World Conference on Timber Engineering
Oslo 2023

VALUES OF RECLAIMED TIMBER

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ABSTRACT: France's current 'wood wastes' management seems inefficient in settling on a durable reclaimed timber branch that would support reuse practices in architecture. We assume that there is a set of 'values' attached to timber members that should be revealed to estimate their market value better. Through the literature, we observe that the economy of a deconstruction project used to be considered significant, while embodied carbon is nowadays of major concern. Moreover, as Circular Economy and Cascading concept emerged, the meaning of durability has decreased in favour of reversibility that could guarantee a flow of material circulation. The problem is that these ideas involve probable rebound effects due to energy engaged in transportation and the transformation of reclaimed resources. Our reflection comes from a field study experience where we participated in the reuse process of timber members deconstructed from a textile mill. We observed that the lack of economy and the lack of 'values' identification resulted in depreciating the operation's efficiency, whose initial objective was to maximise the extraction and diffusion of reusable elements as much as feasible. Our research focuses on construction materials and massive structural timber members, which still seem challenging to reintegrate into new buildings.

KEYWORDS: Reclaimed Timber, Value, Reuse, Economy, Deconstruction.

1 INTRODUCTION

Since it appears as a solution to mitigate the environmental impacts of the construction sector, 'reuse' tends to become a current practice again [1]. Structural elements, such as timber joists, extracted from existing buildings must be able to respond to the direct competition of new timber products in terms of cost, availability, and traceability. Compared to past centuries, the reuse of reclaimed materials demands more information to fit contemporary norms and laws that rule the construction sector. Consequently, assessment, extraction, refurbishment and reintegration of reclaimed materials, which constitute the reuse process, should be considered interconnected, to ensure an optimised transmission of information and material in parallel between all stakeholders involved.

In France, less than 4% of what is qualified as 'wood wastes' produced by deconstruction and demolition worksites are reused or up-cycled. In contrast, it is estimated that 85% of that annual amount of 'wood wastes' comes from structural elements, including 46% with a section superior to 70x150 mm ^{2}, and that a third are 'cut-to-length' [2]. Thus, let us think: is the supposed high potential of demountability of timber structures enough to make the use of reclaimed timber a current and effective architectural practice? It seems not. We wanted to gather assumptions about reclaimed timber members' values, to enlighten research on the subject. From a reduced perspective, the construction sector is about individuals producing materials that others will buy to construct buildings. Thus, we assume that the reuse process should aim to create 'values' attached to existing timber members, but, through a combination of architectural, technical, social and ecological aspects, not only from an economic perspective.

We observed that 'the economy' (also in the sense of minimising the use of material [3-4]) of deconstruction and reclamation was present in early studies from the 2000s [5-6]. An orientation of research that got sense since Architecture, Economy and Ecology are interdependent, deeply linked by their etymology, *'οἶκος'*, the ancient Greek term [7-8]. In France the construction sector weight (in added value) in 2021 is 5.7% of the Gross Domestic Product, even up to 30% if we enlarge to the industry sector and real estate branches which are also concerned by our habitat management [9]. This shows that the economy of the construction sector is deeply related to social and political aspects. Besides, family structure, population growth and ecological ambitions impact the development of the construction sector [10], and reuse has a role to play in it.

To build this paper we rely on readings based a wide span of texts related to reuse, timber, and sustainability. These different resources help us to analyse our case study, a textile mill deconstruction, in which we focus our attention on the reuse process of timber members.
To introduce our subject, part 2 emphasises that reuse is not an objective in itself but that it is more a solution to overcome a lack of durable uses. In a previous paper [11], we have exposed the fact that we should speak about 'resource' and 'deconstruction', instead of 'waste' and 'demolition'. Since architecture is about communication [12] we should be careful of the meaning of the terms we use. We will follow that idea by questioning concepts of circularity and cascading in part 3. Part 4 presents which 'values' are concerned, before concluding in part 5 in what way prices, market values, and deconstruction costs should be studied to support that subject.

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https://doi.org/10.52202/069179-0470

2 SUSTAINABILITY AND DURABILITY

2.1 WHY RECLAIMING TIMBER

In France, two main reasons drive the development of strategies to reuse reclaimed timber. Both have got climate change for trigger. On the one hand, like other countries, France has introduced the obligation to assess the material composition of buildings that owners want to demolish or rehabilitate. Materials must be quantified, qualified and classified according to whether they should be reused, repurposed (up-cycled), recycled (down-cycled), or landfilled [13]. Thus, political decisions aimed to enhance better material sorting during deconstruction. This resulted in the potential availability of timber members that used to be discarded.

On the other hand, it is now commonly known that the construction sector can take advantage of timber construction to store carbon and allow us to build and renovate our dwelt environment in the future [14]. Additionally, climate change has already put and should increase, pressure on forests and thus can create tension around wood resources [15]. Thus, developing strategies to reuse timber could help in the future to be resilient to unexpected climatic events, therefore allowing us to pursue the development of the timber sector while limiting the pressure we put on forest regeneration [16-17]. Timber members susceptible to being deconstructed and stored in the building stock could be seen as a local source of timber, already extracted and manufactured.

2.2 HIERARCHY OF PRACTICES

Following the words of Fivet et al. [18], '*maintain in time an already manufactured capital*', in place, we could say, '*with effect to simultaneously contribute to the natural capital protection and the fulfilling of human capital*' there is a hierarchy, almost a moral one, in the way we now decide to manage our built environment. Preserve it, transform it, or expand it. Climate change effects challenge the construction sector to find ways to reduce its impact on our shared environment while guaranteeing access to comfort. Two interconnected parameters drive the evolution of practices, resource extractions and carbon emissions. The dilemma is that to reduce the energy consumption of already built square metres and future ones, we will need new resources, as the human population grows, and part of the building stock becomes technically obsolete. These resources will need to be as renewable and limited as possible, like the energy used for their extraction, transformation, and implementation. Consequently, following the 9 R's [19] principles, the reuse of construction material is not the priority. To sum up a transposition of that hierarchy of actions could be structured as follows:

- Stop building and preserve uses of existing ones.
- Rehabilitate and develop existing buildings.
- Redesign at different scales (from furniture to urban) with 'Design for…' principles [20-21].
- Use renewable materials that store carbon and emit few to be produced.
- Use fewer materials.
- If Adaptive Reuse is not feasible, reuse existing materials.
- If Reuse is not feasible, Up-cycle, Down-cycle, or Energy Recovery.

2.3 PRECARITY OF REUSE

All those perspectives of actions are part of a vast aim to turn our economic system toward a 'circular' dimension instead of a 'linear' one.

Stop building and preserving the existing as much as technically and economically feasible, by rehabilitation seems to be a robust solution. But adaptive reuse has three primary limits:

- The presence of polluted materials, asbestos, lead or hydrocarbons, can condemn building components to landfills.
- Deterioration of the building due to a lack of maintenance and abandonment can foster demolition or deconstruction instead of adaptive reuse.
- Inadequacy of uses between the existing and the future programme, at different scales, from room to the city block level, can tip the balance in favour of demolition or deconstruction at best.

If they credit the fact that demolition or deconstruction will happen, these three parameters should also warn us on the limits of the 'Urban Mining' concept; pollutions and deteriorations deeply influence sorting towards landfilling, energy recovery, or recycling in best cases.

2.4 REVERSIBILITY LIMITS, THE IKEA ANALOGY

Worldwide, craft timber structures, from Half-timbered houses [22-23] to Minka [24], including Maloca house [25] and their contemporary examples [26], follow a logic of prefabrication that include reuse aptitudes by default. They integrate a dimension of demountability deeply connected with the way wood is transformed into construction material, close to human scale, and assembled with reversible joints. But being made from wood is not a guarantee of reversibility for a building. Although the technicity of certain materials and of building composition has increased, it is not an indefectible sustainability label. The most famous and experienced example of the limits of reversibility is Ikea furniture items. These latter are not renowned for their ability to be disassembled multiple times without losing quality, degrading their structural abilities and their global durability. Even if they can easily be repurposed, transformed or adapted, a loss of pieces and integrity seems inevitable [27-28]. Following the Ikea case study, the material's quality and 'purity' are also part factors potentially condemning furniture pieces after dismantling. The closer a material is to its original form, the more it is reusable or repurposable, and the less it is losing quality or generates loss through time and use. For example, stone blocks, hewn wooden beams or earth are construction materials 'Close to Cradle' that might lose part of their unity but not their absolute integrity. During the documentation of our case study, we observed that the first-floor joists were not linked to the steel beams that support them (see Figure 1. a and 1. b). They were only placed and wedged by a notch cut at their ends. This design facilitates the deconstruction and allows to deconstruct by hand without involving machine assistance. Figure 1.a shows an operator lifting a joist with his right shoulder to 'denotch' it and sliding a wooden wedge between the joist and the steel beam. In Figure 1. b, we can see the second step of joist deconstruction, which consisted in using two ropes attached to

 https://doi.org/10.52202/069179-0470

the joist extremity to take it down in two movements. Ikea's furniture reuse problem is not precisely proportional to building scale. Still, some reversible design strategies have weaknesses that we should consider, or at least assume as inevitable losses, such as screws and nails or wooden bars with sections inferior to 5 x 5 cm [29].

Figure 1.a et 1.b: *1.a shows joists 'denotching' from the I-steel beam. 1.b shows the descending of a joist with the rope system.*

3 SEMANTICS OF RECLAIMED TIMBER ECONOMY

3.1 CIRCULARITY AND CIRCULATION

3.1.1 Circularity. Feasible to what extent?

Since the reuse of reclaimed timber is inscribed in the scope of 'Circular Economy', we wanted to explore and precise some aspects of this concept regarding the 'values' we will develop in the following parts. 'Circular Economy' and 'Circularity' concentrate all the attention and seem to crystallise the economic frame of reuse practices [30]. Still, it must be used carefully because they are concepts with multiple interpretations [31-32]. It somehow glorifies an economic system we would like to see happen, but which demands massive socio-economic efforts, or can only stay abstract due to the limits of physics laws.

Even if wood, with other plant-sourced materials, seems to be the best example of an object that starts from a 'point' and could return to this same 'starting point', closing a perfect loop, it never strictly happens in practices. Even if the scenario of wood chips or ashes scattered on top of forest soil is not utopian, it depends on a rigorous protocol [33-34]. Bringing back, after centuries of use, the residues of a joist where the tree was first cut seem complex enough never to happen. Even more if it has been repurposed into furniture, then into particleboard, paper, to be finally burned. The closest architectural demonstration to the circularity concept is the Maloca house [25], which was built, reused, and burned in the same area.

3.1.2 Circulation. A concept that needs delimitation.

Another argument toward precautions with the use of the 'circularity' term is that the complete process briefly described earlier can make us drift from the first objective of sustainability of the circular economy, limiting resource extraction and carbon emission induced by increasing the time of first use. Circularity lets us think that, as we can 'close the loop', we can endlessly extract and operate natural resources. For reclaimed timber, a rebound effect of circularity is depicted by Ghyoot et al. [1] with the example of TerraMai, who collects reclaimed wood from Asia to South America to sell it in the USA. Similar globalised circularity was identified through interviews with carpenters or resellers who mainly bought reclaimed wood from Poland [35]. In addition to the impact of transport, this wood can also be crafted, implying energy consumption. Besides, as Ghyoot et al. exposed it, this migration of resources from developing to developed countries take part to destabilises the socio-economic systems of origins, mainly by depriving the local inhabitants of material resources that would still be useful to them. In those terms, we considered circularity and circular economy as a system in which materials can circulate or move or go through, in the sense of expressing a flow of products through time and space. But even there, the idea of movement keeps ambiguous statutes because movement and transportation imply energy whereas the immobility of things means 'continuity of use', which is less harmful to the environment.

3.2 THE STAIRCASE BEHIND THE CASCADE

3.2.1 Toward the 'tread' extension.

The cascading concept is much more honest on the downgrade aspect of material uses. As Niu et al. [36] propose, cascading is much more complex, suggesting that the materials can go up and down in terms of economic and 'use value'. But cascading keep the metaphor of water flow (waterfall), with water returning to this starting point, still support, like the loop of Circular Economy, an abstracted view of a much more complex system. Speaking of a 'staircase' seems clearer in depicting how we manage wood products through time and 'use value'. Step by step, a cubic metre of wood gets dispersed and disseminated in soil and air through different appropriation processes. At least, the representation of optimal sustainable use of a cubic metre of wood is not to go down the staircase, step after step but to extend as long as feasible the length of the 'tread', seen here as a platform, as figure 2 expresses it.

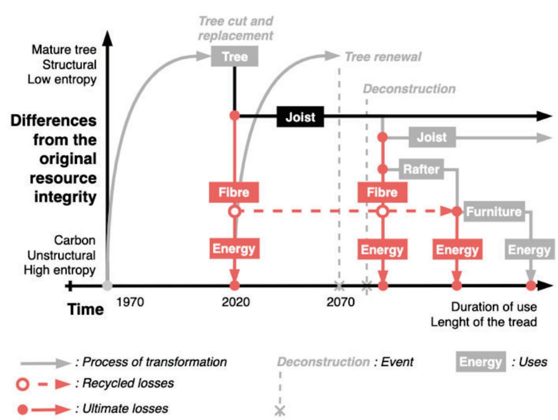

Figure 2: *Diagram of the 'staircase' of timber uses. It shows that the risers, as the steps, should be limited as much as possible, while the treads should be extended as much as possible. The joist black line illustrates the 'platform'.*

https://doi.org/10.52202/069179-0470

3.2.2 Designed to last and limit the entropy.

A sustainable conception of timber construction should find a way to combine all the 'Design for…' approaches [20].
Hazardous and composite materials have created disorders in reappropriating the building stock. Asbestos and lead are the more telling examples. Specifically for wood, treatment has brought more disorders; if we take into account that a better design should consider durability and design strategies not to put the wrong species in the wrong place, or at least to take on a limited lifespan. Glues or too-strong binders are the worst enemies of reuse. An example of this phenomenon is the up-cycling of brick panels in a housing project of 92 flats called Resources Rows, designed by the architecture firm Lendager Group and built in 2020 in Oerestad, Copenhagen [37].
A similar effect can be found in the car industry; where the increased complexity impacts building reliability through time and adaptability [38-39]. This points out the necessity to channel conception toward 'pure' and 'natural' material, closer to their original form when extracted. 'Closer to Cradle' may be better than Cradle to Cradle. Initiatives have taken a pathway in that sense [40-41]. The final challenge is not to see the log house as the best solution but to consider its parameters to integrate it into more creative solutions, such as the 'Breathing wall mass timber research project' supervised in the framework of the Rural Studio, in 2021 [42].

3.2.3 Definitions for wood that goes Up and Down.

A fascinating aspect of wood material is its transformability and appropriability faculties. That specificity opens a broad panel of potential futures for a single piece of timber.
To illustrate our thinking, we will use here the example of a floorboard piece. If reuse is not reached, it can be at best up-cycled or, in most cases, down-cycled. In France, it is estimated that on the annual average amount of wood waste of the construction sector, 48% is energy recovered, 42% is recycled, 7.5% is landfilled, and 2.5% is reused/up-cycled [2]. French legislation (Environment Code, Article L. 541-1-1) differentiates reuse (*réemploi* = re-employed) from up-cycling (*réutilisation* = re-utilisation) and down-cycling (*recyclage* = recycling). See Godina's lexicon [43], which depicts these terms toward 'universal' definitions. We see here how complicated it is to escape from terms that include '-cycling'.

- Reuse/*Réemploi* may not involve a radical transformation of the element, such as cuts. A floorboard must keep its original use, but it could be brushed, planed, varnished, etc.
- Up-cycling/Up-grade/*Réutilisation*, would mean here that our floorboard could becomes something between furniture and glue laminated beams.
- Downcycling/Down-grade/*Recylage* signifies that the floorboard will be crushed and, for example, used for particleboard production. Recycling, unlike Up-cycling, completely make the original timber piece disappear.

3.2.4 Where cascading gets blurred by prices.

Up- and Down-cycling blurs the cascading process. If we look for example at the market value of 1m3 floorboards and transform them into a chair with a similar design, niche products (Scrapwood Oak Chair) are seven times more expensive than mass products (Lisabo); see Figure 3. Mass products chairs keep the same value as a newly produced cubic metre of floorboards for the same volume of wood. On the contrary, based on volume unit, a cubic metre of glue laminated beam is worth less than one transformed into a chair or a cubic metre of reused floorboards.

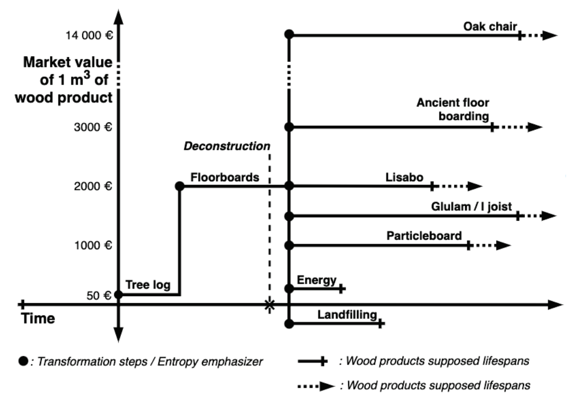

Figure 3: *Diagram of the market value of 1m3 of wood products market after their first use, here as floorboards, and from their original shape as a tree log.*

Consequently, we see that timber elements can go up and down through the 'cascade', see Figure 4, blurring the concept of cascading.

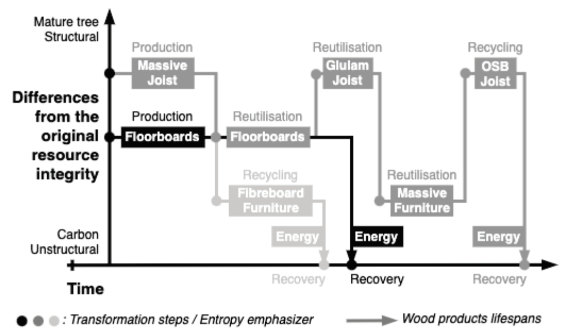

Figure 4: *Diagram of the three main scheme wood products lifespans, black: 'platform', dark grey 'crenel', light grey: 'staircase'.*

Up-cycling can contribute to down-grade the material (cuts, crushes, …) but can increase the value of the same cubic metre of wood. Oriented Strand Board or particleboard down-grade an original joist but can so up-grade if it is turned into an I-joist with panel web ('Steico Joist 45' professional price at a cubic metre, average web-based panel for glulam beam).
Up-cycle can save most wood resources, but not at no cost; material loss must be carefully considered in the transformation process. Student works involved in the research show that an average of 30% of the material will be lost in reappropriating the reclaimed timber. One group had to build furniture out of floorboards, and another a micro-house (4m2) based on a batch of cut-offs from our case study [35]. Other researchers identified a loss of up to 46% of the volume that will be recycled or recovered [44].

https://doi.org/10.52202/069179-0470

More recent work on the evaluation of timber purchase with the aim of up-cycling confirms these tendencies towards a range between 30 and 50% of loss in the reclamation of timber members produced before the 1950s, mostly not standardised. Consequently, as the original volume of wood is transformed, its virtual embodied carbon stock depreciates due to energy (and so related Green House Gas) involved in the transformation.

3.3 ON LIMITS OF BRAND-DUFFY SCHEMES

3.3.1 Layers that hide the need for durability.

Stewart Brand's scheme [45] (expansion of Frank Duffy's concept) conveys a misinterpreted general idea that the lifespan of materials (element, component) has definite lengths. Technical useful life is subject to multiple and variable factors influencing lifespan lengths. These include urban reconfiguration, frequency and degree of building occupancy, degree of climatic exposure, degree of rehabilitation, and natural wear of the material, all linked to 'uses' and, thereby, to the 'human factor'. Users also take part in determining the length of the lifespan with criteria of comfort, optimal use, norms, trends, and perception of wear.

All those criteria reveal that we must think about life expansion rather than life cycles that can legitimate a materials turnovers independently from useful life, a logic present in the office real estate industry.

3.3.2 Unusable or old-fashioned?

From Duffy and Brand's scheme perspective, what is not structural is not supposed to last more than decades [46]. But wood objects proved multiple times their ability to last after decades, if not centuries. Figure 5 shows examples of a dining room where most non-structural components are aged more than the supposed end of their lifecycle. The house containing these objects was built during the 1930s. The present owner, attached to the idea of limiting his environmental footprint, chose to perpetuate the use of objects that could be judged obsolete but still fit his needs.

Besides, this example introduces two values, sentimental and aesthetic. The first relates to our relationship with an object if it has an intimate story, as in our example case. The second one is related to artistic dimensions and subjectivity of taste, which is less present but not absent for structural elements. Thus, these two values are strong because they are the foundation of preservation and transmission, two parameters favouring continuity of use. Museums are the main manifestations of this statement, conserving objects defined as having high aesthetic value and being considered with a sentimental aspect by a population.

Let us again take the example of the 'Oak Chair in Scrapwood' design by Piet Hein Eek [46]. It supports the idea that if floorboards cannot be reused, they still have value after being up-cycled, with the assurance that a 500 € chair will probably last longer than or as long as the building that contains it or used to contain it.

Other concepts have tried to review the Brand-Duffy proposition from a more technical perspective [47] but keeping the structure of 'cycles', which conveys the idea of a substantial turnover of building components. Replacement should be possible essentially if it is technically necessary. Still, independently from a life cycle perspective, a wooden table can be used for decades, and tiles for plumbing are supposed to be reparable. Systems (HVAC) could be less machine aided by following passive principles [48-49], thus limiting maintenance and needs for components with rapid wear.

Figure 5: *M.dF's dining room. In the upper left is a classic example of 'Lundia' shelf in massive wood, dating from the late 1970s early 1980s; in the centre, the table is made with reclaimed planks and used as it has been since the 1930s; back in the centre, the double door in wood and glass (paint in white) is an original feature of the house since the 1930s; on the right, the sideboard is dated from the 1940/50s.*

4 VALUES OF A RECLAIMED TIMBER MEMBER

4.1 HISTORICAL VALUE

We start here with the most subjective value, as we introduced in part 3.3.2 and as know-how value expressing it in part 4.2, price and reclamation criteria depend not only on material aspects. Values attached to timber members also rely on their 'story'. Which building contains it? Has this building played a role in the site's historical background? A prominent example of that concept was brought to the public when Notre-Dame de Paris burned on April 19th 2019. More than losing a roof, a system dedicated to protecting the cathedral interior from climate contingencies, more than losing over 1500m^3 of wood, the cathedral loses her 'forest', the timber-frame nickname that emphasises roof personification and gives it a 'mystical value'. Moreover, the roof's members were precious archives of the medieval climate [50]. This gives more credit to the preservation of old pieces of wood present in buildings worldwide, or at least to the collection of data they contain. Historic value can be acquired after the first period of use, as an example of a barn built in 1920 in Rheinau (Swiss), reported by J.Brütting and C.Fivet [18-51]. The latter was constructed out of reclaimed timber members of a bridge built in 1810 in Eglisau. The historical value of the original bridge was transferred and developed by the fact that it became a barn, still in use a century after.

4.2 KNOW-HOW

Following the example of Bridges, the website 'Bridgehunter.com' [52] gathered at least 55 examples of bridges that were relocated, i.e. reused. More than a practical way of crossing a gap, these bridges stand for a legacy of timber engineering and are historical landmarks. With the idea that timber members have embodied immaterial values, we can assume that both crafted and industrial components and their elements can be characterised by their 'added values'. These added values stem from their design that 'contains' hours of conception to accomplish specific structural objectives (e.g. a span of a dozen meters) and hours of labour to transform wood to fit the design. Reclaimed timber members got added value for works already done and knowledge they can conserve and convey [53]. Since the medieval age, timber members have been included in chains of reclaimed materials [54]. At that time, timber reclamation might have been based on the aim of preserving a previous wood selection (related to strength grade), judged good for a structural purposed, still after reclamation. In addition, reuse interests must have been motivated by preserving the benefice of efforts made to extract and transform, by hand, a raw piece of wood into a usable member, indirectly including human energy and its apprenticeship [55]. Work, labour, as illustrated in Sebastião Salgado's book 'Workers' [56] or expressed in Graeber's theory of value [57], show how connected humans are or used to relate to what they produce, which is not only part of having an economic impact but also a cultural once.

4.3 EMBODIED CARBON

Notre-Dame de Paris fire can be supposed to have emitted over 1800 m ^{3} of C02. Following this example, embodied carbon in reclaimed timber can be seen as a value that must be part of its traceability when sold. Then, CO2 seems to be only the visible part of the iceberg of the environmental impact. It misses resources unextracted and unimpacted to produce new members (ozone, soils and water acidification, eutrophication, air and water pollution, abiotic resources depletion, fossil or not, unused energy, unproduced wastes, …). This lets us consider which values should be taken into account, whether there is a hierarchy, and how data can be collected, evaluated and transmitted concurrently to the element progression in the cascade/stairs, as represented by Figure 2. Recent advancements have been made toward assessing the environmental impact of reclaimed materials [58]. Nonetheless, the externalities of reuse still need to be investigated, by considering all the reuse process, which could entail, for example, deconstruction, milling, transportation, and implementation in the new project. All these activities also participate in increasing our entropy [59]. Furthermore, the environmental impact becomes even more complex if we include facts such as the renewal of biomass that occurred as long as a timber member remained in use and the induced avoided purchase of new products. Until now, the French Environmental Reglementation (RE 2020, see Decree n° 2021-1004) defines the framework for the Life Cycle Assessment (LCA) of new construction. In the LCA, reclaimed materials are currently worth 0 kg of CO2 by default. Thus, creating support to reuse initiatives might not remain a permanent rule. Here we saw that carbon value estimation and traceability would be necessary to reach an accurate LCA that integrates reclaimed timber members, to recognise the impact depicted above. Biogenic carbon could become part of a carbon market that would increase timber member market value.

4.4 MARKET VALUE AND USE VALUE

4.4.1 How much is it? About price estimation.

As we experienced through our field study, see part 5; price is a significant value parameter that could channel timber members toward reuse or not. In other words, value creates value. A low estimation and a lack of purchasers will limit the efforts of a preserved deconstruction, thus limiting in return the quality and the quantity of the timber members that could be sold. We hypothesise that the market value attributed to a timber member is also a label of its 'use value'. The higher the market value, the closer the timber member is to reuse. A lower price indicates a low aptitude to respond to the original use and to be competitive to new products and up- and down-cycling orientations [60].

As we will see in part 5.2.2, to evaluate the latent value of the timber stock of our case study, we align the latent market value of the building stock to the identified prices of the new and reclaimed products on the market by equivalence, as close as possible, by matching, length, section and species. We then adjust the latent value using coefficients: 1 (new, as new or with high historical value), 0.7 (reusable as it is), 0.5 (reusable with low processing) and 0.3 (reusable with high processing), 0.1 (up-cyclable).

4.4.2 Stock and logistics, blind spots of the reclaimed timber value.

The management of the reuse process takes part in adding or removing values, heightening the role and the aspects dual of stock and logistics. During their use, timber members are stored 'for free'. After deconstruction, the created supply of timber members must be protected from climate degradation (e.g. rain, UV, snow…) and eventual thefts (see part 5.2.1). When the protection used to be free, it can now cost to preserve the timber stock integrity. It could be said that value chains do not like storing 'useless' items, as demonstrated by numerous methods developed in the car industry and construction sectors, from Fordism to Lean construction [61]. If it is useless on the site, if it should be moved to find a use, or transformed to be used, it will cost, degrading profit margins, or at worse, diverting initiative in favour of reclamation towards recycling.

4.5 MECHANICAL PROPERTIES

The process of grade identification participates in attesting the value of timber members when facing insurance organisations who need proof of quality and durability/sustainability to ensure that the material will not be charged for the sinister in case of doubt. In that sense, if we look at the etymology of the term 'value', '*valere*' in Latin means to 'be strong' and to 'be valid for'. 'Strong for' (resistant enough), 'valid for' (mechanically adequate), structural purpose. What gives its value to a timber member is its faculty to bear loads. Values attached to mechanical properties are hard to evaluate in a context where we face 'unknown' pieces of wood, sometimes

https://doi.org/10.52202/069179-0470

without any load background and characterisation traceability. To complete the reuse of deconstructed timber elements, a grade datum is necessary for load simulation and structure design accomplishment. As we know, ageing has no significant incidence on bending strength and bending stiffness [62]. Nonetheless, this fact raises an important question concerning the sorting of timber elements to avoid reusing timber that does not enter the norms' criteria (NF EN 338, EC5). Variability of quality, from a mechanical perspective, engages us in developing strategies to avoid potential future disorders:

- Precise assessment methods to identify sources of 'de-grading', before and during the deconstruction.
- Evaluate timber mechanical properties of some pieces and extrapolate to sort them by similarities (dimensions, context of use, aspect, tree species, etc.) and create batches.
- Oversize structures made of reclaimed timber members.
- Consider a batch of timber members as part of one unique grade (C18, lower grade, for softwood and structural use, in our case).
- Evaluate timber mechanical properties of every piece to sort them individually.

Despite its seeming simplicity, this visual grading method is hard to apply on reclaimed timber following the norms ISO 9709:2018 and EN 14081-1+A1 due to aspects gaps with new timber products. A merging with approaches developed in EN 17121 should be interesting to elaborate a specific norm [63]. Another fact of poor adaptability of existing norms is the constraints induced by the reuse process. A strict application of the norms on reclaimed timber can take 5 to 10 minutes for two persons, without including handling time for and between each piece of wood. Therefore, visual grading of an entire timber stock from a building deconstruction can take days and cost enough to degrade the profit margin of the resale. Besides, the gap between norms conceived for brand-new timber products will reject reusable members. From our experiences, we see through visual grading a practice that could help to pre-classified batches of members before their machine grading based on significant characteristics. In our case study, we have experimented vibratory grading method based on MOE evaluation. Bending stiffness is determined by calculation after the caption of the frequencies with accelerometers. As the method is in the reliability assessment process, it is not relevant to give robust results. But trends are identified to avoid risks of keeping timber members inferior to the expected MOE, 7 kN/mm ^{2,} for structural members. Another trend identified is a division into 4 groups, see figure 6. One group is between 7 and 9 kN/mm ^{2}, a second between 9 and 11 kN/mm ^{2}, and a third from 11 kN/mm ^{2}. Each represents more or less a third of our sample batch, with the last of the 4 groups composed of timber members evaluated under 7 kN/mm ^{2}, representing less than 5% of the batch. The main problem is that MOR remains unknown, and mechanical evaluation must be completed to be reliable. But from our perspectives, MOR assessment is still constraining in determining grades, it demands heavy equipment and can generate losses. Therefore, we focus our research on non-destructive and reliable techniques. We try to maximise 'values' embodied in the timber members by preserving as many timber products as possible to sell them, so that they will be effectively reused and be able to transmit their 'values' once again.

Total	Weight (kg)	4 296	Average	Length (m)	4,77		Average	MOE (MPa)	10 079
	Length (m)	310		Section (cm)	25	12		Grade	C20
	Volume (m3)	9,4		Weight (kg)	73			Density (kg/m3)	464

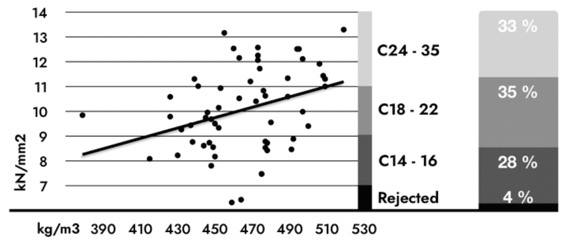

Figure 6: *In the upper part, the table gives general information on the joists batch studied. Lower part graphs depict the supposed strength grades and associate classes (EN 338), based on stiffness assessment with vibratory technique.*

5 AVOIDING FAILURES BY VALUATION

5.1 CASE STUDY CONTEXT

5.1.1 Description of the site.

Our case study is a textile mill, supposed to have been built around 1910 in Épinal, northeast of France. The specific part of the factory we studied was supposed to be designed for the offices of administrative activities. It then became a space for storing archives in the attic and first floor, and the last recent occupation of the ground floor was dedicated to a sewing workshop and a store. But still, we have not yet been able to track down the whole history of the building, which limits the structural analysis introduced in part 4.5.

The building was located in an urban renewal area; a part of the factory was kept, mainly shed volumes, to host economic activities. Our building was demolished to be replaced by a new collective housing project.

We estimate that over 80 m ^{3} were at least 'up-cycled'. The initial stock of wood was evaluated at 146 m^3 in total, with 126 m ^{3} judged as healthy to be reclaimed for 'reuse', eliminating 17 m ^{3} damaged by fungi, insects, or polluted materials (tar mainly present on roof members) and 3 m ^{3} due to cut-offs.

5.1.2 Socio-economy of the project.

At the time of the field study, in spring 2021, timber product prices were rising unexpectedly. Meanwhile, reclaimed timber members extracted from our site were not affected by this phenomenon. Even the contrary happened while the reusability of the timber members was shared by all stakeholders taking part in the deconstruction.

In our case study, materials were proposed explicitly for sale to private individuals and not oriented towards private professional purchasers. However, in the early stage of the deconstruction, a sawmill offered to buy all the timber members' stock. That choice influenced the final rate of reuse and up-cycling.

We conclude from that experience that the more we divide the original stock by many uncertain buyers, the more we augment dispersion and loss of the resource. Besides, regarding the survey of the 'reuse practices', private individuals mainly up-cycled the timber stock, using joists as a post or cutting them in length for other structural purposes. Only floorboards were mostly strictly reused. This mismatch also provides evidence for the need for a method to define resource prices. On the one hand, sellers need to estimate the latent value of their timber stock to 'take the risk' of investing in deconstruction instead of demolition. On the other hand, buyers (companies) need timber members to be 'certified' to ensure their future clients that they are still safe to be reintroduced in new construction. Timber members are less susceptible to convince of their reusable faculties without 'values' attached and thus without investigation to create traceability.

5.2 LACK OF VALUE, LACK OF ECONOMY

5.2.1 If it is worth to be stolen, it is worth to be sold.

What could be seen as anecdotal looks relevant regarding the lack of values attached to reclaimed timber members. A batch of a hundred joists, part of timber members that were supposed to be reused, has 'disappeared', stolen, maybe reclaimed, by an anonymous person unmasked until now.

The main reason for this 'failures' was that the contractors did not achieve to include this batch in its new project, which was already drawn but still not under construction. Its original storage place, an empty yet still standing part of the textile mill owned by the town hall, needed to be evacuated, letting the joists batch outside, stored on the building site, with no protections, waiting to be reclaimed.

Disappearance, or thefts, advocate for the embodied value in what we could call a brownfield, industrial wasteland, or old building. Here, it points out that this joist batch has values, but these values were not taken into consideration enough to prioritise their final and effective reuse.

Another telling fact of the market value of elements waiting to be reclaimed is the need to close the access to the deconstruction site (also for security reasons) and the surveillance applied to avoid thefts. Recently we notably observed the change from human oversight toward camera-assisted monitoring to avoid guards' complicity with an organised group of thieves (EPFGE site visit).

5.2.2 What it costs and what it is worth.

For our case study, we compare the balance sheet of effective earnings, identified until now, with the potential earnings if prices have been better estimated and sales better organised to maximise profit, with no processing.

As Figure 7 shows it, after re-evaluation (with the method exposed in part 4.4.1), earnings from timber stock sales could have been able to finance its deconstruction and the connected practices linked to it, such as species analysis. Related to the cost of deconstruction, we observed that manual deconstruction is slower than mechanical deconstruction. The latter is ten times more expensive if we look at the cost per hour, circa 15 compared to 150€ from data we collected during the field study, with operators being paid following the French minimum wage at that time, 2021, taxes and fees included. Manual deconstruction involved punctual aids of equipment such as mobile scaffold towers, and portable power tools. Mechanical deconstruction involved equipment such as telescopic handlers or crane trucks.

As energy costs rise [64], we assumed mechanical practices would be less resilient than manual practices. Human portable size of construction materials could be allowed to keep a low cost of deconstruction in the future. Besides, if norms are respected, involving human work instead of machines participates in a more sustainable way of deconstructing also at a social level. At the same time, waste management and treatment costs are rising year after year [65]. Discarding a cubic metre of timber members costs 25€/m3 (0.5 wood density) in 2022; this does not include deconstruction costs and waste management up to the collection point. The global cost is estimated at 45€/m3 (0.5 wood density) [66]. As a comparison, we estimated that the average price for extracting a cubic metre of wood from our case study was around 322€ (including extraction of building layers to access timber members), while the estimated price of a reusable cubic metre of timber members was 465€.

Timber members types	*Joists*	*Trusses*	*Purlins*	*Boards & Floorboards*	*Rafters*	Total	Economic efficiency
Potential earnings at estimate prices	*30 205 €*	*6 972 €*	*6 719 €*	*12 541 €*	*2 365 €*	*58 802 €*	*11 784 €*
Potential earnings at effective prices	*2 752 €*	*6 000 €*	*309 €*	*2 882 €*	*702 €*	*12 645 €*	*-34 373 €*
Effective earnings at effective prices	*1 397 €*	*0 €*	*197 €*	*1 180 €*	*480 €*	*3 254 €*	*-43 764 €*

Deconstruction practices	*Project manag.*	*Wood assess.*	*Manual decon.*	*Mechanical decon.*	*Waste manag.*	Total
Deconstruction costs for the timber stock	*1 200 €*	*14 650 €*	*11 236 €*	*13 883 €*	*6 050 €*	*-47 018 €*

Figure 7: *This table present earnings differences and their impact on final economic efficiency of the deconstruction.*

6 CONCLUSIONS

Reuse of reclaimed timber is not guaranteed by the reversibility and appropriability of the wood material. The continuity of original use is in direct technical and economic competition with recycling and energy recovery. But reuse, compared to these, is still a relevant practice to limit our entropy. We introduced this paper with reflections on sustainability, durability, circular economy and cascading of wood products. These terms need to be more carefully used and reconsidered. We proposed that the lifespan of wood products and their representation should rely on the material integrity, rewarding the extension of the original use rather than steps of transformation. In response, we illustrated that idea with the concept of the 'staircase'. Based on observations we made during the deconstruction of a disaffected textile mill, we got interested in the role of values attached to timber members. After the deconstruction of our case study, we re-evaluated the estimated latent value of the timber stock and compared it with the effective cost of the work site. We also experienced grading practices that could give the right value to structural timber members. We found that taking care of the 'values' could optimise the reuse process and its effectiveness, by remunerating a preserving deconstruction with the earnings from reusable or up-cyclable timber members' sales. This paper only gives a glimpse of the subject of reclaimed timber 'values'.

https://doi.org/10.52202/069179-0470

These values need to be confronted with other field studies to get a comparison and collect price data that appear challenging due to the frequent approximation of stakeholders about the unit of time, volume, weight, costs, and prices. The full reuse of all the timber members extracted from our case study has not been completed until now. We will continue the restitution of research that is related to it by describing the final process of timber members' reintegration. We present here trends rather than final results, and future works will continue to investigate this theme through other deconstruction worksite visits, interviews and reviews. Assessment practices are at the heart of the creation of values. Wider research should be done to identify universal values and clarify the way they are assessed. A connection can be made with heritage approaches as they are similar in many ways.

ACKNOWLEDGEMENT

The French Agency for Environment and Energy Management (ADEME-CLIMAXION).
Mixed Research Unit N° 3495 Model and Simulations for Architecture and Heritage, Research Centre in Architecture and Engineering, Nancy National School of Architecture. (UMR N° 3495 MAP-CRAI, ENSA NANCY).
Épinal National School of Wood Technologies and Industry. (ENSTIB).
Public Establishment of Land of Great-East Region. (EPFGE).

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