The models will allow selection of the best structural quality trees and logs and increasing the yield and profit of processing industry.

WS150: Density Profile Evaluation of Laminated Wood Beams through Resistograph

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The search for alternative materials for construction due to the shortage of traditional materials potentiated studies on the viability of wood usage as a structural element. In this context, in 1906 the Swiss carpenter Otto Hetzer presented structural beams of glued laminated timber (MLC); this technique facilitates the construction of large structures of varied sizes and shapes. Traditionally, the regulatory standards state that the characterization of wood properties is made through destructive evaluation processes. This practice demands time and extra material, because the sample is destroyed after the test, thus appropriate studies on characterization techniques in this context are necessary. That is, an effective characterization by means of nondestructive methods, for which specimen extraction is not required because the evaluation is performed on the part or structure itself. This study aimed at evaluating the density profile of glued laminated Eucalyptus wooden beams using resistograph device and correlating them with results obtained by the method established by the NBR 7190 (ABNT, 1997). There were five beam samples. A sample of each plank that composed the piece was removed, and the apparent density was determined. The test with resistograph was conducted in three sites in the regular direction of the fibers in the beam. The correlation between the density of the planks that compounds the beam and the range of the extent of penetration was 0.51 (beam 1) to 0.82 (beam 2). The correlation between the density and the extent of penetration was significant; therefore the resistograph was attested to be an easy work tool in the field and of great potential use for future work.

WS151: Plant Health Evaluation and Fall Risk of *Tilia Tomentosa* in the Town of Amarante, Portugal

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The objectives of this study were to evaluate the plant health and the risk of falling of individuals of *Tilea tomentosa* using visual inspection and instruments for internal prospecting. The trees were located in a private park in the town of Amarante, Portugal. First, the dendrological characteristics were observed and evaluated, including dendrometric parameters such as diameter at breast height (DBH), average crown radius, total height, and height of the base of the crown. Subsequently, the visual inspection was performed to assess the condition of the trees and the local conditions, using as a basis the VTA method (Visual Tree Assessment). In the diagnostic process were also used tools such as rubber hammer, ladder, binoculars, and instruments for internal prospecting. The evaluation of causes of declining health was based on predisposing factors, inducing factors and acceleration factors. We evaluated five adult and two young trees. The adults have an average age of 90 years, average DBH of 91.1 cm, and average height of 19 m; the young have an average age of 8 years, average DBH of 8.5 cm, and average height of 4.9 m. At the end of the evaluation process was recommended the removal of four individuals due to the presence of irreversible damages, featuring a low phytosanitary condition and a high risk of falling. The three remaining trees were classified as regular plant quality and moderate risk, and the appropriate management practices were recommended to reduce the risk.

WS153: Evaluation of Ten Years Old *Eucalyptus grandis* by Impulse Excitation Technique

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The Impulse Excitation Technique (IET) has been recently used among other nondestructive tests, in which the specimen undergoes impact of short duration that induces acoustic signals composed of natural vibration frequencies, from which can be calculated the longitudinal modulus of elasticity of material. The objective of this research was to study the modulus of elasticity in static bending (E_M) and dynamic longitudinal modulus of elasticity (E_d) of *Eucalyptus grandis* wood using the IET. We used 14 specimens with length 1150 mm and cross section of about 50 mm x 50 mm, removed from the first 3 m of the base of four 10-years-old *Eucalyptus grandis* trees, from Itapeva-SP region. The specimens were subjected to Sonelastic PC Based on the IET to determine the E_d values, and then static bending tests were conducted to determine the E_M values using a Universal Testing Machine (30t), following the requirements of ASTM E-1876/09 and NBR 7190/97, respectively. There were obtained E_d and E_M average values equal to 17.8 GPa and 14.3 GPa, respectively. A correlation between the E_d and E_M values was studied by regression analysis (software R and $\alpha = 5\%$) with the equation $E_M = 1.0053 + 3.1929E_d$ and $R^2 = 0.8428$. The R = 0.92 value shows that the two variables have high correlation and demonstrates the efficiency of the IET in the characterization of stiffness in static bending of the analyzed species and their subsequent rating for use in structures.

WS154: Additional Variables with Acoustic Velocity to Predict Structural Lumber Quality Obtained from the Trees and Logs in *Eucalyptus globulus* Labill

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Acoustic technologies have been well established as material evaluation tools in the past several decades, and their use has become widely accepted in the forest products industry for quality control and products grading. It is well recognized that natural variation in wood properties is enormous within trees and logs, and end product properties are dependent on the quality of incoming wood supplies. In this study, we investigated how acoustic velocity is affected by different individual tree and log traits. Five *Eucalyptus globulus* trees were selected in Galicia region (Spain). The following variables were measured for each tree: stress wave velocity measured with ST300 tool, total height, diameter at breast height, and the crown length. The trees were felled in logs (20) and the following variables were measured for each log: acoustic velocity with HM200, average log diameters, and log vertical position in a tree. The logs were sawed into boards (375) and acoustic velocities were measured with HM200. Statistically significant relationship was obtained between all tree and log variables and acoustic board velocities. The fitted tree and log model explains 84.2 % and 94.5% of the variability in the board acoustic velocities. This information would enable the wood processing sector to optimize resources and future investments with the aim of increasing industrial efficiency. The data would enable identification of the proportion of the trees in the stand with high stiffness. It would also enable identification of logs of poor structural quality, which could then be used for other more appropriate purposes.

WS157: Comprehensive Study on Measuring Elastic Constants of Engineered Wood-Based Panels by Modal Testing with Different Boundary Conditions

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Engineered wood products have been widely applied in wood construction due to their stable physical and mechanical properties. Elastic constants are the fundamental mechanical properties for the structural application of engineered wood-based panels. Determination of elastic constants of composite material by modal testing based on the theory of transverse vibration of orthotropic plates has been proven to be an effective method. Boundary condition (BC) and corresponding calculation method is the key affecting its practical application in terms of setup implementation, frequency identification, and accuracy and calculation efforts. In order to find a suitable BC for nondestructive testing of engineered wood-based panels, three BCs with corresponding calculation methods were adopted for measuring elastic constants, namely in-plane elastic moduli (E_x, E_y) and shear modulus (G_{xy}), of oriented strandboard (OSB) and medium density fiberboard (MDF) in this study. The BCs with corresponding methods are a) all sides completely free (FFFF) with finite element modeling, b) one side simply supported and the other three free (SFFF) with one-term Rayleigh frequency equation, and c) a pair of opposite sides simply supported and the other pair free (SFSF) with improved three-term Rayleigh frequency equation. The results from different modal testing methods will be compared with standard static testing method. Comprehensive discussion will be made for recommendation on evaluation of elastic constants of wood-based materials by modal testing.

WS158: New Empirical Production Models for Poplar Plantations on Farmland—A Toolbox for Improved Management and Planning Operations

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Interest in utilizing trees for bioenergy production has increased drastically in recent decades. Poplars (*Populus* spp.) are an exotic group of species in Sweden. Hybrid poplar plantations with short rotation (≤ 20 years) established on farmland in south and central Sweden have shown promising production figures and been in focus as a future potential bio-fuel feedstock. Results from 20-year-old poplar plantations show a total production of up to 300 t d.w. ha^{-1}. Mean annual volume production is on average around 20-25 m^3. Taper, biomass, and volume models were developed for individual poplar trees. One model was developed for biomass estimations of individual stumps (including roots) and another model was developed for biomass estimation of second-generation coppiced poplars. We have finally studied the properties of false heartwood of poplar stems growing at 22 sites in Sweden. The models usage is nondestructive. 1) Biomass and Volume models for individual Poplar trees: The developed biomass equation uses dbh (diameter at breast height, 1.3 m above ground) as independent variable and estimates the stem, twigs and leaf fractions separately or together. One equation with dbh (D) and total height (H) as independent variables were constructed for stem volume estimation (V) and compared with a number of published equations. 2) Biomass models for Poplar stumps and second-generation coppices: There are two ways to manage the remaining stumps after harvest: excavation or management of sprouts established on stumps. Models for estimation of individual stumps and coppice biomass were developed. Biomass production of 1000 excavated stumps could be 45-50 t d.w. ha^{-1}. The stump was 74% on average of the total stump-root biomass. Roots (>50 mm) made up the remaining 24%. Biomass of 7-year-old coppices on 1000 stumps could be 30-35 t d.w. ha^{-1}. 3) Taper model for individual Poplar trees: Taper models estimate diameter (d) using DBH, corresponding height (h) and total height (H) as independent variables and are useful for estimating properties of different assortments with mini diameter restrictions. The objective was to develop a simple taper equation with good ability to predict diameter at a given height and compare it with common published taper equations. 4) Models for prediction of false heartwood properties in Poplar stems: All the sampled stems contained false heartwood. At 0–50% of stem height, all sampled trees were discolored and at 90% of stem height, 33% were discolored. The percentage of false heartwood area by stem area was highest at 1% and 10% of stem height (26.6% and 24.7%, respectively). Equations were constructed describing the correlation between diameter at breast height and the diameter of false heartwood at different stem heights aimed for stems to be used for construction. However, most of the fast-growing poplars in Sweden are expected to be harvested as biofuel.

WS159: Application of X-Ray Densitometry in the Evaluation of Quality and Mechanical Properties of Biomass Pellets

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The use of the X-ray technique and X-ray densitometry to determine pellet particle distribution and to understand the biomass compaction and its effects in pellet properties has been limited. The present work evaluates the quality of pellets manufactured with several lignocellulosic materials by using X-ray photography for studying surface cracks and irregularities, and by using X-ray densitometry to evaluate density and its variation in longitudinal and transversal directions. Density values and their variation

were correlated to pellet mechanical properties (mechanical durability and compression resistance). It was found that X-ray photography may be applied to evaluate the presence of cracks and irregularities in the pellet surface; however, these are not indicators of pellet durability or compression resistance. Moreover, density evaluation by the X-ray densitometry technique allowed determination of pellet mechanical resistance and durability. A negative correlation was observed between the force at break and the coefficient of variation of density. No correlation was found between mechanical durability and average density or its variation. According with above results, X-ray technique can be utilized to study pellet quality.

WS160: Measurement of Stiffness of Standing Tress Using Acoustic Velocity Measurements Made through Tree Stems

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Acoustics techniques are commonly used for nondestructive testing (NDT) of wood. Standing tree stiffness measurements are commonly calculated using acoustic time of flight (TOF) velocity measurements. These velocity measurements are generally obtained by inserting two probes into a tree stem on the “same face” of the tree, separated vertically by about a meter. The acoustic velocity is obtained by measuring the propagation time of a stress wave between the two probes. Studies have suggested that these TOF measurements are biased to measure the outerwood stiffness rather than that of the tree stem as a whole. However, the stiffness of tree stems increase from pith to bark. To try to compensate for this, some studies have been made of TOF measurements on “opposite faces” of the tree, with the probes separated vertically by about a meter. However, none of these studies have allowed for the anisotropic nature of wood. This resulted in stiffness measurements that were too low. Also, most have not included the true propagation path distance in the TOF velocity measurements, which has resulted in stiffness measurements that varied with the diameter of the tree stem. In this study, a technique is presented that uses TOF measurements on the opposite faces of the tree stem to attempt to obtain an average stiffness through the tree stem. Unlike previous studies, this technique allows for the anisotropic nature of wave propagation in wood and the propagation distance. The modulus of elasticity (MOE) values obtained using this technique are compared to MOE values obtained using TOF measurements, which were obtained using on the “same face” technique, and also using acoustic resonance.

WS161: Experimental Measurement of Acoustic Guided Wave Propagation in Logs

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Acoustic nondestructive testing (NDT) techniques have been developed to measure the stiffness of wood using acoustic velocity. For stiffness measurements of standing trees, the velocity measurements are generally obtained by driving two pikes into the tree stem facing each other at an angle of 45 degrees to the tree stem, hitting one with a hammer, and measuring the time it takes for the signal to first reach the second transducer. This time of flight (TOF) method uses only the very start of the received signal and ignores the rest of the signal. This paper investigates if there is additional information that can be obtained from acoustic signals in tree stems, which potentially could be used to measure wood properties. The wave propagation in a log was investigated using shear transducers for transmission and reception in pitch-catch configuration. These transducers were initially attached to spikes driven in the logs. It was found that the angle and orientation of the spikes significantly affected the received signal. Measurements were also made with transducers attached directly to the logs. The alignment of the transducers allowed different guided wave modes, including what were assumed to be longitudinal and torsional wave modes, to be excited and measured. More study is required on guided waves in tree stems to see how these can be used to improve the measurement of tree stem properties of interest.

WS162: Study on Termite Detection using Two-Frequency CW Radar System

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Owing to termite wood-eating habits, many termite species can do great damage to wooden structures. Their habit of remaining concealed often results in their presence being undetected until the timbers are severely damaged and exhibit surface changes. The termite detection can be performed by detecting the Doppler shift of the received signal to an electromagnetic wave irradiated in wood, resulting from the activity of termites within the timber. According to the detection method, it is believed that it can be performed efficiently in non-contact sensing of termites. Furthermore, it is considered to be possible at low cost, and detection is performed easily without requiring special qualifications during operation. The CW radar has the advantages of low power consumption and simple radio architecture. Moreover, CW radar can also cancel out clutter noise by proper adjustment of the radio front-end architecture. The two-frequency CW system transmits signals with two almost same frequencies using time division method, transmission and reception system is made simply. In the two-frequency CW system, the occupied frequency bandwidth is narrow and it is good in interference. Furthermore, the two-frequency CW system has excellent suitability for detection of close targets, according to the distance accuracy, which is dependent on the S/N instead of frequency bandwidth. In this paper, we propose the detection method to detect the Doppler shift of the received signal from the activities of termites and verify detection experiment of termites in the cavity of the timber that mimics the damage caused by termites using two-frequency CW system method.