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Assessment on Strength and Stiffness Properties of Aged Structural Timber

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Abstract

Despite the growing popularity of wood and wood-based products in the construction industry, there has been insufficient focus on assessing the condition, preservation, and potential reuse of existing timber. While numerous standards evaluate the quality of freshly sawn timber, there is currently no standardized system for assessing the strength properties of aged and reused timber. The lack of these guidelines is also one of the reasons the results obtained in numerous research are often fluctuating, and we cannot draw clear conclusions. The matter is further complicated by the lack of data on old in-situ wood and its exploitation, which would help to evaluate its condition. Consequently, there is a real practical need to assess the condition of old timber to avoid unnecessary demolition and the loss of valuable and structurally sound building material.

What sets this study apart from others is that, in addition to destructive testing, the 4-point non-destructive (ND) bending tests were conducted on all four faces of test specimens. This provided an opportunity to assess the wood visually and then find connections to associate external characteristics with real properties. This methodology aimed to determine whether it is feasible to visually assess the most practical way to use wooden elements in construction. If this question arises, which face of the beam would be better suited for the tension side and which for the compression side? The old timber used in testing originated from an old library building located on Vaksali Street, Tartu, Estonia and is estimated to be about 120 years old.

This paper investigates and compares the collected data with a Nordic standard for grading fresh-sawn timber and two established Italian standards for visually assessing aged timber. This comparison contributes to developing a standardized framework for future visual assessments. ND and destructive four-point bending tests were performed to validate and find appropriate visual characteristics to determine the strength and stiffness of the timber elements. The primary goals of this study were first to compare the results obtained from existing ND methods with actual results and secondly to provide guidelines for better visual grading of wood in the future, based on Nordic Standard INSTA 142 (2010) and Italian standards UNI 11119 (2004) and UNI 11035 (2010)

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Contrary to previous research conclusions, the visual assessment results yielded unexpected outcomes. The results show that the grading standards significantly underestimated the real strength of the wood, and even more, none of the visual assessments overestimated the real strength of the specimens. Therefore, based on prior research and the findings derived from this study, there is evident a substantial potential for extensive development and optimization within this field.

Keywords: structural timber; visual grading; in-situ assessment; MoE; bending strength.

Introduction

Timber has been used for construction for centuries, making it an old but renewable natural resource. However, in light of increasing competition with other structural materials and striving for eco-friendliness, it is crucial to have a comprehensive understanding of the varying structure and properties of wood and their influence on performance expectations and long-term usage suitability. Timber, a growing trend among architects and civil engineers, is a versatile and valuable material with many excellent properties that make it highly desirable for construction projects. Since wood is a heterogeneous mixture, visually grading it is a challenging task to handle. Although reusing materials, conserving existing buildings, and reducing carbon footprints have been debated for quite some time, we still do not have a comprehensive joint set of guidelines to help grade existing wood.

This study aimed first to compare the outcomes derived from existing non-destructive methods with the results from visual assessment and secondly establish recommendations for improved visual grading of wood in the future. The assessment was conducted based on the Nordic Standard INSTA 142 (2010), along with the Italian standards UNI 11119 (2004) and UNI 11035 (2010).

Arriaga et al., 2022 and Piazza et al., 2008 have examined the mechanical properties of wood over time, both in small-scale specimens and larger structural timber, with a particular focus on the potential for circular use of wood. However, the results of these studies are not always in agreement due to the complex nature of the influence of various factors on the properties of the wood, such as the duration of the load and the original condition. Arriaga et al., 2022 conducted research that studied the inadequacies of grading existing in-situ timber using standards designed for grading new timber. Their study found that such standards often led to high rejection rates. Specifically, the researchers observed that certain effects, such as distortion and fissures, were more prevalent in large, old cross-sections but were prohibited in grading new timber. However, these effects had a relatively insignificant impact on the mechanical properties of the timber. Moreover, one requirement that cannot be met in most cases with old structures is accessibility, meaning that the structures already in place were often inaccessible from all four faces of the pieces, further complicating the grading process. Another trouble was the lack of specific characteristics of historic structures that made the predictions unreliable. As part of their study, Arriaga et al., 2022 measured the defects using the Spanish visual grading standard UNE 56544 and discovered that by applying all the requirements envisaged, the grading resulted in an 84% rejection rate. As such, the researchers concluded that standards for grading new timber were ineffective for assessing in-situ structures.

Piazza et al., 2008 researched assessing the strength and stiffness of timber in in-situ structures using non-destructive testing (NDT) and visual strength grading. One of the main objectives of the study was to compare the visual assessment results obtained using two different standards, UNI 11119 (2004) and UNI 11035 (2010). The research highlighted that knots are considered the most severe among all natural defects in wood. This is because knots can significantly impact the strength and stiffness of the timber and affect the behaviour of the structure as a whole. However, the study also found that knots alone are not reliable predictors of strength since the correlation between knot size and strength varies with species and the way in which their effect on strength was evaluated. Research further revealed that when in-situ wood was assessed, compromises could be made as the position of defects along and across the element could be considered with reference to the acting stresses. For instance, knots located in the tension zone significantly reduce the bending strength, while in compression, the presence of sound and tight knots can increase the hardness and shear strength of the wood. In such cases, the knots behave like pegs, providing additional support. The study found that visual grading generally underestimates the actual stiffness of the material. Furthermore, the research revealed that the visual grading according to UNI 11119 (2004) underestimated results more and had a lower correlation coefficient between true strength and predicted than the visual grading done according to UNI 11035 (2010).

The UNI 11119 (2004) is an established Italian national grading standard that sets forth objectives, procedures, and requirements for diagnosing the state of conservation and estimating the strength and stiffness of in-situ wooden elements in load-bearing structures of buildings included in cultural heritage. This standard involves performing inspections on site and using ND techniques and methodologies. UNI 11119 applies to numerous wood species and specifies admissible exceptions to the procedures envisaged in now withdrawn EN 518 (1995) that is replaced by EN 14081 (2019) to make it applicable to in-situ wooden elements. Certain criteria and rules indicated in **Table 1** below are used to classify the wooden elements to divide the test samples into categories based on specific characteristics. After determining the class and species of the wooden element, **Table 2** determines the maximum allowable stresses and the modulus of bending elasticity. The tables above provided in this chapter only pertain to spruce, as it is the only wood species tested in this particular study.

Another standard mentioned in the Piazza et al., 2008 is also an Italian grading standard called UNI 11035 (2010) that identifies the most common types of structural timber and indicates the rules to be

Table 1

Classification rules for wooden structural in-situ elements (translated form UNI 11119 (2004))

Characteristics		Category in work		
		I	II	III
Wane		≤1/8	≤1/5	≤1/3
Various injuries Frost cracks Ring shake		Absent	Absent	Eligible, provided in limited extent
Single knots		≤1/5 ≤ 50 mm	≤1/3 ≤ 70 mm	≤1/2
Group of knots		≤2/5	≤2/3	≤3/4
Slope of grain (%)	In radial section	≤1/14	≤1/8	≤1/5
	In tangential section	≤1/10	≤1/5	≤1/3
Radial shrinkage cracks	Eligible, provided they do not pass			

Table 2

Maximum allowable stresses and mean modulus of bending elasticity (MoE) for structural in-situ elements

Maximum allowable stresses (N/mm^2)							
Species	Category in work	Compression		Static bending	Tension parallel to the grain	Shear parallel to the grain	Bending MoE
		Parallel to grain	Perpendicular to grain				
Spruce (*Picea abies Karst.*)	I	10	2,0	11	11	1,0	12 500
	II	8	2,0	9	9	0,9	11 500
	III	6	2,0	7	6	0,8	10 500
The maximum allowable tensile stress perpendicular to the grain is conventionally assumed to be equal to zero.							

adopted to carry out the visual classification to pertain strength and stiffness characteristics according to EN 338 (2016). Its requirements apply to types of new timber for structural use. This standard can also be applied to old, in-situ wooden elements, provided all of the following conditions are met: the element must belong to one of the types of wood envisaged in this standard, the visibility and accessibility of the element must be extended to at least three longitudinal faces and one transversal. The characteristic strength values used in this study are shown in **Table 3**. The table only pertains to the values for spruce (group conifers 1) since it is the only wood species tested in this research.

The two standards mentioned above, UNI 11119 (2004) and UNI 11035 (2010), have several distinct differences. To begin with, UNI 11035 (2010) is primarily designed for evaluating new wood, but it can also be used for assessing old wood as long as it is not covered under the assessment of UNI 11119. This distinction arises from the fact that UNI 11119 (2004) is explicitly created to evaluate old load-bearing structures of buildings that fall within the scope of cultural heritage. Consequently, UNI 11035 (2010) can be used to assess old timber that is not considered part of the heritage protection framework. Another notable difference is that UNI 11035 has a more extensive set of criteria, which requires at least three longitudinal faces and one transverse face of the wooden element to be visible for grading. On the other hand, UNI 11119 (2004) also necessitates three longitudinal faces to be shown but with the possibility of having fewer faces displayed, as long as stated in the grading report, and it does not mandate the display of transversal faces. Another difference between the two standards is that UNI 11035 (2010) provides characteristic strength, stiffness, and density values, which are fifth-percentile values, whereas UNI 11119 (2004) offers allowable stress values. The grades referring to the two codes can be compared with the help of the following equation (1):

Table 3

Strength and stiffness characteristics from UNI 11035 (2010)

Properties		Spruce		
Characteristic values for the types of wood considered in standard EN 338		-	C24	C18
Resistant categories		S1	S2	S3
Bending (5- percentile), N/mm^2	$f_{m,k}$		25	18
Modulus of elasticity (MoE) parallel to grain (medium), kN/mm^2	$E_{0,mean}$		11.8	10.5
Modulus of elasticity (MoE) parallel to grain (5-percentile), kN/mm^2	$E_{0,05}$		7.9	7.0
Density (average), kg/m^3	ρ_{mean}		450	450

$$\sigma_A = f_k \frac{k_{mod}}{1{,}5\gamma_M} \tag{1}$$

Where: σ_A - allowable stress [N/mm^2], f_k - 5 - percentile characteristic value of strength [N/mm^2], k_{mod} - modification factor used in EN 1995-1-1 (2005), γ_M - partial factor for the material property (1.3 as proposed in Eurocode 5).

The Nordic visual strength grading rules for timber, also known as INSTA 142 (2010), is a standardized grading system used in Denmark, Finland, Iceland, Norway, and Sweden for coniferous wood. The grading rules are specifically designed for timber sourced from northern and northeastern Europe. The primary purpose of INSTA 142 (2010) is to provide a systematic method for assessing the strength and quality of the timber based on three main types of observations. These include identifying strength-reducing features such as knots, the size and shape of the wood, and any biological attack present on the wood. (Lycken et al., 2020) The sorting classes are named according to decreasing strength T3, T2, T1, and T0 and vary between coniferous species (INSTA 142, 2010).

Methods

The old timber used in the tests originated from an old library building located on Vaksali Street, Tartu, Estonia and is estimated to be approximately 120 years old (Parts, 2017). There were a total of 19 specimens tested in this research, which were divided into two groups: 15 with smaller cross-sections (CS) (~100x100mm) and 4 with larger CS (~180x180mm). Before performing visual assessments and NDT, two random samples from each group were selected for destructive testing. This objective was to ascertain the amount of force equivalent to 40% of the maximum allowable limit when conducting NDT. The distribution is shown in **Table 4**.

Table 4
Distribution of specimens

	Smaller CS	Larger CS
Selected for destructive testing	9, 20	19, 24
Selected for visual grading and ND tests	1, 4, 5, 6, 7, 8, 10, 11, 14, 15, 16, 17, 21	22, 23

All of the specimens were photographed, given a number, and each face was marked with a letter A...D. The letter given to the beam's face indicates its location on the compression side during the 4-point bending test. Every ND bending test was performed on all four sides of the sample.

The length of each specimen was measured with a tape measure, and the CS dimensions were measured with a Vernier calliper with 1 mm accuracy. The calliper was used to measure the parallel distance (A-C and B-D) by attaching one outer jaw to the flatter face and the other jaw to where it first contacts the specimen. This method gives a marginally larger area than the actual CS area but is a convenient practice to carry out on-site. Since the width and thickness varied within a test piece, three separate dimensions were taken at different positions, and the final measurement was calculated as their arithmetic average.

To measure the moisture content, all timber samples were kept in the laboratory of Construction Test Hall of Tallinn University of Technology for two months before conducting the tests, with an average temperature of (20±2) °C and a relative humidity of (45±5)%. After the bending test was completed, a section free of resin bark and knots from the end of the beam was cut to determine the moisture content and density of the whole beam. The moisture samples were then immediately weighted using an electronic scale with a resolution of ±0.1 g and placed in a ventilated oven at (103±2) °C until the mass remained constant within 0.1% in 2 h according to EVS-EN 408 (2012) and EVS-EN 13183 (2002). The test slices were then removed from the oven and again weighted.

The standard EVS-EN 408 (2012) was used to measure the global and local modulus of elasticity (MoE) in bending. All beams had a minimum length of 19±3 times the depth of the section. Small steel plates with widths of 50 and 100 mm were inserted between the beam and the loading heads and between the beam and the supports for smaller CS-s and larger CS beams, respectively. They were placed to minimize local indentation. The initial $F_{max,est}$ for the ND bending tests was determined to be 8 kN for the beams with a smaller CS and 30 kN for a large CS. The tests were carried out with an Enerpac P80 hydraulic hand pump and an Enerpac hydraulic cylinder RC506 with a capacity of 50 t.

Initially, three gauges were installed to measure deformation and calculate the local modulus of elasticity. However, upon analyzing the data, it was determined that only the middle gauge would be used moving forward. This decision was based on the fact that the old timber used was twisted, causing the gauges to shift during the application of the load, but without a bend actually occurring. This movement made it challenging to plot the load-deformation graphs accurately, as the beam would bear the load even if its loaded sides were not yet parallel to the supports, resulting in illogical deformations. The test setup is presented in **Fig. 1**.

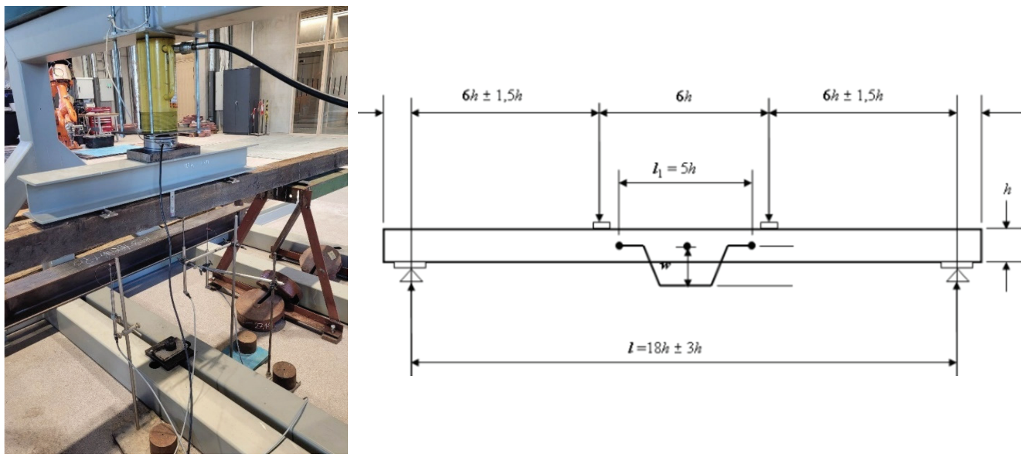

Fig. 1

Four-point bending test setup

The slope of grain (SoG) was measured using the method described in DIN 4074 (2012), as shown in **Fig. 2**, using the following equation:

$$F = \frac{x}{y} * 100 \tag{2}$$

Where: x – the deviation of the shrinkage crack [mm], y – crack projection length [mm].

SoG refers to the deviation of wood fibres from a line parallel to one edge of the sawn timber. When considering the overall characteristics of wood, the primary factors contributing to mechanical properties variation are typically SoG and wood density. (Mania et al., 2020)

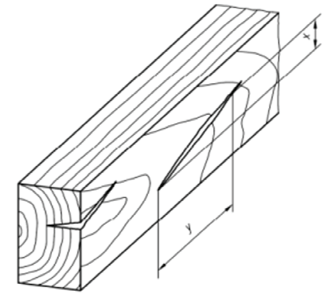

Fig. 2

Determination of SoG according to shrinkage cracks (x and y are shown in Equation **2**)

Another defect to be measured was distortion. The study aimed to measure three types of distortion shown in **Fig. 3** - bow, crook, and twist. Cup deformation could not be measured, nor was it necessary because the standards for visual grading used in the study did not provide any limitations to cup size, and the test specimens were square in shape rather than board-shaped, so cupping was not prevalent.

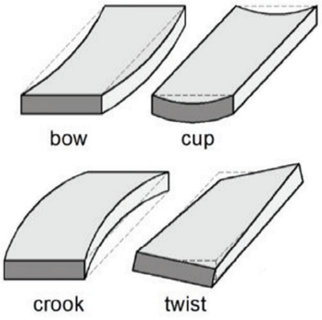

Fig. 3

Definition of distortion modes

To measure bow and crook, sides A-C and B-D (see **Fig. 4**) of the specimen were chosen, respectively. The distortions were measured according to EN 1309 (2018). To measure twisting, the specimens were placed on a flat and even surface with one end of the beam tightly held against the surface, and the distance of the raised end from the plane was measured. Although this method may not give the most accurate results, it provides a more conservative result in favour of backing up. However, it is not possible to measure the raise of only one corner when dealing with old timber anyway, as both bows and twists co-occur in such cases.

A total of 15 specimens were analyzed, but according to all standards (INSTA 142 (2010), UNI 11119 (2004) and UNI 11035 (2010)), samples number 1 and 21 were deemed unsuitable for further analysis due to exceeding wane proportions, insect damage (see **Fig. 4**) and curly grain (see **Fig. 5**). Although UNI 11119 (2004) allows for specimens with localized insect damage to be considered if degraded areas are excluded from the effective section, this was not possible in the current situation.

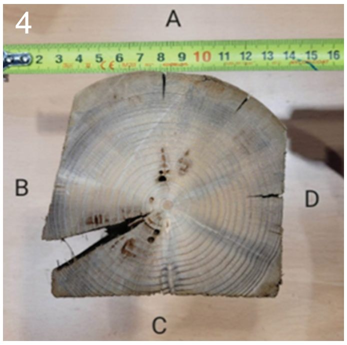

Fig. 4

Specimen 1 CS with visible insect damage

Fig. 5

Specimen 21B with visible curly grain

Results

The results of visual grading are presented in **Tables 5**, **6**, and **7**.

Based on the data in **Table 5**, it can be inferred that the test specimens have been visually assessed to be in good condition. The table reflects design values, which, before applying partial safety factors common for sawn wood, using **Eq. 1**, allows specimens to be graded to strength classes according to EVS-EN 338 (2016). Most specimens fall into the first or second category, indicating that their bending strength should be at least f_d=9 N/mm^2. This classification places more than half of the specimens in the strength class C18, while the remainder are in the C24 class or higher. Only one test specimen (nr 6) has been rated in the third category, leading to its classification as belonging to the C16 class. Such a high percentage of test specimens belonging to the C18 and higher strength classes suggests that reusing the material is a favourable option, given that higher strength classes are indicative of higher quality materials.

Table 6 shows how the specimens have been categorized according to the UNI 11035 (2010). Compared to UNI 11119 (2004), several additional parameters were included for analysis, but still, following the guidelines of UNI 11035 (2010), the results remained very similar to the former one. In the UNI 11035 grading system, the strength classes distributed according to the EVS-EN 338 are already given, so they do not need to be calculated from design values. In terms of categorization, the results are closely resembling those obtained from UNI 11119 (2004), with five specimens ap-

Table 5

Results of visual assessment according to the UNI 11119 (2004)

Category	Number of specimens	Maximum allowable stresses (N/mm^2)					
		Compression		Bending strength	Tension parallel to the grain	Shear parallel to the grain	Bending MoE
		Parallel to grain	Perpendicular to grain				
I	5	10	2,0	11	11	1,0	12 500
II	7	8	2,0	9	9	0,9	11 500
III	1	6	2,0	7	6	0,8	10 500
Not graded	2	-					

Table 6

Results of visual assessment according to the UNI 11035 (2010) standard

Category	Number of specimens	Class
S1	5	-
S2	7	C24
S3	1	C18
Not graded	2	-

Table 7

Results of visual assessment according to the INSTA 142 (2010)

Category	Number of specimens	Class
T3	5	C03
T2	7	C24
T1	1	C18
T0	0	C14
Not graded	2	-

pointed to the highest category, 7 to the second and 1 to the third. In terms of characteristics, the grading by UNI 11035 (2010) goes a step further, placing more than half of the specimens in the strength class C24, while the remainder have at least C24 or better properties. Only one test specimen has been rated in the third category, which leads to its classification as belonging to the C18 class.

To determine the validity of statements in the literature suggesting that the assessment standards designed for new wood may not be applicable to evaluate old wood, comparing the results obtained with one of the standards specifically devised for new wood became relevant. As seen in **Table 7,** the results are similar to the previous ones. One of the main differences with applying criteria given in INSTA 142 (2010) is that, for instance, knots are distinguished by their location on situating either on the flatter face or edge face of the sample, and it also sets special criteria for squared CS timber. Additionally, the group of knots is not measured in the same way as in UNI 11119 (2004) and UNI 11035 (2010) but rather taken into account as the largest knot dimension equal to the sum of the largest permitted flat side knot and the largest permitted edge side knot. For square timber, the same parameter is explained as the largest knot size not greater than four times the size of the largest permitted single knot. This approach makes the assessment of a group of knots more sparing than in UNI 11119 (2004) and UNI 11035 (2010). One additional difference, which was not drawn out in this work but can likely happen in the case of a larger sample, is the categorization according to the width of annual rings, which is strictly more limited in INSTA 142 (2010).

It was essential to determine the moisture content of the samples to allow comparison at a later stage. The results of these measurements are displayed in **Fig. 6** and **Fig. 7**.

The density of wood was determined with a moisture content of 12% based on EVS-EN 338. Since the density was determined prior to the failure of the test, the density of each sample was divided by 1,05 (for softwoods) according to EVS-EN 384 (2022). The following histograms, **Fig. 8** and **Fig. 9**, illustrate that the frequencies of the test specimens' densities vary significantly.

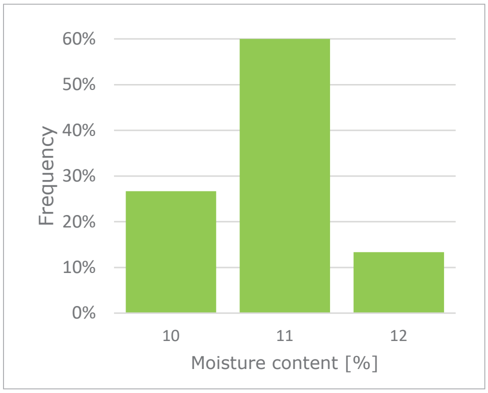

Fig. 6

Frequency diagram of MC for beams with smaller CS (~100x100 mm)

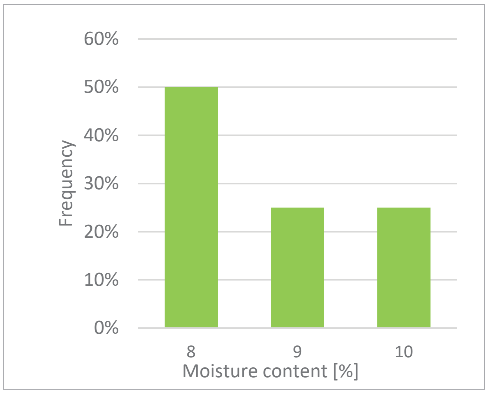

Fig. 7

Frequency diagram of MC for beams with larger CS (~180x180 mm)

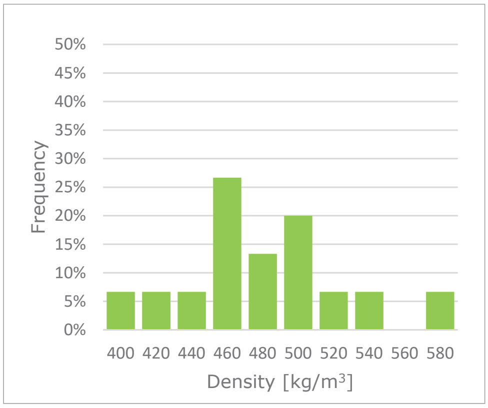

Fig. 8

Frequency diagram of density for beams with smaller CS (~100x100 mm)

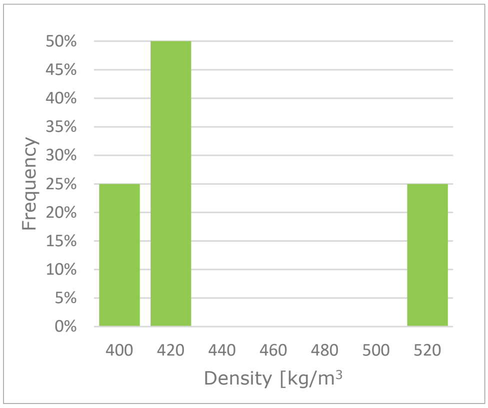

Fig. 9

Frequency diagram of density for beams with larger CS (~180x180 mm)

The global bending modulus of elasticity obtained from the ND bending test has been adjusted to the static modulus of elasticity corresponding to the 12% moisture content. **Fig. 10** shows the smallest MoE_{stat} values obtained from the 4-point bending test carried out on beams with smaller CS dimensions. In the case of beams with a larger CS, the histogram of the static modulus of elasticity is not presented due to the small number of test specimens. The results for larger CS-s were MoE_{stat}=39 834 N/mm^2 for specimen 22 and MoE_{stat}=17 964 N/mm^2 for specimen 23.

Again, the results are highly variable, ranging from 8 000 N/mm^2 up to 17 000 N/mm^2, making it difficult to conclude. Only a value of 10 000 N/mm^2 appears to be more prevalent than others, indicating that the distribution of modulus of elasticity values may be approaching a normal distribution. However, since the specimens' cross-sectional dimensions and moisture contents were very similar, it suggests that the value of elastic modulus in addition to MC may be more influenced by factors such as the material composition, exploitation, and different types of defects such as knots, SoG and degradation.

The results of the semi-destructive bending test on each face are presented in **Fig. 11** with the addition of the average value and the E_0 values of sawn coniferous wood corresponding to strength classes C18 and C24 of EVS-EN 338. Based on the data provided, it is evident that a prominent trend emerges in eight of the test specimens, representing 73% of the sample of smaller CS. This trend suggests that the position of the test specimen, specifically the location of the sides in relation to the tension and compression zone, is a critical factor in determining its strength

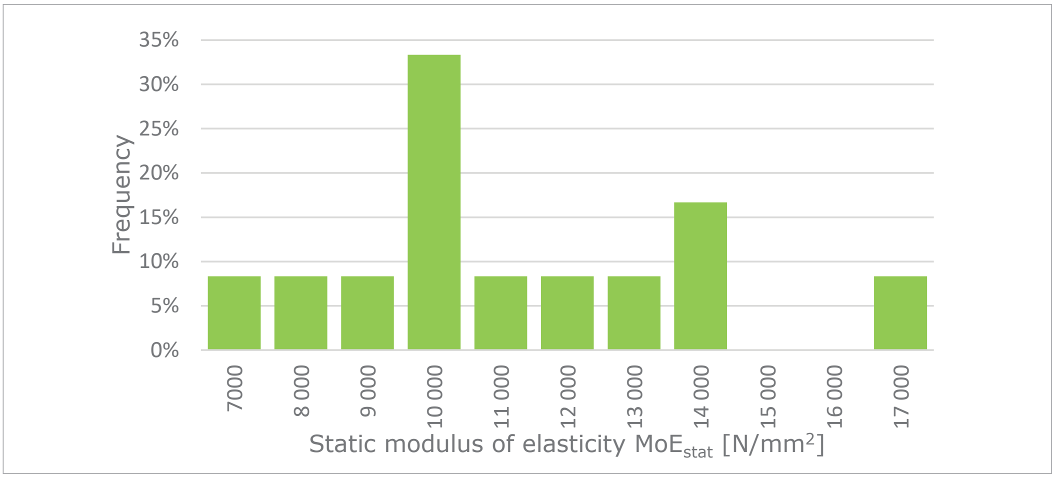

Fig. 10

Frequency diagram of static modulus of elasticity for beams with smaller CS (~100x100 mm)

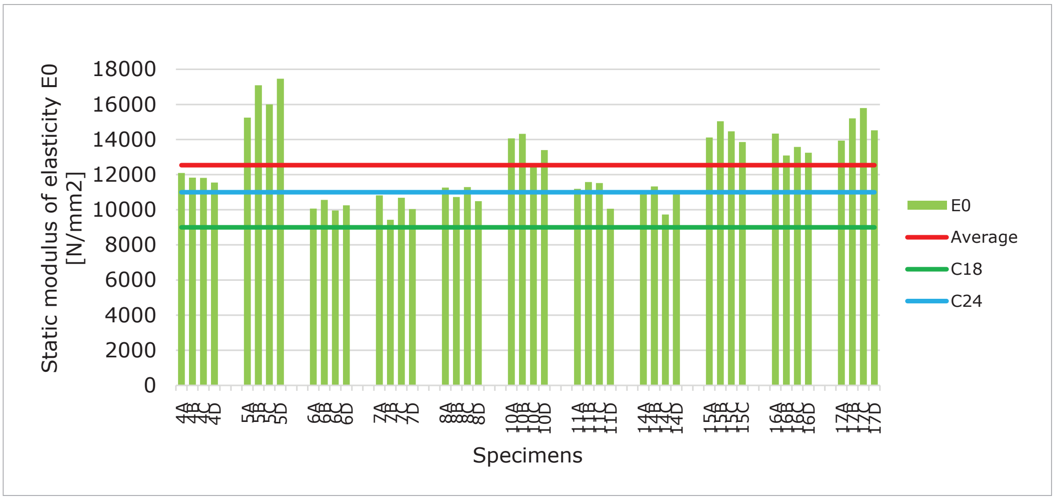

Fig. 11

Bending MoEstat of smaller CS specimens of each face characteristics. Although the graph shows noticeable fluctuations in the data, the variability is counterbalanced by test specimens that produce nearly identical results from all faces, resulting in a fluctuation averaging at only 5,3% across the entire sample. However, it can be inferred that the orientation of the grain in the specimen can also influence its behaviour under load.

The histogram presented in **Fig. 12** displays the bending strength values obtained from the destructive bending test of the test specimens. The faces for DT were chosen according to the previous bending tests, based on which the test pieces were fractured according to the face with the lowest stiffness. The histogram (see **Fig. 11**) reveals that the most frequent bending strength values are slightly lower than the high average value of 50 N/mm^2. The reason for the high average value is attributed to two specific test specimens (5 and 10), which demonstrated exceptionally high bending strength values of 77 N/mm^2 and 79 N/mm^2, respectively. The bending strength results of specimens with the larger CS-s were 55 N/mm^2 for specimen 22 and 28 N/mm^2 for specimen number 23.

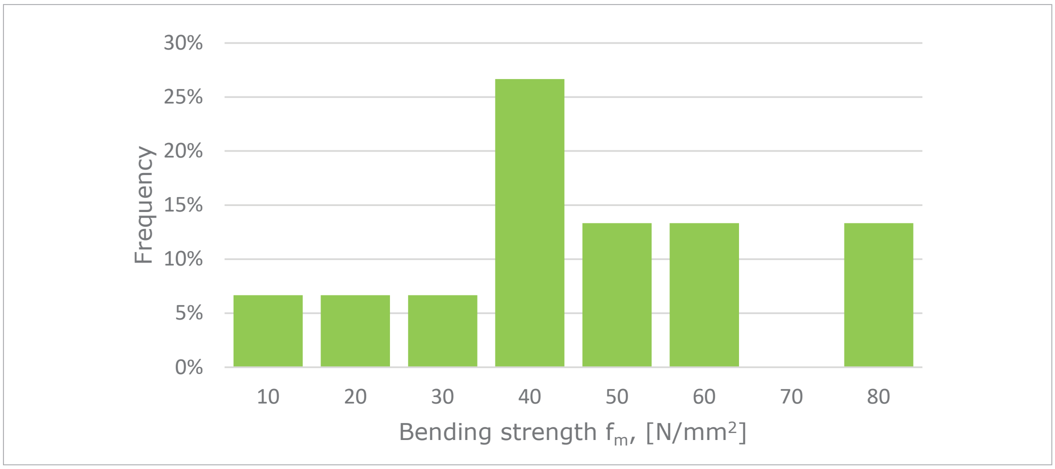

Fig. 12

Frequency diagram of bending strength values for beams with smaller CS-s

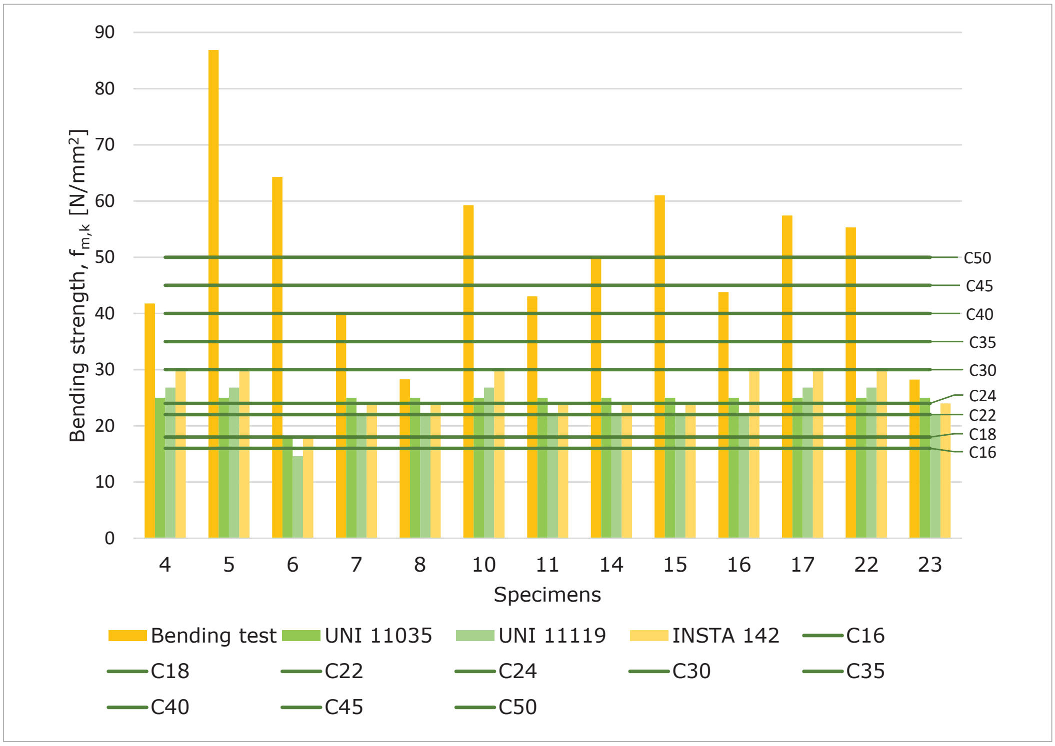

Fig. 13

Comparison of test and visual grading results

Discussion

The visual assessment process involved an examination of 15 specimens, with the aim of categorizing them based on visual characteristics. Notably, individual knots were found to have the most pronounced impact on visual categorization, surpassing the influence of knot groups. It is important to note that knots are considered a group only if the surrounding grain is visibly disrupted. Consistent with the findings of numerous previous studies, it was apparent that knots held great significance in the categorization of the specimens, accounting for a substantial 87% of the cases. The other 13% encompassed different contributing factors, with 7% attributed to wanes and/or insect damage, while the remaining 7% were influenced by curly grain and exceeded the limitations set by the SoG. Knot groups were observed in only 8% of the cases among the test specimens investigated in this research. While they contributed to the categorization process, they never emerged as the determining factor due to the presence of a dominant single large knot on the same face of the test specimen, which invariably played the decisive role.

Fig. 13 very effectively illustrates the notable variability between the results obtained from actual bending tests and those derived from visual evaluation using different standards. The dark yellow bars in the graph visibly surpass the other bars and even surpass the results of the C24 strength class. This observation further emphasizes the notable difference between the visual evaluation standards and the real strength of the tested wood. A noticeable disparity becomes apparent when comparing the visual strength sorting results with the strength classes obtained by the bending test. While the visual strength sorting categorizes the wood into the highest class of C30, the bending test reveals a significantly higher strength class for 46% of the sample- C50.

The exceptionally positive outcomes achieved in this study can be partly attributed to the seemingly high quality of the original timber, which exhibited favorable results in visual evaluation, not to mention destructive tests. Looking ahead, it remains reasonable to establish a distinct unified system for assessing old wood, particularly in cases where the condition of specimens significantly differs from those examined in this study, rendering the existing standard for new wood less applicable. In this regard, the authors of this study believe that the Italian UNI 11119 (2004) standard provides the most suitable foundation to assess old wood visually. This is for several reasons:

1. Of the three standards considered, UNI 11119 (2004) stood out as the one with the fewest number of parameters to evaluate. This streamlined approach allowed for faster assessment compared to the other standards.
2. UNI 11119 (2004) enables the evaluation of test specimens from three faces or less if stated in the report. Additionally, it does not require the visibility of transverse faces. As elements within a structure are frequently inaccessible from all sides, this standard is the most practical for in-situ assessment.
3. By employing a minimal number of parameters, this standard focuses solely on factors with the most significant impact. It omits measurements of deformations that, as demonstrated in this study, have no decisive influence on class determination or correlation with actual strength. In contrast to the INSTA 142 (2010) and UNI 11035 (2010), which involve time-consuming measurements of various distortions, this standard prioritizes practicality by disregarding non-essential criteria.

We propose several improvements to address the shortcomings of the UNI 11119 (2004) to make visual evaluation more precise and user-friendly in the future. The suggested propositions are as follows:

1. Addition of exclusions. Keep all the parameters reflected in UNI 11119 (2004) but add the possibility of excluding specimens according to different knot locations and fibre deformations. In the example of this work, the weakest specimen was the one with curly grain, the presence of which was not explicitly limited in the standard. In the future, it would be advisable to exclude test specimens with such fibre deformations immediately.

2. Conversion of results. Instead of presenting allowable stresses as a result of categorization, the standard should provide the strength classes stated in EN 338 to create a more unified system.
3. Addition of strength classes. In order to improve the accuracy of the visual assessment process, it is essential to add more classification categories according to EN 338, enabling elements to be placed in a wider variety of strength classes, similar to INSTA 142 (2010), rather than limiting them solely to C16, C18 and C24 as indicated in the Italian standards utilized in this research. This approach would help prevent both over- and underestimation of element strength.
4. Graphic content. For the descriptions of various defects to be unambiguous, it is necessary to add visual material in the form of photos and figures to the standard. This also has the potential to help speed up the grading process.

We also recommend using the UNI 11119 (2004) as a basis for grading aged timber in Northern Europe, while proposing specific adjustments to the classification values. This recommendation stems from the observation that wood grown in Northern Europe appears to exhibit notably superior properties compared to wood grown in regions like Southern Europe. Hence, further research and testing are important to establish categories that accurately correspond to the characteristics of wood from the Nordic region.

Conclusion

The average bending strength of the sample, including values of the two specimens visually graded further unusable, was 44 N/mm^2. Excluding this data, the average bending strength increased to 50 N/mm^2. All beams given a visual assessment grade exceeded the thresholds for the C24 strength class, 46%, even exceeding the indicators of the C50 class. The static modulus of elasticity of the square test pieces varied between 0-11% depending on the face, with an average result of 5,3%. This implies that the slight advantage gained by placing the strongest side of the specimen in the tensile zone is relatively insignificant. Furthermore, no correlations could be established upon comparing the static modulus of elasticity with the results obtained through visual inspection.

Contrary to previous research conclusions, the visual assessment results yielded unexpected outcomes. Previous studies suggested that visual evaluation standards designed for new wood result in a high rejection rate for old wood, making it an impractical approach. However, the Nordic standard for new wood exhibited the lowest error percentage, underestimating the strength of the elements by an average of 48%. In contrast, the UNI 11035 (2010) and UNI 11119 (2004) had higher error percentages, underestimating the strength by 50% and 54%, respectively. When considering the most crucial defects, the findings of this study are consistent with those in the existing literature. Specifically, singular knots were identified as the determining factor in approximately 87% of cases when categorizing the specimens.

A significant drawback is the limitat ion in visually sorting timber beyond the C30 class INSTA 142 (2010) and up to the C24 class according to UNI 11035 (2010) and UNI 11119 (2004). While this prevents structurally hazardous situations, it results in constant over-dimensioning of elements, leading to economic repercussions and increased wood consumption, which hampers environmental sustainability. While this study shows promising findings for reusing old timber and extending its lifespan, drawing firm conclusions based on a small sample size would be premature. More research is needed to validate these results and assess the reliability of visual evaluation as the sole tool. Currently, additional evaluation methodologies are recommended to ensure more reliable conclusions. Furthermore, investigating the impact of different types of knots, wood fibre defects, and the position of wood pith within the cross-section on element characteristics is essential for a better comprehensive understanding of the subject matter.

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