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Sustainable design concepts for short span, timber-only structures

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Abstract

In this study, a novel, low-tech design concept for short span structures is introduced. The structural system is entirely based on wooden products, mainly salvaged material. Individual timber boards with uniform or variable dimensions are connected with hardwood nails to load bearing members. The paper introduces the design concept and explores features and design possibilities ranging from different spans with related thickness of the deck, to integrated seating, signs or railing. The approach is driven by the following three guiding aspects: firstly by the limitation of the possible timber board patterns, which result from the used material; secondly by the assembly process, which aims for the ease of use and its robustness against assembly-errors; thirdly by the arrangement of the nails, which allows for the highest possible grade of flexibility in design and material uses and which respect the aforementioned aspects.

Keywords: Sustainability, timber structure, salvaged material, architecture, low-tech, conceptual design, wood nails, natural trails

1 Introduction

The construction sector is one of the major contributors to environmental burden. In Europe buildings cover about 40% of the total energy consumption and 36% of CO2 emissions [1]. However, the European targets, such as the reduction of the greenhouse gases until 2019 (40% compared to 1990), are ambiguous. This and other targets of the European commission and other institutions indicate the importance of reducing the environmental impacts throughout the entire construction sector. Accordingly, sustainable and more environment-friendly structural concepts and structures are becoming increasingly relevant.
Timber, as a natural grown building material, can play a key role in this process, in particular due to its large potential of reducing CO2 emissions. So far, the full environmental potential of timber has not yet been realised. Currently, the share of re-used and recycled timber is very limited. The same applies for recovery of construction and demolition waste. One example is salvaged timber material from the fabrication process of engineered wood products or from construction processes that is mainly incinerated for energy recovery.

Figure 1: Salvaged material from a four weeks period from a regional housing company.

In this paper a design concept for short span timber structures using salvaged material connected with wooden fasteners is presented. The most relevant aspects for the design concept are introduced and preliminary results from the experimental investigations are summarized. The paper concludes with an outlook to further investigations and the potential for structures and other applications.

1.1 Salvaged material

Considering the entire construction sector, including strength grading and the fabrication of engineered wood products, a large amount of salvaged timber material can be recognised. Examples for salvaged timber material are:

- Strength grading: Cut-offs or rejection
- Manufacturing process of engineered wood products: Cut-offs
- (Pre-)fabrication process: Cut-offs of timber boards due to e.g. over length
- CNC milling of plate elements: Cut-out of openings (windows, doors, etc)
- Concrete formwork and falsework

The dimensions and quality of the salvaged material varies between the examples above, however, in most cases the material has structural quality. As already mentioned, salvaged wood material is currently mainly incinerated for energy recovery, but the potential is quite large: Figure 1 illustrates the salvaged material of a four week period from a regional housing company. Considering the large timber product industry, e.g. the yearly roundwood consumption of Finnish sawmills is more than 27 million m^3 (2018, [2]), the large environmental potential of using salvaged material become obvious.

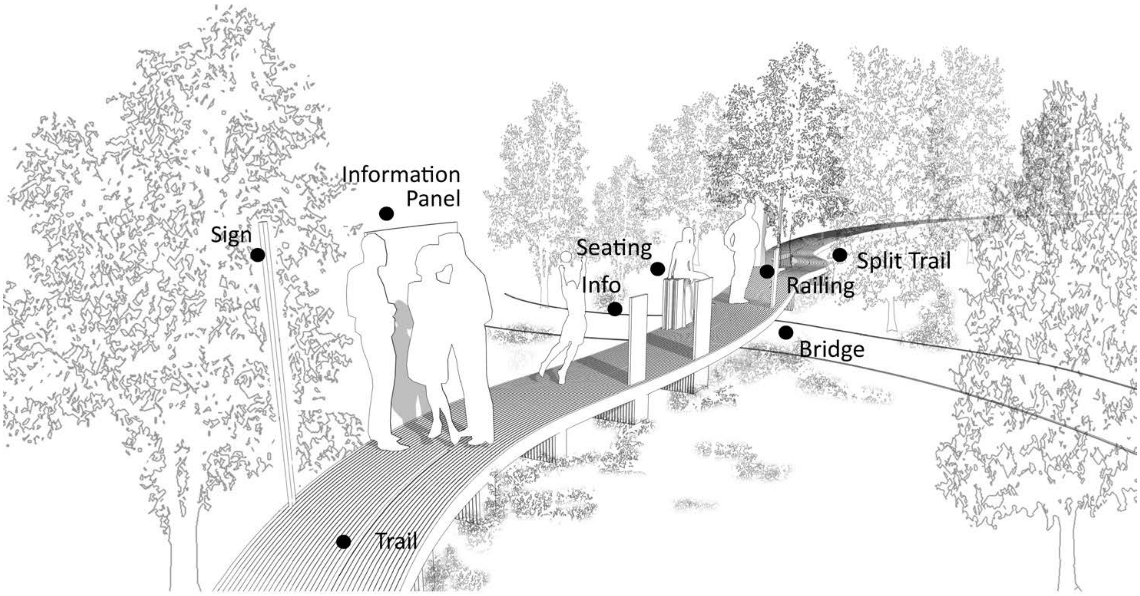
2 Application-based design concept

The below presented design concept using salvaged material connected with wooden fasteners might be appropriate for a wide range of applications, but within the framework of this paper the applications are limited to natural trails including short span bridges. Natural trails are widely used in Finland, in particular in wetlands in order to make nature easier and more safely

Figure 2: Example of a natural trail crossing a smaller creek near the Kymi riverfront.

accessible for the society (Figure 2). A large amount of these trails are located in areas with particular attention to the nature, such as natural parks; accordingly, an appropriate place for a timber-only applications. Natural trails are not always, but usually, made from structural timber. The most common approach is to assemble the deck from timber boards that are regularly supported. The distance between the supports (span) depends on the ground (wetland, dryland, river, etc.), the quality of the timber boards used for the deck and the pedestrian traffic. Nevertheless, the span of the deck typically is limited to a range of 1.5 to 4 meters. Even though the span is limited, structural timber is used, that can be also applied to other applications.

As a novel, low-tech design concept for short span structures, our approach is driven by the motivation to create nail-laminated timber decks from salvaged material using wooden nails (Figure 3). In order to achieve this aim the following aspects were considered:
Above-mentioned low-tech design concept is understood as the counterpart to high-tech and refers to an approach, which is developed under the aspects of easy function, easy production, easy service, robustness and easy maintenance (see also Filz [4]).
The proposed concept follows the main principles of nail-laminated timber decks (see e.g. Gutkowski and Williamson [3]). However, the here presented structural system is entirely based on wooden products. From an environmental perspective any use of salvaged material would be beneficial as it would either substitute non-sustainable materials or substitute sustainable materials that can be applied in for other purposes. The used timber is supposed to be salvaged material from regional companies, which guarantees sustainable solutions. So, the wood industry itself serves as a source for the short span load bearing members. Accordingly the available material will come in variable but sufficient quality, and it will vary much in length, and cross-sectional dimension. The variation of the dimensions of timber boards has direct impact on the configuration and resulting patterns of the decks. It is aimed to use the timber boards without further processing, like cutting, milling, or plaining. However, further processing is still possible if needed.
The above-mentioned variety in available material results in irregular patterns. Since the upper deck surface is supposed to be planar (Figure 3), the variation of the board widths can be easily



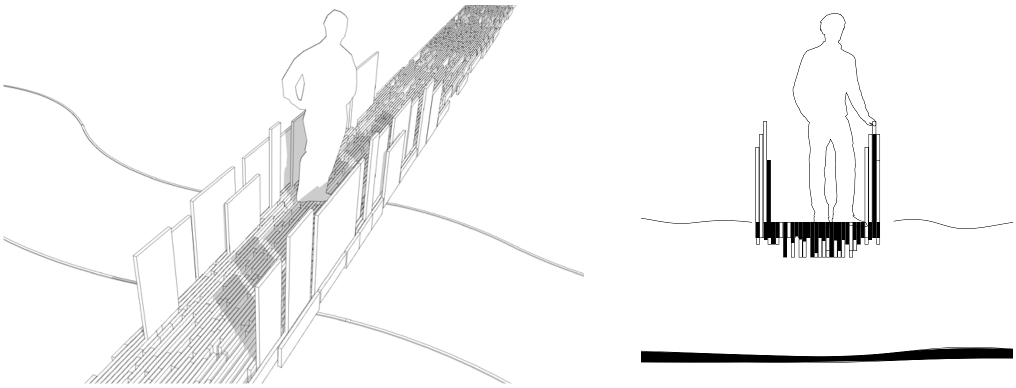


Figure 3: (top) Design concept illustrating a set of possible applications, (bottom, left) railings proposal, (bottom, right) cross-section.

handled by having variable deck thicknesses, and even be advantageously used to increase the cross-sectional height at longer spans. Considering a reduction in self-weight and/or varying board width, the deck-patterns become even more irregular and show a certain percentage of perforation.

One of the novelties of our study, is that the individual timber boards with uniform or variable dimensions are connected with hardwood nails from LignoLoc® to load bearing members. The hardwood nails are fabricated out of compressed beech wood permeated with resin. The resin positively influence the durability and thus allow outdoor applications, however, in the long run, the project is aiming for timber-only structures. The mechanical properties of the wooden nails allows the use of pneumatic nailing devices without pre-drilling. After assembling the wood nails they form a bond with the surrounding timber, it was one of the aims of this project to utilize this effect for the design. Due to the high strength requirement wood nails with a relatively large diameter of 4.7 mm to 5.3 mm are used. The application of nails with large diameter without pre-drilling, result in high splitting forces. Accordingly, particular attention has to be taken on

the minimal board thickness, the distance between the single nails as well as their distance to the edge of the timber board.
The assembly is assumed to happen on site from individual pieces or small prefabricated units. In this regard, the selection of appropriate nail patterns for the connection of boards represents a guiding parameter not only for the stability and the design aspect, but also for the ease of assembly process, and simultaneously for its robustness against assembly-errors. Even though long cut-offs or even full length boards from rejection for example due to warp might be available from sawmills, our approach focused on very short boards with less than one meter length. Depended on the selected nail diameter, the nail patterns are defined by the distance between the single nails as well as their distance to the edge of the timber board. Accordingly, shorter boards are more restrictive for the generation of board patterns and the percentage of perforation.

Referring to above described, systematic analysis and pruning of unwanted design points based on parameters of interest, the design space has been well defined. Its first exploration features design possibilities and functionalities ranging from different spans with related thickness of the deck, to straight and curvilinear path planning in plan and in longitudinal section, to integrated seating, signs or railing, and much more (Figure 3).

3 Experimental investigations

Experimental investigations to realize the connection between adjacent timber boards using hardwood nails have been performed. Due to the variable dimensions of the salvaged material different nail patterns have been investigated. As mentioned above, the project is in conceptual phase and, accordingly, the main purpose for the preliminary experimental investigation is expand the knowledge needed to optimise the design concept and not only to validate the approach. This also explains the limited scope of the experimental work.
Below, a short summary of selected parts from the ongoing, experimental investigations can be found. A comprehensive study based on more intense testing will be presented after finalising the experimental investigations.

3.1 Material and method

The preliminary part of the experimental investigation contains (I) shear tests on single nails and nail groups in order to find suitable nail orientation (Figure 4, left), and (II) bending tests on nails connections to identify appropriate nail pattern (Figure 5).

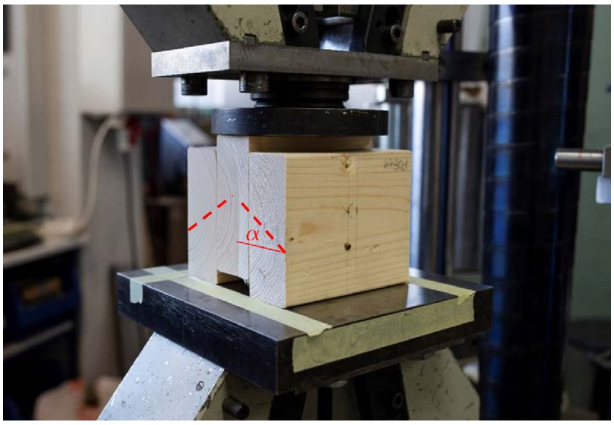
For the investigation two different types of timber boards been used; the selection has been performed in order to utilize the potential of one regional housing company:

- Cross-sectional dimensions: $w \times t = 123 \times 48$ mm, strength grade: C24
- Cross-sectional dimensions: $w \times t = 100 \times 25$ mm, quality: pl/vl (flat surface/export quality)

Several different board and nail arrangements were investigated. For the specific arrangements, appropriate wooden nails with variable length ($l = 65, 75, 90$ mm) and variable nail diameter ($d = 4.7, 5.3$ mm) have been used.

3.2 Shear tests – Nail orientation

For the shear test three timber boards ($w \times t = 123 \times 48$ mm) are connected with two wooden nails, one nail from each side. In order to utilize the bond of the wooden nails with the surrounding timber, the nails are allocated with variable nail orientation $\alpha = 0, 30, -30°$. The tests



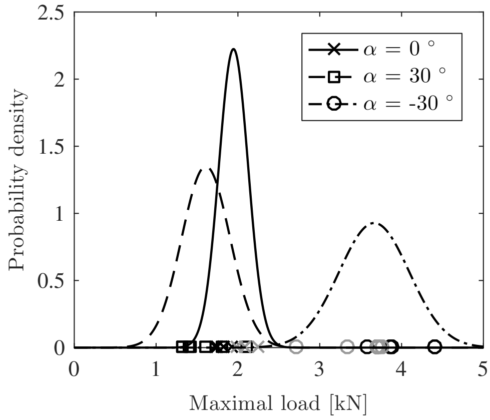


Figure 4: Shear tests: (left) one test sample with $\alpha = 30°$, (right) test results. The black symbols indicate $d = 4.7$ mm and the grey symbols indicate $d = 5.3$ mm

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were performed with two different nail diameter ($d = 4.7, 5.3$ mm). The results (Figure 4, right) clearly indicate the potential of tensile loaded wood nails ($\alpha = -30°$), whereas the influence of the nail diameter d seems to be small (the black symbols indicate $d = 4.7$ mm and the grey symbols indicate $d = 5.3$ mm). At this point it has to be mentioned that further investigations with larger inclination $\alpha = 45°$ were planned. However, when manufacturing the samples many fabrication errors accrued, mainly due to the smaller edge distance, and accordingly this test series has not been investigated.

3.3 Bending tests – Nail pattern

Bending test have been performed in order to identify appropriate nail pattern. Therefore several different nail pattern were investigated. In Figure 5 two test samples are exemplary illustrated. The left samples shows a connection of three timber boards $t = 25$ mm. The connections contains six nails $l = 75$ mm, $d = 47$ mm (each nail is connected to all three timber boards). The nails are inclined in opposing direction; half of the nails with $\alpha = 30°$ and half of the nails with $\alpha = -30°$.
In the right sample in Figure 5 illustrated a connection of three timber boards $t = 48$ mm. The connections contains two times seven nails $l = 75$ mm, $d = 53$ mm (each nail is connected to two timber boards). The nails are inclined in opposing direction $\alpha = 30°$ and $\alpha = -30°$.
The results from the bending test indicate a large potential for the design approach. However, the tests also indicated some challenges that have to be considered in the design. In particular the splitting force in thin timber boards requires large end distances.

3.4 Further steps

It is planned to fabricate a test bridge as illustrated in Figure 6 and perform bending tests in order to identify the load bearing capacity. Furthermore, the long term behaviour of the nails bridge deck will be planned on a prototype.

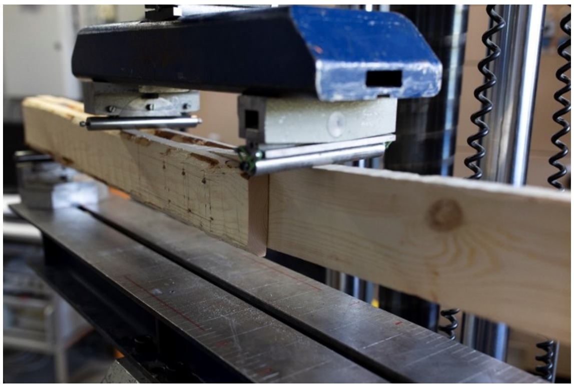

Figure 5: Bending tests: (left) test sample with three $t = 25$ mm timber boards and six inclined nails $\alpha = 30, -30°$; (right) test sample with three $t = 48$ mm timber boards and two times seven inclined nails $\alpha = 30, -30°$.

Figure 6: Bridge deck: (left) possible arrangement of the timber boards to form a the bridge deck; (right) possible application (here the timber boards are not connected with wood nails).

4 Conclusion

In this paper, a novel, low-tech design concept for short span structures is introduced. The approach is driven by the motivation to create nail-laminated timber decks from salvaged material using wooden nails. Salvaged timber material is available in sufficient quality, but variable length, and variable cross-sectional dimension. The variety in available material results in irregular patterns. The upper deck surface is supposed to be planar (Figure 3), the variation of the board widths can be easily handled by having variable deck thicknesses, and even be advantageously used to increase the cross-sectional height at longer spans. Considering a reduction in self-weight and/or varying board width, the deck-patterns become even more irregular and show a certain percentage of perforation.

The approach is driven by three guiding aspects: firstly by the limitation of the possible timber board patterns, which result from the used material; secondly by the assembly process, which aims for the ease of use and its robustness against assembly-errors; thirdly by the arrangement of the nails, which allow for the highest possible grade of flexibility in design and material use and which respect the aforementioned structural and architectural potential in sustainable design approaches and low-tech considerations.

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