Selective demolition of a roof in a building constructed in 1920s in the Valencian Community (Photo: Author).

Reuse process for timber elements to optimise residual performances in subsequent life cycles

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Abstract: The reuse of wooden elements is a sustainable operation, which makes the best use of the material's grey energy. Currently, structural timber from selective demolition is mainly used for non-structural functions, with a lowering of its performance, due to the lack of standard and specific regulation. In fact, the visual grading used to define the structural characteristics of wood does not evaluate information deriving from the previous life cycles of the component. In the paper, taking samples of rectangular timber elements from selective demolitions made in the Valencian Community, the structural values that are assigned by visual strength grading legislation were compared with the real resistance values identified by experimental analysis to verify their compliance. The verification showed that the visual grading is not able to optimize the performance of the timber element in its reuse. Therefore, the purpose of the research, illustrated in the paper, is to find a reuse process for structural wooden elements to enhance residual performances. The identified process introduces additional steps compared in the current visual grading, that include a consideration of the effective modalities of reuse evaluated according to the worst defects and information arising from previous life cycles.

Keywords: timber life cycle, structural reuse, historical beams, visual grading, experimental analysis, sustainability.

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1. Introduction

The current needs of environmental sustainability require greater attention for saving resources (air, water, soil, materials). According to the UNEP Report 2021, buildings use about 40% of the world's energy, 25% of global water, 40% of global resources, emit about 1/3 of greenhouse gas emissions and are responsible for about 50% by weight of waste (Figure 1).

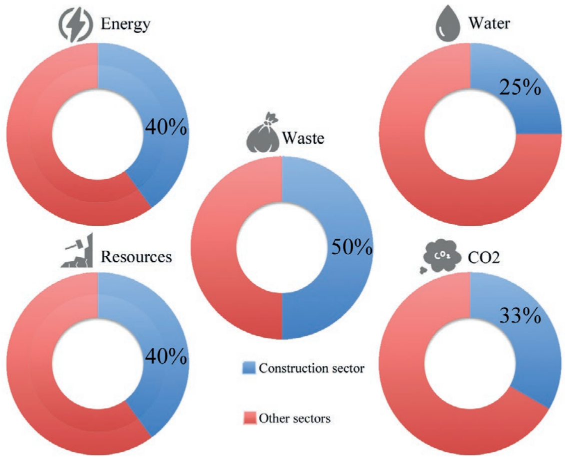


Figure 1 | Impact of the construction sector on environmental pollution (based on UNEP data).

The reduction of C&D (construction and demolition) waste is one of Europe's primary objectives. In fact, Directive 2008/98/EC (Article 11, paragraph 1), modified by Directive 2018/851/EC, introduces for Member States the obligation to promote selective demolition, i.e. a method of deconstruction of the building that allows to increase the amount of material that can be reused/recycled. The same Directive identifies the environmental hierarchy of end-of-life scenarios (Article 4, paragraph 1) and considers reuse a more sustainable scenario of recycling, in which, while safeguarding material resources, in the production processes, the environment is affected by the expenditure of energy and water.

The reuse of building materials from selective demolition makes it possible to reduce the environmental impact resulting from the use of raw materials, to safeguard the soil by limiting the amount of material sent to landfill and to avoid the emissions that would occur in the production from scratch of a material/component that has to perform the same functions as the decommissioned material/component.

A material is no longer considered waste if, as a result of recovery operations, it is transformed into a marketable product that is intended for new use (Directive 2008/98/EC).

For each material that has already undergone a life cycle, it is therefore necessary to identify possible new uses. Their identification is based on the analysis of the residual and potential (which would be obtained through possible reconditioning treatments) performance of a material. The better the performance of the material, the greater the possibilities of use. The correct identification of the performance allows to exploit the grey energy of the material with consequent advantages from an environmental and economic point of view.

The timber elements resulting from selective demolition are often destined to be recycled into chipboard, wood fiber or fiber-cement blocks. This practice, when a timber element fulfilled a structural function during the first life cycle, devalues and deems almost worthless the residual performances of the elements destined for recycling without a proper assessment of their potential for reuse. Assuming that a timber element has performed its structural function for a certain number of years and that it has proved to be suitable because it has not failed structurally over the years and no degradation has occurred, when it is disassembled for reuse, it should be verified according to current legislation/standard and would probably be discarded (see paragraph "3. Results"). This is a paradox for which "disassembly lowers the performance of wood". Wood is an anisotropic material, therefore its structural performance is assumed with safety margins based on its characteristics (species, defects, etc.) by systematizing the timber components into homogeneous categories. This is an approximation. In reality, each timber element is different from the other and, therefore, it has a structural operation that is punctually different. Moreover, if we consider that structural design regulations take into account statistics for safety purposes, i.e. structural dimensioning is conditioned by the events that statistically occurred in a given place (earthquake, wind, snow etc.), it is paradoxical that a timber element that has experienced some of those events without being damaged, is no longer considered suitable also because of the safety margins resulting from those same events.

In the light of this, it is evident that the information deriving from the life cycle is an added value of knowledge of the component that is currently not taken into consideration.

This paradox is caused by the lack of specific regulations for the reuse of timber elements for structural purposes. To define the structural characteristics of a timber element, whether new or used, the same standard is used (EN 338:2016, EN 14081-1:2016+A1:2019, EN 1309-3:2018). The standards for the visual grading do not specify if the analysed timber is new or used, but define only the range within the defects have to comply.

There are numerous researches to identify the correlation between the true mechanical properties of timber elements for structural use and the results derived from non destructive evaluations (visual grading, ultrasound grading, near infrared reflectance spectroscopy, resistograph, sclerometer test, etc.), but in the majority of cases they are referred to new timber elements (Capuz Lladró et al., 2003) (Hermoso Prieto et al., 2007) (Íñiguez González et al., 2007) or to onsite timber elements (Brol et al., 2012) (Cruz et al., 2015) (Sousa et al., 2015) with a historical and artistic value, for which it is necessary to make assessments without disassembling, mainly for their preventive conservation (Van Roy et al., 2018). Differently the proposed research is directed to timber elements deriving from selective demolition, with the purpose to individuate the real mechanical properties to promote an immediate process of reuse, reducing the waste destined for recycling or thermal valorisation.

2. Method

The purpose of the research is to find a reuse process for timber elements to enhance residual performances. The research focuses on visual grading, because this method is internationally regulated by specific standards, it is not affected by boundary conditions and it is immediately applicable in the construction site after the disassembly.

The method of the research is based on these steps:

1. to find timber beams from selective demolition, the beams must be intact i.e. they must not be subject to biological degradation and must not have problems of structural failure;
2. identification of the species of beams by microscopic analysis and selection in homogeneous groups of the same species;
3. visual grading of the beams according to the standards in force, identification of the unsuitability/suitability for use and the possible resistance class;
4. experimental analysis (even destructive) carried out in a laboratory to identify the real strength and stiffness properties and density;
5. comparison between the worst defect identified in the visual classification that conditioned the unfitness/suitability for use and the assumed strength class, and the real strength and stiffness properties and the worst defect that conditioned the failure;
6. assessment of the approximation of the current standards in defining the strength values of an element that has already undergone one or more life cycles;
7. identification of additional steps in the current visual grading, which includes a consideration of the effective modalities of reuse evaluated according to the worst defects and information arising from previous life cycles.

The research was carried out using rectangular timber beams resulting from selective demolitions of buildings built in 1920s in the Valencian Community. The choice of this territory was mainly derived from three reasons. The first is that it is an area where selective demolition is widespread and, therefore, there is a large availability of waste material, including timber elements which are currently reused for non-structural purposes (underestimating performance). The second is that the traditional construction typology of the floors is made up of timber beams with vaults made of flat clay bricks and which had a concrete filling and sometimes a false ceiling made of reeds and lime plaster (Figure 2) Even the traditional roofs are made up of timber beams and joists, flat clay bricks and tiles (Figure 3) (Diodato et al., 2015). The timber beams are “a typical waste”. The third is that local legislation does not provide for stringent historical constraints on dated buildings (contrary to what happens in other European states) and, therefore, it was possible to analyse materials deriving from buildings of the 1920s and which before the demolition (which took place in 2016) have already lived about 95 years.

The beams were selected from selective demolitions of buildings forming part of terraced houses, built in the same years and with the same construction system. Since the selective demolition involved only some of the houses that are part of the terraced houses, it appears that in the undemolished buildings there remain beams similar to those investigated that continue to perform their structural function even today.

The microscopic analyses carried out on the beams have shown that they belong to conifers. In particular the beams belong to the family which includes *Pinus sylvestris* L., *Pinus Nigra* Arnold and *Pinus Mugo* Turra (Figure 4).

The Spanish legislation for conifers appears in UNE 56544:2011. The legislation establishes a correlation

Figure 2 | Jack arch floor in Valencian Community.

Figure 3 | Traditional roof in Valencian Community

between the characteristics, defects and properties of resistance. The legislation identifies critical points that cause a weakening of the mechanical properties and it defines the resistant type and consequently the specific values. We have analysed n. 12 including those elements with a 17.50 cm x 5.8 cm cross section and about 300.0 cm length. As established by the standard for each element in its dry state the following points of analysis were considered: the diameter of the knots on the larger face, the diameter of the knots on the closer face, the rate of growth, the fissures (shrinkage cracks, lightning cracks, frost cracks or cracks), the ring shakes, the reaction wood, the slope of the grain, the resin pockets, the wanes, the biological alterations (mushrooms and insects) and the warps (bow, crook, twist and cup). When the timber elements had a length longer than the minimum required for subsequent tests, they were divided into two parts and classified again as detached parts. So, for the same element, we have the values of the visual grading both when intact and when divided into two equal parts. This analysis was performed in order to evaluate the influence of the integrity of the element on its disassembly and on its reuse in order to assess how possible cuts of the worst defects affect the classification results. The visual grading classes have been defined through the standard EN 1912:2012/AC:2013 as a function of the species, the strength classes and the characteristic values. Hereafter experimental analyses were performed in the laboratory to detect moisture, density, modulus of elasticity and flexure strength, from which it is possible to obtain the derived quantities. Initially we did the non-destructive tests and later the destructive tests. The test for defining the local modulus of elasticity, global modulus of elasticity and bending were performed according to standard EN 408:2011+A1:2012. The elements were subjected to mechanical tests. A load with a speed of 0.174 mm/s and reaching a maximum of 16 MPa was applied. A graph load/deformation was plotted and the part between 4 and 16 Mpa was used. A correlation coefficient of 0.99 or greater was detected and the modulus of elasticity was calculated using the formulas as indicated

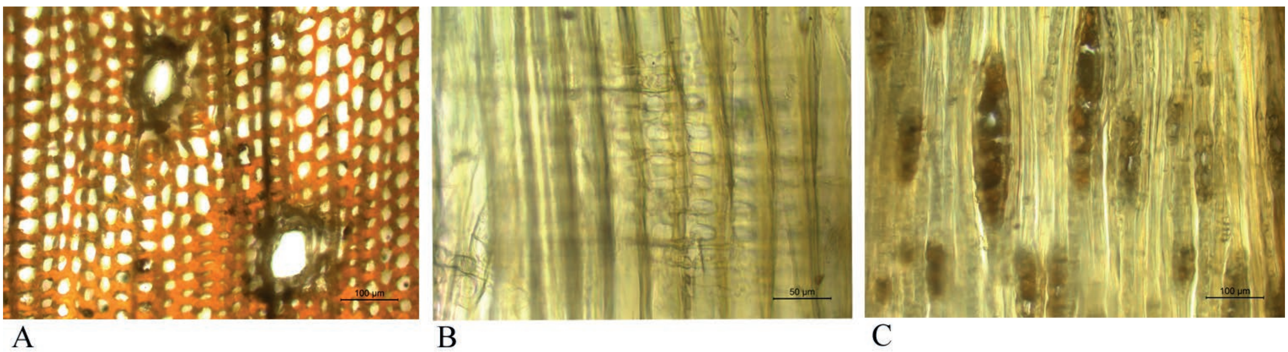


Figure 4 | Microscopic analysis carried out on timber elements deriving from selective demolition. A: Cross-section, B: Radial section, C: Tangential section.

in the standard. A failure value equal to 40 Mpa has been assumed, making a comparison between new elements with the same species and visual category. The standard provides that in the determination of the modulus of elasticity, the applied strength should not be greater than 0.4 Fmax. Subsequently, the flexure test was performed.

The next step was to measure the moisture of the timber element (using technical standard EN 13183-1:2002/AC). The final analysis consisted in the calculation of the density.

3. Results

The visual grading, made according to the standard UNE 56544:2011 and UNE EN 1912:2012, provided the results expressed in table 1.

The table 1 also shows the worst defect affecting the visual class. In the table 1 the element classified in its entirety is indicated with a unique numeric value (Example 1), while the element rated for parts is indicated with a double numerical value (Example 1-1). For example, the element n.1 considered in its entirety (3.0 meters long) cannot be used for structural use because it presents a group of knots whose overall diameter is greater than the limits set by the regulations, a two ring shake in one of two heads and two wanes.

We divided the element into two parts (1.50 meters long) the knot group and one of the two wanes (1-1), and the ring shake and the other wane on the other element (1-2). If we consider the elements in their entirety (3.0 meters long) or divided into two parts (1.50 meters long), the presence of different type of defects that affect the visual class and the widespread placement of them render them unsuitable for structural use.

Element n. 2 (3.0 meters long) is rejected when considered in its entirety due to the presence of a group of knots and two wanes. When it is divided into two parts (1.50 meters long), the defects that affect visual class are localized in element n. 2-1, while element n. 2-2 does not present defects affecting its structural use and is therefore assigned the ME-2 visual class. The experimental analyses produced the results expressed in the table 2.

In the table 2 in green were highlighted the elements that according to the visual grading were compatible with a structural use.

It is possible to compare the worst defect according to the visual grading and defects that cause the structural failure to understand the reliability of the visual grading (Table 3). There is a mismatch between the worst defect according to the visual grading and the defects that lead to structural failure of the element. In fact, the visual grading identifies the strength class of the timber element to put it on the market, therefore without knowing its future use and considers the worst

Table 1 | Results of visual grading.

Code	UNE 56544:2011 Visual class	UNE EN 1912:2012 Strength class	Worst defects identified by visual grading
1	Rejected	Not present	Group of knots n.3-4-5, wanes, ring shakes
1-1	Rejected	Not present	Group of knots n.3-4-5, wanes
1-2	Rejected	Not present	Wanes, ring shakes, group of knots n.15-16
2	Rejected	Not present	Wanes, knots n.15-16-17
2-1	Rejected	Not present	Wanes, knots n.15-16-17
2-2	ME-2	C18	Group of knots n.18-19
3	Rejected	Not present	Wanes and knot n.14
3-1	Rejected	Not present	Wanes
3-2	Rejected	Not present	Knot n.14
4	Rejected	Not present	Group of knots n.2-3, knots n.12, 13
4-1	Rejected	Not present	Group of knots n.2-3, knot n.12
4-2	Rejected	Not present	Knot n.13
5	Rejected	Not present	Knot n.26, group of knots n.6-7-8-9-10-11-12-13-14
5-1	ME-2	C18	Knots n.1-2-15
5-2	Rejected	Not present	Knot n.26, group of knots n.6-7-8-9-10-11-12-13-14
7	ME-2	C18	Warps, rate of growth, knots n.1-3
8	ME-1	C27	---
10	Rejected	Not present	Fissure
11	Rejected	Not present	Ring shake
12	ME-2	C18	Warps, group of knots n. 2-3,knot n.14
13	Rejected	Not present	Wanes, group of knots n.6-7
14	Rejected	Not present	Twist

Table 2 | Results of experimental analysis.

Code	Density (kg/m³)	Moisture (%)	Local modulus of elasticity (MPa)	Local modulus of elasticity w 12% (MPa)	Global modulus of elasticity (MPa)	Global modulus of elasticity w 12% (MPa)	Bending strength (Mpa)
1-1	520,98	10,52	9272,66	9409,90	8635,36	8763,16	37,42
1-2	526,47	9,26	10953,88	11254,02	10927,52	11226,93	57,78
2-1	483,44	10,26	14715,58	14971,63	12049,56	12259,22	46,66
2-2	527,26	8,73	8404,21	8679,02	9162,46	9462,07	37,87
3-1	503,80	9,98	13062,74	13326,61	10548,63	10761,71	30,74
3-2	499,54	9,49	9137,13	9366,47	8865,06	9087,57	26,79
4-1	529,84	10,68	7592,62	7692,84	7898,91	8003,18	26,99
4-2	520,33	9,77	8373,61	8560,34	7457,21	7623,51	28,79
5-1	493,66	10,24	9682,79	9853,20	10315,60	10497,16	46,84
5-2	477,85	10,51	6774,19	6875,13	6974,39	7078,31	16,31
7	531,71	9,86	8734,63	8921,56	8896,36	9086,74	47,33
8	577,88	9,54	8504,19	8713,39	8257,74	8460,88	38,22
10	577,74	10,97	18480,35	18670,70	12020,95	12144,77	56,11
11	541,59	9,56	7379,56	7559,62	8519,69	8727,57	31,85
12	491,64	9,37	10508,04	10784,40	9443,50	9691,86	35,33
13	456,73	9,39	10502,73	10776,85	8039,97	8249,81	14,95
14	440,51	10,96	5481,31	5538,32	5835,50	5896,19	23,79

defect regardless of its location (if it is at the top of the element, if it is in the middle). It is a precautionary choice. Otherwise the failure occurs due to the defects that affect the area of maximum stress, i.e., in the case analysed, the defects in the middle third of the beam. In the test, therefore, a precise load pattern is assumed; it is a significant difference compared to the visual grading.

4. Discussion

The analyses carried out first show that most of the timber beams would not be currently considered suitable for use according to the visual grading (without considering the effects of the division into two parts, only 3 elements would be usable). The history of these beams, on the other hand, has shown that in a given load condition they were able to perform their structural function without damage to the building and safeguarding the safety of people. In buildings adjacent to the demolished ones, beams similar to those analysed are still used. The visual grading underestimated the structural characteristics of the elements because it is affected by the worst defect regardless of its location.

The experimental analyses indicates that approximately 33% of discarded elements (elements n. 1-1, n. 1-2, n. 2-1, n. 10) have resistance values greater than the minimum value (element n.12) of elements that were accepted for structural use according to the visual

Table 3 | Comparison between the worst defect according to the visual grading and defects that cause the struc tural failure.

Code	Worst defects identified by visual grading	Defect that causes the structural failure
1-1	Group of knots n.3-4-5, wanes	Knots n.3-5-18-25
1-2	Wanes, ring shakes, group of knots n.15-16	Wane, knot n.29
2-1	Wanes, knots n.15-16-17	Knots n.2-3, presence of one nail
2-2	Group of knots n.18-19	Knot n.8
3-1	Wanes	Wanes, knots n.2-3-26, shrinkage cracks
3-2	Knot n.14	Knots n.8-9-14
4-1	Group of knots n.2-3, knot n.12	Knots n.3-12
4-2	Knot n.13	Knots n.34-39
5-1	Knots n.1-2-15	Knot n.8
5-2	Knot n.26, group of knots n.6-7-8-9-10-11-12-13-14	Knots n.10-11-12
7	Warps, rate of growth, knots n.1-3	---
8	---	---
10	Fissure	Fissure
11	Ring shake	Knots n.4-5
12	Warps, group of knots n. 2-3,knot n.14	Knot n.3, anthropic damage
13	Wanes, group of knots n.6-7	Group of knots n.1-2
14	Twist	Knots n.5-8

grading. The elements n. 1-2 and n. 10, which among all the elements have the best resistance values, were discarded according to the parameters of the visual grading. The characteristic values provided by visual grading are compared with the data obtained experimentally. The experimental data have to be greater than the data provided by the visual grading, namely they do not have to be included in the 5 percentile values, in order to prove the reliability of visual grading. This comparison is done in reference to the density, modulus of elasticity and bending strength. The legislation is widely precautionary. Unlike the characteristic values related to bending strength, the modulus of elasticity, density and the average value of the density are always smaller than the real values. Visual grading is always cautious and, therefore, can be used for the definition of the strength class, but it is not always responsive to real values. The mechanical properties of the element are often underestimated. This case has greater relevance in the case of reuse because, unlike the case of a new element, the load conditions that the timber element is able to stand are already known. The comparison between the strength classes identified with the visual grading and the real values resulting from experimental analysis reveals that a timber element, according to the current standards and although suitable, can be discarded and labelled for non- structural use. Whereas on one hand it is a guarantee of safety, on the other hand, the non-structural use of an element (which for its properties could be structural used) minimizes its performances and yields a lower durability, with a consequential impact on sustainability, cushioning the embodied energy in a fewer number of years and often with economic impacts for those who operate virtuous reuse mechanisms. Moreover, we made a comparison between the worst defects identified by visual grading (Table 3): those defects that have certainly conditioned the assignment of the strength class and those that have influenced the structural failure to identify a potential equivalence between the two analyses.

Among the parameters defined in the visual grading, the positioning of defects respect to the application of the load is not taken into consideration. In the case of new elements with the purpose to define uniform criteria for marketing, this is a precautionary measure. This is because it is not possible to know in advance how the timber element will be used in reference to the location of use and consequently the side for the application of the load. Also, it is not possible to know if the element will be cut or will be used in its original length, nor is it known at the time of sale what type of load it will bear. Unlike in the case of reuse of elements that have already lived a lifecycle, the visual analysis, made without considering the above-mentioned variables, produces inconsistent results, because in most cases the failure of the elements is significantly influenced by the worst defects located in the middle third and due to load modes, as seen from the data generated by experimental analysis. A specific visual grading for reuse elements should therefore give priority to considering information from the first life cycle of the element.

From a structural point of view, it is necessary to take into consideration the same defects currently evaluated by the visual grading (knots, wanes, etc.) but with respect to the most stressed area, i.e. considering the loading scheme (supported beam, cantilever beam etc.) and the loads actually sustained during the first life cycle. From an environmental point of view it is necessary to consider the climatic conditions (temperature, humidity level), the territorial characteristics (presence of xylophagous insects) and the positioning of the element (internal or external). In this way it will be possible to take into account certain data and information about the behaviour of the element under certain conditions. These conditions give us a guarantee of safety in reuse.

For the reuse of a timber element for structural purposes it is possible to act in two ways: the first is already feasible at present and consistent with the legislation and standards in force, the second is a proposal resulting from the research carried out and wants to push the reflection on the need for specific regulation.

4.1 Cutting of the worst defects for increasing mechanical performance

In the first mode, the aim is to put the element back on the market as a “new element”, i.e. without knowing how it will be used (scheme and loading conditions). The visual classification is carried out and, if it is no longer suitable for structural use due to localized defects, targeted cuts of the timber element are made. In fact, the analysis shows that in some cases the cutting of part of the element causes an increase of the visual class and consequently of the strength class.

When the defects that affect the visual class are knots, wanes, shakes, ring shakes or biological alterations positioned in a localized way, the removal of the part containing the defects results in the increase of the performance of the part without defects or with minor defects. The evaluation of the effectiveness of this way of acting depends on the type of defects present. In the timber elements analysed, this mode of operation was useful for elements 2 and 5 but was not useful for elements 1, 3 and 4. When the defects can be removed, it is possible to use the element for a structural use (otherwise the element must be discarded) or to improve the visual class of an element whose defects are within the range stipulated by

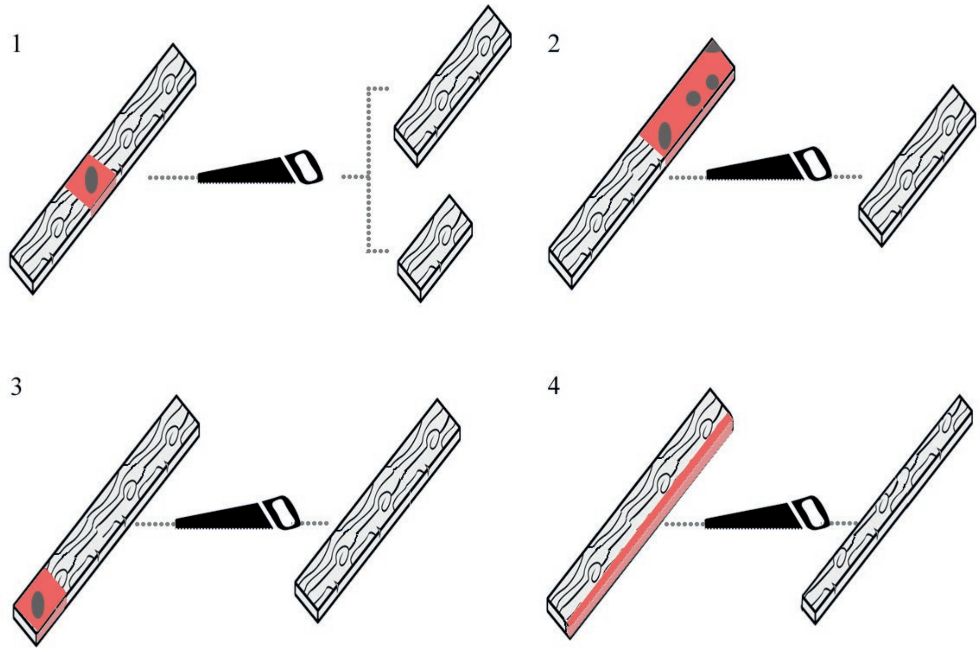


Figure 5 | Examples of the elimination of worst defects aimed at increasing mechanical performance. 1-elimination of knot centrally located, 2-elimination of group of knots, 3- elimination of knot head 4- elimination of the wane.

the legislation. Considering that this approach produces a reduction in the length of the element, the operation can be considered convenient when the size is not less than 1.50 meters, below this value the potentialities of reuse are reduced. It is more convenient to consider other. When the worst defects that affect the visual class are knots, wanes, ring shakes, cracks or biological degradation it is possible to increase the resistant class by making appropriate cuts (Figure 5).

4.2 Re-putting the element in the market: example of used timber beam label

This research, however, suggests the use of this technique to enhance the performance of elements that can be reused immediately. To ensure this, the length of the element after the cut is significant for the purposes of a possible structural use.

In the second mode, the aim is to put the item back on the market as "used". At the time of demolition, the following information must be noted:

- structural: mode of use (beam, pillar), span or height, position of the element (e.g. for a beam: compressed part and tensioned part), load diagram, load bearing capacity.
- environmental: place of use (longitude and latitude), risk class (EN 335:1995), humidity measured on site.

A microscopic analysis must then be carried out and the species identified. Subsequently the visual grading will then be carried out according to the current standard, but only considering defects that are in the area of maximum load, taking into account the loading diagram of the first life cycle. The dimensional parameters of the defects must be increased by 20% and similarly the length of maximum load zone must be increased by 30%, so that the visual class will provide a safety margin in the results obtained.

The visual classification will provide results related to actual use and not potential use. The strength class obtained in this way can be verified by comparison with the load detected during demolition. The most conservative strength class will be considered between that obtained from the loads present in the first life cycle and that obtained through visual grading, done as described above. In the reuse of the element with conditions similar to those of the first life cycle it will therefore be possible to refer to this visual class, if instead it is considered to reuse the wooden element according to a load pattern different from that of the first life cycle, it will be necessary to refer to the visual grading used for the new elements, since the life cycle already experienced is not able to provide us with useful information from a structural point of view. Regardless of the structural aspects, knowledge of the environmental characteristics of use of the element in the first life cycle optimises reuse by increasing durability.

In fact, from an environmental point of view, knowing the resistance of an element to certain conditions can allow a safer reuse. The elements analysed deriving from selective demolition in the Valencian community operated in a risk class 1 (EN 335:1995), in an area exposed to termite attack (Isoptera Brullè). The internal position of the building and the use as a beam have therefore favoured the durability of the elements that have not been subject to biological degradation, except for rare exceptions in the header that can be solved by cutting them.

Once these operations have been carried out, the wood elements used will be provided with a unique recognition code and a specific label indicating the structural and environmental conditions of the first life cycle and the relative visual class determined as described above (in the area of maximum load increased with a safety coefficient) and indicating the lowering of the resistance class in the event of reuse in a different form.

An example of a label is given in the figure 6.

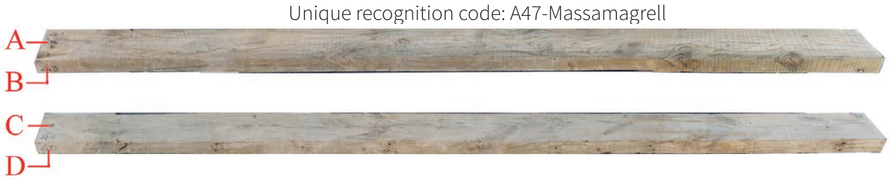
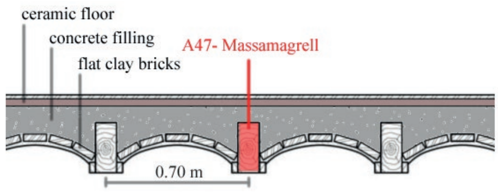
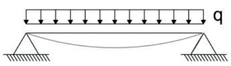
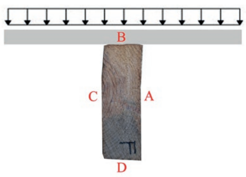
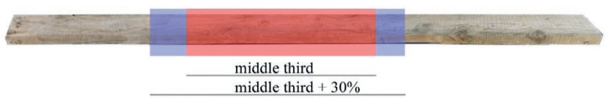
Unique recognition code: A47-Massamagrell	
	
Dimensions: 300.0x 17.50x 5.8 cm	
FIRST LIFE CYCLE	
Location:	Massamagrell (Valencia), latitude: 39.570422, longitude: -0.336119
Assumed laying year:	1920
Demolition year:	2016
Risk class (EN 335:1995)	Classe 1
Humidity measured on site	10.54%
q - Estimated load on the beam: structural and non-structural permanent loads + variable loads (2 KN/sqm)	4,6 KN/ml
Constructive scheme	
Loading diagram:	
Beam orientation:	
STRENGTH CLASS FOR USES SIMILAR TO THE FIRST LIFE CYCLE	
Analysis area for visual grading	
Standard used considering the above mentioned area of analysis (middle third + 30%)	Standard UNE 56544:2011 and UNE EN 1912:2012
Strength class	C18
STRENGTH CLASS FOR USE IN CONDITIONS OTHER THAN THE FIRST LIFE CYCLE	
Standard used	Standard UNE 56544:2011 and UNE EN 1912:2012
Strength class	Structural use not allowed

Figure 6 | Example of label for a timber beam derived from selective demolition.

5. Conclusions

The only chance for the designer/technician who wishes to proceed to reuse is to perform again the visual grading according to the parameters set by current regulations/ standards.

The elements that would be discarded today were used in the past; we are witnessing an increase in the level of performance required by the elements. Just think that many of the elements analysed in this research, according to current visual grading, would not be appropriate to structural use because they do not meet the minimum requirements, while from their installation (1920) until their demolition (2016) they have performed structural functions.

In the procedure of reuse, the knowledge of the history of the element is a decisive part. We have more information than the new elements, i.e. the loads that the element endured with a specific structural scheme, the occurred deformations, the placement of shrinkage cracks and the resistance to biological attack in a specific environmental class.

If we treat a wooden element that has already undergone a life cycle with the same parameters used for a new element, it means that we are not considering these parameters, in order to exploit its real potential. It follows that in the concept of reuse, the element cannot be considered without taking into account its new intended use. It is necessary to systematize the residual performance of an element, the information obtained by analysing the first life cycle and the possible intended uses and to consider specific parameters for the evaluation with respect to this variables.

Visual grading of new elements can be considered satisfactory according to the logical path to which the elements are subjected and according to the impossibility of knowing in advance the mode of reuse. Despite the consensus on the validity of visual grading in terms of safety for elements that have already undergone a life cycle, the definition of modes of visual grading that allow a greater compliance with real mechanical performances and the definition of a specific classification, produce advantages not only in terms of security but also of environmental sustainability.

The analysis carried out in these tests shows the limits of visual grading and the need to define a more structured methodology that, with a different operating procedure, introduces additional phases compared with the current visual grading, increasing the level of safety and at the same time maximizing reuse.

In particular, it is essential to note down information from the first life cycle at the time of demolition. If the element is to be introduced in the market without giving indications on how to use it, it is possible to proceed by equating that element to a new one, i.e. according to the visual grading. In order to optimize the reuse, however, can be assessed the opportunity to cut one or more parts of the element or divide it into several parts, with respect to the length of the element and the type and placement of defects, in order to increase the strength class that derives from visual grading.

If the element is to be re-introduced into the market providing indications on how to use it, a visual grading must be carried out considering the area of maximum stress according to the structural scheme detected in the first life cycle and applying safety coefficients.

In this way the element used can be put back on the market with a specific label that describes the conditions of use in the first life cycle (structural and environmental) and identifies different classes of resistance: one in case the second life cycle takes place in the same way as the first life cycle and one in case the conditions are different.

The procedure described allows to optimize the reuse of structural timber elements without underestimating their performance.

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