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PILOT PROJECT: MODULAR CONSTRUCTION WITH SECONDARY MATERIALS IN A CIRCULAR ECONOMY

Colin M. Rose[1], Jonas Breidenbach[2], Patrick Quinn[3], Julia A. Stegemann[4]

ABSTRACT: Earlier research has shown the technical feasibility of using secondary timber, recovered from demolition, as feedstock for the manufacture of mass timber. This paper outlines the state of play in 'mass secondary timber' (MST) from a research and practice perspective. It describes a recent pilot project, in which we applied our MST research in the context of a case study modular building. Timber has been gathered that would otherwise have entered demolition waste streams. Instead, it has been prepared for reuse and manufactured into structural 'glued-laminated secondary timber' (glulamST) and 'cross-laminated secondary timber' (CLST). The components are developed as a kit-of-parts that can be adapted for application to other building typologies, and are designed for disassembly, upgrade and future reuse. The pilot is in itself reusable; the paper showcases its appearance at four locations between July 2024 and March 2025. Based on our experiences from carrying out the case study, we discuss the stages of physical processing, the pilot's impact, and reflect on the steps needed to scale this innovation to an industrial level.

KEYWORDS: reuse, industrial upcycling, mass secondary timber, CLT, localised supply chains

1 – INTRODUCTION

Materials from demolition, currently treated as waste, present opportunities to improve on business-as-usual waste management and develop new approaches to reuse, recycling, reuse and repurposing [1]. An example is diverting secondary timber (ST) from demolition into production feedstock for the manufacture of mass timber. We began investigating the feasibility of this idea [2] as a means of enabling practitioners to specify secondary materials. Manufacturers of what we have termed 'cross-laminated secondary timber' (CLST) and 'glued-laminated secondary timber' (glulamST) could deliver a reliable supply of certified structural products – in contrast to the fragmented and informal supply infrastructure for direct material reuse. Our research has indicated good feasibility and predictable structural performance [2], [3], but this industry remains in the early stages of its emergence.

Godina et al. [4] recently introduced 'mass secondary timber' (MST) as a catch-all term for the use of secondary timber in CLT, glulam, DLT, NLT, etc. From almost no research on this topic a decade ago, it has become a significant area internationally over the last few years. An ongoing review was begun in January 2015 to ascertain whether the concept of MST had already been implemented in practice or investigated by other researchers [5, pp. 288–289]. At that point, we were aware of no businesses aiming to manufacture MST and only occasional allusions to the idea were found in the academic literature [6], [7]. Neither of these studies acknowledged the benefit of greater potential lifespan and performance compared to typical downcycled products in a timber cascade, and neither author appears to have pursued the idea beyond passing reference.

In 2015, an Australian study recommended that with government support, greater demand for mass timber products could provide a market for wood emerging from demolition [8]. Having examined timber deconstruction and reuse practices in the USA and the UK, Bergsagel recommended that 'research should be conducted on the material efficiency of producing laminated engineered wood products from a more variable reclaimed timber

[1] Colin M. Rose, Dept of Civil, Environmental & Geomatic Engineering, University College London, UK, colin.rose@ucl.ac.uk; ORCID: 0000-0002-5059-6530; UK CLT LLP

[2] Jonas Breidenbach, Dept of Civil, Environmental & Geomatic Engineering, University College London, UK; UK CLT LLP

[3] Patrick Quinn, Dept of Civil, Environmental & Geomatic Engineering, University College London, UK; Bartlett School of Planning, University College London, UK; Royal College of Art, London, UK

[4] Julia A. Stegemann, Dept of Civil, Environmental & Geomatic Engineering, University College London, UK; UK CLT LLP

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feedstock. This could be for the whole section, or only for the central laminations' [9].

We reviewed publications that examine the mechanical performance of MST in [3]. Around this technical literature there is a growing body of work on MST from a range of perspectives, e.g. testing different product formats [10], [11], [12], [13], [14], means of production [15], environmental benefits [16], economic considerations [17] and wider changes needed to bring MST to market at scale [18], [19]. The underlying fundamental challenge of structural reuse of ST is also receiving increased attention, for instance in defining the need for and establishing new standards [20], [21], new engineering design procedures [22] and NDT of mechanical and fire performance [23], [24], [25].

In terms of manufacturing MST, we developed a prototype at furniture-scale in 2016 [5, pp. 126-131, 178]. Cases of full-scale construction or other prototyping are rare. Vaagen Timber manufactured a prototype CLT panel from ST [26]; Norsk Massivtre assemble basic NLT components with screwed connections and with Omtre have delivered a barn project using 75% ST [27], [28]. Urban Machine with All Bay Lumber have begun producing DLT [29]; Urbanjacks finger-joint ST for applications that are soon expected to extend to structural use and production of CLT [30]. Nordic CLT and Omtre have developed CLT-like products that use offcuts from conventional mass timber production [31], [32], which can be stacked like bricks in load-bearing solid wall construction. 'C-CLT' made by The Urban Woods appears to be a similar format but uses recovered pallet wood for the middle layers and primary timber for the outer layers. Anecdotally, this is being used for one wall in a current development.

In this context, we see our recently completed pilot project, known as CascadeUp, as a first of its kind. It is made from 100% ST; it demonstrates the products at building-scale in structural use; and it has been in use in the public realm at a series of events. This paper provides background on the project, explains its design and construction, and the potential for this and other pioneering projects to act as springboards to accelerate MST production to industrial level.

2 – BACKGROUND

The construction industry creates vast quantities of waste. The UK consistently generates around 4.5 Mtpa of waste wood, around half of which comes from the construction industry. Approximately 60% of UK waste wood goes to energy recovery [33], releasing its sequestered carbon, despite the potential for recycling at higher value. About 30% of waste wood is recycled, but this is mostly low-quality downcycling into short-lived single-use products such as chipboard, animal bedding and mulch. Meanwhile, the UK is already the world's second largest net importer of new wood, with >80% of

Figure 1. CascadeUp pilot at launch event, Here East, London, July 2024 (credit: Digby Oldridge/UCL)

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domestic demand met by imports [34]. While the UK lags behind France's RE2020 environmental policymaking [35], a Timber in Construction Roadmap can be expected to increase UK demand for timber [36]. At European level, production of mass timber would need to increase nearly fivefold to meet a 'high ambition scenario' of 50% bio-based residential construction by 2030 [37].

Improving the supply of secondary timber from demolition back into the construction industry could help to achieve this, whilst mitigating risks such as rising prices and rising price volatility of construction timber, as seen in 2021 [38] (up 97% according to one supplier). These trends are likely to continue: supply is affected by wildfires, tree diseases, insect attack and supply chain problems, and faces increasing competition over the use of land; while the World Bank predicted in 2016 that global demand for wood products would rise by 4% a year for the next 30-40 years [39].

To unlock the environmental, social and economic opportunities of circular use of wood, there is an urgent need for enterprises to drive feasible alternatives to current waste management. Business-as-usual management of ST is a result of systemic issues, including inefficient and destructive collection, low availability of technology to process ST, undetermined manufacturing processes and logistics, and market uncertainty. These challenges will continue to be addressed by a growing global research and business community. This paper makes the case for progress towards the goal of high-quality, high-value industrial upcycling of ST through practical action.

3 – PROJECT DESCRIPTION

The pilot was conceived as a modular, reusable building, in partnership with Portakabin, who have been at the forefront of volumetric modular construction in the UK since 1961 and now operate internationally. As a supplier of demountable buildings that works on a leasing as well as for-sale model, Portakabin is intrinsically a circular economy business. They are seeking ways in which circular economy principles can furthermore be embedded in their sourcing and use of materials.

Portakabin uses steel frame construction in its standard modules; separately, they are investigating integration of mass timber components. In this project we examined a switch to MST as a full structural system. Our goal as researchers, and as founders of UK CLT LLP, a startup that aims to manufacture MST commercially, was to demonstrate MST products' appearance and applicability, build a stronger understanding of feedstock sourcing, production and assembly processes, and raise awareness and scrutiny of the idea of MST by placing it in the context of real or potential suppliers and customers.

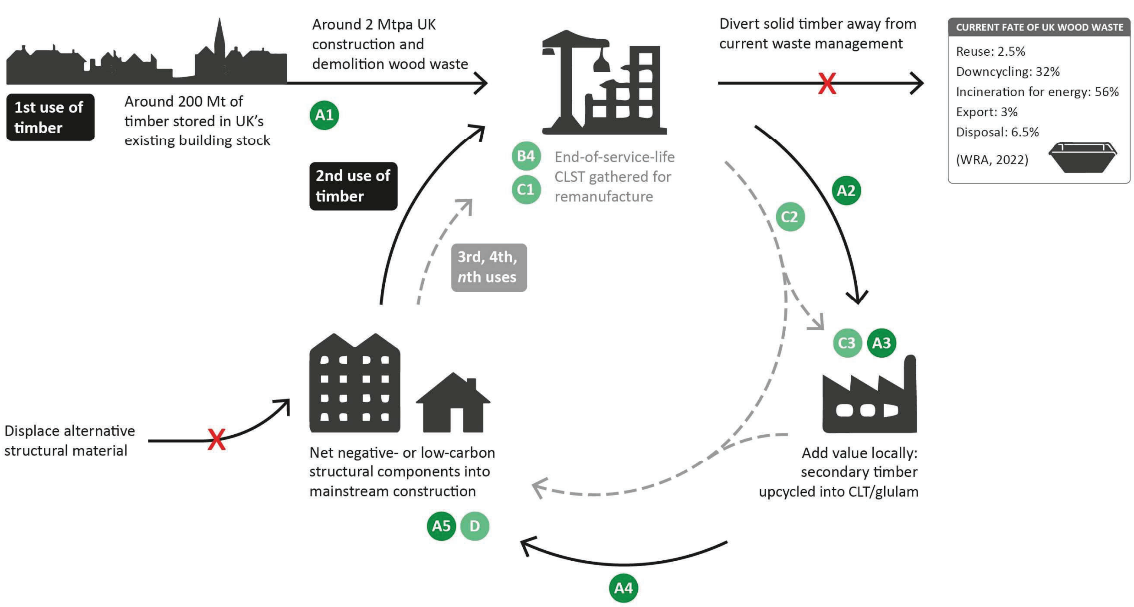

Figure 2. Life cycle schematic of MST [5] updated to Wood Recyclers Association (WRA) data from 2022 [33]; in-use stocks data from [42]

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4 – DESIGN PROCESS

With the goal of 'full' circularity – developing products that both use secondary materials and are designed to enable multiple future uses – the pilot was based upon a 'kit-of-parts' that can be adapted for application to other building typologies, and is designed for disassembly, upgrade and future reuse. Product passports maintain a digital record of key information based on Madaster's platform. The floor is made up of three CLST panels around 600 mm wide rather than a single panel: panel dimensions are standardised to increase the probability of their future use as part of a coordinated kit-of-parts. This smaller-scale panelised approach to modular construction is coupled with a volumetric modular approach, similar to the systems used by Portakabin.

For demonstration purposes, the pilot is effectively a cross-sectional slice through a notional Portakabin module, at one-third of its typical length. This sectional cut reveals the construction of the building and allows it to act as an open-fronted stage and a welcoming platform. Its overall dimensions are approximately 3.4 m in height, 2.6 m wide and 2.0 m front-to-back.

Design was led by the team at UCL with structural design provided by EURBAN. Typical Portakabin modules can be lined up to create larger internal spaces. To match this capability, our version of a single module comprises a glulamST frame, so that the sides could be open. CLST wall and floor panels are connected to the frame. Beams at floor level and roof level have cross-sectional dimensions of 120x300 mm and columns are 120x120 mm. These glulamST components were made up of 120x60 mm boards. CLST floor panels are 120 mm thick, made up of three 40 mm lamellae. CLST wall panels are 72 mm thick, made up of three 24 mm lamellae.

5 – RESULTS AND DISCUSSION

5.1 FEEDSTOCK SOURCING

The timber used in CascadeUp was all from secondary sources within a 30 km radius of the project's base in East London. The locations included two demolition sites in central London, a reclamation company and a community-led wood reuse enterprise. Identifying the sources was challenging, partly because information about forthcoming demolition materials is not yet systematised, and partly because we were working to a tight timeframe. This was a result of carrying out a one-off demonstrator project; the time-criticality of individual batches would be mitigated in a larger, ongoing production process.

With access to storage space and transport, an MST manufacturer can begin to build a reputation amongst demolition, deconstruction and design practitioners. Related businesses like Retrouvius in the UK and RotorDC in Belgium, and our own experience as UK CLT, suggest that once an organisation's capability is recognised, people start to proactively offer secondary materials.

5.2 FEEDSTOCK PROCESSING

Linear yield rate was 75% and volumetric yield rate was 31% [40]. This could be improved by applying scanning and imaging techniques to more efficiently ascertain three-dimensional geometry and characteristics such as knot positions, and to establish optimal machining. It could also be improved by taking a 'supply-led' design approach (as opposed to typical demand-led design), e.g. in working to thicknesses and widths derived from the feedstock rather than from typical primary wood dimensions. This approach becomes more plausible with

Figure 3. Gathering feedstock from demolition sites; preparing CLST panel lay-up; installing CascadeUp at Here East

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scaled-up operations – but an optimal balance needs to be struck between cost and resource efficiency when determining whether to minimise processing and store multiple thickness and width stocks, or process boards to fewer, more consistent section sizes.

5.3 MANUFACTURE, ASSEMBLY AND FUTURE DISASSEMBLY

Manufacturing CLST panels of a smaller format to frame opening rather than making large panels and then cutting out window and door openings avoided a significant volume of production. Smaller panels meant they could be manually handled and assembled by 2-4 people. Only the roof cassette panel had to be lifted by forklift due to height. This modularity facilitates manufacture in smaller facilities, making localised, decentralised mass timber production more feasible. It could enable the use of existing, less highly-specialised production facilities, reducing the level of investment required. A further benefit may be to steer attitudes and convert existing skills, practices and infrastructure towards greater circularity, increasing timber industry resilience, rather than forming parallel ST and MST supply chains.

The smaller panel format allows disassembly without the need for cranes, and further repairs or adaptations to the panels in a standard woodworking workshop – avoiding the barrier of transporting components back to very large and distant facilities to be reprocessed.

Disassembling the CascadeUp pilot is readily possible, but there is more work to be done to optimise the kit-of-parts design to simplify adaptability, disassembly and reassembly.

5.4 PILOT IN USE

In July 2024, the pilot was exhibited at Here East in London's Queen Elizabeth Olympic Park (Fig. 4a), staging a launch event with a presentation and panel discussion and receiving a school visit. It was then transported to central London for the second half of the UCL Festival of Engineering (Fig. 4b), where we raised awareness of circular economy and timber construction with members of the public visiting the festival and a wider UCL academic community. In September 2024,

(a) (b)

(c) (d)

Figure 4. Exhibiting CascadeUp at (a) Here East (credit: Digby Oldridge/UCL);(b) the UCL Institute of Education (credit James Tye/UCL); (c) London Design Festival 2024 at OXO Tower (credit Anthony Sajdler); (d) Futurebuild 2025 at ExCeL (credit James Allen/UCL)

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CascadeUp was co-located with Timber Development UK's Wood Awards as part of London Design Festival (Fig. 4c), a major event with 600,000 visitors from 75 countries. The pilot hosted a panel discussion for the BuildZero research project, daily talks for visitors, and engagement with industry, policymakers and the public. Most recently, in March 2025, it formed part of the main entrance welcome feature to Futurebuild 2025, being adapted for use as a 'photo booth' and driving further engagement with industry (Fig. 4d).

It has been transported between events and storage using a HIAB truck and lifted as a single element into a range of locations. The pilot has proven itself to be readily reusable and adaptable to different functions and sites.

The goal now is to identify a longer-term opportunity to site the pilot, where it can continue to inspire conversations about secondary materials in construction and be used e.g. as a stage, or modified to host meetings, provide a shelter, etc. So far it has retained its original form but it could be upgraded for external use, extended to form e.g. the entrance to a larger building, or taken apart and the components used in a different form.

When no further reuse of the building as a whole or its components is possible, the timber can be recycled into panel products and then finally incinerated for energy recovery.

5.5 COLLABORATORS AND SUPPLIERS

A crucial step taken in our development of this pilot, and in other practical work relating to MST production (section 1), is to foster the partnerships needed to translate research into action. The project has allowed us to develop relationships with collaborators and suppliers, including for sourcing feedstock, adhesives, fasteners, structural design, a material passport platform, and places of production in addition to UCL's research facilities. Tangible demonstrator projects help to generate further interest from potential customers and collaborators, accelerating the route to wider uptake.

In building our networks to source timber we have also been offered significant quantities of used mass timber – in one case due to a major design change; once after temporary use; and once when a 20th century building was being redeveloped. As more buildings constructed with mass timber reach end-of-life, there will be a growing need for infrastructure to handle these resources. This could sit alongside MST manufacturing.

5.6 END MARKETS

The volumetric approach to modular construction, as exemplified by Portakabin, is one potential avenue for the use of MST. This particularly suits (though is not limited to) temporary buildings, such as for construction site accommodation, meanwhile use sites or temporary classrooms for schools. The panelised modular approach opens up other avenues for scaling the use of MST, including residential extensions, small homes, self-build, galleries, museums and other cultural and public buildings – UK CLT has been approached about all of these potential uses.

5.7 CARBON IMPACTS

Extending timber's lifespan in structural use maintains carbon sequestration over the long term. Improving the adaptability of the kit-of-parts, designing for disassembly and reuse, and maintaining a digital record of key information in product passports improves MST's chances of enduring multiple structural lifecycles. With each structural use, MST could displace carbon-intensive alternatives like concrete, steel and masonry, increasing the overall proportion of timber construction.

A less preferable scenario would be for MST to displace the use of conventional mass timber. We have previously contributed to a glulamST demonstrator, as part of the CIRCuIT project [41, pp. 38–51], which compared lifecycle carbon impacts of glulamST and conventional glulam. Given that glulamST production has not been commercialised, this study relied on assumptions about e.g. ST haulage distances and energy needed for drying and processing. It found a 40% saving in embodied carbon (A1-A3; reduction of 132.6 kg CO_2/m^3) when using ST. As the study was based in a UK context with conventional glulam imported and notional local production of glulamST, cradle-to-site embodied carbon was reported separately, with the carbon saving rising to 50% (A1-A4; reduction of 202.8 kg CO_2/m^3). Assessing biogenic carbon in the context of ST is highly dependent on the system boundary, but the study reported an improvement of 196% (1085.7 kg CO_2/m^3 more carbon storage) compared to business-as-usual ST management and conventional glulam production.

5.8 SCALING MASS SECONDARY TIMBER PRODUCTION

In regions with existing mass timber production, the simplest route to scaling MST production may be in partnership with established manufacturers, potentially beginning with 'hybrid' products where only the crosswise lamellae of CLT or middle lamellae of glulam are ST [2], [9], [16]. This route has some potential in the UK, but there is relatively little suitable homegrown timber and mass timber manufacture is at an early stage in its development. What does exist is in Scotland, while the most dense generation of wood waste and greatest demand for mass timber is in London; carbon and economic benefits dissipate with these transport distances.

One of our findings from the pilot project is that ST can be sourced and processed into MST in a city region like London. This emerging localised supply chain could scale through a network of decentralised MST operations, building upon and adding new revenue streams to existing places of production (section 5.3). Distributed manufacture of MST might also be achieved by moveable micro-factories that can be replicated and deployed on sites close to large-scale regeneration. These nimble approaches to reuse and industrial upcycling might furthermore provide models for localised, circular supply chains that address other construction material flows.

5.9 NEXT STEPS

Given the pressing need to increase mass timber production and the limits on sustainable wood supply that can be harvested from forests [37], an important next step is to understand the contribution that MST could make. Researchers could project potential global growth in production of MST and demonstrate its value in terms of product outturn, stimulating local economies and creating new, good-quality, green jobs.

There is growing momentum in addressing the underpinning technical challenges of structural reuse of timber (section 1). As a subset and extension of this field, there is a need to coordinate the work of researchers and businesses globally who have the shared ambition of enabling and implementing MST. A formalised network could shortcut unproductive duplication of effort, allow teams to build on each other's findings and move forward strategically with the right questions. Healthy competition between businesses will help drive progress; it would be important for an MST network to establish clear delineation between areas of competitive advantage for businesses, and challenges that could be overcome collaboratively to the benefit of any MST business.

Figure 5. Exhibiting CascadeUp with illustrative 'process panel' at the UCL Institute of Education (credit Gersende Giorgio)

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Alignment of testing methods for ST could create larger datasets more swiftly, supporting the development of standards for the lamellae used in MST – and thus accelerating towards increased confidence from designers, contractors and insurers.

The proliferation of activity around MST should be celebrated, and continually stoked through new, ambitious projects that push the boundaries in a range of different ways. Our next steps will include seeking the right context and framework for the delivery of a full MST building, in collaboration with progressive clients and practitioners. Strong connections between academia and business are likely to be the best way to address challenges and propel this innovation towards practical realisation at scale.

6 – CONCLUSION

Through a pilot building case study, we have demonstrated MST products employed in a structural capacity. The building has been in practical use in the public realm at a series of events. It provides a tangible manifestation of circular construction and has acted as a platform for raising awareness amongst the public, industry and policymakers. Pilot projects can help to familiarise mainstream construction industry with new ideas, attracting collaborators and early adopters and priming the market for future uptake.

Constructing the pilot has allowed us to plan and analyse process steps, gather data on yield rates, and develop partnerships needed to translate research into action. An assessment of the material's carbon impact suggests significant savings in embodied carbon and improvements in biogenic carbon when compared to conventional mass timber and typical ST management.

The pilot is based on a smaller panel format than is typical for CLT, with a view to increasing standardisation, reusability, and the possibility of decentralised, local manufacturing. MST production could scale by leveraging smaller existing places of production, through replicable and re-deployable micro-factories, or in partnership with established mass timber manufacturers. A coordinated global network of MST-focused businesses and researchers is proposed to accelerate progress towards industrialisation.

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