Building Knowledge:
Research Highlights

Modular and Prefabricated Housing
Ideas, Innovations, and Considerations to Improve Affordability, Efficiency, and Quality

Background

Modular and prefabricated units are built on an assembly line in a plant and transported to the construction site. Prefab or modular building systems can have advantages over traditional on-site construction:

- Site work can happen at the same time as units are being built in the plant;
- Units can be built when weather does not allow outdoor construction;
- Efficiencies and manufacturing principles realized on the assembly line can result in savings; and
- Because units are built indoors and closely supervised they can be of higher quality.

However, there are also a variety of potential challenges with modular and prefabricated construction:

- Modular units and prefabricated systems may have to travel long distances to the site, which can be costly or lead to damage;
- Modular and prefabricated units are typically lifted off the truck and on to the foundation with a crane, which can be expensive;
- On-site integration of units, systems or pods can be a challenge, and there can be scope gaps;
- If units or systems get damaged on route or deficiencies are noticed once the unit is on-site, it can be ambiguous whether site labour or the plant is responsible for making the repairs; and
- Modular units using standard designs may not work in all climates and mistakes in the design can be repeated on the fast moving assembly line.

The Real Estate Institute of BC, the Manufactured Housing Association of BC and BC Housing with funding from the Real Estate Foundation of BC wished to identify ideas, practices, and innovations to overcome these challenges and help maximize the potential benefits of modular and prefabricated construction for housing. This report examines eight research questions:

1. **Unit design and construction**: What are practices in the modular and prefabricated design and construction process to improve the time efficiencies and cost effectiveness?
2. **Materials**: What are the materials that can improve affordability, sustainability and performance?
3. **Transportation**: What are options for transporting modular and prefabricated housing units to development sites to ensure the process is as time efficient and cost effective as possible?

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4. **Housing Form**: What types of modular and prefabricated buildings are proving affordable, efficient and durable? What innovations are being made?

5. **On-site**: What are the options for on-site integration of modular and prefabricated housing units at development sites to ensure the process is as time efficient and cost effective as possible?

6. **Emergency Lodging**: What are lessons learned around using modular and prefabricated construction for temporary housing for those displaced during a natural disaster?

7. **BC Climatic Appropriateness**: Are the best practices identified through this study appropriate for BC's climate and landscape?

8. **Sustainability**: What are best practices to maximize the environmental sustainability of modular and prefabricated housing units during the construction phase and in terms of energy consumption once the units are occupied?

This report provides an overview of what was identified in the literature. The report is only meant to provide a summary of the literature. It is important to note that each project is unique and options covered in this report will not work in all situations.

This information may be helpful to the residential modular and prefab construction industry as it provides a scan of emerging ideas and some best practices. This report can also be used by housing organizations who are considering the use of modular and prefab construction as background reading to inform discussions with designers, site construction workers, and modular or prefabrication plants.

Examples of ideas and practices to maximize the potential benefits of modular construction and prefab, as well as address some of the challenges include:

Unit Design and Construction

- Project integration techniques such as use of BIM and inclusion of the on-site construction team in pre-planning stages can help prevent mistakes or integration issues;
- Efficiencies may be realized on the assembly line through practices such as automation, twinning production lines, running 24 hour shifts, building modules from the inside out, and automating parts of the assembly line; and
- Tools that increased the chances of success on a modular or manufactured project – particularly larger, more complex projects, include: Modular Test Fit (MTF), Building Information Modeling (BIM), Computer Aided Design and Manufacturing (CAD-CAM), and Computer Numerical Control (CNC) in manufacturing. These are part of the integrated design and project delivery processes (IDP, IPD).

Materials

- Composite wood materials (engineered and manufactured wood-based products such as engineered joists, beams, and wall and floor system) can offer increased strength, as well as faster building times and lower carbon emissions;
- Despite being combustible, heavy timber and panelized wood products can be designed to have good fire performance, due to the char layer that forms to protect remaining wood from fire;
- Panelized building systems can lead to faster construction time, increased thermal and structural performance and lowered labour costs; however, some panels may have challenges around increased capital costs, sound performance, off-gassing, the need for specialized trades, and special procedures to ensure joints are sealed appropriately;

- Using the structural properties of mass timber systems can provide reliable, affordable, high performance buildings on an accelerated schedule and have potential for mid- and high-rise;
- Laminated veneer lumber (LVL) can be used in wood curtain wall instead of the conventional mullions, reducing the environmental footprint of the building and supporting local economies;
- Steel framed modules can provide increased durability and have been used in recent projects with non-standard modules (i.e. all modules were not identical);
- Agricultural and landscaping materials, such as modular green roofs and green wall panels, are being used to offer lower greenhouse gas emissions and improved indoor air quality;
- Recycled-content and reused materials are being used in modular and prefab products to increase its sustainability; challenges include off-gassing and ensuring materials are non-toxic;
- New materials are emerging that meet rigorous health, sustainability and durability standards such as BuiltGreen, LEED and the Living Building Challenge; and
- Shipping containers have been used as student residences, offices, hotels, malls, affordable housing, shelters, and emergency lodging.

Transportation

- Air bag lift systems can be used where CSA Z-240.10.1 foundations are approved in the place of expensive cranes;
- Barges can be used to transport multiple units at a time to coastal areas, to save time and money; and
- Space saving structures such as prefab panels, stackable or folding modules, can be more efficient to transport by truck.

Housing Form

- Modular units can be combined side-by-side or top and bottom to create larger or more units or to extend existing buildings;
- In taller, steel-framed modular projects, after roughly ten floors of modular, there is a need for a concrete or steel core to act as structural support against wind, seismic and other loads. In taller mass timber projects, structural support cores (housing utilities, elevator and stairs) can be created with hybrid systems including wood, steel and concrete, or concrete and steel; and
- Modular and prefabricated construction has been used for six-storey and high rise multi-unit buildings, dormitories or work camps, micro units, and flex housing.

On-site Assembly

- 3D designs and pilot modules can help ensure alignment of mechanical, plumbing, electrical connections between modules; and
- Documenting covered connections through digital pictures or bar code scans can help inspectors find hidden elements and on-site labour do connections without damage to the unit.

Emergency Lodging

- Lightweight yet sturdy materials mean cranes may not be necessary;
- Foldable, stackable, or panelized units can be stored for immediate use after disaster and can be reused (following other disasters) if properly stored;
- Hinged walls and simple locking systems allow for fast assembly without skilled labour;
- Units should have hook ups that are compatible with transportable electrical/mechanical units;
- If units are not in storage, pre-existing agreements with private manufactures to prioritize emergency lodging units can speed delivery after disaster;
- Built in solar hot water or solar electrical panels can offer affordable, on-site services;
- Walls should be built with thermal materials to protect residents from extreme weather, as there will likely be little opportunity to install insulation once on-site;
- Moveable partitions as walls allow floor plans to be repurposed depending on the household composition of displaced residents or other space needs at the site;
- Using some modular units to create common indoor space (e.g. for day care, classrooms, or recreational areas) in transitional housing can help create a sense of community;
- Pre-testing unit designs before a disaster strikes can help ensure units are comfortable;
- If permanent housing construction takes longer than anticipated, units can be adjustable so that they can be connected through exterior openings to create larger units; and
- Temporary shelter is ideally built of durable materials and built to meet code requirements so that it can offer an option for permanent housing.

BC Climatic Appropriateness

- Multiple new innovative materials and systems such as panelized wall and floor systems, heat recovery systems, in-floor heating, and high performing windows and doors for all climates provide a wide variety of choices of high performance modular and prefab buildings for all BC climates.

Sustainability: Not Just Efficiency

- Sustainable modular and prefabricated buildings can include solar ready, Passive House designs, built-in renewable energy, socially and ecologically sustainable materials, water harvesting and water reuse such as embedded rainwater harvesting, greywater and water reuse systems as well as built-in composting toilets, innovative energy systems and super insulated envelopes.

On the next page is a summary of some ideas, practices, and innovations referenced in this report, which potentially address challenges and maximize benefits of modular construction. Beside each idea, practice, and innovation is an icon or icons to suggest how the idea, practice, or innovation might help optimize modular construction (e.g. improve affordability, timelines or efficiency, sustainability, or quality). The legend in the centre of the graphic below defines each icon. This graphic is not a comprehensive overview, but rather just suggestions about how the idea, practice, or innovation might contribute to optimizing modular construction.

The full report, which includes literature review and environmental scan sources, can be found at:

BC Housing
Manufactured Housing Association of B.C.
Real Estate Institute of B.C.

Unit Design & Construction	Materials	Transportation
IDP / IPD	Panelized wood	Space saving structures
BIM	Mass timber	Barges
Modular Test Fit	Shipping containers	Stackable / foldable modules
Assembly Line Efficiency	Durability	Air bag life systems

Housing Form	Ideas to optimize	On-site Assembly
Mid / high rise	**Affordability**	Digital Pictures
Micro Units	**Efficiency**	Barcodes
Extending Existing Buildings	**Sustainability**	3D designs
Flex housing	**Quality**	Pilot modules

BC Climatic Appropriateness	Sustainability	Emergency Lodging
All climates with planning	Net zero energy	Lightweight Materials
Panelized wall & floor systems	Solar-ready	Pre-existing agreements
Heat recovery systems	Embedded rainwater harvesting	Hinged walls & simple locking systems
In-floor heating	Passive house design	Pre-testing designs

This report is intended to provide readers with general information only. Issues and opportunities related to modular, prefabricated, and manufactured housing and construction are complex. Readers are urged not to rely simply on this report and to consult with appropriate reputable professionals and specialists where appropriate before taking any specific action. The authors, contributors, funders, and publishers assume no liability for the accuracy of the statements made or for any damage, loss, injury or expense that may be incurred or suffered as a result of the use of or reliance on the contents of this report. The views expressed do not necessarily represent those of individual contributors, BC Housing, BC Real Estate Institute, Manufactured Housing Association of BC, and the Real Estate Foundation of BC.