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DEVELOPMENT OF A PRELIMINARY, USAGE SPECIFIC PRODUCT DOCUMENTATION FOR RECLAIMED GLT – A NORWEGIAN CASE STUDY

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ABSTRACT

Background and aim. The paper aims to collect background information about the production of glued laminated timber (GLT) in Norway and to suggest content for usage specific product documentation for GLT intended for reuse based on laboratory work combined with practical experience from two case studies.

Methods and Data. Bond line quality in reclaimed GLT was assessed by testing the resistance of delamination. Adhesive systems were tentatively identified using stained microscopy sections and FTIR spectroscopy.

Findings. The paper illustrates the consequences of the youngest industrial history from the wood working industry in Norway for the reuse of glued laminated timber in load bearing applications. It shows difficulties with on-site evaluation of building products and points out the conflict between desired comprehensive knowledge of properties of reclaimed building elements and the need to keep destructive testing at a minimum.

Theoretical / Practical / Societal implications. The authors consider the findings of the paper practically relevant as they show the complexity of evaluating the reuse potential of a relatively simple building product. At the same time, they propose a solution for how this complexity can be overcome by suggesting test methods and deriving categories for usage specific product documentation.

KEYWORDS: Glued laminated timber, delamination, adhesives, casein, documentation

1 INTRODUCTION

Glued-laminated timber (GLT) is a type of engineered wood made by bonding together finger-jointed lamellae under pressure to form a large structural component. GLT is widely used in building applications such as columns, beams, and arches in mid to high-rise public, private and commercial structures. Due to the high added value compared to structural timber, sophisticated design, the high adhesive costs and the amount of stored carbon, GLT is considered highly relevant for reuse. However, architects and planners will need product documentation to include reused GLT in new structures. This paper describes specific criteria and methods to investigate reclaimed GLT with the aim of collecting information as a basis for issuing usage specific product documentation. A comprehensive outline of the history of adhesive utilization in Norway is compiled as framework for the investigations, which include state-of-the-art laboratory methods and practical experience. Compared to the mind map based holistic approach described by Yahmi et al. (2023), the current study breaks down the considerable list of material-related barriers for reuse into a clear list of criteria tailored to the specific situation in Norway,

1.1 BACKGROUND

GLT consists of strength-graded according to NS-EN 14081, finger-jointed lamellae, typically made of spruce in the Nordic countries, and can be produced in various shapes and sizes. It can be adapted to all types of load-bearing structures due to its variable cross-section and good formability. The requirements to timber used in the production of GLT, to adhesives and overall quality of GLT are defined in NS-EN 14080.

From a production standpoint, it is easier to manufacture GLT from spruce than from pine, which has a lower resin content. Impregnated pine lamellae are used in structures expected to be exposed to significant moisture variations. These lamellae undergo a moisture increase during the impregnation process, followed by drying, which can affect the bonding quality. A distinction is made between homogeneous GLT (where all lamellae have the same strength class) and combined GLT (where the best-quality lamellae are placed in the outer parts of the cross-section). Combined GLT optimizes the yield from the timber resource and is therefore the most common type. The product standard NS-EN 14080 requires that the moisture content of all lamellae in a GLT cross-section be within 6-15% at the time of production, with a maximum 5% moisture variation between lamellae being bonded together. This ensures optimal bonding conditions and minimizes stresses that could lead to cracks. Some small cracks are expected, but they rarely affect the load-bearing capacity of GLT.

Reusing GLT can be expected to significantly contribute to both environmental sustainability and societal well-being by reducing the demand for virgin materials and minimizing construction waste. While research specifically focused on glulam reuse is not available yet, more general studies on timber reuse list environmental benefits—such as lower greenhouse gas emissions, reduced energy consumption, and prolonged material life cycles. For example, the deconstruction and reuse of timber elements in buildings can result in nearly zero CO_2 emissions, largely due to wood's carbon sequestration capabilities and optimized end-of-life strategies (Di Ruocco et al., 2023).

1.2 ASSESSMENT OF GLT PRIOR TO DISASSEMBLY OF CONSTRUCTION

1.2.1 Lamellae in GLT

Lamellae used in the production of GLT are usually strength graded. It is not possible to assess the strength class of the lamellae in a beam because only the sides of all lamellae are visible. If there is uncertainty regarding the strength classification of the lamellae, it is advisable to grade conservatively and assume a lower quality than what was standard at the time of production if the visual impression implies this.

Cracks in lamellae due to drying or internal stresses are not considered to affect the load-bearing capacity of the GLT. However, mechanical damage of lamellae should be considered as reducing the GLT's capacity and must be deducted from the cross-section used as a basis for evaluating its strength class.

1.2.2 Finger joints

A comprehensive inspection of finger joints is not practically possible. However, the finger joints in the top and bottom lamellae of the GLT can provide an indication of the quality of the finger joints throughout the entire GLT structure. General requirements to finger joints according to NS-EN 14080 are:

- Finger joints must not contain knots with a diameter greater than 6 mm or grain deviation
- The distance between knots larger than 6 mm in diameter and the finger joint must be at least three times the knot diameter.
- There should be no gaps between the fingers that are not filled with adhesive.

1.2.3 Bond lines

The bond lines must be tight to ensure the proper transfer of stress between the lamellae. Open bond lines indicate ageing of the adhesive and/or high internal stresses in the GLT. Open bond lines in newly produced GLT are obvious production failures, and a GLT beam with open bond lines would not pass the producers' quality control. Therefore, open bond lines disqualify reclaimed GLT for the use in load-bearing constructions. Thus, they must be repaired before the GLT can be used again.

1.2.4 Other criteria

For surface-treated GLT, the ability to inspect the material before and after disassembly is reduced. Still, it is unlikely that the surface treatment itself would prevent the reuse of GLT. Lead paint is the only surface treatment hazardous to health that has been used in Norway. However, it has been banned in 1929 (Lovdata, 2025) – about 29 years before the first production of GLT in Norway in 1958 (NLF, 2015). Therefore, this type of paint is considered unlikely to be found on GLT potentially available for reuse in Norway today.

If the GLT is made from impregnated wood, a chemical analysis of the lamellae must be performed to determine whether they were treated with a preservative containing chromium or arsenic**.**

The emissions from cured adhesive, regardless of adhesive type, are not harmful to health.

1.3 EVALUATION FOR RE-USE

GLT consists of lamellae made from finger-jointed lumber. Wood is known to react to moisture through dimensional changes. Such changes can create a dynamic stress pattern in the GLT, where the extent of the stress depends on indoor climate conditions and how they fluctuate throughout the year. If the movements become too large, joints, connections, and bond lines may be affected over time.

Climatic stresses such as temperature, rain, wind, and snow will influence the GLT and can reduce its capacity over time. Additionally, design rules and snow load requirements might have changed compared to those valid when the original structure was designed. This must be considered when assessing GLT for reuse. Thus, it should be assumed that the product would need reinforcement to fully utilize its span, even if it is in good condition.

For untreated GLT, fire resistance can be assumed to be equivalent to untreated wood (D-s2, d0). If the GLT is impregnated or surface-treated, the type of impregnation and/or treatment must be identified to obtain information on its fire resistance.

Cracks that weaken the GLT's capacity can be repaired using approved adhesives. Currently, epoxy or

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polyurethane adhesives are commonly used for on-site repair of timber structures. Requirements for these adhesive types are specified in NS-EN 17418.

1.3.1 Original documentation

Original labelling facilitates the most efficient reuse since the properties of the specific GLT are either included in the label or can be relatively easily obtained by contacting the manufacturer or institutions involved in the relevant control scheme during the production period.

1.3.2 Assessment of load history

The load history of a structure is important to determine the probability that the construction has been exposed to loads exceeding its designed capacity. Potential overloading, such as heavy snow loads, may weaken joints or the GLT itself, which could reduce the residual capacity compared to the originally designed capacity. This assessment is the least reliable, as it is difficult to get a complete picture of the structure's load exposure over time.

1.3.3 Identification of the adhesive

The type of adhesive used in the production of a GLT beam is crucial to determine whether the beam can be reused in a load-bearing structure. This is because some adhesives that were commonly used in Norway in the early days of GLT production are no longer permitted for use in modern GLT manufacturing.
If this information is not part of the labelling or available from other sources, the color of the bond line becomes an important criterion.
Dark brown/black glue lines indicate the use of phenol-resorcinol (PF) or phenol-formaldehyde-resorcinol (PRF) adhesives (Hunt et al. 2018), which are known for their durable bond lines and thus high value for the reusability of GLT. This type of adhesive is approved for the production of load-bearing GLT according to current standards.
Light-colored bond lines may indicate the use of casein adhesive, which is protein-based and derived from milk. Casein adhesive was the only adhesive system available for GLT production in the Nordic region until World War II. Since casein adhesive is not moisture-resistant, it was only used in GLT constructions for indoor applications. It is not approved for the production of load-bearing GLT structures today.
Urea-formaldehyde (UF) adhesive also results in light-colored bond lines and is covered by NS-EN 14080. Currently, there is no UF adhesive approved for load-bearing GLT structures, but UF adhesive was previously commonly used in GLT for climate classes I and II.
Other adhesives that produce light-colored glue lines, such as MF (melamine-formaldehyde), MUF (melamine-urea-formaldehyde), polyurethane (PUR), and emulsion-polymer isocyanate (EPI), are approved under NS-EN 14080 and can be assumed to have met the requirements for adhesives approved for GLT at the time of production.

1.3.4 Suggestions for characterizing reclaimed GLT by testing

The testing requirements should depend on the available documentation for the product. CE-certified GLT is assumed applicable for load-bearing structures without further testing if the load history assessment does not indicate that the GLT's capacity was overutilized in previous use.
For older GLT or GLT that is believed to have been overutilized in a previous application, testing of the bond lines should be mandatory.
Testing the capacity of finger joints requires the removal of large sections from a beam, making it impractical. Instead, a visual assessment of the visible finger joints as outlined above should be decisive.
The capacity of the glue joints between lamellae, however, can be tested with a relatively small sample extraction. NS-EN 14080 specifies different testing requirements depending on the service class in which the GLT beam will be used:

- For service classes 1 and 2, the shear strength of the glue joint under compression is required.
- For service class 3, the resistance to delamination must be tested within the limits defined by the standard.

A scaled test program consisting of shear strength testing and assessing the resistance to delamination, depending on intended future use of the GLT, is assumed to provide necessary information for the classification of GLT for reuse.

2 MATERIAL AND METHODS

Two sets of sections from glued-laminated timber (GLT) beams, I and II, both recovered during the deconstruction of public buildings in the vicinity of Oslo, were used in this work. All samples were cut from full sized GLT beams which had been transported to intermediate storage locations in the Oslo region.

2.1 MATERIAL

The first set of sections (I) consisted of 19 GLT samples (A-S) from beams presumably produced in 1967-1969 used in the roof of the old Aker hospital. The beams had cross sections of GLT 450-650 mm x 120-200 mm (h x w) consisting of 14, 21 or 18 lamellae with corresponding 13, 20 or 17 light-coloured bond lines.

The second set of sections (II) consisted of four GLT samples (A-D) from beams produced in 1963, used in the roof of the old gymnasium "Rykkinnhallen". The beams had a cross-section of 90 x 633 mm (h x w), each consisting of 19 lamellae and corresponding 18 dark-coloured bond lines. The two upper lamellae in section A had been damaged during the deconstruction of the building, the corresponding bond lines were therefore excluded from the investigations.

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2.2 METHODS

2.2.1 Assessment of bond line quality

The bond line quality of the samples was investigated by assessing the resistance to delamination of the bond lines according to NS-EN 14080, method B. For this, a 75 mm wide sample was taken from each section. The number and total length of the bond lines per sample was recorded before the samples were impregnated with water and subsequently dried to approximately their original mass. Immediately after reaching the final mass, the length of the openings per bond line was recorded and the delamination calculated as percentage of the total bond line length.

2.2.2 Identification of adhesives

The identification of the light-coloured adhesive present in set I was important to find out if the GLT was bonded with UF or casein adhesive. MUF would have also resulted in a light-coloured bond line but this adhesive type was first used in the production of GLT in Norway in the 1980's (Treteknisk, 1999) and is therefore not an alternative for the beams of set I produced before 1970.

UF adhesives are covered by NS-EN 14080 and would potentially allow the re-use of the GLT in load-bearing application in service class 1 and 2 (NS-EN 1995-1-1), casein has never been covered by EN 14080 and would exclude the GLT for any load-bearing application. FTIR-spectroscopy was applied to identify the adhesive type used.

Samples from the hardened adhesives from set I and II, a UF- and a PRF reference were ground with mortar and pestle. The samples were analyzed with a FTIR spectrometer (Cary 630 FTIR spectrometer (Agilent Technologies, Inc., USA)) with a diamond ATR (Agilent Technologies, Inc., USA). The results were analysed with the software MicrolabExpert (Agilent Technologies, Inc., USA). An ATR correction was conducted prior to a 2-point base line correction for all spectra.

FTIR is a widely available technology frequently applied for the identification and investigation of wood adhesives and their curing reactions. However, the results of the FTIR-analysis did not allow a clear identification of the adhesive sample from the light bond line as either UF or casein. Therefore, ninhydrin was applied to indicate amino acid components (Lennart, 2005) present in casein adhesives but absent in UF-adhesives. A 70 µm thick section of a light-coloured bond line from section set I was prepared on a sliding microtome, stained with an aqueous solution of ninhydrin and dried at room climate for 16 hours. Light microscopy at 10x magnification was conducted on an Olympus BX60 (Olympus Europa SE & Co. KG, Germany).

Given the background information in this study, ninhydrin staining would have been sufficient to distinguish between the two relevant types of adhesive.

3 RESULTS

3.1 BOND LINE QUALITY

The bond line quality of set I (average delamination of 14.8 %) was significantly lower than the bond line quality of set II (average delamination of 3.1 %) (Table 1).

For set I, only samples J, R and S fulfilled the delamination requirement of maximum 4 % delamination after one test cycle, and maximum of 8 % delamination after two test cycles given in NS-EN 14080. The resistance to delamination for all samples from set II was better than the requirement of maximum 4 % delamination after one test cycle given in NS-EN 14080.

Table 1: Results from testing the bond lines' resistance to delamination

Set	Sample	Number of bond lines	Total delamination	
			[mm]	[%]
I	A	13	793	24.4
	B	13	234	7.2
	C	13	421	13.0
	D	13	356	11.0
	E	13	229	7.0
	F	13	277	8.5
	G	13	281	8.6
	H	13	528	16.2
	I	13	503	15.5
	J	13	106	3.3
	K	20	496	16.5
	L	20	1101	36.7
	M	20	714	23.8
	N	20	882	29.4
	O	20	263	8.8
	P	20	722	24.1
	Q	20	582	19.4
	R	17	267	3.9
	S*	17	445	6.5
II	A	16	50	3.0
	B	18	63	3.9
	C	18	38	2.3
	D	18	51	3.1

3.2 IDENTIFICATION OF ADHESIVE

3.2.1 FTIR spectroscopy

The FTIR-spectra for the light-coloured adhesive from set I and a reference UF-sample are shown in Figure 1. The black line for the spectra of set I shows the characteristic vibrational bands and 2920 and 2850 cm^{-1} linked to the higher concentrations of CH_2-groups in amino acids (Ptiček and Siročić, 2017). As expected the vibration peak of carbonyl groups was found between 1300 and 1100 cm^{-1} and at 1652 cm^{-1} (Ptiček and Siročić, 2017). Typical casein peaks, according to Ptiček and Siročić (2017), that were absent in our spectra are those

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linked to amide stretching at 1585 cm^{-1} and the ones resulting from carbonyl groups (C=O) in the range of 1725-1750 cm^{-1}.

The spectra of the UF-adhesive show the band of N-H stretching of secondary amines around 3300 to 3350 cm^{-1}. The stretching of carbonyl groups (C=O) and C-N-stretching of secondary amines are represented by the peaks at 1632 and 1550 cm^{-1}, respectively (Liu, 2017). The band at 1380 to 1330 cm^{-1} is assigned to -CH_2OH groups in UF resins, the peak at 1130 cm^{-1} illustrates the C-O aliphatic ether (Singh et al., 2014).

The spectrum of the adhesive from set I suggests that the adhesive is based on casein rather than UF. To invalidate the uncertainties linked to the described absences of some typical casein peaks, the bond line will be investigated using a staining solution and light microscopy.

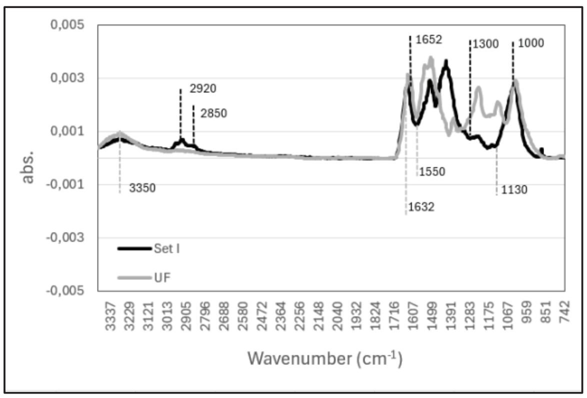

Figure 1: FTIR-spectra of adhesive sample from set I (assumed casein) and of reference UF-sample.

The dark-coloured bond lines in the samples from set II indicate a phenolic adhesive. The FTIR-spectra from the adhesive found in the bond line from set II (black line) and the spectra of the PRF-reference are shown in Figure 2. Both profiles show peaks at the characteristic bandwidths of 1595 cm^{-1} and 1500 cm^{-1} which are assigned to the C=C aromatic rings that are embodied into the cured adhesive (Özparpucu et al., 2022). The peaks in the spectral range between 1500 to 1310 cm^{-1} are related to the methylene and methyl groups of the adhesive (Alpert et al., 2012) which are a part of the methylene bridges between phenol-resorcinols (Poljansek and Krajnc,2005). The peak at 1085 cm^{-1} has been described by Poljansek and Krajnc (2005) and Bobrowski and Grabowska (2015) as linked to the ether bridges between methylol groups developed during condensation reactions. Thus, the adhesive used in set II is identified as PRF.

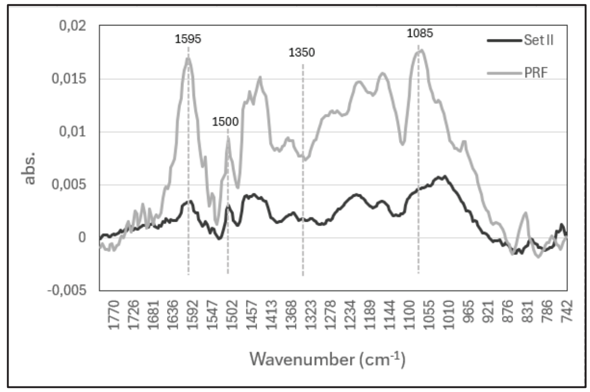

Figure 2: FTIR-spectra of adhesive sample from set II (assumed PRF) and of reference PRF-sample.

3.2.2 Light microscopy

The light-coloured bond-lines in the samples from set I indicate a casein or UF type adhesives. The color reaction of the bond line stained with ninhydrin (Figure 3) proved the presence of proteins, confirming the use of a protein-based adhesive, in this case casein, and excludes an UF adhesive which does not contain proteins.

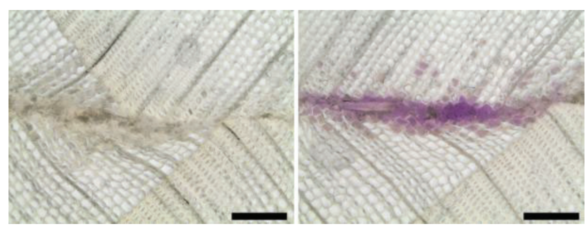

Figure 3: Microscopy images (10x magnification) of a light-coloured bond line in a sample from set I before (left) and after staining with ninhydrin (right). Scale bar 200 µm.

Taking into consideration the widespread application of casein adhesives in the GLT during the relevant period (Treteknisk, 1999), we assume that the GLT beams in set I are bonded with a casein adhesive.

3.3 DISCUSSION

The investigations of samples from set I showed low resistance to delamination for the samples from set I and proved that the GLT was bonded with a casein adhesive. Samples from set II showed high resistance to delamination, the relevant adhesive was identified as PRF.

Casein adhesives are also known to fail in the presence of water. Thus, the high delamination values for set I can most likely be explained by the use of a casein adhesive. PRF adhesives on the contrary are known for their excellent water resistance. Thus, the low delamination values for the samples from set II is characteristic for this type of adhesive.

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Besides the diverging moisture resistance of the two adhesive types, intense tensions in one of the sample sets due to pronounced changes in moisture content during the service life or weakening of the timber close to the bond line by wood destroying organisms could explain the difference in resistance to delamination (Yahmi et al., 2023). The former would manifest itself in widespread cracking in the lamellae which would have been detected during preparation of the samples. The latter requires wetting of the GLT over elongated periods of time, accompanied by obvious discoloration of the lamellae and macroscopic alterations in the wood structure. Also these signs of damage would have been visible during sample preparation.

Another reason could be ageing of the bond lines. Still, both adhesive types have shown high reliability in application and long-term investigations (Deppe and Schmidt, 1994, Raknes, 1997).

Therefore, the differences in resistance to delamination between set I and II can be explained by the inherent difference in moisture resistance of casein and PRF adhesives.

3.4 SUGGESTIONS FOR A USAGE SPECIFIC PRODUCT DOCUMENTATION FOR RECLAIMED GLT

The reuse of GLT beams in load bearing applications requires the structural integrity of the beams, reliable bonding and sufficient capacity to carry the loads in the future applications.

A usage specific product documentation should show relevant national building codes and product standards applicable to the actual material, e.g. NS-EN 14080 for GLT beams. Furthermore, essential conditions and properties for the intended use should be listed (service class, cross-section, strength class and outer appearance).

The fulfillment of these usage-specific requirements should be documented by the seller, based on test reports from experts.
In this context it is important that destructive testing should be reduced to a minimum, of course within the limits of responsibility.
As mechanical testing will lead to the destruction of entire beams, the focus of an assessment should be on

- visual evaluation of the general condition of the beam and the quality of the lamellae and finger joints.
- conservative reduction of load bearing capacity in case of mechanical damage.
- scaled extend of service class specific testing of bond lines according to standard tests defined in NS-EN 14080.

Since the beams of sets I and II were produced before the product standard for GLT, NS-EN 14080 was in place, all three requirements need to be fulfilled. The investigations in the current paper address the aspect of reliable bonding only. The bonding of beams of set I is found not to fulfil today's requirements, the bond lines of samples from beams of set II, however, yielded sufficient resistance against delamination to allow the reuse of the GLT in load bearing applications in all service classes.

4 CONCLUSIONS

This paper compiles background information relevant for the assessment of reclaimed glued laminated timber (GLT) for reuse. It gives an overview over adhesive systems applied in the production of GLT in Norway, gives examples for the analysis of bond line quality and identification of relevant adhesive systems based on two national case studies and concludes with recommendations for a usage specific product documentation for the reuse of GLT.

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