PROCEEDINGS OF THE 65TH SWST INTERNATIONAL CONVENTION

SWST 65TH INTERNATIONAL CONVENTION
JULY 10-15, 2022
PEPPERS SALT RESORT & SPA, KINGSCLIFF, NSW, AUSTRALIA
A GLOBAL PERSPECTIVE OF THE PRESENT AND FUTURE UTILIZATION OF RENEWABLE MATERIALS

SOCIETY OF WOOD SCIENCE & TECHNOLOGY

**JULY 10-15, 2022
PEPPERS SALT RESORT & SPA
KINGSCLIFF, NSW, AUSTRALIA**

Edited by

**Susan LeVan-Green, Editor
Wood and Fiber Science**

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FOREST PLANTATION AND NON-WOODY RENEWABLE MATERIAL IMPACTS ON ECOSYSTEM, SOCIETY, ECONOMY, VALUE-ADDED PRODUCTS
Chairs: Felix Wiesner, University of Queensland, Australia and Sheldon Shi, University of North Texas, USA

Natural Durability of Young Planted Hardwoods in North Eastern NSW

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Abstract

Not Available

Multiple Ecosystem Services Of Monoculture Hardwood Plantations: A Case Study Of Spotted Gum Forests In Queensland

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ABSTRACT

Forest managers are increasingly encouraged to consider the multiple ecosystem services that forests provide. Spotted gum (*Corymbia citriodora* subsp. *variegata* - CCV) hardwood plantations can provide economic benefits while providing important ecosystem functions. This study aimed to determine the fiber services (timber production, volume and bioenergy) and co-benefits (CO_2 sequestration and belowground carbon storage) from an 18-year-old spotted gum plantation in Queensland. To accomplish this objective, equations of total stem volume of living trees and merchantable sawlog volume have been developed. Forest inventory data were combined with species-specific biomass equations to estimate the total timber production, merchantable volume, bioenergy, belowground carbon and CO_2 sequestered in spotted gum plantations. Results showed that mean total stem volume and commercial sawlog volume were 302.4 m^3 ha^{-1} and 139.2 m^3 ha^{-1} respectively. Mean tree biomass (excluding commercial timber) with potential use for bioenergy was 47.6 Mg ha^{-1}. Trees sequestered 278.3 Mg ha^{-1} of CO_2 equivalents and tree roots contributed about 17.1 Mg ha^{-1} to below-ground carbon storage. These findings show that monoculture plantations provide potential multiple values in terms of timber production, biomass production and carbon storage and demonstrate the opportunity to optimise environmental and economic values of hardwood plantations. This is especially the case for spotted gum, a hardwood plantation species with great potential in Queensland which accounts for 62% of the existing total hardwood plantation estate.

Biomechanical and Viscoelastic Properties of Sweet Sorghum Stalk and its Correlation with Composition

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ABSTRACT

The biomechanical strength of the sorghum stalks are crucial properties for the yield due to its direct impact of lodging behavior. From the structural constituents of the stalk, the rind (outer sclerenchyma tissue) provides the principal structure supporting cells against tension and bending loads. In this work, the biomechanical and viscoelastic behavior of the rind from the internodes of two sweet sorghum varieties (Della and RG), grown in two different growing seasons, were evaluated using three-point micro-bending tests. Besides, the mechanical properties have been correlated with their corresponding chemical composition, and the microfibril angle of S2 cell wall by XRD. The biomechanical and stress relaxation behavior of the two varieties were found considerably different. The result revealed that Della variety was stiffer and resistant to loads than RG. Two features of the rind biomechanical properties, modulus of elasticity (MOE) and modulus of rupture (MOR), showed a significant reduction for RG. Particularly, reduction of MOR by (35.7-52.3%) and MOE (36.6-52.9%) has been detected for RG. Changes in the stalk rind biomechanical properties were found attributed to cell wall components. Lignin and cellulose content were found positively correlated to stiffness of the rind and its viscoelastic property. The load bearing capacity variation of the two varieties are likely influencing their loading behavior.

Strategies for Reducing Drying Collapse in Difficult-To-Dry Plantation Grown Timber

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ABSTRACT

Eucalyptus plantations are one of the largest wood resources, and while typically primarily grown for fiber or biomass, there is an increasing interest to use this resource for solid wood products. However, timber from such short-rotation eucalyptus plantations is often 'difficult-to-dry' suffering collapse during this process. To make such timber suitable for higher-value solid wood products, this study explores two strategies for reducing collapse in plantation-grown eucalypts: a) reducing collapse through a breeding program, by selecting genetically less-collapse prone planting stock and b) technical solutions to allow the drying of collapse-prone timber without collapse.

Following earlier work in Australia in the early 2000s, breeding trials of *E. globoidea* and *E. quadrangulata* were assessed at 8-9 years of age. Thousands of trees were sampled, using a 13-mm-diameter purpose-built corer, for collapse in heartwood and sapwood, extractive content and basic density. Heartwood collapse was under genetic control with the heritability ranging from 0.19-0.40. Heartwood collapse was negatively correlated with basic density and positively correlated with extractive content. The collapse was lower in the sapwood than in the heartwood and lower heritability was revealed for sapwood collapse. Sapwood collapse was negatively correlated with basic density as for the heartwood collapse. Consequently, collapse in this future eucalypt resource can be minimised through breeding, potentially eliminating the problem.

The technical solution for reducing collapse in the current resource was based on the knowledge that permeability of timber can be increased by 'micro'-steam explosions, e.g. through radio-frequency or microwave heating, consequently reducing collapse during drying. A more energy-efficient method to heat timber is passing an electric current through it, i.e. Joule heating. *Eucalyptus nitens* log samples cut from a plantation were subjected to Joule heating at two power intensities prior to conventional drying. Subsequently, shrinkage and collapse were determined and compared to an untreated control. Tangential collapse reduced significantly (~53%) with the high power (HP) Joule heating. Maximum tangential shrinkage was significantly lower due to the reduction in the collapse in Joule heated samples as normal shrinkage was not affected by Joule heating. Thus, Joule heating of logs prior to drying has potential for improving the drying quality of collapse-susceptible timber. However, any technical drying solution, in contrast to planting superior genetics, is associated with ongoing costs to the wood processing industry.

Keywords: Breeding, Collapse, Drying Quality, Joule Heating, Plantation Eucalypt Timber

Assessing Hemp Hurd Particles Dimensions for the Manufacture of Low-Density Particleboard

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ABSTRACT

Legal barriers prohibited the cultivation of industrial hemp (*Cannabis sativa*) in Australia and around the word for many decades. The 2017 legalization of hemp seeds for human consumption has revitalized this industry and led to a hemp renaissance in Australia. While hemp seeds are appreciated for their nutraceutical value, the xylemic inner core of the stem (hemp hurd) is widely regarded as a by-product. Hemp hurd has a very low specific gravity and resemblance to

low-density timber species, which makes it a prospective constituent for lightweight composite panels increasingly used in the ready-to-assemble furniture industry. A study was developed to evaluate the performance of ultra-low-density hemp hurd particleboards. A critical initial step was the evaluation of hemp hurd particles considered as constituent for such lightweight composites. A characterisation protocol for bio-aggregates was implemented and particle size distributions and granulometry assessments were conducted on fine, medium, and coarse particle size categories by means of 2D digital image analysis. The results confirmed that sieve apertures predominantly regulated particle width and were less effective in controlling particle length. Coarse particles recorded higher degrees of residual bast fibres and were the most difficult particle category to assess. Furnish from smaller particles was more immaculate as the percentage of residual bast fibres decreased with particle size. Particle elongation increased rapidly with material finesse leading to the most elongated particles in the fines and a reduction (square shape) as particle size increased. 2D image analysis was found to be an efficient and economical approach to assess large volumes of particulate matter as sieving remains the principal method of particle separation in many experimental and laboratory settings. Results from the particle size analysis formed a key component in the evaluation of the hemp panels' physical and mechanical properties.

Keywords: Hemp hurd, ultra-low-density particleboard, hemp composite panels, 2D image analysis, particle size distribution, granulometry

INTRODUCTION

Changing perceptions and the rise of global hemp cultivation provide valorisation opportunities for the plant's underutilised xylemic core (hemp hurd). Low volumes of hemp hurd are currently used as filler in cementitious and lime-based building materials ('hempcrete'), sold as mulch or animal bedding, or burned as residue after the seeds are harvested. The chemical resemblance to softwood and low specific gravity of hemp hurd form desirable attributes for constituents in engineered lightweight panel products. The low weight-to-strength ratio and non-structural performance requirements are especially attractive for decorative panel and flat-pack furniture. Customer acceptance of lightweight flat-pack furniture is rising as they enjoy the ease of handling and the required product performance compared to established equivalents. In response to a decline in wood fibres from

conventional resources, hemp hurd was investigated as an alternative lignocellulosic fibre material for ultra-low-density particleboard.

A key challenge in the development of novel particulate composites is the adequate characterisation of particle dimensions. Particle analyses can be conducted in many ways and to varying degrees of accuracy. However, high-end equipment is costly (e.g., 3D analyser) and the procedure is time-consuming when large quantities of particles are manually examined.

This study applied a particle characterisation protocol for bio-aggregates based on 2D image analysis as suggested by Amziane et al. (2017). The use of open-source digital image analysis software ImageJ and minimal hardware requirements allowed for the analysis of large volumes of hemp hurd particles at very reasonable costs. The results of the particle characterisation provided i) detailed information about particle dimensions and shape characteristics for each respective particle size category (PSC) and ii) formed a key component in the evaluation of the hemp panels' physical and mechanical properties (not reported in this study).

MATERIALS AND METHODS

Particle size categories

Mechanically decorticated hemp hurd chips (*Cannabis sativa,* 'Frog One') were obtained from the Gippsland region in Victoria, Australia. The chips were rinsed under running tap water at 20°C to remove impurities, dried at 75°C for 6 h and finally conditioned at 23°C and 65% relative humidity to 12% equilibrium moisture content (EMC). All subsequent processing steps involved hemp material conditioned to EMC. One hundred (100) g of cleaned hemp chips ranging from 10 to 55 mm in length were ground in a cutting mill (Fritsch Pulverisette 15, Germany) equipped with a sieve insert of 6.0 mm square perforation. This particle mix (furnish) was screened by mechanical shaking (VobroVeyor, Australia) for 2 min through stacked 300 mm diameter stainless steel laboratory sieves (ISO 3310-1) with mesh apertures following 4.0, 2.0, 1.0, and 0.6 mm. Particles left on the 4.0 mm mesh and particles passing the 0.6 mm mesh were deemed too coarse and too small, respectively, and excluded from the study. Subsequently, three particle size classes (PSC) were considered for the particle size analysis (Figure 1).

Figure 1: Particle size categories of hemp hurd furnish considered for particle size analysis: fine (≥ 0.6 to 1 mm) (left), medium (≥ 1 to 2 mm) (center) and coarse (≥ 2 to 4 mm) (right)

Image analysis and granulometry

Following the methodology described by Picandet (2013), 1 kg of furnish per PSC was reduced by quartering to approximately 5 g, respectively. The particles from each sample were manually arranged on the surface of a standard flatbed scanner to prevent intersecting. An 8-bit grayscale image was taken of each arrangement at 600 dpi against a black background and stored as tag image file format (TIFF). This process was repeated for each PSC until the complete sample was captured. Image processing and measurements were conducted with the open-source software ImageJ (Ver 2.0.0-rc-69/1.52p). Particle areas were isolated from the background via colour thresholding and the image binarized. Two iterations of an enhancing opening algorithm were applied to eliminate solitary fibres and the effect of outcrops caused by attached fibres. The minimum detection area was set to 0.29 mm^2 to exclude dust. Each image was manually assessed for acceptable particle segregation and deficient particle selections were excluded from further analysis. The description of complex objects can be achieved by approximation with recognised geometric shapes (Igathinathane et al., 2008; Picandet, 2013). In the case of hemp particles, a fitted ellipse was adjusted to match the projected area and centre of gravity of a corresponding particle. The radii of the resulting ellipse were used to define particle width and length. Particle geometries were measured, and shape descriptors calculated using the particle analysis tool and the shape filter plugin in ImageJ (Wagner et al., 2013). A schematic depiction of the processing steps is presented in Figure 2.
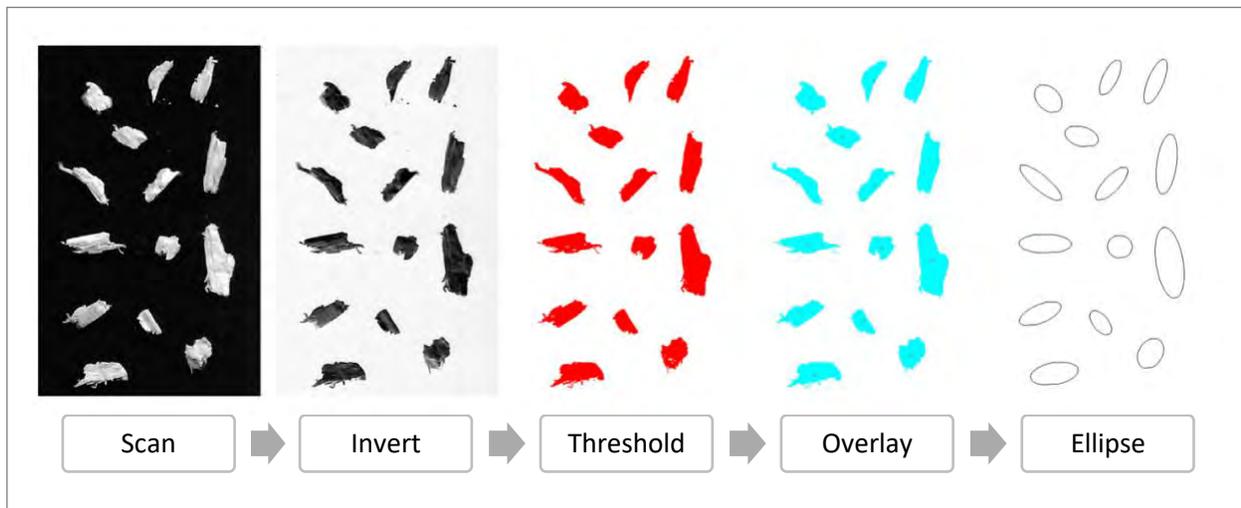
Figure 2: Principle of 2D image analysis in ImageJ

Equating with a fitted ellipse is a useful approach for solid (convex) shapes and provides robust width approximations even in the presence of fibrous outcrops and protuberances observed in many bio-aggregates (Picandet, 2013). However, complex particles become more concave (less solid), which reduces the representation accuracy through an ellipse. Following Picandet (2013), the effect on the particle size distribution (PSD) by rejection of particles with solidity (S) values of < 0.50, < 0.63 and < 0.75, respectively, was calculated. A small percentage of particles lost through solidity filtering was deemed acceptable to increase ellipse representation accuracy. Subsequently, only particles with S > 0.75 were considered for the granulometry evaluation. Estimated mass distributions by particle width and length were calculated for each of the three PSCs based on the individual particle area and the assumption of proportionality of particle width to average thickness and uniform density of the material (Picandet, 2013).

RESULTS AND DISCUSSION

Image analysis and granulometry

Each particle scan was assessed for deficient particle selections during image processing, as shown in Figure 3. For some voluminous particles, the particle surface opposite the scanner's glass platen protruded into the field of vision as a 'blurry outcrop', which incorrectly exaggerated the particle's documented area. These sections fell outside the threshold settings and were manually identified and removed. Secondly, the coarse PSC contained larger quantities of particles from the outer part of the stem with residual bast fibres still attached. These fibres were often identified by ImageJ as smaller separate particles (islands) and were equally removed to maintain only accurate area selections of the rigid, voluminous part of the particle. Further comminution separated the smaller particles from most of these fibres which often agglomerated on the mesh surfaces during the sieving process.
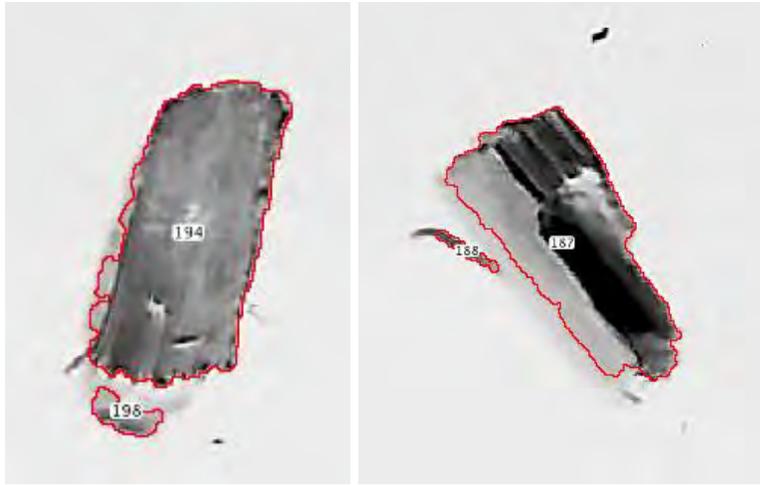
Figure 3: Example of disjointed areas (islands) (left) and incomplete particle selection (right) leading to the rejection of some voluminous particles in ImageJ

With most of the fibres removed during size reduction, the medium and fine PSC, respectively, showed substantially fewer residual fibres. Between the 3 PSCs, coarse contained the most voluminous particles and had the highest percentage of deficient selections removed (4.6%) followed by substantially lower percentages for medium (1.3%) and fine (1.0%) as shown in Table 1. The separation of highly porous hemp chips into smaller aggregates followed the direction of capillaries and cells innately oriented longitudinally along the stem axis. This produced woody hemp particles with predominantly elongated shapes and the representation of their projected areas through ellipses was deemed appropriate. However, particle shapes were also influenced by equipment type and configurations during the comminution process. Tearing and shredding motions equally produced complex particles shapes with high concavity which reduced the approximation accuracy through an ellipse. Solidity thresholds were used to filter out particle shapes unsuitable for ellipse representation and are presented in Table 1. The results showed only a marginally greater loss at 5.9 % in the coarse PSC and little difference between medium and fine PSCs at 4.7 % and 4.8 %, respectively, at the highest threshold setting of S > 0.75. The rejection of such small percentages was deemed acceptable as particle representation through the image analysis process was thereby greatly enhanced. Consequently, only particles with S > 0.75 were considered for further evaluation and the combined rejection of particles per PSC followed coarse (10.5%) > medium (6.0%) > fine (5.5%).

Table 1: Gradual refinement of particle count for the granulometry evaluation

Particle size category	Particles scanned (N)	Particles rejected in ImageJ (%)	Particles considered for filtering (N)	Particles rejected (%) at solidity (S)			Combined particle rejection at S >0.75 (%)	Considered for evaluation at S >0.75 (N)
				>0.50	>0.63	>0.75		
Coarse	1,988	4.6	1,896	0.3	1.4	5.9	10.5	1,785
Medium	8,393	1.3	8,282	0.1	0.9	4.7	6.0	7,893
Fine	8,373	1.0	8,290	0.2	1.2	4.8	5.8	7,889

Particle size distributions

The PSDs for each particle size category are presented as estimated mass (M%) distributions in Figure 4. The distribution by mass recognizes the proportionally greater impact larger particles can have on material properties. Particle length and especially particle elongation are thought to influence particle orientation and arrangement (e.g., packing efficiency) in the finished product and are often associated with the anisotropy of a material (Picandet, 2013). It follows that weighting the influence of e.g., elongation by particle mass is most appropriate for hemp particleboards. To understand the particle dimensions in more detail, 3 distinct ranges per PSD were identified and assessed separately. The ranges were chosen based on the most dramatic change of slope occurring for most PSDs at the lowest ($<D_{20}$) and the largest ($>D_{80}$) 20 %, respectively.
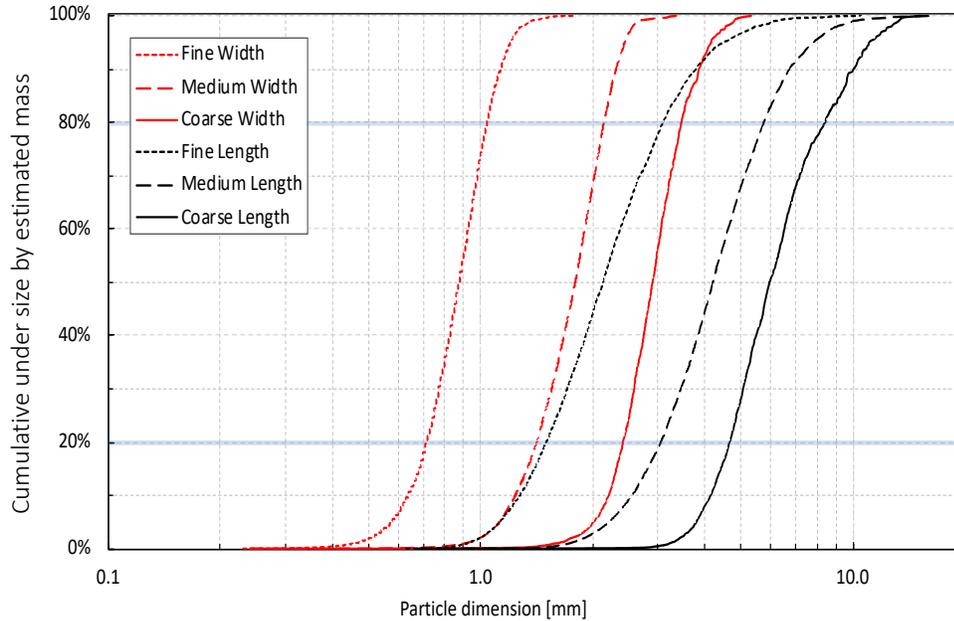
Figure 4: Estimated mass distribution per particle size category for particle width (red) and length (black) at logarithmic scale. Blue lines indicate D_{20} and D_{80} and mark the separation of each particle size distribution (PSD) into three distinct ranges ($<D_{20}$; D_{20} - D_{80}; $>D_{80}$) for individual observation

The distribution parameters for the lower range ($<D_{20}$), the bulk (D_{20} - D_{80}) and the upper range ($>D_{80}$) are presented in

Table 2. Minimum particle widths recorded in each PSDs measured 0.24 mm for both coarse and medium and 0.23 mm for fines. Similarly, minimum particle lengths for coarse, medium and fine were 0.69 mm, 0.68 mm and 0.63 mm, respectively. Maximum particle width measured 5.34 mm, 3.45 mm, and 1.77 mm for coarse, medium and fines, respectively. Maximum particle length for coarse, medium, and fine was measured at 15.20 mm, 16.25 mm, and 10.05 mm. The smallest difference of mean particle elongation was observed in the lower range ($<D_{20}$) of each PSD with 1.93, 2.03 and 2.01 for coarse, medium, and fine, respectively. The mean elongation increased in the bulk range (D_{20}-D_{80}) to 2.07, 2.34 and 2.42 and again in the upper range ($>D_{80}$) to 2.59, 3.00 and 3.42 for coarse, medium, and fine, respectively. The mean elongation increased from lower to bulk to the upper range following fine > medium > coarse PSD. Compared to the bulk range, particles within the lower range of the fine PSD were on average 17% less elongated and 42% more elongated in the upper range. For the medium PSD this was 13% and 28%, respectively. The coarse PSD had the least variation of mean elongation with particles in the lower range 7% less elongated and 25% more elongated in the upper range. The maximum values confirmed that sieve apertures predominantly regulated particle width and were less effective in controlling particle length. The highest particle length of 16.25 mm, for example, was recorded in the medium and not the coarse PSD. The similarity and presence of the smallest particle dimensions across all PSDs confirmed that complete particle separation was not achieved via mechanical screening for 2 min. Particle characterisation of bio-aggregates based on sieve apertures alone does, therefore, not suffice to describe the heterogeneity of the PSD. Differences in mean particle elongation were marginal in the lower ranges of all PSDs and increased rapidly with material finesse. The highest mean elongations were recorded in the bulk range and upper range of the fine particle PSD.

Table 2: Properties of estimated mass particle size distributions (PSD) per range* and granulometry

Orientation	Variable per range	Coarse	Medium	Fine
Particle width (mm)	$<D_{20}$ Max	2.41	1.42	0.72
	$<D_{20}$ Min	0.24	0.24	0.23
	$<D_{20}$ Mean	1.83	1.10	0.58
	$<D_{20}$ SD	0.59	0.24	0.10
	D_{20} - D_{80} Max	3.46	2.14	1.04
	D_{20} - D_{80} Min	2.41	1.42	0.72
	D_{20} - D_{80} Mean	2.83	1.72	0.85
	D_{20} - D_{80} SD	0.28	0.20	0.09
	$>D_{80}$ Max	5.34	3.45	1.77
	$>D_{80}$ Min	3.47	2.14	1.04
	$>D_{80}$ Mean	3.87	2.32	1.13
	$>D_{80}$ SD	0.37	0.16	0.09
Particle length (mm)	$<D_{20}$ Max	4.76	3.05	1.50
	$<D_{20}$ Min	0.69	0.68	0.63
	$<D_{20}$ Mean	3.52	2.24	1.18
	$<D_{20}$ SD	1.07	0.51	0.20
	D_{20} - D_{80} Max	8.34	5.76	3.08
	D_{20} - D_{80} Min	4.67	3.05	1.50
	D_{20} - D_{80} Mean	5.86	4.03	2.05
	D_{20} - D_{80} SD	0.92	0.71	0.41
	$>D_{80}$ Max	15.20	16.25	10.05
	$>D_{80}$ Min	8.44	5.76	3.09
	$>D_{80}$ Mean	10.01	6.95	3.88
	$>D_{80}$ SD	1.34	1.26	0.88
Mean elongation (ϵ)	$<D_{20}$	1.93	2.03	2.01
	D_{20} - D_{80}	2.07	2.34	2.42
	$>D_{80}$	2.59	3.00	3.42

* D_{20}: lower range, D_{20} - D_{80}: bulk range, D_{80}: upper range, ε is the arithmetic mean elongation

CONCLUSIONS

Three hemp hurd particle size classes (fine, medium, and coarse) were evaluated as constituents for ultra-lightweight particleboard by means of 2D image analysis. The percentage of residual bast fibres (contamination) decreased with particle size. Consequently, furnish containing fine hemp particles was the most immaculate and produced the smallest percentage of deficient particle selections. Any differences in particle elongation were marginal for the smallest particles in all PSCs. However, particle elongation increased rapidly with material finesse leading to the most elongated particles in the fine PSC and a reduction (approaching a square) as particle size increased. The results confirmed that sieve apertures predominantly regulated particle width and were less effective in controlling particle length. The greatest particle lengths were recorded in the medium and not the coarse particle size category. 2D image analysis was found to be an efficient and economical approach to assess large volumes of particulate matter as sieving remains the principal method of particle separation in many experimental and laboratory settings.

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Forest plantations in the southern United States: Environmental benefits and economic sustainability

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ABSTRACT

Timber plantations in the southern United States have increased rapidly in the last several decades. Thanks to plantation management, the region became the leading supplier of industrial roundwood in the world, and timber plantations will continue to provide an increasing share of industrial wood furnish. Still, timber plantations account for only about 20 percent of forest area in the region. They allow producing more wood on less area and create opportunities for conserving natural forests. This paper summarizes current key data on timber plantations in the region; presents results of analyses regarding timber investment returns for principal plantation species; and discusses strategic factors such as timber prices, government support, environmental considerations, land ownership, and forest certification that influence plantation investments. The role of southern timber plantations in mitigating global climate change is also discussed in the context of rising interest in forest carbon sequestration projects, rising carbon prices, and current carbon market developments. Implications for world timber plantation regions and future investments are discussed.

RESIDENTIAL AND COMMERICAL BUILDING INNOVATIONS: MASS TIMBER DEVELOPMENTS WHOLE BUILDING PERFORMANCE
Chair: Jon Shanks, University of Tasmania, Australia

Life Cycle Assessment of Construction Process in Mass Timber Structure

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ABSTRACT

Today, life cycle assessment (LCA) is a leading method in mitigating the environmental impacts emerging into the building sector. In this paper, LCA is used to quantify the Green House Gas (GHG) emissions during the construction phase of the largest Mass Timber residential structure in the United States, Adohi Hall on the University of Arkansas campus.

The energy used for the operation of buildings is the most dominant source of emissions in the building industry (Abergel et al., 2017). Successful efforts at increasing the efficiency of building operation in terms of emissions have, however, made the role of embodied carbon more noticeable in the building life cycle (Wolf et al., 2017). Nevertheless, most of the studies focus on the manufacturing stage, and only a few have focused to date on the construction process. Specifically, less data is available about environmental impacts associated with mass timber installment as new emerging material. First, this project begins with the quantification of materials and inventory of equipment used for the building construction, and second, it continues with the determination of the embodied carbon associated with running the equipment for materials installation. As important, the Global Warming Potential (GWP) resulting from the transportation of materials and equipment to the site is also quantified. Since GWP constitutes most of the 40% of energy-related CO_2 emissions (Abergel et al., 2017), this study is also exclusively limited to GWP.

The research conveys a good understanding of hotspots in terms of emissions generated throughout the construction process. Moreover, the results are compared with those from the literature about the construction process in conventional structures' (steel or concrete) to provide a measure of environmental efficiency related to mass timber as new material.

Keywords—Construction Process, Building, GWP, LCA, Mass Timber

The promise of affordable multistory modular mass timber housing: An unfulfilled agenda

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ABSTRACT

Growing urbanization requires affordable housing solutions that need to meet sustainability goals. Factory built volumetric modular construction results in minimal on-site construction, with benefits of improved quality, safety and efficiency from repeatability. Multi-story CLT based modular construction offers the potential to provide efficient, cost-effective and sustainable housing, but has not been widely delivered. A review of a number of CLT based multistory modular housing projects in North America that have not been successfully delivered has identified a number of common barriers. These include difficult paths for code compliance, lack of designer guidance, minimal practitioner experience, issues with CLT supply and limited factory set-up. These barriers make this form of construction expensive and implementation becomes unrealistic. A number of countries in Europe are embracing multistory CLT based modular housing and are proving that this approach is viable, can be built efficiently and showing barriers can be overcome. Mass timber construction is growing and expanding in North America and the technology transfer from Europe into North America to solve the barriers to CLT based modular construction needs to occur at a faster pace. Multi-story CLT based modular residential housing may take many years to eventuate in North America, but as more developers, architects push boundaries and as more cities require sustainable construction, the faster the identified barriers can be overcome.

Keywords: Modular buildings, Cross laminated timber, Multi-story housing, Interdisciplinary design

INTRODUCTION

In every country there is a desire to build affordable and sustainable housing, often with a focus on higher-density. Medium rise multi-family housing is part of the fabric of all modern and growing cities as populations become more urbanized. With the need to have more sustainable construction governments, owners, developers and the design community continue to look for more innovative and efficient construction methods. Mass timber products such as cross laminated timber (CLT) is seen a possible enabler of highly sustainable multi-story construction that can be delivered efficiently and cost-effectively when used for modular builds. Smith (2015) showed that there are possible savings of up to 16% in cost and 45% in schedule with modular construction.

To date, the promise of CLT enabling affordable and sustainable multi-story housing has not been widely delivered, a disappointing outcome given that cities from Los Angeles to Sydney need more cost-effective residential buildings. So, what is the hold-up? CLT based modular residential buildings face a myriad of design, engineering and supply barriers and this paper identifies common barriers and outlines possible solutions. Case study projects that were not constructed are used as the basis for identifying barriers, categorized into code, practitioner expertise, design, supply and assembly.

MULTISTORY CLT BASED MODULAR HOUSING – WHAT IS IT?

Modular construction in simple terms is a three-dimensional or volumetric module that is assembled and fitted out in a factory, then delivered to site as the main structural element of a building (Lawson 2014)

(see Figs. 1 and 2). Modular construction for multi-family housing is based on each module having the floor, ceiling and walls prefabricated, with varying levels of internal fit-out. There are numerous articles, journal papers and information on modular construction and a myriad of related terms including modern methods of construction, industrialized wood construction, prefabrication, off-site construction, design for assembly etc. (Gibb 1999).
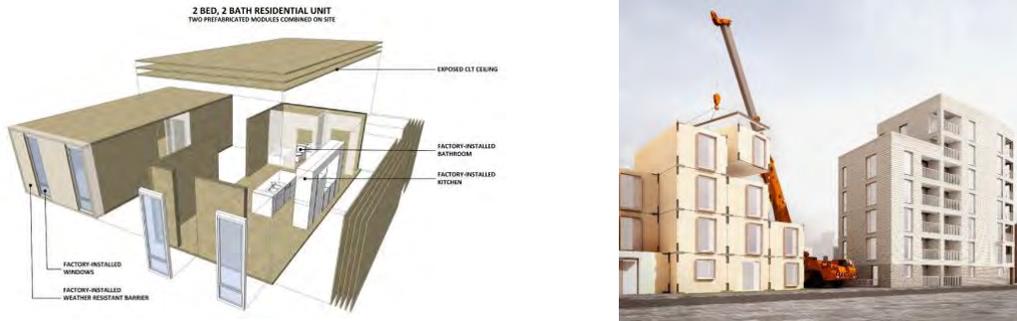
Figure 1: Schemes for multistory CLT modular housing construction (Weber Thompson, left); (Waugh Thistleton Architects, right)

The objective of modular construction is for each residential module to be fully factory made resulting in minimal construction occurring on-site, with the site phase requiring the final finishing, waterproofing, connection of water, gas, electrics and commissioning. Multi-story mid and high-rise modular buildings are becoming relatively common globally where the modules and primary structure are formed from steel, with reinforced concrete stair and elevator shafts. With the need for buildings to reduce embodied carbon, CLT panels are an obvious material choice for modular construction, given the structural, fire, acoustic and thermal properties each pre-fabricated panel can offer. Many architects have studied and planned how a CLT based modular building for residential housing would be constructed and have considered the benefits and challenges (Weber Thompson 2017, Alter 2018, Curtis 2021, Perkins and Will 2021 for example). Few projects have been constructed in North America and none have been constructed over three floors. In comparison, countries such as Germany, Switzerland, Austria and Sweden have numerous multi-story CLT based modular housing; examples include: St. Christophorus-Weg in Judenburg, a four floor residential building; Woodie in Hamburg, a six floor dormitory; Sara Cultural Centre in Sweden, a 20 floor building with CLT modular hotel units (see Fig. 2). Other European countries are taking note and considering how similar construction can be built.
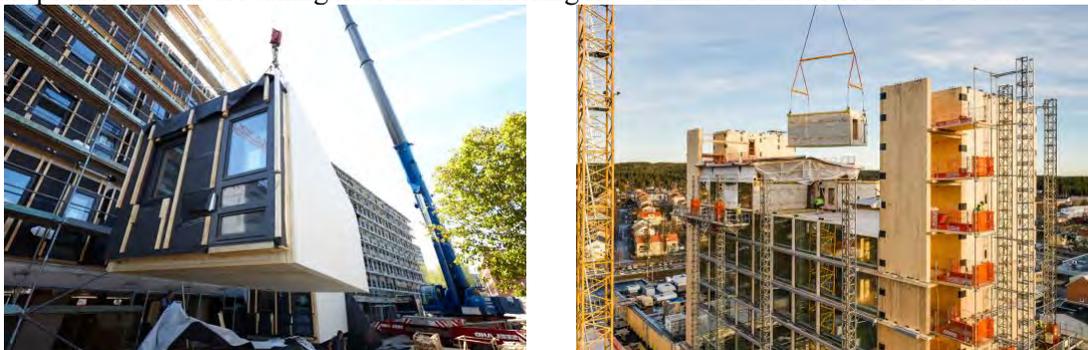
Figure 2: Completed multistory CLT modular housing: Woodie student dormitory (Sauerbruch Hutton) (left); Sara Cultural Centre (White Arkitekter) (right)

BARRIERS TO COMPLETION

Volumetric modular construction has many benefits that are often communicated, especially with regard to the efficiency and quality control that occurs in a factory, more availability for independent checking and the cost-effectiveness of repeatability. Other important impacts include the much improved safety and conditions for workers in the controlled factory environment (see Fig. 3). With these benefits in mind,

many projects commence and use CLT as the primary material. But as the project works through the initial design stages, barriers and impediments to the implementation of CLT based modular construction become apparent. Barriers to the uptake and completion of modular construction are not new and have been identified for decades (National Research Council 2009). The use of mass timber adds another layer of complexity. There have been numerous studies into the specific barriers facing modular construction, though few have examined the use of CLT, with some considering light frame timber. A summary of the identified barriers is outlined in this paper, focused on the use of CLT.

BUILDING CODES AND STANDARDS

Building codes are written to reflect typical buildings and unfortunately modular construction is not typical. Building codes and standards do not address modular construction and therefore modular buildings suffer numerous conservative burdens as designers try and find ways to squeeze the construction within existing code requirements. Fire safety drives many of the conservative outcomes.

Figure 3: Factory assembly of CLT modules

The 2021 International Building Code (IBC), used in all states of the US, allows high-rise mass timber construction, with solutions conservatively prescribing fire safety solutions that result in inefficient outcomes. The combination of modular and CLT based construction results in a near-impossible code approval path, with unworkable code compliant solutions required for exterior walls, concealed spaces and inter-module joints. The lack of a clear code compliance approach, combined with the resulting cost inefficiencies and building approval uncertainties result in CLT based modular construction being very unattractive.

Solutions are difficult in this area given that CLT based modular construction is very uncommon, even for low-rise. Codes and standards are barriers to CLT based modular construction and significant work is needed to improve requirements to enable construction. Building codes such as the IBC need to continue to evolve and keep pace with innovations in construction, needing to fit modular and timber based solutions within existing and amended code provisions. Guidance to designers is also limited though improving and is often the first step in code change. Recent documents include those from University of Melbourne (2017), CSA (2020), BRE (2021) and RIBA (2021) for example, though these guides do not address CLT. Forming a working group to develop improvements in codes and standards for cost-effective solutions requires an investment in research and a realization that codes are a barrier and need to improve.

EXPERT PRACTITIONERS

Mass timber construction requires practitioners who understand the strengths and weaknesses of CLT and can design accordingly. Experience with CLT design is limited in North America, like many markets, though rapidly expanding. Experience with multi-story steel frame based modular construction is even less widespread, and again, growing. Experience with multi-story, CLT based modular construction is rare, globally. Design of a multistory CLT based modular housing requires knowledgeable and

experienced designers for the architecture, all disciplines of engineering, and pre-construction. A well-designed mass timber building results in assembly, rather than construction, which is the primary aim for modularization and to reach that point of efficiency requires significant up-front design and detailing. Rahman (2014) investigated a number of different barriers to modular buildings and showed that experience with modular and prefabricated construction resulted in a much improved opinion of the barriers, indicating that project experience was key to overcoming perceived and actual barriers. Smith's (2015) research also indicated that knowledge, skills and the existing construction culture were barriers to uptake.

To reduce barriers in this form of construction requires experienced practitioners. Progress needs to occur through investment in training, learning on projects and also learning through working with those who have successfully completed projects. Design firms can gain experience by partnering on projects and also investing in their own training (Hickok Cole 2019). Building authorities also need to have expertise and experience with modular construction to approve plans and determine what is factory inspected versus site inspected, and how to achieve factory inspections, when the factory can be hours or days away. The growing use of remote inspections also assists.

MODULE AND BUILDING DESIGN

The design for assembly of modular buildings is a very specific skillset given the aim of the documentation is to enable efficient factory construction, followed by suitably speedy and efficient site assembly. Modular design requires a very fundamental multi-disciplinary approach by the design team of the architects, engineering consultants and build team, for the successful delivery. Decisions for one discipline will always impact another and an innovative solution for one part of the build may be a non-starter for another. Key engineering disciplines for CLT based modular include structural, MEP services (mechanical, electrical, plumbing), fire, acoustics and building enclosure (moisture control), who need to highly coordinate their requirements with the architectural intent and the specific processes of the factory build, before any construction begins.

The design of CLT based multistory modules for housing is primarily driven by the MEP approach to reticulation, which can be carried out by two differing methods: (1) Circulate all module MEP within the volume (within the four surfaces of the long walls, floor and ceiling) with no penetrations through the walls, floor or ceiling, and all MEP services penetrate only through the shorter end walls; or (2) Module designed with MEP services penetrating through walls, floor or ceiling and circulating within the concealed spaces between the modules. Each approach has pros and cons. Keeping all MEP services within the module reduces useable space but allows for better utilization of the CLT panels as an acoustic, fire and structural solution. Whereas, allowing the MEP services to penetrate the walls, floor or ceiling creates more useable space in the module but results in problems for fire and acoustic sealing, can be more limiting for on-site connections and repairs of MEP services can be challenging. Another method of keeping the MEP within the unit and increasing useable space is to "chase" some services into the CLT walls, floors or ceiling, whereby cut-outs are made into the panels and the electrical and plumbing services are located within the chase. Whilst this creates a clean solution without taking space, the panel may not be capable of having multiple or deep chases as this reduces strength, fire and acoustic resistance (see Fig. 4).

Figure 4: CLT modular construction showing penetrations in ceiling for MEP services (left); CLT wall with chase for electrical outlets

Utilizing learnings from case study projects, the following are a brief summary of some design issues and barriers that require coordination and solutions from an engineering perspective, given contrasting needs and requirements.

Structure: Modular buildings typically have significant lateral stiffness in only one direction, due to the modules having long walls to two sides only. Openings between modules can be very difficult to include. Lateral forces need to transfer between modules via connections that need to be stiff that is difficult to construct. Seismic diaphragms and highly problematic to design and build, as is the integration of steel braced frames.

Fire: The physical space between modules creates multiple vertical and horizontal combustible concealed spaces that need to be protected, with solutions being difficult for on-site build and to weatherproof. Connections between modules require fire resistance ratings and this positive fixing works against acoustics, moisture control and ease of build. Penetrations through floors and walls need to be fire sealed and prevent hot gasses passing into inter-module concealed spaces. Exterior walls are load-bearing CLT and difficult for code compliance (or possibly not permitted to be CLT).

Acoustics: Thicker build-ups to walls and floors required to achieve acoustic separations, work against the thin structures wanted. Isolation between modules is optimum, whereas the structural solution requires positive connections between modules. Architects desire exposed timber, whereas an acoustic solution would cover up most of the timber.

Building enclosure: Factory fitted water resistive barriers are needed for site assembly, but not needed permanently and are also combustible. Module to module gaps can be used for moisture control but are then filled for fire and sealed by structural connections. Finished roof requires a continuous water-proof membrane, which is inefficient for factory built modules, needing a site based solution.

As a further example, the connectivity between modules represents the difficulties with the engineering of CLT based modular buildings. There is no standard method to connect modules and the building design requires some of the most comprehensive inter-disciplinary thought. The inter-module junction impacts the vertical and horizontal load transfer, fire resistance, vibration transfer, acoustic resistance and prevention of moisture transmission. The connections between modules are a weak link given their lack of stiffness and the connection design must also be accessible for site assembly, creating a gap of 25mm and up to 100mm. Gijzen (2017) researched the design of CLT junctions for load transfer and provided options for an efficient connection between CLT modules. The gap between modules creates a possible route for vertical and horizontal fire spread and therefore needs to be fire sealed (Just 2017), typically

through compressible mineral wool, given this also offers moisture resistance. Glocking (2021) identified fires in the inter-module voids as being a major concern for the insurers.

The growing adoption of building information modelling (BIM) by both designers and builders has provided a much improved inter-disciplinary working environment for the coordination of building detailing. BIM enables much faster identification of possible issues and assists with solutions, able to be carried out with multiple designers working concurrently and remotely from each other.

TIMBER SUPPLY
Another limitation for the roll-out of CLT modular construction is that CLT is not a cheap commodity building product in North America and in many markets globally. It is near impossible to build affordable housing when the main construction material is priced at a premium. It is also difficult to deliver efficient solutions when the material has significant price fluctuations, in an industry where minimizing financial risk can determine the building product selection. Market demand for all mass timber products continues to grow and supply is limited, though with more suppliers gaining North American certification, supply could be less constrained in the near future (2 to 5 years).

FACTORY ASSEMBLY
The attraction of modular construction is the efficient factory construction. To achieve this desired efficiency requires a factory set up for CLT modular construction, has a forward order book and skilled workers. These factories thrive in Europe and deliver high-quality builds, but do not currently exist in North America. The high initial investment cost of a CLT based modular factory is a significant barrier and breaking through that barrier appears to be difficult, given the other hurdles of design, approval and supply. Failures of firms like Katerra have also not helped confidence (Rabeneck 2021). Light timber frame prefabrication and panelization is going from strength to strength in North America, with prefabricated walls, bathroom pods and whole single-family houses now being produced in factories. This provides the basis for a timber frame prefabricator to make the leap to CLT modular in the future.

WAY FORWARD AND SOLUTIONS
The issues described above can be solved and identification of market barriers is the first step in developing the changes needed. North America has been many years behind Europe in embracing multi-story mass timber construction but is undergoing a rapid change in the adoption of mass timber. The lack of design guidance and code compliant solutions means that technical barriers are difficult and expensive to overcome. The previously discussed example of connectivity between modules currently requires an engineered solution that would need to have structural, fire, acoustic and moisture management testing - a very high compliance threshold for building approval. The required proof of performance requires significant monetary and time investment, which for most projects is a financial burden too high to work through. This approach differs in many parts of Europe where designers have more latitude to engineer solutions, adapt products and use engineering judgement. The testing based compliance approach in North America and judgment and experienced based approach in Europe can both work successfully. At the present time, multistory CLT based modular construction for housing is progressing and expanding quickly in Europe, whereas in North America, no construction is occurring. Only time will tell if the current CLT modular buildings completed in Europe provide a robust construction solution that can be replicated.

Multi-story CLT based modular residential housing may take many years to eventuate in North America, but as more developers, architects push boundaries and as more cities require sustainable construction, the faster barriers can be overcome. There are some positive signs with firms like Forterra seriously considering opening a CLT based modular factory (Hinchliffe 2022). Given how quickly both Canada and the US have embraced the implementation of high-rise CLT in codes and with new construction

proving very successful, investment in solutions for the design, approvals, supply and assembly for multi-story modular CLT housing may be forthcoming.

CONCLUSIONS

Multi-story modular housing using CLT is possible and is highly sustainable. Unfortunately, barriers with codes and guidance, practitioner experience, CLT supply and factory assembly push up the price, making CLT based modular construction more expensive than both typical 'post and beam' mass timber buildings and steel framed modular construction. Affordability then becomes unrealistic. A number of countries in Europe are embracing multistory CLT based modular housing and are proving that this approach is viable and can be built efficiently. The technology transfer into North America now needs to occur. Given how quickly North America has caught up with the implementation of CLT into building design and construction, multistory CLT based modular housing may be just around the corner.

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Volumetric and Fracture Effects due to Moisture Intrusion in Douglas-Fir Larch Cross-Laminated Timber

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ABSTRACT

Cross-laminated timber (CLT) is increasingly used in mid-to high rise construction in many countries as architect and engineers seek out renewable, carbon neutral materials. While mass timber elements have many advantages, they are also still susceptible to environmental damage, including moisture intrusion and eventual biological degradation. Elevated moisture contents can cause a variety of issues in timber, ranging from internal stresses due to differential moisture expansion between wood layers to increased susceptibility to fungal or insect attack. While most mass timber elements are designed to remain dry throughout their expected service life, wetting can occur during transport, construction, or in service. Understanding the possible effects of moisture intrusion on panel properties will be important for assessing the risk of damage identifying the most appropriate prevention/remedial measures. A combined experimental and numerical study was conducted to better understand the anisotropic expansion of Cross-Laminated Timber and associated damage due to fracture. Twelve (12) 3-ply V1 Douglas-fir CLT blocks (300 mm square) were exposed to one month of rain in Western Oregon and then allowed to dry, simulating exposure during construction and subsequent return to equilibrium moisture content after closure of the building envelope. Bulk moisture contents were measured over time and density changes (as a measure of moisture uptake) were assessed prior to treatment, after one month of rainfall exposure and after eleventh months of dry storage using computerized axial x-ray tomography. The results were used to delineate differences in density resulting from moisture uptake as well as changes in internal structure as a result of drying. Moisture tended to accumulate in the non-edge-glued joints during wetting, while internal cracks became increasing frequent in the dried samples. Additionally, a numerical material point method (MPM) model for anisotropic damage mechanics of orthotropic materials was used to assess fracture within CLT layers caused by differential expansion between those layers during wetting and drying cycles. Results from both the physical and numerical specimens will be discussed and compared, along with discussion of scaling and further investigation.

Experimental Testing to Validate Moisture-safe CLT Assemblies in Hot and Humid Climates

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ABSTRACT

Current trends suggest that engineered wood products (EWPs) will play a more important part as a viable solution for multi-storey structures, given their environmental credential. Cross-laminated timber (CLT), in particular, is beginning to see increased interest in Australia, due to the robust structural properties resulting from the manufacturing process of this EWPs, which is composed of timber layers, glued together with the grain running perpendicular. However, there are still several knowledge gaps about the application of CLT assemblies in tropical and subtropical climates, in particular, their long-term hygrothermal behaviour. This is especially concerning in Australia, due to a history of low performance buildings and a lack of specific knowledge in how to construct structures for durability and occupant health. Therefore, the study illustrated in this presentation aims to develop and experimentally validate climate-specific CLT detailing able to manage moisture risks in subtropical and tropical regions of Australia. It seeks to understand what the most reliable assemblies and junction details for CLT buildings are, that can dry sufficiently to control the risk of interstitial and surface moisture accumulation.

For this purpose, a CLT micro-unit has been designed and built at QDAF Salisbury research facility, exposed to the ambient subtropical climate, while a small structure, employing the same assemblies of the micro-unit, has been placed inside a controlled climatic chamber to simulate exposure to a tropical environment. Both experiments have been set up to investigate the moisture performance and hygroscopic characteristics of the CLT structures over two phases: during and post-construction. The first phase of the study, now completed, monitored changes in moisture content of CLT panels according to their position and exposure face. The second phase, underway, investigates the change in vapour flow through the CLT assemblies once construction is complete and the building interior is air-conditioned. The experiments allow to evaluate the specific effects of various factors, including the influence of weather resistant membranes, location of the insulation layer, and exposure of unprotected walls to high humidity and high temperature during the first phase of construction. Assessing these parameters may help identify the most appropriate assembly to be used in hot and humid climates to avoid moisture risks.

Preliminary results support findings in the literature which suggest it is important to adhere the weather resistant membrane to the face of the CLT, while also protecting the edge grains, to ensure the durability of the timber during construction wetting. Membranes with increased resistance to moisture diffusion prove to be beneficial in tropical climates. Interestingly, the results also show advantages in using internal insulation, compared to external insulation, which is the popular installation method in cold and temperate

climates. Findings of this study will help inform mass timber designers about correct solutions to minimise the risks of moisture accumulation in CLT construction in subtropical and tropical climates by identifying moisture-safe assemblies and interior ventilation practices.

Fire Performance of a Hybrid Glulam-FRP Beam

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ABSTRACT

Within the scope of this work, a prototype hybrid Glulam-FRP (Fibre Reinforced Polymer) beam was conceived and developed to deliver an enhanced floor timber structures with improved fire and serviceability performance. In essence, FRP's relatively higher residual capacity at elevated temperatures, compared to timber, compensates for timber's loss of strength and stiffness at elevated temperatures or even when charring during a fire.

In applications where a certain fire performance is needed for the load-bearing mass timber structure of a building, the end-result of this work aims at setting the basis for a prototype hybrid Glulam-FRP manufacturing techniques that could be used to deliver load-bearing floor timber structures with enhanced fire performance. This is a meaningful shift in how FRP materials are currently constrained in load-bearing applications where structural integrity must be maintained during or after a fire.

A key challenge in developing this hybrid system was to find an efficient way to combine the superior properties of the reinforcement material by embedding it inside the timber, hence being protected from the effects of a fire and not causing an intervention to the timber aesthetic appeal. Modernizing the fabrication was also essential to achieve effective implementation at an industrial scale by minimizing technical intervention to the conventional manufacturing process of laminated timber with enough precautions to eliminate or mitigate the debonding between Timber and FRP. At the same time, an adhesive typically used in laminated timber was also used to bond Timber and FRP, ensuring the bonding interface between the two elements in the composite system and avoid long duration incompatibility between timber and FRP.

To assess the bending behaviour of hybrid Glulam-FRP beams during and after a fire, a comprehensive investigation conducted herein through an experimental approach based on four-point bending loading conditions. The experimental framework comprised four-point bending experiments for mid-scale hybrid Glulam-FRP beams at normal ambient conditions, residual testing conditions after burning and cooling the midspan section of the beams, and transient testing conditions by heating the midspan section of the beams to a well-controlled heating condition defined by a target incident heat flux – beams were kept under a sustained load in bending. Heating conditioning (for residual and transient conditions) was done using gas-fired radiant panels coupled with a purposely built four-point bending setup. The heating condition was controlled to achieve a specific target incident radiant heat flux, and while for residual testing conditions beams were heated up to a target charring depth, for transient-state testing conditions beams were heated up until the moment of failure.

Outcomes of the experimental studies show that hybrid Glulam-FRP beams have an increased bending moment capacity and stiffness at ambient conditions, and during and after fire – beams with FRP show an increase of up to 47% for bending strength at normal ambient conditions and 56% for residual conditions. When loaded during heating, hybrid Glulam-FRP beams show an increase in the time-to-failure of more than 175%.

KEYWORDS: Hybrid Glulam-FRP beam, FRP, prototype, fire performance, bending behaviour.

Mass Timber Alternatives in Construction with Plantation Hardwoods

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ABSTRACT

Australia's volume of plantation hardwood pulplog from 2020, is projected to remain constant above 8,000,000m^3 by harvest period (every four years) to 2064. Of this volume and period, approximately 3,000,000m^3 will be harvested in Tasmania. By comparison, the volume of hardwood plantation sawlog will rise from 663,000m^3 to just short of approximately 1,000,000m^3 nationally over the same harvest period, of which approximately half will derive from Tasmania. While the established Tasmanian pulplog sector will remain constant, the rise in recently matured plantation sawlog will become available for manufacturers to transition from native sawlog resources to plantation. As native production sawlog harvesting declines there will be an increase in the desire to promote native sawlog use in high value, bespoke appearance applications as opposed to competitive low value structural applications. This change in the manufacturing sector reduces the availability of structural timber for building and construction.

To compensate this, alternative timber resources for structural applications is paramount, to ensure demand for structural building products such as cross laminated timber (CLT) and glue laminated timber (GLT). The available volume of plantation pulplog and sawlog are two options that can bridge this gap in the structural market. Since 2020, CUSP building solutions has invested in an innovative manufacturing process and an extensive research program to uncover the remarkable physical and mechanical properties of some of the available plantation hardwoods in Tasmania, such as *Eucalyptus nitens* species. Through collaborations with different Universities, companies, and research institutes worldwide, CUSP has created a superior structural product range using low-value fibre to transform into strong and reliable engineered products. These types of products enable cutting-edge technology such as digital fabrication and computational design to provide solutions for the built environment, which is currently experiencing a global timber shortage, particularly in Australia, where most of the CLT is imported from overseas. CUSP has proven that locally acquired plantation hardwood can offer an alternative for the construction industry, and this has been demonstrated by several residential and commercial building designs across Tasmania that are currently specifying mass timber products as the preferred structural material.

Keywords: Plantation, hardwood, *Eucalyptus nitens*, mass timber, CLT, GLT.

INTRODUCTION

Across Australia it is projected that 8,000,000m^3 of plantation hardwoods will be consumed for pulp production every year to 2064, of which 3,000,000m^3 will come from Tasmania. By comparison the

volume of sawlog plantation hardwoods nationally will be 1,000,000m³, of which half is projected to come from Tasmania. In 2017, Derikvand et al. raised several constraints and opportunities for structurally low-grade wood from Australia's plantation Eucalyptus estates, particularly in Tasmania. Since this foundation of context specific research questions were highlighted, significant ground has been made to progress the utilisation of plantation hardwoods in the building sector. As highlighted by Derikvand et al. (2017) there is an opportunity "to develop higher-value solid wood products and corresponding applications in building construction for some part of the plantation hardwood resource in order to fill growing market gaps" (p1.) These gaps specifically refer to the production of mass timber products. Currently hardwood products in the construction industry originate from native forests or from import markets. Now more than ever, we are witnessing exponential growth with mass timber products such as Cross-Laminated Timber (CLT) in timber construction (Kurzinski et al., 2022). Unfortunately, existing mass timber standards and codes are not designed for fibre managed plantation hardwoods that are available en masse in Tasmania. All of them have been developed for softwoods which possess very different characteristics and performances. Several barriers to making mass timber elements out of available plantation hardwood species in Australia have already been identified and presented in previous studies (Ettelaei, et al., 2022a, b; Ettelaei, et al. 2021; Derikvand, et al., 2019 a, b ,c; Derikvand, et al., 2018 a, b; Derikvand, et al., 2017; Jiao, et al., 2019; Kotlarewski, et al., 2019; Kotlarewski, et al., 2018; Pangh, et al., 2019).

Acknowledging those barriers and knowing that there was a global shortage of timber, and that Australia exports vast volumes of plantation hardwood logs & woodchips, CLTP Tasmania has invested in innovative manufacturing process, and talented professionals to create a world-leading mass timber product from plantation *Eucalyptus nitens*. In 2021, CLTP Tasmania launched CUSP building solutions as a brand to facilitate Australia becoming self-sufficient in mass timber production. During that journey, CUSP building solutions has worked closely with the University of Tasmania (UTAS) and other institutions to develop mass timber products with remarkable mechanical properties and unique aesthetical characteristics. Therefore, the aim of this paper is to present the advances that address some of the identified issues in recent studies and demonstrate how those barriers have been overcome through significant investment in research and development in a novel pilot plant that is producing hardwood CLT building solutions in Tasmania.

MASS TIMBER INDUSTRY WITH PLANTATION HARDWOODS: *WHAT ARE THE OBSTACLES AND HOW TO OVERCOME THEM?*

In response to the aforementioned publications this paper breaks down the challenges to utilising plantation hardwoods in mass timber applications and demonstrates the response to progressing the novel products that are currently satisfying an Australian market demand.

1. Resource characteristics and grading

Almost all recent research has challenged the characteristics present in E. nitens. This includes the type of knots, their dimensions, frequency, position, internal and surface checking, slope of grain, density, moisture content, creep, vibration, acoustics, machinability, and origin of the board from position in the log and the tree. Existing Australian Standards (Standards Australia, 2000; 2006; 2007b) for visual stress grading, as well as preestablished stress-graded groups (Standards Australia, 2010), don't apply for plantation hardwoods, as they were written based on experimental testing on native resources with different characteristics. Earlier UTAS research (Derikvand, et al., 2019 c; Derikvand, et al., 2018 b) showed AS rules do not match experimental results with that fibre, therefore, new grading rules have been proposed. Experimental tests have been conducted in partnership with UTAS and CUSP to set up a reliable visual stress grading framework that works for manufacturing GLT and CLT products. CUSP has developed two characteristic grades (High- and low-strength grades) used to determine the optimal application for mass timber.

Figure 1. Bending tests performed at UTAS in high strength (left) and low-strength (right) boards graded following in-house CUSP grading rule.

An alternative to the traditional fibre managed plantation resource is the thinned and pruned resource. Thinning and pruning plantation eucalyptus increases fibre recovery and improves overall visual grade. Based on previous research and internal testing conducted at CUSP, the ideal age for high strength graded boards is between 20 to 25 years old as opposed to a 16-year-old fibre managed tree. However, young fibre with lower strength characteristics or suitable material from untinned and unpruned coupes can fit other purposes where knots could be beneficial, such as rolling shear strength in CLT or building applications knots are aesthetically requested.

2. Sawing challenges

Sawing fibre managed logs has its challenges, especially sub 250mm small end diameter logs. Key to the success of this process is the investment of contemporary equipment and infrastructure that can accommodate smaller logs at a young age. Typically, juvenile logs host significant tension and internal stresses due to rapid growth. Sawing quality significantly impacts kiln drying, and sawing impacts board deformation, distortion, and seasoning within the timber. For best recovery, fibre managed plantation eucalyptus is backsawn which supports rapid drying schedules and GLT and CLT production.

Figure 2. E. nitens logs (left) and backsawn boards in E. nitens CLT (right).

3. Drying challenges

Plantation hardwoods are prone to collapse and check on the surface and internally. Significant moisture content gradients during drying can induce internal stresses that lead to an internal fibre rupture (Nolan et al, 2003). Green eucalyptus has very high moisture content before going into the kilns. Initial moisture content in green of swan boards is around 130% with green density around 1000kg/m^3. To avoid significant gradients, E. nitens requires high relative humidity and low temperatures during initial drying. Final drying requires reconditioning to improve collapse which demands high energy to produce steam at

high temperatures. Generally, drying plantation eucalyptus requires close attention to detail and fast reaction to accommodate changes in the drying cycle.

Figure 3. E. nitens boards during drying (left) before and (right) after reconditioning.

4. National and international manufacturing standards and building codes

There are no standards for plantation hardwood grading or manufacturing GLT and CLT products with such a resource. However, research developed in the last two decades can establish the basis for new hardwood standards. Current standards should acknowledge that current performance requirements prescribed for softwood feedstock and products are not applicable for plantation resources. UTAS, CUSP, and other institutions around the world are collecting and presenting evidence to prove that current provisions should be adopted for hardwood behaviour, for instance, limits and methods for delamination tests in GLT and CLT, and existing declared characteristic values prescribed in AS 1720.1 (Standards Australia, 2010).

Figure 4. CUSP solution with E. nitens for the Australian Pavilion Dubai World Expo 2020

5. Finger Jointing and its performance

Given the various and frequent characteristics present in plantation hardwoods, finger jointing has been employed to dock out strength reducing features and less than desirable visual characteristics. Additionally, finger joints are critical for producing long lamellas, as they are required to manufacture GLT and CLT of varying lengths. Finger joints significantly impact the final strength of structural timber members. The finger joint geometry, the adhesive, the amount of adhesive, the type of application, the clamping pressure and time are important factors (Franke et al, 2014). CUSP has put a significant effort into improving, controlling and monitoring the performance of E. nitens finger joints strength and bond quality. Moreover, research is underway at UTAS to determine the impact finger jointing has on structural performances versus the compromise of increased manufacturing for multiple joints required to reconstruct a product that satisfies building standards, codes and context specific timber product applications.

Figure 5. Production of E. nitens finger jointed lamellas for GLT and CLT (left) and bending strength test on finger joints at CUSP in-house laboratory (right).

6. *Face gluing performance*

CUSP has conducted several tests to understand the performance of one-component polyurethane (Adhesive type 1 according to EN15425:2017 and AS/NZS 4364:2010) on E. nitens surface. European standards have been used to test the performance of CLT gluelines. However, EN standards for GLT and CLT only cover certain species, and E. nitens is not included in that list. Therefore, CUSP has worked closely with different manufacturers to ensure the bond quality of their products meets the specific requirements prescribed in those standards and achieves the same performance levels as other products made of traditional wood species. Some relevant parameters controlled during the manufacturing process include environmental conditions, wood surface temperature, wood surface preparation, wood sizing, wood moisture content, glue rates, glue spread, glue quality, applied pressure, assembly time, and pressing time.

Figure 6. Glue application on E. nitens layers for GLT (left) and CLT (centre). Wood fibre failure mode on CLT glue lines opened after a delamination test (right).

7. *Full-scale testing*

There is minimal research on plantation hardwoods, particularly E. nitens mass timber products at commercial scales. CUSP has engaged different institutions to perform structural in both GLT and CLT to obtain the declared properties of those products. Tests have shown that numerical models can predict the strength and stiffness of those products at a large scale if the feedstock properties are known. Full-scale testing is also conducted in house to control and monitor the declared properties of mass timber products.

Figure 5. Full-scale bending tests on E. nitens CLT panels (left) and GLT beams (right).

8. Modelling and engineering design tools
CUSP has worked with engineering and design firms to validate existing engineering design tools to predict the strength and stiffens to hardwood planation GLT and CLT products. Span tables and other predesign tools have been prepared accounting for the requirements for ultimate states and serviceability states (Cusp, 2021).

9. Fire performance
There has been a lot of progress on the fire performance of timber products in Australia, however there is no research on plantation E. nitens as a mass timber application. Experimental tests have shown that E. nitens CLT has superior fire resistance, lower charring rates than other CLT products made of softwood, and higher Fire resistance levels (FRL) than other EWP with the same geometry. In recent tests, CUSP E. nitens CLT of 175mm and 225 mm thickness achieved 120 min FRL after being exposed to standard fire tests (Standards Australia, 2014), with distributed loads of 4 KPa and 8 KPa, respectively. CLT charring rates have been found between 0.48 to 0.55 mm/min, up to 25% lower than conventional charring rates reported in other softwood CLT products.

Figure 6. Full-scale standard fire tests on E. nitens CLT floors. Distributed load applied on the unexposed side (left) and exposed side (right) after 121 min of fire exposure.

DISCUSSION
In recent years, worked developed at CUSP have progressed the utilisation of this Australian en masse plantation resource. CUSP has achieved results thanks to a significant investment in human resources, equipment, material, research, and development in partnership with UTAS and other contracted parties. Aligned with a substantial investment in research and development, a strict quality assurance framework for the manufacturing of EWP made of plantation eucalyptus is required to deliver safe and high-quality structural products for the construction industry. Although there are no current Australian Standards for CLT manufacturing, building code compliance and manufacturing standards for other glue-laminated

products require a tight quality control to meet the performance requirements prescribed in other national and international codes. Existing research and test results have already shown E. nitens products have remarkable physical and mechanical properties. This evidence proves that plantation hardwood mass timber is an excellent alternative for the Australian construction industry that currently relies on limited available fibre, native plantations or imported fibre. CUSP has already delivered building solutions, and with more work to increase production efficiencies and optimise product performance, E. nitens products will be at the leading edge of the Australian timber industry.

Figure 7. CLT panels delivered by CUSP for a prefabricated cabin in Tasmania, Australia.

Current and Future work

There is an existing presence of UTAS PhD's working on optimising grading, E. nitens: GLT, finger joint performance and optimisation, GLT modelling, CLT creep, thermal performance and thermal comfort, durability, fire, connections and lateral stability. There remains a substantial body of work to further investigate acoustic performance of mass timber, hygrothermal performance, effective and environmentally friendly durability treatments, life cycle assessments of hardwood mass timber, carbon sequestration, additional grading methods in both green and dried fibre, big data analysis and machine learning to optimise captured data during manufacturing, design for manufacture and assembly, computational design, and bigger manufacturing capabilities to process billets, and increased automation to reduce waste and utilise waste in additional post-production products.

CONCLUSIONS

Since 2017, Tasmania has advanced considerably in the mass timber development race to supply locally grown and manufactured mass timber building solutions for the construction industry. From grading for inclusion in mass timber, to context-specific detailed testing such as fire performance, CUSP building solutions and UTAS have started and journey to fulfilling standards and codes to demonstrate the potential and integration of an en masse resource for an environmentally considerate future without compromising on performance or visual appeal. Initial results show that structural and technical performances can place plantation hardwoods products as a top engineering and architectural engineered building solution, as it combines strength with aesthetic characteristics.

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Mass Timber Alternatives in Construction with Plantation Hardwoods

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RESIDENTIAL AND COMMERICAL BUILDING INNOVATIONS: MASS TIMBER DEVELOPMENTS MASS TIMBER STRUCTURAL PERFORMANCE AND STRUCTURAL SYSTEMS
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Bibliometric and Visualisation Study of Glulam research: Overview and Global Research Trends over the 10-year Period (2011-2020)

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ABSTRACT

Glued laminated timber (glulam) is a well-researched area; however, there are few or no publications focusing on the research topics and trends in this field. Understanding these trends can help scholars to better focus their future research towards specific areas of glulam. In this study, research publications concerning glulam for the period from 2011 to 2020 were analysed using visualisation maps created in VOSviewer. The 10-year period was considered to provide an overview of the research outputs. Six research clusters were identified in addition to the highest contributing countries and journals in the field of glulam research. Moreover, the two 5-year periods were considered to analyse the research trends for glulam, and the cluster "composite glulam structure" was observed to be increasing in the second 5-year period; emerging research topics and prominent countries were also obtained. This study allowed, firstly, to demonstrate the increasing scientific interest in the field of glulam research and, secondly, to highlight the shift towards new topics such as "composite glulam structure" and the "environmental impacts of glulam products". This research may present a useful overview helping researchers and policymakers to identify research gaps and overlaps in the glulam scientific field.

Keywords: glued laminated timber; VOSviewer; bibliometric research; research trends

INTRODUCTION
The development of glulam, which consists of multi-layer wood boards glued together, has broadened the practical scope of timber adoption in construction. It has been used in a variety of structures such as long span bridges and high-rise buildings (Zmijewki & Wojtowicz-Jankowska, 2017). Many landmark buildings have been constructed using glulam, in line with perspectives on sustainability (Littlefield, 2010). Glulam as engineered wood products, involves far fewer carbon dioxide (CO_2) emissions than mineral-based building materials (cement and steel) (Winchester & Reilly, 2020). Glulam is one of the key solutions to encourage carbon sequestration. However, timber is a natural material, the properties of which are influenced by the environment. The performance of the industrial processing Glulam is varied depending on tree species, growing environment, and ages. Therefore, research into various aspects of glulam is essential for its efficient use and adoption in construction.

Despite glulam being a well-researched field (Figure 1), there have been few publications that describe the research trends, current dominant topics, and development over time in this field. Such publications present a useful overview for researchers and policymakers to identify research gaps and overlaps in the glulam scientific field. Previous attempts to describe research trends and topics in glulam have been limited to specific research areas: Kandler et al. reviewed the framework of finite element methods to give an overview of alternative ways to compute the effective stiffness of glulam (2015); Cao and Chen summarised the state of the art of shear behaviour of glulam beams and classified several theoretical approaches of the shear design method (Cao & Chen, 2018); Wessels et al. described the concept of processing pathways for manufacturing high-value, green-glued, finger-jointed Eucalyptus engineered products and reviewed existing research related to this kind of engineered products (Wessels et al., 2020).

This study has undertaken bibliometric analysis, which describes research trends and directions in a certain research area or discipline, to visualise the overview of the research fields. This visualisation-based research has been used in timber research. For instance, Taoum and Baldock used bibliometric analysis to observe research trends in structural timber and cross-laminated timber (CLT) (Taoum & Baldock, 2020).

The paper's objectives are to analyse the dominant research topics and the evolution of research trends in glulam throughout the period from 2011 to 2020 using a bibliometric approach. This was achieved through analysing the visualised maps generated by the text mining tool, VOSviewer.

MATERIALS AND METHODS

The Elsevier Scopus database was used to identify publications in glulam for use in this study. The search was conducted by using the search term "glulam" or "glued laminated timber" or "gluelam" or "glam" or "GLT", and limited to peer-reviewed articles only. A total of 959 articles were found for the period from 2011 to 2020 initially. Subsequently, manual data screening was carried out, where each paper's title and abstract were reviewed, and unrelated articles were removed. These included mainly three types of articles. The first type includes the papers which are in research fields other than engineered wood, for instance, IT research, art and science research, and agricultural research. This is because "glam" is an abbreviation of "Gray Level Aura Matrix" (Champion & Rahaman, 2020), "Galleries, Libraries, Archives, and Museums" (Kanadam & Chereddy, 2016), and "General Large Area Model" (Osborne, Rose, & Wheeler, 2013). The second type consists of papers where the words "glued", "laminated", and "timber" are used in the abstract but occur in separate sentences (Bakalarz, Kossakowski, & Tworzewski, 2020). The last type includes the articles that focused on bamboo, as this study defines timber as the material produced from trees.

Eventually, a total of 742 articles were included in the data analysis and map generations for this paper.

A scientific mapping approach was applied to the articles retrieved from the Elsevier Scopus database. The text-mining tool, VOSviewer (N. J. van Eck & Waltman, 2010), was used to create the so-called visualisation maps. VOSviewer offers a range of visualisation maps.

In the network visualisation term map, the terms (keywords, countries, or journals) are represented by circles and labels (N. J. van Eck, Waltman, L., 2020). The size of the circle and label represents the term's weight, which is determined by the number of the term's occurrences in the publications. A more significant term can be distinguished by a larger circle and label size, which means a higher weight. With regards to keywords, the size of the circle and label reflects the occurrence of a certain keyword. For the analysis of countries, the size of the circle and label shows the number of publications by researchers in that country. When the circle and label represent journal, their size is determined by the number of citations of that journal. Additionally, the circles and labels are connected by links. These links can be co-occurrences of key terms, co-authorships according to countries, or the citations of journals (depending on the content of the map). These links have weights that are calculated by the number of co-occurrences, co-authorships, or citations, and only the strongest links are displayed on the map. Furthermore, the distance between the two labels indicates their relatedness. A closer location between two labels means a stronger relatedness between them. Finally, different colours on the map indicate different clusters, and a term may belong to only one cluster.

RESULTS AND DISCUSSION

Yearly articles published from 2011 to 2020 are displayed in Figure 1.
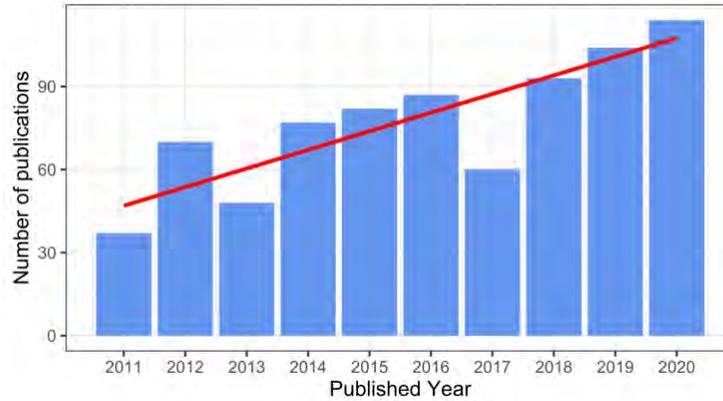
Figure 5. Yearly articles published from 2011 to 2020.

Figure 5 shows a general increasing trend of publications on glulam from 2011 to 2020 (except for 2017). This trend is marked by a relatively low number of publications and a slight increase in the total number of publications for the period of 2011–2013 (from 37 to 48 publications a year), followed by a sharp increase in 2014 (77 publications). From 2014 to 2016, the increase in yearly publications was slight (like the previous period), followed by a significant drop in 2017 (60 publications). The number of publications in 2018 has significantly increased and exceeded that in 2016 and has been steadily increasing from 2018 to 2020 (from 93 to 114 publications a year). The number of articles concerning glulam has tripled in the past decade (from 37 to 114 publications a year). This growth rate exceeds the growth in the total number of Timber papers (from 531 to 1150 publications a year, from 2010 to 2019) (Taoum & Baldock, 2020).

CO-OCCURRENCE OF TERMS

In line with the data collection methodology, bibliometric data retrieved from Scopus were imported into the text mining and visualisation tool VOSviewer. The co-occurrences network visualisation map of the terms was generated. In creating these maps, the inclusion and exclusion of key terms were based on the following:
- The minimum number of term occurrences was set at 5;
- Binary counting was used, i.e., only the presence or the absence of a term in a paper (more accurately its title or abstract) mattered; the number of occurrences in each paper's abstract or title was not considered. This means that the occurrence attribute indicated the number of abstracts in which a term occurred at least once;
- A thesaurus file was used to combine similar words, such as "bond behaviour" and "bonding performance", "design approach" and "design method", to remove general terms, for instance, "ability", "benefit", "case", and to eliminate terms that are the topic words of this study, namely, "glued laminated timber", "glulam", and "GLT".

Overview of the Research Topics

Based on the above, the network map of term co-occurrence for the 2011–2020 period was generated. A total of 321 out of 13,759 terms identified by VOSviewer were shortlisted and are visualised in Figure 6.

Figure 6. Network map of the co-occurrence of terms (Glulam) for the 2011–2020 period.

Six clusters were identified in the network map (Figure 6), and top 10 terms according to number of occurrences for each cluster are listed in Table 1:

Cluster 1 (red, 86 terms) is a collection of terms on studies of mechanical behaviour. Three research topics can be identified: mechanical properties (represented mainly by the terms "modulus", "tensile", "shear stiffness"), lamination (represented mainly by the terms "adhesive", "finger joints", "lamination", "thickness", and "delamination test"), and wood properties (represented mainly by the terms "elasticity", "density", "moisture content", and "shrinkage"). The terms "strength" and "mechanical behaviour" occupy a central part of the whole map.

Cluster 2 (green, 78 terms) contains terms related to the research on connections. This could be observed by the terms, "diameter", "rod", "steel plate", "crack", "self-tapping screw", "hole", and "bolt". Nonetheless, the term "experimental result" has the highest weight of total links and occurrences in this cluster, which means the experimental method is the most widely used methodology in connection studies.

Cluster 3 (blue, 61 terms) represents industry research. Three research topics can be identified in this cluster: structural application (represented mainly by the terms "frame", "panel", "wall", "bridge", "composite", "building"), industrial chain (represented mainly by the terms "LVL", "CLT", "industry", "construction", "manufacturing", "designer"), and environmental sustainability (represented mainly by the terms "energy dissipation", "emission", "energy", "carbon"). The terms "construction" and "building" have the highest weight of total links and occurrences in this cluster and are relatively close to the centre of the map.

Cluster 4 (yellow, 53 terms) contains terms in reinforcement research. This could be observed by the terms, "reinforcement", "polymer", "fibre", "CFRP", "GFRP". In this cluster, the term "experimental analysis" and "numerical analysis" have a high weight of total links and occurrences, which means they are both widespread analysis methods in reinforcement studies.

Cluster 5 (purple, 23 terms) assembles terms related to research on fire. This could be observed by the terms, "temperature", "fire", "fire resistance", "fire test", "heating", and "elevated temperature", among others. "Cross section" has the highest occurrence in this cluster (56 occurrences).

Cluster 6 (lake blue, 20 terms) represents research on composite glulam structures. This could be observed by the terms, "composite beam", "composite action", "concrete slab", "TCC", and "shear connector". Nonetheless, the

term "shear performance" has the highest weight of total links and occurrences in this cluster, which means that the shear behaviour of the composite glulam structure is the most salient issue in this cluster.

Table 1. Top 10 terms according to number of occurrences for each cluster.

Cluster 1: mechanical behaviour		Cluster 2: connections		Cluster 3: industry	
Terms	**Occurrence**	**Terms**	**Occurrence**	**Terms**	**Occurrence**
strength	256	experimental analysis	332	construction	101
adhesive	131	experimental result	179	building	85
mechanical behaviour	110	failure	170	steel	44
lamination	88	connection	142	clt	41
species	72	joint	116	frame	37
modulus	68	grain	96	damage	35
shear stiffness	58	length	81	lvl	34
thickness	58	column	66	panel	33
density	56	ductility	63	wall	29
elasticity	56	direction	49	energy dissipation	27
Cluster 4: reinforcement		**Cluster 5: fire**		**Cluster 6: composite structure**	
Terms	**Occurrence**	**Terms**	**Occurrence**	**Terms**	**Occurrence**
beam	304	cross section	56	shear performance	76
stiffness	185	temperature	50	screw	43
reinforcement	78	structural element	43	concrete	36
numerical analysis	67	fire	36	curf	27
tensile	61	depth	31	floor	24
fem	56	design method	31	epoxy	23
deflection	52	fire resistance	31	calculation model	18
structural behaviour	52	fire test	22	bearing capacity	17
deformation	46	larch	20	composite beam	14
ultimate bearing capacity	45	exposure	17	frequency	14

Overview of Research Trends

To further explore the research trends in the past decade, the 10-year period of research data regarding glulam was divided into two discrete 5-year periods: 2011 to 2015 and 2016 to 2020.

A total of 131 out of 6011 terms for the 2011–2015 period was shortlisted and visualised in Figure 7. At the same time, a total of 224 out of 9566 terms for the 2016–2020 period was shortlisted and visualised in Figure 8.

The network maps of the co-occurrence of terms (Figure 7 and Figure 8) show that in the first 2011–2015 period, there are only five research clusters that include "mechanical behaviour", "connections", "industry", "reinforcement", and "fire"; In the 2016-2020 period, the "composite glulam structure" cluster emerged and remain relevant in the period. The new cluster has a geographic distribution. There are 238 papers including 95 papers reported by Asian researchers and 63 reported by European researchers on this new cluster topics.

With regards to research topics, some terms related to environmental sustainability such as "environmental impact" and "LCA" occurred only during the second period (2016–2020). Except for the dominant application (i.e., "beam", "board", "column", "frame"), the application of glulam has transferred from "panel" and "roof" in the first 5-year period to "bridge", "floor", and "composite structure" in the second 5-year period. In addition, although "adhesive" and "glue line" are consistently research objectives throughout the whole decade, the specific adhesive names (i.e., "MUF" and "PRF") were not mentioned in the second period.
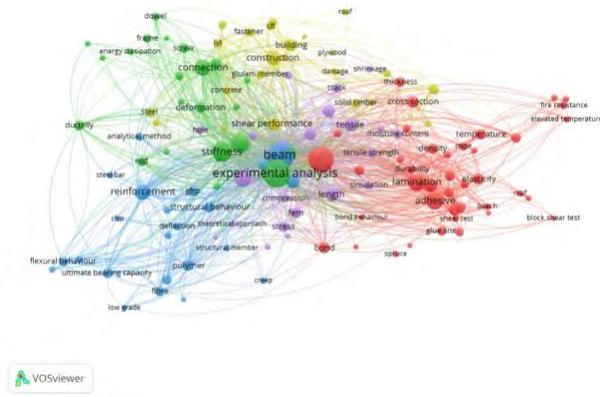
Figure 7. Network map of the co-occurrence of terms (Glulam) for the 2011–2015 period.
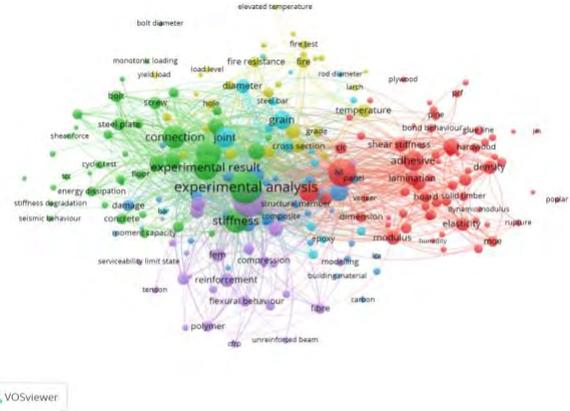
Figure 8. Network map of the co-occurrence of terms (Glulam) for the 2016–2020 period.

With regards to specific wood species, in the first 5-years period, "Norway spruce", "softwood", and "spruce" occurred in the term list, but they disappeared in the list of the second 5-year period; "ash", "Douglas fir", "eucalyptus", and "Japanese cedar" appeared instead. That means the study of glulam on hardwood, such as "ash" and "eucalyptus", was growing in the second 5-year period. Whereas "beech" and "larch" occurred in the term list of two 5-year periods, which means that these two species attracted scholars during both periods.

Finally, European countries appear most related to the study of glulam. Specifically, in the first 5-year period, "Germany" occurred in the term list, but it disappeared in the list of the second 5-year period; and was replaced by "Canada" and "Japan". This means these two countries received more research outputs in the second 5-year period, and it is also the reason for the appearance of the term "Douglas fir" (North America species) and "Japanese cedar" (Japanese species).

CO-AUTHORSHIP OF COUNTRIES

Based on different factors, countries contribute unequally to glulam research. As described in the Data Collection and Visualisation section, network maps showing the co-authorship of countries have been generated. The minimum number of documents and citations were input as 3 and 20, respectively, in VOSviewer. Ultimately, 30 countries out of a total of 60 met this threshold, of which 25 are visualised in Figure 9. The remaining 5 countries did not have connections in the network, so they were ignored.

It can be seen from Figure 9 that countries which are geographically close to each other tend to have more academic cooperation, for example, European countries (i.e., Austria, Sweden, Switzerland, Italy, Finland) and Asian countries (i.e., South Korea, Japan, Indonesia, Malaysia, China) are in the green cluster and red cluster, respectively. Nonetheless, there are exceptions, such as Canada and the United States, which are both North American countries, but these two countries were not in the same cluster and had a very weak link (link strength of 0) between each other in the research field of glulam.

The quantitative measurements of the different countries are provided in Table 2. In terms of the number of publications, China is ranked highest with 148 articles and followed by Japan and Germany with 71 and 64 articles, respectively; the yearly publications of the three countries are illustrated in Figure 10. This figure reveals that all three countries' publications were fluctuating, and the number of articles published by Chinese researchers has increased significantly since 2016. The average year of publication for China is 2017.4, which is proof of China's emergence in glulam research in the second 5-year period. Other countries published far fewer papers on glulam in the past ten years.

However, in terms of influence and mutual citations, European countries (i.e., Ireland, Iceland, Belgium, Italy, United Kingdom) have been playing a significant role in glulam research as they have higher average citations and average normalised citations. Moreover, some countries (i.e., Japan, South Korea, and Brazil) generally have lower average citations and average normalised citations. The reason could be related to the language used, as researchers in these countries use alternative languages to English, for example, Japanese, Korean, and Portuguese, for glulam research. In this study, 64.8% Japanese researchers used the alternative languages, and the percentage are 50.0% and 32.3% among Korean and Portuguese researchers respectively.
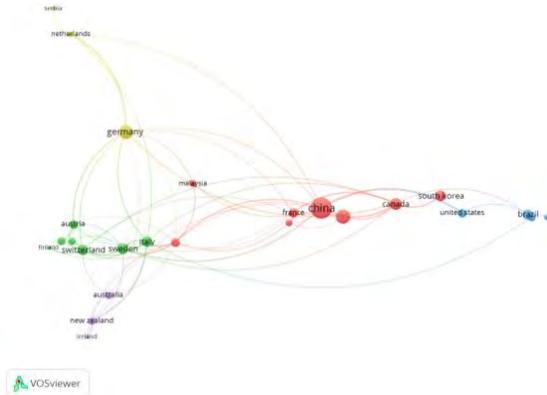
Figure 9. Network map of countries' co-authorship (Glulam) for the 2011–2020 period.
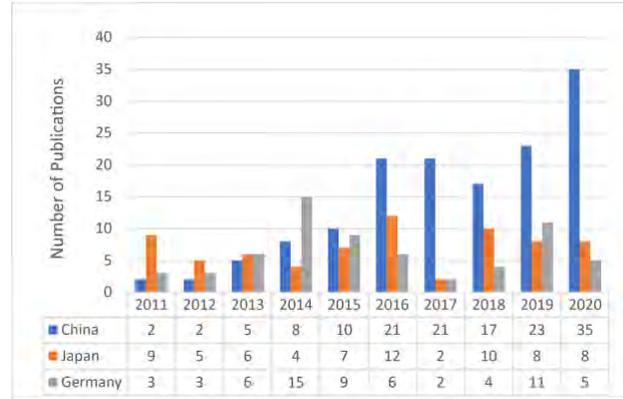
Figure 10. Yearly publications of the top three countries for the 2011–2020 period.

Table 2. Top 10 countries with most Glulam articles.

Label	Total link strength	Documents	Citations	Avg. pub. year	Avg. norm. citations
China	25	148	670	2017.4	0.96
Japan	6	71	116	2015.7	0.18
Germany	18	64	414	2015.7	1.15
Canada	18	48	283	2016.9	1.39
South Korea	3	38	132	2015.9	0.47
Sweden	12	37	351	2015.7	1.30
Italy	22	36	406	2015.9	1.63
Switzerland	13	36	248	2015.8	0.87
Brazil	2	35	155	2016.3	0.74
France	10	30	199	2016.2	0.98

CONCLUSIONS

The network structure and the conceptual evolution of research on glued laminated timber (glulam) from 2011 to 2020 were obtained by using a scientific mapping approach to analyse the bibliometric data retrieved from the Elsevier Scopus database.

One whole 10-year period and two discrete 5-year periods were considered, and scientific mapping results of the co-occurrence of terms in the abstract, keywords, title, the co-authorship of countries, and journal citations were obtained. The 10-year period was considered in order to provide an overview of the research outputs of glulam. Six research clusters (i.e., "Mechanical Behaviour", "Connections", "Industry", "Reinforcement", "Fire", "Composite glulam structure") were recognised; countries (i.e., China, Japan, German) observed to be the most active in the research of glulam were identified; journals (i.e., "Construction and Building Materials", "Engineering Structures", "European Journal of Wood and Wood Products") contributing most articles in the field of glulam research were also identified. Furthermore, the two 5-year periods were considered in order to analyse the research trends of glulam, and the cluster "Composite glulam structure" was observed to be increasing in the second 5-year period; emerging research topics (i.e., "environmental impact", "LCA", "bridge", "floor", and "composite structure") were obtained; the countries with the highest occurrence in the term analysis shifted from European countries to "Canada" and "Japan".

An in-depth discussion was conducted based on these scientific mapping results. Firstly, the research regarding glulam was heavy concentrated on the configuration (i.e., laminations, adhesive, finger joints, connections), the mechanical properties (i.e., flexural properties, tensile properties, compressive properties, and shear properties), and the improvement of mechanical performance (reinforcement). Secondly, the analysis shows that composite glulam structures (i.e., TCC, STC) are an emerging research cluster. In addition, hardwoods will increasingly gain a

more important role as a sustainable material resource, which will impact glulam production. Furthermore, awareness regarding sustainability is increasing among scholars in the glulam research field.

Finally, research gaps have been identified. The long-term performance of the timber composite structures could be studied. Additionally, corresponding to the demand to benefit the community economically, more research should be conducted in investigating the application of new species in glulam. Therefore, studies on the recycling of glulam products will attract scholars because of the contribution to environmental sustainability. Furthermore, with the development of technology, the intelligent upgrading of manufactory of glulam may promote more research output in this study area.

ABBREVIATIONS

CFRP	Carbon Fibre- Reinforced polymer	LVL	Laminated Veneer Lumber
CLT	Cross Laminated Timber	MUF	Melamine Urea Formaldehyde
GFRP	Glass Fibre- Reinforced polymer	PRF	Phenol Urea Formaldehyde
GLT	Glued Laminated Timber	STC	Steel Timber Composite
LCA	Life Cycle Analysis	TCC	Timber Concrete Composite

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The Effect of Various Factors On Rolling Shear Properties Of Southern Pine And Radiata Pine From Australia

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ABSTRACT

Rolling shear (RS) is one of the key design parameters that contribute to the effective bending stiffness of cross laminated timber (CLT) panels. This article first discusses the suitable test methods for assessing rolling shear properties of CLT feedstock then presents the effect of density, modulus of elasticity (MoE) and moisture content on the RS modulus and strength of southern pine and radiata pine timber from Australia. RS tests were conducted using recommendations outlined in EN 408.

This investigation revealed that sample preparation, testing procedure and post processing of results can significantly affect experimental outcomes, especially the RS modulus. Various factors in sample preparation such as plate material and type, glue type, and, more importantly, the relative location of reference points used for deformation measurement should be carefully chosen to ensure consistent and reliable results of RS.

Southern pine had notably higher RS modulus and strength compared to radiata pine with mean RS modulus of 87.12 MPa and 74.74 MPa and mean RS strength of 3.05 MPa and 2.63 MPa for southern pine and radiata pine respectively. Density and MOE showed a weak correlation with both RS modulus and strength. There was an obvious decrease of RS modulus by 18% when the wood moisture content changed from 8% to 12%, whereas it decreases almost 33% when the wood moisture content changed from 12% to 16%.

Determining Methods to Evaluate In-plane Sher Modulus of Cross-Laminated Timber

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ABSTRACT

With increasing demands for high-rise timber buildings, Cross Laminated Timber (CLT) is widely used for various structural elements. Due to the complexity in structure, tall timber buildings are extremely difficult to design by hand. Therefore, computer-based structural design is required, and in-plane shear modulus for CLT is necessary as an input. However, test standards or methods for measurement of the in-plane shear modulus of CLT are currently not provided or insufficient. In this study, a method using picture frame is proposed for measuring in-plane shear modulus, since picture frame could transfer crosshead load into the pure shear stress of the specimen. Acrylic sheet, plywood panel and CLT panel were used. Load was transferred from the universal testing machine(Instron) to the acrylic sheet and plywood via dowels, CLT via lag screws because of the thickness of the CLT panel. The acrylic sheet, which is an isotropic material, was tested to determine the measuring area and verify pure shear state occurred by the picture frame. Displacements were measured in both directions (active and passive), and both sides (front and back). In-plane shear modulus of acrylic sheet was evaluated with measured displacements and loads, then compared to the literature values. The plywood panel was tested to determine the test protocol, and two stage load cycle test protocol was suggested. CLT panel was tested according to the determined measuring area and test protocol. Evaluated in-plane shear modulus of CLT was 693 MPa and it was found that the picture frame test method is appropriate for the stiff massive wood panel.

Keywords: Cross Laminated Timber, In-plane, Shear modulus, Massive wood panel

Image-based Method for Diagnostics of Penetration Firestop Systems in Cross-Laminated Timber Specimens Subjected to ASTM E418 Test

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ABSTRACT

While the newest changes to the international building code (IBC) allow mass-timber panels to be used as walls, floors and roofs in buildings up to 18 stories, such buildings must meet strict fire safety standards related to their size and construction type. The code prescribes fire resistance ratings for mass timber elements and assemblies, as well as for joints between the elements and fire stopping systems protecting penetrations cut through the panels for electrical, plumbing and mechanical conduits. That fire rating criteria are aimed at preventing structural collapse and the spread of the fire from one compartment to the rest of the building. These tests are designed primarily as a tool allowing engineers and fire marshals make choices and decisions crucial for fire safety of buildings. However, they do not provide much meaningful feedback for manufacturers of the materials being tested, who may be interested not only in the time to failure, but also in the margins by which elements of the design passed or failed as well as the weakest and strongest elements in the design of a barrier. This is particularly true for firestop systems protecting penetrations that constitute weak points posing a risk to fire integrity of a barrier that may otherwise have excellent fire rating on its own. The goal of this study was to develop a quantitative diagnostics method for the assessment of the effect of firestopping systems on the charring patterns in cross-laminated timber exposed to standard ASTM E418 fire performance test. The main hypothesis was that such diagnostics may be enhanced through automated analysis of the final char front patterns revealed by sections of panel specimens through the penetration openings taken after completion of the tests. A machine vision method has been developed and used for comparative assessment of the effectiveness of fire stopping systems in four CLT assemblies subjected to ASTM 418 fire tests in an earlier project. The final char front line and a set of reference features were used to isolate disturbances of char patterns around the penetration. The widths, depths and areas of these disturbed patterns allowed meaningful quantitative comparison of the effects of firestop systems used in the tests.

Keywords: cross laminated timber, CLT, fire performance, penetration firestop systems, image analysis, diagnostics

INTRODUCTION

Cross laminated timber is a novel construction material that is enabling innovative, low-carbon construction technology, expanding the possibilities for use of mass-timber in construction of large, high-rise buildings. While the newest changes to the international building code (IBC, ICC 2021) allow mass-timber panels to be used as walls, floors, and roofs in buildings up to 18 stories, such buildings must meet strict fire safety standards related to their size and construction type. The code prescribes fire resistance ratings (FRR) for mass timber elements and assemblies, as well as for joints between the elements and fire stopping systems protecting penetrations cut through the panels for electrical, plumbing and mechanical conduits. That fire rating is determined in the course of standard tests (e.g. ASTM E119, ASTM 2020, for building construction and materials, or ASTM E418 for penetration firestop systems, ASTM 2017) as the resistance to standard fire exposure measured as time to failure (in hours),

which may be either 1) structural collapse, 2) passage of hot gases or flames across barrier or 3) temperature transmission through the barrier above certain threshold. The latter two criteria are aimed at preventing the spread of the fire from one compartment to the rest of the building.

Installation of continuous grids of plumbing, electrical, mechanical, and other service installations in buildings necessitates creating a number of penetrations of various sizes through walls and floors to accommodate such services. Such penetrations constitute weak points posing a risk to fire integrity of a barrier that may otherwise have excellent fire rating on its own. The risk is mitigated by protecting penetrations firestopping systems designed to protect the gap between the conduits and the penetration. The effectiveness of such systems installed on penetrations through wall and floor assemblies is evaluated by ASTM 418 standard fire test (ASTM 2017) in which the assemblies are exposed to standard time-temperature fire curve. Fire performance of fire stopping systems protecting penetrations in mass timber panels is one of key areas of study in fire performance of mass-timber buildings.

These tests are designed primarily as tools allowing engineers and fire marshals make choices and decisions crucial for fire safety of buildings. However, they do not provide much meaningful feedback for manufacturers of the materials being tested, who may be interested not only in the time to failure, but also in the margins by which elements of the design passed or failed as well as the weakest and strongest elements in the design of a fire stopping systems and on the way they interact with flammable barrier.

In 2017 a series of such ASTM E418 tests on CLT panels with penetrations was conducted by the Oregon State University Department of Wood Science and Engineering team for the Framework project (Framework 2017, Pickett 2018). Fire tests were conducted at the Western Fire Center in Kelso, WA (WFCi 2018).

In these tests, four CLT panels with five penetrations each were exposed to a horizontal fire resistance test per ASTM E814 standards. Figure 11 shows a) assemblies prior to testing b) a furnace side view of an assembly during the fire exposure test, and c) the charred side of an assembly after the test.

The progress of temperature profiles through the assembly and along the penetrations was monitored with thermocouples. The WFCi report (WFCi 2018) included F-rating, defined by the standard as time to flame occurrence on the unexposed surface, F-rating, defined as time to temperature rise at fire stopping system opening, more than () above the initial temperature, or to flame occurrence on the unexposed side of the firestop system (ASTM 2017) for each penetration of each assembly. The report also included a "record of observations of significant details of the behavior of the firestop system during the test and after the furnace fire is extinguished… [including] cracks, deformation, flaming, and smoke issuance […as well as] continued burning within the firestop system after termination of the fire test."

a)   b)   c)

Figure 11 Fire testing of fire stopping systems on CLT assemblies performed at the Western Fire Center in 2017. a) assemblies prior to testing, b) furnace view of an assembly during testing, and c) an assembly after the test

However, the standard dataset and prescribed observation have been created before mass timber panels were certified for tall buildings and do not describe the interaction between the conduits fire stopping systems and flammable barrier. The hypothesis of this project is that such data can be obtained from examination of charring patterns in the penetrations in panel specimens after the tests, when the conduits were removed.

The goal of this study was to develop a quantitative diagnostics method for the assessment of the effect of firestopping systems on the charring patterns in cross-laminated timber exposed to standard ASTM E418 fire performance test. The main hypothesis is that such diagnostics may be enhanced through automated analysis of images taken after completion of the tests.

METHODS

The general approach was to cut the panels tested in 2017 into smaller blocks in a way that perpendicular sections crossed at the center of each penetration and design a machine vision procedure to process digital images of sections revealing the final char front patterns in the vicinity of each penetration. The objective of the analysis was to determine exact position of the final char front in relation to the unexposed surface of the CLT sample and the position of the original surface of the penetration. Reference char patterns away from the penetration were used to isolate disturbances of char patterns around the penetration. The widths, depths and areas of these disturbed patterns allowed meaningful quantitative comparison of the effects of firestop systems used in

Figure 12 Cutup plan for the panels

the tests. The cutup of the panels was designed in a way that four cross-sections meet at each penetration creating a sample of four charring profiles per penetration (Figure 12).

Pictures were taken of the sides of each sub-section so that image analysis tools could quickly gather data on the panel. Figure 13 a) shows a sample cross-section. Figure 13 b) visualizes the set of images available for a single panel. Each image in b) is really two images, one for each of the two sub-sections that meet at that edge.
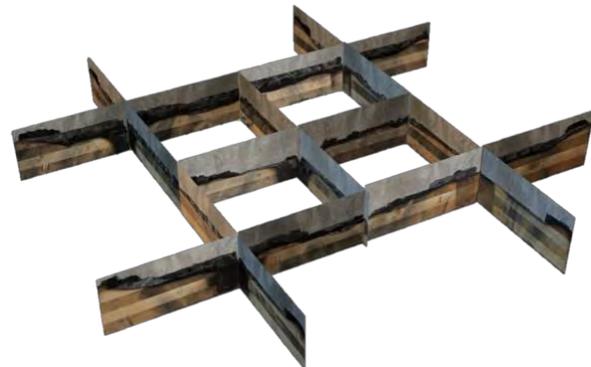
a)   b)

Figure 13 Digital image documentation of the charring pattern in the vicinity of the penetrations: a) a sample cross-section and b) visualization of a set of images related to each panel.

A composite reconstruction of a section through the entire assembly based on individual section images in Figure 14 shows the charring patterns near and away from the penetrating conduits. A relatively consistent char rate can be expected across most of the panel, but penetrations introduce a disturbance that may result in greater charring along the opening, which may indicate the effectiveness of the fire stopping systems with various types of conduits (e.g. cast iron or PVC). This is the concern for the structural integrity of the panel. The differences in char pattern along a cast iron conduit (marked with shades of gray) and PVC conduit (marked with shades of blue) are highlighted in the composite image. The comparison suggests that the heat conductivity of cast iron and heat capacity of a massive cast iron pipe affects the charring pattern in a different way than a PVC pipe of similar diameter. Meaningful quantitative comparison of these patterns in the affected areas requires measurements capturing their geometric characteristics.

In this study, both were facilitated by a machine vision method executed in Java script within ImageJ image analysis software package developed by the National Institute of Health (NIH 2011). The script processes pools of digital images of sections showing the final position of char, and outputs measurements describing the charring patterns in affected areas. The goal of the script is to identify the *char triangle*, which is the 2-dimensional cross-section of wood that has charred because of the penetration (Figure 15).
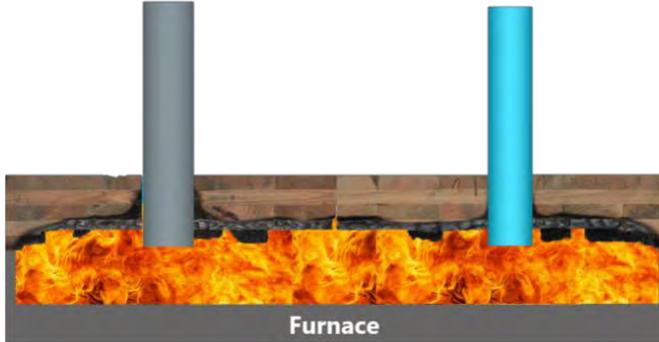
Figure 14 Charring pattern of a CLT panel near penetrations during fire exposure reconstructed based on images of charred block sections.
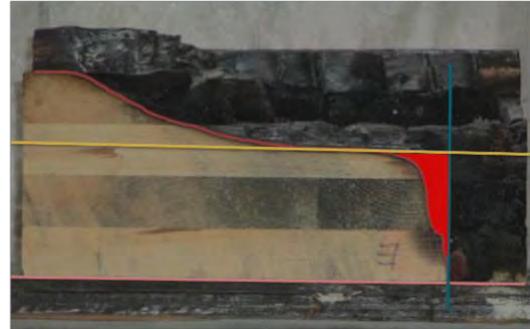
Figure 15 The "char triangle" and the "identifiers" within a sample image

This area can then be measured in order quantify the charring caused by the penetration. The *char triangle* is identified using a set of reference lines (R), or *identifiers* that locate key features of the wood and of the charring. The principal steps of the procedure are:

1. Segmentation of the images into areas identified as char, uncharred wood and background
2. Identification of the unexposed surface of the specimen (R)
3. Identification of the position of the external edge of the penetration created to accommodate conduits (R)
4. Identification of the position of the final char line on the exposed surface of the specimen
5. Identification of the reference position of the final char line away from the penetration (R)
6. Use lines identified in steps 1 to 5 to isolate the *char triangle* affected by the penetration
7. Calculate the radius, depth, or maximum distance from the penetration, and the area of the *char triangle*.

Multi-stage process of image segmentation is illustrated in Figure 16.
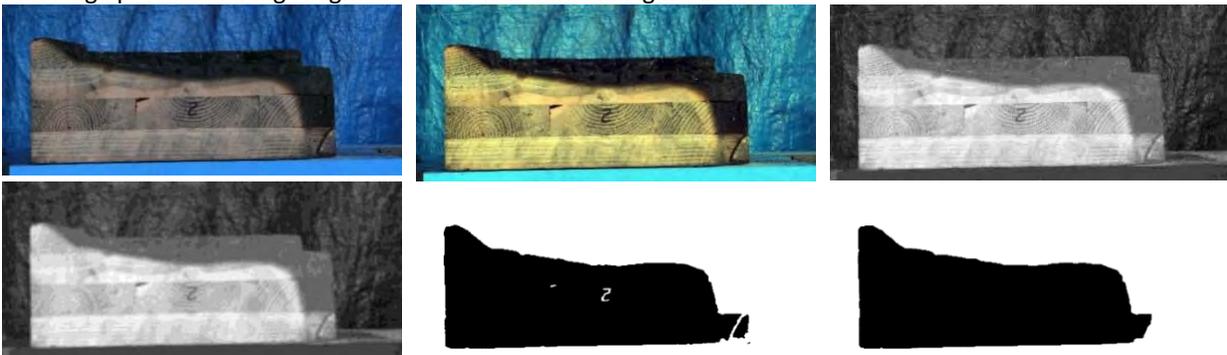
Figure 16 Stages of image processing leading to identification of unburned wood contour

The greatest challenge is Step 3, the identification of the original position of the edge of the penetration when it offers poor contrast (examples shown in Figure 17). In the current version of the script the difficulty is bypassed by a decision of a human operator of the script.
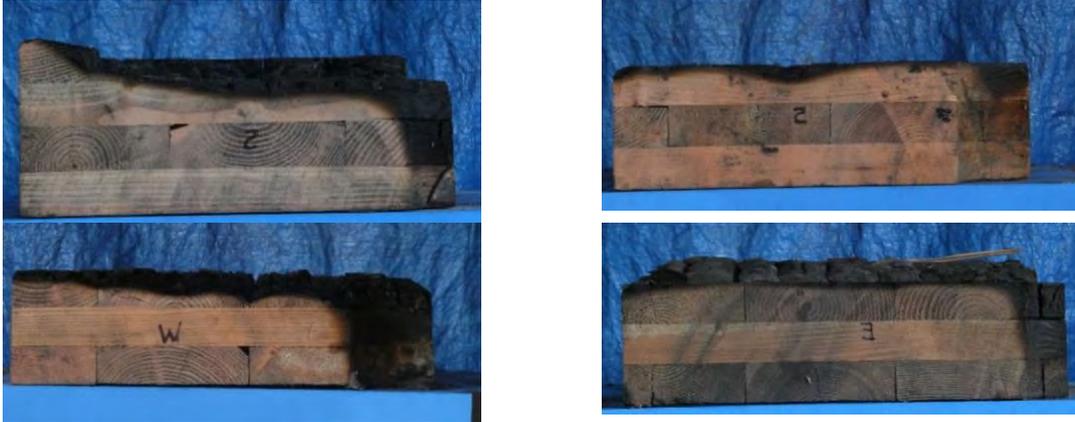
Figure 17 In most cases penetration edge is difficult to identify.

Another challenge is Step 5, automatic determination of the reference position of the final char line away from the penetration. Even absent penetrations or other disturbance, wood does not char in an uniform manner and the final position of the char line is not flat. This difficulty was solved by selecting an arbitrary *maximum possible radius of influence* that is a distance from the penetration edge at which it is not expected to affect the char pattern even in a worst case. The actual maximum extent of the affected area was determined either as the maximum or an inflection point in the char line within this *radius* (Figure 18).

Figure 18 Extent of the effect of penetration found as an inflection point in the chat line.
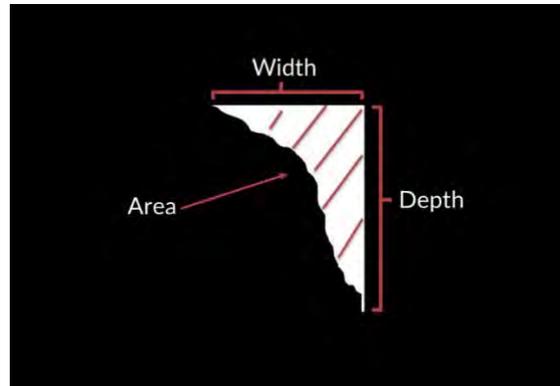
Figure 19 Output parameters of the char triangle

These reference points and lines allow determination of the *char triangle*, the extent of the area affected by the penetration. The script allows overlaying the contour of the *char triangle* on the original image for visual assessment of accuracy. The width, depth and area of the *char triangle* are then sent to the output as respective extent, depth and area of the char pattern disturbed by the penetration (Figure 18).

The reliability and precision of the machine vision script was assessed by comparison with char lines located manually by human analysts in a simplified round robin procedure.

RESULTS

Sample outcomes of the procedure in terms of the affected area and width (in pixels) are shown in Figure 20 where the effect of combinations of the conduit type (cast iron pipe, threaded steel, PVC or Aquatherm pipe represented as *penetration number* on the horizontal axis), two different fire stopping systems applied (Hilti and 3M) on penetrations through CLT panels delivered by two different US suppliers (marked by color code as T1, T2, T3 and T4). Discussion of the performance of individual systems is beyond the scope of this presentation. For this methodological work it is important that the method clearly allows differentiation between the performance with a level of statistical significance (the error bars show one standard deviation).
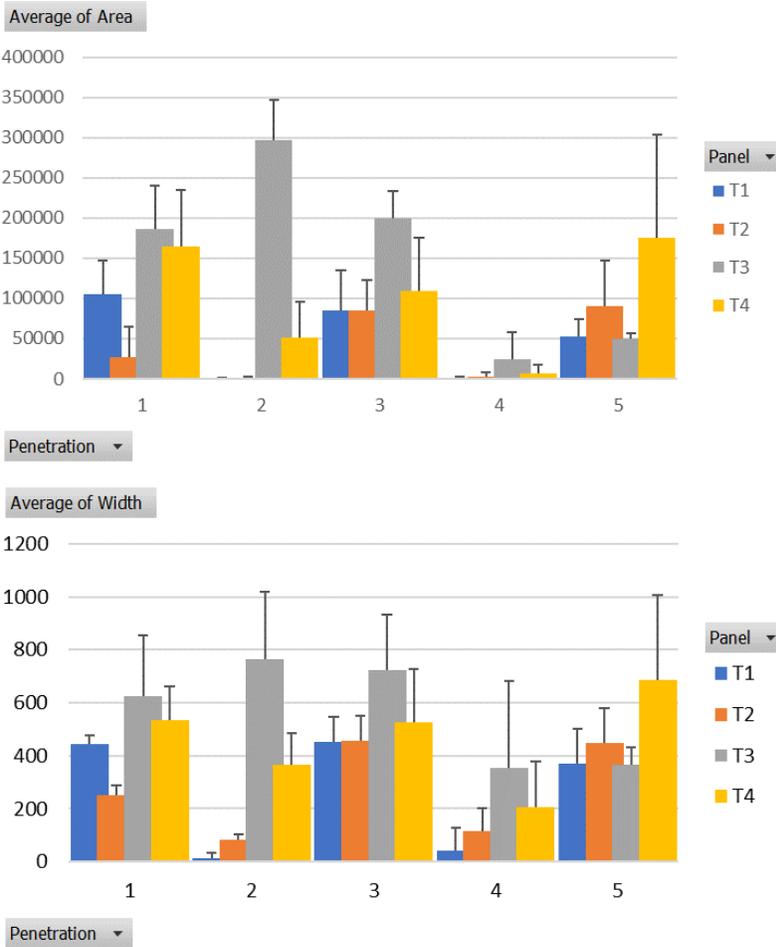
Figure 20 Sample set of output data generated by the machine vision method on the panels tested at WFCi in 2017.

CONCLUSIONS

A machine vision procedure was designed to compare the magnitude of the effect of penetrations on charring patterns in CLT panels based on information extracted from digital images of sections revealing the final char front patterns in the vicinity of each penetration. Reference char patterns away from the penetration were used to isolate disturbances of char patterns around the penetration. The widths, depths and areas of these disturbed patterns allowed meaningful quantitative comparison of the effects of firestop systems used in the tests.

Future work will focus on correlation of the R- and T-ratings and observations from the standard reports with the outcomes of the image vision method presented here.

ACKNOWLEDGEMENTS

Research internships were arranged by the ASE internship program by Saturday Academy. This project was completed with our mentor professor from the OSU College of Forestry, Dr. Lech Muszyński, and the Tallwoods Institute.

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Latest Research on The Progressive Collapse of Post-And-Beam Mass Timber Buildings and the Consequences on the Development of Mass Timber Connections

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ABSTRACT

Due to the brittle nature of the timber material in shear and tension, the lack of continuity between prefabricated elements, and connections lacking ductility, mass timber buildings are deemed to be less robust than their steel and reinforced concrete counterparts. In fact, achieving robustness for these buildings is so challenging that it is addressed first in design offices. Nevertheless, there is still little understanding on the ability of this type of buildings to redistribute the load after the loss of a load bearing element. This gap in knowledge unsatisfactorily leads to design "guesses" and either uneconomical conservatism or unsafe designs. This paper summarises the research performed at Griffith University on quantifying the robustness of post-and-beam mass timber buildings. Experimental and numerical investigations were performed on 2D frames and 3D substructures, both quasi-statically and dynamically. The structural behaviour of the system and its ability to generate alternative load paths to resist the accidental load was quantified. It was found that the beam-to-column connections are key to achieve robustness. The paper concludes with the proprieties that these connections must satisfy to produce robust buildings, leading the way to the development of new mass timber connections.

Bending Performance of Timber-Concrete Composite Slab with a Notched Plywood Shear Connector

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ABSTRACT

In this study, the bending performance of TCC slabs with notched plywood shear connectors was evaluated. Two types of test specimens were designed using the gamma method specified in Eurocode 5, with the lower timber layer examined under normal conditions and after 2 hours of exposure to fire. The test results were compared with bending performance estimated with the gamma method. It seemed that the gamma method can be used to predict the bending performance of TCC with a notched plywood shear connector since the difference was quite small from the engineering point of view. Based on the test results, a span table for non-residential buildings was derived and it was compared with the enabled spans of NLT, and TCC slabs which used self-tapping screws and truss plates as shear connectors in the past research. The TCC slab developed in this study could be designed over a larger span under the same load level, which was approximately 1.3 and 2.0 times greater than TCC slabs in the past research and traditional NLT slab, respectively.

Keywords: Timber-concrete composite, Shear connection, Structural plywood, Slab Gamma method, Notched connection

Acknowledgments

TUESDAY, JULY 12

RESIDENTIAL AND COMMERCIAL BUILDING INNOVATIONS: MASS TIMBER DEVELOPMENTS 2: CLT FROM ALTERNATIVE SPECIES
Chair: Jon Shanks, University of Tasmania, Australia

Developing Structurally Reliable Cross-Laminated Timber Panel from Australian Fast-Growing Plantation Eucalyptus Nitens

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ABSTRACT

In recent years, mass timber has received a lot of attention from the timber industries as a renewable, sustainable material for building applications in Australia. With increasing availability of growing plantation hardwood in Australia, the timber manufacturing sector has become interested in discovering the opportunities and investigating the possible application of the plantation eucalypt species to produce engineered timber products from this resource. The main part of hardwood plantation in Australia is dominated by plantation Eucalypt with approximately 208,000 ha of *Eucalyptus nitens (E. nitens)* species in the Tasmania region and are mainly managed to produce low-value products such as pulp and woodchips. Although fast-growing eucalypt plantation is not milled commercially for structural purposes, finding value-added use and developing engineered timber products from this resource could be a sustainable alternative for the timber industries and construction sectors. Manufacturing structural products from fibre-managed plantation eucalypt can lead to the replacement of imported wood products with Australian grown and processed plantation hardwood timber and create a new marketplace for this resource in the Australian and international building market. Cross-laminated timber (CLT could be a potential sustainable product recovered from this resource and supply material for commercial buildings. CLT is often considered a renewable product to traditional construction materials and is gaining more interest in Australia. The use of CLT panels brought various benefits for timber industries to make a practical product from low-value products of eucalypt plantation. To date, limited studies have been conducted to investigate the potential of fast-grown plantation *E.nitens* species to be used as a material in the production of mass-laminated timber, especially for building purposes. Given this, adequate structural performance is required to satisfy the requirements of the standard using Eucalyptus plantation for structural purposes. In order to define the goodness of *E. nitens*CLT panel, a robust understanding of the material's characteristics and structural capacity under loads expected in the building is required if the product is to be used for structural purposes. This study presents the results of an extensive experimental study on developing structurally reliable CLT panel from fast-growing plantation E. nitens. The structural behaviour of heterogenous CLT panel using combination of structural grades in panel lamella is also evaluated. One of the significant characteristics of the CLT panels studied in this research was the

heterogeneous configuration and the use of various combination of material for the inner and outer layer to make full use of a range of timber grade in the panel lamella. The mechanical performance of these novel panels through theoretical approaches is further assessed and compared to those experimental results. The rolling shear properties of these panel is also evaluated, indicating satisfactory performance to meet serviceability requirement and comparable results to those recommended in European standards for softwood CLT. The collected experimental and numerical results reveal an overall mechanical behaviour of heterogonous CLT panels with a great opportunity for construction applications. This presentation provides an important insight into supporting the potential engineering applications of CLT panel products fabricated with eucalypt plantations.

Non-Destructive Evaluation of the Global Elastic Properties for Large-Scale Cross-Laminated Timber Panels through Various Strip Specimens

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ABSTRACT

This article outlines the achievements of the research team in the development, use and assessment of a non-destructive evaluation (NDE) system for predicting the global elastic parameters of cross laminated timber (CLT) panels (referred to in this study as NDE-P). Current methods for confirming predicted elastic parameters of CLT involve an analytical solution derived from the shear analogy method (SAM) or static testing of sections of the panel post-manufacture. These methods are governed by (i) the feedstock parameters (such as grade and board size) for the SAM approach, and (ii) the section sizes as dictated by the standardised testing methods used. These static sections are often taken from the outer perimeters of the panel across each axial direction to allow for the major and minor elastic parameters (E_x and E_y), as well as the primary shear (G_{xy}) property to be calculated. From these static sections, the reduced width allows for the section to be governed by beam theory and assessed using NDE for beams (referred to in this study as NDE-B). Through this study an NDE approach developed using experimental modal analysis has been evaluated for its effectiveness in determining key elastic parameters against both NDE-B and static testing. The test piece size for NDE-B and static testing has been evaluated through a width of 300 mm. The results of the NDE-P system against the SAM analytical results have been used to present the target elastic parameters based on the CLT layering grades and board dimensions. Results showed that the NDE-P method for full-size panels compared against static values showed an agreement of 70%, 76%, and 71% for the two elastic moduli E_x and E_y, as well as the primary shear value G_{xy}. NDE-B for strip sections 300 mm wide produced a further 87%, 96%, and 83% agreement against static results. These various testing approaches have evaluated the variability of CLT panels of varying thickness and the application of full-size NDE testing against the testing of CLT sections.

LCA Comparison of a Mass Timber Building with an Equivalent Steel Alternative

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ABSTRACT

The main purpose in the first tier of the study is to quantify and compare the embodied environmental impacts associated with alternative materials applied to Adohi Hall, a residence building at the University of Arkansas campus, Fayetteville, AR. Adohi Hall. Constructed with mass timber, this structure is compared to the same building with a steel frame. Specifically, the comparative analysis will be primarily focused on the respective envelopes, in addition to floors and roofs.

Based on the defined goal and scope of the project, all materials used in the buildings are compared in terms of Global Warming Potential (GWP), from the cradle to the construction site. Cradle to the construction site includes the material manufacturing stage (raw material extract, process, supply, transport, and manufacture) plus transportation to the site (module A1-A4, based on standard EN 15804 definition). In this study, GWP is primarily assessed, to the exclusion of other environmental factors.

The second tier of this work is to evaluate Tally's performance as a Life Cycle Assessment (LCA) tool capable of conducting a cradle-to-grave analysis. As opposed to other software applications, Tally is specifically targeted at buildings LCA, and it is also designed to run on a platform called Revit. This unique functionality causes Tally to stand out from other LCA tools in the building sector.

The third and last tier is dedicated to assessing the strengths and weaknesses of Tally as the most popular LCA application in the building sector. The results of this study provide insights for making more environmentally efficient decisions in the building environment and help in the move forward to reduce Green House Gases (GHGs) emissions and GWP mitigation.

Keywords— Comparison, GWP, LCA, Mass Timber, Steel

CIRCULAR ECONOMY, SUPPLY CHAIN, MARKETING AND OPERATIONS ISSUES IN WOOD PRODUCTS
Chairs: Michael Burnard, InnoRenew CoE, Slovenia and Kyra Woods, NIFPI, Australia

Carbon Flows between Forests and the Built Environment: A Narrow Systems Approach

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ABSTRACT

Global forests sequester vast amounts of carbon, although deforestation in many parts of the world are converting 'stored' forest carbon to 'atmospheric' carbon. In many sustainability managed forests, timber harvesting produces logs that are converted into lumber and durable wood products, which in turn displace energy intensive materials such as concrete and steel in buildings. Woody biomass can also be used directly for energy production displacing coal or natural gas.

The use of forest biomass to product durable wood products is a particularly challenging system to analyze since there are a number of relatively immediate carbon releases, e.g., wood drying; short term releases, e.g., decay of forest residues; and longer term sequestrations, e.g., durable wood in structures. The impacts of substituting a durable wood product for steel or concrete in a structure also have a significant impact on the overall carbon cycles. Considering a narrow (plot-level) perspective, to truly be 'carbon neutral' the wood-based carbon (trees) must be regrown to some size to 'recapture' the emitted carbon. From this perspective, forest managed for commercial lumber production can take anywhere from 25 years to 75 years, or more, to reach some level of maturity. Alternatively, carbon can be accumulated in a sustainably managed forest at varying rates depending on stand age, and harvesting. This work will attempt to highlight some of the major operations that impact these different carbon flows.

Sensing Technology and Artificial Intelligence Algorithms for Tree Detection And 3D Reconstruction, And Classification of Tree Quality Features During Harvesting Operations

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ABSTRACT

Achieving the highest value from a plantation resource relies on quality, timely, and accurate measurement of key-value influencing tree features to support real-time optimised decisions about log selection. In addition to diameter and length measurements, current onboard optimisation systems rely on operator assessment of other critical features like stem sweep, limb diameter, limb angle, and internal characteristics like stiffness and strength. These operators' repeated observations, judgments, and operations may result in reduced productivity and value losses. With emerging and new technology like LiDAR, photogrammetric point clouds, high-definition stereo imaging, image analysis, machine learning, acoustics, NIR, etc., becoming more accessible and affordable, there is an opportunity to capture some of the features that operators currently estimate. Based on these new measurements, tree cutting patterns could be optimized and automation increased, reducing the requirement for operator intervention (forced cuts), resulting in higher resource utilization and value recovery, and increased harvest productivity. This study aims to investigate the potential application of sensor technology to measure stem quality features (e.g., sweep, branch size) to maximise value recovery during harvesting operations. The study will test potential sensing technology (Lidar, stereoscopy, depth imagery, and photogrammetry) and AI algorithms (machine/deep learning) for the automated, real-time identification of stem quality features (e.g., DBHOB, height, sweep, and branch/knot size) during harvesting operations. The study will also test the potential use of sensor technology to improve length and diameter measurements and automated log grading that can increase harvester productivity if it was faster than human decision-making. Also, several AI (deep learning) models will be developed for tree detection and 3D reconstruction and the automated detection of trees and quality features. To adequately cover the range of species and forest conditions, the study will be carried out in three locations: TAS (Eucalyptus nitens), SA (Radiata Pine), and NSW (Radiata pine). At each location, measurements will be made on standing trees to be able to characterise sweep and branch size, as well as estimate DBH. These features will be compared with predictions obtained with the AI algorithms. Some of the sensors to be tested will include RGB cameras, depth cameras, and mobile LiDAR sensors.

Keywords: Sensing technology, Artificial Intelligence, Harvesting Operations, Tree Detection, 3D Reconstruction, Tree Quality Features

Life Cycle Cost Analysis of Cross-Laminated Timber in a Building Structure

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ABSTRACT

Most of the whole building Life Cycle Assessment (LCA) studies on mass timber buildings indicate sustainability benefits of this new material relative to conventional products such as concrete and steel. A comprehensive understanding of the efficiency with economic competitiveness of this material in buildings, demands a total economic evaluation in addition to environmental impacts. Previous studies show this material could be more expensive than steel and concrete due to the limitation of production and manufacturing capability. Costs and environmental impacts resulting from the whole-life use of this material have not been studied intensively. Especially the economic benefits associated with the high potential of recycling have been little studied and disclosed to date, in particular, the economic role of the salvage value of the material because of its high potential of being mostly recycled and having a high salvage value. This work purposes to investigate the economic contributions of cross-laminated timber (CLT) applied to floor decks and roof of a glulam structure, inherent in the Adohi Hall residential building, on the campus of the University of Arkansas, Fayetteville. In this building, approximately 1410 tonnes of CLT were used for roofs and interior floors. The building is already completed and in use, facilitating the collection of accurate data for the purchase price, transportation, construction, operation, and maintenance. Regarding the end of life, however, not much data exists about this new material, and assumptions must, therefore, be made for data associated with recycling, reusing, or disposal. In this study, 60% of the material is assumed to be re-sale for 50% of the original purchase value as recycled at the end of building service life. The remaining 40% of CLT will be transported to the landfill. The study is going to examine the role of reusing material and salvage value using sensitivity analysis. A 4% discount rate and 20% tax rate are assumed, and 60 years of service life is assumed for this building. The total life cycle cost of CLT for this building, based on the deterministic model, is $ 7,858,000. Based on Monte Carlo simulation with 1000 trials by using Probability Management, the average value of total cost is $ 7,848,000, which is very close to the deterministic model. The similarity of results of the probabilistic model and the deterministic model gives validation to the results. Furthermore, the examined effect of the recycling rate and salvage value of the material revealed that both factors are sensitive to the total life cycle cost of CLT. Increasing the percentage of recycled material at the end of building life leads to a high reduction in the total cost. The higher the salvage value, the lower the total cost for CLT material. The results illustrate the total cost is more sensitive to salvage value than the recycling rate.

Keywords: LCC, CLT, Recycling, Salvage value, Sensitivity analysis

Circularity in Europe's Woodworking Sector: Policy, Practice, and Perspectives on the Future.

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ABSTRACT

Transitioning from a linear to a circular economy has been an important part of Europe's strategy to counteract climate change. With the introduction of the European Green Deal in December of 2019, this transition received greater attention and activities to analyse and implement circularity have been

increasing throughout Europe. Circularity within the bioeconomy has been especially relevant as the balance between material and energetic use of biomass is often seen as in conflict, and renewable materials are often cited as good alternatives to more energy intensive products. In the construction sector, where material and energy use are high – and building renovation is needed to increase energy efficiency – circular approaches that increase the recovered material content in building solutions are topics of interest. In the woodworking sector, many firms already implement circular practices, either on their own or by participating in value chains that maximise the reuse of materials. Good practices of both mechanisms are available across Europe, and many of them may be transferrable from firm to firm or region to region. Both specific and generalized good practices were identified and analysed in the WoodCircus project. These practices, coupled with an extensive series of interviews of European companies and analysis of the changing policy environment in Europe revealed the current state of the art in wood sector circularity, barriers and their impacts, and opportunities for change. Based on this information, six key recommendations were made to wood sector stakeholders in industry, policy, and the public to accelerate the transformation of the sector to become a leader in the circular bioeconomy. The recommendations focused on wood use in the built environment, efficiency in transforming wood-based materials, building on existing circular practices in industry, re- or up-skilling employees in the woodworking sector, the need for a supportive RDI environment, and the substitution potential of wood-based products.

Keywords: policy, Europe, circular economy, bioeconomy, best practices

The Sensitive Question of Commoditization in the Mass Timber Panel Industry

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ABSTRACT

The mass-timber panel industry is an exception in the traditional commodity-oriented forest products industry at large, even if one compares it to other sophisticated engineered wood products (EWP). All structural cross-laminated mass-timber panels discussed are specialty products, by which we understand that all panels are custom produced and fabricated for specific projects. The large dimensions (up to 20 m x 4 m) and mass (up to 5.5 metric tons) as well as the embedded value of individual panels makes finishing and cutting blank panels to needed sizes at the construction site practically impossible. Therefore, prefabrication of structural mass-timber panels with robotized machinery capable of handling massive panels a necessity, not an option. The mass-timber panel construction would not be possible otherwise. However, prefabricated panels may only be produced once the entire construction project is finished to the minute detail from architectural and engineering design, to construction site logistics. This quite naturally provides a high premium on integration of the design, manufacturing and construction aspects of the project and on tight collaboration of all parties from very beginning. The situation provides incentives for vertical integration of companies along the supply chain, and discourages production of commodity blank panels not assigned to any specific project. Currently, the industry is not prepared to carry the cost of intermittent storage of massive panels and of waste generated if standard-sized panels would have to be substantially trimmed for specific projects. Producing prefabricated panels finished for specific design and on-time delivery to the construction site is for the time being the most efficient solution.

While there are companies that are offering prefabrication services on "commoditized panels," it remains to be seen how they will fare. All these circumstances define the mass timber panel industry a specialty industry, with products delivered to the market not as standardized panels but as building shells or even finished buildings. There are intrinsic barriers preventing commoditization of massive cross-laminated panels even in most developed markets.

This does not mean that the commoditization is not possible in the future. However, it is more likely that it is going to focus on commoditization of certain types of highly modular designs than on blank panels.

The presentation will focus on both sides of the equation: contemporary barriers preventing commoditization of the structural blank mass-timber panels and on potential paths to certain level of commoditization in mass-timber panel industry considered more generally as one in which production of panels is a step in delivering of a building as an end product.

Value Chain Analysis for Veneer-based Engineered Wood Products (EWPs) Manufactured from Fijian-Grown Coconut Palm

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ABSTRACT

Coconut plantations are a valuable economic and social resource for many Fiji communities. A major issue is emerging with many of Fiji's coconut plantation becoming senile, resulting is a significant reduction in fruit production. Removal of senile palms and replanting with newer varieties is necessary to restore industry viability, however is a costly exercise. The sale of senile coconut logs for the manufacture of engineered wood products (EWPs) could incentivize farmers to initiate this renewal process. The use of senile coconut palms for EWP manufacture would require a new value chain to be created and would be expected to stimulate economic growth and improve livelihoods in the rural Fijian coconut farming communities. At the same time providing a new resource to the timber industry to assist with the growing demand for wood products. The analysis of a value chain follows the sequences of value-added steps to be identified, from log supply to product manufacture through to product end-use. This study will develop an understanding of the actors and their functions within the potential new coconut EWP value chain which will include farming communities, harvesting and haulage contractors, log processing and product manufacturers, wholesalers, retailers, end-users, amongst others. The value chain will be mapped in order to gain an appreciation for their role and probable interactions. The governance and policy compliance environment that the value chain needs to work within will also be reviewed. The study is expected to identify a number of constraints that may prevent an efficient value chain from being formed and where possible, solutions will be proposed. This will provide useful guidance for the potential development of a new industry for Fiji.

Key Words: Engineered Wood Products, Senile Coconut Stem, Value Chain, Value Chain Mapping, Value Chain Actors.

END-OF-LIFE OPTIONS FOR ENGINEERED WOOD PRODUCTS/TREATED TIMBER IN A CIRCULAR ECONOMY

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ABSTRACT

Australians are excellent consumers of products. These products ultimately end up as waste materials and need to go somewhere. Australia produces around 28 million tons of waste per year with around 50% currently ending up in landfill, including a significant amount of timber, engineered wood products (EWP's), and preservative treated wood (PTW). Limited landfill capacity and changes in public perceptions have encouraged development of robust re-use and recycling systems for paper, metals, and plastic, forming part of an increasing interest in circular economy approaches. Timber has amazing structural properties with strong environmental attributes being renewable and recyclable, but traditionally has limited end-of life options, especially for EWP's/PTW's. EWPAA is coordinating the development of a large-scale effort within the Cooperative Research Centre Program (CRC-P), engaging with timber product and EWP manufacturers, timber importers, the vineyard industry, frame and truss plants, as well as adhesive and preservative suppliers to address this issue. Researchers at the Queensland Department of Agriculture and Fisheries, Deakin University, Queensland University of Technology, and the University of the Sunshine Coast along with Planet Ark are all part of the project team. The project team will consolidate estimates of volumes of EWP's and PTW's in the disposal stream and their location, assess residual preservative/resin issues related to transport to re-processing sites, develop transport models to optimise economic collection, and assess the feasibility of various reuse/recycle pathways, including re-sawing, composite panel production, combustion, and composting for each material – pathways that are in use around the world. This project will help solve disposal issues, convert waste to products, create new products, and support employment and industry growth.

DURABILITY, WOOD DECAY AND PRESERVATION 1
Chair: Bill Leggate, Queensland Government, Department of Agriculture and Fisheries, Australia

Effect of Nano-particle Characteristics and Concentration on Timber UV Performance: A Large Field Exposure Test

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ABSTRACT

Wood has a well-known susceptibility to ultra-violet light degradation, leading to premature replacement. A variety of products have been developed to protect against this damage, but most provide less than 12 months of protection and must be reapplied for continued protection. Developing improved coatings would help reduce wood losses. Nano-particles have a variety of attractive properties that may make them suitable UV protectants. The effects of nano-particles on surface appearance, colour, and wettability of radiata pine (*Pinus radiata*) sapwood samples were investigated over 20 weeks of outdoor exposure. Nanometer to micron-sized water dispersions of ZnO, α and γ Fe_2O_3, rutile and anatase TiO_2, Fe_3O_4, $Fe(OH)_3$, spherical and porous SiO_2, and α and γ Al_2O_3 were used to evaluate the effects of concentration and crystal shape on UV performance. Surface colour changes were characterized by measuring CIE $L*a*b*$ parameters, while surface wettability changes were assessed using water droplet contact angle. Wood appearance changed markedly over the 20-week exposure and mould fungi appeared on the surface. Nano-particles protected wood from photo-discoloration to differing degrees with rutile TiO_2 and alpha Fe_2O_3 providing the most effective protection with performance improving at higher concentrations. Larger micron-sized alpha Fe_2O_3 provided more sustained UV protection. Mould growth reduced the yellowness on wood surfaces and thus influenced overall colour change. Nano-particles did not reduce wettability of wood after UV exposure. While none of the systems completely prevented UV damage, some showed promise and further trials are underway using combinations of nano-particles.

Keywords: Nano-particles; Wood surface; UV protection; Colour change; wettability

Investigating moisture uptake of LVL and CLT panels exposed to free water pooling-Phase 1-developing experimental setup

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ABSTRACT

Moisture movement into the mass panel structures of LVL and CLT was monitored and measured when panels were exposed to free water. The trial aimed to simulate flash flooding and plumbing leaks where water pooling happens on the surface of panels in different directions. The trial explored the effects of wood grain directions exposed (end grain and non-end gain) and exposure time (1 to 96 hours of free water pooling) on moisture uptake into the depth of panels. Sections of LVL and CLT were edge painted and sealed on selected surfaces for the free water exposure trial. Sampling was conducted by coring sections out from the panels and sub sectioning the core into 5 mm sections and oven drying the subsections to determine moisture changes in the structure. Results showed the differences in moisture uptake of CLT and LVL structures and potential effects of exposure direction, position of edge gaps and glue lines in moisture uptakes and moisture content.

In CLT face sections, moisture uptake was limited to the top 20-25 mm of the panels; however, the moisture content exceeded the decay threshold of 20%. For CLT face samples, a drying trial was conducted after more than five weeks of free water exposure where the final moisture content of solid (1P) and two-piece with glue line (2P) samples due to exposure to water were 52 and 48%, respectively. The moisture monitoring during ambient drying of a panel showed localised moisture in sections of the panel and the rate/speed of drying in different depths of the panel. For edge and end direction exposures, higher moisture gain was observed for all sub-samples collected in comparison with face exposed panels.

For LVL sections, the end-grain direction gained higher moisture in comparison with the face and edge sections, where the maximum moisture gain was limited to the top surface.

Overall LVL panel sections' moisture uptake was lower in three directions in comparison with CLT samples. The potential effects of various environmental factors, arrangement of veneer layers (thickness and potentially species), glue type (thickness of glue line) and effects of exposure directions on water gain needs to be studied further. The next phase of the study will investigate specific characteristics (including porosity, permeability, diffusivity and glue properties) of species used in mass panel manufacturing in each grain direction, effects of glue line on moisture gain and movement and effects of multiple glue lines in CLT versus LVL on moisture gain and drying behaviours.

EFFECT OF WOOD DECAY AT EARLY STAGES ON SCREW WITHDRAWAL CAPACITY

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ABSTRACT

Wood decay fungi can be highly destructive and a widespread cause of timber structures deterioration, especially in tropical and sub-tropical areas. Fungal attack is mainly divided into three types based on the appearance of decayed wood, i.e. brown rots, white rots, and soft rots. This study addressed brown and white rots. Although decay fungi grow in wet timber, brown rots are also tolerant of low moisture conditions, therefore they are commonly found in wood structures aboveground. In contrast, white rots are predominantly present at or below the ground line in wood that is in ground contact. The early stages of fungal decay are of extreme importance, as they tend to dramatically decrease some mechanical properties while remaining unnoticed and result in little mass loss. Subsequent repair or remediation consumes considerable amounts of time and money.

The effects of fungal decay on timber properties have frequently been studied, mostly on single samples. However, timber structures depend on the performance of connections, hence, it becomes of great importance to understand the effects of decay on connection performance as well as the decay process itself. In addition to this, connections are often the weakest elements in timber structures. Nevertheless, there is a considerable lack of information on the loss of performance of timber connections due to fungal attack. Understanding this performance loss can help fabricators design systems and guide builders in the designing of more durable structures.

One of the most common types of fasteners used in timber connections is screws. The withdrawal capacity is used to predict the strength of the connection and understanding the impact of fungal decay on withdrawal capacity is of utmost importance for the design of durable screwed connections. In this work, the withdrawal capacity of stainless-steel screws driven into the side- and end-grain faces of untreated Radiata pine was evaluated after being exposed to *Oligoporus placenta* (brown rot) and *Trametes versicolor* (white rot) for 18, 26 and 34 weeks.

Ability of shallow preservative barriers to protect Australian eucalyptus heartwood timbers: accelerated testing

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ABSTRACT

Heartwood is highly resistant to fluid movement, making it exceedingly difficult to achieve the preservative treatment required by many national standards, including those in Australia. Pressure treatment of heartwood generally results in a shallow envelope (<5 mm) surrounding a largely untreated core. This is a major issue in many of the lower durability plantation hardwood timbers in Tasmania that contain high percentages of heartwood. Preservative treatment of these materials should theoretically remain effective as long as the preservative barrier remains intact. Long term studies on softwoods such as spruce decking suggest that barrier treatments can provide decades of protection. While these results are promising, it is unclear whether shallow heartwood treatments would perform as well on lower durability hardwoods. Field tests would take decades to produce meaningful results, while accelerated laboratory or field trials might help bridge the testing gap. The purpose of this project is to develop accelerated decay methods for assessing the ability of shallow barrier treatments to protect lower durability plantation hardwoods. Components of this research include exploring pre-exposure leaching, the effects of check development on barrier performance and methods for assessing preservative chemical mobility as it redistributes on untreated surfaces. The results will be used to assess the potential for barrier treatments for above-ground applications, shorten the times required to demonstrate their efficiency, and support new markets for these emerging materials.

KEYWORDS: Low durability hardwoods, Tasmanian oak, Shining gum, heartwood, laboratory tests, barrier treatments, accelerated decay, chemical mobility

Evaluation of Microwave-based Technology for Detection of West Indian Drywood Termites in Timber

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ABSTRACT

The West Indian drywood termite (*Cryptotermes brevis*) is an invasive insect pest in Australia that can cause extensive structural damage to homes, other wooden structures, and wood-based objects such as furniture. The biology, ecology, and behaviour of *C.* brevis differs significantly from subterranean termites, in that they neither live in the ground nor maintain contact with the soil and do not construct mud tubes. As a result, West Indian drywood termites can be extremely difficult to detect because of their small colony sizes and slow development rate especially at the early stages of infestation. Currently, detection relies mainly on visual inspection of structures, with pest inspectors looking for expulsion holes in wood, dry faecal pellets, and alate wings on windowsills or near lights. Unfortunately, not all of these indicators appear in all infestations; in fact, there may be no evidence of an infestation in the early stages of colony establishment. As a result, reliable detection of West Indian drywood termite activity requires combining visual inspection with more advanced movement detection devices. Termatrac™ T3i is a microwave technology-based device that emits a stream of microwave signals into the timber. This wave is then reflected back to the device when it strikes a moving object such as a foraging termite. This detection is interpreted on a screen in the form of a moving bar and line graph. This device is very effective at detecting subterranean termites in structures, but its ability to detect smaller colonies of less active termites e.g., drywood termites has not been explored. In a laboratory trial with naturally infested boards TermatracT3i was able to detect the presence of drywood termites 97% of the time with few false positives at the highest sensitivity level. In a separate trial the device was also capable of detecting a single termite movement and was not affected by varying number of termites. The maximum reliable wood depth for detection was 45 mm, but sensitivity declined with increased wood density as well as change in grain orientation. These results support the use of this device for detecting *C. brevis* in household and building structures and further field trials are underway.

SUSCEPTIBILITY OF AUSTRALIAN COMMERCIAL TIMBERS TO WEST INDIAN DRYWOOD TERMITE

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ABSTRACT

Timber damage due to termite feeding is common in Australia and financial losses can reach millions of dollars per year. Since its accidental introduction in the 1940's, West Indian drywood termite (*Cryptotermes brevis* (Walker)) has become an important localised pest in several regions of Queensland, and is still considered one of Australia's National Priority Plant Pests. Control of this pest is essential, and preventing colony establishment is one of the most efficient ways to achieve this goal. Developing an appropriate integrated pest management scheme requires comprehensive knowledge of the species' ecology, including their host range. The ability of *C. brevis* to form viable colonies in construction timbers has been investigated overseas but is not well documented for species used in Australia. I investigated the ability of *C. brevis* to attack three softwood (hoop pine (*Araucaria cunninghamii*), radiata pine (*Pinus radiata*) and a southern pine hybrid (*P. elliottii* x *P. caribaea*)) and three hardwood (silky oak (*Grevillea robusta*), spotted gum (*Corymbia citriodora variegata*) and shining gum (*Eucalyptus nitens*)) timber species as well as hoop pine plywood. These materials are all relevant to the construction industry. Colony success was assessed in a six-week no-choice assay, measuring survival rate of termites, mass loss in wooden units, change in mass of termites, and frass production. This trial provides insights into the potential for successful termite colonisation in these wood types. The results can be applied to construction practices to limit the spread of *C. brevis* through the informed use of resistant materials where appropriate. Further work into the factors contributing to timber resistance to attack, including extractives content and density, will also be investigated. Use of resistant timber species may represent a more sustainable prevention method that avoids the need for costly in-service treatments such as fumigation.

Keywords: Sustainable Pest Management, Resistant Timber Selection, Colony Success.

INTRODUCTION

Many wood species are susceptible to West Indian drywood termites across the world, although information on host selection often simply states that softwood and hardwood species can be colonised (e.g. Horwood, 2008), without specifying which timbers show resistance. This has been addressed in other countries (e.g. Cosme Jr et al., 2018; Minnick et al., 1973) in the context of the timber available in that location. Harder, denser timbers have shown better resistance to colonisation (Cosme Jr et al., 2018), so this trend would be expected when investigating new types of wood. Beyond this, there is little information that can be used to assess a wood species for susceptibility to termite attack if it has not been done experimentally.

Hoop pine (*Araucaria cunninghamii*) is a well-known host for *C. brevis* in Australia (Peters, 1990). Serious damage occurs in Queensland houses constructed with this timber. Maples (*Flindersia spp.*), red cedar (*Toona australis*) and silky oak (*Grevillea robusta*) are also host species (Peters et al., 1996). Beyond these, susceptible timbers are not known in Australia, a serious gap in knowledge when planning for termite prevention. Certain timbers may demonstrate significant resistance to termite colonisation and, as such, their utilisation in construction may prevent or limit the spread of termites.

MATERIALS AND METHODS

Termite collection

West Indian drywood termites were collected from an infestation in Maryborough, Queensland. Termite species was confirmed by faecal pellet shape. Infested materials (floorboards and door panels) that showed a positive result with the Termatrac™ T3i device were harvested from the site and transported to the laboratory where they were stored at 25 ˚C and 70 % RH until needed. Collected wood sections were manually split, exposing the termite galleries, and all individuals were transferred onto filter paper in Petri dishes (maximum 50 termites per dish) and kept in controlled environmental conditions (25 ˚C and 70 % RH) for a minimum of three weeks to acclimate to these conditions before use in any experiment. This time lag allowed for mortality to occur in termites injured by the collection process, eliminating them from experimental inclusion. In all experiments, only larger pseudergates with no evidence of wing-buds were used. Although it was not confirmed microscopically, these were likely to be at least in the third instar.

Wood host choice

Five wood species utilised in Australia were selected for study (see *Table* 1).

1   *Table* 1. Characteristics of timbers evaluated against West Indian drywood termite

2   attack in laboratory trials

Wood Species	Common name	Solid/Composite	Why chosen	AS5604 Termite rating
Araucaria cunninghamii	Hoop pine	Solid timber sapwood	Well known host/positive control	Not resistant
Pinus radiata	Radiata pine	Solid timber sapwood	Common in construction	Not resistant
Pinus elliottii elliottii x P. caribaea hondurensis	Southern pine	Solid timber sapwood	Important QLD plantation timber	Not resistant
Eucalyptus nitens	Shining gum	Solid timber heartwood	Widely planted in southern states	Not resistant
Grevillea robusta	Northern silky oak	Solid timber heartwood	Commonly used in interiors	Not resistant
Corymbia citriodora variegata	Spotted gum	Solid timber heartwood	Commonly used in exterior exposures	Resistant

3

4   A hoop pine plywood treatment was also selected to investigate the resistance of an
5   engineered wood product. As this material is made of hoop pine, it would be expected to
6   be suitably colonised by the termite and so any differences in resistance can be assumed
7   to be conferred by the lamination process. It is relevant to know whether gluing and
8   pressing during lamination changes the resistance of the material to termite attack as this
9   process is seeing increased usage.

10

11   **Wooden unit construction**

12   Wood feeding units were successfully trailed in pilot studies (data not shown). Briefly,
13   V-shaped units were constructed from two identical veneers (5 cm × 2 cm × 0.5 cm),
14   glued along the long axis using PVA glue and a template to ensure a consistent V angle
15   (*Fig.* 1). Veneers originated from at least three parent boards per timber species. The
16   hoop pine plywood used veneers 0.25 cm thick as these were all that was available. Units
17   were placed into Petri dishes (10 cm diameter) that had been roughed to facilitate termite

1 movement, and these were placed into 400 ml plastic containers with holes for
2 ventilation. Four replicate controls without termites were created per wood
3 species/material to monitor changes in mass not related to termite attack.
4

5
6 *Figure 1.* inverted V-shaped wooden unit developed to evaluate the ability of termites to
7 attack a given timber substrate.
8
9 **Wooden unit acclimation**

10 Previous studies (Steward, 1982) suggest that *C. brevis* prefers moisture contents
11 between 12 and 18 %. The feeding assemblies were originally conditioned to ~12 % MC,
12 which is at the lower range of wood moisture preference. In order to raise the moisture
13 content, plastic boxes (50 cm × 35 cm × 25 cm) were prepared that contained a saturated
14 solution of potassium chloride (KCl) (Winston & Bates, 1960). This created stable
15 humidity of approximately 80 % (±5 %) in the boxes, confirmed by analysis with
16 Minnow™ 1.0TH loggers. Wooden test units were placed in this environment for three
17 weeks before the trial. The final moisture contents in the samples at the end of the trial
18 were determined by weighing each sample, oven drying (Thermoline TO-235F) at 103 ˚C
19 and then reweighing them.
20
21 **No-choice assay**

22 The ability of West Indian drywood termite to attack a given timber was assessed in a no-
23 choice trial. Twenty-five West Indian drywood termite pseudergates were weighed
24 (±0.001g) and transferred from filter paper to the test units using a fine paint brush. A
25 control group of termites was also included, being transferred to fresh filter paper to
26 allow differentiation of handling mortality from that caused by diet. Containers holding
27 each unit were placed back into the controlled environment boxes and left undisturbed for
28 six weeks, with the exception of control (no termite) units, which were weighed
29 periodically (nine times total) to measure any changes in mass over the trial. The trial was
30 conducted in two halves to limit the effect of any experimental error with four replicates
31 at a time for each treatment (a total of eight replicates per treatment).
32
33
34

1 **Assessing colony success**

2 After six weeks, termites and frass were gently removed from the units and all three
3 components (termites, remaining wood, and frass) were weighed separately on an
4 electronic balance. Colony performance was assessed using several measures. Termite
5 survival was measured by simply counting the surviving members in each replicate. The
6 change in termite mass was assessed by:

7 $$\frac{initial\ average\ termite\ mass - final\ average\ termite\ mass}{initial\ average\ termite\ mass}$$

8
9 where initial average termite mass was calculated as the mass of the full complement of
10 25 termites, and the final average termite mass was calculated as the total mass of
11 surviving termites/number of surviving termites.
12
13 The percentage mass loss in the wooden units was calculated by recording the mass
14 before and after the feeding trial. The value was adjusted based on the change in dry mass
15 of the control units. This value indicates the amount of wood consumed by the termites
16 and therefore is a direct measure of resistance. The dry mass consumption of each timber
17 type was estimated by:

18 $$Initial\ dry\ mass - final\ dry\ mass$$

19
20 where initial dry mass was determined by:

21 $$initial\ wet\ mass - (initial\ wet\ mass$$
22 $$* average\ initial\ moisture\ content\ of\ controls)$$

23
24 and initial moisture content of control was calculated by:

25 $$\frac{initial\ wet\ mass - dry\ mass}{initial\ wet\ mass}$$

26
27 Feeding rate was also assessed by measuring the fresh mass of frass produced in each
28 replicate after the assay. The damage done to the wood by the termites was also assessed
29 post-trial, using a 0-5 rating scale (*Table* 2). Several qualitative factors such as presence
30 of any reproductive form of termite (alates/ neotenics) in the colony and the form(s) of
31 damage done to the units (scratching, tunnelling, sealing entrances etc.) were also
32 recorded.
33
34 *Table* 2. A 6-point rating scale for drywood termite damage done to provided wooden
35 units. Adapted from (Maistrello, 2018).

Rating	Common name	Factors
0	No attack	No damage seen
1	Attempted attack	Superficial erosion of insufficient depth to be measured on an unlimited area of the test specimen or attack to a depth of 0.5 mm provided that this is restricted to an area or areas not more than 25% surface area in total
2	Slight attack	Erosion of <1 mm in depth is limited to not more than 50% of the surface area of the test specimen or single

		tunnelling to a depth of up to 3 mm or a combination of both
3	Moderate attack	Erosion of <1 mm in depth over more than 50% of the surface area of the test specimen or erosion of >1 mm to <3 mm in depth limited to not more than 25% of the surface area of the test specimen, or isolated tunnelling of a depth > 3 mm not enlarging to form cavities or a combination of these
4	Strong attack	Erosion of >1 mm in depth of more than 25% of the surface area but limited to not more than 75% of the area of the test specimen or tunnelling penetrating to a depth > 3 mm but < 5 mm and enlarging to form a cavity in the body of the test specimen or a combination of both
5	Extreme attack	Erosion of >1 mm over more than 75% of the surface area of the test specimen or tunnelling of 5 mm or more that enlarges to form a cavity or a combination of both.

Data analysis

The data obtained was analysed using IBM SPSS (V 28.0.1) software. The data were checked for normality, then one-way analysis of variance (ANOVA) tests were performed on the numerical data followed by Tukey's HSD *post hoc* tests to assess for significant changes in colony success factors. Combined groups of softwoods and hardwoods were tested for significance by students' t-test. The damage score data is categorical so was analysed using a Kruskal-Wallis H test- followed by pairwise Dunn-Bonferroni *post hoc* tests.

RESULTS

Preliminary results

To date, only half of the trial has been completed and therefore conclusions drawn from the data may not represent the full picture of the trial. Overall, mean termite survival rate across different conditions was 68.25 ±2.77 %. Maximum mean termite survival was seen after feeding shining gum and the lowest on the spotted gum (*Fig.* 2). Analysis showed significant difference between wood types ($F_{7,24}$=2.91, p=0.024), though *post hoc* tests identified the only differences coming between the shining and spotted gums. Softwood and hardwood data were grouped and showed no significant differences upon analysis (t_{22}=0.10, p=0.921).
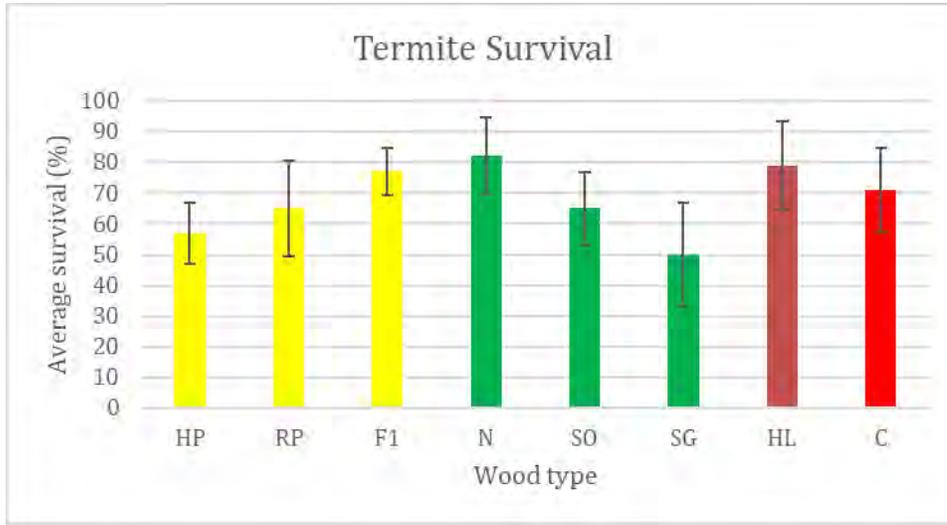
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2   *Figure* 2. Average termite survival rates after feeding of different woods for the 6-
3   week in no-choice test. (HP= hoop pine, RP= radiata pine, F1= southern pine hybrid, N=
4   shining gum, SO= silky oak, SG= spotted gum, HL= hoop pine laminate, C= filter paper
5   control. Yellow= softwoods, green= hardwoods, orange= manufactured wood product,
6   red= control.)
7

8   Termite mass change data demonstrated large variation within and between groups, with
9   most treatments finding both increases and decreases in average mass (*Fig.* 3). No
10   statistical difference was observed between groups ($F_{7,24}$=1.85, p=0.124) or between
11   softwoods and hardwoods (t_{22}=1.37, p=0.184).
12
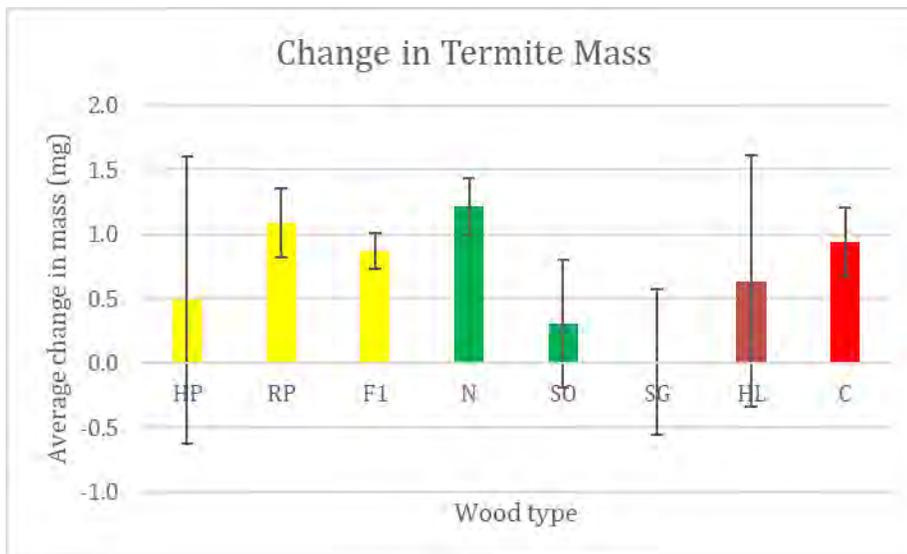
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14   *Figure* 3. Change in average termite mass after the 6-week no-choice feeding trial.
15   (HP= hoop pine, RP= radiata pine, F1= southern pine hybrid, N= shining gum, SO= silky

1   oak, SG= spotted gum, HL= hoop pine laminate, C= filter paper control. Yellow=
2   softwoods, green= hardwoods, orange= manufactured wood product, red= control.)
3   Frass production saw discrepancies between the softwood and hardwood groups, with the
4   later treatments producing less frass, with the exception of the shining gum where similar
5   frass production to the softwood groups was seen (*Fig.* 4). The filter paper control saw
6   minimal frass produced. Analysis demonstrated a strong significant difference between
7   the treatments ($F_{7,24}$=13.46, $p<0.001$) which was also true when grouping soft and
8   hardwoods (t_{22}=3.14, p=0.005). *Post hoc* tests revealed the differences lie between many
9   of the groups.
10
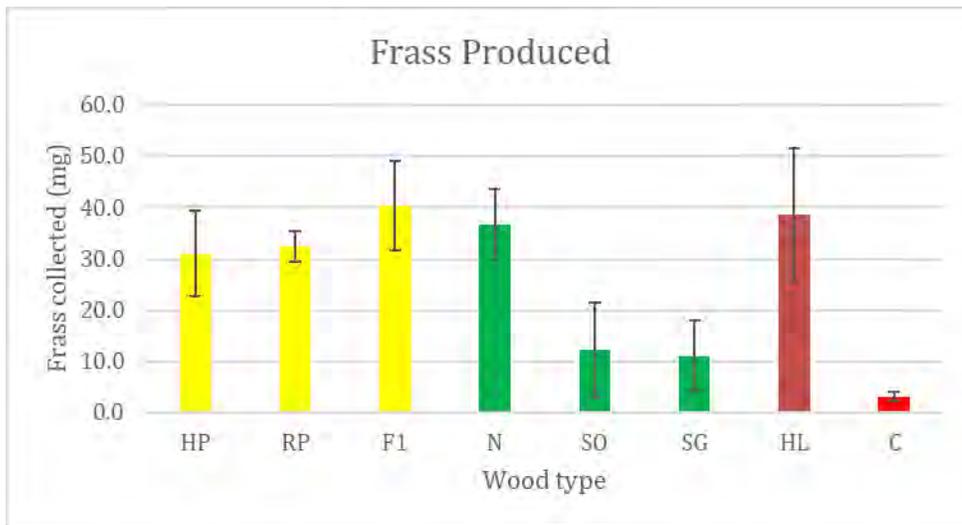
12   *Figure* 4. Average frass production of termites during the 6-week no-choice feeding
13   trial (HP= hoop pine, RP= radiata pine, F1= southern pine hybrid, N= shining gum, SO=
14   silky oak, SG= spotted gum, HL= hoop pine laminate, C= filter paper control. Yellow=
15   softwoods, green= hardwoods, orange= manufactured wood product, red= control).
16

17   Wooden unit mass change was assessed by average percentage change, adjusted using the
18   average mass change of the surrogate units. All conditions lost mass during the trial and
19   saw similar trends to the frass production data. The pines generally demonstrated more
20   mass loss compared to the hardwoods, with the exception of shining gum (see *Fig*. 5).
21   Analysis again demonstrated a strong significant difference between groups ($F_{7,24}$=9.52,
22   $p<0.001$) and revealed significance between several groups. Similar significance was
23   seen when grouping softwoods and hardwoods (t_{22}=2.68, p=0.014).
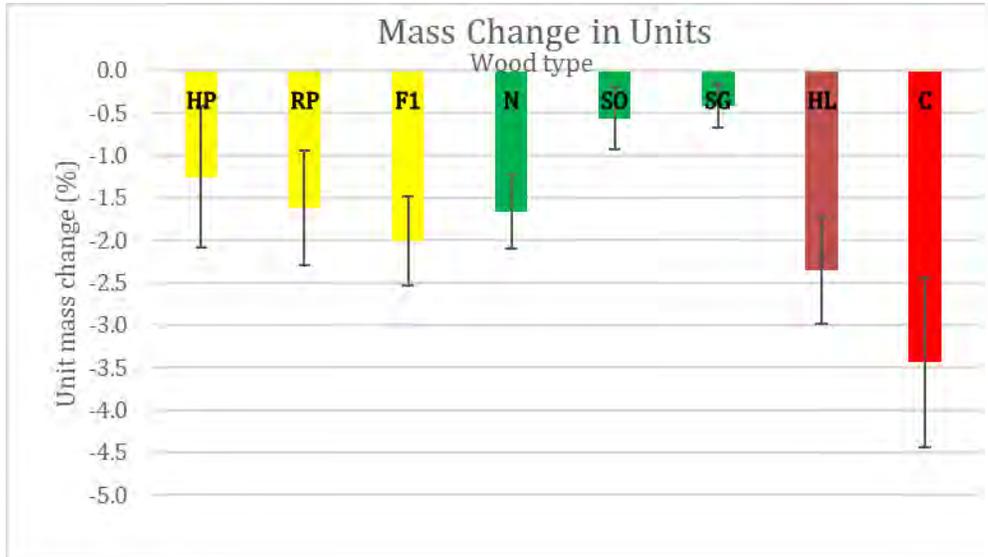
1

2   *Figure* 5. Percentage change in mass of wooden units during the 6-week, no-choice
3   feeding trial (HP= hoop pine, RP= radiata pine, F1= southern pine hybrid, N= shining
4   gum, SO= silky oak, SG= spotted gum, HL= hoop pine laminate, C= filter paper control.
5   Yellow= softwoods, green= hardwoods, orange= manufactured wood product, red=
6   control).
7

8   Finally, the damage score data was assessed for trends between groups. Although
9   replicates within groups saw some variation, the Kruskal-Wallis H test highlighted a
10   statistical difference between wood types (H_6=16.65, p=0.011). *Post hoc* analysis
11   identified the relevant differences were only between spotted gum-radiata pine and
12   spotted gum-shining gum (*Fig.* 6).
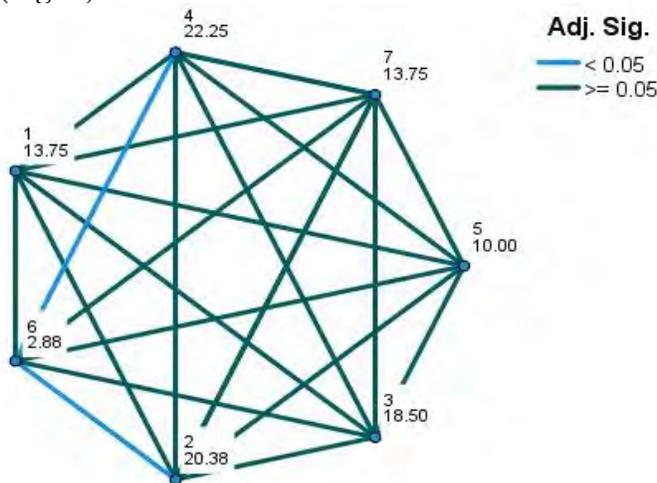
13

14   *Figure* 6. Pairwise Dunn-Bonferroni *post hoc* analysis matrix of damage scores between
15   wood types. Light blue connections signify statistical differences and green connections
16   non-significance (1= hoop pine, 2= radiata pine, 3= southern pine hybrid, 4= shining
17   gum, 5= silky oak, 6= spotted gum, 7= hoop pine laminate).
18

CONCLUSIONS

Tentative conclusions can be made from the first set of results, to be tested against the whole data set later. The softwood species demonstrated high levels of susceptibility, as expected, with the shining gum exhibiting similar levels of termite feeding. Despite *E. nitens* belonging to the hardwoods, which were anticipated to show resilience, the wood has lower density values to many other hardwood species and as such fits in with the susceptibility of the softwoods. As the hoop pine is a known host of the termite, the resistance shown in this trial was surprising and may suggest that West Indian drywood termites colonise this timber due to its availability rather than preferential selection. Interestingly, the hoop pine plywood presented as less resistant than the unmanufactured timber. The changes in material properties between the two products are likely responsible for the variation in resistance. High rates of termite survival were seen across treatments, even within colonies that demonstrated little feeding. This suggests that individuals were able to survive the trial without significant feeding, limiting the effectiveness of survival rate as an appropriate measure of wood resistance in this experimental set up.

An expected outcome of the trial is the optimisation of management processes due to the increase in knowledge of host preference. If more is known regarding the termite's choice of wooden host, current prevention methods can be adapted to increase success. For example, wooden material known to be resistant to attack will not require the same level of preventative action as other timber that is susceptible. Therefore, management plans can be specifically targeted to vulnerable timbers and reduced in naturally resistant ones, providing more economic strategies and increasing sustainability.

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POSTERS
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Suitability of corn stalk (Zea mays L.) and citric acid solution for single layer particleboard: effect of particleboard density on bending strength and thickness swelling

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ABSTRACT

The growing population is leading to rising demand for the fulfilment of daily necessities including building materials and furniture products. Corn stalk is an agricultural by-product that is abundant and underutilised in many countries such as Australia and Indonesia. This research investigates the potency of corn stalk for eco-friendly particleboard production using citric acid as the adhesive. Three adhesive percentages were applied that is 25%, 15%, and 10%w/v for targeted densities of 0.5 g/cm^3 and 0.7 g/cm^3. All the panels were pressed for 10 minutes at 200°C with a pressing pressure of 2.4 MPa. Water absorption and thickness swelling, as well as bending strength of particleboard, were assessed following Japanese Standard (JIS) 5908-2003. The standard that is commonly used for base particleboard testing in furniture application. The result shows that the higher density of particleboard the better properties in bending strength. The bending strength of particleboard with 0.5 g/cm^3 density was in the range of 3.2-3.8 MPa. For 0.7 g/cm^3 particleboard, the bending strength was between 6.02-7.47 MPa. The value of bending strength from 0.7 g/cm^3 is imminent to the standard. On the other hand, the particleboards' water absorption (WA) and thickness swelling (TS) properties showed better results in lower density particleboard. It is found that the WA and TS values of 0.5 g/cm^3 particleboard were 77.82-88.84% and 3.13-5.48% consecutively. For 0.7 g/cm^3 particleboard, the WA and TS values were 49.95-62.39% and 8.70-19.90%. The TS value for 0.5 g/cm^3 particleboard was meet the standard of base particleboard. Since

the wood supply is facing shrinkage over the period the search for an alternative for furniture raw materials is important. Results of this preliminary research are promising and could potentially alleviate our reliance on an ever-shrinking wood resource to satisfy our need for raw material to manufacture particleboards for furniture application.

Keywords: *eco-friendly particleboard, corn stalk, citric acid*

Study on the atom transfer radical polymerization according to the structural difference of organosolv lignin and the physicochemical characteristics of ligno-bioplastics

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ABSTRACT

Lignin is one of the main components in lignocellulosic biomass which has a rigid structure, antioxidant property, and high thermal stability. Therefore, lignin has the potential to be used as an additive or a precursor of bioplastics. However, because of random radical coupling, the heterogeneous distribution of functional groups limits the valorization of lignin. Moreover, lignin has different structural characteristics according to the extraction conditions. To overcome the drawbacks, various chemical modifications are needed. Recently, many types of research have been conducted in terms of lignin valorization. Especially, atom transfer radical polymerization (ATRP) was conducted using lignin as a macroinitiator.

In this study, the aspect of physicochemical properties of lignin-g-myrcene was investigated by controlling organosolv lignin characteristics. First, to control the structural characteristics such as phenolic, aliphatic hydroxyl group contents, and molecular weight, the organosolv lignin conditions were controlled. Second, after extraction of three types of organosolv lignin, each lignin was modified to macroinitiator for atom transfer radical polymerization (ATRP). Finally, ATRP was conducted using methyl methacrylate as a monomer.

As lignin is a heterogeneous biopolymer, the structural characteristics of organosolv lignin were controlled through controlling extraction conditions. Three types of organosolv lignin were extracted with different reaction conditions such as organic solvent concentrations, sulfuric acid concentrations, and reaction temperatures, result in exhibiting different hydroxyl group contents and molecular weight. After extraction of organosolv lignin, the lignin was reacted with bromoisobutyryl bromide (BiBB) to make a macroinitiator for ATRP. Then, the methyl methacrylate was used in ATRP as a monomer. The product could be used as an additive for bioplastics to overcome the drawbacks of bioplastics.

The characteristics of the organosolv lignin were differentiated according to the extraction conditions. A phenolic hydroxyl group contents tended to increase as the extraction temperature and sulfuric acid concentration increased. As the reaction temperature increased and the ethanol concentration decreased, the molecular weight of organosolv lignin was tended to decrease. Using the organosolv lignin, ATRP was conducted with methyl methacrylate. The molecular weight of the polymer increased after ATRP progressed. Then the polymer was molded into a dog bone-shaped specimen to investigate tensile strength and nominal strain at break. Furthermore, to investigate the thermal properties of the polymer, thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis were conducted. Meanwhile, optical properties of PMMA grafted ethanol organosolv lignin in PLA (EOL-g-PMMA/PLA) film were also evaluated using UV-Vis spectrophotometer.

After the ATRP, as EOL-g-PMMA has T_m, melt blending was possible. EOL-g-PMMA imparts thermal stability in the PLA matrix. Especially, HL-g-PMMA which produced from high severity extraction conditions provided the highest thermal stability among three types of EOL. In addition, the PLA blend that containing 10% of EOL-g-PMMA showed similar tensile strength and nominal strain at break with neat PLA. In addition, it exhibited higher UV absorption property compared to neat PLA film and PMMA containing PLA film.

Keywords: Organosolv lignin, ATRP, PLA, thermoplasticity

Optimising the Adhesive Performance of Engineered Wood Products made from Tasmanian Plantation Eucalypt

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ABSTRACT

In recent years, the timber manufacturing sector has become interested in the possibilities of producing value-added timber products from the growing availability of fast-growing Eucalyptus plantation logs in Australia. The majority of this hardwood plantation has been developed and managed for pulpwood application. Developing engineered timber products such as cross-laminated timber (CLT) and glued-laminated timber (GLT) could be sustainable alternatives recovered from this resource which significantly increases the efficiency of the plantation resource. Manufacturing structural timber products from fibre-managed plantation eucalypt can lead to the replacement of imported wood products with plantation hardwood timber and create a new marketplace for this resource in the Australian and international building market. To facilitate the application of plantation eucalypt timber in structural wood products, it is essential in some segments of the industry to verify the adhesive performance of mass-laminated timber elements from this resource. The adhesive is a crucial component in CLT and GLT elements and the quality of the glue bond needs to be evaluated before such a resource can attain sufficient requirements of structural performance. To date, very little is known about the mechanical properties, processing parameters, and adhesion performance of the potential engineered products from this resource. This study evaluates different glue types, the effect of different processing parameters, and surface treatment on the face bonding quality of GLT and CLT elements made from *Eucalyptus nitens* timber resources. The aim was to evaluate the glue performance and identify effective processing parameters for improving the bonding quality of the products. For this purpose, two glue types (one-component polyurethane (1CPUR) and resorcinol formaldehyde (RF)), three surface treatments (surface sanding, surface planning, primer application), and three processing parameters (press time, press pressure, adhesive spread rate) were considered in the evaluation. Two existing test methods of delamination and shear block (wet and dry) test under AS1328 standard were performed. Based on the results of CLT assemblies, it can be concluded that press pressure had a significant impact on enhancing the bond performance whereas, press time and adhesive spread rate did not have a remarkable effect on percent of delamination. It is also worth noting that the PUR glue spread rate of 180 g/m^2 was adequate for producing mass laminated timber from *E. nitens* timber. The results of GLT assemblies indicated that the use of primer when using PUR glue improved the adhesion performance of *E. nitens* mass timber. Furthermore, face milling prior to gluing was found to positively affect the bonding performance compared to surface planning. R F adhesive demonstrated high bonding performance compared to PUR glue when using surfaced planed. In conclusion, press time among manufacturing parameters and face milling and primer application among surface treatment were found to be significantly affected the bonding quality. Overall, our findings reveal important new information for product and process optimisation for any industry looking to make mass timber elements from the abundant plantation *E.nitens* resources. Further research would be of great help in optimising the bonding performance of mass laminated timber elements from this resource.

Wood-water Relationships of Fast-grown Wood Species Coming from Indonesia and Austria

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ABSTRACT

At the COP 26 (26th UN Climate Change Conference of the Parties) countries agreed on strengthening the implementation of a climate-driven agenda. Here, the Association of Southeast Asian Nations (ASEAN) have issued a statement with pushing the agenda to scale-up and shift investments towards sustainable and climate-resilient infrastructure. Timber is viewed as a green building materials, with a huge variety of construction systems that are widely found in developed countries, but rarely found in the Southeast Asian region. To fill this gap of timber utilization, especially of fast-grown species from Southeast and Eastern Asia, is of foremost importance. To better understand the complex properties of these lesser known fast-grown species, the wood-water relationships have been investigated and linked to their anatomical properties. Here, the fast-growing wood species coming from Indonesia were: sengon (*Paraserianthes falcataria*), jabon (*Anthocepalus cadamba*), acacia (*Acacia mangium*). As a comparison, Austrian grown empress tree wood (*Paulownia tomentosa*) was also investigated. The aforementioned species are subjected to water-vapor sorption analyses, using a dynamic vapor sorption (DVS) apparatus, operated also at different temperature levels. During full sorption - desorption cycles, camera images were taken along the RH steps, to determine quantitatively the dimensional changes at high resolution. The density of vessels and ray cells per millimeter squared were determined, and related to the collected sorption data. Results give insights to water-vapor caused swelling and shrinking, taking place at the cellular-tissue level, including high spatial resolution radial/tangential ratios. Therefore helps to better understand the suitability of these lesser-known wood species to be used in timber constructions.

Strategies for Reducing Drying Collapse in Difficult-To-Dry Plantation Grown Timber

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ABSTRACT

Eucalyptus plantations are one of the largest wood resources, and while typically primarily grown for fiber or biomass, there is an increasing interest to use this resource for solid wood products. However, timber from such short-rotation eucalyptus plantations is often 'difficult-to-dry' suffering collapse during this process. To make such timber suitable for higher-value solid wood products, this study explores two strategies for reducing collapse in plantation-grown eucalypts: a) reducing collapse through a breeding program, by selecting genetically less-collapse prone planting stock and b) technical solutions to allow the drying of collapse-prone timber without collapse.

Following earlier work in Australia in the early 2000s, breeding trials of *E. globoidea* and *E. quadrangulata* were assessed at 8-9 years of age. Thousands of trees were sampled, using a 13-mm-diameter purpose-built corer, for collapse in heartwood and sapwood, extractive content and basic density. Heartwood collapse was under genetic control with the heritability ranging from 0.19-0.40. Heartwood collapse was negatively correlated with basic density and positively correlated with extractive content. The collapse was lower in the sapwood than in the heartwood and lower heritability was revealed for sapwood collapse. Sapwood collapse was negatively correlated with basic density as for the heartwood collapse. Consequently, collapse in this future eucalypt resource can be minimised through breeding, potentially eliminating the problem.

The technical solution for reducing collapse in the current resource was based on the knowledge that permeability of timber can be increased by 'micro'-steam explosions, e.g. through radio-frequency or microwave heating, consequently reducing collapse during drying. A more energy-efficient method to heat timber is passing an electric current through it, i.e. Joule heating. *Eucalyptus nitens* log samples cut from a plantation were subjected to Joule heating at two power intensities prior to conventional drying. Subsequently, shrinkage and collapse were determined and compared to an untreated control. Tangential collapse reduced significantly (~53%) with the high power (HP) Joule heating. Maximum tangential shrinkage was significantly lower due to the reduction in the collapse in Joule heated samples as normal shrinkage was not affected by Joule heating. Thus, Joule heating of logs prior to drying has potential for improving the drying quality of collapse-susceptible timber. However, any technical drying solution, in contrast to planting superior genetics, is associated with ongoing costs to the wood processing industry.

Keywords: Breeding, Collapse, Drying Quality, Joule Heating, Plantation Eucalypt Timber

Applying Image Analysis Techniques and Spectral Segmentation to Generate a Virtual Board Representation for Simulating Moisture Migration in a Laminated Timber Panels.

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ABSTRACT

Moisture induced stresses can cause timber boards to warp, expand and contract, and it is therefore essential to understand how the heat and mass transfer phenomena affect the strength and durability of laminated timber products such as laminated veneer lumber (LVL) and cross-laminated timber (CLT). In this work, a novel method is developed that utilizes image analysis and spectral segmentation to produce a three-dimensional mesh of a laminated timber panel. The mesh is then used to simulate the moisture migration and temperature distribution of the panel when exposed to a range of psychometric climate conditions (including hot and humid conditions) typically experienced in Queensland, Australia.

Starting with a photograph or a scan of the end grain of a timber board, an image mask is produced by employing thresholding and image smoothing techniques. This mask highlights the darker latewood sections of the board providing a binary image of the growth ring locations. The growth rings are then identified using a recursive bipartitioning spectral segmentation algorithm. This information allows the nodes of the mesh to be aligned along the edges of the growth rings to accurately capture the significant changes in wood density. Lastly using the light intensity data of the image, the density (and hence porosity) of the board can be associated with each mesh element. The method allows for a three-dimensional reconstruction of a virtual timber board that includes density variation information from a single image. The *TransPore* model previously used to simulate the drying of a timber board is extended to describe the moisture ingress and egress in multiple boards that are glued together. The glued surfaces are represented using imperfect contact boundary conditions that allow for discontinuous jumps in moisture content at the same node. The model provides a powerful tool that can ultimately be used to study how the glued surfaces affect the moisture migration, stresses, and strains of laminated timber products.

Life Cycle Assessment for Transporation of Cross-Laminated Timber (CLT) Panels from Three Origin Points of Supply

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ABSTRACT

Cross-laminsted timber (CLT) used in the U.S. is mainly imported from abroad. In the existing literature, however, there are data on domestic transportation, but little understanding exists about the environmental impacts from the CLT import. Most studies use travel distances to the site based on domestic supply origins. The new Adohi Hall building at the University of Arkansas campus, Fayetteville, AR, presents the opportunity to address multimodal transportation with the overseas origin, and to use real data gathered from transporters and manufacturers. The comparison targets the environmental impacts of CLT from an overseas transportation route (Austria-Fayetteville, AR) to two other local transportation lines. The global warming potential (GWP) impact, from various transportation systems, constitutes the assessment metric. The findings demonstrate that transportation by water results in the least greenhouse gas (GHG) emission compared with freight transportation by rail and road. Transportation by rail is the second most efficient and by road the least environmentally efficient. On the other hand, the comparison of the life cycle assessment (LCA) tools, SimaPro (Ecoinvent database) and Tally (GaBi database), used in this research, indicate a remarkable difference in GWP characterization impact factors per tonne.km (tkm), primarily due to the different databases used by each softward.

Keywords—Comparative Analysis, Building, GWP, LCA, Transportation, CLT

Comparative Analysis of Thermal Comfort Performance of Wood, Brick, and Concrete

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ABSTRACT

Recently, there is an increase in the temperature of outdoor spaces such as streets, plazas, etc., in many compact cities. Therefore, thermal comfort in public outdoor spaces is now considered to be one of the greatest challenges worldwide. In response to this issue, this study aims to compare the thermal effect of various building materials on public spaces. Three materials, wood, brick, and concrete will be examined using a case study which is going to be presented by reference to a real public urban space, which is a corridor located at 17 Shahrivar street in Tehran, Iran. In this study, ENVI-met 4 software was applied to evaluate the level of thermal comfort of the three materials, wood, brick, and concrete. For simulation of the microclimate of the area, meteorological sampling was analyzed on the hottest days in summer in July and the coldest days in winter in January 2020 at the meteorological station of Geophysics Center, the University of Tehran (under 5 km distance from the case study). The results showed, respectively, wood, brick, and concrete have the best function to gain thermal comfort in the corridor during the summer. However, in the winter, brick provides better thermal comfort than wood in the examined case study. Concrete in both seasons is the worst material in terms of thermal comfort. Based on the quantitative analysis in this study, the weight assigned to wood, brick, and concrete in terms of the urban space thermal comfort, in order, are 0.7, 0.6, and 0.3. The results of this study clarify how much each material could change the level of thermal comfort in the corridor of 17 Shahrivar. The finding of this research asserts that wood and brick as local materials could provide better thermal comfort than concrete in the outdoor spaces of Tehran.

Keywords: Thermal Comfort, Outdoor Space, Wood, Brick, ENVI-met 4

Trial Study of the Effect of Glue Type on Finger Joint Strength of Plantation *E. nitens*

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ABSTRACT

Gluing *Eucalyptus nitens* (a hardwood species) to make structural timber elements is a new frontier in the global timber industry. Very little is known about the finger joint efficiency of *E. nitens* sawn boards or how it bonds when different adhesives are applied. Our goal for this study, was to establish the glue type effect on finger joint efficiency of *E. nitens*. In this study, there were six sample groups considered three types of glue, two geometries, and one surface treatment. Three groups of samples had been manufactured by using two one-component polyurethane (PUR) adhesive from different manufacturers and Resorcinol Formaldehyde (RF) adhesive. Two comparison groups of samples had been made by spreading primer before applying two PUR adhesive. In addition, one group of samples had been manufactured by using PUR(a) with a different finger joint length. Each sample had been ripped into three specimens by table saw. One of the specimens was shaped by bandsaw into tensile test sample with waisted section, and the other two specimens were tested by three-point bending tests, one as horizontal finger joint. The finger joint efficiency on both bending and tensile strength by using different adhesive have been observed. In bending tests, vertical finger joint has higher efficiency of MoR, but not MoE. Primer helps improve the finger joint efficiency of MoE, but not MoR. Geometry affects bonding performance of finger joint significantly. Finger joint with the length of 20mm performed better than that with 10mm. In the tensile tests, PUR (b) performed best in terms of the tensile strength. Further study by making more samples from fibre managed *E.nitens* and *Eucalyptus globulus* are forthcoming.

Keywords: finger joint; adhesive; hardwood; E. nitens

Binderless Bio-based Cathode from Wood

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ABSTRACT

Activated carbon can be a good material for electrochemical storage applications due to its low cost, low toxicity, and good total surface area. Wood is a good carbon containing precursor material to produce activated carbon. Wood is anisotropic, with mechanical properties varying depending on the direction of load. Wood also contains internal channels for water and nutrient transportation, which can be taken advantage of for charged ion transportation in electrochemical storage. However, during the wood-carbon conversion process, some of the natural structures can be destroyed making the biocarbon brittle and fragile. Current usage of biomass derived activated carbon for electrodes involves crushing and grinding the activated carbon into fine powder, then using polymer-based resins, such as polyvinylidene fluoride (PVDF) or Polytetrafluoroethylene (PTFE) to bind the activated carbon powders together. Crushing and grinding destroys the macrostructures of the activated carbon, and the microstructure of the activated carbon becomes disordered in powdered form. Polymer resins are non-conductive, and they block the internal pores of the activated carbon, lowering the electrochemical performance of these activated carbon electrodes. In the current study, thin slices of a hardwood species, balsa, and a softwood species, southern yellow pine, are cut to 0.5 mm thick from different directions: longitudinal, transversal, or tangential. These slices are then activated physically under vacuum with different activation temperatures (700 °C, 850 °C, or 1050 °C). The total surface area and porosity of these slices are tested with Brunauer-Emmett-Teller (BET) method with nitrogen, their mechanical properties tested with traditional bending and loading tests, and their electrochemical properties are explored with cyclic cytometry. This study presents a new bio-based cathode product for battery and supercapacitor with no polymer binders, which benefit the engineering process of future activated carbon to utilize the natural internal structures of the biomass precursors for electrochemical storage applications.

Keywords: activated carbon, electrochemical storage, surface area, biomass, mechanical properties

Multiple Ecosystem Services Of Monoculture Hardwood Plantations: A Case Study Of Spotted Gum Forests In Queensland

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ABSTRACT

Forest managers are increasingly encouraged to consider the multiple ecosystem services that forests provide. Spotted gum (*Corymbia citriodora* subsp. *variegata* - CCV) hardwood plantations can provide economic benefits while providing important ecosystem functions. This study aimed to determine the fiber services (timber production, volume and bioenergy) and co-benefits (CO_2 sequestration and belowground carbon storage) from an 18-year-old spotted gum plantation in Queensland. To accomplish this objective, equations of total stem volume of living trees and merchantable sawlog volume have been developed. Forest inventory data were combined with species-specific biomass equations to estimate the total timber production, merchantable volume, bioenergy, belowground carbon and CO_2sequestered in spotted gum plantations. Results showed that mean total stem volume and commercial sawlog volume were 302.4 m^3 ha^{-1} and 139.2 m^3 ha^{-1} respectively. Mean tree biomass (excluding commercial timber) with potential use for bioenergy was 47.6 Mg ha^{-1}. Trees sequestered 278.3 Mg ha^{-1} of CO_2 equivalents and tree roots contributed about 17.1 Mg ha^{-1} to below-ground carbon storage. These findings show that monoculture plantations provide potential multiple values in terms of timber production, biomass production and carbon storage and demonstrate the opportunity to optimise environmental and economic values of hardwood plantations. This is especially the case for spotted gum, a hardwood plantation species with great potential in Queensland which accounts for 62% of the existing total hardwood plantation estate.

Measurement of Wood Moisture Content Variations in the French Forest Resources

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ABSTRACT

The knowledge of the wood moisture content in standing trees is useful for optimizing the wood transport as well as the wood drying. Studies dealing with this property are few and often focused on small geographical areas.

The measurements of wood moisture content were made on increment cores sampled during fifteen consecutive months on about twenty thousand cores sampled in the French forests (Leban et al., 2017). Each core was CT scanned two times, after sampling and after drying. The processing of the tomographic images (Jacquin et al., 2019) permits to obtain for each core, the wood density "green" and "ovendried". Then the initial moisture content and basic density were calculated.

Here we present the results of the variations of the wood moisture content between August 2018 and October 2019, for the ten most important French forest species: *Quercus petraea, robur* and *pubescens*, *Fagus sylvatica*, *Carpinus, Pseudotsuga menziesii, Pinus pinaster, Pinus sylvestris, Abies alba*, *Picea abies*. The intra-tree variation pattern of wood moisture content is species dependent and we point out a huge between tree variability.

These results confirm and show that (i) at the intra specific level, the standard deviation of moisture content increases with moisture content, (ii) at the inter specific level, moisture content of softwoods is higher than for hardwoods, (iii) softwoods have higher seasonal variations of moisture content than hardwoods except for *Pseudotsuga menziesii*, (iv) the wood moisture contentin standing trees drops sharply in the beginning of summer except for *Pinus pinaster*, (v) high wood basic density implies low wood moisture content and (vi) the within species variations of wood moisture content are driven by the basic wood density variations.

Keywords: Wood Moisture Content, Increment Cores, Variation, Basic Density, Seasons, Species, Carden software, XyloDensMap.

INTRODUCTION

Every year, the French National Forest Inventory (NFI) collects about thirty thousand tree cores from seven thousand forest plots. In 2015, the XyloDensMap (XDM) was launched with the objective to enrich forest information by collecting the increment cores that were previously left on ground after the counting of the number of annual rings (tree age) and the measurement of the growth increments of the last five formed annual rings. The increment cores were stored in polycarbonate alveolar plates and send to the INRAE lab for the measurement of the wood basic density. During 15 consecutive months, we also measured the wood moisture content (MC).

Wood moisture content is the ratio of the mass of water in wet wood to the anhydrous mass of wood (Dietsch et al., 2015). It is a useful physical property for the forestry-wood industry because at least three actors in the industry use it: the forest manager, the transporter, and the processor. Knowing the MC of wood allows the forest manager and log transporter to define the best options for minimizing the amount of water. The wetter the wood, the heavier it is, and therefore, the higher the transport loads (Tomczak et al., 2018). Secondly, information on wood moisture would also help to optimize drying, which is often necessary before the conversion of rough sawn timber in end-products (Longuetaud et al., 2017).

Previous studies on wood moisture have demonstrated the existence of intra-tree variations in this property (e.g., Fiora and Cescatti, 2006; Longuetaud et al. 2016, 2017; Tomczak et al. 2018). Nevertheless, none of them had projected to a national scale. It is in this context that the present study, which follows up on the work of (Randriamananjara, 2019) was developed.

MATERIALS AND METHODS

Protocol for measuring density and moisture content of wood cores and data acquisition

As mentioned above, the wood cores collected in the field were inserted in sealed polycarbonate plates and posted to the INRAE laboratory.

Each increment core is identified by the position of the core within each plate and by the plate number. This allows to associate the new wood properties measurements with the field measurements performed by the NFI staff (species, number of trees per hectare, sampling date, soil type, stand type, etc.).

Each plate contains a maximum of 15 cores, 17 plates were grouped together to form a package. Five packages passed together through a medical scanner, the first scan was made with fresh cores, and the second one was made on the same cores after drying during 48 hours at 103°C. For each scan we stored tomographic images of the cores, these images were then processed by the mean of the Carden software (Jacquin et al. 2019)

The output of this processing consist in two wood density profiles per core (fresh and ovendried) with one axial resolution of 0.625 mm.

By combining both wood density profiles we calculated the basic wood density and the wood moisture content.

Calculation of moisture from the average density

Knowing that the wet cores underwent a journey from their place of collection to the INRAE laboratory, we know that despite their conditioning, they lost part of their moisture by evaporation. We measured in a separate experiment the amount of water lost during the transport of the cores by post and undertake a correction. For each species, a linear regression was established between the wood MC and the time between the date of arrival and the date of collection in order to bring the date of collection to zero (Randriamananjara, 2019):

$$H(\%)_{j=0}=(\Delta_y/\Delta_x*\Delta_j) + H(\%)_{cal} \quad \text{Equation (1)}$$

With the knowledge that

$$H(\%)_{cal}=(\rho_h/(\rho_0*(1-R_{VT})-1))*100 \quad \text{Equation (2)}$$

With:
- ρh: wet density per slide or core at the sampling date.
- $\rho 0$: dry density per slide or core at the sampling date.
- H (%) j=0: the estimated moisture content of the wood at the sampling date.
- H (%) cal: the moisture content of the wood at receipt of the cores.
- $\Delta y/\Delta x$: the regression slope of the moisture content between the sampling time and the arrival.

RESULTS AND DISCUSSION

Variation in moisture content between tree species

At the species level, the variance of MC is positively correlated with MC (Fig. 1). At the interspecific level, softwoods have a higher MC than hardwoods. We can observe that *Abies alba* has the highest moisture content.
This following graph depicts that at the intra specific level, the standard deviation of MC increases with moisture content. When a species has high MC, it also has high standard deviation. It is the case for *Pinus pinaster, Pinus sylvestris, Norway spruce* and *Abies Alba*.
At the inter-specific level, the MC of softwoods is higher than for hardwoods. It is explained by the fact that hardwoods vessels areas is small, in consequence, the lumen can be full with a small amount of water. In opposite, softwoods have tracheids and the lumen are big and can contain bigger amount of water.

Figure 1: Moisture content of 10 trees species

Seasonal variation in moisture content

As the measurement of MC spans 15 consecutive months, we can measure the MC variations across the 4 seasons of one year (Fig. 2). Regardless of the time of year, except for *Pseudotsuga menziesii*, softwoods always have a higher MC than hardwoods. For softwoods, *Abies alba* has the highest MC throughout the season, reaching up to 101.79%, and the lowest is attributed to *Pseudotsuga menziesii*. Generally, over the entire 15 consecutive months, hardwoods show a little seasonal variation in moisture and a lower moisture level than softwoods.
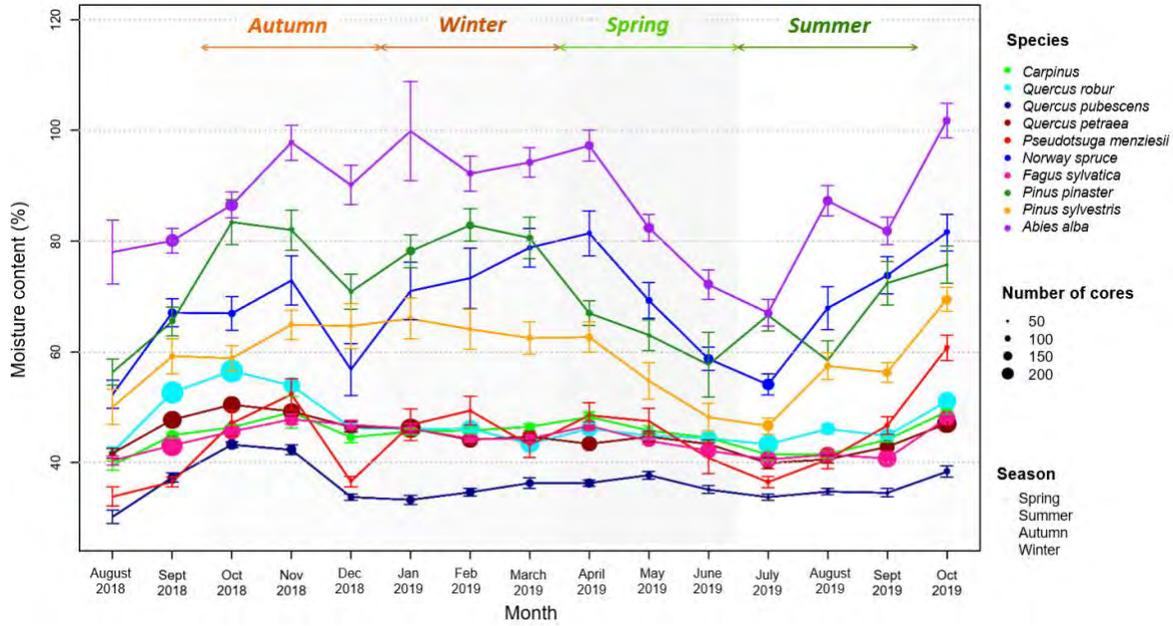
Figure 2: Wood moisture content in function of seasons

Wood MC variations and wood basic density

In the following graph the blue doted upper curve represents the maximum wood MC content (Fig. 3). Each dot represent the MC for one species, the size of the dot is proportional to the number of cores. The two vertical black segments above "poplar" and "chestnut" represent the amount of air present in the wooden cell (no water). Altogether, we can see that softwoods have a higher MC than hardwoods. This is explained by their lower basic density. Poplar is one outlier as it has the lower wood basic density and the higher wood MC. As they have denser wood, hardwoods have less space available than softwoods for the storage of free water in their stems. In other words, at the interspecific scale, the proportion of air decreases when basic density increases.

Figure 3: Moisture content in function of basic wood density

Between-tree variation in moisture content

An overall radial increase in pith-to-bark MC was observed for *Abies alba*, *Pinus pinaster, Norway spruce,* and *Pinus sylvestris* (with a MC differences of +20%, p <0.005) (Fig. 4). Knowing that the sapwood holds the highest moisture content, *Pseudotsuga menziesii* showed a strong radial increase in moisture from the pith to the bark with an elevation of 35%, p <0.001. The MC near the pith of *Pinus sylvestris* is lower compared to the outer parts, this species has the least variation in intra-tree MC among softwoods. In all hardwoods, a small radial increase was observed with a variation of +5%, p <0.001). Nevertheless, a significant difference in MC between the three radial positions was observed, except for *Carpinus*, which showed only a difference between the middle part and the sapwood part (Fig. 5).

Figure 4: Between tree moisture content of softwoods
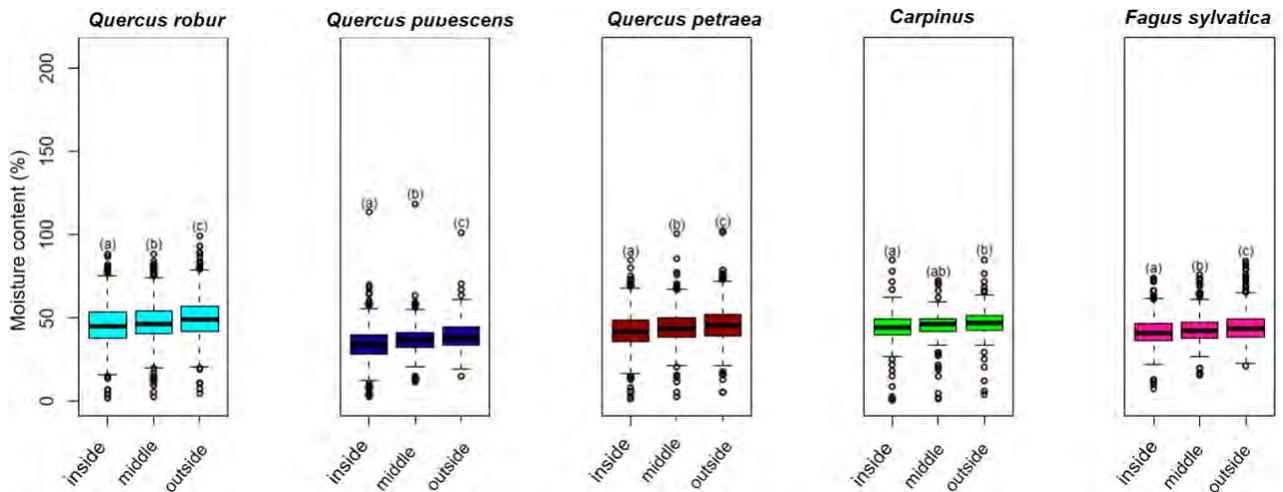
Figure 5: Between tree moisture content of hardwoods

CONCLUSIONS

This first analysis of the intra-tree variations of wood MC in relation with the wood basic density variation provides a new original data set that improves our knowledge of the wood properties variations in the French forest resources.

The originality is twofold as we have measured the wood MC variations over fifteen consecutive months for ten forest species and for each species we measured the intra-tree pattern of variation at breast height.

Over the sampling period the wood MC varies between 30-100% for softwood and between 15-55% for hardwoods.

Clearly for softwoods there is a higher MC difference between heartwood and sapwood between 20 and 35%, while those for hardwoods were in the range of 5-10%.

In this work, we have illustrated that the wood MC variations need to be presented in relation with the wood basic density variations, that wood moisture content of the tree stems candidate for defining the ability of trees to face a severe drought period.

More broadly, this new data set paves the avenue for other investigations aiming at better understand and explain the observed differences between species and their hydraulic functioning especially in the present context of increased tree mortality caused by the climatic change.

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Effect of Hemicellulose Hydrolysate Addition on Drying and Redispersion Behavior of Cellulose Nanofibers

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ABSTRACT

In recent years, various nanomaterialization methods of cellulose have been developed, and nanocellulose utilization in a wider industrial field is being actively attempted. Nanocellulose has shown excellent physical and thermal properties comparable to petrochemical-based polymer materials. For this reason, The demand for scale-up of nanocellulose production and commercialization of these based products is increasing. However, for efficient storage and transport of the product, the nanocellulose needs to be dried, which causes irreversible agglomeration of nanocellulose. The reason for the aggregation of nanocellulose during the drying process is known to be due to the formation of a strong hydrogen bond between the cellulose molecules. Because of intermolecular hydrogen bonding, nanocellulose loses its intrinsic nano-properties, and for this reason, generally, many commercialized nanocellulose products are supplied in a water-dispersed suspension.

In this study, using the hydrolysis product of hemicellulose that constitutes wood together with cellulose as an additive, an efficient drying and redispersion system of nanocellulose was established. For this purpose, xylose, a pentose sugar, was used as a model additive. A CNF/xylose mixture was prepared by varying the content of xylose, and the morphology, transparency, and shrinkage of the film were analyzed after preparing a film by oven drying. The redispersion behavior of CNF/xylose film according to time was measured, and the dispersion stability of the CNF redispersion suspension was evaluated through a precipitation test for 24 hours. After centrifugation of the redispersion mixture, the supernatant was separated to get rid of xylose, and the removal of additive was confirmed by FTIR measurement.

As a result of the oven drying of CNF films, many wrinkles were observed on the surface of the CNF film without the addition of xylose, which is a phenomenon caused by aggregation between CNF fibers. As the xylose content increased, the film showed a uniform surface. As a result of morphology analysis through FE-SEM, in the case of CNF without xylose, agglomeration of fibers was developed during dehydration, but the nanofiber structure of CNF was better observed as the amount of added xylose increased. As a result of measuring the redispersion kinetics of the CNF/xylose film, the dispersion rate of the CNF/xylose film was significantly faster than that of the pure CNF. When comparing the dispersion stability of the

redispersed CNF suspension, the sample with added xylose showed excellent stability, whereas the phase separation of the CNF and water was clearly observed for neat CNF after 24 hours. In the characteristic evaluation to confirm the removal of the additive, the FTIR graph of CNF with xylose was different from that of pure CNF. However, the xylose removed CNF sample showed the same graph as pure CNF, proving that xylose was completely removed.

Keywords : Cellulose nanofibers; Hemicellulose hydrolysate; Xylose; Drying; Redispersion

Acknowledgements

Development Strategy of Cationized Nanocellulose Hydrogel Adsorbent for Effective Cr(VI) Removal

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ABSTRACT

Nanocellulose has a large specific surface area and is advantageous for water treatment. However, its application as an adsorbent was limited due to poor processability. Therefore, this study developed a high-performance cellulose hydrogel adsorbent by an aqueous solution dissolution method and cationic modification. As a result, the adsorbent showed 578 mg/g of Cr(VI) removal capacity and was reusable 9 times. This study will provide fundamental insight into fabricating structural stable nanocellulose-based materials and technical information about environmental restoration.
Keywords: Cellulose; Nanocellulose; Cr(VI) chromium; Cationization; Adsorbent

Dancing Wood Fibers - Engage Children in Wood Science with Triboelectricity

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ABSTRACT

The triboelectric effect was already known in ancient Greece. Electricity is derived from the Greek word ελεκρον, which means amber. Friction is called *tribeia* in Greek (τρίβω), so frictional electricity can be translated as *triboelectricity*. If amber is rubbed on a fur, the fur is charged positively and the amber negatively. When two materials with solid surfaces come into contact, charge is transferred from one surface to the other. This charge transfer is called contact electrification or frictional electricity. When the materials are separated again, the imbalance of the electrostatic charge becomes obvios and the static electricity becomes visible. During contact, each of the two materials develops a charge of opposite polarity.

Children are already quite familiar with this phenomenon, as if an air balloon is rubbed against a piece of clothing, the electrostatic charge causes it to stick to the clothes, or it can make a colleagues' hair stand on end. However, the triboelectric effect, also occurs in processes of everyday life. This poster is designed to explain the physical principles underlying the triboelectric effect to children in a visually appealing manner. The effect is demonstrated on wood fibers by means of electrical charges through friction, with the wood fibers getting magically animated to actually "dance".

Keywords: science communication, education, wood fibers, triboelectricity, electrostatic charging

Serviceability Performance of Cross-Laminated Timber Panels from Fibre Managed Plantation Hardwood

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ABSTRACT

The aim of this research is to investigate the serviceability performance of cross-laminated timber (CLT) panels made from fibre managed plantation E. nitens. Historically, most of the CLT products used in construction industry have been made of softwoods because they have better workability, while hardwoods normally have a lot of strength-reducing features (SRFs). Tasmania currently has a large volume of fibre managed E. nitens in plantations which normally used to produce low-value products such as woodchips. However, with the development of technology, more and more researchers are looking for ways to turn this low-value material into high-value products, and CLT is one of the ideal options. Recently, the mechanical properties of CLT panels constructed from fibre-managed E. nitens have been measured by some researchers. However, the studies on their serviceability performance are limited and worthy to investigate. From my proposal, I will conduct three main experimental tests to determine the serviceability performance of the CLT panels. Firstly, a short-term serviceability bending test will be performed to check against deflection of CLT panels under service limit states (SLS) requirements. Secondly, the vibration test will be implemented to assess the dynamic response of the CLT panels to human-induced activities such as footstep from normal walking. Finally, a long-term bending test for at least one-year period will be conducted to determine the creep behaviour of CLT panels. These tests have never been done on CLT panels constructed from E.nitens, and the results will be beneficial to the industries that consider using fibre-manage E. nitens as raw materials in CLT construction because they will illustrate how those structural elements work within their serviceable lifespan.

Keywords: Cross-laminated Timber, Fibre-managed E. nitens, Serviceability, Bending test, Vibration test, Creep bending test.

Economic Ripple Effects of Cross Laminated Timber Manufacturing in Japan

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ABSTRACT

Recently, timber is promoted in Japan to ensure the efficient use of artificial forests that have reached a suitable age for logging as well as a measure to tackle global warming and revitalize forestry. As a result, Cross Laminated Timber (CLT)—which has unique structural characteristics and thermal insulation properties—has come into prominence. Timber is utilized by various industries, including forestry. The timber industry includes different stages such as production, processing, transportation, and construction. Given that CLT, as a new type of timber, has received widespread attention, it becomes necessary to study its economic ripple effects. This study targeted CLT manufacturers in Japan to quantitatively evaluate the economic ripple effects of CLT through an input–output analysis, which is used to estimate the independent relationship between different economic sectors and industries. Based on the results of a survey of CLT factory's revenue expenditure, we use an extended input-output table to calculate the economic ripple effects of CLT manufacturing in Japan in 2020. The results of the study show that lumber, logs, wholesale, road freight transport (excluding private transport), and electricity are the top five sectors with the largest impact of CLT manufacturing. In terms of total economic ripple effect of CLT, the economic ripple effect multiplier is more than twice, and the size of induced employment is also more than twice the size of direct effect employment. In addition, compared with glued laminated timber (GLT), the economic ripple impact of manufacturing CLT is greater than that of manufacturing GLT for the same values of timber production.

Key Words: Economic Ripple Effects, Cross Laminated Timber, Input-Output Analysis, Timber Manufacturing

Comparing the Serviceability of Different Species Used for Flooring Under Extreme Indoor Environmental Conditions: A Tasmanian Case study

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ABSTRACT

Serviceability of timber flooring is influenced by many factors depending on its end use application. The resistance to indentation and abrasion, dimensional stability and long-term retention of appearance properties are some of the main considerations. However, the laboratory testing regimes conducted under induced conditions to evaluate these properties might not always provide accurate information or replicate in-service behaviour. Although, in-service trials take longer to generate results, they are important in deciding the serviceability of a certain timber floor when subjected to exposure conditions closely related with its expected end use. In this study, five panels consisting solid, strip timber boards of native grown *Eucalyptus obliqua, E. pilularis* (Blackbutt), *E. sieberi* (Silvertop Ash) were installed along with Tasmanian plantation grown fibre managed *E. nitens* and sawlog managed *E. nitens*. These test specimens were installed in a corridor located in a glass atrium at an educational institution in Launceston, Tasmania. The floor was monitored for twelve months to compare the impact of traffic and environmental conditions and visual observations were recorded. Since the corridor has glass roof and walls, the timber was exposed to direct sunlight during daytime over four seasons. In preliminary observations, fibre managed *E. nitens* started to show cracks few weeks after installation. *E. obliqua* and sawlog managed *E. nitens* showed good stability and in-service behaviour in comparison with dense timber such as *E. pilularis* and *E. sieberi* under extreme environmental conditions and exposure to moderate traffic.

Keywords: *E. obliqua, E. nitens*, serviceability, in-service trial, timber flooring

Greenhouse Gas Emissions and Embodied Energy Analysis of Equivalent Performance Structure Members by Building Material

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ABSTRACT

The building sector actively evaluates the environmental impact as climate change becomes serious. It is common to set the functional unit as unit volume or unit weight to conduct Life-Cycle Assessment. For this reason, it is inappropriate to directly compare the buildings designed with different materials based on Life-Cycle Assessment data of materials. This study aims to quantitatively compare the environmental impact of beam members designed with various materials. Specifically, 28 beams were designed by selecting three types of materials: reinforced concrete, steel, and wood, and seven types of spans ranging from 4.5m to 7.5m to evaluate greenhouse gas emissions and embodied energy. In this study, a functional unit is defined as quantity input to perform the equivalent architectural function. Greenhouse gas emission is about 1.8 times for steel beams and 0.7 times for timber beams compared to reinforced concrete beams of the same span and embodied energy shows a similar trend to greenhouse gas emissions. As the span increases, greenhouse gas emissions and embodied energy increase regardless of the material, but the amount and trend of increase vary depending on the material. This evaluation differs significantly from comparing studies defining existing functional units by volume or weight, suggesting that it is essential to compare them based on equivalent performance in environmental impact evaluation by building material.

Keywords: Greenhouse Gas, Embodied Energy, Life Cycle Assessment, Reinforced Concrete, Steel, Timber

Evaluation of biodegradability and characterization of biodegradable plastic depending on lignin content

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ABSTRACT

Recently, the problem of microplastics and plastic waste has arisen due to the rapid increase in plastic usage. As one of the solutions, biodegradable plastics that are decomposed by natural factors such as microorganisms and sunlight are in the spotlight. Various standards for evaluating the biodegradability of such biodegradable plastics have been proposed, but studies on biodegradability characteristics according to biodegradation conditions and plastic properties are insufficient. Therefore, it is required to evaluate the biodegradability aspects according to the properties of plastics under various conditions.

In this study, the biodegradation aspects of polymers in which polylactic acids (PLA) and polyhydroxyalkanoates (PHAs), which are biodegradable plastics, are blended in different ratios are investigated under various biodegradation conditions. In addition, the biodegradability aspect of the blended biodegradable plastic after chemical modification of lignin to control the biodegradability of the biodegradable plastic, lower the price, and impart physical properties was evaluated. The biodegradability evaluation was conducted based on ISO 20200 method. The optimal decomposition temperature was searched for by setting the temperature conditions after embedding the sample prepared in the activated compost. During the evaluation, the weight loss due to biodegradation is measured through a weighing scale, molecular weight changes through Gel Permeation Chromatography, thermal properties through Thermogravimetric Analysis, and crystallinity region change through X-ray Diffraction are observed. In addition, the bacteria that act on the biodegradation were identified through 16s rDNA sequencing. As a result, in the case of temperature conditions, almost no biodegradation occurred at 40°C, but the biodegradation rate increased as the compost temperature increased. In the case of blended plastics according to the ratio of PLA and PHAs, the weight loss rate decreased as the PHAs mixing ratio increased. In the case of molecular weight, it decreased as the biodegradation period increased, and the decrease in molecular weight also increased, looking alike a tendency to weight loss. In the change of the crystallinity region, the amorphous region was strongly expressed before the initial sample was buried in the compost, but as time passed, the peak of the amorphous region decreased, on the contrary, the peak of the crystalline region gradually increased. At 60 days, the crystal region in acetylated lignin PLA

increased compared to 30 days, which is thought to be due to the hydrolysis of the acetyl group introduced into the hydroxyl group to reduce the molecular weight and increase the crystal region. The thermal decomposition property of plastics containing lignin are decomposed at a higher temperature due to heat resistance, which is one of the intrinsic properties of lignin. As biodegradation progressed, there was a steadily decreasing change, but the residual amount of acetylated lignin PLA increased compared to PLA and lignin PLA as of 60 days, which is the occurrence of char residue. Acetylated lignin has improved physical properties and heat resistance compared to kraft lignin, which contributes to compatibilization.

Keywords: Biodegradable plastics, PLA, PHA, ISO 20200, Acetylation Lignin, Lignoplastics, Biodegradation test

Sustainability Communication of Wood Sector in Comparison to Textile and Car Industry

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ABSTRACT

With next generations in mind, we need to think about our planet's limitations in all our current actions and we need to be aware the resources we are using today are not permanent. One solution towards this can be by using renewable materials, which (as the word suggest) can be renewed and reused after the end of their life cycle. For more sustainability-oriented society, an important shift in people's perceptions is needed, hence we need to invest in creating more awareness about the importance of sustainability with different stakeholders, and appropriate marketing and communication strategies can make a great difference.

The objective of this research was to study the sustainability communication in three-pillar paradigm of sustainability – economic, environmental, and social to understand if there are any differences among these three pillars in three different sectors producing products for general public. The wood, textile, and car industry were selected. Additionally, these three sectors were selected based on past studies concluding that they are part of industries contributing similar amount to the CO2 emissions. For each of the sector representative company was selected based on size of the company (number of employees), geographical location and brand value. The selection of the representative companies was IKEA Group representing the wood industry, H&M representing textiles, and Volkswagen Group representing car manufacturing industry. The analysis applied qualitative content analyses of their web pages. The analysis of the online communication of selected companies demonstrated all the selected industries communicate about similar topics in the sustainability communication. All three studied representative companies communicated on their webpage the most about the environmental aspect of sustainability, while the social and economic one were less frequently used. There were not any significant differences found. The wood industry although utilizing renewable natural material communicates about the sustainability similarly as the other two studied sectors.

Advanced Finite Element Modelling Technique to Simulate Delamination Of Cross-Laminated Timber Under Out Of Plane Loading

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ABSTRACT

Development of finite element models for reliable prediction of glue interface delamination occurring in cross-laminated timber (CLT) is quite challenging. The inherent softness of timber material combined with rolling shear and fibre fracture characteristics make it difficult to distinguish between timber and glue failure. In this paper, a bi-linear traction separation based cohesive zone (CZM) modelling for glue interface is used in conjunction with continuum damaged mechanics (CDM) built an orthotropic material model to predict the failure behaviour of CLT. The parameters for CZM were calibrated and established using test results obtained from double cantilever beam (DCB) Mode-I and end-notch flexure (ENF)-Mode-II fracture tests conducted on adhesive timber bond. A full-scale CLT panel was also simulated, and the observed behaviour was compared with relevant experimental results obtained from bending and shear tests showing good agreement between test and the adopted FE modelling techniques. The developed FE model was shown to capture pure glue delamination as well as combined glue and timber fracture. Numerically obtained results demonstrated good predictions for failure strength, modulus of elasticity, and the overall post-elastic load-displacement response of the CLT panel.

Effect of Moisture and Fungal Attack on CLT Connection

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Abstract

Cross-laminated timber (CLT) is increasingly utilized in larger structures throughout Australia. CLT performance in the Northern Hemisphere is not necessarily a good indicator of how it will perform in Australia and/or other sub-tropical/tropical climates. Large areas of Australia have a sub-tropical climate conducive to developing elevated moisture levels suitable for fungal attack while much of the mainland experiences heavy termite pressure. An overlooked risk of moisture intrusion followed by biological attack is the potential effect on the timber connections that ensure structural integrity. While a variety of connectors are used in mass timber buildings, self-tapping screws are widely used for wall-to-wall and wall-to-floor connections. These connections are assumed to stay dry; however, moisture intrusion can occur during construction as well as through leaks or condensation in service. Understanding the effects of moisture intrusion and potential associated fungal attack on the mechanical properties of the connection is critical for ensuring reliable and durable structural performance. This research examines the effects of elevated moisture content coupled with fungal attack on structural performance of self-tapping screws in CLT. Samples subjected to different wetting regimes followed by fungal exposure will be assessed for losses in structural capacity as well as fungal-associated changes in wood properties i.e. loss of density. The results will help guide the development of improved methods for assessing moisture effects on mass timber as well as highlight the possible effects of moisture and fungal attack on connector behaviour.

Key Words: CLT, connections, moisture, durability, decay

Making Knowledge about Renewable Materials Accessible and Engaging with Educational Videos based on Instructional Design

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ABSTRACT

The shift to using renewable materials is essential to help create a sustainable future on a planet with limited resources. Research and innovations in wood science are greatly improving, but findings need to reach the widest possible audience so they can be used in practice and benefit us all. Learning through watching online videos has become ubiquitous both before and during the COVID-19 pandemic, so it is important to understand how it affects viewers and to study guidelines to make educational videos more effective, both for learners and educators.

Over the years, extensive research has been conducted on designing effective multimedia lessons based on the cognitive multimedia learning theory and cognitive load theory – theories that aim to inform educators on how to design learning materials in accordance with the way human cognition works. Recently, researchers and practitioners alike have also focused on ways to engage learners and affect the emotions that could promote learning with an approach called emotional design. However, the principles of learning with video may differ depending on the subject covered and the characteristics of the learners, making it imperative to test different approaches on different populations.

Deeper knowledge about renewable materials and how to work with them is vital not only for various industries but also for the general public, who are the final users and investors in these innovations. For this reason, we developed five educational videos, with a total length of 24 minutes, with the goal of teaching people with little or no previous knowledge about wood as a building material. The videos introduced them to concepts like advantages and disadvantages of using wood-based materials in construction, service life and performance limits, wood degradation processes like weathering, wood decay, and insect damage, and how to combat them by selecting the right materials, protective design measures and maintenance.

In a series of experiments, we tested how successfully people learned from the five educational videos, and what are the effects of several instructional design interventions like the different

emotional tones of the narrator and the addition of subtitles to the videos. After viewing the videos, participants completed a knowledge test on the content of the videos, which consisted of questions related to remembering the presented content (i.e., retention), and to the ability to use the newly gained knowledge in novel situations (i.e., transfer).

The presentation will introduce evidence-based principles of designing effective learning materials, based on examples of learning materials on building with wood, and present how the learners perceived educational videos and how much they learned from them. After providing a general overview, we will focus on more specific findings, for example, that despite learning about wood as a sustainable construction material, participants still held on to their presumption that using wood for construction harms the environment. These findings are necessary to ensure that newly developed knowledge from wood science gets transferred to a wide array of stakeholders in a digestible and understandable manner to promote better adoption and faster sustainable development.

Keywords: online learning, multimedia learning, instructional video, emotional design, renewable materials, sustainability, knowledge transfer

Comparisons of Wood Quality Among Pines: Naturally Regenerated Longleaf vs. Planted Longleaf and Planted Loblolly

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ABSTRACT

Longleaf pine (*Pinus palustris*) once dominated the southeastern U.S. landscape, but changes in land use have reduced its habitat to only a small fraction of its original range. Longleaf pine naturally produces high quality wood but has not traditionally been considered a productive plantation species compared to other southern pines such as loblolly (*Pinus taeda)* and slash (*Pinus elliotti*) pine. Minimal research has been conducted on longleaf pine wood properties, hindering understanding of how silvicultural decisions affect its wood quality. We compared wood and fiber quality for four species-site combinations: planted longleaf pine on forest cutover sites, planted longleaf pine on old agricultural field sites, longleaf pine in naturally regenerated stands, and loblolly pine in plantations. We sampled three stands from each of these four combinations, totaling eleven stands in southwest Georgia and one in the panhandle of Florida. We felled 10 trees per stand and collected wood disks at various heights up the stem. We generated a comprehensive wood quality assessment by measuring ring-by-ring specific gravity and acoustic velocity incrementally up each tree. We used the data, to construct models and create whole-tree property maps. The results of this research will provide landowners and timber companies insight into how regeneration methods and growing sites influence longleaf pine wood and fiber quality.

Keywords: Southern Pine, Wood and Fiber Quality, *Pinus palustris*, *Pinus taeda,* Specific Gravity, Acoustic Velocity, Regeneration Method

Real-time Monitoring of the Hygrothermal Performance of a CLT School Building

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ABSTRACT

Emerging wood products, such as cross-laminated timber (CLT), and wood fiber insulation (WFI) are sustainable, renewable, and low carbon footprint building products, which have been recognized as alternatives to steel, concrete, and fossil-based insulation, e.g., extruded/expanded polystyrene foam (XPS/EPS). With the first domestic WFI manufacturing plant born in Maine, the University of Maine began a pioneer study to investigate the hygrothermal performance and energy consumption of a CLT building insulated with WFI in June 2021. CLT and WFI have decent to excellent moisture buffer capacity and considerable latent heat. When exposed to an ambient environment, wood naturally buffers fluctuations in humidity by adsorbing moisture vapor to save them in the cell walls as bound water and then slowly releasing it when the humidity drops. This process is accompanied by heat release and heat gain due to the phase change of water vapor and bound water. It has shown potential to effectively reduce the impact of spikes or drops in humidity and temperature on a room's ambient feel. This study aimed to investigate the hygrothermal performance of an all-wood building constructed with CLT and mechanically fastened WFI. The monitoring data included are, temperature and relative humidity through the thickness of the insulation, the equilibrium moisture content of the WFI, the moisture content of the CLT, indoor and outdoor conditions, and finally building energy consumption. These data will be used to compare lab-scale data to the in-situ measurements, validate building design practices and modeling results, and evaluate the long-term structural health of the building.

Ability Of Shallow Preservative Barriers To Protect Australian Eucalyptus Heartwood Timbers: Accelerated Testing

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ABSTRACT

Heartwood is highly resistant to fluid movement, making it exceedingly difficult to achieve the preservative treatment required by many national standards, including those in Australia. Pressure treatment of heartwood generally results in a shallow envelope (<5 mm) surrounding a largely untreated core. This is a major issue in many of the lower durability plantation hardwood timbers in Tasmania that contain high percentages of heartwood. Preservative treatment of these materials should theoretically remain effective as long as the preservative barrier remains intact. Long term studies on softwoods such as spruce decking suggest that barrier treatments can provide decades of protection. While these results are promising, it is unclear whether shallow heartwood treatments would perform as well on lower durability hardwoods. Field tests would take decades to produce meaningful results, while accelerated laboratory or field trials might help bridge the testing gap. The purpose of this project is to develop accelerated decay methods for assessing the ability of shallow barrier treatments to protect lower durability plantation hardwoods. Components of this research include exploring pre-exposure leaching, the effects of check development on barrier performance and methods for assessing preservative chemical mobility as it redistributes on untreated surfaces. The results will be used to assess the potential for barrier treatments for above-ground applications, shorten the times required to demonstrate their efficiency, and support new markets for these emerging materials.

KEYWORDS: Low durability hardwoods, Tasmanian oak, Shining gum, heartwood, laboratory tests, barrier treatments, accelerated decay, chemical mobility

In-Depth Characterization Of Bondlines In Cross-Laminated Timber Made With Preservative-Treated Lumber

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ABSTRACT

Mass timber construction projects are rapidly increasing in number in North America but this technology encouters durability issues in termite-prone areas. To combat this issue, chemical treatments must be incorporated into mass timber elements to prevent termite attacks. However, pressure treatment is either unfeasible for large panels or may cause problems with bondline integrity if done prior to layup and we sought to investigate this problem. Douglas-fir 2 x 6-inch lumber or untreated cross laminated timber (CLT) panel sections were treated with one of three different preservative systems, pressure treatment with borates, pressure treatment with an all-organics preservative system (PTIP+IPBC) or dip treatment with propiconazole, tebuconazole and imidacloprid + borate (PTI). Treated and untreated lumber was used to manufacture CLT panels using one of two resins, melamine formaldehyde (MF) or Polyurethane (PUR). Delamination, shear block and wood failure were tested according to PRG-320. The all-organic preservative treatment passed delamination test standards when pressure treated lumber was used to layup panels, while utilizing borate-treated lumber for panel manufacture resulted in failure. To further determine if the preservatives cause a negative interaction with the adhesives, Dynamic Mechanical Analysis of MF and PUR mixed with treating solutions of each tested system. In-depth bondline characterization was done by sampling 18 locations of each panel treatment and visualizing bondlines using fluorescence microscopy. Adhesive penetration was quantified by counting cell impregnation in cross section. Data collected will be used to measure the impact of preservative treatments on CLT and will provide fundamental data that will help improve mass timber durability.

Novel Insights Into Self-Sustained Smouldering Of CCA-Treated Timber Poles

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ABSTRACT

Chromated copper arsenate (CCA) is one of the most widely used wood preservatives in Australia for protecting timber from fungal and insect attack in exterior infrastructure, due to its relatively high efficiency and strong reactions with the wood. Smouldering, the flameless oxidation of the solid phase porous char that is formed during a fire, is a known issue for CCA-treated timber after fire exposure. Smouldering can progress without flame and destroy or damage timber structures after flaming combustion has ceased. Since chromium and copper may act as catalytic promoters of smouldering combustion, CCA-treated timber infrastructure is considered especially susceptible to this process. CCA-treated electricity poles, fence posts, and railway sleepers have been reported to continue to degrade through smouldering combustion for an extended period after bush fires have passed, although the majority of reports on this issue have been anecdotal. Developing a better understanding of smouldering mechanisms would help in the development of better prevention methods.

A novel testing method was developed to assess self-sustained smouldering propagation after an imposed external heat supply was removed. This methodology was derived from the ENA pole test procedure and added internal temperature measurement, to quantify the severity of self-sustained smouldering in addition to visual observation. CCA-treated spotted gum pole sections were treated to meet Standard AS/NZS1604 for Hazard Class H5. All tested pole sections were instrumented with 1.5 mm diameter stainless steel sheathed thermocouples (TC) placed into predrilled holes at varying distances from the exposed surface to measure solid-phase temperatures. A radiant panel system provided the heat source based on a calibrated incident heat flux corresponding to the closest distance between the panels and the pole surface. Both non-treated controls and CCA-treated pole sections were subjected to constant heat flux and subsequent ventilation for a limited time.

Both CCA treated and untreated pole sections sustained surface char damage during heating and flaming, but only the former was severely damaged from self-sustained smouldering. No self-sustained smouldering was observed visually or via thermocouple measurements on the non-treated pole after flaming combustion. A CCA-treated pole subjected to a 50 kW/m^2 heat flux was still smouldering 21 hours after the initial heating including the untreated heartwood. This level of damage poses further

interesting questions with respect to the heartwood, which was untreated and thus expected to have a higher smouldering threshold temperature for smouldering oxidation.

The full paper will explain experimental results from different test configurations (i.e. heat exposure and flow condition) through analysis of the temperature development along the cross-section. Those results can be used to identify the governing factors that induce and influence smouldering, and explain why smouldering was observed in the non-treated heartwood region.

Effect Of Repeated Wetting And Drying On Withdrawal Capacity And Corrosion Of European Screws In Treated And Untreated Australian Sawn Timber

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ABSTRACT

Joints often govern the overall structural strength, stiffness, and most of the ductility in a timber structure. An appropriate connection design should not only consider structural performance but also address any potential performance loss while in service. Factors such as fastener coating, chemical preservation, or timber moisture content (MC) commonly affect the functionality and how long joints can last.

Screws are one of the most widely used fasteners in timber structures, due to their high axial load capacity and ease of installation. Understanding the effects of moisture and associated corrosion on performance loss of screwed joints is important for improving overall building performance. Most previous research either focused on relationships between MC and screw withdrawal strength, or fastener corrosion in treated timber; however, the effects of cyclic moisture intrusion on the structural performance of screws in treated timber is a crucial research gap that has not yet been addressed.

European connectors and fasteners are increasingly employed in Australia making it important to assess their suitability in the context of Australian timber construction. Differences in regulations may render some European fasteners unsuitable for Australian timber products, and the combination of European zinc-coated screws (i.e., thinner coating thickness of 7μm) with copper chrome arsenate (CCA) treated timbers is one such example.

Our research experimentally evaluated the effects of cyclic moisture changes on the withdrawal performance of European proprietary screws in Australian CCA treated timber. A total number of 88 yellow-zinc (YZ) and nickel-zinc (NZ) coated screws were installed in both Australian CCA treated and untreated Southern Pine (Slash/Caribbean hybrid pine) and subjected to a maximum of 24 moisture cycles. Changes in screw withdrawal properties and mass loss were used to assess performance loss and corrosion rates, respectively.

Withdrawal strength of all tested screws decreased to 55-75% of the initial prediction in the first 3 cycles of this test campaign, however, a clear recovery was observed between 3 to 12 cycles. Eventually, all screws lost at least 50% of their initial withdrawal strength regardless of timber treatment or fastener type after 24 moisture cycles. NZ screws in CCA treated timber exhibited better corrosion resistance in the first 3 cycles than YZ screws; however, this difference vanished with more moisture cycles. The corrosion rate of YZ screws in CCA treated timber was 40% higher than in untreated timber. While NZ screws had relatively better corrosion resistance than YZ screws, overall results indicated that the screws tested were not suitable for long-term use in CCA treated timber due to the strength loss caused by corrosion.

Anti-inflammatory effect of sesquiterpenoids extracted from major coniferous species in Korea

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ABSTRACT

Essential oils have been found to have excellent anti-inflammatory activity, but studies on sesquiterpenoids in essential oils and their interactions are insignificant. Therefore, studies on anti-inflammatory activity and interaction of sesquiterpenoids have been required.

To evaluate the anti-inflammatory activity of sesquiterpenoids, their cytotoxicity to RAW 264.7 cells was evaluated. Elemol, α-eudesmol, and β-caryophyllene oxide were treated in RAW 264.7 cells(4 X 104 cells/mL) at concentrations of 1000, 500, 100, 10, 1 μg/mL. As a result of cytotoxicity evaluation by EZ cytox assay, the cell viability was less than 80% at concentration of 1000 μg/mL. However, at concentrations of 500, 100, 10, 1 μg/mL, cell viability was higher than 80%. To measure the synergistic effect, the cytotoxicity of elemol + α-eudesmol, elemol + caryophyllene oxide, and α-eudesmol + caryophyllene oxide was measured. As a result, all three combinations showed cell viability over 80% at concentrations of 500, 100, 10, and 1 μg/mL. LPS-induced RAW 264.7 cells (4 X 104 cells/mL) were treated with sesquiterpenoids to measure nitric oxide (NO) and cytokine production. To measure NO inhibitory activity, sesquiterpenoids were treated in RAW 264.7 cells seeded at 4x10^4, and no plus detection kit (Intron bio, Korea) was used. Elemol, eudesmol, and caryophyllene oxide showed maximum NO inhibitory activity at 500 μg/ml of 19.2%, 21.2%, and 21.8%. Compared with negative control, dexamethasone, which showed NO inhibitory activity of 26.3%, the activity was slightly lower. Also, to investigate the synergistic effect, combinations of elemol + α-eudesmol, elemol + β-caryophyllene oxide, and α-eudesmol + β-caryophyllene oxide were used. As a result of treatment with LPS-induced RAW 264.7 cells, the combination of elemol + α-eudesmol showed NO inhibitory activity of up to 41.7%, and the best effect was achieved. Additionally, isobologram was applied to investigate the additional no

inhibitory activity synergistic effect. As a result, the fractional inhibitory concentration index (FICI) value less than 1 was found most often in elemol + α-eudesmol. To measure cytokine inhibitory activity, sesquiterpenoids were treated in RAW 264.7 cells seeded at 4 X 104 cells/mL, and elisa kit (R&D system, USA) was used. Elemol, α-eudesmol, and caryophyllene oxide showed maximum TNF- α inhibitory activity at 500 μg/ml of 78.1%, 76.9%, and 69.6% respectively. In addition, the combination of elemol + α-eudesmol showed maximum TNF- α inhibitory activity of 89.4% and showed better anti-inflammatory effect than that of dexamethasone, which had a maximum TNF- α inhibitory activity of 78.1%. Elemol, α-eudesmol, and β-caryophyllene oxide showed maximum IL-1β inhibitory activity at 500 μg/ml of 47.9%, 71.4%, and 79.6%. In addition, the combination of elemol + α-eudesmol showed up to 94.8% of IL-1β inhibitory activity, and better anti-inflammatory effect compared to dexamethasone, which had maximum IL-1β inhibitory activity of 78.1%.

  By mixing elemol with α-eudesmol, it showed better anti-inflammatory effect than existing anti-inflammatory agent, dexamethasone. This synergistic effect enhances the potential as natural anti-inflammatory agent.

Keywords: elemol, α-eduesmol, β-caryophyllene oxide, RAW 264.7 cells, anti-inflammatory effect, synergistic effeect

Oil Heat Treatment of Timber: Durability Enhancement vs Loss of Mechanical Properties

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ABSTRACT

Wood durability can be affected by environmental factors, including biological attacks (e.g. fungi, insects) and moisture changes in the surroundings. Therefore, timber is often treated to improve its durability. Chemical treatment is one of the most common treatments for timber, where preservatives are impregnated into the wood to improve its biological resistance. Nevertheless, many preservatives are toxic, raising environmental and health concerns. Several restrictions have been introduced to the utilization and disposal of chemically treated timber, which limits its applicability.

Thermal treatment is an alternative to the use of preservatives that do not incur the utilization of toxic chemicals. In this process, the timber is treated at high temperatures (commonly $150 - 230$ °C) in absence of oxygen. This increases the water repellence of the wood, reducing the dimensional changes and the chances of biological attacks. However, degradation of the wood can occur during the thermal treatment, with the consequent loss of mechanical performance.

Thermal treatment of wood using vegetable oils and in the low-temperature range has demonstrated its potential to overcome the loss of mechanical performance. The treatment temperature is a crucial parameter to achieve a compromise between the improvement of the water repellence characteristics and the loss of mechanical performance. Lower treatment temperatures can considerably reduce this energy-intensive process, reducing the loss of mechanical performance while still producing noticeable improvement on the wood hydrophobicity. Nevertheless, the study on treatment effects on the mechanical performance with treatment temperature is limited.

This project aims to investigate the effect of heat treatment on the water repellence characteristics and the mechanical properties of Radiata pine samples treated at 120, 150 and 180 °C using linseed oil. Water repellence was assessed by water immersion tests, contact angle and the equilibrium moisture content. The mechanical performance was assessed through a three-point bending, compression parallel to the grain, and hardness tests.

KEYWORDS: Timber treatment, Oil heat treatment, Linseed oil, Temperature, Mechanical performance, Radiata Pine, Hydrophobicity, Water repellence.

REGULAR POSTERS

Potential Uses of Papua New Guinea Lesser-known Hardwood Timber Species

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ABSTRACT

Papua New Guinea has a wealth of timber species, but the commercial markets have concentrated on a few popular species such as kwila (*Insita bijua),* rosewood (*Pterocarpus indicus),* taun (*Pometia pinnata)* and vitex (*Vitex cofassus)*. Reliance on only a few species sharply increases the risk of over-harvesting that will be detrimental to overall forest health. However, there are many lesser-known or under-utilized hardwood timber species with similar physical and mechanical properties, as well as machining, bonding, durability and permeability properties that could serve as attractive substitutes. Some of these species are locally used, but are not as well characterized for commercial use. Developing property data on these species would open new markets and reduce pressure on the more commonly used timbers, thereby reducing the tendency to over-harvest. These timber species may also have potential for plantation establishment.

This project compared the properties of the less utilized species *Hopea iriana, Homalium foetidum, Castanospermum australe, Eucalyptus pellita, Xanthophylum papuanum, Anisoptera thufiera,* and *Pangium edule* with *I. bijuga, P. indicus, P. pinnata, V. cofassus* and*E. deglupta. Hopea iriana* had the best mechanical and physical properties of all tested species and provided significantly better results in the other tests. *Eucalyptus pellita, H. foetidum, and Pangium edule* provided better than average results while *X. papuanum, A. thurifera, C. australe, P. indicus, P. pinnata, V. cofassus* and *E. deglupta* provided above average results. *P. pinnata* and *P. edule* bonded very well with polyvinyl acetate while bonds tended to be weaker with *I. bijuga, P. indicus, V. cofassus, X. papuanum* and *A. thurifera.*The remaining species were very difficult to bond and had poor processing characteristics including drying (seasoning) and machining (dressing).

Hopea iriana, H. foetidum, C. australe, E. pellita, X. papanum, A. thurifera and P. edule all have potential to serve as substitutes for the more commonly used species.

Key words: Papua New Guinea   Timber   Potential less-utilized

Effects of Real Sampling Conditions

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ABSTRACT

No Abstract Available

Ability Of Waterborne Organo-Metallic Preservatives To Protect Radiata Pine Heartwood Decking

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ABSTRACT

Preservative treatment markedly extends the useful life of timber in exterior exposures, but treatment is largely limited to the more permeable sapwood. Heartwood, however, is inevitably present in many timbers resulting in shallow treatments surrounding an untreated core. The ability of this barrier to provide prolonged protection to the interior heartwood has been the subject of much debate and conjecture. Extensive testing in Canada has shown that barrier treatments perform well on softwood decking in above-ground exposures, but there are no similar tests under more extreme exposure conditions. The performance of radiata pine heartwood decking treated with either chromated copper arsenate (CCA) or alkaline copper quaternary compound (ACQ) was evaluated over a 25 year exposure at a sub-tropical site located in Northern New South Wales. Performance was compared to untreated decking as well as radiata pine sapwood decking treated with the same chemicals. The decks were visually rated on a scale from 10 (perfect, no decay) to 0 (completely destroyed). While some untreated deck boards survived, they were in extremely poor condition. Ratings for untreated sapwood averaged 0.36 (out of 10) while those for heartwood averaged 1.10 (out of 10) indicating that both materials were in extremely poor condition. Ratings for CCA and ACQ treated sapwood decking averaged 6.32 and 6.56, respectively, while those for heartwood decking averaged 6.33 and 5.03. The results indicated that both treatments were performing extremely on all-heartwood boards and confirm the field trials results performed under much less severe conditions. The results validate the ability of relatively thin barrier treatments to protect softwood heartwood under sub-tropical conditions.

Physical and Mechanical Performance Testing of the Hybrid Hardwood-softwood CLT Panels Obtained from One of the First Hardwood CLT Structures

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ABSTRACT

Cross-laminated timber (CLT) is an engineered wood product (EWP) that has been gaining popularity throughout the world, helping to define a new class of structural timber products known as "mass" timber. It is an Engineering Wood Products (EWP) solution that complements the existing light frame and heavy timber options, also an ideal substitution for concrete, masonry, and steel construction systems. By using CLT in building construction, more carbon shall be captured and the use of nonrenewable resources can be avoided. Currently, CLT construction is primarily made of softwood species. Hardwood species are being studied as part of the CLT movement. In recent years, a few exemplary demonstration structures have emerged to support this effort. CLT samples used in this study were obtained from one of the first hardwood CLT demonstration structures, made of mixed wood species (softwood core and hardwood exterior plies). The purpose of this study was to address whether hybrid CLT made of mixed wood species could provide sufficient physical and mechanical performance for structural and or non-structural applications. Bending tests were performed on hardwood CLT panels obtained from the first hardwood CLT structure, Conversation Plinth, exhibited in Columbus Indiana in 2018. Results of the test were studied, explained, and benchmarked. In conclusion, there are efforts to incorporate hardwoods into CLT construction to find a better use for abandoned, lower-quality materials throughout the U.S. However, results suggest that CLTs produced from mixed hardwoods do not provide consistent results and the mode of their application should be further investigated. Future studies are exploring the opportunity of using hybrid panels made of single hardwood species for the exterior plies and single softwood species for the core.

Correlation Between Wood Characteristics by Social Network Analysis

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ABSTRACT

Social network analysis has recently attracted a lot of attention not only in social science but also in natural science. Social networks are defined as entities called actor and their relationships. Social network analysis assumes that such social networks are a major component of social systems and presents various concepts and methods for measuring and analyzing relationship structures in terms of relationships between members. In this study, the correlation between wood characteristics was investigated by using social network analysis tool (UCINET; Analytic Technology). The wood characteristics were determined by 29 cell structures, 13 physical properties and 12 moisture characteristics presented in Korean Standard (KS F 1551 "Terminology of Wood-Properties and Defects of Wood"). The cell structure, physical properties and moisture characteristics were hypothesized as one set, and the correlation within each set was analyzed by 1-mode network. First, the term definition of specific wood characteristics in KS F 1551 is set to be interrelated when other wood characteristics are included. The nondirected-binary network of wood characteristics showed that the betweenness centrality in cell structures was shown in the order of Annual Ring, Radial Direction and Cambium. The betweenness centrality in physical properties was shown in the order of Dimensional Stability, Shrinkage and Swelling. The betweenness centrality in moisture characteristics was shown in the order of Fiber Saturation Point, Moisture Content, and Moisture Gradient. Second, the relationship is established by using the frequency of keywords of scientific articles in the Web of Science Database. The frequency of each wood characteristic included in the keywords was investigated in the list of scientific articles that searched for two different wood characteristics by title and subject respectively. The directed-valued network of wood characteristics showed that the betweenness centrality in cell structures was shown in the order of Cell, Juvenilewood and Annual Ring. The betweenness centrality in physical properties was shown in the order of Density, Shrinkage, and Dimensional Stability. The betweenness centrality in moisture characteristics was shown in the order of Moisture Content, Equilibrium Moisture Content and Fiber Saturation Point. Furthermore, when 2-mode network analysis is performed to analyze the correlation between sets of wood characteristics, a highly centralized wood characteristics can be found and more wood characteristics can be derived.

Preparation of Lignin/PVA Blend and Dialdehyde Cellulose Crosslinked Fibers for Dye Removal

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ABSTRACT

Due to environmental pollution and the depletion of fossil resources, research on woody biomass is increasing. This study investigated the possibility of using lignin as an adsorbent for water restoration. A lignin/PVA blend fiber was prepared, and a cellulosic crosslinking agent improved water stability. As a result, the fiber showed 253.37 mg/g of methylene blue removal capacity and maintained 95% adsorption efficiency in 5 regeneration. This study suggests the application of lignin as an adsorbent and will contribute to the research and utilization of woody biomass.

Keywords:
Lignin/PVA; Cellulose crosslinking; Dye removal; Bioadsorbent

Termite Resistance of Australian Timber Species

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ABSTRACT

The relative termite resistance of black wattle, radiata pine, Tasmanian oak, Fijian mahogany, jarrah, and spotted gum was assessed in field tests to high levels of subterranean termite feeding pressure using a modified version of the Australasian Wood Preservation Committee (AWPC) "Protocols for assessment of wood preservatives" (AWPC, 2015) in North Queensland (Qld) and the Northern Territory (NT). The two sites were chosen for their well-documented activity of the economically important wood feeding subterranean termite species: *Coptotermes acinaciformis* (Qld and NT sites) and *Mastotermes darwiniensis* (NT site only). Forty end-matched test specimens were tested for each timber species. Samples were retrieved after 6 months of exposure and returned to the laboratory where they were conditioned and weighed to determine mass losses due to termite attack. Species exhibiting more than 5% mean mass loss were considered to be not resistant to termites. The tests revealed some interesting differences in performance of three of the reference species; Fijian mahogany which is variously described as a moderately resistant or resistant species was found in these tests to be resistant to *M.darwiniensis* in NT but not resistant to *C. acinaciformis* at either site. Samples of spotted gum, which is regarded as a termite resistant species by both AS5604 and AS3660, suffered little or no attack (<1% mass loss) by *C. acinaciformis* but were significantly attacked by *M. darwiniensis* with an average mass loss of 27%. Jarrah which is listed as a termite resistant timber according to both Australian Standard AS5604 and AS3660 was found to be not resistant to attack by either termite species at either site. Termite resistance is a complicated concept. Published literature on termite resistance can be confusing and in some cases contradictory. A review of the current data and testing methodology on the natural resistance of timber to subterranean termites is recommended.

Deconstruction Costs, Carbon Footprint and Circularity Options for Two Mass Timber Test Structures. Empirical data collection.

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ABSTRACT

In opposed to the traditional "use and dispose" model, a circular economy (CE) aims to maximize the resource value through recycling or reusing. For the last five years, discussions on the paths for circularity in the construction industry have considerably increased in the research community. The building and construction sectors are expected to adopt CE concepts by promoting recycling and reuse of materials and products in order to reduce carbon footprint over the life cycles of buildings. One of the most promising ways to maximize recycling or reuse potentials of building materials and assemblies is deconstruction rather than demolition of buildings when they reach the end of their life cycle.

Mass timber buildings have great potential for deconstruction and reuse. Mass timber buildings assembled on-site from prefabricated elements using mechanical connection systems are expected to allow easy disassembly at the end-of-life (EOL) stage of buildings. Either partial or whole deconstruction without incurring some level of damage and attrition to recovered material, a necessary condition to secure the embedded carbon, seems to be a non-trivial challenge given the size and weight of massive structural panels. Successful implementation of CE concepts and reliable life cycle assessment (LCA) of the impacts of recovering mass-timber panels requires a thorough examination of related technical and economic aspects. These include: 1) technical feasibility of mass timber building deconstruction, 2) expected attrition rate of recovered panels, and 3) the cost and carbon footprint associated with deconstruction. The mass timber industry is still relatively young compared to that of other traditional construction materials. Hardly any mass timber building has reached even mid-service life, and none is known to reach the EOL stage. This makes reliable empirical data essential for assessing the circularity potential of mass timber buildings extremely hard to find.

This study aims to address the shortage of data by analyzing deconstruction procedures of medium- and large-scale mass timber test structures. The Oregon State University research team has launched qualitative and quantitative research of mass timber building deconstruction by observing a few multi-story test structures. In this study, the research methodology for data collection is highlighted; the outcome of this study will include a preliminary observation protocol for mass timber building deconstruction based on a questionnaire and interviews to identify data to be collected for future research. In future research, both quantitative and qualitative data such as the attrition rate of recovered panels, labor and equipment hours, and productivity and mapping of deconstruction activities will be collected. Data collected from these structures will be used as a resource to perform cradle-to-cradle LCA incorporating reuse potential of panels and deconstruction cost estimation for mass timber buildings, which will be helpful in understanding both environmental and economic viability of mass timber use, deconstruction, and reuse.

Key Words: Circular Economy, Mass Timber, Deconstruction, Reuse, End-of-Life, Observation

Measuring Post-Tensioning Losses in Mass Timber Shear Wall Panels

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ABSTRACT

The 2021 International Building Code (IBC) allow mass-timber buildings up to 18 stories. Current IBC seismic design provisions aim primarily at protecting life safety of occupants. The new area in seismic design research is focused on damage mitigation and resilience, which aims at reducing seismic damage to levels that not only save buildings from decommission, but also accelerate post-event re-occupancy. One of the proposed resilient solutions has been low-damage lateral force resisting system (LFRS) developed recently in New Zealand and in the United States. LFRS timber buildings incorporate mass-timber panels anchored with post-tensioned (PT) steel rods serving as self-centering shear walls. These systems accommodate the seismic demand allowing controlled rocking of the structural wall elements while the post-tensioned steel rods act as elastic springs ensuring re-centering of the structure after an earthquake with no excessive structural damage. In addition, the rocking movement is damped by dispensable energy dissipators, u-shaped elements mounted between adjacent shear wall elements.

However, the effectiveness of such systems depends on its ability to maintain the tension applied in the steel rods during at time of construction at a required level until the seismic event, which may be years or decades. Tension losses due to deformations in the mass-timber panels exposed to long-term compression in varying climate environment can activate the rocking motion at lower intensity earthquakes or negatively affect the re-centering capability. Limited data from monitored operative post-tensioned timber buildings over relatively short period of time suggest that 20-25% of the tension may be lost in 50 years. The sources of tension losses in PT rocking systems are attributed to interaction of viscoelastic and mechano-sportive creep in mass-timber panels. However, scarcity of comprehensive data poses a challenge for effective modelling that would allow reliable predicting of tension on long term.

The purpose for this research is to measure post-tensioning losses in CLT and MPP shear walls exposed to loads in variable climate conditions and to develop a model for reliable prediction of the effects of such exposures. The experimental program is designed to effectively separate the fundamental components of in-plane deformations in mass-timber panels by parallel testing on three sets of reference small-scale specimens: 1) PT loaded panels exposed to a series of humidity cycles, 2) unloaded panels exposed to the same series of humidity cycles, and 3) PT loaded panels exposed to constant climate. In addition, PT loss is monitored in full-scale (9.1 m tall) CLT and MPP post-tensioned shear walls exposed to variable indoor climate in a large structural testing lab exposed to naturally varying indoor conditions for at least one year to validate the model developed based on the small-scale specimens. Results of the study will enable engineers to confidently design post-tensioned mass timber rocking walls, leading to the use of these engineered products in mid- to high-rise structures in a safe and environmentally friendly way.

Prototype Method to Evaluate the Fire Performance of CLT Floor-to-Wall Connections

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ABSTRACT

Panelized mass timber structures, such as those with cross-laminated timber (CLT) floors and walls, fasten floor and wall elements together in a variety of ways. The fire performance of such panel-to-panel connections is critical to prevent horizontal or vertical fire spread within a building and prevent structural collapse. The performance of these connection greatly depends on the embedment of connection materials such as plates or dowels, into the CLT and the performance of the connecting materials themselves. However, little is known about the behavior of such connection during a fire, where the strength and stiffness of metal connectors degrades with increasing temperature and the cross section of the panels themselves is reduced due to charring. Characterizing the fire performance of these connections is therefore an important step in enabling the broad acceptance of CLT in the construction industry. However, there is no universal testing methodology to evaluate the fundamental behavior of such connections. The development of a testing method and evaluation criteria is an important step to normalize the discussion of the fire behavior of mass timber connections.

The prototype test method developed in this project is expected to allow meaningful evaluation of fire behavior of CLT floor-to-wall connections. The results from the first series of tests are expected to improve the understanding of the behavior and to evaluate the methodology. Four uninsulated connections, including floor and wall elements, were tested. The specific connection geometries were selected to represent common strategies in the North American mass timber industry. Each connection was subjected to a mechanical load, exposed to the ASTM E119 standard fire over a horizontal gas fire furnace for one hour, then allowed to cool naturally for one-hour. The temperature distribution within each connection was recorded. The deformation of the floor panel was recorded at multiple points along its span in order to characterize connection settlement and rotation. After the tests, the asemblies were dissected to observe damage in critical areas for which deflections and temperature data were collected. The behavior of the connector geometries during the tests will be compared and evaluated. The method will be evaluated, and suggestions made for future work exploring floor-to-wall mass timber connection fire behavior.

Structural performance of particleboard shear walls made by bonding with timber studs

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ABSTRACT

In this study, particleboard shear walls were developed and the lateral load-carrying capacities were evaluated. Seven types of specimens were manufactured by varying the wood species, the stud size, the number of particleboards, and the manufacturing method (glue or nail). (1) Load-carrying capacities of the glued-produced specimens were 71.5~75.9 kN/m. These were about 3 times higher than the typical light-frame shear wall and higher than the experimental data of the CLT wall in the CLT handbook. This would be due to the difference in the structural capacity of the used hold-downs. (2) All the specimens were failed at the hold-down and angle bracket, and no damage at the glue layer between a particleboard and wood studs. (3) Load-carrying capacity of the nail-produced specimen was about 20% lower than the glue-produced specimens. The capacities of glue-produced specimens with various combinations, species, stud size, and the number of particleboards, were not significantly different.

Keywords: Particleboard, Shear wall, Wood, Timber, CLT, Glue, Nail

*Acknowledgements

Characterizing Softwood Sawn Products in Australia

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ABSTRACT

The Australian structural timber producers through the National Institute for Forest Products Innovation are undertaking a project 'Characterizing Softwood Sawn Products in Australia' to capture a representative sample of softwood sawn-timber production from sawmills over a full year.

The timber is currently being tested at the University of South Australia material testing laboratories at Mawson Lakes, South Australia. The data are being analyzed to provide feedback to the industry on the structural properties of their sawn timber products; and provide a benchmark of Machine Graded Pine (MGP) properties that can be compared against the results of previous and future test programs.

The project is also performing extensive laboratory testing to establish the physical and mechanical properties of samples collected from 13 participating timber mills throughout the country (accounting for approximately 90% volume of locally sawn structural softwood), provide analysis and reporting to confirm the properties of the structural products currently being provided to the market in comparison to the design properties specified in AS1720.1-2010: Timber Structures – Design Methods. The outcomes of this study will generate sufficient data to evaluate the properties of structural softwood timber as well as evaluate the temporal variations of the structural properties of this material. Underpinning the characteristics of the existing structural softwood grades will help timber mills to ensure the products supplied to the market are fit for purpose.

This project provides an excellent opportunity to build capacity for supporting the MGP system by training young researchers who could potentially take those experiences back to the industry at the end of the project.

Correction of the effect of wood moisture variation on the calibration of NIRS discrimination models: case of three Dalbergia species from Madagascar

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ABSTRACT

Near Infrared Spectroscopy (NIRS) associated with chemometric analysis is an alternative technique that has been used in recent years for the identification of forest species. However, little attention has been paid in the literature to the field application of this technique where external influences can affect the chemical composition of the wood and the responses of the spectrometer. Changes in the experimental environment (temperature, relative humidity) affect the moisture content of the wood due to its hygroscopicity, thus varying the responses of the spectrometer and reducing the robustness of the classification models. The consideration of these influence quantities is therefore of primary interest if one wants to use the calibration models in uncontrolled environments. In this context, the present study aims at correcting the effect of wood moisture variation on the calibration of discrimination models of three Malagasy rosewood species (*Dalbergia chlorocarpa R. Vig., Dalbergia orientalis Bosser & R. Rabev* and *Dalbergia purpurascens Baill*.) from near infrared spectra of wood. To conduct the study, 99 wood microcores were collected from 99 trees located in and around several protected areas in Madagascar. The cores were conditioned to four moisture levels Th(%) = [8, 12, 16, 20]. Six spectra were measured on the heartwood portion of each micrcore for each of the four moisture states. The samples were divided into three batches: S0 for uncorrected model calibration, S1 for model correction, and S2 for testing. A PLSDA(Th%=12%) model was calibrated from the X0[Th=12%] spectra acquired at 12% humidity. A decrease in the performance of the PLSDA(Th%=12%) model is found when it is used to predict the test spectra X2[Th (%) = 8%], X2[Th (%) = 16%] and X2[Th (%) = 20%] measured at the other three moisture states. This allowed the effect of humidity variation on model performance to be understood, with the percentage of well classified dropping from 83% to 33.3% from the classification of the X2[Th=12%] and X2[Th=20%] test spectra. Three methods including A priori Correction, Model Update and EPO were used to correct and improve the robustness of the models. The EPO and Model update orthogonalization methods allowed to better take into account the perturbations linked to the variation of the wood moisture in the models. The use of both methods improved the performance of the

model from 55% to 70% of well classified individuals from the prediction of the test spectra X2[Th%=8%], X2[Th%=12%], X2[Th%=16%] and X2[Th%=20%]. The results are promising for the use of the tool in the routine identification of Dalbergia wood from Madagascar. The enrichment of the spectral data by PIR spectra of wood taken at narrower moisture intervals is important in order to have spectra more representative of the moisture states of wood that could be encountered on site.

Key words: *Dalbergia,* Discrimination, NIRS, moisture content

Environmentally Friendly Wood Composites Based on UF Resin Modified by Protein Formaldehyde Scavengers

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ABSTRACT

Technology of gluing is one of the important steps in the industrial upgrading process for wood-based composites production. Within the frame of application of urea-formaldehyde (UF) resins, it is necessary to respect the adhesive formulations and production technology process to improve the quality of product, reduce manufacturing costs, and eliminate negative effects on human health. The aim of this study was to reduce the release of formaldehyde from wood composites by developing and testing new more effective protein-based environmental formaldehyde scavengers. Fibril proteins of leather, mainly collagen and keratin are the most significant from the view for application in poly-condensation adhesive mixtures. Collagen is the widespread animal protein component of skin, tendon, bones and ligament. Keratin is the main component of hair, fur, feathers, hooves, horns and outer surface of the skin. Keratin is characterized by a high content of sulphur amino acid cysteine with a typical formation of disulphide bridges. These samples were characterized by FTIR-ATR and XPS spectroscopy, thermo-oxidative stability was studied by differential scanning calorimetry (DSC), emission of formaldehyde was tested according EN ISO 12460-4 by desiccator method and quality of gluing according to standards EN 314-1 and EN 314-2. The results showed decrease of formaldehyde emission for each addition of collagen, cysteine and cystine in comparison with the reference sample. FTIR spectra confirmed the reactivity of UF resin with collagen and creation of stronger methylene and peptide links. The most significant decrease of formaldehyde up to 44 % was obtained for cysteine prepared from sheep wool. Tested plywood bonded by modified UF adhesive can be classified in emission class E0.5 and fulfils the requirements of the standard for quality of gluing. Collagen and keratin samples prepared for this study might therefore have a great potential for application as the environmentally friendly formaldehyde scavengers of wood-based composites.

Key Words: Wood Composites, Urea-Formaldehyde Resin, Collagen, Keratin, Plywood, Formaldehyde Emission

Surface Modification of Selected Wood Species by Atmospheric Plasma

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ABSTRACT

The surface of various European hardwood species (beech (*Fagus sylvatica* L.), maple (*Acer pseudoplatanus* L.) and birch (*Betula pendula* L.)) was pre-treated by atmospheric discharge plasma (ADP). The aim of low-temperature discharge plasma modification of wood surface was to improve the hydrophilicity and the adhesive properties of wood. The ADP modification in air was suggested as an appropriate, efficient and ecologically friendly method for the increasing of the polarity of wood surface. The increase of polar component of surface energy of plasma-modified wood was observed. The water contact angle on the investigated wood surfaces diminished with prolonged time of ADP modification from 74° to 30°. During ageing, the water contact angle of plasma-treated wood surfaces returned rapidly after two days from 37° to 67°. The results of FTIR investigation confirmed the increase of the wood hydrophilicity/polarity in all cases caused by the increase of –OH group concentration due to irradiation by ADP plasma. The content of COOH, C–O and C=O groups after treatment by plasma significantly increased. The plasma-treated wood surfaces are interactive for application of adhesives or paints and varnishes up to 2 days after modification by plasma.

Key Words: Hardwoods, Atmospheric Discharge Plasma, Water Contact Angle, Surface Chemistry

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From Static to Dynamic Mechanical Model of Green Wood

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ABSTRACT

Finite-element simulations are power-full tool for description of tree response to dynamic loading, provide insight to problem and allows sensitivity analyzes. The appropriate numerical model is given by the proper definition of input geometry, boundary conditions and material. Relevant material model of wood respect mainly tree species, gree-state, orthotropicity, elasticicty, plasticity and static to dynamic nature of loading. Unlike geometry the definition of material model of wood requires a set of parameters which is not possible to obtain by direct *in-situ* measurement.

The set of laboratory experimental sub-tasks for the description of material static parameters of green wood of important representatives (*Fagus silvatica*) took place. The bi-linear material model validated by the small-specimen standard static tests was created and verified in implicit finite-element solver. The static material model parameters were consequently applied in the starting position of developing of dynamic response model in explicit finite-element solver. The dynamic material model was experimentally validated by sets of small-specimen bending impact tests with use of high-speed camera data based image analysis. The developed material model was applied in real-scale 3D laser-scan based numerical models and validated by bending tests in static testing machine as well as by frequency-resonance dynamic methods. The correspondence of mechanical response of developed material model to the experimental data allows applications of real-scale finite-element modeling in tree response assessment.

Prediction of Moisture Content Distribution During Drying Process by Using Approximate Solution of Moisture Diffusion Equation

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ABSTRACT

When the wood is dried, properties suitable for the end use of the wood can be obtained. And the wood that is not dried properly may have drying defects during processing or using. If an appropriate drying method is applied according to the size and drying characteristics of the wood, it is possible to shorten the drying time and energy consumption as well as to maintain the quality of the wood. In this study, air drying and kiln drying were carried out using pine and oak wood, and the moisture content distribution inside the wood during the drying process was predicted through an approximate solution of the moisture diffusion equation. In order to calculate the moisture content distribution inside the wood during the drying process, diffusion coefficients for each direction of pine and oak wood were measured at some specified temperatures including common air drying conditions like 20°C and 40°C. Based on the measured diffusion coefficient, the diffusion coefficient was calculated at the temperature corresponding to the air drying and kiln drying condition. Using the calculated diffusion coefficients, an approximate solution of the water diffusion equation was obtained to predict the distribution of moisture content in the wood during the drying process. For the drying experiment, specimens with a cross section of 200 mm × 200 mm (R × T) were used for each species, and kiln drying was performed according to mild schedule. As a result of comparing the moisture content of the specimens measured during the drying process and the predicted moisture content, some unexpected difference and crossover between those two were found at any drying time, early and late stage, and at any drying part, inner and outer section. It is expected that more reliable prediction will be possible if the diffusion coefficient is applied to each section by dividing the section and calculated considering all diffusion directions and the surface wood drying is analyzed with consideration of surface moisture emission resistance.

Effect of microwave heating for production of kraft lignin-derived activated carbon

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11   ABSTRACT
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13   This study aims to develop an adsorbent for water pollutants, and for efficient process
14   development, lignin-derived activated carbon was prepared under microwave (MW) heating. A
15   conventional method using a furnace for the production of activated carbon has a complicated
16   procedure and high energy consumption. MW heating is a promising alternative for raising the
17   material temperature in a short time, but this requires the presence of MW absorbers in the
18   material. Inorganic salts exist in kraft lignin mass-produced as a by-product of the pulping
19   process, and since they are MW absorbers, activated carbon can be produced by MW heating a
20   mixture of lignin and a catalyst such as KOH or NaOH. In contrast to the conventional activation,
21   which consists of a two-step process of carbonization and chemical activation, the MW-assisted
22   activation performs carbonization and chemical activation simultaneously. In addition, because
23   the MW process uses a solid catalyst, rapid activation is possible with minimizing drying step.
24   Activated carbon was prepared by heating a mixture of KOH and lignin (solid-liquid ratio 3:1)
25   with MW power of 450, 700, and 1000 W for 10, 20, and 30 minutes, respectively. The carbon
26   content and specific surface area (SSA) of the activated carbon were investigated by elemental
27   analysis and BET analysis, respectively. From elemental analysis, the carbon content of the
28   untreated sample was 61.4%, which increased with the increasing reaction severity of MW
29   heating. The carbon content of activated carbon heated by 1000 W for 20 minutes was increased
30   to 88.2%. The SSA of lignin was greatly increased by MW heating. The SSA of the untreated
31   sample was increased from 0.53 to 2898.4 m2/g by heating with 1000 W for 10 minutes.
32   Regardless of the MW power tested, the activated carbons had similar SSA, whereas an increase
33   in heating time resulted in a decrease in SSA. This was attributed to carbon loss due to
34   excessively high temperatures. Therefore, considering the reuse through the reactivation process
35   in the manufacture of the adsorbent, heating with 450W for 10 minutes could be more efficient.
36
37   Keywords: activated carbon, lignin, microwave, pore activation, specific surface area
38

1 **Long-term moisture and dimensional behavior of a nail-laminated**
2 **timber slab**
3

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ABSTRACT

In this study, moisture and dimensional changes of a nail-laminated timber (NLT), which is
timber-plywood composite exposed to the outdoors, were monitored. Since wood repeatedly
swells and shrinks due to moisture adsorption and desorption, it is important to accurately
measure the moisture content (MC) to secure the structural stability of the wooden structure. The
dimensions of the NLT were 1000 (width) $\times$ 1000 (length) $\times$ 140 (height) mm, and k-type
thermocouples and temperature-humidity probes were installed into the NLT to observe changes
in temperature and relative humidity (RH). In addition, tape-type displacement transducers were
installed in the width, length, and height directions of the NLT to observe the dimensional
change. All observations were saved and visualized in a data logger. This study analyzed the data
collected for 196 days from April 14, 2021, to October 26, 2021, and during this period, concrete
was poured on the NLT on October 5, 2021. Changes in outdoor climate conditions caused
changes in temperature and RH inside the NLT. Since May 18, the daily average of over 80% of
high RH outdoor conditions continued, and the internal RH of the NLT steadily increased. The
RH value was 57.8%, which was 25.7% lower than outdoor RH during the same period. This
difference was a result of the humidity control of the wood materials. Based on the observed
temperature and RH data, the internal MC of the NLT was calculated to be a minimum of 6.7% at
the start of monitoring and then continued to increase, reaching a maximum of 13.7% on
September 19th. An increase in the internal MC of NLT was accompanied by an increase in
dimensions. The width at which the cross-sections were exposed increased the most, and the
increase in length was the smallest. On the other hand, the height was repeatedly increased and
decreased. The dimensional change pattern of NLT closely resembled its internal moisture
fluctuation. This result proves that the dimensional change of NLT is caused by the moisture
change. At the maximum MC of 13.7%, the width and length were increased by 0.30% and
0.06%, respectively. After pouring concrete, the internal MC was increased up to 14.5%, and the
width was increased up to 0.48%. As time passed, the MC was decreased according to the
outdoor conditions, but the increased width was not fully recovered. This could be a permanent
deformation due to the concrete load. Future studies will investigate the internal moisture
behavior of NLTs under outdoor conditions with decreasing RH.

Keywords: dimensional change, moisture content, nail-laminated timber, structural wood, timber-
plywood composite

Effect of High Temperature Drying with Load on Reduction of Residual Stress and Correction of Warp of Japanese Cedar Lumber

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ABSTRACT

While sawing logs along the pith to produce lumber, warps would occur in lumber due to the release of residual stress. Correction sawing should be performed to correct warps, so warps decrease the yield of lumber. Therefore, it is crucial to find a way to produce straight lumber without correction sawing. The present study focused on a series of high temperature drying with load, and it was confirmed that residual stress was eliminated, and warp was corrected after a series of high temperature drying with load. Besides, the optimal schedule conditions of high temperature drying were determined. After 6 months of storage, the treated lumber remained straight and residual stress in lumber did not recover. By applying high temperature drying with load to warped lumber, it is possible to dry lumber and correct the warps at the same time.

Keywords Kiln Dry; Residual stress reduction; High temperature drying; Growth stress; Lumber warp

EARLY RESEARCHERS

Suitability Of Corn Stalk (Zea Mays L.) And Citric Acid Solution For Single Layer Particleboard: Effect Of Particleboard Density On Bending Strength And Thickness Swelling

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ABSTRACT

The growing population is leading to rising demand for the fulfilment of daily necessities including building materials and furniture products. Corn stalk is an agricultural by-product that is abundant and underutilised in many countries such as Australia and Indonesia. This research investigates the potency of corn stalk for eco-friendly particleboard production using citric acid as the adhesive. Three adhesive percentages were applied that is 25%, 15%, and 10%w/v for targeted densities of 0.5 g/cm^3 and 0.7 g/cm^3. All the panels were pressed for 10 minutes at 200°C with a pressing pressure of 2.4 MPa. Water absorption and thickness swelling, as well as bending strength of particleboard, were assessed following Japanese Standard (JIS) 5908-2003. The standard that is commonly used for base particleboard testing in furniture application. The result shows that the higher density of particleboard the better properties in bending strength. The bending strength of particleboard with 0.5 g/cm^3 density was in the range of 3.2-3.8 MPa. For 0.7 g/cm^3 particleboard, the bending strength was between 6.02-7.47 MPa. The value of bending strength from 0.7 g/cm^3 is imminent to the standard. On the other hand, the particleboards' water absorption (WA) and thickness swelling (TS) properties showed better results in lower density particleboard. It is found that the WA and TS values of 0.5 g/cm^3 particleboard were 77.82-88.84% and 3.13-5.48% consecutively. For 0.7 g/cm^3 particleboard, the WA and TS values were 49.95-62.39% and 8.70-19.90%. The TS value for 0.5 g/cm^3 particleboard was meet the standard of base particleboard. Since the wood supply is facing shrinkage over the period the search for an alternative for furniture raw materials is important. Results of this preliminary research are promising and could potentially alleviate our reliance on an ever-shrinking wood resource to satisfy our need for raw material to manufacture particleboards for furniture application.

Keywords: *eco-friendly particleboard, corn stalk, citric acid*

Advanced Finite Element Modelling Technique to Simulate Delamination Of Cross-Laminated Timber Under Out Of Plane Loading

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ABSTRACT

Development of finite element models for reliable prediction of glue interface delamination occurring in cross-laminated timber (CLT) is quite challenging. The inherent softness of timber material combined with rolling shear and fibre fracture characteristics make it difficult to distinguish between timber and glue failure. In this paper, a bi-linear traction separation based cohesive zone (CZM) modelling for glue interface is used in conjunction with continuum damaged mechanics (CDM) built an orthotropic material model to predict the failure behaviour of CLT. The parameters for CZM were calibrated and established using test results obtained from double cantilever beam (DCB) Mode-I and end-notch flexure (ENF)-Mode-II fracture tests conducted on adhesive timber bond. A full-scale CLT panel was also simulated, and the observed behaviour was compared with relevant experimental results obtained from bending and shear tests showing good agreement between test and the adopted FE modelling techniques. The developed FE model was shown to capture pure glue delamination as well as combined glue and timber fracture. Numerically obtained results demonstrated good predictions for failure strength, modulus of elasticity, and the overall post-elastic load-displacement response of the CLT panel.

Wood Surface Inspection Using Deep Neural Networks

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ABSTRACT

Accurate grading of lumber is an important process for production quality control, but the grading by visual inspection has the risk of misclassification with low work efficiency as it relies on the lumber grader's subjective judgment. In the present situation where it is difficult to guarantee an accuracy of more than 80% from lumber grading by visual inspection, it is required to develop a more accurate and reliable method for classifying wood defects. This study aims to develop a wood grading system based on deep neural networks. A wood defect detection model was constructed using Mask R-CNN, which has been reported excellent performance in instance segmentation, and its performance was investigated. 304 macroscopic images were acquired from Korean pine wood, then four types of knots (decayed knot, encased knot, sound knot, and spike knot), bark, and cracks were annotated on the wood surface images using VGG Image Annotator. The detection model was designed not only to visualize the location and type of wood defects on the surface images but also to calculate the reference value of defects for grading the lumber based on the Korean Industrial Standard (KS F 2151, Visual grading for softwood structural lumber). The mAP (mean average precision) with an IoU (intersection over union) threshold greater than 0.5 was used as a performance metric. The mAP of the model on the validation set was 57.0% for all defect types, whereas the mAP of the model for 4 types of knots was 80.4%. The drops in the mAP for all defect types was attributed to its poor performance for cracks. The model detected many microcracks that were not annotated. The model can be further improved through the augmentation of the image dataset and the improvement of the annotation quality.

Heterogeneity of density of green beech wood caused by fungal deterioration and its impact on mechanical testing

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ABSTRACT

This study investigates the effect of wood degradation and its heterogeneity caused by the wood-decaying fungus *Kretzschmaria deusta* on mechanical (elastic bending modulus of elasticity (MOE_t) and modulus of rupture (MOR)) and vibro-acoustic parameters (dynamic elastic modulus ($MOED_t$) and longitudinal stress-wave velocity (c_l)) of green beech wood specimens. According to the results, degraded samples have a statistically proved higher variability of density distribution than reference intact specimens. The application of paraffine wax on the specimens' faces didn't attenuate the heterogenic distribution of density among the samples' length. A relevant correlation between density variability and MOR was proven. $MOED_t$ has a stronger linear relationship to MOR than c_l. Presented results can be in future applied to obtain more reliable results of non-destructive methods used for wood decay identification in wood.

Keywords: Green wood, Non-destructive testing, Wood degradation

INTRODUCTION

Fungal degradation is one of the most important factors influencing tree stability (Kobza et al. 2021). Wood decaying fungi are generally classified according to their degradation process of the wood cell wall into white, brown and soft rot fungi (Rayner and Boddy 1988). The degradation of each cell wall component reduces mechanical properties (Ibach and Lebow 2014). Generally, the degree of fungal degradation is described by weight loss (Witomski et al. 2016). Unfortunately, this parameter does not always correlate with the degree of strength reduction, which is, one of the most important parameters concerning tree stability assessment. In fact, strength loss can occur even without observable weight loss (Witomski et al. 2016). Non-destructive testing (NDT) methods are considered more reliable during the assessing of wood mechanical properties caused by wood degradation (Hering et al. 2012). A common group of NDT techniques are vibroacoustic methods, which can be used to obtain a reliable estimation of static mechanical properties of wood (Chauhan and Sethy 2016). Two main techniques representing this group are the resonant frequency technique (Bucur 2006), and the measurement of time of flight (TOF) of stress waves (Wang et al. 2001). The latter method is applied in acoustic tomography, a technique used to detect defects in a cross-section of the assessed stem (Cristini et al. 2021). Another NDT technique is computed tomography (CT) , which can be used to measure the heterogeneity of fungal deterioration (Kobayashi et al. 2019).

Kretzschmaria deusta is one of the most important wood-decaying fungi of urban trees (Schwarze et al. 2004). It often causes stem failures in the basal zone of different common species for the urban environment (Terho and Hallaksela 2008). This wood-decaying fungus causes soft rot, a specific degradation pattern typical for Ascomycetes. Soft rot is represented by two morphologically different decay patterns known as

Type I (cavity formation) and Type II (cell wall erosion) (Daniel 2014). Mechanical properties of intact green wood have been investigated in the past (Niklas and Spatz 2010). However, the impact of wood-decaying fungi on mechanical properties of green wood still requires further exploration. A detailed description of the degradation of beech wood caused by *K. deusta* and its influence on physical and mechanical properties can be used to implement device-supported methods for non-destructive assessment of green wood.

MATERIALS AND METHODS

For this experiment, small orthotropic bending samples (7x7x100 mm) of European beech (Fagus sylvatica L.) were crafted. For samples' crafting, only intact sapwood was used. Specimens' oven-dry mass was obtained through drying in a kiln for two days at $103\,°C$ and weighting. Higher moisture content ($60 \pm 10\%$) was established through vacuum impregnation with demineralised water. Moisture content (MC), green density (ρ_w) and conventional density (ρ_c) were calculated from sample dimensions and dry/wet (before and after degradation) masses.

Specimens went through incubation in Kolle flask inoculated with a *K. deusta* strain on a malt extract agar medium (5%). Both faces of half of the samples destined for fungal deterioration were covered with pure paraffin wax to try to reduce the primary degradation at the edges of the inoculated specimens. After 12 weeks of fungal exposure, all specimens assessed with vibroacoustic techniques and destructive static mechanical testing.

In order to calculate a coefficient ratio to obtain the longitudinal dynamic modulus of elasticity ($Edyn_l$) from the bending on $MOED$, larger intact specimens with the same dimensions' ratio (40x40x600 mm and 60x60x900 mm) were crafted and conserved in clean water to reach a moisture range over the fibre saturation point ($MC = 60 \pm 10\%$).

Fig. 1: Degraded samples before testing (A), static bending testing (B), and vibro-acoustic assessment (C).

Resonant frequency technique was used to determine $MOED$. Vibrations were measured using Doppler's laser vibrometer PDV-100) and recorded using dynamic signal acquisition module DEWE-41-T-DSA with DEWESoft. Records of vibrations were transformed from time domain to frequency domain using the Fast Fourier Transform (FFT) processed using MATLAB®. Obtained frequency was used for the calculation of $MOED$ in tangential (t) and radial (r) directions using the following equation:

$$MOED_{t/r} = \left(\frac{2f_{t/r}}{2.25\pi}\right)^2 \frac{ml^2}{I_{t/r}} \tag{1}$$

where f is the resonant frequency of the first bending mode, m is the sample mass, l is the sample length, and I is the moment of inertia. Because of the small sample size, a conversion coefficient ratio from $MOED$ to longitudinal dynamic modulus of elasticity ($Edyn_l$) was determined on the larger intact specimens. c_l was then calculated through the following function:

$$c_l = \sqrt{\frac{Edyn_l}{\rho_w}} \tag{2}$$

Afterwards, all samples (degraded and reference) went through static 3-point bending testing (ZWICK Z050). Modulus of rupture (MOR) was calculated as the bending stress at the highest applied force. Displacement measurement was based on Digital Image Correlation technique. For image acquisition, two cameras were used (AVT Stingray Copper F504B, image-capture frequency: 2 fps). Images were processed in MERCURY SW (Sobriety Ltd.), where displacement was calculated as the movement of a point probe located under the pressure point. Bending modulus of elasticity in tangential direction (MOE_t) was established by a least-squares method fitting data in the zone of linear elastic behaviour in the working diagram of each sample. Data have been processed by MATLAB®.

All degraded and 11 intact specimens were scanned with a computed tomography (CT) system DeskTom (RX Solutions, France) with a resolution of 80 μm. For each sample, 1,000 cross-sections in the longitudinal direction were obtained. To obtain the longitudinal density distribution of each specimen, all cross-sections were imported into MATLAB® as numerical matrixes, and the mean value was calculated for each of them. The density obtained by CT scanning (ρ_{CT}) was calculated for each specimen as the mean of the numerical vector used for the longitudinal density distribution.

RESULTS AND DISCUSSION

According to the results showed in Fig. 2A, density variability among the length of degraded samples is evidently higher than the variability of intact ones. A statistically relevant difference between the variation coefficients of degraded and intact samples was also proved through a Kruskal-Wallis test ($\alpha < 0.01$). Nevertheless, no relevant difference was proved between degraded samples with and without paraffine wax. Observing the average values for each group in Fig. 2B, is possible to state that the application of paraffine wax did not limit the degradation at the edges of the samples. On the contrary, untreated samples showed a more linear distribution of density than specimens with paraffine wax (Fig. 2B).
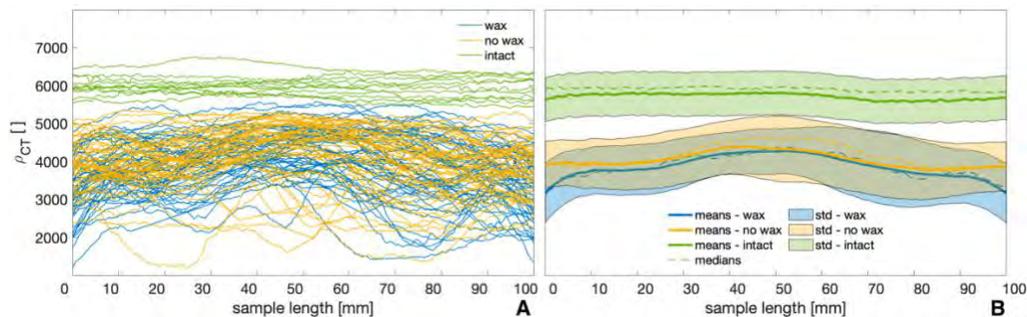
Fig. 2: Singular density profiles of degraded and reference specimens (A) and average values for each slice and their variability expressed through their standard deviations (B)

A strong linear relationship was proved between densities measured with CT (ρ_{CT}) and gravimetric method (ρ_c) ($r^2 = 0.81$), showing a good reliability of CT scanning for density assessment.). Freyburger et al. (2009) also demonstrated a very strong linear relationship between CT scanning and gravimetric method ($r^2 > 0.99$) using a calibration data set of tropical wood samples. Lower coefficient of determination obtained in this study is probably caused by the higher heterogeneity of wood due to fungal degradation.

A statistically relevant difference between degraded and reference samples for all investigated static and dynamic parameters (MOR, MOE_t, $MOED_t$ and c_l) was also proved ($\alpha < 0.01$). As shown in Fig. 3, no significant difference was proved between degraded samples with and without paraffine wax. Nevertheless, a relevant correlation was proved between density variability (coefficients of variance) and MOR (Spearman's correlation coefficient (Sc)= –0.58). This relationship can be explained by the strong correlation between ρ_c and density variability (Sc= –0.69). According to above-mentioned results, the

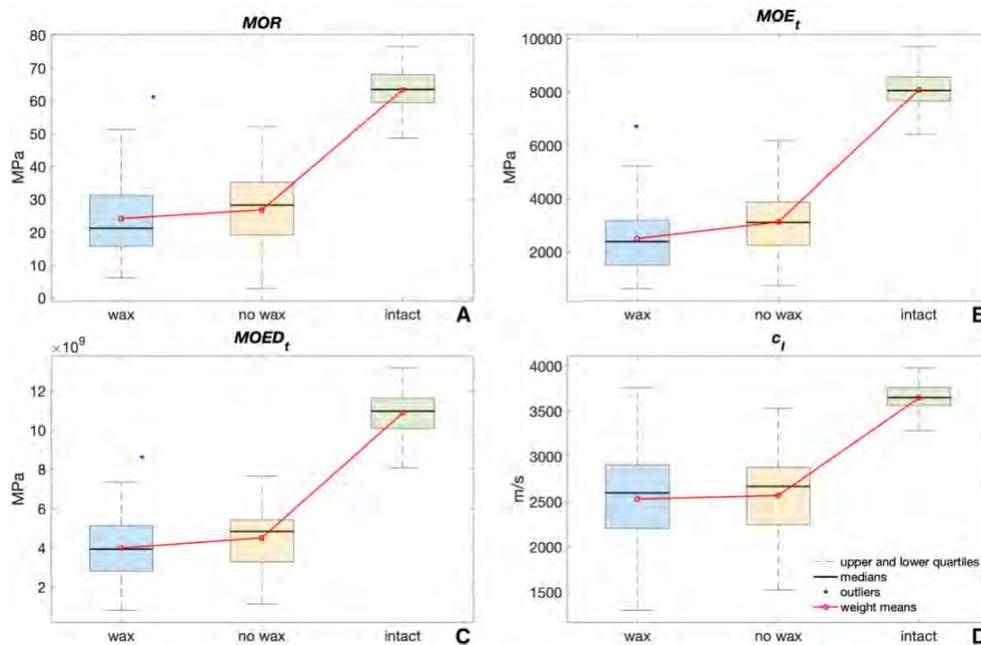variability of density due to fungal degradation should be considered during the assessment of MOR reduction.

Fig. 3: Graphic representation of the difference between degraded and intact samples for MOR (A), MOE_t (B), $MOED_t$ (C) end c_l (D).

As presented in Fig 3C/D, $MOED_t$ of degraded specimens have lower variability than c_l. Considering also the fact, that the linear relationship between MOR and $MOED_t$ ($r^2 = 0.71$) is stronger than the one between MOR and c_l ($r^2 = 0.58$) is possible to conclude that the knowledge of absolute values of ρ_w for degraded wood can be used to improve results obtained from non-destructive assessment of degraded wood.

CONCLUSIONS

Obtained results proved relationships between static mechanical and dynamic parameters of wood degraded by *K. deusta* in relation to the heterogeneity of density distribution.

According to the obtained results, the following statements can be made:

- A relevant correlation between density variability and MOR ($Sc = –0.58$) was proved.
- A statistically relevant difference between the variability of density distribution of degraded and intact sample was proved.
- The application of paraffine wax on the specimens' faces didn't attenuate degradation at the samples' edges.
- $MOED_t$ of degraded samples showed a lower variability than c_l.

According to the on the presented results, the knowledge of absolute values of ρ_w used for the calculation of $MOED$ can be used for a better estimation of the presence of degraded wood in standing trees during non-destructive device-supported assessment methods.

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Non-Destructive Evaluation of the Global Elastic Properties for Large-Scale Cross Laminated Timber Panels through Various Strip Specimens

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ABSTRACT

This article outlines the achievements of the research team in the development, use and assessment of a non-destructive evaluation (NDE) system for predicting the global elastic parameters of cross laminated timber (CLT) panels (referred to in this study as NDE-P). Current methods for confirming predicted elastic parameters of CLT involve an analytical solution derived from the shear analogy method (SAM) or static testing of sections of the panel post-manufacture. These methods are governed by (i) the feedstock parameters (such as grade and board size) for the SAM approach, and (ii) the section sizes as dictated by the standardised testing methods used. These static sections are often taken from the outer perimeters of the panel across each axial direction to allow for the major and minor elastic parameters (E_x and E_y), as well as the primary shear (G_{xy}) property to be calculated. From these static sections, the reduced width allows for the section to be governed by beam theory and assessed using NDE for beams (referred to in this study as NDE-B). Through this study an NDE approach developed using experimental modal analysis has been evaluated for its effectiveness in determining key elastic parameters against both NDE-B and static testing. The test piece size for NDE-B and static testing has been evaluated through a width of 300 mm. The results of the NDE-P system against the SAM analytical results have been used to present the target elastic parameters based on the CLT layering grades and board dimensions. Results showed that the NDE-P method for full-size panels compared against static values showed an agreement of 70%, 76%, and 71% for the two elastic moduli E_x and E_y, as well as the primary shear value G_{xy}. NDE-B for strip sections 300 mm wide produced a further 87%, 96%, and 83% agreement against static results. These various testing approaches have evaluated the variability of CLT panels of varying thickness and the application of full-size NDE testing against the testing of CLT sections.

Binderless Bio-based Cathode from Wood

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ABSTRACT

Activated carbon can be a good material for electrochemical storage applications due to its low cost, low toxicity, and good total surface area. Wood is a good carbon containing precursor material to produce activated carbon. Wood is anisotropic, with mechanical properties varying depending on the direction of load. Wood also contains internal channels for water and nutrient transportation, which can be taken advantage of for charged ion transportation in electrochemical storage. However, during the wood-carbon conversion process, some of the natural structures can be destroyed making the biocarbon brittle and fragile. Current usage of biomass derived activated carbon for electrodes involves crushing and grinding the activated carbon into fine powder, then using polymer-based resins, such as polyvinylidene fluoride (PVDF) or Polytetrafluoroethylene (PTFE) to bind the activated carbon powders together. Crushing and grinding destroys the macrostructures of the activated carbon, and the microstructure of the activated carbon becomes disordered in powdered form. Polymer resins are non-conductive, and they block the internal pores of the activated carbon, lowering the electrochemical performance of these activated carbon electrodes. In the current study, thin slices of a hardwood species, balsa, and a softwood species, southern yellow pine, are cut to 0.5 mm thick from different directions: longitudinal, transversal, or tangential. These slices are then activated physically under vacuum with different activation temperatures (700 °C, 850 °C, or 1050 °C). The total surface area and porosity of these slices are tested with Brunauer-Emmett-Teller (BET) method with nitrogen, their mechanical properties tested with traditional bending and loading tests, and their electrochemical properties are explored with cyclic cytometry. This study presents a new bio-based cathode product for battery and supercapacitor with no polymer binders, which benefit the engineering process of future activated carbon to utilize the natural internal structures of the biomass precursors for electrochemical storage applications.

Keywords: activated carbon, electrochemical storage, surface area, biomass, mechanical properties

Preparation of Gelatin Based Hydrogel Reinforced by Hemicellulose Based Crosslinker and Its Properties

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ABSTRACT

Aim of this study is to produce hemicellulose based crosslinker to reinforce gelatin based hydrogel. Gelatin is gel like materials derived from collagen in animal body parts. Because gelatin is nontoxic for human body and its inherent absorbent capacity, gelatin based hydrogel is widely used as biomaterials in medical field for drug delivery. However, low mechanical properties of gelatin deteriorate stability of gelatin during drug delivery. To overcome these problem, additional crosslinker for reinforcing gelatin structure is required to improve stability of gelatin. Glutaraldehyde, which contains dialdehyde is commonly used as crosslinker. However, toxicity of glutaraldehyde makes usage of hesitating. Therefore, non-toxic crosslinker which could improve mechanical properties of gelatin. Hemicellulose, which is natural polysaccharides rich in lignocellulosic biomass, is non-toxic materials and by modification, hemicellulose can be used as crosslinker for gelatin. In this work, hemicellulose is extracted from lignocellulosic biomass, and further modification, hemicellulose is adopted to crosslinker for gelatin. And properties of hemicellulose reinforced gelatin hydrogel is evaluated.

Hemicellulose was extracted from biomass and chemical modification was conducted to use hemicellulose as a crosslinker. Then, modified hemicellulose was adopted to gelatin for gelatin structure reinforcement. Then, physical properties and mechanical properties of reinforced gelatin hydrogel were evaluated. And drug releasing property of gelatin was also investigated.

Quercus serrata was used as hemicellulose source. Major chemical composition of *Quercus serrata* was as followed; glucose (44.54±0.73%) xylose, mannose and galactose (XMG, 15.02±0.19%), arabinose (0.87±0.03%), and lignin (30.26±0.36%). To obtain high purity hemicellulose, sodium chlorite was treated to deliginification. Then, alkaline extraction using sodium hydroxide was adopted to hemicellulose extraction. By alkaline extraction, 13% of hemicellulose was extracted based on raw materials. Extracted hemicellulose was mainly composed of xylan, and molecular weight of hemicellulose was 35,367 (M_w). After sodium periodate treatment, molecular weight decreased to 3,805 (M_w) and aldehyde content was 69%. Xylan dialdehyde was introduced to gelatin hydrogel, and degree of crosslinking increased as content of xylan dialdehyde increased. On the other hand, swelling ratio decreased as content of xylan dialdehyde increased. Besides, mechanical properties increased until the content of crosslinker was 15% (wt%), and drug releasing test using methylene blue as a model drug was also conducted. As a result, releasing of methylene blue increased when pH was 2.

The hemicellulose based crosslinker for gelatin was produced and properties of reinforced gelatin hydrogel were evaluated. Mechanical properties of reinforeced hydrogel increased until the content of hemicellulose crosslinker was 15%. On the other hand, swelling ratio decreased as content of crosslinker increased. And drug releasing test, drug releasing capacity increased when crosslinker was added.

Acknowledgement

Economic Ripple Effects of Cross Laminated Timber Manufacturing in Japan

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ABSTRACT

Recently, timber is promoted in Japan to ensure the efficient use of artificial forests that have reached a suitable age for logging as well as a measure to tackle global warming and revitalize forestry. As a result, Cross Laminated Timber (CLT)—which has unique structural characteristics and thermal insulation properties—has come into prominence. Timber is utilized by various industries, including forestry. The timber industry includes different stages such as production, processing, transportation, and construction. Given that CLT, as a new type of timber, has received widespread attention, it becomes necessary to study its economic ripple effects. This study targeted CLT manufacturers in Japan to quantitatively evaluate the economic ripple effects of CLT through an input–output analysis, which is used to estimate the independent relationship between different economic sectors and industries. Based on the results of a survey of CLT factory's revenue expenditure, we use an extended input-output table to calculate the economic ripple effects of CLT manufacturing in Japan in 2020. The results of the study show that lumber, logs, wholesale, road freight transport (excluding private transport), and electricity are the top five sectors with the largest impact of CLT manufacturing. In terms of total economic ripple effect of CLT, the economic ripple effect multiplier is more than twice, and the size of induced employment is also more than twice the size of direct effect employment. In addition, compared with glued laminated timber (GLT), the economic ripple impact of manufacturing CLT is greater than that of manufacturing GLT for the same values of timber production.

Key Words: Economic Ripple Effects, Cross Laminated Timber, Input-Output Analysis, Timber Manufacturing

Challenges Faced in Introducing Non-Conventional Timber for Flooring Applications: An Australian Case Study

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ABSTRACT

The Australian Timber flooring industry is largely dependent on high density, native forest timber as their primary resource. However, the continuing decline of accessibility to high density, native timber, competing interests of the role of native forests and the increasing demand for social license implicate the need to introduce alternative timbers for flooring applications. Australia's hardwood plantation timber destined for pulpwood production may present a resource opportunity to meet flooring product demands. Many of Australian hardwood plantation forests have been managed for pulpwood production and are harvested at younger ages producing low density, high feature sawn boards. Although plantation timber might not be a straightforward replacement for native forest timber due to its different characteristics, there lies a potential in using this resource for value-added flooring applications. However, introducing non-conventional timbers into Australian flooring market is challenged by many factors. Recent studies have indicated the performance characteristics of plantation *Eucalyptus nitens* but there are limited studies that monitor the species in-service particularly for flooring application as solid boards and as an engineered wood product. Furthermore, the lack of understanding of consumers and specifier perceptions, conventional marketing criteria and restrictions of reliable data/guidelines are some of the factors which restrain the use of alternative timbers in flooring market: either as a solid or engineered flooring product. The present study discusses these gaps in knowledge and provides recommendations to facilitate the introduction of non-conventional timber species for flooring applications.

Keywords: Australian timber flooring, plantation hardwood, native forest timber, solid timber, engineered timber

Molecular Level Community Analysis of Fungal Colonisation of Timber in a Field Test Site.

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ABSTRACT

Timber durability is an important factor for engineering structures for long service life and although wood is one of the most durable of cellulosic materials, approximately 10 % of wood cut globally replaces timber that fails in service. While termites cause substantial damage in Australia, fungal decay remains the leading terrestrial factor contributing to wood failure in service. Traditionally wood is assessed for durability using a combination of field and laboratory decay tests. These methods work well when assessing durability, but reveal nothing about the offending species and their communities. Metabarcoding coupled with high throughput sequencing has been used increasingly in this field to help reveal the identities of the communities involved in wood decay; however, these studies have focussed on more temperate climates in the Northern Hemisphere. We are using metabarcoding and high throughput sequencing to identify the communities responsible for wood decay in subtropical climates located in South-East QLD.

Stakes representing five species of Eucalypts and one species of pine with a range of durabilitys have been exposed at three micro sites (sun, semi-shade and shade) at the DAF Maroochy research Facility in Nambour. The site had not been previously used for durability trials. Stakes have been removed at intervals to track fungal succession and fungal DNA has been extracted directly from wood, with the metabarcode sequencing of the internal transcribed spacer (ITS), a widely used universal fungal barcode sequence, to compare different communities of fungi responsible for the decay process. The results will help us to better understand the fungi associated with various stages of degradation as well as the influences of microsite and wood species on community structure.

With these results we can answer the questions: What fungal communities occur at the Nambour site? Does fungal distribution differ between wood species or microsite? And do fungal assemblies occurring in subtropical climates differ from those in temperate climates? These data also have the potential to contribute to the development of more targeted wood protection strategies.

Keywords: Durability, Decay, Fungal Colonisation, Eucalypts, High Throughput Sequencing, Metabarcoding

Sustainability Communication of Wood Sector in Comparison to Textile and Car Industry

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ABSTRACT

With next generations in mind, we need to think about our planet's limitations in all our current actions and we need to be aware the resources we are using today are not permanent. One solution towards this can be by using renewable materials, which (as the word suggest) can be renewed and reused after the end of their life cycle. For more sustainability-oriented society, an important shift in people's perceptions is needed, hence we need to invest in creating more awareness about the importance of sustainability with different stakeholders, and appropriate marketing and communication strategies can make a great difference.

The objective of this research was to study the sustainability communication in three-pillar paradigm of sustainability – economic, environmental, and social to understand if there are any differences among these three pillars in three different sectors producing products for general public. The wood, textile, and car industry were selected. Additionally, these three sectors were selected based on past studies concluding that they are part of industries contributing similar amount to the CO_2 emissions. For each of the sector representative company was selected based on size of the company (number of employees), geographical location and brand value. The selection of the representative companies was IKEA Group representing the wood industry, H&M representing textiles, and Volkswagen Group representing car manufacturing industry. The analysis applied qualitative content analyses of their web pages. The analysis of the online communication of selected companies demonstrated all the selected industries communicate about similar topics in the sustainability communication. All three studied representative companies communicated on their webpage the most about the environmental aspect of sustainability, while the social and economic one were less frequently used. There were not any significant differences found. The wood industry although utilizing renewable natural material communicates about the sustainability similarly as the other two studied sectors.

Real-time Monitoring of the Hygrothermal Performance of a CLT School Building

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ABSTRACT

Emerging wood products, such as cross-laminated timber (CLT), and wood fiber insulation (WFI) are sustainable, renewable, and low carbon footprint building products, which have been recognized as alternatives to steel, concrete, and fossil-based insulation, e.g., extruded/expanded polystyrene foam (XPS/EPS). With the first domestic WFI manufacturing plant born in Maine, the University of Maine began a pioneer study to investigate the hygrothermal performance and energy consumption of a CLT building insulated with WFI in June 2021. CLT and WFI have decent to excellent moisture buffer capacity and considerable latent heat. When exposed to an ambient environment, wood naturally buffers fluctuations in humidity by adsorbing moisture vapor to save them in the cell walls as bound water and then slowly releasing it when the humidity drops. This process is accompanied by heat release and heat gain due to the phase change of water vapor and bound water. It has shown potential to effectively reduce the impact of spikes or drops in humidity and temperature on a room's ambient feel. This study aimed to investigate the hygrothermal performance of an all-wood building constructed with CLT and mechanically fastened WFI. The monitoring data included are, temperature and relative humidity through the thickness of the insulation, the equilibrium moisture content of the WFI, the moisture content of the CLT, indoor and outdoor conditions, and finally building energy consumption. These data will be used to compare lab-scale data to the in-situ measurements, validate building design practices and modeling results, and evaluate the long-term structural health of the building.

Process Induced Discoloration – A Case Study on Tasmanian Blackwood

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ABSTRACT

In Australia, Blackwood (*Acacia melanoxylon (R.Br)*) is primarily used in appearance-based applications. Drying appearance grade Blackwood without defect is of primary importance, however, in some cases up to 40% of the timber is affected by significant discolouration following drying. Drying-induced discolouration represents substantial economic losses for the timber industry. This is not a new problem, and the Australian timber industry has previously experimented with several different methods to control discoloration, but without significant success.

Globally, drying-induced timber discolouration has been widely researched and the majority of cases are thought to be caused by environmental factors. However the environmental factors are different in every case and determining which of those factors are causal can be challenging.

To identify the types of discoloration that are occurring and determine variables that might cause discoloration, this research employed a large-scale, comprehensive rack survey of yard and shed drying timber at a case study site in Smithton, Tasmania. Information was recorded on every discoloured board that was processed during a one year period, and the data are now being processed on two levels: within rack data, to show whether there is correlation between the vertical and horizontal location of discoloured boards within each rack; and general data about each rack during the drying period, such as its location in the yard or shed, drying duration, seasonal data, and other factors. So far, the research has identified five types of discolouration, and found that all major types of discoloration were associated with the location of the sticks separating the layers of boards in the drying racks. Initial statistical analysis suggests multiple distinct causal factors including climate, drying time and rack positioning.

Simulation of Tree Oscillation Mode Shapes

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ABSTRACT

Tree oscillations are a natural response to wind loading. The shape and frequency of response oscillation are given by the geometry and material properties (global stiffness) of the tree. The oscillation shape of the stem is characterized by complex displacements, where the positions with large displacements are likely to be the locations of stem failure. The shift of frequency and mode shapes may signalize changes of material properties connected with the presence of defects. The proper interpretation of stem oscillation, therefore, may allow observation of the probability of tree failure and such an approach is highly required by the present situation on urban forestry.

The movement of twelve trees was captured by optical technique during "pull and release" tests. From the captured images the three-dimensional displacements of the stem in the time-domain were reconstructed. The oscillation modes of trees were evaluated in correlation with their allometric parameters. At the same time, the series of computations with the parametric finite-element model of the tree (represented by the beam structure) took place. The resulting model displacements were compared with experimental stem deflections based on digital image correlation analysis. The validated numerical models provide a testing group for what-if scenarios which enable to observe the effect of the internal defect on the dynamic response of trees.

Effect of High Temperature Drying with Load on Reduction of Residual Stress and Correction of Warp of Japanese Cedar Lumber

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ABSTRACT

While sawing logs along the pith to produce lumber, warps would occur in lumber due to the release of residual stress. Correction sawing should be performed to correct warps, so warps decrease the yield of lumber. Therefore, it is crucial to find a way to produce straight lumber without correction sawing. The present study focused on a series of high temperature drying with load, and it was confirmed that residual stress was eliminated, and warp was corrected after a series of high temperature drying with load. Besides, the optimal schedule conditions of high temperature drying were determined. After 6 months of storage, the treated lumber remained straight and residual stress in lumber did not recover. By applying high temperature drying with load to warped lumber, it is possible to dry lumber and correct the warps at the same time.

Keywords Kiln Dry; Residual stress reduction; High temperature drying; Growth stress; Lumber warp

Influence of sample scale on dynamic and static bending testing of green wood

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ABSTRACT

With the growing share of deciduous forests in Central Europe, the area of its use is also growing. In an effort to find the best way to process all felled wood, non-destructive testing (NDT) methods offer an advantageous option for wood grading. The relationship between the dynamic modulus of elasticity (MOED), the static modulus of elasticity (MOE) and the modulus of rupture (MOR) has been described many times. Nevertheless, in order to use NDT methods for the grading of fresh felled timber on site, it is necessary to describe these relationships for greenwood and on different scales.

This study presents the effect of samples size on dynamic and static bending mechanical properties of greenwood. 3 different groups of bending samples (20x20x300 mm, 40x40x600 mm and 60x60x900 mm) from European beech (*Fagus sylvatica* L.) and linden (*Tilia cordata* Mill.) wood were tested with a moisture content above the fiber-saturation point. A frequency-resonance method test was performed to determine the MOED and internal damping. At last destructive testing by three-point bending was performed to determine the MOE and MOR of greenwood. The analysis of the results focused on the influence of changing dimensions on static mechanical and dynamic properties. Furthermore, the relationship between vibroacoustic and mechanical properties of wood was evaluated. These results can be beneficial for the NDT assessment of greenwood.

Keywords: Size effect, NDT , lumber assessment, high moisture content, flexural stiffness

INTRODUCTION

In recent years, the problem of coniferous forests has been evident in Central and Western Europe. Naturally, the area of deciduous forests increases and thus the amount of processed hardwood(Ministry of Agriculture of Czech Republic, 2018; Seintsch & Weimar, 2012). Seintsch & Weimar, (2012) emphasize concerns about the future shortage of softwood for construction purposes and add that hardwood will probably need to be used for construction purposes as well. For this reason, there is a need to expand scientific knowledge of construction hardwood use. In order to use suitable wood for construction purposes, its grading is crucial. Different device techniques for non-destructive testing (NDT) of wood, especially acoustic methods, can better determine the flexural strength that is important for structural timber.

Acoustic NDT methods for wood assessment use mainly well-known relationships between sound propagation and mechanical properties of wood (Wang et al., 2003; Haines et al., 1996; Halabe et al., 1995). The frequency resonance method (FRM) is an NDT vibroacoustic method based on the measurement of natural frequencies of mode shapes (Unterwieser & Schickhofer, 2011). This method is frequently used because the flexural mode shape can be compared with the static response in bending (Hassan et al., 2013). However, most scientific data confirming the

relationship described above come from small standard samples. Rais et al. (2014) and Straže et al.(2022)used this method to assess greenwood long logs. Their results shows that it is possible to use this method on timber *in-situ*. However, in this case, there are two substantial factors, different sample dimensions and high moisture content (MC). So far what Bodig & Jayne (1982) states that the mechanical properties above the fiber saturation point (FSP) are constant, Unterwieser & Schickhofer (2011) states that the vibroacoustic properties change even with increasing MC. The MC of green hardwood is mostly 70-90% (Požgaj et al., 1993; Simpson & TenWolde, 1999; Tsoumis, 1991).

This work focused on phenomena of scaling effect of vibroacoustic and mechanical properties of green hardwood. From literature (Baar et al., 2012; Bohannan, 1966; Bucur, 2006) is known that dimension influence dynamic and mechanical properties of wood. The most often mentioned approach is based on Weibull's weakest link theory. This theory is based on considerations of element failure in the weakest point. Weibull's distribution also adds that with increasing volume, the probability of occurrence of defects increases. Hoffmeyer et al., (2000) stay that the use of this theory in bending wood testing is not entirely accurate. He mentions the results of (Madsen & Tomoi, 1991) and others, who perceive the thickness of the tested samples as decisive more than the volume. Bohannan (1966) states the depth and length ratio (span/depth ratio) of the sample is fundamental in bending load. Therefore, depends on which specific dimensions change to change the load response of the wood. Although the amount of scaling effect literature is quite extensive, most research has been carried out on softwood (Schlotzhauer et al., 2017). In his study, he investigated the size effect of tensile and bending compressive loads on selected species of deciduous woods. For bending loads, its results confirm Weibull's theory because the average strength of the specimens decreased with increasing size. Previous studies researching the scaling effect mostly reported results on dry samples with an MC ±12%.

The question is whether it is possible to analyze at the basic level the relationship between the vibroacoustic and mechanical properties of green hardwood if the dimensions change in a certain ratio.

MATERIALS AND METHODS

Two hardwood species, European Beech (*Fagus sylvatica* L.) and Linden (*Tilia cordata* Mill.) were used in this study. From the wood of each species, three different dimension types of bending samples were produced. The dimensions of the first (standard) group were 20x20X300 mm where the longest dimension corresponds to the longitudinal direction of the wood fibers. These dimensions were derived from the Czech standard for static three-point bending (4SN 49 0115). The second group had dimensions two times larger (40x40x600mm) and the third group had three times larger dimensions (60x60x900) compared to the basic group. All samples were produced as specially orthotropic samples so that the individual dimensions correspond to the radial, tangential and longitudinal direction. Although the samples were made of greenwood, it was not certain that the moisture content of the wood did not fall below the FSP. For this case, all samples were placed in water, the basic group of samples was immersed for one week and the other two groups for two weeks. After that the samples were left in a closed box above the water level for the same length of time. The moisture content should thus be evenly distributed and stabilize above the FSP.

The samples prepared in this way were first tested by non-destructive testing methods and subsequently by static destructive loading. Non-destructive testing was performed using the FRM. The samples were impacted by a rubber mallet and the flexural vibrations were registered using a

Polytec PDV100 laser vibrometer, and two KS94B-10 accelerometers. The signal was captured using a DEWETRON-41-T-DSA device (sampling frequency 20kHz) and then the frequencies of the resonance bending modes were recognized using MATLAB R2021a software. This data was used to calculate the bending Dynamic Modulus of Elasticity (MOED) according to the formula (1) and the damping (Tanδ) using the formula (2).

$$MOED = \left(\frac{2f}{2f}\right)^2 \cdot \left(\frac{ml^3}{I}\right) \qquad (1)$$

f is the frequency of the first transverse mode shape, m = sample mass, l is the sample length, I is the moment of inertia.

$$Tan\delta = \frac{LDD}{\pi} \qquad (2)$$

$$LDD = \pi \frac{\Delta f}{f} \qquad (3)$$

Δf is bandwidth with a half amplitude of fundamental frequency f

Destructive tests were performed by three-point bending according to the Czech standard 49 0115. The group of standard samples was tested on a ZWICK z 50 standard testing machine. Samples groups with larger dimensions were tested on a LabTest 6.500 H testing machine. Destructive tests were set up to ensure the same conditions for all tested groups, the most important was to preserve a span depth ratio = 12. Sample deflection was recorded by two CCD cameras (AVT Stingray Copper F-504B) equipped with LED headlights. The displacement was obtained from cameras pictures by digital correlation image (DIC) using software MercuryRT.

The data from the cameras and the test machine were synchronized so that the individual displacements correspond to the given force. The modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated from synchronized data. The data analysis was performed in MATLAB R2021a software. MOR was calculated from the F_{max} as given in the following equation formula (4). MOE was calculated by formula (5).

$$MOR = \frac{3 \cdot F_{max} \cdot l_s}{2 \cdot R \cdot T^2} \qquad (4)$$

$$MOE = \frac{(F_{40} - F_{10}) \cdot l_s^3}{4 \cdot R \cdot T^3 \cdot (u_{def,40} - u_{def,10})} \qquad (5)$$

Where udef,40 and udef,10 are the deflections at force levels F40 and F10 (mm) and ls is the span of supports (mm). R and T are diameters in radial or tangential direction.

RESULTS AND DISCUSSION

The
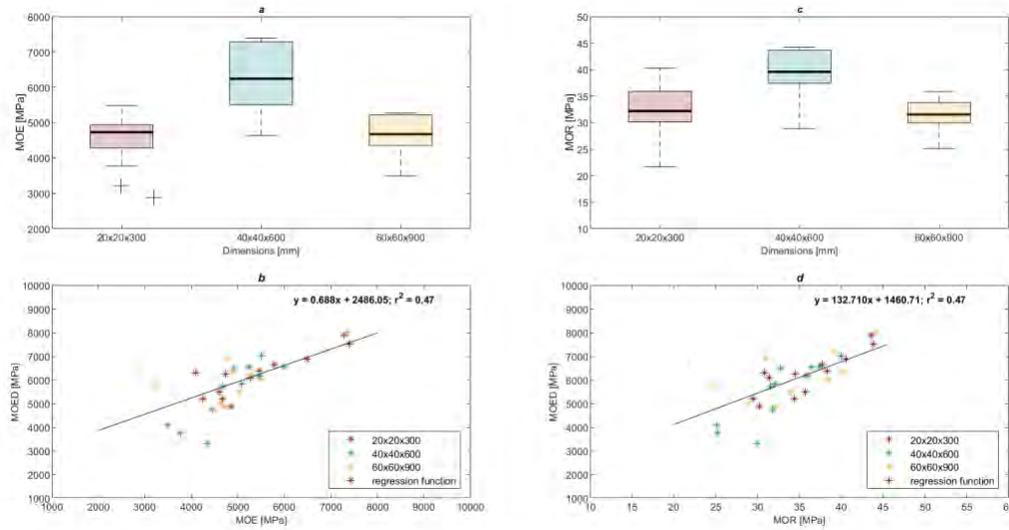
number of samples varies for each group, because it was difficult to produce samples with larger dimensions without defects and with the correct structure orientation. In Table 1 is a visible difference between beech and linden specimens. That was most likely caused by the different wood structures. In Table 1 we can also see that the Tanδ had high variability. Statistical tests did not show any relationship between Tanδ and MOE or MOR.

Table 1. Summary of evaluated data of different scale samples of Europian Beech and Linden - mean ±SD

	Dimension	MOE	MOR	MOED	Tanδ	Density	MC	n. samples
	mm	MPa	MPa	MPa		kg*m^{-3}	%	
Beech	20x20x300	9843 ±740	71 ±5	12562 ±780	0.01 ±0.05	974 ±71	70 ±11	28
	40x40x600	12258 ±1360	85 ±13	13543 ±1410	0.012 ±0.003	882 ±43	54 ±10	20
	60x60x900	11730 ±1810	78 ±14	13674 ±1960	0.017 ±0.013	950 ±45	54 ±5	16
Linden	20x20x300	4522 ±700	32 ±5	5668 ±1000	0.014 ±0.003	828 ±35	133 ±9	17
	40x40x600	6277 ±900	39 ±4	6886 ±836	0.015 ±0.002	967 ±15	162 ±12	9
	60x60x900	4828 ±592	32 ±4	5652 ±768	0.024 ±0.013	90 9 ±32	158 ±12	7

 In Figure 1 a,c can be seen that the higher values of MOE and MOR of linden wood had the middle group samples (dimensions 40x40x600 mm). Kruskal-Wallis test (α <0.05) confirmed a statistically relevant difference between samples with the middle group and other groups. MOED values of Linden wood showed a similar trend to both MOE and MOR, but statistical tests did not confirm a significant difference between the groups.

Figure 1. Graphic results of Linden samples; Analysis of variance of MOE (a) and MOR (c) values for different sample sizes, part (b) shows the dependence of MOE on MOED with colour highlighting of individual groups of samples, part (d) shows the dependence of MOE on MOED with colour highlighting of individual groups of samples

Analysis of variance results of MOE and MOR values of beech wood (Figure 2 a, c) show a similar trend as linden wood. The mean is again highest for samples with dimensions 40x40x600 mm. Due to the large variance, the Kruskal-Wallis test (α <0.05) did not show a statistical difference.

The results did not match with Schlotzhauer et al. (2017), who stay that the strength in bending decreases when dimensions increase.
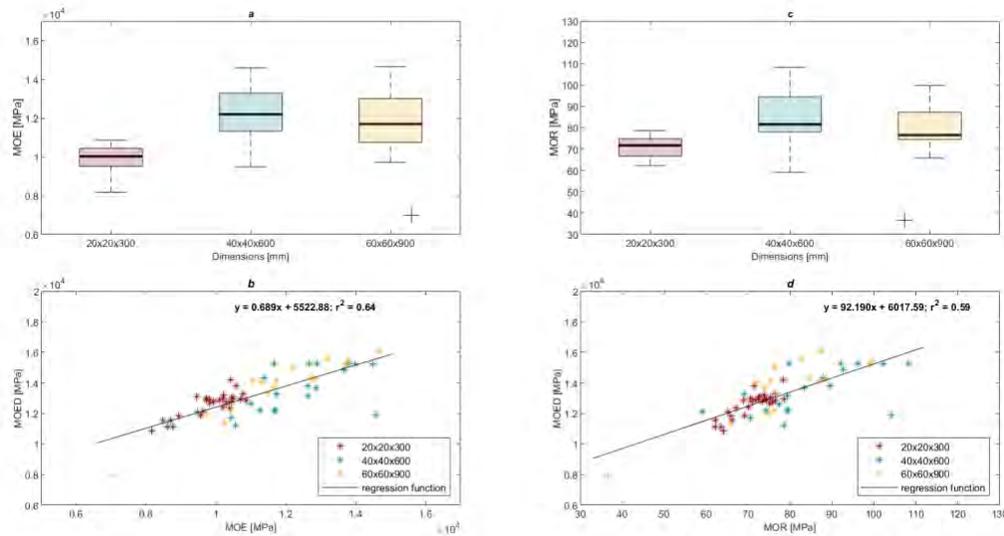
Figure 2.

Graphic results of Beech samples; Analysis of variance of MOE (a) and MOR (c) values for different sample sizes, part (b) shows the dependence of MOE on MOED with colour highlighting of individual groups of samples, part (d) shows the dependence of MOE on MOED with colour highlighting of individual groups of samples

Correlation regression analysis shows a relatively strong relationship between MOED obtained by FRM and MOE and MOR from destructive tests (Figure 1b, d and Figure 2 b, d). In Figure 1 b, d you can see the dependence which is not influenced by the sample size. Due to the regression equations, a basic prediction model could be used to predict the MOE and MOR of green hardwood from larger dimensions of wood. This study proves that this is only possible if the dimension ratio is respected.

CONCLUSIONS

A gradually increase or decrease in MOE, MOR and MOE were not confirmed for green linden and beech wood. The highest values of MOE, and MOR were in both tree species in the samples from the middle group, which had dimensions two times bigger than the standard samples. These results can be justified by compliance with the span/depth ratio for all tested samples. Basic prediction models were derived from the relationship between MOE, MOR and MOED, which can determine the mechanical properties of a smaller sample such as MOE, and MOR from MOED values measured on a 3 times bigger sample of green hardwood. This work involved increasing the dimensions of the sample only in a ratio of 1: 2: 3 with the same span/depth ratio.

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NEW DEVELOPMENTS IN CERTIFICATION/LEGALITY/WOOD FORENSIC/RENEWABLE MATERIALS
Chairs: Michael Powell, Biotica EC,Australia and Rob McGavin, Queensland Government/Department of Agriculture and Fisheries, Australia

Revision of the Australia / New Zealand Standard for Sustainable Forest Management

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ABSTRACT

The Australian Standard for Sustainable Forest Management AS/NZS 4708 is completing it's periodic revision and is due for publication in coming months. This presentation provides an overview of the revision process, the principles upon which the revision has been based and highlights some key new initiatives.

AS/NZS 4708 underpins the PEFC endorsement of sustainable forest management in both Australia and New Zealand. Key aspects of the revision include the alignment with the 2018 update to PEFC requirements for sustainable forest management including a review of chemical use and significant biodiversity values. New initiatives have been introduced to simplify certification processes for small forest growers including practical interpretations for trees outside forests (agroforestry and small-scale forestry) and group certification mechanisms.

Potentiality of Portable Low-Cost Near Infrared Spectrometer as a Precious Wood Identification Tool in Madagascar

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ABSTRACT

Madagascar's precious woods belong to the genera *Dalbergia* (Fabaceae) and *Diospyros*(Ebenaceae). They are highly valued and heavily traded due to interesting intrinsic qualities including density, non-porosity, durability, and color. This fact results in higher selling prices than for other wood species. Over the past 20 years, illegal logging of precious woods has become a recurring problem in Madagascar. Indeed, illegal trade has continued unabated, as permits are frequently falsified to indicate wrong origin or wrong species names to avoid difficulties at checkpoints in transfer ports. Reliable identification of these precious woods is thus important for law enforcement. Recently, Near Infrared Spectroscopy (NIRS) has been recognized as one of the powerful non-destructive methods for species discrimination. It allows rapid and multiple analysis at low cost level and does not require extensive sample preparation once the discrimination model is calibrated. There are different models of NIR spectrometers, characterized their sizes, wavelength ranges and spectral resolutions. To popularize the method to forest officers and control agents, to help them in the identification of the species of seized logs or during routine controls, this study aims to test the potentiality of a low-cost portable spectrometer (USD 1,000) for wood species discrimination. Two hundred and forty five 5 mm diameter wood cores of the *Dalbergia (Dalbergia occulta, Dalbergia madagascariensis, Dalbergia baronii)* and *Diospyros*(*Diospyros analamerensis, Diospyros chitoniophora, Diospyros toxicaria*) were collected. Each wood core was lightly sanded and stabilized at 12% moisture content. Four to five spectra were measured on the heartwood using NIRscan Nano spectrometer from Texas Instrument (Dallas TX, USA). This spectrometer covers the spectral region from 900 to 1,700 nm and has a resolution of 10 nm. Spectra were pretreated with the Chemflow software using three different pretreatments. For Dalbergia species discrimination, the best model gave a prediction error of 18%, i.e. 82% well-predicted samples. For Diospyros species, a prediction error of 19.6% was obtained, i.e. 80.4% well predicted samples. Thus, even if the NIRscan Nano spectrometer's resolution is low, it is suitable for developing countries such as Madagascar, as a tool to help in the management of forest resources. Moreover, its portability allows it to be used in the field, outside of research laboratories. However, several optimizations are still necessary to use the tool and the model in the management of precious wood in Madagascar, in particular in terms of variables selection,

combination of preprocessing methods, use of others classification and discrimination methods and the removal of the influence of moisture content on the discrimination model.

A Novel Bench-Scale Test Method to Characterise the Ignition Conditions for Timber Protected with Intumescent Coatings

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ABSTRACT

Mass timber structures are becoming increasingly prominent in Australia and across the globe as an avenue to a more sustainable building industry. Advances in the manufacturing of mass timber structures have led to the mainstream use of Engineered Wood Products (EWPs). A key challenge associated with using EWPs in a building is the presence of exposed (or expressed) timber may influence the fire scenario. For instance, (1) during the incipient stages of a fire, timber walls and/or ceiling might ignite and burn ahead from the fire front, resulting in a rapid fire growth; (2) when a fire is fully developed, its intensity and duration might be influenced by the presence of burning timber; and (3) during decay (and cooling) stages of a fire, timber may continue to burn even after the fuel load (e.g., furniture) in the compartment is consumed. Hence, use of mass timber in a building could challenge the suitability of typical fire safety solutions conceived for traditional concrete or steel structures.

Thin intumescent coatings, widely used in the steel industry due their proven fire performance and aesthetic considerations, are usually applied to achieve a coating thickness of a few millimetres, and when heated, swell multiple times the original thickness forming a thick layer of a foam-type material with low thermal conductivity and density – creating a thermal barrier keeping the temperature of the protected material relatively cold. However, there has been little published research on the fire performance and overall effectiveness of clear thin intumescent coatings used on mass timber structures. Experimental research outcomes on intumescent coatings for steel structures have been traditionally based on the standard fire resistance testing, which has been historically challenged by the fire science community due lack of repeatability and control of heating conditions – especially at the beginning of the test when intumescent coatings begin to swell.

There is an emerging need for the fire safety engineering community to recognise, assess, and mitigate the different levels of fire challenges associated with mass timber structures. This research study aims to understand and characterise the fire performance of clear thin intumescent coatings that could be used to protect mass timber structures. Specifically, it describes the development of a novel bench-scale fire test method, purposely conceived to investigate the fire behaviour of clear thin intumescent coatings applied to mass timber. The test method uses a setup of moveable radiant panels coupled with a sample holder having an integrated spark igniter. The objective of this test setup is to characterise the flammability

behaviour (e.g., critical heat flux for and time to ignition) for bare mass timber and mass timber protected with clear thin intumescent coatings. Compared to traditional testing, this test method can control the heating conditions at the target surface of an intumescent-coated sample, while the spark igniter is kept in a position that allows for it to be effective as the transient swelling takes place.

Key Words: Mass Timber, Engineered Wood Products, Clear Thin Intumescent Coating, Bench-Scale Test, Flammability, Fire Safety Engineering

An Overview of Sustainable Forest Management in Australia and New Zealand

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ABSTRACT

NOT AVAILABLE

The Immediate and Short-Term Degradation of the Bordered Pits on Wood Radial Surfaces in the Cement Alkaline Environment Measured by AFM

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ABSTRACT

A combination of lignocellulosic materials and cement or concrete matrix has been used for some time but never found a widespread use. A potential degradation of lignocellulosic materials in the cement alkaline environment causes the durability concern. The lignocellulosic materials start to degrade from the mixing with cement and continue in the service life. Bordered pits serve as the pathways for fluids between tracheids in the softwood, with a cellulose membrane in the middle chamber and an over-arching border situating around, which is part of the cell wall. Atomic force microscopy (AFM) provides nanoscale resolution in imaging and mechanical measurements of materials in the natural state. In this study, we measured the immediate and short-term degradation of pit membranes and pit borders on wood radial surfaces with AFM after treatments in the calcium hydroxide solutions from 1 h to 27 days. We considered the effect of the elevated temperature caused by the cement hydration heat. Morphology and adhesion force curves were developed on the identical pits using the relocating method (Li and Kasal 2021) before and after each treatment, thus reducing the error resulting from spatial variability. We measured adhesion forces and jump-off force ratios (Li and Kasal 2022), surface moduli and deformations to monitor the degradation process. The results showed that the surface roughness of the pit membranes and borders increased after treatment. The untreated pit border showed an amorphous morphology, and turned into a structure with particles in the size of 100-200 nm. The adhesion forces are sensitive to the surface chemical components: the adhesion forces of the membranes of the pit torus were not significantly changed with the treatment time – the membranes only had one component, cellulose; the adhesion forces of the pit border shifted along two sigmoidal curves (Li and Kasal 2022) and showed three stages of degradation – the removal of the extractives, the degradation process of the hemicelluloses-lignin matrix, and the exposure of the cellulose aggregates. The surface modulus of the pit torus degraded faster than that of the pit border: the surface modulus degraded almost completely after 48-h treatments; The surface modulus of the pit border decreased to 83-95% of the untreated original (CI) after 10 days and to 20-23% of the untreated original (95% CI) after 27 days of treatment.

Keywords: bordered Pit, cement alkaline solutions, AFM, force-displacement curves, morphology

Dynamic Vapor Sorption – A Versatile Technique for Wood Material Characterization

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ABSTRACT

Moisture control and measurement are critical parameters for wood and wood composites. For instance, moisture plays a key role in the fungal degradation and weathering of wood-plastic composites. Sorbed water molecules on the surface of wood also affect the rate of photochemical degradation. Moisture sorption behaviour and diffusion processes are also of interest for evaluating drying kinetics. Dynamic Vapor Sorption (DVS) methodology has been used to study water and organic vapor sorption properties of wood materials where vapour sorption kinetics would determine the long-term storage stability of the materials. Organic vapor sorption studies would also allow the study of material surface energetics, volatile organic compounds (VOCs) sorption capacity, and herbicide/insecticide retention behavior. The vapor sorption studies on several examples including wood, insulation materials, fibres and biomaterials illustrate how gravimetric moisture sorption experiments can be used to study the stability of these materials. Experiments were expanded to include chemisorption and physisorption studies of water and formaldehyde on building materials. The open hysteresis and difference in mass at the start and end of the experiment indicated the retention of formaldehyde.

In-Situ Log Labelling and Earth Observation to Ensure Timber Legality

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Abstract
Illegal logging poses a global challenge with significant negative impacts. It results in a loss of biodiversity and causes obstacles to both climate protection as well as to efforts on reducing poverty. In addition, is it leading to market distortions and creates competitive disadvantages. Illegal logging harms the positive reputation of wood, as being a nature-compatible and renewable. In industrialised nations legislations are set forward to combat illegal logging. Examples are the Australia's Illegal Logging Prohibition Act, the European Union Timber Regulation, or the US Lacey Act. Illegally felled wood has been repeatedly placed on market as certified wood, misleading consumers who are demanding legally produced wood products. Main factors associated with illegal logging are: (1) timber certification is usually based on a predominantly document-based review of the forest management plan and process chains. (2) on-site inspections and ecological assessments of logging activities take place only sporadically. The object of this study was to develop a technology able to verify the origin of single logs on a global scale. A GNSS-based tracking system is suggested that can breakdown timber supply chains through automated raw material labelling, data assortment and information distribution. An innovative IoT (internet of things) tree-labelling device has been developed, able to tamper-proof tag felled tree stems through physical imprinting, right at the location of harvest. Tree stem specific data are embedded as well as blended online by remote sensing workflows. The imprint-tagged tree stems can be recognized at any processing facility by means of image recognition algorithms. Merging the wood tracking system with a satellite-based forest monitoring system is offering efficient, cost-effective and reliable verification tools for forest resources. The resulting data allow first time improved estimations of forest biomass monitored through satellites. The developed system is designed to meet industry requirements. By ensuring confidence in legality assessments through multi-factor authentication, necessary counterfeiting efforts will decisively increase. The obtained results will help to improve sustainable forest management, as demanded in SDG 13 "Climate Change", and SDG 15 "Life on Land". Certification bodies may use the services to better verify reported timber harvests, and more easily detect illegal and unreported logging activities. The results of this research are applicable to remote forest regions, which cannot be verified on-site, for e.g. logistical reasons. Forest owners will be able to check whether or not timber has been felled in a designated region. The potential applications are diverse and they are relevant to various stakeholders, offering great market opportunities.

Key Words: Wood Traceability, Illegal logging, Remote Sensing, Sustainable Forest Management

WOOD PROPERTIES AND PHYSICS
Chairs: Graeme Palmer, Southern Cross University, Australia and Maryam
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Modelling Of Moisture Movement and Wetting Process in Wood Product Composite Systems

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ABSTRACT

The ingress of moisture into massive wood product composite systems, such as cross-laminated timber (CLT) and laminated veneer lumber (LVL), can have significant impacts on their performance due to biological and physical degradation. Therefore, understanding the ingress of water into these products when exposed to free water and humid environments is critical to predict product performance and life span during and post construction.

In this work, we consider the extension of an existing single-board wood drying model to allow for the ingress of moisture, and accommodate configurations of multiple boards (or thin veneers) laminated together in different orientations. We treat each board as a homogeneous material, and account for glue lines between boards by controlling the moisture transfer between layers. We have used experimental data measuring moisture content in cores extracted from sections of CLT and LVL panels to calibrate our model. The initial modelling outcomes have shown excellent agreement between our model and experiments for moisture ingress in sections of LVL and CLT panels when exposed to liquid water. The model has also been used to predict the drying process after panels were exposed to moisture, which is another key factor for their use in construction. This model provides a flexible tool that can be used to investigate the moisture distribution in wood product composite systems subjected to a range of external conditions.

Prediction of Green and Dry Board Properties from Pre-Harvest Inventory and Resi Assessment Data

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ABSTRACT

Pre-harvest inventory metrics (including Resi traces) were collected from 10 sites in the Green Triangle region of south-east South Australia. Logs were harvested and processed in a structural sawmill through to the drymill with stiffness data collected. There was a large range in site quality, log size, heartwood percentage, log velocity, dry board density and dry board MoE between sites. At the site mean level, Resi metrics were able to estimate tree/ log under bark diameters and to rank stands by log velocity, dry board density and dry board MoE. The inclusion of other factors (log SED, tree slenderness, etc) in the MoE model improved predictions of mill output, although it remains to be seen if this finding holds in general and if the improvement is sufficient to justify the extra effort. Resi predictions of stiffness in stands could be used to target the best stands for a mill producing structural timber, or alternatively, the Resi could be used to divert the lowest stiffness stands away from such a structural mill.

Keywords: Resi, sawn board, density, stiffness

INTRODUCTION

In recent years the IML PD-series Power Drill (Resi) has received widespread acceptance as a tool for commercial pre-harvest assessment of stand-average wood quality in Australia. Its rapid, low-cost measurement capability, combined with its accuracy and precision for estimating wood density, and consequent prediction of log stiffness (MoE) has been demonstrated in a range of industry and Forest and Wood Products Australia (FWPA) funded studies (Downes et al., 2016; Bailleres et al., 2019; Downes et al., 2019).

The work described here was part of an FWPA and industry funded study (PNB548-2021) and covers the analysis of data generated in a OneFortyOne Plantations (OFO) mill trial which took place in early 2021. The overarching purpose of the study was to inform the understanding of the importance of fibre quality to an integrated forest growing and wood processing business.

The specific objective of the trial was to relate Resi-based predictions of fibre quality at the level of a harvesting unit, to actual dry mill board output when batches of logs originating from the respective harvesting units are processed through the mill.

MATERIALS AND METHODS

IN-FOREST DATA CAPTURE

Between October 2020 and January 2021, 64 pre-T3 and pre-clearfall (CF) harvesting units were assessed for wood density using a standard Resi sampling design (5-9 plots per site). These sites spanned a range of geographic locations, age classes (25-35yrs) and site qualities (best to poorest). Ten sites were selected as study sites which
- comprised three pre-T3 (schedule for their third thin) sites and seven pre-CF (clearfall) sites,
- spanned the range of measured average wood density,
- ensured geographic, age and site quality diversity

The ten sites were well distributed across the landscape in the Green Triangle region of South Australia and Victoria.

At each site a circular plot was established that was representative of the stand and accessible to harvesting equipment. The radius of the plot varied such that it contained adequate trees to generate circa 100 sawlogs suitable for processing through the mill. Plots in the T3 sites were larger again to allow for the fact that only 30-40% of smaller trees were harvested – with tree selection favouring smaller trees. In each of the plots all trees were measured for DBH, tree height, features (sweep, branching, defects). Trees selected for thinning were labelled. Resi traces were collected on all plot trees using standard procedures (at breast height but avoiding whorls or other swellings; perpendicular to lean).

The time lag between felling and mill processing did not exceed one week. Trees were harvested and cut into 4.85m lengths. A single log length simplified downstream material handling. All logs received a unique number identifying site, tree and log. Log ends were spray painted with a site specific colour to assist segregation in the mill. HM200 sonic velocity data were collected from each log along with log lengths. A single Resi trace was collected approximately 10 cm from the small end of every log. Where possible these traces were collected as bark-to-bark traces.

The Resi web application (https://forestquality.shinyapps.io/FWPA-4) was used to post process the raw Resi traces. Pith and bark locations were manually checked. Where bark-to-bark traces were collected, predictions were made based on the entire trace. Otherwise, results are based on pith-to-bark data. Acoustic velocity and MoE predictions were made using existing regression relationships developed against basic density estimates.

MILL PROCESSING AND DATA CAPTURE

Logs were processed through the green mill one site at a time and tracked by site. Simplified cut patterns were used to ease trial management. Only 40 mm thick boards were recovered, except for site 1, for which 50 mm thick boards were also cut. For analysis purposes the 50 mm boards from site 1 have been grouped with the 40 mm boards except where explicitly noted. Consequently, the only products considered are 200x40 and 100x40.

Prior to the trimmer 98% of the boards were 4800 mm in length. After the trimmer 92% were untrimmed and the rest were a mix of 3600 (<1%), 3900 (<1%), 4200 (4%) and 4500 mm (2%). As boards exited the green mill they were sorted (binned) by GTM grade (HI, LD, SAP) and board dimension. GTM grading was performed using a gamma-ray instrument. Additional labelling was applied to ensure that each bin of boards could be traced individually through the kiln and dry mill.

In the dry mill all boards were split, gauged and trimmed to produce only 90 mm wide final products of various lengths: 49% were 2400 mm, 33% 4800 mm, 11% 4200 mm and 6% 2700 mm. Dry board density was measured using X-ray attenuation at 5 mm intervals along the board length. MOE was measured in flexure using a Metriguard grader at 20 mm intervals along the length. All data captured was collated and stored in a project database. Analyses and reporting were done in R (R-Core-Team, 2020) using RMarkdown.

RESULTS AND DISCUSSION

FOREST DATA

Table 1 describes the sites selected for the trial. Site quality varied from 1.3 (site 4) to 4.2 (site 9) with a higher number indicating a poorer quality site. Stand age varied from 23 years (site 3)

to 38 years (site 9) with older stands generally having lower stocking. Stand age had little relation to average DBHOB except that the three youngest stands had the smallest average diameter. Logs from sites 2, 3 and 4 (younger sites) are significantly smaller. Logs from site 3 also had significantly lower acoustic velocities (Figure 1).

Table 1: Description of selected trial sites

Site Number	Site Name	Site Quality	Final Stocking (sph)	Year planted	No. Stems harvested	Mean DBHOB (cm)	Mean Tree height (m)	Slenderness (m/cm)
1	IslandSwamp	2.1	242	1989	16	44	33	0.75
2	SnowGums	2.4	442	1997	41	31	31	0.99
3	Bowds	1.4	425	1998	44	31	28	0.89
4	MyoraSouth	1.3	384	1997	39	31	31	1.00
5	Picks	3.0	272	1992	26	45	33	0.74
6	Alleyns	2.0	242	1990	23	49	30	0.62
7	Littles	2.7	218	1992	28	42	31	0.75
8	Furner	3.6	266	1985	27	39	29	0.74
9	McPhees	4.2	265	1983	26	43	36	0.82
10	Glenaulin	1.7	297	1987	21	46	36	0.78
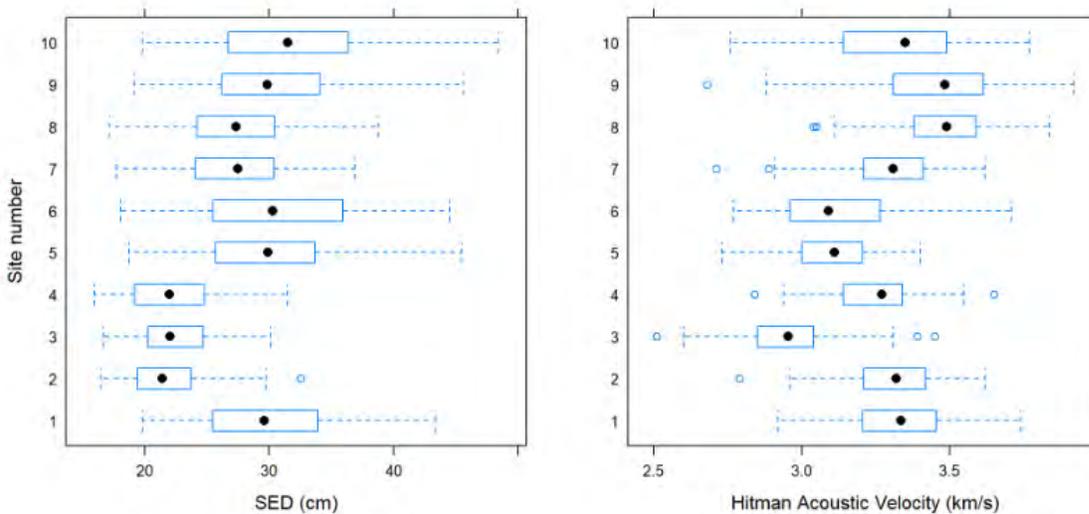
Figure 1: Log small end diameters and acoustic velocities by site. 3 logs with velocities less than 2.2 km/s have been removed as outliers.

MILL DATA

The near doubling of board numbers from green to dry (Table 3) is due to splitting of the boards in the dry mill. Greenmill recovery ranged from 48% (site 3) to 59% (site 1), increasing in proportion to average log diameter. Recovery percentages in this trial are not representative of

typical mill performance due to the simplified cutting pattern used. SAWSIM® simulation indicates that the loss in recovery due to the saw pattern employed was on the order of 5-6%, with recoveries from edge board being most strongly influenced.

Table 3: Board summary info by site

Site No.	No. green boards	No. dry boards	Green board volume (m3)	Dry board volume (m3)	Volume Recovery (green) %	Volume Recovery (dry) %	SAP %	dry MC (%)	Dry density (kg/m3)	MoE (GPa)	MGP10 %	Bow (mm)	Crook (mm)	Twist (deg)
1	536	842	16.4	12.5	59	45	62	10	490	12.4	96	3.5	3.9	2.7
2	551	739	10.9	8.0	49	36	37	12	505	11.0	84	3.2	2.8	3.3
3	552	720	10.8	7.8	48	35	39	10	460	8.3	62	3.3	3.8	3.9
4	573	772	11.2	8.2	48	36	42	10	488	10.3	77	2.9	3.2	3.3
5	779	1499	21.4	15.9	55	41	44	11	491	10.2	84	2.7	3.4	2.3
6	686	1311	19.3	13.9	55	39	53	10	489	10.6	81	2.7	3.4	2.2
7	682	1148	16.5	12.2	53	39	64	11	520	12.8	94	2.2	2.6	2.4
8	647	1073	15.6	11.6	54	40	70	11	542	13.9	97	2.7	2.7	3.0
9	820	1510	22.5	16.4	56	41	51	11	532	13.6	95	2.6	2.8	2.8
10	811	1594	23.0	17.1	58	43	62	13	524	12.3	93	2.4	3.2	2.6

Green board density (Figure 2a) permits an indirect assessment of green log density which can be used to improve predictions of board stiffness based on log acoustic velocity. Variation in green board density is mainly driven by moisture content, although basic density also has an effect.

The distribution of dry board density (Figure 2b) measured in the dry mill shows site 3 produced lower density lumber, with the remaining sites appear to make up two groups: lower density from sites 1, 2, 4, 5 and 6 and higher density from the rest (sites 7, 8, 9, 10). Site 8 had the highest density.
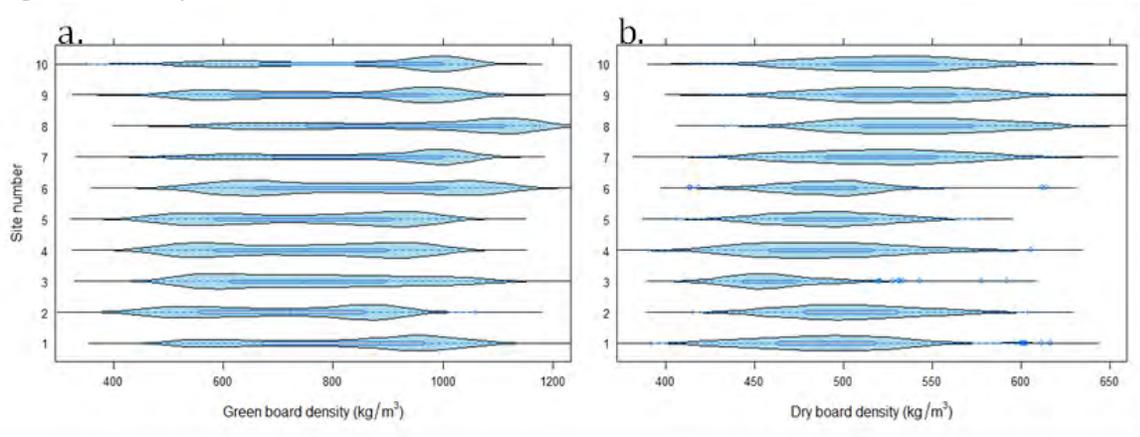
Figure 2. (a) Board green density and (b) Board dry density by site

Board stiffness (MoE)

Sites appeared to fall into three groups: high (1, 7, 8, 9 and 10), medium (2, 4, 5, 6) and low (3). While the means of these groups differ, the variances were similar. Figure 3(a) shows the relationship at a site level between average log acoustic velocity and dry board stiffness, as has been found in other studies, it is the basis for using log acoustics to segregate logs into quality classes on the skid or in the mill.
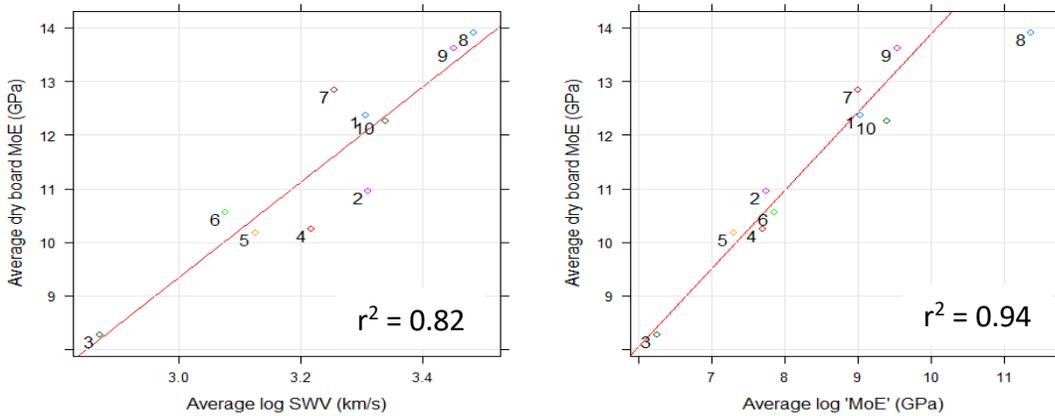
Figure 3: Prediction of site average dry board stiffness from (a) log acoustic speed alone (SWV) (b) log MoE (log acoustic speed^2 x log green density)

Log green density, typically measured by weighing the log or estimating the amount of heartwood, improves the relationship between log acoustic velocity and board stiffness. While this trial collected neither individual log weights or heartwood fractions, the board green density values were used to estimate site average log green density and Figure 3b shows the how using log MoE improved the prediction of average board stiffness. Site 8 is an oddity, the green density for this site maybe unreliable.

RESI PREDICTIONS OF MILL PRODUCTION

Dry board density

Site-level Resi prediction of wood basic density was strongly correlated with measured dry board density (Figure 4) based on (a) pre-harvest standing tree Resi and (b) Resi from all logs. In subfigures (a, b) 'core density' refers to under-bark means analogous to an increment core sample.

Dry board MOE

Figure 5 compares site average dry board MoE with predictions (prmoe) based on Resi traces from standing trees (a) and logs (b). Both models correlate well enough ($r^2 \approx 0.6$), though it is notable that including traces collected on all logs, rather than just at breast height, does not

improve the correlation markedly. While the correlations are good, both models under predict the actual value, like the offset noted above for density predictions
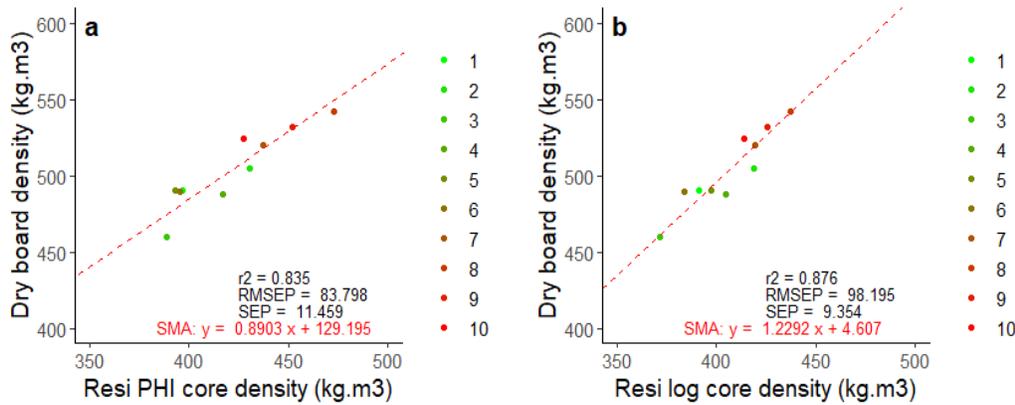
Figure 4: Site average dry board density versus Resi density (a) pre-harvest (PHI), core density (b) log, core density. Coloured dots indicate sites.
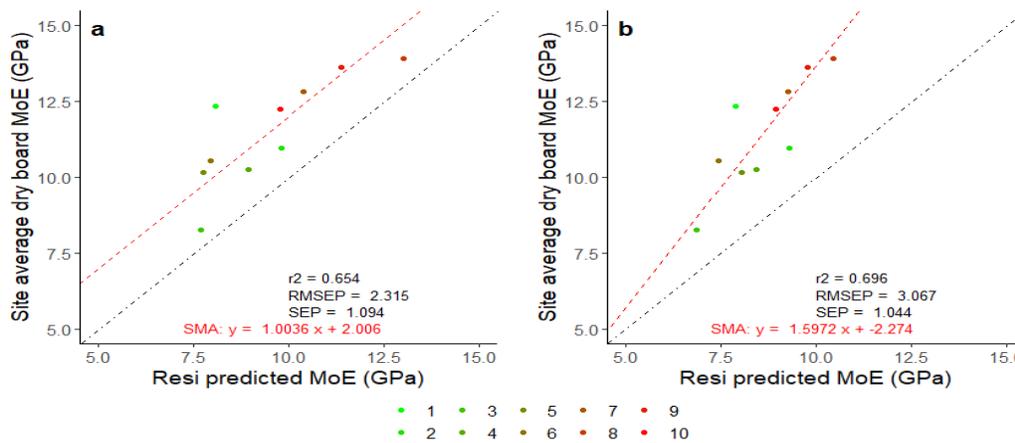
Figure 5: Resi-predicted MoE (prmoe) from preharvest traces at BH (a) and small-end log traces (b) against site mean dry board MoE

Inclusion of other predictors

Previous work (Downes et al 2019) had noted that including tree slenderness (ratio of tree height and tree diameter at breast height) can improve the prediction of mean Board MOE at the site level. Including slenderness improves R^2 from 0.65 to 0.77 (Table 4), although from a statistical point of view slenderness adds insignificantly (*p*-value is large). Adding tree age also provided minimal improvement. On a dataset as small as this trial is at site level, including extra predictors without *a priori* cause is liable to result in overfitted models. With that caution in mind, it appears that average SED (see Figure 1) may add significantly.

CONCLUSIONS

At the site level Resi derived measures:
- Can be used to estimate tree/log under bark diameters.
- Are correlated with site average log velocity, dry board density and board MoE.

Prediction of board MoE (at site level) is improved by including other factors such as tree age, tree slenderness and log SED. This dataset spans too few sites to determine if these factors improve predictions universally, a meta-analysis merging this dataset with that from previous similar trials is underway. Furthermore, the improvement due to including these extra factors may not be sufficient to justify the extra effort and cost.

Table 4: Summary of models using tree slenderness, age and SED to better predict site level mean board MoE.

Predictors	Resi	Resi+Slenderness	Resi+Age	Resi+SED	All
	p	p	p	p	p
(Intercept)	0.093	**0.026**	0.398	0.475	0.660
prmoe	**0.005**	**0.003**	**0.029**	**0.001**	0.116
slenderness		0.107			0.742
tree age			**0.021**		0.999
log sed				**0.015**	0.457
Observations	10	10	10	10	10
R^2 / R^2 adjusted	0.654 / 0.611	0.768 / 0.702	0.846 / 0.802	0.861 / 0.821	0.864 / 0.755

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Developing a Continuous Measurement Setup for Electrostatic Surface Charges, Implemented in Woodworking Processes

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ABSTRACT

When two materials with solid surfaces come into contact, an electric charge is transferred from one surface to the other. When the materials are separated again, the imbalance of the electrostatic charge becomes obvious, along with the static electricity visible due to different surface work functions of the prevalent materials. In wood machining mechanical friction is invariably associated with contact electrification as soon wood surfaces get in contact with a wood working tool.

Electrostatic surface charges of wood could play a role as a novel primer treatment in coating. Currently, there is no measuring system to monitor electrical surface charges, which could be directly implemented into a woodworking process. This research is concerned with the development of a universally applicable continuous measurement setup, which is then compared to a commercial discontinuous detection method.

A self-designed and self-made measuring system that uses the electric fieldmeter EFM 115, Kleinwächter® GmbH, Germany, has been developed, which is essentially a small electric field mill with high sensitivity for measuring electric direct voltage fields. The EFM is connected to a measuring box that is a faraday cage to shield against electrostatic charges. Electromagnetic fields (E) striking the box from outside cause a force effect $F = Q * E$ on the freely moving charges (Q) of the sheet metal. The measurement setup allows quantification of the electrostatic surface charge at zero energy transfer by using the principles of electrostatic induction and measuring the accumulated electric field strength generated, expressed in V/m with a resolution of ± 5 V/m.

To verify the obtained data measurements are simultaneously performed with an electrostatic sensor (SK-H050, Keyence, Belgium), in combination with an Ioniser Monitoring Unit (IMU). The SK-H050 measures the surface charge in volts at a defined measuring distance of 25 mm or 100 mm, with a measuring accuracy of ± 10 V. This validation revealed that the results of the two readings differed only in the range of measurement inaccuracies. We successfully developed a continuous measuring system, able to monitor electrical surface charges. The equipment can be directly implemented into woodworking processes.

Keywords: Triboelectricity, electrical field strength, surface charge, wood machining, wood processing

Comparison Between High Temperature and Continuous Drying of Southern Pine in Terms of Drying Quality and Permeability

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ABSTRACT

Continuous Drying (CD) is the fastest growing trend internationally in softwood kiln drying and the future for timber drying is moving from batch processes to continuous drying processes. Significant energy savings up to 30% and improvement in drying quality have been reported using CD compared to high-temperature batch drying (HTD).

This article compares the drying quality parameters (moisture distribution, moisture gradient, distortion, drying stress and case hardening) and permeability between dried timber boards using HTD and CD. Plantation-grown southern pine boards from Queensland were dried using CD and HTD.

All the measurements were conducted in accordance with Australian/New Zealand Standards. A significant decrease in moisture gradient, moisture variation, drying stress and case hardening was observed in CD dried timber. There was no significant difference in distortion between CD and HTD that could influence southern pine timber utilisation. Although the difference in gas permeability was not significant, the CD dried timber exhibited significantly higher liquid permeability than HTD.

Measurement of Wood Moisture Content Variations in the French Forest Resources

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ABSTRACT

The knowledge of the wood moisture content in standing trees is useful for optimizing the wood transport as well as the wood drying. Studies dealing with this property are few and often focused on small geographical areas.

The measurements of wood moisture content were made on increment cores sampled during fifteen consecutive months on about twenty thousand cores sampled in the French forests (Leban et al., 2017). Each core was CT scanned two times, after sampling and after drying. The processing of the tomographic images (Jacquin et al., 2019) permits to obtain for each core, the wood density "green" and "ovendried". Then the initial moisture content and basic density were calculated.

Here we present the results of the variations of the wood moisture content between August 2018 and October 2019, for the ten most important French forest species: *Quercus petraea, robur* and *pubescens*, *Fagus sylvatica, Carpinus, Pseudotsuga menziesii, Pinus pinaster, Pinus sylvestris, Abies alba, Picea abies*. The intra-tree variation pattern of wood moisture content is species dependent and we point out a huge between tree variability.

These results confirm and show that (i) at the intra specific level, the standard deviation of moisture content increases with moisture content, (ii) at the inter specific level, moisture content of softwoods is higher than for hardwoods, (iii) softwoods have higher seasonal variations of moisture content than hardwoods except for *Pseudotsuga menziesii*, (iv) the wood moisture contentin standing trees drops sharply in the beginning of summer except for *Pinus pinaster*, (v) high wood basic density implies low wood moisture content and (vi) the within species variations of wood moisture content are driven by the basic wood density variations.

Keywords: Wood Moisture Content, Increment Cores, Variation, Basic Density, Seasons, Species, Carden software, XyloDensMap.

INTRODUCTION

Every year, the French National Forest Inventory (NFI) collects about thirty thousand tree cores from seven thousand forest plots. In 2015, the XyloDensMap (XDM) was launched with the objective to enrich forest information by collecting the increment cores that were previously left on ground after the counting of the number of annual rings (tree age) and the measurement of the growth increments of the last five formed annual rings. The increment cores were stored in polycarbonate alveolar plates and send to the INRAE lab for the measurement of the wood basic density. During 15 consecutive months, we also measured the wood moisture content (MC).

Wood moisture content is the ratio of the mass of water in wet wood to the anhydrous mass of wood (Dietsch et al., 2015). It is a useful physical property for the forestry-wood industry because at least three actors in the industry use it: the forest manager, the transporter, and the processor. Knowing the MC of wood allows the forest manager and log transporter to define the best options for minimizing the amount of water. The wetter the wood, the heavier it is, and therefore, the higher the transport loads (Tomczak et al., 2018). Secondly, information on wood moisture would also help to optimize drying, which is often necessary before the conversion of rough sawn timber in end-products (Longuetaud et al., 2017).

Previous studies on wood moisture have demonstrated the existence of intra-tree variations in this property (e.g., Fiora and Cescatti, 2006; Longuetaud et al. 2016, 2017; Tomczak et al. 2018). Nevertheless, none of them had projected to a national scale. It is in this context that the present study, which follows up on the work of (Randriamananjara, 2019) was developed.

MATERIALS AND METHODS

Protocol for measuring density and moisture content of wood cores and data acquisition

As mentioned above, the wood cores collected in the field were inserted in sealed polycarbonate plates and posted to the INRAE laboratory.

Each increment core is identified by the position of the core within each plate and by the plate number. This allows to associate the new wood properties measurements with the field measurements performed by the NFI staff (species, number of trees per hectare, sampling date, soil type, stand type, etc.).

Each plate contains a maximum of 15 cores, 17 plates were grouped together to form a package. Five packages passed together through a medical scanner, the first scan was made with fresh cores, and the second one was made on the same cores after drying during 48 hours at 103°C. For each scan we stored tomographic images of the cores, these images were then processed by the mean of the Carden software (Jacquin et al. 2019)

The output of this processing consist in two wood density profiles per core (fresh and ovendried) with one axial resolution of 0.625 mm.

By combining both wood density profiles we calculated the basic wood density and the wood moisture content.

Calculation of moisture from the average density

Knowing that the wet cores underwent a journey from their place of collection to the INRAE laboratory, we know that despite their conditioning, they lost part of their moisture by evaporation. We measured in a separate experiment the amount of water lost during the transport of the cores by post and undertake a correction. For each species, a linear regression was established between the wood MC and the time between the date of arrival and the date of collection in order to bring the date of collection to zero (Randriamananjara, 2019):

$$\mathbf{H(\%)_{j=0} = (\Delta_y/\Delta_x * \Delta_j) + H(\%)_{cal}} \quad \text{Equation (1)}$$

With the knowledge that

$$\mathbf{H(\%)_{cal} = (\rho_h/(\rho_0*(1-R_{VT})-1))*100} \quad \text{Equation (2)}$$

With:
- ρh: wet density per slide or core at the sampling date.
- $\rho 0$: dry density per slide or core at the sampling date.
- $H (\%) j=0$: the estimated moisture content of the wood at the sampling date.
- $H (\%) cal$: the moisture content of the wood at receipt of the cores.
- $\Delta y/\Delta x$: the regression slope of the moisture content between the sampling time and the arrival.

RESULTS AND DISCUSSION

Variation in moisture content between tree species

At the species level, the variance of MC is positively correlated with MC (Fig. 1). At the interspecific level, softwoods have a higher MC than hardwoods. We can observe that *Abies alba* has the highest moisture content.

This following graph depicts that at the intra specific level, the standard deviation of MC increases with moisture content. When a species has high MC, it also has high standard deviation. It is the case for *Pinus pinaster, Pinus sylvestris, Norway spruce* and *Abies Alba*.

At the inter-specific level, the MC of softwoods is higher than for hardwoods. It is explained by the fact that hardwoods vessels areas is small, in consequence, the lumen can be full with a small amount of water. In opposite, softwoods have tracheids and the lumen are big and can contain bigger amount of water.

Figure 12: Moisture content of 10 trees species

Seasonal variation in moisture content

As the measurement of MC spans 15 consecutive months, we can measure the MC variations across the 4 seasons of one year (Fig. 2). Regardless of the time of year, except for *Pseudotsuga menziesii*, softwoods always have a higher MC than hardwoods. For softwoods, *Abies alba* has the highest MC throughout the season, reaching up to 101.79%, and the lowest is attributed to *Pseudotsuga menziesii*. Generally, over the entire 15 consecutive months, hardwoods show a little seasonal variation in moisture and a lower moisture level than softwoods.
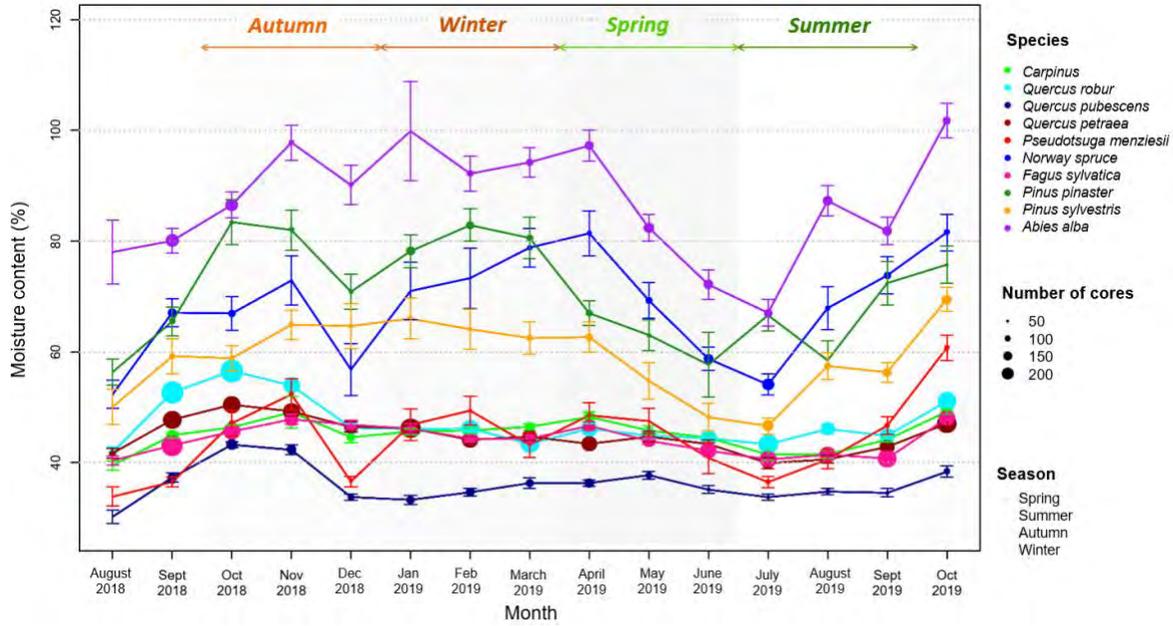
Figure 13: Wood moisture content in function of seasons

Wood MC variations and wood basic density

In the following graph the blue doted upper curve represents the maximum wood MC content (Fig. 3). Each dot represent the MC for one species, the size of the dot is proportional to the number of cores. The two vertical black segments above "poplar" and "chestnut" represent the amount of air present in the wooden cell (no water). Altogether, we can see that softwoods have a higher MC than hardwoods. This is explained by their lower basic density. Poplar is one outlier as it has the lower wood basic density and the higher wood MC. As they have denser wood, hardwoods have less space available than softwoods for the storage of free water in their stems. In other words, at the interspecific scale, the proportion of air decreases when basic density increases.

Figure 14: Moisture content in function of basic wood density

Between-tree variation in moisture content

An overall radial increase in pith-to-bark MC was observed for *Abies alba*, *Pinus pinaster, Norway spruce,* and *Pinus sylvestris* (with a MC differences of +20%, p <0.005) (Fig. 4). Knowing that the sapwood holds the highest moisture content, *Pseudotsuga menziesii* showed a strong radial increase in moisture from the pith to the bark with an elevation of 35%, p <0.001. The MC near the pith of *Pinus sylvestris* is lower compared to the outer parts, this species has the least variation in intra-tree MC among softwoods. In all hardwoods, a small radial increase was observed with a variation of +5%, p <0.001). Nevertheless, a significant difference in MC between the three radial positions was observed, except for *Carpinus*, which showed only a difference between the middle part and the sapwood part (Fig. 5).

Figure 15: Between tree moisture content of softwoods
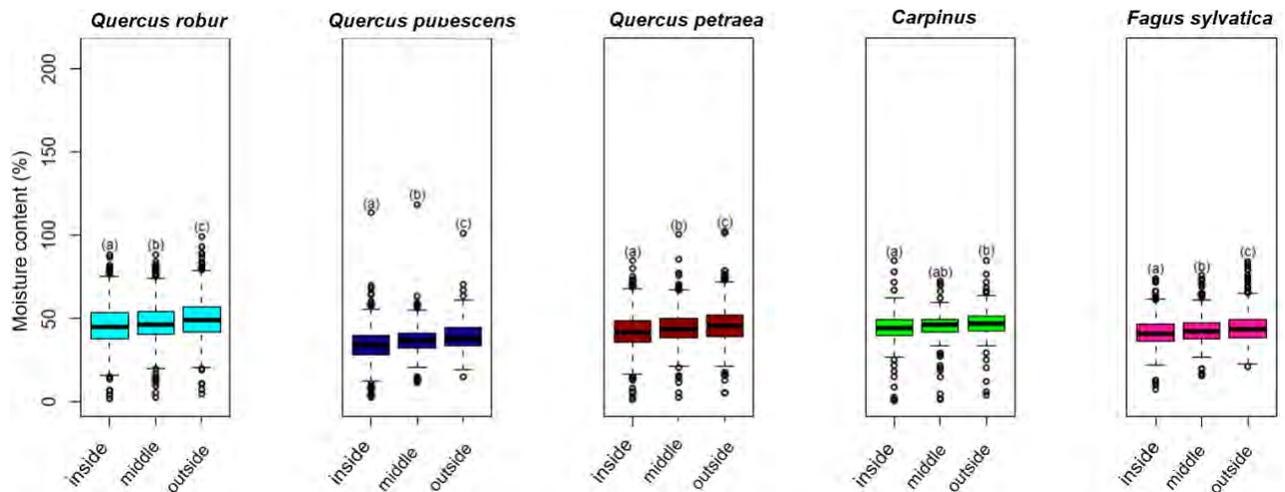
Figure 16: Between tree moisture content of hardwoods

CONCLUSIONS

This first analysis of the intra-tree variations of wood MC in relation with the wood basic density variation provides a new original data set that improves our knowledge of the wood properties variations in the French forest resources.

The originality is twofold as we have measured the wood MC variations over fifteen consecutive months for ten forest species and for each species we measured the intra-tree pattern of variation at breast height.

Over the sampling period the wood MC varies between 30-100% for softwood and between 15-55% for hardwoods.

Clearly for softwoods there is a higher MC difference between heartwood and sapwood between 20 and 35%, while those for hardwoods were in the range of 5-10%.

In this work, we have illustrated that the wood MC variations need to be presented in relation with the wood basic density variations, that wood moisture content of the tree stems candidate for defining the ability of trees to face a severe drought period.

More broadly, this new data set paves the avenue for other investigations aiming at better understand and explain the observed differences between species and their hydraulic functioning especially in the present context of increased tree mortality caused by the climatic change.

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Managing Wood Dust in the Wood Industry with Innovative Technologies

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ABSTRACT

Processing of wood by means of sawing, cutting, defibration or sanding, are the most common steps in the wood working industry. Wood fine dust is a health hazard, requires cleaning efforts, reduces service life and increases energy consumption. This contribution is focusing on novel dust-reducing measures, with the goal to improve the wood dust management for the wood industry. New types of circular sawing blades as well as sanding paper are presented that have the potential to generate less dust during operation. Further, machine housing along with dust exhaust systems have been also investigated, with key findings now being internationally patented. Using the triboelectric charging effects, especially the tool-machine transition is most critical in terms of fine-dust generation, in it includes also the problem of dust coming from different sources ("hybrid-dust". These topics are addressed in the presented research, with novel solutions such as magnetic control devices. The presented data and findings include application examples that are now in the process of industrial up-scaling.

Comparisons of Wood Quality Among Pines: Naturally Regenerated Longleaf vs. Planted Longleaf and Planted Loblolly

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ABSTRACT

Longleaf pine (*Pinus palustris*) once dominated the southeastern U.S. landscape, but changes in land use have reduced its habitat to only a small fraction of its original range. Longleaf pine naturally produces high quality wood but has not traditionally been considered a productive plantation species compared to other southern pines such as loblolly (*Pinus taeda)* and slash (*Pinus elliotti*) pine. Minimal research has been conducted on longleaf pine wood properties, hindering understanding of how silvicultural decisions affect its wood quality. We compared wood and fiber quality for four species-site combinations: planted longleaf pine on forest cutover sites, planted longleaf pine on old agricultural field sites, longleaf pine in naturally regenerated stands, and loblolly pine in plantations. We sampled three stands from each of these four combinations, totaling eleven stands in southwest Georgia and one in the panhandle of Florida. We felled 10 trees per stand and collected wood disks at various heights up the stem. We generated a comprehensive wood quality assessment by measuring ring-by-ring specific gravity and acoustic velocity incrementally up each tree. We used the data, to construct models and create whole-tree property maps. The results of this research will provide landowners and timber companies insight into how regeneration methods and growing sites influence longleaf pine wood and fiber quality.

Keywords: Southern Pine, Wood and Fiber Quality, *Pinus palustris*, *Pinus taeda,* Specific Gravity, Acoustic Velocity, Regeneration Method

Comparative Analysis of Thermal Comfort Performance of Wood, Brick, and Concrete

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ABSTRACT

Recently, there is an increase in the temperature of outdoor spaces such as streets, plazas, etc., in many compact cities. Therefore, thermal comfort in public outdoor spaces is now considered to be one of the greatest challenges worldwide. In response to this issue, this study aims to compare the thermal effect of various building materials on public spaces. Three materials, wood, brick, and concrete will be examined using a case study which is going to be presented by reference to a real public urban space, which is a corridor located at 17 Shahrivar street in Tehran, Iran. In this study, ENVI-met 4 software was applied to evaluate the level of thermal comfort of the three materials, wood, brick, and concrete. For simulation of the microclimate of the area, meteorological sampling was analyzed on the hottest days in summer in July and the coldest days in winter in January 2020 at the meteorological station of Geophysics Center, the University of Tehran (under 5 km distance from the case study). The results showed, respectively, wood, brick, and concrete have the best function to gain thermal comfort in the corridor during the summer. However, in the winter, brick provides better thermal comfort than wood in the examined case study. Concrete in both seasons is the worst material in terms of thermal comfort. Based on the quantitative analysis in this study, the weight assigned to wood, brick, and concrete in terms of the urban space thermal comfort, in order, are 0.7, 0.6, and 0.3. The results of this study clarify how much each material could change the level of thermal comfort in the corridor of 17 Shahrivar. The finding of this research asserts that wood and brick as local materials could provide better thermal comfort than concrete in the outdoor spaces of Tehran.

Keywords: Thermal Comfort, Outdoor Space, Wood, Brick, ENVI-met 4

THURSDAY, JULY 14
WOOD MODIFICATION AND BIOENERGY: CHEMICAL, THERMAL, EPL, BIOLOGICAL, OTHERS
Chair: Mark Brown, University of Sunshine Coast, Australia

Real Time Gas Modeling for Biomass Pyrolysis Using Triple Gaussian Functions

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ABSTRACT

The objective of this work is to develop a model to describe the gas productions in real time for biomass pyrolysis. Southern yellow pine (SYP) was used as the biomass source to create the gas production curves. The gas production readings were recorded using an external gas sensor array. To validate the efficacy of the sensor array, gas concentrations readings were measured and compared to the results obtained from GC-MS, FTIR, and surface area analysis. The effects of dwelling temperature and temperature ramping rate on the gas production were investigated. Using the data from the gas production curves, a mathematical model based on the triple Gaussian functions was developed. The triple Gaussian model uses three separate Gaussian functions to describe the characteristics of the three separate ranges of the gas production curve: Carbonization Range, Gasification Range, and Modification Range. For each of the Gaussian functions, the components of the Gaussian equation A, σ, and μ defined the shape of the function, starting time and ending time of the separate ranges of the model. By comparing the components of the triple Gaussian function against the processing parameters, the changes that occurred in the different ranges of the model show relationships between the components of the function and the parameters used. Through applying the triple gaussian model, the effect of processing parameters on the gas production were discussed.

Production and Evaluation of Combustion Properties of Rice Husk Briquettes as Alternative Energy Source

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Abstract

Rice husk is the outermost part of the rice seed which is a hard layer and a waste material from rice milling. Rice husk includes biomass that can be exploited for various requirements such as industrial raw materials as well as energy sources or fuel but only a small group of people use it. Briquettes were produced using rice husk biomass and Gum Arabic binder. Therefore, this study was carried out to evaluate the combustion properties of briquettes produced from rice husk as an alternative fuel source to firewood and charcoal which are drivers of deforestation. Two different briquette samples were produced; Treated briquette samples and Un-treated briquettes samples which are produced at two levels of feedstock's (rice husk) 200g and 300g with 100g and 150g of binder level of gum arabic as binding agent. The combustion properties examined include moisture content, ash content, volatile matter, and fixed carbon, calorific value, also determined. The result obtained for the percentage moisture content ranged from 9.93±0.50% - 9.95±0.024% for 100% treated and 150% treated rice husk respectively, while 100% and 150% binder level of un-treated rice husk has the highest moisture content ranging from 12.09±0.33% - 12.50±0.50%. The amount of volatile matter of treated rice husk briquette samples was lower at both 100g and 150g binder level with 18.98±0.17% - 19.54±0.33 % respectively. The percentage volatile matter of treated

rice husk briquette samples was lower at both 100g and 150g binder level with 18.98±0.17% - 19.54±0.33 % which implies that the quantity of binder used contributed to the amount of volatile matter present. The result of % volatile matter of treated rice husk has a higher fixed carbon content ranging from 59.95±0.17 – 58.15±0.17% across the two binders level used while that of the untreated briquette was lower. The heating value of treated rice husk 4057.67±0.33-3993.42±0.33Kcl/kg was recorded for briquette sample produced at 100g and 150g of binder level respectively while a lower heating value of 3845.83±0.50 - 3762.14±0.50 was observed for the untreated briquette samples. The briquettes produced showed high calorific values which make rice husk suitable as potential raw material for alternative source of domestic energy via densification process.

Keywords: Treated and Untreated rice husk, briquette, gum Arabic, combustion properties, alternative fuel.

INTRODUCTION

The biomass constitutes the agro-wastes destined for conversion into biofuels. At the moment potential crops for biofuel production in the country are cassava, sugar cane rice and sweet sorghum for bioethanol; palm oil, groundnut, and palm kernel for biodiesel because of their high yield and current production output in the country. Biomass briquetting is the best renewable source of energy for healthy environment and economy. Biomass briquettes are made from agricultural waste and serve as alternative for fossil fuels such as oil or coal; it's also used for heating boilers in manufacturing factories, and has further applications in developed countries. Biomass briquettes are a technically renewable source of energy and produce less carbon emissions than traditional coal briquettes. It's a completely eco-friendly. Most materials containing lignite and cellulose are suitable for densification. We cannot destroy the wastage totally. But we can use it with the help of briquetting plant and produce the briquettes, which ultimately produce the energy we need. Biofuels offer the advantage of coming from large, mainly under-utilized biomass resources that are sustainable and renewable in a closed carbon cycle that reduces environmental input.

Briquetting can be defined as a process through which loose materials of biological origin are compacted to improve the handling qualities of raw materials and enhancing volumetric energy value of the biomass.

Fuel briquettes are also made from grass, leaves, rice husk and any type of paper, which are compressed after processing in a lever press into the required sizes. These fuel briquettes are made without polluting the environment, they are environmentally-friendly as they utilize waste materials (Shrestha, 2006). Biomass briquettes are a renewable source of energy and avoid adding fossils carbon to the atmosphere. The extrusion production technology of briquettes is the process of extrusion screw wastes (straw, sunflower husks, buckwheat, etc.) or finely shredded wood waste (sawdust) under high pressure. There is a tremendous scope to bring down the waste of convention energy sources to a considerable level through the development, propagation of non-convention briquettes technology i.e. briquettes machine, briquettes plant, biomass briquettes plant for production of agro residue briquettes to meet thermal energy requirement. Turning organic waste matter (bio- waste) into carbonized fuels could be one of the most promising options to stimulate waste collection. (Mike, 2019).

The consistent use of fossil fuel for energy has detrimental effect on both human health and the ecosystem causing deforestation resulting to soil erosion, desert encroachment, atmospheric pollution and the eminent global warming (Elinge *et al.,* 2011). Energy demand has been a challenge especially in developing countries. Reliance on fossil fuel is hampered by continuous rise in prices, depleting oil reserves and the eminent greenhouse effects (DOE, 2009; DOE, 2008). Therefore, there is need for cheap and affordable alternative energy source.

The main purpose of this study is to produce briquettes using rice husk as an alternative source of energy and to evaluate the combustion related parameters such as percentage (%) Ash content, percentage (%) Volatile matter, percentage (%) Fix carbon and heating values of briquette samples.

MATERIALS AND METHODS

2.1 SAMPLE COLLECTION AND PREPARATION

The raw material used for this study (rice husk) was sourced from the nearby local rice milling factory, located at Bade Local Government Area of Yobe State, Nigeria. Also gum Arabic was used as the binding agent for agglomeration of the rice particles. The bind was selected because its availability, relatively cheap, and have good binding potential and it was gotten from Rubber

Research Institute of Nigeria. Both feedstocks was sun dried and prepared ready for further use as shown in Fig. 1a and b

Fig.1a: Rice husk sample
Source: Field survey 2020

Fig. 1b: Prepared Gum Arabic binder

The gum Arabic was prepared into slurry with about $10cm^3$ of cold water. Approximately 500ml of water was poured into the prepared power of gum Arabic and stirred to form the paste.

The rice husk was subjected to hot water pretreatment by soaking in hot water at 100^0C for 24 hours to reduce impurities after which the excess water was drained using a sieve and subsequently subjected to open space drying. Care was taking during drying to prevent impurities from coming in contact with the treated rice husk. Meanwhile briquettes were produced from untreated rice husk and treated rice husk.

2. 2 *Fabrication of Manual Briquette Machine*

The materials selection for the briquetting machine components was based on the available construction material, cost and their availability of technical know-how of the fabricator. The machine molds and pistons were produced from cylindrical galvanized steel alloy to prevent rust as shown in Figure 2.

Handle

Galvanized
Cylinder
Briquette
Molder

Figure 2:
Manual briquetting

Machine

Source: Field Survey (2020)

2.3 *Briquette production process*

Briquette samples were produced from both Treated and Untreated rice husk at two production measurement levels: for Treated briquette 200g of rice husk to 100g of binder while for Untreated 300g of rice husk to 150g of binder (1:1). Six replicates of briquette samples were produced at different material composition levels. Twelve briquette samples each were produced for both treated and untreated briquette samples making a total of 24 briquette samples. After the production, the briquette samples were air-dried for 30days.

| Figure 3a: Treated Briquette Sample | Figure 3b: Untreated Briquette Samples |

2.4 *Determination of combustion related properties of the briquettes.*

2.1.4.1 Moisture Content
The moisture content of the briquette samples was determined and calculated as ratio of the weight of moisture to the initial weight of sample, according to Adekunle, *et. al.* (2015) procedure as expressed in percentage as given in Equation1 below:

$$percentage\ moisture = \frac{W1 - W2}{W1} \times 100 \dots \dots \dots \dots . equation \ \ (1)$$

Note: W1 = weight of sample before oven drying, (gram).
W2 = weight of oven dried sample, (gram).

2.4.1 Ash Content

Ash content of the briquette's samples were determined using a furnace residue from fixed carbon determination were heated in a furnace at 590^{0}C, for two hours and transferred into a desiccators to cool down the materials turned into white ash and weighed. Same procedure was repeated three time at 1hr interval until the weight was constant. The weight was recorded as the final weight of the ash, according on ASTM (1990). The percentage ash content was then calculated using Equation 5.

$$\%Ash\ content = \frac{Weight\ of\ ash}{Original\ weight\ of\ sample} \times 100 \dots \dots \dots \dots \dots equation \ (2)$$

2.4.2 Volatile Matter

The briquettes percentage volatile matter content was determined using Lenton furnace. The residue of dry sample from moisture content determination preheated at 3000C for 2hrs to drive off the volatiles, the leftover sample was further heated at 4700C 2hrs, to ensure complete elimination of volatiles, just before the materials turns to ashes, and then cooled in desiccator,

based on the Adekunle *et. al.*, (2015) procedure. The crucible with known weight and its content was weighed and expressed as the percentage weight loss, the Percentage volatile matter was computed using Equation 3.

$$Volatile\ matter\% = \frac{final\ weight}{original\ weight} \times 100 \dots \dots \dots \dots. equation \quad (3)$$

2.4.3 Fixed Carbon Content

Fixed carbon was determined by using the data previously obtained in the proximate analysis and according to García, *et. al..(*2012) using the formula in Equation 4.

$$FC\ (\%) = 100\% - MC\ (\%) - AC\ (\%) - VM\ (\%)\dots\dots\dots\dots equation\ (4)$$

2.4.4 Heating Value

The heating value of the briquettes samples was determined using equation 4 below:

$$heating\ value\ (kcal/kg) = \frac{galvanometer\ \times calibration\ constant}{weight\ of\ samples} \dots \dots \dots equation\ (5)$$

RESULTS

Table 1: Results of the combustion properties of rice husk briquettes.

Binder Levels	Specie Treatments	% Moisture Content	% Ash Content	% Volatile Matter	% Fixed Carbon	Heating Value Kcl/kg
100g	Treated	9.93±0.50	11.13±0.05	18.98±0.17	59.95±0.17	4057.67±0.33
	Un-Treated	12.09±0.33	13.03±0.50	28.08±0.50	46.79±0.67	3845.83±0.50
150g	Treated	9.95±0.024	12.35±0.50	19.54±0.33	58.15±0.17	3993.42±0.33
	Un-Treated	12.50±0.50	14.05±0.55	29.31±0.67	44.12±0.83	3762.14±0.50

DISCUSSION

The moisture content of briquette samples produced from 100% treated and 150% treated rice husk ranged from 9.93±0.50% - 9.95±0.024 which implies a lower moisture level. While 100% and 150% binder level of un-treated rice husk has the highest moisture content ranging from

12.09±0.33% - 12.50±0.50 as shown in Table 1. The result obtained for both treated and untreated samples were within the range report of Ige Ayodeji *et.al.* (2018) that reported moisture content of less than 18% for watermelon briquette and Sesame stalk and 10.6% and 10.8% of rice husk and sawdust briquettes charcoal reported by Thliza, *et. al.* (2020). The variation observed may be due to hot water pretreatment process and hydroscopic nature of the rice husk prior to production of briquette. This means that the higher the moisture of the briquettes the lower the combustibility of the briquettes produced. Therefore, the treated briquette samples have more burning efficiency than the untreated briquette sample. And also, the briquette samples produced at the binder level of 150g has a higher moisture content making the briquettes produced at 100g binder level of more advantage. Therefore, the increase in moisture content of the briquette with increase in binder concentration could be as a result of initial movement of the liquid gum arabic binder to pores spaces between the rice husks (Gbabo *et al.,* 2018). Figure 1 shows that there is a significant difference between the treated briquette samples and untreated briquette samples and binder level in the % moisture content of the briquettes produced with rice husk.
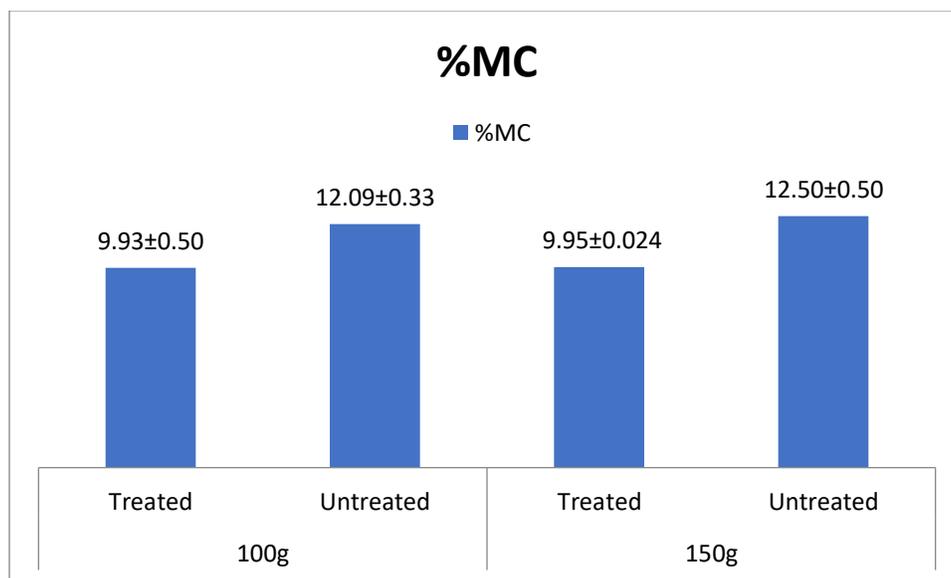
Figure 1: percentage moisture content (%MC) and binder level (grams) of briquettes

After combustion of briquette samples the remaining incombustible material sample expressed in percentage is known as the ash content. This can only affect the burning process after the amount is increased. The lower the ash content the better the quality of fuel briquettes. Hence, the samples produced has low ash for both 100g and 150g of treated rice husk briquette samples which ranged between 11.13±0.05 - 12.35±0.50% while moisture content recorded for the untreated briquettes is a little bit higher compared to what was obtained for the treated briquette samples as evident in table 1. Therefore, the treated briquette samples accumulated less ash content than the untreated briquette samples. Increase in ash content level indicates low combustibility of the briquettes (Gbabo *et al.,* 2018).
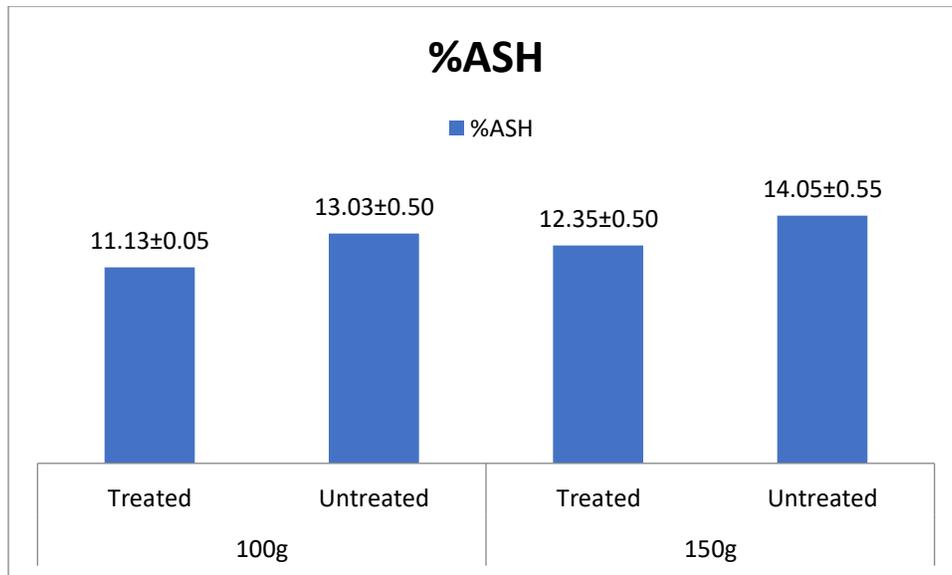
Figure 2: percentage ash content and binder level (grams) of briquette

The amount of volatile matter of treated rice husk briquette samples was lower at both 100g and 150g binder level with 18.98±0.17% - 19.54±0.33 % respectively while the volatile matter for the

untreated samples was higher than treated briquettes and this ranged between 28.08±0.50 - 29.31±0.67% respectively as shown in Figure 3, which implies that the quantity of binder used contributed to the amount of volatile matter present in the briquette samples produced. This is the combustible and non-combustible gas or the combination of both that is usually released while the briquette burns. They contain hydrocarbon compounds. Therefore, volatile matter is the unstable materials that tend not to remain in one state but will transit rapidly by vaporization expressed in percentage. Higher volatile matter further indicates that the briquettes can be ignited easily and also increase in flame length (Elinge *et al.,* 2011). Briquettes with a favorable ignition have a better thermal efficiency with less environmental hazard (Praveena *et al.,* 2014).
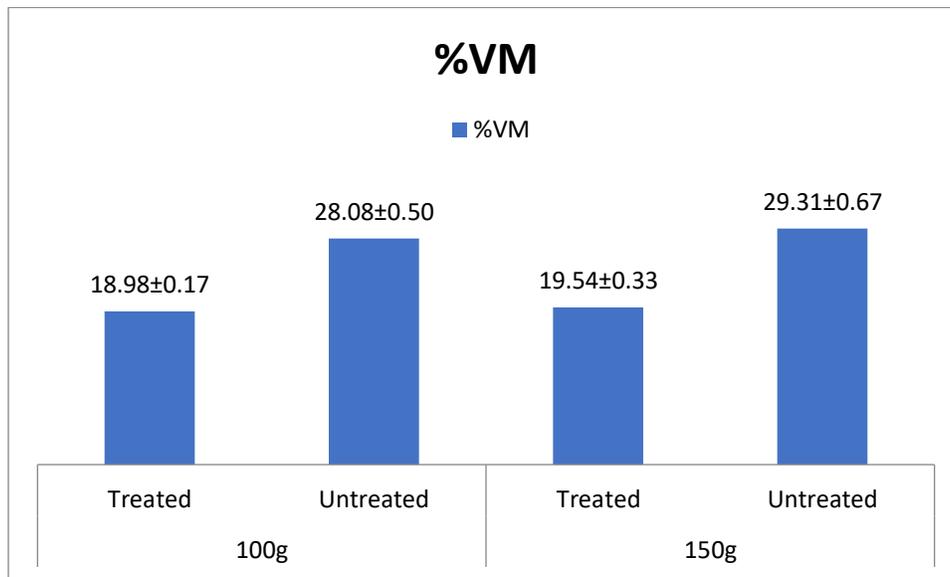
Figure 3: Percentage volatile matter (%VM) and binder level (grams) of briquette

The fixed carbon of the briquette, predict a rough estimate of the heating value of a fuel and acts as the main heat producer during burning (Akowuah *et. al*., 2012). The result of the fixed carbon revealed that the briquette produced from treated rice husk has a higher fixed carbon content ranging from 59.95±0.17 – 58.15±0.17% across the two binders level used while that of the untreated briquette was lower. The results of fixed carbon obtained are less than the result of the bio-coal of groundnut shell of 33.68% reported by Ikelle *et. al.* (2020). Briquettes are better with

higher fixed carbon because the corresponding calorific value is usually higher as reported by (Praveena, *et. al.* 2014).
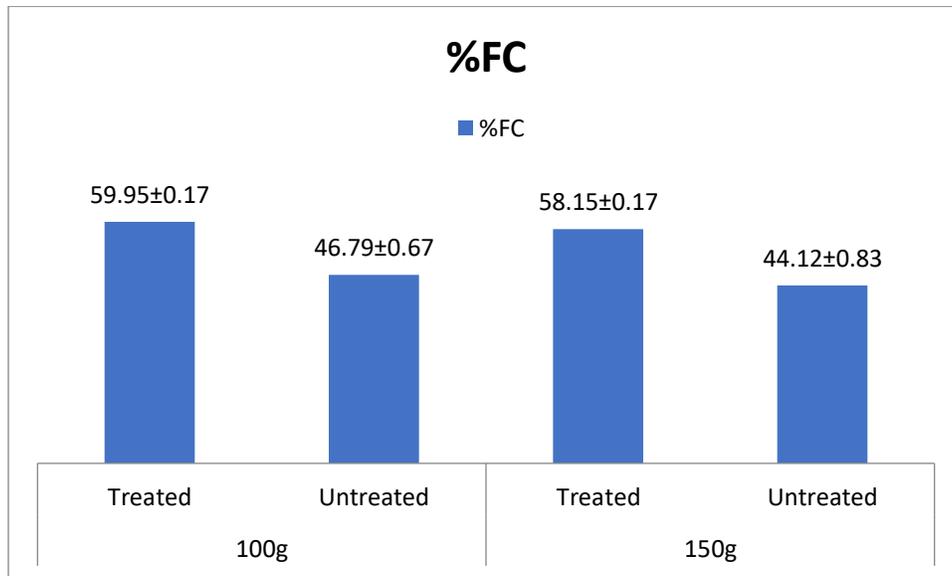
Figure 4: percentage fixed carbon (%FC) and binder level (grams) of briquette

Calorific value is the most important combustion property for determining the suitability of a material as fuel. The heating value of treated rice husk 4057.67±0.33 - 3993.42±0.33Kcl/kg was recorded for briquette sample produced at 100g and 150g of binder level respectively while a lower heating value of 3845.83±0.50 - 3762.14±0.50Kcl/kg was observed for the untreated briquette samples. Heating value of the rice husk briquettes increased at the binder level of 100g and decreased at the binder level of 150g. This means that the higher the binder level the lesser the heating value. This could be due to higher moisture content in the pore spaces of the biomass which rarely evaporate. As a result of this, the water content in the briquette became higher and reduced the heating value. (Erzam *et al.,* 2017) The result also indicates that the treated briquette samples have more heating values than that of the untreated briquette samples.
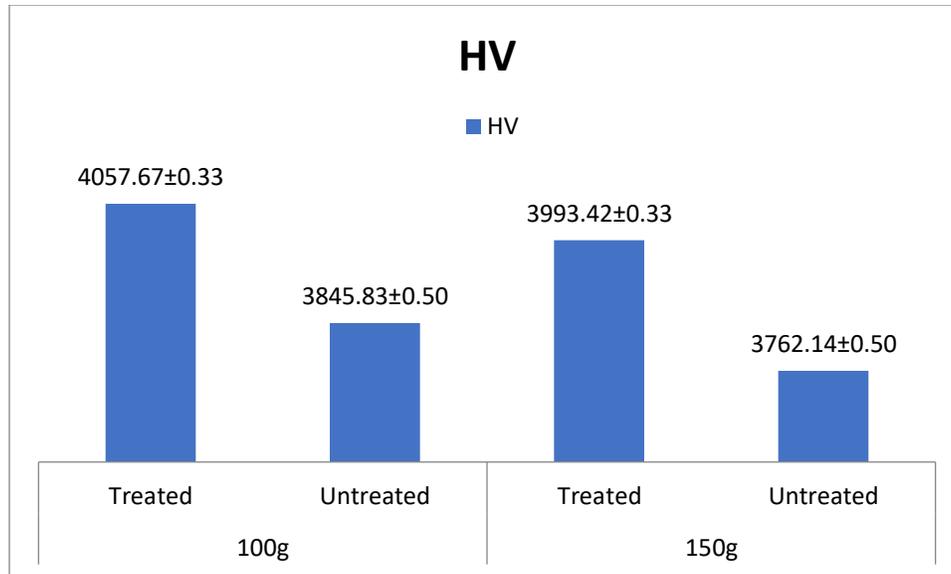
Figure 5: heating value (HV) rice husk of briquette

CONCLUSION

This study reveals the potential of rice husk as a suitable raw material for the production of briquette. This was achieved with the use of manually operated briquetting with addition of gum Arabic as the binding agent. Briquette was produced from treated and untreated rice husk prior briquette production. This was done to compare the quality of briquettes produced. Consequently, the briquettes produced shows high heating values, less volatile matter and good burning efficiency especially treated samples. This means that the briquettes are suitable for domestic purposes; serve as alternative to conventional fossil fuel and fuel wood; and can be transported over long distances without disintegration due to its solid form and good handling properties. Briquettes produced at the binder level of 100g shows high performance than the ones produced at 150g binder level. The treated briquettes samples gave more efficient outcome than the untreated briquette samples. Based on the outcome of the study it's assumed that better improved quality briquette can be produced through the use of automated screw briquetting machine.

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Novel Insights into Self-Sustained Smouldering of CCA-Treated Timber Poles

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ABSTRACT

Chromated copper arsenate (CCA) is one of the most widely used wood preservatives in Australia for protecting timber from fungal and insect attack in exterior infrastructure, due to its relatively high efficiency and strong reactions with the wood. Smouldering, the flameless oxidation of the solid phase porous char that is formed during a fire, is a known issue for CCA-treated timber after fire exposure. Smouldering can progress without flame and destroy or damage timber structures after flaming combustion has ceased. Since chromium and copper may act as catalytic promoters of smouldering combustion, CCA-treated timber infrastructure is considered especially susceptible to this process. CCA-treated electricity poles, fence posts, and railway sleepers have been reported to continue to degrade through smouldering combustion for an extended period after bush fires have passed, although the majority of reports on this issue have been anecdotal. Developing a better understanding of smouldering mechanisms would help in the development of better prevention methods.

A novel testing method was developed to assess self-sustained smouldering propagation after an imposed external heat supply was removed. This methodology was derived from the ENA pole test procedure and added internal temperature measurement, to quantify the severity of self-sustained smouldering in addition to visual observation. CCA-treated spotted gum pole sections were treated to meet Standard AS/NZS1604 for Hazard Class H5. All tested pole sections were instrumented with 1.5 mm diameter stainless steel sheathed thermocouples (TC) placed into predrilled holes at varying distances from the exposed surface to measure solid-phase temperatures. A radiant panel system provided the heat source based on a calibrated incident heat flux corresponding to the closest distance between the panels and the pole surface. Both non-treated controls and CCA-treated pole sections were subjected to constant heat flux and subsequent ventilation for a limited time.

Both CCA treated and untreated pole sections sustained surface char damage during heating and flaming, but only the former was severely damaged from self-sustained smouldering. No self-sustained smouldering was observed visually or via thermocouple measurements on the non-treated pole after flaming combustion. A CCA-treated pole subjected to a 50 kW/m^2 heat flux was still smouldering 21 hours after the initial heating including the untreated heartwood. This level of damage poses further interesting questions with respect to the heartwood, which was untreated and thus expected to have a higher smouldering threshold temperature for smouldering oxidation.

The full paper will explain experimental results from different test configurations (i.e. heat exposure and flow condition) through analysis of the temperature development along the cross-section. Those results can be used to identify the governing factors that induce and influence smouldering, and explain why smouldering was observed in the non-treated heartwood region.

Evaluation of the optical, thermal, and mechanical properties of cellulose nanofibril composite film with hydrophilic lignin

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ABSTRACT

The aim of this research is to fabricate composite film only composed of cellulose and lignin. In addition, the scientific renovation of this study is that hydrophilic lignin, produced by oxidation with peracetic acid, was used to improve the functionality of cellulose nanofiber (CNF) composite film. Biomass-based materials are considered as new biomaterials in the future because of the carbon-neutral and biodegradable characteristics. To manufacture the materials, CNF has been widely utilized to fabricate materials such as packaging film, adsorbents, and hydrogel. However, some properties such as UV protection and thermal stability are needed to be improved for the application in the industry. Additionally, lignin is one of the main components of wood, and it has innate thermal stability and UV shielding ability which are demanded by various materials. In this study, to enhance a variety of functionality of CNF film, a composite film produced using CNF and hydrophilic lignin was fabricated and thermal, optical, and mechanical properties were evaluated.

At first, lignin was oxidized with acetic acid and hydrogen peroxide. To reveal the carboxyl group on the lignin structure, Fourier transform infrared (FT-IR), carbon-13 nuclear magnetic resonance (13C NMR), elemental analysis, and zeta potential analyses were carried out. As a result, carboxylated lignin (C-lig) was produced and used as CNF film additives. And then, to fabricate CNF-C-lig composite film, C-lig was added into the CNF suspension with the ratio 0, 5%, 10%, and 20% to evaluate the effect of C-lig on CNF film. To figure out the characteristics of CNF-C-lig composite films, atomic force microscopy (AFM), ultraviolet-visible (UV-Vis) spectroscopy, water contact angle (WCA), specific water vapor transmission ratio (SWVTR), and thermal and mechanical property analyses were conducted. Consequently, the flatness of the film was improved. When lignin is added into the CNF film, the more lignin added, the more the film wrinkled. However, in the case of the C-lig, the more C-lig added, the smoother the composite film surface was. As a result of the AFM analysis to observe the surface

morphology, both CNF film and CNF-C-lig composite film maintained nano-scale morphology on the surface. In addition, when the C-lig was added to the CNF film, the height of the surface film decreased from 79 nm to 30 nm. In the case of the UV protection ability, the more C-lig added into the film, the higher amount of UV protection obtained. When CNF composite film with C-lig, WCA decreased from 57.1° to 43.1°, and SWVTR decreased from 93.66 g·μm/m^2·day to 47.79 g·μm/m^2·day.

In conclusion, CNF-C-lig composite film was successfully fabricated with improved functionality such as flatness, UV protection, WVTR, and thermal stability.

Keywords: Lignin, hydrophilic lignin, peracetic acid oxidation, CNF-lignin composite, Biomass-based functional film

DURABILITY, WOOD DECAY, AND PRESERVATION 2
Chair: Bill Leggate, Queensland Government/Department of Agriculture and Fisheries, Australia

Improving The Durability and Fire Resistance Of Tasmanian Eucalyptus Species

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ABSTRACT

Many of Australia's *Eucalyptus* species have low natural durability and fire-resistance, which reduces their value, versatility, and potential usefulness as wood products for the built environment. Conventional wood preservation techniques, such as vacuum pressure impregnation (VPI) using fluid preservatives, result in exceedingly shallow penetration due to the high proportion of refractory heartwood in these species. To address this, a National Institute for Forest Products Innovation (NIFPI) funded project on improving durability in Tasmanian hardwoods was established together with the Tasmanian timber industry, the University of Tasmania, and multiple interstate and international research collaborators. A variety of durability and fire-retardant treatment methods were trialled in this project, including: the use of VPI in combination with additional chemical adjuvants; varying the thicknesses of sawn boards, laminates, and veneers; non-pressure methods like dip-diffusion; supercritical carbon fluids (SCFs); pre-treatments like incision, compression, and microwaving; and non-chemical methods like thermo-hydro-mechanical modification. An overview of the results from each of the trials is provided in this paper, indicating that of the trials undertaken, combined or dual-treatment approaches appear to achieve the best results, reducing the thickness of the timber element is also effective, and further research to refine and optimise the SCFs process for Tasmanian *Eucalyptus* is warranted.

Keywords: preservative treatment, Tasmanian hardwoods, *Eucalyptus*, durability, fire-retardant treatment

Structural Wood-products and Their Biological Risk in the Built Environment of New Zealand

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ABSTRACT

Wood and timber-based panel products are attractive building materials. In recent years the use of mass-timber technology has opened up new opportunities to use these manufactured panel products in multi-story buildings. In New Zealand, there is high demand for wood panels so pre-fabricated buildings can be built quickly to overcome housing shortage (Buchanan et al. 2008; Burgess et al. 2013). Building professionals are acknowledging the various benefits of wooden buildings including better performance in an event of fire or earthquake (Buchanan 2018) and benefits of carbon sequestration during the life of the building (Stocchero et al. 2017).

However, subsequent to the failure of untreated radiata pine in "leaky buildings" (Hunn et al. 2002) and changes in regulations (Standards New Zealand, NZS 3640, 2003), that require preservative treatment of most of the framing used in New Zealand buildings, the use of untreated manufactured products such as oriented strand board (OSB) plywood, laminated veneer lumber (LVL) and cross-laminated timber (CLT) in structural situations has been questioned. The New Zealand building standard (NZS 3602:2003 Timber and Wood-based Products for use in Building) requires that plywood used as wall bracing be preservative treated. While the existing standard for framing lists untreated LVL as acceptable (Standards New Zealand, NZS 3602, 2003), amendments to the Australian/New Zealand joint standard related to Engineered Wood Products include requirements for preservative treatment (Australian/New Zealand Standards, AS/NZS 1604.4). In many parts of the world, there are no requirements for the preservative treatment of CLT and OSB although OSB in some structural components such as "I" beam joists and purlins are being preservative treated in New Zealand.

This research was conducted to assess the decay resistance of LVL, OSB (Oriented Strand Board) and CLT produced from radiata pine in an accelerated trial. This testing method is used in establishing the effectiveness of wood products in framing subject to intermittent wetting. The results showed untreated OSB and CLT were very susceptible to decay. In comparison, LVL was less susceptible. Testing conducted on CLT using the surface application of boron preservative prevented decay. Further work is needed to understand the full extent of moisture ingress in wooden panels during the construction and service of multi-story buildings and to improve the durability of panel products.

Stiffness and Energy Characterization of Fungi Degraded Cross Laminated Timber (CLT) Connections

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ABSTRACT

Connections play a vital role in the structural performance of mass timber buildings. They provide strength, stiffness, stability, and ductility and contribute to structural integrity. The aim of this study was to evaluate declines in energy dissipation and stiffness of Cross Laminated Timber (CLT) connection assemblies caused by fungi over a 40-week exposure and compare these changes across various wood species.

Connection assemblies consisted of two blocks of CLT (13 X 8 X 4 inches), joined by a metal L-bracket to simulate a wall-floor system in real buildings. CLT assemblies made from Douglas-fir, southern pine, spruce-pine-fir, or European spruce were exposed to two brown rot fungi for 10, 20, 30, or 40 weeks. The energy dissipated by the connections and stiffness at three different segments of the load-displacement curve were obtained by performing quasi-cyclic tests based on an abbreviated CUREE loading protocol. Existing engineering models which have previously been used by engineers to evaluate seismic performance of buildings were used to divide the curve into the three different segments and characterize stiffness at each of these segments.

All wood species experienced substantial degradation in energy, dissipation, and stiffness with increased fungal exposure time. There were also noticeable patterns in the behavior of the connections based on fungus and wood species. The results from these experiments provide important information for engineers in the design, construction, and repair of mass timber buildings across the globe.

Key Words: Cross-laminated timber, connections, Douglas-fir, southern pine, Spruce pine fir, European spruce, brown rot,

Natural Durability of Young Plantation and Native Forest Regrowth Eucalyptus cloeziana (*Gympie messmate*)

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ABSTRACT

Naturally durable hardwoods are highly valued, particularly for exterior applications where conditions are conducive to fungal attack. *Eucalyptus cloeziana* (Gympie messmate) is native to Queensland, Australia and produces naturally durable heartwood. Plantations of this species have been established around the world. Understanding the durability of the emerging *E. cloeziana* plantation resource will be important for ensuring that resulting products are fit for purpose. This study evaluated timber density, extractives content and decay resistance in plantation and native forest regrowth resources.

Cross-cut discs from 12- to 13-year-old plantation trees were sampled at breast height. Native regrowth discs were cut from 3.6 to 4.6 m up the bole to sample beyond the area subjected to heartrot and termite attack (pipe). The discs were sampled across their diameter to investigate density, extractive contents and decay resistance. Heartwood was classified into inner, middle, or outer zones.

Density increased from pith to bark for both plantation and native forest trees. Inner heartwood density of the plantation timber was significantly lower than that of the native forest regrowth timber. While the total extractives content of the outer heartwood was comparable in the plantation and native forest regrowth trees, the inner heartwood of the latter contained a significantly greater level of extractives. In laboratory accelerated decay tests, all heartwood zones of plantation and native forest regrowth *E. cloeziana* were resistant to decay by the white-rot *Pycnoporus coccineus*. The inner heartwood of the plantation timber was, however, susceptible to decay by the brown rot *Fomitopsis ostreiformis*. The results illustrate the potential variations in wood quality parameters when moving from native forest to more heavily managed plantation resources.

Further studies are underway to investigate the radial variation in durability characteristics of plantation eucalypts and consider practical implications to support optimum management.

EDUCATIONAL ISSUES, DIVERSITY, EQUITY, AND INCLUSION IN OUR INDUSTRY
Chairs: Hongmei Gu, USDA FS, FPL, USA and Keith Crews, University of Queensland, Australia

Demystifying Wood? Or Learning to Love the Enigma?

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ABSTRACT

Inclusive, practice-based, collaborative research between wood scientists, engineers, and architects may help to demystify wood science and accelerate the uptake of novel wood products in applied architectural contexts. Designing with timber is an urgent, political act for architects and engineers who are concerned with reducing the environmental impact of buildings. Various life cycle analyses of buildings show that increasing the use of timber building products derived from sustainably managed forests can help to reduce overall embodied carbon. But specifying timber in architecture and design can be fraught due to the vagaries and variability of the material, making it easier to design with non-renewable materials like concrete or steel with the confidence that they will perform homogeneously. Some species of wood perform extremely reliably, but due to high demand and diminishing supply, they are increasingly seen as a non-renewable resource. In Australia, renewable, short-rotation plantation species that are abundantly available, like *Eucalyptus nitens* or *Eucalyptus globulus* (also called Plantation Oak, have complex qualities which are only just beginning to be properly tested, quantified, and characterised. Around the world, wood scientists are currently working hard to improve the durability, dimensional stability, appearance, and structural performance of fast grown plantation species, to make them more predictable and suitable for architectural applications but the 'unknowns' may still prejudice architects and engineers against specifying this material. Drawing on literature about drivers and barriers to uptake of new technologies in other disciplines, as well as the author's own experience, this paper hypothesises that interdisciplinary, collaborative research with wood scientists may entice architects and engineers to fall in love (and design with enigmatic materials like plantation *Eucalyptus*.

Keywords: environmental design, wood science, collaborative practice-based research, interdisciplinary, plantation *Eucalyptus,* engineering, architecture

Making Knowledge about Renewable Materials Accessible and Engaging with Educational Videos based on Instructional Design

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ABSTRACT

The shift to using renewable materials is essential to help create a sustainable future on a planet with limited resources. Research and innovations in wood science are greatly improving, but findings need to reach the widest possible audience so they can be used in practice and benefit us all. Learning through watching online videos has become ubiquitous both before and during the COVID-19 pandemic, so it is important to understand how it affects viewers and to study guidelines to make educational videos more effective, both for learners and educators.

Over the years, extensive research has been conducted on designing effective multimedia lessons based on the cognitive multimedia learning theory and cognitive load theory – theories that aim to inform educators on how to design learning materials in accordance with the way human cognition works. Recently, researchers and practitioners alike have also focused on ways to engage learners and affect the emotions that could promote learning with an approach called emotional design. However, the principles of learning with video may differ depending on the subject covered and the characteristics of the learners, making it imperative to test different approaches on different populations.

Deeper knowledge about renewable materials and how to work with them is vital not only for various industries but also for the general public, who are the final users and investors in these innovations. For this reason, we developed five educational videos, with a total length of 24 minutes, with the goal of teaching people with little or no previous knowledge about wood as a building material. The videos introduced them to concepts like advantages and disadvantages of using wood-based materials in construction, service life and performance limits, wood degradation processes like weathering, wood decay, and insect damage, and how to combat them by selecting the right materials, protective design measures and maintenance.

In a series of experiments, we tested how successfully people learned from the five educational videos, and what are the effects of several instructional design interventions like the different

emotional tones of the narrator and the addition of subtitles to the videos. After viewing the videos, participants completed a knowledge test on the content of the videos, which consisted of questions related to remembering the presented content (i.e., retention), and to the ability to use the newly gained knowledge in novel situations (i.e., transfer).

The presentation will introduce evidence-based principles of designing effective learning materials, based on examples of learning materials on building with wood, and present how the learners perceived educational videos and how much they learned from them. After providing a general overview, we will focus on more specific findings, for example, that despite learning about wood as a sustainable construction material, participants still held on to their presumption that using wood for construction harms the environment. These findings are necessary to ensure that newly developed knowledge from wood science gets transferred to a wide array of stakeholders in a digestible and understandable manner to promote better adoption and faster sustainable development.

Keywords: online learning, multimedia learning, instructional video, emotional design, renewable materials, sustainability, knowledge transfer

"WOODSOLUTIONS - An Overview of FWPA's Construction Sector Technology Transfer Program

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ABSTRACT

No Abstract Available

The Use of the Biomimicry Methodology for Nature-Inspired Sustainable Education – a Shared Project in Two Cooperating Institutions

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Abstract

The exchange of teaching methodology and experiences from teaching global sustainability issues and design courses is an example of positive international collaboration. The main focus was on a biomimicry methodology as a teaching subject in two undergraduate courses with similar content, taught at two international institutions, Technical University in Zvolen, Department of Furniture and Interior Design, and Purdue University, Department of Forestry and Natural Resources. Two faculty from mentioned institutions collaborated as part of the Erasmus+ project and delivered a newly developed teaching methodology at both institutions during combined in-person and virtual mobilities. The primary purpose of teaching activities was to show opportunities to teach bioinspiration methods and biomimicry principles to students with variable backgrounds at both institutions interested in natural resources, environmental sciences, and design subjects. The activities culminated in biomimicry products (function cards database and the final group projects). While working under different time constraints, students from both institutions addressed given assignments differently and delivered exciting outputs, which showed students' diversity of creative approaches. Involved students fulfilled the goal of interdisciplinary team collaboration mainly due to their broad yet different training backgrounds. Team size, students' skill sets, study areas, seniority, and expertise, also influenced project outcomes. The developed teaching methodology was proven to be highly effective in addressing sustainability issues by interdisciplinary teams through bioinspired methods.
Keywords: biomimicry, nature-inspired, education, teaching methodology

WOOD PROPERTIES AND PHYSICS 2
Chairs: Graeme Palmer, Southern Cross University, Australia and Maryam Shirmahammadi, Queensland Government/Department of Agriculture and Fisheries

Quality assessment of glue bond on plywood- *Eucalyptus* hybrid (*Eucalyptus deglupta* and *Eucalyptus cammaldulensis*) based on the length of pressing time

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Abstract
The objective of this research aimed to evaluate the most influenced on A-bond based on the length of pressing time for plywood. The plywood made from *Eucalyptus* hybrid (*Eucalyptus deglupta* and *Eucalyptus cammaldulensis* known as K7) from Burapha's Argo-Forestry Co; Ltd plantation. The peeled veneer's thickness was 2.5 mm. Veneer has been air-dried until the moister content reached in the range of 14 to 16% and then continue to drying by steaming kiln to 6%. Plywood panels were assembled from 5-plies of veneer with using Phenol Formaldehyde (PF-402) from TOA company, Thailand. The temperature of 120°C with 23 MPa of pressure have been applied at three different time length i.e, 10 min, 12 min and 14 min. The samples of A-bond test were conducted based on AS/NZS 2754.1(2016). The specimens' dimension is 12.5 x 152 x 152 mm^3. A total of 30 samples per pressing time were tested in accordance with AS/NZS 2098.2:2012. This standard test method involves the preconditioning of the test samples before chiselling apart the glue lines and assessing the bond quality. Samples are steamed for 6 hrs at 135°C within a pressurised vessel (autoclave). The results showed that the A bond quality or glue failure percentage of plywood in average 65.72% of the treatment at 10 min, 57.02% (12 min), and 68.90% for 14 min. This implied that there is no significant difference between the length of pressing time at 10min, 12min and 14 min. It is suggested that further experiments should be undertaken with a higher temperature and longer time of pressing.
Keywords: A bond, Hot-pressing, *Eucalyptus* hybrid (clone-K7), Phenol Formaldehyde (PF-402).

Introduction
Wood is a hard-fibrous tissue found in many plants. It has many favorable properties such as its processing ability, physical and mechanical properties, aesthetics, and being environmentally and health-friendly. People have been using wood for many purposes for thousands of years. They primarily used it either as a fuel or construction material for making houses, tools, furniture, packages, artworks, and paper [1] [2].
Additionally, engineered wood is one of the most reliable materials. It has successfully been used in a variety of applications as wood. It is produced from a combination of wood, adhesive, and fiber reinforcement that are bonded together by pressure and heat [3]. Plywood is a flat panel built up of sheets of veneer called plies, united under pressure by a bonding agent to

create a panel with an adhesive bond between plies. Plywood can be made from either softwoods or hardwoods. It is always constructed with an odd number of layers with the grain direction of adjacent layers oriented perpendicular to one another [4]. Structural panels are not sold by species name. Instead, they are classified by their intended structural application such as sheathing, siding, concrete form, or marine - grade plywood [5].

Adhesive bonding of wood plays an increasing role in the forest products industry and is a key factor for efficiently utilizing the timber resource. The main use of adhesives is in the manufacture of building materials, including plywood, oriented strand board, particleboard, fiberboard, structural composite lumber, doors, windows and frames, and factory-laminated wood products [6]. Structural adhesives that maintain their strength and rigidity under the most severe cyclic water saturation and drying are considered fully exterior adhesives. Adhesives that degrade faster than wood under severe conditions, particularly water exposure, are considered interior adhesives. Between exterior and interior adhesives are the intermediate adhesives, which maintain strength and rigidity in short term water soaking but deteriorate faster than wood during long-term exposure to water and heat. Unfortunately, adhesives that are the strongest, most rigid, and most resistant to deterioration in service are typically the least tolerant of wide variations in wood surface condition, wood moisture content, and assembly conditions, including pressures, temperatures, and curing conditions [7]. For example, based on the Technical Datasheet of Phenol-Formaldehyde (PF-402). This type of adhesive is waterproof adhesive. It is used for veneer-based products for exterior adhesive that curing at high temperature of 120°C for 4 min of length of hot pressing, 130°C (3 min), and 140°C (2 min) (Reference).

Based on the above recommendation, an experiment was conducted and it was reported that's the glue bond quality of *Eucalyptus* hybrid (*Eucalyptus deglupta* and *Eucalyptus cammaldulensis* known as K7). The K7-plywood from two type of adhesive PF-402 (A-bond) and MUF (B-bond). The plywood of 7 plies (14 mm thick) were manufactured at hot pressing of 130°C for 9.0 min with the set value of 25 Mpa in the machine (Hot press machine model BY214*4/2A-1). The A and B bond were tested in different conditions, i.e. A-bond samples were steamed for 6 hrs at 135°C within a pressurised vessel (autoclave) at 200kPa and then using pressure-chisel to apart the glue lines to assessment the percentage of glue failure. And B-bond samples are boiled for 6 hrs at boiling temperature of 100°C. The results showed that glue failure average in the same value at 65% [7]. Another experiment, a bond quality of plywood (Red Mahogany) manufactured of 5 plies (15 mm thick) at 140°C for 11.3 min with 1.3 MPa. The result showed that A-bond glue failure in average value at 75% [8].

As a general recommendation from the Datasheet (Reference), further experiments on K7 should be investigated for added value on production. i.e, reducing cost from applied energy and pressing time could benefits to plywood manufacture industries.

The objectives of this research are to assess the glue bond test of plywood (four glue lines) based on the length of pressing time (10 min, 12 min, and 14 min) under the temperature of 120°C.

Materials and Methods

Eucalyptus K7 logs of 7 years old were obtained from plantation of Burapha Agro-forestry Company Limited, located in Nongbua Village, Phonehong District, Viantiane Provinces, Lao PDR. The logs diameter was between 15-25 cm with 150 cm in length of cut and transferred to

the Wood Science and Wood Products Research Center at Faculty of Forest Science (FFS), National University of Laos (NUOL). The K7 logs were debarked by Log Debarker machine (Model: BBP1400D). Then, logs were peeled by using the Spindleless Peeling Lathe (Model: SL1350/3, BSY Industry Company). The rotation was 500 - 1,200 minute (RPM). A clipping veneer has a dimension of 2.5×1,250×1,250 mm (thickness, width, and length).

The veneers were measured, visual grading and air-dried in the building of ambient conditions and then dried to a final moisture content (MC) of 6-8 % by a steam kiln.

Glue spreader machine (Model: YQ65-1200) was used for spreading the Phenol-formaldehyde adhesive (PF-402) TOA company (Thailand). The rate of applied adhesive was between 160-180g/m². The next step was Cool Press machine (Model: BY814*4/3B) was used to press the plywood for 20 min with applied 19MPa, then the plywood was delivered to the hot press machine (Model: BY214*4/2A-1) treated at temperature of 120ºC with 23MPa at three lengths of time, i.e., 10min, 12min and 14min.

Preparing tested sample of A-bond testing was based on the AS/NZS 2754.1:2016. The samples of 12.5 x 1200 x1200 mm (Figure 1 ((a)) were then cut by using the circular saw (Model: BJ 6113-45) to be the dimension of (12.5 x 150 x150) mm (5 specimens per panel) (Figure1.a). Quality assessment then was done using AS/NZS 2269.0:2012 for Plywood – Structural – Specifications specify that the bonding between plies of products needs to be of varying classes depending on the required durability. There total of 90 specimens of A-bond testing from 18 different panels. The 18 panels were divided to 6 panels which are to be tested based on the length of time (10, 12, and 14 min). Finally, the AS/NZS 2098.2:2012 was used for chiselling apart the glue lines and assessing the bond quality. For instance, all specimens were steamed for 6 hrs at 135°C within a pressurised vessel (autoclave) at 200kPa and then using pressure-chisel to apart for four glue lines (Figure 1(b)) to assessment the percentage of wood failure in gluelines, i,e; Glueline1A and Glueline1B are located at the first line from the surface of plywood and other two (Glueline2A and Glueline2B) are located inside the plywood.
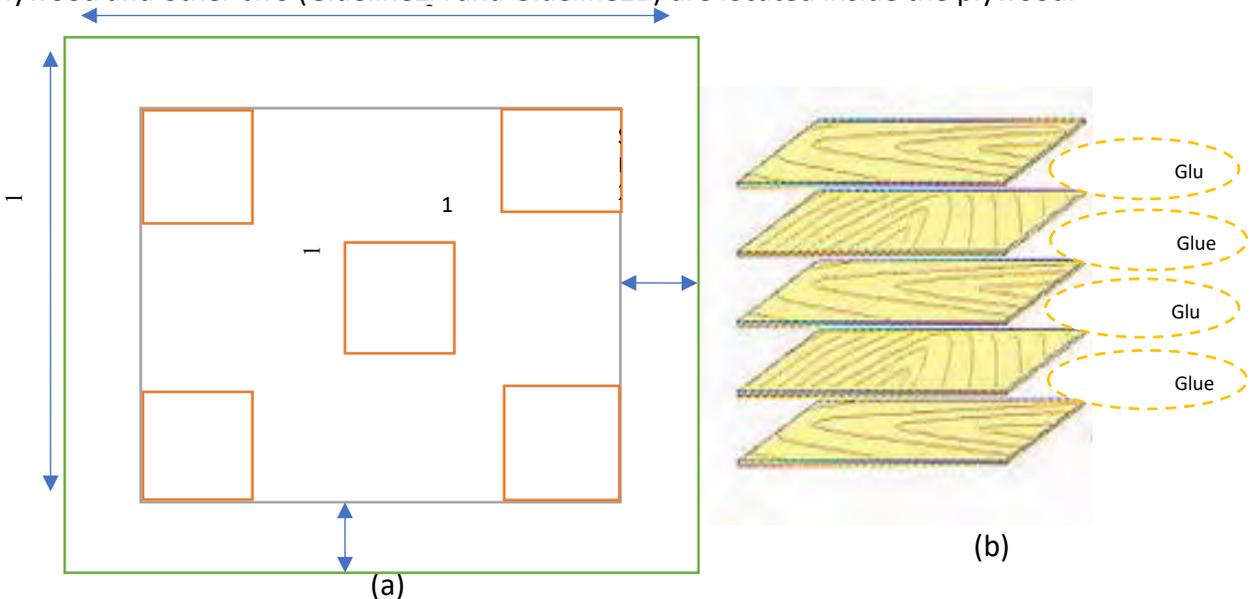
Figure 1 (a) samples cutting points and (b) glueline testing sample

Results and Discussion

The average percentage of wood failure in gluelines were summarized in figure 2, the wood failure in gluelines have been assessed based on three lengths of pressing time under the same level of temperature (120ºC). The average of glueline failure for the treatment of 10 min was 65.7%, 12 min (60.3%), and for the 14 min was found at 66.7%. The comparison between group of pressing time was done by ANOVA method and found that there were significantly different between the group of the 10 min, 12 min, and 14 min at P=0.03. The average wood failure in glueline was high at the outter line (Glueline1A and Glueline1B) The maximum wood failure in glueline ranged from 61-75%. The lowest wood failure are the gluelines located inside the plywood (Glueline2A and Glueline2B), the wood failure in glueline was from 54-60% as shown in (Figure 2).

The results of wood failure in glueline of the 10 min of pressing time was 65.7% that was equaled to the previous findings made by Manychanh (2020) under the same standards of quality assessment method but the hot press temperature of the current study was 10ºC lower than the previous study. When taking into account of consideration of wood failure in glueline was also similar, for instance, the maximum of wood failure in glueline at the case was 85-95% and the inner gluelines was in ranged of 46-55%. These results implied that the treatment under the 130ºC with 9 min of the previous study and the current study (120ºC with 10 min of pressing time) required increasing the pressing time to optimize the rigid of adhesive to ensure the better yield of wood failure in glueline inside of the plywood.

previous study it is believed that the previous study
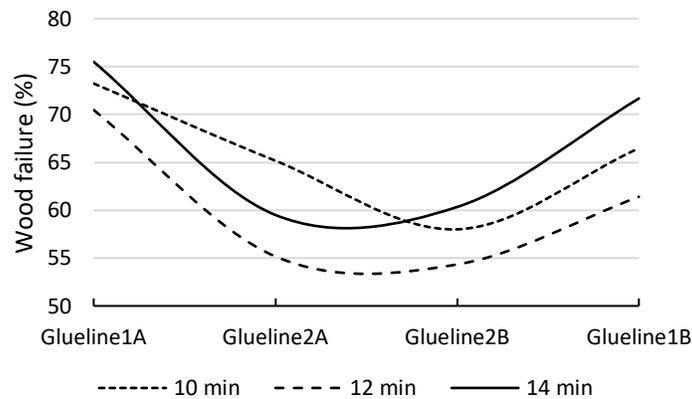
Figure 2. Wood failure in glueline based on length of pressing time (10 min, 12 min, and 14 min)

Further analysis of between glueline comparison for each group of treatment for 10 min, 12 min, and 14 min (Table 2).

Time (min)	Between glueline	P-*value*
10	Glueline1A and Glueline2A	0.04
	Glueline1A and Glueline2B	0.00
	Glueline1B and Glueline2B	0.03
12	Glueline1A and Glueline2A	0.01

	Glueline1A and Glueline2B	0.00
	Glueline1A and Glueline2A	0.00
14	Glueline1A and Glueline2B	0.00
	Glueline2A and Glueline1B	0.01

Conclusions

The average of wood failure in glueline for the treatment of 10 min was 65.7%, 12 min (60.3%), and for the 14 min was found at 66.7%. The comparison between group of pressing time was found that there were significantly different between the group of the 10 min, 12 min, and 14 min at P=0.03. The wood failure in glueline at the outer layers was higher than inside, for instance, the maximum of wood failure in glueline at the outer layers was from 85-95% and the inner gluelines was in ranged of 46-55%.

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Wood Properties of CRISPR Gene-edited Black Cottonwood

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ABSTRACT

In the past 20 years, different genetic techniques have been used to study individual genes in the lignin pathway. However, there is a need for using strategic engineering of monolignol genes to achieve specific desired wood traits for commercial applications. This can be achieved using the novel CRISPR gene editing research tool which makes genome editing more precise, much simpler, and faster than other existing techniques. Our research is the first attempt to characterize wood properties from CRISPR-engineered black cottonwood *(Populus trichocarpa)* trees designed to have superior bioprocessing properties. The assessment will improve our understanding of the relationship between lignin content/composition, and wood properties such as growth, anatomical, physical, and mechanical characteristics. Stem explants from 6-month old greenhouse-grown black cottonwood of genetically edited and wild-type samples were used for this study. Stem diameter and height were recorded at harvest, and stem sections were cut from the base 20-40 centimeters for anatomical, chemical, specific gravity, and modulus of elasticity measurements. The results and analyses of the investigation are discussed in this presentation.

Key Words: CRISPR Gene Edited Black Cottonwood, *Populus trichocarpa*, Anatomical and Chemical properties, Specific Gravity and Modulus of Elasticity

Quality Assessment of Teak Boards Dried in a Solar Kiln

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Abstract

The objectives of this research aimed to assess the quality of teak boards dried in a solar kiln during the drying process until the end of the drying batch. The assessment focused on residual drying stress development, timber distortion, and change in moisture content. A 2 m^3 laboratory solar kiln based at the National University of Laos, Faculty of Forest Science, Lao PDR has been used in this study. Three different thicknesses of teak boards were used (20x120x800) mm, (30x120x800) mm, and (40x120x800) mm with a total of 13 boards for each size loaded into the solar kiln with an air velocity of 1m/s. The solar kiln operated from 8 am until 5 pm. The kiln temperature oscillated from 22±2°C with Rh=90±12% at 8 am then reached the maximum of 36±3°C at 3 pm with RH=48±11%. The residual drying stress development measurement and collapse were based on the timber assessment of drying quality (*AS/NZS 4787-2001*, 2001), and the change of moisture content was measured based on the Oven Dry method. The timber distortion (Cupping, spring, bow, and twist) is based on the timber hardwood visually stress graded for structural purposes (*AS 2082-2007 - Standards Australia*, 2007). The results showed that moisture content decreased from 70% to 12% by 27 days for 20 mm thick boards, 33 days (30 mm), and 41 days (40 mm). There was no internal check and collapse found during the drying until the end of the drying batch. The maximum stress for the 20 mm board is 3.2 mm, 30 mm (3.4 mm), and 40 mm (3.4 mm). Timber distortion was found under the permissible level except for the twist of 20 mm thick boards.

Keywords: Moisture content, drying teak boards, solar kiln, and timber distortion.

Introduction

The quality of wooden products refers to customer requirements based on the variety of the specific need of end-users. Thus, drying of timber is the most important part of wood processing before it is processed for furniture or wood production and making sure that dried

timber has been assessed based on required standards. Several drying methods have been applied to drying timber. Drying schedules are varies based on drying methods and board thicknesses. However, the drying practice like solar kiln dryers has been broadly considered and used in wood processing for decades because of their environmentally friendly method and cost-effectiveness.

Timber quality assessments of boards dried in any method including the timber boards dried in a solar kiln for assessing the residual drying stress development measurement and collapse and can be assessed using the Australian and New Zealand standards (*AS/NZS 4787-2001*, 2001). The timber distortion (Cupping, spring, bow, and twist) is based on the Timber hardwood visually stress graded for structural purposes (*AS 2082-2007 - Standards Australia*, 2007).

The solar drying kiln is most suitable where the solar radiation is high (Simpson and Tschernitz 1984). Thus, Laos is one of the countries that is located in tropical latitudes, It was also confirmed that solar kiln drying can be suitable for Laos (Phonetip, Ozarska, et al., 2018). However, drying timber like Teak, using a solar kiln in Laos, is not yet available, due to the limitation of technical assistance. Only conventional kilns have been used in the wood industry in Laos. Therefore, (Phonetip, Brodie, et al., 2018) introduced simulating solar kiln conditions, using a conventional kiln, for conducting experiments in drying timber. Later on, a modified design of a solar kiln has been adopted and constructed by Phonetip et al., (2021) for Vientiane, Laos, so this is available for a real experiment in place.

In continuation of supporting wood processing companies for the high quality of wooden products through drying practice, the technical skills and develop the drying schedules by using the solar kiln are required. Especially, the *Tectona grandis* (Teak) boards of different thicknesses.

Teak forests occur naturally in the Asia-Pacific region over an area of about 23 million hectares in India, Laos, Myanmar, and Thailand. About one-third (8.9 million hectares) of the natural Teak forest in India. Teak is being grown in plantations in at least 36 tropical countries across the three tropical regions. Of the estimated 187.1 million hectares of global forest plantations in 2000, about 5.4 million hectares (3%) were teak (FAO, 2001).

Teak is one of the timber species that is being increased in plantation areas and distributed to the wood processing sector in Laos. The total area of teak plantation in Lao PDR was estimated to be approximately 40,000 ha (Midgley et al., 2017), i.e. Luang Prabang Province in Laos has 15,000 ha of teak. Teak has been promoted for domestic wood processing, to mobilize this teak resource as an alternative to timber from natural forests (Smith et al., 2020). Therefore, developing the drying schedules of this timber species could contribute to improving drying quality and provide insights into parameters such as drying time and timber quality after drying. The period from February until June offers high solar radiation in Laos (Sun Path Chart Program, 2020). However, if the drying can be done with high-quality boards during dry season (November to February) would be an outcome for further use of drying schedules in the wood industry. Additionally, it was found that the Faculty of Forest Science (Vientiane Capital City, Laos) is one of the most suitable locations for drying timber using solar kilns (Phonetip, Ozarska, et al., 2018).

The objectives of this research aimed to assess the quality of teak boards dried in a solar kiln from the drying until the end of the drying batch. The study focused on drying residual stress, changes in moisture content, drying time, and timber distortion.

Materials and methods

Solar kiln and control settings

Drying technique using a solar drying method has been applied based on the availability of high insulation in tropical latitudes (T. Simpson, 1998), and recommendation that has been made from the simulation of drying teak board using physical simulation technique to a real experiment by using a solar kiln (Phonetip, Brodie, et al., 2018).

A 2m³ laboratory solar kiln (Phonetip et al., 2021) located at the National University of Laos, Faculty of Forest Science, Lao PDR (18°02'29.5"N &102°37'51.9"E) has been used in this study. The solar kiln operated/repeated from 8 am until 5 pm. The temperature was set at a maximum of 60°C with the lowest of Rh=25%. with an air velocity of 1 m/s. This experiment was conducted in Winter (December 2021 to January 2022) in Vientiane, Lao PDR.

Timber preparations and test methods

The plantation teak is grown on the Faculty of Forest Science campus in 1993. A diameter at breast height of 28 cm was used in this study. Three different thicknesses of teak boards were prepared (20x100x800) mm, (30x100x800) mm, and (40x100x800) mm with a total of 13 boards for each size loaded into the solar kiln. The spacer of sticks for the timber stack is 25 mm x 25 mm and the width of 400 mm.

Figure 1 described the schematic of timber stack inside the solar kiln and Figure 2 showed the sample preparation to measure residual drying stress and the change of moisture content for the boards of 20 mm, 30 mm, and 40 mm thicknesses based on the timber assessment of drying quality (*AS/NZS 4787-2001*, 2001) followed by the moisture content was measured based on the Oven Dry method. The specimens were taken every 2 days at 5 pm for the 20 mm thick board, 4 days (30 mm thick board), and 6 days for the 40 mm thick board until the end of drying batch.
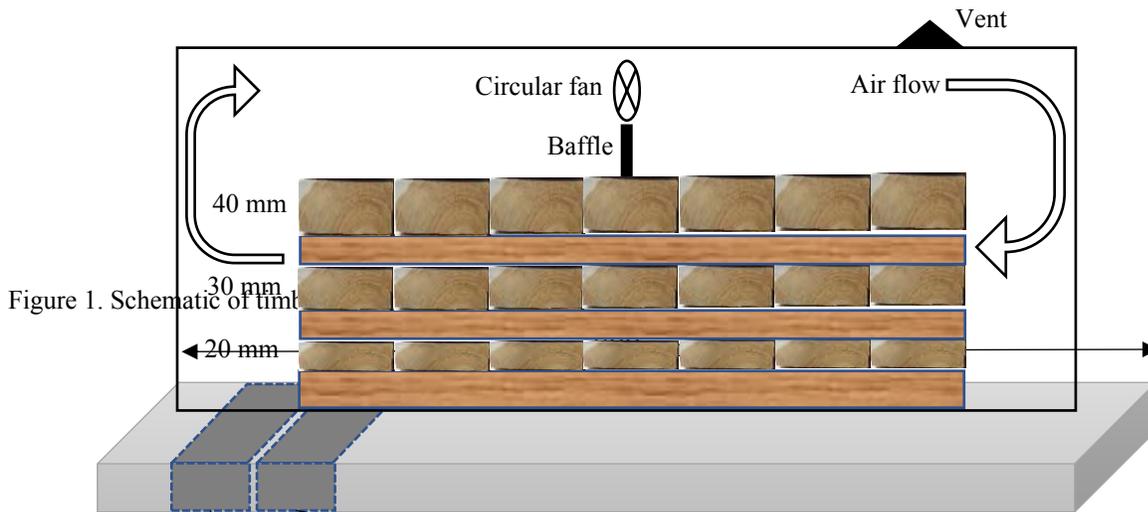
Figure 1. Schematic of timber stack

Figure 2. Sample preparation for drying residual stress and moisture content for 20 mm, 30 mm, and 40 mm thick boards.

Residual drying stress specimen   Moisture content specimen

The timber distortion (Cupping, spring, bow, and twist) is based on the Timber hardwood standards Australia, 2007).

Results

Oscillation of the temperature and relative humidity

Figure 3 shows the oscillation of temperature and relative humidity inside the solar kiln that perform during the drying period from 8 am to 5 pm. The kiln temperature oscillated from 22±2°C with Rh=90±12% at 8 am then reached the maximum of 36±3°C at 3 pm with RH=48±11%. The kiln temperature oscillation during winter (December to January) of Vientiane, Laos looked similar to Melbourne, Australia, i.e. 28°C oscillated to the maximum of 36°C (Phonetip et al., 2019). The temperature then dropped to 31±3°C with Rh=50±11% at 5 pm. The maximum temperature inside the solar kiln reached below the setting value (60°C) because during the experiment was conducted it was the coldest weather period in Vientiane, i.e. the precipitation at 0.03 to 0.15mm/day, and the maximum ambient temperature is 26°C and the lowest relative humidity was 56% (NASA, 2022) as shown in Figure 4. Thus, this implies that drying timber using a solar kiln from December to January located at 18°02'29.5"N &102°37'51.9"E should be considered the maximum temperature setting to 40°C instead of 60°C, and the relative humidity should be at 50% instead of 25%, this can reduce the cost from reducing energy to supply for sucking heat from the heat collector through controlling of heating fans.
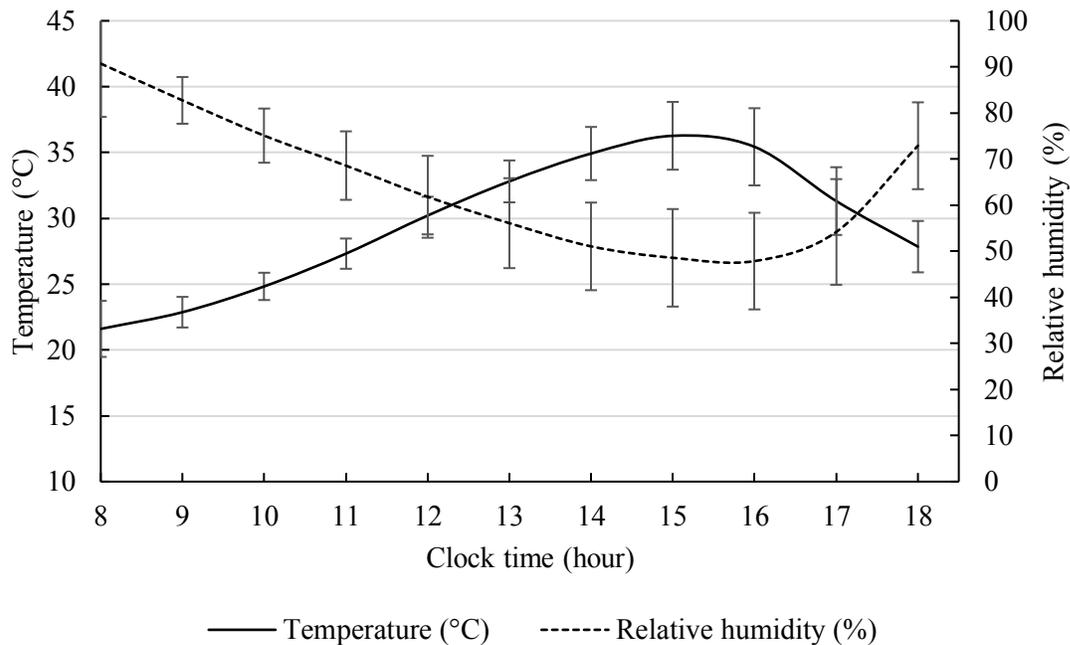
Figure 3. Oscillation of temperature and relative humidity inside the solar kiln
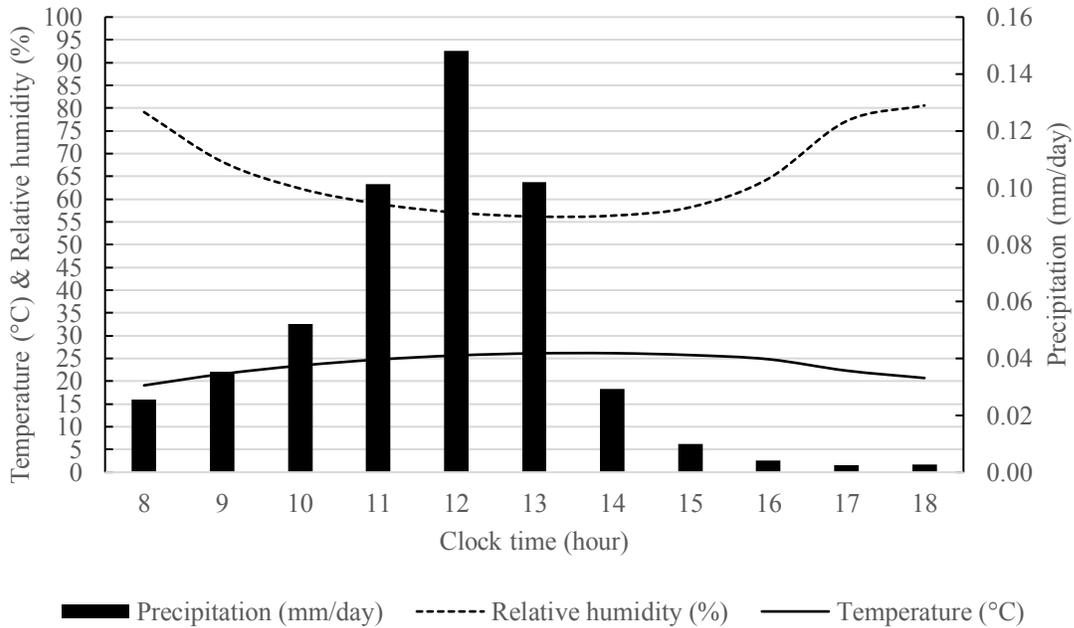
Figure 4. The ambient temperature, relative humidity, and precipitation at the location of the solar kiln (NASA, 2022).

The changes in moisture content

The drying rate (Figure 5) is decreasing as per the increase of the board thickness for the drying from green down to fiber saturation point (*fsp*=25%) and from *fsp* to 12%, i.e., the 20 mm, 30 mm, and 40 mm the drying rate was 4%, 3%, and 2% per day (Green boards at 70% of moisture content to *fsp*); and the drying rate from the *fsp* to 12% were 0.8%, 0.7%, and 0.6% per day, respectively under the condition of drying shown in figure 3 with the air velocity of 1 m/s. The drying rate of 40 mm thick board of *Tectona grandis* (0.6%/day) was found that is faster than *Eucalyptus delegatensis* board (0.3%/day) by two times (Phonetip et al., 2019) under the similar drying conditions.
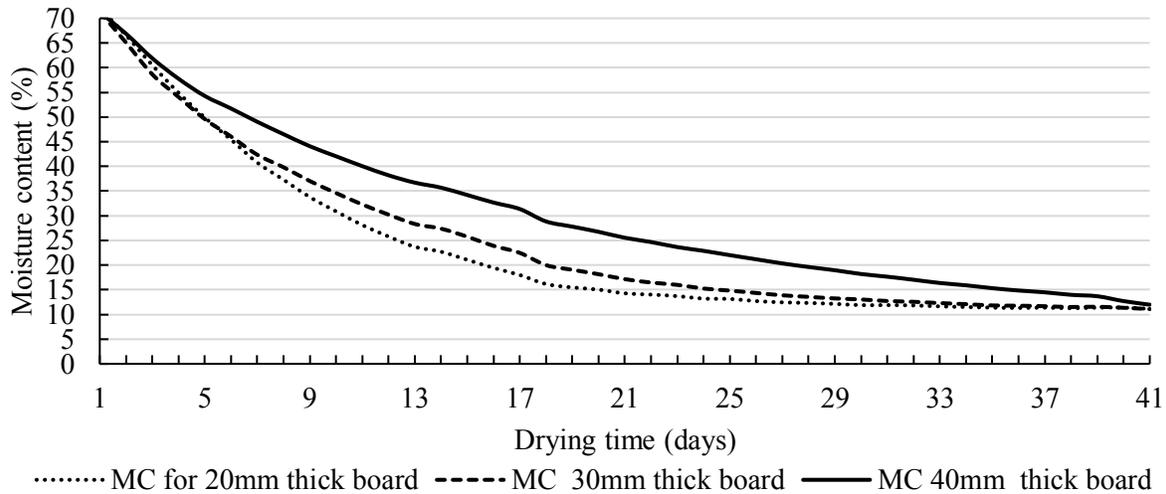
Figure 5. Moisture content decreased on different thick boards (20 mm, 30 mm, and 40 mm) as per drying time (days).

The drying rate of the board of 20 mm thick is slower than that found by Phonetip et al., (2020) for the teak board of 30 mm (4.7%/day) from green to *fsp*. Due to the drying schedule of the previous study simulated the temperature of high solar radiation based in April in Vientiane, Laos, i.e the oscillation of the temperature was from 40 to 54°C with the Rh=80% for greenwood, Rh=60% (MC>40%), Rh=40% (MC=30) while this current study was set inconsistent at Rh=25% with the maximum of the available temperature of 36±3°C from the beginning until the end of the drying batch. It is believed that using the current drying schedule could help in reducing cost in drying practice through the controlling of set values of the relative humidity at the ambient condition in the particular location for the teak boards from 20 mm and 25 mm thick.

The drying time for 20 mm thick boards from the *fsp* (25%) down to 12% took 15 days, 18 days (30 mm thick boards), and 20 days (40 mm thick boards). These findings for the 20 mm thick boards were 6 days slower than that of 25 mm thick boards which have been studied by Phonetip, Brodie, et al., (2018) because of the lower temperature of 36±3°C during the winter season compared to 54±2°C (summer) in Vientiane, Laos. It is suggested that for a better comparison further study should be undertaken on using the same thick boards to be dried by using the solar kiln method during summer.

Post drying quality of teak boards
Residual drying stress

Figure 6 showed that thicker boards created maximum residual stress earlier than thinner boards, i.e. the maximum residual stress of 40 mm is at 3.4 mm on day 7, for the 30 mm thick board of teak is 3.4 mm on the day 12, and the 20 mm thick board is 3.2 mm of residual stress at day 14. The study found that the maximum of residual stress was higher than that has been studied by Phonetip et al., (2020) by approximately 2 times, i.e. the maximum of residual drying stress was 1.53 mm at the time of moisture content reached *fsp* for the 25 mm thick of teak board at the day 7 which happened earlier than this study. This study informed that although the timber dried at the temperature of 36°C with Rh=45%, this condition can create high residual stress than timber boards dried at a high temperature (54°C) with a high Rh setting (Rh>40%).
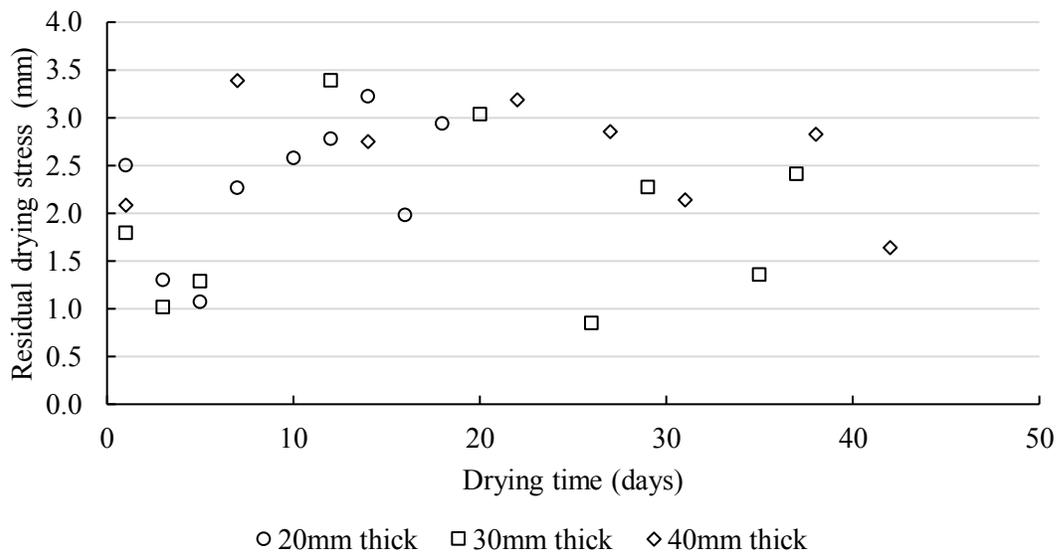
Figure 6. Residual drying stress for 20 mm, 30 mm, and 40 mm thick boards

Timber distortion

At the end of drying batch, the quality assessment has been undertaken. The table 1 showed that the distortion of boards of 20 mm, 30 mm, and 40 mm thickness are under permissible level, i.e.

Spring, twist, and cupping were under permissible of 7 mm. The bow of boards of 20 mm, 30 mm, and 40 mm thick are under the permissible of 10 mm based on the standard of quality assessment method *AS/NZS 4787-2001*, (2001) and *AS 2082-2007 - Standards Australia*, (2007), except the twist of the 20 mm thick boards (70% of sample boards are under the permissible of 7 mm).
The three sample boards that were found to be over the limit of permissible level of twist could be caused by the natural defects (nots) as seen in the Figure 7 (a, b) and the combination of heartwood and sapwood (Figure. 7 (c)). However, a proper stacking technique of lumber before loading the timber into the kiln drying, it is suggested that weights placed on top of a load of lumber or restraining devices that exert pressure are frequently used to reduce warp in the top layers of a stack. Thus, bow and twist are reduced (W. Simpson, 1991). In this study authors did not use any assisted materials as per the suggestion due to the small scale of the laboratory experiment.

(a)

(b)

(c)

Figure 7. Three sample boards exceed the permissible level of twist (7mm).

Under the drying conditions produced a good quality of *Eucalyptus delegatensis* boards of 40 mm thickness, i.e. the distortion were under permissible limit, except twist was out of the permissible level (Phonetip et al., 2019). This implies that *Tectona grandis* and *Eucalyptus delegatensis* boards offered a minimal distortion at under the permissible level, except twist under the drying condition of temperature oscillation shown in Figure 3.

Table: Statistical results of the timber quality assessment at the end of the drying

Parameters	Maximum of distortion (mm)		
	20mm thick boards	30mm thick boards	40mm thick boards
Bow	3.0	5.0	6.0
Spring	2.0	6.0	5.0
Cupping	0.0	2.0	1.0
Twist	11.0*	1.0	7.0
Collapse	0.0 (grade A)	0.0 (grade A)	0.0 (grade A)
Internal checks	0.0 (grade A)	0.0 (grade A)	0.0 (grade A)

* 70% of the total sample (10 samples) are under the permissible of 7 mm

The results also showed that internal checks and collapse has not been found (Figure 8). In contrast, internal checks (grade C) and collapse (grade C) were found in *Eucalyptus delegatensis* boards (Phonetip et al., 2019) under the oscillation conditions of temperature and relative humidity as shown in Figure 3.

20 mm thick board

30 mm thick board
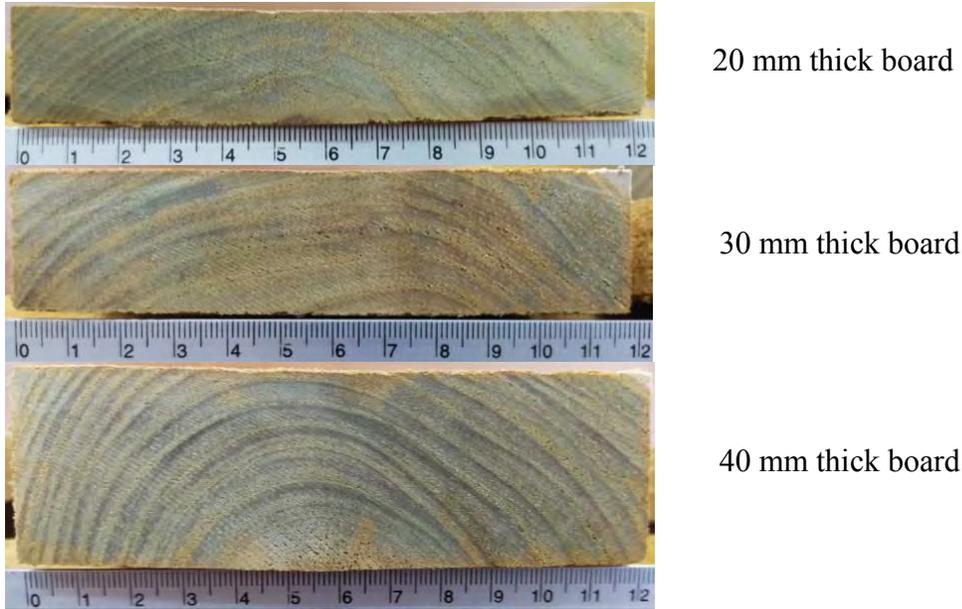
40 mm thick board

Figure 8. Crosscut samples for checking the internal checks and collapse

Conclusions and recommendation

Drying time for *Tectona grandis* boards in a solar kiln for 20 mm thick boards from the fibre saturation point (25%) down to 12% took 15 days, 18 days (30 mm thick boards), and 20 days (40 mm thick boards) during winter season (December to January) in Vientiane, Laos. The assessment of timber quality at the end of drying batch produced a high quality of boards based on the Australian and New Zealand standards assessment method. For instance, the maximum of residual drying stress of 40 mm and 30 mm thick boards are reached at 3.4 mm, and the 20 mm thick board is 3.2 mm. The spring, twist, and cupping were under permissible of 7 mm, except the twist of the 20 mm thick boards (70% of sample boards are under the permissible of 7 mm), and bow of 20 mm, 30 mm, and 40 mm thick are under the permissible of 10 mm.

It is believed that using the current drying schedule could help in reducing cost in drying practice through the controlling of set values of the relative humidity at the ambient condition in the particular location for the teak boards from 20 mm and 25 mm thick.

It is also suggested that for a better comparison further study should be undertaken on using the same thick boards to be dried by using the solar kiln method during summer.

Acknowledgment

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Analysis of Char and Energy Production from the Combustion of Woody Biomass from Different Hardwood Species

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ABSTRACT

Not Available

Applying Image Analysis Techniques and Spectral Segmentation to Generate a Virtual Board Representation for Simulating Moisture Migration in Laminated Timber Panels

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ABSTRACT

Moisture induced stresses can cause timber boards to warp, expand and contract, and it is therefore essential to understand how the heat and mass transfer phenomena affect the strength and durability of laminated timber products such as laminated veneer lumber (LVL) and cross-laminated timber (CLT). In this work, a novel method is developed that utilizes image analysis and spectral segmentation to produce a three-dimensional mesh of a laminated timber panel. The mesh is then used to simulate the moisture migration and temperature distribution of the panel when exposed to a range of psychometric climate conditions (including hot and humid conditions) typically experienced in Queensland, Australia.

Starting with a photograph or a scan of the end grain of a timber board, an image mask is produced by employing thresholding and image smoothing techniques. This mask highlights the darker latewood sections of the board providing a binary image of the growth ring locations. The growth rings are then identified using a recursive bipartitioning spectral segmentation algorithm. This information allows the nodes of the mesh to be aligned along the edges of the growth rings to accurately capture the significant changes in wood density. Lastly using the light intensity data of the image, the density (and hence porosity) of the board can be associated with each mesh element. The method allows for a three-dimensional reconstruction of a virtual timber board that includes density variation information from a single image. The *TransPore* model previously used to simulate the drying of a timber board is extended to describe the moisture ingress and egress in multiple boards that are glued together. The glued surfaces are represented using imperfect contact boundary conditions that allow for discontinuous jumps in moisture content at the same node. The model provides a powerful tool that can ultimately be used to study how the glued surfaces affect the moisture migration, stresses, and strains of laminated timber products.

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research in enhanced value
added wood processing and
wood durability

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Expertise: Non-destructive
wood testing. Resistance
drilling. Silviculture. Sofwood
and hardwood wood quality

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Eucalyptus processing, LVL,
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technical support

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Attendees – 65th International Convention of SWST
July 10-15, 2022, Peppers Salt Resort & Spa, Kingscliff, NSW, Australia

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wood preservation,
standards, wood quality
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Expertise: Higher Education

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mill studies

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Technical, timber quality and
product compliance

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Expertise:

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Value Added to Hardwoods

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Expertise: De-carbonization
of buildings at the
transportation and on-site
construction phase

Moein Hemmati
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in outdoor spaces and ENVI-
met models

5

Attendees – 65th International Convention of SWST
July 10-15, 2022, Peppers Salt Resort & Spa, Kingscliff, NSW, Australia

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activated carbon on
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Expertise: Forest biomass
and carbon sequestration of
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Expertise: Physical property
of wood: wood moisture
content, wood density and
wood basic density of
temperate species

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Expertise: Program in
Environmental Materials
Science

Peter Jurkovič
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polymer technology, wood
based panels, formaldehyde
emission

6

Attendees – 65th International Convention of SWST
July 10-15, 2022, Peppers Salt Resort & Spa, Kingscliff, NSW, Australia

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Expertise:

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Lignin valorization, Biomass
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pretreatment, Hemicellulose
valorization, Biomass to
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environmental materials &
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materials science

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industries.

7

Attendees – 65th International Convention of SWST
July 10-15, 2022, Peppers Salt Resort & Spa, Kingscliff, NSW, Australia

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Expertise: Timber drying,
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engineered wood products

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treatment of wood, adhesive
bonding, and environmental
impact assessment of new
materials

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FWPA's policy of supporting
R&D projects across the
entire forest and wood
products value chain,
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Expertise:

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Attendees – 65th International Convention of SWST
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Timber, Serviceability
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aplication biopolymers in
wood technology, gluing,
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projects, resource
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processing systems,
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generation of appearance
products from plantation
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technology and developing
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Lao PDR through capacity-
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timber durability and service
life

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healthy built environments,
timber buildings, sustainable
construction

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Attendees – 65ᵗʰ International Convention of SWST
July 10-15, 2022, Peppers Salt Resort & Spa, Kingscliff, NSW, Australia

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Attendees – 65th International Convention of SWST
July 10-15, 2022, Peppers Salt Resort & Spa, Kingscliff, NSW, Australia

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advanced forestry education
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15

Attendees – 65th International Convention of SWST
July 10-15, 2022, Peppers Salt Resort & Spa, Kingscliff, NSW, Australia

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NDT methods, Green wood
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Nanjing Forestry University (NJFU) is located in Nanjing, Jiangsu, China. With the history dating back to 1902, it is one of the first 3 established forestry universities in China, and has developed into a comprehensive university honorably supported by the National Double First-Class Initiative.

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