Figure 1. Mass timber panelized products.

Mass Timber: Knowing Your Options

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Mass timber building systems are becoming more popular throughout North America as creative and cost-effective alternatives to concrete and steel construction. While post and beam timber frame buildings have been around for centuries, new panelized products have begun to change the way we build with wood.

The term 'wood construction' is often associated with light wood frame, a tried and tested method of creating buildings from dimensional lumber and sheathing. Mass timber, however, is a fundamentally different type of construction. Light wood framed buildings are typically erected on site, while mass timber buildings are usually prefabricated as a kit-of-parts which can be erected quickly and smoothly.

The intent of this article is to introduce practicing engineers to mass timber panel products available in the North American marketplace and to highlight some key considerations unique to each.

The Timber Advantage

There are several advantages to mass timber building systems, with the first being construction speed. On mass timber projects, it is possible to see the superstructure completed 25% faster than a steel, concrete, or light wood frame counterpart. Almost invariably, reducing time on site reduces construction costs. Fully coordinated shop and erection drawings can create a smooth and efficient flow on site, where small and large pre-fabricated elements can be installed within a matter of days.

Additionally, mass timber project sites typically require only 10% of the number of trucks to service them when compared to a concrete alternative. As most of these projects use large, prefabricated timber panels for the decking system, the labor required on the active deck can be reduced to 25% of that of a concrete alternative. With all of these factors working together, site noise is significantly reduced thereby reducing the impact on the local community.

Aside from these construction phase advantages, mass timber can be an important part of the building industry's larger narrative about sustainability, which has evolved into a fundamental market force. Structural engineers play a significant role in shaping the built environment – from creating architecturally expressive structural designs to choosing the materials used in those design. Timber is a renewable resource and should be considered in new building designs for its low embodied energy and carbon-storing abilities. It is also a beautiful material; leaving it exposed creates an opportunity to express the structure as part of the architecture.

Common Panelized Products

Several mass timber panelized products are being used as alternatives to concrete, steel, light wood frame, and masonry buildings throughout North America and Europe. *Figure 1* (left to right, and top to bottom) shows the following:

- Nail-Laminated Timber (NLT)
- Glued-Laminated Timber (GLT)
- Cross-Laminated Timber (CLT)
- Laminated Strand Lumber (LSL)
- Laminated Veneer Lumber (LVL)
- Timber-Concrete Composites (TCC)

Nail-Laminated Timber (NLT)

NLT floor, roof, and wall panels have been in use since the early 1900s. These panels are typically comprised of Spruce-Pine-Fir or Douglas Fir 2X lumber stock, stood on edge and nailed together side by side. However, any wood species could be used for the lamination stock. Plywood is used to sheathe the panels, providing in-plane stiffness and shear resistance for lateral diaphragm loads. The panels can be fabricated in a shop

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Figure 2. Mountain Equipment Co-Op Head Office. Courtesy of Ed White.

Figure 3. Kin Centre Complex. Courtesy of JS Photography.

environment or they can be nailed together on-site by any reputable carpenter.

Robust moisture protection during fabrication and erection is a must for NLT panels, as they are susceptible to swelling perpendicular to the grain. To mitigate these potential swelling issues, a 2X lamination should be left out every 20 feet and installed back in after the panels have acclimatized.

NLT is a non-standardized one-way panel system. Standards for the base material exist in the form of typical dimensional lumber grading rules.

Typical Panel Dimensions:
- Thicknesses: 2.5 to 11.5 inches
- Lengths: 8, 10, 12, 16 feet
- Max Width (Prefabricated): 4 feet

Where spans exceed 16 feet, interlocking finger-jointed lumber may be used or a staggered butt-jointed pattern may be specified. However, these longer panels tend to be less cost-effective when compared to simple span panels less than 16 feet. Additionally, a fluted profile can be created to help with acoustics and the visual appearance of the material (for example, alternating 2X4s with 2X6s in one panel).

A recent project which used NLT panels in the floor and roof systems is the Mountain Equipment Co-op Head Office in Vancouver, BC, Canada (*Figure 2*). Panels were prefabricated in 4-foot widths and 40-foot lengths using butt-jointed laminations.

Glued-Laminated Timber (GLT)

GLT floor and roof panels are similar to glued-laminated timber or "glulam" beams laid on their sides, with the lamination lines running vertically. Typical species used in glulam are Spruce-Pine-Fir, Douglas Fir, Black Spruce, Alaskan Cedar, or Port Orford Cedar. Similar to NLT, plywood is used to stitch the panels together and to act as a diaphragm.

The panels can be produced by any glulam supplier and shipped to site as a pre-fabricated product. Some glulam suppliers are able to provide a fluted soffit, which can help with acoustics and give a unique visual appearance.

GLT panels also require robust moisture protection during erection, as they are susceptible to swelling perpendicular to the grain. One way to mitigate these potential swelling issues is to add a ¼-inch gap between each 2-foot panel, leaving room for expansion and contraction throughout the construction phase and the first few drying seasons.

GLT is a standardized one-way panel system, covered by the American National Standards Institute (ANSI) A190.1-2012 *Standard for Glued Laminated Timber*.

Typical Panel Dimensions:
- Thicknesses: 3.125 to 8.5 inches
- Max Lengths: 40 to 60 feet depending on supplier
- Typical Spans: 15 to 30 feet
- Max Widths: 2 feet, or increments of 1½ inches

A recent project which used GLT panels as the secondary roof framing is the Kin Centre Complex in Prince George, BC, Canada (*Figure 3*).

Cross-Laminated Timber (CLT)

CLT panels were developed in Europe in the early 1990s and are now considered to be the most versatile and robust product for use in mass timber buildings. CLT can be used for floor, roof, and wall panels. CLT panels are comprised of 2X stock that is laminated together in an alternating crosswise pattern, similar to plywood veneers. Typical species used in CLT are Spruce-Pine-Fir, Douglas Fir, or Black Spruce. Due to CLT's cross laminations, the panels afford significant in-plane shear capacity and can be used as diaphragms or shear walls in building lateral systems. In these cases, panel-to-panel joints need to be carefully detailed for in-plane shear transfer. However, current U.S. building codes and material standards do not recognize the use of CLT in a lateral capacity. Special provisions may be negotiated with the authority having jurisdiction.

CLT panels are currently produced to APA standards at only a few fabrication plants in North America, but many more plants exist in Europe. In-plane panel dimensions are quite stable due to the cross laminations, but the thickness of the panels remains susceptible to swelling and shrinkage. For buildings that load CLT perpendicular to grain over multiple stories, it is important to consider the shrinkage and compression that can occur through the depth of the panel as they accumulate over the height of the building.

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Figure 4. UBC Brock Commons Student Residence rendering. Courtesy of UBC and Acton Ostry Architects.

Figure 5. Guildford Recreation Centre.

CLT is a standardized product that is often used in a one-way decking capacity. However, it can also be used as a two-way bending member. In North America, the product is covered by The Engineered Wood Association's (APA) PRG 320 *Standard for Performance-Rated Cross-Laminated Timber*.

Typical Panel Dimensions:

- Thicknesses: 4.125 inches (3-ply) to 12.375 inches (9-ply) – Many more thicknesses/layups are available depending on supplier
- Max Lengths: 30 to 60 feet depending on supplier
- Typical Spans: 10 to 35 feet
- Max Widths: 8 and 10 feet depending on supplier. Wider panels are available from European suppliers

Currently, an 18-story student residence building is being constructed as a CLT hybrid in Vancouver at the University of British Columbia (*Figure 4, page 23*). The building has 16 floors of two-way, 5-ply CLT panels on glulam columns. There are no beams in this building, creating a flat, point-supported surface for easy service distribution, analogous to concrete flat plate construction.

Laminated Strand Lumber (LSL)

LSL panels are a one-way system made from flaked wood strands that have a length-to-thickness ratio of approximately 150. Combined with adhesive, the strands are oriented and formed into a large mat or billet and pressed together. Typically, the billets are ripped into smaller beams and rim boards for light wood frame construction, but they can also be left in their larger panel form.

Aspen is used as the fiber of choice for LSL panels by most of the larger North American suppliers. Plywood is typically used to sheathe the panels, providing in-plane stiffness and shear resistance for lateral diaphragm loads. Although there is some in-plane member stiffness due to the semi-random orientation of the flakes, it is not recommended nor recognized by the material standards for diaphragm applications.

In-plane panel dimensions are stable due to the fiber orientation. However, as with CLT, the thickness of the panels remains susceptible to swelling and shrinkage.

Typical Panel Dimensions:

- Thicknesses: 1.5 and 3.5 inches
- Max Length: 64 feet
- Typical Spans: 10 to 20 feet
- Max Width: 4 feet

Although mass timber products are often used for floor and roof panels, the larger scale of LSL billets offers unique opportunities to machine large structural components out of a single piece, minimizing connections. The recently completed Guildford Recreation Centre in Surrey, BC, used machined LSL billets to create the webs in prefabricated roof trusses spanning 90 feet (*Figure 5*).

Laminated Veneer Lumber (LVL)

LVL panels are a one-way system comprised of glued plywood veneers stacked in parallel, essentially a thicker, single-direction plywood. Typically, the billets are ripped into smaller beams for light wood frame construction but, similar to LSL, they can also be left in their larger panel form.

Douglas Fir is used as the veneer in LVL panels. Many suppliers in North America can supply LVL beams and billets. Plywood is typically used to sheathe the panels, providing in-plane stiffness for lateral diaphragm loads. It is not recommended to use LVL panels in diaphragm applications, as the product is not cross-laminated.

Similar to LSL, the in-plane panel dimensions are stable; however, the thickness of the panels remains susceptible to swelling and shrinkage.

Some Canadian and European suppliers also laminate LVL beams on edge into panels, which exposes the end and edge grain of the veneers rather than the face grain in a typical exposed LVL billet. This technique gives a clean, visual aesthetic and can be used to produce a larger range of thicknesses.

Typical Panel Dimensions – LVL Billet:

- Thicknesses: 1.75 and 3.5 inches
- Max Length: 66 feet
- Typical Spans: 10 to 20 feet
- Max Width: 4 feet

Typical Panel Dimensions – Secondary LVL:

- Thicknesses: 3.125 to 11.5 inches
- Max Length: 60 feet
- Typical Spans: 10 to 40 feet
- Max Width: 4 feet

Timber-Concrete Composites (TCC)

Timber-concrete composite panels consist of a thicker layer of concrete on the top side and a mass timber panel on the bottom side. The concrete acts as a compression element while the timber acts as the tension element, giving flexural stiffness. There are several ways to engineer the connection between the concrete and timber, generating the required shear flow. They range from glued-in perforated steel plates to fully threaded screws installed at an angle.

TCC floor systems are very efficient and can achieve high span-to-depth ratios. The depth of the concrete topping also allows for electrical conduits and in-floor heating lines to be hidden inside the floor system. Any of the mass timber panels previously mentioned can work as the tension lamination in a TCC floor system.

Typically, the concrete is cast on-site directly on top of the timber panels, connecting them together. However, precast versions of the concrete compression element are possible by installing proprietary screw sleeves within the concrete. Additionally, timber-concrete composite T-beams are possible with wood beams rather than a wood panel.

Building Codes + Material Standards

All of the products listed above are covered in the *International Building Code* (IBC 2015). Projects falling into construction types III, IV (Heavy Timber), and V are the likely candidates for a mass timber alternative. Depending on the occupancy classification, the permitted height for these construction types can be up to 85 feet. Although Type I and II construction are limited to non-combustible materials, mass timber roofs are permitted. Additionally, there are taller mass timber projects in New York and Oregon, which are negotiating jurisdictional approvals with the local building authorities.

All of the products are covered in the *National Design Specification* (NDS 2015) for timber design. NLT, GLT, and CLT can be designed in accordance with Chapters 4, 5, and 10 respectively. LSL, LVL, and Secondary LVL should be designed in accordance with Chapter 8. Reference values are not provided for LSL or LVL in NDS 2015, as they are unique to each supplier's APA product reports.

It is possible to calculate individual CLT panel capacities with the Kreuzinger shear analogy method. However, NDS 2015 also requires that the resistance values be taken from the individual supplier's APA product reports and then further modified with the Chapter 10 factors.

Under current U.S. codes and material standards, all of the mass timber panel products require plywood sheathing for in-plane diaphragm stiffness and shear resistance. The use of CLT without plywood is indeed a viable solution but must be negotiated with the authority having jurisdiction. Plywood diaphragms on mass timber panels can be considered as "fully blocked" when detailing with the NDS 2015 *Special Design Provisions for Wind and Seismic* (SDPWS).

Conclusion

A broad variety of mass timber products is available in today's market, suitable for many project types in the North American building industry. Knowing your product options is critical when starting to design a mass timber building system. With this introductory information, engineers should be able to make informed design decisions regarding each product.

Mass timber construction has been in use in Europe for decades, with great success. This style of construction continues to grow in popularity in North America. As engineers, we have the opportunity to play a significant role in shaping and promoting this type of construction. With mass timber, architecturally expressive and sustainable structures can be created, adding value to your client's project.■