UNIVERSITY OF TORONTO
SCHOOL OF CITIES

# SCALING UP MODULAR CONSTRUCTION

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English

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## DESIGN

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# RESEARCH QUESTION

How can modular housing be scaled up, with an emphasis on overcoming constraints in relationships between developers, manufacturers, and construction companies?

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# EXECUTIVE SUMMARY

This report seeks to address how modular housing can be scaled up, with an emphasis on overcoming constraints by focusing on the relationships between developers, manufacturers, and construction companies. The report is broken down into four sections consisting of (1) Overview, (2) Barriers and enablers of scaling up, (3) Examples of overcoming barriers, and (4) Recommendations.

Section 1 explains that modular construction refers to various building methods that assemble a structure on-site from already-made components (Murray-Parkes et al., 2017). All components follow an off-site factory-produced method, typically consisting of repetitive modules and units for easy assembly. The benefit of off-site production is that it can respond to site-specific environments or can be mass produced to fit a variety of environments (Ferdous et al., 2019).

Section 2 explains that modular construction offers numerous benefits, especially when realized at scale, but several barriers hinder its widespread adoption. These barriers occur at the project, organizational, and industry scales and require solutions at all three. The section explores the barriers and suggests possible solutions, with a particular focus on the relationship between the stakeholders in the Canadian context.

Section 3 draws on case studies to identify key strategies that facilitate successful modular housing projects and Section 4 reviews the recommendations for modular construction to scale up its practice, including project and organizational changes, and industry partnerships to advocate for big picture change.

## RESEARCH LIMITATIONS

The study explores international literature and case studies on scaling up modular construction. As next steps, it would be beneficial to study modular construction practices in Canada through primary research, case studies, and comparative analysis.

# 1. OVERVIEW

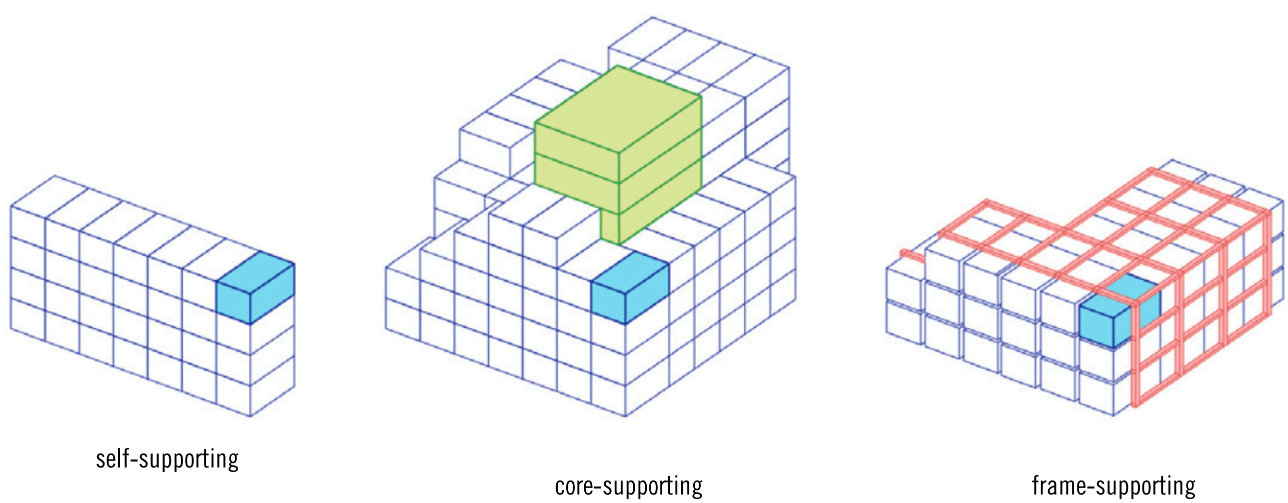
## WHAT IS MODULAR CONSTRUCTION?

There is no singular term for modular construction, and the terms modular construction, offsite construction and prefabrication are used interchangeably (Bertram et al., 2019). Modular construction refers to various building methods that assemble a structure on-site from already-made components (Murray-Parkes et al., 2017). All components follow an off-site factory-produced method, typically consisting of repetitive modules and units for easy assembly.

*Modular construction refers to various* ***building methods that assemble a structure on-site*** *from already-made components*

Modular construction uses the same materials – such as timber, steel, and concrete – as traditional building methods, but is different in the various structural components and materials used in precast construction. For instance, modular buildings may have precast facades, staircases, and slabs which are enforced by panels and steel frames (Ferdous et al., 2019). Generally, modular construction can take three forms: (1) self-supporting load-bearing modules, (2) core- supporting modules or (3) frame-supported modules (Ferdous et al., 2019) (Figure 1). All its offsite components must be individually structurally stable to endure transportation and on-site assembly.

**Figure 1: Three possible forms of modular construction**

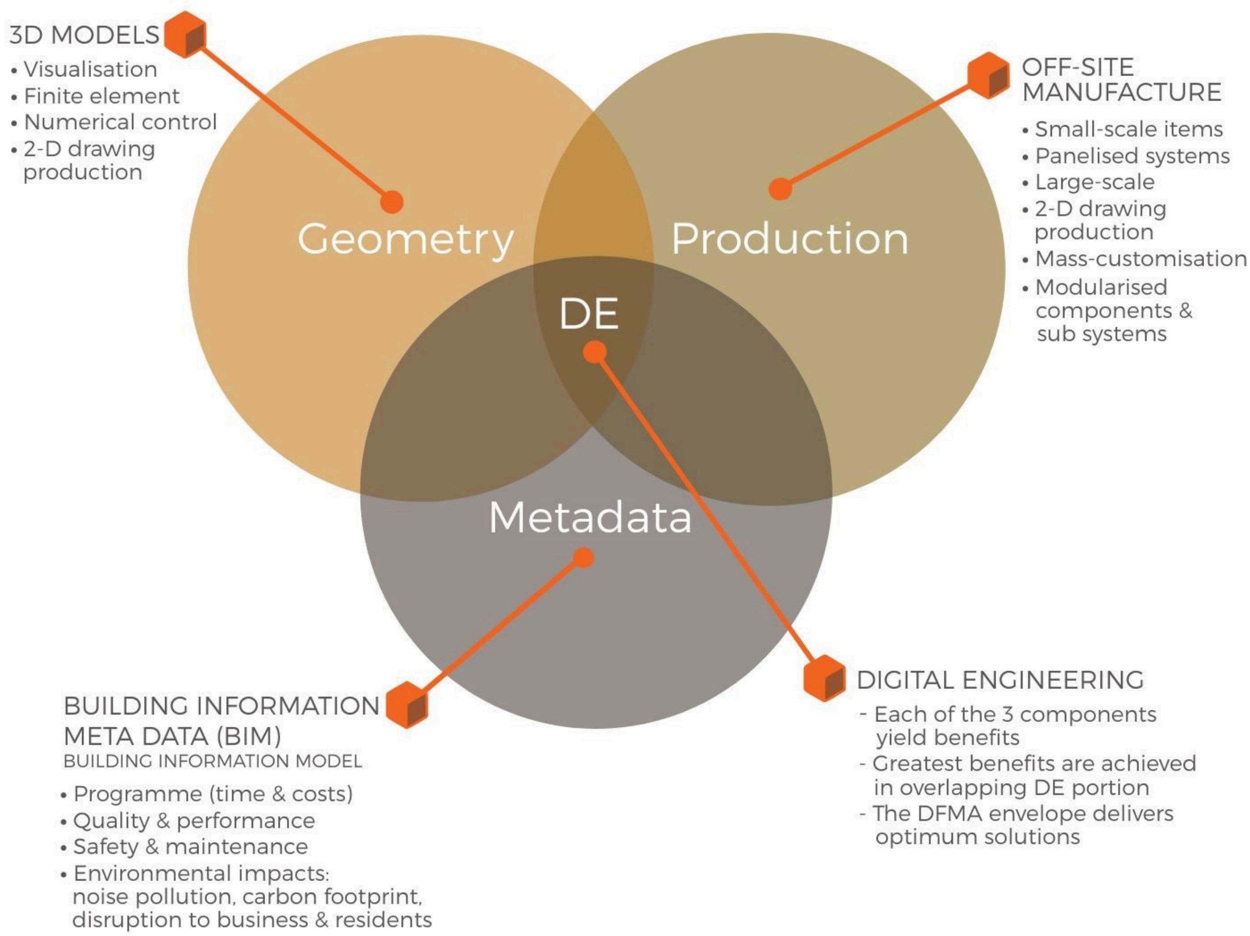



Source: Bellini et al., 2023

Modular building methods have become increasingly popular in Canada, encompassing 4- 6% of all construction, due to their ability to minimize on-site labour and construction material unpredictability (Dragicevic & Riaz, 2024; CSA 2023). As each building component is made under predictable conditions in a factory, risk is minimized in the prefabrication process (Murray-Parkes et al., 2017). Prefabrication requires designing each component of a building while simultaneously designing the assembly process needed for each piece to fuse in creating modular components (Murray-Parkes et al., 2017).

To make sense of the process involved in modular construction, Murray-Parkes et al. coined the term Design for Manufacture and Assembly (DfMA) (Figure 2).

**Figure 2: DfMA design process**




Source: Murray-Parkes et al., 2017

## WHAT ARE THE ADVANTAGES OF MODULAR CONSTRUCTION?

Modular construction is successful in that it offers numerous solutions to challenges that occur in on-site construction. While there are many benefits to modular construction, the main ones include: (i) decreased on-site construction time, (ii) a safer and more diverse workforce, (iii) quality control, (iv) increased opportunity for green building methods, (v) cost-effectiveness in the construction process and labour, and (vi) opportunity for affordable construction.

### *i) Decreased construction time*

The time needed to construct modular buildings is significantly reduced compared to traditional building methods. Modules can be manufactured as the site is prepared for construction (Henderson, 2020) saving 10-25% compared to traditional construction costs through reduced labour, site overheads, and construction management (Bertram et al. 2019). Time efficiency is further expedited through reduced site activity, improved safety conditions, and reduced risk of on-site construction material theft (CMHC 2020). As modular construction sites are typically smaller and have a speedy on-site assembly, they cause less construction noise and neighbourhood disruptions, and use less energy (Murray-Parkes et al., 2017). A big factor in the efficiencies of modular construction is that companies treat modular building as products rather than projects (Blanco et al., 2023). They do this by prioritizing best-in-class manufacturing capabilities, including sophisticated digital design platforms and lean, efficient production lines (Blanco et al., 2023).

> *The **time needed to construct modular buildings is significantly reduced** compared to traditional building methods.*

### *ii) A safer and more diverse workforce*

Modular construction is safer for workers. When construction takes place in a weather-controlled environment, the absence of rain and snow eliminates slippery surfaces and cuts down on slips and falls. It also eliminates the risks of exposing electrical lines to moisture, which can cause electrocution (Boxx, 2018). Because factory-based construction work has more predictable hours and more locations than on-site construction, a more diverse labour force, in terms of gender and age, can be attracted (Modular Building Institute, 2024). For instance, at Lindbäcks, a modular construction company in Sweden, 30% of the workforce is female (Mari, 2024).

### *iii) Quality control*

Quality control makes modular construction more reliable. As components are made in a factory-controlled setting, they are not subject to outside elements that could hinder the building process or threaten the integrity of the structure. Creating building components in a factory-controlled setting reduces resource waste and time lost to weather constraints. All materials used are carefully chosen to fit the needs of a project, be liftable by a crane, and fit the energy requirements for construction (Ferdous et al., 2019). The standardized framework, repetition of design (Mari, 2024), and ability to confirm design details prior to production (Mitchell, 2021) all allow for greater accuracy.

### *iv) Greener buildings*

The modular building process also allows for reduced energy consumption in the construction of buildings. Traditional building practices account for 32% of energy consumption, 30% of carbon dioxide emissions, and 30-40% of waste generation (Ferdous et al., 2019). Modular construction alternatively reduces landfill waste by 70% and delivery vehicle emissions by 70%. Air sealing and overall energy efficiency impact can also be affected (CMHC, 2020).

### *v) Cost effectiveness*

Modular construction presents opportunities for cost-effective building practices. For instance, the price per square foot of modular housing can be half the cost of produced on-site homes. (Goodman, 2023). As all module pieces are built off-site, the entirety of the building can be made in a factory, cutting labour and construction costs. Time costs can also be lessened, as factories can run around the clock, making it achievable to meet construction deadlines (Ferdous et al., 2019). Prefabricated factory construction can also increase productivity, allowing for high-volume automation in structural standardization, and so for higher modular production and larger buildings (Murray-Parkes et al., 2017). The “right design” can improve productivity by 3-12%, and productivity will go up as more expertise is established (Bertram et al. 2019).

Additionally, the detailed upfront design lowers project costs by 5-8% by minimizing on-site rework and redesign (Bertram et al. 2019). This saves time, material and labour, offering greater cost precision and control due to limited change orders (Smith & Rice, 2015).

### *vi) Opportunity for affordable housing construction*

Modular construction does not inherently mean affordable construction costs, but costs can become more predictable if they are intentionally controlled in the design and planning process (Wilson, 2023). Project costs are determined through initial meetings with the modular manufacturer, who details design specifications and transportation costs. Some examples of cost variables include the fabrication process, production time, facility capability, trucking distance between facility and site, and number of trips required (Wilson, 2023).

In some cases, depending on project location, it can be more cost effective to make modules as large as possible within regulations and to pay for police escorting/special routing to reduce the amount of modules that must be built and the number of trips made (Wilson, 2023). Ultimately, modular construction needs to be understood as a combination of hard and soft costs, the outputs of which are a lifecycle investment (Wilson, 2023): although upfront costs are high, if the project is implemented correctly, it will ultimately be cost-effective and will create value into the future (Wilson, 2023).

## WHERE HAS MODULAR BECOME THE NORM?

Modular forms of construction are under increased scrutiny as construction labour supply lags behind housing demand globally (Bertram et al., 2019). Several Scandinavian countries (Sweden, Finland, Norway) and Japan have scaled up modular construction, with several other jurisdictions (Germany, Austria, U.K.) investigating this approach.

Modular construction in Sweden dates back to the 1960s Million Home Program.[1] Today, almost 45%[2] of multistorey residential buildings integrate prefabricated elements into their construction framework (Lessing & Stehn, 2020). Swedish modular firms use a customer-centered business model to ensure design flexibility and quality of products (Manley & Widén, 2019).

A major operator of modular housing in the country is BoKlok, which is a subdivision of the famous Swedish furniture company Ikea and the construction company Skanska (Lessing & Stehn, 2020). Ikea became popular during the Million Home Program, when they introduced flat pack furniture to fit mass-produced apartments ("First Store in Stockholm Paved New Roads - IKEA Museum," 2024). BoKlok has been operating since 1995 and has built over 10,000 prefabricated homes since its inception (Lessing & Stehn, 2020).

**Figure 3: BoKlok modular neighbourhood Växhuset in Mariastaden**

Source: BoKlok Växthuset - Nybyggda Lägenheter i Helsingborg, 2024

The company specializes in small scale detached housing, townhomes, and residential buildings of 2-6 storeys which cater to the needs of families in need of affordable housing (Figure 3) (Lessing & Stehn, 2020). Fully 85% of total production is factory built, including structural frames, insulation, windows, doors, electrical components, heating, ventilation and air conditioning, flooring, kitchen, bathroom, and external cladding (Lessing & Stehn, 2020).

Off-site construction has been a driving force in Japan since the establishment of the Japan Housing Corporation[3] in the 1950s (Liu et al., 2019). Modular housing was seen as the solution to the housing shortage created by bombing during WWII, as well as by the accelerated birthrate – a global phenomenon after the war (Liu et al., 2019). Today, the modular housing market continues to be strong, making up 15% of the stock of single detached homes (Lessing & Stehn, 2020) – Japan builds more than 70,000 prefabricated buildings per year (Liu et al., 2019; Bayliss & Bergin, 2020).

To meet the high demand of the country's housing market, Japan relies on high-tech and large-scale production facilities to produce the off-site components of modular construction (Manley & Widén, 2019). The advancement of the modular sector allows firms to customize housing options through standardized manufacturing and automation (Manley & Widén, 2019).

A Japanese company that has been leading the way in large scale modular construction is Sekisui House. The company began building modular housing in the 60s and has since expanded into Australia, Singapore, China, and the U.S. (Buntrock, 2017). As of 2013, the company had built 1,038 multistorey residential towers, and its pace has not slowed down (Buntrock, 2017).

**Figure 4: CG image of the Heim Sagamihara Suite Yokoyamadai building, a 9-story mixed-use development completed by Sekisui House in 2023, and designed to mimic the Tanzawa Mountains in the distance**

Source: Sekisui Chemical Co., Ltd., 2024

# 2. BARRIERS AND ENABLERS TO SCALING UP

The need to improve productivity in Canada's construction sector is now recognized by housing advocates and the federal government (Government of Canada, 2024; Taskforce for Housing and Climate, 2024). In the current global scenario of housing crises and labour shortages, modular construction can be the broadscale 'game-changer' in the industry (McKinsey & Company, 2019; Taskforce for Housing and Climate 2024; Government of Canada, 2024). Modular offers numerous benefits, especially when realized at scale, but several barriers at the project, organizational and industry scales hinder its widespread adoption. This section explores the barriers and suggests possible solutions, with a particular focus on the relationship between the stakeholders in the Canadian context.

*In the current global scenario of housing crises and labour shortages, **modular construction can be the broadscale 'game-changer'** in the industry.*

## BUILDING CODE STANDARDIZATION

The regulatory environment can pose a substantial barrier to scaling up modular construction. Building codes and regulations, which vary by province and municipality, are typically designed for traditional construction methods. The complexity of building code differences can make scaling up across provinces and territories, or even scaling up beyond one municipality, difficult. In North America, building codes are "prescriptive", specifying materials and their usage and creating an inefficient pace of work. Conversely, in Sweden building codes are based on "performance", creating the space for builders to be innovative in achieving outcomes (Mari, 2024).

Development permits and rezoning do not necessarily move as fast as modular projects (CMHC, 2021). Since time is money, regulatory delays and the need for repeated approvals can lead to project delays and increased costs. In such a landscape, manufacturing companies are forced to navigate a complex web of local, provincial, and federal regulations to ensure compliance of the modules. It is therefore important for construction contracts to account for jurisdictional variations and to include clauses that ensure all stakeholders adhere to the relevant building and working codes and regulations (Azghandi-Roshnavand, 2019). In the longer term, CMHC (2021) suggests coordinating building codes across all regions by improving the National Building Code and supporting harmonization by provinces and territories. The advocacy lead could be the Canadian Home Building Association's Modular Construction Council, which was formed in 2017 to prioritize the development of codes, standards and regulations by liaising with officials, government and regulatory bodies (Modular Construction Council, 2024).

In Canada, all modular projects must meet the same building standards as conventionally-constructed buildings (CSA Group, 2023). Standard *CSA A277:16 (R2021): Procedure for certification of prefabricated buildings, modules, and panels*, issued in 2009, ensures that modular projects meet the National Building Code and the planning and organizational requirements applicable to the work that takes place in-factory. As of 2019, there were 147 factories in the country certified to build residential structures (Mitchell, 2021).

In-factory inspections take place at various stages of the manufacturing process. When on-site, the certification process can limit inspections by Authorities Having Jurisdiction (AHJ) to the connection of the in-factory modular components to the on-site elements. This saves both time and money (Mitchell, 2021). However, it must be noted that the regulatory framework is not fully adapted to support modular construction in all Canadian provinces (Dragicevic et al., 2024).[4]

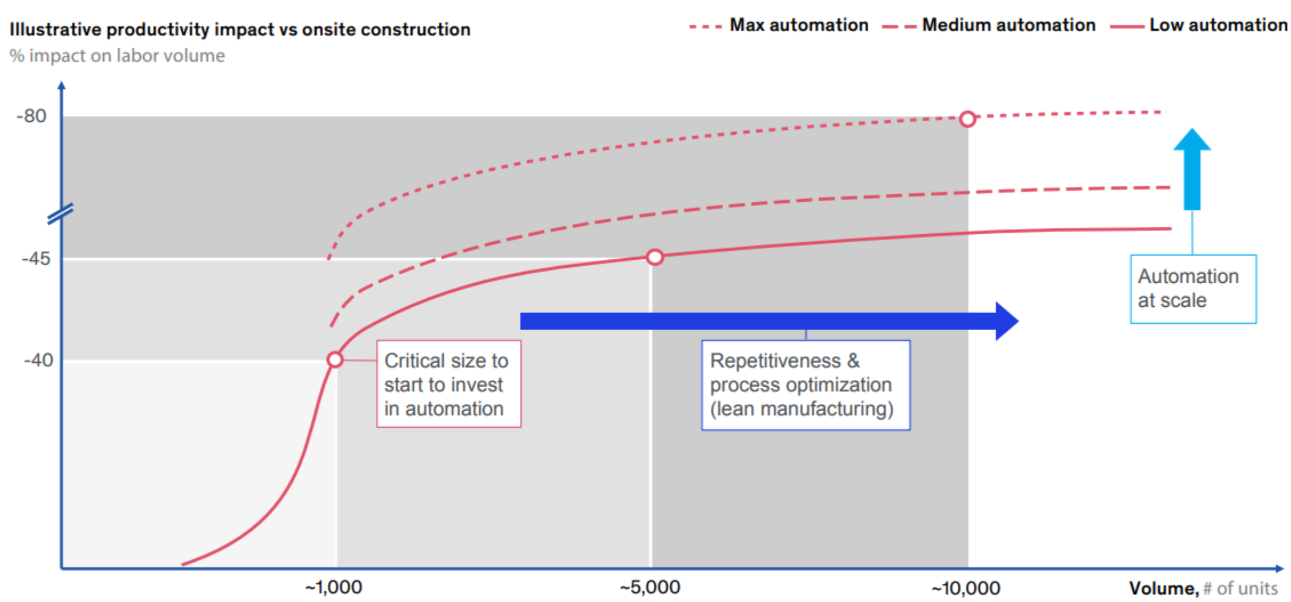
## FINANCING

Smith and Rice (2015) note that the project cost is not necessarily reduced in modular construction – in fact, it sometimes comes at a premium. This will remain the case until modular construction becomes mainstream. Economic costs can be front-loaded in modular construction: in the early stages of scaling, modular construction requires investments in materials and skilled trades training, while the early stages of a project bear the costs of detailed design and additional materials for safe transportation.

To reach economies of scale in the output phase, Bellini et al. say companies need to reach a maximum productivity of approximately 1,000 units per year. Another 5% boost in productivity can be achieved if companies produce 5,000 per annum (Bellini et al., 2023) (Figure 5).

### Figure 5: How to achieve economies of scale in unit production

The first critical productivity step is achieved at approximately 1,000 units a year, beyond which productivity gains slow down.



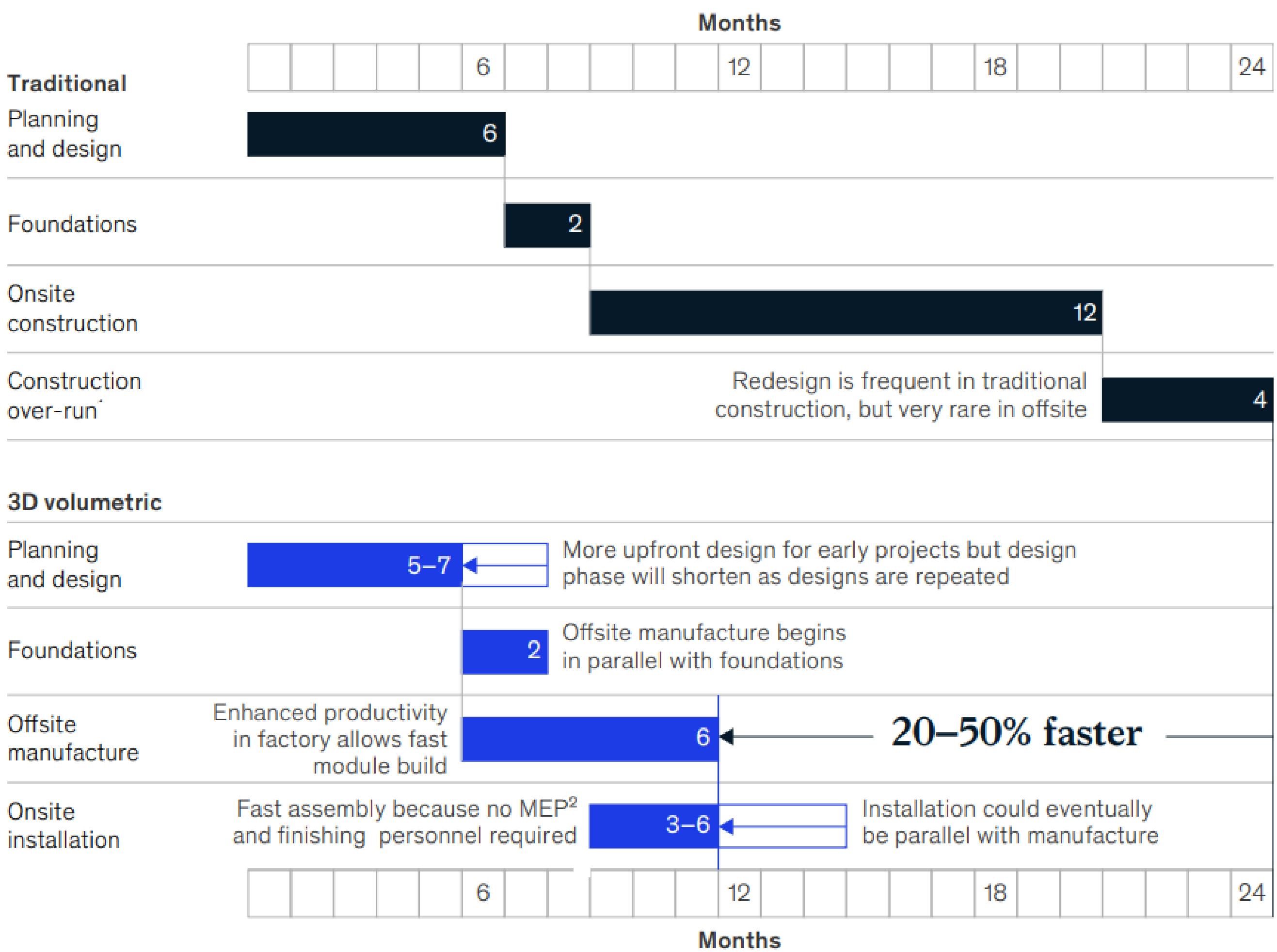

Source: Bertram et al., 2019

However, as it scales up as a proportion of total construction, modular can reduce overall project costs by up to 20% and construction time by 50% (Figure 6 and 7). As the industry gains more experience and integrates technology and transportation efficiencies, these numbers will likely improve (Bertram et al. 2019).

The financial arrangements in modular construction contracts are more complex compared to traditional construction. Payments are often required at different stages, such as at the completion of manufacturing and after the delivery and assembly of modules – so both before on-site construction commences. Innovative payment structures, such as milestone payments or escrow accounts, can help manage financial risks and ensure that funds are available when needed (Azghandi-Roshnavand, 2019).

**Figure 6. Traditional construction timeline and offsite 3D volumetric timeline**

Using 3D volumetric modules can deliver 20-50 percent schedule compression.
Example apartment project construction duration, traditional vs offsite 3D volumetric




Source: Bertram et al., 2019

The current private and public lending practices rarely align with this project flow, severely limiting the availability of financing options for modular projects (Dragicevic et al., 2024). The stakeholders involved in modular construction operate independently of the mainstream construction industry. This means that there are still many small operators, a limited number of companies able to make long-term investments, and a high risk of bankruptcy (Erlich, 2023). The lending rates for modular construction continue to be higher, since it is a relatively new method and not always fully understood by the financing industry (Bertram et al. 2019). This problem can be curtailed with greater uptake for modular construction and new lending and borrowing norms set in place.

As modular construction removes the need for subcontractors, it in turn removes their profit margins. In traditional construction, on-site risks are borne by contractors. Conversely, in modular construction they are often shifted to off-site manufacturers, which allows contractors to limit the need for expansive general liability policies. In turn, insurers and underwriters are forced to lower inflated premiums for on-site work (George, 2018).

Unfortunately, the insurance industry charges premiums for risks associated with the different forms of modular construction. There are risks related to the financing, payment schedules, and contractual obligations between the various stakeholders involved in the project. The insurance costs can be mitigated with early communication among the stakeholders and by including fire safety engineers as part of the project team (Mitchell, 2021).

In U.S. states such as Colorado, special financial programs are offered to encourage modular construction. The state investment is designed to advance innovative construction methods and meet housing demand (Office of the Governor, 2024). When such programs are consistent, they will ensure growth, and possibly amalgamation, within the sector.

*The current* ***private and public lending practices rarely align with this project flow,*** *severely limiting the availability of financing options for modular projects.*

## CONTRACTS

The design process involved in modular construction requires high levels of information flow amongst all team members to ensure adequate problem-solving in offsite production (Mitchell, 2021). To achieve this, contracts must be made to encompass implementation in different production settings, such as operations, assembly, and installation (Arashpour, 2020).

Smith and Rice (2015) recognize the need for all stakeholders to be well versed with the project requirements well before the construction begins. Modular construction requires a non-linear approach to construction contracts, which is a different alignment and process from traditional Design-Bid-Build (DBB) contracts. Mitchell (2021) points to the Integrated Project Delivery (IPD), P3, or Design-Build as more successful procurement models, which involve collaboration amongst the owner, design team, contractors, manufacturer and builders early in the design process. IPD optimizes offsite construction processes by fleshing out details during the design development process: firm construction budgets can be developed, and many typical site construction project risks can be eliminated.

Project contracts must clearly define the responsibilities and liabilities of all the moving parts in the distinct project phases – manufacturing, delivery, and construction/assembly (HCR Law, 2024). This includes items pertaining to intellectual property rights, inspection in the factory and on site, insurance, and insolvency risks between owner and manufacturer. In addition, the contracts must refer to payments in each phase of production and the transfer of ownership of modules, possibly while they are still at the factory being built (HCR Law, 2024).

In 2020, ConsensusDocs Coalition, along with Modular Building Institute (MBI) and other industry leaders, released ConsensusDocs 753 Standard Prefabricated Construction Contract – in which a constructor, general contractor, design-builder, or construction manager contracts with a prefabricator (ConsensusDocs, 2023). It is an “off-the-shelf" solution for addressing important contractual and legal aspects of the off-site construction process (ConcensusDocs, 2023). The contract can be purchased off the ConcensusDocs website for the use of modular construction firms that want to understand the contract process.

Smart Contracts are a digital agreement tool used by modular construction companies to help finance projects efficiently. These contracts combine technology with legislation to ensure that payments are carried out (Christie & Mante, 2022). They follow a blockchain of command – taking information from outside sources in real time and generating outputs that facilitate the smart payment process (Christie & Mante, 2022). The key to the success of smart contracts are the enforcement measures that follow established legal systems in construction (Christie & Mante, 2022). For example, the U.K. amended its *Housing Grants, Construction and Regeneration Act 1996*, to require the implementation of SMART Contracts, making it easier to enforce real consequences (Christie & Mante, 2022).

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## SITE SELECTION

Modular construction may not need as much below-grade preparation or on-site work (depending on module type – panelized/volumetric, partially/fully serviced), but it does eventually require on-site storage and large cranes to move the modules into place. Volumetric modular systems require heavier special rigging and spreader-bars. For adequate reach of this equipment, these buildings are better suited to flat and square-ish plots, rather than steep slopes or deep plots (Mitchell, 2021). Other site considerations include accessible storage facility for modules, overhead powerlines, road widths, and the option for temporary street shut down. Despite these constraints, the disruption caused by modular construction is much less compared to traditional construction methods, owing to its shorter duration (Figure 6) (Bertram et al. 2019).

## DESIGN

The standardization of modules can clash with the desire for unique and customized building designs, as it may limit architectural creativity and flexibility (Erlich, 2023). Modular construction has tended to be most popular for projects with a high level of "repeatability" of floor layouts, systems and finishes; for example, hotels, supportive housing and student accommodation. To accommodate aspirations of uniqueness, one can learn from the automotive industry: each car model looks and feels different due to its finishes, but on the backend, production uses a constant and unchanged processing line to deliver the custom features.

*Most popular for projects with a high level of* ***"repeatability"*** *of floor layouts, systems and finishes*

## LOGISTICS AND TRANSPORTATION

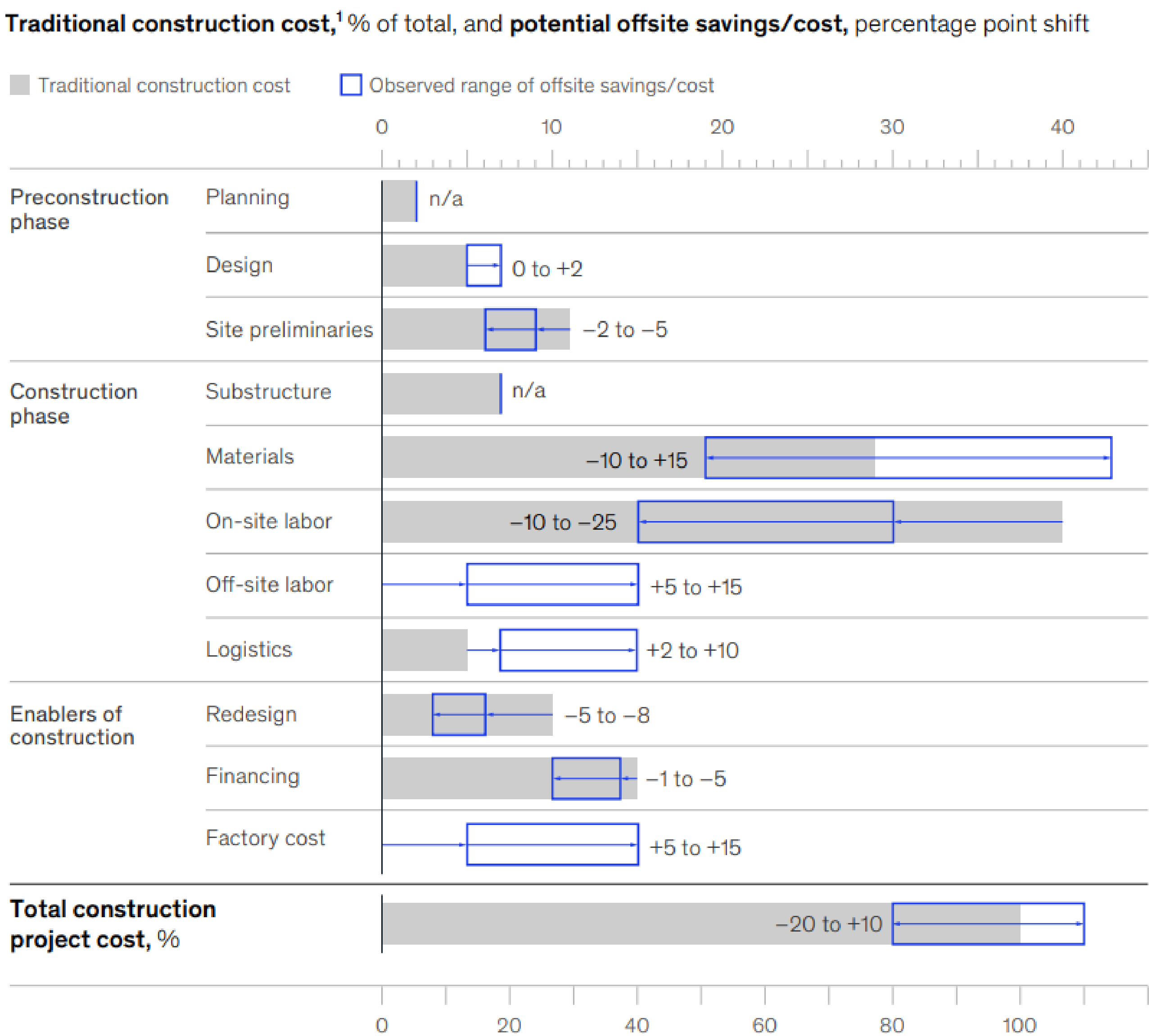
As with all construction methods, supply chain and logistics are crucial to the successful and timely delivery of projects. However, transportation of (semi-)complete modules is a unique barrier associated with this construction method – once manufactured, the modules must reach the construction site. In modular construction, as off-site manufacturing and on-site foundations are being prepared simultaneously, the reliance on efficient logistics is doubled.

Smith and Rice (2015) note the factory's distance to the project site as a significant concern. Trucks loaded with volumetric modules move much more slowly, and moisture damage during transportation or storage can be a risk (CMHC, 2021). There is a significant increase in the cost of materials between modular and traditional construction practices, as the former requires additional materials for structure and for weather-proof transportation. These barriers impact both tight sites within large cities and remote ones further away from factories. It is recommended that manufacturers consider all transportation and regulatory factors in design and engineering to minimize costs (CMHC, 2021; Mitchell, 2021), and that developers consider the distance to the project site when contracting with manufacturers. Eventually, as modular construction uptake increases, more local factories will crop up, reducing travel distances.

Modular components can be large and require specialized transportation, handling, storage, permits, and vehicles. This is especially difficult if transporting across provincial or international lines (Mitchell, 2021) – unfamiliarity with local transportation regulations regarding wide or heavy loads can be disruptive to the commute (Azghandi-Roshnavand, 2019). These concerns can be managed with a detailed study of travel routes – verifying widths, underpasses, tunnels, and curves (Bellini et al., 2023) – and a detailed project plan that only brings the modules to the prepared site when they are ready to be hoisted up (Niu et al., 2019). Where possible, projects should utilize existing infrastructure, such as the well-established shipping industry (McKinsey & Company, 2020).

### Figure 7. Traditional construction cost and potential offsite savings and costs

There is an opportunity for 20% savings - but at a risk of up to 10% cost increases if labour savings are outweighed by logistics or materials costs.




Source: Bertram et al., 2019

The logistics and transportation costs can be minimized if manufacturers optimize deliveries, thus reducing logistics costs and cashing in on economies of scale (McKinsey & Company, 2019). In addition, best practices suggest that construction contracts should include all pertaining risks and timelines relating to transportation, handling, and storage (HCR Law, 2024).

Municipal levers can facilitate the process. In 2023, *CSA Z250:21: Volumetric Modular Construction — Guide to Compliance and Approval Processes* was issued in Canada to complement the CSA A277 by focusing on the process and procedures for before and after the factory phase – mapping the approval process and ensuring safe delivery of volumetric modular buildings. Compliance with this standard safeguards the projects, as it includes considerations of temporary weatherproofing, repairs, lifting, and detailed placement plans (CSAGroup, 2023).

## DIGITALIZATION IN DESIGN

The lack of precise planning technology brings a lot of inefficiencies to the construction industry, allowing projects to be exposed to risks as they move from the design to assembly phase. Building Information Modeling (BIM) software offers the precision needed in the construction design industry, though the industry has been slow in its uptake (Gledson, 2021). BIM is one of the most efficient building methods to come out of intelligent design interventions: it creates a computable dataset that is shareable among the professionals within the design and construction teams. It folds in design, material and coordination with details of mechanical, electrical and plumbing (Korman et al., 2011). 4D BIM technology integrates 3D BIM with time-related information such as the start and end dates of construction activities, sequencing, and dependencies (Gledson, 2021). Geospatial data (GIS) such as project 3D, city 3D model, road network and logistics route layers, can be integrated to manage risks associated through all the project phases, from design to assembly (Niu et al., 2019). Furthermore, BIM can interlink cost and life-cycle analysis (Korman et al., 2011). Integration of such technologies can aid in mapping the complex logistics of modular construction.

In Canada, BIM is slow to emerge as there is industry-wide hostility towards its adaptation due to high initial investment costs and a lack of skills/knowledge, guidelines, and training (Nasrazadani et al., 2023). Unlike other countries around the world, Canada does not have a government mandate around the usage of BIM, leading to a lack of urgency in its adoption (Nasrazadani et al., 2023). There is also a disproportionate usage of BIM amongst architecture, engineering, and construction companies, hindering collaboration between fields. Inconsistent delivery of design drawing formats in the field leads to issues of visualization, clash detection, dimension ambiguity, and constructability of the original design (Nasrazadani et al., 2023).

*Building Information Modeling (BIM)* ***software offers the precision needed in the construction design industry****, though the industry has been slow in its uptake.*

In response to the preferred usage of BIM, the U.K. has created BS 7000-4:2013 – a document detailing British standards on design management systems (BSI Knowledge, 2013). National BIM programs in the U.K. are led by the Department for Business, Energy and Industrial Strategy, the government's BIM Task Group, and Digital Built Britain (Hairstans & Duncheva, 2020). The move towards BIM signals a move towards digitization in the U.K.'s built assets to improve effectiveness and efficiency in building production, allowing for more opportunities for partnership growth in the technology sector (Hairstans & Duncheva, 2020).

McKinsey & Company has (2019) shared a successful example from LendLease, an Australian real estate company that relies on digitalization. They create a "digital twin" ahead of construction, using every detail of the project. This tool aids construction projects by accelerating and automating design, production, and operational processes, to achieve industrialized efficiency and ensure collaboration.

Another example of BIM utilization is the open-source 3D digital platform Speckle. The company is native to the U.K. and their goal is to streamline the 3D software design process between real time collaboration, data management, versioning, and automation (AEC Systems Ltd., 2021). Speckle allows designers to extract and exchange data in their 3D drawings from one software to another, making it easier for collaboration between various companies and organizations (AEC Systems Ltd., 2021). They make sharing any computational design manageable by converting files and removing any software discrepancies.

# 3. EXAMPLES OF OVERCOMING BARRIERS

This section draws on case studies to identify key strategies that facilitate successful modular housing projects.

## BALANCING STANDARDIZATION AND CUSTOMIZATION

Balancing standardization and customization is essential for the scalability of modular housing. While modular construction is inherently rooted in the concept of replication and standardization, it must also cater to the diverse needs and preferences of individual homebuyers. Excessive personalization can be detrimental to a business strategy, but insufficient customization can also hinder project success. The approach taken by Lindbäcks exemplifies this balance by using 80% standardized components and 20% customized elements, streamlining production while allowing for necessary design adaptations (Lindbäck, 2017).

Lindbäcks implements a strategic mix of 80% standardization and 20% customization to maintain efficiency, while offering a level of personalization necessary for successful projects. They emphasize early engagement with external architects and create comprehensive architectural manuals to ensure all team members are aligned from the outset (Lindbäck, 2017). This minimizes costly design adjustments later in the project, highlighting the importance of early and detailed planning in modular construction.

Understanding the target audience through market research is crucial for developing standardized module options that cater to common needs while allowing customization. Manufacturers now offer pre-designed modules with various options for layouts, sizes, and functionalities, enabling buyers to select modules that suit their requirements for bedrooms, bathrooms, living areas, and additional features like balconies or home offices (Lindbäck, 2017). This balance ensures that modular homes are not only affordable and quick to build, but also appealing and adaptable to individual tastes.

## STRATEGIC PARTNERSHIPS

Strong industry partnerships are vital for the successful scaling of modular housing. Japan's success in stakeholder collaboration began with the establishment in 1963 of Prefabricated Construction Suppliers and Manufacturers Association (PCSA), which later became an incorporated association under joint jurisdiction of Japan's Ministry of Land, Infrastructure, Transport and Tourism and the Ministry of Economy, Trade and Industry. Under its portfolio, PCSA runs subcommittees for building standards, design, insurance and education. The collaboration between government bodies, private sector, and education institutions has led to the development of policies and incentives that drive innovation and adoption of modular construction in the country.

Sweden displays strategic partnership through networking relationships between the material industry associations of wood and concrete. The Swedish Wood Association has 32 firms that work in the prefabrication industry, representing 75% of detached dwellings (Steinhardt et al., 2020). The Swedish Concrete Association has 27 firms working in prefab construction and represent 90% of newly built multi-residential buildings (Steinhardt et al., 2020). Together, these associations collaborate to improve innovation in production systems (Steinhardt et al., 2020). The partnership allows for new ways of employing modular construction methods and creates strong avenues of collaboration between firms seeking various building methods through materiality.

Additionally, the BoKlok on the Brook project in Bristol, U.K., is a prime example of how to effectively scale up modular housing. The BoKlok initiative, originally launched in Sweden in 1996 by Skanska and IKEA, has successfully scaled up and expanded into the U.K. market, demonstrating the effectiveness of their strategic partnership in overcoming the challenges associated with modular housing development. The aim was to provide affordable, sustainable, and well-designed homes using modular construction techniques. Their combined expertise – Skanska's construction prowess and IKEA's design and logistical capabilities – created a robust framework for delivering quality homes at scale. The BoKlok on the Brook project in Bristol, which aims to create 211 homes, is a practical manifestation of this longstanding partnership.

One of the key advantages of this partnership lies in the innovative design and construction efficiency. IKEA's involvement brings a unique design philosophy focused on simplicity, functionality, and affordability. Their experience in product design ensures that the homes are aesthetically pleasing, user-friendly, and cost-effective. The standardization of components facilitated by IKEA's approach means easier and faster construction, allowing for bulk production of components that reduce costs and time. On the other hand, Skanska provides extensive knowledge in large-scale construction management, ensuring that projects adhere to stringent quality and safety standards. Their expertise helps navigate complex construction regulations and standards, ensuring streamlined project execution.

## PRECISION PLANNING AND COORDINATION

Precision planning and coordination are crucial in modular housing projects, particularly in urban environments with limited space and complex logistics. The Linzer Strasse project in Vienna, Austria, highlighted the importance of meticulous planning and coordination. The use of Binderholz Cross Laminated Timber (CLT BBS), a prefabricated multi-layered solid wood module used as walls, ceilings, and roofs allowed for efficient use of space and streamlined the building process. Short construction times, a high degree of prefabrication, simple details, and relatively small component thicknesses contributed to creating a more time efficient and flexible process for the transportation of the materials on-site (Binderholz, 2020). This project demonstrated how careful planning and innovative material use can overcome spatial constraints and optimize urban housing solutions.

The HoHo Vienna project further highlights the importance of precision planning and coordination. As one of the tallest timber buildings in the world, HoHo Vienna required meticulous logistical planning. The assembly of timber elements, which included 800 glued laminated timber supports and 14,400 square meters of cross-laminated timber as external wall elements, was executed with remarkable efficiency. Each floor's timber assembly took only about 10 days, even under challenging winter conditions. Advanced logistical strategies played a crucial role, such as delivering components pre-fitted with windows and minimizing transport trips to the site. The sophisticated logistics ensured all components were delivered from Carinthia to Seestadt (305 km) in only 50 lorry trips (HoHo Vienna, 2021). This approach not only streamlined the construction process but also reduced the project's environmental impact, demonstrating how precision planning and coordination can facilitate the efficient scaling of modular housing.

Lessons from these projects demonstrate the importance of rigorous planning and logistics for modular construction projects of all sizes and scales.

# 4. RECOMMENDATIONS

The recommendations for developers to scale up their practice include project and organization changes, and industry partnerships to advocate for big picture change.

## PROJECT-SPECIFIC

Site selection must be specific to the type of modular construction (panels or volume), keeping in mind all logistics and transportation associated with the project. Detailed studies of specific transportation routes and regulatory requirements for moving large modular components are essential. This involves planning for specialized transportation and storage needs, for projects in both remote and densely populated areas.

There should be a great focus on adopting an IPD approach i.e. engaging stakeholders early in the project lifecycle to foster collaboration and optimize the offsite construction process. The IPD approach integrates legal, financial, and regulatory experts into the project team – along with the designer, owner, and consultants – to develop specific contracts that address the challenges of the project. The subsequent contracts can automate and enforce payment terms, ensuring financial stability and trust among all the stakeholders. The contracts ensure smooth fund and ownership transfers when aligned with unique project milestones.

## ORGANIZATION-SPECIFIC

Investing in technology and automation, such as BIM and Speckle, will enhance productivity and efficiency in modular construction. These tools can help visualize and optimize project details before manufacturing begins, reducing errors and rework. BIM allows for precise planning and reducing risks associated with miscommunication between stakeholders. Speckle, on the other hand, can facilitate the communication and integration between the various engineering, architecture, and construction applications that are used in the modular building lifecycle. Utilizing such software will enhance communication between construction component makers, developers, and local construction crews, and speed up project timelines.

Coupling those technical tools with automated financial and payment tools like smart technology can ensure timely cashflow and financial stability to the modular manufacturer. Such financial tools, if proven useful to developers, can be embedded in contracts with clients.

To reduce risks associated with contracts, it may be beneficial to refer to ConsensusDoc as a starting point to design modular construction-specific contracts.

## INDUSTRY-SPECIFIC

Industry-wide initiatives to develop specialized systems for modular construction will be crucial to meeting the growing demand for affordable, high-quality housing. For example, customized ConsensusDocs for Canada could be beneficial across the industry and stakeholders.

Affordable housing organizations can leverage their position to advocate for harmonization at the provincial and national levels to facilitate the widespread adoption of modular construction:

***Standardized building codes:*** The National Building Code needs to be updated to be more adaptable and transferrable, reducing the complexities associated with regional variations, and encouraging scaling up modular construction. The country-wide standards and their application can regularize the construction practice.

***Financing structures and support programs:*** Advocating for continuous government programs that finance modular projects – such as continuing the Rapid Housing Initiative, creating other initiatives with broader scopes, or following Colorado's example – will be essential to helping the industry gain momentum. These programs can facilitate bulk orders of modules, pre-approved designs, skill training, and investments in digital infrastructure.

***Transportation regulations:*** As recommended by CMHC (2021) a national standard for transportation logistics should be established, facilitating the movement of modular components across the jurisdiction lines in the country.

# NOTES

1. The program, governed by Swedish ruling government, set and accomplished a goal to construct one million new housing dwellings over a ten-year period, between 1965 and 1974.

2. Some literature suggests that Sweden has 45% of industrialized construction (Mari, 2024), while others quote 45% as the combined share in Sweden, Finland and Norway (Bertram et al. 2019).

3. Urban Renaissance Agency (UR) is a Japanese semi-governmental organization. It was originally established in 1955 as the Japan Housing Corporation to address urban and housing agendas in Japan (UR n.d.).

4. CSA A277 certification is required in Alberta, Quebec and the Yukon, but merely recognized in other Canadian provinces and not required (CHBA n.d.).

# BIBLIOGRAPHY


AEC Systems Ltd. "About." *Speckle - The Platform for 3D Data*. January 30, 2021. https://speckle.systems/about/.

Arashpour, M. "Design for Manufacture and Assembly in Offsite Construction and Relationship with Concurrent Engineering." *In Offsite Production and Manufacturing for Innovative Construction*, 1st ed., Vol. 1, 111–128. Routledge, 2020. https://doi.org/10.1201/9781315147321-6.

Azghandi Roshnavand, M. "Smart Contracts and Payment in the UK Construction: The Legal Framework." Master's thesis, Concordia University, 2019. https://spectrum.library.concordia.ca/id/eprint/985955/13/Azghandi%20Roshnavand_MSC_W2019.pdf.

Bayliss, S., and R. Bergin. *The Modular Housing Handbook*. RIBA Publishing, 2020. https://books.scholarsportal.info/uri/ebooks/ebooks6/taylorandfrancis6/2020-11-10/1/9781003106296.

Bellini, O. E., M. Arcieri, and M. T. Gullace. "Off-Site Modular Housing Systems – Expeditious Solutions for Student Residence." *AGATHÓN | International Journal of Architecture, Art and Design* 14 (2023): 152–163. https://doi.org/10.19229/2464-9309/14122023.

Bertram, N., S. Fuchs, J. Mischke, R. Palter, G. Strube, and L. Woetzel. "Modular Construction: From Projects to Products." *McKinsey & Company*, 2019. https://www.mckinsey.com/capabilities/operations/our-insights/modular-construction-from-projects-to-products.

BinderHolz. "Residential Building Linzer Straße, Vienna: Austria." Accessed October 18, 2024. https://www.binderholz.com/en-us/mass-timber-solutions/residential-building-linzer-strasse-vienna-austria/.

Blanco, J. L., D. Dauphinais, R. Palter, and G. Hovnanian. "Modular Building Systems Could Address Many of the US Construction Industry’s Current Woes, but the Sector Needs to Remodel Itself First." *McKinsey & Company*, May 10, 2023. https://www.mckinsey.com/capabilities/operations/our-insights/making-modular-construction-fit.

"BoKlok Växthuset—Nybyggda Lägenheter i Helsingborg." *BoKlok*. Accessed June 13, 2024. https://www.boklok.se/kop-bostad/sok-bostad/boklok-vaxthuset/.

Brookfield, Kristin. “Barriers to Prefabrication and Modular Construction: Housing.” International Housing Association, 2022. https://www.internationalhousingassociation.org/fileUpload_details.aspx?contentTypeID=3&contentID=282941&subContentID=769009&channelID=38488.

BSI Knowledge. BS 7000-4:2013. December 31, 2013. https://knowledge.bsigroup.com/products/design-management-systems-guide-to-managing-design-in-construction?version=standard.

Buntrock, Dana. “Prefabricated Housing in Japan.” In *Offsite Architecture*, 1st ed., 190–213. Abingdon: Taylor & Francis Group, 2017. https://doi.org/10.4324/9781315743332-12.

Burgess, Gemma, Michael Jones, and Kathryn Muir. *Housing Digital Built Britain Network Position Paper 2: What Is the Role of Offsite Housing Manufacture in a Digital Built Britain?* Cambridge: University of Cambridge, September 2018. https://www.cdbb.cam.ac.uk/files/2._position_paper_off-site_housing_manufacture_web.pdf.

Christie, D. S., and J. Mante. "Smart Contracts and Payment in the UK Construction: The Legal Framework." In *Blockchain for Construction*, edited by T. Dounas and D. Lombardi, 167–184. Springer Nature, 2022. https://doi.org/10.1007/978-981-19-3759-0_9.

Canada Mortgage and Housing Corporation (CMHC). "Building Housing Quickly When It Matters Most." 2020. https://www.cmhc-schl.gc.ca/blog/2020-housing-observer/building-housing-quickly-when-matters-most.

Canada Mortgage and Housing Corporation (CMHC). "Key Lessons from Modular Housing Across Canada." 2021. https://www.*cmhc*-schl.gc.ca/nhs/nhs-project-profiles/2021-nhs-projects/key-lessons-modular-housing-across-canada.

ConsensusDocs. "All Association Guidebook." August 30, 2023. https://www.consensusdocs.org/wp-content/uploads/2023/08/ConsensusDocs-All-Association-Guidebook-Aug-30-2023.pdf.

Constructing Excellence. "Innovation: Gateshead Innovation Village." December 22, 2020. https://constructingexcellence.org.uk/home-group-gateshead-innovation-village/.

Dragicevic, N., and K. Riaz. "Seizing the Modular Construction Opportunity." Canadian Standards Association, 2024. https://www.csagroup.org/wp-content/uploads/CSA-Modular-Opportunity-PublicPolicySnaphot-EN_Accessible.pdf.

"Environmental, Social, and Governance (ESG) in Modular Construction." Modular Building Institute, 2024. https://www.modular.org/governance/.

Erlich, Mark. "Why Modular Building Hasn't Revolutionized Construction." *Harvard Business Review*, published December 21, 2023. Accessed October 18, 2024. https://hbr.org/2023/12/why-modular-building-hasnt-revolutionized-construction.

Ferdous, W., Y. Bai, T. D. Ngo, A. Manalo, and P. Mendis. "New Advancements, Challenges and Opportunities of Multi-Storey Modular Buildings – A State-of-the-Art Review." *Engineering Structures* 183 (2019): 883–893. https://doi.org/10.1016/j.engstruct.2019.01.061.

Ferdous, W., A. Manalo, A. Sharda, Y. Bai, T. D. Ngo, and P. Mendis. "Construction Industry Transformation Through Modular Methods." In *Innovation in Construction: A Practical Guide to Transforming the Construction Industry*, edited by S. H. Ghaffar, P. Mullett, E. Pei, and J. Roberts, 259–276. Springer International Publishing, 2022. https://doi.org/10.1007/978-3-030-95798-8_11.

"First Store in Stockholm Paved New Roads—IKEA Museum." WordPress På Azure, 2024. https://ikeamuseum.com/en/explore/the-story-of-ikea/ikea-in-stockholm/.

Gledson, B. "Enhanced Model of the Innovation-Decision Process for Modular-Technological-Process Innovations in Construction." *Construction Innovation* 22, no. 4 (2022): 1085–1103. https://doi.org/10.1108/14714172210708873.

Goodman, L. S. "Confronting the Housing Supply Shortage: Policy Options." *Business Economics* 58, no. 3 (2023): 158–165. https://doi.org/10.1057/s11369-023-00326-2.

Goulding, J. S., and F. P. Rahimian, eds. *Offsite Production and Manufacturing for Innovative Construction: People, Process and Technology.* 1st ed. Routledge, 2019. https://doi.org/10.1201/9781315147321.

Hairstans, R., and T. A. Duncheva. "Core Offsite Manufacture Industry Drivers." In *Offsite Production and Manufacturing for Innovative Construction*, 1st ed., Vol. 1, 257–284. Routledge, 2020. https://doi.org/10.1201/9781315147321-11.

HCR Law. "Modular Construction – Some Legal Considerations." Accessed October 18, 2024. https://www.hcrlaw.com/blog/modular-construction-some-legal-considerations.

HoHo Wien. "Information." September 14, 2021. https://www.hoho-wien.at/en/information/.

Jaksch, S., A. Franke, D. Österreicher, and M. Treberspurg. "A Systematic Approach to Sustainable Urban Densification Using Prefabricated Timber-based Attic Extension Modules." *Energy Procedia* 96 (September 2016): 638–649. https://doi.org/10.1016/j.egypro.2016.09.121.

Lessing, J., and L. Stehn. *Industrialised House Building: Concepts and Its Application in Sweden*. 1st ed. Vol. 1. Routledge, 2020. https://doi.org/10.1201/9781315147321-5.

Lindbäck, S. "Efficient Production and Assembly of Customer-Specific Multi-Storey Houses from Space Modules with Architectural Freedom." 2017. https://events.forum-holzbau.com/pdf/28_IHF2017_Lindbaeck.pdf.

Liu, Y., C. Mao, and X. Wang. "Offsite Construction Driving Forces: A Critical Reflection of Hofstede's National Culture Model." In *Offsite Production and Manufacturing for Innovative Construction*. Routledge, 2019.

Love, P. E. D., D. J. Edwards, S. Han, and Y. M. Goh. “Design Error Reduction: Toward the Effective Utilization of Building Information Modeling.” *Research in Engineering Design* 22, no. 3 (2011): 173–187.

Maleki, B., M. del M. Casanovas-Rubio, K. D. Tsavdaridis, and A. de la Fuente Antequera. “Integrated Value Model for Sustainable Assessment of Modular Residential Towers: Case Study: Ten Degrees Croydon and Apex House in London.” *Sustainability* 16, no. 2 (2024): Article 2. https://doi.org/10.3390/su16020497.

Manley, K., and K. Widén. “Prefabricated Housing Firms in Japan and Sweden: Learning from Leading Countries.” In *Offsite Production and Manufacturing for Innovative Construction*. Routledge, 2019. https://doi.org/10.1201/9781315147321.

Mari, F. “How an American Dream of Housing Became a Reality in Sweden.” *The New York Times*, June 8, 2024. https://www.nytimes.com/2024/06/08/headway/how-an-american-dream-of-housing-became-a-reality-in-sweden.html.

McKinsey & Company. “Voices on Infrastructure: Scaling Modular Construction.” September 2019. https://www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/voices%20on%20infrastructure%20scaling%20modular%20construction/gii-voices-sept-2019.pdf.

Mitchell, C. “State of Prefabrication in Canada: A Market Study of Mass Timber, Panels, and Volumetric Modular Construction.” Forestry Innovation Investment, 2021. https://static1.squarespace.com/static/5f7cb04329e107165b649ccc/t/6261bf54edcd29756a7241ef/1650573145289/STATE+OF+PREFABRICATION+IN+CANADA+-+April+2022.pdf.

Modular Construction Council. “Canadian Home Builders’ Association.” 2024. https://og.chba.ca/CHBA/CommitteesCouncils/Modular_Construction_Council/CHBA/CommitteesCouncils/Modular_Construction_Council.aspx?hkey=8d3e09e4-d034-464f-b3d6-4a4bbd2c621a.

Murray-Parkes, J., Y. Bai, A. Styles, and A. Wang. *Handbook for the Design of Modular Structures*. Monash University, 2017. https://construye2025.cl/wp-content/uploads/2022/07/Handbook-for-the-design-of-modular-structures-Monash-University.pdf.

Nasrazadani, H., K. Shahi, A. Shahi, and B. McCabe. “Building Information Modeling in Canada: A Multidisciplinary Practical Analysis.” In *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021*, edited by S. Walbridge et al., 81–92. Springer Nature, 2023. https://doi.org/10.1007/978-981-19-1029-6_7.

Niu, S., Y. Yang, and W. Pan. “Logistics Planning and Visualization of Modular Integrated Construction Projects Based on BIM-GIS Integration and Vehicle Routing Algorithm.” In Modular and Offsite Construction (MOC) Summit Proceedings, 579–586. 2019. https://journalofindustrializedconstruction.com/index.php/mocs/article/view/141/139.

Office of the Governor. “More Housing Now: Gov. Polis Announces Upcoming Proposition 123 Funds Will Prioritize Modular and Innovative Housing Projects.” Colorado Governor Jared Polis, July 1, 2024. https://www.colorado.gov/governor/news/more-housing-now-gov-polis-announces-upcoming-proposition-123-funds-will-prioritize-modular.

Österreicher, D., T. Fischer, and M. Huber-Humer. “Temporary Housing Environments in Urban Areas – Challenges and Key Findings for Implementation.” *MATEC Web of Conferences* 396 (2024): 17003. https://doi.org/10.1051/matecconf/202439617003.

“Part I Industry 4.0 and Drivers for Change.” In Innovation in Construction. Switzerland: Springer International Publishing AG, 2022.

Poirier, E., A. J. Arar, S. Staub-French, P. Zadeh, and D. Bhonde. “Investigating Factors Leading to IPD Project Success in Canada.” Integrated Project Delivery Alliance, 2022. https://doi.org/10.13140/RG.2.2.30076.21124.

Schibline, A. “Modular: Homes of Future’s Past?” November 2021. https://doi.org/10.13140/RG.2.2.24639.84640.

Sekisui Chemical Co., Ltd. “Design & Land.” 2024. https://www.sekisuiheim.com/safeandsound/sgmhy-lead-town/hs-sgmhy/design.html.

Smith, R. E., and T. Rice. “Permanent Modular Construction: Process, Practice, Performance.” Integrated Technology in Architecture Center, College of Architecture and Planning, University of Utah, 2015. https://www.meehleis.com/wp-content/uploads/2015/05/2015_Off-Site_PMC_Report-Ryan-Smith.pdf.

Steinhardt, D., K. Manley, L. Bildsten, and K. Widen. “The Structure of Emergent Prefabricated Housing Industries: A Comparative Case Study of Australia and Sweden.” *Construction Management and Economics* 38, no. 6 (2020): 483–501. https://doi.org/10.1080/01446193.2019.1588464.

“Supporting Efficient, Safe and Affordable Modular Construction Practices through Standards.” Canadian Standards Association, 2023. https://www.csagroup.org/wp-content/uploads/CSA-ModularConstruction-CaseStudy-EN_Accessible.pdf.

Walters, A. “Network—Housing Digital Built Britain.” July 5, 2018. https://www.cdbb.cam.ac.uk/CDBBResearchBridgehead/Networks/2018Network_Housing.

Wilson, J. “Modular & Off-Site Construction Guide.” American Institute of Architects, November 30, 2023. https://www.aia.org/resource-center/modular-site-construction.

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