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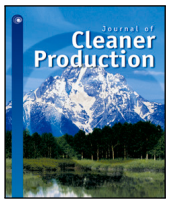

Strategies for salvaging and repurposing timber elements from existing buildings in the UK

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ABSTRACT

The reuse of construction materials and the elimination of construction and demolition waste is at the core of the circular economy in the construction sector. Timber is one of the most promising sustainable construction materials; however, there is no regulation, guidance or route within current business models to promote its circularity or certify that the recovered wood material is fit for a new life. This research investigates strategies for salvaging and repurposing timber elements from existing buildings, by reusing or upcycling timber into engineered wood products — referred to as mass secondary timber (MST). Through systematic interviews of key stakeholders of the timber construction supply chain in the UK, including contractors for construction and demolition, this research identifies barriers and opportunities for salvaging structural timber and for repurposing reclaimed timber. The findings show that whilst deconstruction requires a different skillset from that of demolition, there are virtually no technical barriers for salvaging wood. The challenges are related to the time and logistics needed for careful deconstruction, the reconditioning of the reclaimed wood and the lack of an established supply chain that enables its reuse. Strategies for reclamation and repurposing are proposed in view of the processes that could be implemented now to pave the way for the development of a circular value chain for timber construction.

1. Introduction

Construction, demolition and excavation waste represents 62% of annual UK waste (DEFRA, 2023a). Whilst diversion rates from landfill are high, most building components are recycled or downcycled (DEFRA, 2023a, 2012), therefore reducing their value and being in the lower end of the waste hierarchy (European Commission, 2024). To make significant impact, we need to make reusing existing buildings and the materials held within them the norm for the construction industry. Only in this way will we reduce construction and demolition waste, our reliance on new virgin materials and the extraction of non-renewable raw materials; all of which are having an impact not only on associated carbon emissions but also on ecological impacts such as habitat loss and destruction (UKGBC, 2024). Circular economy in the construction sector aims at reducing the impact of the built environment on climate change, which is responsible for 37% of global emissions (UNEP, 2022, 2023), by minimising waste, keeping materials in circulation for longer in higher value forms and conserving the natural resources. It considers the optimal use of resources, including the disassembling of buildings to allow for the reuse of materials (WGBC, 2023). However, most of the existing buildings that have reached their end-of-life and those that are currently being demolished were not designed for disassembly making it difficult to salvage for reuse. There is a lack of knowledge on how to transition to a circular economy in the construction sector. The business and commercial perspectives, together with the absence of incentives and stakeholder awareness, pose a significant challenge (Adams et al., 2017).

Timber is one of the most promising sustainable construction materials. It is a renewable material that sequesters carbon as it grows, and when sustainably sourced from managed forests (TRADA, 2019), can not only act as a carbon sink but also enables a reduction in embodied energy in comparison to conventional materials such as concrete and steel. This, along with the efficient use of timber in design, offers a

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huge potential to help mitigate the impact of the built environment on our climate and natural habitats. In addition, the carbon emissions associated with the production of timber are typically lower than the carbon stored in timber during sequestration (Churkina et al., 2020; Orr et al., 2021). This further motivates the long-term storage of carbon in timber members by their use in long-lasting timber buildings and its reclamation at their end of life. Nevertheless, the use of structural timber in construction is mostly restricted to a single service life, which limits the potential to fully exploit the sequestered carbon in timber.

Additionally, due to the variable nature of timber (Dinwoodie, 2000), and the dependence of the strength of timber on different parameters (e.g. species, density, moisture content and physical properties such as knots), strength grading methods have been developed for sorting timber into classes (Ridley-Ellis et al., 2016) — for example, C24, where, C is the class for softwoods and 24 is the characteristic bending strength in N/mm^2. This is useful for determining design values and for sourcing timber for a given specification. However, current strength grading methods are not applicable to reclaimed wood (Sandberg et al., 2022), and these are just beginning to emerge. Recently, the Norwegian standards 'prNS 3691 Evaluation of recycled wood' were under consultation, and are (to the knowledge of the authors) the first standards for the assessment of reclaimed wood with the aim of reusing it (Treteknisk, 2024). These are important, as it has been reported (Stenstad et al., 2020; Llana et al., 2022, 2023a) that current visual grading methods may be too stringent for reclaimed wood, as issues such as creep, age, damage and other aspects intrinsic to used wood are not considered.

In this view, this research will seek to answer the following question: "What are the strategies to reclaim and reuse or upcycle structural timber elements in buildings?"

1.1. Background

There are a few initiatives across government and industry levels that guide or incentivise the reclamation and reuse of construction materials. The London Plan 2021 (Mayor of London, 2021) states that circular economy principles should be taken into consideration in all referable applications. The Plan recommends consideration of how construction and demolition waste is managed on site, stored, and administered to promote reuse, as well as how the proposal's design enables material reuse at end of life. Elliott Wood Partnership (2024) developed a reuse guide, as part of a research project on accelerating material re-use led by Grosvenor (2024). The guide maps the steps needed to assess the reuse potential of structural materials in existing buildings against the RIBA stages (Elliott Wood Partnership, 2021), most of which are to be considered from the outset. Similarly, for the design of new buildings, early involvement of demolition contractors during the design stage has been found to significantly improve the end-of-life phase by encouraging design for deconstruction informed by the knowledge and experience of demolition contractors (Osaily et al., 2019). Recently, pre-demolition, pre-reclamation or pre-redevelopment audits have been developed with the aim of understanding the materials within the existing building structures and maximise their reclamation, recycling and reuse (ICE, 2008; BRE, 2017; Smeyers et al., 2022; NFDC, 2019). In 2021, the Waste Wood Assessment Guidance for the Construction and Demolition sector (CIWM, 2021; WRA, 2024b) was published for the first time with the aim of ensuring that waste wood was properly classified, is not misdescribed and is processed into appropriate end uses, and there is a clear understanding of the waste wood materials that are hazardous.

In the UK, the total waste wood arising in 2023 was 4.5 million tonnes (WRA, 2024a). More than 97% of the wood was processed, suggesting that less than 3% was sent to landfill (WRA, 2024a). The majority of the waste wood is reprocessed for biomass (65%). The rest of the waste wood ends up as: feedstock for the panel board industry (22%); animal bedding, equine surfaces, other recycling and reuse (8%); and exports (5%) (WRA, 2024a). Demand for biomass likely impact current timber reuse or recycling options (TRADA, 2022a). There are also reclamation businesses or social enterprises such as Community Wood Recycling (2024) collecting wood waste from construction and demolition activities but this represents only a small fraction. In the UK, the amount of wood reclaimed has decreased significantly in the last decades (CRWP, 2007). The most recent survey to 78 reclamation businesses based in the UK reported around 26,000 tonnes of reclaimed wood at a given time (Bougrain and Doutreleau, 2022). This represents less than 1% of the waste wood generated in the UK every year.

Design for deconstruction and reuse of structural timber has been having a lot of attention in the last few years (Tingley and Davison, 2011; Cristescu et al., 2020). However, the challenges associated with reclaiming materials from the existing building stock are of a very different nature as these were not designed for deconstruction. Addis (2006) provides some guidance for the reuse of structural timber in situ and the reuse of salvaged or reconditioned timber products. TRADA (2022b) outlines how timber is reused or recycled. However, there is no specific regulation, guidance or route within current business models to enable its circularity (i.e. recovery and repurposing) and assessment to certify that the material is fit for repurposing.

Alongside the reuse of reclaimed timber, a few studies have investigated the use of reclaimed timber as feedstock for the manufacturing of mass timber products such as CLT and glulam — referred here to as CLST (cross-laminated secondary timber) and glulamST (glued-laminated secondary timber). Promising results were reported on the mechanical properties of these materials. Rose et al. (2018) found no significant differences between the compressive strength and stiffness of CLST and CLT. Bergsagel et al. (2022) reported values for bending strength and stiffness of glulamST beams equivalent to those used for structural purposes. Some studies reported a reduced strength on reclaimed timber in comparison with new timber (Cavalli et al., 2016; Rose et al., 2018; Llana et al., 2022; Stenstad et al., 2020), however, this needs to be fully understood. The challenges associated with upcycling reclaimed timber were highlighted. These include, the lack of grading methods, the low manufacturing yield, and the presence of metal fixings that impact grading, and hamper cleaning and manufacturing process (Rose et al., 2018; Bergsagel et al., 2022; Llana et al., 2022, 2023b; Dong et al., 2024).

1.2. Aims

The main purpose of this research study is to gain insight into the barriers and opportunities for the reclamation of structural timber at end of life and its repurposing (reuse or upcycling) in the UK. Herein, the upcycling of reclaimed timber into engineered wood products for structural use is referred to as Mass Secondary Timber (MST). Table 1 presents the key terms and definitions used in this study, where applicable, these are in line with the key sustainability terms provided by Di Benedetto (2021).

This research undertakes an industry review via interviews with multiple stakeholders. The research objectives are:

- To identify the priorities (drivers, challenges, and opportunities) of the relevant stakeholders;
- To propose strategies to reclaim and repurpose timber structural elements in buildings.

The scope of the research is limited to UK practice and stakeholders across the building and construction value chain, for instance demolition and main contractors (also referred to as general contractors). The research is limited to reuse ex-situ and the reclamation of structural sawn boards (softwoods and hardwoods) from existing building structures that were not designed for deconstruction. From the reclamation perspective, engineered wood products such as glulam or CLT were not included in the study. This is because reclamation and reuse strategies are expected to be different from those of sawn timber, and it is

Table 1
Glossary.

Key term	Definition
Repurposing	Repurposing refers to the reuse or upcycling of structural timber by retaining or increasing its value respectively, as opposed to downcycling which keeps material in circulation but at lower value than the original.
Upcycle	Upcycle refers to the manufacture of new structural products using reclaimed timber materials to create products with higher value, i.e. enhanced structural properties, with the potential of replacing concrete or steel members.
Reuse	Reuse refers to use again timber components in the same way they were originally designed (largely maintaining their shape and function) to retain their value, e.g. reuse a timber beam as a timber beam after cleaning it, removing metals, etc.
Recycle	Recycle refers to significantly modifying the properties (in other materials usually by separating them into its individual components) of a structural timber element to create another product, usually of lower value (i.e. downcycling) and with no use for construction, e.g. for the manufacturing of recycled wood products such as animal bedding.
Salvage	Salvaged material refers to the recovered or reclaimed structural timbers from demolition/deconstruction sites for its future use either by direct reuse or upcycling. Sometimes, also referred to as reclaimed timber, second-hand timber and secondary timber.
MST	Mass Secondary Timber: Structural mass timber products, such as CLT and glulam, but made from secondary timber recovered from demolition, with provided certification.
CLST	Cross-laminated secondary timber made with reclaimed timber.
glulamST	Glued-laminated secondary timber made with reclaimed timber.

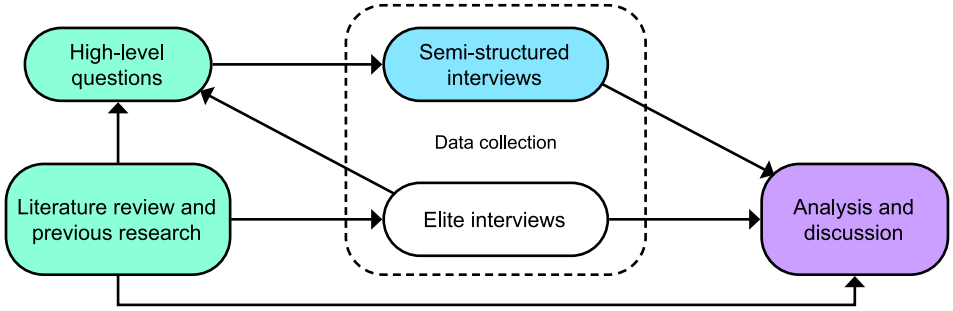

Fig. 1. Methodology.

anticipated that these products will contribute only a small portion of the wood waste generated in the coming years. However, the possibility of upcycling reclaimed wood into products of higher value such as MST was considered from the repurposing perspective.

2. Methodology

Fig. 1 shows the overall flowchart of the methodology. The methodology is based on a series of interviews: semi-structured interviews and elite interviews. The semi-structured interviews were carried out with two main groups of stakeholders — demolition and main contractors, and the objective was to gain an understanding of the current practice, barriers, challenges, and opportunities of reclaiming and reusing structural timber. Elite interviews refers to conversations with key stakeholders or experts in the field via personal communication (video-conferencing, telephone conversations and emails). These were carried out throughout the research and served different purposes such as informing the questions for the semi-structured interviews, as well as the overall analysis and discussion of the research.

The methodology includes three key stages. The first stage consists of defining high-level questions of enquiry, informed by the literature review and previous research undertaken at Elliott Wood Partnership (2024) and elite interviews. The second stage involves the data collection via the semi-structured interviews. In the third stage, findings are synthesised and analysed.

2.1. Semi-structured interviews

The questions for the semi-structured interviews were devised to examine the current procurement processes (in relation to contractors, suppliers, and so on) and how these processes are (or could be) linked. Demolition and main contractors are considered to explore the barriers and opportunities from both ends, as well as identifying possible ways of harnessing the opportunities. The main interview topics are shown in Table 2, including the references consulted for preparing the interview questions. As mentioned, the interview questions were also informed by previous research undertaken by the authors (Elliott Wood Partnership, 2021; Grosvenor, 2024) and by insights from the elite interviews. The full set of interview items including follow-up questions, are provided as Supplementary Material. The interviews were undertaken from May to August 2021. The duration was one hour on average. All the participants for the semi-structured interviews were from the UK, and their profiles are in Table 3. Prior to the interviews, the interviewees were provided with a document outlining the project aims, relevant definitions, main interview topics and agenda. Ethics guidelines for confidentiality and data protection were followed at Elliott Wood Partnership (2024), where the interviews were conducted.

2.2. Elite interviews

The elite interviews enabled gathering first-hand experiences from experts in the field and insights from ongoing research projects not readily available in literature from different stakeholders. These helped to map the current practices in relation to timber or experiences from specialists in different areas. All the participants were from the building sector, their profile are available in Table 4. Whereas the scope of the research was bounded to identifying the priorities of the stakeholders in the UK, one of the elite interviewees was a deconstruction specialist in the USA and a deconstruction and reuse specialist in Belgium. These were included due to their significant amount of experience in the business.

Table 2
Interview topics.

Interview topics	References consulted
Demolition contractors	
Demolition process	IDE (n.d.)
Reclamation experience	Smeyers et al. (2022), Cristescu et al. (2020), InFutUReWood (n.d.), Addis (2006), RotorDC (2024), Adams et al. (2017)
Wood waste	DEFRA (2012), CIWM (2021), Smeyers et al. (2022), WRA (2021)
Early involvement of demolition contractors	Osaily et al. (2019)
Demolition contracts	ICE (2008), BRE (2017)
Main/General contractors	
Experience using second-hand structural timber in construction	Addis (2006)
Barriers for using second-hand structural timber	Addis (2006), Adams et al. (2017), Heinrich and Lang (2019), Cheshire (2019)
Sourcing second-hand timber or upcycled secondary timber	Salvo (2024), Opalis (n.d.), Ashwells (2024), Community Wood Recycling (2024)
Reuse opportunities	Rose et al. (2018), Rose (2019), Llana et al. (2020), Bergsagel et al. (2022), Cristescu et al. (2020), InFutUReWood (n.d.)

Table 3
Profiles of interviewees for the semi-structured interviews.

Interview	Company sector	Company size	Participant's experience (in years)
A	Demolition	Small	50-60
B	Demolition	Small	20-25
C	Demolition	Large	5-10 25-30
D	Demolition	Medium	25-30
E	Demolition	Small	10-15
F	Demolition	Large	30-35
G	Construction and Demolition	Medium[a]	30-35[a]
H	Construction	Medium	30-35
I	Construction	Large	20-25
J	Construction	Large[a]	10-15[a]

[a] Data not provided directly by the interviewees, estimated from online search.

2.3. Sampling approach

The selection of the participants was based on a combination of purposive and snowball sampling, for both the semi-structured and elite interviews. Potential interviewees were identified via different methods, for example, referrals by colleagues or researchers working on similar areas, key stakeholders identified from previous studies (Elliott Wood Partnership, 2021) and by investigating the practices of potential companies working on the demolition or construction sectors online. The participants in the semi-structured interviews were to some extent familiar with the research area and in some instances engaged in industry discussions around similar topics. Therefore, their input is valuable to map the state of play in the demolition and construction sector regarding the reclamation and potential reuse or upcycle of timber from existing buildings. The number of participants was limited by the time constraints of the project, consisting in one year.

2.4. Data analysis

The data collected via the semi-structured interviews was manually analysed using thematic analysis (Braun and Clarke, 2006). The video recordings of the interviews to the two main stakeholder groups were transcribed using Otter.ai (2024). The transcripts were read and manually corrected against the recordings, if required. For the elite interviews, notes were manually taken. Relevant statements and keywords were highlighted and grouped into the corresponding interview topics for the interpretation of data.

3. Barriers for reclaiming and repurposing structural timber

Barriers and opportunities for reclamation and reuse were found to be inherently related and were grouped into three categories (see Table 5): reclamation, future reuse and market and supply chain.

3.1. Reclamation barriers

All the participants (demolition contractors group) had at least one example of reclamation experience with timber. They indicated that there are no specific methods in place for determining which materials are deemed waste and which could be potentially recycled or reused. Determining whether timber was going to be salvaged or not was generally left to the contractor's discretion. In general, unless the timber members are heavily damaged due to rot, fire, infestation, contamination, or serious cracking, demolition contractors sort timber materials through inspection.

Barriers related to time limitations, logistics and cost associated with reclamation steps during deconstruction were found to be key inter-related barriers. Time limitations – usually driven by client's aspirations – were mentioned by all interviewees. Reclamation processes may reduce the speed of demolition leading to increased costs. Deconstruction may require more operatives and it is usually done by hand, whilst demolition is usually done using machines (i.e. mechanical demolition). Reclamation processes may also increase the logistics and planning. Activities such as carefully moving timber materials around, segregating and temporarily sorting wood waste on site need consideration. Usually, there is not enough time for proper timber waste segregation, de-nailing or de-screwing on-site due to its slow, manual process.

There are additional challenges, such as finding long term storage for the salvaged timbers, identifying potential buyers, negotiating costs and possibly changes to contracts to indicate who will own the salvaged material. Generally, demolition contractors have the rights over the materials arisings from demolition (NFDC, 2023). However, the ownership of materials may vary and is determined by the terms outlined in the contract. There is usually insufficient time for all these additional steps as demolition contractors are usually involved at later stages. In addition, reclaimed material could end up stored for years until they find a suitable buyer. There are also health and safety constraints, and challenges with moving and storing materials, especially in small sites with limited access and space.

Other potential barrier identified by the interviewees was the inherent damage to the salvaged timber due to the use of conventional mechanical demolition methods. They voiced that careful deconstruction requires specific skillsets amongst workers, different to demolition (e.g. carpentry to make clean cuts).

All the participants mentioned that reclamation should be encouraged by legislation, similar to the landfill tax, a demolition tax on all the materials that are not salvaged or through planning requirements. Planning conditions have been proposed in London the conditioning reuse of materials (e.g. a percentage of steel used in construction to be reclaimed) (City of Westminster, 2024), when arguably they should be conditioning salvage of materials for reuse (e.g. a percentage of joists to be salvaged from demolition) to improve supply.

Table 4
Profiles of interviewees for the elite interviews.

Area of expertise	Role(s)	Country	Experience (in years)
Timber	Chief executive	UK	40-45
Timber	Sustainability director	UK	30-35
Timber	Timber technical consultant	UK	0-5
Timber reclamation	Managing director Operations and marketing manager	UK	20-25 10-15[a]
Reclamation	CEO Director	UK	5-10 0-5
Dismantling, re-erection and maintenance of historic buildings	Curator	UK	15-20
Timber deconstruction	Director	USA	25-30
Deconstruction and reuse	Co-founder	BE	15-20
Demolition	Head of research and development	UK	5-10[a]
Steel reuse	Managing director	UK	30-35
Reuse, circular economy, resource efficiency, waste management, sustainable materials	Technical director and director/co-founder	UK	20-25
Materials sustainability and circular economy in the built environment	Built environment lead	UK	10-15
Sustainability and circular economy	Graduate design engineer	UK	0-5
Upcycling timber - manufacturing	Managing director	UK	15-20[a]
Upcycling timber, circular economy and architecture	Senior Research Fellow	UK	15-20
Upcycling timber - research	Wood research and structural engineer Wood research, architect and project manager Wood research and structural engineer	UK	5-10 10-15 5-10

[a] Data not provided directly by the interviewees, estimated from online search.

Table 5
Barriers and opportunities for reclamation and reuse of structural timber.

	Reclamation	Future reuse	Market and supply chain
Barriers	Time	Lack of supply chain	Lack of demand
	Logistics	Certifications	Uneconomic
	Cost	Specifications	Security of supply
	Demolition methods	Insurance	Limited market
	Skillset		Amount of timber in buildings
	Safety		Unknown reclamation market
	Uncertainties		Clients
Opportunities	Pre-demolition audits	Private builders	Reclamation yards
	Surveys	Private residential sector	Established markets
		Others	Timber manufacturers

3.2. Repurposing barriers

The lack of an integrated supply chain that can support the activities between reclamation and reuse demotivates reclamation of timber itself. The repurposing barriers voiced by the stakeholders includes the lack of an established supply chain and infrastructure, uncertainties around certifications, specifications, risk and insurance.

The relevant aspects contractors would look for if sourcing reclaimed timber products are certifications (e.g. CE marking, Forest Stewardship Council (FSC) and Programme of Endorsement of Forest Certification (PEFC)) and performance (e.g. strength grading), warranties, treatment history, aesthetic finish (from a client's perspective) and availability. From the perspective of risk and insurance, unlike new timber that is graded and CE marked, reclaimed timber currently lacks certification and therefore it is difficult to guarantee that the material is fit for purpose. Without certifications, there is the risk of using an inconsistent material, e.g. maybe a piece of timber is rotten but this is not visibly evident. The perception was that buildings with reclaimed timber may find it difficult to obtain insurance, especially in the commercial sector as opposed to the private residential sector. Furthermore, designers usually specify new graded timber and reclaimed timber is generally of unknown specification. Overall, the contractors voiced the importance of getting rid of disincentives (e.g. lack of re-certifications, security of supply and cost) rather than having more incentives.

A potential barrier for the adoption of MST is the lack of manufacturing companies to fabricate these products in the UK at large scale. The business viability for manufacturing companies to produce MST is unclear, leading to a lack of companies trying to do this. Buckland Timber (2024), a UK based glulam beam manufacturer with experience using reclaimed timber mentioned that the biggest barrier for the manufacture of glulam products from secondary timber was identifying and removing metallic fasteners, as this is key to enable a smooth manufacturing process without damaging the tools.

Most participants highlighted that reusing reclaimed timber as a structural element for its second life would be very challenging. Only one participant provided an example where timber was reclaimed from a listed building and reused in another listed residential building. From the experience of demolition contractors in selling reclaimed wood, the materials were mostly reused as furniture, feature timber, cladding and floorboards or for temporary elements used in construction. With respect to the reuse experience of the main contractors, only reuse of shutters two or three times for slipform or jumpform for concrete pouring were mentioned and some of the participants did not have any experience.

3.3. Market and supply chain barriers

A number of barriers related to the supply, demand and economics of waste wood identified by stakeholders can be categorised under market-related barriers. There is currently limited demand for reclaimed timber for structural purposes. Clients and designers play a key role as they could be advocating for the increase of use of second-hand timber. On the other hand, the lack of a reclaimed timber market that guarantees security of supply in the required quantities and timescales is also a challenge. In fact, a number of contractors voiced that they would not know where to look for second-hand timber or MST products. If they were required to source reclaimed timber, they would need to invest time finding the right place (supplier or manufacturer) and material until a mature market is developed. The perception is that there is very little structural timber to reclaim to create a market due to the typical building types in the UK, in particular in the commercial sector. Some of the participants consider the private residential sector to be most suitable for the reuse of second-hand timber.

There were various responses indicating that some clients were increasingly asking about reclamation of building materials (not necessarily limited to wood), whereas some contractors have not had such conversations with their clients. In the latter, it is difficult for the demolition contractors to include reclamation in their programme as the perception is that it will take more time and therefore the cost will rise making them less competitive. Savings in waste management costs and any revenue from selling reclaimed timber are uncertain. As the circular market develops, the costs, processes and activities associated with the deconstruction and salvaging of materials will be more common, making the added value and path to reclamation clearer. In addition, due to the high labour costs in the UK, alongside the subsidised cost of primary material extraction, reclaimed timber is uneconomic in comparison with new timber. Finally, it is likely that testing and re-certification of reclaimed wood may increase costs.

4. Opportunities for reclaiming and repurposing structural timber

There were several opportunities identified from the interview programmes, some of which have already taken place but have not been fully harnessed (see Table 5).

4.1. Salvaging opportunities

Based on the participants' experience, carefully disassembling old traditional timber structures that were not designed for deconstruction is not the main barrier. However, it requires a different skill set to that from demolition, and there are aspects that needs to be considered, like logistics, safety, understanding the site, disassembly plan, on-site segregation, etc.

The principal drivers that made reclamation possible based on the participants experiences were: clients sustainability aspirations or through planning restrictions; financial incentive of selling the reclaimed timber; wood members easily identified in good condition or probably in good condition; the nature of the demolition/deconstruction method selected for the building facilitating reclamation, and; period pieces (e.g. from historical buildings) not normally found on the market today. Below, the list of key salvaging opportunities identified:

- ***Pre-demolition audits.*** Pre-demolition audits are useful to identify material that could be salvaged. There are currently a few audit guidelines in place (ICE, 2008; BRE, 2017; Smeyers et al., 2022; NFDC, 2019) that could be used, and the contractors could plan in accordance to these. However, pre-demolition audits are not business as usual. Some of the participants have pointed out that clients are starting to ask for these, especially in the past few years, albeit these are procured very late during the design process, leaving little opportunity for materials identified for reuse by the audit to be designed into the scheme, or planned for reuse elsewhere (Rose and Stegemann, 2019).
- ***Surveys.*** Visual surveys and structural surveys to create structural sketches and a list of itemised materials identified as salvageable and to identify the type and condition of members and joints. These will enable the demolition contractor to plan the deconstruction method accordingly.
- ***Logistics plans.*** When the programme allows enough time, individual slots could be arranged with different reclamation businesses to remove and collect the timber members.
- ***Demolition method.*** If deconstruction occurs following the top-down approach, materials can be salvaged at every floor as demolition progresses – e.g. cutting the floor, salvaging material by stacking it, bundling it, storing it and sending it for reclamation. If demolition machines (or ground bearing machines) are used, the only point where it is possible to salvage material is once the building has been pulled down. This can be achieved by sorting individual timbers by picking them from the ground.
- ***New job opportunities.*** There is potential for job creation for the new activities required on-site during auditing and the demolition or deconstruction process. These include, quantifying and assessing timber members, separating and sorting the timber materials on-site, cutting rotten ends, removing nails, storing or protecting the material from the weather and transportation.
- ***Early involvement of demolition contractors.*** Involving demolition contractors early in the design process will enable more precise information about the amount of work required for the reclamation, as opposed to rough calculated estimates. Pre-demolition audits could be carried out at early stages to advise on the deconstruction method, and find potential buyers based on the timbers with reuse potential identified.
- ***Waste Wood Assessment Guidance.*** The guidance could help to identify non-hazardous timber members with the potential to be repurposed.
- ***Demolition contracts.*** Some of the changes to contracts that could incentivise reclamation over demolition mentioned by the stakeholders were relaxing contractual specifications to have more weighted tenders including criteria such as salvaging and carbon, time to enable safe and rapid deconstruction, financial incentive and clients setting clearer circular economy goals, such as reclamation percentage targets.

4.1.1. Example of timber deconstruction experience in the USA

The timber deconstruction industry in the USA is larger than in the UK due to the vast amount of timber construction. The Building Deconstruction Institute (2024) is an example of this industry, with 32 years of experience deconstructing buildings and saving the materials from about 5000 projects.

Similar to the interviewed demolition contractors, they initially invested a considerable amount of time and labour dismantling a building in comparison to demolition activities. However, their experience enabled them to become faster and more efficient and they can now offer "hybrid deconstruction" using machines and labour to maximise their resources. They use machines for removing non-recyclable or non-reusable materials, cleaning, sorting and moving materials around, and workers for the careful dismantling and handling of valuable materials including timber. In addition, one of their reuse strategies is salvaging assemblies rather than individual elements. For example, instead of spending time disassembling a timber wall, the wall is salvaged as an assembly and reused as a wall saving time during deconstruction and in the future construction.

They voiced that one of the main challenges of the deconstruction industry is that they are being measured against the demolition industry. However, more value should be placed in deconstruction considering the amount of material reclaimed for higher value reuse as opposed to recycling and downcycling.

They have three business model strategies that enables them to be competitive with the demolition industry:

1. The extra labour is compensated by the profit of selling reclaimed materials and the savings of disposing the material. In order for this to work, demand should exist, and they need to have confidence in the value of the materials.
2. Tax benefit can be a powerful tool (e.g. gained through charity donations), when used with ethical responsibility, to enable disassembly as a cost-effective option.
3. Owner reuse, when the material is reused on-site by the same client.

They value reclaimed materials by comparing with materials that are currently in the market and period pieces that are no longer made or are unique (based on characteristics such as age, aesthetics, e.g. rustic or antique look, texture, patina, etc. qualities gained in the last 100 years). Materials are usually sold to small-scale contractors for small projects or buildings, as in this way they avoid the challenges of re-certifying the material.

4.2. Repurposing opportunities

The opportunities identified for reusing and upcycling reclaimed timber were different. There was a perception that the opportunities for direct reuse (e.g. reuse a joist as a joist) were mainly for builders working in the private residential sector (e.g. homes, extensions, or sheds), temporary works and historical buildings with timber structures. Other reuse opportunities were for floorboards and furniture. In contrast, upcycling reclaimed timber into MST was not perceived as being restricted to use in the private residential sector only. Contractors would consider its use as long as the product is reliable (e.g. re-certified and comparable to engineered wood products made with new timber) and available in the marketplace. Some of the opportunities identified for repurposing timber were:

- ***Properties of reclaimed timber.*** Properties such as the dimensional stability or weathering of old or mature timber could be used as a selling point as they are sometimes regarded as superior from that of new timbers. It has been highlighted by some of the participants that reclaimed or mature timber was of better quality than new timber. This was usually associated with the dimensional stability of mature timber, no wear issues, better workability, lower moisture content, straighter pieces, better growth ring densities and so on. However, more research is required to fully understand the properties comparing mature timber from older buildings and new timber.
- ***Clients' aspirations.*** Currently, tenders are setting embodied carbon (A1-A5 lifecycle modules) targets for contractors; to achieve this reclaimed timber is an attractive option. There is also potential for adopting reclaimed timbers for PassivHaus designs.
- ***Efficient design.*** Design could be adapted to other section sizes to fit the available material. For example, if C24 is specified but the available reclaimed timber is considered to be C16, then the section sizes can be adapted to fit the available sizes and enable the reuse of reclaimed timber. A database of available stock could help designers in this regard. Alternatively, the design brief can allow for flexibility to accommodate the sizes of the reclaimed timber (e.g. lengths and cross-sections) as data becomes available (Bergsagel and Heisel, 2023); or computational design strategies could be implemented to design structures using a known available stock inventory of varying sizes and properties (Bukauskas et al., 2017).
- ***Modular design and off-site manufacturing.*** Modular construction, prefabrication and methods for the design of demountable timber products were identified as opportunities for reclaimed timber and MST. There is no craftsmanship on site, thus construction can proceed more swiftly. In addition, they offer the opportunity for the manufacturers (or main suppliers) to take back the products at their end of life to put them back into the market and enable their future reclamation.
- ***Mass secondary timber, MST.*** Opportunities to create MST of high structural value and providing certification of the produced materials. In addition, the increasing prevalence of mass timber construction means that at the end of their life there might be products available for reuse. Large CLT or CLST panels and glulam or glulamST beams could be deconstructed and cut to desired lengths to be repurposed, subject to proven longevity of adhesives.
- ***Underutilised domestic timber market.*** There is a serious shortage of structural timber in the UK with 80% of domestic hardwood being used for fuel and energy, and over 50% of home-grown softwood going into fencing and pallets. The UK is also the world's second biggest net importer of timber. Using reclaimed timber could be a timely opportunity and complement growth in better utilisation of home-grown timber.
- ***Business opportunities.*** Opportunities to create a supply chain for reclaimed timbers and a market for the production of MST products.
- ***Local supply chains for MST.*** The environmental impact due to transportation (evaluated in module A4 of the life cycle assessment) where mass timber products are imported can be significant. Production of MST products in the UK provides further low carbon timber opportunities.

4.3. Value chain opportunities

An opportunity highlighted was to have a blended approach to source second-hand timbers from reclamation yards as well as from established markets currently selling new timber. The government could even incentivise retailers to sell reclaimed timber. Opportunities for timber product manufacturers were identified in the form of collecting waste timber for free to process for reuse. Subsidies or tax incentives for the whole supply chain were also voiced, especially for stakeholders that would require extra work and time like demolition contractors.

5. Strategies for salvaging and repurposing structural timber

The gap between reclamation and reuse is the main challenge facing the supply and demand of reused wood materials. On the one hand, reclamation does not occur as there is no demand and no marketplace to take and recondition the reclaimed material for structural purposes. On the other hand, designers and contractors do not specify or buy reclaimed wood materials or MST as there is no established market in which to source certified materials complying with the industry standards (Rose and Stegemann, 2018).

Ideally, the opportunities described above would enable the reuse of structural timber in the near future. However, none of those processes are currently in place, and is not clear who needs to take responsibility for the different steps and initiatives needed. What is evident is that the UK construction industry (Astle et al., 2023; ACAN, 2024; ASBP, 2024) has been engaged in circular economy and reuse talks and research over the past years and that conversations and sharing of knowledge is crucial for accelerating progress. In 2023, the UK government published the timber in construction roadmap (DEFRA, 2023b) and emphasised the need to collaborate with industry to increase the circularity of timber across the supply chain. Here, we discuss some of the aspects mentioned by the interviewees that could help us achieve reuse now and pave the way for the development of a future reuse market for structural timber. The flowchart shown in Fig. 2 outlines possible strategies we could harness now for salvaging timber from existing buildings and enabling its further repurposing processes.

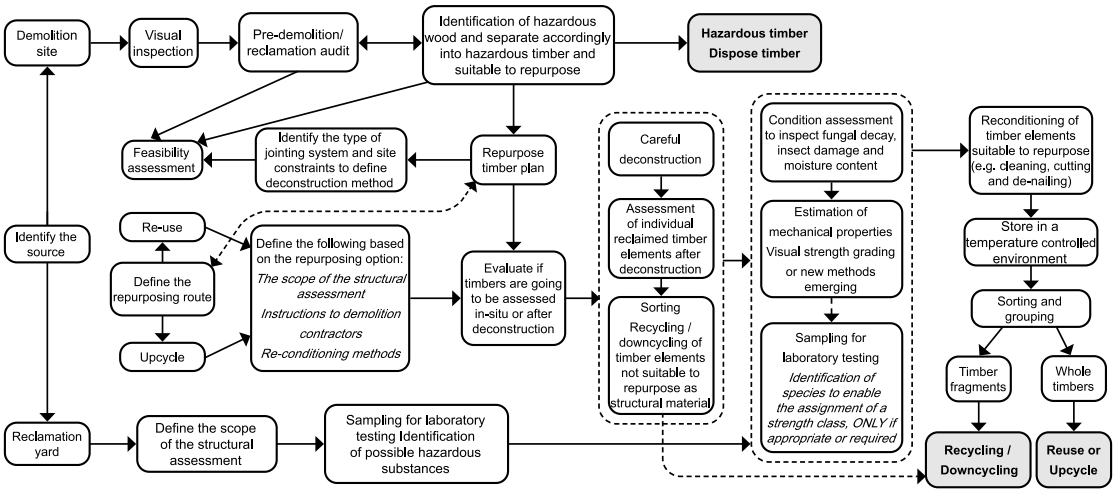

Fig. 2. Strategies for enabling reclamation and reuse/upcycling of timber from existing buildings.
Source: Adapted from Elliott Wood Partnership (2021).

5.1. Identify the source

One of the first obstacles for contractors is that they are not aware of any supplier or yard where they can source second-hand timber for structural applications. In the UK, the Material Reuse Portal (2024) is an online platform to find reclaimed construction materials from different marketplaces. They also have a list of other online platforms from which materials can be sourced. For example, Salvo (2024) which provides a directory of reclamation businesses including those supplying timber and they can also provide support to source reclaimed materials.

It is also possible to reclaim timber from another or the same site with coordination between demolition and building contractors for logistics, delivery and timings. However, there are challenges with the logistics of this approach (Bergsagel et al., 2022). In these scenarios, it would be possible to record the previous use of the timber members and possibly their previous service life.

5.2. Visual inspection and audits

A visual inspection can be carried out to make an inventory of the timber elements to be salvaged (e.g. timber floorboards, walls, beams, rafters, columns, etc.). Elliott Wood Partnership (2021) provided guidance on the initial studies needed to create an inventory and structural sketches of the material with the potential to be reused. These include, desk study, site walk round, surveys and structural investigations.

Pre-demolition audits provide information about the amount of materials expected to arise from demolition projects and provide recommendations on the waste management routes. They also provide advice on hazardous materials and materials with potential to be reused or recycled. The Waste Wood Assessment Guidance for the Construction and Demolition Sectors can help providing guidance for the identification of the hazardous waste wood.

5.3. Feasibility assessment and repurposing plan

Additional time and cost associated with the reuse of structural timber depends on the source from which the material is supplied. Timber sourced from reclamation yards will require reconditioning such as cleaning, de-nailing, cutting, etc. as well as a testing or an appraisal plan to verify that the material is fit for purpose. Besides the additional time and cost that this requires, timber sourced directly from demolition sites needs to be evaluated for careful deconstruction and recovery too. The early involvement of demolition contractors at this stage can provide detailed information on the demolition methods to maximise the recovery of the identified materials, as well as reasonably accurate estimation of the extra time needed to enable reclamation.

Defining the repurposing route (either direct reuse or upcycle of reclaimed timber) will help to define the scope of the demolition works, the testing programme required and the reconditioning plan (cut, cleaning, denailing, etc.) to make the material ready for its future use.

5.4. Careful deconstruction and testing

For timber members to be reclaimed from existing buildings, a preliminary assessment to evaluate the feasibility of carefully dismantling timber members is needed. There are logistics and safety considerations that need to be considered for dismantling, handling, segregation and stockpiling on-site, transporting and storing of the timber members.

In addition to this, a condition assessment and visual strength grading can be considered alongside demolition contractors (or deconstruction specialists) and the relevant structural investigation company. As mentioned, there are no standards available for the assessment of reclaimed timber. Therefore, it is crucial for designers to work closely with a competent timber expert or grader to agree a plan of action of how to best assess the reclaimed wood for the intended purpose (either reuse or upcycle). BM TRADA (2024) provides a list of certified companies that offer services such as visual strength grading. It is important to find the company offering the required services at a convenient location, as the services may vary. For example, some companies would be able to assess in-situ structural timbers before deconstruction, while others may require members to be delivered. Visual strength grading can be challenging in-situ, as this is only possible if the strength grader has access to inspect the 4 faces of the timber and there is no paint or coating. There are non-destructive test methods, however, these are usually carried out in timber members of the same size and therefore consistency in the shape and size of the members could be difficult to obtain with reclaimed timber without prior processing. Furthermore, any fixings (e.g. nails or screws), splits, notches, etc. could hamper this process. Nevertheless, recent research (Dong et al., 2024; Llana et al., 2023a) have shown promising results using non-destructive tests for the estimation of the elastic modulus of reclaimed timber.

At the moment, whether the assessment of timbers will be done before or after deconstruction, in-situ or at a reclamation yard, depends on the project size, scope and challenges. In the future, carrying out the assessment (e.g. grading) of reclaimed timbers centrally at a designated reuse centre or sawmill for reclaimed members could make more sense economically.

5.5. Sorting and reconditioning of wood materials

Once demolition and testing are completed, the reclaimed timber elements are to be reconditioned for reuse or upcycle. The wood materials are cleaned, de-nailed and re-sized accordingly and stored in appropriate conditions. Any small sections or fragments from the re-sizing (i.e. waste) can be sorted, developed into by-products or send out for recycling. The whole pieces of timber can then be sorted and grouped into the materials that are going to be reused and upcycled.

6. Discussion

The main barriers and opportunities identified for the reclamation and reuse of structural timber were grouped into reclamation, future reuse and market and supply chain, as these were found to be interdependent. Similarly, previous research (Charef et al., 2021) has found barriers for the implementation of the circular economy in the construction sector to be interrelated among different aspects.

From the interviews, it was revealed that no significant technical barriers are associated with the reclamation and reuse of wood. Similarly, other studies identified manual deconstruction as a method for salvaging timber members whilst keeping their quality (Sandberg et al., 2022). Minor barriers related to technical issues can be overcome with appropriate skillsets, training and equipment. The barriers are principally within the supply chain and particularly related to cost, time, security of supply and re-certifications, which present a series of challenges. Furthermore, since there is lack of demand for second-hand timber, extra efforts are needed to find storage and buyers for the materials whose value is not evident. Other studies have reported similar challenges with the temporary storage and the logistics and coordination between the stakeholders (Bergsagel et al., 2022; Smeyers et al., 2022). Most of the interviewees highlighted that legislation is needed in order to incentivise and enable careful deconstruction to make it commercially viable, and in particular to set realistic targets for reclamation and reuse.

Some opportunities were identified to facilitate the reclamation of timber from existing buildings. For example, surveys for the identification of timber members with reuse potential, desk studies, inventories and pre-demolition audits. However, all of these, along with the planning for the logistics involved, increases the amount of work that needs to be done from the outset. In addition, whereas there are guidelines available for pre-demolition audits (ICE, 2008; BRE, 2017; Smeyers et al., 2022; NFDC, 2019), an effort is needed to develop a harmonised guideline.

The principal barrier for reuse was the lack of re-certifications to guarantee that the material is structurally sound and fit for reuse. While current grading standards are not applicable to reclaimed wood, alternative methods have been proposed by considering factors inherent of reclaimed wood (Sandberg et al., 2022). Nevertheless, these methods are just beginning to emerge (e.g. in Norway Treteknisk, 2024), and thus it was suggested to contact an experienced timber grader or expert. Furthermore, new graded timber is normally required to comply with the specifications for structural timber. Therefore, using reclaimed timber without re-certification or specifications poses risk for constructors. In addition, other studies highlighted that reclaimed wood can be often of low quality and that new technologies are required to maximise the yield and cascading use (Cristescu et al., 2020). Another aspect worthy of consideration is the assessment of reclaimed members, to prioritise efficient use of material by selecting for example large sections for reuse and medium size sections for the manufacturing of MST (Llana et al., 2020). All these may require additional efforts in sorting and reprocessing the wood materials to increase its value. This could pose an additional challenge, particularly since the consensus was that the principal reuse opportunities for structural timber at present were limited to the private residential sector and small contractors.

The responses for using upcycled timber products made with reclaimed wood (e.g. CLST or glulamST) were more positive than those for direct reuse. MST was not considered as restricted to the private residential sector only. This is significant as the value of using upcycled timber is arguably greater than simply reusing it as these have superior properties and therefore the potential to replace a concrete or steel element, saving significant amount of embodied carbon (Rose, 2019). The main challenge for the UK is the lack of infrastructure capacity for the manufacture of these products. Sharing knowledge and technology across countries could boost the development of local circular value chains. At a technical level, it was highlighted that the presence of metals in reclaimed wood is one of the principal challenges when used as feedstock for the manufacturing of new products.

There is a huge need for the development of a value chain in order to make reclamation and reuse a norm in the construction industry. Currently, supply and demand for second-hand timber are disconnected and therefore we are relying on virgin materials, whilst generating waste at the same time. As mentioned, while most wood waste is currently processed (WRA, 2024a), the majority of it ends up in the lower tiers of the waste hierarchy, mostly used as biomass. This is important because approximately two thirds of the wood consumed in the UK is imported (TDUK, 2024), and thus, there is a need to maximise wood resources and minimise waste.

From the market point of view the perception is that repurposing structural timber is economically non-viable. Before a reuse market for structural timber is established, other reuse routes are necessary such as reuse in the new development on the same site, reuse from site to site or reuse via reclamation yards. Clients have been identified as one of the main barriers but also the main drivers when reclamation has been achieved. Therefore, conversations with clients and among stakeholders about material reuse and circular economy aspirations are crucial in particular at earlier stages. Overall, policies and legislation are needed to incentivise the reclamation and repurposing of timber, and investment is needed to drive development of new links in this value chain. Nevertheless, policy delivery so far has been around recycling rather than prioritising reuse (Carr et al., 2024). The requirement for circular economy statements (Mayor of London, 2021) to accompany planning applications in London is a step forward, but it focuses mainly on large developments and therefore does not cover the private residential sector identified as one of the main immediate opportunities for timber reuse. Promotion and incentives to facilitate the transition to a circular economy are therefore needed for small scale projects too.

The findings of this study are limited to the number of interviews conducted as well as the sectors considered. Interviews with reclamation yards, timber merchants and contractors working in the private residential sector can provide insight into the areas of the supply chain that need to be developed and the challenges of direct reuse. Moreover, the results were focused on the UK sector. However, the barriers identified for reclamation and repurposing as well as the fragmented supply chain are common barriers and the mapping of these against potential opportunities can be further used to investigate strategies applicable to other locations. These may be driven by local economy, regulations, aspirations, and material availability.

7. Conclusions

This research investigates the drivers, barriers and opportunities of salvaging timber from existing buildings and using the reclaimed timber as a structural material or for the development of mass secondary timber (MST). Overall the main challenges lie within the lack of an established supply chain and market that enables the reclamation and repurposing of timber at different levels. It is technically possible to salvage and reuse structural timber. Nevertheless, if deconstruction is compared against demolition without considering its added value, and as long as the extraction of virgin materials is too cheap, it will be more difficult for all the extra processes, work and economics not to be

perceived as a barrier. This research collated the identified strategies to help navigate the activities needed to facilitate the reclamation and repurposing of structural timber from existing buildings.

Key short recommendations for reclamation, reuse and upcycling of secondary timbers were outlined with the aim of promoting the development of a value chain that supports material reuse and the circularity of wood in construction. It is recognised that some of these processes might not be straightforward in practice due to the lack of standards, market and supply chain to enable this to happen. However, insight from projects (even small-scale projects) are necessary for the understanding of the processes required to make reclamation and reuse a norm and for the development of evidence needed to support policies and funding to incentivise reclamation and reuse with added value. As a starting point, pushing for incentives is crucial as well as having early conversations with clients, contractors and designers about the circular economy and sustainability aspirations of the project.

CRediT authorship contribution statement

Martha Godina: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Penny Gowler:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Colin M. Rose:** Writing – review & editing, Conceptualization. **Eduardo Wiegand:** Writing – review & editing. **Harry F. Mills:** Writing – review & editing. **Antiopi Koronaki:** Writing – review & editing. **Michael H. Ramage:** Writing – review & editing. **Darshil U. Shah:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jclepro.2024.144629.

Data availability

The authors do not have permission to share data.

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