Modular and Prefabricated Housing:
Literature Scan of Ideas, Innovations, and Considerations to Improve Affordability, Efficiency, and Quality

Produced by:
BC Housing
Manufactured Housing Association of BC
Real Estate Institute of BC

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LA's Star Apartments: modular and prefabricated, six-storey residence built for Skid Row Housing Trust, LEED Platinum pending.
Photo used with permission from Gabor Ekecs.

Disclaimer

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.

Note to Reader

The digital version of this document can be found through the following sites:

- BC Housing: www.bchousing.org
- The Real Estate Institute of BC: www.reibc.org
- Manufactured Housing Association of BC: www.mhabc.com

The print version of this document has detailed URL references that can be used to manually access information online.

A note on language and definitions. This report most commonly uses the terms prefabricated and modular as they are terms that have a larger societal meaning beyond the building and construction industry. Prefabricated is used to mean systems such as panelized systems, prefab pods or other units or systems that are built within a factory and arrive on-site ready to be put together or dropped into the building. Modular is used to mean modules that are built in a factory that may be completely or partially finished, but that arrive on-site and are either placed or stacked, and include what is defined as manufactured homes.

Within the building and construction industry, there are a variety of terms to used refer to modular and prefabricated building and construction methods, including manufactured (often referring to a home "built on a non-removable steel chassis to which wheels are attached for towing to the site")[1], modular (usually referring to factory-built modules transported to the site on flat-bed trucks and assembled for single-family homes, duplexes, townhouses, or stacked to create a multi-family building)[1], MOC (Modular and Off-Site Construction) and others. Because this report is intended to be read by a wide range of people including the construction industry but also including managers at affordable housing organizations that may or may not have a technical background, we have preferred to use simpler language that could be understood by industry as well as the broader public.

The ⓘ symbol is used in the Executive Summary to highlight some of the ideas, practices, and innovations discussed in the report that can help optimize affordability, efficiency, quality, and sustainability of modular and prefabricated housing.

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[1] CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer

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Executive Summary

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 lean manufacturing principles realized on the assembly line can result in savings;
- 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, they 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;
- 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 purpose of this study is 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 nine 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?
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 prefabricated and modular 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.

This report finds a variety of notable practices that are not just pushing the modular and prefabricated industries forward, but are in some cases offering new solutions compared with standard building construction methods. Projects in the US, the UK, Australia, France, Austria, Asia as well as Canada are pushing the boundaries on how quickly prefab and modular construction can be erected on-site, with some projects going up in days and other months. Projects in Canada, the UK and Australia are among those aiming to build the highest wood building using prefabricated, structural composite wood systems. The majority of the modular, prefab and manufactured projects noted in this report have significant sustainability and health considerations, which can add value to housing not just in terms of better mental and physical health outcomes but in terms of the financial paybacks embodied in low or no energy and water bills. Finally, the current growth of the modular and manufactured industries has led to the potential for emergency shelters that have the opportunity to be developed into long term housing, if designed properly. 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;
- 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**;
- **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;
- **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;
- 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;
- 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;
- 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**.

Below 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.

Figure 1 Overview of Ideas, Practices, and Innovations

Introduction

Globally, modular and prefab buildings have a long history. The Mongolian Yurt is a building technology that is thousands of years old and prefabricated to be easy to transport. In North America, housing kits were brought to the east-coast in the seventeenth century, and entire homes began to be transported in the late nineteenth century by a Nova Scotia company which shipped modular wood-frame homes within North America and also to the Caribbean.[2] In modern times there are several countries where modular construction is commonly used for housing. In Sofia, Bulgaria, it is estimated to be over 60% of the population living in prefabricated buildings.[3] In 2009, the United Nations spent $72 million on prefabricated buildings.[4] A 2011 Globe and Mail article reported that while "in Scandinavia up to 80 per cent of housing is prefab, and modular housing of this type is common in Germany and other parts of Europe, there's relatively little multi-family modular housing in North America."

Modular units are usually[5] built on an assembly line in a plant and then transported to the construction site. Using modular and prefab can have advantages over traditional on-site construction.[6,7] Building the units indoors means site work can happen at the same time or that units can be built when weather does not allow outdoor construction, thereby speeding up construction timelines. Shorter timelines and efficiencies that can be realized through an assembly line approach can result in cost efficiencies. As well, because modular and prefab products are built indoors away from the elements and closely supervised at each step, they can be of higher quality. Due to precise planning and the sturdy builds of these construction products, they can – if designed appropriately - also offer a sustainable solution.

However, there are also challenges with modular and prefabricated construction.[8] Modular and prefab units may have to travel long distances to get to the site, which can be costly or lead to damage to the units. Units typically travel by truck, which means units are lifted off the truck and on to the foundation with a crane, which can also be expensive to transport to the site. As well, on-site integration of units can be a challenge as units or finishes can be damaged while hooking up mechanical, plumbing, and electrical connections. Also precise planning is needed to ensure the unit and site hook ups align. In addition, if units get damaged on route or deficiencies are noticed once the unit is on-site, it can be ambiguous in terms of whether site labour or the plant is responsible for making the repairs. Lastly, 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 purpose of this study is to identify ideas, practices, and innovations that help maximize the potential benefits of prefab and modular construction for affordable housing. Where possible, this report will suggest challenges and considerations with each idea, practice, and innovation. A secondary purpose to this research is to determine how to maximize efficiencies of modular and prefab products to examine potential use of these forms of housing as emergency lodging. This report also pulls ideas, practices, and innovations from other construction forms that are not currently used in modular construction, but could be considered as part of the modular construction process or finished product.

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2 CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer
3 United Nations In Action. 2009. http://www.un.org/webcast/pdfs/unia1217.pdf
4 UN Procurement Factsheet: http://www.un.org/fr/hq/dm/pdfs/ocss/Procurement_factsheet.pdf
5 Our interviews revealed that for a small minority of projects (especially undertaken in summer with land available nearby) some contractors set up outdoor areas to build modules that are then transported to the construction site close by. This only works when there is no rain forecast.
6 BC Housing, Modular Lessons Learned Focus Group Summary Report, 2011: https://www.bchousing.org/
7 "Putting the Pieces Together." Wood Works and Zeta Communities. www.zetacommunities.com/LiteratureRetrieve.aspx?ID=207742
8 Source: BC Housing, Modular Lessons Learned Focus Group Summary Report, 2011 - https://www.bchousing.org/resources/About%20BC%20Housing/Research_Reports/Modular-Housing-Research.pdf

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 industries 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 / or prefabricated construction as background reading to inform discussions with designers, site construction workers, and suppliers.

By looking at plant processes, transportation, materials, on-site integration, and housing form, this report will examine seven core 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 of modular and prefabricated housing?
2. **Materials:** What are materials 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?
4. **Housing Form:** What types of modular and prefabricated buildings are proving affordable, efficient and durable? What innovations are being made?
5. **On-site Assembly/Connections:** 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 prefabricated and modular housing units during the construction phase and in terms of energy consumption once the units are occupied?

Information in this report was gathered through the following sources:

- Case studies of modular and prefabricated housing projects, as well as non-housing projects using modular and prefabricated construction;
- Literatures review, including articles from industry newspapers, magazines, and industry newsletters, as well as academic research reports on modular and prefabricated construction;
- Lessons learned, consultant research and evaluation reports;
- Background research conducted by Eco Structures Design Build Inc.;
- Select expert interviews to validate research findings.

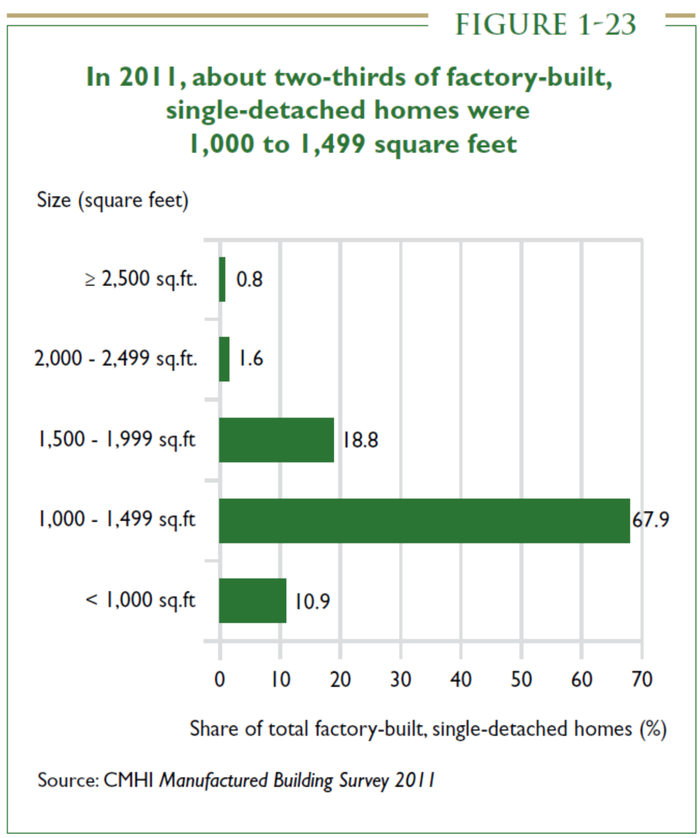
Background

In 2011, prefabricated and modular housing represented 12.5% of all single detached housing starts in Canada.[9] Most of the units that are built are smaller (see Figure 2).

In Canada, according to CMHC research,[3] roughly 90% of modular or prefabricated houses are delivered through builders, developers and retailers, with the remaining 10% going directly to DIY consumers who build their own homes.

In 2011, McGraw-Hill released their *Prefabrication and Modularization* report, in which they reported on a survey of over 800 architecture, engineering and contracting (AEC) professionals in the United States. Findings suggest that 35% of respondents had been using this form of construction at least 4 weeks. Among those using prefab and modular, the following critical findings include: [10]

Figure 2 Most Factory-Built Units Are Smaller



The same study found significant sustainability benefits to prefabricated and modular construction: 77% report that construction site waste is decreased—44% by 5% or more.

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[9] CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer
[10] McGraw Hill Smart Market Report: "Prefabrication and Modularization Increase Productivity: Construction Report." May 11, 2011. http://construction.com

Figure 3: 66% Report Project Schedules Decreased—35% by 4 or More Weeks

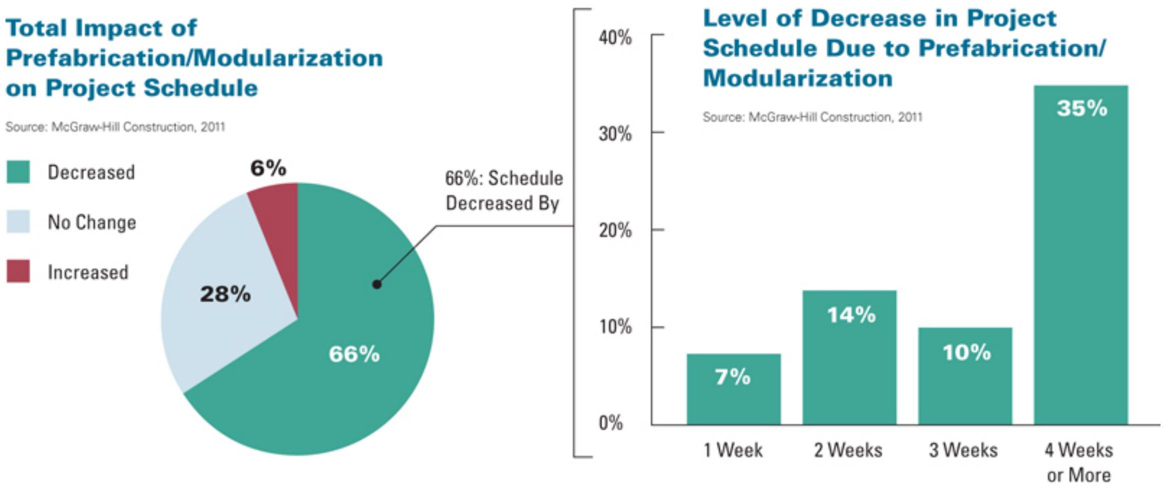
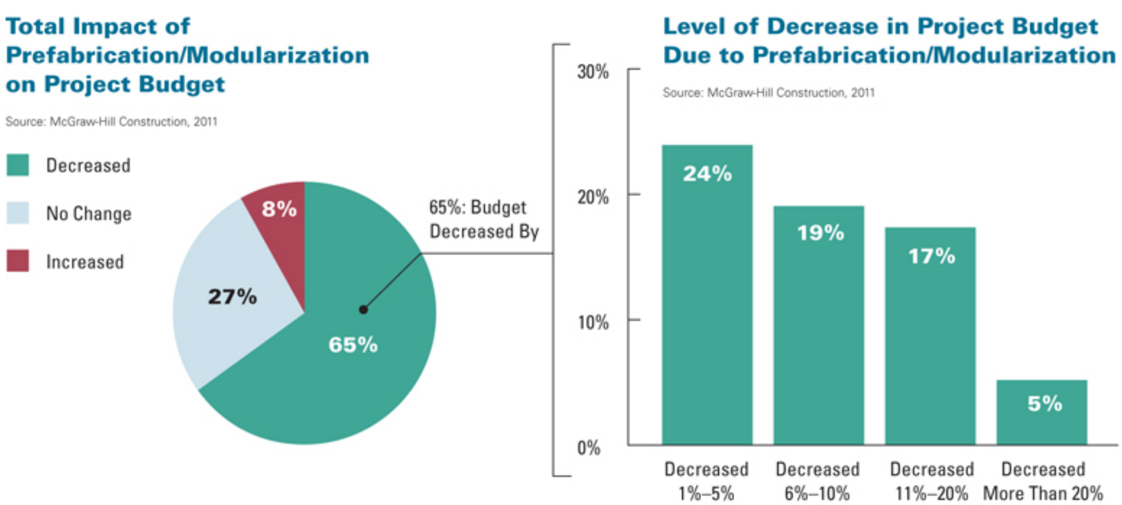


Figure 4: 65% Report Project Budgets Decreased—41% by 6% or More



1 Unit design and construction

What are the practices in the modular and prefabricated design and construction process to improve time efficiencies and cost effectiveness?

Many practices involve ways to ensure good communication and management of a project as it moves from concept through design, construction and occupancy. Modular and prefabricated design, construction and operations often require heightened integration of systems of communication, information management and project management due to tightened timelines and efficiencies.

Several studies and articles point to a suite of tools that increased the chances of success on a modular or manufactured project – particularly larger and more complicated projects with multiple units.[11], [12] These include Modular Test Fit (MTF), Building Information Modeling (BIM), Computer Aided Design and Manufacturing (CAD-CAM), and Computer Numerical Control (CNC) in manufacturing. These together are part of the integrated design and project delivery processes (IDP, IPD).

Tools to optimize success on a modular or prefab 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**).

1.1 Project Integration (IDP, IPD), Building Information Modeling (BIM)

"It looks simpler than it is. There's an awful lot of coordination."
Jonathan Weiss, president of Equinox Management and Construction, developer of the Modules, Philadelphia, as reported in *The New York Times*

The American Institute of Architects (AIA) currently defines IPD (Integrated Project Delivery) as "a project delivery method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction."[13] Because of the increased coordination and tight timelines required of many modular and prefab projects, integration is not just a best practice – it is often seen as a necessity for success in larger projects.

Early inclusion and consultation is central to the integrated design process (IDP) and integrated delivery processes (IDP). Pre-planning and integrated involvement of all stakeholders (including the modular or prefab contractor, construction managers and on-site trades) is critical to realize potential cost- and time-saving benefits of modular and prefab construction. For example, at the Wood Innovation and Design Centre in Prince George, the construction team was brought on during the design phase, and this was seen as critical to getting the wood fabricated appropriately but also to have collaborative design, where all of the individuals involved, from architects and engineers to trades and sub-trades, have looked at the potential conflicts in advance to ensure there are solutions.[14]

[11] Sources include those below in footnotes 12 and 13, as well as Background Research by Eco Structures Design Build Inc.
[12] 2014. Background Research by Eco Structures Design Build Inc.
[13] "Integrated Project Delivery – An Updated Working Definition". American Institute of Architects California Council July 15, 2014.
[14] The Wood Innovation and Design Centre. http://www.unbc.ca/engineering/wood-innovation-and-design-centre

A recent Survey of International Tall Wood Buildings noted that amongst the ten projects profiled, there was a greater "blending of professional roles" which created a strong ethic of collaboration, which was identified as being crucial to advancing new solutions in this emerging sector.[15] Building Information Modeling (BIM) can assist with the integration of both the design process and the project delivery (IDP and IPD). BIM is collection of electronic data that represents not just the physical building but also its functions. In includes energy models, transportation models, as well as models for on-site integration, green rating systems and systems such as LEED and LEEP, and can include scheduling. BIM, used collaboratively by an integrated team, can help with planning, scheduling and decision making throughout the design process.[16]

BIM helps with cost estimates, scheduling, energy modeling and coordination between project participants such as engineers, fabricators, contractors, trades and others. The Royal Architectural Institute of Canada (RAIC) describes the Integrated Design Process: "it brings together key stakeholders and design professionals, such as building owners, facility managers, developers, designers, engineers, consultants, and occupants, as a core team to work collaboratively and interactively from the early planning stages through to building occupation." BIM can also facilitate modular test fit modeling to determine if modular construction or modular components are appropriate for the housing project in the early planning stages.

The increased need for integration between all roles and disciplines throughout the design, construction and operation process is assisted by computer-aided technologies. Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) involve the use of computer software to design and manufacture products, and on larger projects this can significantly help modular and prefabricated designs, as it provides an organizational structure for the added coordination. CAD and CAM are both compatible with BIM. While still not used in every project, computer-aided design can help improve the quality and communication of designs between the designer and the owners, project participants, sub-consultants, architect, engineer, landscape architect, citizens and others. Instead of having one paper drawing, the electronic files can be shared much more quickly, and also plugged into other systems such as building energy modeling or other performance assessments. Computer numerical control (CNC) is a term that represents machines and processes that are automated and controlled by computers and/or software programs. In larger scale manufacturing of manufactured, modular and prefabricated components it can add value and increase returns on investment through ensuring precision in fabrication and coordination.

1.2 Lean Manufacturing + Assembly Line Efficiencies

Assembly lines for modular and prefabricated construction typically operate more quickly than on-site construction. Lean manufacturing practices can include practices such as ensuring that materials are close to workers when they are needed. Lean manufacturing has been shown to increase overall construction labour efficiencies by 15–20% (though these can be offset by transportation costs).[17] Others point to lean manufacturing tools such as the "5S: sort, straighten, shine, standardize, and sustain" which include standardized work, taking time to plan work, managing variations, and mapping the "value stream" and studies have shown how these lean manufacturing tools have brought value to modular manufacturers.[18] The graphic below illustrates the results of this efficiency: prefab and modular buildings can produce significant time savings.[19]

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.

[15] Perkins + Will. May 2014. "Survey of International Tall Wood Buildings." Forestry Innovation Investment and the Binational Softwood Lumber Council. http://www.rethinkwood.com/
[16] National BIM Standard – United States. National Building Information Model Standard Project Committee, http://www.nationalbimstandard.org/faq.php#faq1
[17] Spring 2014 "The fabulous new face of prefab." http://www.albertaconstructionmagazine.com/

Figure 5: Modular Construction Timeline

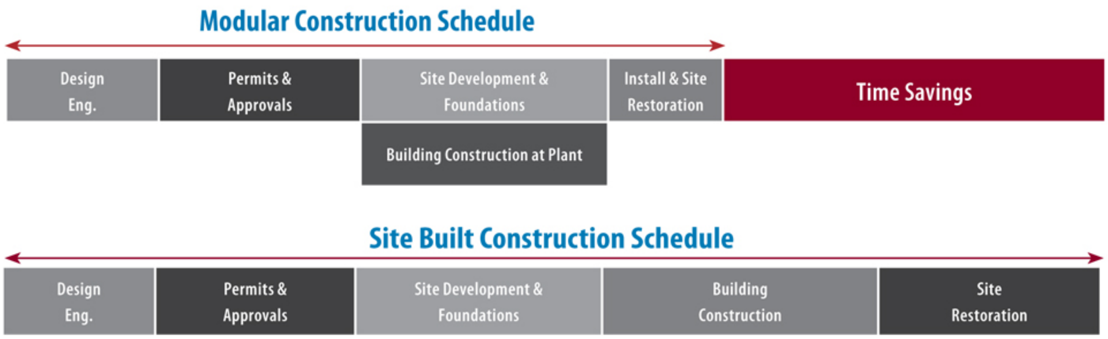


Image credit: Modular Building Institute

Some innovations, practices and options to further increase the efficiency of modular production lines include:[20]

- Twinning production lines to allow the plant to work on multiple orders;
- Modular construction is done indoors, so can have multiple shifts in a day;
- Conveyor belts can be used to move units or materials;
- Working from the inside out can allow more work to be done on a unit at the same time (e.g. starting by building the frame, not exterior walls, allows workers open access to install fixtures);
- Automating parts of the assembly lines through robotic arms (e.g. like Toyota has done for their car assembly lines) can add efficiency and precision to repetitive tasks.

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.

[18] Yu, H., Al-Hussein, M., Al-Jibouri, S., and Telyas, A. 2013. "Lean Transformation in a Modular Building Company: A Case for Implementation." Journal of Management. Engineering., 29(1), 103–111.
[19] Image courtesy of Modular Building Institute via Wikimedia Commons.
[20] Sources: http://dspace.mit.edu/bitstream/handle/1721.1/77129/825120099.pdf?sequence=1

Figure 6: MacDougal Street Apartment, NY, 2012

Photo used with Permission from Concern for Independent Living

1.3 Quality Assurance

Many reports and interviews with experts confirm that modular and prefabricated construction can lead to higher quality housing because the units are built using precise measurements and the indoor process protects units from damage from the elements and allows for close supervision of every part of the construction process. Despite these benefits, there can be questions about quality assurance.

In BC, prefabricated buildings, prefabricated modules, and prefabricated panels all must materially or substantially comply with the majority of the technical requirements of the BC Building Code. In addition to compliance with provincial building codes and municipal bylaws, the three standards that apply to modular buildings in Canada are all managed by the Canadian Standards Association (CSA):

- **CAN/CSA A277:** Procedure for Factory Certification of Buildings. This standard is used to certify the factory. CSA A277 is a standard to certify factories that build prefabricated buildings, prefabricated modules and prefabricated panels for buildings (including prefabricated walls and roofs, or panels for walls and roofs). Future editions, perhaps as early as 2015, will further clarify technical requirements for modules and panels.

- **CAN/CSA Z240 MH Series:** Manufactured Homes. This sets standards for constructing manufactured homes. Because in BC, all prefabricated buildings, prefabricated modules, and prefabricated panels must comply with the technical requirements of the BC Building Code with the exception of Z240-compliant manufactured homes, Z240 is a technical standard that applies to complete 1-storey single family homes.

- **CSA Z240.10.1:** Site Preparation, Foundation and Anchorage of Manufactured Homes. This standard is referenced in the BC Building Code and provides technical requirements for site preparation, surface foundations and installation of one-storey buildings (beyond manufactured homes) on surface foundations, including anchorage and skirting. For multi-module buildings, the standard also provides requirements addressing continuity of the building structure, building envelope and fire blocking.

In 2013, the CMHC's Canadian Housing Observer reported that in Canada in 2012, there were 123 factories certified under CSA A277, which is the procedure for the factory certification of buildings, and as you can see in the below table, most of those factories are in Canada.[21]

Figure 7: Factories Certified Under CSA A277

Number of factories certified under CSA A277, the Procedure for the Factory Certification of Buildings, selected provinces, Canada, China and United States, 2001, 2006 and 2012

Certified building factories			
Region	**2001**	**2006**	**2012**
British Columbia	7	8	14
Alberta	16	28	35
Saskatchewan	4	6	13
Manitoba	3	3	7
Ontario	6	6	6
Quebec	17	18	16
New Brunswick	5	5	5
Newfoundland and Labrador	1	1	-
Canada	**59**	**75**	**96**
China	-	-	1
United States	1	5	26
Total	**60**	**80**	**123**

Source: Adapted from Canadian Manufactured Housing Institute (CMHI), CSA-International, Intertek Testing Services and Quality Auditing Institute.

Image credit CMHC

Additional certifications are increasingly used to quantify the healthy, energy efficiency and overall sustainability of modular construction, and these include the Passive House, BuiltGreen BC, Living Building Challenge, and LEED certifications. For more on these systems and how they can be used with modular building, please see the Sustainability section.

Other options to ensure stakeholders involved in modular projects are comfortable with the quality assurance include[22]:

- conducting workshops for municipal inspectors to provide overview of the quality assurance processes and standards used by the industry;

[21] CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer

[22] BC Housing, Modular Lessons Learned Focus Group Summary Report, 2011: https://www.bchousing.org/

- allowing clients to hire their own inspectors to come to the plants and inspect units while they are on the assembly line.

1.4 Design-Build + Turnkey Leader

Turnkey management approach brings the management of the entire project under one leader so that the client is, in essence, handed the keys at the end. It is a holistic service that provides the product finalized and ready for use. In many cases researched throughout this effort, modular and prefabricated projects are good candidates to use the turnkey, or turnkey leader method.[23] A Turnkey leader can be the Project Manager. Project management software such as Microsoft Project which uses a Critical Path Method has been identified as helping to map out the overall project from concept through operation.[26] This can help address challenges with on-site integration of prefabricated and modular units and systems, and reduce or eliminate ambiguity if defects or damage are noticed on-site after delivery.

1.5 Identifying and Sharing Best Practices and Innovations

Background research conducted by Eco Structures Design Build Inc. identified the need for centres of excellence and innovation to conduct research and share learnings, best practices, and innovations across the industry (e.g. at the University of Alberta).

[23] 2014. Background Research by Eco Structures Design Build Inc.

2 Materials

What materials can improve affordability, quality, sustainability and performance?

This section reviews panels, steel frames, composite wood materials, concrete, hybrid systems, shipping containers, agricultural, landscaping, red-list, recycled and reused materials. Many methods, including panels, steel frames, composite wood materials and hybrid systems, can boast faster on-site construction times and accelerated construction times overall, even accounting for the factory time to build these prefabricated and manufactured modules and systems. There can be financial benefits, particularly related to the accelerated schedules. There can be challenges with new systems in terms of finding trained labour to build them and to ensure that any new system connects appropriately with more typical on-site construction practices. Other challenges can include the increased complexity of coordinating new systems and roles from concept through construction and operation of the building.

2.1 Panels

Structurally Insulated Panels (SIPs) have been used in North America since at least the 1930s, when the US Forest Products Laboratory tested skinned panels in an effort to conserve wood. One early stressed-skin house in 1937 brought in First Lady Eleanor Roosevelt to do the dedication. Further development of structural insulated panels took place in the 1940s, when paperboard insulation was used, sandwiched by plywood, among other materials. In the 1970s, foam core products gained attention, and the 1980s brought the rise of SIPs of many types (further described below). In North America, after 2000, there has been enormous growth and interest in European passive house technologies, which use panelized construction and are described further in the composite wood materials section.

Panelized building systems can bring the benefits of accelerated construction time, increased thermal and structural performance, and reduced labour costs. Challenges can come from increased first costs (also called capital costs or building costs), which are usually balanced (often overwhelmed) by the long-term savings resulting from reduced energy expenditures. Other challenges can include creep (in which materials shrink or change form over time), sound performance, off-gassing, and a complexity and precision of construction that requires specialized training. Significant care needs to be taken to seal joints in any exposed structurally insulated roof or wall panels to ensure there is no condensation under the roof or wall membrane, as this should be able to be done without increasing the construction budget[24]. It is important to ensure a manager or architect does periodical site visits to ensure these joints are sealed properly.

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.

One of the most common pre-fabricated products in the North American market is the Structural Insulated Panel (SIP). SIPs can be used for walls, floors or roofs and most commonly are made of Oriented Strand Board (OSB) outer panel walls into which is

[24] "Elementary Classroom in Bertschi School: Pro Bono Participation at LEED® Gold Bertschi School http://www.morrisonhershfield.com/

sandwiched the insulating material – most commonly expanded or extruded polystyrene (EPS or XPS), or a rigid polyurethane foam. However, SIPs can also be made of plywood (including pressure-treated for below-grade foundation walls), steel, aluminum, cement board, stainless steel, fiber-reinforced plastic, magnesium oxide with agricultural fiber as the insulating core.[25]

Figure 8: What are these walls made of? SIPs

Picture courtesy the SEEDcollaborative, a non-profit committed to "sustainably restorative, inspirational learning spaces."

New materials are emerging that meet rigorous health, sustainability and durability standards. SIPs have been built to achieve certifications such as BuiltGreen, LEED and the Living Building Challenge.

As noted by researchers and engineers that worked on one of the first certified Living Building projects, the added expense of SIPs can make them liable to be cut during the "value engineering" process.[26] However, the benefit of a SIP with a high R-value is in its ability to reduce costs over the life of the building, so cutting them to reduce first costs (capital or building costs) can defeat long-term and much larger financial benefits.

[25] http://en.wikipedia.org/wiki/Structural_insulated_panel
[26] Smith, Kevin et al. June 24, 2011. "Getting to Net- Zero Energy: Lessons Learned from a Living Building Challenge." http://www.aashe.org

SIPs have been used on other high performance projects, including the Bertschi Living Building Science Wing in Seattle, a certified Living Building, and the SEEDcollaborative, shown above.[27] SIPs have also been used on two of CMHC's EQuilibrium™ Housing projects: Avalon Discovery 3 and Laebon CHESS projects. The Avalon Discovery 3, in Red Deer, Alberta, uses exterior walls created through a double layer of SIPs, which achieves a very high insulating value of R-72; the Laebon CHESS building in Red Deer uses the single SIP layer to achieve an insulating value of R-44.[28]

2.2 Wood

Figure 9: Exterior Char Layer, Wood Innovation and Design Centre, Prince George

Photo credit Wilma Leung, pictured during construction

Heavy-timber is a term used to mean large wood column and beam structures and Mass Timber is usually used to mean a wood panel system (see the above section on Composite Wood). Wood-framed modular units are perhaps the most common form of modular unit currently use in British Columbia. Dimensional wood is used, along with heavy timber and / or composite wood in the growing business of prefabricated panelized wood construction (see next section for more information). Wood construction provides the structure for many of BC's modular and prefabrication factories that build everything from oil-field housing to mobile homes to high-end single and multi-storey homes to university centres (pictured above).

Notable recent projects such as CMHC's ÉcoTerra™ project (below), Monad (see the Sustainability section) and San Francisco's 4 storey, LEED Platinum 38 Harriet Street, completed in just 4 on-site days, offer some hints about where the use of wood is heading. Other builders are building their own prefabricated units just off-site – for

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.

[27] Living Building Challenge Case Studies. Certified Projects. http://living-future.org/case-study/bertschiscience
[28] CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer

example one expert interviewed talked about using a field in BC's interior during the summer to construct the homes while site work was being done, to shorten the construction schedule, and in this case it was not done in a factory but out in the open with the good fortune of good weather.

Despite being a combustible material, both heavy timber and panelized wood products can be designed to have good fire performance, due to the char layer that can form which protects remaining wood from fire.[29]

This blackened char layer is pictured above as an external design feature of the Wood Innovation and Design Centre. The Prince George Wood Innovation and Design Centre had to undertake a series of fire tests to demonstrate that the joints between the CLT panels would maintain the one hour fire separation required by code.[30]

Figure 10: ÉcoTerra™ Roof Module with Solar Thermal + Photovoltaic Array

Photo courtesy Canada Mortgage and Housing Corporation's EQuilibrium™ Housing

[29] MGB Architecture. The Case For Tall Wood Buildings. http://www.woodworks.org/publications-media/research-papers/
[30] The Wood Innovation and Design Centre. http://www.unbc.ca/engineering/wood-innovation-and-design-centre

2.3 Composite Wood Materials

Composite wood products include a large range of materials and wood-based systems that are composed with various wood and other materials. They include engineered and manufactured wood-based products such as engineered joists, beams, wall- and floor-systems, many of which can replace steel due to their increased strength. Below are three types of engineered wood products[31]:

Cross-Laminated Timber (CLT): These panels are considered structural and composite wood, composed of boards of pressed and dried wood which are glued together with every other layer at 90 degree angles to the last. Adhesives can be non-toxic.

Glued Laminated Lumber (GLULAM): This is another structural composite wood produce manufactured with layers, this time of dimensioned lumber, and also glued together.

Laminated Veneer Lumber (LVL): Dried 3 mm thick softwood is glued together to create this product.

Composite wood materials (engineered and manufactured wood-based products such as engineered joists, beams, and wall and floor system) offer increased strength, as well as faster building times and lower carbon emissions.

The growth of prefabricated, composite wood products around the world has accelerated in the last few years. Composite wood materials also include systems with non-wood materials as well, such as are used in buildings like the CSH Case Study Hamburg which uses a prefabricated floor / ceiling system made of timber-concrete composite[32]. In British Columbia, UBC's Earth Sciences Building and Prince George's Wood Innovation and Design Centre represent models of what is possible with composite wood construction and prefabricated wood components.

Reports suggest there are roughly 50 six-storey wood frame residential buildings completed in BC, many of which include a variety of wood and other prefabricated components.[33] This new trend is the result of innovations in mass timber systems, enabled by regulatory changes, which allow the structural use of mass wood products to a new degree. The result is that many prefab and modular products that use wood composite can provide reliable, affordable, high performance buildings on an accelerated schedule.

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.

A *Timber Tower Research Project*, from Skidmore, Owings & Merrill published in 2013 showed how a "mass timber" system could be used to build up to 42-stories[34]. Benefits of this type of construction include faster building times and lower environmental and carbon footprint. Now that it is built, BC's 30 metre high Wood Innovation Design Centre in Prince George, B.C. is one of the tallest all-wood buildings in the world.[35] This project was given special approval from the BC Government to build despite it being higher than currently allowable under the code for wood buildings. Globally, regulators are watching this trend in taller wooden buildings. Australia's Forté, a 32.17 meter building built in 2012, is, at the time of this writing, the tallest mass wood building in the world.

[31] University of Northern British Columbia. Engineering Department: "Construction of the Wood Innovation & Design Centre." http://www.unbc.ca/
[32] "Smart Price House: Case Study Hamburg." August 2013, International Building Exhibition Hamberg. White Paper. http://www.iba-hamburg.de/
[33] Taggart, Jim. March 25th, 2014. "Prefabrication in wood." http://www.sabmagazine.com
[34] Skidmore, Owings & Merrill. http://www.som.com
[35] Sieniuc, Kat. Jun. 15 2014. "All-wood B.C. building sets green standard." *The Globe and Mail.*

A recent Survey of International Tall Wood Buildings funded by Forestry Innovation Investment and the Binational Softwood Lumber Council profiles ten tall wood buildings around the world (although predominantly in Europe) and presents lessons learned, including the fact that these ten projects have developed new mass timber construction processes, expanded the capacity of the building industry, streamlined approval pathways for other projects to follow, and provided market recognition to tall wood construction in general.[36]

Figure 11 Three Dimensional Wall Section of Structural Wood Panel System

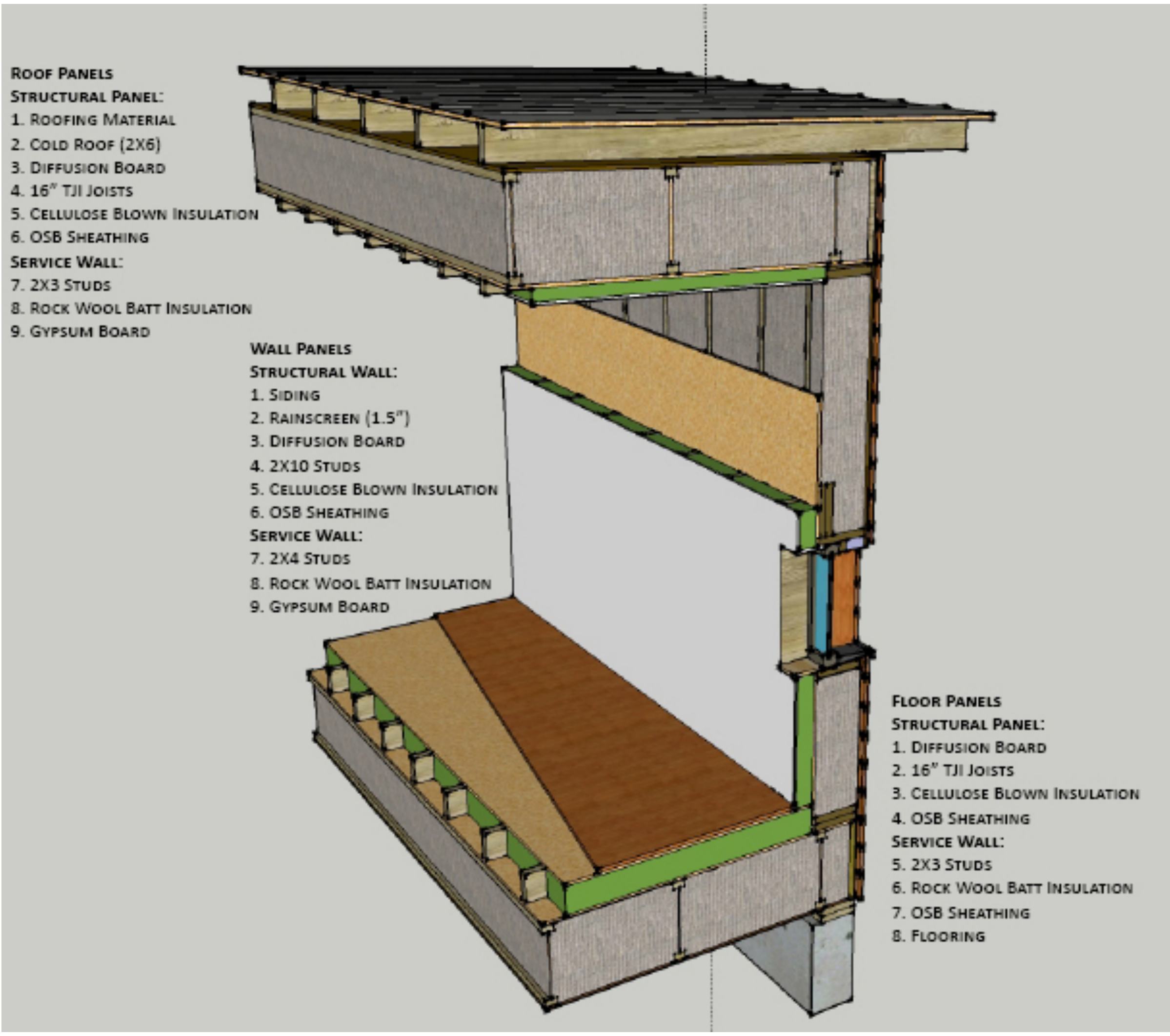


Photo used with permission from BC Passive House

36 Perkins + Will. May 2014. "Survey of International Tall Wood Buildings." Forestry Innovation Investment and the Binational Softwood Lumber Council. http://www.rethinkwood.com/

Whistler's Rainbow Passive House was finished in 2012 in part to celebrate BC's emerging Passive House industry. The home has been qualified for Whistler's "Restricted Housing Initiative," a local affordable housing program. Rainbow was inspired by the Vancouver 2010 Olympic Austria Passivhaus, which used many products from Europe. However, 90% of the products used in the Rainbow House were regional Canadian products. [37] It contains a variety of composite wood products, included in the cross laminated timber (CLT) roof, wall and floor structural panel system[38], including passive house rated "outsulated" wood windows, OSB sheathing and TJI joists, as seen below.

Also considered a wood composite material, some wood panel systems may include the use of wood windows. Locally made triple pane windows are increasingly being used on high performance projects in the Pacific Northwest such as the passive house project Kiln Apartments, in Portland, Oregon[39] and the Janey, also in Portland Oregon.

The Prince George Wood Innovation Design Centre (WIDC) has used laminated veneer lumber (LVL) in the curtain wall instead of the conventional aluminum mullions. This application of wood curtain wall is innovative due to the fact that it is unprecidented at this scale, at least in Canada, and paves the way for other large scale use of wood in curtain wall systems.[40] The advantages of using wood windows can include better insulation values, reduced environmental and greenhouse gas footprint and support for local industry.

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.

[37] Maurer, Alexander. January 25, 2013. "German Passivhaus Institut Darmstadr Gives Official Nod to Rainbow Passive House.

[38] http://www.bcpassivehouse.com/theprefabpanelizedsystem/paneldescription.html

[39] "Wood Specification: Passive Design and Framing Techniques http://www.rethinkwood.com/

[40] http://www.woodfirstbc.ca/sites/default/files/WIDC_FactSheet_WEB_0.pdf

Figure 12 Prefab Wall Panel Installation at Affordable Duplex, Whistler, BC, 2012

Photo credit Marken Design + Consulting

2.4 Steel

Steel framing is most commonly associated with on-site construction in which steel columns and I-beams are framed together in a rectangular grid that frames the building. For mid and high-rise modular and prefabricated construction, steel frames are used for their light weight, ease of transport and recyclability. Please see the below section on Sturdy Materials for more information. Challenges with steel can include its increased energy intensity throughout its lifecycle, as well as its thermal conductivity and bridging, and its acoustic properties.

Steel framed modules can provide increased durability and have been used in recent projects with non-standard modules.

Figure 13: One9 - Nine storey, Steel Frame Melbourne Apartment Built in Five Days

Photo credit Hickory Group

Steel frame modular multi-family residential buildings are now being developed in the US, UK, Japan, China and Australia with significantly reduced on-site construction times, and at larger heights. On-site construction is now measured in weeks and days. Research suggests that cold-rolled steel framed modules may be stacked to roughly 10 stories safely, while modules using a stronger structural steel can be built even higher.[41] Beyond roughly 10 stories, depending on seismic or wind conditions, there may be a need to have a concrete, steel or other structural tower to which to secure the modules. Some see this secondary frame as being key to allowing modular units to go to much greater heights. Some examples of this type of construction are below.

[41] Berg, Nate. November 1, 2013. "Piecemeal Potential: The sky may be the limit for prefab modular towers." Architect Magazine. http://www.architectmagazine.com/

In Japan, property developer and builder of pre-fabricated and green homes and multi-unit residential buildings, Sekisui House, use both timber and steel frames in its buildings. Like many international mdoular and prefabricated companies, including at least one in Canada, they in 2010 entered the Australian market, where modular and prefabricated building – particularly the market for steel framed, mid-rise MURBs – is growing very quickly.

Figure 14: Thames Valley University's Concrete Core (left), Modular Units (right)

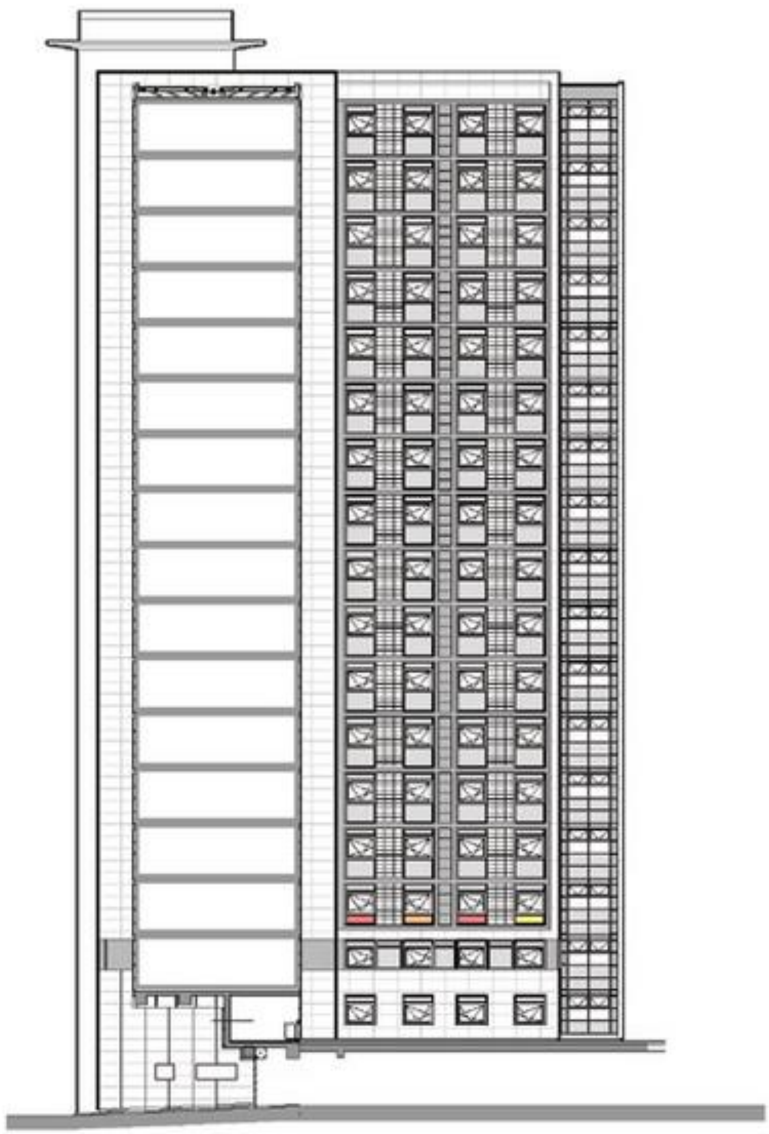


Photo credit Paragon

In the United Kingdom, there has been what has been hailed – as far back as 2006 – as the "dawn of the modular skyscraper.[42]" Projects include University of Wolverhampton's 25 storey modular, Thames Valley's 1000 dormitories constructed on seventeen storeys of modular (seen right), and many others.

[42] Soltani, Sonia. 2006. "The only way is up." http://www.building.co.uk/

In Australia, the One9 Project was built with 36 modules in just five (on-site) days. The modules were equiped facades and flooring (both wood and carpets), built in furniture and balconies. The proprietary building system, developed by Australian architect Nonda Katsalidis, depends on factory-built modules that are unusual in that they do not use a standardized module size. An earlier project, 3 East, built in Richmond, Australia, is a seven storey apartment building completed in 11 on-site days.

In the United States, another steel frame project recently completed also using non-standardized modules, is New York's The Stack, a seven storey, 28 unit, multi-family rental built in 2014 that includes moderate income housing with a number of affordable units.[43] The modules are steel and concrete. Other US steel framed modular MURBs include The Stack,
NYC, USA (seen in next picture), Nehemiah Spring Creek,
NYC, MacDougal Street Apartment, NY.

Figure 15: The Stack: NY's Tallest Modular Project is Steel Framed

Photo courtesy of GLUCK+

[43] http://gluckplus.com/project/the-stack

2.5 Concrete

Concrete construction is common for site-built projects where reinforced concrete and tilt-up concrete construction are used. Precast concrete and concrete block are two well-known and commonly used forms of prefabricated construction. Some advantages of concrete include its compressive strength and durability. Disadvantages include the very low tensile strength, requiring some form of tensile strength to be added (rebar, in reinforced concrete) to allow it to meet seismic and wind loads. In addition, concrete can provide a thermal bridge to allow heat (or cooling) to leave a building, thus reducing the energy efficiency of the building envelope as a whole. Concrete balconies that are an extension of a buildings' concrete floor slab through the building envelope are a textbook example of thermal bridging. See sections on Panels, Composite Wood and Sustainability for more examples of concrete in prefabricated and modular buildings.

Perhaps the best known modular concrete project in Canada is Habitat 67, in Montreal. Built in 1966 on the Saint Lawrence River, this project was planned to be 1,000 affordable housing units. It ended up as 158 homes, made up of 354 pre-cast concrete modules, arranged in different configurations to support fifteen distinct housing types to allow a diversity of housing choices. Unfortunately the homes came in significantly above the affordable price range, with a cost of roughly $140,000 per unit in 1967[44]. Another notable concrete modular project is the Nakagin Capsule Tower in, Tokyo, Japan. The smaller spans allowed by concrete modular construction are not as useful in modern development as the project had anticipated.[45] Current mid and high-rise modular projects in New York City – the B2 and The Stack - use steel and concrete modules. See the Hybrid, Steel and High Rise sections for information on concrete innovations.

Figure 16: Habitat 67 (Montreal): 156 Not-So-Affordable Modular Concrete Homes

Photo credit Brian Pirie

With any building material, ongoing research needs to inform best practices for structural integrity and seismic loading. Recent experiments show that than eight-inch concrete shear walls are less likely to

[44] Meinhold, Bridgette. 08/20/09. "Habitat 67: Montreal's Prefab Pixel City." Inhabitat. http://inhabitat.com
[45] Velamati, Sri. 2012. "Feasibility, Benefits and Challenges of Modular Construction in High-rise Development in the United States: A Developer's Perspective." http://hdl.handle.net/1721.1/77129 MIT Center for Real Estate. Program in Real Estate Development

suddenly fail in an earthquake, which has led to revisions in building codes across the country.[46] These concerns about seismic loading has implications for modular concrete buildings as well.

2.6 Hybrid Systems

Figure 17: Wood Hybrid Modular System at Life Cycle Tower One (LCT One), Austria, 2012

Photo credit Rhomberg

Many buildings that use modular, manufactured and/or prefabricated components use a variety of these components with at least minimal components of final, on-site construction. Hybrid prefabricated or modular construction is seen in a wide range of combinations. For example, most site-built homes include prefabricated roof trusses and cabinetry[47], and prefabricated modular bathroom units (pods) are now becoming more common in everything from health care to commercial to residential buildings in North America and around the world[48]. As a result, there can be a variety of opportunities and challenges with different forms of hybrid construction.

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. The student dorms at the University of Wolverhampton are an example of a hybrid system, where a concrete core poured on-site is gives necessary structural stability to a 25-story modular student residence.[49]

[46] Adebar, P. March, 2013 "Compression failure of thin concrete walls during 2010 Chile earthquake: lessons for Canadian design practice." Canadian Journal of Civil Engineering.
[47] CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer
[48] Lawson, Mark, with Ray Ogden, Chris Goodier. 2014. Design in Modular Construction. CRC Press.
[49] Berg, Nate. November 1, 2013 . *Architect.* "Piecemeal Potential: The sky may be the limit for prefab modular towers." http://www.architectmagazine.com/performance-metrics/piecemeal-potential.aspx

In taller composite wood or “Mass Timber” buildings, the last decade has witnessed an evolution of what is seen as possible. Several of the systems that are intended to reach greater heights – going up to 30 storeys or higher - are hybrid wood and steel or concrete systems.[50] The building system pictured above is from Austria – the CREE system – and can be built up to 30 storeys high. Panelized, prefabricated wall systems is an area in which there is much global competition currently, and promises potential opportunities for affordable, sustainable housing. Please see Steel, Composite Wood and High Rise sections for details.

For smaller or mid-sized projects that have a site with an existing building on it, there can be an advantage of simply adding modular or prefabricated buildings on to the existing structure. Modular units can provide a fast construction time even with a tight infill site. As with all construction, structural loading must always be checked by an engineer and all designs must comply with municipal bylaws.

One such example in British Columbia is the Victoria Airport Travelodge, an almost 20,000 square foot, modular building which adjoins the front of an existing 2-storey hotel in Sidney, BC. One advantage of modular construction in this case was the fact that the project is a tight infill just off a major highway, so the addition of four storeys that were modular allowed a “just-in-time” delivery. Even the non-combustible, two-hour rated firewall, elevator shaft and stairwells were built into the modules.[51] For more information on other projects that add to existing projects, see the below section Extending Existing Structures. In smaller projects, for buildings that are being transported long distances, there can be an advantage to prefabricated panelized systems in addition to modules due the more compact travel allowed by prefab, therefore costing less and resulting in potentially less travel damage.

Figure 18: First ÉcoTerra™ Module Installed on Poured-In-Place Basement

Photo credit CMHC

[50] Green, Michael C. Feb 22, 2012. “THE CASE FOR Tall Wood BUILDINGS: How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Building Structures. mgb ARCHITECTURE + DESIGN, Equilibrium Consulting, LMDG Ltd, BTY Group. http://cwc.ca/
[51] Victoria Airport Travelodge, Sidney, BC. http://www.britco.com/

2.7 Agricultural and Landscaping Materials

Many green products such as green roofs, green walls, wall panels and landscaped materials are using modular construction to turn out high quality products. One example is a prefabricated straw bale wall panels ("bio-SIPs") used on the following projects, built in Peterborough, Ontario:[52]

- Camp Kawartha Environment Centre at Trent University, 2009;
- Habitat for Humanity house in, 2010;
- "Canada's Greenest Home," 2012.

Bio-SIPs can bring the benefit of using local, environmentally-friendly materials with low or no off-gassing. This can reduce the embodied GHG emissions of the project and help ensure not only a high quality of air inside the building (without chemical off-gassing), but no or little off-gassing for workers building the SIPs. Below see the process of a team building a bio-SIP before taking to the site. Plaster – either lime, cement, clay-based or other, is used to seal off the straw-bales to improve fire resistance, seal off water and moisture, and wall off rodents.[53]

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.

Figure 19: Team Builds Bio-SIPs

Photo credit Chris Magwood

[52] http://endeavourcentre.org
[53] Holladay, Martin. Jul 29 2011. "Musings of An Energy Nerd." http://www.greenbuildingadvisor.com/

Green roof and wall products also can be prefabricated and boxed. Bagged or pre-grown vegetated mats can be shipped or delivered ready to unroll.

One critical consideration is regional appropriateness of the vegetation: it may be worth the spending on a local landscape architect or green roof designer to design the first system and produce larger quantities from there[54].

Figure 20: Modular Laneway House With Green Roof Option

Photo credit Smallworks

Green roofs designed in a different geographic region may not always be appropriate, so consultation with an expert is suggested before using a pre-fabricated or modular approach to a landscape system. Beside is an image of a Vancouver company's laneway house model that comes pre-designed with greenroof.

2.8 Recycled and Reused Materials

Material re-use and recycling is emerging from construction around the world as a practice that can provide innovations towards more efficient and sustainable products. Green building certification tools such as LEED and BuiltGreen, among others, encourage the use of recycled and reused materials. Materials such as gypsum wallboard, paint, fill, concrete, roofing, cellulose insulation, ceiling tile, ceramic or porcelain tiles, countertops, ductwork, exterior sheathing, fiberglass insulation, carpet and carpet underlayment, and steel are examples of products that commonly use recycled materials.[55] The use of recycled building materials is now more common in North America, and many modular and prefabricated manufacturers are using these recycled-content materials. Also common now is the use of reclaimed or reused materials, which in modular or

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.

[54] King, Jason. March 27, 2008. "Green Roof in a Box?" http://landscapeandurbanism.blogspot.ca/2008/03/green-roof-in-box.html
[55] List of Common Recyclable Materials and Recycled-Content Building Products. http://www.usgbc.org/

prefabricated construction may present challenges due to the limited availability of materials and the need for a steady supply of materials for repeatable units.

In addition to the many LEED and green residences referenced throughout this report, most of which certainly contain a number of recycled content materials, one international example of a highly recycled prefabricated home is the Rubber House - one of 12 homes in an experimental, affordable settlement named 'De Eenvoud' in the Almere region of the Netherlands.[56] The Rubber House is a two-bedroom home which uses recycled and reclaimed materials that have been prefabricated for precision and speedy assembly (the construction process was complete in three months). There can be challenges with plastics recycling[57] that can include, in some cases off-gassing,[58] or bringing toxic materials into contact with the human skin that were not designed for that purpose.[59]

2.9 Red-List Materials

Figure 21: Healthy Building Materials in Prefabricated + Modular Construction

Photo used with permission from The SEEDcollaborative. This is an image from a SEED classroom, a modular portable built to the Living Building Challenge level.

[56] Meinhold, Bridgette. 11/04/11. "The Rubber House is a Prefab Home Made from Secondhand Materials in The Netherlands." http://inhabitat.com
[57] Biddle, Mike. 2014. "From Plastic Trash to Treasure." Zero Waste Conference 2014. http://www.metrovancouver.org/ZWC/PRESENTATIONS/Pages/default.aspx
[58] Off-gassing is when a product gives off a chemical in gas form. Common experiences of this include the "new car" or "new shower curtain" smell.
[59] McDonough, William and Michael Braungart. 2002. *Cradle to Cradle: Remaking the Way We Make Things*. North Point Press.

Increasingly, modular buildings are not just efficient but use more sustainable materials, certified by systems such as the Living Building Challenge's Red List, Declare,[60] the Environmental Product Declaration[61],[62] and Cradle to Cradle.[63]

New materials are emerging that meet rigorous health, sustainability and durability standards such as **BuiltGreen, LEED** and the **Living Building Challenge**.

Canadian and BC modular and prefabricated builders are increasingly turning to sustainable, healthy, local products to compete in the local and international marketplace.

The same kinds of materials can be used in a building that is abiding by the Red List – interviews with those involved in Red List buildings suggested that a smaller palate of more common materials were used, such as dimensional lumber, steel beams, gypsum, etc. More focus is placed on avoiding materials such as PVC, Halogenated Flame Retardants and Phthalates, which can impact people who work with or live in the buildings, as well as ecosystems upstream and downstream from the product (meaning ecosystems that are impacted by the manufacturing and disposal of the product).

2.10 Shipping Containers

> "We saved a lot of money by using containers, but we didn't just turn them into a cheap house. We focused those resources on things like bamboo materials, heated concrete floors and a hot-water-on-demand system."[64]
>
> Victoria-based residential designer Keith Dewey, speaking in the Vancouver Sun about shipping container home

Shipping containers are built to carry large loads and be able to be stacked high in shipping areas, and as such, an increasing number of architects and designers around the world see used, and even new, containers as an innovative, prefab and modular way to build everything from banks to malls to housing. They are available the world over, reliable to transport, and can offer an affordable structure to a building, provided an engineer certified their structural strength after windows, doors and utility holes have been cut.

Shipping containers have been used as student residences, offices, hotels, malls, affordable housing, shelters, and emergency lodging.

In 2001, the first Container City was built in London's Docklands neighbourhood, with twelve studios, with three being added in 2003 for a total of fifteen. In 2006, one of the first two-storey shipping container home project was built in the US.[65] In the same year, one thousand apartments of student housing were built in what is still the largest container housing complex in the world in Amsterdam, called Keetwonen.[66] In 2010, in the French university town, Havre, Residence A Docks was built of containers and now provides 100 student residences.[67] Shipping

[60] http://declareproducts.com/
[61] http://www.usgbc.org/
[62] http://www.cagbc.org/AM/Template.cfm?Section=News_and_Media_Room&Template=/CM/ContentDisplay.cfm&Contentid=16542
[63] http://www.c2ccertified.org/
[64] Juschka, Amy. September 29, 2014. "A house built of shipping containers." *Vancouver Sun*.
[65] Industrial Designers Society of America – Los Angeles http://idsala.wordpress.com
[66] Uittenbroek, Caroline with Professor Will Macht. 2009. "Sustainable Containers: Cost-Effective Student Housing." PSU Center for Real Estate.
[67] http://fr.wikipedia.org/wiki/R%C3%A9sidence_A_Docks

containers are increasingly being used for everything from coffee shops (in Tukwila, Washington)[68] and pop-up grocery stores[69] intended to supply fresh groceries in what had been a "food desert"[70] (in Seattle, Washington), to food carts[71] in from Montreal to Paris to NYC, to a mall (Boxpark Shoreditch in East London)[72] to affordable to high end multi-storey, dense residential buildings from Vancouver to NYC.[73]

Shipping container buildings and shelters are also serving an increasingly role in emergencies and for vulnerable populations: they have been transformed into emergency shelters (in Nanaimo, BC, among many other places) and refugee camps (such as Zaatari, Jordan[74] and Kilis, Turkey[75] and around the world). Large hotel companies have built many hotels with specially-built containers – one hotel company plans to have built 670 such hotels in the UK, Ireland and Spain by 2020.[76] New York City's Office of Emergency Management has designed an Urban Post-Disaster Housing Prototype that is a "shipping container-style modular system" designed to be stacked or set up between other buildings as infill and has flexibility depending on the needs of the emergency tenants.[77]

Figure 22: Imouto Container Housing Project, 2013

Photo credit Atira Women's Resource Society

[68] Falk, Tyler. 17 January 2012. "Starbucks opens store made from recycled shipping containers". SmartPlanet. http://www.smartplanet.com
[69] http://stockboxgrocers.com/about/
[70] Meinhold, Bridgette. 09/19/11. "Stockbox Grocers to Convert Shipping Containers into Local Grocery Stores in Food Deserts." http://inhabitat.com
[71] Halperin, Karin. Jul 2, 2012. "Shipping Containers: Home Sweet Home. http://abcnews.go.com
[72] Michler, Andrew. 12/06/11. "Boxpark: London's first Pop-Up Shipping Container Mall Opens in Shoreditch." http://inhabitat.com
[73] Yoneda, Yuka. 03/11/13. "Couple Moves into Cool Shipping Container Home in New York City." http://inhabitat.com
[74] Ferguson, Adam. JULY 4, 2014. "Refugee Camp for Syrians in Jordan Evolves as a Do-It-Yourself City." *The New York Times*. http://www.nytimes.com
[75] McClelland, Mac. February 13, 2014. "How to Build a Perfect Refugee Camp." *The New York Times* Magazine. http://www.nytimes.com
[76] Paulsen, Monte. April 12, 2010. "Green and Affordable Homes, Out of the Box: Shipping containers hold the potential to revolutionize urban housing." http://thetyee.ca
[77] Ball, David P. February 3, 2014. "Seven-storey shipping container housing planned." *24 hours Vancouver*. http://vancouver.24hrs.ca/

Some environmentalists question the use of high-energy steel for homes, especially when it means taking it out of the recycling loop. Steel is one of the most recycled materials in the world, with recycling rates approximating 100% in North America. The recent boom in reusing shipping containers for homes takes these shipping containers out of the recycling stream and into use in a market where they most often displace low energy wood, which has reasonably good thermal properties, is renewable and carbon-capturing.

However, while steel is highly recyclable in North America, for a variety of reasons, including the high cost of shipping the container back empty to its original location, shipping containers stack up in ports unused. As designer Keith Dewey noted in the Vancouver Sun, there is energy needed to do that recycling: “You can create a really sumptuous space and the benefit of it is that you're doing as little environmental harm as possible by reusing something that is destined to take a bunch more energy to recycle.” Or as Janice Abbot of Atira Women’s Resource Society notes: “Of the three R’s, reuse comes before recycling.”

Designers and builders of shipping container buildings point to their flexibility, cost-effectiveness, structural integrity in addition to the environmental benefit of reuse. A decommissioned shipping container that has reached the end of its useful life may - once windows are carved out - need to be reinforced and will certainly need to be certified as structurally sound by an engineer. Despite these expenses, the overall cost can be significantly below the costs of more traditional construction.

3 Transportation

Figure 23: Truck Delivery of Fort St. Johns Passive House

Image used with permission by BC Passive House

What are best practices for transporting modular and prefabricated housing units to development sites to ensure the process is as time efficient and cost effective as possible?

Transporting modular and prefabricated units and products from the plant to the construction site can be challenging. Units can be damaged by road and other transport; transportation can be expensive. This section explores options to increase the efficiency of the transportation process and minimize damage to units while in transit. In Canada, modular buildings can use modules up to 4.9 m (16 feet) wide and 18.3 m (60 feet) long and modules are more typically transported using a flat-bed truck, but this section examines options and challenges with a variety of systems.[78] In BC, transport sizes are regulated by the Commercial Transport Procedures Manual, Chapter 4: “Commodity/Load Oversize Guidelines and Permits,” which details the overall height, length and width allowable in different regions and highways in British Columbia.

BIM can be a critical tool for the integration of prefab, modular and on-site transportation schedules.[82] Determining an optimal modular or prefab size to allow for ease of shipping is the result not just of government regulations regarding size limitations but also on the location of the project, whether there is access to a staging site adjacent or nearby, the optimized crane size as well as the overall dimensions and massing of the final building.[82]

Industry experts interviewed as part of background research for this report suggested that for transportation to downtown, urban core projects within BC’s lower mainland, there was an optimum modular size of modules: a module width of 14.4 feet, length of 77 feet, and height of 13 feet (giving a floor area of roughly just over 900 square feet.[79] The same experts suggested that the best size for a modular unit being transported to the downtown area of Vancouver would be closer to a module width of 14.3 feet, length of 56 feet and height of 11 feet, which was the result of more compact streets and greater crane limitations as well

[78] CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer
[79] 2014. Background Research by Eco Structures Design Build Inc.

as the "maximum module weight to crane lift capacity."[82] Modular sizing as based on allowable limits on BC Ferries were also developed by Eco Structures as follows:

Figure 24: Maximum Modular Shipping Size

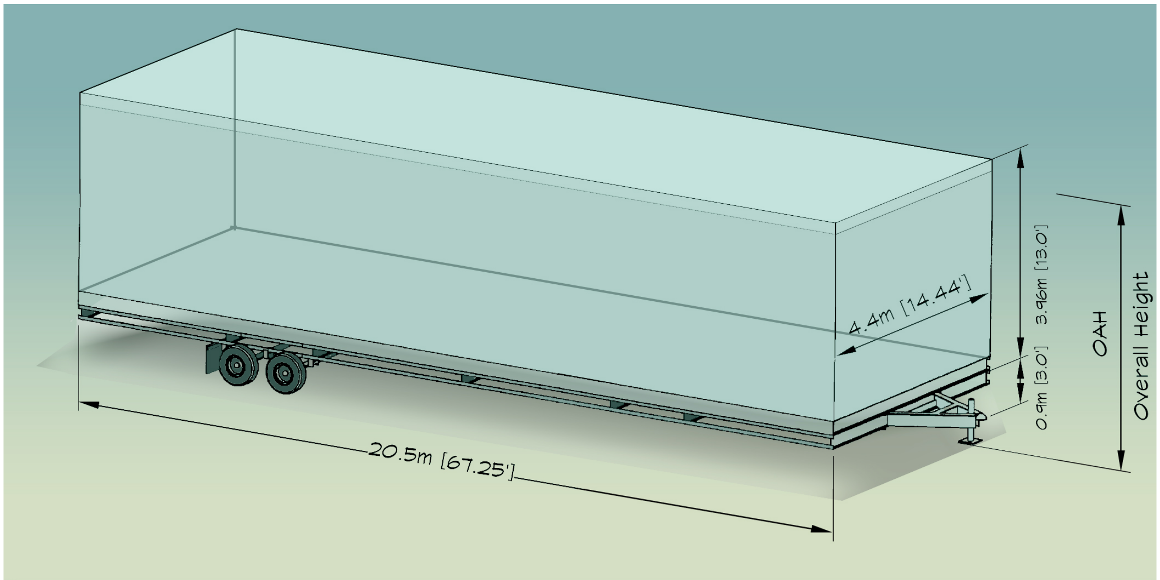


Image credit Eco Structures Design Build Inc.

3.1 Air Bag Lift Systems

On sites where CSA Z-240.10.1 foundations are approved, cranes may not be necessary[80]. Many transportation trucks have air bag lift systems that allow a trailer to back over the site and lower the module onto the foundation. This system is ideal for single storey structures, as cranes or other equipment would be needed to add another storey.

Air bag lift systems can be used where CSA Z-240.10.1 foundations are approved in the place of expensive cranes.

3.2 Barges

Barges have been used in some cases to transport units to coastal areas. Barges allow multiple units to be transported at once, which saves time and money.

Modules can be left on the barges rather than moving them to a construction site. This could be ideal as temporary housing (e.g. for resource development workers), as the barge could be moved to other areas in need of temporary housing once the need for temporary workers declines in the original location. A Netherlands community of 75 prefabricated

Barges can be used to transport multiple units at a time to coastal areas, to save time and money.

[80] 2014. Background Research by Eco Structures Design Build Inc.

floating homes which come together to form something of a town, is another such example.[81],[82] Units traveling to coastal communities can also be transported by trucks driving onto ferries.

3.3 Space Saving Structures

Modular and prefabricated construction does not need to involve fully finished cubes. Pre-fabricated panels and folding structures can be more efficiently transported to sites. Panelized construction (please see section on "Panels" above) is a form of modular where the walls and floors are constructed in a plan and then transported to site.[83] Some manufacturers offer steel frame structures that fold, or structural wood systems that stack, allowing units to be transported on one flatbed truck. Folding or stacking structures also mean that the square footage and height of the modules are not limited by the size of the truck and highway regulations, allowing for larger homes or building spans if desired.[84]

Space saving structures such as **prefab panels, stackable** or **folding modules**, can be more efficient to transport by truck.

3.4 Sturdy Materials

Some modular builders, designers and contractors prefer materials such as steel frame units which they argue offer more durability to help get units to the site while reducing the risk of damage. For example, the Alberta government has replaced many of its older, wood-framed portables with steel-framed modular classrooms that can provide the needed durability to allow for the classroom to be moved multiple times.[85]

3.5 Roofs

> "One of the limits of modular construction was that, because of the need to transport it on trucks, the roof was limited to a 30-degree pitch. Snow doesn't shed well at that angle and that can affect the performance of the electricity generating photovoltaic system integrated into the roof."[86]
>
> CMHC Senior Researcher Rémi Charron, speaking about ÉcoTerra™

One of the findings of the CMHC team that studied the project as well as the team that worked on it was that in the future, combining panelized and modular may provide benefits. There may be greater need for longer periods of highly technical labour on site with the addition of a panelized approach.

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81 Michler, Andrew. 03/26/11. "Incredible Floating Pre-Fab Neighborhood Pops Up in The Netherlands." http://inhabitat.com/huge-modern-floating-dutch-pre-fab-neighborhood/

82 2014. Background Research by Eco Structures Design Build Inc.

83 Al-Hussein, Mohamed et al. September, 2009. "North Ridge CO2 Analysis Report: Comparison between Modular and On-Site Construction." Integrated Management & Realty Ltd. http://www.modular.org/IMAGES/foundation/NorthRidgeCO2Report.pdf

84 Rust, Cathy. May 6th, 2011. "Blu Homes Prefab Home Manufacturer Comes to Canada." BEC Green. http://becgreen.ca/2011/05/blu-homes-prefab-home-manufacturer-comes-to-canada/

85 News Release. September 19, 2008. "Province moves forward with construction of 18 new schools in Calgary and Edmonton. http://education.alberta.ca/

86 "ÉcoTerra™: Approaching Net Zero through Integrated Design." Fall 2011 Newsletter. National Housing Research Committee. http://nhrc-cnrl.ca/sites/default/files/67511_EN_w_0.pdf

Figure 25: Truck Delivery of Fort St. Johns Passive House, Including Modular Roofing

Image used with permission by BC Passive House

Roofs are also a challenge in modular developments regarding how they are sealed and finished. In interview with a development manager on an Australian modular, affordable housing project, The Nicholson, it was mentioned that in a variety of ways, despite Australia's fast pace on modular multi-family developments, they are still very much in the learning phase. The roofing at The Nicholson was sealed, but cracks developed between the nodules and leaks caused problems and had to be fixed. This building provides 58 affordable rental properties out of a total of 199 apartments.

3.6 Crane Optimization

According to background research by Eco Structure Design Build Inc., essential to reducing the costs of related to the use of cranes to move modules from the truck to the prepared site is minimizing any delay time in picking up modules and moving units off the truck once on site. The on-site crew's ability to set down the module, unbuckle it from the crane, and return the pin for the next lift while other crew members tie the module in place also help save time and, therefore, money.

4 Housing Form

What types of modular and prefabricated buildings are proving affordable, efficient and durable? What innovations are being made?

Modular and prefabricated housing can be extremely versatile in terms of housing form, and keeps pushing the boundaries as more projects are built to higher densities. Modular and prefabricated construction lends itself to the infill building, the laneway home, single detached, row houses and duplexes, and multi-storey structures. This section looks at ways of combining modules to create various housing structures.

4.1 Combining Modular Units to Create Larger Units

While modular units are constrained by the size restrictions of the transportation mode (typically 400-600 square feet), there are options to build larger units using modular construction. Single 400-600 square foot modules can work for singles, but larger spaces may be needed if the units are meant to serve, for example, couples, families, and people with mobility aids. Below are some options:

- Units can be placed side by side with an opening to create 800-1,200 square foot units, more suitable for families;
- Temporary walls can be installed in the plant where units will be joined on-site to provide support while the units are transported to the construction site;
- 400 square foot units with suitable openings can be staggered to create L-shaped units;
- Units can also be divided into three or four parts and / or joined with other units to create alternate unit designs or building footprints. For example, see LA's Star Apartments in the Extending Existing Structures section, below;
- Units do not have to joined side-by-side; they can join top to bottom to create multiple floors;
- Modules can also be split to create more than one unit per module or to add common space to a building.

Modular units can be combined **side-by-side** or **top and bottom** to create larger or more units or to **extend existing buildings**.

Figure 26: LEED Platinum Modular Home, White Rock

Photo credit Method Homes.

This above custom home in South Surrey includes prefabricated and modular components and is made of several modules.

Figure 27: Nehemiah Spring Creek's over 800 homes, NYC's First Modular Social Housing

Photo used with permission from Alexander Gorlin Architects

On 45 acres of former landfill in east Brooklyn, the Nehemiah Spring Creek project has been labeled both the "largest affordable housing development for first-time homebuyers in New York City" as well as one of, if not the first modular housing in New York City.[87] The individual modules are brought to site and joined into two, three and four storey townhomes. Another project that provides some affordable units is NYC's The Stack, in which 56 modules combine to make 28 apartments: 2 three-bedrooms, 14 two-bedrooms, 6 one-bedrooms and 6 studios.[88]

Another example is the Rosa Parks wooden modular affordable housing residence in Floirac, near Bordeaux. Developed and initially operated by Aquitaine, Aquitanis, the affordable housing developer, the below images show how the modules can fit together in a variety of ways. This project was begun in November 2013 and built 2014. These are factory-built, timber-framed modules factory furnished with electricity, plumbing, bathroom and kitchen units.[89] These units are required to be "Basse Consommation" or low energy consumption and need to be 40 KW / h per m2 per year or less, and are expected to be constructed for 1280 euros HT m2 (this means "Hors Taxes" or "before" or "without tax") in 2014.[90] The final site is planned to include 50 building units such as the initial one pictured below. The image below shows first "assembly" T3 on the ground floor and duplex T4 above.

Figure 28: Rosa Parks Modular Affordable Housing, in Floirac, near Bordeaux

Photo credit Aquitanis[91]

The use of modules can also go the other way – where one module is divided into two (or, in rare circumstances for emergency shelter, more) units. LA's LEED Platinum Star Apartments is a six storey modular residence (see how the modules stack in this article:[92]), where 102 unit apartments were created from 51 modules.[93] Likewise in the Campbell River Housing for the Homeless, one shipping container is used for eight temporary shelter units.

The MacDougal Street Apartments supportive housing in NY used 84 modules to create 65 studio apartments and used the other modules to create common space, a computer room, exercise area and

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[87] http://gorlinarchitects.com/projects/nehemiah-spring-creek/
[88] [88] Sataw, Julie. March 8, 2013. "More Units Going Up in a Snap." *The New York Times*. http://www.nytimes.com
[89] "Sur le chantier de Rosa Parks." http://www.blog-rivedroite.fr/actualites/sur-le-chantier-de-rosa-parks/
[90] http://www.innovcity.fr/2010/09/08/rosa-parks%C2%A0-le-logement-social-modulable-en-bois-et-basse-consommation-est-ne/
[91] "Le Projet Rosa Park prend forme." http://www.aquitanisphere.com/le-projet-rosa-parks-prend-forme.htm?ob=a&act_id=146
[92] Gonchar, Joann. October 2012 "Paradigm Shift: In an era of tight budgets and sophiticated digital tools, architects take modular construction beyond the single-family house." *Architectural Record.* http://continuingeducation.construction.com/
[93] "Star Apartments is Modular Building Institute's October Building of the Month." October 07, 2014. http://www.prweb.com/

dining area.[94] In the Victoria Hall dormitory built at the University of Wolverhampton, 657 regular student bedrooms and 100 studios were created from 805 modules, with the other modules creating other shared spaces within the 25 storey dormitory.

Of course, the units – in addition to being combined into less or more units – can simply be turned into units one for one. At Edmonton's Canora Place, twenty seven modules were turned into 30 units, with most of those units simply being one entire module. This is housing for individuals in Edmonton that were chronically homeless and / or had addictions or mental health challenges. It is a three-storey apartment building with 15 bachelor units, 14 one-bedroom apartments and one two-bedroom apartment.[95] Below is an image of the building being completed at minus 32 degrees in November 2010.

Figure 29: Canora Place: 27 Modules Set at -32 Degrees Celcius

Photo credit Champion Canada

4.2 Extending Existing Structures

Modular units can provide opportunities to extend existing housing or add density, amenity, energy or functionality to a site without a lot of site work. Modules can be added to extend the footprint of a building or to rooftops to add floors. Modules can also be added to non-housing structures to create housing.[96]

- Lightweight core panel structures may allow one or two additional floors to be added to a building without having to reinforce the foundations or structures of the build existing building.
  - Any additions to a building would require a professional engineer's sign-off;
  - Zoning, permits, and licensing issues may also need to be explored.
- Modular housing placed on commercial rooftops could be used as affordable housing;

[94] Concern For Independent Living Opens The MacDougal Street Apartments, a New 65-Unit Supportive Housing Project in Crown Heights, Brooklyn. http://www.prnewswire.com/
[95] http://www.homewardtrust.ca/programs/completed-details.php?id=5
[96] 2014. Background Research by Eco Structures Design Build Inc.

- Exteriors of modular additions can match the existing building by creating facades using the same type of materials (e.g. bricks);
- Adding modular additions to older buildings can create an opportunity to add accessibility features such as elevators.

Figure 30: LA's LEED Platinum Star Apartments: 6 Storey Modular Residence

Photo by Gabor Ekecs used with permission.

Star Apartments is a six-storey modular supportive housing project in LA opened in October 2014[97], and is built on the top of an existing one-storey commercial building that was renovated as part of the construction process, and is an example of a building that extends an existing structure.

Another example is 25 Leonard Avenue, Toronto, Ontario, a two-phased affordable housing located downtown Toronto's which aims to help homeless individuals to stabilize their lives and secure work. Built by St. Clare's Multi-faith Housing Society, modular units were added to the roof of an existing medical building, which was renovated as part of the project.[98]

[97] Couch, Robbie. 10/10/2014. "New Skid Row Homeless Apartment Complex Has A Running Track And Art Studio." The Huffington Post. http://www.huffingtonpost.com

[98] Alter, Lloyd. September 27, 2005. "Non-profit Prefab being built in Toronto." http://www.treehugger.com

Figure 31: Muhlenburg Dormitory at Muhlenburg College in Pennsylvania

CREDIT: PHOTOS COURTESY NRB, INC.

Photo taken from: https://www.modular.org/Awards/AwardEntryDetail.aspx?awardentryid=1175

The Muhlenburg Dorm in Pennsylvania was originally built in 1910. The college wanted to 12 new dorm rooms, including 9 that are ADA accessible, and an elevator to make the building ADA compliant. The college also wanted the addition to match the circa 1900 exterior façade. To accomplish this, the college created a non-combustible steel and concrete addition using 20 modules, as well as one prefabricated tower section.

4.3 Mid-Rise, Multi-Unit Modular and Prefabricated Housing

In the past, woodframe construction in British Columbia was only permitted up to four storeys, but recent changes in the BC Building Code now allow woodframe construction up to six storeys. Globally, there are not many countries that allow wood construction past eight storeys, as is done in England and Norway.[99] In Canada, Ontario, Quebec and the City of Calgary have followed BC's lead and now allow wood buildings up to six storeys.[100]

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**.

The innovation of allowing this higher density construction with wood is that for many municipalities and citizens, mid-rise buildings are seen to offer opportunities for densification without significantly changing the character of a neighbourhood. Mid-rise construction in steel or concrete can be financially challenging, so the mid-rise wood construction enables a range of developments to occur in a neighbourhood aside from the low and high rise developments. Neighbours may also be less resistant to six storey new builds using modular or prefabricated construction because they allow for quicker on-site construction timelines and less disruption during the on-site construction.

Examples of six-storey modular developments include LA's Star Apartments, a 102 modular apartments built on top of an existing one-storey commercial building which was retrofitted as part of the construction

[99] http://www.proholz.at/project-database/detail/lct-one/?L=1&cHash=e9d9abe3ffc72fa5f0aa3bb361ef51c7
[100] 2014. Background Research by Eco Structures Design Build Inc.

process,[101] and MacDougal Street Apartments, a six-storey, 65-unit supportive housing project in New York City which was completed in 12 on-site days.

Another industry trend to watch that has significant implications for the development of affordable mid-rise buildings is the growth in modular hotels, including the Marriott in Moncton as well as the Victoria Airport Travelodge built in Sidney, BC, a 17,586 square foot building that was constructed with 31 modules and adjoins the front of an existing 2-storey hotel[102]. For more discussion of this project, see the section on hybrid construction.

4.4 High Rise, Multi-Unit Modular and Prefabricated Housing

Figure 32: Prince George's Wood Innovation & Design Centre: 29.3 Metres Tall

Photo credit Wilma Leung

[101] http://www.mmaltzan.com/projects/star-apartments/
[102] Victoria Airport Travelodge, Sidney, BC. http://www.britco.com/

While high-rise modular and prefabricated construction are used in other countries and regions such as the United States, Europe China and the United Kingdom, it is not as wide-spread in Canada. There are an increasing number of modular steel high rise[103],[104] and mass wood prefabricated high rise buildings built globally. For a list of some of the larger mass wood buildings, please see the above Global List of Tall Wood Buildings Figure, and there are many others in Canada in the higher mid-rise range. The image below is of the Wood Innovation & Design Centre in Prince George, one of the tallest mass wood buildings globally, at 29.3 meters tall.[105] Both modular and prefabricated construction can shorten the time needed on-site when doing high rise construction, which can be beneficial especially when building in dense urban areas. Some examples of high rise modular include the following:

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.

- Prince George's Wood Innovation & Design Centre: 29.3 metres;
- University of Wolverhampton, 25 storey dorm (in 2009, tallest modular in Europe);[106]
- T30 Hotel, Hunan Province, China, 30 storey hotel built in 15 days;[107]
- The Ark, China, 15 storey hotel built in one week;[108]
- 30-Story Broad Group hotel prototype near Dongting lake built In 15 days.

Currently the B2 project in New York is under construction and aiming to be the world's largest pre-fabricated building, using modules shown over the page. Steel and concrete modules are often chosen for high rises, and the engineering of a factory-welded steel-framed chassis is what B2 can be structural.[109]

Many lessons come out of existing prefab and modular high rise projects, including:

- High rise modular buildings may require lead-time to develop regulatory approvals as many codes do not include modular construction techniques;
- Modules can be combined with on-site techniques;
- Exterior building manufactured cladding systems and interior partitions can be installed and finished almost simultaneously;
- Floor and ceiling assembly can be loaded with all modular components.

There are a series of innovations related to the Broad Group's projects in China, and specifically the largest of them – the 30 story hotel prototype near Dongting lake. Those innovations have been researched for this report by Eco Structures Inc, who has identified the key innovations of this work as:

1. "Large steel framed floor-ceiling systems; lightweight cement floor toppings & finished tile flooring; under floor mechanical including HVAC, plumbing & electrical completed, sound insulation installed, finished ceilings including lighting finished on the bottom of the component.

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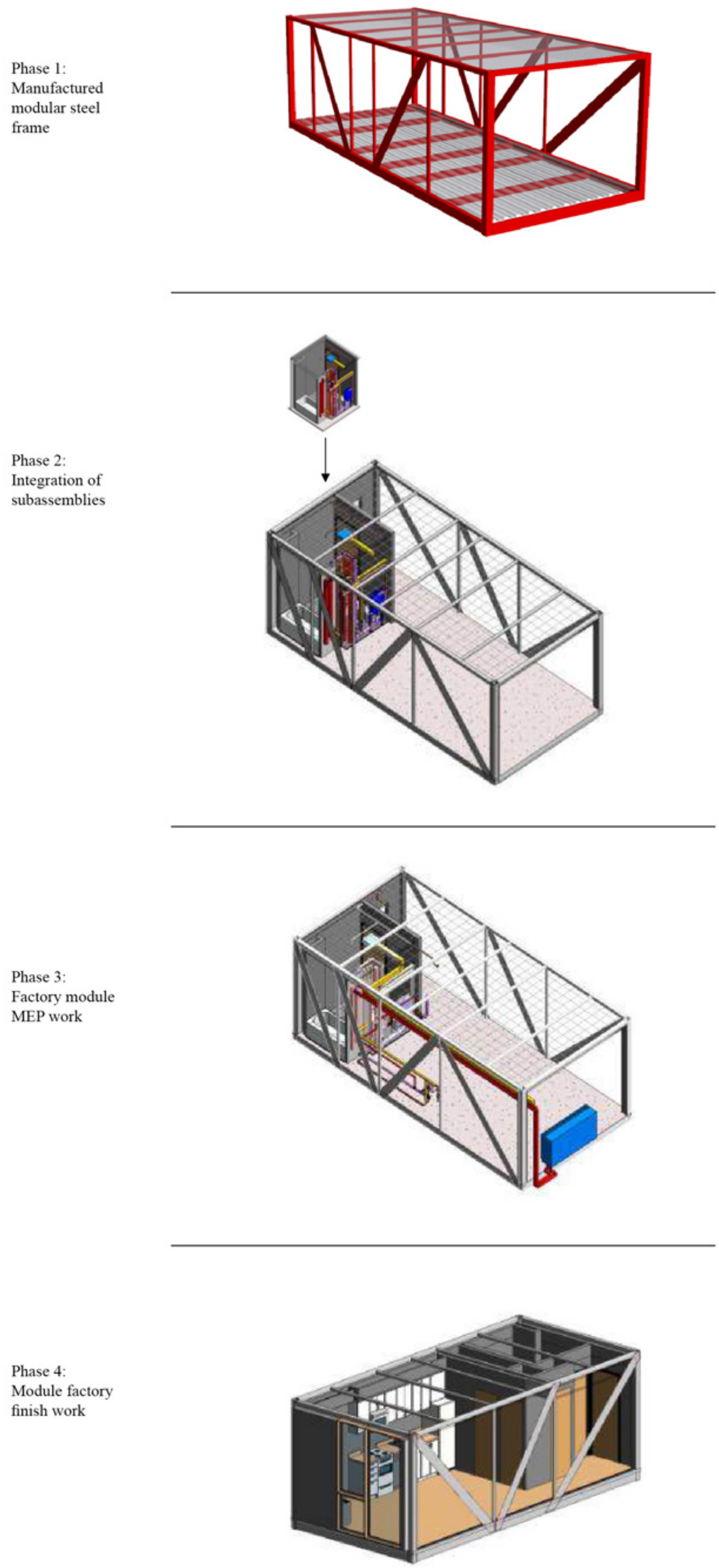
103 Kastenbaum, Steve. February 1st, 2012. "High rise housing going modular." http://news.blogs.cnn.com
104 2014. Background Research by Eco Structures Design Build Inc.
105 "Flying at higher Game with Wood." http://architecture.mapolismagazin.com/
106 Guthrie, James B. August 11, 2010. "An American perspective: skyscraper architecture goes modular in the UK." http://www.bdcnetwork.com/
107 Newcomb, Tim. "10 of the Biggest, Boldest Builds of 2012." *Popular Mechanics*.
108 Schiavenza, Matt. July 29 2013. "Building a Hotel in Six Days." http://www.theatlantic.com/
109 Farnsworth, David. "Engineering the factory-built tower." ARUP Connect. http://www.arupconnect.com/

2. Floor- ceiling assembly loaded with all other MOC components for the floor space on top of the floor assembly and several of these stacked for shipment by truck to site.
3. Site lift and assembly done with multiple specialty crews integrating structural connections with large MOC components.
4. Exterior building manufactured cladding systems and interior partitions installed and finished simultaneously.
5. Multiple crane and hoisting systems used to increase rate of assembly.
6. Building is 5 times more earthquake-resistant than conventional buildings.
7. 5 times more energy efficient.
8. Exterior envelope has a 15 cm glass curtain wall insulation, 4 glass leaf paned windows, external automated solar window shading devices, internal between window pane automated window insulation curtains.
9. Heating Cooling System has Heat recovery fresh air systems throughout (HRV), delivering 20 times purer indoor air than outdoor air using a 3 stage air filtration system."

The image, below, shows the engineering used at the B2 project in New York – aiming to be the world's largest pre-fabricated building. The factory-welded steel-framed chassis is used structurally at this site.

Figure 33: Fabrication Phasing on B2 BKLYN: World's Largest Pre-fabricated Building



4.5 Dormitory and Work Camp Structures

Research shows that areas with resource development booms see an influx of temporary workers as well as students training for work in the resource sector. This puts pressure on local housing markets. Research has also found that work camps are preferred over living out allowances, as this method of housing temporary workers is less disruptive to the local housing market.[110] Modular housing can be ideal for work camps as it can be built quickly and potentially moved to other areas experiencing resource booms once industries move into the operations phase.[111] Findings include:

- Modular units can be built as dormitories for either work camps or post-secondary institutions;
- Sleeper modules with accompanying modules for corridors, cafeterias, and recreational space (e.g. gym or sports simulators) can work for both work camps and post-secondary institutions.

Figure 34: University of Wolverhampton: 24-Story Modular

Photo credit John M, licensed for reuse under Creative Commons Licence

Examples of mid- to high rise student modular include:

- **Victoria Hall, University of Wolverhampton,** a 24-story residential tower, Europe's tallest modular building in 2009;
- **The Modules, Temple University**, 72 units of modular construction built in 2010 in Philadelphia as affordable student housing;
- **Keetwonen, Amsterdam**, is 1,000 apartments of student housing built in what is still the largest container housing complex, in 2006;
- **Residence A Docks**, built in 2010, in the French university town of Havre, of containers. Now provides 100 student residences.

[110] CitySpaces Consulting, Kitimat Housing Action Plan, 2014 http://www.kitimat.ca/assets/Municipal~Hall/PDFs/Kitimat%202014%20Housing%20Action%20Plan.pdf

[111] http://www.altafab.com/

The Manchester, England-based O'Connell East Architects used a concrete core to give structural stability to a 25-storey modular student residence in Victoria Hall at the University of Wolverhampton, one of the tallest prefab modular buildings in the world. Because the ground floor was constructed on site, it is often considered to be only 24 stories of modular.[112] Other dormitory developments worth noting include those at Bryn Athyn College, Ferrum College, Appalachian State University, and Dutchess Community College in Poughkeepsie, NY.[113] With the increased interest and performance of both modular building as well as LEED and methods like Passive House, increasingly there is data to support these methods as high performing both in terms of energy as well as financial management.

Figure 35: LEED Dormitory Modular Costs w and w/o Passive House

Image credit Modular Building Institute

The comparison of Elm and Hickory Halls at Emory and Henry University in Virginia is one example[114].

Figure 36: 15 Three-Story Buildings in 4 Months: Fort McMurray, Alberta

Photo credit Champion Canada

[112] Berg, Nate. November 1, 2013 . *Architect.* "Piecemeal Potential: The sky may be the limit for prefab modular towers." http://www.architectmagazine.com/performance-metrics/piecemeal-potential.aspx
[113] Modular Building Institute. http://www.modular.org/htmlPage.aspx?name=Modular_dorms_greener_faster_smart
[114] http://www.modular.org/HtmlPage.aspx?name=Modular_Passive_House_Dorm_MA

There are many examples of work-force or work camp structures in Canada and globally, particularly in the resource sectors such as oil, gas and mining.

Examples include:

- **Work Camp in Fort McMurray**, Alberta, Canada. In four months, 438 modules were delivered to Fort McMurray, Alberta, to build work-force housing for over 1,500 oil sands workers that included a recreational area. There were fifteen, three storey buildings built in a four-month period. The yellow towers seen in the image below are sewer and water.[115] Work happened 24 / 7 to meet the deadlines.
- **Saadiyat Construction Village, United Arab Emirates**, a 20,000 man labour village to provide accommodates for construction workers and operational staff. There were 56 buildings made up of over 4,300 steel framed modules, and has the capacity to be expanded to house 40,000 workers in the future. Energy-efficient cooling systems were used alongside solar hot water systems which were placed on the roofs. It was started in 2008 and completed in 2010, and ATCO built an open-air factory nearby to deliver the units.[116]

There are many other examples throughout the US, Canada and globally, but these two give a sense of the scale and speed that is possible.

4.6 Micro Units

Micro units are becoming more popular in urban areas to help add density and create more affordable housing options. While the use of modular and prefabricated construction can contribute to this trend, there is some concern about the affordability, psychological implications, and social implications for occupants of micro homes. [117,118,119] Below is a micro-unit rental and affordable housing project in New York City. At seven storeys, The Stack, which used steel and concrete modules, was completed in 2014.

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115 Josuttes, Ken. April 2013. "Camp Noralta Completed!" https://championcanadavp.wordpress.com/

116 http://www.hlgroup.com/en/project/projects/saadiyat-construction-village.html + http://www.atcosl.com/en-ca/Projects/Workforce-Housing-Saadiyat

117 Urist, Jacoba. DEC 19, 2013. "The Health Risks of Small Apartments: Living in tiny spaces can cause psychological problems." http://www.theatlantic.com/

118 Sorkin, Michael. July 29, 2014 "Little Boxes: Micro-apartments have become trendy in planning circles, but their austerity is just another limit on the aspirations of the poor." *The Nation.*

119 Sataw, Julie. March 8, 2013 "More Units Going Up in a Snap." The New York Times.

Figure 37: The Stack, NYC's Tallest Modular Includes Rental + Affordable

Photo courtesy of GLUCK+

4.7 Flexible Housing

Flexible housing allows occupants to change the size and room composition of the home over time to accommodate changing household dynamics and space needs.[120] The household may start out as a single person or couple who only requires a one-bedroom unit, but over time may want to add bedrooms or other common spaces to adjust to a growing family or desires for additional space. Modular units can be designed to allow households to grow or shrink homes over time as needed.

- Modules can offer a range of bedrooms, bathrooms, studies, play rooms, living rooms, and kitchens that can be lined up or otherwise assembled together to meet the occupants' needs;
- Modules can come with moveable partitions, which can allow occupants to partition the units depending on their space requirements over time;
- Modules can come with flexible transitions between two units to allow a household to use the second unit as a mortgage helper suite or additional family space as needed;
- Modules can be finished with multiple uses in mind to allow rooms to be easily transformed to meet changing household needs (e.g. a module can be designed to serve as a bedroom, home office, playroom, or home library);
    - These modular pods can be added to modular or non-modular structures to increase or remove space as needed.

4.8 Exterior Finishes

Modular housing projects can face neighbourhood resistance due to perceptions about the look of the final building and how it will fit into the community. Neighbours may picture modular housing projects as trailer parks. Adding exterior finishes can help finished buildings fit into the neighbourhood or even make an architectural statement. Finishes can include:

- Varying roof lines;
- Staggered units to create uneven exterior walls or other unique footprints;
- Circular floor plans give buildings a different look (e.g. Victoria Hall student residence in the UK);
- Facades including wood, masonry, or other unique materials;
- External balconies, attached to corner posts of the modules or with loads transferred to the ground;
- Varying window configurations.

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[120] Sources for ideas below: http://inhabitat.com/intermodes-kilmore-house-is-a-series-of-efficient-modular-pavilions-in-australia/kilmore-house-intermode-1/?extend=1; http://becgreen.ca/2011/05/blu-homes-prefab-home-manufacturer-comes-to-canada/; http://commongroundwa.org/organization/NHMI-cost-effficient-models; http://becgreen.ca/2011/05/blu-homes-prefab-home-manufacturer-comes-to-canada/

4.9 Repurposing Modules for Alternative Uses

This section examines the benefits and challenges of repurposing modular and prefabricated buildings. It is developed from research, interviews and experiences of different agencies, including that of BC Housing.

The design of modular units lends this form of construction to the opportunity to be repurposed. Firstly, the units are designed to withstand transportation, so they can be moved from one location to another. Secondly, the modules also make disassembly and re-assembly more feasible and efficient for transportation or rebuilding units in a different housing form.

For example, units may be built for a temporary purpose (e.g. temporary camps for resource sector workers, event housing, emergency lodging, etc) and then donated or sold at a low cost to housing providers to develop more cost-effective affordable housing compared to developing housing from scratch. An example of modular units that were repurposed was the units originally built as temporary housing for the 2010 Olympic and Paralympic Winter Games. As part of the legacy of the 2010 Olympic and Paralympic Winter Games, these units were repurposed as 156 affordable and permanent rental apartments in communities across BC. BC Housing managed the construction and repurposing of many units of housing in partnership with the Province of British Columbia and the Vancouver Organizing Committee for the 2010 Winter Games (VANOC). The units were originally built with a bedroom and bathroom. When the units were repurposed, two units were combined into one unit. Part of the wall between two units was removed, the bathroom on one side became a kitchen, and the bedroom on one side became a living room. Below is a graphic that show how some of the units were taken from being single storey units connected via a corridor into larger, double loaded units that were stacked to a height of three stories.

Another way modular units could be used is to respond to changing housing needs in communities. For instance, if units were originally designed to serve seniors in a community, but the demand for seniors housing decreases in that community and increases in another community, the units could potentially be moved to the other community to better meet changing demand. Alternatively, the units could be repurposed by combining modules to create larger units for families if demand for seniors housing decreased and demand for family housing increased.

Potential benefits of repurposing modular units:

- Cost savings for end users (e.g. reduced costs for planning, design, construction materials, etc);
- Less environmental impact due to units designed for temporary purpose being re-used;
- Ability to meet changing demand for housing;
- Can increase time efficiency of construction process for end-users;
- Leaving legacy of permanent affordable housing.

Figure 38: Repurposed Housing: Olympic Housing to Affordable Legacy

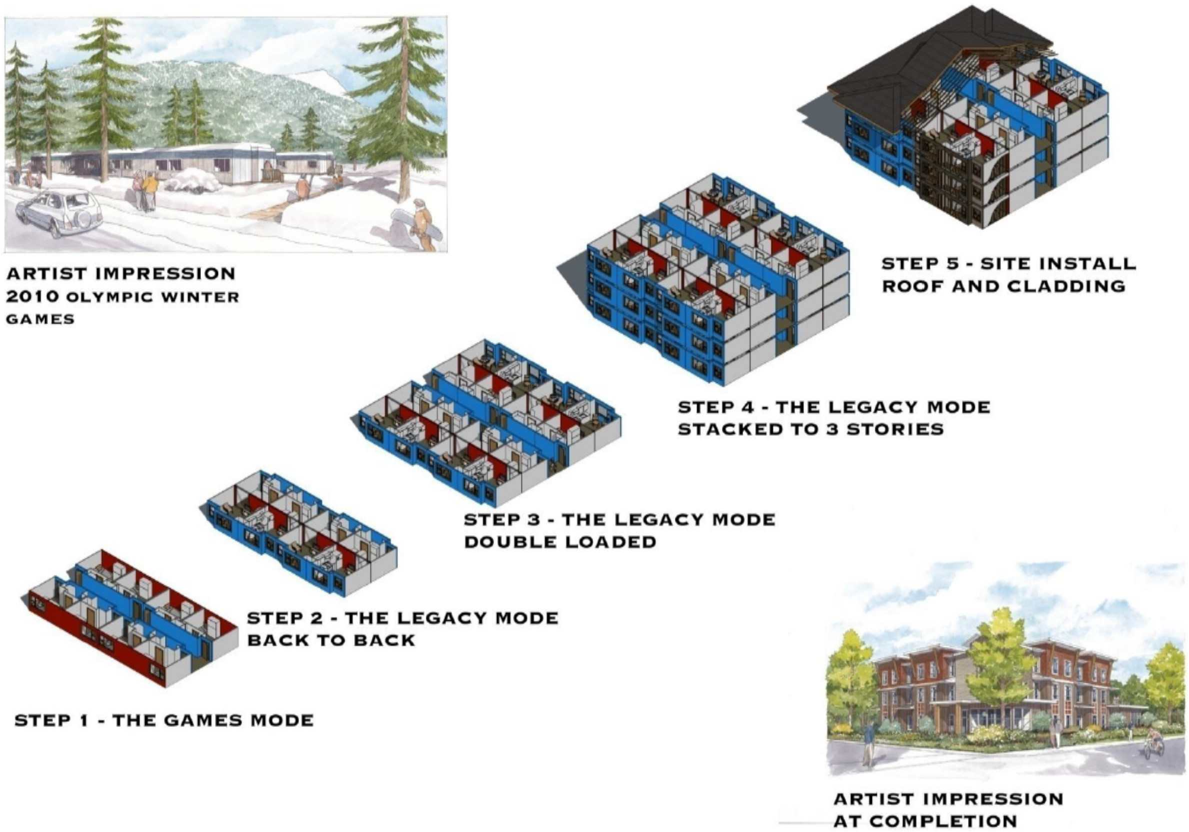

Photo credit Burrowes Huggins Architects.

Repurposing modular units can have challenges and additional considerations need to be taken into account. Changes from the original unit design to accommodate the new purpose need to be considered in the pre-planning phase and original construction. Some redundancies may need to be built into the original module to accommodate the end purpose. Considerations include:

- If units are originally placed as single storey structures and are repurposed into multi-unit structures, some of units will need to be built to withstand the additional weight loads;
- If units are originally built for one climate zone but may be transplanted to another, they need to be designed to the higher energy efficiency and weatherization standards or may become financially unsustainable to operate in a harsher climate and may need costly retrofits;
- Additional utility connections may need to be added to modules if modules will ultimately be transformed into more than one unit;
- Exterior placement of windows and doors need to considered if units are combined or stacked in different configurations from the original structure;
- Interior walls may need to be moved, taken down or added, so design features should accommodate those changes;
- Modules may need to be built so they are sturdy enough to withstand more than one transport;
- Depending on how far units have to travel, the costs of travel could outweigh the potential cost savings of re-using units.

5 On-site Assembly/Connections

What are the best practices for on-site integration of modular housing units at development sites to ensure the process is as time efficient and cost effective as possible?

Integrating modular units at the construction site can be challenging in terms of ensuring precise connections to foundations, attaching units together, connecting to service hook ups, etc. Lining up electrical, plumbing, and mechanical connections from modular units built off-site to the construction site hook ups can be especially challenging when it comes to on-site integration. As well, finished walls and floors can be damaged as electrical, plumbing, and mechanical connections are made on-site.

One key innovation in this regard is the use of BIM – Building Information Systems – which can be used from conceptual design through the IDP (Integrated Design Process) and through construction and into operation. BIMs can be used with other electronic data management systems such as Direct Digital Controls (DDC) or building control or automation systems.

5.1 Involvement of All Stakeholders in Pre-Planning

When using modular, manufactured and prefabricated building components, it is critical to have certified professionals working from conceptual design and preplanning all the way through to on-site inspection, commissioning and retro-commissioning. In order to ensure smooth on-site integration, pre-planning should include the on-site construction manager to ensure that on-site consideration and integration issues are thought through in the planning stage.[121] BIM is a critical tool to map out the on-site work beforehand. Project teams need to be aware of the potential for scope gap – the situation where it is not clear where the responsibilities lie for the integration of the prefab or modular components rest.[122]

Ralph Fasano, executive director of Concern for Independent Living spoke about the differences between a modular project and on-site: “The major noticeable difference with modular construction is that a one-floor platform can turn into a six-floor building in two weeks. But the foundation of the first floor has to match the modules by a fraction of an inch; otherwise the whole building will be off.” He also spoke about the need to coordinate the two construction contractors – the contractor that builds off-site and the one that builds on-site to ensure the project could move ahead at the planned pace.[123]

[121] Source: BC Housing, Modular Lessons Learned Focus Group Summary Report, 2011: https://www.bchousing.org/resources/About%20BC%20Housing/Research_Reports/Modular-Housing-Research.pdf
[122] 2014. Background Research by Eco Structures Design Build Inc.
[123] “Member Profiles: Concern for Independent Living.” Supportive Housing Network of New York. http://shnny.org/

5.2 Key Components of Connection (Methodology for Check Offs)[124]

There are usually two crew chiefs leading the on-site portion of a prefab or modular project: the on-ground shuttle and crane lift specialist, and the on-building crew chief leading the teams setting and stitching the modules or prefab panels together. According to Eco Structures Design Build Inc. background research, core areas to be checked off include:

- “Digital photo records taken of all code and standard related assemblies that will become buried and inaccessible in the finished components. As units are set together, these can then be referenced if at a later time a regulatory authority requests a confirmation of assembly compliance;
- A code system for each record taken should be established with the BIM and CPM systems and the recorder should be briefed ahead of time on the process so that nothing is missed. A number of modular product providers use a barcode method for scanning each system into the computerized record.
- Quality control checklists for each key component assembly with appropriate authority sign-off (electrical, mechanical, structural, architectural);
- Fire stop and fire assembly details executed, recorded and signed off;
- Structural and seismic assemblies completed and calibrated, recorded, inspected, and signed off. Note this is an area where the industry may want to do some more value engineering and research to add these accepted details to the design engineering tool kit for MOC products. The CWC would be a good partner to have as part of this task group;
- Electrical and data assemblies placed in connection chases and checked for integrity;
- Domestic water and waste lines checked for positioning;
- Fire suppression sprinkler systems and assemblies as MOC components;
- Rainscreen and insulation assembly components properly placed;
- Sound performance assemblies completed;
- Other project specific details checked and signed off.”

5.3 3D Designs

While two-dimensional drawings are important for the design of the units, three dimensional designs can help all stakeholders think through the on-site integration aspects of the modular design, including exactly how units will link together in a multi-unit project, how units will link to the foundation, and how units will be connected to service hook ups.[125] Having 3D designs means the plants and the on-site labour will be working off the same designs to ensure units line up with the site-prep work.

3D designs and **pilot modules** can help ensure alignment of mechanical, plumbing, electrical connections between modules.

[124] 2014. Background Research by Eco Structures Design Build Inc.
[125] Source: BC Housing, Modular Lessons Learned Focus Group Summary Report, 2011: https://www.bchousing.org/

5.4 Pilot Module

When doing a large scale project, it could be useful to create a full model of the modular unit before running the full order of the design down the assembly line. Having the full model of the unit can help the construction manager see where all the connections will be in the unit. As well, the full model gives stakeholders the opportunity to examine the design to see if anything was missed before a mistake is repeated in all units once the design hits the assembly line.[126]

5.5 Training for On-site Construction Team

Some construction teams may be reluctant to work with modular construction due to lack of familiarity with the housing form. The modular and prefabricated industry could consider providing training to construction teams to improve their comfort with the technology. Interviews with contractors and experts mentioned that appropriate training is certainly critical, and also that some modular builders are moving towards turn-key construction, so that it is their own labour that comes from the factory to install the modules on-site.

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.

5.6 Creating Sturdy Multi-Storey Structures

When modules are assembled into multi-storey structures on-site, load-bearing techniques should be considered.[127] With steel-frames, loads can be transferred through side walls of modules or corner supported where loads are transferred via edge beams to corner posts.

Modules assembled into multi-storey structures must be resistant to wind and other forces. Solutions include: [128]

- Diaphragm action of boards or bracing with walls;
- Separate braced structure using structural steel from core elevator and stair area;
- Reinforced concrete or steel core or units clustered around a braced corridor.

5.7 Integrating Corridors, Stairwells, and Elevators

For multi-unit modular structures, and especially multi-storey buildings, consideration needs to be directed toward how to integrate corridors, stairwells, and elevator shafts:[129]

- Corridors, stairwells, and elevator shafts can be site-built while modules are being built in the plant;
- Cores cane be concrete, steel, or structural wood[130] and can provide space for stairs and elevators;
- Half of the corridor can be incorporated into each module and then paired to create a full corridor;
- Modules can be designed to serve specifically as corridors rather than a unit.

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[126] Source: BC Housing, Modular Lessons Learned Focus Group Summary Report, 2011: https://www.bchousing.org/
[127] Velamati, Sri. 2012. "Feasibility, Benefits and Challenges of Modular Construction in High-rise Development in the United States: A Developer's Perspective." http://hdl.handle.net/1721.1/77129 MIT Center for Real Estate. Program in Real Estate Development
[128] Velamati, Sri. 2012. As above.
[129] Sources: BC Housing, Modular Lessons Learned Focus Group Summary Report, 2011 - https://www.bchousing.org/resources/About%20BC%20Housing/Research_Reports/Modular-Housing-Research.pdf; http://dspace.mit.edu/bitstream/handle/1721.1/77129/825120099.pdf?sequence=1;
[130] Hofstätter, Werner. April 13, 2014 "Constructing an All-wood Building: The Wood Innovation and Design Centre." http://www.constructioncanada.net/

6 Emergency Lodging

Figure 39: Solar-powered Emergency Shelter Used for Syrian Refugee Housing

Photo credit IKEA[131]

What are lessons learned around using modular construction for temporary housing for those displaced during a natural disaster?

Organizations such as the United Nations and the US Federal Emergency Management Agency have been using modular housing as emergency lodging after disasters resulting in housing loss and people being displaced. For example, modular housing was used after Hurricane Katrina in 2005, the Gujarat earthquake in India in 2001, the Central Java earthquake in 2006, and the Kobe earthquake in Japan in 1995, and Slave Lake flooding in Canada in 2011. Modular construction can be used as emergency lodging, especially if there are pre-selected companies that can build modules quickly with limited construction materials or labour available following a disaster. This section discusses lessons learned of using modular housing as emergency lodging after a disaster. [132]

6.1 Rapid Deployment of Modular or Prefabricated Housing to Disaster Areas

Getting units to the disaster zone quickly can be a challenge following a disaster. Interviews suggested that it can be beneficial to have modular or pre-fabricated units in storage, however other research suggests there are risks to storage as well[133]. Even if there are modular units waiting in storage in case of a disaster, getting units over long distances or roads that have been damaged can be difficult. Also transporting units one by one to the site could take too long if many households have been displaced. Some ideas and lessons learned from previous use of modular units following a disaster include:

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131 Cameron, Charley. 12/17/13 "IKEA's Solar-Powered Flat Pack Shelters Approved for Syrian Refugee Housing." http://inhabitat.com/
132 Lessons learned discussed below pulled from various sources: http://m.inhabitat.com/all/the-modularflex-disaster-shelters-pop-up-where-you-need-them-most#1; http://www.gizmag.com/modularflex-folding-disaster-shelter/26418/; http://www.gizmag.com/reaction-exo-emergency-housing/22726/; http://www.modular.org/HtmlPage.aspx?name=NYC_UrbanHousing_MA; http://wbi.worldbank.org/wbi/Data/wbi/wbicms/files/drupal-acquia/wbi/drm_kn4-3.pdf
133 Simmons, Ann, M. November 15, 2006 "The Nation: FEMA emergency homes go to waste." http://articles.latimes.com/

- Materials could be lightweight yet sturdy, so that a crane is not necessary to remove units from the truck to the site, but units can withstand the elements once on site;
- Foldable (accordion style), stackable (with floors stacked and separate wall/ceiling molds stored like cardboard coffee cups), and panelized units can be stored more easily so that they are available immediately following a disaster (i.e. they do not need to be built) and can be reused at a later time if needed following another disaster;
- Foldable, stackable, and panelized units can be transported with more than one unit per truck to get the units to the site more efficiently;
- If units are in storage, keeping a range of units by bedroom size (1 to 3 bedroom units) can allow households to stay together;
- Hinged walls and simple locking systems allow collapsible units to be reassembled quickly once on-site without skilled labour;
- Modular units should be designed with easy hook ups to transportable electrical/mechanical units;
- If units are not available in storage, having pre-existing agreements with private manufacturers to prioritize building units in the case of a disaster can be helpful;
- Alternative materials, such as container housing, may be more readily available and converted into modular housing if units are not available in storage (e.g. High River, Alberta);
- Many residents will need furniture, so transporting units fully furnished can help residents move in faster;
- Having modular units with built-in connections for solar panels can be an efficient way of connecting the units to electricity and, if in urban areas, put less pressure on the municipal electrical grid.

Learning's in this area are ongoing, and the US Federal Emergency Management Association as well as the United Nations High Commissioner for Refugees are two organizations worth watching.

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 electrical panels can offer affordable, on-site services.

6.2 Finding Suitable Land after Disaster

Finding suitable land for emergency lodging following a disaster may not always be easy due to damage or debris. Also, land available may not be flat or otherwise prepped for housing.

- Multi-storey modular in disaster areas could be advantageous due to its smaller footprint;
  - However, multi-storey modular units need to have simple assembly systems, as there may be limited equipment available (e.g. cranes) or it may not be possible to transport heavy equipment to the site;
- Placing units too far from displaced residents' original homes can result in some units being unused, as residents may wish to stay closer to their social networks and sources of income.

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.

6.3 Ensuring Safety and Comfort of Units for Residents

Some findings from the literature include:

- 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;
- Lack of coordination across various manufacturers supplying modular units after a disaster can lead to variations in the quality of construction;
  - Having specifications around the minimum standards and quality of the units prepared in advance or as part of pre-existing agreements with manufacturers can help improve the quality and consistency of units provided, even if built quickly;
- Units built quickly with bare-minimum standards can result in units that do not adequately protect residents from extreme weather and could potentially include materials that are unhealthy for occupants;

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.

- 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;
- Units need to be built with adequate sound insulation to allow residents to be comfortable, especially if they end up in the units for extended periods of time;
- Units need to be built with storage areas for residents to store their belongings;
- Residents feedback about comfort of units should be documented, so that as resources and time are available, units can be improved;
- Using some modular units to create common indoor space (e.g. for day care, classrooms, or recreational areas) in transitional housing communities can help create a sense of community and opportunities for displaced residents to generate income if forced to move far from their previous employment locations;
- 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;

- Pre-testing unit designs before a disaster strikes can help ensure the units are comfortable for residents.

6.4 Moving from Transitional to Permanent Housing

There are three stages of emergency lodging. There is the immediate lodging, which tends to be temporary structures, such as tents or spaces in a gym. One example is seen in the image at the beginning of the Emergency Lodging section of the solar-powered emergency shelter used for Syrian refugee housing. This temporary, emergency shelter can last between a day and several months, and usually is intended to be used for less than a year, although in international refugee situations, sometimes these emergency type shelters are used much longer[134].

> Temporary shelter is ideally built of **durable materials** and **built to meet code requirements** so that it can offer an option for permanent housing.

Then there is transitional emergency lodging, where more semi-permanent housing is erected for displaced residents. That is typically used for up to five years, but it is often not intended to be permanent. However, it can be built to allow for a permanent solution (see the image and discussion of the Katrina Cottages below). Finally there is permanent housing. While in some cases, modular housing will just be used as transitional emergency lodging, after some disasters, decisions were made to upgrade the transitional modular units to permanent housing.[135]

After megadisasters, particularly in the developing world, there is often a philosophy of building something smaller and using that structure to facilitate an on-going upgrade[136]. One example is the "roof first" concept of transitional shelter which came out of the response to the 2006 Central Java earthquake in Yogyakarta where the government allowed residents to incrementally finish the building. Another approach is seen with the "Katrina Cottages" built following Hurricane Katrina in 2005 where temporary cottages were intended to allow residents time to build their own home[137]. In many cases, Katrina Cottages were built to be permanent[138], and offer a higher standard of living and greater safety than other alternatives such as trailers.

The preferred approach here is to see the development of temporary housing as a potential solution not just to the need for temporary shelter but also for the need for permanent housing; the temporary shelter is ideally built of durable materials and built to meet code requirements so that it can offer a legitimate option for permanent housing. There are significant financial and cultural benefits of initially constructing more durable interim lodging units that meet the building code requirements.

[134] The UN Refugee Agency "estimates that 10% of the world's refugee population live in tents, many of which don't provide adequate insulation from the heat or the cold and offer no electricity, with the average stay in a camp being around 12 years." From: "Ikea brings flatpack innovation to emergency refugee shelters: Swedish furniture giant has teamed up with the UN Refugee Agency to develop a longer-lasting flatpack shelter." The Guardian. Tuesday 2 July 2013. http://www.theguardian.com/artanddesign/architecture-design-blog/2013/jul/02/ikea-flatpack-refugee-shelter

[135] The World Bank Institute. "KNOWLEDGE NOTE 4-3: CLUSTER 4: Recovery Planning - Transitional Shelter." http://wbi.worldbank.org/wbi/content/knowledge-notes-cluster-4-recovery-planning

[136] Prinz, Gary S. with Alain Nussbaumer. "On Fast Transition between Shelters and Housing after Natural Disasters in Developing Regions." Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland. http://infoscience.epfl.ch

[137] Maly, Elizabeth and Yoshimitsu Shiozaki. "Toward People-centered Post-Disaster Housing Recovery in Tohoku: Learning from examples of transitional housing in Yogyakarta, Indonesia and Mississippi, United States." http://www.iiirr.ucalgary.ca/files/iiirr/B3-5_.pdf

[138] Abt Associates Inc. with Amy Jones & Associates. February 2, 2009. "Developing A More Viable Disaster Housing Unit: A Case Study of the Mississippi Alternative Housing Program." Prepared for: Department of Housing and Urban Development, Office of Policy Development & Research, Federal Emergency Management Agency. https://www.fema.gov/pdf/about/programs/ahpp/ahpp_ms_cs.pdf

Figure 40: Katrina Cottages: Temporary and Permanent Shelter

Image credit Inhabitat

This approach also can the long term benefit of eliminating the expense and complexity of relocation, though, as in the Hurricane Katrina response, relocation is impossible to avoid in many cases. After Hurricane Katrina many displaced residents were granted temporary Katrina Cottages as long as they had the land to locate the cottage. Many of these units are still in use today, and were designed with sturdy materials and to meet codes to allow this possibility.

Figure 41: Katrina Cottage Weathers Hurricane Isaac, - Sep 20, 2012

Photo courtesy FEMA, photo credit David Fine

7 BC Climatic Appropriateness

Are the best practices identified through this study appropriate for BC's climates and landscapes?

Modular, manufactured and prefabricated homes can be built to be appropriate for any climate and most landscapes. Many Canadian and US companies provide homes appropriate for most if not all of BC's climates zones. BC officially has 14 biogeoclimatic zones, which range from desert to alpine tundra. Some of the Northern BC climates are closer to the biogeoclimatic zones found in eastern Canadian provinces than to the Coastal Western Hemlock zone that is home to most British Columbians in the lower mainland and capital region.

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.

Some challenges have been identified by research and interviews regarding the use of certain high efficiency HVAC equipment in BC's colder climates. Some challenges were raised with respect to the use of Heat Recovery Ventilators (HRVs) in smaller modular units due to sound issues, and with the use of HRVs in extremely cold climates, due to problems experienced with HRVs defrost cycles working at the temperatures experienced in Canada's more Northern Climates. This issue has also been identified by CMHC and CMHC has identified a need for a "Northern HRV performance specification" and is advocating for the "draft of a Northern HRV technical specification."[139] Other issues have been identified with the use of high efficiency furnaces (currently required under federal building codes in all buildings covered by the building code) for smaller, stand-alone modular or mobile homes.[140] However, expert interviewees confirmed what Hank Starno, president of MHI Canada, communicated to the CBC, which is that with the appropriate insulation of plumbing and HVAC systems, high efficiency furnaces should be workable in all of BC climates.

The below image is not of British Columbia but of New Brunswick. It does, however, speak to those who question whether the highest performance modular buildings can be built in colder climates. Eco Terra Drive is an award-winning, multi-family building that is not just energy efficient - it is net zero energy. It is built in one of Canada's colder climates.

[139] Canada Mortgage and Housing Corporation. August 2012. "Northern Mechanical Ventilation Equipment Design and Testing." Technical Series 12-105. RESEARCH HIGHLIGHT. http://www.cmhc.ca/odpub/pdf/67676.pdf

[140] Harvey, Mark and Lisa Mathews. Feb 05, 2014. "High-efficiency furnaces ill-suited for mobile homes, plumber says." http://www.cbc.ca/

Figure 42: Eco Terra Drive, Fredericton, NB, a Net Zero Energy Modular Community

8 Sustainability: Not Just Efficiency

What are current best practices to maximize the environmental and social sustainability of modular and prefabricated housing?

This includes not just during the construction phase and the energy consumption once the units are occupied, but also materials and water impacts during occupancy and well as upstream and at end-of-life.

In 2011, McGraw-Hill released their *Prefabrication and Modularization* report, in which they reported on a survey of over 800 architecture, engineering and contracting (AEC) professionals[141] and they found significant sustainability benefits to prefabricated and modular construction: 77% report that construction site waste is decreased—44% by 5% or more. Increasingly, modular and prefabricated buildings are including much more than just efficiency of design, construction and operation in their list of benefits. Sustainable modular and prefabricated buildings can include solar ready and passive house designs,[142] renewable energy, such as the inclusion of rooftop solar arrays; materials that are socially and ecologically sustainable (please see the section on Materials), water harvesting and reuse (through the embedded rainwater harvesting, greywater and water reuse systems as well as built-in composting toilets), and innovative energy systems and super insulated envelopes.[143], [144], [145], [146]

The benefits are in fulfilling environmental and social sustainability mandates as well as in the human health and productivity benefits of green and sustainable buildings, but they can also include financial returns on investments.[147] There can be challenges with using some of the systems such as roof-integrated PV, in-floor radiant heat and solar hot-water. However, builders are seeing a demand and finding ways to make these systems work. In Canada, several schools projects highlight the new interest in high-performing green modular buildings. In Alberta, modular schools are being purchased hundreds at a time, built to LEED Silver standards.[148] Below is a schematic of a modular building developed by a US non-profit organization the SEEDcollaborative, from Seattle WA, and shows what is possible.

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**.

The SEEDcollaborative image visually describes the following a model building developed by a non-profit group. Increasingly, Canadian companies will need to be able to build to these higher performance levels. The SEEDclassroom has the following specs:

- Net-zero water and Net-zero energy,
- LBC materials Red List compliant,

[141] McGraw Hill Smart Market Report: "Prefabrication and Modularization Increase Productivity: Construction Report." May 11, 2011. http://construction.com
[142] Wong. Terrell. "Passive Buildings in Canada." http://www.stonesthrowdesigninc.com/passive-buildings-in-canada.html
[143] Goodwin Andrew, Inhabitat Magazine. 10/15/2012.
"Method Homes to Debut Net-Zero Prefab Paradigm House Next Month in San Fransisco." http://inhabitat.com
[144] Atkinson, Cathryn. 2013, August. "New Pemberton plant promotes energy-efficient technology: BC Passive House to construct homes from 2014." Pique News. http://www.piquenewsmagazine.com/
[145] Greenfab. 2012. "Installation of the 1St LEED Platinum Modular Home in Seattle, WA." http://www.greenfab.com/
[146] Seed Collaborative: http://theseedcollaborative.org/
[147] http://www.cagbc.org/CAGBC/Programs/LEED/CommercialInstitutional/Owners_and_property_.aspx
[148] http://education.alberta.ca and http://www.sheltermodular.com/alberta-ministry-of-education/

- Abundant natural day lighting,
- Solar photovoltaic array,
- Efficient mechanical systems including an energy recovery ventilator (ERV),
- Rainwater collection and filtering,
- Living wall fed by treated greywater,
- Ongoing performance monitoring led by students,
- Composting toilet,
- Structural Insulated Panels (SIPs) R-49 ceiling + R-40 wall insulation.

Canadian architects, engineers and builders are already turning to sustainable methods of construction. The increased use of wood is seen as an environmental benefit in itself, as it is a renewable resource that reduces our climate impacts every time it is used.

Figure 43: High Performance Elements of SEEDclassroom

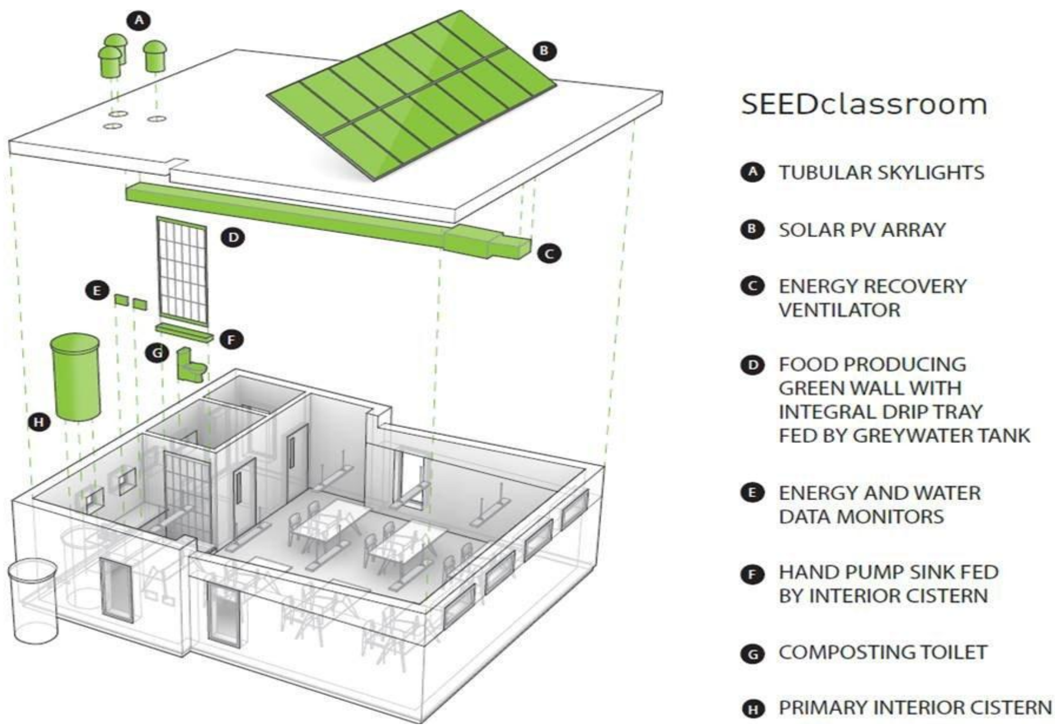


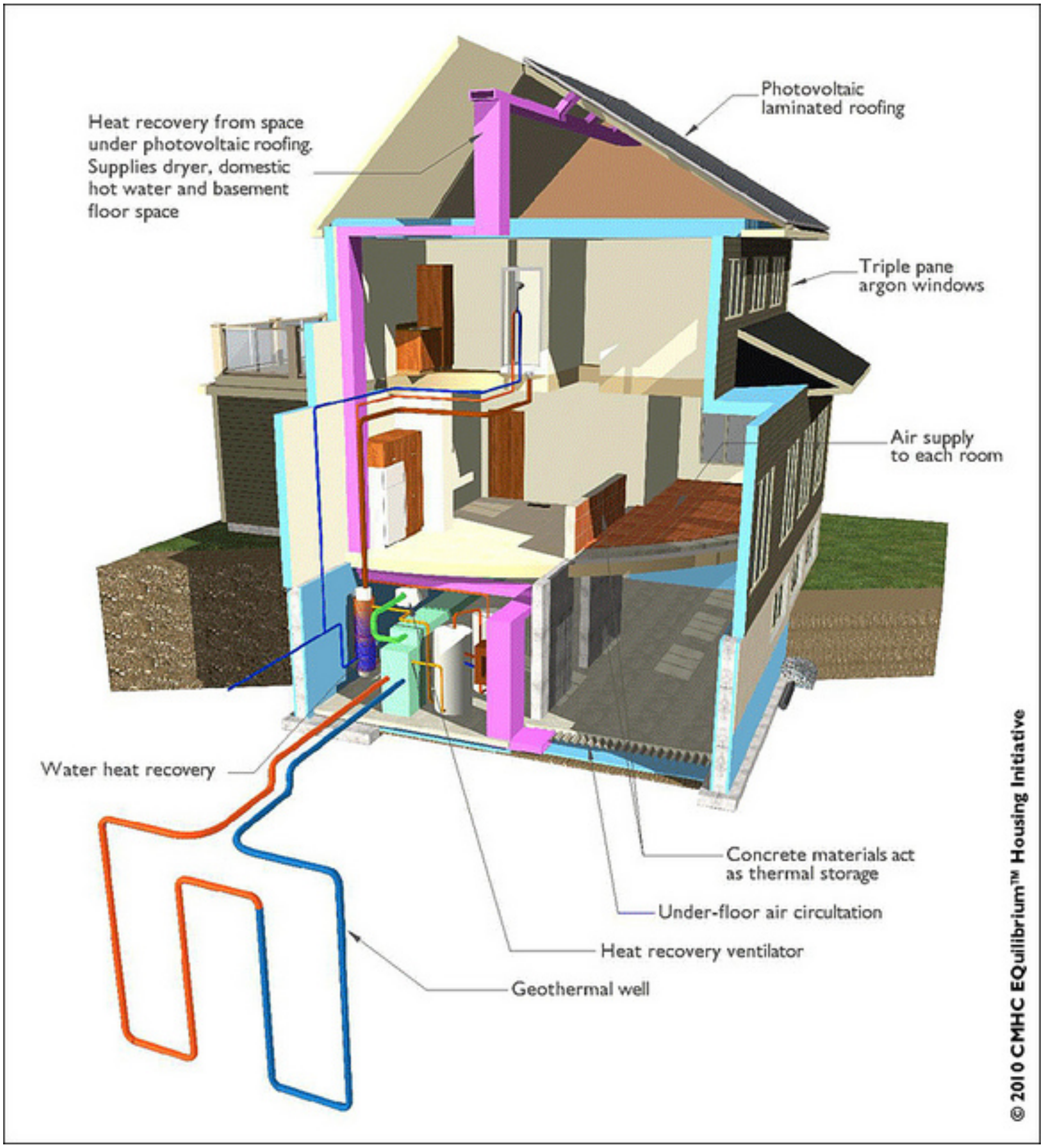
Image courtesy of SEEDcollaborative, a non-profit committed to “sustainably restorative, inspirational learning spaces.”

The above image shows the green features very similar to modular projects in British Columbia such as Monad, an award-winning, multi-family, four-storey modular project with three stories of residential (4 units) and a ground level of retail, all built on a standard, 33-foot, single-family lot in Vancouver - on 4th Avenue in Vancouver, BC.[149] Green features at Monad included green roof, roof garden, solar thermal panels and geoexchange heating and cooling. The home transported the modules prior to instillation of some of the features, such as the in-floor radiant heating system. However, other modular builders use staple-up systems[150] or capillary mats manufactured to be installed between the joists to result in a large radiant

[149] Ditmars, Hadani. 2011, February 17. “A factory-made modern home.” The Globe and Mail.
[150] “First LEED Platinum Habitat for Humanity Home Combines Solar and Radiant.” http://www.wattsradiant.com/

panel[151] – both of which are systems that allow more to be done before the module is transported. Another Canadian green project – this one aiming for net zero energy as part of CMHC's EQuilibrium™ Housing, ÉcoTerra™ also had a variety of noteworthy systems integrated into the modules, seen below in the schematic of the energy systems.

Figure 44: ÉcoTerra™ - Designed for Net Zero Energy



[151] Krippendorf, Jessica. Mar 14, 2011. "Modular structures helping to meet LEED targets." Journal of Commerce. http://www.journalofcommerce.com/

As noted in CMHC's 2013 Canadian Housing Observer, Canadian prefabricated and modular producers are already promoting the sustainability and energy efficiency of factory-built construction, as it is "easier to ensure that gaps in insulation are reduced and that air-sealing is effective, making for a much tighter, more energy-efficient building envelope." Many Canadian producers are aiming to produced or have already produced net zero energy or net zero ready residential buildings where the high performance envelope combines with solar and / or geothermal technology and waste heat recovery.[152], [153]

[152] CMHC (Canada Mortgage and Housing Corporation). 2013. Canadian Housing Observer. www.cmhc.ca/observer
[153] 2014. Background Research by Eco Structures Design Build Inc.

Concluding Comments and Next Steps

The modular and prefabricated building market is growing quickly both in North America and globally. British Columbia's affordable housing sector has much to gain from these new types of construction where it can combine sustainability, durability, affordability and speed of construction. In all of the housing forms that concern affordable housing providers – from temporary emergency shelters through to permanent single family homes through mid and high rise – this report found examples of modular or prefabricated residential construction that provide learning for the affordable housing sector and beyond.

This research suggests that when it is considered from the conceptual phase and planned appropriately, modular and prefabricated construction can save time and money, and add sustainability and performance; in other instances, modular and prefabricated construction has run into challenges. Some ideas, practices, and innovations to potentially address challenges and maximize benefits of modular construction identified through this research include:

Idea, Practice, Innovation	Improve Quality	Increase Affordability	Shorten Timelines	Increase Sustainability
Project integration techniques (e.g. BIM, inclusion of on-site construction team in pre-planning, etc)	X	X	X	X
Assembly line efficiencies (e.g. 24 hour shifts, twinning production lines, automation)		X	X	
High performance materials (e.g. SIPs, composite wood, steel frames, hybrid systems, red list materials, containers)	X	X	X	X
Alternatives to use of cranes to move units off truck onto site (e.g. air bag lift systems)		X	X	
Alternatives to trucks for transportation		X	X	
Using modular construction to extend or add accessible features existing structures		X	X	X
Using modular construction for six-storey or high rise buildings		X	X	X
Incorporation of other housing form trends and needs to modular construction (e.g. micro units, flex housing, dorm + worker housing)	X	X	X	X
On-site integration techniques (3D designs, pilot modules, digital pictures, bar codes etc)	X	X	X	
Alternative modules (e.g. foldable, stackable, panelized, hinged walls, simple locking systems, etc)		X	X	X

Next Steps

Several principles and practices, highlighted in the table above, stand out. They include the importance of the integrated design process and integrated project delivery. They also include the lean manufacturing approach, the use of BIM (building information modeling) and Modular Test Fit, all of which are providing benefits to the industry and these benefits can extend to the resulting projects.

Industry-based research could explore these and the other best practices and innovations identified throughout this report to identify how to move forward. It has been recommended that an industry-wide taskforce be developed to identify opportunities and to grow the market, and our research supports the view that this approach would bring enormous value.[154]

Industry-based research to advance BC and Canada's modular and prefabricated building industry would likely benefit not just the social housing sector but the overall building industry. Industry support centres, as well as centres of excellence, could also provide value to this emerging and promising industry.

Careful analysis needs to be done on any given project to assess whether or not the project is a good fit for modular or prefabricated construction materials, methods, delivery and whether the on-site coordination is feasible. This study identifies ideas, practices, and innovations to overcome these challenges and help achieve the benefits of affordable, modular and prefabricated, residential construction.

[154] 2014. Background Research by Eco Structures Design Build Inc.

Appendix A: Acronyms

ANSI: American National Standards Institute
ASTM: American Society for Testing and Materials
BCSEA: BC Sustainable Energy Association
BETC: Oregon's LEED Business Energy Tax Credit
BIM Building Information Modeling
BPI: Building Performance Institute

CAD: Computer Aided Design
CaGBC: Canada Green Building Council
CAM: Computer Aided Manufacturing
CanPHI: Canadian Passive House Institute

CanSIA: Canadian Solar Industry Association
CEA: Community Energy Association
CEELF: California Energy Efficiency Loan Fund
CEMF: Clean Energy Municipal Financing
CHP: Combined Heat and Power
CLT: Cross-Laminated Timber
CMA: Census Metropolitan Area
CMHI Canadian Manufactured Housing Institute
CNC: Computer Numerical Control (programming)
CPM: Critical Path Method[157]
CSA: Canadian Standards Association
DER: Distributed Energy Resources
EFS: Energy Finance Solutions
EIM: Energy Improvement Mortgage
ERS: EnerGuide Rating System
ESCO: Energy Service Company
EUI: Energy Use Intensity
FIT: Feed-in tariff
GHG: Greenhouse Gas
gWh: Gigawatt hours
HERS: Home Energy Rating System
HRV: Heat Recovery Ventilator
IDP: Integrated Design Process
ILFI: International Living Future Institute[158]

IPD: Integrated project delivery
kW: kilowatt
kWh: kilowatt hour
LBC: Living Building Challenge
LBE: Lead by example
LCC: Life Cycle Cost
LED: light-emitting diode
LEED: Leadership in Energy and Environmental Design
LEEP: Local Energy Efficiency Partnership (NRCan)
LVL: Laminated Veneer Lumber
MHA: Manufactured Housing Association of BC
MBI: Modular Building Institute (US)
MEMPR: Ministry of Energy, Mines and Petroleum Resources (BC)
MMC: Modern Methods of Construction[155]
MOC: Modular and Off-Site Construction
MPBA: Modular and Portable Building Association (UK)
MPSSG: Ministry of Public Safety and Solicitor General (BC)
MTF: Modular Test Fit Modelling[156]
NESEA: Northeast Sustainable Energy Association
NPV: Net Present Value
NRC: National Research Council
NRCan: Natural Resources Canada
NZE: Net Zero Energy
nZEB: Net Zero Energy Building
OBF: On-Bill Financing
PACE: Property Assessed Clean Energy
PHIUS Passive House Institute of the US
PMC: Permanent Modular Construction
PV: Photovoltaic
QUEST: Quality Urban Energy Systems of Tomorrow
RAIC: Royal Architectural Institute of Canada
RDSI: Renewable and Distributed Systems Integration
R-Value: Thermal resistance given in units of ft^{2}o°Foh/Btu
TAF: Toronto Atmospheric Fund
TIP: Tariffed Installation Program
UBCM: Union of BC Municipalities
UDI: Urban Development Institute
vAC: Volts of Alternating Current
vDC: Volts of Direct Current
VOC: Volatile Organic Compound
WIDC: Wood Innovation Design Centre in Prince George, BC
ZEH: Zero Energy Home

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[155] This refers to construction that includes manufactured construction systems that are built both on and off-site, including panelized, hybrid, and sub-component assemblies that may or may not be paired with conventional building components. For more information see: BRE "BeAware Supply Chain Resource Efficiency: Sector Report. Modern Methods of Construction (MMC)." https://www.bre.co.uk/filelibrary/pdf/rpts/BeAware_MMC_Sector_Report_02Mar09.pdf
[156] Also known as Modular Component Test Fit Modelling
[157] It can also be used for Construction Project Management or Capital Program Management
[158] Formerly International Living Building Institute.

Appendix B: List of Prefabricated and Modular Projects

Please note this is an informal and incomplete list which intentionally focuses predominantly on multi-unit residential buildings. This is not to intended to be a complete listing; only to give a flavor of the kinds of buildings that are built using modular and prefabricated technologies.

Name	Year built	Country	City	Res Units	M or N-M[159]	Type[160]
Moxy Hotels	2014 +	Germany, Austria, United Kingdom, Ireland, Belgium, Italy, the Netherlands, Denmark, Finland, Norway, Sweden	Milan, London, Munich, Berlin, Frankfurt, Oslo, etc.	50 hotels[161] 2014 – 2019 (150 to 300 rooms each); 150 hotels by 2023	M	Hotels
B2 Atlantic Yards	Tba 2014	USA	Brooklyn	6,000	M + N-M	MURB
Star Apartments[162]	2013	USA	Los Angeles	102	N-M	MURB
The Stack	2014	USA	NYC	28	M+N-M	MURB
One9 building[163]	2014	Australia	Melbourne	34	M	MURB
38 Harriet	2013	USA	San Francisco	23	M	MURB
Onion Flats Stable[164]	2013	USA	Philadelphia	27	1/3rd N-M	MURB
Seniors' Rental Income Initiative	2011	Canada	21 sites, many in rural and Northern communities	385	N-M	Town-houses
Elam Hall Student Accommodation	2011	New Zealand	North Island	468	N-M	MURB
Canora Place	2010	Canada	Edmonton	30	N-M	MURB
Olympic Legacy Housing	2010	Canada	Whistler: then to Chetwynd, Chilliwack, Enderby, Saanich, Sechelt, and Surrey	150	N-M	MURB
Independent Living BC	2006	Canada	Barrier (12 units), Ashcroft (12 units), and Golden (8 units).	30	N-M	S-F
Stony Mountain Plaza	2011	Canada	Wood Buffalo	125	M[165]	MURB

159 Market or Non-Market?
160 Multi-Use Residential Building (MURB), Single Family (S-F), Commercial (C), Mixed-Use (M-U), or Hotel
161 Linton, Eric. March 05 2013. "Marriott And IKEA Joining In European Budget Hotel Chain." International Business Times. http://www.ibtimes.com/
162 http://skidrow.org/wp-content/uploads/Star-Leed-for-Homes.pdf
163 Walsh, Christine. 2014. "One9 Apartment Tower Constructed in Only Five Days." http://www.jetsongreen.com
164 Walsh, Christine. Oct. 9, 2013. "Philadelphia's First Passive House Multi-Family Complex Ready for Occupancy. http://www.jetsongreen.com

Name	Year built	Country	City	Res Units	M or N-M[159]	Type[160]
The Modules, Temple University[166]	2010	USA	Philadelphia	72	M	MURB
Brighton Housing Trust at Richardson's Yard[167]	2013	UK	Brighton	36	N-M	MURB
Atira Women's Resource Society Housing[168]	2013	Canada	Vancouver	12	N-M	MURB
Campbell River Housing for the Homeless	2013	Canada	Campbell River	16	N-M	Emergency Shelter
Greene Town Center (The Greene)	2008	USA	Beavercreek	120	M	M-U
Travellodge – 3 container-construction hotels		Netherlands	Amsterdam			
Container City[169]	2001	UK	London	15	M	MURB
Travellodge[170]	2008	UK	Uxbridge	120	M (hotel)	Hotel
Riverside Building	2005	UK	London	24	M	MURB
Rosa Parks Residence	2014	France	Floirac	51[171]	N-M	MURB
Starbucks Coffee[172]	2012	USA	Tukwila	n/a	M	C
Stockbox Pop-Up Grocery Story[173]	2011	USA	Seattle	n/a	M	C
Muvbox: snack and pop-up lobster cart	2010[174]	Canada, USA, France	Montreal, Toronto, NYC, Paris	n/a	M	C
Boxpark Shoreditch Shopping Mall[175]	2011	East London	UK	n/a	M	C
Keetwonen[176]	2006	Netherlands	Amsterdam	1000	?	MURB
Platoon Kunsthalle[177]	2009	Korea	Seoul	n/a	M	C
Box Office[178]	2011	USA	Providence	12	M	C
MacDougal Street Apartment[179]	2012[180]	USA	New York City	65	N-M	MURB
St. Clare's	2006	Canada	Toronto	77	N-M	MURB

165 CMHCProfile: http://www.cmhc-schl.gc.ca/en/inpr/afhoce/afhoce/prpr/upload/Stony-Mountain-Plaza-EN.pdf
166 Kaysen, Ronda. June 14, 2011 "Squeezing Costs, Builders Take New Look at Prefab." *New York Times.*
167 Walsh, Christine. Nov. 2, 2013. "Shipping Containers Serve as Homes for Brighton Homeless." http://www.jetsongreen.com
168 http://www.atira.bc.ca
169 http://www.containercity.com/projects/container-city-l
170 http://inhabitat.com/travelodge-shipping-container-hotel/
171 http://www.aquitanisphere.com/accueil.html notes will be 44 social rented housing and 7 social housing homeownership units on this site.
172 Falk, Tyler. 17 January 2012. "Starbucks opens store made from recycled shipping containers". SmartPlanet. Retrieved 19 May 2014.
173 http://stockboxgrocers.com/about/
174 Halperin, Karin. Jul 2, 2012. "Shipping Containers: Home Sweet Home. http://abcnews.go.com
175 Michler, Andrew. 12/06/11. "Boxpark: London's first Pop-Up Shipping Container Mall Opens in Shoreditch." http://inhabitat.com
176 http://www.tempohousing.com/projects/keetwonen.html
177 "Platoon Kunsthalle / Platoon + Graft Architects." http://www.archdaily.com
178 Meinhold, Bridgette. Sept 13, 2011. "The Box Office Recycles 32 Shipping Containers Into 12 Colorful Offices in Providence." http://inhabitat.com
179 Supportive Housing Network of New York. http://shnny.org/learn-more/member-profiles/concern-for-independent-living/
180 PRNewswire-USNewswire. June 1, 2012. "Concern For Independent Living Opens The MacDougal Street Apartments, a New 65-Unit Supportive Housing Project in Crown Heights, Brooklyn." http://www.prnewswire.com

Name	Year built	Country	City	Res Units	M or N-M[159]	Type[160]
Multifaith Housing Society[181]						
Cycle tower One (LCT One)	2012	Austria	Dornbirn	n/a	M	C
LEED Platinum Triplex[182]	2010	USA	Los Altos	3	N-M+M	MURB
The Nicholson[183]	2011	Australia	Melbourne	197	M+ N-M	MURB
Little Hero	2010	Australia	Melbourne	63	M	MURB
Victoria Hall	2009	England	Wolverhampton	805	M	MURB
The Ark	2010	China	Changsha	?	M	MURB
T30 Hotel	2011	China	Hunan Province	358[184]	M	MURB
North Ridge Place[185]	2009	Canada	St. Albert	48	N-M	MURB
3 East	2013	Australia	Richmond	57	M	MURB
Nehemiah Spring Creek[186]	2008[187]	USA	Brooklyn	800	N-M	Town-houses
Victoria Airport Travelodge	?	Canada	Sidney	?	M	MURB
Nakagin Capsule Tower	1972	Japan	Tokyo	140	M	MURB
Habitat 67	1967	Canada	Montreal	158	M	MURB

181 CMHC Project Profile. http://www.cmhc-schl.gc.ca/en/inpr/afhoce/afhoce/prpr/upload/66114w_en.pdf
182 Hickman, Matt. May 23, 2011, "Keeping it in the (multi)family: Los Altos LivingHome." http://www.mnn.com
183 http://www.hickory.com.au/projects/
184 Taken from: http://travel.cnn.com/shanghai/play/time-lapse-video-china-built-30-story-hotel-360-hours-458199 This is 316 regular hotel rooms, 32 suites, eight "ambassador suites" and two "presidential suites."
185 Canada Mortgage and Housing Corporation. "Project Profile: North Ridge Place, St. Albert, Alberta." http://www.cmhc-schl.gc.ca/en/inpr/afhoce/afhoce/prpr/upload/66947w_EN.pdf
186 http://gorlinarchitects.com/projects/nehemiah-spring-creek/
187 The first phase was completed in 2008; 3rd phases completed by 2013. Info from: Ontario Association of Architects: http://www.oaa.on.ca