Issue Theme: Mass Timber and Tall Wood Issues

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Use of mass timber as a structural system is on the rise again in North America. Replacing traditional structural systems such as concrete and steel for non-residential applications, this renaissance of the legacy heavy timber construction system combined with newly introduced mass timber panel products is gaining momentum in the US and Canada for taller wood structures. Recent projects like the 220,000 square foot T3 office building in Minneapolis, the 18-story UBC Brock Commons Tallwood House in Vancouver, BC, and the under-construction 12-story Framework project in Portland, OR, have captured the attention of builders, designers, and code officials alike. Accordingly, the second annual International Mass Timber Conference – Forest to Frame was held in Portland, Oregon March 28-30, 2017. There were four education tracks, including a track for Architecture/Engineering. Three presenters in that track agreed to turn their presentations into papers for this issue of Wood Design Focus. We appreciate their contribution to this theme.

The first paper explores the topic of tall wood building enclosures. Tall wood structures have the benefit of prefabrication and can potentially be installed very quickly saving construction time and cost. They do however have challenges including sensitivity to moisture if not properly protected during construction or in-service. This is where the critical integration of building enclosure and façade elements come into play, and it is becoming apparent through research and project experience from the first cohort of taller wood buildings in North America that the integrated design and erection of the building enclosure and façade components to protect mass wood structures is critical to the success of these buildings.

The second article deals with fire safety of exposed mass timber in high-rise buildings. A high-rise building with a combustible structural frame introduces a number of fire safety issues, and the extent of fire hazard posed by the exposed mass timber is one aspect to address. The building code allows low- and medium-rise buildings to have primary structural elements as exposed mass timber. But once a building becomes a high-rise, the building is required to meet a higher standard for fire protection and structural performance in fire. Exposed mass timber as part of the primary structural frame needs to be addressed correctly to allow for its use.

Finally, the third paper discusses dowel-laminated timber (DLT), a relatively new mass timber product in North America. DLT, known as dübelholz (literally “dowelled wood”) in Europe, is a structural mass timber panel which can be used for floor, wall, and roof structures. In many ways, it is similar to nail-laminated timber (NLT), but without the nails. Panels are made from softwood lumber boards stacked like the boards of NLT, but friction-fit together with hardwood dowels instead of nails. DLT panels, unlike NLT panels (due to the nails) may be processed using CNC machinery. This allows for panels which can contain pre-integrated electrical conduit and other service runs.

We hope you find this issue of Wood Design Focus informative. As always, comments and questions are welcome.

John “Buddy” Showalter, P.E.
Editorial Board Chair
Interest in taller wood buildings utilizing cross laminated timber (CLT), nail laminated timber (NLT), and structural glued laminated timber (glulam) is growing rapidly in Canada and the United States. On the west coast, recently completed projects including the 97 foot tall, 6-story Wood Innovation and Design Center (WIDC) in Prince George, BC, the 180 foot tall, 18-story UBC Brock Commons Tallwood House in Vancouver, BC, and the upcoming 12-story Framework project in Portland, OR, have captured the attention of the international construction industry. Several other taller wood buildings are on the horizon and feasibility studies are currently being performed for mass timber buildings over 30 stories in height. Tall wood buildings have been a reality in Europe longer than North America, and there is much to learn from the European experience. However, conditions unique to the North American construction industry create many challenges for the design team in demonstrating the safety, durability, and economics of these buildings, all while forming public perception of wood at taller heights.

**Wood Structure and Building Enclosure – A Race to the Top**

Structural systems for tall wood buildings are new to the industry and are unique in their design and construction. Heavy use of CLT or NLT panels and glulam beams/columns along with innovative connectors are features of taller wood buildings. Concrete and steel are also utilized with mass timber elements to create “hybrid tall wood structures.” Tall mass timber wood structures have the benefit of prefabrication and can be installed...
very quickly saving construction time and cost. To achieve this time savings, advanced computer models are often utilized to draw all components individually in 3D and combined to model the completed building. The 3D model for each component part is then linked directly to the wood and connector fabrication facilities to ensure the perfect fit of all components on site. Once complete, the model is then used to simulate construction of the building in 4D to optimize the on-site build schedule. An example for the UBC Tallwood House is shown in this video by CADMakers - https://www.youtube.com/watch?v=ATKpFtzCVFU.

Tall wood structures have many challenges that need to be overcome prior to construction. The greatest challenges include public perception and gaining acceptance with local code authorities. The most significant issues that need to be addressed to achieve this acceptance are fire safety, building movement, and durability. Wood is more sensitive to moisture than concrete or steel, especially during construction if not properly protected. This is where the integration of building enclosure and façade elements come into play. On tall wood buildings in North America, the integrated design and erection of the building enclosure and façade components to protect mass wood structures during construction is critical to the economics, durability and overall success of these buildings. This is where the notion of a race to the top arises – build the structure fast, but build the enclosure just as fast to protect the wood structure and take full advantage of the time saving benefits of a prefabricated building.

**Wet West Coast Challenges**

The Pacific Northwest of Canada and the US is a temperate rainforest climate where persistent rain is expected for most of the fall, winter and spring months. In this climate, construction can proceed 12 months per year due to relatively mild temperatures. In this region, tall buildings are typically constructed of cast in place concrete that is poured year-round without the need for hoarding and heating. Building façades are installed in a vertical assembly line many floors below the concrete operations typically using moisture tolerant unitized curtain wall, window wall or steel stud assemblies. During construction, it is common for water to wet the structure and façade systems during and after installation.

Wood structural systems for WIDC (left) and UBC Tall Wood House (right) without building enclosure elements shown. (IMAGES COURTESY OF MICHAEL GREEN ARCHITECTURE AND ACTON OSTRY ARCHITECTS)
from both the interior and exterior as rainwater flow is managed inside the building.

On tall wood buildings, mass timber elements including CLT, NLT, glulam, and other engineered components absolutely need to be protected from excessive wetting during construction. This requirement precludes the use of many conventional cladding systems unless the building is fully hoarded during construction. On buildings such as UBC Tallwood House, where scaffolding and hoarding is not practical or economical, the following risk mitigation strategies can be employed to help prevent heavy timber components from getting wet during construction:

1. Build and enclose very rapidly during the summer dry season;

2. Pre-protect heavy timber elements with appropriate membranes;

3. Prefabricate enclosures for quick installation;

4. Install factory finishes or coatings to reduce water absorption;

5. Employ an effective construction site water management plan.

NLT as a floor and roof panel is particularly challenging in rainy and damp coastal environments due to the tendency for the nailed framing to swell when wetted. The Nail Laminated Timber Design Guide recently published by the Binational Softwood Lumber Council (2017) provides practical guidance on avoiding these problems with considerations for climate and assembly design. CLT can handle wetting much better than NLT as it does not swell along the length or width, however, research and field experience over the past few years strongly suggests that panels should be coated with a factory applied water repellant, particularly at the edges and exposed end grain to reduce the amount of wetting during construction. If NLT or CLT gets too wet during construction, it will take significant time for the wood to dry out and this can result in costly construction delays.

Simple design strategies that allow wood that is wetted during construction (or could become wetted in-service due to leaks) the ability to dry out go a long way in making these buildings more durable. On WIDC, the roof system

Poorly protected and wetted NLT roof assembly (left) at a project in BC compared to a well-designed and moisture managed CLT roof assembly at WIDC (right).
was installed over strapping over the CLT roof beams and open to the interior above the mass timber structure. When the plywood was wetted during construction as a result of snow melt, it was easily and quickly dried out from the interior by moving interior air between the plywood roof sheathing and the CLT beams.

Prefabrication and Detailing of the Façade
The two key differences that need to be considered early in design for tall wood buildings which are unique from other building types are summarized as follows:

1. Need for Speed
The building enclosure for larger and taller mass timber buildings should be erected and sealed water-tight as fast as possible following the erection of the wood structure. This necessitates the use of offsite prefabrication and minimal site work to prepare for installation of wall and roof panels. In addition, materials used within the enclosure panels, whether they be structurally fabricated of wood, steel, or concrete need to be accommodating of inclement weather and tolerant of moisture during construction. Pre-installation of windows and thoughtful design of panel joints and interfaces for ease of sealing is therefore crucial.

2. Ensure Durability
Materials used within the building enclosure need to be robust and essentially “high-rise appropriate.” Given the potential short- and long-term vertical expansion/contraction and lateral drift of the wood structure, they also need to be more tolerant of movement. Thermal efficiency is necessary for code compliance as is the use of non-combustible materials. Wood structural components can be just as durable as steel or concrete when properly protected and have the added benefit of being more thermally efficient when bypassing installed insulation.

UBC Brock Commons Tallwood House – World’s Tallest Modern Wood Building
The building enclosure and façade of UBC Tallwood House consists of an innovative prefabricated steel stud rainscreen curtain-wall assembly that is pre-insulated, pre-clad, and has factory installed windows. Design of connections and air and water sealing of panel joints and interfaces was carefully considered given the tall wood structure they were designed to protect. While steel studs were utilized in the panelized structure, feasible curtain-wall designs were also developed and prototyped for wood-framing, CLT, and precast concrete as part of the project.

Prefabricated wall and window system being installed at UBC Tallwood House.
During the early schematic design phase for the UBC Tallwood House, the following criteria were outlined by the design and construction team for the façade system:

- A panelized façade that could be installed and sealed air and water tight at a pace of one floor per day.

- A durable moisture tolerant panel with windows pre-installed that could be installed and sealed without access to the exterior side.

- A wall assembly that met the current energy code target (R-16 effective) but could easily be scaled up if needed to meet more aggressive overall building energy performance targets.

- Be constructed of non-combustible materials or where wood is used, meet fire code requirements.

- Economical, and for this project, an installed cost of less than $50/square foot, which locally at the time was in line with pre-cast sandwich panel and aluminum window-wall systems.

With these criteria in mind, various prefabricated wall panel design options were explored for the project. These included both a bottom bearing small panel option which could be installed using small hoists installed like a window wall, and a larger top-hung curtain-wall panel option with preinstalled punched windows mounted using the site crane. A costing and scheduling assessment of both panel concepts by the construction team favored the larger panel option given the anticipated installation of the structural members and the significantly reduced level of slab edge preparation and membrane work required.

Given the preference for a larger hung prefabricated panel, the architectural design of the façade proceeded with this concept and aesthetic. The next step in the design process was to select a structural system for the panels and work with a local contractor to design a façade system to meet the project criteria. To spur design innovation and in the spirit of competition, three sub-contractors were tasked with the design and mock-up construction of a wood-frame/CLT, steel-stud, and pre-cast sandwich panel. Each team fully designed their panel, installed a set of panels on an offsite mock-up and submitted a tender for their system. Ultimately the exterior insulated steel stud backup wall was selected as it met the project criteria and budget.
Once the steel stud unitized curtain-wall approach was selected, the design was finalized and a full scale Performance Mock-up (PMU) was constructed and tested for assembly time, air, water, structural, seismic drift/deflection and condensation performance. The performance mock-up testing identified improvements to panel connections, windows, air and water seals, and corner panel connections. The panel cladding was also changed from light gauge steel to a high-pressure wood-fiber laminate for aesthetic reasons. The mock-up was installed in a record 60 minutes and is the fastest PMU installation that the authors have ever witnessed.

Upon the successful completion of the performance mock-up, full scale assembly of the panels was started in the manufacturer’s facility.

During the summer of 2016, 24 prefabricated panels per floor were successfully installed at a speed of two floors per week (instead of the initially anticipated 1 floor per
week), closely trailing the CLT floor and glulam column structural system. The strategically designed panel joints were sealed from the building interior following panel installation and tolerances were such that these panel joints are difficult to distinguish from other cladding joints. After the building was closed in and the roof installed, additional batt insulation within the stud cavities was installed followed by a vapor barrier membrane and drywall. Onsite commissioning was performed to confirm that the panel and window air and water tightness met project performance specifications. This fast and simple installation of the prefabricated panel system allowed the structure and façade of the world’s current tallest modern wood building to be installed in a record breaking 9 weeks and contributed to the overall success of this project.
Onward and Upwards
Looking ahead, there will continue to be innovation in design and construction of fast and durable facades for taller wood buildings. New prefabricated panel designs incorporating CLT panels and connection technologies from unitized curtainwall systems are already being developed for the “next tallest” wood buildings in North America.

References
Cad Makers 4D construction sequence: https://www.youtube.com/watch?v=ATKpFtzCVFU

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Fire Safety of Exposed Mass Timber in High-Rise Buildings

David Barber – Arup

Introduction
Multi-story buildings using mass timber for the primary structural elements are being planned and constructed within the US. This is due to the need for green and sustainable architecture and to utilize the efficiencies in construction that mass timber can bring. Cross-laminated timber (CLT) is being used for walls and floors, often combined with glulam as the gravity structural frame. With the growing resurgence of mass timber as a construction material in the US, there is also significant interest in high-rise buildings with mass timber elements exposed, to capture the beauty and warmth of wood and to also show the sustainability credentials. A high-rise building with a combustible structural frame introduces a number of fire safety issues, and the extent of fire hazard posed by the exposed mass timber is one aspect to address.

Code Compliance
Each State within the US adopts one or more model building codes. All 50 states adopt the International Code Council’s (ICC) International Building Code (IBC) (ICC, 2015), with some states also adopting NFPA 101 Life Safety Code (NFPA, 2015). Many States further amend the model codes to provide the basis for construction compliance.

Within the IBC, mass timber construction is referred to as combustible construction, with concrete and steel construction referred to as non-combustible construction. The IBC requires buildings with an occupied floor above 75ft (defined as high-rise) to have an increased level of fire protection and structural performance, with non-combustible construction used for the primary structural elements. A high-rise utilizing mass timber can currently only be approved by the Authority Having Jurisdiction through an “alternative materials, design and methods of construction and equipment” approach to the building permit.

Building Fire Resistance
What is a Fire Resistance Rating?
A fire resistance rating (FRR) forms the basis of approving building elements for use in construction. A structural element that is tested to achieve a FRR is exposed to a standard time temperature curve, meeting ASTM E119 (ASTM, 2016). The element has to resist the energy released by the furnace fire, measured against criteria for load-bearing, integrity and insulation. For example, a mass timber glulam floor beam that has passed a two hour fire test has been proven to have enough mass, heat resistance and load-carrying capacity to resist the energy released from the standard test furnace fire and passed other strict criteria specified by ASTM E119.

Why is a FRR Required?
The IBC has fire protection requirements that provide for occupant life safety, access and equipment for firefighters, and prevention of fire spread to neighboring buildings. Protection requirements for the building structure vary with height and area. Low rise buildings of up to three stories have minimal fire protection for the structure and may suffer significant damage in a fire. Buildings are permitted to be larger or taller if they include fire rated structural members, fire separated compartments, separation from neighbors; or if
sprinkler protection is installed. Medium rise buildings of up to six stories are required to have a one hour FRR and are limited in area. With sprinkler protection or separation by fire walls, larger floor area is permitted. High-rise buildings (75ft or over), are required to have a FRR of two hours to the primary structure, sprinkler protection and many additional fire protection features. For buildings over 420ft, all fire ratings are three hours for the primary structure and two hours for floors.

**High-Rise Building Fire Protection**

For a high-rise building, the expected structural performance in fire is increased. High-rise construction is represented by construction Types IA and IB, which require non-combustible construction. For buildings up to 12 floor, the FRR for the structure can be reduced to one hour, provided additional reliability enhancements are made to the sprinkler protection and occupant alerting. The reduction from two hours to one hour is recognition that evacuation can occur relatively quickly and fire department intervention external to the building can still occur with a degree of success, even in the highly unlikely situation of sprinkler failure.

Buildings over 12 floors are required to have a minimum of two hours FRR to all primary structural elements and floors, with columns being three hours. The higher fire ratings are required to support the longer evacuation time for occupants and fire department intervention via fire protected stairwells and fire service access elevators (required once a building is 120ft). The building is to remain structurally intact even in the highly unlikely case of sprinkler failure and delayed fire department intervention. The approach of providing high-rise structural fire ratings based on resisting a “fully developed fire,” - a fire that burns until decay - is consistent in codes internationally and domestically (Department of Commerce, 1942). Hence, there is a significant difference in expected structural performance in fire for a high-rise building, when compared to a medium or low-rise building.

**Exposed Mass Timber – Another Engineering Problem?**

When choosing to use mass timber as part of the building structure for a high-rise building, architects and building owners are requesting that mass timber be partly exposed and not hidden behind a protective cladding. There is concern and debate in the design and approval community as to whether exposing mass timber that forms part of the building structure is a fire hazard and therefore, should be fully clad by non-combustible protection (also referred to as encapsulation); or can be engineered so that it can be exposed.

**Mass Timber FRR**

While combustible, the inherent fire resistance provided by mass timber building elements such as CLT and glulam is distinctly different from the fire resistance of light wood frame members. Sawn and engineered wood have fire resistant properties that have been very well researched and understood, with significant standardized fire testing undertaken in North America (White, 2015). Buildings that utilize engineered mass timber products can achieve the IBC required fire resistance ratings (FRR) of two hours or more, without relying on additional passive fire protection such as fire rated gypsum wallboard.

**Compliant Buildings with Exposed Timber**

CLT is now recognized within the 2015 IBC for use as a building material and mass timber can be exposed within construction Types III, IV and V as an interior finish and as part of the building structure. Type IV construction is being utilized for modern mass timber buildings, where sprinkler protected buildings can be constructed up to five floors for residential or six floors for offices, and even higher when the construction is over a non-combustible podium (to a maximum of 85ft). Exposed timber for Type IV buildings at five or six floors (residential or business respectively) is a reasonable compromise in fire safety, given the fire likelihood, fire protection measures provided, and firefighting intervention that can occur.
High-Rise Buildings with Exposed Mass Timber – Issues To Be Addressed

A high-rise building that is constructed with areas of the mass timber primary structure exposed will need to resist a fully developed fire, in the highly unlikely scenario where sprinklers have failed and the fire department has limited intervention. If too much timber is exposed, then the total combustible fuel within the space (furniture, fixtures and exposed timber) can result in a fire that releases more energy than the primary structure can resist, resulting in localized structural failure.

Accounting for areas of exposed timber (not protected by a non-combustible finish) is a significant technical challenge to analyze and one that differs from a building with a non-combustible structure. As with all new building technologies, new engineering problems arise to be solved. There are several aspects to be addressed for exposed timber.

Combustible Interior Finishes

The IBC allows combustible interior finishes within high-rise buildings. Wood can be used as an interior finish on floors or walls. Flame spread for exposed wood is required per ASTM E84 (ASTM, 2015). The IBC permits wood as an interior finish within an office or residence, provided it meets a minimum Class C interior finish classification, when sprinkler protection is installed.

Room Fire Dynamics Influenced by Exposed Timber

A second aspect to be addressed is exposed load-bearing timber within a room (compartment), such as load-bearing beams, columns or the underside of a CLT floor, and how that exposed timber impacts fire dynamics. In the very rare event of a fully developed fire, fire growth rate, heat release rate (HRR), fire duration and fire temperature can be influenced by exposed timber. Fire testing (see section below) has shown that exposed timber can increase the fully developed fire peak HRR and lengthen the fire duration, due to added combustible fuel of exposed timber, when compared to a compartment without any exposed timber. To provide a FRR for timber load-bearing members, the member is increased in sectional area (AWC, 2015). But increasing the sectional area also introduces more combustible fuel to the room. Thus, the FRR to be provided for the

Figure 1: Type IV building, using CLT. (IMAGE COURTESY OF ARUP)
exposed load-bearing timber structure needs to be determined to include the fire load introduced by the structure itself. The primary issue to be addressed by a fire protection engineer is the total energy released from a fully developed fire, which is influenced by the area of exposed timber and compartment ventilation.

**Basis of Mass Timber Protection**

To limit the area of exposed mass timber or extend the FRR (White, 2009), non-combustible finishes, such as fire rated gypsum wallboard can be used. For non-combustible structures, fire resistance ratings can be achieved by applying products such as gypsum wallboard to the primary structure. For mass timber buildings, non-combustible protection can be installed over exposed timber to prevent it becoming part of the fire fuel (it will also enhance the FRR). The non-combustible protection to the mass timber is required to stay in place for the duration of the expected fire, through to decay, to prevent the mass timber forming part of the compartment fuel.

**Fire Testing Of Exposed Mass Timber**

There have been a number of full size fire tests of rooms with exposed CLT which have been very informative. Fire testing has been carried out on compartments with exposed CLT panels (walls or underside of floor) in Canada, Europe and US (Frangi, 2008; Wilinder, 2010; Craft, 2011; Aguanno, 2013; McGregor, 2013; Medina, 2014; Hox, 2015; Kimball, 2017; Hadden, 2017). The aim of the fire testing has been to understand how exposed timber influences fire size and duration and to also understand the effectiveness of CLT protection systems.

Fire testing has shown consistencies in the results (Barber, 2016) and that large areas of exposed timber can impact fire size and fire duration, as exposed timber can provide an additional volume of combustible fuel.

**Reaction of CLT to Fire**

The fire testing has also shown the impact of CLT that is susceptible to premature failure of the plys at the adhesive interface, before complete charring occurs. This has been referred to as delamination, de-bonding or stickability (Klippel, 2016). Delamination is the process in CLT where small pieces of mostly charred CLT separates from the unburnt CLT base as the charring reaches the ply interface. The separation of the char occurs due to the ply adhesive weakening under increased temperatures.

Delamination is an important issue for exposed mass timber, because if the char that protects the unburnt
timber falls off, unburnt timber is exposed to the fire. This results in an increase in burning at the freshly exposed timber, until a new layer of char has formed. The extent of delamination varies between panel manufacturers. Delamination is accounted for within the methodology to calculate char rate in panels within the CLT Handbook (Karacabeyli, 2013). Where the CLT specified has been shown to be susceptible to delamination under fire conditions, then the area exposed will need to be limited. If the CLT being specified has been shown through fire testing to not delaminate and the charring is the same as for solid or glulam timber, then the exposed CLT area can be engineered as the CLT behavior is predictable.

**Summary**

High-rise buildings that are constructed with mass timber as the primary structure are being planned due to the sustainability benefits they offer, the increased speed of construction and the potentially higher financial returns. The IBC allows low and medium-rise buildings to have primary structural elements as exposed mass timber. But once a building becomes a high-rise, the building is required to meet a higher standard for fire protection and structural performance in fire.

For buildings designed with areas of exposed timber as part of the primary structure, the influence of the exposed timber on the fire dynamics needs to be understood to allow it to remain exposed and not protected by a non-combustible cladding. Areas of exposed mass timber will increase the heat release rate if a fully developed fire can grow, but the influence can be assessed and engineered. If the area of exposed mass timber is not determined to be acceptable, then it could result in a fire that releases more energy than the primary structural elements can resist. Given the need to understand exposed mass timber primary structure in high-rise buildings, models have been developed to assess the impact. Hence, exposed mass timber as part of the primary structural frame needs to be addressed correctly to allow for its use.

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Dowel Laminated Timber – A New Mass Timber Product in North America

Lucas Epp, P.Eng – StructureCraft

Introduction
Use of mass timber as a structural system is on the rise in North America. Replacing traditional structural systems such as concrete and steel, these prefabricated solid wood panels create a construction method that is fast, clean, and sustainable – not to mention aesthetically pleasing. With recent projects like the 220,000sqft T3 office building in Minneapolis, the cost-competitiveness of mass timber is now being shown at scale.

Dowel Laminated Timber (DLT), known as dübelholz (literally “dowelled wood”) in Europe, is a structurally efficient and economic mass timber panel which can be used for floor, wall, and roof structures. In many ways, it is similar to Nail Laminated Timber (NLT), but without the nails. DLT panels are the only 100 percent mass timber product – they involve no glue or nails.

History of mass timber
Before describing DLT in detail, it is important to understand Nail Laminated Timber – the oldest mass timber product, which has been in use in heavy timber structures for over 150 years. Examples exist in the warehouse districts of many cities. Large industrial buildings like the 500,000 sqft, 8-story Butler Building (Minneapolis, built in 1906) used solid-sawn posts and beams with NLT floor panels to create a robust structural frame.

NLT is created from dimensional lumber stacked on edge – nominal 3”, 4”, 6”, 8”, 10”, or 12” boards which are laminated and fastened together with nails. Plywood or OSB sheathing is often added to the top side to provide a structural diaphragm. This system became prevalent, leading the National Lumber Manufacturers Association to create Heavy Timber Mill Construction Buildings in 1916, an illustrated guide to structural and fire detailing of these heavy timber structures.

Heavy timber construction fell out of main stream use with the industrial revolution and the rise of steel and concrete as primary building materials.

However, this is starting to change as the construction industry realizes the importance of sustainable construction. Wood is the only primary structural material that is renewable and grows naturally.

Julius Natterer, a famous Swiss timber engineer, re-introduced the concept of NLT (known as brettstapel, literally “stacked elements”) to Europe in the 1970s. Natterer
saw NLT as a mass timber product that could be produced by anyone, and encouraged manufacturing throughout Europe. However, the nails inside NLT meant that CNC machining of these panels was impossible, and manufacture by hand was laborious.

**History of dowel laminated timber**

In the early 1990s, DLT/dübelholz was developed by Alois Tschopp (Tschopp Holzbau) with Pirmin Jung in Switzerland. They saw this product as a superior product to NLT/brettstapel in every way – it used only wood, it was CNC machinable, and production of the panel was possible with automated machinery. They proceeded to create the first automated machinery line for DLT.

In Europe, DLT is a well-known and well used mass timber product. Although both products were developed around the same time, CLT has developed a larger market share in Europe, as the big glulam manufacturers saw CLT as a glued product which would be easy to expand into. DLT remained the realm of smaller manufacturers – the largest manufacturer produces around 15,000m³/year. Interestingly however DLT is often cheaper than CLT in Europe, and is gaining more interest, due to DLT being 100% wood.

Recent larger and taller wood buildings in Europe have used DLT as floor and wall panels (E3, Berlin). There are over 15 manufacturers of DLT in Europe, primarily located in Switzerland, Germany, and Austria.
DT in North America
StructureCraft has recently installed the first DLT production plant in North America. This high capacity, fully automated DLT machinery line will be the fastest and largest capacity worldwide, and is intended to introduce a new cost-competitive mass timber product to the rapidly growing market in North America.

DLT manufacturing
Dowel Laminated Timber panels are made from softwood lumber boards stacked like the boards of NLT, but friction-fit together with hardwood dowels instead of nails. The dowels hold each board side-by-side, forming a stiffer and stronger connection than the nails in NLT. Each board lamination in a DLT panel is finger-jointed, creating a stiffer and stronger panel than NLT as it eliminates the board splices and butt-joints which are characteristic of NLT.

DLT panels may be processed using CNC machinery, unlike NLT panels (due to the nails). This creates a high tolerance panel which can also contain pre-integrated electrical conduit and other service runs.

Panelized Building Elements
DLT panels are prefabricated in sizes of up to 12 feet wide and 60 feet long. Each panel is put through a panel planer to ensure a dimensionally accurate and planed surface. Prefabricated panels can be factory finished with sealers or stains.

Finish and Geometric Possibilities
DLT is a versatile product, and naturally lends itself to creating unique aesthetics on the exposed face of the panel. Each of the laminations are run through a profile molder, meaning many different profiles are achievable, from notches and reveals to flowing curves.

Residence using DLT for walls, roof, and floors.
Curved DLT Panels.

Curved DLT panels can be created by milling custom profiles into each lamination, creating a flexible panel which, like an accordion, can accommodate curves perpendicular to the span direction of the panel. The radius for these curves is limited only by the bending stiffness of the dowels, which are located centrally in the panel. These panels are created initially flat and then curved into shape on site.

Fluted panels (e.g. 2x4-2x6-2x4) can create a unique soffit aesthetic if exposed, and allow the running of electrical conduits or sprinklers in the gaps.

Unique to DLT as a mass timber product, acoustic profiles can be integrated directly into the bottom surface of a panel. This can help a designer achieve acoustic objectives while keeping the wood exposed and allowing for a wide variety of surface finishes.

Some panel profiles achievable with DLT.
Any wood species incorporated in the International Building Code (IBC) and referenced National Design Specification® (NDS®) for Wood Construction can be used in DLT, as only specified strength and stiffness for each lamination is required. Full-scale panel testing is not required to determine structural performance – a significant advantage to DLT as a product.

A range of wood species is achievable with DLT – Spruce Pine Fir, Douglas-Fir, Western Red Cedar, and Alaskan Yellow Cedar panels are shown here.
Structural performance
As a floor or roof deck, DLT is a highly efficient structural panel. Similar to NLT or GLT (glulam on flat), all of the wood fiber runs in the direction of the span. This provides the most efficient use of material for floor and roof systems which are typically one-way spanning between beams or walls.

From a structural perspective, each individual lamination spans between supports, meaning calculation of the panel stiffness and capacity is simple. The structural design of each lamination in a panel is covered by the NDS and applicable grading rules. Structurally finger-jointed lumber is used for spans longer than 20ft, meaning no reduction in strength or stiffness is required for longer panels. This is a big advantage over traditional NLT where butt joints in laminations require a 20-30% reduction in panel strength and stiffness (refer to Nail Laminated Timber Design Guide, Table 4.1 and 2015 IBC 2306.1.4).

The Uniform Building Code (predecessor to the IBC) has recognized laminated decking since 1927. The requirement for minimum fastening of the boards together ensures that the panel acts as an element and not individual boards. The ¾” diameter hardwood dowels in DLT create the same interlayer shear capacity between boards as the original 20 penny nail requirement which was specified in the IBC.

Machine stress rated lumber can be used to increase strength and stiffness of the panel.

Diaphragms and Shear Walls
Plywood or OSB sheathing atop the panel gives shear capacity to DLT panels for use as structural diaphragms in floors and walls. The sheathing also allows for simple nailed connections between panels with strips of plywood. The shear capacity of the sheathing applied overtop the DLT panels can be calculated like a typical nailed plywood diaphragm per Special Design Provisions for Wind and Seismic (SDPWS) 4.2.7.1.
**Bearing Walls**
DLT panels can be used as structural bearing walls with the DLT exposed on both sides, or sheathed one or both sides as a shear wall.

**Two-Way Spans**
Smaller two-way spans or weak-axis cantilevers (up to 2-3ft cantilevers or 4-6ft simple spans) can be achieved in DLT panels by using screw reinforcement inside the panel. Screw reinforcement for a weak-axis cantilever can be designed using a strut-and-tie truss analogy to design angled shear and compression screws, and using the plywood sheathing as a tension flange.

Larger minor axis cantilevers can be achieved using steel or wood outriggers set atop or notched into the top of the panel.

**Detailing for Moisture**
When detailing DLT panels, designers need to account for moisture movement – wood expands perpendicular to grain as moisture content increases. Incorporation of small gaps between panels deals effectively with this issue. The T3 Minneapolis structure had a floor plate which was 220ft wide, and which experienced both snow and rain during winter construction. The gap between panels effectively dealt with expansion of the panels during construction, and there were no issues with moisture damage or remedial works required. The key is in detailing for the movement, and letting panels dry out after they get wet.

Use of OSB sheathing with a pre-applied moisture-resistant top coating and taped joints is a newer solution to this issue. Along with providing a path for the water to move off the floor plate, this strategy provides significant protection from moisture, and greatly reduces expansion of the panels.
If a gap is provided between panels, it can be filled in afterwards with lumber, or retained to create a visual delineation between panels – as it was on the T3 building. From a fire design perspective, the gap between panels is not an issue if a continuous topping layer or plywood spline is provided. Similar to a plywood spline between CLT panels, this continuous layer prevents air movement between floors, thus ensuring char development remains uni-directional (NLT Guide 3.3.2). The local authority having jurisdiction (AHJ) for the T3 building accepted permanent gaps between NLT panels for this reason.

**Fire performance**
DLT can be used in all types of combustible construction.

From a fire perspective, DLT behaves the same as NLT.

Both the IBC and the National Building Code of Canada (NBCC) recognize NLT and provide guidance for both structural and fire design. No product-specific standard is required, as the structural design of each lamination element is covered by the building codes. It is resistant to fire, and has long met the requirements of heavy timber in North American building codes. NLT can be used in all types of combustible construction.

The fire resistance of mass timber panels is now widely proven – the char developed during a fire creates a self-protection layer. Research recently completed by FPInnovations showed that a 2x8 NLT floor panel with concrete topping can achieve a 3-hour fire resistance rating under full load (Osborne, 2015).

The inherent fire performance of mass timber removes the need for intumescent coatings and dropped ceilings that would be required for a steel structure, and allows the wood to be exposed as a permanent soffit.
Acoustics
As with all mass timber systems, it is important to address acoustic separation between mass timber walls and floors, which can be achieved through appropriate detailing. Acoustic mat should be used in floor buildups with no dropped ceiling.

Vibration and timber-concrete composites with DLT
The stiffness of mass timber panels is important in long-span floor systems where consideration of floor vibrations often govern the required panel thickness.

A concrete topping is often required for acoustic performance, and this topping can be made composite with DLT panels to increase the panel stiffness. In Europe, many different techniques of creating composite action between the DLT and the concrete topping are used, including:

- Fully threaded screws inclined in the direction of the shear flow
- Milled notches in the DLT panel, continuous perpendicular to the direction of the span
- Use of fluted DLT, with the flutes turned up so the concrete topping flows between the higher laminations

Summary
Dowel laminated timber takes mass timber construction one step further to create a 100% wood panel which can be CNC machined and incorporate acoustic treatment into an exposed wood soffit. Due to its efficiency, aesthetics, and cost effectiveness, DLT will help lead the push towards wood construction.

DLT also extends the range of mass timber options available in North America, and supports the trend towards prefabrication as the future of building construction.
References


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