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Advancing Timber for the Future Built Environment

REUSE: GUIDELINE ON THE ASSESSMENT OF THE TECHNICAL INTEGRITY OF DISASSEMBLED TIMBER MEMBERS

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ABSTRACT: The transition towards a circular construction sector necessitates the safe and regulated reuse of structural timber products. Ensuring the technical integrity of disassembled timber members is crucial to fostering confidence in their reuse. This paper presents key findings and methodologies for assessing the mechanical properties of reclaimed timber members, emphasizing non-destructive testing (NDT) techniques. The result of this research is a comprehensive guideline for evaluating used timber members towards their second structural life. Additionally, it introduces classification methods and adapted design approaches to account for prior load history. By establishing a structured framework for the reuse of timber members, this research aims to contribute to the advancement of sustainable construction practices and the broader adoption of circular economy principles in the timber industry.

KEYWORDS: timber, glulam, reuse, guideline, non-destructive testing

1 – INTRODUCTION AND MOTIVATION

Degradation of building materials during service life is unavoidable [1]. Hence, the extent of degradation is one of the key questions for any professional involved in the in-situ assessment of structural members. Numerous examples demonstrate that timber can remain structurally intact for several hundred years if kept dry. Timber is therefore a suitable material for circular construction. A prerequisite for this is the verification of structural integrity and appropriate refurbishment prior to second use.

Circular and environmental-friendly construction is indispensable in order to achieve climate policy goals. Consequently, the cautious use of materials, the exploitation of recycling potential, and the reuse of suitable building products, such as timber members, become increasingly important. Although numerous studies have been realized in view of this objective over the last decade, see e.g. [2], implementation in practice is not yet gaining momentum. Towards this aim, the Ministry of Regional Development and Housing Baden-Württemberg funded a project that resulted in a technical guideline to enable a safe and regulated reuse of specific construction products from timber and steel. Key results of this project, realized by the two institutes represented by the authors, are presented in this paper.

In the following chapters, the content of the guideline will be presented. The guideline includes a general, material-independent part, followed by material-specific annexes. This paper presents the complete content of the timber-specific annex while summarizing key aspects of the main part.

Background information relevant to the understanding of the provisions is presented in italics for improved comprehensibility. Due to space constraints, only selected background information can be provided, primarily focusing on new technical approaches developed in this study, i.e. visual grading supported by devices and adaption of the modification factor for reuse. For an overview of the full background, it is referred to the final report [3].

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GUIDELINE FOR THE REUSE OF STRUCTURAL TIMBER PRODUCTS

2 – GENERAL

The general part of the guideline outlines the process for obtaining technical approvals for reused structural products under German building law, followed by definitions of key terminology.

The general part of the Annex "Material-specific requirements for timber structures" clarifies that this guideline is applicable to the following structural timber products from softwood.

- Sawn timber (without finger joints[5]).
- Glued laminated timber (without universal finger joints[5]) - this excludes glued laminated timber with urea-formaldehyde (UF) glue. *See also [4]. UF glue was used in Germany in the years 1950 to 2007.*
- Combined components made of glued laminated timber (exclusion criterion as above[5]) and sawn timber
- OSB panels (not covered in this paper)

3 – ASSESSMENT OF EXISTING BUILDING

3.1 GENERAL

The chapter "assessment of existing building" in the main part of the guideline describes the procedure for this assessment and gives key information that should be obtained during a preliminary assessment (of available planning documents and technical documentation). This is supplemented by a paragraph on handling suspected contamination by hazardous substances. If a decision is made in favour of reusing structural products, key information that should be obtained or verified (against the planning documents) during a detailed in-situ assessment is given. These steps include an assessment of the reversibility of connections and hence the potential for damage-free disassembly. This is supplemented by recommendations on the necessary qualification of the person carrying out this assessment. The timber specific requirements for this assessment as given in the Annex to the guideline are given in the following.

3.2 PRELIMINARY ASSESSMENT

The following extreme actions, effects and condition characteristics prohibit the reuse of affected timber members or affected parts thereof in connection with this guideline:

- Damage caused by fire – if charring of more than d_{char} = 5 mm has occurred
- Damage caused by seismic actions or accidental actions such as explosion or impact
- Extensive destruction of wood structure, e.g. from insects or decay
- Fiber fracture
- Crushing of fibers in and perp. to grain direction
- Glued members with adhesives of adhesive type II according to EN 301 [5]
- Indications of improper bonding (e.g. bondline thickness exceeds limit values, improper finger joint pattern in the laminations)

3.3 DETAILED ASSESSMENT

Tab. 1 lists relevant characteristics for the assessment of timber members that should be taken into account in the assessment by a competent person / expert. *(Background information: a competent person could be civil engineers or architects with more than 5 years experience in related field; an expert could be check engineers, publicly appointed experts, and civil engineers with 10+ years experience in related field, see [6] for details).*

Table 1: Assessment characteristics for the reuse of timber members

Features	Indications
surface	- surface contamination - discoloration, graying - paint, wood preservative - moisture accumulation spots (from existing or past moisture accumulation) - mold, algae - soot deposits, burn marks, charring
rot/corrosion insect attack	localized or extensive destruction of the wood structure
deformation a) designed b) unplanned	a) precamber (global) b) deflection (global) - twisting (global) - buckling (global) - deviations from straightness (global) - curvature (global/local) - deformation (local)
cracking	detectable in: - wood - bondline

[5] *For finger-jointed solid timber and glued laminated timber with universal finger joints, the specifications should be supplemented by specifications for the assessment of finger joints.*

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Features	Indications
adhesive	adhesive type (information on the adhesive that allows conclusions about possible bonding with casein or urea formaldehyde)
weakening of the cross-section	e.g. drill hole, hole, cut-outs, notches and mortises
defect (damage)	e.g. fiber fracture, crushing of fibers in and perp. to grain direction, e.g. from impact
wear and deterioration	localized or extensive material removal
Hazardous substance / wood preservatives (WP)	in case of suspicion, analysis for: - Arsenic (active substance in WP) - Copper (active substance in WP) - Mercury (substance in WP - Lead (color pigments in paints) - Chromium (color pigments in paints, WP) - Chlorine (PCB) (flame retardant in paints and varnishes, follow PCB directive) - Fluorine (active substance in WP) - PCP (pentachlorophenol) (active substance in WP, follow PCP guideline) - Lindane (HCH) (active substance in WP) - DDT (active substance in WP) - Tar oil (PAH) (active substance in WP)

The final dimensions and deformations of the members should be measured after disassembly. Printed or imprinted marks are often present on structural and finger-jointed timber used in non-visible applications.

Glulam has been graded during production. Permanently legible markings on the surface of glued laminated timber or documentation such as delivery notes or the gluing book ideally provide information on the strength class.

Timber often shows superficial signs of weathering and wear (small shrinkage cracks, graying, washing out). Therefore, the appearance should not be the sole basis for the decision.

4 – DISASSEMBLY

The following steps should be carried out or accompanied by a competent person in the order indicated, see also flow chart in Fig. 1:

1. In suspected cases, a material analysis (exploration for contamination and impurities), depending on the quantitative and qualitative reuse potential, e.g. by an accredited testing laboratory in the form of sampling in the laboratory on the basis of drill cores or by a mobile laboratory unit. *Background: in Germany, timber members were predominantly treated with wood preservatives until the year 2000.*
2. Decision for or against careful disassembly, taking into account the reversibility of fasteners
    a. In the event of a decision against → dismantling/selective dismantling
    b. In the event of a decision in favour → continue with step 3
3. Determination of quantity, timber quality, fasteners used
4. Organizational, technical and manual planning and execution of disassembly. The timber members shall be protected against precipitation at all times.
    a. Transport to a center for secondary raw materials, to a dealer for building materials, to a covered interim storage facility or similar for further assessment and refurbishment.
    b. Direct transport to a construction project after in-situ assessment and possibly in-situ refurbishment.

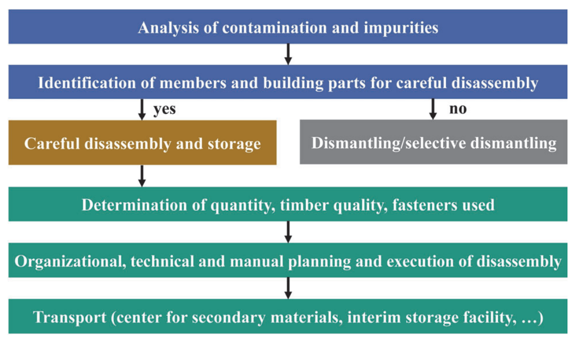

Figure 1: Steps for careful disassembly and recovery

If necessary, the disassembly concept should be supplemented by static verifications of specific states of disassembly. Companies carrying out the disassembly should provide evidence of related experience.

5 – ANALYSIS OF PHYSICAL AND MECHANICAL PROPERTIES

5.1 GENERAL

Physical and mechanical properties can be assessed using non-destructive, semi-destructive, or destructive testing methods. Non-destructive and destructive testing should be seen in the context of four different negative influences on the initial technical integrity of the timber members*, see Fig. 2 (background information)*. As far as possible, only degradation caused by natural effects should be quantified by testing (non-destructive or destructive). Degradation caused by non-intended effects, due to disassembly and transport and weakening due to processing for first use should be considered separately, see levels 2 and 3 in Fig. 3.

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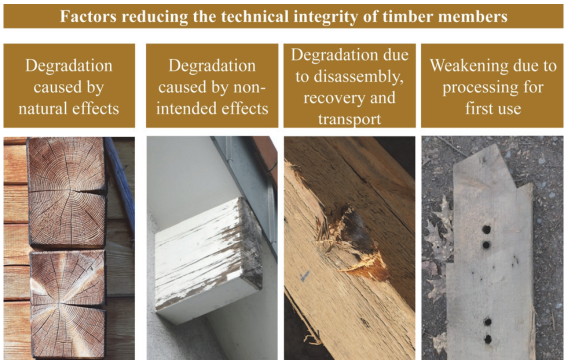

Figure 2: Exemplary illustration of factors reducing the technical integrity of timber members

5.2 DESTRUCTIVE TEST METHODS

To maximize the reuse of timber members, semi-destructive (see section 5.3) or, preferably, non-destructive testing methods (see 5.4) should be used.

In exceptional cases, destructive testing methods may be considered. These are suitable if a sufficient number of similar members are recovered (large collective) and therefore a part of them can be tested destructively. EN 408:2012-10 [7] should be used to determine the local modulus of elasticity in bending and the bending strength parallel to grain. The selection of specimens and the definition of locations to be tested should be such that they are representative of the recovered collective. At least 40 test specimens should be provided for a random sample. In case of small variability in density, strength and modulus of elasticity, the sample may be reduced to minimum 20.

5.3 SEMI-DESTRUCTIVE TEST METHODS – DRILL CORES

Drill cores can be taken to determine wood species, local density, type of adhesive, quality of adhesive bonds according to EN 14080:2013-09 [8] (shear tests – Annex D, delamination tests – Annex C), type of surface treatment and potentially the mechanical properties of small clear specimens. They are also suitable (e.g. in case of a large amount of members) to assess the general condition of the wood at locations representative of the entire member.

Diameters between 10 and 40 mm can be chosen, whereby a diameter of 35 mm (outer diameter of drill bit 50 mm) is established. Drill core extraction for testing should not compromise the reuse potential of the timber member.

Depending on the objective of the assessment, a distinction is made in terms of area of extraction of drill cores:

1. If the effects of degradation caused by natural effects or high stresses are to be quantified, drill cores should be taken in the corresponding areas. After core removal, the drill holes shall be completely sealed with suitable wood cylinders corresponding to the grain direction of the surrounding wood and bonded in such that the effects of the core removal are minimized.
2. If information on the wood species, local density, type of adhesive, quality of adhesive bonds, local shear strength, surface treatment, etc. are determined using drill cores, these should only be taken in areas of the member that are subject to low shear, tension perp. to grain and bending stresses to minimize the effects of drill core extraction on member properties.

For some of the information to be determined using drill cores (adhesive type, quality of the adhesive bonds and surface treatment), it is necessary to involve accredited laboratories.

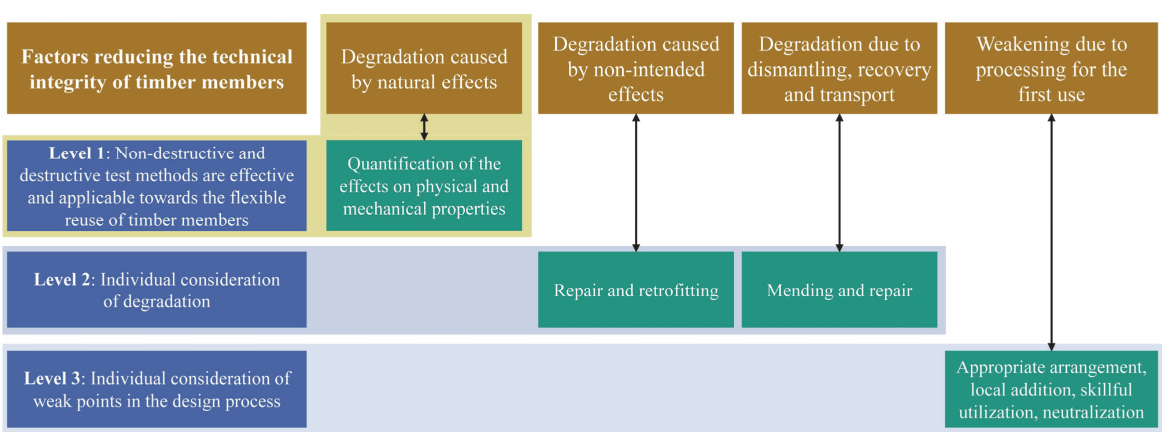

Figure 3: Levels of technical handling of used timber members

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5.4 NON-DESTRUCTIVE TEST METHODS

5.4.1 GENERAL REMARKS

Fig. 4 illustrates the possibilities of visual grading with or without support by devices. Both non-destructive grading methods described below shall be applied to every member that is to be considered for reuse. Grading shall be carried out by competent and trained persons.

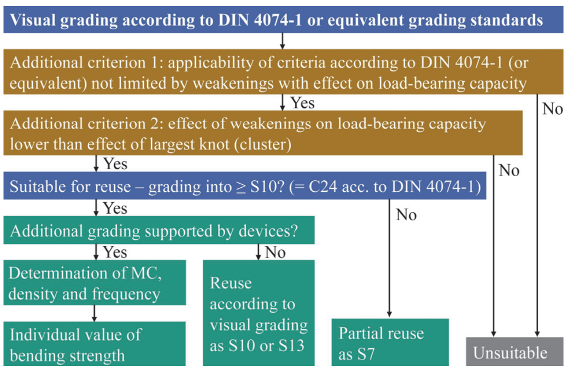

Figure 4: Grading of sawn timber

5.4.2 VISUAL GRADING OF SAWN TIMBER

DIN 4074-1:2012-06 [9] or equivalent national grading standards shall be applied for the visual grading of timber. For softwood timber already used as structural member, two additional criteria shall be taken into account:

1. In order to apply the grading rules, it shall be verified that no weakening, with effect on the load-bearing capacity, from processing for the first use or from disassembly, recovery and transport is located in the direct proximity of knots or knot clusters (see Fig. 5). Direct proximity can be excluded if the distance between the weakening and the knot or knot cluster is larger than the larger cross-sectional dimension.
2. For members with weakenings from processing based on first use or damages from disassembly, recovery and transport that should solely be assessed by applying the grading rules, it shall be ensured that the effect of weakenings or damages on the load-bearing capacity is lower than the effect of the largest knot (cluster). For this purpose, the limit values for knots may be applied accordingly. To account for the different effect of knots and holes on the load-bearing capacity (see Fig. 5, below), holes in proximity to the edges of the member should be evaluated applying a diameter equal to twice the hole diameter (the background to this rule is given in [10]). To account for the effect of splintering parallel to grain at the member edges, the limit values for wane may be applied.

For softwood timber members predominantly used in edgewise bending that should be visually graded in accordance with DIN 4074-1 [9], the two additional criteria may be applied in analogy to the abovegiven rules, see Fig. 5.

Curvature in members that has increased due to creep may be disregarded in the classification into a grade, if further use as member prone to stability failure is excluded.

The information on visual grading may be transferred to machine-supported visual grading (scanning machines).

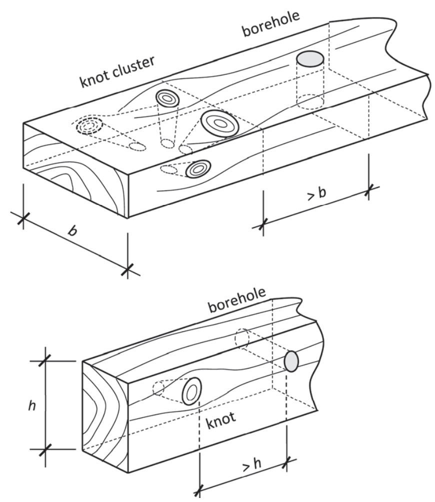

Figure 5: Illustration of additional criteria on a board with hole and knot cluster in flatwise bending (above) and timber member with hole and knot in edgewise bending (below)

5.4.3 COMBINED VISUAL AND DEVICE-SUPPORTED GRADING OF SAWN TIMBER

Background: In addition to visual grading, it is possible to determine the gross density (using a scale) and the dynamic modulus of elasticity on the basis of 1st order longitudinal vibrations. With this combination, it is possible to calculate an expected value of the bending strength for each individual member with a relatively simple set of instruments. The following approach is based on the work by Blaß&Frese [11]. Visual grading supported by devices leads to an extended set of information, allowing for more reliable reclassification.

In addition to 5.4.2, a combination of visual grading and grading supported by devices is possible. This method can be applied to determine or estimate an expected value and a statistically validated value (e.g. a 5th percentile) in the sense of an individual value for the bending strength.

To determine the 5th percentile, it is recommended to subtract from the expected value the standard deviation s_e of the error terms of the underlying regression relationship, multiplied by the factor x, so that the "true" unknown bending strength of a sawn timber member lies with a probability of 5% below or 95% above the individual calculated value, see equation (3).

The procedure is as follows, see Fig. 6:

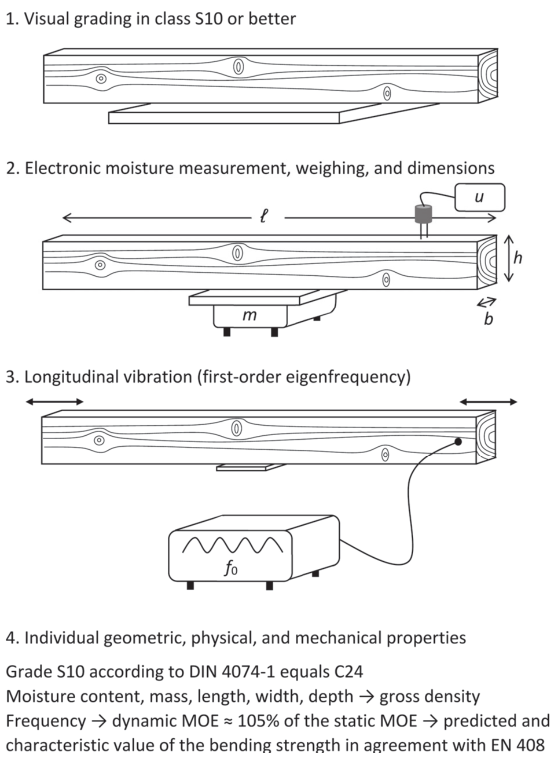

Figure 6: Procedure for combined visual grading and grading supported by devices

The sawn timber should be carefully disassembled, recovered, and immediately stored in a dry, covered location. The further procedure is applicable to sawn timber that is graded into S10 or better in accordance with DIN 4074-1 [9]. The timber moisture content should be determined by electrical resistance measurement. The width (b), depth (h), length (l) and mass (m) are measured and the 1st order longitudinal frequency is determined.

The gross density ρ_{gross} and the dynamic modulus of elasticity are determined according to eqs. (1) and (2)

$$\rho_{\text{gross}} = \frac{m}{l \cdot b \cdot h} \quad (1)$$

$$E_{\text{dyn}} = (2f_0)^2 \cdot \rho_{\text{gross}} \quad (2)$$

In eq. (3), a multiple (x) of the standard deviation s_e of the error terms is subtracted from each expected value, so that the "true" unknown bending strength of a sawn timber member is below the individual calculated value ($f_{m,in}$ in N/mm^2) with a low specified probability.

$$f_{\text{m,in}} = 13{,}4 - 0.0132 \cdot b - 0.0449 \cdot h - 0.0414 \cdot \rho_{\text{gross}} + 0.00454 \cdot E_{\text{dyn}} - x \cdot s_{\text{e}} \quad (3)$$

Applying the recommended value $x = 1.65$ as factor to determine characteristic values and the standard deviation $s_e = 9.32$, $x \cdot s_e = 1.65 \cdot 9.32 = 15.4\ N/mm^2$. For each individual member, the nominal probability of non-exceedence is then 5%.

5.4.4 NON-DESTRUCTIVE ASSESSMENT OF GLUED-LAMINATED TIMBER

5.4.4.1 GENERAL

Depending on the manufacturing process, boards for glued laminated timber are visually or machine graded. If the original classification of the laminations or the glulam member can be determined, the procedure in Fig. 7 should be followed.

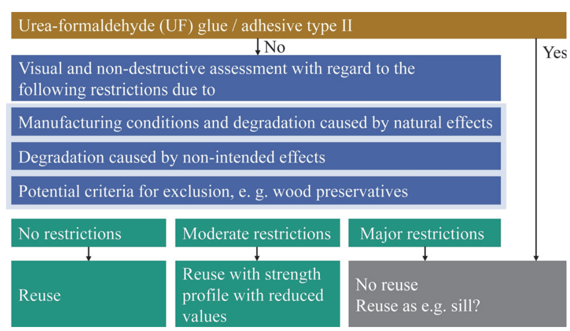

Figure 7: Reclassification and assessment of glued laminated timber

Non-destructive assessment primarily aims to detect degradation caused by natural effects. These are

- Deterioration of the adhesive bonds (e.g. open bonds between laminations and open finger joints)
- Cracks, visible from the outside
- Inner cracks and cup shake that are not visible (suspected[6] or only visible on the end grain)
- Shear failure

Based on these findings, any reduction in load-bearing capacity should be quantified.

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5.4.4.2 ASSESSMENT

The following inspections shall be carried out by a competent person to assess the potential for reuse of a glulam member. It shall be distinguished between restrictions (1 and 2) and criteria for exclusion (3a, 3b):

1. Restrictions due to manufacturing conditions and degradation caused by natural effects
   - Exceptionally large knots or knot clusters – compared to the grading criteria – in the two outermost laminations
   - Open finger joints in the outermost laminations
   - Shrinkage cracks and open adhesive bonds between laminations – recommendation: $t \leq b/8$ from each side, measured with 0.1 mm feeler gauge (see Fig. 8, left)
   - Inner cracks and cup shake that are not visible (suspected[6] or only visible on the end grain) – recommendation: $t \leq b/4$ (see Fig. 8, right)
   - Deformations such as twist and curvature
   - Mechanical wear, such as abrasion, cleaning
   - Coloration including stains from moisture without further moisture accumulation
2. Restrictions due to degradation caused by non-intended effects
   - Moisture accumulation in the member ($u \geq 20$ %), e.g. due to roof leaks or unplanned condensation
   - Decay or fungi
   - Insect attack
   - Degradation due to non-intended use (e.g. damage from impact with effect on load-bearing capacity)
   - Degradation due to inadequate maintenance (e.g. leakage, moisture accumulation at drainage, missing plugs)
   - Damages due to neglect and vandalism (e.g. grooves, holes)
3. a) Potential criteria for exclusion
   - Wood preservatives and paints with hazardous substances
   - Internal impurities that should be taken into account when cutting into smaller pieces or for planning, e.g. nail remnants, non-reversible screws
3. b) Criteria for exclusion
   - Glued laminated timber with urea-formaldehyde (UF) glue; further information can be found in [4].

Some of the information required as part of the inspection can be determined on drill cores extracted from the glulam member (semi-destructive test method, see 5.3). For some of the information to be determined using drill cores (adhesive type, quality of the adhesive bonds and surface treatment), it is necessary to involve accredited laboratories.

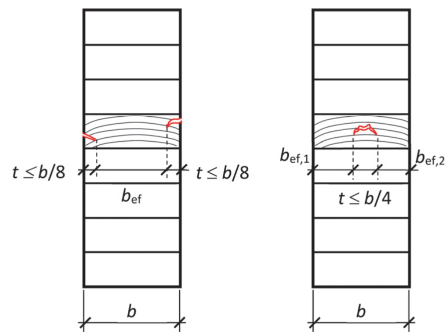

Figure 8: Shrinkage cracks measurable from the side faces (left) and inner cracks (detectable on the end grain) (right) in a glulam cross-section

5.4.4.3 EVALUATION OF THE RESULTS

The information obtained during the assessment shall be evaluated by a competent person.

A decision should then be made for each individual glulam member, if it may be reused with a complete strength profile, whether it may only be reused with a strength profile with reduced values or whether no reuse is possible without refurbishment. In strength profiles with reduced values, for example reduced shear strengths ($f_{v,red}$) or tensile strength perp. to grain ($f_{t,90,red}$) can be specified, which take into account the effect of larger cracks (crack depth beyond standardized limits) and/or further crack growth during the period of reuse (additional performance capacity / reserve for degradation).

6 – REFURBISHMENT

For the refurbishment of timber members, the following procedures are recommended:

- Removal of all foreign particles and contamination from member surfaces
- Removal of hidden metal parts after localization with a metal detector

[6] Such cracking can e.g. occur under the following conditions: strong, rapid moisture increase (e.g. between manufacture and use or between use and conversion). Severe cracking visible from the outside can also be an indication of internal cracking. For assessment, see Section 5.4.4.2.

- If necessary: removal of existing coatings, e.g. by sandblasting with dust-suction system
- If necessary: trimming or planing the timber to a standardized rectangular cross-section
- Cleaning the member surfaces

Removal of hazardous contamination shall be realized by a qualified, best certified, specialist company.

7 – DESIGN

7.1 GENERAL

The design for ultimate and serviceability limit states of structures using reused members shall be realized in accordance with the design standards currently introduced by building authorities, as is the case for new members. In the design process, the technical properties of the reused members, determined during the assessment before and after disassembly, shall be taken into account.

Reclassification into a strength class should be treated separately from evaluating how long a timber member can reliably maintain its load-bearing function in its second service life. During its first service life, the timber member has experienced a load history of permanent and variable loads, which it does not "forget" after disassembly. Members to be reused shall therefore not be designed as a new member without further ado.

It is not possible to accurately estimate the effect of the load history of the first service life on the load-bearing capacity during the second service life. Therefore, an approach is proposed that uses reduced modification factors (k_{mod} values). The application of this format requires expertise and experience.

7.2 CONSERVATIVE ASSUMPTIONS

In case of doubt about the extent of the detrimental effects on the technical integrity of the wood and the timber members, it is recommended to consult an expert. The following design measures have, depending on the individual situation, a positive effect on the robustness of the structural (sub)system made (in part) of reused timber members:

- Use in structures under compression parallel or perpendicular to grain (e.g. stocky columns or sleepers)
- Structural designs in which global equilibrium is based in particular on the load-bearing capacity in bending and compression parallel to the grain (positive effect of the semi-quadratic interaction in compression and bending)
- Avoiding connections prone to splitting
- Avoiding tensile stresses perpendicular to grain caused by loading or geometry, e.g. no reuse of pitched cambered beams without reinforcement in apex zone, no tapered edges under tensile stresses perpendicular to the grain
- Specification of strength profiles with reduced values, for example reduced shear strength ($f_{v,red}$) or tensile strength perp. to grain ($f_{t,90,red}$)

7.3 ADAPTED MODIFICATION FACTORS

Background: To the authors' knowledge, no sufficient studies or technical results were available at the time of developing the guideline to substantiate a state-of-the-art for adapted modification factors for the design of timber members for a second use.

The reliability of timber members is only invariant as long as no damage mechanism has occurred. The accumulation of damage in timber members is typically highly non-linear. Only stresses that lead to high degrees of utilisation will have a significant effect on the accumulation of damage [12]. Because of the natural variability in strength properties of timber members, their real strength is often significantly higher than their calculated characteristic values. In combination with the difference between the design loads and the real loads on the member during service life, this implies that only extreme stresses will have an effect in terms of damage accumulation.

The established models of the duration-of-load (DOL)-effect all show a disproportionately low reduction with increasing time. When plotted on a logarithmic scale, the reduction in these models is close to linear.

This relationship allows for a cautious linear extrapolation. This approach is used by [13] when specifying the DOL effect for the Australian Industry Standard on Recycled Timber. Provided that used timber is reclassified before reuse, modification factors extrapolated according to this approach may be used. Interpreting the resulting DOL-curves, [13] specifies the following values for members under permanent load: $k_{50a} = 0.57$, $k_{100a} = 0.53$ *and* $k_{200a} = 0.48$. *The authors thus suggest a reduction of the modification factor of 10% for loads of permanent load-duration, for loads of medium duration, they obtain a reduction in the single-digit percentage range (2%).*

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The assumption of linear damage accumulation, on which the established DOL (duration-of-load) models are based, enables the superposition of the load-duration of the governing load combination of the first use and the governing load-duration of the intended second use of a reused member. The precondition for this superposition is that the service class of the first use and the second use are the same. Applying the approximately linear relationship between the load-duration on a logarithmic scale and reduction of load-carrying capacity, the (extended) load-duration class LDC_{reuse} can be used to determine modification factors $k_{\text{mod,reuse}}$.

Following this approach, modification factors for the design of timber members to be reused, $k_{\text{mod,reuse}}$, should be determined with eq. (4) applying the reduction factor $k_{\text{red,reuse}}$. This approach enables the adjustment of the load-bearing capacity of the timber member to enable design for a second use and another service life of at least 50 years. For this design, $k_{\text{mod,reuse}}$ is to be determined, applying the less favorable load-duration class from the first and the second use.

$$k_{\text{mod,reuse}} = k_{\text{red,reuse}} \cdot k_{\text{mod}} \tag{4}$$

with

$k_{\text{red,reuse}} = 1{,}0$ for LDC instantaneous, short- and medium-term in first or second use

$k_{\text{red,reuse}} = 0{,}9$ for LDC long or permanent in first or second use

In practical application, questions arise from the fact that both the load-duration of the governing load combination of the first use and the load-duration of the governing load combination of the second use of the reused member shall be considered.

In some cases, it will not be possible to reliably determine the governing load combination and related load-duration of the first use. The majority of members that currently feature potential for reuse (e.g. rafters, floor beams) will not have been exposed to loads of long or permanent duration that resulted in utilization of magnitudes that would lead to a significant duration-of-load effect. However, if there are indications of high loads of long or permanent duration, the load-duration class "long" or "permanent" should be applied.

Although an established state-of-the-art for adapted modification factors to design timber members for a second use is currently missing, the following further findings support the assumption of a decreasing DOL effect over time:

1. *Strength tests, known to the authors, on old structural timber showed no 'ageing', see e.g. [14]*
2. *Neither the interviews with experts nor the literature study gave indications of damage on real structures due to high load duration*
3. *The reuse of timber members was common practice in former centuries without knowledge of reduction factors as applied today*

In order to confirm these tendencies, investigations should be carried out on members that have been exposed to high permanent loads for a long time. Despite corresponding efforts, such members could not be found in the timeframe of this project. In the opinion of the authors, this could also be an indication that high loads of long load-duration are rare in timber structures.

It is important to note that an exclusive consideration of the service life or load-duration is not sufficient when designing timber members for a second structural life. Additional factors such as the previous and future climatic conditions and the previous and future type of loading shall be included in the assessment and evaluated by a competent person.

8 – SUMMARY

Ageing alone does not change the strength and stiffness properties of timber members, see e.g. [14]. However, timber members in use are subject to degradation due to natural effects and non-intended effects, potentially affecting their technical properties. Therefore, reused timber members cannot be treated the same as new members. The natural effects and non-intended effects shall be taken into account during reclassification and (adapted) design; if necessary, refurbishment can be carried out.

9 – OUTLOOK

The guideline presented in this paper is intended to support planners, experts and authorities in the realization of the reuse of structural timber products in individual construction projects by providing them assistance for obtaining technical approvals for use in construction. The experience gained from the implementation of these pilot projects should form the basis for the future development of technical regulations such as technical approvals and standards.

The focus of the guideline is on sawn timber and glulam made from softwood. For finger-jointed solid timber and glulam with universal finger-joints, it is necessary to add specifications. Further studies on the effects of inner cracks in glulam members would build confidence with regard to the reliable reuse of glulam members. In the medium term, one objective should be to quantify more precisely the effect of an extended load duration in combination with a changing load history due to reuse on the load-bearing capacity (i.e. the modification factor k_{mod}) and the long-term deformation (i.e. the creep coefficient k_{def}).

The determination of wood preservatives was not considered in this project. A faster and more precise determination of wood preservatives compared to today would help to remove a central obstacle to the reuse of timber members.

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