WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

CASE STUDIES FROM FINLAND: IMPROVING THE PRODUCTIVITY OF INDUSTRIAL WOOD APARTMENT BUILDING CONSTRUCTION

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ABSTRACT: Since the early 1990s, Finland has been actively engaged in the development of multi-story timber-frame buildings. According to the size specifications outlined in the current Finnish fire regulations as of January 1, 2018, it is feasible to build residential, office, hotel, and care center with timber frames and facades, extending up to 8-story. As of February 2025, Finland has completed the construction of 200 wooden apartments buildings exceeding 2-story, totaling about 6,000 apartments. Despite positive feedback from residents, clients, and builders, wooden apartment buildings have not yet achieved sufficient competitiveness for widespread adoption. To enhance the productivity and competitiveness of industrial wooden apartment building construction in Finland by 20%, a two-year research project was undertaken from (2020-2022). This project was funded by both the industry and the Finnish Ministry of the Environment. It included two extensive case studies in Finland, utilizing modular volumetric construction methods and encompassing about 770 apartments in total. The study concluded that competitiveness of wooden apartment buildings can be significantly improved by standardizing design solutions and optimizing both industrial modular manufacturing and on-site operations. Furthermore, productivity gains can be realized through enhanced design management, the implementation of effective project and contract models, and improved site logistics.

KEYWORDS: multi-story buildings, industrial wood construction, modular volumetric construction method, competitiveness, Finland.

1 – INTRODUCTION

The productivity of construction in Finland has stagnated for decades. Although the construction industry is one of the largest sectors in the world, its productivity growth lags behind other industries [1]. The construction sector is also one of the biggest contributors to greenhouse gas emissions [2]. The Finnish government aims to achieve carbon neutrality by 2035, making it essential to implement rapid measures to reduce emissions in construction [3]. As in other industries, improving productivity and reducing emissions can be achieved by streamlining processes, increasing automation, and advancing industrialization [4]. The Industrial Timber Construction Productivity Leap project / Tuottavuusloikka (2020–2022) was launched in Finland based on these premises. Multi-story timber buildings using volumetric modular construction were chosen as the solution, drawing on Finland's previous experiences and perspectives on timber apartment buildings.

Residential buildings constitute two-thirds of Finland's building stock, totaling nearly 3.2 million registered dwellings [5]. Over the past two decades, Finland has seen an annual construction of 35,000–45,000 new dwellings, resulting in an annual renewal rate of just over one percent for residential buildings [6]. Following Spain, Finland stands as Europe's second most apartment-oriented country, with 47% of all dwellings located in apartment buildings [7]. Approximately three-quarters of the new dwellings constructed each year are housed within apartment buildings, and the average Finnish apartment building comprises 32 dwellings. Concrete has maintained its dominance in the apartment building market in Finland over the past sixty years [8]. Since 1995, Finland has permitted the construction of wooden apartment buildings taller than two stories, marking a significant development in building regulations and construction practices in the country. As of February 2025, Finland has completed the construction of 200 wooden apartments buildings exceeding 2-story, totaling about 6,000 apartments. This positive trajectory is substantiated by the findings of a wooden apartment project survey conducted in June 2022, which projects the construction of approximately 14,000 new wooden

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 https://doi.org/10.52202/080513-0444

apartments in the coming years. Including two-story small apartment buildings, the current market share of wooden apartment buildings in Finland stands at approximately 6% [9]. Despite receiving positive overall feedback these buildings have not yet attained a competitive edge sufficient for widespread adoption in the market.

From September 1, 2020, to August 31, 2022, a two-year research project was conducted in Finland with the objective of enhancing the productivity and competitiveness of industrial wooden apartment building construction by 20% [10]. This initiative was funded jointly by industry stakeholders and the Finnish Ministry of the Environment. The research focused on two significant case projects utilizing modular construction techniques, totaling approximately 770 apartments. One of these projects, Kalon in Jyväskylä, consisted of 165 apartments across 5 floors, encompassing approximately 9,200 square meters (Figure 1). The second project, TOAS Hippos in Tampere, comprised 600 apartments spread across 4 to 8 floors, with approximately 26,000 square meters of residential space (Figure 2). As a lightweight material, wood enables the efficient manufacturing of large volumetric elements in controlled weather conditions within factories (Figure 3). In Finland, volumetric modular construction has had decades of tradition in the construction of single-family houses. Now, this method of production is also being established for the construction of wooden apartment buildings. Volumetric modular construction is considered in this research project as a fundamental principle of industrial wood construction. The primary aim was to demonstrate that wooden apartment buildings could be constructed with a 20% improvement in efficiency and competitiveness compared to the standards observed in 2020.

Figure 1. Kalon project, Jyväskylä

The planned actions in the Tuottavuusloikka projects were divided into six work packages, each aimed at addressing identified bottlenecks in timber apartment construction:

- Work Package 1: Analyzed the current state of timber apartment buildings in Finland and assessed their development potential.
- Work Package 2: Based on the analysis, practical measures and recommendations were developed for all project stakeholders to improve the productivity of timber apartment construction. Key strategies included:
  - Mass customization
  - Advancing partial prefabrication
  - Shifting more work to the factory
  - Enhancing calculation tools to support management and decision-making
- Work Package 3: Examined and defined contract models and legal frameworks to facilitate the adoption of new operational models in upcoming timber apartment projects.
- Work Package 4: Compiled a standardized design library, including the most critical prefabricated details and solutions developed during the projects. The library is openly accessible.
- Work Package 5: Focused on architectural development of timber apartment buildings, considering perspectives from clients, user needs, and industrial production.

- Work Package 6: Communicated the project findings to stakeholders to ensure knowledge dissemination and industry-wide impact.

Figure 2. Hippos project, Tampere

Figure 3. Volumetric modular elements in factory

2 – PROJECT FORM AND CONTRACT MODEL

In modular timber apartment construction, selecting the appropriate project and contract model is crucial to fully leveraging the advantages of timber construction. The Industrial Timber Construction Productivity Leap project included two case studies that were implemented using different contract and execution models.

In the Kalon project in Jyväskylä, the construction company executed the project under a turnkey contract model, where the construction company assumes full responsibility for the entire project, including design coordination, procurement, and risk management. This model allows the construction company to mitigate market uncertainties by carrying out the majority of the work in-house rather than relying on subcontracting, which is the common approach [11]. By increasing the share of in-house work, it is possible to achieve a competitive and predictable cost structure. Additionally, development work is more manageable when the execution remains under direct control [12].

This type of contract model is also beneficial for the client (i.e., the investor), as it simplifies project management. However, the turnkey model requires the construction company to possess significant expertise in the efficient production and delivery of modular elements and other prefabricated components, as well as sufficient experience in collaboration with the client and other project stakeholders [13].

The Hippos project of the Tampere Student Housing Foundation (TOAS) was implemented as an alliance project, which involved the client, the main contractor, and key design stakeholders. The core principle of the alliance model is that the project does not have a fixed price; instead, a management system is established in which risks and rewards are shared collectively among the parties. Typically, the alliance process is divided into two phases:

1. Development Phase:
   - The project design is prepared.
   - A target budget for the project is established.
2. Implementation Phase:
   - If the alliance approves the outcomes of the development phase, the project proceeds to the construction phase under the same collaborative contract.

This approach aims to foster collaborative decision-making, optimize risk management, and enhance project efficiency throughout the construction process.

In the Hippos project, the timber component supplier was not originally a member of the alliance, which ultimately proved to be the right decision. As construction was about to begin, the anticipated risks materialized, and the project did not progress as originally planned. Before construction started, the Finnish modular element manufacturer went bankrupt due to multiple factors [14]:

- Difficulties caused by the COVID-19 pandemic

- A significant rise in timber prices

- Supply chain disruptions caused by the war in Ukraine

These factors substantially increased construction costs. Consequently, a new supplier from Estonia was negotiated to provide the modular timber elements. Ultimately, out of the 600 planned apartments, only the first 200 were completed using timber modular elements. These were procured as a separate purchase by the client under a traditional procurement contract. The remaining 400 apartments were decided to be built with conventional concrete structures by TOAS. This case highlights the high sensitivity of the construction industry to economic fluctuations, demonstrating how multiple external factors can significantly impact project feasibility and execution.

3 – DESIGN

The architectural design of a timber apartment building is significantly influenced by zoning regulations, the site's integration into its surroundings, cardinal directions, and the client's specific goals for the project [15]. In Finland, zoning plans and regulations can mandate timber construction, specifying requirements for both façades and structural systems [16]. Additionally, timber construction can be encouraged and guided through land allocation conditions [17]. The zoning plan establishes the fundamental principles and broader framework for construction, which also has a substantial impact on overall costs. Key aspects regulated by zoning include:

- Permitted building volume
- Building height
- Basic building massing (e.g., structural depth, entrances, staircase arrangements, roof shape, eave solutions, and balcony configurations)
- Façade materials

The competitiveness of industrial timber construction improves significantly when architectural design is integrated holistically with production, construction, factory operations, and on-site assembly from the early stages of the design process [18]. Efficiency is further enhanced when standardized design solutions are made available to designers in advance.

One of the primary challenges of timber apartment building construction has been, and continues to be, the perception of high risks and difficulties in communication between different stakeholders in the design process [19]. To achieve competitiveness in industrial timber construction, projects must invest in system-level design, which enables the use and competitive sourcing of standardized, industrially manufactured components. Financial expertise also plays a critical role in this approach [20]. The design phase must clearly define how much of the building can be prefabricated in a factory and what portion must be completed on-site.

Modular construction (using prefabricated volumetric elements) offers excellent opportunities for extensive standardization and the utilization of parametric design [21]. As part of the Industrial Timber Construction Productivity Leap project, three different standardization solutions were developed to improve the efficiency of the design process:

- A standardized timber apartment building concept
- A library of standardized building components and connections
- A parametric design-based configurator

These approaches enhance productivity by streamlining the design and construction processes, ensuring greater predictability and efficiency in timber apartment building projects.

https://doi.org/10.52202/080513-0444

The basic floor plan of a modular timber apartment building must be determined in the early stages of design. By modifying the width and length of the modular elements, the apartment sizes can be standardized, while adjusting the number of modules allows for variations in the building dimensions and total number of apartments (Figure 4).

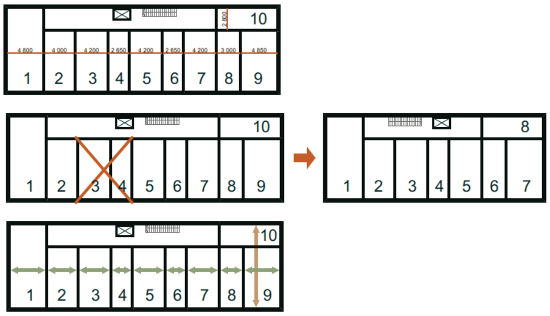
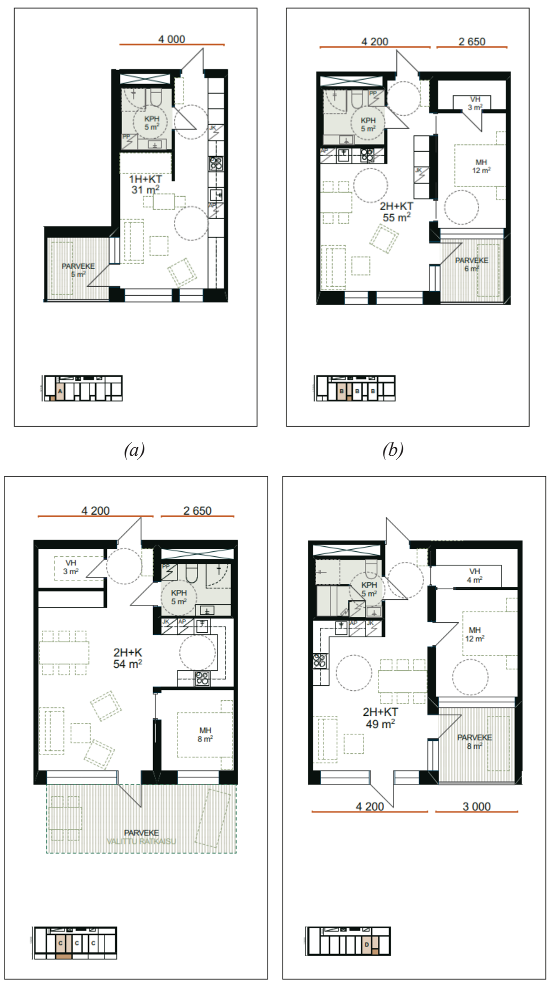


Figure 4. Modifying a timber apartment building's floor plan using variations in modular elements



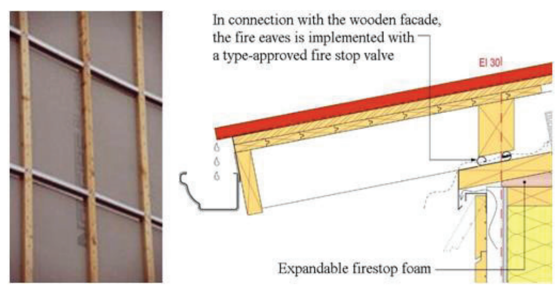
(a) (b)

(c) (d)

Figure 5. Various apartment solutions in a timber apartment building using modular elements with four different plans (a-d)

In modular timber apartment buildings, the structural frame is formed by stacked wooden modular elements, which also define the apartment boundaries. The load-bearing walls are aligned across floors to ensure structural stability. Vertical service shafts run in a straight line through the building, allowing for an efficient and organized routing of mechanical, electrical, and plumbing (MEP) systems. These shafts are a fundamental part of the building's design and must be strategically placed in the early design phase. For ease of maintenance and accessibility, service shafts are accessed from the stairwell side (Figure 5). This approach ensures design flexibility while maintaining efficiency in manufacturing and assembly, optimizing both construction costs and material usage.

In Finland, wooden buildings exceeding 2-story must be equipped with an automatic sprinkler system. The load-bearing wooden framework should primarily be safeguarded with A2-s1,d0 class fireproof protective coatings, typically consisting of gypsum boards. Furthermore, thermal insulation must meet at least an A2-s1,d0 fire class rating, typically achieved with mineral wool. Fire barriers should be integrated into the ventilation gap and eaves of wooden facades. While facades may have a wooden appearance (fire class D-s2, d2), it is mandatory for the facade of the ground floor to be constructed using a fire class B-s2,d0 material. Special attention is given to the fire safety of timber facades and eaves in timber apartment buildings. The required fire protection solutions are illustrated in Figures 6.



(a) (b)

Figure 6. Fire barriers in the ventilation gap and eaves of the wooden facade: (a) fire stops of the wooden facades; (b) The air space of wooden facades must be separated from the attic space by A2 class fire board (30 min. sheeting) and façade and attic should be ventilated separately (Images by authors).

4 – MANUFACTURING

Work efficiency is significantly higher in controlled factory conditions compared to construction sites exposed to weather conditions. One of the key advantages of timber construction is its lightweight nature, which enables modular construction using volumetric elements [22]. In the manufacturing of modular elements, it is beneficial to apply the best practices and principles learned from other industries, such as automotive industry.

Productivity can be improved not only by optimizing the manufacturing process on the production line but also by carefully planning the pre-production phases and systematically measuring post-production productivity and quality [23]. When designing and operating a production line, it is essential to have precise knowledge of work phases, their duration, the technologies used in each step, and potential improvements. Since modular elements vary, some level of adjustment is always required in the production line.

To maximize efficiency, the benefits of serial production must be fully utilized. The manufacturing process should not merely replicate on-site construction within a factory—instead, it should leverage the advantages of industrialized mass production to ensure consistency, efficiency, and high quality [24] (Figure 7).

(a)

(b)

Figure 7. (a-b) Modular element production for timber apartment buildings must be automated serial manufacturing, not "on-site construction in a factory

During the work planning phase, element drawings are analyzed to determine the necessary work stages involved in production. At the same time, internal and external subcontracting strategies are planned. The more thoroughly the work planning phase is executed, the smoother the production process will be, and manufacturing costs can be estimated with greater acuracy.

Following this phase, prototype model elements are often produced to evaluate the feasibility of the planned solutions and assess the quality of execution. If the elements for a new building project are well-designed and work stages are balanced on the production line, the next step is to analyze and define a reasonable and achievable production cycle time for manufacturing.

This is followed by production planning, a key component of industrial manufacturing. By measuring work productivity, it is possible to assess how well the preparatory stages of production have been executed. A highly productive workflow ensures that production runs smoothly and without interruptions, allowing workers to focus on executing the planned work stages efficiently.

5 – LOGISTICS

Logistics plays a crucial role in modular timber construction, as the transportation of volumetric elements by road involves specific restrictions and cost implications that must be considered in industrial construction [25]. However, in a well-designed timber apartment project, transportation constraints do not significantly limit design solutions or overly dictate the planning process.

In Finland, the most common maximum dimensions for modular elements in road transport are [26]:

- Width: 5.5 – 5.7 meters
- Length: 12.0 – 12.5 meters
- Height: 3.4 meters (determined by a 1.0-meter-high truck trailer and a 4.4-meter underpass clearance)
- Maximum vehicle weight: 76 tons

From a production and logistics perspective, the optimal module size is 30 – 33 m², as this keeps the element weight within 15 – 17 tons, allowing for standard crane equipment to be used on-site. CLT modules weigh approximately 450 kg/m² on average (Figure 8).

In Finland, modular elements are typically transported and lifted into place during nighttime hours when traffic is lighter, ensuring smoother logistics and minimizing disruptions [27].

(a)

(b)

Figure 8. (a-b) The logistics of modular element transportation and installation must be well-organized, especially on constrained urban sites

https://doi.org/10.52202/080513-0444

6 – CONSTRUCTION SITE

Findings from the Industrial Timber Construction Productivity Leap project confirmed that installing timber façade cladding on modular elements is always more efficient in a factory setting than on-site. On construction sites, the need for lifting equipment, as well as weather-related factors such as snow, ice, rain, wind, and temperature fluctuations, slow down the installation process and increase construction costs.

Similarly, building services (MEP systems) should be pre-installed as much as possible in the factory to improve efficiency [28]. For example, vertical service shafts should come with all necessary pipes and conduits pre-installed, so that only final connections need to be made on-site. Ideally, even the shaft's enclosing wall elements should be fully assembled in the factory, except for the required access openings (Figure 9). By maximizing factory-prefabrication, construction time and costs can be significantly reduced, improving overall productivity and ensuring higher quality control [29].

Figure 9. The connection and maintenance of vertical service shaft installations in modular elements are carried out from the stairwell side

The operational and overhead costs of a construction site differ significantly in modular timber projects compared to traditional on-site construction methods [30]. The extent of factory prefabrication directly affects the overall project schedule, which in turn impacts various site-related costs, including:

- Site administration expenses
- Site facilities and their maintenance
- Temporary heating of the building
- Site security and surveillance

In Finland, construction costs are categorized using the Talo 80 classification system, which provides a structured framework for evaluating operational and overhead costs in modular timber apartment construction [31]. These costs can be estimated based on the specific requirements and efficiencies of the modular building process, where a shorter construction time typically results in lower overall site expenses compared to traditional methods.

The operational and overhead costs of a construction site differ significantly in modular timber projects compared to traditional on-site construction methods. The higher proportion of factory prefabrication affects the overall construction schedule, which in turn influences site administration, facility maintenance, heating, and security costs.

According to the Finnish Talo 80 classification system [31], the cost components for modular timber apartment construction can be assessed as follows:

81 Temporary Structures on Site

- Site Facilities:
  - The need for site facilities (size and duration) depends on the extent of factory prefabrication.
- Storage and Protection:
  - Modular elements contain all necessary materials, eliminating storage needs for these components. Storage requirements for other elements depend on factory prefabrication levels.
- Factory-produced elements are weather-protected.
- Storage costs include on-site storage, nearby area storage, or factory storage.
- Occupational Safety:
  - Modular buildings require minimal fall protection (e.g., elevator shafts).
- Workers are secured with safety harness systems during modular installation.
- Scaffolding and Mast Lifts:
  - No scaffolding costs if façade cladding is pre-installed at the factory.

82 Temporary Installations on Site

- Electrical Installations:
  - In an optimized scenario, modular elements arrive as fully assembled units, reducing the need for temporary site electrical work.
  - Some site power distribution is still required.

83 Site Machinery and Equipment

- Cranes:
  - Mobile cranes are used for modular installation.
  - Additional equipment needs depend on the degree of prefabrication.

84 Tools and Work Equipment

- Tools and Machinery:
  - Modular elements arrive as ready-to-use units, minimizing on-site tool and machinery needs.
  - Personnel lifts and standard tools are required for installation.

85 Site Consumables

- General Supplies:
  - The requirement depends on the extent of prefabrication.

86 Site Utilities and Energy Consumption

- Electricity, Water, Gas:
  - Reduced utility needs as modules arrive pre-installed.
- Heating:
  - Modules are pre-insulated, reducing the need for temporary heating.

    - Faster project schedules allow construction during warmer months, further minimizing heating costs.

87 Site Transport and Waste Management

- Waste:
    - Only packaging waste is generated from modular elements.
    - Overall waste costs depend on the level of factory prefabrication.

91 Site Administration

- Management Requirements:
    - Administrative needs (staff and duration) depend on site workload and schedule.
    - In an optimized scenario, only 1–2 site managers are required.

92 Auxiliary Construction Work

- Site Facility Maintenance:
    - Cleaning requirements depend on site workload and duration.
- Cleaning and Clearing Work:
    - Ideally, modular interiors require no cleaning on-site.
    - Cleaning needs increase if elements require repairs, arrive incomplete, or are used for on-site storage.
    - Costs are approximately one-third of those in traditional construction.
- Final Cleaning:
    - Modules are delivered in a "vacuum-clean" state.
    - Cleaning needs increase if elements require adjustments or are stored improperly.
- Impact on Total Site Costs

Well-planned modular projects significantly reduce site supervision and construction time, leading to lower operational and overhead costs compared to conventional construction [32]. However, during the final project handover phase, the amount of work remains unchanged, as regulatory inspections, approvals, and commissioning procedures must follow standard building regulations (Figure 10).

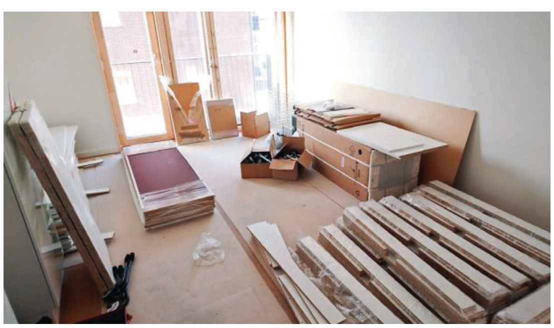


Figure 10. Using a finished apartment as a storage space for finishing materials increases construction site cleaning costs

7 – CONCLUSION

The advancement of productivity in industrial wooden apartment building construction necessitates a comprehensive enhancement of the entire construction process rather than isolated optimizations. Key to improving the competitiveness of wooden apartment buildings is the standardization of design solutions and the optimization of both industrial modular manufacturing and on-site operations. Furthermore, productivity gains can be realized through effective design management, project implementation models, contract models, and streamlined site logistics. Achieving a significant leap in productivity requires collaborative efforts from all stakeholders involved, including developers, designers, industrial prefabricators, on-site operators, and crucially, the end-users of the apartments. It is incumbent upon designers and industry leaders to implement and operationalize the changes and standardized developmental areas identified through the research project. It should be noted, however, that the project did not yet address the implementation of parametric design software or the integration of robotics and automation in modular production. These areas represent potential avenues for further advancement. Additionally, there is a need for continued efforts to gather and refine cost data specific to wooden apartment building construction. In conclusion, the path towards enhancing productivity in industrial wooden apartment building construction requires ongoing collaboration, innovation, and systematic improvements across all facets of the construction process.

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