Joint CSCE Construction Specialty & CRC Conference 2025
Conférence conjointe spécialisée en construction de la SCGC et CRC-2025

Montréal, Québec
July 28-31, 2025 / *28-31 juillet 2025*

Standardization of certain aspects of light-frame wood modular volumetric prefabrication for multi-storey residential buildings

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ABSTRACT:

The affordable housing crisis presents a major challenge that requires immediate action. Often affected by inflation and stagnant productivity, this situation highlights the importance of innovation in construction to increase production capacity particularly in light-frame wood prefabrication. Offsite manufacturing in timber construction in Québec offers potential solutions to improve industry productivity while addressing long-standing issues of cost efficiency and environmental impact. After a comprehensive review of the existing literature on light-frame wood prefabrication and on the role of standardization in the modular prefabrication industry, this study will highlight how standardization increased collaboration and productivity in different regions of the world and will identify relevant directions and their local applicability. The objective is to understand why greater standardization in modular volumetric prefabrication has not yet been adopted in this field, to determine what could be standardized (according to interviewed expert stakeholders) and by whom. Semi-structured interviews were conducted with various stakeholders in the prefabrication industry to gather their perspectives and concerns regarding standardization. The collected data was analyzed using an analysis matrix highlighting divergent and convergent views among participants to identify effective methods for introducing a model for greater standardization in the light-frame wood modular volumetric sector.

1. INTRODUCTION

1.1 Context

Housing affordability and accessibility in major urban centers have reached critical levels. In Canada, between 2018 and 2022, housing costs increased by 20%. According to Statistics Canada (2024), nearly 50% of tenants in affordable housing reported facing significant financial strain in 2022, struggling to meet basic obligations. Such trends are not surprising, given that of the 15.5 million Canadian households, 1% are on waiting lists for social and affordable housing (Statistics Canada, 2024). These numbers underscore the pressing need for comprehensive policy solutions.

While this social crisis impacts individuals' daily lives, the construction industry also has to confront its enduring challenges: stagnating productivity and environmental footprint associated with conventional construction. For years, traditional construction has trailed in productivity as compared to other industries, such as manufacturing (McKinsey, 2024). This stagnation in performance has unfortunately persisted. Contributing factors include a shortage of skilled labor, the sector's relative unattractiveness as a career choice, and insufficient investment in innovation and modernization. To address these challenges, the construction industry should undergo a transformation, embracing new methodologies and increasing investment to improve its performance on all levels.

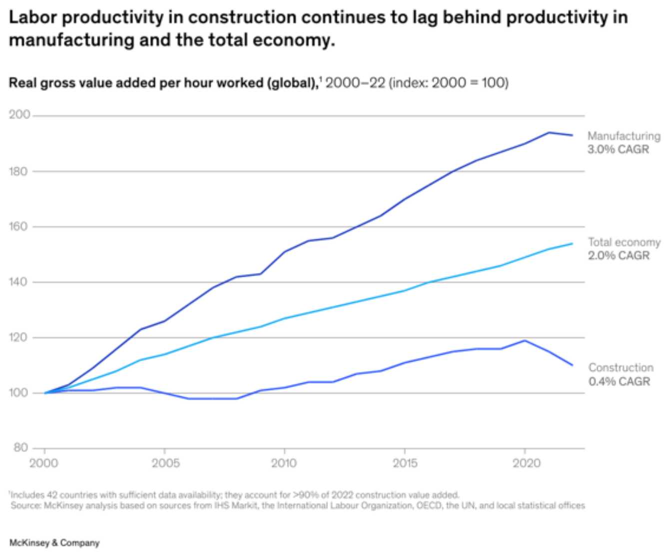

Figure 1: Labour productivity trends in manufacturing and construction over the years (McKinsey, 2024)

One of the key issues addressed by the present research is the productivity deficit within the construction industry. It also shines the light on the environmental implications of the sector. A recent report by the United Nations on the Global Status for Buildings and Construction states that "the building sector […] is estimated to be responsible for around 21 percent of all global greenhouse gas" (United Nations, 2024). In addition to these extremely high emissions levels, the industry is one of the highest energy consumers worldwide, with "energy demand in buildings account[ing] for around 37 percent of total global energy demand and 37 percent of energy and process-related CO_2 emissions for buildings operation and materials production" (United Nations, 2024). These figures are particularly concerning, especially as environmental awareness begins to gain traction within the construction industry, enhancing the need for urgent and effective interventions.

1.2 Problem statement

Some of the prevailing challenges confronting affordable housing availability come from the extreme fragmentation of the construction manufacturing sector. Thus, when a multi-storey residential building has to be built using light-frame wooden prefabricated structure, the manufacturers (usually small family-owned factories) are not able to reply to the bid together, as they have different production processes, and the final products will not be uniform. Thus, this research explores the potential of the standardization of certain elements of light-frame wood prefabrication for multi-storey residential buildings in order to build efficiently bigger projects such as multi-residential ones. The hypothesis is that the standardization of some aspects of the products, or of the production processes, would enhance the productivity by optimizing supply chains, allowing bulk purchasing and crosspollinating manufacturing strategies. A literature review will study the benefits of using prefabricated light-frame wood construction, how its standardization can mirror successful practices from other industries, and how other countries have addressed similar challenges. The objective of this study is to explore the reasons behind the present lack of an existing standardization, to identify the components that should be standardized, to determine who could lead this initiative, and to understand how it can be implemented. Interviews were conducted with various stakeholders to gauge their responses to research questions, in order to direct potential strategies for standardization in connectors, details, processes and supply chains.

2. LITERATURE REVIEW

2.1 Benefits of prefabricated light-frame wood

This literature review explores the impact of prefabricated light-frame wooden structures from both an environmental and a productivity perspective.

Various scientific studies have highlighted the environmental benefits of prefabrication, particularly when using wood. For instance, Svajlenka et al. (2017) conducted a comparative study showing that prefabricated panelized timber panels when compared to conventional masonry, reduce both embodied energy and CO_2 emissions. These environmental parameters were assessed using the Life Cycle Assessment (LCA) method, specifically the "Cradle to Gate" approach (Svajlenka et al., 2017). Building on this, Evison et al. (2018) noted that some environmental benefits of Mass Timber Construction (MTC), such as its reduced carbon footprint, are not yet fully valued by the market. While these studies do not specifically address modular prefabrication with light-frame timber, they provide strong evidence of the environmental advantages of wood-based construction. The use of light-frame wood in prefabrication allows manufacturers to minimize waste through controlled production environments. For example, some companies have repurposed small wood chips from the cutting process to create eco-friendly insulation. Additionally, a 2011 survey by McGraw Hill Construction found that 44% of companies believed construction site waste could be reduced by 5% through prefabrication (Gharbia et al., 2023). Similar benefits have been demonstrated in other industries as a result of a standardization, which was found to reduce variability in options and minimize errors in final products (Smith, 2011). These findings suggest that adopting standardized practices in prefabricated light-frame wooden elements could further enhance their environmental and operational efficiency.

Secondly, the use of prefabricated light-frame wooden building elements is reported to enhance productivity thanks to the relocation of construction in a controlled and protected area. By controlling the production environment in the prefabrication factory, it becomes possible to design, manufacture, assemble, and operate more efficiently. Wood (2021) pointed that “the productivity of factory staff is 80% relative to 20% productivity of on-site workers”, engaging higher productivity and reduced labor expenses. This productivity improvement can be attributed to the implementation of Design for Manufacturing and Assembly (DfMA) and Design for Deconstruction (DfD), which substantially increase productivity. DfMA allows for a better design, which implies lower work off-site and rework on-site. Numerous studies have demonstrated that, in comparison with conventional construction methods, the implementation of offsite manufacturing, modern methods of construction (MMC), DfMA, and DfD has been shown to "improve quality [...], health and safety [and] productivity" (Abrishami & Martin-Duran, 2021). Prefabrication, in general, has been shown to enhance the safety of the workforce, whose operations have been streamlined: namely, workers, who act as prefabricators, no longer work in outdoor environments where the weather is unpredictable, or at elevated heights, where there is a higher risk of falling - instead, they work in a controlled environment, such as a factory (Wood, 2018).

The implementation of DfMA in the early stages of a project facilitates the optimization of manufacturing processes and of designs; a better design from the very beginning of a project contributes to enhanced cost control. The adoption of offsite construction, particularly in combination with modular prefabrication, has shown a "greater degree of predictability in cost" (Smith, 2016). Using DfMA enables to proactively consider manufacturing and assembly aspects within the project's design phase. This approach has the potential to reduce both time and cost by utilizing standard components, reusing previously designed elements, and employing modular design principles. (Cao et al., 2022).

The above points highlight the advantages of light-frame wood prefabrication in comparison with traditional construction methods. Nevertheless, the extreme fragmentation and the product variability of the industry in this sector (among other factors), prevent these advantages to be systematically achieved.

2.2 How can we follow the example of other industries?

Enhancing modular light-frame wood prefabrication through standardization may present significant challenges considering how each company has a specific production process. Therefore, it is interesting to examine how other industries have successfully implemented standardization in their production processes to identify applicable methodologies.

The steel construction industry faced a serious need for standardization in the aftermath of World War I because of the lack of inspection continuity. This led to the collaboration of industry leaders, who brought together their expertise to develop a comprehensive set of practices. They needed to “establish[..] a single code authority that would be recognized by building code authorities and designers to eliminate the confusion that then existed in the construction industry, caused by the numerous and different manuals each containing proprietary information” (Galambos, 2016). The establishment of the first AISC Specification in 1923 can be attributed to the collaborative efforts of two professors, two structural engineers, and one architect. These individuals aimed to develop a performance-based specification that would serve as a unifying standard within the industry. The introduction of this specification can be regarded as a significant milestone (Nyman et al., 1973; Galambos, 2016). Developing such specifications or standards calls for a continuous dialogue among industry stakeholders, with additional actors coming in as the process rolls out. The significance of this development was recognized by the then-Secretary of Commerce, Herbert Hoover, an engineer and later President of the U.S., who commended the AISC in a formal letter (Galambos, 2016). This demonstrates that the convergence of diverse stakeholders, including government representatives, was crucial in promoting the implementation of the specification to address the pressing need for steel construction during that period. This collaborative effort culminated in the establishment of a standard that is currently embraced by most of the industry.

An additional noteworthy example is in light-frame steel prefabrication, where manufacturers advocate for the utilization of "standard sizes" in design and project development. This approach enables them to maintain "materials in stock and utilize standard jigs and machinery settings in production, which shortens the supply lead times" (Gorgolewski, 2009). The aspiration for a uniform fundamental form in the steel industry emanated from manufacturers and fabricators, who recognized the potential benefits of standardization. Repetitive production facilitates the establishment of standards for units, thereby enabling economic efficiencies. This notion was further substantiated by a report published by the Construction Industry Research and Information Association (CIRIA) in 1999, titled "Adding value to construction projects through standardization and pre-assembly" (Gorgolewski, 2009).

It is evident that the steel construction industry has adopted a standardization approach, encompassing both light-frame and steel structure applications. This standardization has been facilitated by the collaborative efforts of manufacturers, who have exerted pressure to implement standard design and process. In light of this, it is pertinent to question whether light-frame wood modular volumetric prefabrication could be subject to similar standardization measures.

2.3 What can be learned from other countries?

In Europe, there is greater understanding of the value of standardization in general, as compared to Canada. Anastasiades et al. (2021) emphasize the potential benefits of standardization for both the construction industry and the environment, as it fosters a circular economy through the utilization of wood and modularity. However, it is crucial for contractors and designers to perceive this type of standardization not as a threat to their work, but as an opportunity for advancement. By standardizing building component dimensions and connections, the demand for these building components will increase, and consequently, their reuse will be enabled and facilitated (Anastasiades et al., 2021). This analysis demonstrates that there is significant ongoing reflection concerning standardization in the global construction industry.

Another perspective has emerged in Sweden, where the light-frame panelized wood prefabrication approach focuses on the conceptualization of subassemblies, thereby achieving a certain degree of design freedom while leveraging the advantages of manufacturing (Smith et al., 2022; Wood, 2018). Moreover, Sweden maintains a competitive edge over other countries through the operation of its extensive, automated factory lines. The integration of robotics within the assembly line has transformed the construction sector, aligning it more closely with the automotive manufacturing industry. This approach, influenced by Toyota's lean production methods, which prioritize minimizing waste and empowering workers to contribute to efficiency gains, has enabled Lindbäcks, a leading Scandinavian manufacturer of modular homes, to enhance its production efficiency and outperform its competitors (Morley, 2017). This example highlights the advanced position of these European leaders.

In Japan, there is also a higher utilization of prefabricated light-frame wood systems. The high cost of land necessitates a rapid return on investment for developers, leading to a preference for modular construction methods due to their rapid construction time (Gorgolewski et al., 2009). Japan's expertise in this modern construction method can be attributed to its long-standing experience, which was initiated by public investments after the Second World War, that promoted the adoption of offsite construction. This was followed by measures to enhance standardization, primarily driven by industry initiatives (Smith et al., 2022). The absence of prejudices about prefabrication in Japan has contributed to the advancement of modular prefabrication (Smith et al., 2022). Investors in Japan prioritize modular prefabrication due to its reputation for delivering high-quality outcomes (Smith 2011).

As demonstrated by the examples of Europe, Sweden and Japan, there is a considerable potential for enhancement in the prefabrication industry. To maintain competitiveness and a substantial presence in the market in the coming years, Québec must align its efforts with those of its counterparts.

3. RESEARCH METHOD

The objective of this study is to explore the potential for standardization of certain aspects of the light-frame modular volumetric timber construction. As a first step, it is necessary to understand the motivations behind standardization for different stakeholders. To this end, semi-directive interviews were conducted with various stakeholders. This method is intended to facilitate discussion focusing on the investigators' predetermined agenda while permitting the interviewee to articulate their perspectives. To ensure data consistency, an analysis matrix is constructed to systematically compile responses and facilitate reliable comparative analysis.

The matrix is divided into four categories. The first category is *the interviewee's background and affiliation*. Here, we seek to contextualize the interviewees' answers by examining their experience in the industry, the number of projects they undertake annually, fabrication processes, etc. To ensure a clear comparison between stakeholders, it is essential to understand their differences, client interactions, and business models. The second category is *the interviewee's idealistic approach to standardization*. In this part, we address the core of our research, namely, their perspectives on standardization. The third category is *the interviewee's realistic view of the question*. Following an examination of their idealistic notions regarding specific aspects of standardization, we will address the question of the pragmatic feasibility of implementing standardization. We aim to understand, on the one hand, how standardization could facilitate the production of modular prefabricated light-frame wood dwellings, and, on the other hand, which type of standardization could be established. The fourth category is *the interviewee's thoughts on who must drive and engage such an initiative*. Here, the potential implementation will be examined, with the aim of understanding which type of governance should be put in place to implement and manage such standardization, according to the interviewees.

Table 1: Analysis matrix

Participant	Context/ Distinction	Idealist View	Realistic approach	Leading figures
Domains / Contact	Seniority Business model, contract used, Actual innovation, differences	Process Market involvement Code and contract Design	New process Design	Who How
Manufacturer …				

General contractor …	
Architect …	
Association …	
Doctorate …	

For example, for each categories, we asked the participants: "*How long have you been on the modular volumetric prefabricated market?", "What do you see as an idealistic standardization concerning the process of prefabricating modular volumetric?", "What standardization can be implemented right now and would be beneficial for the industry?", "Who should lead this initiative of standardization and how?".*

In average two people representing each of the following categories were interviewed: *manufacturers*, *general contractors*, *architects*, *associations presidents*, and *doctoral researchers*. The analysis matrix allowed us to direct our enquiries at specific topics while also ensuring that the interviewees have the autonomy to articulate and elaborate on their perspectives. After the transcription of the interviews, a qualitative comparison of the overall data will be undertaken.

The aim of the interviews is to gather as many perspectives as possible concerning the standardization of light-frame modular volumetric wood. Ideally, we would also like to extract some ideas concerning technical solutions that the interviewees would like to see in the future. In general, the objective is to collect the interviewees' perspective to ensure that standard solutions that might be proposed in a future project meet the expectations of different stakeholders.

4. FINDINGS

Even if only half of the interviews have been conducted by now, we managed to gather some interesting findings. For example, some contradictory motivations were identified in the interviewees' responses. For instance, when we suggested the idea of a standardization in order to be able to engage in larger-scale projects bidding, manufacturers sought to enhance their market presence by implementing such standardization. However, the family-oriented nature of their business compelled them to withhold their knowledge and processes. In another case, a manufacturer underscored the difficulties in adopting a universal standard for modular prefabrication, noting that each company, as a family-owned entity, operates under unique processes that render standardization impractical. For example, one of the manufacturers explains that in their processes to a project, they are willing to manage to do the transportation and the installation on-site because of their capacity to do so. By interviewing associations, we gained insights into alternative perspectives, as evidenced by the strong conviction in future standardization expressed by two individuals from the same association. The implementation of enhanced digitalization, such as the expanded use of building design software with manufacturer feedback, is poised to give rise to a certain degree of standardization. A notable finding was the divergence in approach and vision between manufacturers and association directors regarding specific projects, including major initiatives by the government. Manufacturers regarded this initiative as utopian and unrealistic, while association directors advocated for and supported it as a revolutionary endeavour. Moreover, interviewing a general contractor allowed to understand his motivations behind the lack of interest in using modular prefabricated light-frame wood solutions.

5. CONCLUSIONS

To conclude, this study proved, through its literature review, that it is possible to implement a certain standardization in the modular volumetric prefabricated light-frame wood industry. Moreover, it is apparent that the use of modular volumetric light-frame wood is more than beneficial from an environmental, productivity efficiency and cost reduction perspective. The Quebec light-frame wood volumetric prefabrication industry can learn from the standardization process in the steel industry, as well as from the positive experience in other counties like Sweden and Japan.

Based on semi-structured interviews with industry representatives, our research highlighted the divergence in the opinions of the different categories of interviewees on the question of the implementation of a certain level of standardization. It is apparent, based on these interviews, that the respondents adopt a nuanced stance regarding the standardization of certain aspects of light-frame wood modular volumetric prefabrication for affordable housing. A common motivation among them is to develop various standardization types such as standard sanitary pods with the aim of enhancing productivity, increasing volume, and augmenting affordable housing orders. While addressing societal crises necessitates prompt action, it is crucial to recognize the need for a comprehensive transformation, a process that will require time. It should be noted that this research is a part of an on-going Master's research project. Thus, the contribution of this work sought to be the beginning of a larger research concerning this standardization. Having addressed the stakeholders' perceptions of standardization, we plan to propose a standardization process framework in a subsequent work. The limitations of this study stem mainly from the short duration of the Master's research. Thus, the period dedicated to interviews was limited, hence the need to extend these findings with further interviews. That work should consider all the feedback collected to date and formulate a proposal that will be utilized and accepted by the industry.

ACKNOWLEDGMENTS

The authors would like to personally thank every participant for their availability, and their desire to share their thoughts about our research.

REFERENCES

Abrishami, S. and Martín-Durán, R. 2021. BIM and DfMA: A Paradigm of New Opportunities. *Sustainability* 13, No. 17: 9591. https://doi.org/10.3390/su13179591.

Anastasiades, K., Goffin, J., Rinke, M., Buyle, M., Audenaert, A. and Blom, J. 2021. Standardization: An Essential Enabler for the Circular Reuse of Construction Components? A Trajectory for a Cleaner European Construction Industry. *Journal of Cleaner Production* 298: 126864. https://doi.org/10.1016/j.jclepro.2021.126864.

Cao, J., Bucher, D.F., Hall, D.M., and Eggers, M. 2022. A Graph-Based Approach for Module Library Development in Industrialized Construction. *Computers in Industry* 139: 103659. https://doi.org/10.1016/j.compind.2022.103659.

Evison, D.C., Kremer, P.D. and Guiver, J. 2018. Mass timber construction in Australia and New Zealand—status, and economic and environmental influences on adoption. *Wood and Fibre Science* 50, nº Special: 128-38. https://doi.org/10.22382/wfs-2018-046.

Galambos, T. 2016. History of the AISC Specification.

Gharbia, M., Chang-Richards, A., Xu, X., Höök, M., Stehn, L., Jähne, R., Hall, D., Park, K., Hong, J. and Feng, Y. 2023. Building Code Compliance for Offsite Construction. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* 15, No. 2: 04522056. https://doi.org/10.1061/JLADAH.LADR-856.

Gorgolewski, M. T., Grubb P. J. and Lawson, R.M. 2009. Design of Residential Buildings, *Modular Construction using Light Steel Framing, The Steel Construction Institute.*

Mischke, J., Stokvis, K. and Vermeltfoort, K. 2024. Delivering on Construction Productivity Is No Longer Optional, *McKinsey & Company*.

Morley, J. B., 2017. Production Line: How Sweden Is Pioneering Automated, Prefab Timber Construction, *Architizer Journal*. https://architizer.com/blog/inspiration/industry/swedish-modular-housing/.

Nyman, D.J., Fenves, S. J. and Wright, R.N. 1973. Restructuring study of the AISC Specification, *civil engineering studies, structural research series,* n°393.

Smith, R.E., Rupnik, I., Schmetterer, T. and Barry, K. 2022. Offsite Construction for Housing: Research Roadmap, *U.S. Department of Housing and Urban Development, Office of Policy Development and Research*.

Smith, R.E., 2016. Offsite and Modular Construction Explained, *National Institute of Building Sciences.*

Smith, R.E., 2011. Prefab Architecture: A Guide to Modular Design and Construction, *John Wiley & Sons,* Hoboken, New Jersey.

Statistique Canada. 2024. L'abordabilité du logement au Canada, 2022, *Le Quotidien*, nº 11.

Švajlenka, J., Kozlovská, M. and Spišáková, M. 2017. The Benefits of Modern Method of Construction Based on Wood in the Context of Sustainability, *International Journal of Environmental Science and Technology* 14, No. 8: 1591-1602. https://doi.org/10.1007/s13762-017-1282-6.

United Nations Environment Programme. 2024. *2023 Global Status Report for Buildings and Construction: Beyond Foundations - Mainstreaming Sustainable Solutions to Cut Emissions from the Buildings Sector*. https://doi.org/10.59117/20.500.11822/45095.

Wood, B. 2021. Delivery Platforms for Government Assets Creating a marketplace for manufactured spaces.

Wood, B. 2018. Platforms Bridging the gap between construction + manufacturing.