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Assessment of Different Measurement Methods/Techniques in Predicting Modulus of Elasticity of Plantation *Eucalyptus nitens* Timber for Structural Purposes

Azin Ettelaei [1,*], Assaad Taoum [2] and Gregory Nolan [1]

[1] Centre for Sustainable Architecture with Wood, University of Tasmania, Launceston 7250, Australia; gregory.nolan@utas.edu.au
[2] School of Engineering, College of Sciences and Engineering, University of Tasmania, Hobart 7005, Australia; assaad.taoum@utas.edu.au
* Correspondence: azin.ettelaei@utas.edu.au

Abstract: The mechanical properties of plantation Eucalyptus Nitens timber are currently assessed by applying visual stress grading (VSG) designed for the sawn timber from the mature plantation and do not represent the actual characteristics of the resource. However, the well-known limitation of VSG application for this resource led to the discovery of other methods to grade the timber to its relevant structural grade. There is potential for hardwood plantations in Australia to supply wood to the timber industry and be used in structural applications. However, it is necessary to employ criteria to evaluate the structural properties of this resource before it could be satisfactorily used for structural purposes. This research aimed to assess the use of non-destructive technique (NDT) through acoustic wave velocity (AWV), machine stress grading (MSG), and multiple linear regression (MLR) model to predict the modulus of elasticity (MOE) as a grade-determining factor. The results showed that there was a strong correlation (R^2 = 0.88) between the dynamic MOE (MOE_{dyn}) and static MOE (MOE_s) of the boards, proving the NDT as a reliable method for the MOE estimations of *E. nitens* timber. The results from the MLR model also showed that the density and AWV are effective parameters and their combination can be practical to estimate the MOE. There was a high correlation between the MOE obtained from MSG and MOE obtained from four-point bending, demonstrating that the MSG method through the flat-wise bending can be a suitable method for fast grading. The results also indicated that the measured MOE in the edgewise direction correlates with both the flatwise and longitudinal directions. The results also showed that the *E. nitens* timber resource has the potential to be used in structural applications with a wide range of MOE from 7 GPa to 21 GPa.

Keywords: *Eucalyptus nitens*; structural applications; hardwood plantation; structural grading; modulus of elasticity

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1. Introduction

Tasmania, with approximately 233,900 ha of hardwood plantation, has the second-largest estate of plantation hardwood in Australia. Of these hardwood plantations, *Eucalyptus nitens* (*E. nitens*), with approximately 208,000 ha, is one the most common species planted in the state [1]. Given its scale, timber producers are seeking to recover structural timber products such as cross-laminated timber (CLT) and glued-laminated timber (GLT) from this resource [2–5]. The majority of this hardwood plantation is managed for pulpwood application in mostly untinned and unpruned stands, which increases the variability of timber in mechanical properties due to the frequent presence of natural features such as knot and slope of grain [3,6,7]. These characteristics generate significant variation in strength, i.e., modulus of rupture (MOR) and stiffness, i.e., modulus of elasticity (MOE) of the sawn boards recovered from fibre-managed plantation *E. nitens* [8,9] and increase the complexity of using this resource for structural use [10]. In Australia, hardwood timber can be graded (F-rating) in accordance with the Australian Standard AS 2082 [11] based on the visual characterisation of potential strength-reducing characteristics (SRCs) on each board. This standard has been successfully used for commercial timber recovered from the mature non-plantation resource. The fast-grown fibre-managed eucalypt plantation is generally harvested at the age of 15 to 20 years old. It contains a significant amount of SRCs and juvenile wood, meaning that the current visual grading standard is not appropriate to evaluate this resource [9,12,13]. Previous studies found that the current visual stress grading standard is not suitable for young, fast-growing fibre managed plantation *E. nitens* and *E. globulus* [7,12,13].

Currently, in Australia, the timber industry has some challenges with an inefficient use of the sawn board from fibre-managed *E. nitens* plantation due to inappropriate criteria for sorting and grading this resource. The frequent presence of SRCs on plantation *Eucalyptus* sawn boards increases the variability properties and additional docking and processing costs [2,3,14,15]. This results in excessive waste and defect removal of lower quality material with more SRCs and high production costs from timber processing. The efficiency of material utilisation and timber industry probability will improve by segregating wood resources into their relevant structural groups. Timber grading is the process of segregating timber into groups with similar structural properties [16].

The modulus of elasticity (MOE) is one of the grades determining properties that defines the mechanical properties of the timber and determines the stiffness and suitability of timber in using the load-bearing component for structural application [6,17–20]. MOE demonstrates the mechanical grade of the timber, which can be determined by static bending tests and non-destructive testing methods [19,21]. Different types of non-destructive evaluation techniques (NDT), including stress wave propagation, ultrasonic wave velocity, and resonance, have been employed during the past few decades to estimate the stiffness of wood [22,23]. The dynamic modulus of elasticity (MOEdyn) can be measured using these techniques based on stress waves, ultrasound, and vibration frequencies [24]. These methods are fast and do not damage the material structure; these methods are becoming increasingly popular for determining wood properties. In recent years, researchers have investigated various approaches to predict the mechanical properties of the wood using a combination of NDT methods and different predictive models, including finite element analysis and machine learning models for better estimation of mechanical properties [10,17,25]. Some researchers have reported that the combination of predictive models with wave propagation and other physical properties such as density can be a reliable predictor tool for wood characterisation [17,26]. Opazo-Vega et al. [10] investigated the suitability of using different non-destructive vibration-based tests. They combined the operational modal analysis and finite element numerical simulations with the transverse vibration test results to estimate the MOE of *E. nitens* timber boards. The results showed that vibration-based non-destructive techniques could be an appropriate way to predict the MOE of the *E. nitens* boards [10]. Although extensive research has been carried out on evaluating the suitability of NDT methods to predict strength grade properties and their relationships with the mechanical properties of softwood species, a few studies have explored this method for hardwoods [10,17–19,22,25,27].

There are various tools and methods to estimate the timber MOE; however, there has been limited work to predict high variable eucalypt timber board using data obtained via the NDT method. There is not much information available on the mechanical properties of the Australian fast-growing eucalyptus timber and appropriate methods to predict the MOE of the individual boards from this resource. Processing of fibre-managed *Eucalyptus* plantation into structural timber products has received much attention from the timber industries in Australia.

There is the potential for hardwood plantations to supply wood to the timber industry and to be employed in structural applications. However, it is necessary to employ an approach and criteria to evaluate grade-determining properties of fibre-managed *E. nitens* resource before such a resource could be satisfactorily used for structural applications and engineered timber products. Developing a reliable method and tool for predicting the mechanical properties can provide an effective grading system and improve the efficient use of the material and reduce the waste arising from the rejection of low-value boards from timber processing.

This study sought to compare different techniques in predicting MOE as a grade determining factor and identifies critical parameters and approaches for estimating the mechanical properties of *E. nitens* timber to be used in structural timber elements such as CLT elements. In this context, the NDT technique through AWV, MSG method, and an MLR model using physical properties are employed and evaluated (Figure 1). The measured MOE_{dyn} through different approaches was compared with MOEs measured through the edgewise bending test as AS 4063.1 [28]. One of the characteristics of the evaluation methods used herein was the use of the different positions of the boards for assessment, i.e., edgewise-four-point bending, three-point bending through MSG, and longitudinal direction applied by the NDT technique. The dynamic modulus of elasticity obtained from these methods was then compared with those obtained from the static modulus of elasticity obtained from the non-destructive four-point bending test to evaluate the effectiveness of each technique in predicting g the stiffness of the boards. The effectiveness of the mechanical properties of the timber in predicting the MOE values and, consequently, structural grading of *E. nitens* timber resource was also evaluated. The obtained results from this study create a profile of material characteristics for the plantation eucalypt sawn timber that can assist the development of CLT and GLT panels by better understanding the resource. The timber boards used in this study will be considered as part of a more extensive study for manufacturing cross-laminated timber panels. The result of this study makes a significant contribution to improving resource utilisation efficiency and manufacturing sector's profitability.

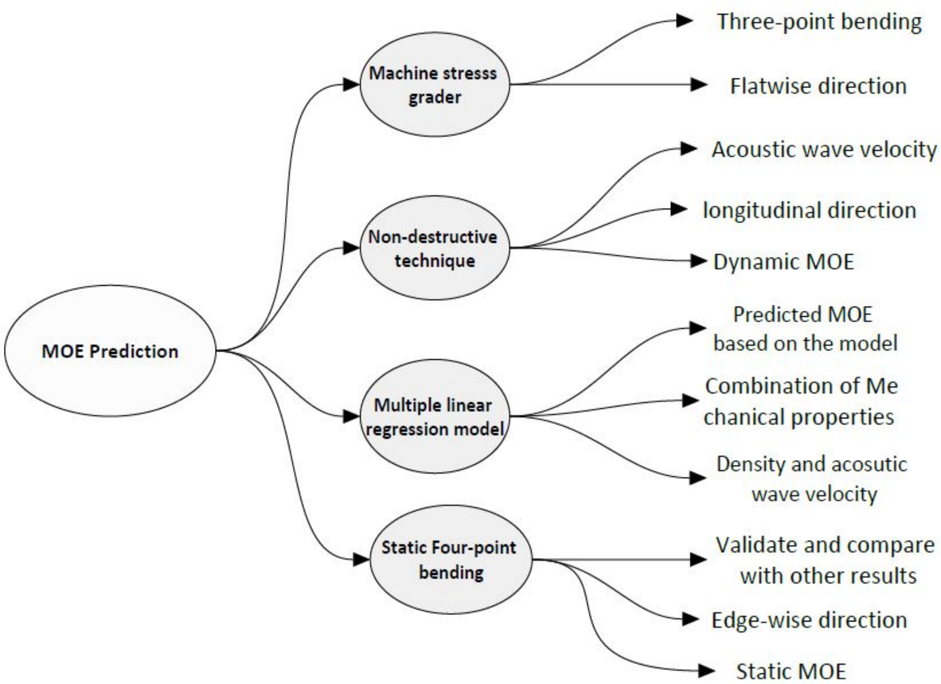


Figure 1. Potential approaches for evaluation of *E. nitens* timber.

2. Materials and Methods

2.1. Timber Resource

The timber boards used in this study constituted 160 boards that were sourced from 21-year-old fibre-managed plantation *E. nitens* in southern Tasmania, Australia (Figure 2). All the sawn boards were air-dried to a nominal MC of 12% in the mill and were finally dressed to a nominal cross-sectional area of 35 × 90 mm^2. Of these 160 boards, 40 boards from the batch were randomly selected to test under edgewise four-point bending until failure under AS4063.1 to evaluate the actual structural capacity of the *E. nitens* timber. According to AS 2878, a minimum of 30 specimens is sufficient to evaluate material characteristics [29]. The second group (120 boards) were used to predict the MOE_{dyn} through the NDT technique, MSG method, and MLR model. To validate the result from MOE_{dyn} through the evaluating methods, a non-destructive four-point bending test was carried out according to AS 4063.1. in the elastic region to prevent any failure or fracture of the timber boards.

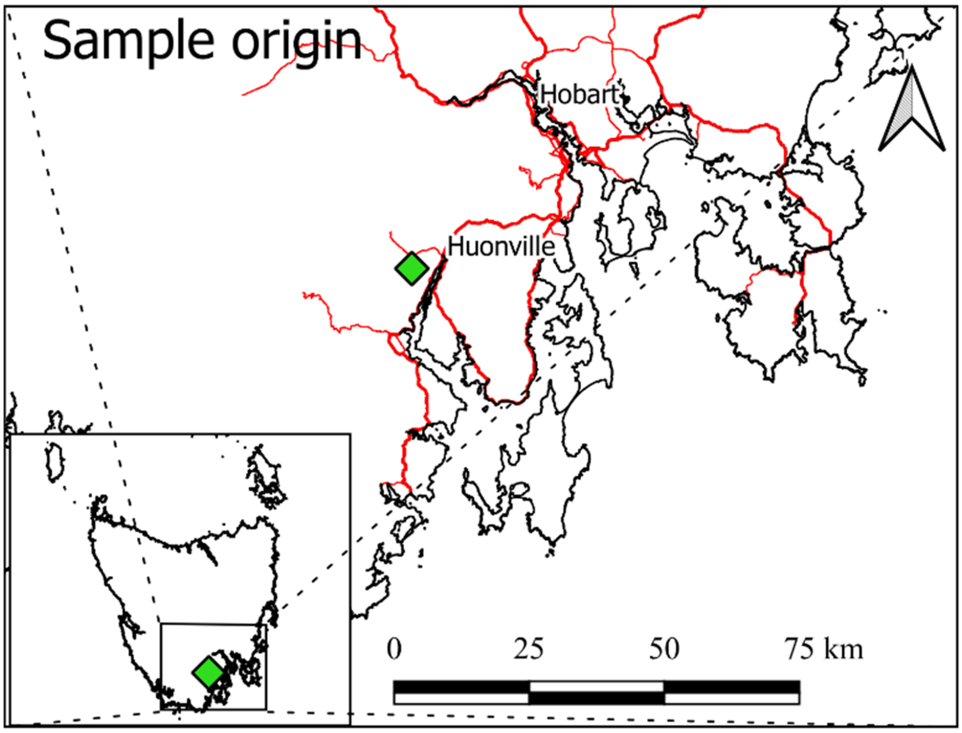


Figure 2. Resource origin.

2.2. Basic Density and MC of the Boards

The basic density and MC of all the boards were measured by cutting three specimens with a cross-sectional area of 35 × 35 mm^2. The basic density was calculated according to AS 1080.3 [30] using the following equation:

$$\rho = \frac{m_1}{v} \times \frac{100}{(100 + w)} \quad (1)$$

where ρ is the basic density (kg/m^3), m_1 is the green mass of the specimen (kg), v is the volume of the specimen before oven-drying (m^3), and w is the MC of the specimen (%) was calculated according to AS 1080.1 [31] as:

$$w = \frac{m_1 - m_0}{m_0} \times 100 \quad (2)$$

where m_0 is the oven-dry mass (kg).

2.3. Techniques and Measurements in Estimating the Modulus of Elasticity

2.3.1. NDT Technique through Acoustic Wave Velocity

The non-destructive technique was employed to estimate the MOE through the acoustic wave velocity (AWV) of the boards using the portable device Director HM200TM (Figure 3). The stress wave is generated by hitting the hammer at one end of the board and travels longitudinally over the specimen and back to its point of origin. The sensor on the device detects and displays the stress wave velocity. The MOE_{dyn} estimated using the following equation:

$$MOE_{dyn} = \rho \times AWV^2 \tag{3}$$

where ρ is basic density (kg/m^3) and AWV is acoustic wave velocity (km/s).

Figure 3. Acoustic wave velocity measurement of the *E. nitens* boards.

2.3.2. Machine Stress Grading

The MOE of the boards were measured through Machine stress grading using PLESSEY Stress Grader at CUSP Building Solutions, Tasmania, Australia. Machine stress grading classifies the timber on the basis of structural properties, and the different groups are assigned a stress grade. The boards in the MSG moved through the machine and were subjected to a flat-wise three-point force applied by a load roller between two support rollers (Figure 4). The screen of the stress grader indicates the deflection measured along the length of the board, and a grade mark will be applied on the board. Depending on the adjustment, the machine can apply a side spray as the board travels through the machine and spray heads mark the grades at the same distance with several grades on each piece of the board. The screen of the stress grader also shows the calculated deflection at the end of the grading process. This study used the average grading mode to grade the boards, which sprays a tail mark at the end of the process. Besides the sprayed mark on each board, the average deflection measured by the machine was also employed to calculate the MOE values using the following equation:

$$w_0 = \frac{PL^3}{48EI} \tag{4}$$

where L is the support span length (mm), P is the applied force (N), E is the young Modulus (MPa), I is the second moment of area (mm^4).

Figure 4. Machine stress grading of the timber boards.

2.3.3. Static Four-Point Bending Test

In order to validate the obtained values from the above methods and assure consistent results, a four-point bending test was performed. The boards were tested according to AS/NZS 4063.1 [28] in four-point edgewise bending using Calibre STFE10 Machine at a load-head speed of 7.5 mm/min over a span length equal to 18 times the depth of the boards (Figure 5). The MOE of the boards of the first group was measured until the failure point. The test of the second group was conducted non-destructively by applying a 1.96 kN load in the linear-elastic range and without breaking the samples. The MOE values of all tested boards were calculated as per AS 4063.1 using the following equation:

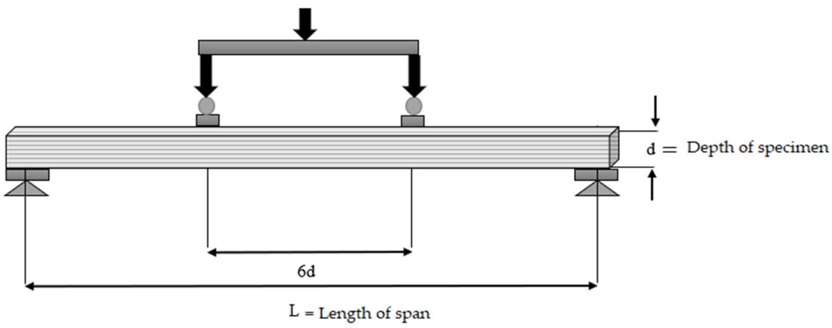
$$\mathrm{MOE} = \frac{23L^3}{108bd^3}\left(\frac{F_2 - F_1}{e_1 - e_2}\right) \tag{5}$$

where L is the test span length (mm), d is the width of the boards (mm), b is the thickness of the boards (mm), F_2 and F_1 are respectively 40% and 10% of the maximum applied load at failure point (N) for destructive bending; F_2 and F_1 are respectively maximum load, and 10% of the maximum applied load at failure point (N) for non-destructive bending, e_2 and e_1 are displacements (mm) at F_2 and F_1, respectively.

The MOE values were adjusted based on the actual MC of each board under AS 2878 [29].

Figure 5. Four-point bending test setup using Calibre STFE10 Machine.

The MOE_{dyn} values of the boards obtained from the test methods used in this study allow us to predict and compare the values at the different orientations of flatwise through MSG, edgewise through four-point bending and longitudinal through portable device Director HM200TM by measuring AWV. Figure 6 demonstrates the schematic of the techniques and position of the boards subjected to loads in MSG, four-point bending, and vibration via NDT.



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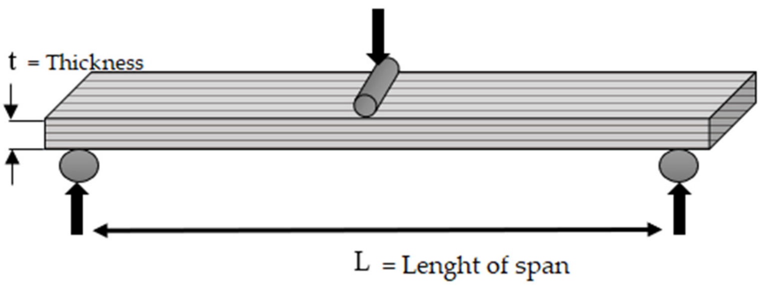


(**b**)

Figure 6. *Cont.*

(**c**)

Figure 6. Schematic of measurement methods for predicting MOE of the boards. (**a**) Edge-wise four-point bending using Calibre STFE10 Machine, (**b**) Flat-wise three-point bending using MSG, (**c**) Longitudinal acoustic wave velocity.

2.3.4. Predictive Model Using Multiple Linear Regression

The preliminary correlation between variables was analysed using simple linear regression and Pearson correlation coefficient. The analytical procedure of the obtained results provided further support to perform multiple linear regression to assure that a correlation exists between the dependent variable (MOE) and independent variables (e.g., density, AWV). The Pearson correlation was investigated between the test variables (e.g., basic density, AWV) and the MOE values to measure the degree of the linear relationship between variables. The Pearson correlation showed that the variables are well correlated with adjusted MOE values and were highly significant ($p < 0.00$). Afterwards, the multiple linear regression in R studio was performed to find the best combination of parameters to estimate the MOE values. The density and AWV values were employed in the model as input factors to build up the predictive model.

3. Results and Discussion

3.1. Physical Properties of the Boards

The average values of MC and basic density of the 160 boards were 12.3 ± 0.95% and 568.6 ± 54.41 kg/m^3, respectively. The minimum and maximum density values were 453.3 and 710.7 kg/m^3, respectively. The mean, minimum, and maximum values of measured AWV of *E. nitens* boards were 4.90 km/s, 3.98 km/s, and 5.85 km/s, respectively. Figure 7 demonstrates the density versus measured AWV of the boards.

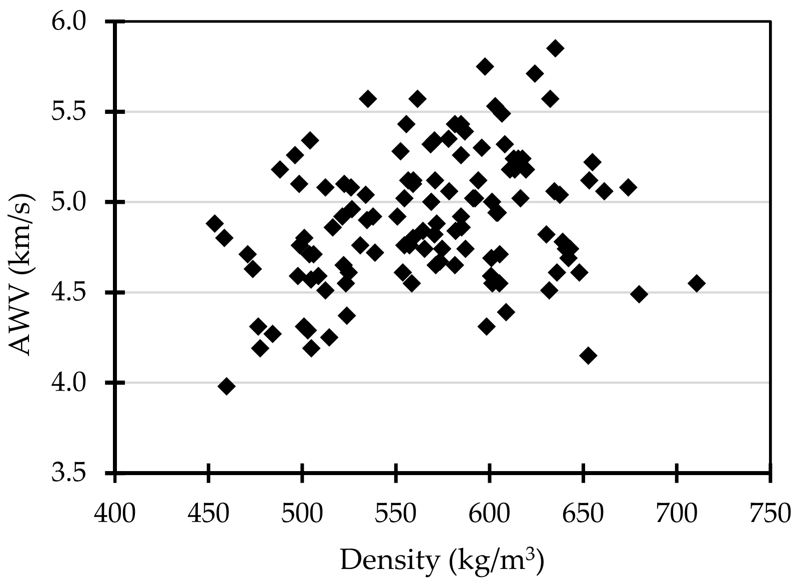


Figure 7. Density versus acoustic wave velocity distribution of the fibre-managed *E. nitens* timber boards.

3.2. Actual MOE and MOR Values for the 40 Tested Boards

The MOE and MOR values of the 40 boards were measured to validate and compare with the predicted values of the 120 boards through the different methods. The minimum and maximum MOE values of the tested boards were 7.6 GPa and 17.7 GPa, respectively. The results showed that there is a high variation in MOE and physical properties of the boards from this resource. Figure 8 demonstrates the MOE versus MOR values of the 40 tested boards obtained from the destructive four-point bending test. The average MOE and MOR values of the 40 boards were 13.4 $\pm$ 2.54 GPa and 60.3 $\pm$ 21.3 MPa, respectively. The MOE values of the tested boards in this study were higher than those values of the 16 years old resource reported by Derikvand et al. [9]. The regression analysis indicated that more than 76% of the variation in MOR values of the boards could be explained by their MOE values (Figure 8). This analysis also indicated that the MOE of the boards is significantly correlated to the average MOR of the boards.

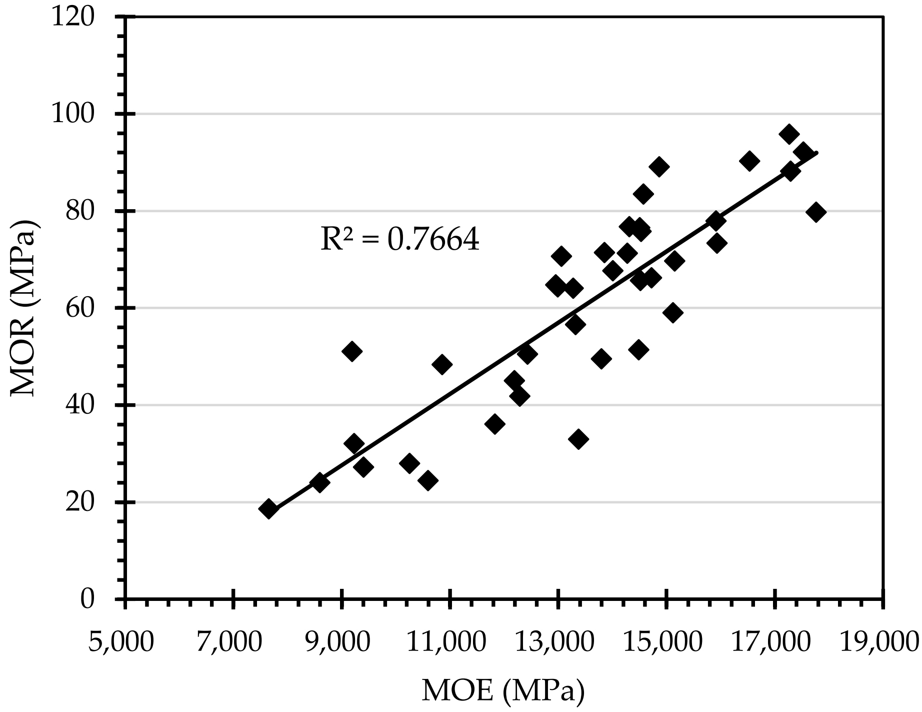
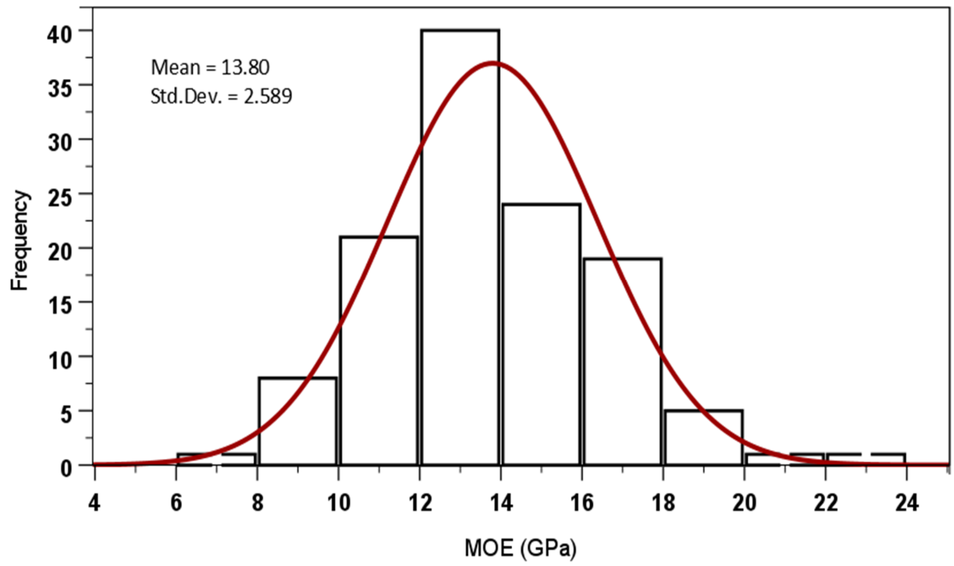


Figure 8. MOE versus MOR values of tested boards.

3.3. Prediction of Dynamic MOE Values of the 120 Boards through Different Methods and Criteria

3.3.1. Non-Destructive Edgewise Four-Point Bending

To be able to compare the measured MOE values with those predicted given by NDT, MSG, and MLR model, the boards were tested under a non-destructive edgewise four-point bending test in the linear–elastic range obtained from the Australian Standard static bending test (AS/NZS 4063.1). Figure 9 shows the statistical distribution of the obtained MOE_s values of the boards. It can be seen that the distribution of the measured data of MOE is slightly left-biased, meaning that there were more samples with MOE of less than 14 GPa. As shown, the mean values of the samples were 13.8 GPa. The fifth percentile, known as the characteristics value, indicates that 5% of the samples have MOE values of less than 9.4 GPa.



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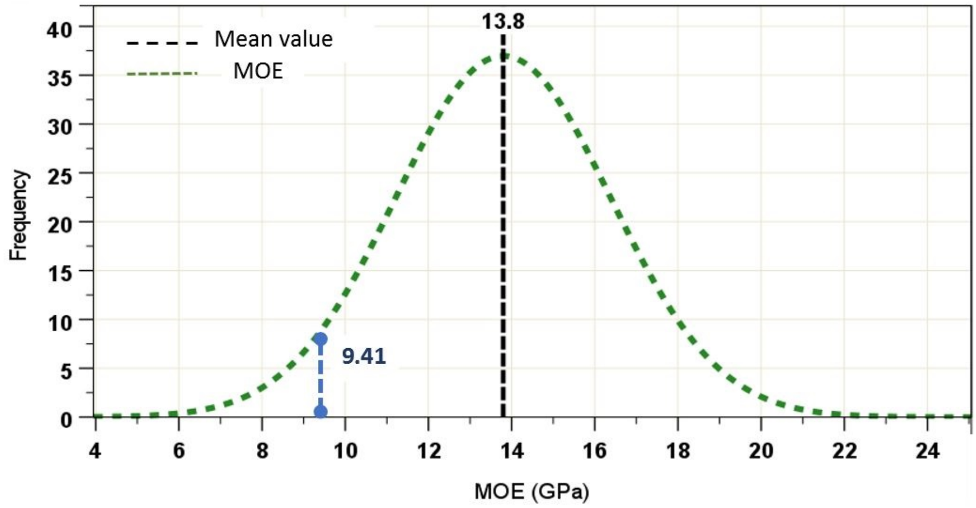


(**b**)

Figure 9. Statistical distribution of boards population (**a**) Normal distribution of the MOE of the *E. nitens* timber boards (**b**).

3.3.2. Acoustic Wave Velocity through NDT Technique

Figure 10 compares the measured static MOE and the predicted MOE values obtained from NDT through AWV. It can be seen that the AWV is highly correlated with static MOE values of the boards ($R^2 = 0.74$). A strong correlation was also found between MOE_{dyn} determined by AWV and static MOE obtained from edgewise four-point bending. The obtained R squared values represent that the measured MOE values using the orientation of edgewise and longitudinal are highly correlated. Furthermore, the Pearson correlation was investigated between the density and AWV with the static MOE values to measure the degree of the linear relationship between variables (Table 1). The Pearson correlation showed that the variables are well correlated with adjusted MOE values and were highly significant ($p < 0.00$). It can be seen that the density and AWV of the boards appeared to be positively correlated to the static MOE of the boards; however, density was not as effective as AWV for predicting MOE separately. This is also in line with the earlier observations, which showed that density is one of the main factors in determining the mechanical properties, but it cannot merely predict the mechanical behaviour of timber. The calculated characteristic value of the dynamic MOE through AWV was 13.6 GPa calculated under AS/NZS 4063.2 [32], exactly matching that value for static MOE (13.6 GPa) obtained from edgewise four-point bending.

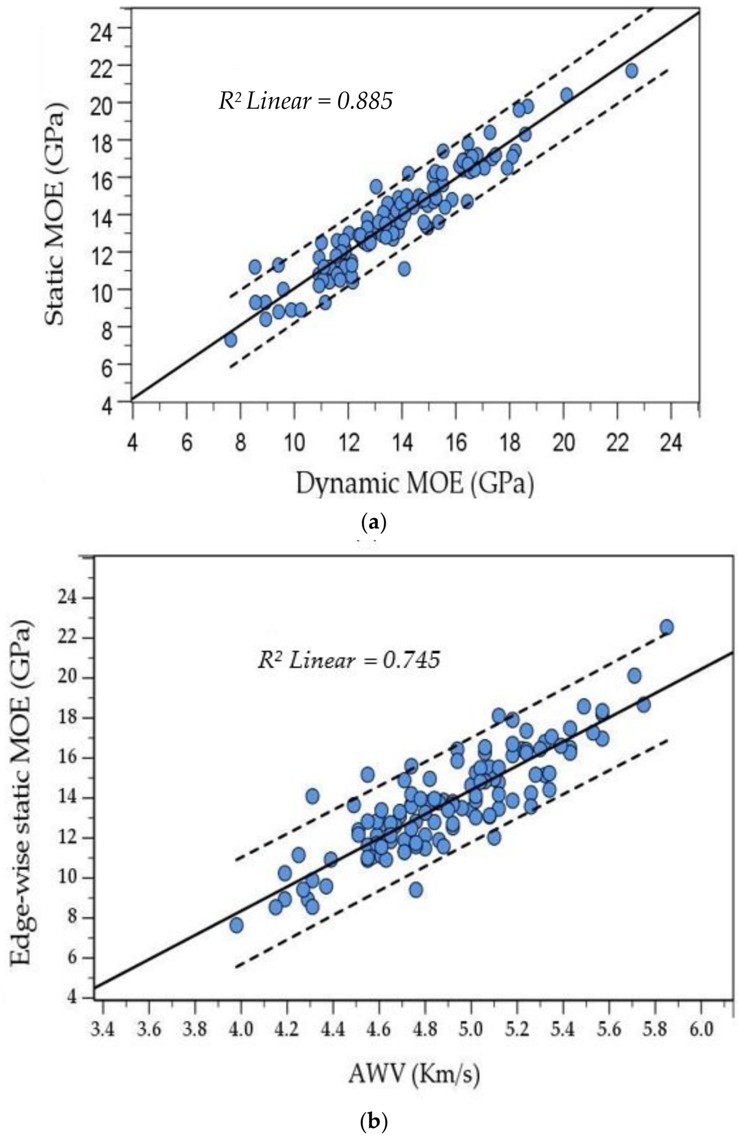


Figure 10. Correlation between static MOE and dynamic MOE predicted through AWV (**a**) and Correlation between static MOE and AWV (**b**).

Table 1. Pearson correlation between the test variables of *E. nitens* sawn boards.

		Static MOE	**Basic Density**	**AWV**	**MOE_{dyn}**
Static MOE	Pearson Correlation	1	0.581 **	0.863 **	0.941
	Sig. (2-tailed)		0.000	0.000	0.000
	N	120	120	120	120

** Correlation is significant at the 0.01 level (2-tailed).

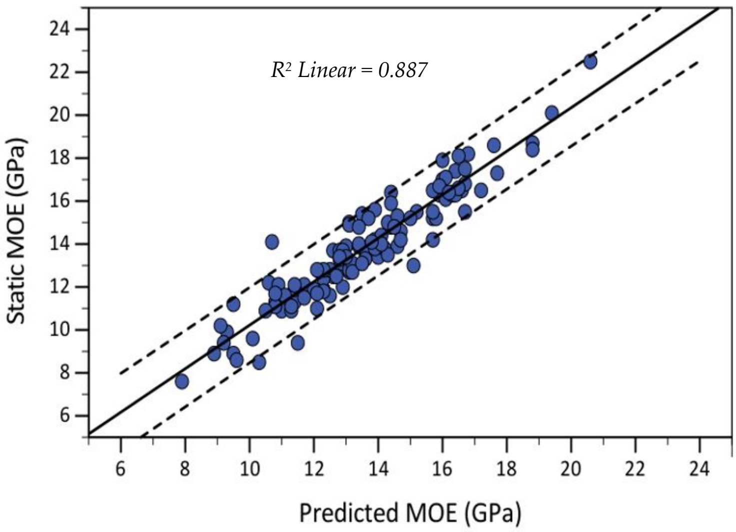
To further assess the effectiveness of these measured parameters to predict the MOE values, the MLR model was performed. In this regression model, we used density and AWV as input parameters. The interaction between the boards' density and AWV (ANOVA, p = 0.000, Table 2) indicated that the combination of density and AWV parameters could be practical to estimate the MOE values. Figure 11b presents the three-dimensional plot of the fitted regression model to estimate the MOE values of each board as a function of AWV and density values. The model equation was suitable to predict the MOE values, which is as follows:

$$MOE_{predicted} = 15.6 - 0.04 \times \text{Density} - 2.70 \times \text{AWV} + 0.014 \times \text{Density} \times \text{AWV} \quad (6)$$

Table 2. The results of the ANOVA test.

Variable	Df	Sum Sq	Mean Sq	F Value	Pr (>F)
Density	1	270.45	270.45	324.382	<0.001 **
AWV	1	424.71	424.71	509.406	<0.001 ***
Density: AWV	1	9.72	9.72	11.653	0.0008838 ***
Residuals	116	96.71	0.83		

Significant. codes: 0 '***' 0.001 '**'.



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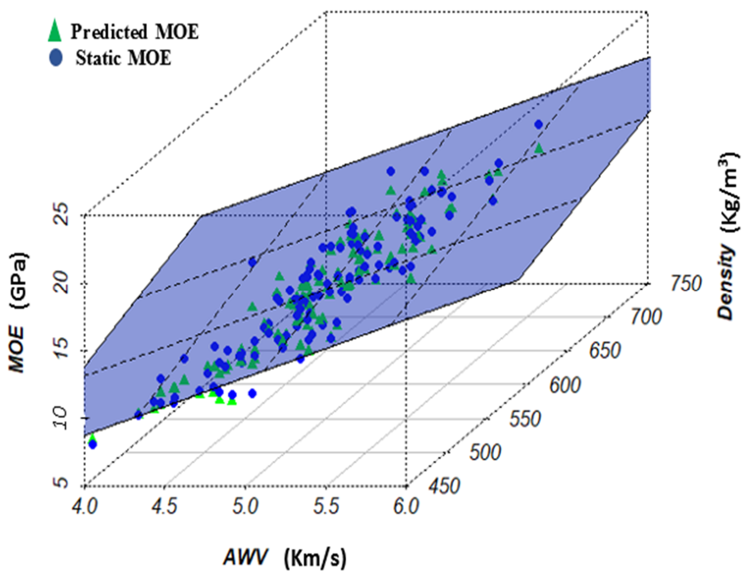


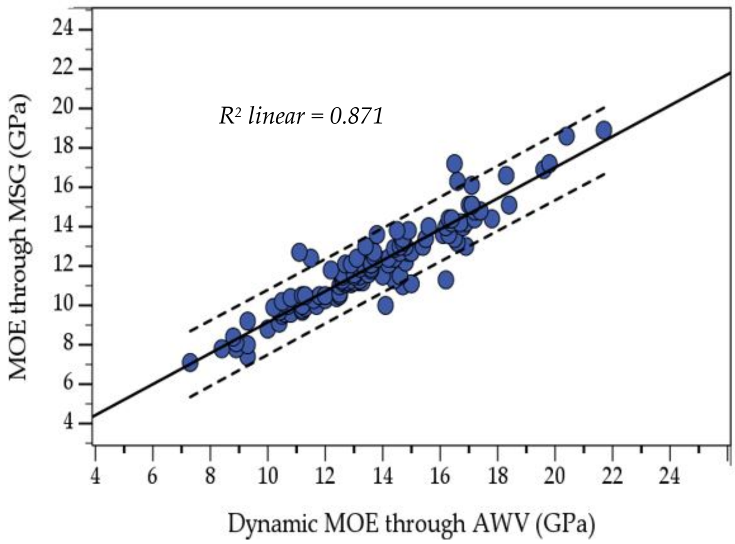
(**b**)

Figure 11. Correlation between the predicted MOE and static MOE values (**a**) Three-dimensional scatter plot of AWV, density and MOE values of the boards (**b**).

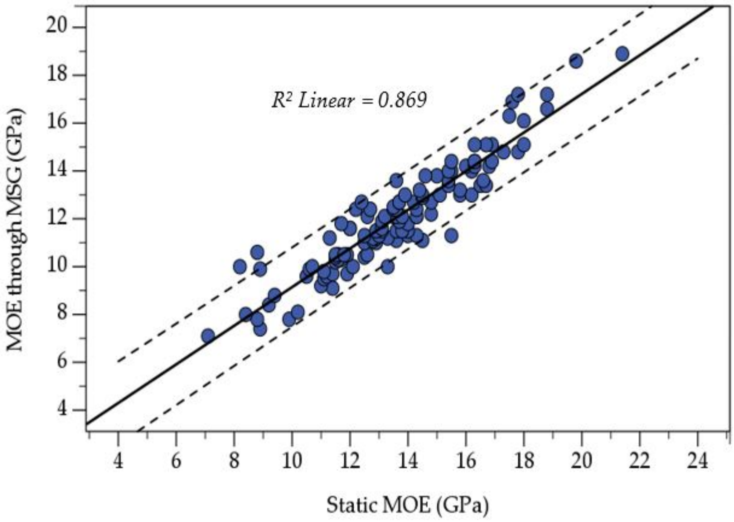
The equation was suitable for estimating the MOE values of the *E. nitens* timber, indicating that the combination of density and AWV variables can significantly improve the prediction of mechanical properties. This further support the suitability of NDT techniques used in this study, which employed both density and AWV values to predict the MOE. Figure 11a shows the Correlation between the predicted MOE values using the fitted model and static MOE values of the boards. As can be seen, the predicted MOE was highly correlated with the static MOE with the R^2 value of 0.88, demonstrating the ability of these models in predicting the MOE values. The average of the predicted MOE values was also 13.5 GPa which is comparable to those obtained from both 40 boards and 120 boards groups. Similar results were found by previous researchers, who pointed out that MOE_{dyn} values of three Eucalyptus species (*E. delegatensis*, *E. globulus*, *E. nitens* and, *E. regnans*) are affected by density [25,27]. Fathi et al. [17] claimed that wave velocity is a suitable parameter for MOE prediction and an important input factor for developing predictive models. Baar et al. [18] pointed out that the non-destructive evaluation using wave propagating shows a good correlation with those MOE values from bending tests and can be a reliable method for the stiffness prediction of timber. Rodolfo et al. [24] reported that the mechanical properties of *Eucalyptus camaldulensis* wood present a satisfactory estimation of MOE values. Furthermore, the NDT method through wave propagation was shown to be a suitable method to predict the MOE values of the timber species [24].

3.3.3. Machine Stress Grading

Figure 12 shows the Correlation between the dynamic MOE through AWV and static bending MOE with the predicted MOE using MSG. A high correlation was found between the predicted MOE via MSG and NDT through AWV, with R2 values of 0.87 (Figure 12a). Similar to that, there was also a high correlation with the static MOE values with R^2 value of 0.86 (Figure 12b). This high level of Correlation shows that the flat-wise bending position is highly correlated with edgewise and longitudinal measurement orientation. This also further supports that the MSG method might be suitable for grading the *E. nitnes* timber boards. Figure 13 compares the predicted MOE values for each measurement method. The mean values of the predicted MOE were highly similar, with differences of less than 1%, except for the MSG method, which showed a lower average MOE value compared to other methods. The edgewise static bending showed higher MOE compared to flatwise MOE for the MSG method; however, there was a high correlation between the MOE values measured through edgewise and flatwise bending. In the edgewise four-point bending test, the MOE is determined under a pure bending moment, while in the three-point flatwise bending test, the thickness of the board and shear stress is also considered, which might marginally reduce the MOE value. The results also indicated that the predicted MOE values for different orientation measurements of NDT and edgewise bending and also linear regression model calculated by the parametric methods were almost equal. More specifically, the predicted MOE values calculated by the linear regression model considering mechanical properties were slightly lower than the other predicted values. The characteristic dynamic MOE values of the boards through NDT and the characteristic MOE static values in edgewise orientation were 13.6 GPa. By comparing the obtained values with the characteristic values for the design according to AS 1720.1 [33], the standard MOE value of structural hardwood timber was able to meet the requirements of the standard modulus with grades F14. The standard MOE of all measurement methods exceeded the standard modulus of elasticity for (F14 = 12,000) stress grade.



(a)



(b)

Figure 12. Correlation between the predicted MOE through MSG method and dynamic MOE through NDT (**a**), Correlation between the predicted MOE through MSG method and static MOE (**b**).

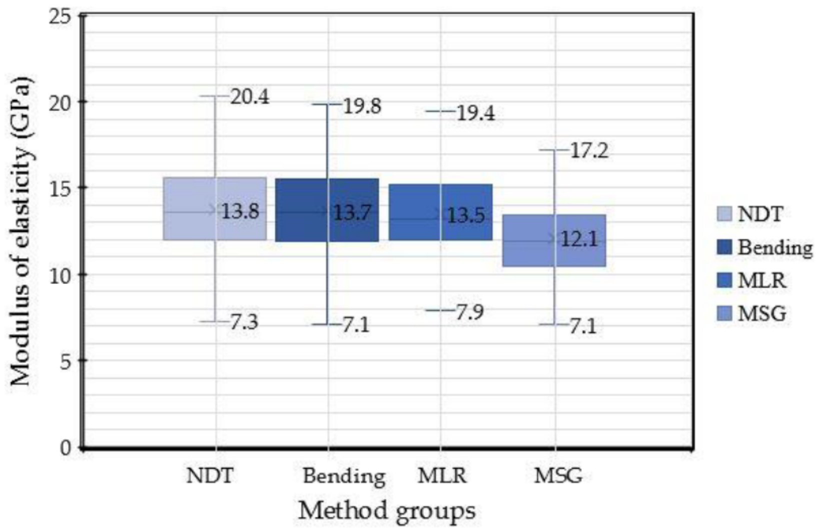


Figure 13. Comparison between the measurement methods of predicting modulus of elasticity.

4. Conclusions

The results presented in the current chapter provide useful information on the structural capacity and properties of the fibre-managed *E. nitens* timber and promote the application of this resource for building purposes. In this study, different techniques in predicting MOE as a grade determining factor were compared, and critical parameters and approaches for estimating the mechanical properties of *E. nitens* timber to be used in structural timber elements were identified. Based on the experimental tests and analysis, we determined the following key conclusions as follows:

A strong linear relationship (R^2 = 0.88) was observed between the dynamic and static MOE of the boards, proving the NDT as a reliable method for the MOE estimations of fibre-managed *E. nitens* timber boards. There was also a positive correlation between the measured AWV with static MOE values of the boards (R^2 = 0.74), given that acoustic wave velocity might be an important factor for predicting the MOE of fibre managed *E. nitens* boards. The density was also positively correlated with the static MOE values; given this, the use of selected physical-mechanical properties of *E. nitens* timber as a function of propagation speed and the MOE dynamic is feasible.

- MLR model as a function of mechanical properties demonstrated to be an effective method in predicting the MOE values of *E. nitens* timber boards. A strong linear relationship (R^2 = 0.88) was observed between the predicted and static MOE of the boards, showing that the combination of the density and AWV of the timber boards can be practical to estimate the MOE values based on the equation $\text{MOE}_{\text{predicted}} = 15.6 - 0.04 \times \text{Density} - 2.70 \times \text{AWV} + 0.014 \times \text{Density} \times \text{AWV}$. This demonstrated that the physical–mechanical properties of the timber showed to be effective to predict the MOE values. This is also in line with the results obtained from the NDT technique that density and AWV can be practical parameters in predicting the MOE of the *E. nitens* timber boards.
- There was also a high correlation between the estimated MOE through MSG with static and dynamic MOE values of the boards, demonstrating that the flat-wise bending position is highly correlated with edgewise and longitudinal measurement orientation. According to the statistical analysis, the mean values for MOE predicted from the different methods were highly similar, with a difference of less than 1%, except for the MSG method, which showed a lower average MOE. The average MOE of the boards obtained from the NDT technique, static bending, MSG, and MLR model were 13.8 GPa, 13.7 GPa, 13.5 GPa, and 12.1 GPa, respectively.
- The distribution of measured MOE demonstrated that the majority of the *E. nitens* timber boards have MOE values of less than 14 GPa. In particular, the characteristic MOE value of the *E. nitens* timber board determined from static bending was 13.6 GPa and was able to meet the requirements of the standard modulus with grades F14 according to AS 1720.1. The standard MOE values of all measurement methods used in this study exceeded the standard modulus of elasticity for (F14 = 12,000) stress grade for the 21 years old fibre-managed *E. nitens* timber resource.
- The results showed that the timber from fibre-managed *E. nitens* resource is highly variable in properties; e.g., MOE ranged from low-grade 7 GPa to high-grade 22 GPa and can be used for structural timber products with different lamination configurations in grade.

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