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Challenges hindering industrialized wooden multi-story construction from a contractor's perspective: a case study from Finland

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Abstract

Purpose – Industrialized construction (IC) is growing globally as an alternative and supplemental construction concept. High expectations have been set for IC to solve existing problems in the industry and enhance productivity. This study aims to identify the most intriguing challenges hindering industrialized wooden multi-story construction (WMC) in the Finnish context from a contractor's perspective.

Design/methodology/approach – Methodologically, this study was a qualitative, single-case study with an inductive approach. Data were collected through five semi-structured interviews and analyzed using NVivo software. Observations were coded and classified into 10 categories and finally synthesized into 3 themes.

Findings – The results revealed that industrialized WMC companies are generating many innovations, primarily occurring at the company level. However, shortages in product systems and operation models, such as concept inflexibility and insufficient design fidelity and quality control practices, hinder the progress of industrialization. The findings also indicate that within the pre-fabrication context, production capacity management and cash flow management are key control factors in industrialized WMC. Strong variation in regulatory interpretation by authorities creates a significant challenge for IC concept development and project management.

Originality/value – This study endorses the existing research findings, highlights a new perspective on challenges in IC and highlights the importance of increasing cooperation between companies engaged in industrialization measures, accelerating the development of individual companies and fostering a more appropriate industry structure.

Keywords Industrialized construction, Wooden multi-story construction, Product system, Industrial operation model, Pre-fabrication, Challenges

Paper type Research paper

1. Introduction

Construction is a key economic activity in many countries (Allmon *et al.*, 2000). Due to the size of the industry, its performance plays a significant role in national productivity (Allmon *et al.*, 2000; Correia and Ribeiro, 2022; Pekuri *et al.*, 2011). High performance is critical for a company to succeed. Traditionally, construction is a project-based business; it has not reached labor productivity levels similar to those of other industries such as manufacturing (Pekuri *et al.*, 2011; Van Tam *et al.*, 2021). For a good reason, productivity issues persevere in discussions between researchers and practitioners.

The construction sector has been expressing steadily increasing interest in industrialized construction (IC). Contractors' difficulties in fulfilling the expected quality requirements, controlling project risks, and achieving their own financial goals are largely known within the

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industry, as well as in research (Annunen and Haapasalo, 2022; Pekuri *et al.*, 2011). The economy experiences this persistent haunting phenomenon internationally. The IC has harbored many expectations to change the prevailing state of affairs. Surprisingly, regardless of the numerous efforts over the decades, IC has not closed the productivity gap with other industries (Pekuri *et al.*, 2011; Van Tam *et al.*, 2021). Some argue that IC has failed to address productivity issues within the construction sector.

IC is considered a novel approach for solving existing problems. Productivity development, including efficiency- and quality-level improvement, is the dominant driver of this progression in companies (Crowley, 1998; Koskela, 1992). The practical implications of industrialization are the creation and maintenance of a defined product portfolio and repetitive processes in product development and supply chains (Tolonen *et al.*, 2015). A key part of industrial operations also involves the continuous improvement of these elements (Annunen and Haapasalo, 2022; Lessing, 2006). Adopting an industrial operating model and continuously improving it creates conditions for companies' productivity improvement.

Furthermore, industrial operation models and the reduction in environmental impacts are significantly linked (Jaillon and Poon, 2008; Yunus and Yang, 2012). One part of the Finnish government green transition objective is to increase the volume of public wooden construction by up to 45% of all new buildings by 2025 (Emre Ilgın and Karjalainen, 2023; Koskinen *et al.*, 2023). This goal is still far away, but there is still an increasing number of private companies focusing on wooden construction in their strategies (Emre Ilgın and Karjalainen, 2023). Interestingly, it is more or less a rule that they simultaneously invest strongly in the industrialization of their operational models. At its best, this kind of strategic choice could lead to a breakthrough in IC, and consequently solve productivity and sustainability challenges in the long term.

Based on this industry setting, this study aims to identify the challenges faced in implementing industrialized wooden multi-story construction (WMC) in one of the leading contractors in Finland. This study concisely introduces the state-of-the-art Finnish WMC from an industrialization perspective, including the identified challenges and opportunities. This study also aimed to materialize the latest and most significant pain points in industrialized WMC implementation to complement the existing scientific discussion and provide some initiatives to practitioners.

To achieve the research objectives, the following research question (RQ) was formulated:

RQ. What are the most critical issues for the success of industrialized WMC?

First, this study consists of a literature review focusing on the themes of industrialized construction, wooden construction, and obstacles to industrializing WMC. The research method has been described in the literature review. The empirical findings of this study are summarized in the results section. In the discussion, this study's contributions to the research and managerial implications based on the findings are indicated.

2. Literature review

IC is one of the major approaches in attempting to solve productivity issues in construction (Andersson and Lessing, 2020). Various technical applications have been observed, such as precast concrete systems, metal-frame buildings, and prefabricated components (Razkenari *et al.*, 2019). Different types of industrialized technical systems for WMC have been introduced (Hurmekoski *et al.*, 2015). In Europe, industrialized WMC domains have been centralized mostly in Nordic countries, the Alpine region, and the British Isles (Hurmekoski *et al.*, 2015). In addition to productivity concerns, WMC promotion is strongly driven by its sustainability benefits, which have been supported by many governmental initiatives in Europe (Emre Ilgın and Karjalainen, 2023; Hurmekoski *et al.*, 2015).Interestingly, efforts to gain productivity gains through IC have not been straightforward (Annunen and Haapasalo, 2022). Several obstacles to higher productivity have been identified and summarized (Attouri *et al.*, 2022; Razkenari *et al.*, 2019; Xue *et al.*, 2018). One large-scale question featuring industrialization obstacles is the varying regulations between countries, and even within regions (Lu, 2009; Mao *et al.*, 2015). Thus, it is critically important to develop a related understanding of these specialties in different operational environments.

2.1 Industrialized construction

In the early 90s Koskela (1992) found that, in the construction industry, production was seen as a conversion process instead of flow. Moreover, he identified a great opportunity to improve construction flows despite certain peculiarities, such as one-of-a-kind projects, site production, and temporary organizations, and indicated the need for industrialization efforts and mobilization of process development concepts (Koskela, 1992). Simultaneously, the manufacturing industry has demonstrated notable productivity gains (Womack *et al.*, 1992). The basis for this advancement lies in Toyota-originated lean philosophy and methodologies (Womack *et al.*, 1992). Past studies have discovered remarkable improvements in productivity and resource efficiency through lean-related manufacturing practices (Crowley, 1998; Schmenner, 1988; Womack *et al.*, 1992).

Yu *et al.* (2013) described how construction has been implementing industrialized practices for decades using different approaches. Positive productivity progression was initially achieved, but increasing custom user requirements suppressed this evolution (Yu *et al.*, 2013). The new renaissance of industrialization increased in the 1990s (Yu *et al.*, 2013). New lean philosophy-based theories and tools for construction have been developed and existing tools have been applied. The last planner system (Ballard, 1994) and TFV theory of production (transformation, flow, and value creation) (Koskela, 1992) are examples of novel approaches and innovations for developing industrialized construction.

Since then, researchers have progressively refined the concept of industrialized construction (Annunen and Haapasalo, 2022; Lessing *et al.*, 2015; Lessing and Stehn, 2019). These models are largely inspired by manufacturing, but have been developed to fit the context of construction. Annunen and Haapasalo (2022) set six preconditions for industrialized construction: target markets and products, product portfolio, product data and process data, operative business processes, continuous improvement and governance, and owners. Another conceptual framework of industrialized construction, more precisely the framework of industrial house building, was proposed by Lessing (2006) and Lessing *et al.*, (2015), where the model consists of eight areas complemented by continuous improvement. According to the model, technical building systems and prefabrication are at the heart of industrialized construction, but they are supported by elements such as the planning and control of processes, customer and market focus, reuse of experience and measurements, use of ICT, logistics, and long-term relations (Lessing, 2006; Lessing and Brege, 2015). Entwining all operations, digitalization, and data management has recently been seen as one of the most significant change factors in construction value chain management (Andersson and Lessing, 2020).

Globally, IC have different terms. In the USA, prefabricated preassembled modular off-site fabrication (PPMOF) in the UK, modern methods of construction (MMC), and, for example, in Malaysia, industrialized building systems (IBS) cover industrial construction-related topics (Attouri *et al.*, 2022). According to Kauppinen *et al*. (2024), defining IC has been approached from seven viewpoints globally: utilizing prefabrication or offsite production, utilizing standardization and repetition, describing the sector through an industrial strategy, integrating processes and resources for construction, adopting practices from manufacturing industries, through technological investments and construction mechanization, and having no agreed-upon definition.

2.2 Benefits and challenges of industrializing construction

Previous studies have extensively investigated the advantages and disadvantages of industrializing construction (Table 1). In addition, Attouri *et al.* (2022) and Hwang *et al.* (2018) reviewed the literature and compiled the commonly identified benefits and limitations of IC. To highlight a few anticipated and frequently cited positive aspects, IC can reduce on-site construction time (Choi *et al.*, 2019; Hu *et al.*, 2019; Lu, 2009), enhance productivity (Choi *et al.*, 2019; Gibb and Isack, 2003; Hu *et al.*, 2019), and elevate quality (Choi *et al.*, 2019; Goodier and Gibb, 2007; Hu *et al.*, 2019; Rashidi and Ibrahim, 2017). In the United States, one of the primary drivers for adopting IC is to lower project costs (Lu, 2009). However, it is worth noting that many practitioners acknowledge challenges in realizing these benefits (Choi *et al.*, 2019).

Pointing at common hindrances, the IC sector continues to grapple with inadequate integration of advanced technologies, limited automation utilization, insufficient standardization, higher overall costs, inflexibility for design modifications, and lack of expertise (Attouri *et al.*, 2022; Razkenari *et al.*, 2019; Xue *et al.*, 2018). Moreover, challenges include securing skilled labor (Choi *et al.*, 2019; Goodier and Gibb, 2007), demands for large-scale production (Gibb and Isack, 2003), and an underdeveloped organizational culture of industrial thinking (Hwang *et al.*, 2018; Qi *et al.*, 2020; Tam *et al.*, 2007), all of which impede the advancement of industrialization.

The challenges in industrializing construction are very similar, regardless of the operating environment (Annunen and Haapasalo, 2022; Larsson *et al.*, 2014; Maxwell and Aitchison, 2016). The aforementioned obstacles and benefits have been extensively examined in the Unites States and China. Similar results have also been obtained in Nordic countries (Annunen and Haapasalo, 2022; Larsson *et al.*, 2014; Maxwell and Aitchison, 2016). Construction and industrializing construction are complex and multidimensional issues; therefore, Maxwell and Aitchison (2016) place great emphasis on continuous improvement. Changes occur gradually and span several decades.

Table 1. Benefits and challenges in IC

Benefits	Challenges
Reduction of on-site construction time Choi *et al.* (2019), Hu *et al.* (2019), Lu (2009)	Inadequate integration of advanced technologies Attouri *et al.* (2022), Razkenari *et al.* (2019), Xue *et al.* (2018)
Enhance productivity Choi *et al.* (2019), Gibb and Isack (2003), Hu *et al.* (2019)	Limited automation utilization Attouri *et al.* (2022), Razkenari *et al.* (2019), Xue *et al.* (2018)
Elevate the quality level Choi *et al.* (2019), Goodier and Gibb (2007), Hu *et al.* (2019), Rashidi and Ibrahim (2017)	Insufficient standardization Attouri *et al.* (2022), Razkenari *et al.* (2019), Xue *et al.* (2018)
Lower project costs Lu (2009)	Higher overall costs Attouri *et al.* (2022), Razkenari *et al.* (2019), Xue *et al.* (2018)
	Inflexibility for design modifications Attouri *et al.* (2022), Razkenari *et al.* (2019), Xue *et al.* (2018)
	Lack of expertise Attouri *et al.* (2022), Razkenari *et al.* (2019), Xue *et al.* (2018)
	Securing skilled labor Choi *et al.* (2019), Goodier and Gibb (2007)
	Demands for large-scale production Gibb and Isack (2003)
	Underdeveloped organizational culture of industrial thinking Hwang *et al.* (2018), Qi *et al.* (2020), Tam *et al.* (2007)
	High capital costs Brege *et al.* (2014), Rahman (2014)

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Koppelhuber *et al.* (2017) also discussed the economics of IC. Many technical advantages are present and acknowledged in IC, but research on its cost competitiveness is lacking. Business models in IC have been studied and new concepts have been developed (Brege *et al.*, 2014; Hall *et al.*, 2022; Lessing and Brege, 2018), but their economic viability should be better understood. Critical bottlenecks that need to be addressed for IC companies include high capital costs and closely connected problem of a lack of economies of scale (Brege *et al.*, 2014; Rahman, 2014).

2.3 Industrialized wooden construction in Finland

Wooden construction has a long history (Emre Ilgın and Karjalainen, 2023). While wood has been a natural and easily accessible construction material in certain areas in history, wood has especially ecological existence among the other optional construction materials (Emre Ilgın and Karjalainen, 2023; Hilodo and Oliynyk, 2022). The original natural wood material has been refined into many new building materials, such as glued wood, oriented strand board (OSB), or cross-laminated timber (CLT), which have improved technical properties and enable more sophisticated building structures (Hilodo and Oliynyk, 2022).

Today, in the context of wood construction, there are a wide range of miscellaneous types of buildings and technical systems (Emre Ilgın and Karjalainen, 2023; Hurmekoski *et al.*, 2015). Wood is used as the main construction material in detached houses, row houses, churches, and public buildings. In Finland, wooden construction gradually emerged in industrial production in the 1950s (Emre Ilgın and Karjalainen, 2023). Common examples include log houses and detached house component production (Emre Ilgın and Karjalainen, 2023). Since the early 1990s, there have been increasing efforts to promote wooden construction in Finland (Emre Ilgın and Karjalainen, 2023), whereas concrete construction has experienced significant growth. At that time, wooden construction was not capable of competing with concrete construction, which had established reasonably good performance (Emre Ilgın and Karjalainen, 2023). Moreover, during this period, wooden apartment buildings were noticeably absent (Emre Ilgın and Karjalainen, 2023).

Finnish legislation allows the construction of up to eight stores of WMC (Hurmekoski *et al.*, 2015). Hurmekoski *et al.* (2015) introduce three main used technical systems for WMC. The platform technique consists of flat elements in which a pole frame or massive wood frame can be used (Hurmekoski *et al.*, 2015). The post-beam technique bears the load from posts and beams when it allows more freedom in the spatial interior design (Hurmekoski *et al.*, 2015). The modular element system is the most complex; however, it provides the highest prefabrication level (Brege *et al.*, 2014). Fourth, a recent prevalent technical system for multi-story buildings is a log-based system (Emre Ilgın and Karjalainen, 2023). These different structural systems compete in the markets, but new system innovations have recently been launched.

WMC has been promoted by public sector in Finland, for example, by setting the target market share of wooden public buildings to 45% by 2025 (Koskinen *et al.*, 2023). In addition, new targets have been proposed for wood-construction programs. Improvements in industrialized low-carbon wooden construction productivity, knowledge strengthening, and regulation development are included in the proposal (Koste *et al.*, 2023). WMC combined with industrialized operation methodologies exists and will remain a strategic focus in the Finnish construction sector (Koskinen *et al.*, 2023).

In addition to sustainability, the WMC is tightly connected to the IC. For decades, wooden construction components have been fabricated in factories (Hilodo and Oliynyk, 2022), the degree of prefabrication has steadily increased, and more complex components have been fabricated. With this historical background, supplemented by regulatory changes, this development has enabled the industrialization of WMC. Currently, WMC is widely aiming to industrialized operation modes, including prefabrication and modularization (Hurmekoski *et al.*, 2015).

3. Research process

3.1 Research approach

This study was conducted using an inductive qualitative approach. A Furthermore, a single-case design was selected. According to Yin (2013), a single-case selection is appropriate when certain specific circumstances occur. A single-case design is vital when a case is unique (Yin, 2013). The basis for this approach was the strategic choice made years ago by the case company. This large-scale company decided to focus on industrialized WMC, and on the Finnish scale, significant investments were made in related development. The same track has been continued by the case company, and the evolution of industrialization within the organization and industry is aimed at promotion.

Another rationale for advocating single-case selection is the revelatory case (Yin, 2013). All dimensions of industrialized construction and organizational practices, including related documentation, were widely opened by the case company and allowed deep insight into the case. Moreover, the selected interviewees were identified as having a large experience of industrialized WMC, not only from the case company but also from other companies. Another interviewee's background and the role of the industrialized WMC concept owner were found to provide an exceptionally wide and deep understanding of the different areas of industrialized WMC with reference to the frameworks of IC introduced in the literature (Annunen and Haapasalo, 2022; Lessing, 2006; Lessing *et al.*, 2015).

One argument for a single case is longitudinal research (Yin, 2013). The progression in development activities of industrialized practices, including concept and product development, or the challenges faced by the case company, was followed for two years. Triangulation measures were also strengthened by longitudinal study. This background justified the choice of the company as a case study, and it was assumed by the researchers that numerous interesting and critical issues concerning industrialized WMC could be identified. The strength of the selected research approach is that it obtains rich data and a deep understanding of critical phenomena within a chosen context (Yin, 2013). The research process is illustrated in Figure 1.

3.2 Data collection

Primary data were collected through unstructured interviews (Bryman and Bell, 2015). The interviews were supported by the process description of the case company's WMC project, which consisted of five main stages and 47 sub-stages. A 47-point process description was selected for the primary interview framework. This description was followed chronologically, from the beginning to the end of the interviews. The process description provided a plain but solid framework for interviews and ensured that all value chain perspectives were addressed. The final interview session was complementary and focused on planning tools and development activities.

The interviews were divided into five sub-sessions. The contents and duration of each session are presented in Table 2. The interviews totaled 10 h and 24 min, and they were

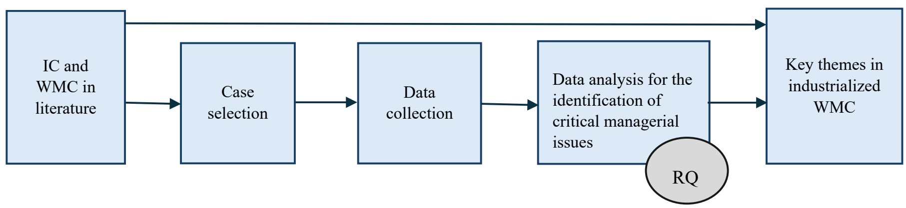

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Figure 1. Research process

Table 2. Interviews and their contents

Sub-session	IC process stages and sub-stages	Duration
Interview 1	Conceptualization (10 sub-stages)	1 h 19 min
Interview 2	Planning and design (11 sub-stages)	1 h 48 min
Interview 3	Pre-fabrication (6 sub-stages)	1 h 23 min
Interview 4	Site-production (14 sub-stages) and guarantee (6 sub-stages)	3 h 08 min
Interview 5	Planning tools and development activities	2 h 46 min

Source(s): Table created by authors

recorded. Two experienced interviewees were chosen: one was a product manager responsible for the entire wooden multi-story house concept and its development (Interviewee A), while the other was a product development manager focusing primarily on product and system development (Interviewee B). During the interviews, various project stages and practical examples from past projects were described by the interviewees, including but not limited to related successes and failures. Clarifying questions were posed by the interviewers.

Data source and investigator triangulation (Bryman and Bell, 2015) were implemented to validate the interview data. The case organization was observed longitudinally for a total of two years by the research group, and numerous validating activities took place during this period concerning the case company and the IC industry as a whole. The primary data for analysis were acquired through interviews. The validation data were gathered from multiple sources and divided into internal and external sources. Internally, from the case company, process descriptions, BIM models, and various technical documentations were utilized, as well as a visit to the construction site of the case company. Moreover, the case organization's concept development activities were followed. Externally, factory tours were conducted in other IC companies. A larger perspective on the operations of the case company was provided through discussions with the partners of the case organization. Presentations in IC domain forums, articles in public media, and press releases by IC companies were followed.

Several workshops were organized by the research group during the 2-year research period to incorporate triangulation measures. In the workshops, both internal and external triangulation data were reflected in the primary data and analyzed. Examples of the reflective activities executed by the research group workshops included the comparison of primary data to the listened-to IC-related forum presentations, the comparison of the challenges of pre-fabrication identified in other IC companies presented during the factory tours, and the comparison of the information of collaboration methods provided by the partners of the case company. These triangulation activities allowed the evaluation and validation of the findings from the primary data with a critical mindset and connect them to the wider industrialized WMC context.

3.3 Data analysis

The interview data were transcribed and the analysis was conducted in three stages. The data analysis process is illustrated in Figure 2. Initially, the transcribed material was examined to identify general topics of interest without a specific classification. The goal was to identify intriguing aspects based on the material and to establish possible classification frames. NVivo qualitative data analysis software was used in the analysis, which resulted in 878 individual observations. Comprehensive notes were taken during this analysis, capturing significant findings and comments related to the industrialization of WMC.

In the second stage, based on the notes and findings from the first phase, the most intriguing topics were identified and formulated into ten categories and referred to as critical issues (Table 1, Chapter 4.7). These critical issues were given titles and content descriptions. Subsequently, the material was reanalyzed using the developed classification. The most

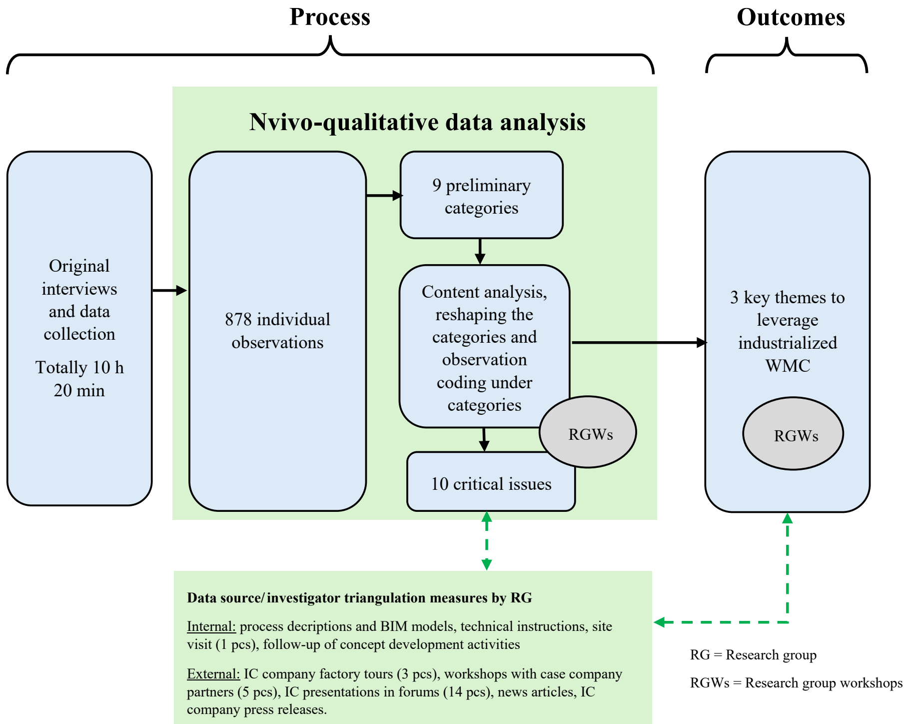

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Figure 2. Data analysis process

noteworthy findings for each category were identified and incorporated into the classes, although not necessarily all of the initially observed findings. Furthermore, to support the analysis and conclusions, the critical issues were organized into higher-level managerial areas, representing broader aspects of general management. These derived areas were not tied to any specific theoretical framework but were established to align with the available research data. In the third stage, the researchers analyzed the findings within each category, summarized them, and updated the category descriptions. During this phase, the most compelling details were emphasized to support the summarized descriptions. Finally, three key themes of industrialized WMC are developed for further discussion.

3.4 Case description

The case company is considered to be one of the largest Finnish contractors in the field of IC. Over the past decade, the company has experienced rapid growth, transitioning from a small- and medium-sized enterprise to a large corporation. Significant investments in modular wooden construction and pre-fabrication have been made by the company over the years. The principal motivation behind these initiatives has been to enhance efficiency through industrialized methodologies, akin to those utilized in other industries for decades. In practical terms, concentration has been placed on developing modular products, streamlining repetitive business processes, and enhancing quality from the conceptualization stage to maintenance. To achieve this objective, partnerships have been fostered and integration with subcontractors has increased. This involved the refinement of concepts, technical systems, and practical value chain operations through close collaboration.

Industrialization in WMC is growing trend in Finland, but many construction companies are cautiously approaching it (Aapaoja and Haapasalo, 2014). IC remains a minor phenomenon in the construction sector. The company can be viewed as a disruptive force in the marketplace. Their dedicated focus on industrialization has garnered significant interest in a company's innovation and performance. Moreover, as a business model, IC has concentrated on wood material-based products in Finnish multi-story construction (Hurmekoski *et al.*, 2015). Although there are a few competitive product systems available, none are concrete-based. While the overall volumes in the WMC remain low, competing against concrete-based houses presents a significant challenge. The paradigm of construction is aimed to be changed by the case company, among other contenders, through achieving a breakthrough in the Finnish market. In particular, this is a question of cost competitiveness compared with concrete-based construction.

4. Results

The key findings of the study were formulated in ten critical issues to be managed in industrialized WMC. These topics were categorized into six higher-level managerial areas. These areas and critical issues are data-driven and do not follow any theoretical models. Each issue represents an individual challenge or opportunity identified within the company, illustrating the critical issues of the business to be controlled in the IC. It is important to note that these results are not listed in any order of significance.

4.1 Concept and product development

Three specific issues are identified in the concept and product development areas. Business concepts in IC can vary, embracing different ways of specifying product and production. These concepts can be evaluated based on their flexibility in serving different stakeholders, including the business needs of producers. In this context, the most prominent stakeholders are the customers and local permitting authorities. The company encountered numerous challenges in meeting the product-related requirements established by permitting authorities, according to interviewee A:

> Local permitting authorities strongly control the composition of apartments in houses, specifying the number of studios, one-bedroom, and two-bedroom apartments, as well as providing key figures such as the average size of apartments. For example, the average size increases. Therefore, we must develop our module library to meet these requirements.

Moreover, customers have specific goals to be fulfilled, as interviewee B stated:

> Larger investors typically have the same interior selections for all apartments, but may request some specific furniture used in their other properties, not from our library. This is based on the need to unify maintenance processes and minimize maintenance costs.

Overall, the product concept was viewed holistically, encompassing the basic principles for configuration and customization, although it did not necessarily require full configurability. There was recognition of the need for case-specific solutions that could be applied in different situations. Consequently, the inability of the product system to enable proper configurability gives rise to demands for flexibility in customization.

Due to the low volumes and high cost of products, product development in IC cannot always employ the same quality assurance methods used in other industries. Furthermore, existing methodologies were not designed to cater to the unique nature of product development in IC. Currently, new product revisions are often piloted directly into customer projects. The absence of proper verification and validation procedures has led to numerous issues and challenges in pilot projects.

On a positive note, IC serves as a robust platform for innovation. The research material revealed dozens of new product innovations and process improvements. These innovations are driven partly by the need to enhance concept flexibility to meet the requirements of customers and permitting authorities and, more significantly, to improve operational efficiency. The industrial operation model naturally provides a framework for standardizing and maintaining these new innovations, leading to increased productivity benefits. Interviewee A described examples of new innovations as follows:

> We developed an adjustable-element-based foundation system. We have to reduce the foundation construction time from 1–2 week down to 3 days. The initial results are promising. We have also had some other development projects aimed at reducing lead-times.

4.2 Competence development

Industrialization demands significantly new and distinct skills compared to traditional construction. Process-oriented thinking, commitment to operational procedures, and quality assurance measures are the key competency areas in industrial operations. The working methods and culture inherited from traditional construction do not support the fulfillment of these new requirements. Traditional culture emphasizes workers' personal skills and responsibility for decision making and problem solving. Interestingly, young talents were identified as a key enabler of this cultural transformation.

When precise management of the value chain is necessary at every stage, collaboration between contractors and subcontractors becomes crucial. Contractors are compelled to decide whether to employ subcontractors or utilize their own resources to oversee operations at a high level. Research findings indicate that, if a specific project stage is highly sensitive to value chain interference, the use of subcontractors becomes riskier. Establishing long-term partnerships with subcontractors or keeping operations in-house was perceived as a low-risk option.

4.3 Process management

Numerous examples in the research material underscore the significance of detailed planning in the product, process, and project management areas. Elements in the IC value chain are closely interconnected, and issues in one portion can easily cause harmful effects in another. This phenomenon has inspired new operational innovations. Disruptions in the value chain weaken the flow of operations, which is further linked to project costs. Interviewee A told:

> We must control the entire value chain from start to finish. There is no room for disturbances in these processes. For this reason, even the smallest details in the sub-processes must be completed everywhere.

Pre-fabrication and site assembly are key areas in which planning failures evoke significant consequences. Within both areas, the fixed unit costs are large, encouraging investment in detailed planning. Even short disturbances can remarkably increase the project cost price. Practical examples of supporting planning tools such as clash detection, task planning, and detailed project planning are mentioned.

4.4 Industry collaboration

The traditional construction industry relies heavily on project-based operational models, leading to fragmented delivery chains. Practically, this translates to single-product production, wherein companies are unable to leverage the benefits of repetitive and scalable production methods. Although IC enables repetitive and scalable production, it underutilizes the potential for cooperation and integration among companies. Interviewee A considered cooperation opportunities and related risks.

> We have invested considerable resources in developing our products. If we would sell out these, our competitors dismantle and copy them, saving millions of euros in development costs immediately.

> However, in the future, as the WMC market expands, I believe that we can sell these products outside the company.

The findings of this study indicate that individual companies are developing their own product and production concepts, and they are suffering from challenges in creating a proper demand for their products. The potential of integrated, larger company consortiums, where individual organizations specialize and collaborate in the joint development and standardization of product concepts and value chains, is evident. The existing challenge was described with the following example, as commented by interviewee A:

> Currently, there are several bathroom modules in the market. They vary in their technical structure and are produced in different ways. Finland has 3D module producers, but their growth is limited by their infrastructure. New companies constantly emerge, and some fail or close. This business takes time and money before it achieves a breakthrough.

The company allocated many resources to product development. If they were to sell these products, the risk of competitive replication was considered high. Conversely, the opportunity to sell modules when the WMC market expands was viewed as an opportunity. The industrialized WMC market was still considered too immature for external sales. Proper market demand was anticipated within a five-to ten-year timeframe.

4.5 Economy management

Cash flow management and factory capacity management play significant roles in the IC. These aspects require a deep understanding of the critical operational methods to ensure proper economic management. According to the research material, factory capacity management has emerged as one of the most crucial managerial dimensions for planning and controlling the value chain throughout projects. The industrialized operation model restricts capital at an earlier stage of projects compared to traditional construction projects. This necessitates essential cash flow analyses at both project and overall business levels. The break-even point for each project must be forecast and monitored to effectively manage company finances. Successful cash flow management demands meticulous planning and involves negotiations with customers, as traditional installment standards are not suitable. Interviewee A expressed the significance of cashflow management as follows:

> One important issue is cost follow-up of the projects. Cash flow analyses must be conducted to understand the accumulation of costs and to identify the point at which the project starts to generate profit.

> Cash flow management is quite challenging in IC if you don't figure out its significance and if you don't communicate it effectively to the customer. Explaining the need for payments at specific stages is the main point of negotiation with customers. They argue that there is nothing on the site yet, but I must explain that everything is already prepared in the factory. Typically, cash flow analysis looks very bad for a long time if we cannot obtain an installment plan approved by the customer. This is challenging because IC is a new operational model and agreement models are still based on traditional concrete-based construction. However, this approach must be modified.

In factory capacity management, the most significant pressure is concentrated during the project conceptualization stage. Achieving seamless workload in a factory requires a stable and predictable work queue. In worst-case scenarios, factory ramp-down and ramp-up costs can be substantial. Interview B stated:

> In the case where we have had a longer lay-off at the factory, we cannot be sure if we get the workers back. They can change jobs. Therefore, it is important that we do not need to use layoffs or limit production.

Interviewee A estimated the capacity adjustment cost high and emphasized the meaning of value chain synchronization:

> If the factory operates at an insufficient load and is far from its maximum capacity, the typical causes include too few projects, insufficient development sites, a stalled permitting process, or similar issues.
>
> It is difficult to calculate all expenses of production ramp-down and ramp-up. There are many consequences of this. Our factory team performed some calculations for different scenarios. I do not know the details well, but the price tags are significant.
>
> Synchronizing project timelines with factory capacity utilization may be the most challenging task. How markets can change in the coming years is a complicated question. Therefore, managing the entire process is crucial piece of the puzzle.

Common reasons for an insufficient production load are a lack of projects, insufficient development sites, and stalled permitting processes. Long-term market fluctuations can also complicate capacity management planning. Synchronizing project timelines with factory capacity utilization is considered to be the most challenging task.

4.6 Authority relationship management

Construction-related regulations were initially designed for traditional construction and were further developed by identifying changes in the field. IC can be viewed as a radical innovation in multi-story construction, and therefore, the differences in products and operation models significantly deviate from traditional construction practices.

The research findings illustrate that the existing regulations in Finland encompass requirements and procedures that are not frequently applicable to industrialized WMC. Permitting authorities are responsible for adhering to existing regulations and their interpretations are based on this foundation. Consequently, numerous conflicts arise between industrialized practices and the interpretation of regulations. In addition, the processing times by authorities and regional building plans were identified as changing factors. Interviewee A:

> From the perspective of permitting authority, authorized project personnel are responsible for both the project itself and manufacturing processes. They put pressure on them regarding factory quality assurance matters and require third-party audits for manufacturing. The main contractor holds responsibility, regardless of where the components are produced. There is room for improvement in these procedures in Finland.
>
> We have a problem with the Finotrol product certificates. Our products have received CE approval and meet all requirements, but the permitting authorities do not understand this logic. They do not accept product certificates but require third-party audits, for example, for VAC-assemblies. They also require all separate CE certificates for each part, instead of approving the module CE certificates as a whole. This causes extra expenses.
>
> When I am forecasting, I have few projects here. In this specific project, the permitting process is delayed or complaints have been made regarding the regional building plan. I am trying to schedule the factory shutdown next to the holiday season.

From the perspective of permitting authority, authorized project personnel are responsible for both the project itself and manufacturing processes. Project personnel are pressured by factory quality assurance. Permitting authorities require third-party audits for manufacturing, and the main contractor holds responsibility regardless of where the components are produced. For example, although the manufactured assemblies are CE approved, separate CE certificates for each individual part are required instead of approving module CE certificates.

In Finland, the largest cities are developing and consolidating municipality-level building permitting and inspection practices. The aim was to improve the predictability of the permitting process within cities. Nevertheless, although these enhancement activities have aided IC contractors, many inappropriate requirements persist. Varying practices were concretized with an example by interviewee A:

This project was in Espoo, and we were forced to make a plastered facade. In Helsinki, a wooden facade can be installed on wooden multi-story buildings, even though the regional building plan stated otherwise. This is just one example.

4.7 Synthesis

Three key themes were discerned from the critical issues and managerial areas, as summarized in Table 3. Establishing a common and optimal product system and developing a suitable operation model for contractors and stakeholders to execute it (*product system and operation model)* form the fundamental basis of business. Addressing the issue of the *pre-fabrication* rate is crucial in terms of value chain management and company economics. Finally, involving regulatory stakeholders in creating an enabling *regulatory context* for the industry is essential.

5. Discussion

Implementing an IC is a complex and enduring process that requires deep engagement in the development and control of its elements. Discussions on the opportunities and challenges of IC in the literature, primarily associated with WMC, are abundant. They depict the image of many operational benefits of IC in construction from the perspective of quality and efficiency, while simultaneously narrating the struggles faced owing to numerous barriers (Attouri *et al.*, 2022; Hwang *et al.*, 2018). IC is implemented within a specific geographical and temporal context, during which relevant questions are continuously evolving. Moreover, industrialized WMC is still on the path to achieving cost competitiveness and business success. This study contributes to this discourse by highlighting three key themes that need to be internalized to leverage the development of industrialization: the product system and operational model, pre-fabrication, and regulatory context.

5.1 Product system and operation model

IC companies should have a clear business model operationalized through an industrial operation model (Annunen and Haapasalo, 2022). Examining the details, the study's findings on poor competence management and attitudes towards IC support previous arguments about companies facing challenges in maintaining a development-oriented organizational culture (Hwang *et al.*, 2018; Qi *et al.*, 2020; Tam *et al.*, 2007) and building IC-related skills (Choi *et al.*, 2019; Goodier and Gibb, 2007). Difficulties related to concept flexibility and trade-offs due to inflexibility are also consistent with existing literature (Andersson and Lessing, 2020; Hwang *et al.*, 2018; Lessing and Brege, 2015). These isolated challenges should be solved, but the study findings are triggering an initial focus on larger issues.

Hurmekoski *et al.* (2015) found that Finland has three different WMC techniques in the market, while in many other European countries, there is only one dominant WMC technique in place. The findings of this study identified the lack of cooperation within the industrialized WMC sector. In the Finnish context, IC is undergoing a period of significant transformation, but according to the findings, concurrently, it appears to be disoriented. The industrialized WMC domain is generating many new innovations in product systems and operational concepts developed by various companies. However, these diverse concepts or products, such as bathroom modules, are in competition, hindering the progress of the IC's competitiveness compared to traditional construction methods. Based on this study's findings, at the domain level of IC, new ways should be explored to align company interests and strategies concerning product systems and operations to enhance the domain's development. While the IC requires high volumes (Blismas *et al.*, 2005), the current market size in Finland does not favor the presence of multiple separate techniques within the WMC sector. In addition, the findings reveal that there is hesitation to progress with inter-company cooperation. This orientation can prevent the development of common industrialized WMC concept, which would amalgamate the strengths of existing concepts. Enhanced attitudes and new skills (Attouri *et al.*, 2022;

Table 3. Key themes and critical managerial issues in industrialized WMC

Theme	Managerial area	Critical issue
I. Product system and operation model	1.Concept and product development	*Concept flexibility:* Inflexibility in product and production concepts leads to challenging trade-offs between customer requirements, authority requirements and own concept requirements. Low alignment with the concept increases the operational and economical risks of the projects *Maturity of product development methodologies:* Immature product development processes and quality assurance concepts causes technical and operational problems in piloting projects *Product and operation model innovations:* Industrial operation model generates continuously new product innovations and methodological innovations
	2. Competence development	*Competence management and attitudes:* Current competence type and attitudes on the industry limits the industrialization. Young talents adopt industrial practices quickly and promote industrialization
	3. Process Management	*Fidelity of planning:* Industrialized construction requires detail level and flawless planning on product, process, and project level to achieve high performance operations. Defects and issues on delivery chain results easily on unprofitable projects
	4. Industry collaboration	*Fragmentation of industrial construction:* Industrialized construction domain is fragmented in Finland. Development of industrialized construction is focused on company level, when the potential of industry or consortium level cooperation in product system development and specialization is wasted
II. Pre-fabrication	5. Economy management	*Cash flow management:* Industrialized construction and pre-fabrication ties up capital at early stage, which asks well planned cash flow management actions through the projects and emphasizes short lead times of projects, especially on on-site production stage *Factory capacity management:* Due to capital-intensity of prefabrication, factory capacity management optimization raises the most critical planning dimension in industrialized construction over single projects or other value chain portions
III. Regulatory context	6. Authority relationship management	*Varying interpretation, processing and planning:* Construction regulation is normative in its nature, but local permitting authorities can interpret it strongly case by case. Processing times and regional building plans are varying by cities. This leads frequently to negotiation setting between contractor and permitting authorities. This issue complicates the product standardization *Inappropriate inspection practices:* From the permitting authority perspective the industrialized procedures and construction methods are not always acceptable, because they cannot be inspected or approved according to prevailing inspection practices

Source(s): Table created by authors

Razkenari *et al.*, 2019; Xue *et al.*, 2018) are required to create innovative partnerships and achieve synergies to move towards successful industrialized WMC.

5.2 Pre-fabrication

Prefabrication has been recognized as an integral part of Industrialized Construction (IC), marking one of the initial stages of IC implementation. Its strategic dimensions have been emphasized in the literature (Johnsson, 2013; Lessing *et al.*, 2015). Previous research has also identified challenges, such as high initial investments (Gibb and Isack, 2003; Hwang *et al.*, 2018; Mao *et al.*, 2015) and the requirement for high volumes (Blismas *et al.*, 2005), as obstacles to engaging in IC. Building on this context, this study's findings highlight the same issues, while underscoring its operational aspects. Effective cash flow management and optimized factory capacity were pivotal for achieving high performance in IC.

In particular, the research data emphasizes factory capacity management as the most crucial managerial area. The study's findings suggest that the entire value chain should be managed with a focus on maintaining consistent factory capacity utilization. Instead of project-based thinking, process-thinking elevates a more important mindset to improve factory capacity management. According to the findings, the pre-fabrication process flow should be primarily controlled over single projects or other value chain portions.

The high overall costs of IC are recognized in the existing literature (Attouri *et al.*, 2022; Razkenari *et al.*, 2019; Xue *et al.*, 2018). Data analysis demonstrates that pre-fabrication ties up capital at the early stage of the individual projects, causing an economic challenge to turn the cash flow positive early enough. Traditional installment standard practices are based on on-site activity progression, but they are not applicable in the case of pre-fabrication. While the literature acknowledges the critical meaning of cost management, the study's findings underline its operative dimensions in the form of factory capacity management and cash flow management.

5.3 Regulatory context

In the literature, conflicts between IC companies and regulatory requirements, as instructed by permitting authorities, have been widely reported (Choi *et al.*, 2019; Hwang *et al.*, 2018; Mao *et al.*, 2015), as well as insufficient inspection practices to control prefabricated construction components (Mao *et al.*, 2015). Nevertheless, this study distinctly showed that the interpretation of regulations by authorities is one of the major hindrances to the industrialization of WMC. It should be noted that this observation was limited to Finland and the case company. Thus, its broad generalization should be approached with caution, even though similar situations can be expected to occur elsewhere.

With several isolated IC concepts currently present in the Finnish marketplace, according to the findings, developing regulations becomes complex because of the need to find suitable common requirements that accommodate all these varying concepts. Practically, the results illustrate that this frequently appears as a negotiation setting between contractors and permitting authorities. The findings strengthen the existing discussion in the literature, but highlight the drawback of the fragmentation of the industrialized WMC sector and contractors' differing concepts to interpretation of the regulation.

5.4 Managerial implications

To overcome these challenges, practitioners should be open to close cooperation. Initially, this could mean a shift in mindset from protecting one's own business to fostering extensive discussions about the developmental needs of the entire industrialized WMC sector. These discussions should encompass various topics, including user experiences with different end-products, technical advantages of various product systems, concept flexibility, cost structures, and capital requirements. This dialog would enable the creation of a new vision for what the groundbreaking industrialized WMC concept could be in the Finnish and, furthermore, in the Nordic context. As a natural progression of such collaboration, negotiations about company roles in the new value-creation processes would follow. While formulating a new industrialized WMC concept, specific attention should be directed to the pre-fabrication concept, which optimizes the production capacity to fit the market size and can be flexible in varying market fluctuations.

To notice all critical aspects and foster change, regulators and permitting authorities should be engaged at an early stage of this collaboration. Technical advancements in product systems and delivery processes must be coordinated with regulatory development to facilitate practical changes. Considering the slow and multifaceted nature of legislative processes, fostering a shared understanding of IC and the meticulous preparation of regulations is crucial.

6. Conclusions

For decades, the construction sector has been struggling with productivity issues and exploring ways to overcome these challenges. Since the early era of industrialization, IC has set many expectations to enhance productivity by using methodologies similar to those of other industries. Industrialization of construction has occurred widely within wooden construction and has been enlarged from single-house construction to wooden multi-story construction in recent decades. However, expectations have not been fully achieved in terms of productivity improvement.

In this study, we found ten critical managerial issues in controlling industrialized WMC in the Finnish context. They were grouped into six upper managerial areas and further synthesized into three main themes. The industrialized WMC sector is essential to establish a dominant product system in the marketplace instead of several competing systems. Pre-fabrication and factory capacity management raise the most significant managerial issues within industrialized WMC. Moreover, the key actors within the domain should consistently coordinate the development of the regulatory context to achieve the anticipated operational environment for industrialized WMC businesses.

A single-case study design was used in this study. Generalizing individual findings should be approached cautiously; however, they should be validated in future research. The limitations inherent in a single-case study were mitigated by selecting a case company that was deeply involved in industrialized WMC and utilizing data source and investigator triangulation. Additionally, in-depth semi-structured interviews were conducted with two highly experienced managerial-level developers in the industrialized WMC sector to further enhance the rigor of the study.

In future research, interesting questions would lie in the barriers of inter-organizational cooperation and specialization of the organizations. Exploring potential organizational and technological solutions to accelerate both horizontal and vertical integration can yield valuable insights. Additionally, understanding the role of permitting authorities and governmental parties in this integration process presents an intriguing area of inquiry. Subsequent research could enhance and validate the findings of this study by testing it across a larger sample of IC companies. The shared understanding of the fundamentals of industrialized WMC among practitioners, regulators, and permitting authorities is crucial. New educational concepts within IC and expanding educational offerings can provide new opportunities to achieve this goal.

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