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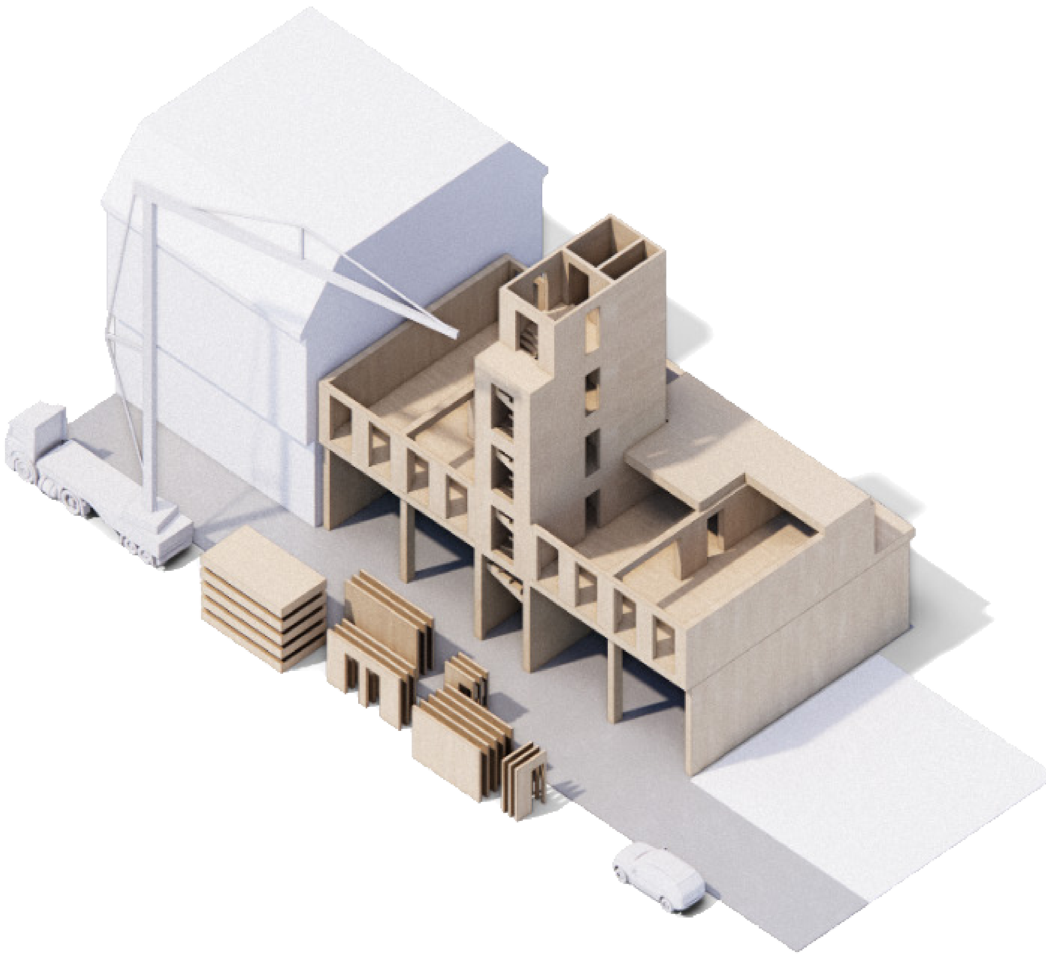

Benefits of Modular and Prefabricated Wood Construction

For:
Assembly Corp.

Prepared by:
Ha/f Climate Design

February 2025

Assembly

Assembly is a leading force in addressing the housing crisis that plagues cities across Canada. With a commitment to sustainability and efficiency, we provide innovative housing solutions that transform urban landscapes. We understand the challenges faced by investors, developers, municipal governments, and nonprofits; and our mission is to support them by revolutionizing the design and construction process to deliver on-time and on-budget, every time.

Through our prefabricated and modular approach, we create sustainable timber housing units that are assembled on-site, allowing for faster, more efficient construction. Our focus on mid rise infill density ensures that our homes not only provide development opportunities in highly desired city centres, but also prioritize social infrastructure and community well-being.

This report has been prepared by Ha/f Climate Design in support of research and development at Assembly Corp. Ha/f conducted an expansive literature review following which this report enumerates the environmental and economic advantages of prefabricated and modular construction in comparison to traditional on-site construction. The study also looks at the benefits of using regenerative biobased materials like wood instead of more conventional building materials like concrete and steel, and reviews the growing potential for locally sourced bio materials in Canada. The concluding section of this report includes a schematic design stage Life Cycle Assessment of a modular wood and concrete midrise building respectively, and compares their relative upfront carbon footprints.

Ha/f Climate Design was founded to halve the emissions of the built environment this decade. We partner with designers, builders and policy makers on capacity building, research, industry education, and policies to address the whole life cost and carbon impacts of buildings, landscapes, and infrastructure.

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/ Executive Summary

Buildings are a major contributor to greenhouse gas emissions - responsible for roughly 39% of global emissions. While efforts in recent decades have focused on reducing operational carbon emissions, embodied carbon emissions from building materials have been overlooked. In Canada, in the last few years there has been a growing acknowledgement of the extensive embodied carbon footprint of the extraction, production and provenance of building materials, construction processes, repair and replacement cycles as well as emissions associated with the demolition and end of life of buildings.

In response to federal and municipal regulations to mitigate the whole life carbon footprint of buildings in recent years, the construction industry in Canada is actively seeking ways to minimize their environmental impact while improving time and cost efficiency. As a part of this effort, adoption of modular construction practices and biobased building materials like mass timber have emerged as viable strategies to help lower embodied carbon emissions, and streamline the building process. At each stage of a project there are a cascading set of decisions that can serve to either increase or decrease carbon emissions of construction.

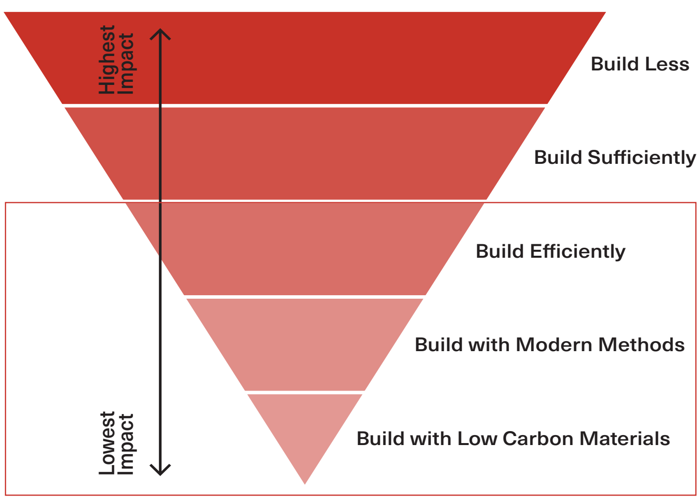

Fig 1. Hierarchy of Carbon Mitigation diagram. Adapted from Institution of Structural Engineers 2021.

The Hierarchy of Mitigation diagram (Figure 1) illustrates that the greatest potential for carbon reduction lies in minimizing new construction by building less and designing buildings for sufficiency. This report focuses on how modular wood construction fits the requirements of the following three tiers of the mitigation hierarchy: building efficiently, utilizing modern construction methods, and incorporating low-carbon materials.

Benefits of Off-site Construction

A breakdown of the benefits of modern methods of construction like prefabrication and onsite assembly highlights how modular construction can help reduce the embodied carbon footprint, cost, and project schedules.

Advances in Construction Practice

The findings from this report highlight that reducing carbon in construction goes beyond material selection—it also involves improving efficiency, minimizing waste, and optimizing resource use throughout the process. As Canada works to achieve both climate and housing objectives, modular and prefabricated wood construction offers a path towards more efficient and sustainable building practices.

Biobased Materials

Additionally, the use of low-carbon, bio-based materials like timber have the added benefit of carbon sequestration in its growing phase and allows for local provenance from Canadian farms and forests.

Comparative Life Cycle Assessment

A comparative life cycle assessment (LCA) evaluates the carbon savings and efficiency gains between two construction scenarios for a six storey, midrise residential building located in Toronto. The baseline scenario assumes a reinforced concrete structural system and traditional construction methods, while the alternative scenario assumes prefabricated mass timber building modules that are assembled on site. The results show that modular wood construction can reduce upfront carbon emissions by 52-58%, significantly lowering the environmental impact of new buildings.

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Literature Overview

This section surveys key advancements in prefabrication and modular design, highlighting their impact on efficiency, sustainability, and the future of construction.

1.0

1.1 / Benefits of Off-site Construction

In traditional construction, building materials are typically transported to the construction site and entire structures are built on site from the ground up. Construction timelines are likely to be slower due to dependence on favorable weather conditions and the necessity to coordinate between various trades. Construction costs are higher due to longer schedules and onsite labour expenses whereas quality control has more variability than consistency.

With advancements in technology, construction methods have evolved significantly, shifting towards factory-built, modular and prefabricated homes that can be quickly assembled on site. An off-site home is constructed inside a factory, where structural components, windows, doors, framing, and insulation are fabricated within a climate-controlled environment. Simultaneously, the site is prepared for onsite assembly. This form of construction helps save time and reduces project timeline. With the help of automation and standardised processes at factories, the quality of the building modules are consistently maintained. Streamlined processes on site also lead to much lower emissions associated with construction processes and a significant reduction in construction waste.

Modular construction is especially well-suited for infill development in dense urban neighborhoods where prolonged construction periods cause disturbance to residents and impact local businesses. By assembling building components off-site, this construction method significantly reduces on-site construction time, while minimizing noise, dust, and traffic congestion.

Fig 2. An infill development project in Ossington, Toronto uses prefabricated modular construction. Source: Assembly Corp.

1.1 / Benefits of Off-site Construction

Prefabrication of Building Elements

Prefabrication is a type of off-site construction where building components are manufactured off-site before final assembly. It enables faster build times and cost efficiency by streamlining workflows, reducing project durations, and lowering expenses.[1] Prefabrication enhances sustainability by minimizing on-site waste, lowering transportation emissions, and optimizing material use. This systematic approach improves quality control and durability through precision engineering and standardized materials. Additionally, prefabrication increases workplace safety by reducing site-specific hazards and helps address on-site labor shortages. Site security also improves, as prefabricated components require less on-site storage, minimizing risks of theft and vandalism.

According to multiple studies, factory-built construction has the potential to reduce project completion time by up to 50% and lower costs by 20% or more.[2] For example, prefabricated mass timber panels, such as cross-laminated timber (CLT), are widely used in Canada for their sustainability and ease of installation.[3] These panels, produced in controlled environments, reduce construction waste and improve energy efficiency.

Modular Construction

Modular construction, while based on prefabrication principles, involves assembling entire sections or "modules" of a building in a factory before transporting and installing them on-site. While prefabrication focuses on individual components, modular construction fabricates standardized building sections—such as fully completed rooms or apartment units—with pre-installed finishes, electrical, plumbing, and insulation. By allowing simultaneous site preparation and module production, modular construction minimizes delays and optimizes workflows.

Modular construction significantly reduces waste and material usage due to its precision controlled factory environment, with reports indicating up to 90% less waste and 20% material savings compared to traditional methods. Additionally, it lowers energy consumption by an average of 67% during construction and reduces transportation emissions.[4] UTILE developed a 155-unit mid-rise student housing complex in Rimouski, Quebec, utilizing prefabricated modular construction. This method allowed for faster project completion, addressing the pressing need for affordable student accommodations.[5]

Fig 3. A factory built prefabricated wall component being assembled at a construction site in Toronto. Source: Assembly Corp.

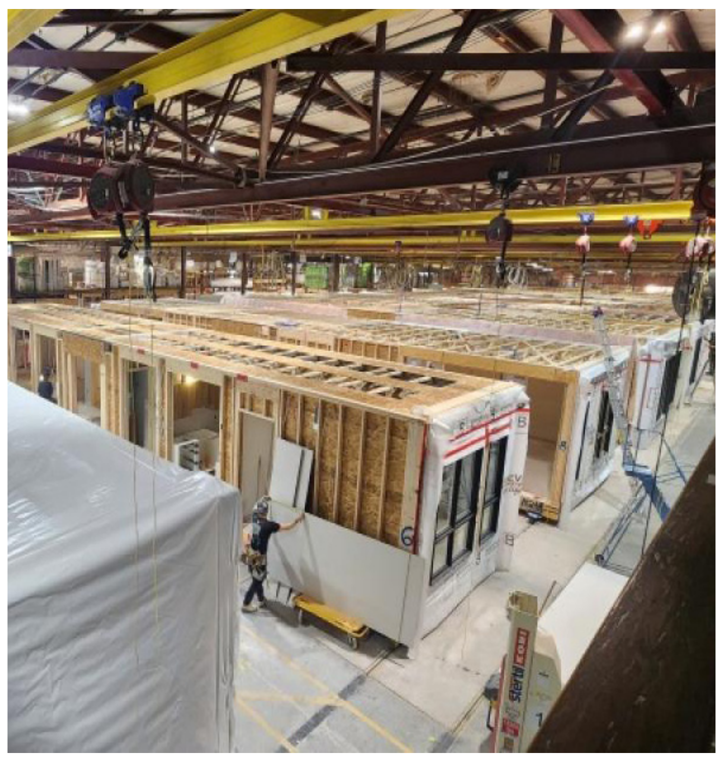


Fig 4. Building modules being assembled in a factory for UTILE's student housing projects. Source: Utile

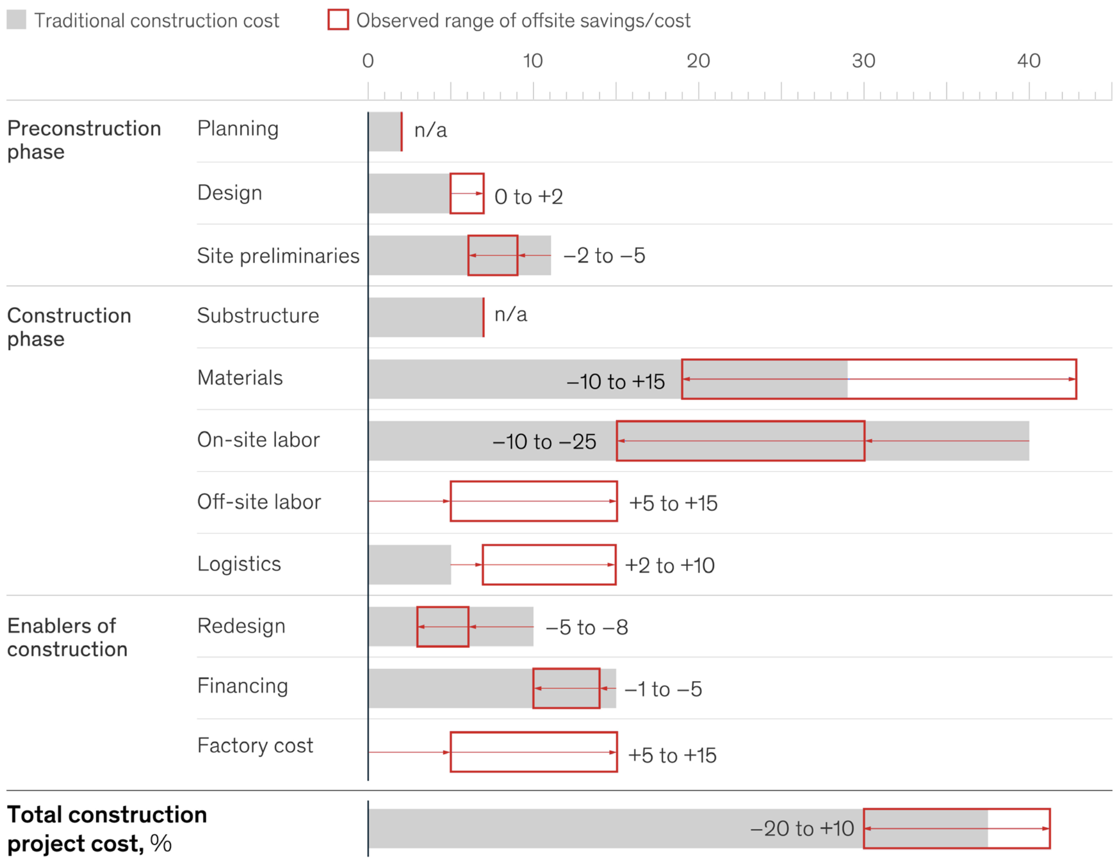
1.1 / Benefits of Off-site Construction

Time and Cost Efficiency

Modular and prefabricated construction methods can significantly improve time and cost efficiency. Once modules are transported to the site, installation can occur in a matter of days or weeks, rather than months. This accelerated timeline benefits developers by reducing financing costs, enabling faster occupancy, and improving return on investment. With efficient planning, costs can be reduced starting from the early pre-construction phase.

Figure 5 illustrates the cost breakdown of traditional construction projects and the potential savings and cost shifts when adopting modular construction methods. The key takeaway is that modular construction offers up to 20% in cost savings, primarily by reducing onsite labor and site overheads. Factors such as factory costs, financing, and redesign can further influence cost reductions. While the graph shows a potential increase in material costs, this can be mitigated by optimizing local material procurement, automation, and design standardization.

The global adoption of off-site construction has led to remarkable achievements, such as the rapid completion of high-rise buildings in record time. Projects like Mini Sky City in China was built in just 19 days, and the 30-story T30 Hotel was completed in 15 days.[6] As demand for faster, more efficient building solutions grows, modular construction continues to reshape the industry.



[1]Indicative breakdown: varies by project.
Source: US Federal Highway Administration; McKinsey Capital Projects & Infrastructure

Fig 5. Comparative costing analysis showing cost savings from traditional construction vs off-site modular construction; Source: McKinsey & Company

1.2 / Advances in Construction Practice

Design for Manufacturing and Assembly

Design for Manufacturing and Assembly (DfMA) is a methodology that streamlines production by integrating design, engineering, and manufacturing to enhance efficiency, reduce cost and minimize material waste. It combines the principles of Design for Manufacturing(DFM) and Design for Assembly(DFA) to create a seamless construction process. DfMA is typically categorised into five levels, component manufacture, sub-assembly, non-volumetric preassembly, volumetric preassembly, and modular building out of which 80% of the work happens off-site.[7]

Currently, in the construction sector, DfMA is gaining traction as modular and prefabricated wood systems benefit from automation, precision engineering, and off-site fabrication. Governments and investors are supporting DfMA due to its cost-effectiveness, reduced labor needs, and alignment with sustainability goals. One of the recent additions to DfMA is the use of AI-driven design tools, robotics, and precision timber processing to optimize modular assembly. Automation enables higher efficiency, improved quality, and promotes circular economy principles such as disassembly and reuse.

Automation

Automation is one of the key advancements in off-site construction. It is revolutionizing the construction industry by integrating robotics, artificial intelligence (AI), and digital fabrication technologies to enhance efficiency, precision, and safety. In modular and prefabricated construction, automation streamlines manufacturing, reduces human error, and increases project timelines. Technologies such as robotic arms, CNC (Computer Numerical Control) machines, and 3D printing enable high-precision fabrication, minimizing material waste and improving quality control. Automation in construction has the potential to boost productivity by up to 50% while significantly reducing costs.[8]

AI-driven project management tools are also transforming construction by optimizing scheduling, resource allocation, and risk management. Automation increases workers' safety by limiting exposure to hazardous conditions, particularly in high-risk environments like demolition, excavation, and construction sites.

Fig 6. Factory built components being installed at a construction site in Toronto; Source: Assembly Corp.

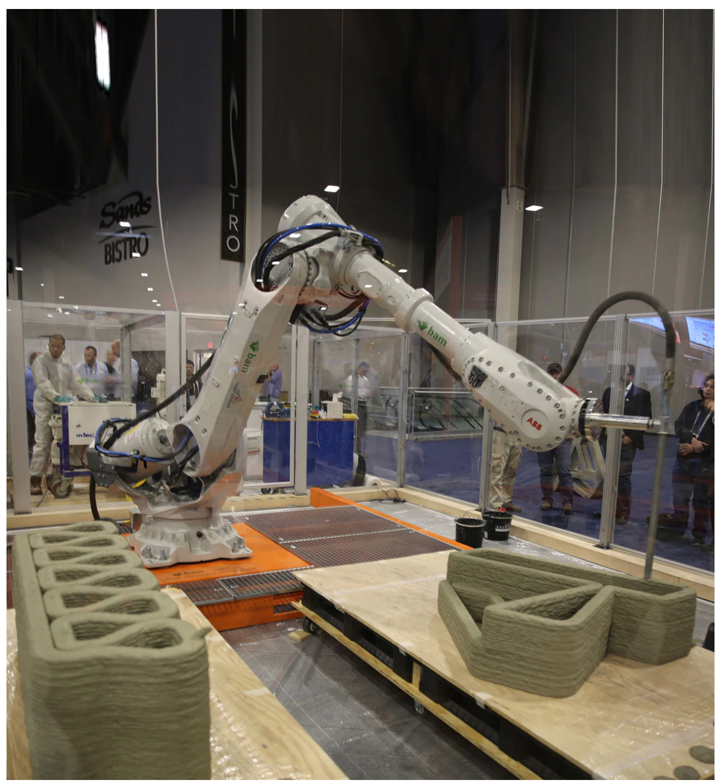


Fig 7. 3D Clay printing of building blocks using robotics; Source: McKinsey & Company

1.2 / Advances in Construction Practice

Disassembly and Reuse

Design for Disassembly (DfD) is a sustainable approach to building design that allows structures to be easily taken apart, so materials and components can be reused, repurposed, or recycled instead of being wasted. Deconstruction enables significantly higher reuse and recycling rates, with up to 25% of materials in residential structures being reusable and up to 70% recyclable.[9] By reducing landfill waste and the need for virgin resource extraction, deconstruction supports a more circular and sustainable construction industry.

The construction sector is increasingly adopting disassembly and reuse. Innovations such as reversible connections and reusable modular components facilitate easier deconstruction and material recovery. Companies in the modular industry are integrating these practices to enhance long-term sustainability, reducing embodied carbon and material costs. Beyond industry adoption, disassembly and reuse are gaining recognition in architectural movements focused on adaptive reuse and circular construction.

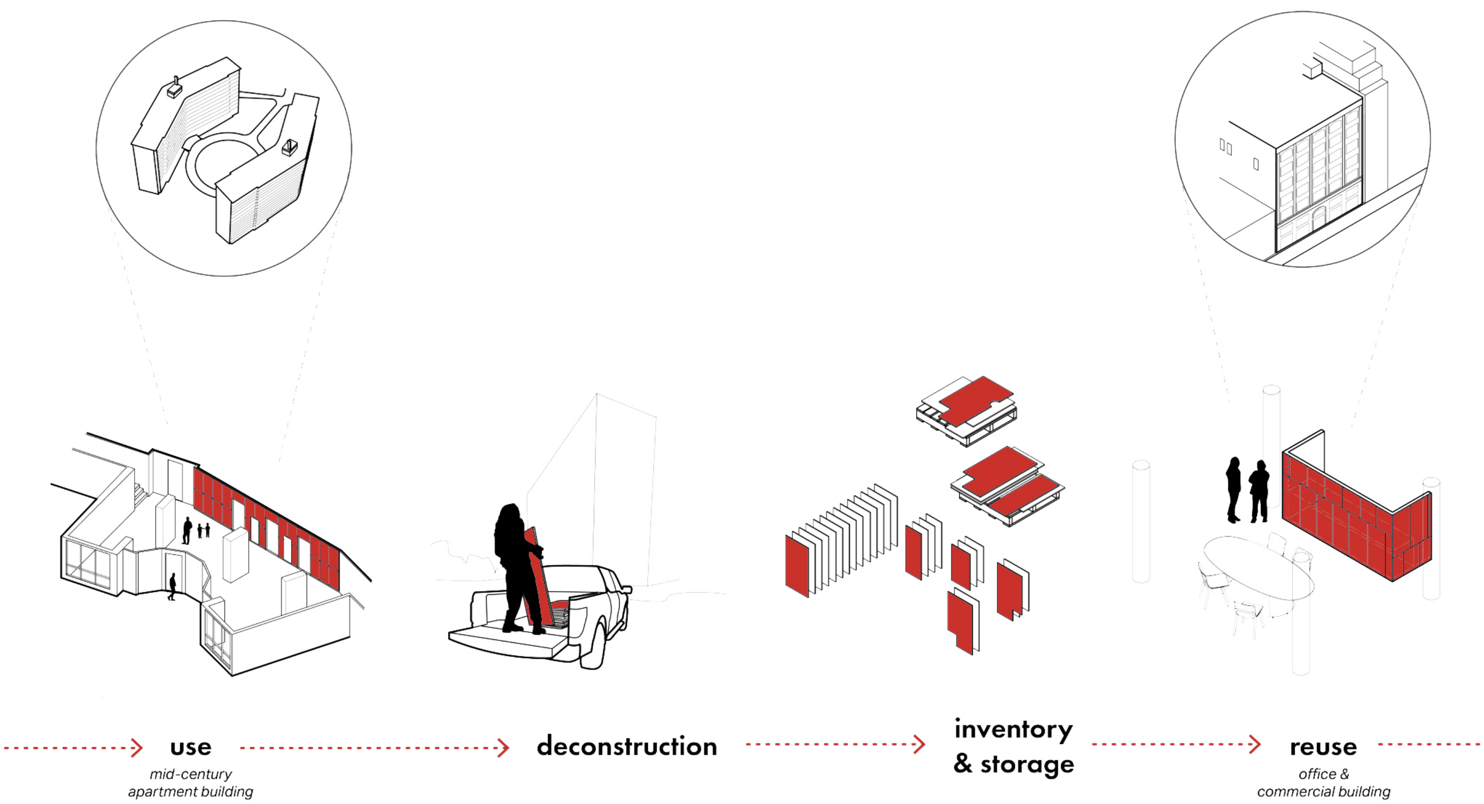


Fig 8. Diagram showing the process of disassembly and reuse of building materials; Source: Giaimo Architects

1.3 / Biobased Materials

From a life cycle assessment perspective, prefabrication and modular design enable the efficient use of diverse construction materials, including low-carbon biobased materials like timber. By optimizing material use and reducing waste, these methods enhance sustainability while supporting carbon sequestration and circular economy principles.

Timber and Other Biobased Materials

Biobased construction materials are derived from organic, renewable sources like plants, trees, and agricultural byproducts, which inherently contribute to reducing greenhouse gas emissions by absorbing carbon dioxide during their growth phase. Timber is an abundantly available resource that is both bio-based and low in embodied carbon. With its low impact, renewability, biodegradability, and carbon sequestering characteristics makes it a valuable material for sustainable construction. As timber remains as one of the most prominently used materials in the construction industry, it is essential to source it responsibly. Sustainable forest practices ensure that timber is sourced sustainably to prevent environmental degradation. Typically, companies get the certified timber to promote biodiversity, protect ecosystems, and support local communities.[10]

With recent innovations in mass timber production, various types of timber have been tested and are currently being used in the construction industry. Two prominent being, Cross-Laminated Timber (CLT) and Glue-Laminated Timber (Glulam). While each type of mass timber has its unique strengths and applications, all of them contribute to reducing the carbon footprint of the construction industry while providing high-performance building solutions.

Apart from timber, other materials such as hemp, cork, and straw bale are increasingly used in the Canadian construction market. These bio-based low-carbon materials are part of Canada's ongoing effort to build more sustainably and reduce the construction sector's environmental footprint. By utilizing locally sourced materials, promoting the use of renewable resources, and embracing innovative construction methods, the Canadian construction industry can contribute significantly to reducing embodied carbon and fostering a more circular economy.

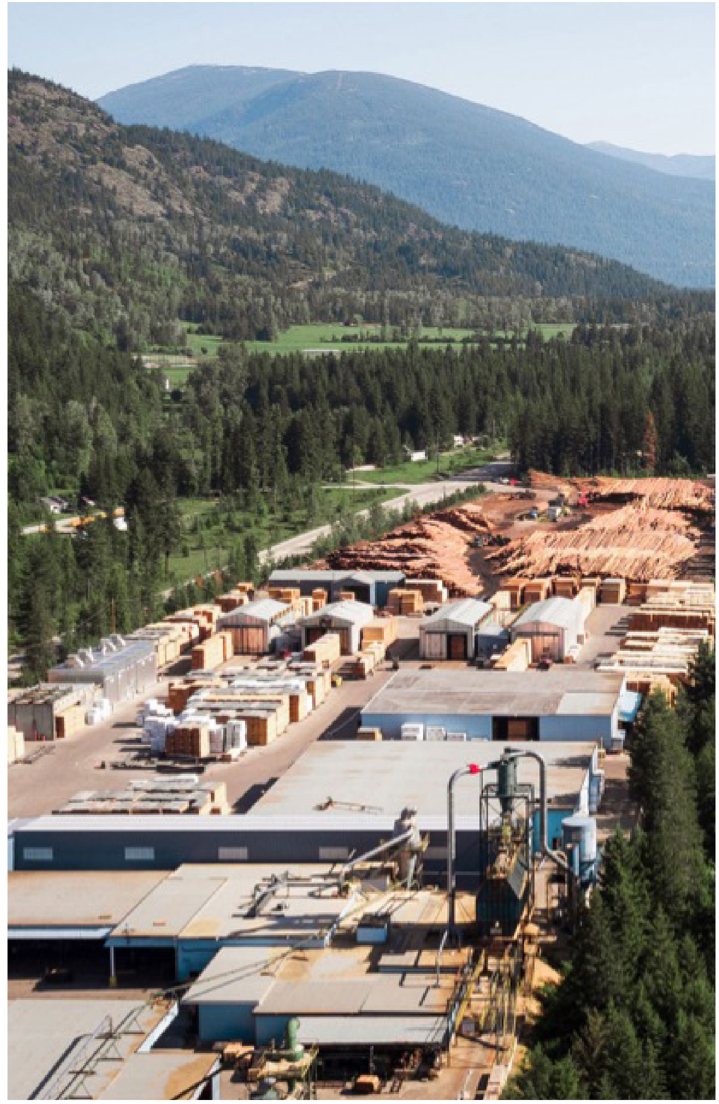


Fig 9. Kalesnikoff lumber site in British Columbia; Source: Kalesnikoff

1.3 / Biobased Materials

Low Embodied Carbon

Low embodied carbon materials are those that have a significantly reduced environmental impact during their entire lifecycle, including production, transportation, and installation. The concept of embodied carbon is crucial in addressing climate change because it considers the hidden emissions associated with the materials used to construct buildings, not just the operational emissions during a building's use. These materials are designed to either require less energy to produce or to have a smaller carbon footprint in terms of extraction, manufacturing, transportation, and disposal.

Traditional materials like concrete and steel are known for their high embodied carbon due to the energy-intensive processes required to manufacture them, such as cement production for concrete or smelting for steel. In contrast, low embodied carbon materials like timber, bamboo, recycled metal, and hempcrete can significantly reduce a building's overall environmental impact (see Figure 10). Timber, for instance, acts as a carbon sink, absorbing and storing carbon dioxide throughout its growth and even during its lifecycle as a building material.[11]

Fig 10. The Construction Material Pyramid by CINARK - Center for Industrialized Architecture, The Royal Danish Academy showing hierarchy of upfront embodied emissions of construction materials in Denmark.

1.3 / Biobased Materials

Carbon Sequestration

Wood and other biobased materials absorb and store carbon dioxide (CO_2) throughout- their growth cycle, significantly reducing the product stage emissions of building components that are made out of them. Unlike conventional materials such as concrete and steel, which generate high CO_2 emissions during production, sustainably harvested wood products continue to act as carbon sinks over time.[12]

Engineered wood products such as cross-laminated timber (CLT) and glulam enhance this potential while offering structural durability. In modular and prefabricated construction, carbon sequestration benefits are further amplified through waste reduction and material efficiency. As demand for low-carbon buildings rises, carbon-sequestering materials are becoming central to sustainable architecture.

Synergy with Prefabrication

The integration of biobased materials with prefabrication enhances sustainability and efficiency in construction by optimizing resource use and minimizing waste. Prefabrication involves assembling building components in a controlled factory environment, ensures precise material usage and reduces construction errors, thus making it an ideal approach for biobased materials such as mass timber. These materials have significantly lower embodied carbon, and actively sequesters carbon dioxide (CO_2), further strengthening the environmental benefits.

Canada is increasingly investing in modular timber structures, recognizing the synergy between prefabrication and biobased materials as a pathway to greener construction.[13] The controlled factory setting improves quality control, leading to more durable, airtight, and energy-efficient buildings. Additionally, prefabricated wood components can be designed for easy disassembly and reuse, aligning with circular economy principles and extending their lifecycle.

Supporting Canadian Forestry

Biobased materials, particularly timber, are transforming Canada's construction industry as the nation prioritizes sustainable building solutions. With an abundant, responsibly managed forestry sector, Canada is well-positioned to expand the use of wood-based construction, reducing reliance on high-carbon materials like concrete and steel. Government incentives and private investment are driving innovation in engineered wood products such as cross-laminated timber (CLT) and glulam, which offer strength, durability, and low embodied carbon.[14]

In modular and prefabricated construction, biobased materials support circular economy principles by enhancing carbon sequestration, reducing waste, and improving material efficiency. As demand for climate-friendly construction rises, timber and other biobased materials will play a crucial role in shaping Canada's built environment.

Fig 11. On-site installation of prefabricated building components at a construction site in Toronto; Source: Assembly Corp.

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Comparative Life Cycle Assessment

This section presents a comparative life cycle assessment (LCA) of a six-story building, analyzing the efficiency and environmental impact of prefabricated wood versus concrete construction.

2.0

2.0 / Comparative Life Cycle Assessment

Introduction to Life Cycle Assessment

Life Cycle Assessment (LCA) of buildings is a systematic method for evaluating the environmental impacts associated with a building throughout its entire life cycle. It considers carbon emissions at all stages, from raw material extraction to demolition and disposal, often referred to as cradle to grave.

As seen in Figure 13 below, A1-A5 Upfront Carbon refers to the embodied carbon emissions associated with the extraction, manufacture and transport of building materials and construction phases before the building; B2-B5 stages refers to the embodied carbon emissions associated with the maintenance, repair, replacement, and refurbishment of building materials;C1-C4 stages refers to the embodied carbon emissions associated with the building's end of life, including deconstruction, demolition, transportation, waste processing, and disposal. Stages B6 and B7 comprise the operational carbon emissions from energy used to heat, light, ventilate and power a building in use.

Carbon Emissions vs Carbon Intensity

In LCA reporting, typically two kinds of metrics are used. Total Embodied Carbon Emissions refer to the material emissions associated with all reported stages of the carbon life cycle. This number is reported in tonnes of carbon dioxide equivalent or tCO2e. When we talk about mitigating the carbon impact of a project this is the number that we are eventually trying to reduce.

However, to allow for meaningful comparison of the carbon impact of buildings of different sizes an Embodied Carbon Intensity per Square Metre metric is used where the total emissions are divided by the gross floor area of a building. This number is reported in kilograms of carbon dioxide equivalent by square meter or kgCO2e/m2.

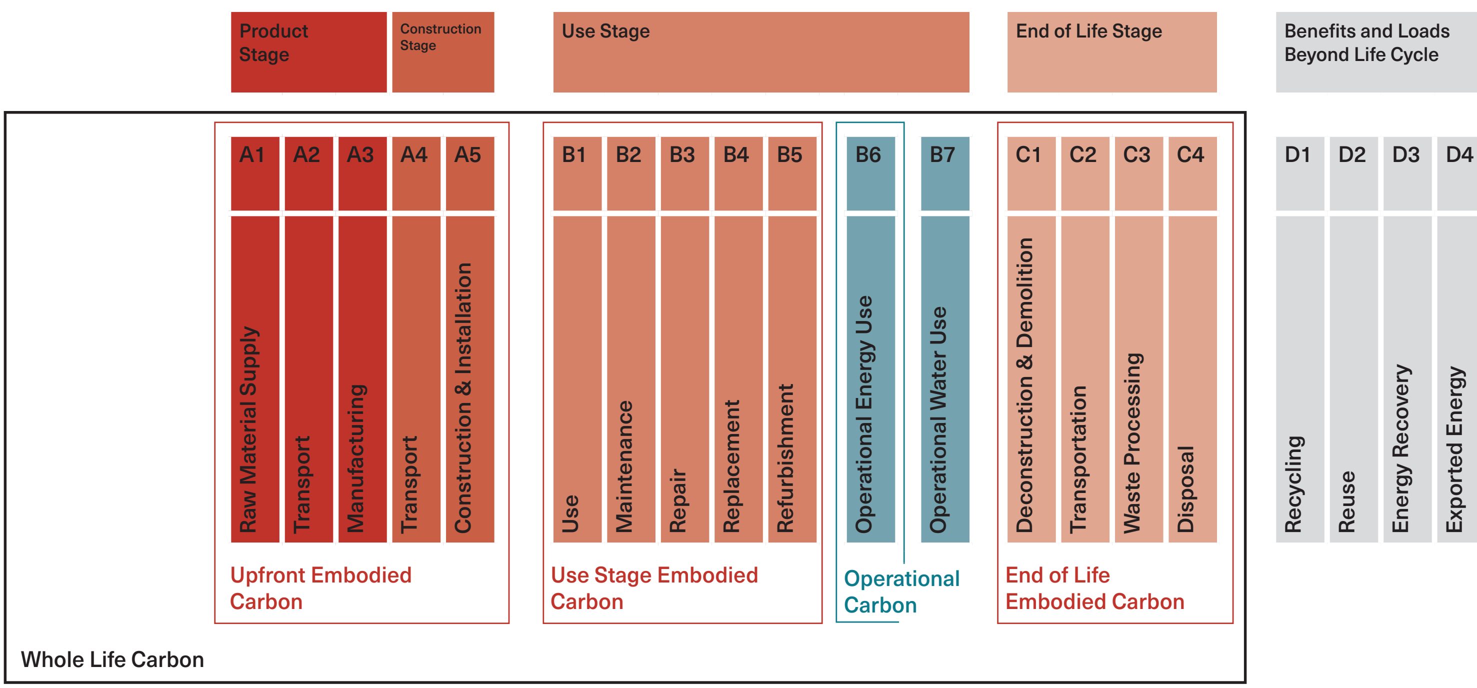


Fig 12. Life Cycle Assessment boundaries and carbon stages as per EN 15978 and ISO 21930.

2.0 / Comparative Life Cycle Assessment

Upfront Emissions of Modular Wood vs. Concrete Construction

A1-A5 Upfront Carbon refers to all embodied carbon emissions incurred in the initial construction of a project and it is typically where the bulk of a building's embodied carbon emissions lie. Ha/f used an early stage Life Cycle Assessment tool, Preoptima Concept, to do a comparative analysis between two construction scenarios for a 14,000 square metre, six storey, midrise residential building located in Toronto.

The baseline scenario assumes a reinforced concrete structural system, with an average column grid dimension of 8m x 8m (typical). The exterior wall system is a precast panel with mineral wall insulation and gypsum interior lining, with a 30% window to wall ratio and double glazed aluminium frame windows. The A1-A5 upfront carbon emissions of this baseline construction scenario is 4,218 tCO2e, with 80% of the emissions associated with the A1-A3 product stage emissions. The transport (A4) and onsite construction emissions (A5) add up to 20% of the upfront emissions.

The alternative scenario changes the structural system to glulam frame and CLT wall and floor slabs, with an average grid dimension of 6m x 6m (typical in timber construction). As seen in Table 2 below all other design parameters are kept consistent. The upfront carbon intensity reduces from 312 kgCO2/m2 to 143 kgCO2/m2.
Further carbon savings

Studies indicate that the impact of the A4 and A5 stages can be reduced by 40-60% due to minimizing construction schedules and the massive reduction in construction waste. Taking this into account, Figure 14 shows that the modular timber construction can achieve an embodied carbon intensity of 130 kgCO2/m2, which is a 58% reduction from the traditional concrete construction scenario.

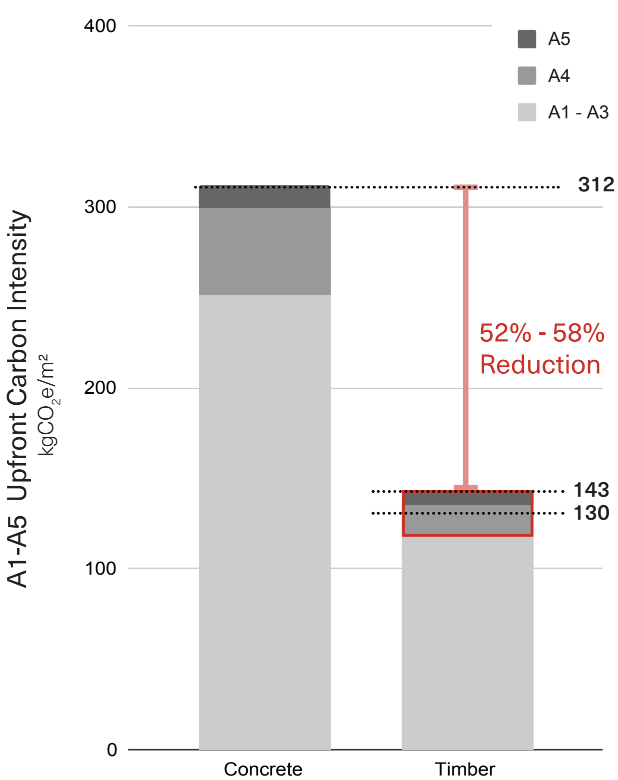
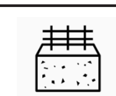
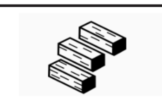


Fig 13. Comparative LCA at a schematic design phase between a six-storey concrete building and a six-storey modular wood building shows an Upfront Carbon reduction of 52-58% .

Table 1. Design inputs and LCA results for concrete and timber midrise construction using the Preoptima Concept LCA tool.

		
A1 - A5 Upfront Carbon Intensity	**312** kgCO2e/m2	**143** kgCO2e/m2
A1 - A5 Upfront Carbon Emissions	**4,218** tCO2e	**1,932** tCO2e
Gross Floor Area	14,000 m2	14,000 m2
Structural System	Reinforced Concrete	CLT and Glulam
Average Grid	8 x 8 m	6 x 6 m
Window to Wall Ratio	30% Glazing	30% Glazing
Wall System	Precast panel with mineral wool insulation	Biobased rainscreen
Roof System	Single ply membrane	Single ply membrane

/ Appendix: Endnotes

Endnotes

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