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PRODUCTION FEASIBILITY STUDY ON STUDS OF RECLAIMED TIMBER

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ABSTRACT: This study explores the feasibility of reclaimed timber as lamellae in glulam studs. Reclaimed timber was collected at a waste management site, cleaned and visually strength graded according to the Nordic INSTA 142 and the new Norwegian standard for visual strength grading of reclaimed timber, NS 3961. Seven protypes of glued studs with selected layers from reclaimed as well as reclaimed timber that was intentionally damaged in the laboratory, were produced and tested. Results indicate that visually graded reclaimed timber is of sufficient quality to be used as material in glulam production. The work described in this abstract is a part of the Norwegian Green Plattform Project "circWOOD", funded by the Norwegian Research Council (Project number 328698).

KEYWORDS reclaimed timber, visual strength grading, split glulam, industrial production, mechanical properties

1 – INTRODUCTION

The utilization of reclaimed timber has been a central research topic in Norway within the research project circWood [1]. This article describes the design, production and testing of glulam from reclaimed timber. The aims of the study were to grade reclaimed timber according to a national standard for visual grading of reclaimed timber, to evaluate the material's suitability for an industrial process and to document the strength properties of glulam with selected layers of reclaimed and artificially damaged reclaimed timber.

Timber is commonly used as load-bearing frame of buildings in Norway. Currently, circular use of building materials is receiving increased attention. The possibility of reclaiming the solid wood components after demolition is an opportunity to implement circular value chains in the forest industries and in the construction sector.

1.1 NORWEGIAN STANDARD FOR STRENGTH GRADING OF RECLAIMED WOOD

A Norwegian series of standards for evaluation and grading of reclaimed timber was published in 2025: NS 3691 [2]. Visual strength grading according to NS 3691, part 3, is based on INSTA 142 [3], the current standard for visual strength grading of softwood timber in the Scandinavian countries. The latter is supplemented by rules to address impurities like fasteners, concrete residues, biological decay and damages from previous use, such as cracks and holes. The rules in NS 3691 distinguish between structural and non-structural damage, holes with a diameter of 7 mm or less are considered non-structural [2].

By grading timber into the R-classes described in NS 3691 part 3 it is assured that this material meets current requirements for construction timber. The R-classes indicate characteristic values adapted for declared solid reclaimed wood: R14, R18 and R24 [2]. A general rule is that grading according to NS 3691 cannot upgrade timber compared to earlier strength grading results.

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In Table 1 the labels of the strength classes defined in NS 3691 are compared to strength classes defined in EN 338 [4] and INSTA 142 [3] sorted by bending strength, Modulus of Elasticity (MoE) (stiffness) and density.

Structural damage is accepted in strength classes R14 and R18 and indicated by addeing the letter "'s" indicates that the piece of timber has properties equivalent to higher strenght than indicated in the strength class, but is graded into a lower class due to a structural defect. As an example, a piece of timber graded as class R24 with a hole of 10 mm diameter on one of the edges will be downgraded to R18s.

It is important to note that R-classes may deviate from the characteristic properties given in NS-EN 338 [4]. For example, density is not considered when grading according to NS INSTA 142 or NS 3691-3. Therefore, visually graded timber can be free of knots or previous deterioration and achieve the highest strength class even if the density does not meet the characteristic value defined in NS-EN 338 [4].

Table. 1 Comparison of strength classes defined in NS 3691 [2[, EN 338 [4] and INSTA 142 [3].

NS 3691	R14	R14s	R18	R18s	R24
EN 338	C14	C18	C18	C24/C30	C24/C30
INSTA 142	T0	T1	T1	T2/T3	T2/T3

2 – BACKGROUND

Reclaimed timber differs from new timber due to its previous use, which introduces several concerns regarding its properties and performance.

2.1 MODULUS OF ELASTICITY (MOE)

Several studies conclude that the MoE remains unchanged or is minimally affected over time [5], [6]. Kránitz [7] found no significant change in the dynamic MoE of spruce from demolished buildings (120–250 years old) compared to newer samples. Tests were conducted using a three-point bending test on samples (20×20×400 mm) under standard conditions (20°C, 65% RH). An observation suggested an higher dynamic MoE for older spruce samples compared to newer ones., although this can only be considere a trend due to the high standard deviation (σ = 1496 N/mm²). Kránitz [7] also noted differences between test methods, with standardized bending tests being the most relevant. Ultrasonic and vibration frequency measurements often show higher elastic parameters due to simplified calculation methods.

Erhardt et al. [8] found no significant change in MoE between 18th-century Norway spruce samples and newer samples from the same geographic origin.

2.2 BENDING STRENGTH

More studies indicate reduced bending strength for aged wood, but consensus is lacking [5]. The study conducted on 120–150-year-old spruce samples showed a slight increase in bending strength for older samples. Llana et al. [9] found no significant difference in bending strength between tested beams of spruce and fresh wood, though their sample size (n=19) was limited. Contrastingly, Krajewski et al. [10] reported a 19% average reduction in bending strength for pine samples 250–500-year-old.

2.3 DURATION OF LOAD (DOL)

DoL effects on reclaimed wood are significant, often leading to a greater reduction in bending strength than in MOE [11]. Prolonged load can cause plastic deformation, altering molecular structure and reducing bending strength [7]. This phenomenon, known as creep, is exacerbated if wood dries under load. Niemz et al. [6] argued this is rare for solid and laminated wood, as construction timber typically operates at 10-30% of its maximum capacity. They recommend an initial reduction factor of 0.6-0.9 for load-bearing capacity if wood has been used continuously for over 20 years. Load effects are cumulative over time, meaning that intermittent and constant load durations have similar impacts[12].

2.4 BIOLOGICAL DEGRADATION

Biological degradation and rot are critical considerations for reclaimed wood. Brown rot can cause up to 80% of mass loss in the Northern Hemisphere [6]. Even a 10% mass loss from brown rot can reduce E-modulus and bending strength by up to 70%. The reduction in mechanical properties results from depolymerization of lignin and holocellulose components [13].

3 – PROJECT DESCRIPTION

The current study explores the possibility to include reclaimed timber in a glued laminated stud. Prototypes with different configurations of reclaimed timber and reclaimed timber with additional artificial damages were produced by bonding lamellae of reclaimed timber and Norway spruce graded C24. The resulting beams were resawn into two studs, as described in the national Technical Approval TG 20015 [14].

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3.1 EXPERIMENTAL DESIGN

A total of seven different prototypes were designed, six with different configurations of the reclaimed lamellae (Table 2, Figure 2), to challenge the limits set by NS 3691 [3] and in the national technical approval [14], and a reference.

Table 2: Description of prototypes

Prototype	Replicates	Description	Artificial damage	Strength class acc. to NS 3691-3	Damage exceeding requirements in	
					NS 3691-3	TG 20015
P1	10	1 butt joint in center lamella	Hole Ø 35mm	R24	X	X
P2	10	1 butt joint in center lamella	–	R18		X
P3	10	3 butt joints in center lamella	–	R24		X
P4	10	Continuous bottom lamella	Hole Ø 35mm	R24	X	X
P5	10	Continuous bottom lamella	Hole Ø 22mm	R24		X
P6	10	Continuous bottom lamella	2 lateral incisions in the bottom lamella	R24	X	X
P7	10	Reference according to TG 20015	–	C24		

4 – EXPERIMENTAL SETUP

Uncoated and none-impregnated pieces of reclaimed timber (RT) with cross-sections of 48 x 98 mm and a minimum length of 63 cm were manually selected at a waste collection site 40 km south of Oslo. Metal contaminations were removed on-site.

After visual strength grading according to NS-INSTA 142 [3] and NS 3691-3 [2], the RT was planed to lamellae of 34 mm thickness. Six different configurations of RT lamellae (P1 to P6) were prepared, all 250 cm in total length. Configurations P1-P3 and P4-P6 aimed at different set-ups of the center and bottom lamella, respectively. Defined mechancial damage was applied to some of the lamellae to reduce their mechanical capacity. Figure 1 shows damage being applied by drilling 35 mm holes for prototpype P4.

For the reference (P7), new spruce lamellae with a strength class of C24 were prepared.

All lamellae were planed to a final thickness of 32 mm one hour prior to the production of the glulam. A polyurethane adhesive was applied and the glulam beams were pressed with a pressure of 0.8 N/mm^2.

RT-lamellae with configurations P1, P2, P3 were used in the center lamella position of the respective prototype glulam, RT-lamellae with configurations P4, P5, P6 were used in the bottom lamellae of the glulam prototypes. The reference glulam P7 was produced according to the national techical approval [14] from new timber with strength class C24. Five pieces of reference glulam were produced per prototype.

After curing, each glulam beam was resawn into two studs named according to the prototype of the glulam. Thus, ten replicates of each prototype stud were produced (N=10). The studs were were subesquenlity planed to the final cross section.

Prototype studs P1, P4 and P6 (Figure 2) were chosen to challenge tolerances defined in NS 3691-3 [3], protype studs P1 – P6 were defined to challenge the national technical approval [14]. P7 did not challenge any technical documentation.

In P1 and P4, the diameter of the holes in the center and bottom lamellae, respectively, exceeded the maximum allowed diameter relative to the edge zone on a rectangular piece of timber. According to NS 3691-3 [2], the edge zone is "the area from each edge equal to the largest of (1/4 b, 25 mm)".

P2 complies with th national technical approval [14] and NS-EN 3691-3 [2]. The strength class of the middle lamellae, however, was R18 compared to R24 in the standard configuration of the stud.

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Prototype P3 was chosen to exceed the number of butt joints (1) allowed by the national technical approval [14].

The 22 mm holes in the bottom lamellae of P5 were within the allowed diameter relative to the edge zone on a rectangular piece of timber according to NS 3691-3 [2]. There the edge zone is defined as "the area from each edge equal to the largest of (1/4 b, 25 mm)".

The two lateral incisions in the bottom lamellae of prototype P6 challenged the ban of incisions defined in NS 3691-3 [2]

P5 was designed to resemble the maximum allowed hole diameter according to NS3691-3 [2].

The MoE, bending strength and density were determined according to NS-EN 408 [15]. The shear strength of the bond lines was assessed according to NS-EN 14080 [16].

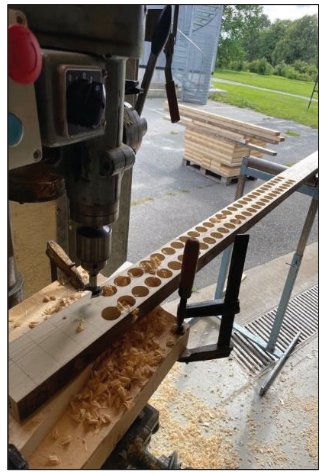

Figure 1. Preparation of lamellae for prototype 4 (22 mm holes)

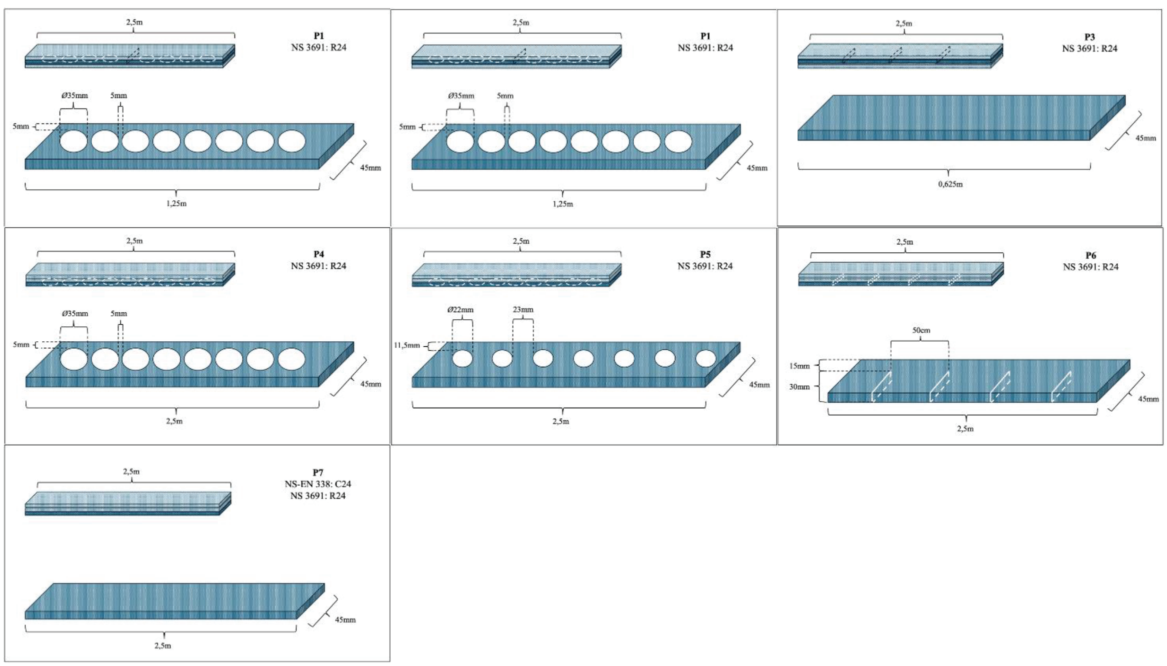

Figure 2. Design of specimencs P1 to P7.

5 – RESULTS

A total of 85 pieces of reclaimed timber were graded according to NS 3691 [2] and NS-INSTA 142 [3] for comparison. The grading results show a systematic downgrading of the best timber quality according to NS 3691-3 (Table 3). In general the quality of the reclaimed timber is good as more than 90% met the requirements of the two highest classes (Table 4). Experiences with the practical application of the new standard for reclaimed wood were positive. As with other visual standards, it requires training to become familiar with the evaluation criteria and to quickly distinguish between the various features and thresholds. Understanding the difference between structural significant and neglidgible damages required some time.

Ideally, the number of timber pieces assigned to each strength class should correspond between the

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standards. The results of this study confirm this. The only exception was timber graded T3, the highest strength grade in INSTA 142 [3], which were systematically downgraded to R24 according to NS 3691-3. This is due to the fact that NS 3691-3 is limited to strength class C24 by design.

For all samples in this study graded as R24 (N=50), 96% correspond to T2 or higher. For all samples graded as R18/R18s (N=10), 100% were graded T1 or higher.

5.1 MOISTURE CONTENT

The moisture content ranged from 12.5% to 14.8%, with an average of 14% (Figure 3).

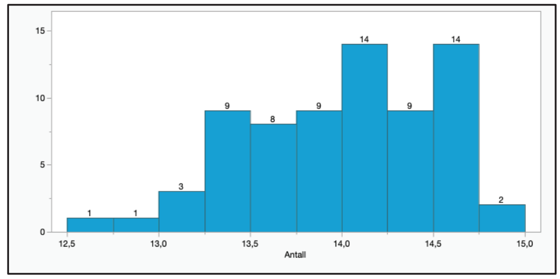

Figure 3: Moisture content for all samples

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Table 3: Grading results obtained according to different standards.

Specimen	NS3691	INSTA142	Stamp
1	R24	T2	C24
	R24	T2	C24
	R24	T2	C24
	R24	T2	C24
	R24	T1	N.A.
	R24	T1	N.A
	R24	T2	C24
	R24	T2	C24
	R24	T3	C24
	R24	T3	C24
2	R18	T1	N.A
	R18	T1	N.A
	R18	T3	N.A
	R18	T3	N.A
	R18s	T3	N.A
	R18s	T3	N.A
	R18	T1	C24
	R18	T1	C24
	R18	T1	N.A
	R18	T1	N.A
3	R24	T3	N.A
	R24	T3	N.A
	R24	T3	N.A
	R24	T3	N.A
	R24	T2	N.A
	R24	T2	N.A
	R24	T2	C24
	R24	T2	C24
	R24	T3	C24
	R24	T3	C24
4	R24	T2	C24
	R24	T2	C24
	R24	T3	N.A
	R24	T3	N.A
	R24	T2	N.A
4	R24	T2	N.A
	R24	T2	N.A
	R24	T2	N.A
	R24	T3	N.A
	R24	T3	N.A
5	R24	T2	N.A
	R24	T2	N.A
	R24	T2	C24
	R24	T2	C24
	R24	T2	N.A
	R24	T2	N.A
	R24	T2	N.A
	R24	T2	N.A
	R24	T3	N.A
	R24	T3	N.A
6	R24	T2	N.A
	R24	T2	N.A
	R24	T3	N.A
	R24	T3	N.A
	R24	T2	C24
	R24	T2	C24
	R24	T2	N.A
	R24	T2	N.A
	R24	T2	C24
	R24	T2	C24
7	–	–	C24
	–	–	C24
	–	–	C24
	–	–	C24
	–	–	C24
	–	–	C24
	–	–	C24
	–	–	C24
	–	–	C24
	–	–	C24

5.2 MODULUS OF ELASTICITY

Mechanical properties are shown in Table 4. A one-way ANOVA analysis (Figure 4) shows the observed MoE for all samples. There was a statistically significant difference in MoE between at least two sample types ($F=40.27$; $p<0.001$).

5.3 BENDING STRENGTH

A one-way ANOVA analysis (Figure 5) shows the observed bending strength for all sample types. There was a statistically significant difference in bending strength between at least two sample types ($F=28.45$; $p<0.001$).

Table 4: Mechanical properties of the prototypes

Protoype	MoE (kN/mm^2)			Bending strenght (N/mm^2)			Density (kg/m^3)		
	$E_{m, g, mean}$	$E_{m, s}$	$E_{m, 0,05}$	$f_{m, mean}$	$f_{m, s}$	$f_{m, 0,05}$	$\rho_{t, mean}$	$\rho_{t, s}$	$\rho_{t, 0,05}$
1	9.7	1.1	8.9	29.2	5.3	24.9	453	33	430
2	11.3	1.4	10.4	50.6	10.8	42.9	442	38	415
3	11.4	1.1	10.7	49.8	6.6	45.0	444	30	422
4	6.1	0.7	5.5	23.4	6.7	18.5	423	22	407
5	8.1	1.0	8.1	31.9	5.1	28.3	445	30	423
6	10.1	0.6	9.6	30.4	6.1	25.9	462	16	451
7	11.8	0.8	11.3	54.2	9.1	47.7	459	21	444
Total	9.8	1.0	9.2	38.5	7.1	33.3	447	27	427

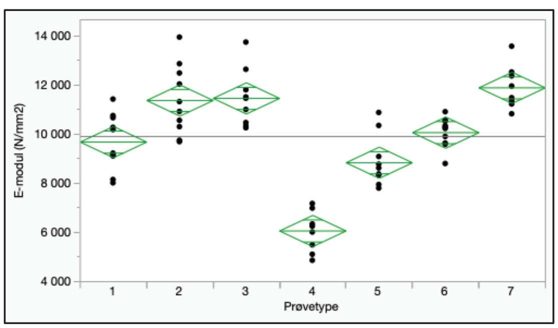

Figure 4: Modulus of elasticity (vertical axis) of the individual samples of the protoypes (horisontal axis).

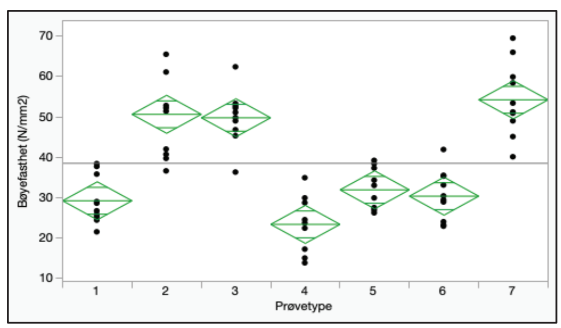

Figure 5:Bending strength (vertical axis) of the individual samples of the protoypes (horisontal axis).

6 – CONCLUSION

Reclaimed timber (RT) can be used in selected layers of glulam to supplement new timber without adjustments of the industrial production process.

The high quality of the RT collected at the waste collection site site implies a high commercial value of the material itself. However, lack of infrastructure for

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processing of RT (e.g. selection, cleaning, grading and transport) might raise the costs for ready-to-use RT above those for new timber.

In general RT without large defects, such as cracks/checks, incisions, holes or biological degradation, has strength properties that reflect strength grading of the new timber.

Laminated studs from visually strength graded RT has similar properties to laminated studs made of new timber. The use of severely damaged RT on the tension side of a gluelam stud will result in failure to meet relevant strength requirements.

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