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Prediction of global bending stiffness of timber beams by local sampling data and visual inspection

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Abstract

The results of visual inspection according to UNI 11119:2004 and bending tests made to 20 old chestnut (*Castanea sativa* Mill.) beams, according to EN 408:2010, were statistically analyzed in order to provide a consistent and feasible procedure to predict their modulus of elasticity (MOE) in bending. Local data obtained from smaller size specimens was used for predicting the global mechanical properties of full structural size members and was compared to the results of mechanical tests. The predicting models took into account the visual strength classes and influence of defects in the determination of the MOE. Moreover, random sampling selection was considered in order to demonstrate the possibility of using smaller representative samples, thus avoiding excessive need of removal of on-site samples and allowing for a lower number of mechanical tests. The models using random sampling selection predicted the behavior of full size scale elements accurately, with strong correlations to the experimental results (coefficient of determination r^2 ranging from 0.70 to 0.79) and a percentage error lower than 20%, thus allowing a reliable estimation of mechanical

characteristics of existing timber members with a combination of visual inspection and local sampling.

Keywords

chestnut beams, modulus of elasticity in bending, sample extraction, predicting models, random sampling selection

1. Introduction

Bending is the most common loading type in the structural use of sawn timber and, consequently, bending strength is usually the critical strength property (Piazza and Riggio, 2008). Nocetti et al. (2010) found that the best predictor of strength properties of chestnut timber elements was the modulus of elasticity (MOE), followed by a knot parameter. Therefore, it is essential to obtain accurate predictions of the MOE. García et al. (2007) obtained coefficients of determination r^2 for pine species of up to 0.71 for predictive models of global MOE, including visual grading parameters, density and non-destructive variables (longitudinal wave transmission velocity) as independent variables. In Nocetti et al. (2010), lower linear regression correlations were found for hardwoods, compared to softwoods. In the case of chestnut timber a r^2 of 0.54 was found between the MOE obtained in the laboratory and by machine stress grading. Lee et al. (2005) established a prediction model for bending properties of glued laminated timber using knot parameters and MOE distributions of lumber laminate as main input variables, obtaining strong correlations between predicted and measured MOE values. Lee and Kim (2000) also found better results in predicting glued laminated timber MOE with the use of localized MOE of lamina, when compared to the long span MOE of lamina. The relationship between local and global modulus of elasticity in bending has been investigated in several previous studies (Boström 1999; Denzler et al. 2008; Ravenshorst and van de Kuilen 2009; Ridley-Ellis et al. 2009), together with its consequences in structural timber grading (Nocetti et al 2013).

For the estimation of the mechanical properties of existing structural timber elements it is common practice to attend to results of mechanical tests made to small clear wood specimens extracted from the element. However, this mechanical characterization often provides higher results compared to the mechanical behavior of the structural element, as it is affected by the influence of defects. On the other hand, visual inspection often leads to conservative estimates of the element's mechanical behavior. Therefore, these two approaches provide an upper and lower bound for the mechanical characterization of existing timber elements. Correlations between non-destructive tests and the mechanical properties of chestnut timber have been studied in Feio et al. (2007) for small clear wood samples and Calderoni et al. (2010) and Faggiano et al. (2011) in old structural timber elements. The results from Wang et al. (2008) indicated that the visual grades could identify different strength class timber samples, with higher visual grading corresponding to higher MOE in bending. However, Vega et al. (2012) concluded that, for chestnut timber elements, visual grading parameters of the members did not play a significant role in the prediction of MOE. This is corroborated by Piazza and Riggio (2008), which pointed out that the adopted grading methods of chestnut elements showed lower correlations than other two tested softwood species.

Therefore, the present work aims at proposing a consistent and feasible procedure for MOE prediction of chestnut timber elements by using localized MOE results obtained from smaller size samples, complemented with visual grading. This is a clear need for chestnut and a relevant contribution for the increase in knowledge in safety analysis of existing timber structures in general, by using different size scale elements. In these structures usually only limited inspection of members and mechanical characterization of smaller specimens are possible, either due to on-site constraints or time and cost reasons. For this purpose, 20 chestnut beams were visually inspected and tested at different scales. The local data obtained in the smaller size specimens was then used to predict the global MOE of the full structural size members and compared to the results of the experimental campaign. The predicting models took into account the difference between visual strength classes and influence of defects in the determination of MOE. Given the fact that specimens have to be collected for the mechanical tests necessary for strength grading and stiffness characterization, random sampling selection was also considered. This procedure aims at demonstrating the possibility of using smaller representative samples, thus avoiding the need of a large number of on-site samples and lowering the number of mechanical tests needed.

2. Material and methods

2.1. Sampling

Aiming at evaluating existing timber elements through visual inspection of their defects' distribution complemented by laboratorial tests on small clear specimens, twenty chestnut (*Castanea sativa* Mill.) beams were visually inspected and tested in bending at different size scales. The more than a century old timber beams were taken from a building in Northern Portugal, where they served as structural floor beams. The length of the elements varied between 4 m and 6 m with a mean value of 5.32 m and a coefficient of variation (CoV) of 11.8%. The average value for the nominal cross section dimensions were 13.0 cm (CoV = 6.0 %) for width and 18.0 cm (CoV = 3.1%) for height. Even if the variation in the nominal cross section dimensions within each element was low, significant wane was found. This wane was mainly consequence of the initial sawing process rather than from deterioration (elements still presented sharp edges) and did not pose problems to the existing connections to other structural elements.

2.2. Experimental campaign

The experimental campaign was divided into three main phases, corresponding to different scales of the timber members. From one to the next phase, the timber elements were sawn into smaller sizes in order to isolate the influence and location of defects, and also to provide a better definition of the distribution of stiffness and strength along the length and height of element. It is assumed that the tests in the small specimens are an upper bound for the wood property being measured, and the property itself is unknown and must be estimated.

The main experimental phases correspond to the members: (phase 1) in the initial state of conservation as they were in the building, with mean dimensions of 13×18×532 cm^3; (phase 2) after being sawn to beams with 7×15×300 cm^3 dimension (one sawn beam per each old beam); and (phase 3) after being sawn to boards with 7×4×300 cm^3 dimension (three boards per beam). In each phase, the members were visually inspected and graded on each 40 cm segment, using the Italian standard UNI 11119:2004. This standard establishes objectives, procedures and requirements for the diagnosis of the state of conservation and estimates nominal stiffness and strength values for structural wood elements present in cultural heritage buildings. This standard considers the evaluation of a critical cross section representative of a segment of the structural element that due to the presence of defects, position, state of conservation and stress condition regarding a static analysis, is relevant to the global diagnosis of the element. For visual grading, this standard considers three classes (I, II and III) regarding on site diagnosis. The wood element is considered to be from a given class if it fulfills all the imposed requirements. In this study, when the imposed requirements were not fulfilled for any of the mentioned classes, the segment was graded as non-classifiable (NC). The sawn beams and boards were also submitted to 4-point bending test according to EN 408:2010, obtaining local ($E_{m,l}$) and global ($E_{m,g}$) MOE in bending. A single 4-point bending test was made for each sawn beam, while seven consecutive bending tests (centered with the 40 cm segments adopted in visual inspection) were considered along the length of each sawn board. A total of 20 beams were tested in Phase 2, with 4 beams being tested to failure. The beams that were not tested to failure (16 beams) were sawn to 3 boards each, obtaining a total of 336 segments for testing in Phase 3. For the bending tests in sawn boards, segments with 7×4×64 cm^3 were considered with 60 cm and 20 cm for $E_{m,g}$ and $E_{m,l}$ gauge lengths, respectively.

2.3. Data analysis

The results of the experimental campaign in the chestnut timber elements confirmed a strong correlation between the global, $E_{m,g}$, and local, $E_{m,l}$, moduli of elasticity in bending within and between phases (different sizes). Coefficients of determination between 0.82 and 0.89 were found within the same phase, whereas values from 0.68 to 0.71 were found between different phases. Moreover, by variation analysis, different visual strength classes provided significant statistical different ranges for MOE for the corresponding segments (Sousa et al., in-press). The results of $E_{m,g}$ of beams and the $E_{m,l}$ of boards' segments were fitted to Lognormal probability distribution functions considering the use of probability papers and χ^2 goodness of fit tests (with 5% significance level). The frequency of the associated probability distributions for these results is presented in Figure 1. The results of $E_{m,l}$ of boards' segments are differentiated by visual class, evidencing a higher variation for lower grade classes, as well as a lower mean value. Further detail on the experimental campaign sequence and results was dealt in Sousa et al. (2012).

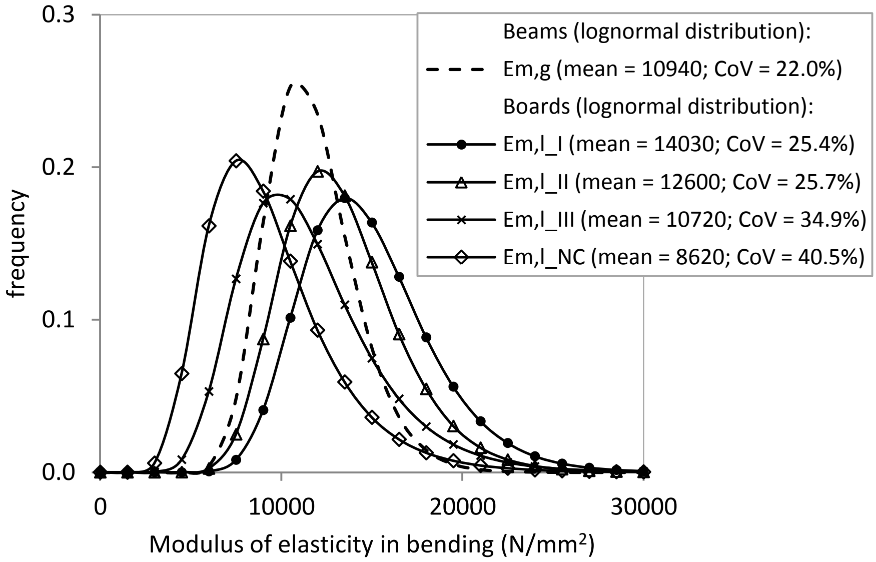
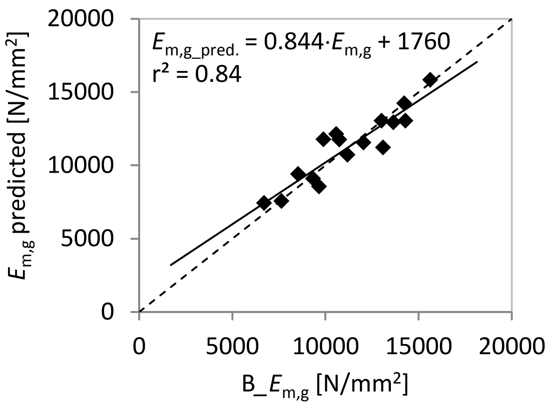


Fig. 1 Frequency distribution and statistical parameters for $E_{m,g}$ of beams and $E_{m,l}$ of boards' segments differentiated by visual inspection class

Visual inspection and results of $E_{m,l}$ of smaller scale specimens were combined to predict the $E_{m,g}$ of structural timber elements. Initially, a benchmark coefficient of determination, r^2, was obtained by means of multiple regression regarding the influence of each set of boards (top, lower and bottom) for the $E_{m,g}$ of the structural size sawn beam. This benchmark coefficient of determination corresponds to the best correlation possible regarding the optimization between the results found in the two different phases of bending tests. The sample size corresponds to the 16 beams that were not taken to failure in Phase 2 and that were also tested in Phase 3 when sawn into boards. In this case, the results of each board are assumed as independent variables and the experimental result are assumed as a dependent variable, resulting in the expression for the predicted value of $E_{m,g}$:

$$E_{m,g}^{predicted} = C_{top} \cdot E_{m,l}^{top} + C_{middle} \cdot E_{m,l}^{middle} + C_{bottom} \cdot E_{m,l}^{bottom} + c \qquad (1)$$

Here, $C_{top} = 0.224$, $C_{middle} = 0.193$, $C_{bottom} = 0.661$ and c = -1820 N/mm^2. These parameters indicate a larger contribution of the lower boards for the prediction $E_{m,g}$. With this relation, a linear fit with the experimental results ($r^2 = 0.84$) is attained (Figure 2). Here, B_$E_{m,g}$ indicates the MOE results of sawn beams in mechanical tests in Phase 2. The analysis of the correlation between each board and the corresponding beam leads to the conclusion that the lower board has a better linear fit to the experimental results with $r^2 = 0.74$, whereas the middle and top boards present lower correlations with, respectively, $r^2 = 0.59$ and 0.40.



$$E_{m,g}^{predicted} = 0.224 \cdot E_{m,l}^{top} + 0.193 \cdot E_{m,l}^{middle} + 0.661 \cdot E_{m,l}^{bottom} - 1820 \left[N/mm^2\right]$$

Fig. 2 Correlation between experimental $E_{m,g}$ of beams with the predicted value taken from a multiple regression of sawn boards $E_{m,l}$

2.4. Influence of defects in mechanical characterization

In order to verify the influence of visual inspected defects and if the assumed visual inspection classes could distinguish segments with different stiffness values, the results of $E_{m,l}$ of the bottom sawn board were analyzed.

In a first analysis, the mean values of $E_{m,l}$ of the bottom board segments visually graded as class I (UNI 11119:2004) were compared to the B_$E_{m,g}$ for each beam. In a second analysis, the segments of each lower board were divided according to their visual inspection and the $E_{m,l}$ of each group was statistically analyzed. After, the mean reduction factor for $E_{m,l}$ to downgrade from class I to the remaining classes was calculated. According to the obtained reduction factors and accounting for the number of segments in a given visual class, a weighted MOE can be calculated for each beam, as given in Equation (2), where $E_{weighted}$ is the weighted $E_{m,l}$ considered for each beam, n_x is the number of segments, α_x is the reduction factor of a given x visual class and E_I is the mean value of the $E_{m,l}$ for segments classified as class I.

$$E_{weighted} = \frac{n_I \cdot E_I + n_{II} \cdot (E_I - \alpha_{II} \cdot E_I) + n_{III} \cdot (E_I - \alpha_{III} \cdot E_I) + n_{NC} \cdot (E_I - \alpha_{NC} \cdot E_I)}{n_I + n_{II} + n_{III} + n_{NC}} \quad (2)$$

2.3. Prediction models

With consideration to the experimental data analysis, it is plausible to assume that one may predict, within a confidence interval, the $E_{m,g}$ value of structural size timber elements by consideration of the $E_{m,l}$ of smaller size samples and the visually inspected distribution of defects along the length and height of the element. To validate this hypothesis, structural models are proposed where the computation of MOE results in sawn boards was considered and compared with the measurements of structural size beams under bending tests. The information of visual inspection is also taken into account for model calibration and improvement.

After defining the benchmark coefficient of determination, two different models were considered regarding the computation of measurements of boards' MOE, either by modeling the sawn boards as separate elements or by modeling a reconstructed full sawn beam (see Figure 3). For both models, the elements were defined by the combination of the results of $E_{m,l}$ in the sawn boards bending tests. To each segment of a board the $E_{m,l}$ corresponding to the nearest bending test result made to the sawn boards is attributed and, after, each segment is modeled as a beam element. Displacements of each node were obtained by use of the direct stiffness method, with the calculation of the $E_{m,g}$ of beams being based on the EN 408:2010 formulation.

The first model (Model 1 - M1) considered the values taken to each segment of a sawn board and then, as result, the MOE would be calculated for the total span length between supports. Although modeling each board separately, the span between supports is equal to the span of a full size beam. The average of the three results for each group of sawn boards that previously composed a beam was taken and compared to the bending tests results obtained from the beams. Therefore, for each beam, three boards were modeled and a mean result was calculated.

The second model (Model 2 - M2) assumed the mean value for the measurements made to the same segment of each set of boards (e.g.: measurements in A1 (top), A2 (middle) and A3 (bottom) for segments 1 (from 10-50 cm)), thus the mean MOE in height per segment. This mean MOE is afterwards considered for the modeling of a full cross section size reconstructed beam and then the results are compared to the beams bending tests results.

For notation purposes, M1_$E_{m,g}$ and M2_$E_{m,g}$ correspond to the MOE predicted respectively from Model 1 and Model 2.

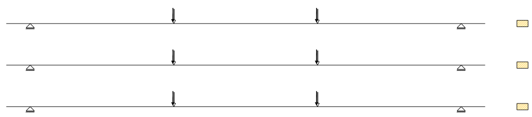
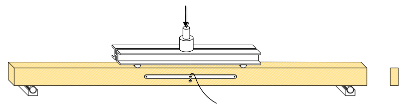
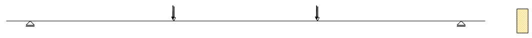
Models		Experimental results
Model 1 (M1): separate boards		
		
Data: $E_{m,l}$ per segment and per board Results: $E_{m,g}$ per board ⇒ E_{m,g_mean}	VS	
Model 2 (M2): reconstructed beam		
		
Data: mean $E_{m,l}$ per segment Results: $E_{m,g}$ per beam		Data: $E_{m,g}$ in mechanical tests Results: $E_{m,g}$ per beam

Fig. 3 Models used for assembling the moduli of elasticity of sawn boards segments for comparison with elastic moduli in the beams bending tests

2.5. Random sampling selection

When assessing the safety of an existing timber structure, it is not possible to obtain the different $E_{m,l}$ along the timber members as in the present experimental campaign. And, it is important to minimize the destructive component of the mechanical characterization related to the extraction of specimens from the timber members. Therefore, it is important to analyze if the use of a representative sample of the different segments in each visual inspection class would permit to obtain a reliable assessment of the global element. For that purpose, after each segment being visually classified, one segment representative of each visual class was chosen randomly and its $E_{m,l}$ is considered for all the other segments with the same visual class. Then, the models would consider such information as input data and compute the $E_{m,g}$ of the reconstructed beam. The random selection of segments was repeated until a significant sample was obtained and then the mean value was correlated to the experimental campaign results. The applied methodology is described in Figure 4.

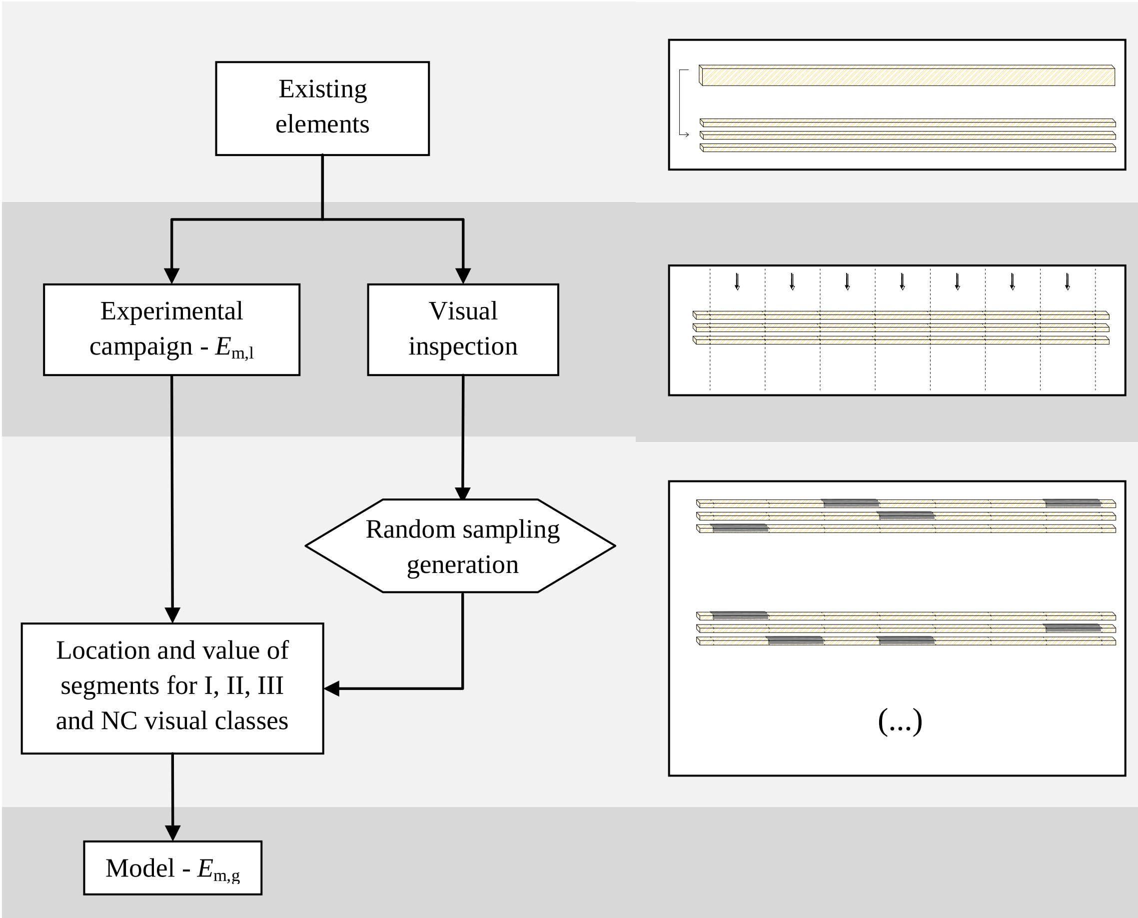


Fig. 4 Implemented procedure for obtaining sets of random variable samples of segments in different visual classes for $E_{m,g}$ prediction by models M1 and M2

3. Results

3.1. Influence of defects

The first analysis, neglecting the influence of defects, considers only the mean value of segments belonging to the higher grading classes. This analysis led to a lower coefficient of determination ($r^2 = 0.66$) than the previous model for the lower boards, where all segments with different visual classes were considered. In addition, stiffness values higher than B_$E_{m,g}$ would be predicted for each beam, since only clear wood samples (or with minor defects) were considered. Therefore, it is necessary to consider the influence of lower visual class segments and quantify the decrease in the mechanical properties for those classes. A mean reduction in $E_{m,l}$ of the class I sample of 6%, 21% and 27% was found, respectively, for downgrading to classes II, III or NC. According to the obtained reduction factors and accounting for the number of segments in a given visual class, a weighted MOE was calculated for each beam, as given in Equation (2).

The results are presented in Figure 5, where it is visible that in comparison with the results from the analysis with only class I values, a stronger correlation is obtained (r^2 = 0.82), evidencing the improvement in the model when considering information from a visual inspection grading. However, the predicted values still overestimate the B_$E_{m,g}$ results.

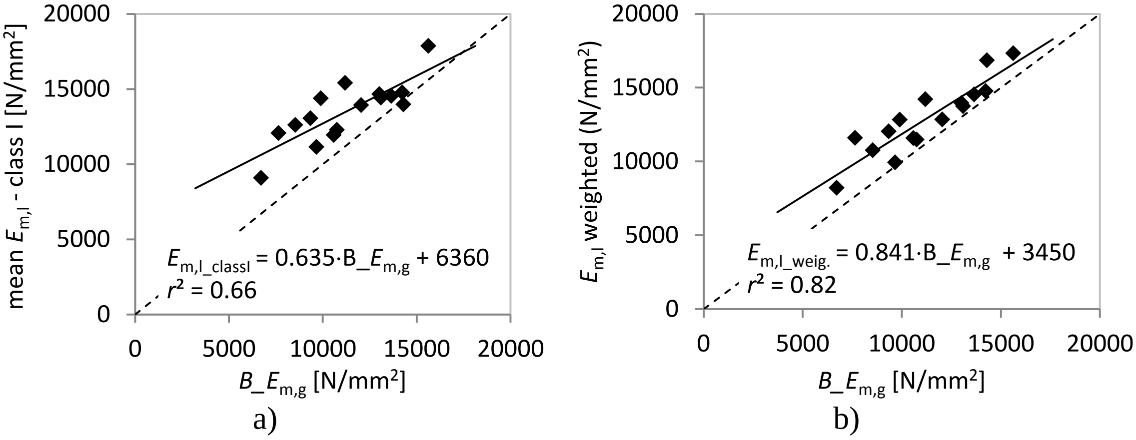
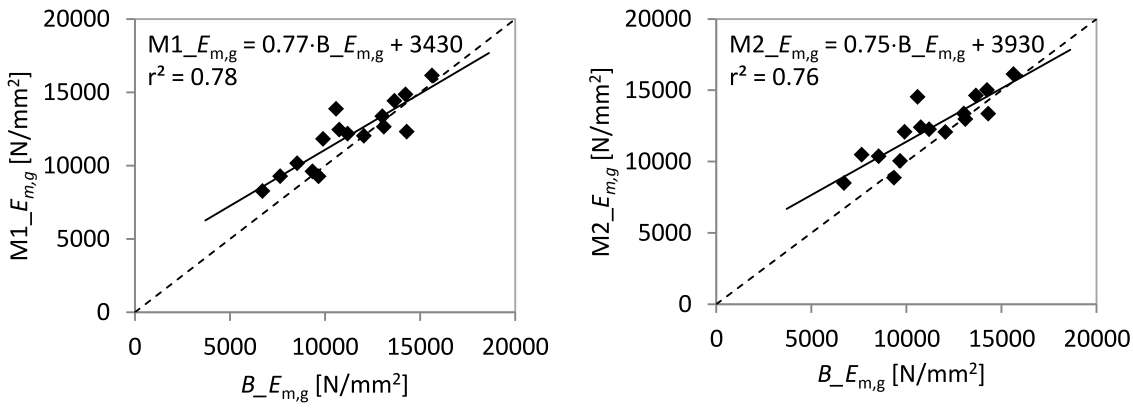


Fig. 5 Correlation between experimental $E_{m,g}$ of structural beams (B_ $E_{m,g}$) and: a) mean $E_{m,l}$ of the segments in the bottom sawn boards graded as class I; b) weighted $E_{m,l}$ by visual inspection grading of the segments in the bottom sawn boards

3.2. Prediction models results

The results of the models are compared to the B_$E_{m,g}$ (Figure 6), and strong correlations are found (r^2 = 0.76 to 0.78). When assuming the values of $E_{m,l}$ from modeling, it is found that the predicted values are in general higher than the experimental values (non-conservative approach). Still, one may conclude that the combination of the different properties of the singular segments may satisfactorily predict the behavior of the global element. This seems also a reasonable assumption because the tests were conducted in linear elastic regime. A similar conclusion is found in Aicher et al. (2002) where the results permitted to state that the measured local MOE and the experimental global MOE are consistent, since the global MOE may be predicted by beam theory or FEM analysis on the basis of the local MOE of segments. It is worthwhile mentioning that in this study, the measurements taken from smaller size specimens were able to adequately predict the higher scale element, despite the fact that the smaller and larger samples presented localized defects.

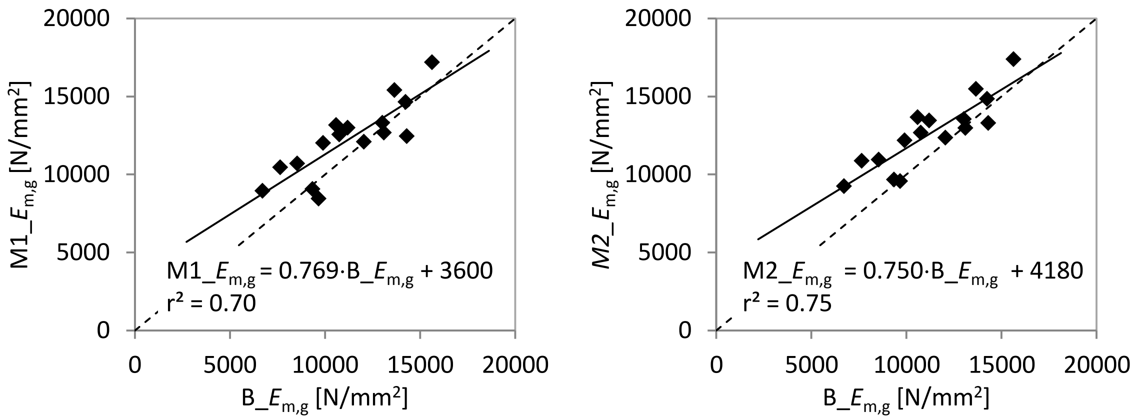


a) b)

Fig. 6 Correlation between experimental $E_{m,g}$ of structural beams (B_ $E_{m,g}$) and $E_{m,g}$, with use of boards' $E_{m,l}$, given by: a) M1; b) M2

3.3. Random sampling results

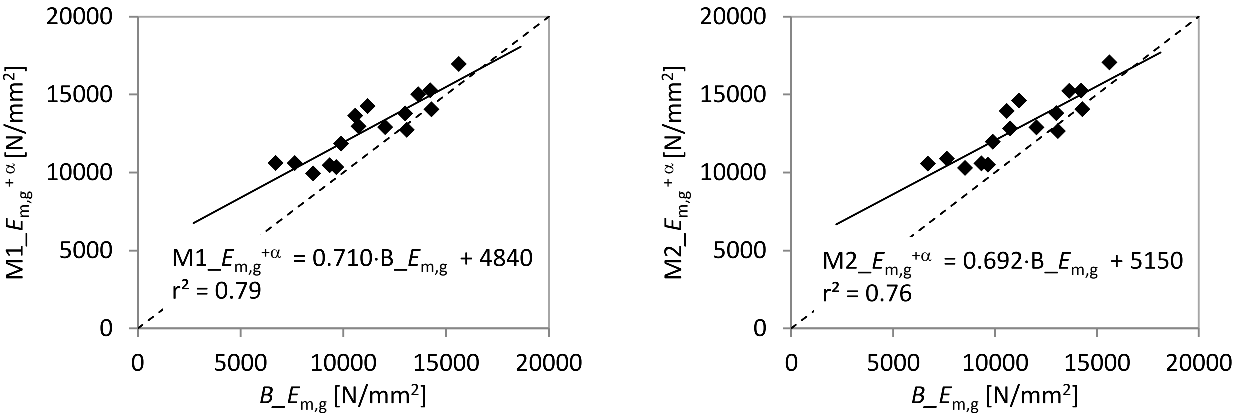
The variation in the results of each beam regarding the randomly generated sample was determined with mean CoV of 16.0% and 15.8% for M1 and M2, respectively. The results are presented in Figure 7 where, considering the previous benchmark correlation, again strong correlations were found (r^2 = 0.70 to 0.75).



a) b)

Fig. 7 Correlation between experimental $E_{m,g}$ of beams with random generated sets of $E_{m,l}$ in segments according to the visual inspection: a) M1; b) M2

In addition, an analysis was considered by selecting only a sample of class I and then assuming the remaining classes as a reduction of that value. Thus, only the information of clear wood samples and the reduction factors according to the visual inspection are considered to attribute each value to the different segments in the model. As mentioned previously in Equation (2), a mean reduction in $E_{m,l}$ for the class I group of 6%, 21% and 27% was found, respectively, for downgrading to classes II, III or NC. Considering these reductions factors and a procedure analogous to the methodology presented in Figure 4, but only by random selecting the values of segments in class I, the MOE were calculated by models M1 and M2. The results are presented in Figure 8 and the variation in the results of each beam regarding the randomly generated sample was also determined with mean CoV of 15.2% and 15.4% for M1 and M2, respectively. The correlations between experimental results and the ones obtained by random selection of segments with a given visual class, evidenced strong correlations with r^2 between 0.76 and 0.79, with better results in M1 considering only a random selected value of class I and the reduction factors.



a) b)

Fig. 8 Correlation between experimental $E_{m,g}$ of beams with random generated sets of $E_{m,l}$ in segments with visual class I and reduction factors for the other classes: a) M1; b) M2

Although strong correlations were found in the prediction of B_$E_{m,g}$ by use of the $E_{m,l}$ and visual inspection information in a random sampling selection, it is also important to evaluate if the error involved in this prediction is admissible regarding the inherent uncertainty in the assessment of timber structures. For that purpose, the percentage error was calculated by comparing the predicted value with the experimental quantity. In this case, the percentage error is the absolute value of the difference divided by the experimental value times 100. Table 1 indicates the calculated percentage error and coefficient of determination r^2 for the results of MOE in different test phases and for the different models. It evidences that the percentage error of the prediction models have a similar range to those obtained from the experimental campaign between different phases and do not exceed an average percentage error of 20%. The exception is the model that only considered the class I samples as representative visual class, with a percentage error of 23.4%, further demonstrating that the influence of lower visual grade segments must be considered. Comparison to the indicative values given by UNI 11119:2004 is also considered accounting to the visual grading of the sawn beams. As non classifiable segments are not given an indicative value, the initial calculation of the percentage error was made for sawn beams classified only as I, II or III classes, obtaining a mean percentage error of 32.7%. As comparison, in Piazza and Riggio

(2008), an absolute value of 28% was found for the error of the visual grading by UNI 11119:2004 in predicting stiffness of elements in structural size. To account the stiffness values of sawn beams graded as NC, the reduction factor found in the experimental results for downgrading from class I to class NC (27%) was considered and the percentage error was recalculated. By consideration of the sawn beams with class NC, a lower mean percentage error was obtained (29.7%). By comparison to the experimental results a mean underestimation of 29% is obtained when the UNI 11119:2004 indicative values are considered, while a maximum mean overestimation of 18% is obtained when models using random sampling were considered. Table 1 also evidences that stronger correlations were obtained for the prediction of $E_{m,g}$ of sawn beams by $E_{m,l}$ of sawn boards when information of visual inspection classes was added.

Table 1 Percentage error, *% error,* and coefficient of determination r^2 for the results of MOE in different test phases and for the different prediction models

	x	y	x/y			*% error* =|1-x/y|·100 [%]			r^2
			min	max	mean	min	max	mean	
*	B_$E_{m,l}$	B_$E_{m,g}$	0.63	1.19	0.99	0.03	36.6	9.36	0.82
	b_$E_{m,l}$	b_$E_{m,g}$	1.00	1.24	1.10	0.48	24.3	10.4	0.89
	B_$E_{m,l}$	b_$E_{m,l}$	0.49	1.06	0.87	1.29	51.3	14.2	0.68
	b_$E_{m,g}$	B_$E_{m,g}$	0.84	1.46	1.07	1.72	46.2	12.6	0.71
	$VI^{classes\ I,\ II,\ III}$	B_$E_{m,g}$	0.56	0.94	0.67	6.28	43.8	32.7	0.39
	$VI^{all\ classes}$	B_$E_{m,g}$	0.56	1.09	0.71	4.49	44.3	29.7	0.40
**	B_$E_{m,g}^{mult.regr.}$	B_$E_{m,g}$	0.86	1.19	1.01	0.03	18.9	7.32	0.84
	M1_$E_{m,g}$	B_$E_{m,g}$	0.86	1.31	1.09	0.02	31.2	11.3	0.78
	M2_$E_{m,g}$	B_$E_{m,g}$	0.94	1.37	1.11	0.37	37.5	12.9	0.76
	$E_{m,g}^{class\ I}$	B_$E_{m,g}$	0.98	1.58	1.23	2.19	58.0	23.4	0.66
	$E_{m,g}^{class\ I\ +\ \alpha}$	B_$E_{m,g}$	1.03	1.52	1.17	2.94	51.9	16.5	0.82
***	M1_$E_{m,g}^{all\ classes}$	B_$E_{m,g}$	0.87	1.37	1.11	0.44	36.8	14.7	0.70
	M2_$E_{m,g}^{class\ I}$	B_$E_{m,g}$	0.93	1.42	1.14	0.89	42.3	15.4	0.75
	M1_$E_{m,g}^{class\ I\ +\ \alpha}$	B_$E_{m,g}$	0.97	1.58	1.16	1.71	58.1	17.0	0.79
	M2_$E_{m,g}^{class\ I\ +\ \alpha}$	B_$E_{m,g}$	0.97	1.58	1.18	1.65	57.5	18.2	0.76

B = sawn beams; b = sawn boards; VI = visual inspection; M1 = model 1;
M2 = model 2

* Experimental results in phases 2 and 3; ** Models for analysis of defect influence;
*** Models using random sampling selection

4. Summary and concluding remarks

This work addresses the correlation between different size scale experimental phases with the intention of obtaining a suitable source of information for prediction of the global modulus of elasticity of structural size elements. Attention is given to the modulus of elasticity in bending given its correlation with other representative properties of timber. Different models for assembling the distribution of local moduli of elasticity are combined with visual strength grading for use in predicting the global modulus of elasticity of structural beams.

For $E_{m,g,}$ prediction, two different models were developed with correlation to the experimental values of r^2 between 0.76 to 0.78, and a multiple regression analysis indicated a larger contribution of the segments in tension for the determination of the $E_{m,g}$ of beams. Combination of the values for segments classified as class I (samples without significant macro defects) and of the percentage of the other classes in a given element led to higher correlations between predicted and experimental values when compared with the model that disregarded the influence of defects (r^2 increases from 0.66 to 0.82).

The main contribution of this work, evidenced by random sampling selection, is the demonstration that it is feasible to predict the behavior of a full size scale element by definition of the mechanical properties of selected segments and visual inspection with strong correlations (r^2 ranging between 0.70 to 0.79), thus minimizing the destructive component of the mechanical characterization related to the extraction of specimens from the timber members. Also, as in machine stress grading (see EN 14081-1:2005), MOE is commonly used as an indicator to allocate a strength class to single timber elements, an accurate prediction of its value is essential to avoid overestimation, which can lead to unsafe structural assessments, and underestimation, which can lead to a waste of resources. In this scope, the presented methodology provides a detailed definition of the variation of MOE along the element length and allows to predict the global stiffness of the element. In combination with UNI 11119:2004, a more accurate strength grading is possible, as values of MOE of clear wood sections are mechanically obtained and sections with defects are downgraded regarding the visual inspection results. The mean percentage error found for all models are lower than 20%, with exception of the model that considers only the mean value of segments with class I. In random sampling selection, although higher correlations are found for the models that consider only a sample of class I and reduction factors between visual inspection classes, also higher mean percentage errors are found, compared with the models that assume random sampling for all classes.

The models adopted for the prediction of the global stiffness of an element, in this work, were calibrated by the results obtained in a specific experimental campaign. Although the methodology may be adapted to different samples, the correlations presented are related to the results of this experimental campaign.

The proposed methodology may be applicable to practical cases, where the extraction of small specimens is possible and a detailed visual grading is considered. However, further research is needed to determine the reduction coefficients between different visual grades and between different size scales.

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