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Structural potential of reclaimed and local timber as new resources in The Netherlands

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ABSTRACT: The paper presents the results of a study aiming at an initial evaluation of the potential of two wood species grown within The Netherlands, as well as the potential of reclaimed material from Dutch deconstruction sites. A total of 28 pieces of Douglas-Fir, 49 pieces of Larch and 32 pieces of reclaimed spruce were first visually graded based on Dutch and German standards. Afterwards, the specimen were evaluated using stress wave and X-ray machine grading methods. Finally, the actual properties of the specimens were determined using four-point bending tests. The density, stiffness and strength results from bending test were directly compared to the mechanical properties assigned by visual grading to evaluate if appropriate grades were assigned. Furthermore, the bending test results were compared to the results from machine grading. The comparison showed good agreement with respect to stiffness and strength, while overestimations by the machine grading methods were noticeable.

1 INTRODUCTION

Within The Netherlands, the term traditional construction methods refers to methods related to masonry, steel and concrete with timber not being considered traditional. While timber was a commonly used material for construction in The Netherlands in the past, the arrival of new materials as the ones mentioned above, lead to a pause in the use of timber. Currently, timber is experiencing a return to the construction sector within The Netherlands. This return is in parts driven by new regulations addressing emission goals (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, Ministerie van Infrastructuur en Waterstaat, Ministerie van Landbouw, Natuur en Voedselkwaliteit, Ministerie van Economische Zaken en Klimaat, 2023; United Nations, 2024), as well as customers decision to use bio-based materials. Generally, wood is considered a carbon-neutral material as it stores carbon dioxide (CO_2) during its growing phase. Additional energy that is invested in wood as a construction material are related to the initial planting, the harvest, drying, processing, and transport. While some of the mentioned contributions require technological advances in order to reduce the associated emissions, transport related emissions can be reduced simply by reducing transport distances. Currently, the majority of wood and wood-products used in the Dutch construction sector are imported from within Europe. In order to reduce transport emissions, wood resources from within The Netherlands are desirable. Potential resources can be found in the local forest stock and reclaimed wood that is freed-up during deconstruction and renovation efforts. Currently, the majority of wood sourced within The Netherlands is used for the generation of energy, thereby releasing the stored carbon. Ideally, timber, virgin and reclaimed in urban mining, can be processed and can be (re-)used, storing the captured CO_2 for (another) service-life. The use of locally sourced woods from Dutch forests would not only help with the reduction in transport related emissions, but would further create a local market. In addition, sustainable forest management is credited with various benefits, such as regeneration of species, enhancing biodiversity, creation of successional habitats of fauna, improve forest health, productivity and value, economic benefits, and climate change mitigation (Albert, 2024).

In order for these resources to be used in structural applications within the construction sector, such as beams and columns, it is necessary to determine their mechanical properties and derive property

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values that can be used within design framework. The design framework uses so-called strength classes that assign properties to wood pieces within them. The criteria to which strength class populations of wood belong varies based on the selected grading approach. One common grading approach is visual grading, in which a population of wood is evaluated based on visual features, such as knot size, cracks, slope of grain, growth rate, as well as its density (NEN Nederlands Normalisatie Instituut, 2007; DIN Deutsches Institut für Normung, 2012). This type of grading rules have been established for different growth areas all over the world and have been in use for a long time. The basis for the association of visual features to mechanical properties is established through relationships from mechanical. While the different grading rules generally use similar visual features for their classification, differences in the used criteria can be found between them. Therefore, different visual grading rules exist that are applicable to different harvest areas. Besides visual grading, grading can be undertaken using material property measurements. A commonly used mechanical property that is measured is the modulus of elasticity (*MoE*). The *MoE* can be relatively easy be measured in in-line processes using bending or stress wave measurements (MiCROTEC). Relationships are established between a measurable value, such as *MoE*, and mechanical properties that either require more effort to measure or can only be obtained using destructive methods, such as strength values. These relationships are established through data from mechanical testing. Naturally, new resources require the determination of these relationships between measurable properties, visual or mechanical, and properties that are needed in design, such as the ones presented in EN 338 (CEN European Committee for Standardization, 2003).

With respect to reclaimed wood, while the material has potentially previously been graded, the initially assigned grade might not be appropriate anymore after unknown exposure to environmental and loading conditions. Cavalli et al. (Cavalli, et al., 2016) summarized results from comparisons of the *MoE* and bending strength values of reclaimed timber. Figure 1 is generated from the results presented by Cavalli et al. and shows their results with (a) bending stiffness (*MoE*) and (b) bending strength (f_m). For larger specimens (highlighted in green) and the construction timber (highlighted in red), the stiffness was evaluated to remain the same over time (with exception of Cai et al. (2000)), while the strength was evaluated to show reductions (with exception of Chini et al. (2001). The results indicate that derived relationships between measurable characteristics (e.g., visual features or *MoE*) and estimated properties (e.g., f_m) for commonly used virgin wood might not be directly applicable for reclaimed wood due to the loss of strength, and therefore need to be newly established. Similarly, relationships for locally harvested wood need to be established. The here presented study aims at evaluating the potential of locally sourced timber from The Netherlands as well as reclaimed structural timber. The stiffness and strength of locally sourced and reclaimed wood were evaluated using both visual and machine grading methods, thereby allowing comparison between the different grading methods and the different specimen groups. Afterwards, bending tests were utilized to evaluate the mechanical properties of the specimens. The results are used to determine their respective potential.

2 MATERIALS

Two groups of materials were evaluated, namely new locally sourced materials and recovered materials. With respect to the new material, two different species were included, namely Douglas-Fir (*Pseudotsuga menziesii*) and Larch (*Pinaceae*). For the reclaimed material (at least 50 years old), Spruce (*Picea*) was used. The Spruce was recovered floor beams of three different deconstruction sites, provided by one company. The dimensions, mass and moisture content (*MC*) of all specimens were measured and presented in Table 1, including the coefficient of variation (in brackets). Additionally, the calculated density at a *MC* of 12% (ρ_{12}) is added.

3 METHOLDOLOGY

First, the pieces were evaluated using two visual grading approaches, based on Dutch visual grading standard NEN 5499 (NEN Nederlands Normalisatie Instituut, 2007; NEN Nederlands Normalisatie Instituut, 2011) which is based on the Scandinavian grading rules DS/INSTA 142 (DS/INSTA, 2009), and the German standard DIN 4074 (DIN Deutsches Institut für Normung, 2012). The grading was

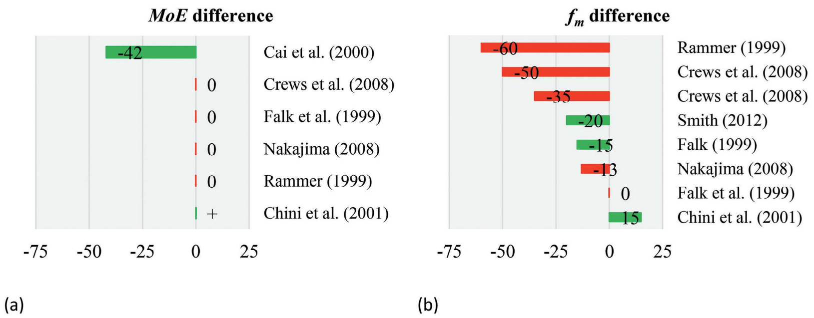


Figure 1. Percentage difference between old and new wood (a) bending stiffness MoE, (b) bending strength f_m Positive values indicate higher values for old wood. (+) and (-) indicate trends if no value is mentioned. (Based on (Cavalli, et al., 2016), large specimens (green), construction timber (red)).

Table 1. Overview of used materials and initial dimensions (with coefficient of variation).

Species [-]	Amount [-]	Length [mm]	Width [mm]	Height [mm]	*MC* [%]	ρ_{12} [kg/m^3]
Douglas-Fir	28	3306 (0.1%)	130 (0.2%)	28.2 (0.2%)	14.2 (11.8%)	511 (11.0%)
Larch	49	3305 (0.1%)	130 (0.2%)	28.1 (0.5%)	12.7 (5.6%)	498 (7.7%)
Spruce	32	3001 (0.2%)	65 (4.6%)	167.1 (3.3%)	26.2 (19.3%)	429 (10.7%)

undertaken by trained graders. Reviewing both standards, NEN 5499 and DIN 4074, showed that the two standards show similarities with respect to which criteria are considered within them, while the assessments differ in detail. The most significant difference between the standards are the strength classes. NEN 5499 uses four different T-grades, while DIN 4074 only has three different S-grades. In order to use these national grades within Europe, national grades are converted into European C-grades based on EN 1912 (CEN European Committee for Standardization, 2012) to be then used in EN 338 (CEN European Committee for Standardization, 2003). Table 2 shows the translation of the national grades into grades used in EN 338. It can be seen that the T- and S-grades generally align in C-grades of EN 338, the lowest grade within NEN 5499, namely T0 has no counterpart within DIN 4074. This means that it is likely that boards that are rejected in DIN 4074 could still be graded within NEN 5499.

After visual grading, the specimens were evaluated using stress wave analysis, namely the Mobile Timber Grade from Brookhuis (Brookhuis), which is certified for machine grading based on EN 14081-2 (CEN European Committee for Standardization, 2010). This method measures the speed of the stress wave in the wood from which the natural frequency can be derived. The *MoE* can be calculated using Equation (1).

$$MoE = \frac{(2 f_0 l)^2 \rho}{1 - 0.01(MC - 12)} 10^{-6}. \quad (1)$$

Table 2. Strength class requirements for characteristic values according to EN 338 and corresponding visual grades as given in EN 1912 for main softwood species (selected grades).

EN 338 Strength Class	Bending Strength $f_{m,k}$ [N/mm^2]	*MoE* $E_{0,mean}$ [N/mm^2]	Density ρ_k [kg/m^3]	National Strength Class NEN 5499 [-]	National Strength Class DIN 4074 [-]
C24	24	11000	350	T2	S10
C18	18	9000	320	T1	S7
C14	14	7000	290	T0	-

where f_0 is the measured frequency in Hz, l is the measured length of the wood in mm, ρ is the measured density of the wood in kg/m^3, and MC is the measured moisture content in percent. The strength can be estimated using established correlations between stiffness and strength (according to EN 338 (CEN European Committee for Standardization, 2003)).

In addition, commercially used scanning technology, namely a MiCROTEC Goldeneye scanner (MiCROTEC), was employed to determine the mechanical properties (Douglas-Fir and Larch only). The device combines X-ray with different technologies. Besides the scanner itself, the setup further included a non-contact moisture meter (MiCROTEC M3 Scan (MiCROTEC)) to correct the measurements. The technology uses the collected information about density, knot distribution, grain angle, and dimensions to derive the MoE and strength. The output from the X-ray scan provides the tensile strength (f_t), as well as the dynamic modulus of elasticity (MOE_{dyn}). Since the comparison aims at a comparison of the bending strength (f_m), the tensile strength was converted. EN 384 (CEN European Committee for Standardization, 2010) provides information about the estimation of characteristic bending strength ($f_{m,k}$) based on tensile strength ($f_{t,0,k}$). Equation (2) presents the estimation function based on EN 384.

$$f_{m,k} = 3.66 + 1.213\, f_{t,0,k}. \tag{2}$$

Lastly, static third-point bending tests based on EN 408 (CEN European Committee for Standardization, 2003) were employed to determine the actual bending strength and stiffness. In the test setup(see Figure 2) two loads were applied at the third-points of the span. The board materials, namely Douglas-Fir and Larch, were tested flat-wise, while the recovered beam materials, Spruce, were tested edge-wise. All tests were undertaken at a span-to-thickness ratio of 18. The loads were applied at a constant displacement rate (Douglas-Fir and Larch at 2 mm/min, Spruce at 5 mm/min), aiming at a failure time between six and ten minutes. The loads were recorded, while the centre-point displacement was recorded using a laser. The load and displacement data was used to determine the initial slope of the load-displacement curve, which was used to determine the apparent modulus of elasticity (MOE_{app}) . The maximum load was used to determine the bending strength (f_m). Equations (3) and (4) were applied to determine the MOE_{app} and the f_m, respectively. The determined MOE_{app} and f_m values were then corrected to adjust for height (k_h), length (k_l), moisture content, and for the fact that the test setup determined a global MOE, using equations from EN 384 (CEN European Committee for Standardization, 2010). The associated processes are here not further described.

$$MOE_{app} = \frac{23\ Fl^3}{108\ \Delta bh^3}. \tag{3}$$

$$f_m = \frac{3\ F_{max}a}{bh^2}. \tag{4}$$

where F/Δ is the linear initial slope from the load-displacement curve in N/mm, l is the span of the specimen in mm, F_{max} is the maximum load at failure in N, a is the distance from the support to the nearest load in mm, and b and h are the width and height of the specimen in mm.

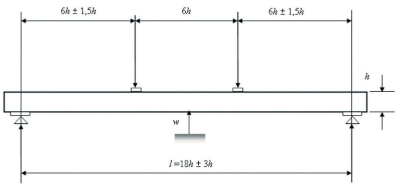


Figure 2. Test arrangement for measuring global modulus of elasticity in bending (CEN European Committee for Standardization, 2003).

4 RESULTS & DISCUSSION

Table 3 shows the amount (#) of specimen, the average density, the average *MoE*, and the average f_m within the different strength class according to NEN 5477 (NEN Nederlands Normalisatie Instituut, 2007; NEN Nederlands Normalisatie Instituut, 2011) and DIN 4074 (DIN Deutsches Institut für Normung, 2012). While NEN 5499 yielded no rejected wood, DIN 4074 rejected between 21-25% of pieces. DIN 4074 showed generally higher yield in the higher strength classes C18 and C24. In addition, the table indicates what percentage of specimen within a group did not directly meet the value stated for the corresponding strength class according to Table 2 (in brackets). It should be noted, that the strength values in EN 338 present 5th percentile values and the *MoE* values present mean values of the overall population and not a minimum requirement for individual specimen. Individual specimen can thereby have lower values (density, stiffness, and strength) than the ones given in EN 338 and still meet the strength class criteria as long as the overall population meets the criteria. Here, a direct individual comparison of the individual pieces with the EN 338 values was undertaken as populations were relatively small.

Looking at the percentages of specimen not directly meeting the values of the assigned strength grade, it becomes clear that stiffness (*MoE*) is the value causing the highest percentages, while density and strength are less critical. Furthermore, it is important to understand that this comparison is made for every piece individually and not for the whole group. The reason is the relatively low sample size and the uncertainty about the materials place of origin. Figure 3 (a) shows the bending test results for *MoE* plotted against the ratio of the bending test results to the value stated in EN 338 as shown in Table 2 (*MoE* vs. $MoE/E_{0,mean}$) for grading based on NEN 5499 and DIN 4074. Figure 3 (b) shows a similar plot for f_m (f_m vs. $f_m/f_{m,k}$). Both plots include a black dotted line indicating the boundary where specimens directly meet the EN 388 value (ratio ≥ 1.0).

A comparison of the test results from the stress wave and X-ray scanner are presented in Figure 4 and Figure 5, respectively. Both figures hold (a) a comparison of the evaluated *MoE*, and (b) the f_m. The comparison of the *MoE* results show that both machine grading methods generally group themselves close to the diagonal line which would present a perfect agreement. For the *MoE* comparisons, it can be seen that both machine gradings frequently overestimate

Table 3. Amount (#), avg. density, avg. MoE, and avg. strength (f_m) of grades according to NEN 5499 and DIN 4074, and percentage not directly meeting the associated properties according Table 2 (in brackets).

Material [-]	Class [-]	NEN 5499 #	Density [kg/m³]	*MoE* [N/mm²]	f_m [N/mm²]	DIN 4074 #	Density [kg/m³]	*MoE* [N/mm²]	f_m [N/mm²]
Douglas-Fir	Reject	-	-	-	-	6	490	7468	31.0
	C14	17	498	9478 (12%)	33.4	-	-	-	-
	C18	8	529	12939	48.7	15	512	11503 (20%)	39.2
	C24	3	543	14912	53.5	7	526	13147 (29%)	49.0
Larch	Reject	-	-	-	-	12	490	9758	33.6
	C14	36	492	10458 (3%)	37.1	-	-	-	-
	C18	12	515	11704	38.4	29	496	10966 (24%)	39.2
	C24	1	490	5942 (100%)	16.0 (100%)	8	515	10972 (38%)	34.0 (13%)
Spruce	Reject	-	-	-	-	7	422	9891	31.3
	C14	8	414	9536 (13%)	30.7	-	-	-	-
	C18	8	434	7905 (75%)*	25.8 (25%)*	2	411	6127 (100%)	22.2
	C24	16	434	11337 (50%)	35.2	23	433	10368 (61%)*	32.7 (9%)*

* Specimen not meeting f_m criteria also did not directly meet *MoE* criteria.

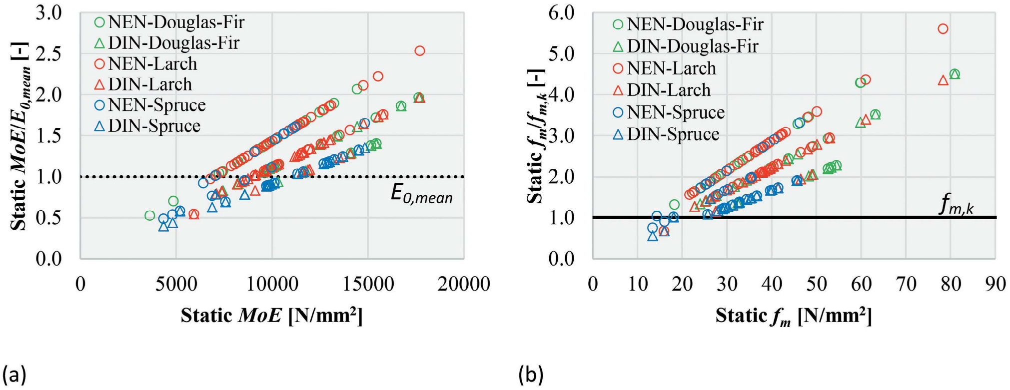


Figure 3. Bending test results vs. ratio of test result to value assigned by strength grade based on EN 338 (ratio ≥ 1.0 meets value), (a) stiffness MoE vs. MoE/$E_{0,mean}$, (b) bending strength f_m vs. $f_m/f_{m,k}$.

the *MoE*. For the bending strength comparisons, it can be seen that the strength values from both machine gradings generally yield good agreement with test results. Overestimations are noticeable. As f_m results from bending tests increase, the strength values assigned by the machine graders seem to become more conservative, accommodating safe design.

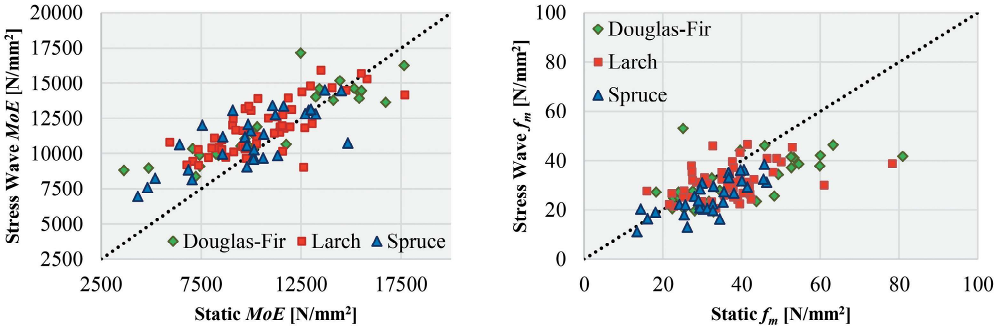
Figure 4 and Figure 5 show the promising potential of the different wood sources. Machine grading enables precise determination of the material properties, while visual grading has to be seen more as an estimation. Machine grading is particularly interesting with respect to reclaimed wood, where populations are likely to be smaller. The reclaimed timber shows no significantly different behaviour in the machine grading methods compared to the virgin wood, suggesting that established methods are likely to be applicable in similar form. The fact that no difference in the graded and measured strength relationship between reclaimed and virgin groups was observed stands in contrast to the findings in the literature (see Figure 1.). It is important to note that these findings have to be seen with respect to the amount of evaluated reclaimed wood and the potential pre-selection introduced by the deconstruction company.

The results show that reclaimed wood has the potential for reuse as structural members. Particularly, engineered wood products like CLT or glulam could benefit from the use of reclaimed materials, as cross-layers and middle lamellas commonly experience lower stresses in bending applications. Basis for structural reuse are reliable processing and (re-)grading processes for reclaimed timber, as design and product standards specifically require the use of graded materials. As a result, appropriate strength classes and design factors need to be developed for reclaimed timber. Dietsch et al. (2025) recently presented a report addressing steps and processes for the reclaiming of timber and made suggestions regarding the incorporation of reclaimed timber in Eurocode 5.

The reuse of timber in structural applications would allow for the extended use of the stored carbon within the wood. An additional service life could reduce the need for new virgin materials and the associated processing emissions. In addition, reclaimed timber can be found in regions with low forestation e.g., The Netherlands. Their use can further reduce the emissions related to transportation of virgin materials. All of these points can thereby contribute to reduce the emissions related to construction.

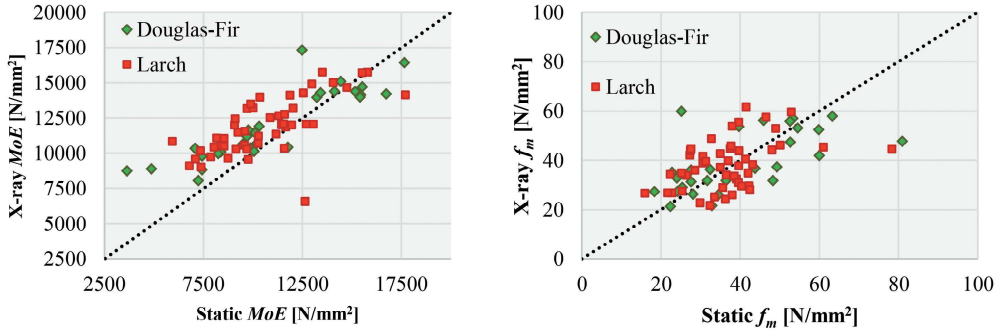
5 CONCLUSION & OUTLOOK

Visual and machine grading combined with static bending was used to study the potential of reclaimed and locally sourced wood. Direct comparison of the strength grade properties assigned by visual grading showed that the modulus of elasticity (*MoE*) was most often overestimated by visual grading. The bending strength (f_m) generally meets the strength value assigned by visual grading. Density requirements were achieved in all cases. *MoE* criteria was met less frequent in visual grading due to the fact that the value assigned by EN 338 is a mean value.



(a) (b)

Figure 4. Comparison of stress wave with static test results, (a) stiffness (MoE), (b) bending strength (f_m).



(a) (b)

Figure 5. Comparison of X-ray with static test results, (a) stiffness (MoE), (b) bending strength (f_m).

The results of the bending tests, stress wave and X-ray measurements showed that the two machine grading methods evaluate the *MoE* close to the values determined by the bending tests. For all three specimen groups, f_m was evaluated in good agreement between grading methods and tests. Overestimations can be seen, while the level of conservatism increases with increasing bending test strength. Compared to the virgin materials, the tested reclaimed wood showed similar overall agreement between the estimated and tested properties, indicating that stress wave grading is promising for secondary timber grading. The mechanical properties are within a similar range as the virgin material, indicating similar potential for (re-)use.

While the presented data provides an indication of the potential of these resources, additional work is needed. Additional tests on a larger quantity of reclaimed wood are ongoing to evaluate the relationships between measurable stiffness and strength. The to-date results of the ongoing study support the here presented findings regarding the potential of reclaimed timber.

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