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WasteBeam – a path for upcycling non-structural wood waste to structural timber beams

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Abstract

This paper investigates the possibility of turning production waste from a manufacturer of non-structural wood products into building components with structural capacity. Based on surface scans of virgin timber entering the factory, the manufacturer cuts it up, discards aesthetically unsatisfactory segments, and reconstitutes the flawless segments into finger-jointed timber ready for further processing. However, the manufacturer keeps discarded flawed segments above a certain minimum length and joins them into timber saturated with imperfections. Aesthetically undesirable in the primary product, this deficiency-rich timber has no direct application. The research studies the potential to employ such deficiency-rich timber in structural glulam. Initial bending tests comparing two qualities of waste timber with C-certified timber show that the strongest specimens indicate strength relevant for construction. Such knowledge easily applies to the structural design of most smaller timber constructions. Still, it would require more detailed and extensive calculation and documentation than C-certified timber. Further, the full-scale construction of a temporary 90 m2 structure proved the finger-jointed timber to be both easy to machine and handle during construction because of high dimensional stability compared to timber with a strong grain structure. This new material has a positive environmental impact but demands alternative structural design and more comprehensive documentation.

Keywords: Timber, glulam, waste upcycling, material testing.

1. Introduction

The climate crisis calls upon building practice and research to consider building materials as scarce and precious resources. In Europe, half of the extracted resources are directed towards the building industry, which also is responsible for more than 30% of the generated waste [1]. Due to its climate-friendly properties, there is a growing demand for wood [2]. This increases the pressure on supplying forests [3], [4]. As such, minimising waste and optimising utilization of raw materials from extraction to on-site building assembly is required. Large-scale industrial processing might generate large quantities of waste when confronted with natural and bio-based materials whose heterogeneous compositions are prone to containing multiple defects. However, such “new” waste from the factory simultaneously exhibits a high degree of consistency despite being undesirable in the finished product.

Since its invention around 1900, Glulam has proven its viability as a building material with unique structural and formal capacities, which has continuously improved through the development of CNC machining methods and advanced timber engineering[5]. This research starts at one of Europe's largest glulam companies. The company, VTI, produces more than 120.000 m3 of glue-laminated wood for the window and furniture industry yearly; the main production facility is located in Vinderup, Denmark, and a smaller facility is in Rezekne, Latvia. This research has so far focused on the Vinderup facility and the processes, workflows, and procedures established here. A notable characteristic of VTI, Vinderup, is its location in Western Jutland, Denmark. Denmark is generally covered with agriculture, leaving little space for forest and wood plantation. The location in Vinderup is far from the forest, and VTI imports all wood from neighbouring Nordic countries such as Sweden, Norway, and Finland and has done so since the establishment of the company in 1976. As such, the growth and success of VTI do not rely on access to resources but on tradesmanship and processing.

The production of furniture and windows wood involves a series of mechanical and aesthetical parameters that must be met. Based on surface scans of virgin timber entering the factory, the VTI cuts it up, discards aesthetically unsatisfactory, damaged, or knot-filled segments, and reconstitutes the flawless segments into finger-jointed timber ready for further processing. However, VTO also keeps the discarded flawed segments above a certain minimum length and joins them into timber saturated with imperfections. Since 2018, this aesthetically undesirable product has been used at a VTI sister company, Norto, for sustainable, waste-based interior products such as wood floors and acoustic and decorative wall covering. However, the amount of waste produced at the VTI facility is far larger than these products can absorb, and most of the discarded wood segment today is transported to the local power plant for burning daily.

This research investigates the possibility of turning the production waste from VTI into building components with structural capacity. Structural wood has a huge market volume but is rarely needed to meet high aesthetic standards as the construction is often covered up. As such, turning non-structural, non-aesthetic waste into structural components could provide a valuable and sustainable alternative to using C-certified virgin timber.

2. The waste streams

VTI produces furniture and window timber for multiple customers with different quality specifications. This naturally produces different amounts and types of waste from the processing. VTI also buys its timber resources from several sawmills in Northern Europe. The majority of the wood is pinewood, but the specifications and quality are varied depending on the sawmill, market supply, and other external factors. VTI has quality agreements with its suppliers but carries out its own quality control for all incoming resources. This is done to plan the production of their own product in the best possible way so that the quality of incoming wood matches the best possible way with the characteristics of VTI's final product. Optimization and resource efficiency are fundamental to VTI production.

At the VTI facility, all timber deliveries are quality checks before processing. This is done through a random sample for each sawmill batch. This is done by manual visual inspection. The result of each quality check is reported to both sawmill and VTI's production manager. This initial quality check does not typically produce any waste directly but is used to predict the amount of future waste for each timber batch when matched with a production order for either furniture board or window timber.

Figure 1: Discarded timber segment at the VTI factory

For both furniture board and windows wood production, VTI utilizes a production line based on an initial, automated surface scan of all individual virgin timber boards. This is followed by an optimizations station where unwanted segments are cut out. The remaining segments are sorted into several categories depending on their future utilization. While furniture boards and window timber production are two separate production lines, each line can simultaneously handle multiple orders, enabling them to optimize the wood across multiple products.

2.1. Window timber

The timber used to produce windows consists of many different profiles of several components with different quality parameters. The wood used for the inner frames needs high aesthetic surfaces with no knots, whereas the nonvisible part can tolerate higher variance. Wood production for the window industry is characterized by transforming solid, virgin timber lengths into glulam and/or glued finger-joined wood lengths. The process is a sorting and optimization workflow where wood is segmented and reassembled into consistent qualities. Since window manufacturers use many different qualities of wood, discarded segments from one board can often be used in another, lower-quality product.

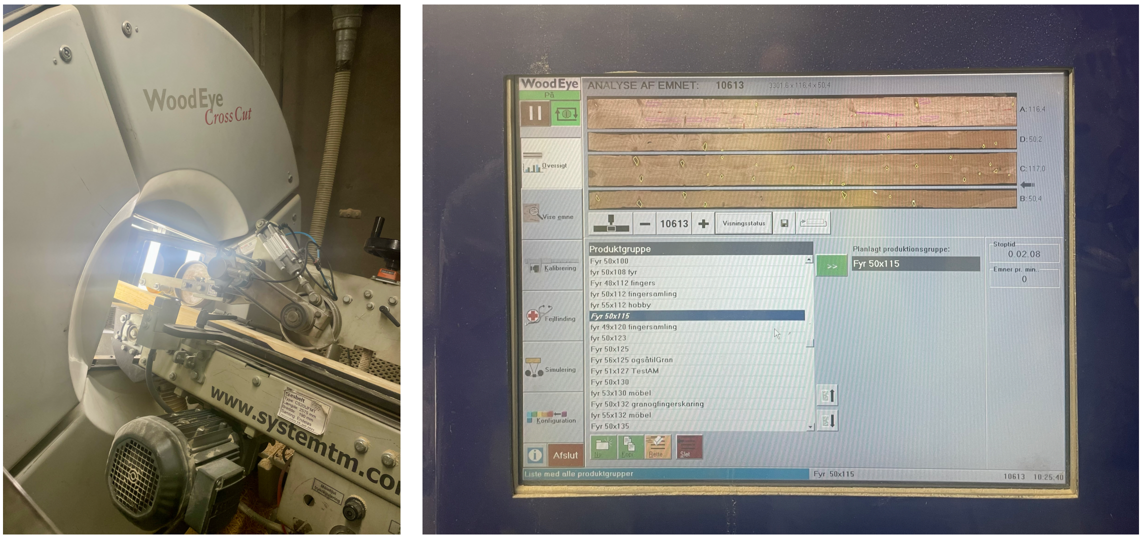

Figure 2: Scanning and optimisation of timber is an automated process

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2.2. Furniture boards

The production of glulam board for the furniture industry dates to VTI's origin. The customers have different quality standards, but generally, the top surface and edge of the furniture boards are of higher quality than the inner and back-facing surfaces. Furniture boards can consist of finger-joined glulam panels but are often of full-length timber glue laminated into panels. As such, the sorting and composition/rotation of each piece of timber in the panel is key to high-quality products and low waste. The scanning and optimization line cuts out any segments with unwanted sets of features. These segments generally have aesthetic flaws such as dark knots, too many knots per meter, edge damage, color fault, or surplus lengths that are too small for the furniture panels. Some discarded segments from furniture board productions also feed into the windows timber production.

2.3. Making use of the waste

The production lines at VTI are highly optimized but still generate larger quantities of waste. Since the waste is generated from timber already sorted at the sawmill, the discarded segments are often aesthetic flaws or features not accepted in the furniture and windows industry. These faulty features are, to some degree, accepted in construction timber. As such, the waste from VTI's production is, in his research, explored as potential resources for construction materials. Upcycling waste to production material is, in many respects, an attractive opportunity. Since construction timber is a high-volume market, it provides an excellent opportunity to direct the extensive and continuous material stream from waste. Furthermore, construction timber is often hidden inside other building elements such as cladding, roof, ceiling, and elastic variance, which would, in many cases, be considered normal and acceptable.

Using alternative wood resources for construction materials is a topic currently explored in architectural research. At SDU-Create, a voxel-based scenario that employs reclaimed timber in a truss-like wood structure was explored [6]. The wood part seems, in this case, to be more or less similar to the waste generated at VTI and provides an interesting approach to custom-optimized beam solutions. In the research project, 'Wood ReFramed, ' Xan Brown also explores reclaimed timber for columns and beams by suggesting a framed structural typology for a varied material resource [7]. This approach mixes new and reclaimed timber into a flexible system with a novel material expression. Hooke Park's field station project takes another approach to excess material resources. Here, smaller branches that would usually be discarded at the harvesting stage make up the essential part of a roof structure. A camera-based robotic workflow transforms the non-linear and varied material into the structure [8].

The existing and ongoing research forms a base for further exploration of waste streams as a resource for construction components. For the VTI waste streams a two-part initial exploration was planned. The first deals with understanding and testing the structural integrity and potential of the waste, and the second explores the waste material in a full-scale construction scenario.

3. Structural test

The first step in examining whether the waste from VTI can be used for structural construction wood is to test the structural capacity of the discarded segment. For this test scenario, mixed waste parts from furniture and windows boards were finger-joined into 3-meter-long boards at the VTI factory using the same production and gluing procedure as the high-quality wood. These boards were then cut into 1-meter beam segments in the lab. Based on visual inspection, these beams were sorted into two categories: strong selection and weak selection. The beams were numbered and photographed on all sides to register joints and knots. For both strong and weak selection, two test scenarios were planned.; Single layer and double layer. For the double layer, two segments were laminated together, creating a board with both glued finger joints in one direction and glued laminated build-up in the other. For both tests, C24-certified timber was used for reference. This meant three categories were tested for both the single-layer and double-layer tests: strong selection, weak selection, and C24 timber.

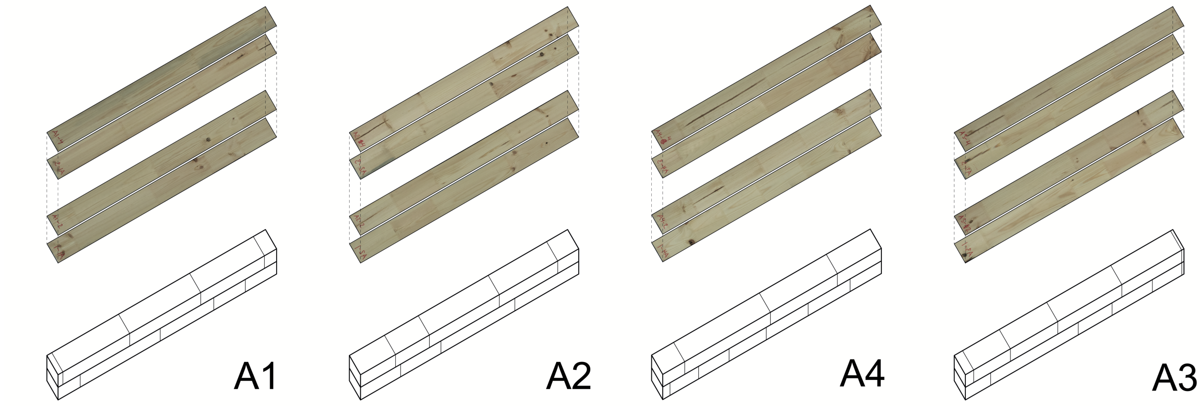

Figure 3: Four examples of double-layer test beams. Each composition is carefully registered.

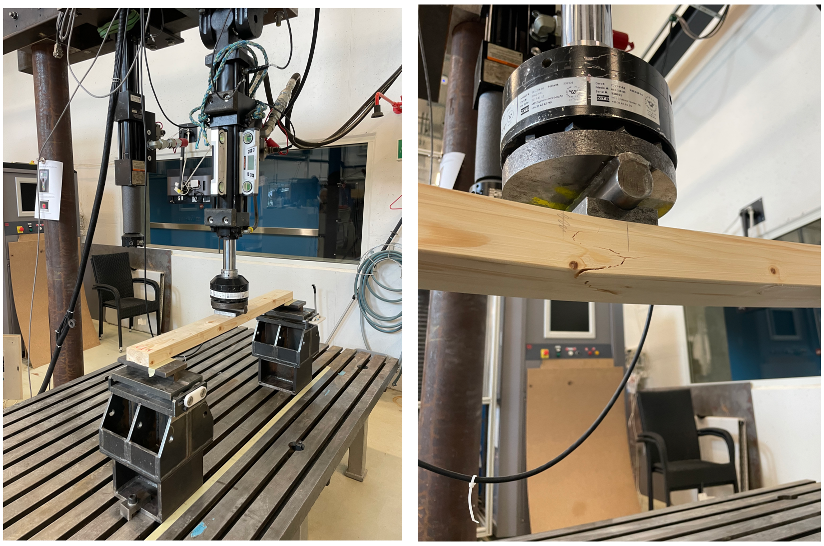

Figure 4: Structural test carried out on two selections of waste beams and compared to C-certified timber.

The structural test was carried out at Aarhus University BærLab, where each individual piece went through a single-point break test. The tests were carried out as a continuous addition of force to the centre of the boards until a breaking point was achieved. This generated a graph with the force and displacement for each board. As such, both breaking point and stiffness can be seen in the graph. Each test was carried out on multiple beams.

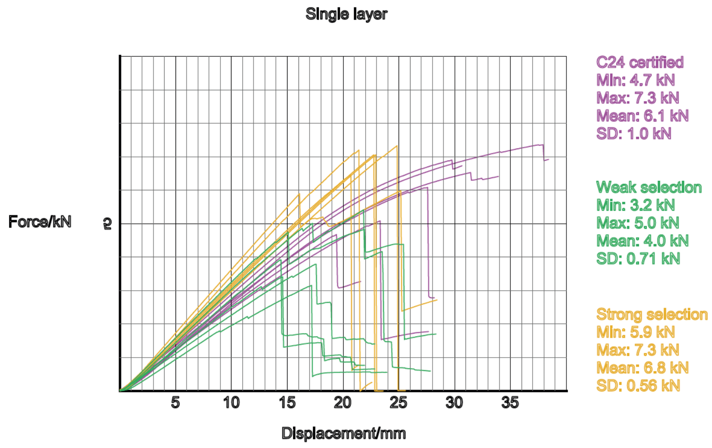

Figure 5: Result from single layers structural test

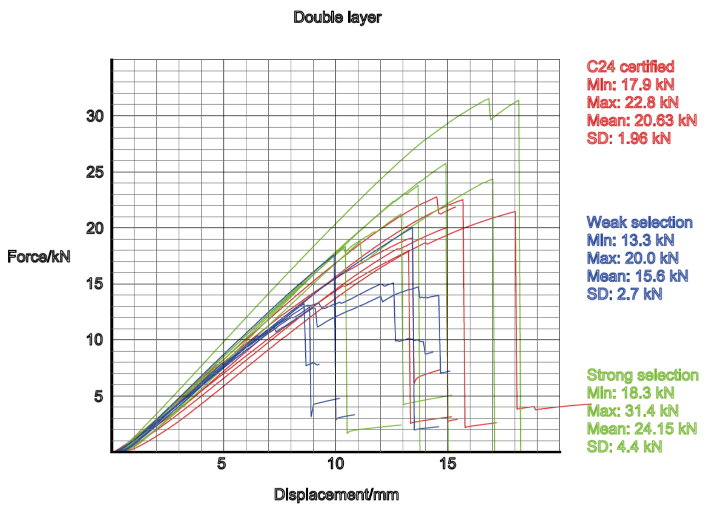

Figure 6: Result from double layers structural test

3.1 Break types and results

For both single-layer and double-layer tests, the results came out quite similar. Generally, the strong selection waste timber proved similar or stronger than the C24 certified construction timber, whereas the weak selection performed under the C24 timber. In all cases, the breaks were initiated at knots in the woods. Sometimes, the break develops from a knot and follows along the laminated parts, but the breaking is concentrated inside the fibers. These results strongly indicate that the quality of the fibers defines the strength of the waste beams and that the many glued interfaces do not provide a weakness in the overall integrity.

Figure 7: The structural testing showed that breakage starts in knots and develops along fibres.

4. Full-scale construction exploration

The waste beams from VTI are created from several smaller waste elements with glued finger joints. While finger joints are not uncommon in glulam and other construction materials, the waste beams hold an abnormally large quantity of joint pr meter. As such, the beams could act differently than ordinary certified construction timber and glulam when used in construction. The possible deviance compared to known material might show up in the machining and assembly process as well as longer-term behaviour. Especially dimension stability is suspected to be a challenge due to the many joints and knots. For that reason, a prototype was designed with the intention of testing both machining, construction and long-term behaviour. The prototype became the construction of a bar at a local music festival. This allowed for several beneficial potentials. First, the construction does not need to be insulated; it just acts as a covered outdoor space. This allows the construction to be visible and easily monitored while being exposed to the weather. Second, the bar construction will be reused for a handful of years, meaning it will undergo assembly, use, disassembly and storage several times. This is an advantageous test scenario as material and dimensional stability will be challenged. To challenge and pressure test the material, the prototype was intentionally designed with a roof construction consisting of an array of pointy self-standing brackets. As the distribution of these roof brackets follows a repeating distance, any warping or twisting in the material will visually show up. Dimensional stability and stiffness in the material are critical to withstand the challenges of weathering, storage, and several assembly/disassembly sequences.

Figure 8: High precision was tested for the prototype.

The prototype used a simple programmatic layout and a parametric digital design linked directly to a CNC-machining workflow through a custom-made post-processer. The CNC workflow allowed for testing a design with varying angles as a part of the overall design and the material's ability to handle precise and explicit machining.

The prototype was designed with both single and multi-layer beams. In both cases, machining and handling went unproblematic, with no warping, delamination or other issues. Similarly, the assembly went flawlessly and proved tolerances were within the margin.

For now, the prototype has only been assembled and disabled one time, and the testing of stability and tolerance is therefore still in progress. The second assembly of the prototype is to be scheduled for June 2024 and will reveal whether a large number of glued finger joints in the beams has caused any issues during the storage period.

Figure 9: The prototype was designed with a roof construction made of pointy brackets to test warping and stability of the WasteBeams.

4. Conclusion and future perspective

The initial structural test and full-scale exploration show a promising potential for upcycling waste wood material to structural beams. The research is, however, quite preliminary and exploring at this stage and needs further development before a complete waste beams scenario is fully formed. So far, full-scale exploration shows that the finger-joint waste beams would efficiently work in a typical workflow together with both hand tools and CNC machining. The structural test shows that the glue interfaces do not cause problems in the beams but also show a significant difference between the strong and weak selection of wood waste. To produce a true WasteBeam, a design that includes both strong and weak waste must be realized as solely strong selection wood waste beams would leave behind a large amount of weak knot-full waste. Therefore, the projection for this research is to construct a series of new beams with a particular focus on the beam's composition. Consequently, an in-progress development uses different truss-like designs for packing the waste parts-. This design would utilize the strong selection of wood waste as top and bottom layers and as a truss-like structure inside the beam. Space in-between would be filled with weak selection wood waste as a stabilizing part. The process is currently ongoing, and the projection is to carry out structural tests and full-scale exploration through 2024. Furthermore, additional engineering capacity will be added to this next phase of the WasteBeam project to find a successful balance between load capacity, waste use and fabrication complexity. The potential of WasteBeam is seen in both the utilisation of waste resources and scalability. Scalability will be especially important when considering future design approaches.

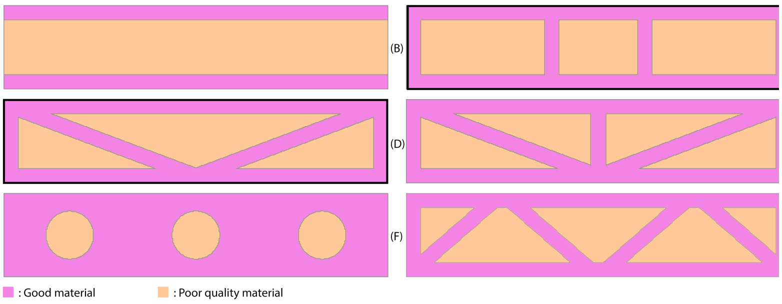

Figure 10: Initial design proposals for WasteBeams consisting of both good-quality and poor-quality waste wood.

Acknowledgements

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