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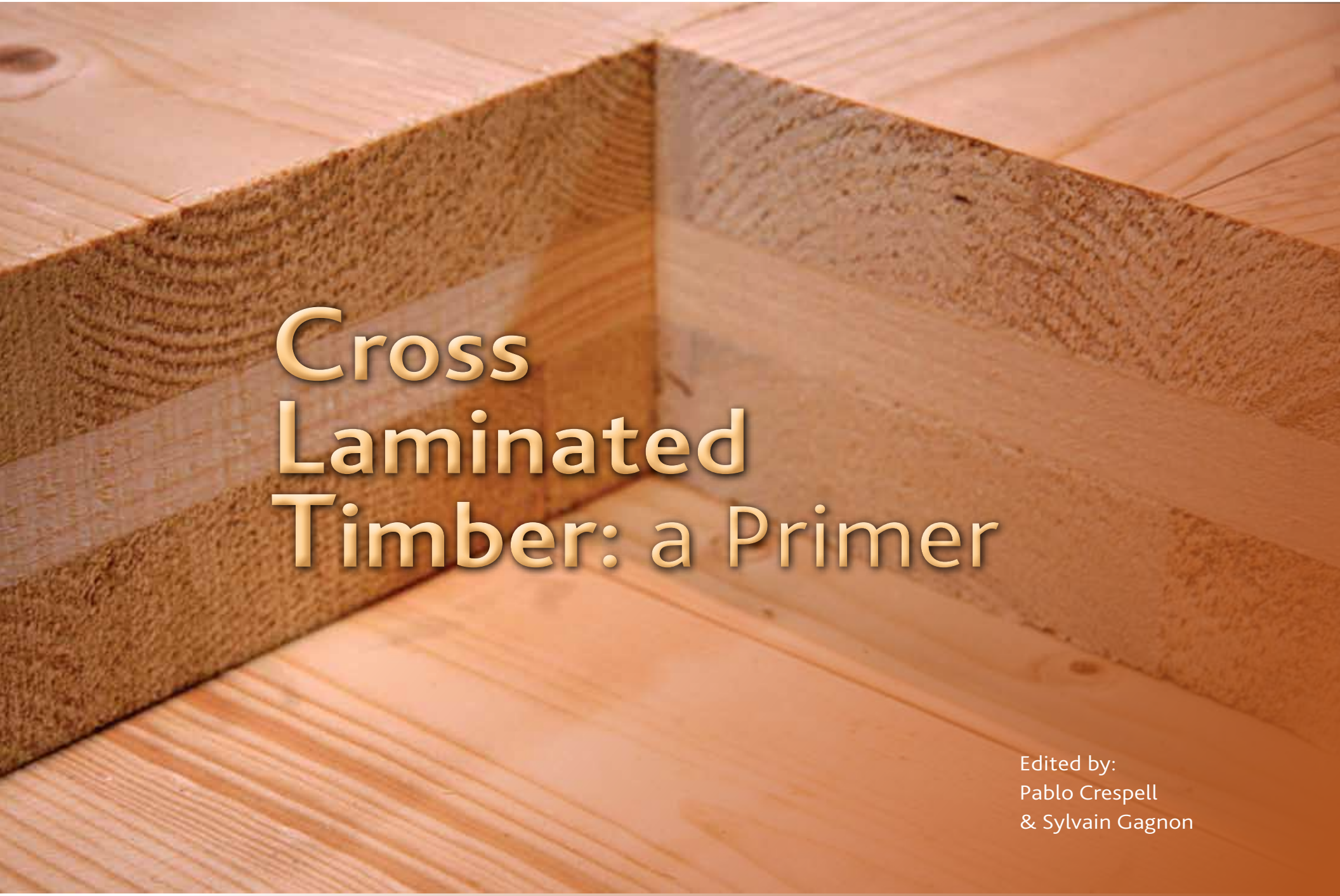

# Cross Laminated Timber: a Primer

Edited by:
Pablo Crespell
& Sylvain Gagnon

Special Publication 52

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# Introduction

Cross laminated timber (CLT) is a novel building system of interest in North American construction. It is a cost-competitive wood-based solution that complements the existing light and heavy-frame options, and is a suitable substitute for some applications which currently use concrete, masonry and steel.

This publication is mostly based on European experience. Application of European results to North America is preliminary until validated for local species and technologies. This primer is not intended for promotional use but rather it is a compilation of the knowledge gathered on CLT to date.

FPInnovations has conducted intensive multidisciplinary research on CLT. These efforts are indicated throughout the document by the Information logo.

For more Information look for the CLT handbook (coming soon).

# The Value Proposition

## Lessons from Europe

Because CLT is made of wood it possesses a number of positive environmental characteristics common to all wood products. These include carbon storage, less manufacturing greenhouse gas emissions than non-wood materials, and an overall lighter environmental footprint than non-wood materials, according to life cycle assessment studies.

CLT buildings can perform quite adequately in terms of sound performance as well as in their resistance to earthquakes and fire. Since it is prefabricated, the system is precise, and provides a construction process characterized by: faster completion, increased safety, less demand for skilled workers on site, less disruption to the community and less waste.

It is a flexible building system, allowing for long spans and it can be used in all assemblies (e.g., floors, walls or roofs). Also, a high degree of finishing preinstalled off-site is possible. Its ability to be used as a panelized and or modular system makes it ideally suited for additions to existing buildings. It can be used jointly with any other material, such as light wood-frame, heavy timbers, steel or concrete, and accepts various finishes.

## North America

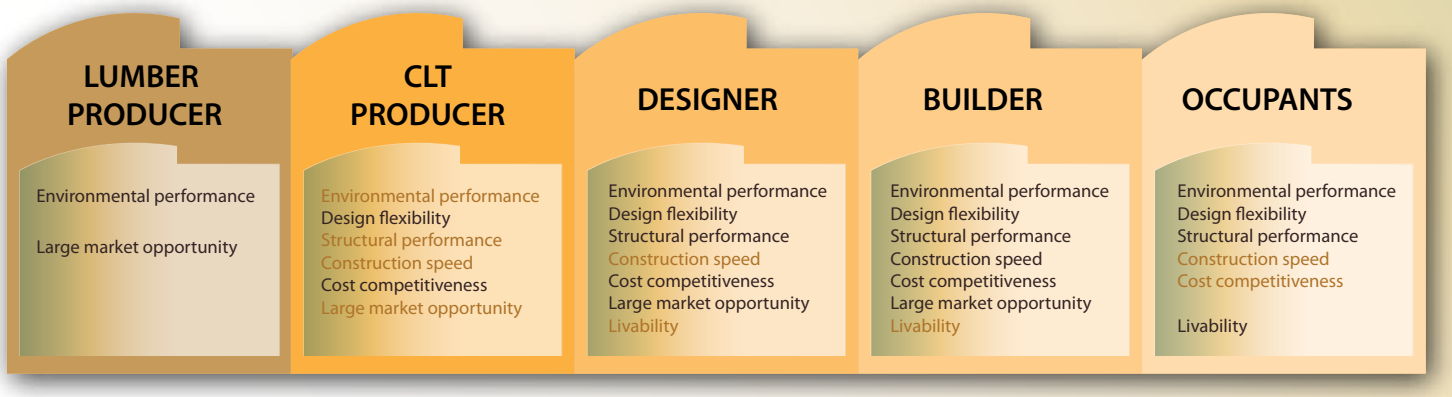
CLT appears to be cost competitive for some building types where currently masonry, concrete and steel are used. Preliminary analyses indicate its feasibility for mid-rise, both residential and non-residential. Other promising building types include institutional (e.g., educational) and box-type warehouses. Feasible applications include elevator shafts, stairwells, balconies, stairs and additions.

These building types and applications represent an important opportunity in the US and Canada. This demand, combined with the high wood usage of CLT may translate into a significant outlet for Canadian lumber.

Figure 1 identifies the different stakeholders and how they may benefit from CLT. These attributes are discussed in detail throughout the document.

**Fig 1**
How different stakeholders may benefit from CLT

**Note:** *Gold color text indicates less importance*




## Challenges

No new product is without its challenges. For CLT these include acceptance by the design and building community, code limitations to building with wood, lumber supply issues, limited production capacity, lack of generic or proprietary standards, and a delay while manufacturers and builders develop information on information on safety, performance and economy.

Having the capability to work with CAD and CNC routers is crucial for any CLT manufacturer. The role of the 'formatter' is converting architectural drawings into machine code that can be read by the CNC router. Networking and web capabilities are likely requirements.

PART One

# THE EUROPEAN EXPERIENCE

## 1 Brief History

Initial development of CLT took place in Lausanne and Zurich, Switzerland in the early 1990s. Several companies started production using proprietary approaches. In 1996 Austria undertook an industry-academia joint research effort that resulted in the development of modern CLT. For several years progress was slow but in the early 2000s construction with CLT increased dramatically, partially driven by the green building movement; but also due to better efficiencies, code changes (e.g., Sweden, Netherlands), and improved marketing and distribution channels. An important factor has been the perception that CLT is a 'not light' construction system. European producers have followed a proprietary approach to manufacturing with European Technical Approval (ETA) reports that allow them to operate, however there are efforts under way to develop a European (EN) standard. Typical building types include multi-family apartment buildings and educational buildings. The countries leading in the use of CLT are: Austria, Germany, Switzerland, Sweden, Norway, and the UK with 0.3 million $m^3$ constructed in place and a 0.6 to 1.0 million $m^3$ forecast for 2015 [15]. New plants are soon to be built in Sweden, Australia[1], and North America[2]. CLT is also known as X-lam ('cross lam') and 'massive timber'.

## 2 European Manufacturers

- KLH (Austria, UK, Sweden): 71,000 $m^3$
- Binderholz (Austria): 25,000 $m^3$
- Martinsons (Sweden)[3] : 5,000 $m^3$
- Moelven (Norway): 4,000 $m^3$
- Stora Enso (Austria): 60,000 $m^3$
- Thoma Holz GmbH (Austria)
- FinnForest Merk (Germany/UK)
- HMS (Germany)

## 3 Product Description

CLT is a multi-layer wooden panel made of lumber. Each layer of boards is placed cross-wise to the adjacent layers for increased rigidity and stability. The panel can have three to seven layers, or more, normally in odd numbers, symmetrical around the mid layer [7]. The solid wood building system consists of ready-to-use building components which are assembled to form complete frameworks. Dimensional lumber is the main input material. It is possible to use low grade for the interior layers and higher grades for the outside and it can be pre-dressed (planed) or dressed at the factory once the panel is assembled. While softwoods dominate, it is feasible to manufacture CLT using hardwoods like poplar or even hybrid panels (e.g., OSB, LSL, OSL and LVL).

*[1] Andrew Waugh, personal communication*

*[2] North America: CST Innovations, Acier AGF, Nordic (Canada), and Montana Sustainable Building Systems (US)*

*[3] Thomas Orskaug, personal communication*

# 4 Manufacturing

## Lumber Drying

- The boards must be kiln dried to a moisture content of 12% ± 2% depending on target location. Proper moisture content prevents dimensional variations and surface cracking. Lumber can be procured dried or further drying may be needed at the factory.

## Finger Jointing (FJ)

- Trimming and finger jointing are used to obtain the desired lengths and quality of lumber. Panel FJ is feasible too.

## Panel Assembly

Panel sizes vary by manufacturer. Typical widths are 0.6, 1.2, and 2.95 m (up to 4 m) while length can be up to 24 m (FJ), and thickness can be up to 0.5 m. The outer layers of panels used as walls normally orient boards with the grain direction parallel to vertical loads to maximize resistance. Likewise, for floor and roof systems the exterior layers run parallel to the span direction. Final width is obtained by joining panels together (See Section 6.3). Transportation regulations may impose size limitations.

- The assembly process can take from 15 minutes to 1 hour depending on equipment and adhesive.

## Panel Assembly Options

- Besides gluing, nails or wooden dowels can be used to attach the layers (e.g., Holz100 by Thoma Holz)
- The middle layer can be lumber or composite materials

Watch a video of the Binderholz plant at: http://www.youtube.com/watch?v=bb-TOnLDmoE&NR=1

## Gluing

Glue is the second input in CLT. Interior/exterior polyurethane (PUR) adhesives are normally used (formaldehyde and solvent free) although MUF and PRF may be used as well. Face and edge gluing can be used. FPInnovations has tested several Canadian species and glues

## Press

The right pressure and homogeneity are critical. Hydraulic presses dominate, however the use of vacuum and compressed air presses is also possible, depending on panel thickness and adhesive used. Vertical and horizontal pressing are applied.

## Planer and Sander

The assembled panels are planed or sanded for a smooth surface.

## CNC Router

CNC routers allow high precision. Panels are cut to size; openings are made for windows, doors and service channels, connections and ducts.

## Quality Control

Compliance with product requirements prescribed in the product standard must be checked at the factory (e.g., bending strength, shear strength, delamination).

## Carpentry Room and Finishing

Installation of insulation and drilling for openings may take place at the factory.

## Packaging and Shipping

See Section 10 ‘Transport’.

# 5 Mechanical Properties and Serviceability

Different methods have been adopted for the determination of basic mechanical properties of CLT in Europe. Some of these methods are analytical in nature while others are experimental. For floor elements, experimental evaluation involves determination of flexural properties by testing full-size panels or sections of panels with a specific span-to-depth ratio. The problem with the experimental approach is that every time the layout, type of material, or any of the manufacturing parameters change, testing is needed to evaluate the bending properties of such products.

In Europe, mechanical properties are provided by each manufacturer on a proprietary basis. In the case of CLT panel products, there is no European standard to date. The approval process includes preparation of a European Technical Approval Guideline (ETAG) that contains specific characteristics/ requirements of the product as well as test procedures for evaluating the product prior to submission to the European Organisation for Technical Approvals (EOTA). The ETA allows manufacturers to place CE marking (Conformité Européenne) on their products.

### FPInnovations

- Reviewed the European analytical procedures for determining mechanical properties of CLT panels in timber construction, summarized them in a report and proposed design provisions following Canadian timber design philosophy.
- Reviewed the creep, load duration and service factors that are employed in Europe, and made recommendations for Canada.
- Reviewed and compiled existing information on the various types of traditional and innovative types of connection systems used in CLT assemblies and buildings, and summarized the information in a report.
- Proposed design methodology to determine vibration controlled maximum spans of CLT floors and summarized it in a report.

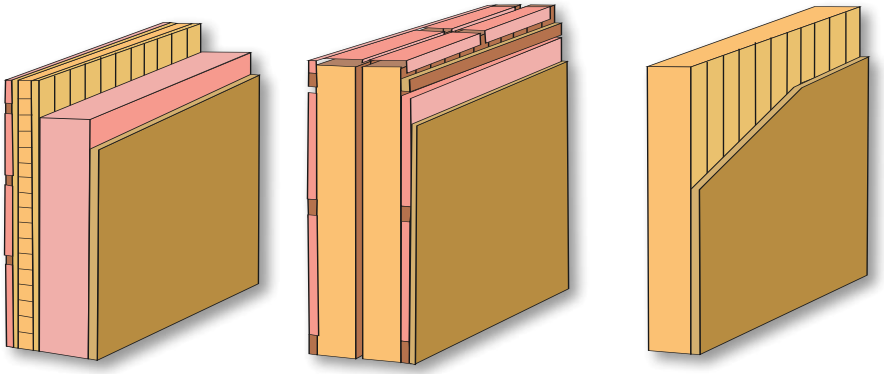
# 6 Assemblies

## Configuration

Assembly configurations are project-dependent. Below is an example from the Limnologen building (Växjö, Sweden):

- **Exterior wall[4]:** 3-ply CLT, exterior insulation (100 to 200 mm), facade (e.g., 5 mm stucco), 1x or 2x gypsum board on furring, optional 100 mm internal insulation.
- **Separation walls:** 2 x 3-ply CLT, insu- lation, gypsum on furring on both sides
- **Partition walls:** 3-ply CLT, gypsum on both sides. Wood or metal stud partitions are quite common and economical. Some load bearing reinforcement may be needed.
- **Floors:** 3 to 7 ply CLT, insulation (e.g., mineral wool), suspended ceiling, and underlayment. T-shaped Glulam beams can also be used together with thinner panels (e.g., 3-ply floor Limnologen). Cassette floors are also feasible when long and clear spans are needed.
- **Roof:** 3 to 5 ply CLT, covering, insulation. It may include Glulam beams or metal joists.

*[4]Exterior walls will typically include a ventilation space plus some type of permeable vapour barrier.*

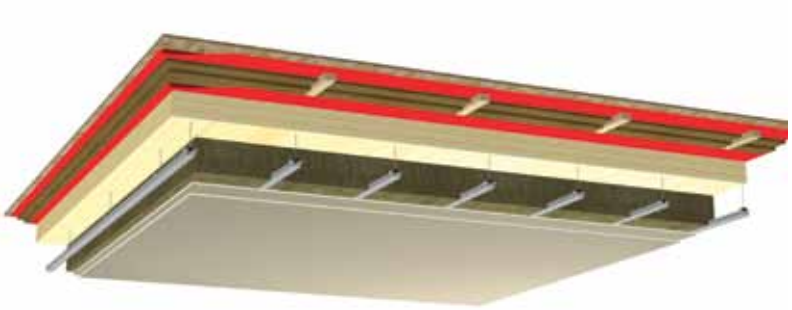


*Wall details from Limnologen (Exterior, separation, partition) [14]*

FPInnovations is conducting research on 'Design Guidelines on Durability for Cross Laminated Timber Construction in North America'.

## Utilities

Electrical, HVAC and water distribution are typically placed in the suspended ceiling space or in cavities above the panels [9,11]. Sound and fire insulation are important factors when deciding how to run distribution lines.

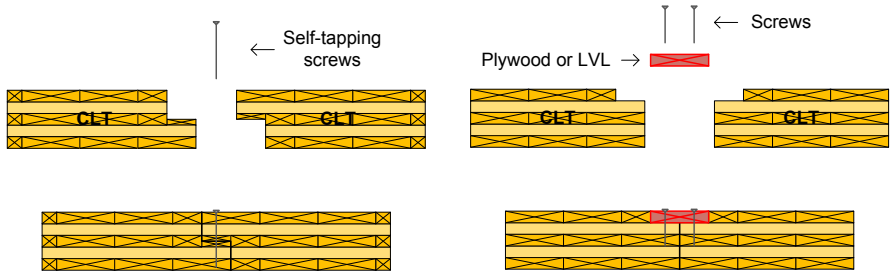


## Connections

Common types of connections in CLT assemblies include:

- Wall to foundation
- Wall to wall (straight)
- Wall to wall (junction)
- Floor to floor
- Wall to floor
- Wall to roof

The basic panel to panel connection can be established through half-lapped, single or double splines made with engineered wood products. Metal brackets, hold-downs and plates are used to transfer forces. Innovative types of connection systems can also be used, including mechanical and carpentry connection systems.



Two major mechanical fasteners are used for connecting CLT panels and assemblies:

- Dowel-type fasteners:
  - Nails
  - Screws (traditional and proprietary self-tapping)
  - Glulam rivets
  - Dowels
  - Bolts
- Bearing-type fasteners:
  - Split rings
  - Shear plates
- Innovative connection systems such as glued-in rods and other types of proprietary connection systems have shown good potential for use in CLT assemblies. The European Yield Model (EYM) design philosophy has been adopted for the design of dowel-type fasteners in CLT.
- The embedment properties of such fasteners in CLT panels however, need to be established as they are directly linked to the density of the wood that goes into the panel, type of fastener, CLT panel lay-up and other panel specific features (e.g., glued or unglued edges).
- Capacity of non-traditional fasteners in CLT can also be established through testing, where design values can be derived following a well-established procedure in Canada, the US and Europe.

FPInnovations is currently researching effective connection systems for wood construction.

# 7 Features

FPInnovations is currently investigating the environmental profile of CLT.

## Environmental Performance

CLT likely has better characteristics than functionally equivalent concrete and steel systems in several aspects of environmental performance.

European marketing literature on CLT often refers to the renewability of wood, recyclability, recoverability, carbon storage, etc.

CLT's cited positive environmental attributes have also been identified as key advantages for CLT in North America [18].

*IVALSA*

A workshop was held in Vancouver, BC in March, 2010 on the fire performance of CLT. The workshop was organized by CWC, BC WoodWorks! and FPInnovations and included a panel comprised of researchers from FPInnovations, Carleton University, NRC, IVALSA and University of Graz.

## Fire Performance

- CLT assemblies can inherently have excellent fire-resistance due to the thick cross-sections which, when exposed to fire, char at a slow and predictable rate.
- CLT construction typically has fewer concealed spaces within wall and floor assemblies which also can reduce the risk of fire spread.
- Charring rate experiments conducted in Switzerland found that the adhesive used in the manufacturing of CLT panels can have a significant impact on the charring rate. This was because the protective char layer that forms and insulates the unburned wood from fire, fell off in layers when some polyurethane adhesives were used. When CLT panels with more traditional adhesives were used, the charring rate was found to be the same as that assumed for solid timber and Glulam members [5].

1. A state-of-the-art paper on fire design of CLT systems will be prepared and peer-reviewed. FPInnovations, CWC and a code consultant will lead this effort in consultation with other code consultants, researchers and designers. The paper will include: research findings and future plans; current code provisions with respect to implementation of CLT systems (code consultants have already undertaken fire design of CLT buildings, and some have indicated that compartmentation may be a viable way to approach the problem); a discussion of using charring rates and the European Design Code approach (FPInnovations staff has already prepared a draft) and developing guiding principles to facilitate alternative solutions; strategy for work to be performed to convert the Alternative Solutions to Acceptable Solutions as defined in the National Building Code; and framework and performance criteria for adopting performance-based fire design with design fires.
2. Code consultants seem to be comfortable using CLT under the 'combustible construction' category, but they recommended that CLT heavy timber construction should be differentiated from light weight 'combustible construction' for use in applications in non-combustible categories.

Watch video at http://progettosofie.ruby-lang.eu/en/research/fire-performance

- The issues of edge-glue vs. face-glue, performance of adhesives in high temperatures, strategies for repair and re-use after the fire, connections, effect of active protection systems (e.g., sprinklers), fire design of exposed CLT in ceilings, quantification of fire loads, use of fire retardant laminations or sheet metal in exterior wall applications have been raised.
- Demonstration tests by IVALSA on a 3-storey CLT building: Fire room was protected by gypsum board, and room contents (and later the CLT wall panels) burned for 1 hour without fire spread to adjacent rooms or floors [6].
- Due to the differences in building codes between Europe and North America, CLT buildings will most likely be sprinklered in Canada.

## Acoustical Performance

It is possible to exceed code requirements for floors and walls. The acoustical performance of CLT has been rated as:

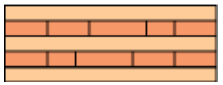
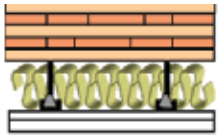
- Sound class B and A in Europe
- Exterior walls: RW[5] = 47 to 52 dB (85 mm panel + 150 mm insulation) (min. 43)[6]
- Partition walls: Rw = 65 to 75 dB (min. 50)
- Ceilings: up to Lnw = 40 dB (max. 53)

Units conversion: STC~Rw; IIC~ 110-Lnw

- **Flanking**

Flanking can be an issue, so some corrective measures have to be taken. The first measure is having a self-supported suspended ceiling. Flanking insulation in floor-to-wall connections consists of metal bars, insulated screws and polyurethane sealant damping strips (e.g., Sylomer®, Limnologen) or laminated natural rubber. Having discontinuous walls across stories and discontinuous floors across units helps prevent flanking. Floating floors also help.

FPInnovations is collaborating with FCBA (France) in the development of acoustical design procedures for CLT. These are selected results, applicable to North America:

| Floor Type | Floor Composition | Airborne (STC) dB | Impact (IIC) dB |
|---|---|---|---|
|  | 5-ply CLT 146 mm | 38 | 26 |
|  | 5-ply CLT + suspended ceiling + fibre glass insulation 200 mm+2 gypsum boards 2 x 15mm | 63 | 62 |

*The second configuration provided ratings exceeding code requirements. These values are adequate for multi-family buildings.*

[5] *Units: Europe: Rw: Weighted sound reduction index, Ln,w: Weighted normalized impact sound pressure Canada: STC: Airbone sound transmission class; IIC: Impact sound insulation class*

[6] *Benchmark from [8] (Adjusted to Europe via personal communication)*

FPInnovations in collaboration with Sintef Byggforsk developed a design method to determine vibration controlled spans for CLT floors that accurately predicts the vibration performance of CLT floors.

FPInnovations conducted a 'Preliminary Assessment of Hygrothermal Performance of Cross Laminated Timber Wall Assemblies using hygIRC and WUFI'.

## Vibrations

- The low damping ratio (about 1% critical damping ratio) is one of the weaknesses of CLT floors.
- Damping to a large extent is affected by the degree of integration of the floor to the surrounding structural parts, especially by the addition of partitions [14].
- Any measures for increasing the damping ratio through CLT product design and CLT floor construction details will make CLT floor systems more cost-effective and better positioned to compete with concrete slabs.
- Elevators can be detailed in such a way that their operation does not create perceptible vibrations.

## Thermal Performance

- European sources often suggest that CLT provides thermal mass for a building, which can be associated with heating and cooling energy reductions [17].
- CLT has the same fundamental thermal properties as the wood from which it is made. In terms of heat capacity and thermal resistance wood is average among building materials. Values for CLT are improved simply through the virtue of its thickness.
- Good air tightness may be achieved. Foam tape is normally used at the joints for this purpose. Edge-gluing of the boards also helps.

FPInnovations is working on 'Design Guidelines on Durability for Cross-laminated Timber Construction in North America'.

*IVALSA*

Watch the video at: http://wwwbinderholzbausysteme.com/fileadmin/user_upload/videos/kobe100-3-Dexp.mpg

## Durability

◀ See in box left.

## Seismic Performance

- Three-and 7-storey full-scale CLT buildings were tested by IVALSA (Trees and Timber Research Institute of Italy) in Japan on the largest shaking table in the world. The buildings performed remarkably well even when subjected to severe earthquake motion like that of the devastating Kobe earthquake (magnitude of 7.2 and accelerations of 0.8 to 1.2 g).
- In the case of the 7-storey building there was no residual deformation at the end of the test. The maximum inter-storey drift was 40 mm (1.3%), while the maximum lateral deformation at the top of the building was only 287 mm[7] [13].
- The CLT buildings showed ductile behaviour and good energy dissipation. Such behaviour was mainly influenced by the mechanical connections used.

FPInnovations is collaborating with IVALSA in the development of seismic design procedures and parameters for CLT construction. FPInnovations is developing Rd and Ro factors.

[7] *Ario Cecotti, personal communication*

# 8 CLT as a Building System

- **Versatile**: CLT's versatility as a building system is a feature that architects and engineers may find appealing. CLT's versatility comes from the fact that panels can be used for all assemblies just by varying the thickness. Furthermore, long spans are possible to achieve:
  - Spans up to 7.5 m with no beams or columns (e.g., 230 mm 7-ply floor)
  - Cassette' floors allow longer spans (e.g., 2x3-ply CLT slabs with Glulam beams in the middle). Cassette is also suitable for cantilever applications [1].
  - The span can go up to 20 m if "folded" structural CLT systems are used.
  - Longer spans require Glulam columns or beams and trusses.
  - Floors can be put directly on columns without carrying beams because of the effective potential of spreading point-loads [3].
- **Feasibility for high-rise construction:** There is ongoing work in Europe aimed at targeting high-rise construction:
  - TRADA worked out a 12-storey building example (36 m)
  - IVALSA designed a 15-storey CLT/steel building
  - Waugh Thistleton simulated a 25-storey CLT/concrete building.

*Courtesy of KLH*

# 9 Construction Features

CLT has all the advantages of prefabricated buildings plus some distinctive features given its massive nature and structural makeup.

- **Rapid construction time:** Fast construction is probably one of the main attributes of CLT. Outputs from 1,000 to 8,000 SF/day can be achieved with small crews and little equipment. Crews of 2, 4, or 8 carpenters plus one or two mobile crane operators are typically employed in Europe. Some advantages include lower capital cost, faster project turnaround and potential insurance benefits due to fast and safe erection. Being wood-based follow-on contractors come in quicker and finish faster.

- **Precise:** European marketing literature and research done on existing buildings suggest that CLT features high dimensional stability:

    - Perpendicular: 1 to 2 mm tolerance for the panels (0.2 mm/m per percent of wood's equilibrium moisture content (10 to14% equilibrium moisture for 35 to 65% relative humidity),
    - Parallel: negligible change.

  This stability plus the use of CNC routers allows pre-installed windows and/or cladding. Pre-installed piping, electrical, insulation and HVAC are also possible. These installations can be placed in the cavity between the plasterboard and the CLT panels.

- **Safe:** As most work occurs off-site at the factory.

- **Less demanding of skilled construction labour:** The erection of the structure mostly requires carpentry skills and power tools.

- **Less waste:** Wet trades are eliminated. Little waste is produced.

- **Less disruption to neighbours:** It is a quick and quiet process, and takes up less space, making it suitable for infill sites and/or additions.

# 10 Construction Process

## Logistics

- Assemblies are divided into ‘elements’. These elements are numbered and shipped according to an assembly plan.
- A crane, light power tools and a small crew are needed to build the structure. Panels are lifted using inserted hooks.
- Walls are placed on top of a grout bedding (lumber board) and foam tape.
- Some walls are temporarily held together until the ceiling is installed, then the walls are secured and the construction moves on.
- In Europe it is customary to have vertically integrated companies that manufacture CLT and build or supervise building. Other manufacturers just deliver the panels to the construction site.

## Weather Protection

- Wall elements may be protected with vapour barriers.
- Optionally, a tent can be used to provide a dry and comfortable construction environment. This can increase output dramatically (efficiency, 2 shifts). The tent moves up with the building.
- Simpler protection systems consist of scaffolding and wrapping around the building.
- Long-term weather exposure is not desirable. Wetting at any time should try to be avoided and CLT should be used at a safe distance above ground level [17].
- Separate cladding has to be provided for exterior walls, normally including a ventilation space.

*Photo Credit FPinnovations*

*Courtesy of KLH*

## Transport

- Wall elements are covered by a tarp and transported (typically on edge) in open trucks. Panels can be delivered with a waxed surface or wrapped in plastic film.
- Floor elements are transported stacked, covered by a tarp.
- Unloading is done with a forklift.

## Crane

- Only mobile cranes are used, not tower cranes.
- The size and number of cranes will depend on the project and whether panels or preassembled 'elements' will be lifted. For instance, Limnologen used a 3.3 ton overhead crane (2 ton elements), integrated with the optional tent (see case study page 15).

*Transport of wall and floor elements at Limnologen [14]*

# 11 Building Performance

- Stability is gained out of the diaphragm action of the wall to floor connections.
- Cross lamination provides dimensional stability and static strength in all directions.
- Settlement effects are negligible (e.g., 20 mm for 7-storey Limnologen building after 1 year).
- High axial load capacity for walls due to large bearing area.
- High shear strength against horizontal loads.
- High buckling capacity.

## Customer Satisfaction

Surveys and anecdotal experience indicate high satisfaction from both occupants of CLT buildings and those involved in the design and construction process:

- Limnologen: Occupants extremely satisfied.
- Murray Grove: Most pleasant construction environment[8].

[8] *Andrew Waugh, personal communication*

# 12 Case Studies

*Courtesy of Will Pryce*

## MURRAY GROVE

| | |
|---|---|
| **Building Type** | Residential: 1+8 stories |
| **Location/Year** | London, England/2008 |
| **Cost** | £3M (£133/ft$^2$) |
| **Floor Area** | 25,307 ft$^2$ (2,352 m$^2$) (floors 2 to 8) |
| **Volume CLT** | 950 m$^3$ (Walls: 128 mm, Floors: 146 mm) |
| **Yield Factor**[9] | 1.33 ft$^3$/ft$^2$ |
| **Shell Construction Time** | 3 days per floor (873ft$^2$/day) [crew: 4 carpenters (KLH)] |
| **Lessons** | CLT choice saved 22 weeks vs. concrete (30%)<br><br>Basement was avoided since there was no need for heating system. No tower crane was used. |

[9] *Yield factor: ft$^3$ of CLT per square foot of floor area.*

http://www.woodworks.org/files/PDF/Presentations/Raleigh_2009Waugh.pdf

# LIMNOLOGEN

| | |
|---|---|
| **Building Type** | Residential: 1+7 stories (last as duplex) |
| **Location/Year** | (4 buildings) Växjö, Sweden/2008 |
| **Cost** | 320M SEK ($53M)  255 - 330 $/ft$^2$ |
| **Floor Area** | 115,000 ft$^2$ (10,700 m$^2$) |
| **Volume CLT** | 4,800 m$^3$ (169,000 ft$^3$) |
| **Yield Factor** | 1.47 ft$^3$/ft$^2$ |
| **Shell Construction Time** | 4 days per floor (1,027 SF/day) (not including tent adjustments) |
| **Lessons** | Tension rods (48/building) were chosen to resist wind lift-up. Load-transferring connectors between walls were not needed.<br><br>Floor heating system is cumbersome Construction speed highly dependent on crew's experience. |

http://www.cbbt.se/website3/1.0.3.0/4/Limnologen_rapport_1_Eng.pdf


*Courtesy of Kier Contractors*

# NORWICH OPEN ACADEMY

| | |
|---|---|
| **Building Type** | Educational: 3 stories |
| **Location/Year** | UK/Autumn 2010 |
| **Cost** | £21M ($29M)  ($284 /ft$^2$) |
| **Floor Area** | 102,000 ft$^2$ (9,500 m$^2$) |
| **Volume CLT** | 3,600 m$^3$  (127,000 ft$^3$) |
| **Yield Factor** | 1.25 ft$^3$/ft$^2$ |
| **Shell Construction Time** | 18 weeks, crew of 8, 2 cranes<br>70 truckloads, 1055 to 7800 SF/day |
| **Lessons** | Avoid too many pre-cut openings. Use bigger generic openings and leave it to the M&E contractor to figure it out on site. |

Watch construction video at: http://www.open-academy.org.uk/content/AcademyBuild.shtml

*Courtesy of Erlend Nybakk*

# I.S.C. NORSK SALSENTER

| | |
|---|---|
| Building Type | Equestrian Center |
| Location/Year | Norway/February 2010 |
| Cost | "Competitive" |
| Floor Area | 16,000 $ft^2$ (1,500 $m^2$) |
| Volume CLT | 225 $m^3$ (7,940 $ft^3$) |
| Yield Factor | 0.49 $ft^3/ft^2$ |
| Shell Construction Time | 5 days, crew of 2, 1 crane, 2 trucks/day, 3228 $ft^2$/day |
| Lessons | Box-type warehouses are an ideal application for CLT: fast and simple to erect, economical. Profitable for CLT manufacturer. |

http://www.saltilpasseren.no/

PART Two

# THE VALUE PROPOSITION FOR NORTH AMERICA

Part 2 presents an assessment of the potential market and cost analysis for CLT in North America, with an emphasis on the US. CLT represents a large market opportunity.

## 1 Markets & Economics

Cost competitiveness by building type was assessed using a representative sample (75%) of the non-residential and multi-family market in terms of building types, average storey classes and floor areas. A reliable online tool was used to cost each assembly and building allowing for a side by-side-comparison of shell (walls, floors, roof and partitions) unit costs between CLT and the usual materials (the target was set as average US, Q3-2009). The configurations used were deemed realistic for each type and included materials, labour, connections, erection and insulation. Further, a 15% adjustment factor was applied to CLT shell cost to account for unknown or secondary factors. Savings in construction time and foundation costs were not included at this time.

### Cost Competitiveness

CLT is a suitable substitute building system for certain concrete, masonry and steel building types, with an overall weighted saving of 25% in shell costs (Table 1).

**Table 1**

Cost competitiveness by building type

| Building Type | Shell cost savings (Million $) | Floor Area (Million ft²) | Number of starts |
|---|---|---|---|
| Mid-rise residential | 15% | 63 | 773 |
| Mid-rise non-residential | 15 to 50% | 214 | 831 |
| Low-rise educational | 15 to 50% | 263 | 2,801 |
| Low-rise commercial | 25% | 495 | 12,027 |
| 1-storey industrial* | 10% | 284 | 4,256 |

***Note**: *Box-type warehouses and manufacturing plants represent a large market opportunity. This building type is also less challenging for both the builder and the CLT manufacturer, allowing better profit margins (see case study).*

## Manufacturing Costs

Simulations yield a variable cost of approximately $17-20 per cubic foot (for a lumber cost of $300/mbf). In CLT manufacturing, lumber accounts for over 50% of the variable costs. The market opportunity assessment used this cost for CLT, marked up by 25%. Similarly, simulations for eastern Canada using MSR S4S redried lumber yielded a variable cost of $17 per cubic foot and a total cost of $20 per cubic foot at the plant.

## Manufacturer's Capital Investment (Europe)

- Small operation: $5 to 6M (4,000 $m^3$/year, 1 line)
- Large operation: $20 to 30M (70,000 $m^3$/year, 2 lines)

## Market Analysis

Table 2 shows the total annual US market. CLT is cost competitive in 66% of the non-residential market, the most competitive being the mid-rise segment at nearly 75%.

## Market Size

In order to quantify the market opportunity, a cost competitiveness factor[10] was assigned to each building type by storey class (low- and mid-rise).

## Market Opportunity for CLT

For 5% and 15% market penetration scenarios, the potential demand for lumber comes to 0.8 to 2.5 billion board feet. Under the same scenarios CLT demand would range from 40 to 130 million $ft^3$ or 1 to 3 million $m^3$ approximately. The estimated value of shell construction is 1.5 to 4.5 billion dollars (Table 2).

**Table 2**

Market Size (Adapted from McGraw-Hill, US 2008)[11]

| | Total | | Competitive CLT | |
|---|---|---|---|---|
| **Storey class** | **Floor area (Million $ft^2$)** | **Floor area (Million $m^2$)** | **Floor area (Million $ft^2$)** | **Floor area (Million $m^2$)** |
| Low-rise (1-4) | 1,633 | 152 | 1,040 | 97 |
| Mid-rise (5-10) | 432 | 40 | 317 | 29 |
| Total | 2,065 | 192 | 1,357 | 126 |

*[10] It is a function of cost competitiveness (shell cost of CLT vs. other materials) and current market share of wood. It works as a modifier (%) to the market size (e.g., opportunity) by building type and storey class.*

*[11] McGraw-Hill square feet data was grossed up by 25% to adjust for sampling issues.*

**Table 3**

Market Opportunity by Scenario (Adapted from McGraw-Hill, US 2008)

| | Floor area (Million ft²) | | CLT (Million m³) | | Lumber (BBF) | | Shell Value ($ Billion) | |
|---|---|---|---|---|---|---|---|---|
| **Storey class** | **5%** | **15%** | **5%** | **15%** | **5%** | **15%** | **5%** | **15%** |
| Low-rise (1 to 4) | 52 | 156 | 0.9 | 2.7 | 0.6 | 1.8 | 1.1 | 3.3 |
| Mid-rise (5 to 10) | 16 | 48 | 0.3 | 0.9 | 0.2 | 0.6 | 0.4 | 1.2 |
| Total | 68 | 204 | 1.2 | 3.6 | 0.8 | 2.4 | 1.5 | 4.5 |

Note: *The Canadian market can be estimated at 5 to 10% of the US market on a floor area basis.*

The short-term opportunity is limited by code limitations and it will depend on the number of early adopters willing to sign off [18]. Besides direct savings, carbon storage may be a driver for adoption and market penetration.

## Other Applications

- Elevator shafts and stairwells: 0.2 to 0.4 BBF
- Balconies and stairs: N/A
- Additions: Low weight, flexibility of design and easy construction make prefabricated systems well suited for additions. Additions represent 15 to 20% of the value of construction ($43 billion in 2008)[10]
- Parkades (e.g., Skellefteå, Sweden[12]) [16]

## Building Code Issues

Current limitations to wood construction are a major obstacle for CLT in North America. Limitations to storey height and floor areas will have to be revisited in light of the properties of CLT as a building system. Therefore, changes to the building codes and the development of proper standards and design values will be crucial to allow market penetration.

[12] *4 stories, 141 stalls, 127 mm CLT floor.*

FPInnovations developed a code standards roadmap for CLT. It provides strategies for acceptance of CLT under 'alternative solutions' for early adopters and also strategies for adoption in the building codes as an 'acceptable solution' for general practitioners.

# 2 Research Initiatives

Research on cross laminated timber has reached a critical mass. These are some of the most important players to date:

- FPInnovations (14 studies under way, plus a CLT handbook)
- Europe (Scandinavia, Switzerland, Austria, Germany)
- Italy (IVALSA)
- Canadian Universities (4)

# 3 Industry Associations and Government Initiatives

The following organizations are playing an important role:

- BC Government 'Wood First' Initiative
- Québec: QMNR & CECOBOIS
- CLT Steering Committee (Strategy for US/Canada)
- Natural Resources Canada (e.g., Demonstration projects)
- Wood Works US and Canada (e.g., Murray Grove showcase)
- APA (development of ANSI Standard)

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