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RECOVERED TIMBER GRADING SYSTEM

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ABSTRACT: There is a big amount of timber to potentially recover from construction and demolition sector that could be suitable for reusing or recycling as structural material. Recovered timber should be properly graded before reuse it and the current standards for new timber are not fitting well for recovered timber. Therefore, recovered timber should be graded separated from new timber. Recently, several research projects tested recovered timber for grading purposes. Regarding mechanical properties, a combination of non-destructive testing, mainly based on longitudinal vibration, and some visual parameters (knots and slope of grain) was shown as a promising method to estimate them. Furthermore, there are other reusability aspects (length, cross-section, warp, metals, hazardous substances, etc.) that should be taken into account in a grading process. Most of the research studies were performed over a limited number of specimens due to the difficulties to recover a big batch of timber from the same structure or with similar characteristics. There is a new European project ongoing called TiReX dealing with an extensive recovered timber testing campaign using timber from several locations in Europe, to create a database to support the development of a recovered timber grading standard.

KEYWORDS: Cascading, Circular Economy, Non-destructive testing, Reclaimed timber, Salvaged timber

1 INTRODUCTION

The construction and demolition sector produces high amount of timber that can be potentially reused or recycled for structural end-uses [1, 2]. Recovered timber is a variable product, far less homogeneous than new timber, regarding warp, size, age, cross-section irregularity, condition, pre-grading. In order to reuse it for structural applications, their mechanical properties should be determined, i.e. this timber should be strength graded. There are few research studies focus on recovered timber grading [3] but in recent times interest grew rapidly [4-6].

According to European standards, timber can be graded using one of the next two systems (but not combining both): visual strength grading (VSG) or machine strength grading [7]. Current European grading standards were developed based on new timber tests and some conditions are difficult to fulfil in the case of recovered timber, e.g., species and grown area should be known, rectangular cross-section (with a maximum wane allowance of 1/3) is compulsory, warp limitations are also very restrictive, large testing campaigns are required, testing a representative sampling from a source and reflect the industrial practice. According to the European standard EN 338 [8], timber properties for design calculations are defined by several strength classes with fixed values for properties: modulus of elasticity (*MOE*), bending strength (*MOR*), density and secondary properties. These strength classes were developed more than 20 years ago based on testing on the most common European softwoods and hardwoods. Therefore, there are relations between *MOE*, *MOR* and density in the strength classes fitting new timber but not recovered timber. In the case of recovered timber, *MOE* is similar to new timber, but *MOR* is usually lower than *MOR* of new timber due to load history and other parameters [9]. Taking into account all these constrains, recovered and new timber should not be strength graded following the same standards, nor should they be graded together. Therefore, a different standardization framework is needed for recovered and new timber [10].

Most of the research studies estimating recovered timber mechanical properties, combined non-destructive testing (NDT) results using longitudinal vibration and visual parameters (knots and slope of grain).

In recent years, several European projects dealt with reusing and recycling timber from demolition source for structural end-uses: CaReWood [11], InFutUReWood [12], RECOWERS [13]. Nowadays, a increasing number of new projects are starting dealing with this topic like Grade2New, sirkTRE or TiReX. Results from some of these research projects are shown in the present work and recovered timber grading aspects are discussed. Furthermore, objectives of a new European project, TiReX are also presented.

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2 MATERIALS AND METHODS

2.1 MATERIALS

Three batches of recovered timber from different species grown in Europe and from three different research projects were studied.

In the InFutUReWood European project, 30 specimens of European oak (*Quercus robur* L.) timber of nominal cross-section 135 by 150 mm and 3 m length recovered in the North of Spain after circa 200 years of service were tested (Figure 1a).

In the RECOWERS European project, 19 specimens of Norway spruce (*Picea abies* (L.) Karst.) of nominal cross-section 95 by 145 mm and 2.6 m length recovered in Ljubljana, Slovenia after 71 years of service were tested (Figure 1b).

In the BIA 2014-55089-P Spanish project, 45 specimens of Salzmann pine (*Pinus nigra* Arnold ssp. *salzmannii* (Dunal) Franco) of nominal cross-section 150 by 200 mm and 5.4 m length recovered in Madrid, Spain after 240 years of service were tested (Figure 1c).

Irregular and rotten ends were removed before testing.

Figure 1. a) European oak specimens from InFutUReWood project b) Norway spruce specimens from RECOWERS project c) Salzmann pine specimens from BIA 2014-55089-P project.

2.2 METHODS

Testing was carried out in 3 European laboratories. European oak was tested in PEMADE-USC (Spain), Norway spruce was tested at the University of Ljubljana (Slovenia) and Salzmann pine was tested in ICIFOR-INIA, CSIC (Spain).

Visual parameters

Visual parameters were measured according to EN 1309-3 [14]. At least maximum knot diameter in face and edge, slope of grain, fissures, wanes, deformations and biological attacks were measured in the 3 batches.

Non-Destructive Testing (NDT)

Three non-destructive testing (NDT) devices were used to record longitudinal vibration:

- Mobile Timber Grader - MTG (Brookhuis, Enschede, The Netherlands) for European oak (Figure 2a);
- Strength Timber Grader - STIG (ILKON d.o.o., Ljubljana, Slovenia) for Norway spruce (Figure 2b);
- Portable Lumber Grader - PLG (Fakopp Enterprise, Sopron, Hungary) for Salzmann pine.

The first mode natural frequency was obtained from the signal recorded by contact accelerometer (MTG) or microphone (STIG and PLG) through Fast Fourier Transform (FFT). Velocity was calculated as two times frequency by length. Dynamic modulus of elasticity (Edyn) was calculated according equation 1:

$$E_{dyn} = \rho \cdot V^2 \tag{1}$$

Where: E_{dyn} dynamic modulus of elasticity; ρ density; V velocity obtained from frequency.

Mechanical testing

Four-point bending tests were carried out according to EN 408 [15] standard (Figure 3). The global modulus of elasticity (MOE_{glo}) and bending strength (MOR) were obtained. Deformation was measured on both sizes and in the bottom middle using LVDTs in the cases of European oak and Salzmann pine, and using camera recording, in the case of Norway spruce. After failure, a slice free of knots and resin pockets as near as possible to the failure point was used for determination of density as mass/volume and moisture content (MC) by oven dry method [16]. MOE_{glo} and density ρ were adjusted to a reference MC of 12 % according to EN 384 standard [17] obtaining MOE_{glo12} and ρ_{12}.

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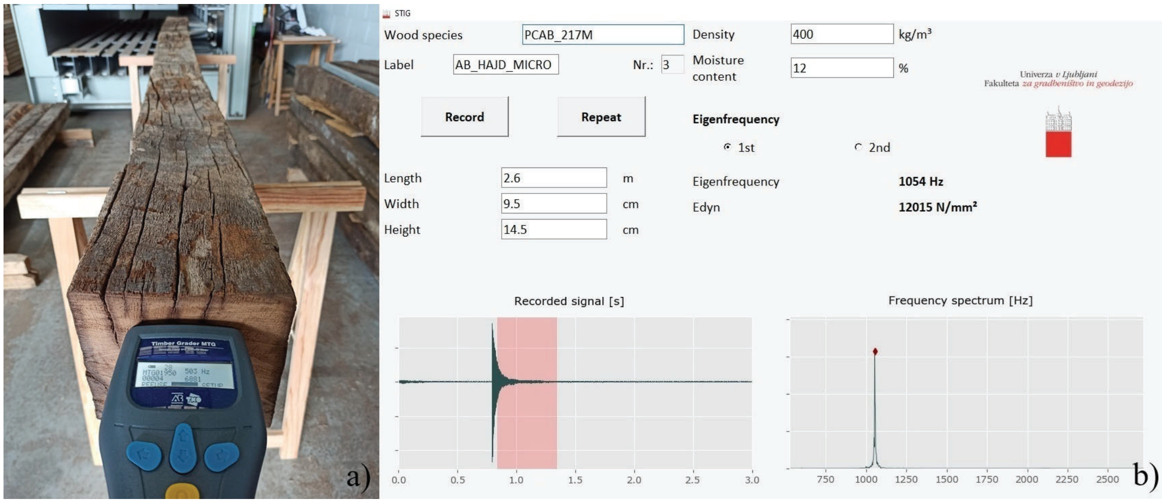

Figure 2. a) MTG measurements on European oak b) STIG software measuring Norway spruce

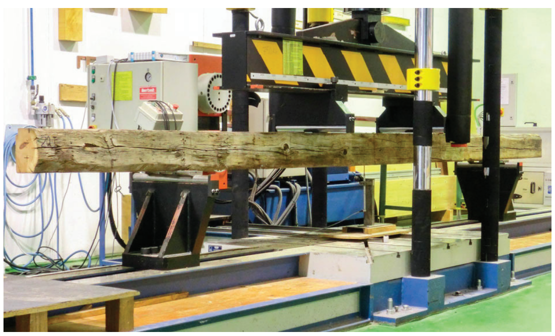

Figure 3. four-point bending test on Salzmann pine

3 RESULTS

3.1 MECHANICAL PROPERTIES ESTIMATION

Results from NDT and mechanical properties are shown in Table 1.

Table 1: MC, NDT and mechanical properties results

Non-destructive testing						
Species	MC		*V*		E_{dyn}	
	Mean %	**CoV %**	**Mean m/s**	**CoV %**	**Mean N/mm²**	**CoV %**
E. oak	14.3	4.99	3556	10.03	8438	23.81
N. spruce	9.7	1.78	5386	4.87	13383	12.85
Sal. pine	8.4	8.51	4612	6.07	10886	14.85
Mechanical testing						
Species	MOE_{glo12}		*MOR*		ρ_{12}	
	Mean N/mm²	**CoV %**	**Mean N/mm²**	**CoV %**	**Mean kg/m³**	**CoV %**
E. oak	5389	28.32	18.4	47.07	737	8.22
N. spruce	11306	15.66	44.1	24.33	444	10.24
Sal. pine	9227	18.19	25.3	35.20	527	10.49

Regression models were developed to estimate mechanical properties from E_{dyn} obtained by NDT and significant visual parameters.

Estimation models for European oak:

$MOE_{glo12} = 0.6134\ E_{dyn} + 213$

$R^2 = 65\%\quad StE = 915$ N/mm²

$MOR = 0.0031\ E_{dyn} - 7.58$

$R^2 = 51\%\quad StE = 6.15$ N/mm²

Including a knot parameter (face knot ratio (*fkr*)):

$MOE_{glo12} = 0.5952\ E_{dyn} - 1497\ fkr + 830$

$R^2 = 69\%\quad StE = 620$ N/mm²

$MOR = 0.0030\ E_{dyn} - 7.39\ fkr - 4.53$

$R^2 = 54\%\quad StE = 6.06$ N/mm²

Estimation models for Norway spruce [13]:

$MOE_{glo12} = 0.9111\ E_{dyn} - 942$

$R^2 = 71\%\quad StE = 1026$ N/mm²

$MOR = 0.0056\ E_{dyn} - 30.58$

$R^2 = 72\%\quad StE = 6.24$ N/mm²

Estimation models for Salzmann pine [18]:

$MOE_{glo12} = 0.7436\ E_{dyn} + 827$

$R^2 = 59\%\quad StE = 1070$ N/mm²

$MOR = 0.0041\ E_{dyn} - 18.79$

$R^2 = 54\%\quad \text{StE} = 6.53$ N/mm²

Including a knot parameter (edge knot ratio (*ekr*)) and slope of grain (*sg*) [18]:

$$MOE_{glo12} = 0.5368\ E_{dyn} - 2865\ ekr - 89.46\ sg + 4382$$

$R^2 = 68\%$ $StE = 971$ N/mm^2

$$MOR = 0.0032\ E_{dyn} - 11.30\ ekr - 0.45\ sg - 4045$$

$R^2 = 59\%$ $StE = 6.29$ N/mm^2

Regression models to estimate MOE_{glo12} from E_{dyn} show determination coefficients (R^2) around 70% and standard errors (StE) around 1000 N/mm^2 for the 3 batches when different visual parameters are included in the model. In the case of *MOR* estimation, R^2 ranged from 54 to 72% and StE is around 6 N/mm^2. Only in the case of Norway spruce estimation models, visual parameters were identified as statistically non-significant variables. In the case of European oak and Salzmann pine, visual parameters improving estimation models are knots and additionally slope of grain for Salzmann pine.

Sample bias due to pre-grading

Recovered timber could be strength graded (visual or machine) or not (ungraded) at the time of original use for construction. This is related with the age of original construction. First European visual strength grading standard (DIN 4074) was published in 1938. Timber used for structural purposes before that time was likely not graded. However, ancient construction carpenters could be applying some kind of classification based on their own experience. Recovered timber could be graded or not, but it is really difficult to know previous grading information at the time of recovering. Few times stamps from machine strength grading can be found in recovered timber (Fig. 4a). If recovered timber was strength graded in origin, more homogenous timber properties are expected than for the case of ungraded timber. If estimation models were developed using ungraded timber and are applied to strength graded timber or vice versa, results can be not accurate or safe. The three batches presented in section 2.1 are 200-year-old European oak, Norway spruce from 1949 and Salzmann pine from 1769. Only in the case of Norway spruce, it could be possible to be graded in origin but there wasn't any information.

3.2 REUSABILITY ASPECTS

Estimation of mechanical properties of recovered timber is not totally fulfilling the grading process. There are additional aspects, mainly not related with physical and mechanical properties, but affecting the possibilities of reuse for structural purposes. These reusability aspects should be recorded and taking into account for a correct recovered timber grading. Some of these aspects are listed below by category.

Dimensional

Length: short lengths are commonly found in recovered timber, due to several reasons. In the past, building spans were generally shorter than nowadays. Furthermore, in traditional construction timber beam ends were embedded inside masonry walls, these areas have a high risk of high humidity. Therefore, most of the large cross-section specimens recovered presented rotten ends. Rotten ends should be removed; hence lengths are even shorter.

Cross-section: irregular cross-section is usually found in large cross-section specimens due old sawn process and wanes. Some specimens are semi-round timber. Commonly, the older is the timber, the less efficient (manual) or more costly the sawing techniques were; hence it is more common to find less processed sections, i.e., more irregular. Irregular cross-section is affecting not only the reusability, but also the estimation of mechanical properties by NDT [19].

Warp: warp creates difficulties during the building process. Warp timber pieces are difficult to fix in a position during construction. This is a problem in new and recovered timber, but more frequent in recovered timber (Fig. 4b). In large cross-section recovered timber is really common to find high warp values. According to EN 14081-1 [20] "even if warp of timber does not directly influence strength, it is strongly recommended that timber for building purposes should be subject to some restrictions in this respect".

Timber with metals and treatments

Metals inside: most recovered timber contains metals inside (screws, nails, connector plates…) (Fig. 4c). In order to reusing, there are two options: remove them or keep them inside. Screws and connector plates are usually easy to remove. Nails are only easy to remove if they are not rusted. Timber older than 100 years, usually contains rusty and broken nails which are extremely difficult to remove. If recovered timber will be sawn or planed it is needed to removed nails. However, in other cases is preferable to reuse it with broken nails inside.

Hazardous substances: recovered could be treated in origin using substances that nowadays are considered hazardous. This is related with the age of original construction, as more than 100 years old timber is improbable to be treated. There are difficulties to identify if recovered timber was treated and to remove those treatments.

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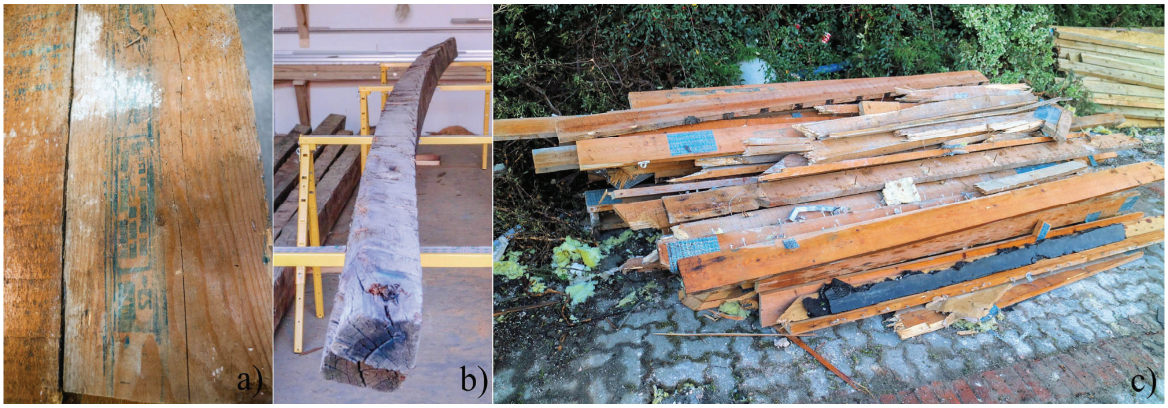

Figure 4. a) stamp on recovered timber in Ireland from original machine strength grading b) warp (twist) in recovered Salzmann pine c) recovered timber in Ireland containing metals

3.3 NEW EUROPEAN PROJECT

In the case of recovered timber, it is really a challenge to obtain large number of specimens from the same building or characteristics for testing. Therefore, most studies were conducted using small batches as batches shown in the present manuscript. The new European project TiReX, starting in mid-2024 is dealing with a large recovered timber testing campaign from several European locations. Partners from Norway (SINTEF-coordinator), Poland (Warsaw University of Technology), Slovenia (ZAG) and Spain (Universidad Politécnica de Madrid-WP1 leader) will perform a testing campaign on circa 800 recovered timber specimens in total, representing timber recovered in each partner country. This testing campaign will include softwoods and hardwoods. The objective is to create a big database from recovered timber in Europe, to boost the development of a European grading standard support by an extensive testing campaign. A new European project TiReX, focussed on a big recovered testing campaign all around Europe including Norway, Poland, Slovenia and Spain, is ongoing.

4 CONCLUSIONS

Recovered timber should be graded separately from new timber, due to their characteristics and also due to the fact that the current new timber grading standards are not fitting appropriately for recovered timber.

The combination of non-destructive testing and visual parameters gives more accurate estimates of mechanical properties as it is shown in several research projects testing. Cautions should be taken into account regarding representative sampling for mechanical properties estimation models' development.

Grading recovered timber is further than estimate mechanical properties. There are some reusability aspects to take into account for structural end-uses, as length, irregular cross-section, warp, metals inside timber and hazardous substances.

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