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POTENTIAL OF REUSING SALVAGED WOODEN MATERIALS IN FABRICATING STRUCTURAL DOWEL LAMINATED TIMBER

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ABSTRACT: Reusing salvaged wooden materials in new structural products offers a promising approach towards a circular economy. In this paper, the potentials and challenges related to reusing salvaged wooden materials in mass laminated timber are explored. Furthermore, the research activities at the group for Wooden Structures (Aalto University) related to the reuse of salvaged timber materials in fabricating dowel laminated timber (DLT) are discussed and the outlook of the subject and the future research needs are summarized. Among others, the research group focuses on the use of DLT in structural applications both as a beam-type element and as a slab-type element. The results show that salvaged plywood plates, which are e.g., used in the construction sector as concrete formwork, can be used effectively to produce tenon connectors for DLT fabrication. In addition, the combination of salvaged timber and new full-scale timber boards in alternate layers have shown to be a promising alternative. In this method, short, salvaged timber elements can be used without any end-to-end joining or gluing. Minimizing the required processing procedures can make salvaged timber more profitable and more attractive to the timber products manufacturing sector.

KEYWORDS: salvaged timber, dowel-laminated timber, wooden connectors, circular economy, climate change, reuse, low processing

1 INTRODUCTION

Over the past years, interest in biobased materials such as timber has increased in different sectors, e.g., due to the challenges related to the climate change. Accordingly, several studies have expected difficulties in meeting the demands for timber in the near future [e.g., 1]. In the case of the construction sector, the cascade use of timber has shown promising potentials for addressing the anticipated demands for timber solutions [1]. In addition, reusing wooden materials could be an effective approach in battling the climate change, and therefore, this subject has been the focus of numerous studies in the recent years [e.g., 2-8].

In this paper, the case of reusing salvaged wooden materials in mass laminated structural elements made with wooden connectors is discussed. A description of the related research and development works at the group for Wooden Structures (Aalto University, Finland) on this topic is also provided. The focus here is on the reuse of salvaged wooden materials in fabricating dowel laminated timber (DLT), both as a beam-type element and as a slab-type element. Finally, the outlook and research needs for breakthrough innovation in the subject area are summarized.

2 POTENTIALS AND CHALLANGES

The concept of reusing salvaged wooden materials is related not only to meeting the future demands for timber solutions, but also to addressing the climate change. Reusing wooden materials offers a potential to reduce the need for new materials, and therefore, preserve the natural resources. Furthermore, salvaged wooden materials are theoretically cheaper than new materials; therefore, if processed economically, they can be used to produce more affordable products. Here, salvaged wooden materials refer to both salvaged timber and salvaged engineered wood products that are often obtained either from a primary application or as waste from a timber production process. Figure 1 shows two examples: cut-offs from a regional housing company and falsework for a concrete bridge. Depending on the material type, several approaches exist in the literature to reuse salvaged wooden materials in new products and applications. Most of the approaches require additional processing on the salvaged wooden materials, e.g., particleboard production or cross laminated timber (CLT) production.

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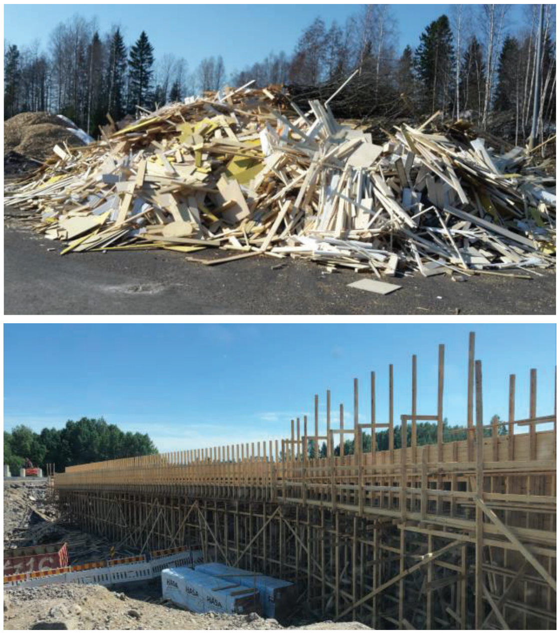

Figure 1: *Examples of salvaged wooden materials; cut-offs from a housing company (top) and falsework for a concrete bridge (bottom).*

Despite the existence of some methods for the case of reuse, it should be acknowledged that no single method can be effective for all types of salvaged wooden materials, considering the variabilities in e.g., type, shape, dimensions, irregularities, and material characteristics. Some salvaged wooden materials may be only good enough to be used for energy. However, for others a fit-for-purpose approach might be best in order to develop certain types of wooden products.

In terms of new products development, the interest in reusing salvaged timber in fabricating mass laminated timber products for structural applications has increased in recent years. Some research works have also already been conducted on this topic (examples of those studies are summarized in Table 1), most of them focused on non-finger jointed CLT.

Nevertheless, the concept of reusing salvaged timber has several challenges that need to be acknowledged, some of which are described in the following:

- Unknown material source: salvaged timber materials come from different sources and usually their original strength class and or their species are unknown. Assigning the correct species for salvaged timber could be quite difficult [13,14] and this creates further obstacles in the segregation and grading of the salvaged timber materials.

Table 1: *Examples of mass laminated timber products developed from salvaged timber materials in the literature. CLT (cross laminated timber), GLT (glued laminated timber), NLT (nail laminated timber).*

Materials used	Product	Ref.
Salvaged timber and new timber	CLT	[4]
	CLT	[7]
	GLT	[9]
Salvaged timber	CLT	[6]
	CLT	[8]
	CLT	[10]
	NLT*	[11]
	NLT	[12]

*Using wooden nails

- Unknown load history: the previous load history of salvaged timber is typically unknown, especially when the source of the materials is not identified. This makes it more difficult to account for issues such as the duration of load effect on the material properties [15].

- Uncertainties related to the mechanical properties: as the initial grade and the previous load history are usually unknown, the salvaged timber materials that are obtained from different sites might have a wide range of mechanical characteristics. In addition, previous research works [e.g., 5] have demonstrated that it is often quite difficult to identify any clear trend on how much some of the mechanical properties of timber may change over time.

- Grading rules: the classification of the material properties is essential for reusing salvaged timber in structural applications; however, the existing grading rules are in general valid only for new timber. One exception is the Australian interim industry standard for recycled timber [16], however, for most regions a strength grading regulation still does not exist.

- Distortions and damages: distortion and other shape irregularities are usually common in salvaged timber. The presence of damages such as fastener holes, slots, or cracks are also common and can affect the performance of salvaged timber [see, e.g., 17].

- Length limitation: another common challenge for reusing salvaged timber is the length limitation. Usually, the usable part of a salvaged timber board could be relatively small and the additional costs for end-to-end joining can affect the profitability of reusing salvaged timber.

- Presence of metallic fasteners: salvaged timber may contain metallic fasters such as nails or screws from the previous applications. This can make the processing of salvaged timber more challenging and time-consuming. In this regard, automated systems have been recently developed for processing salvaged timber, including nail and screw removals; see e.g. [18]. Nevertheless, until such technologies become widely available, post processing of salvaged timber can be difficult and costly.

- Contamination: salvaged timber could be also sometimes contaminated due to exposure to chemicals e.g., wood preservatives or other substances such as wet concrete in falseworks.

- Limited availability and supply: although a large volume of salvaged timber is produced every year, currently the number of companies that are involved in sourcing and distributing salvaged timber is quite limited compared to those for new timber. Therefore, access to continued supply of usable salvaged timber can be difficult for manufacturers of timber products and or builders who may want to use salvaged timber in their projects.

The existence of such challenges warrants in-depth research in order to establish effective approaches to achieve the full extent of advantages that can arise from reusing salvaged wooden materials. This could include e.g., establishing an assessment scheme and or grading criteria that could quantify the mechanical properties of salvaged timber as well as implementing design for deconstruction concepts that could ease the end-of-life disassembly processes and streamline the reuse of salvaged timber.

3 EXPERIMENTAL RESEARCH ON DLT

Given the environmental benefits, the full sustainability potential of reusing salvaged wooden materials in new applications can be achieved if, preferably, no synthetic glues or metallic fasteners are utilized. In this regard, wooden connectors have received particular attention as an alternative solution. In this section, two related projects recently carried out by the authors of this paper are summarized.

3.1 DLT FABRICATED WITH CONNECTORS FROM SALVAGED ENGINEERED WOOD PRODUCTS

The use of wooden connectors in fabricating DLT has been studied intensively [e.g., 19-24]. DLT has been used as a slab-type element by the construction industry in several projects worldwide and a design guide is already available for its application as well, see: [25]. Nevertheless, wooden connectors result in flexible connections; therefore, the composite action of DLT is a challenge to be met when it is used as a beam-type element.

In [26], we aimed to reuse salvaged engineered wood products in fabricating connectors for DLT beams. One of the assumptions was that the superior mechanical properties of connectors from engineered wood products can improve the composite action and, at the same time, enhance the sustainability aspects of DLT beams. The project involved push-out shear tests on dowel and tenon connectors made from Oak, salvaged laminated veneer lumber (LVL), and salvaged plywood. Based on the findings, we then performed four-point bending tests on DLT beams made with the selected connectors (i.e., salvaged plywood tenons, Oak tenons, and conventional Oak dowels as a reference).

The project demonstrated that the DLT beams fabricated with salvaged plywood tenons were efficient and led to approximately 40% higher bending stiffness compared to the conventional DLT beams made with Oak dowels. This approach not only improves the bending stiffness of the DLT beams, but also has the potential to contribute to the circular economy by offering a method for reusing salvaged plywood materials.

3.2 DLT FABRICATED WITH SALVAGED TIMBER LAMELLAE AND SALVAGED PLYWOOD TENONS

Length limitation was identified earlier as a challenge for reusing salvaged timber. Reusing short, salvaged timber elements in mass laminated timber products normally requires significant processing, including gluing and end-to-end joining. However, the associated costs of the additional processing and gluing can make salvaged timber less profitable, and therefore, less attractive to the timber products manufacturing sector. On the other hand, without end-to-end joining and gluing the existing methods of mass laminated timber production may not lead to a product that could meet the structural performance requirements.

A recent project conducted at our group aimed to address this issue by developing DLT floor slabs with a mixture of new (full-scale) timber boards and short salvaged timber elements [27]. The idea was to reuse the salvaged timber elements in every other layer of the DLT slab without end-to-end joining or gluing to reduce the cost associated with reusing the short, salvaged timber elements and to reduce the volume of the full-scale boards that would normally be needed in the conventional DLT.

The concept was evaluated on large-scale DLT specimens. The specimens were composed of three layers of new timber boards (l = 3.5 m) and two layers of salvaged timber elements. The specimens were fabricated with six voids located along the two layers of salvaged timber elements (Stage A in Figure 2). The voids were filled by inserting short, salvaged timber elements with about 2 mm larger lengths (Stage B in Figure 2). The specimens were laminated using salvaged plywood tenons.

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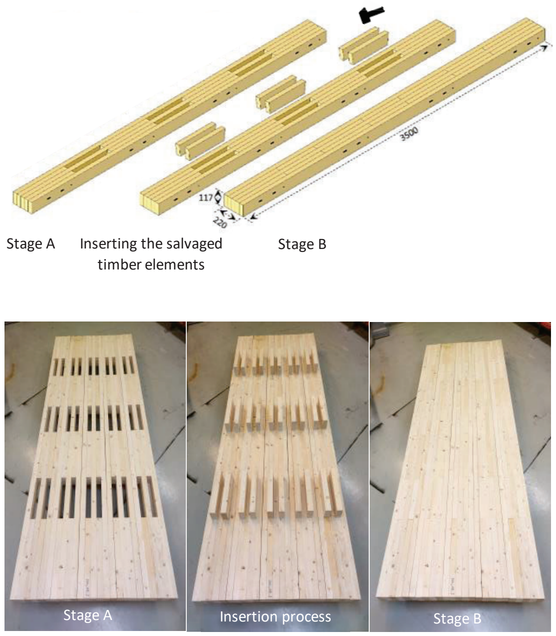

Figure 4: *The fabrication process of the large-scale DLT specimens (top), the actual specimens placed side-by-side to resemble a wider panel (middle), recreated based on [27].*

The vibration characteristics and the bending properties of the specimens were examined in both stages. The results exhibited substantial increase in the bending stiffness and relatively improved vibration characteristics. Overall, the average bending stiffness of the Stage B specimens was about 84% of the expected average bending stiffness of a conventional DLT made with five full-scale timber boards.

Another important finding was that the bending failures occurred almost exclusively in the full-scale timber boards, suggesting that the proposed system may not be so much dependent on the bending strength of the salvaged timber elements. This was due to the fact that the salvaged timber elements were used without end-to-end joining. Therefore, the tension stress caused by the bending loads is resisted predominantly by the full-scale boards.

4 OUTLOOK

Given the current research trends, a promising outlook could be anticipated for the subject of reusing salvaged wooden materials in structural laminated products. In this context, DLT represents a great potential, as it is a cost-effective alternative that does not require gluing. This can directly improve the profitability of salvaged timber materials which may promote their further application in the timber sector. In addition, DLT could be a good option for the construction of affordable housing in less developed areas around the world where access to advanced mass timber production technologies may not be available.

Nevertheless, as highlighted in this paper, there are also important challenges that need to be investigated in order to enable breakthrough innovation in the subject area. Therefore, future research can focus on evaluating ways in which the challenges related to the reuse of salvaged wooden materials can be addressed. Furthermore, when a mixture of new timber and salvaged timber boards are used to fabricate laminated timber products with wooden connectors, different lay ups of the salvaged timber layers could be investigated to identify an efficient lamination system. Investigating the long-term performance under variable service conditions as well as establishing analytical models to predict the mechanical performance are also other vital areas that require further development.

Finally, to better realize the future potentials of salvaged timber, some regulations need to be implemented that can ensure proper ways of sourcing and handling of salvaged timber as well as certifications that can verify its quality. Furthermore, education and awareness about salvaged timber need to be increased in order to improve the consumers perception, create demand, and make products from salvaged timber more available on the market.

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