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Investigating the Reuse of Formwork Wood: Assessing the Structural Qualities

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Abstract

In Belgium, as well as in numerous countries globally, standard-quality wood serves as a building material in a plethora of applications. From permanent structures to temporary solutions, it finds use in auxiliary constructions such as scaffolding and formwork. Formwork wood is abundantly used during construction and represents 30% of the total on-site waste (Osmani [1]). However, it has a limited lifespan due to the on-site solicitations. Typically, it is employed only one to four times before its surface begins to deteriorate, causing imperfections that affect the quality of concrete curing. The wood surface may not respond to formwork requirements but still has qualitative structural properties and great potential for reuse. This research studies and explores the reuse possibilities of formwork wood materials in structural applications, taking the different types of formwork wood into account (beams, boards, fibre and multiplex wood).

First, research was conducted on the uses and the waste management of formwork wood in Belgium by contacting different wood associations, construction companies, and the associations upcycling and reusing construction materials. In parallel, the formwork wood material was collected on several construction sites and prefabrication centres. This collected wood was then tested to determine its current mechanical properties to assess the remaining structural capacity. The tests included bending, tension, and compressive strength testing and non-destructive tests.

The structural wood demand is yearly increasing as is the wood waste production in Belgium. The goal is to find new structural applications and to design a spatial structure with upcycled formwork wood materials to valorise the at-disposal wood material. Finding new applications for the formwork wood will help preserve natural resources, reduce the amount of waste sent to landfills, and reduce the environmental impact of the construction industry.

Keywords: Formwork wood, circularity, waste, structural design, material engineering

1. Introduction

The construction industry is one of the most polluting in the world, representing 37% of global operational energy and processed-related CO2 emissions in 2021 (Environment [2]). It is predicted that global raw material consumption will almost double by 2060, underlying even more the massive potential to reduce greenhouse gas emissions from the reuse of waste material (Lifset et al. [3]). Moreover, that number worsens as more and more waste is generated yearly. Studies show that the amount of construction and demolition (C&D) waste in the US increased ten times faster between 2005 and 2018 than from 1990 to 2005 (US EPA [4]). By 2025 2.2 billion tons of construction waste will be generated annually worldwide ("Construction waste market" [5]). Of that generated waste (wood, drywall, asphalt shingles, bricks and clay tiles), more than 75% is put in landfills (EPA [6]). When a new building is constructed, up to 30% of the materials end up as waste (Osmani [1]). Timber is increasingly used in construction, growing by 4.4% yearly, mainly for formwork (Adhikari and Ozarska [7]). As wood production increases in Europe ("Wood products - production and trade." [8]), waste generation also increases. With the increasing demand, it is important to find ways to valorise waste wood to avoid a shortage of wood, reduce the import of wood from Europe, and preserve natural resources (Pazzaglia and Castellani [9]). In Belgium, 29% of the waste produced comes from the construction industry ("Waste production | Statbel." [10]). Belgium currently produces 1.460.000 m³ of sawn timber annually. Of this production, packaging and formwork lumber account for 28% (Picard [11]). The purpose of the research is to study the reuse of formwork wood materials in structural applications by looking at the mechanical and durability properties of wood and the influence of concrete on the resistance to the environment and sustained loading.

The formwork wood is currently used once to four times to manufacture concrete elements. It is then discarded because the wood surface deteriorates, causing imperfection that affects the quality of concrete curing. The surface of the wood may not respond to formwork requirements, but the element still has qualitative structural properties and great potential for reuse. The exposure to concrete during the formwork makes the wood more difficult to reuse or recycle and gives the impression that it deteriorates the wood. Often, the wood is incinerated. But in fact, concrete has a positive impact on wood and may act as a surface treatment, as found in my preliminary research (Nicolas and Filz [12]). However, the remaining mechanical properties and the effects on the durability of the material need to be investigated in detail. Only some research is done on the reuse of formwork material, and none of those publications consider the influence of concrete on the properties of the material. Nevertheless, in the wood industry, heat and oil-curing treatments are used to enhance the mechanical properties of wood (Wahab et al. [13]). Other research explores chemical treatments to enhance wood properties (Lande et al. [14], Owoyemi et al. [15]). These studies and existing treatments show interest in exploring the influence of concrete on the mechanical properties of wood.

Moreover, timber structures are increasingly used (Psilovikos [16], Premrov et al. [17], "Etat de la construction bois en Belgique | Filière Bois Wallonie." [18]), and Cross Laminated Timber (CLT) is becoming more popular. As waste production is increasing, the need to reuse wood is becoming more important. My goal is to provide an alternative to timber structures using waste material to preserve natural resources.

2. First investigation of the formwork wood

This paper will go through the first investigation of the formwork wood, from gathering the material from construction sites to testing its bending strength.

2.1. Collecting the formwork wood

In the initial phase of comprehending this waste material, formwork wood was collected from various construction sites and prefabrication centres (Figure 1 and 2) in Brussels, Belgium. In total, four distinct types of formwork wood were gathered from 4 construction sites: wooden boards, wooden beams, fibre wood, and multiplex wood. The assortment of formwork types encountered on construction sites varies depending on the project's requirements and applications. For instance, multiplex wood finds greater usage in prefabrication centres due to its higher cost but also its superior durability. Multiplex wood can

be utilized for up to 40 cycles when maintained in a protected environment with proper care. Conversely, wooden boards and fibre wood are more prevalent on construction sites due to their cost-effectiveness. Figure 3 shows a batch of formwork wood collected on one construction site. It shows the variety of formwork used on-site.

Figure 1: batch of used multiplex wood on construction site

Figure 2: formwork wood inside a container

Figure 3: batch of formwork wood collected on construction site

2.2. Preliminary tests

Engaging with waste materials poses a multifaceted challenge due to the inherent variability arising from prior use. Preliminary tests such as flexural bending tests were performed on the wood to get an idea of the mechanical properties (flexural strength, deformation, modulus of elasticity, type of fracture) and reuse potential of the formwork wood. The flexural strength is determined using a 3-point bending test with 70 cm interdistance between the hinged supports (Figure 4 and 5). A force is applied on the formwork wood until rupture and the deflection is measured at midspan by means of a linear variable deformation transducer. These comprehensive tests were conducted across all variants of formwork wood procured. Presently, all types are studied, with the goal of choosing one type of formwork to focus on and design spatial structures with.

Figure 4: 3-points bending test – wooden board [5.7x14 cm²]

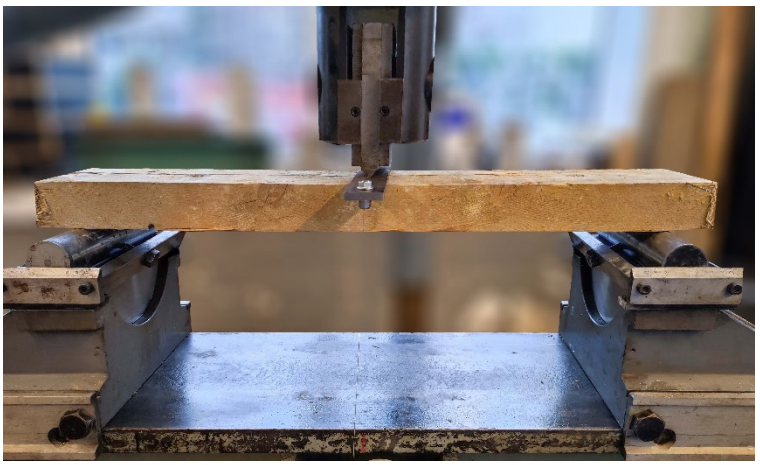
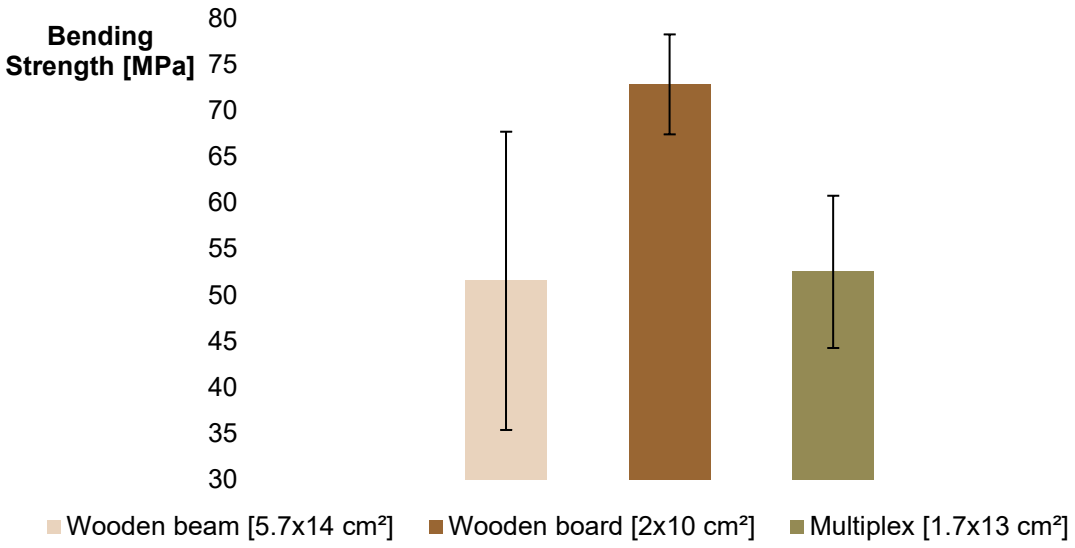


Figure 5: 3-points bending test – wooden board [5.7x14 cm²]



graph 1: Comparison of the bending strength [MPa] of the different types of formwork wood

The results of the 3-point bending test (Graph 1) show a mean flexural strength (MOR) of 52 MPa (wooden beam); 73 MPa (wooden board); 53 MPa (multiplex). The wooden beams and boards are softwood, the species still need to be determined by calculating the density. According to (Niemz et al. [19], Isopescu et al. [20], Green et al. [21]) the multiplex, also called plywood, has a bending strength ranging between 30 and 60 MPa. Softwood samples like Spruce or Douglas have a bending strength ranging from 60 to 80 MPa. The multiplex and wooden board show in average the same bending strength compared to the results found in the literature (ranging from 36 to 73 MPa). The beams that failed prematurely showed observable defects like cracks and porosity.

Further tests are currently ongoing, following European standards, to grade the wood and assess the durability of the wooden formwork. The properties of the formwork wood are being studied through visual observations, non-destructive testing (NDT), and destructive testing.

First, wood defects such as knots, nail holes, cracks, and fibre direction are measured according to Eurocode 14081 (Figure 6). The diameter of knots, the extent of cracks, and the fibre direction are the most influential characteristics affecting the mechanical properties of wood. These defects can be measured, and Eurocode provides guidelines for acceptable dimensions. This serves as a good initial evaluation to predict the wood's behaviour. Using a non-destructive method, the dynamic modulus of elasticity (MOEdyn) is calculated using an ultrasonic pulse velocity device (Figure 7). A four-point bending test is conducted to determine the MOR and the global MOE (Figure 8), which also verifies the accuracy of the MOEdyn calculations.

It is important to study wood properties through NDT (visual observation, defect measurement, and velocity calculation) and destructive methods. The goal is to predict wood behaviour and properties based on visual observations and non-destructive methods and to find correlations between both types of results. This will enable the assessment of large quantities of formwork wood for potential reuse in spatial structures. The next step includes conducting tensile, compressive, and shear tests, in addition to bending tests, to obtain all the parameters necessary for the computational design of the structure.

Figure 6: measurement of the wood defects

Figure 7: NDT with an ultrasonic pulse velocity device

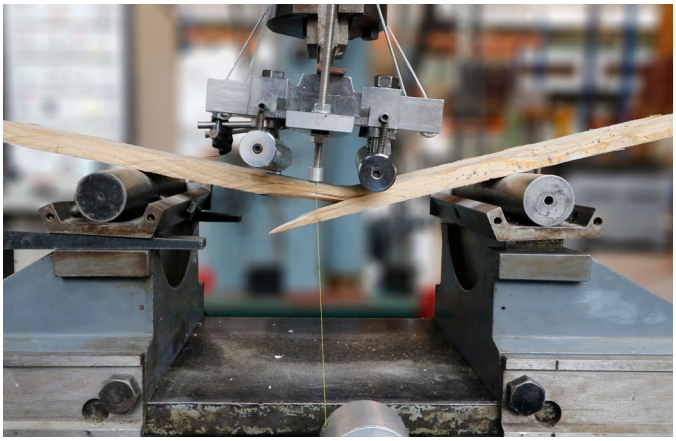


Figure 8: 4 points bending test

3. Conclusion

In Belgium, there is a high demand for reusing formwork wood materials, yet there is a lack of knowledge on how to effectively upcycle them, particularly due to the presence of concrete and oil residues on the surface, which complicates the process. That demand is reinforced by the Green Deal from the EU, which aims to make the European economy more sustainable and circular. Within the Green Deal, there are specific initiatives and policies focused on promoting the reuse of construction materials to reduce waste, minimize environmental impact, and contribute to the transition towards a circular economy. In parallel, the wood structure demand is increasing each year. All of that shows the potential of reusing formwork wood for structural application.

In conclusion, this research has a lot of potential in terms of upcycling construction formwork waste material, circularity and applying this wood in novel structural designs. It targets the material responsible for 30% of the construction waste on-site. The formwork is currently thrown away after 1 to 4 uses due to surface deteriorations that affect the concrete curing and aspect. Nevertheless, the formwork has still good remaining mechanical quality as shown in the results. Hence, the material can be reused in structural applications and further testing will conclude on its applications. However, as durability is important as well, future testing will include a range of durability tests in order to have multiple decision criteria for reusing these formwork wooden elements. In further research, a database will also be created to catalogue the gathered waste wood along with its properties and to be able to draw conclusions based on larger data sets. In addition and to illustrate the reuse potential, a spatial structure will then be designed based on the studied properties of the formwork wood.

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