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# ENGINEERED WOOD PRODUCTS MANUFACTURED FROM RECLAIMED HARDWOOD TIMBER

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**ABSTRACT:** The circular economy is commonly applied in recent years in order to reduce the amount of wood waste with many environmental benefits. The construction and demolition sector generates a large amount of wood waste that can be potentially reused or recycled into different wood-added-value products. The InFutUReWood and the RECOWERS European projects deal with reusing and recycling recovered timber as a structural material. One of the potential applications of recovered wood from construction and demolition sources is in manufacturing Engineered Wood Products (EWP). Twelve Cross Laminated Timber (CLT) panels and twelve glued-laminated timber (glulam) pieces from European oak were manufactured and tested in the present work. Four different 3-layer CLT panel configurations and two different 5-lamella glulam pieces configurations were manufactured using recovered and new European oak timber. The results show that there is significant potential in using recovered timber for manufacturing EWP. The modulus of elasticity of CLT panels and glulam pieces from recovered and new timber is similar while bending strength is lower in the case of EWP from recovered timber than from new timber, but still enough high for structural applications. The timber yield producing EWP from recovered timber is really low due to the great amount of wood waste generated during manufacturing.

**KEYWORDS:** cascading, circular economy, mass timber products, recovered, recycling, salvaged, secondary timber

## 1 INTRODUCTION

The circular economy is a new production model to reduce the amount of waste by reusing it or recycling it as added-value products, reducing the consumption of raw materials. The long-term carbon sequestration stored in timber constructions and the reuse of building materials contributes to the mitigation of climate change. Furthermore, the increase in timber demand for construction purposes in Europe will lead to a lack of enough new timber resources. Therefore, improvement of the circular economy model in the timber sector is absolutely recommended.

Several European projects dealt with this topic in recent years. The CaReWood project (2014-2017) [1] focused on the potential recycling of recovered timber in glued laminated products in order to replace sawn timber for different applications (furniture, window frames, mouldings and fittings). However, no promising results were found for structural applications in load-bearing construction elements, due to wood waste usually comes from different mix species, which it would be difficult and expensive to identify and classify [2].

InFutUReWood was a 3-year European project (2019-2022) that focused on design for deconstruction of timber structures; enhance the current demolition techniques to maximize the amount of recovered timber and recycling of current recovered wood as structural material in different mass timber products [3].

RECOWERS is a 2-year Marie Skłodowska-Curie Actions (MSCA) European project (2022-2023) that focuses on grading recovered timber from demolition for structural purposes [4]. There is a lack of a reliable classification or grading system that estimates the properties of recovered timber in order to reuse it for structural applications.

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The construction and demolition sector creates a large amount of wood waste, much of which is nowadays used for energy recovery and panel manufacture [5, 6]. In the case of Spain, recovered wood is usually used in the form of chips for energy production and manufacturing particleboards [7]. Much of that wood waste has the quality to reuse or recycle in added-value structural products. Potential end-use structural possibilities include high-quality Engineered Wood Products (EWP) such as glued-laminated timber (glulam), solid wood panels, and Cross Laminated Timber (CLT) [8]. Previous tests on CLT from recovered mixed softwood timbers showed higher stiffness capacity and lower strength than CLT from new sawn softwood timber [9]. However, this was based on a limited number of tests.

The main objective of this paper is to compare the mechanical properties of CLT panels and glulam pieces manufactured from recovered European oak timber with CLT panels and glulam pieces manufactured from new sawn European oak timber.

# 2 MATERIALS AND METHODS

## 2.1 MATERIALS

From large cross-section (145 by 165 $mm^2$) European oak (*Quercus robur* L.) pieces recovered from a demolition of a 150-year-old house (Figure 1), recovered timber boards were sawn to a cross-section of 25 by 108 $mm^2$ (Figure 2).

***Figure 1****: Recovered timber pieces*

***Figure 2****: Recovered sawn timber boards*

Planed boards of final cross-section 20 by 100 $mm^2$ and variable-length from recovered and new European oak timber were used to manufacture CLT panels and glulam pieces. A total of twelve 3-layer (two external longitudinal layers and one internal cross-layer) CLT panels were manufactured. Three CLT panels were manufactured from recovered sawn timber, other three using recovered timber only in the longitudinal layers and new timber in the cross-layer, other three using recovered timber only in the cross-layer and new timber in the longitudinal layers and finally three more panels from new timber. Twelve 5-lamella glulam pieces were manufactured; six using recovered timber and six more using new timber. The number of CLT panels and glulam pieces, kind of timber and dimensions are shown in Table 1.

***Table 1:*** *CLT 3-layer panels and 5-lamella glulam pieces characteristics*

| CLT panels | | | | | |
|---|---|---|---|---|---|
| No. | Kind of timber | | Dimensions (mm) | | |
| | Long. layers | Cross layer | Length | Width | Thickness *layer |
| 3 | R | R | 1800 | 300 | 20*3 |
| 3 | R | N | 1800 | 300 | 20*3 |
| 3 | N | R | 1800 | 300 | 20*3 |
| 3 | N | N | 1800 | 300 | 20*3 |

| Glulam pieces | | | | |
|---|---|---|---|---|
| No. | Kind of timber | Dimensions (mm) | | |
| | Lamellae | Length | Width | Thickness *layer |
| 6 | R | 1900 | 100 | 20*5 |
| 6 | N | 1900 | 100 | 20*5 |

R: recovered timber
N: new timber
Moisture content: circa 15%

## 2.2 METHODS

Recovered and new timber European oak boards were planed until a final cross-section 20 by 100 $mm^2$ giving an aspect of ratio of 5. According to European standard EN16351 [10] when the board-dimension ratio is higher than 4, the bending test on CLT panels can be carried out over a span of 18 times the panel thickness. However, in order to avoid rolling shear, four-point bending test over a span of 24 times the thickness was conducted. In case of glulam pieces four-point bending test over a span of 18 times was carried out according to EN408 [11]. The test arrangement for CLT panels is shown in Figure 3 and for glulam pieces in Figure 4.


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*Figure 3: Four-point bending test set-up on a 3-layer CLT panel according to the standard EN16351.*

*Figure 4: Four-point bending test set-up on a 5-lamella glulam beam according to the standard EN408.*

Density and Moisture Content (MC) were determined after mechanical testing from a slice. Density as mass by volume and MC according to EN13183-1 [12]

## 3 RESULTS

***Table 2:*** *Mechanical properties of CLT 3-layer panels and 5-lamella glulam pieces*

| CLT panels | | | | | | |
|---|---|---|---|---|---|---|
| Kind | MOEglo12 | | MOR | | DEN12 | |
| | Mean $N/mm^2$ | CoV % | Mean $N/mm^2$ | CoV % | Mean $kg/m^3$ | CoV % |
| RRR | 12106 | 4.95 | 44.74 | 20.02 | 769 | 3.06 |
| RNR | 11989 | 1.54 | 46.49 | 7.23 | 768 | 2.09 |
| NRN | 11180 | 6.72 | 72.80 | 2.60 | 761 | 2.48 |
| NNN | 11707 | 3.18 | 74.01 | 3.11 | 730 | 2.58 |

| Glulam pieces | | | | | | |
|---|---|---|---|---|---|---|
| Kind | MOEglo12 | | MOR | | DEN12 | |
| | Mean $N/mm^2$ | CoV % | Mean $N/mm^2$ | CoV % | Mean $kg/m^3$ | CoV % |
| R | 11175 | 7.00 | 38.11 | 15.76 | 770 | 4.59 |
| N | 11777 | 8.36 | 73.51 | 17.61 | 713 | 3.40 |

R: recovered timber
N: new timber
MC: circa 15%

Table 2 shows the results of static modulus of elasticity (MOEglo12), bending strength (MOR) and density (DEN12) obtained by mechanical testing adjusted to 12% MC according to EN 384 [13] of CLT panels and glulam pieces by the kind of timber (recovered and new) used for manufacturing.

Due to the small number of specimens, it was not possible to determine the 5º percentile of MOR and density. The lowest value of MOR was 35.81 $N/mm^2$ in the case of CLT panels and 31.87 $N/mm^2$ in the case of glulam pieces. The lowest value of density was 709 $kg/m^3$ in the case of CLT panels and 677 $kg/m^3$ in the case of glulam pieces.

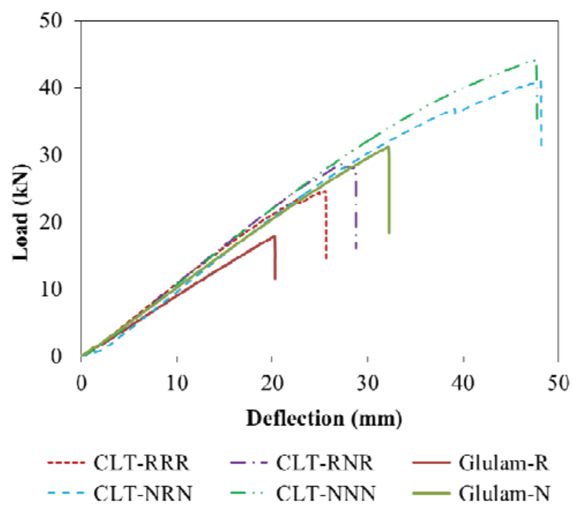


*Figure 5: Load-deformation response in CLT panels and glulam pieces according their timber configuration (R recovered, N new timber).*

Fig. 5 shows load-deformation graphics for the four configurations of CLT panels and the two configurations of glulam pieces tested. The elastic behaviour was similar in all kind of configurations with recovered or new timber. However, the final load is higher by far in the case of CLT manufactured using new timber in the longitudinal layers (NRN and NNN) than those using recovered timber in the longitudinal layers (RRR and RNR) and also in the case of glulam pieces manufactured with new timber (N) is higher than those manufactured with recovered timber (R). In the case of CLT panels, it looks like that the material used in the cross-layer is not affecting the MOR values as was also reported by another author testing CLT from recovered timber [14].

***Figure 6****: CLT panel failure in tension*

Qualitative analysis of rupture sections was carried out after mechanical tests. All of the CLT panels and glulam pieces tested broke by wood failure in the tension face and the central third (between the two point loads), as shown in Figures 4 and 6. No failure differences were visually detected among CLT panels and glulam pieces manufactured with recovered and new timber. Other failures for example by rolling shear or glue-line were not reported.

In order to determine if there are statistically significant differences among the values of MOE and MOR obtained in the mechanical testing of different configurations of CLT panels and glulam pieces, ANOVA tests were carried out at a 95% of confidence interval (Figures 7 and 8).

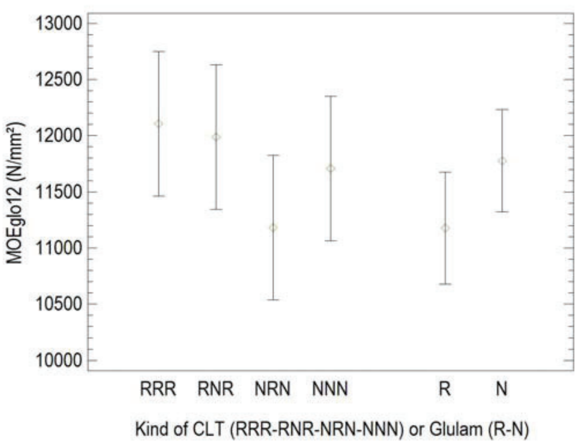


***Figure 7****: MOEglo12 ANOVA mean test for CLT panels and glulam pieces*

In the case of MOE (Figure 7), statistically non-significant differences were found at a 95% confidence interval among different kinds of CLT panels and glulam pieces timber configurations. The MOE of EWP manufactured with recovered European oak timber is not higher or lower than the MOE of EWP manufactured with new European oak timber.

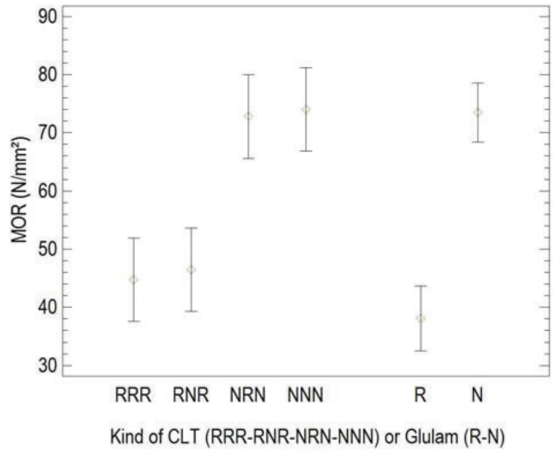


***Figure 8****: MOR ANOVA mean test for CLT panels and glulam pieces*

In the case of MOR (Figure 8), statistically significant differences were found at a 95% confidence interval between CLT panels manufactured using recovered timber in the longitudinal layers (RRR, RNR) and using new timber in the longitudinal layers (NRN, NNN), and also between glulam pieces manufactured from recovered timber (R) and from new timber (N). The MOR of EWP manufactured with recovered European oak timber is further lower than the MOR of EWP manufactured with new European oak timber.

In previous studies testing recovered solid-sawn timber was reported that MOE is not changing over time, while MOR is lower over time in softwoods and hardwoods species [15-17]. Some authors explained this MOR reduction due to the load history [18], others by the nails and holes present in old timber [16], others by the increase of brittleness in old wood [19] and others by the quality of the original timber [17]. Probably the reason will be a mix of all these explanations.

Regarding other authors testing EWP manufactured from recovered timber, Rose et al. [9] reported higher MOE and lower MOR in the case of CLT panels manufactured from a mix of recovered softwood timber species, while Arbelaez et al. [20] reported the same MOE but lower MOR testing CLT panels manufactured with recovered Douglas-fir timber.

Considering the reduction of the MOR in the case of recovered timber and checking the values obtained in the present study, the minimum values of MOR achieved, 35.81 $N/mm^2$ in the case of CLT panels and 31.87 $N/mm^2$ in the case of glulam pieces, are still enough for manufacturing EWP from recovered timber for structural purposes.

Regarding the timber yield of manufacturing EWP with recovered timber, the yield was really low. When boards were sawn from original recovered pieces, a great amount of sawdust is produced and most of the external parts of the pieces are not suitable for EWP because are


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twisted or containing nails. Furthermore, some parts like holes or big cracks should be removed from the boards after sawing. Finally, boards should be planed to the final dimension not more than 24 hours before bonding. In the present study the final yield was around 13% because the original recovered timber was large cross-section. Other authors using as recovered timber medium size cross-sections obtained better yields. In the case of Irle et al. [2] manufacturing glue laminated products the yield obtained was around 30%. In the case of the InFutUReWood project manufacturing CLT panels in Ireland was around 28% [21]. In both cases the yield was approximately double than in the present study. That means that in the timber yield there is a great influence of the dimensions and condition of the recovered timber using for manufacturing EWP.

## 4 CONCLUSIONS

The results from the testing indicate the capability of the recovered timber from demolition sources to be used for the manufacturing Engineering Wood Products (EWP) in the present study Cross-Laminated Timber (CLT) panels and glued-laminated timber (glulam) pieces.

Four-point bending tests showed no significant differences between modulus of elasticity obtained in CLT panels and glulam pieces manufactured from recovered and new timber. While, bending strength was far higher in new than in recovered timber in CLT panels and glulam pieces. In the case of CLT panels only the kind of timber (recovered or new) used in the longitudinal layers is determining the differences in bending strength values.

In spite of bending strength values in CLT panels and glulam pieces manufactured from recovered timber are lower than in the case of new timber, these values are still high enough for structural applications of the manufactured EWP.

Recycling recovered timber in EWP produce a low timber yield (around 13% in the present study), with a great amount of wood waste generate during the manufacturing.

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