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Original Article

Evaluation of Characteristic Strength and Stiffness Properties of Regionally Sourced Pinus Patula Sawn Timber for Structural Application in East Africa

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ABSTRACT

This study investigates the strength and stiffness properties of Pinus patula rectangular sawn timber sourced from sawmills in Rwanda and Western Tanzania, in alignment with Eurocode guidance. The study was designed to provide reliable baseline data for structural engineers considering the use of locally sourced timber for design in the region. Recognising the limited technical information on regional timber, extensive testing was conducted on up to 40 samples from each batch of timber procured for the multi-phased Rwanda Institute of Conservation Agriculture (RICA) project. Timber was sourced from Sao Hill (Tanzania), New Forests Company (Rwanda), and Sawmill East Africa Limited (Rwanda). A custom visual grading process was employed to classify the timber before mechanical testing, and 4-point bending tests were conducted following guidance from BS EN 408 to evaluate modulus of elasticity and flexural strength. Characteristic (5th percentile) values were determined through statistical analysis based on BS EN 14358 guidelines, with characteristic flexural strength values typically ranging between 9-12MPa and MoE averaging between 3000-4000MPa -both significantly lower than European equivalents. This paper discusses the testing methodologies, results, and offers recommendations to enhance the East African timber supply chain. The findings demonstrate that the material is generally suitable for medium span roofs and lightly loaded structural elements, while floor systems may require shorter spans, paired sections, or closer spacing due to lower stiffness values.

APA CITATION

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INTRODUCTION

In East Africa, locally sourced sawn timber offers the potential to serve as an economical and sustainable alternative to cold-formed steel hollow sections commonly used in low-duty structural applications such as roof trusses and purlins. However, the lack of reliable data on the mechanical properties of regionally available timber species has limited its widespread application in structural engineering.

From 2017 to 2022, MASS Design Group (Kigali, Rwanda) designed and oversaw the construction of the Rwanda Institute of Conservation Agriculture (RICA)—a new university campus comprising nearly 70 buildings in Bugesera District, Eastern Province, Rwanda. The university's mission is to train the next generation of leaders in conservation agriculture and support the country's goal of achieving sustainable food independence. With ambitious sustainability objectives, the project prioritised the use of locally sourced natural materials for primary structural elements. Timber was chosen for the 4-meter spanning purlins, 8-meter (typical) spanning roof trusses, and many load-bearing columns.

Pinus Patula timber was selected over other species, including the more commonly used Eucalyptus, due to concerns about Eucalyptus's environmental impacts on climate, hydrology, soil quality, and biodiversity[(1)]. Timber for the project was sourced primarily from sawmills in Rwanda and Tanzania. After initial sorting using visual grading techniques guided by BS 4978[(2)], each timber specimen was weighed and tested in a 4-point bending arrangement according to BS EN 408[(3)]. Results were analysed to identify skewness and outliers, followed by calculations to determine relevant mean and characteristic values.

This paper presents the findings of these tests, evaluates the limitations of the applied methodologies, and discusses the implications for structural engineers working with regionally sourced timber. By providing a comprehensive reference for the mechanical properties of *Pinus patula*, this work aims to support the safe and effective use of this material in structural applications across East Africa.

MATERIALS AND METHODS

Timber Sourcing

Batches of timber for the three construction phases of the project were primarily sourced from three sawmills - Sao Hill (TZ), New Forests Company (RW), Sawmill East Africa Limited (RW) - with varying numbers of batches and specimens tested during each phase. Other mills were trialled for sourcing. However, results from other mills were considered unreliable due to poor manufacturing practices and sourcing from uncertified or poorly managed forests. This paper covers the testing of 339 specimens sourced from the three primary suppliers.

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Structural timber was primarily supplied in 50x200mm sections as this was the most widely used section size on the project. However, some tests were carried out on section sizes of 50x150mm and 100x200mm timbers at certain stages. All timber was kiln-dried to a moisture content of 12-16% and treated with Copper-Chrome Arsenate (CCA) pressure treatment. Specimens from each batch were either sorted (Phase 1) or selected (Phase 2 & 3) for testing based on visual grading criteria.

Visual Grading

Challenges with Visual Grading

During the initial timber selection process, it became apparent that the *Pinus patula* timber sourced from regional East African sawmills did not sufficiently meet the GS or SS visual grading requirements specified in Table 1 of BS 4978[(2)]. Consequently, the timber could not be assigned a typical strength class in accordance with BS EN 1912[(4)]. This limitation was largely attributed to the high prevalence of knots, reflecting suboptimal forest management and timber processing practices. To address this issue, custom visual grading criteria were developed.

Custom Visual Grading Criteria

Visual grading methods and criteria were adapted from BS 4978[(2)] to categorise the timber into two custom categories - Grade 1 and Grade 2 - based on the frequency, size, and location of knots and other defects observed in the timber cross-section.

Key criteria for visual grading included:

- **Knots in the Margin**: The margin is defined as the outer 25% of the section. Knots in this region have a higher potential to reduce bending strength and stiffness due to the outer portions of the member being subject to higher flexural stresses and strains.
- **Knots in the Core**: The core is defined as the central 50% of the section. While this zone experiences less stress under bending, it does contribute to the shear and compressive capacity of the section.
- **Total Knots**: The height of knots (or total height of multiple knots) measured across the section as shown in ***Figure 1***.
- **Decay**: Damage caused by rot, termites or beetles.
- **Sloping grain:** Direction of grain in relation to the length of the timber.
- **Full-depth fissures (splits):** Separation of fibre bonds across the annual rings for the full depth of timber**.**
- **Partial-depth fissures (checks):** Separation of fibre bonds across the annual rings for partial depth of timber.
- **Wane & Want:** Absence of wood from the face or edge of timber due to the edge of the log or processing.

The specific requirements defined for each of the custom grades is shown in **Table 1**. The distribution of specimens falling into Grade 1 and Grade 2 and those which did not meet the specifications for either - recorded as “Not Graded” - from each batch and each saw mill is shown in ***Figure 2***.

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Figure 1: Examples of Knots Passing and Failing Grading Methods

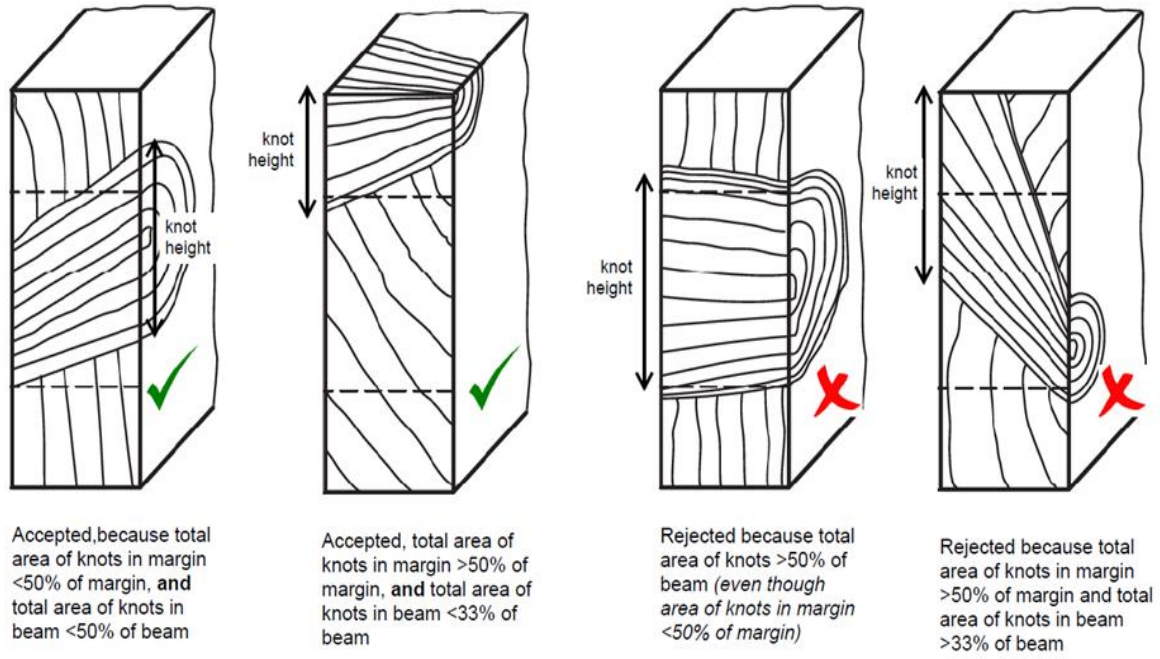
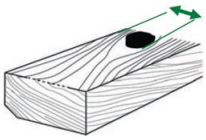
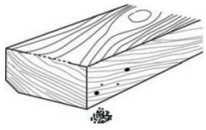
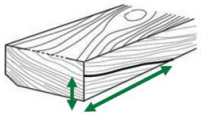
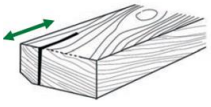


Table 1: Custom Grading Criteria for Grade 1 and Grade 2

Defect Type	Diagram	Grade 1	Grade 2
Total Knots (incl. Knots in Margin and Core		When the total knot height in margins is less than 50% of the margin height, the total height of knots is limited to 50% of the total member depth When the knot height in margins is greater than 50% of the margin height, the total height of knots is limited to 33% of the total member depth.	The total height of knots is limited to 70% of the total member depth.
Decay		Limit: None Acceptable	
Sloping Grain		Limit: 1:6 slope	
Splits		Limits on the length of the fissure: (1) At the ends of members, 100mm (2) Away from ends, 25% of the length of the member, up to a maximum of 1.0m.	

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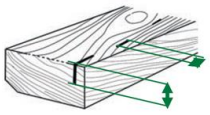
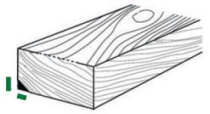
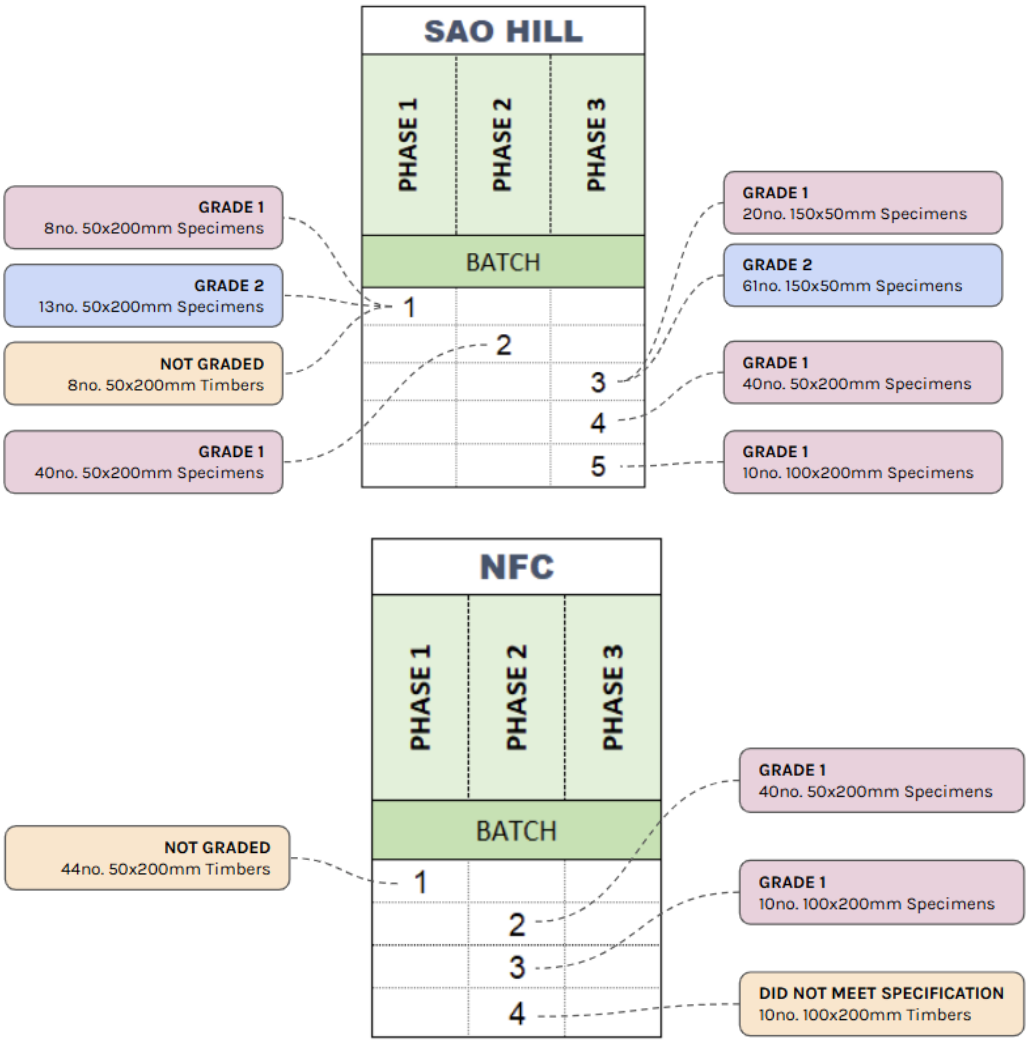
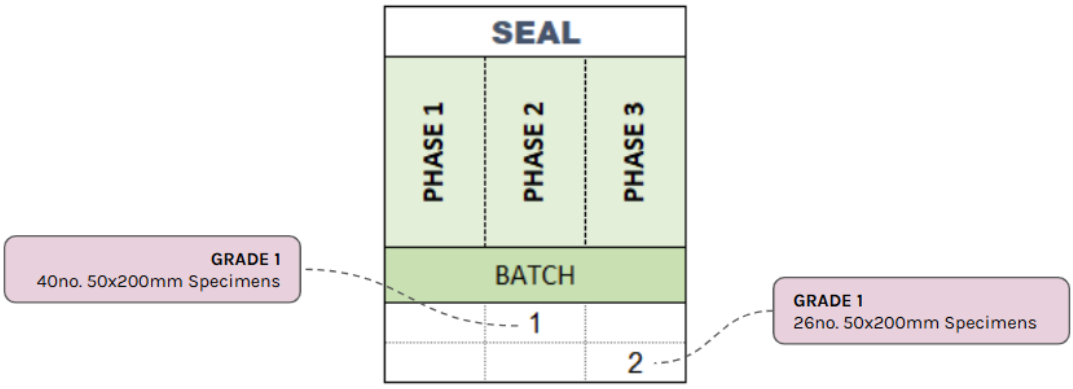
Defect Type	Diagram	Grade 1	Grade 2
Checks		Limit on length of fissure: 50% of the length of the member, up to a maximum of 1.5m. If there is any doubt as to whether a fissure is partial- or full-depth, it is to be treated as full-depth.	
Wane & Want		Limit: 20% of the width or thickness in both directions	

Figure 2: Number of Specimens of Each Custom Grade Tested from Each Batch



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Testing Procedures

Testing Method

The two-meter-long visually graded timber specimens were first measured and weighed, and the density was recorded following Section 7 of BS EN 408. The specimens then underwent a 4-point bending test in accordance with Sections 10 and 19 of BS EN 408[3] to determine the global modulus of elasticity, E_0, and the bending strength parallel to the grain, f_m, respectively. The test set-up is illustrated in ***Figure 3,*** and the method is summarised below:

- Supports were placed 250 mm from each end, creating an effective span of 1500mm.
- A symmetrical load, P/2, was applied at the third points of the span.
- The total load, P, was applied increasingly at a steady rate.
- The test was paused at approximately 5 kN intervals of the total load, P, to record displacement measurements.
- Two critical load points were recorded for each specimen:
    - **First Failure**: The load at which the first audible cracking sound was detected.
    - **Ultimate Failure**: The load at which a sudden, brittle failure occurred, often accompanied by visible splintering of the material.
- The results for each specimen, including the recorded load values, were documented on a standardised data sheet.

Bending Strength Calculation

The bending strength parallel to the grain, f_m, was calculated using the results from the load recorded at First Failure. The calculation follows the standard formula derived from beam theory under 4-point bending, expressed as follows:

For a simply supported beam with span "L" loaded with two point loads of value "F" equidistant from each end at a distance "a", the maximum bending moment which occurs at a consistent rate between the two point loads is defined as[6]:

$$M = Fa$$

Bending stress "σ_m" in a beam is equal to:

$$\sigma_m = M / Z$$

Combining these equations and substituting $Z = \frac{bh^2}{6}$, a = L/3, F = P/2, and $\sigma_m = f_m$ the equation becomes:

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$$f_m = \frac{6\,(P/2)\,(L/3)}{bh^2}$$

Simplified:

$$f_m = \frac{P\,L}{bh^2}$$

Where;

f_m = Bending Strength

P = Applied Load at First Failure

L = Span (1500mm)

b = Breadth of the Section

h = Height of the Section

Modulus of Elasticity (MoE) Calculations

The MoE parallel to the grain was calculated based on load intervals of approximately 5 kN and the corresponding deflection at the early stages of testing, using the following formula derivation:

For a simply supported beam with span "L" loaded with two point loads of value "F" equidistant from each end at a distance "a", the deflection at a point "x" is equal to[6]:

$\delta_x = \frac{F\,x}{6EI}\,(3La - 3a^2 - x^2)$, *when* $(x \le a)$

Resolving for a = x = L/3 and F = P/2:

$$\delta_x = \frac{\left(\frac{P}{2}\right)\left(\frac{L}{3}\right)}{6EI}\left[3L\left(\frac{L}{3}\right) - 3\left(\frac{L}{3}\right)^2 - \left(\frac{L}{3}\right)^2\right]$$

Simplified:

$$\delta_{(a=x=L/3)} = \frac{5}{324}\frac{PL^3}{E\,I}$$

Substituting $I = \frac{bh^3}{12}$, accounting for early loading intervals during testing, and rearranging with E as the subject, the equation becomes:

$$(\delta_2 - \delta_1) = \frac{5}{324}\frac{(P_2 - P_1)\,L^3}{E\left(\frac{bh^3}{12}\right)}$$

Simplified:

$$E = \frac{5}{27}\frac{(P_2 - P_1)\,L^3}{(\delta_2 - \delta_1)\,b\,h^3}$$

Where;

E = Modulus of Elasticity

L = Span

P_1 = Load at First Interval

P_2 = Load at Second Interval

δ_1 = Deflection at First Interval

δ_2 = Deflection at 2nd Interval

b = Breadth of the Section

h = Height of the Section

Limitations of Testing

Several limitations were encountered during the testing process:

- **Limited Access to Specialist Equipment:** Dedicated timber testing machines were not available in Rwanda, requiring the adaptation of a concrete crushing machine using fabricated steelwork to conduct the 4-point bending test. This modification also meant that the rate of loading could not be closely controlled. ***Figure 4*** illustrates the adapted concrete crushing machine.

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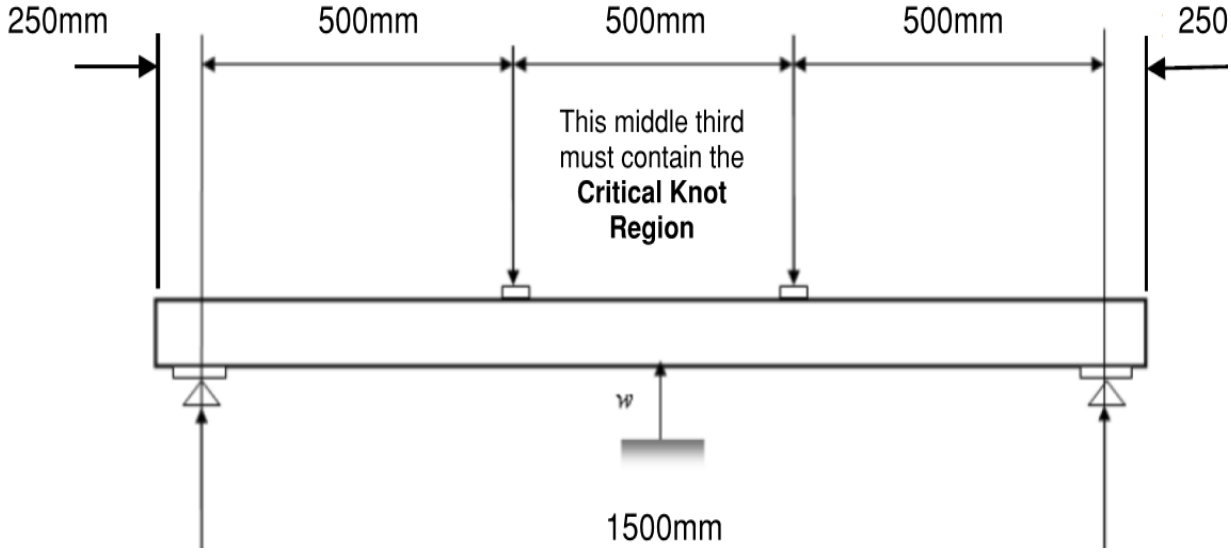
- **Poorly Maintained Equipment:** The strain gauge on the testing machine was not functioning, preventing reliable tracking of timber deflections over time. As a result, deflection was measured manually using a measuring tape at intervals of 5 kN of applied load.

- **Limited Space:** Due to spatial constraints, the decision was made to test the section sizes most commonly used across the project - typically 50x200mm - to ensure a realistic representation of knots and defects across the timber section. However, this meant that, due to limited space within the lab, the specimens did not meet the recommended dimensional requirement of a span equal to 18 times the height as per BS EN 408. This limitation may have affected the consistency of the results.

- **Time Constraints:** Due to the limited time between timber procurement and its scheduled use on-site, testing was restricted to the 4-point bending test only. As a result, it was not possible to conduct additional tests, such as direct shear, compression, or tension tests.

- **Number of Specimens Per Batch:** Visual grading and initial selection of the timber were carried out by the Contractor. On some occasions, this led to incorrect assessments, and fewer specimens were tested per batch/grade than the recommended 40 per sample. The use of fewer samples impacts the calculation of standard deviation (see section on Statistical Analysis), which in turn affects the determination of characteristic properties, resulting in more conservative values.

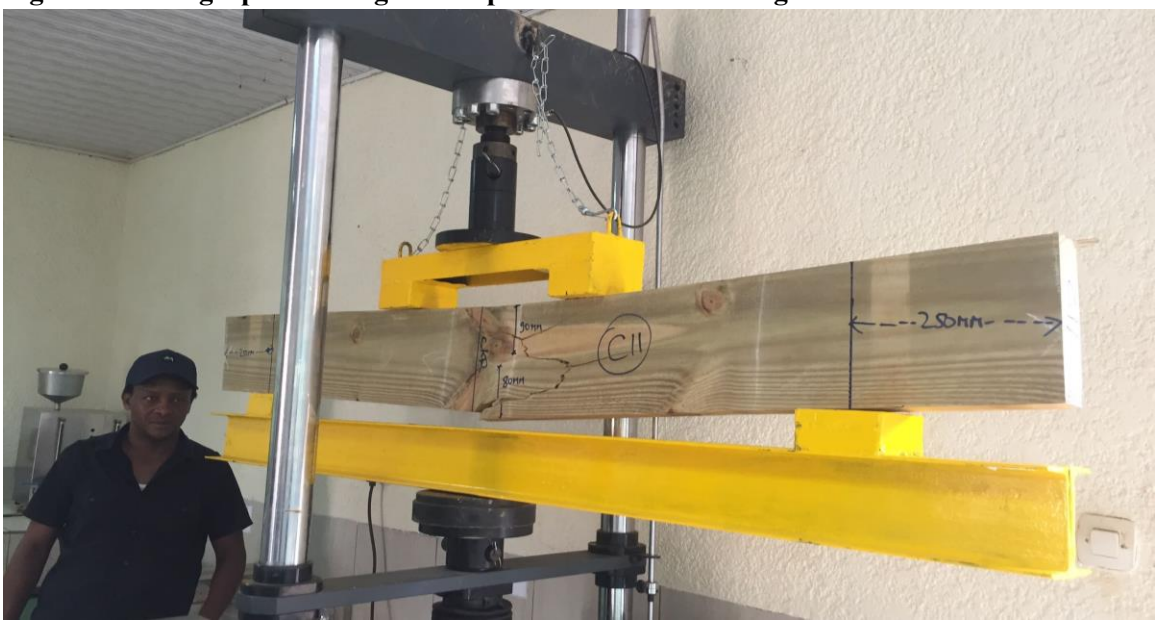
Figure 3: Diagram Showing the Arrangement of the 4-Point Bending Test



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Figure 4: Photograph Showing an Adapted Concrete Crushing Machine



RESULTS

The results exhibited variation within each batch and grade, as shown in the Box-and-Whisker diagrams in ***Figure 3a-c***. Density proved to be the most consistent parameter across all batches and grades. The majority of results fell within the range of 440–560 kg/m³, with average values around 500 kg/m³.

The Modulus of Elasticity (MoE) was generally consistent across all batches and grades, with the exception of two sets that exhibited higher values. Most MoE results fell within the range of 2000 MPa to 5500 MPa. It is important to note that these values are considerably lower than the MoE of typical European strength classes defined in EN 338[(7)], such as C14 (7000 MPa) and C16 (8000 MPa). Given that deflection is often a critical design criterion for structural timber elements, particularly for floors, these recorded MoE results significantly impact the viability of using timber more broadly across the region.

In terms of bending strength, there was no significant difference between Grade 1 and Grade 2 timbers, with results typically ranging from 20–40 MPa, with a few exceptions. However, timber categorised as "Not Graded" consistently returned lower strength values. The slightly lower standard deviation of the larger dataset from Grade 1 led to higher 5th percentile values compared to Grade 2. Despite this, two batches of Grade 1 timber exhibited significantly lower strength than others, and this variation could not be correlated with a specific timber mill.

Finally, it was noted that all timber from Sao Hill tested during Phase 1 showed significantly lower strength compared to other batches in the same visual grading category. This anomaly may be attributed to initial equipment calibration issues, as later batches from Sao Hill showed significantly higher bending strength results.

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Figure 3a: Box and Whisker Plots for Density (Including Outliers)

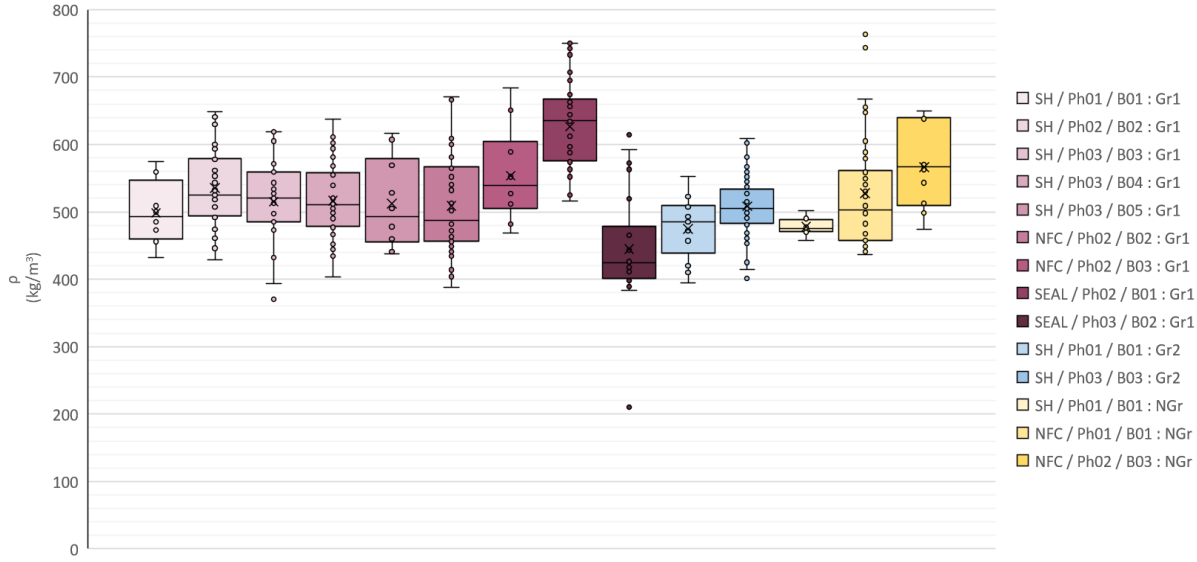
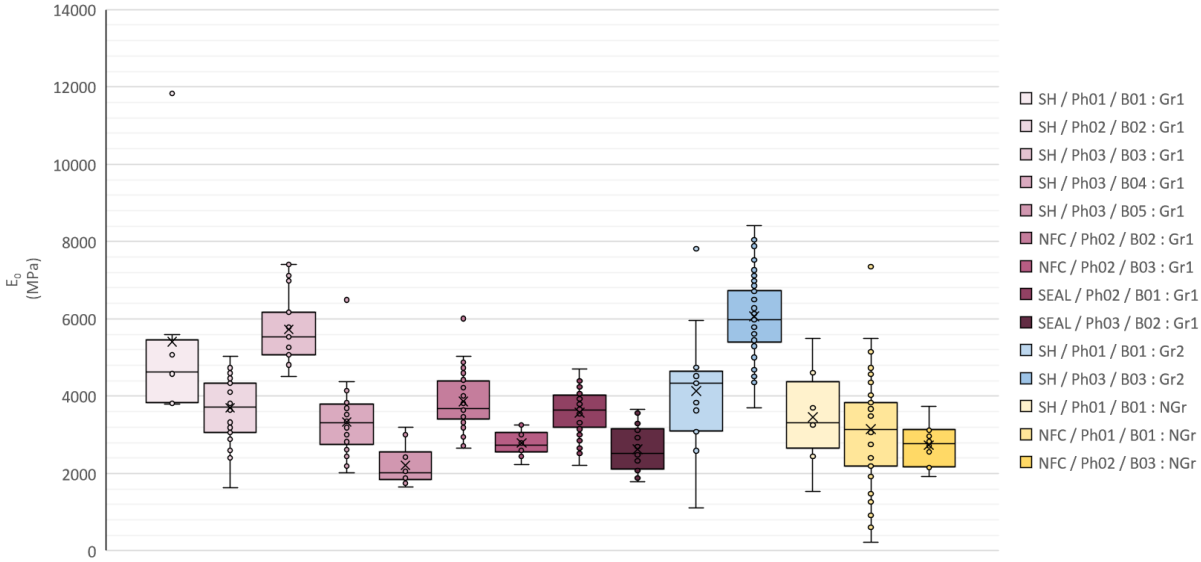


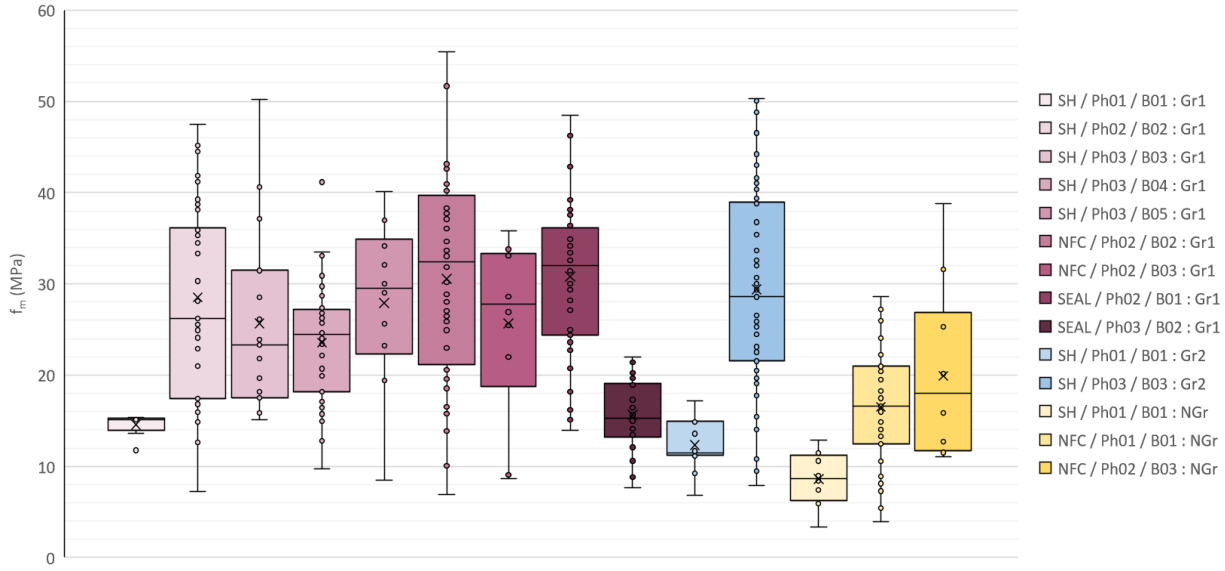
Figure 3b: Box and Whisker Plots for Modulus of Elasticity (Including Outliers)



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Figure 3c: Box and Whisker Plots for Bending Strength (Including Outliers)



Distribution Analysis and Outlier Detection

Each data set was statistically analysed to check for skew in the distribution of results and determine any values considered as outliers.

Determination of Skew

First, skew was checked using the MS Excel SKEW function and comparing this value against $2.SE_{skew}$, where SE_{skew} is the Standard Error of Skewness, calculated as follows[9]:

$$SE_{skew} = \sqrt{\frac{6}{n}}$$

If the skew was more than $2.SE_{skew}$ then the data was treated as Logarithmically Normally Distributed (LND). If the skew was less than $2.SE_{skew}$ then it was ignored, and the data is treated as having Normal Distribution (ND). This assessment was based on the requirement of Clause 3.2.2 c) of BS EN 14358[3] stating that "*strength parameters should be assumed as logarithmically normally distributed unless analysis of the data shows that a normal distribution is more appropriate*". Note that this approach is only applied to strength parameters, and therefore determination of skew was not considered necessary when establishing modulus of elasticity and density properties.

Detection of Outliers

To detect outliers for all properties, the median value was identified, m_n, and the MedCouple, MC_n - a robust measure of direction and magnitude of skew - was calculated using the following equation[8]:

$$MC_n = med_{x_i \le m_n \le x_j}\, h(x_i\,, x_j)$$

Where:

$$h(x_i\,, x_j) = \frac{(x_j - m_n) - (m_n - x_i)}{(x_j - x_i)}$$

Upper and lower outlier boundaries were then calculated using an adjusted Interquartile Range method, which accounts for skew.

The outlier boundary, OB, are defined as:

$$OB_{upper} = Q3 - 1.5\, e^{(\psi\, MC_n)} IQR$$

$$OB_{lower} = Q1 - 1.5\, e^{(\xi\, MC_n)} IQR$$

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Where;

$\psi = 4.0$ and $\xi = -3.5$ when $MC_n > 0$

$\psi = 3.5$ and $\xi = -4.0$ when $MC_n < 0$

and;

Q1 = Lower Quartile

Q2 = Upper Quartile

IQR = Interquartile Range

Any values greater than the upper boundary or lesser than the lower boundary were discounted as outliers, and the remaining data set was used for determining the mechanical properties.

Calculation of Mechanical Properties

Bending Strength

The 5th percentile values were calculated using the method set out in BS EN 14358[5]:

- Applying Section 3.2.2, the mean value and standard deviation were established following Clause d) using Equations (1) and (3) respectively for LND sets and Equations (2) and (4) respectively for ND sets.
- The 5th percentile values were then calculated according to Clause e) using Equation (5) for LND sets and Equation (6) for ND sets. With the factor $k_s(n)$ taken from Equation (10).

This value was then adjusted using the methods defined in BS EN 384[10]:

- Both k_h and k_i from Clause 5.4.3 were taken as equal to 1.0.
- To account for only a single sub-sample at each time of testing, Equation (11) from Section 5.5.2.2 "*Visual Grading*" was used to determine the characteristic value, with $k_n = 1.00$ (See specific section below).

Modulus of Elasticity (MoE) and Density

The mean value was calculated using the method set out in BS EN 14358[5]:

- Section 3.3 "*Calculation of mean characteristic values*" defines the mean value using Equation (14) as recommended in Clause d).

The resulting value was then adjusted following BS EN 384[10]:

- Adjustment for moisture content was implemented following Section 5.4.2 using Equation (2) and Equation (3) for MoE and Density respectively, assuming a reference moisture content of 12%.
- To account for only a single sub-sample at each time of testing, Equation (12) and Equation (13) from Section 5.5.2.2 "*Visual Grading*" was used to determine the characteristic mean value for MoE and Density respectively, with $k_n = 1.00$ (See specific section below).

Sub-Sample Factor, k_n

BS EN 384 Table 1 provides the k_n factor based on the number of sub-samples being considered. Due to cost and time constraints on this project, only one sub-sample was under consideration per batch, which results in the following k_n values:

- Strength properties, $k_n = 0.70$
- Other properties, $k_n = 0.88$

However, given the relatively low strength and stiffness values being recorded during testing, expert consultation was sought to assess the appropriateness of this factor.

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Feedback indicated that the k_n factor accounts for variation in density within timber from the same forest, which is not addressed by visual grading but has the potential to affect strength and stiffness. However, since the density was relatively consistent across all specimens tested from all sawmills, it was decided that for the purpose of this project, the k_n factor may be omitted, therefore applying $k_n = 1.0$ for all calculations of the characteristic properties.

Determination of Other Properties

BS EN 384[10] Figure 4 provides equations for determining other mechanical properties, such as compressive strength, shear strength, and shear modulus, based on bending strength, MoE, and density results. As the *Pinus patula* timber tested is a softwood, the equations for C-classes of timber were applied.

Summary

Figure 4a-c summarises the statistical analysis and calculation of characteristic values for each graded batch. The final results for all relevant mechanical properties for each batch of testing, assuming European-style C-grade property relationships, are presented in **Figure 5**.

Figure 4a: Summary of Statistical Analysis and Determination of Characteristic Density

	Grade	Batch	Original Number of Samples	Section Size	Median (MPa)	Upper Quartile (MPa)	Lower Quartile (MPa)	Number of Samples after Discounting Outliers, n	Mean Value, y (MPa)	Standard Deviation, s (MPa)	Factor ks(n)	5th Percentile Value, p0.05 (MPa)	Moisture Content Adjustment Factor	Subsample Adjustment Factor, kn	Characteristic Mean Value, pk (MPa)
DENSITY	Grade 1	SH / Ph01 / B01	8	50x200	469	522	469	8	499	45.7	2.25	396	0.975	1.0	386
		SH / Ph02 / B02	40	50x200	529	580	504	40	538	56.7	1.83	428	0.985	1.0	422
		SH / Ph03 / B03	19	50x150	520	551	487	18	523	57.9	1.93	411	0.985	1.0	405
		SH / Ph03 / B04	40	50x200	510	556	482	40	517	54.7	1.83	416	0.985	1.0	410
		SH / Ph03 / B05	10	100x200	493	559	465	10	512	62.3	2.09	376	0.985	1.0	370
		NFC / Ph02 / B02	40	50x200	487	566	456	40	509	69.7	1.83	381	0.985	1.0	375
		NFC / Ph02 / B03	10	100x200	540	580	513	10	554	66.3	2.09	415	0.985	1.0	409
		SEAL / Ph02 / B01	40	50x200	635	665	576	40	627	65.1	1.83	507	0.985	1.0	499
		SEAL / Ph02 / B02	26	50x200	424	460	404	20	422	29.5	1.88	366	0.985	1.0	361
	Grade 2	SH / Ph01 / B01	13	50x200	485	507	457	13	475	44.3	2.01	386	0.975	1.0	376
		SH / Ph03 / B03	61	50x150	505	531	483	61	508	42.6	1.81	431	0.985	1.0	425
	Did not meet spec. / Ungraded	SH / Ph01 / B01	8	50x200	476	485	472	8	478	12.8	2.25	449	0.975	1.0	438
		NFC / Ph01 / B01	44	50x200	496	553	453	42	504	72.3	1.83	372	1.000	1.0	372
		NFC / Ph02 / B04	10	100x200	567	621	521	10	566	58.9	2.09	443	0.985	1.0	436

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Figure 4b: Summary of Statistical Analysis and Determination of Characteristic MoE

	Grade	Batch	Original Number of Samples	Section Size	Median (MPa)	Upper Quartile (MPa)	Lower Quartile (MPa)	Skew? And if so, +ve or -ve	Number of Samples after Discounting Outliers, n	Mean Value, y (MPa)	Moisture Content Adjustment Factor	Subsample Adjustment Factor, kn	Characteristic Mean Value, Em,0 (MPa)
MODULUS OF ELASTICITY	Grade 1	SH / Ph01 / B01	8	50x200	4634	5197	3900	Y (+ve)	7	4496	1.05	1.0	4969
		SH / Ph02 / B02	40	50x200	3766	4340	3158	N	40	3723	1.03	1.0	4037
		SH / Ph03 / B03	19	50x150	5528	5980	5109	N	18	5793	1.03	1.0	6281
		SH / Ph03 / B04	40	50x200	3314	3788	2793	Y (-ve)	39	3249	1.03	1.0	3523
		SH / Ph03 / B05	10	100x200	2559	2807	2308	N	10	2668	1.03	1.0	2893
		NFC / Ph02 / B02	40	50x200	3677	4361	3453	N	35	4006	1.03	1.0	4343
		NFC / Ph02 / B03	10	100x200	2742	3005	2604	N	9	2850	1.03	1.0	3090
		SEAL / Ph02 / B01	40	50x200	3649	3995	3200	N	39	3546	1.03	1.0	3845
		SEAL / Ph02 / B02	26	50x200	2519	3077	2134	N	26	2628	1.03	1.0	2849
	Grade 2	SH / Ph01 / B01	13	50x200	4344	4545	3131	N	11	3629	1.05	1.0	4011
		SH / Ph03 / B03	61	50x150	5974	6713	5447	N	58	6165	1.03	1.0	6684
	Did not meet spec. / Ungraded	SH / Ph01 / B01	8	50x200	3308	3925	3049	N	7	3915	1.05	1.0	4327
		NFC / Ph01 / B01	44	50x200	3316	3887	2356	N	41	2979	1.00	1.0	3136
		NFC / Ph02 / B04	10	100x200	2770	3084	2269	N	10	2737	1.03	1.0	2967

Figure 4c: Summary of Statistical Analysis and Determination of Characteristic Flexural Strength

	Grade	Batch	Original Number of Samples	Section Size	Median (MPa)	Upper Quartile (MPa)	Lower Quartile (MPa)	Skew? And if so, +ve or -ve	Number of Samples after Discounting Outliers, n	Mean Value, y (MPa)	Standard Deviation, s (MPa)	Mean of Natural Logs	Standard Deviation of Natural Logs	Factor ks(n)	5th Percentile Value, fm,0.05 (MPa)	Subsample Adjustment Factor, kn	Characteristic Value, fm,k (MPa)
BENDING STRENGTH	Grade 1	SH / Ph01 / B01	8	50x200	15.1	15.2	14.7	Y (+ve)	7	n/a	n/a	2.61	0.1	2.25	11.5	1.0	11.5
		SH / Ph02 / B02	40	50x200	26.2	36.0	19.2	N	38	29.1	9.9	n/a	n/a	1.84	10.8	1.0	10.8
		SH / Ph03 / B03	19	50x150	23.3	30.2	17.8	N	19	25.7	9.6	n/a	n/a	1.92	7.2	1.0	7.2
		SH / Ph03 / B04	40	50x200	24.5	26.9	18.2	N	36	22.2	5.3	n/a	n/a	1.84	12.5	1.0	12.5
		SH / Ph03 / B05	10	100x200	29.5	33.6	23.8	N	10	27.9	8.8	n/a	n/a	2.09	9.6	1.0	9.6
		NFC / Ph02 / B02	40	50x200	32.4	38.8	22.4	N	38	29.3	9.8	n/a	n/a	1.84	11.4	1.0	11.4
		NFC / Ph02 / B03	10	100x200	27.7	33.2	22.9	N	10	25.6	9.3	n/a	n/a	2.09	6.2	1.0	6.2
		SEAL / Ph02 / B01	40	50x200	32.0	35.6	24.4	N	36	29.1	6.9	n/a	n/a	1.84	16.4	1.0	16.4
		SEAL / Ph02 / B02	26	50x200	15.3	18.5	13.5	N	24	16.3	3.3	n/a	n/a	1.89	10.1	1.0	10.1
	Grade 2	SH / Ph01 / B01	13	50x200	11.5	14.9	11.3	N	11	13.1	2.1	n/a	n/a	2.06	8.9	1.0	8.9
		SH / Ph03 / B03	61	50x150	28.6	38.8	21.6	N	61	29.4	10.5	n/a	n/a	1.81	10.4	1.0	10.4
	Did not meet spec. / Ungraded	SH / Ph01 / B01	8	50x200	8.7	10.8	7.1	N	8	8.6	2.9	n/a	n/a	2.18	2.3	1.0	2.3
		NFC / Ph01 / B01	44	50x200	16.5	21.0	12.1	N	44	16.3	6.2	n/a	n/a	1.83	5.1	1.0	5.1
		NFC / Ph02 / B04	10	100x200	18.0	24.1	12.0	N	10	19.9	9.0	n/a	n/a	2.09	1.2	1.0	1.2

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Figure 5: Summary of All Characteristic Mechanical Properties for Each Batch, Assuming C-Grade Property Relationships

Grade	Batch	Characteristic Bending Strength, fm,k (MPa)	Characteristic Comp Strength Parallel to Grain, fc,0,k (MPa)	Characteristic Tens Strength Parallel to Grain, ft,0,k (MPa)	Characteristic Shear Strength, fv,k (MPa)	Characteristic Density ρk (kg/m3)	Mean Density ρmean (kg/m3)	Compression perp to grain fc,90,k (MPa)	Mean MOE, E0,mean (MPa)	5th Percentile MOE, E0,k (MPa)	Mean Shear Modulus, Gmean (MPa)
Grade 1	SH / Ph01 / B01	11.5	14.6	5.35	2.75	386	463	2.70	4969	3329	311
	SH / Ph02 / B02	10.8	14.2	4.84	2.68	422	506	2.95	4037	2704	252
	SH / Ph03 / B03	7.2	11.5	2.15	2.32	405	486	2.83	6281	4208	393
	SH / Ph03 / B04	12.5	15.2	6.06	2.85	410	492	2.87	3523	2360	220
	SH / Ph03 / B05	9.6	13.3	3.90	2.56	370	444	2.59	2893	1938	181
	NFC / Ph02 / B02	11.4	14.5	5.25	2.74	375	450	2.63	4343	2910	271
	NFC / Ph02 / B03	6.2	10.7	1.44	2.22	409	491	2.86	3090	2070	193
	SEAL / Ph02 / B01	16.4	17.4	8.90	3.24	499	599	3.50	3845	2576	240
	SEAL / Ph02 / B02	10.1	13.7	4.30	2.61	361	433	2.52	2849	1909	178
Grade 2	SH / Ph01 / B01	8.9	12.8	3.43	2.49	376	452	2.63	4011	2687	251
	SH / Ph03 / B03	10.4	13.8	4.49	2.64	425	509	2.97	6684	4478	418
Did not meet spec. / Ungraded	SH / Ph01 / B01	2.3	6.5	0.00	1.83	438	525	3.06	4327	2899	270
	NFC / Ph01 / B01	5.1	9.7	0.64	2.11	372	446	2.60	3136	2101	196
	NFC / Ph02 / B04	1.2	4.7	0.00	1.72	436	524	3.05	2967	1988	185

DISCUSSION

Implications for Regional Use

The results show that, while *Pinus patula* from the selected sawmills can be used for structural design, significant variations in strength and stiffness remain even after visual grading. The mechanical properties are notably lower than those found in typical European strength classes.

The bending strength for most batches of Grade 1 and Grade 2 timber is comparable to the South African S5 strength class as defined in SANS 1783[10]. However, the mean Modulus of Elasticity (MoE) for the tested specimens was significantly lower than the recommended 7800MPa for S5 timber in South Africa. This is likely due to the relatively recent forest management practices in the region, which are less established compared to those in South Africa.

Given these results, engineers should approach the use of regionally sourced timber with some caution, especially when sourcing timber from mills with less controlled production standards. Due to the extent of variations observed, testing is still recommended for specific projects to confirm the properties assumed in design.

That being said, regionally sourced *Pinus patula* timber can be a viable solution for structural purposes in the region if used in the appropriate format. It is considered most suitable for roof structures with spans up to 6 meters, where deflections are less perceivable than in floor systems of equivalent spans.

For lightly-loaded floors, it may be necessary to pair timber sections, reduce spans, or use closer joist spacing to meet safety and serviceability criteria. However, floors with imposed loads of 3.0 kPa and above may be difficult to justify with the currently available timber properties.

Other measures to alleviate the load on timber structures include: ensuring suitable truss forms and depths, limiting the number of primary members in direct flexure, oversizing timber elements early in the design, minimising unnecessary loads, and avoiding brittle finishes to reduce pressure on deflection criteria.

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Outcomes from Visual Grading

Although there was significant overlap between grades in terms of mechanical properties, Grade 1 timbers exhibited a more consistent density distribution and lower standard deviations, resulting in higher characteristic properties. This allowed Grade 1 timbers to be used in more critical parts of the structure, while Grade 2 timbers were allocated to secondary elements and those experiencing smaller bending moments. The grading strategy is summarised as follows:

- **Grade 1 timbers:** Used primarily in long-span trusses, cantilevered elements, and columns around braced bays.
- **Grade 2 timbers:** Used for joists, rafters, ring beams along walls, and isolated simple columns.

However, the overlap observed between Grade 1 and Grade 2 specimens indicates that the proposed grading rules may not adequately differentiate structural performance at a larger scale. For practical application in East Africa, this suggests either consolidating the visual grades into a single category or refining the criteria to increase separation.

Sub-sample Reduction Factor, k_n

The authors recognise that applying $k_n = 1.0$ inflates characteristic strength values by 30% and other characteristic properties by 12%. The results included in this report should therefore be interpreted as preliminary indicators of structural potential rather than values for direct code adoption. Future work incorporating larger datasets and calibrated reduction factors is essential to refine these benchmarks.

Accuracy of Testing Equipment and MOE Results

The equipment constraints introduce potential error margins, particularly in stiffness measurements, which the researchers estimate could vary significantly due to manual readings and non-continuous load application.

The MOE values obtained in this study were generally lower than those typically reported for other fast-growing structural softwoods of comparable density. For instance, a recent study on fast-growing Chinese poplar (mean density ≈ 521 kg/m³) reported characteristic MOE values of around 12 GPa and classified the timber as C30 grade [11]. In contrast, the study's *Pinus patula* specimens, with similar or higher densities, exhibited considerably lower MOE values, typically in the range of 3 - 5 GPa. This discrepancy likely reflects methodological constraints rather than inherent material deficiencies. The use of an adapted concrete crushing machine, combined with manual tape deflection measurements, introduced uncertainties in load control and displacement accuracy that may have systematically underestimated stiffness.

The researchers therefore recommend that the MOE values reported here be regarded as baseline estimates, requiring confirmation through testing with specialised timber equipment under standardised conditions.

Effects of Treatment

All specimens tested in this study were CCA-treated, reflecting current commercial practice in Rwanda. As such, the dataset presented here is specific to CCA-treated *Pinus patula*; however, adoption of alternative treatments is both desirable and necessary, and must be accompanied by equivalent mechanical property verification.

While mechanical property data is expected to be broadly valid across treatment types, differences in chemical interactions and long-term durability cannot be excluded. For this reason, future studies should prioritise testing of Boron, ACQ, or natural

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oil treatments to provide a fuller picture of structural and environmental performance.

RECOMMENDATIONS FOR FURTHER WORK

Further Testing

Increasing the volume of testing, particularly for timber sourced from the same sawmills, will enhance the reliability of data.

It would be particularly beneficial to test a larger sample of timbers within the Grade 2 specification, as only two data sets were recorded for this grade. This additional testing would provide valuable insights into whether there is a significant difference between Grade 1 and Grade 2 timbers by allowing for a more balanced comparison between the two grades.

Direct testing of other mechanical properties - including compression, tension and shear strengths - is also highly recommended to ascertain whether relationships between properties are similar to those of the Eurocode "C-grading" system.

Improved Accuracy and Equipment

It is essential to acknowledge the limitations and potential inaccuracies in the tests described in this paper. Due to the limited availability of equipment, funds, and space, the tests were not carried out fully in accordance with the necessary standards. To improve testing accuracy, the following improvements are recommended:

- **Use of Digital Gauges**: The ability to record deflections using digital gauges would improve the accuracy of deflection measurements.
- **Steady Rate of Loading**: Maintaining a consistent rate of loading during testing would provide more reliable results.
- **Correct Height-to-Length Ratio**: Ensuring that the specimens meet the required height-to-length ratios would help improve the consistency and reliability of test outcomes.

Testing at the Point of Supply

Currently, testing is only conducted after the timber has been purchased from the supplier, which means that any timber failing to meet the visual grading specifications incurs costs borne by the Contractor and, ultimately, the Client. To make timber more accessible on the market, sawmills should consider implementing their own grading and testing. This testing could occur before treatment is applied to reduce cost and waste. Timber that does not meet structural requirements could be redirected for alternative uses, such as in furniture production. This approach would reduce costs for the purchaser and create additional revenue streams for the suppliers.

Adoption of Non-Toxic Treatment

While CCA (Chromated Copper Arsenate) treatment is commonly used and effective, it is widely considered to be highly toxic due to the presence of arsenic, posing significant risks to both human health and the environment. Waste CCA-treated timber cannot be recycled as sawdust or firewood and must be disposed of properly, buried far from water sources. Environmental risks associated with CCA include elevated metal and arsenic levels leaching into soil and water, potentially entering the food chain and affecting both animals and human communities. Human health risks linked to CCA-treated timber include cancer and nervous system damage, among others.

To mitigate these risks, alternative treatments which are safer and more environmentally friendly, such as Boron, ACQ (Alkaline Copper Quaternary), or natural oils, should be considered. Suppliers are encouraged to invest in these alternatives to improve the sustainability and safety of their products.

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Improve Forest Management Practice and Policy

The market for structural timber will not expand without improved forest management practices and supportive national policies. Better forestry governance should prioritise longer rotation cycles, selective thinning, and effective pruning practices that improve timber quality and lead to more consistent mechanical properties. This, in turn, would reduce waste, lower rejection rates, and increase confidence in local material. Clearer standards and policy support could enable a more robust value chain, encouraging investment in testing, grading, and treatment infrastructure at the point of supply.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT in order to streamline the writing process. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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