DESIGNING SUSTAINABLE, PREFABRICATED WOOD BUILDINGS

Presented by:

THINK WOOD®

Image courtesy of Lawrence Anderson

LEARNING OBJECTIVES

1. Demonstrate why prefabrication is an efficient and sustainable building practice
2. Evaluate the use of wood components in sustainable prefabricated buildings as well as design and engineering challenges that wood can solve
3. Discuss the advantages of building with prefabricated wood components in terms of speed and efficiency of construction, design flexibility, waste reduction, environmental performance and improved life safety
4. Analyze, through case studies, the different stages of wood building prefabrication from design to installation

CONTINUING EDUCATION

AIA CREDIT: 1 LU/HSW
GBCI CREDIT: 1 CE HOUR

AIA COURSE NUMBER: AR072018-3
GBCI COURSE NUMBER: 0920016493

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PREFABRICATION THEN AND NOW

Prefabricated wood buildings should be considered when designing and building both multi-family and commercial buildings, such as multi-family housing, education, retail, healthcare and institutional buildings, as prefabrication is an efficient and sustainable building practice. Prefabricated wood components used in both light wood frame and mass timber construction can help to solve many design and engineering challenges such as material and process efficiency, environmental performance and life safety.

The practice of prefabricating building elements in a factory was adopted in the United States only in the past century. Prior to that, most buildings were constructed on-site. There was a boom in kit-of-parts building post-World War II. Consumers were enthralled with industrial production and replication, aka mass production, and prefabricated buildings helped fulfill the need for affordable, quality housing post-war. Although mass production has remained vital to our economy and almost all industries, interest in prefabricated buildings fell off in the 1970s. The design and construction industry did not fully embrace the concept because it wasn't well integrated into their traditional business model.

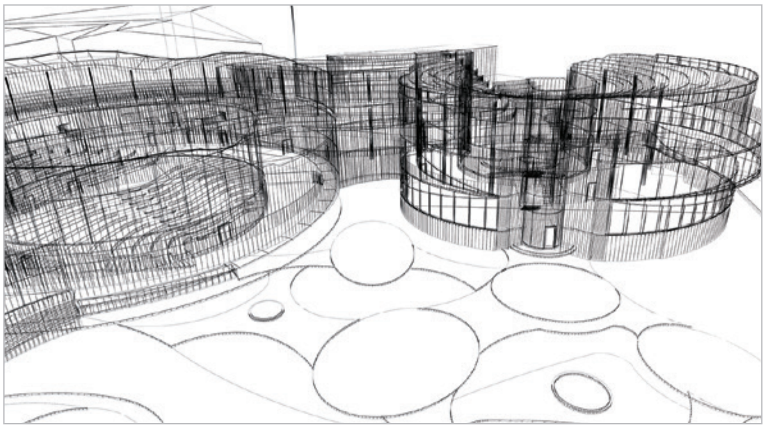
The building industry is now embracing digital tools such as 3D modeling, building information modeling (BIM) and computer numeric control (CNC) machines, making prefabrication and communication amongst building professionals easier. As James

TERMS

Off-Site Manufacture (OSM)
Off-site manufacture is the manufacture of construction components or systems in a factory environment to be transported and assembled on-site.

Prefabricated (Pre-Fab Construction)
Prefabrication can cover off-site prefabrication of materials and parts, prefabrication of components and subassemblies as well as volumetric units or modules.

Modular Construction
Modularization of construction is a way to reduce complexity but still offer customized solutions. The Modular Building Institute defines modular construction as an off-site process performed in a factory setting, yielding three-dimensional modules that are transported and assembled at the building's final location.



The building industry is now embracing digital tools such as 3D modeling, building information modeling and computer numeric control machines, making prefabrication and communication amongst building professionals easier.

Wood prefabrication has a multitude of benefits, including process efficiency, a controlled environment, a greater return on investment, material efficiency, reduced waste both on- and off-site and sustainability.

Timberlake, FAIA, says in the foreword of Ryan Smith's book, *Prefab Architecture: A Guide to Modular Design and Construction*, "We are now capable of sending a fully visualized, and virtually formed, model to a production line, bypassing the document interpretation phase, with all of its back and forth checking, redrawing and margin for additional errors and omissions, ultimately improving the quality of the final product." Also, improved safety measures and greater productivity are now high priorities, which prefabrication can help achieve. The off-site construction environment is a way to provide workers with safer working conditions to reduce the risks of accidents and related liabilities.

An increase in productivity is especially important because of the high demand for, but short supply of, skilled labor in the construction industry. Some believe that standardizing and automating construction in a factory setting deskills the traditional trades. In reality, it upskills the industry and prepares the trades to efficiently deliver buildings through technologically advanced design, fabrication, logistics and assembly. "We think the recession actually benefited our industry," says Thomas Hardiman, Executive Director of the Modular Building Institute. "During the last recession, many skilled laborers left the construction industry and did not return. That, coupled with developers needing to find greater efficiency, made prefabricated buildings more appealing. The construction industry is very reluctant to change. When things were going well, developers and general contractors may not have felt the pain or need to change. Now they do, and there's no turning back."

In addition, environmental views are changing regarding construction waste, the product supply chain, re-use of building materials and carbon footprint. Wood buildings, particularly prefabricated components, can help designers to balance cost objectives, function and environmental impact. James Timberlake says, "Integration modeling, the backbone of off-site fabrication and manufacturing, leans the product supply chain, helps architects and contractors manage the number of materials needed and allows for a positive repurposing of the leftover materials. Further, off-site assembly offers the promise of disassembly and re-use."

BENEFITS OF WOOD PREFABRICATION

Wood prefabrication has a multitude of benefits, including process efficiency, a controlled environment, a greater return on investment, material efficiency, reduced waste both on- and off-site and sustainability. All of these benefits help to meet demands from owners, designers and tenants for better buildings. **Process efficiency** is possible at every stage, from design to fabrication to construction. Detailed planning allows construction processes to be standardized and streamlined, including construction efficiency that meets aggressive schedules and decreases on-site assembly time. Sequencing is improved, as prefabricated components are sorted and loaded onto trucks, minimizing on-site handling. The process is also more integrated with better communication amongst parties, which reduces costly change orders.

Because prefabricated components are produced in a **controlled environment**, quality and precision of components improve, fabrication productivity increases, safety for tradespeople improves and weather is not a factor in slowing down the construction process. **Budgets** should be easier to meet because redundancies and waste in both materials and time are streamlined. Although building components are often more expensive up front, the complete installed cost is usually less because on-site construction is minimized. **Material efficiency** results because prefabricated components are made off-site and typically via modeling technologies that provide extreme precision. **Reduced waste** both on- and off-site minimizes the environmental impact of a project, as specific sizes and dimensions of components are determined in advance and components are made or cut to tight specifications. This also relates to the **sustainable** nature of prefabrication.

According to Ryan Smith, author of *Prefab Architecture: A Guide to Modular Design and Construction*, "The environmental impact of building requires a quantifiable measurement of impact in total lifecycle from design through facilities management. By controlling the means and methods by which buildings are produced through prefab, architects and construction professionals are able to ensure more sustainable materials and practices for construction as well as have a greater opportunity to predict future energy performance. Prefabrication may be used as a method to revamp the sustainability of construction from the perspective of the total lifecycle of a facility, especially regarding demolition or reuse, as the case may be. The capacity of prefab to deliver buildings that respond to time, change and reuse/recycle may be its greatest benefit toward total lifecycle sustainability in the future."

We will review several case studies that demonstrate these benefits, including an extensive case study to conclude the course that details the process of erecting a prefabricated building from design to construction.

CASE STUDY: MOTO

At MOTO the panelized light frame wood wall system created a dramatic speed of construction that allowed each level to be framed in about a week and the entire project in less than a month, making the project viable for the developer. Architecture: Gensler | Photos: Ryan Gobuty

Denver, Colorado

MOTO is an 82,000-square-foot, Type VA mixed-use, 64-unit apartment building with integrated parking and retail that is located in a Denver area known for its rich cultural, artistic and musical offerings. The four-story light frame wood structure is set over a two-level concrete podium with above-grade parking. 3,000 square feet of retail are anchored by two tenants that were selected to work with the theme of the neighborhood and building. One is an old-time barber shop, and the other is a coffee shop/restaurant that serves small dishes and drinks in the evening. With Denver becoming a workforce destination, this project addresses the growing desire for more compact housing with shared amenities.

Wood was used both as the structural material and a design element that sets the building apart from its contemporaries. The massing of the wood frame apartment building is what makes it distinctive; each level slides two feet away from the level below, revealing a cedar soffit on the exterior that creates a unique experience as one moves around the building. The bathrooms, kitchens and corridors stack in plan, but the remainder of the apartments move with the two-foot shift, as opposed to traditional apartment stacking with flat vertical facades. This means the bedrooms on the exterior wall undulate in and out, with every other unit having more area than the other.

The panelized light frame wood wall system created a dramatic speed of construction that allowed each level to be framed in about a week and the entire project in less than a month, making the project viable for the developer. Structural materials include a combination of dimension lumber, I-joists and laminated veneer lumber (LVL), while wood finishes include cedar tongue-and-groove soffits, a cedar trellis that wraps down the façade and pool deck railings, pine slab doors in every unit made from trees killed by the mountain pine beetle and reclaimed veneer pine at the lobby accent wall. The podium is board-form concrete.

The massing of the wood frame apartment building is what makes it distinctive; each level slides two feet away from the level below, revealing a cedar soffit on the exterior that creates a unique experience as one moves around the building. Architecture: Gensler | Photos: Ryan Gobuty

According to Nick Seglie, architect at Gensler's Denver office, "One of the major benefits we saw with wood construction on the apartment levels was that we utilized a pre-fab wall system. They built the walls off-site and brought them on-site. That allowed each floor of the residential units to be framed in about a week. The podium took about four weeks to construct and then an additional four weeks until we were framed out, which was great." Also, "Wood provides a lot of benefits as a construction project because it is easy to work with, it's fast and sometimes less expensive. From a design standpoint, we like to bring it in projects as a finish material whenever possible to create warmth."

PREFABRICATED WOOD CONSTRUCTION

Prefabricated wood buildings are no longer limited to single family housing and smaller temporary workspaces but are now being constructed for innovative buildings demanded by tenants and owners. Sectors with redundancies, such as multifamily housing (e.g., condos, student housing and senior housing), education buildings, commercial retail, healthcare and institutional buildings, are more likely to be built prefabricated.

Computer numerical control machining technology is used at the plant to profile wood panels for installation, and sophisticated connection systems with a high degree of accuracy and efficiency are incorporated during prefabrication. Image courtesy of StructureCraft

Wood has many benefits to the building industry, including aesthetics, environmental performance, strength and rigidity, lighter weight (compared to concrete) and energy efficiency. In prefabricated buildings, wood is particularly beneficial; it has the structural simplicity needed for cost-effective projects and design versatility and it can be rapidly installed with reduced waste.

Prefabricated wood wall and floor panels offer easy handling during construction, and a high level of prefabrication facilitates rapid project completion. This is a key advantage, especially in mid-rise construction from five to 10 stories. Lighter wood panels mean that foundations do not need to be as large and smaller cranes can be used to lift panels higher. For example, at the four-story John W. Olver Design Building at the University of Massachusetts Amherst, four 60-foot-tall cross-laminated timber (CLT) panels comprising one of the building's shear wall cores were lifted and dropped into place with a crane and anchored to the foundation, all in one weekend.

Panelization means framing of dimension lumber or mass timber walls produced with a high degree of accuracy in a factory. Computer numerical control (CNC) machining technology is used at the plant to profile wood panels for installation, and sophisticated connection systems with a high degree of accuracy and efficiency are incorporated during prefabrication. Panelizing lowers cost and speeds up the delivery of walls to a site where framing crews install quickly, when compared with on-site framing. The faster and safer contractors and developers can finish a building, even if off-site construction methods are more expensive, the greater the return on investment. For light wood frame construction, on-site framing is still the norm because it continues to make sense from a quality versus cost perspective, but that is slowly changing. In the future, larger projects that demand panels be erected quickly and en masse are more likely to be prefabricated for light wood frame construction.

Building kits include prefabricated elements or sections that are then delivered and assembled on-site. The kit-of-parts approach, via panelization, is typical for mid-rise wood buildings. Image courtesy of LEVER Architecture

TYPES OF WOOD PREFABRICATION

There are two types of industrialized approaches to prefabricated buildings: building kits (kit-of-parts) and finished modules. Building kits include prefabricated elements or sections that are then delivered and assembled on-site. These may include the roofing package (roof panels, fascia, gutter, etc.), roof structure (ceiling deck and beams), glazing package (windows and entrances) and building structure (wall panels, beam pockets, columns and shear paneling). The kit-of-parts approach, via panelization, is typical for mid-rise wood buildings.

Within panelization it is helpful to understand the difference between open structural panels versus closed structural panels. Open structural panels are a pre-assembled wall framework that is later fitted with other elements such as insulation, exterior cladding and weather barriers on-site. While this aids in time savings and flexibility, there is still a lot of site work involved. By contrast, closed structural panels are complete pre-assembled wall panels that may include windows, doors, plumbing, ducting, electrical, finishes, etc. Closed structural panels are larger and heavier, so a crane is typically needed for on-site assembly.

Finished modules, on the other hand, are an entire building delivered and assembled on-site. Individual modules are joined together to make a single building. They are built in a factory, transported to the site, and when on-site the modules can be placed side by side, end to end or stacked, allowing a wide variety of configurations and styles in the building layout. Finish levels on modular units leaving the factory generally include plumbing, electrical, paint, flooring, fixtures, cabinets and appliances. After the modules are craned into place, licensed sub-trades make electrical, plumbing, mechanical and structural connections before finish work is completed and the building is prepped for occupancy.

QUIZ

1. Which of the following is a benefit of wood prefabrication?
   a. Process efficiency
   b. Controlled environment
   c. Material efficiency
   d. Sustainability
   e. All of the above

2. True or False: Sectors with redundancies such as multifamily, education, commercial retail, healthcare and institutional are more likely to be built prefabricated.

3. Which of the following is the most common type of wood construction in North America?
   a. Cross-laminated timber
   b. Light wood frame construction
   c. Nail-laminated timber
   d. Dowel-laminated timber

4. True or False: Glulam is stronger than steel at comparable weights and stronger and stiffer than dimensional lumber, making the material a cost-effective choice for long, structural spans and tall columns with minimal need for additional support.

5. Which prefabrication approach is typical for mid-rise wood buildings?
   a. Kit-of-parts
   b. Finished modules

6. True or False: Open structural panels are complete pre-assembled wall panels that may include windows, doors, plumbing, ducting, electrical, finishes, etc. They are larger and heavier, so a crane is typically needed for on-site assembly.

7. True or False: Because wood panels are manufactured using CNC equipment to precise tolerances, panel joints fit more tightly, resulting in a high degree of accuracy and better energy efficiency for the structure.

8. At Brock Commons, which technology provided a comprehensive 3D model composed of all building elements, from the structure to interior finishes to the mechanical and electrical systems?
   a. Computer numeric control machines
   b. Virtual design and construction model
   c. Building information modeling

9. True or False: At Brock Commons the tolerances for the mass timber components were ±2 millimeters, a requirement that would have been challenging to meet without the use of the VDC model.

10. Which of the following was a benefit of prefabrication at Brock Commons?
   a. Decreased on-site assembly time
   b. Improved quality and precision of components
   c. Better safety for trades
   d. Reduced waste
   e. All of the above

This article continues on http://go.hw.net/AR072018-3. Go online to read the rest of the article and complete the corresponding quiz for credit.

SPONSOR INFORMATION

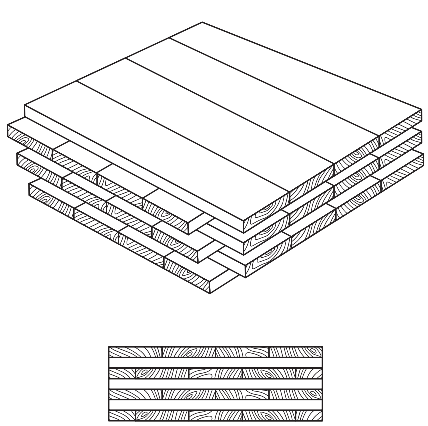
TYPES OF PREFABRICATED WOOD COMPONENTS

Prefabricated wood components may include light frame walls, floors and roof trusses or mass timber elements such as cross-laminated timber (CLT) panels, nail-laminated timber (NLT) panels, dowel-laminated timber (DLT) panels and glue-laminated timber (GLT) columns and beams.

Light Wood Frame

Light wood frame construction has long been the go-to framing choice for low- and mid-rise and, increasingly, commercial buildings. Cost-effectiveness, material use efficiency, ease of assembly, minimal environmental impact and the ready availability of labor and materials make light wood frame construction the most common type of wood construction in North America. Typical light frame roof and floor systems consist of repetitive framing members such as rafters or trusses with wood structural panel decking. Framing components include solid sawn dimension lumber, I-joists, structural composite lumber and parallel chord and pitched trusses. Oriented strand board (OSB) and plywood are used interchangeably as decking and sheathing material for floors, walls and roof decks. There are several approaches to light wood frame construction, and each is suited for a specific application, most often in Type III and Type V categories. As mentioned, on-site framing for light frame construction is still the industry norm, but increasingly elements of these buildings are prefabricated off-site and assembled on the job.

CLT



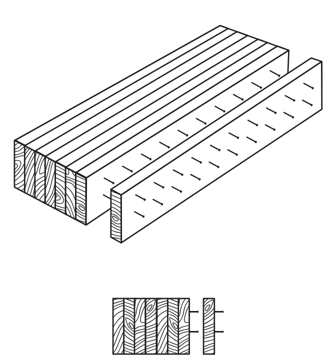
Cross-laminated timber panels are formed by stacking and gluing together successive perpendicular layers of wood. Often all machining and milling of holes is performed at the CLT producer's plant based on the fabrication drawings and CNC machine files and the product is shipped straight to site.

Cross-Laminated Timber

Mass timber is a category of framing styles typically characterized by the use of large solid wood panels for wall, floor and roof construction. Cross-laminated timber panels are formed by stacking and gluing together successive perpendicular layers of wood. The layered stacks are then pressed in large hydraulic or vacuum presses to form an interlocked panel. The panel is then sized and shaped with a CNC machine into a construction-ready component. The number of layers in a panel can range from three to seven or more, and panels can have door and window openings, as well as routings for electrical and mechanical systems, installed before shipment to the building site. In addition to glued CLT, manufacturers have also developed a mechanically fastened CLT using carefully engineered fastening patterns rather than adhesives and pressure.

The cross-lamination process provides improved dimensional stability to the product, which allows for prefabrication of long, wide floor slabs, long single-story walls and tall plate height conditions needed for clerestory walls or multi-story balloon-framed configurations. By the nature of its design, CLT has inherent load-bearing strength and can serve as material for both vertical and horizontal assembly applications. Since wall, floor and roof sections made of CLT are formed off-site in a factory, on-site construction time is much shorter. CLT can be used as a structural system in Type III, IV and V buildings today and in tall wood buildings under alternate means.

NLT



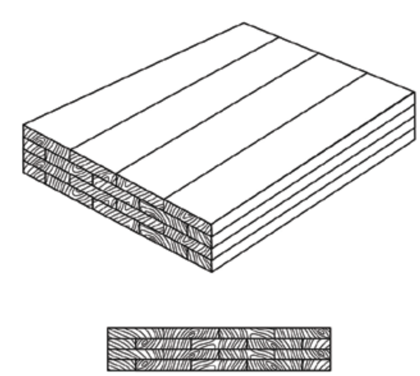
Nail-laminated timber is created from dimension lumber stacked on edge and fastened together with nails. Plywood sheathing is often added to one top side to provide a structural diaphragm and allow the product to be used as a wall panel element.

Often all machining and milling of holes is performed at the CLT producer's plant based on the fabrication drawings and CNC machine files and the product is shipped straight to site. Other times the product is shipped to a fabrication shop for further fitting of steel connections to speed up site erection.

Nail-Laminated Timber

Nail-laminated timber is a mass timber panel system that can be used for floor, wall and roof structures. NLT floor and wall assemblies have been used for more than a century, particularly in warehouses where solid, sturdy floors were required; it is now being recognized again as a valid substitute for concrete slabs and steel decking in commercial and institutional buildings and residential buildings where it is often exposed to create a unique aesthetic. NLT is created from dimensional lumber stacked on edge—2x4, 2x6, 2x8, 2x10, or 2x12 at 1-1/2 inches on center—and fastened together with nails. Plywood sheathing is often added to one top side to provide a structural diaphragm. Plywood sheathing also allows the product to be used as a wall panel element.

GLULAM



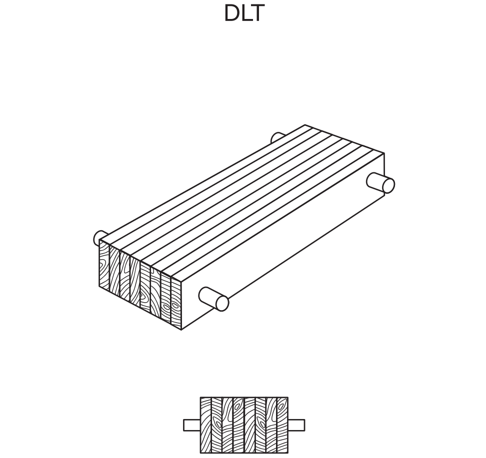
Glulam is stronger than steel at comparable weights, and it is stronger and stiffer than dimensional lumber.[1] That makes the material a cost-effective choice for long, structural spans and tall columns with minimal need for additional support.

Glue-Laminated Timber

Glue-laminated timber (also called glulam) is a structural engineered wood element commonly used for beams and columns in residential and commercial applications. To form a glulam component, dimensional lumber wood laminations are positioned according to their stress-rated performance characteristics. In most cases, the strongest laminations sandwich the beam in order to absorb stress proportionally and ensure the member's longevity. The laminations are jointed end to end, allowing for long spans, and are bonded with a durable, moisture-resistant adhesive. The laminations' grains run parallel with the member's length to improve its strength.

Glulam is stronger than steel at comparable weights, and it is stronger and stiffer than dimensional lumber.[2] That makes the material a cost-effective choice for long, structural spans and tall columns with minimal need for additional support. Glulam is a highly visible form of mass timber in contemporary projects, with long spans framing signature designs that have been left exposed to take advantage of wood's natural aesthetic. In addition to being used in floors, decks and roofs, GLT and NLT mass timber panels are now used for timber elevator and stair shafts in six-story, light wood frame residential mid-rise apartment buildings.

GLT also offers the advantage of being fabricated in controlled environments based on certified manufacturing standards. Like CLT, machining and milling of holes is often undertaken at the producer's plant before the product is shipped to the site. Other times the panels are shipped to the fabricator's shop for further fitting of steel connections.



Dowel-laminated timber is a mass timber product that uses wood dowels as the connector and is ideal for floor, wall and roof structures.

Dowel-Laminated Timber

Dowel-laminated timber is a mass timber product that is wood and uses wood dowels as the connector. From larger panel sizes (12 feet by 60 feet) for faster erection times to a wide variety of wood species, dowel-laminated timber is a mass timber product that is ideal for floor, wall and roof structures. DLT does not include any glue, chemicals, volatile organic compounds (VOCs) or nails, equating to a healthier indoor environment. And because there are no nails or metal fasteners, DLT is easy to process through CNC machines. Unique to DLT as a mass timber product, a wide variety of profiles can be integrated inexpensively into the bottom surface of the panel. Profiles are fully customizable to suit the particular performance and aesthetic requirements of each project.

CASE STUDY: COMMON GROUND HIGH SCHOOL

For the $7.5 million, Type VB, 15,000-square-foot addition, the project team chose a combination of CLT and glulam. The new school building was framed in just four weeks by a crew of five, using prefabricated materials. Architecture: Gray Organschi | Photos: David Sundberg

New Haven, Connecticut

Common Ground High School is located on 20 acres of city park land at the base of West Rock Ridge State Park in New Haven, near the Southern Connecticut State University campus. The Common Ground High School is a program of the New Haven Ecology Project, a nonprofit organization that also operates a community environmental education center and urban farm on the same site.

For the $7.5 million, Type VB, 15,000-square-foot addition, the project team chose a combination of CLT and glulam. The new school building was framed in just four weeks by a crew of five, using prefabricated materials. Black spruce CLT panels act as the tension surface and final ceiling finish in a revolutionary system of prefabricated stressed skin assemblies that span the upper classrooms and circulation spaces. Vertical CLT panels form bearing and shear walls throughout the building, while glulam rafters and heavy timber trusses span the large, ground-floor, multi-purpose space. A treated glulam bridge deck on laminated timber piers provides access from the upper campus. Architect Gray Organschi says, "Black spruce was selected because it's super dense and has an incredibly high bending stress capacity. The grain is tight and very beautiful. It's a very exciting material to work with."

Organschi continues, "Wood is amazing. It is remarkably durable, protective and has enormous bending elasticity, a huge seismic benefit. It's also a beautiful material that looks good even when scuffed. Wood is also forgiving. If you make a mistake in fabrication, you can easily correct it in the field. That's not easy to do with steel, and you certainly can't do that with concrete."

Black spruce CLT panels act as the tension surface and final ceiling finish in a revolutionary system of prefabricated stressed skin assemblies that span the upper classrooms and circulation spaces. Architecture: Gray Organschi | Photos: David Sundberg

BENEFITS OF BUILDING WITH PREFABRICATED WOOD COMPONENTS

Speed and Installation Efficiency

Because wood panels are manufactured for specific applications, they're well suited to a high degree of prefabrication at the plant, equating to speed and efficiency of installation. Panels are prefabricated, complete with pre-cut openings for doors, windows, stairs, service channels and ducts, and shipped directly from

CASE STUDY: STELLA APARTMENTS

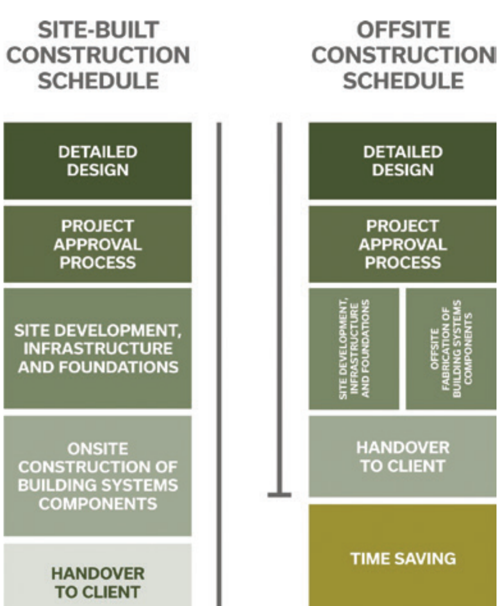
Two things make this project unique: the fact that it includes a Type III building with five stories of wood and a Type V building with four stories of wood on a shared concrete podium and the use of prefabrication to speed the building process. Images courtesy of Lawrence Anderso

Marina Del Rey, California

At this luxury mixed-use development, the design team mixed cost-effective wood framing with a sleek, contemporary exterior. Two things make this project unique: the fact that it includes a Type III building with five stories of wood and a Type V building with four stories of wood on a shared concrete podium, and the use of prefabrication to speed the building process.

One of the keys to Stella's success was coordination. With limited room on-site, the developer, GLJ Partners, hired the framer to begin working on the wall panels about eight months prior to construction, which GLJ estimates "saved a few hundred thousand dollars just in general conditions and supervision."

Adding to the savings, the framer says panelization typically takes 10 to 15 percent off the timeline compared to traditional site-built construction. The construction cost for the project, which includes 244 apartment units, retail space, parking and amenities such as a heated saltwater pool, sand beach and fitness center, was $65 million.



Because wood panels are manufactured for specific applications, they're well suited to a high degree of prefabrication at the plant, equating to speed and efficiency of installation.

manufacturer to job site so they can be quickly and efficiently lifted into place. This can shave months off the construction schedule. Many manufacturers ship panels with pre-installed lifting straps; contractors then use cranes to lift panels into place. In addition, prefabrication is safer because fewer crew members are needed to climb high on scaffolding. Because panels are designed for specific end-use applications, they are often delivered and erected using a "just-in-time" construction method, making wood products ideal for projects with limited on-site storage capacity. Prefabrication may also reduce the exposure of building components to wet weather. That being said, efficient construction can only be achieved when sequencing and project scheduling are determined up front and managed appropriately.

Design Flexibility

Wood can be used for an entire building or any combination of wall, floor/ceiling and roof applications.

Its light weight and other characteristics make it highly adaptable to different types of projects, designs and site conditions like soft soils or tight proximity to neighboring buildings. Kiln-dried wood products have superior dimensional stability, which is better for connection "stability" prior to installation and ensures good accuracy at installation. Wood elements can also be combined with other building materials, enabling flexibility in design, style and finish architecture. When field modifications are needed, one of the advantages of wood over materials such as precast concrete is that changes can be made on-site with simple tools, pending approval by the engineer of record.

Thermal Performance and Energy Efficiency

Thermal conductivity is a measure of the rate of heat flow through one unit of thickness of a material subjected to a temperature gradient. The thermal conductivity of common structural wood is much less than the conductivity of metals with which wood is often mated in construction. It is about two to four times that of common insulating material.[3]

Solid wood panels also provide thermal mass, but the key measures of their thermal performance are U-value (coefficient of heat transfer) and R-value (insulating ability). Both are related to panel thickness. Thicker panels have lower U-values; they are better insulators and therefore require less insulation.

Because wood panels are manufactured using CNC equipment to precise tolerances, panel joints fit more tightly, resulting in a high degree of accuracy and better energy efficiency for the structure. Because the panels are solid, there is little potential for airflow through the system. As a result, an extremely tight building envelope can be achieved.

Resource Efficiency

Wood contributes to efficient use of the resource in several ways. One of the advantages of mass timber is that it can make use of smaller-dimension material that might not otherwise be used in structural applications. Also, since wood panels are manufactured specifically for each project, there is almost no job site waste and manufacturers can re-use any fabrication scraps for stairs and other architectural elements or as biofuel.

In terms of overall resource use, the distinction between light frame and "heavy" construction is important. Mass timber was developed not as a replacement for light wood frame construction but as a low-carbon alternative to "heavy" construction materials such as concrete and steel in building applications where light frame construction is less appropriate, such as in taller buildings or office buildings where few partition walls and minimal floor vibrations are desired.

A mass timber building may require more total wood than a light-frame building, but when compared to steel or concrete in applications where all three are potentially applicable, advantages such as renewability, carbon offsets, low embodied energy and operational energy efficiency make mass timber an environmentally preferable choice. ■

CASE STUDY: BROCK COMMONS TALLWOOD HOUSE, UNIVERSITY OF BRITISH COLUMBIA

As part of Brock Commons' design and preconstruction phase, a virtual design and construction model of the building was created. This VDC model was a comprehensive 3D model composed of all building elements, from the structure to interior finishes to the mechanical and electrical systems. Image courtesy of CADMakers Inc. | Photo Courtesy: naturallywood.com

Vancouver, Canada

A Prefabricated Tall Wood Building—From Modeling to Construction

Located on a large forested peninsula on the west side of Vancouver, the University of British Columbia is at the forefront of the global movement to revitalize mass timber construction and be innovative in the use of engineered wood products in tall buildings. Among the large wood buildings already on campus are the Centre for Interactive Research on Sustainability, the Earth Sciences Building and the Bioenergy Research and Demonstration Facility. The newest addition to the portfolio is the 54-meter-high (18-story) Brock Commons Tallwood House, featuring the first North American use of mass timber products in a residential high-rise.

Brock Commons is one of the University's five high-rise, mixed-use, residential complexes that provide housing for students while acting as academic and recreational hubs for the campus community. While the overall design of the residences is similar, Brock Commons Tallwood House is unique in the use of a hybrid mass timber structure. The foundation, ground floor, second-floor slab and stair/elevator cores are concrete, while the superstructure is composed of prefabricated cross-laminated timber panel floor assemblies supported on glue-laminated timber and parallel strand lumber (PSL) columns with steel connections. The ground floor of Brock Commons is enclosed by a glass curtain wall system. A three-layered CLT panel canopy with a double-folded, standing-seam metal roof provides coverage for pedestrians.

On the upper floors, the building envelope comprise a prefabricated panel system with an R-16 minimum thermal resistance. Each panel is composed of a structural steel stud system; fiberglass batt insulation; a wood-fiber, laminate-panel, rainscreen cladding system; pre-installed window assemblies; and a traditional SBS (styrene-butadiene-styrene) roof assembly on metal decking. The panels measure eight meters wide (to span two structural grids) by 2.81 meters high (to span one story). The 127 by 127 by 13-millimeter steel perimeter angle, which is attached at each floor, supports the panels.

This prefabricated envelope system allowed the building to be rapidly enclosed as the structure is erected, in order to protect the wood components from the weather. The prefabricated portion is composed of the rainscreen cladding system up to the steel studs. The vapor barrier, batt insulation and the interior layer of drywall were applied on-site.

Due to the innovative nature of the Brock Commons Building, understanding how the building would be constructed—including prefabrication of components, trade sequencing and required equipment—was critical to developing a realistic plan for delivering the project on time and on budget.

Design Phase—Virtual Design and Construction Modeling

As part of Brock Commons' design and preconstruction phase, a virtual design and construction (VDC) model of the building was created. This VDC model was a comprehensive 3D model composed of all building elements, from the structure to interior finishes to the mechanical and electrical systems. CadMakers Inc., the dedicated VDC consultant, worked from the consultants' 2D drawings and 3D models concurrently with the development of the stamped construction documents. Every detail, including excavation, was included, along with precise geometries so that any construction process could be animated and any element or set of components could be exported in various formats. The VDC modeler was involved in the Brock Commons Building very early on and was tasked with collecting all relevant project information from the different team members in order to create a singular virtual model of the building with a very high level of detail.

VDC modeling is supported through building information modelling (BIM), which is a data-based project-delivery process centered on the collaborative, multi-disciplinary development of an integrated digital model of the building and its components and systems. The model serves as a tool to support design decisions, coordination and construction planning, and it can later be used to manage the building's operation and maintenance as well as renovations and end-of-life decommissioning. While BIM tools are gaining in popularity around the globe, adoption and implementation are still limited in Canada.

During the design phase, the virtual model was used primarily to assist in design development and decision making. The model was also used for coordination amongst the disciplines in terms of systems layouts, construction sequencing and preparation for fabrication of certain building elements. The modelers worked in close collaboration with the design team, promptly incorporating design iterations and updates and notifying the team of any issues and conflicts that needed to be addressed, in order to ensure that the model was always accurate and detailed in its representation of the project. The VDC model also functioned as a tool for communicating with the construction trades prior to tender. It helped in describing the scope of work relative to the project as a whole and in demonstrating that the design, while innovative, was not complex or highly risky.

The foundation, ground floor, second-floor slab and stair/elevator cores are concrete, while the superstructure is composed of prefabricated cross-laminated timber panel floor assemblies supported on glue-laminated timber and parallel strand lumber columns with steel connections. Image courtesy of naturallywood.com

Pre-Construction Phase—Full-Scale Mock-Up

During preconstruction, the VDC model was used to create a full-size, proof-of-concept mock-up of part of two floors of the building. The mock-up helped to validate the VDC model, as well as the design decisions, with the help of feedback from the trades. It also provided an opportunity to study constructability and installation feasibility, test communication procedures for prefabrication, select installation equipment and identify options for efficiencies. These experiences and knowledge informed the construction planning, including sequencing and prefabrication of assembly packages. The VDC model was also the basis for the fabrication model that was used directly by the CNC machines for the CLT panel stress tests.

The full-size mock-up of a portion of the building was built by the construction management and design-assist trades, using the virtual model as a template. The mock-up is composed of a section of the ground and second floors, spanning 3 bays by 3 bays (approximately 12 by 12 meters). It includes the primary elements and connections that are in the final building, with the exception of the roof assembly (i.e., the cast-in-place concrete core wall and concrete ground floor, the CLT panel floor assembly, the PSL and GLT columns, the building envelope panel and all the relevant connections). All of the engineered wood products were digitally fabricated using the VDC model.

The project team used the mock-up to test and validate the viability of the design decisions and to assess the constructability of the hybrid structural system components and connections between the columns and floor assemblies, between the CLT panels and concrete cores and between the CLT panels and exterior envelope panels. The virtual design models and physical mock-ups were analyzed in advance of production to improve the accuracy of fabrication and the coordination of components and assemblies.

The mock-up also provided an opportunity to test different finishes and cladding in real conditions, including the type of concrete topping and the wood sealer to be used to protect any exposed wood during construction. After viewing the panels at real scale, the university decided to change the exterior panel cladding from an originally specified metal cladding to the wood-fiber laminate cladding.

Pre-Construction Phase—Construction Planning

The VDC modelers worked closely with the construction manager, Urban One Builders, and the rest of the team on the construction planning for Brock Commons. The schedule for the project was very aggressive, which, along with the small size of the site, placed importance on the coordination of the production, storage, delivery and installation of all the building components. The planning was a highly collaborative process; it included input and feedback from all the specialized trades and personnel regarding the constructability and safety of building assemblies and the sequencing of specific activities.

As a key tool within the planning process, the VDC model was used to develop animated simulations that illustrated the sequences of installation and assembly outlined in the construction schedule. Also known as time-based construction modeling, these animations were highly detailed and based on one-hour increments. Animation was essentially a virtual construction process for the building, which allowed the construction manager and the trades to work through the installation procedures in 3D and confirm their feasibility prior to actual construction.

Some assumptions about the time required to complete tasks, for example regarding crane speeds, had to be made prior to the beginning of construction, and these were included in the original schedule. However, over the course of construction, the modelers recalibrated the simulations to reflect the actual durations of activities as they became known, thus improving the planning and scheduling of the remainder of the work.

The model was also employed in financial planning through the development of rapid budget prototyping. Due to the extensive detail available in the model, it was possible to create accurate material quantity estimates in real time. These budgets allowed different options to be analyzed and helped control the project's finances.

Prefabrication and System Design Phase

Prefabrication of structural and envelope components was a key strategy in meeting the project's timelines and budgets. The Brock Commons project used this type of construction approach—i.e., "kit-of-parts" prefabrication—to an extent not usually seen in high-rise residential building construction.

For the mass timber structure, models of the specific components were generated from the VDC model and validated by the architect and structural engineer then transferred directly to the mass timber supplier. This included the wood elements (CLT panels and PSL and GLT columns) as well as the steel connections and drag straps. The steel fabricator was subcontracted to the wood fabricator in order to streamline the process and achieve the tight tolerances. The supplier then modified the model to ensure that the tight tolerances were achieved while accommodating the mechanics of fabrication such as saw thickness and drill-bit diameter and then used the resulting fabrication model to operate the CNC machine to cut the pieces to size and drill the penetration holes. The tolerances for the mass timber components were ±2 millimeter, a requirement that would have been challenging to meet without the use of the VDC model.

The mechanical, electrical and plumbing (MEP) systems on this project were included in the VDC model. Typically, engineers design these systems and their specifications but leave the spatial layouts to the construction trades to decide at the site in conjunction with the construction manager or general contractor. For Brock Commons, the VDC modelers worked with the engineers and the trades to fully design and model the layout of the MEP systems within the building.

This level of detail was required for the prefabrication of the CLT panels so the cutouts for each system penetration could be made during fabrication rather than on-site. It also enabled the

Detailed planning and sequencing made possible by the VDC model, along with prefabrication of major elements, enabled the project team to meet an aggressive schedule and allowed construction processes to be standardized and streamlined. Photo courtesy of naturallywood.com

construction manager and trades to develop an accurate bill of materials and detail the sizes and dimensions of the system components to facilitate procurement, off-site preparation and on-site assembly and installation. For example, the detailed modeling of the mechanical room enabled the cutting and welding of pieces to be done off-site, thus reducing the on-site construction time from the typical three to four months to less than one month.

Effects of the Model on the Construction Process

The detailed planning and sequencing, along with the prefabrication of major elements, enabled the project team to meet an aggressive schedule: The concrete foundation, ground floor and second-floor transfer slabs were completed in 3.5 months; the concrete stair and elevator cores were completed in 3.5 months; and the mass timber structure, the steel roof and the majority of the envelope were completed in about 3 months. Also, detailed planning, made possible by the VDC model, allowed construction processes to be standardized and streamlined.

Interdisciplinary cooperation among the project team during construction was critical. The VDC model was an important tool in facilitating communication between team members by giving everyone a common frame of reference. Construction planning, using the modeling of construction sequences, was a collaborative effort that helped to secure buy-in from the construction trades. The on-time performance required by the aggressive schedule was a challenge for some of the trades that were accustomed to more flexible timelines for on-site work. The trades' input not only helped ensure a realistic work plan and schedule but also helped give them a sense of ownership in the project.

As part of the sequencing, the prefabricated components were sorted and loaded onto trucks to minimize on-site handling. Thus, when a truck reached the construction site, the components could be craned out in the required order and directly installed on the building or positioned in staging areas on each floor. The model helped the construction team visualize the work, establish the loading and installation order for the components and facilitate the coordination between the different crews on-site.

The repetition of the structural and envelope design on each floor and the use of a standardized installation sequence also contributed to the trades' learning efficiencies as the project progressed. For example, based on a productivity analysis of hook time, the first floor of CLT panels (floor three) took 7.3 crane hours to install, while the last floor (floor 18) took 3.1 crane hours. And, the first floor of residential envelope cladding (floor two) took 12.7 crane hours to install, while floor 15 took only 4.4 crane hours.

Prefabrication and just-in-time delivery decreased the extent of on-site assembly time, which was somewhat complex because of the limited size of the construction site. These processes also improved the quality and precision of the components, productivity of fabrication and overall safety for the trades because the detailed work and critical tasks could be completed in the controlled environment of the factory rather than on-site by workers at significant heights in variable conditions. Prefabrication also reduced waste, both on- and off-site, because the specific sizes and dimensions of components were determined in advance by means of the VDC model and the components were made or cut to the tight specific specifications, with limited trial and error being necessary.

END NOTES

1. APA—The Engineered Wood Association *Glulam Resources Kit* https://www.apawood.org/stock-glulam-resources
2. Ibid
3. http://www.awc.org/faqs/green-building/thermal/what-is-the-thermal-conductivity-of-wood-and-how-does-it-compare-to-other-materials

RESOURCES

WoodWorks provides free one-on-one project assistance related to the code-compliant design, engineering and construction of non-residential and multi-family wood buildings. Contact help@ woodworks.org.

American Wood Council provides code support to assure safe and efficient wood building design. Contact info@awc.org.