Chapter

Various Geometric Configuration Proposals for Dovetail Wooden Horizontal Structural Members in Multistory Building Construction

Hüseyin Emre Ilgın, Markku Karjalainen and Olli-Paavo Koponen

Abstract

Adhesives and metal fasteners have an important place in the content of engineered wood products (EWPs). However, adhesives may cause toxic gas emissions due to their petroleum-based nature, while metal fasteners may adversely affect the reusability of these products. These issues also raise important questions about the sustainability and environmental friendliness of EWPs. Thus, there is still room for a solution that is solid and completely pure wood, adhesive- and metal-connectors-free dovetail wood board elements (DWBEs). There are many studies on the technological, ecological, and economic aspects of these products in the literature, but no studies have been conducted to assess the technical performance of DWBEs. This chapter focuses on DWBEs by proposing various geometric configurations for horizontal structural members in multistory building construction through architectural modeling programs. In this architectural design phase, which is one of the first but most important stages, the proposed configurations are based on a theoretical approach, considering contemporary construction practices rather than structural analysis or mechanical simulation. Further research, including technical performance tests, will be undertaken after this critical phase. It is believed that this chapter will contribute to the dissemination of DWBEs for innovative architectural and structural applications, especially in multistory wooden structures construction.

Keywords: timber/wood, dovetail wood board elements, engineered wood products, sustainability, multistory building construction, architectural modeling

1. Introduction

Climate change is dangerously close to spiraling out of control [1, 2]. The probability of this critical phenomenon attributed to human factors is over 90% and requires urgent management of our operations [3]. Buildings are the major contributors to the climate crisis, producing about 40% of annual global CO_2 emissions [4]. Additionally, building operations are responsible for 28% of these total annual emissions, while building materials and construction (often referred to as embedded carbon) are responsible for an additional 11% annually [5].

In this sense, wood as a renewable material is unquestionably ecological and environmentally friendly in terms of low carbon emissions during processing and carbon sequestration: one cubic meter of growing wood can bind about one ton of CO_2 from the atmosphere. If the dry mass of wood is 500 kg, about half of this mass is carbon, namely 250 kg. Thus, timber, which is at the forefront of addressing European climate policy, is considered one of our best allies in resolving climate change, especially due to its environmentally friendly features [6, 7].

Moreover, thanks to its numerous technological benefits such as dimensional stability, uniform strength, ecological properties such as low carbon emission, engineered wood products (e.g., cross-laminated timber, laminated veneer lumber) (**Figure 1**) are increasingly becoming a viable solution in high-rise structures [8–11] as in the cases of the 26 m and 8-story Carbon 12 (Portland, 2018) (**Figure 2**) [12] and the 85 m and 18-story Mjøstårnet (Brumunddal, 2019) (**Figure 3**) [13].

With the standardization of the building industry, adhesives and metal fasteners are often used in engineered wood products (EWPs), replacing traditional wood-to-wood assemblies [14]. It is worth noting here that engineered wood products (EWPs), also called mass timber, composite wood, artificial wood, or fabricated wood, include a range of derivative wood products manufactured by bonding or fastening strips, particles, fibers or wood veneers or boards of wood with adhesives or other fixing methods to generate composite material. Adhesives play a critical role in EWPs, especially by protecting the wood, making the structure light and robust, preventing shrinkage and expansion caused by natural humidity [15, 16], while metal fasteners ensure the overall integrity of the wooden structure [17, 18]. However, adhesives can cause problems in the sustainability and environmental friendliness of EWPs due to toxic gas emissions [19, 20], and similarly, metal fasteners can negatively affect the reusability and recyclability of EWPs [21, 22]. Therefore, there is still room for a solution consisting of solid and completely pure wood, dovetail wood board elements (DWBEs) [23]. Numerous studies have been conducted in the literature on the technological, ecological, and economic aspects of EWPs in construction with different building solutions [24] such as [25–30], and there is limited understating of DWBEs, which mostly includes structural analysis of connection details (e.g., [31–39]). Here, the dovetail wood board elements (DWBEs) can be defined as solid/massive and pure wood structural elements such as floor

(a) *(b)*

Figure 1.
Engineered wood products: (a) cross-laminated timber; (b) laminated veneer lumber (sources: Wikipedia—https://en.wikipedia.org/wiki/Cross-laminated_timber; https://en.wikipedia.org/wiki/Laminated_veneer_lumber).

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Figure 2.
Carbon 12 (Portland, 2018) (source: Wikipedia—https://en.wikipedia.org/wiki/Carbon12).

Figure 3.
Mjøstårnet (Brumunddal, 2019) (source: Wikipedia–https://en.wikipedia.org/wiki/Mj%C3%B8st%C3%A5rnet).

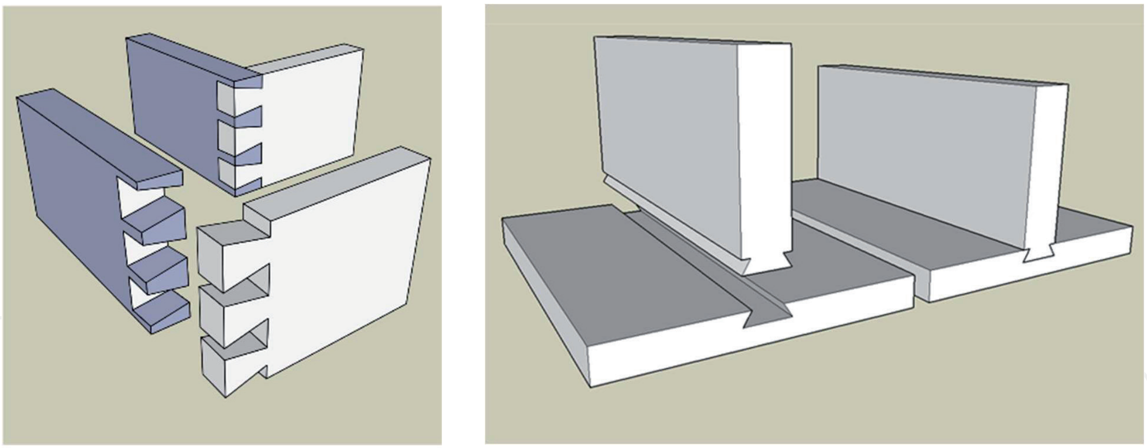

Figure 4.
Dovetail joint as one of the oldest joining techniques in furniture design: (a) a through dovetail joint; (b) a sliding dovetail joint (sources: Wikipedia—https://en.wikipedia.org/wiki/Dovetail_joint).

slabs that use plug-in dovetail form in the joint detail and do not use adhesives and metal connections. More importantly, no studies have been conducted to assess the technical performance of DWBEs in multistory construction [40]. This chapter focuses on DWBEs—based on one of the oldest joining methods (**Figure 4**)—as sustainable material alternatives for ecological engineering solutions by suggesting various geometric configurations for flooring of multistory building construction through architectural modeling programs.

It is worth mentioning here that ecological engineering combines contemporary environmental engineering practices with ecological principles to achieve ecologically oriented goals [41–44]. Today, ecological engineering has become an essential tool, with the use of sustainable materials such as wood to tackle challenges resulting from the climate crisis. Given that buildings account for around 40% of annual global CO_2 emissions, the construction of wooden (multistory) buildings, especially with dovetail wooden elements as more environmentally friendly pure wood material, will contribute significantly to the fight against climate change in terms of ecological engineering approach.

It is believed that this chapter will contribute to the creation of higher value-added circular economy opportunities to support European climate policy as part of bio-economy and sustainable development through the dissemination of DWBEs for diverse and innovative structural applications in the construction sector as an ecological engineering-based solution.

In this chapter, wood or timber refers to engineered wood products (EWPs), e.g., cross-laminated timber (CLT—a prefabricated multi-layer EWP, manufactured from at least three layers of boards by gluing their surfaces together with an adhesive under pressure), laminated veneer lumber (LVL—made by bonding together thin vertical softwood veneers with their grain parallel to the longitudinal axis of the section, under heat and pressure), and glue-laminated timber (Glulam—made by gluing together several graded timber laminations with their grain parallel to the longitudinal axis of the section). Moreover, in this research, "multistory building" and "tall building" are defined as a building with over two-story and eight-story, respectively.

2. Research Methods

This study was conducted through an extensive literature survey mainly including international peer-reviewed journals and similar research projects.

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Furthermore, this chapter was carried out with architectural modeling methods used in the solution of research and design problems in architectural activities. This method enables architects to think, write, discuss, and disseminate as a bridge from theory to practice [45]. It is widely utilized in architectural design research, where it is used by architects as a tool for research methodology [46, 47].

In addition, currently, there is no single approach to creating the object and subject of architectural activity, which inevitably leads to significant differences in research methods and architectural design of objects, especially at such important

LITERATURE SURVEY

⇓

IDENTIFYING THE NEED FOR ADHESIVE- AND METAL-FREE & PURE MASSIVE WOOD ELEMENTS (DWBEs)

⇓

PROJECT CONCEPT
(Inspiration from one of the oldest joining techniques, i.e. dovetail connection)

⇓

INITIAL DESIGN
(Based on current construction practices of conventional EWPs)

⇓

GEOMETRIC CONFIGURATION PROPOSALS

⇓

REVISED & DEVELOPED ARCHITECTURAL PROPOSALS

⇓

STRUCTURAL ANALYSIS

⇓

PROTOTYPE MANUFACTURING

⇓

CONDUCTING TECHNICAL PERFORMANCE TESTS
(Structural, fire, sound/vibration and airtightness/moisture tests)

⇓

MODIFIED & DEVELOPED PRODUCTS
(according to the test results)

⇓

MARKET RESEARCH FOR DEVELOPED DWBEs

Figure 5.
The phases of the preliminary design used as a research method in this study and project's next phases (in italics).

levels of solving this problem [48]. On the other hand, the precise operation of text and project interaction in architectural design research remains a highly debated and relatively unformed topic [49–52].

Hence, main business applications such as AutoCAD, SketchUp, parametric modeling and information modeling methodology of buildings, and complex object modeling methods used in modern architectural design applications (e.g., [53, 54]) were utilized in this study. Here, creative proposals are realized through a mix of drawings and models as visual representations to encourage a fresh and lively approach to architectural research.

Figure 5 shows the phases of the preliminary design used as a research method in this study and the next phases of the project.

3. Findings

DWBE's innovation is based on a new way of combining the understanding of the properties and potential of wood, traditional woodworking skills, mechanical capability to mill large wood boards efficiently and precisely, digital machining control, and digital design. Thus, the architect, structural designer, and production

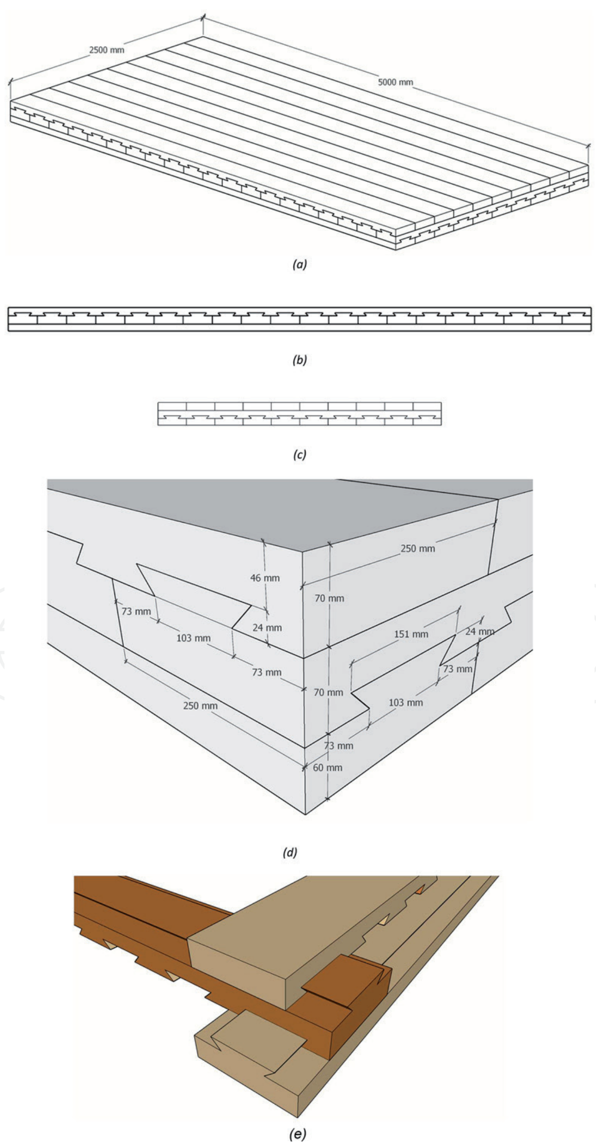

Figure 6.
Dovetail wood elements as floor slab alternative-1 (solid type): (a) isometric view; (b) front view; (c) side view; (d) with representative dimensions; (e) detail.

unit can work on the same file, and the result is the same as desired. The number of layers can be varied, and the width and thickness of the wood can also vary according to need, and the hardness of the board is completely formed without adhesives, nails, staples, or other materials, with no size limitation unlike traditional EWPs such as CLT and LVL.

According to current construction practices of conventional EWPs and critical discussions with various industry professionals as the first step in design, geometrically original and technically sound 2D and 3D horizontal (e.g., floor slab) frame models are presented below.

For comparison with the CLT of equivalent dimensions, the optimal test size of the dovetail wood board will usually be taken as about 200 mm thick (three-layer),

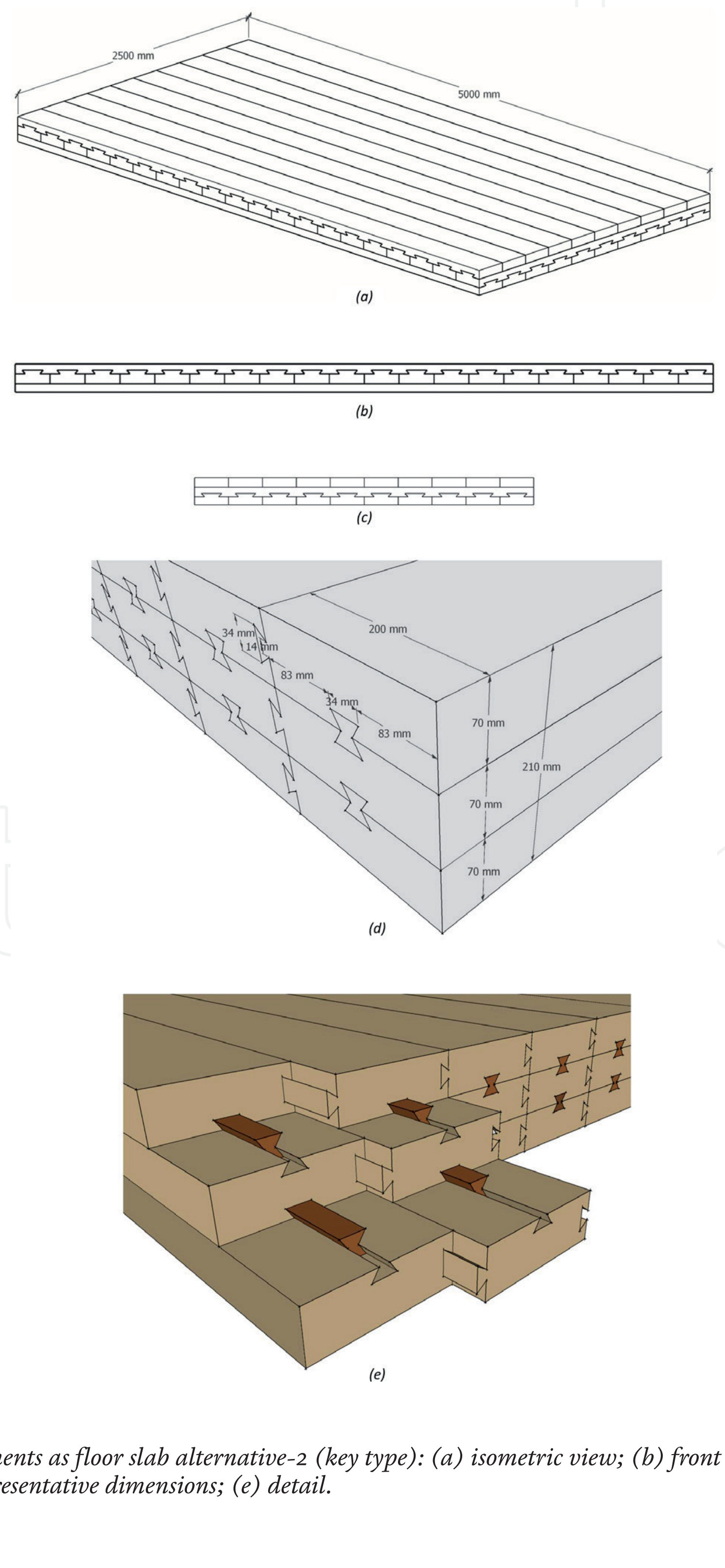

Figure 7.
Dovetail wood elements as floor slab alternative-2 (key type): (a) isometric view; (b) front view; (c) side view; (d) with representative dimensions; (e) detail.

2500 mm wide, and 5000 mm long. Additionally, in the light of the abovementioned practical knowledge and discussions, the design, which was initially considered as five-layer, has been revised to three-layer to minimize the amount of waste products. Moreover, considering structural tests and other performance tests such as fire safety and sound insulation, it is predicted that the dimensions of building components may change, especially after structural analysis.

As can be seen in **Figure 6**, the "solid type" can be used as dovetail wood elements as an alternative to the floor slab, inspired by conventional dovetail connection, one of the oldest joining methods used in ancient temples and churches.

Figure 7 highlights "key type" with a similar structural mechanism with key laminated timber beams. However, since in the current literature, there are few studies (e.g., [55, 56]) on key-laminated beams that show similarities to our key type proposal in **Figure 6**, advantages and disadvantages of our key type can be

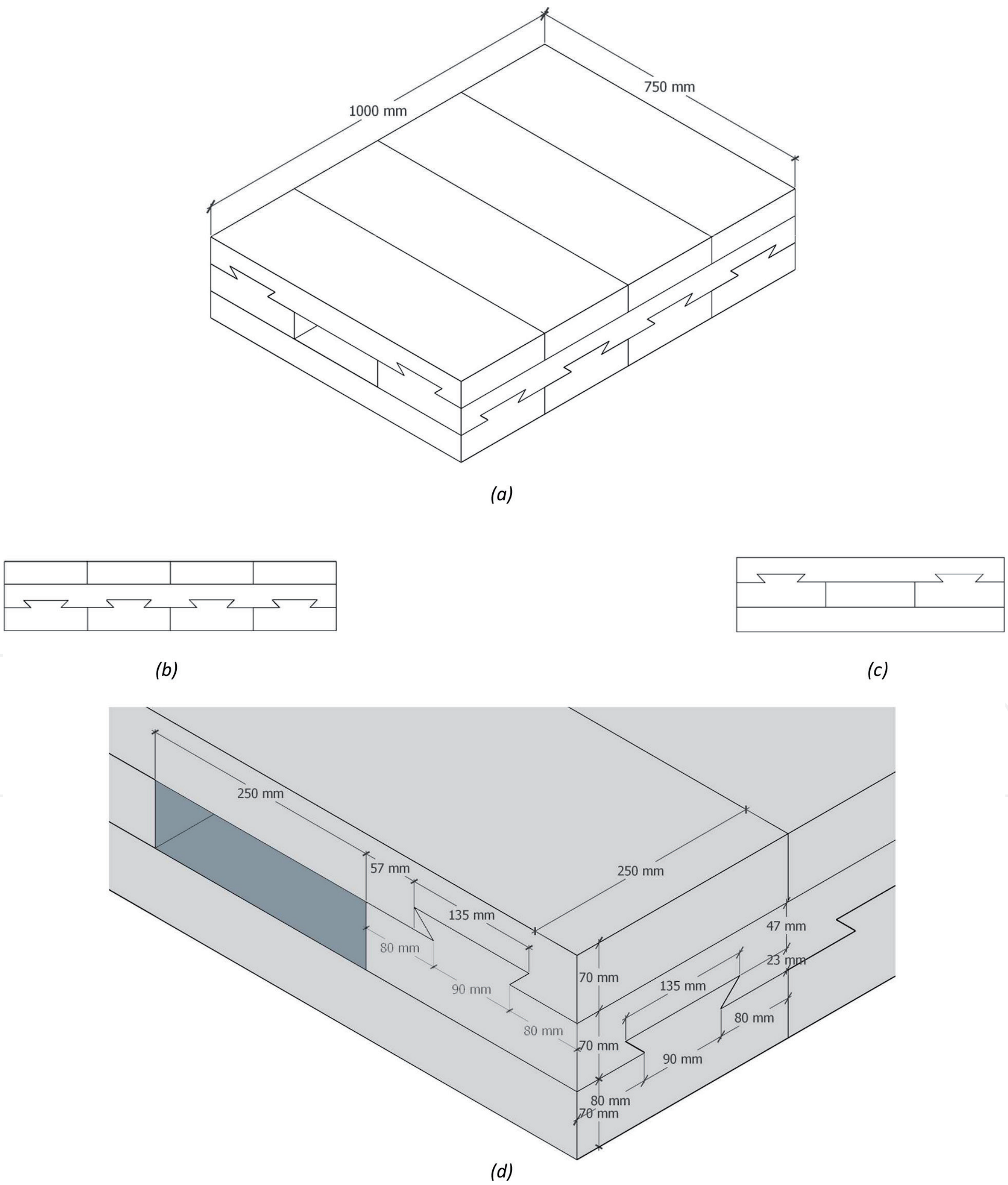

Figure 8.
Dovetail wood elements as floor slab alternative-3 (hollow type): (a) isometric view with dimensions; (b) front view; (c) side view; (d) with representative dimensions.

revealed as a result of structural analyses and subsequent technical performance tests in the laboratory.

As shown in **Figures 8** and **9**, hollow type is a viable alternative due to its many advantages including reducing the dead load, improving the weight-to-strength ratio, ease of plumbing or electrical work, thus saving construction cost as in the cases of hollow concrete slab [57, 58] and hollow-core cross-laminated timber [59, 60].

After the geometric configuration design phase, structural analyses will be made, and it is planned to proceed to the prototype manufacturing phase. In this phase, softwood from gymnosperm trees such as pines and spruces will be used, taking into consideration its advantages such as workability, sustainability, and cost.

Here, first, the solid type shown in **Figure 6** will be manufactured and technical performance tests will be carried out compared with equivalent CLT elements as mentioned above. In this sense, as a result of the first technical evaluations made

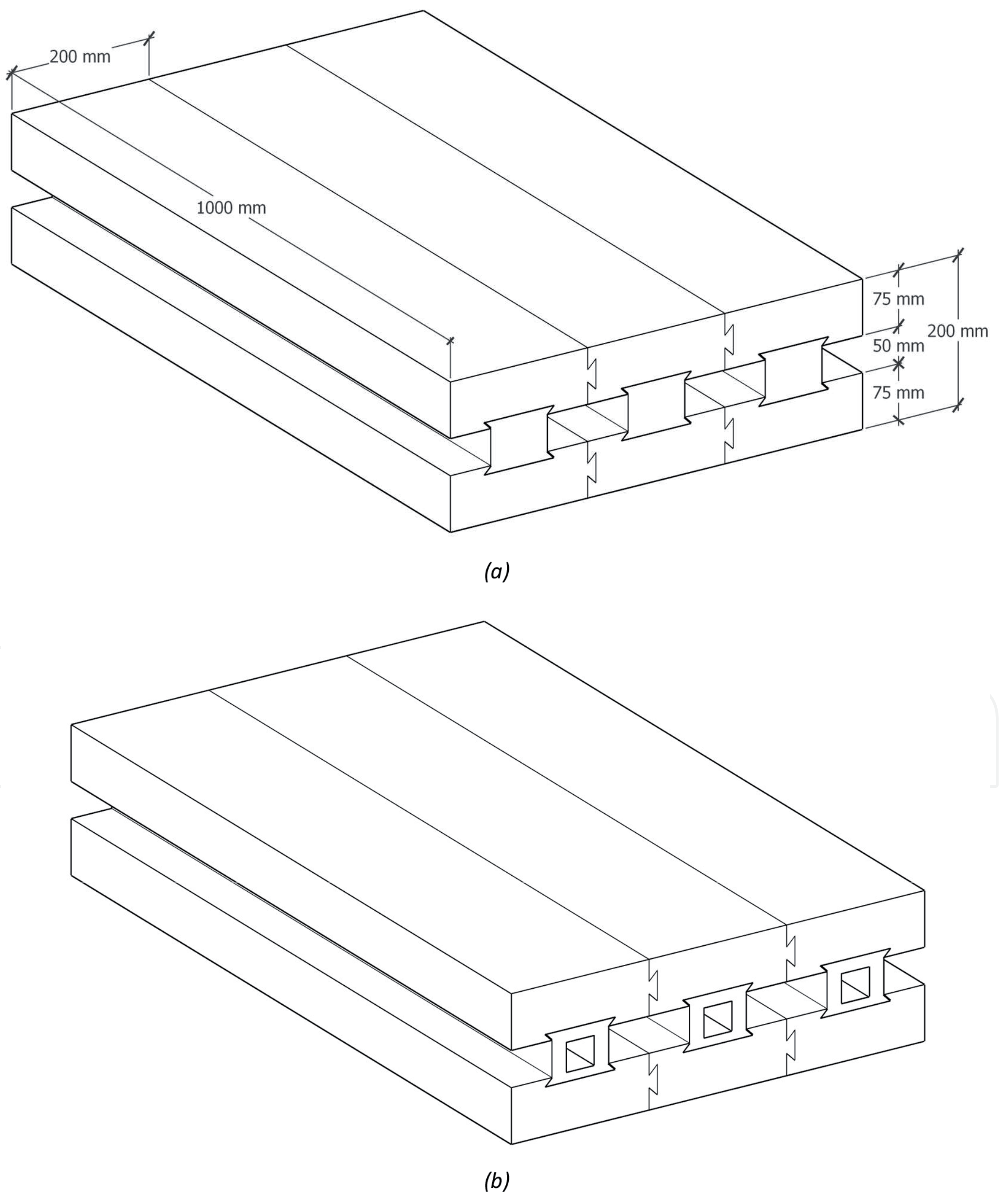

Figure 9.
Dovetail wood elements as floor slab alternatives-4 (hollow type-2).

with wood construction experts and structural designers, it is predicted that the structural performance tests, which represent the most critical phase of the comparison study to be conducted, will yield positive results considering DWBE's solid structure and joint details as seen in **Figure 6**. On the other hand, considering the future performance tests to be carried out as mentioned above, it is anticipated that as shown in **Figures 8** and **9**, hollow types' weight-strength advantage will make a great contribution to their structural performance, and the porous structure will make a big difference in their sound insulation performance.

4. Conclusion

Since there are no patented adhesive and nonmetallic dovetail wood panel solutions in the timber market [40], it has not been possible to carry out a comprehensive discussion on the similarities and differences of our proposals with other solutions. This study aimed to present various geometric configurations for dovetail wooden horizontal structural members in multistory building construction as ecologically sound engineering solutions through architectural modeling programs as the first step to developing DWBEs. The results are at the architectural design stage based on a theoretical approach taking into account current construction practices, but developed products will be finalized through market research after the technical performance tests (e.g., structural, fire, sound insulation, and airtightness tests) and necessary optimization processes. Therefore, currently, though DWBEs uptake for commercial applications is very limited, due to new studies such as DoMWoB project (*Dovetailed Massive Wood Board Elements for Multi-Story Buildings—see Acknowledgments*), the potential of the "innovative dovetail concept" will be further used in high-rise construction.

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Author details

Hüseyin Emre Ilgın*, Markku Karjalainen and Olli-Paavo Koponen
Tampere University, Tampere, Finland

*Address all correspondence to: emre.ilgin@tuni.fi

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