REPORT

FCLT PROJECT | COMBINATION WITH OTHER MATERIALS

5.3.2016

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Insulation and its attachment to CLT

In terms of thermal insulation efficiency of CLT, the natural thermal resistance of wood adds value to CLT assemblies. Precise manufacturing and dimensional stability permits tight tolerances with better energy efficiency and improved insulation of windows, doors and cladding. Furthermore, boards within the CLT wall can be edge-glued to improve thermal efficiency by reducing potential air flow through the wall system. Dimensional stability will also ensure air tightness over time due to reduced potential shrinkage of CLT. (Mohammad, Gagnon, Douglas, Podesto. 10)

For thermal insulation technical aspects a specific thermal conductivity $\lambda = 0.13$ W/(m · K) can be assumed for the uninsulated element. Cross laminated timber elements can be combined on the exterior, free of a thermal bridge, with the most variable insulation materials (wood, mineral fibre insulation materials, thermal insulation bonded systems or rear ventilated facades). Additional interior, insulated installation planes lead to further improvements of the insulation standard. Elements constructed to the passive house standard are not uncommon.

As a result of the specific thermal capacity of wood, the cross laminated timber construction method in space limited areas offers a clear advantage in comparison to the light building constructions. With comparable U-values a, close to, three-fold thermal mass is achieved which leads to a greater phase displacement and amplitude suppression and therefore simultaneously increasing the comfort especially in the summer months. (Mestek, Werther, Winter 2010)

When choosing a suitable exterior insulation material, the common construction practice of building with CLT panels in Europe has been to insulate the panels with wood fibreboard or rigid mineral fibreboard insulation. These products currently have limited availability in some areas of North America, but have ideal properties for CLT construction. (CLT handbook 2011)

Rigid mineral fibre or wood fibre boards are preferred products because they may be rigid enough to allow for furring or cladding supports or be structurally fastened directly through the insulation without the need for additional framing on the exterior. Long screws are available and can be used to attach furring directly through to the CLT panels to support the cladding, if this meets the structural requirements of the cladding attachment. Otherwise, additional support for the insulation should be provided at each floor level. (CLT handbook 2011)

Extruded polystyrene (XPS) or expanded polystyrene (EPS) may also be sufficiently rigid to screw furring (strapping) through; however, the vapour permeability of these foam plastic insulations is relatively low, which reduces the drying capacity of the CLT panel and may trap moisture within the wood panels. Modelling has shown that drying through 3 to 5 in. of either EPS or XPS on the exterior side of a CLT assembly is slow, and can lead to damage to CLT panels that are initially wet, wetted during construction, or exposed to humid indoor conditions or a rainwater leak during service. The use of foam plastic insulation products is not ideal for insulating CLT wall assemblies, particularly for a heating-dominated climate, because of their low permeability and the consequently reduced drying capacity. (CLT handbook 2011)

Less rigid, but vapour-permeable insulation materials including semi-rigid fibreglass or mineral wool boards commonly available in North America, are also suitable for exterior insulating CLT panels, but require additional framing on the exterior of the panels for cladding attachment. Because furring to support the cladding cannot be nailed through these less-dense insulation boards, 2x4 or 2x6 studs or intermittent wood blocks need to be attached or framed to the exterior of the CLT panels for cladding support. Semi-rigid insulation boards would then be placed tightly between the wood framing. (CLT handbook 2011)

The following section shows and describes some of the external wall cladding examples. Principles of functional layer of CLT walling assemblies are described as well.

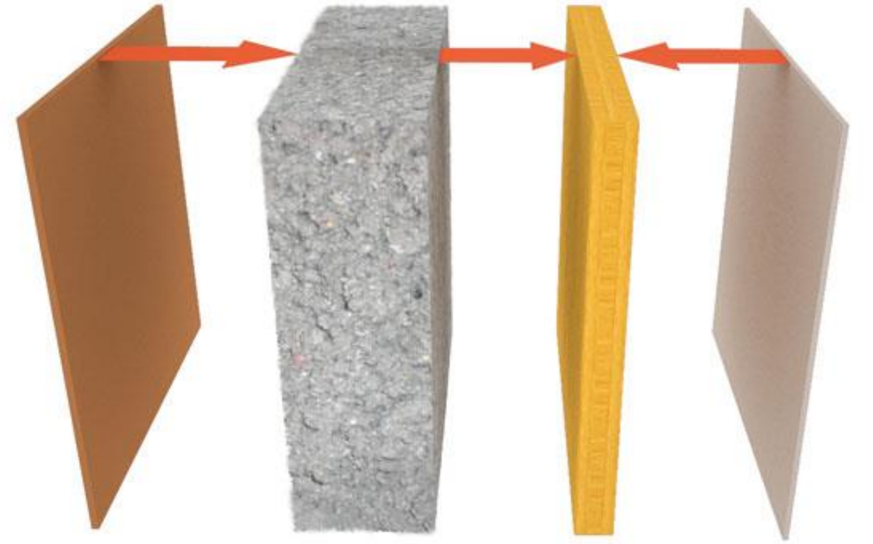

Figure 1. CLT walling assembly. (Adapted from Greenspec)

The preferred location of insulation in the build-up of a wall section is on the outside of the CLT panel. There are several reasons why external insulation is preferred over internal insulation, the main ones are:

1. External insulation allows the insulation layer to be continuous around the structure, whereas internal insulation would be discontinuous where floors or interior walls intersect the external walls or roof. Continuity of insulation is important for reducing thermal bridging and improving energy performance.

2. External insulation provides a high level of decrement delay that protects the CLT structure and the air barrier system from temperature extremes. Apart from easing interior temperature management, the lack of extremes reduces expansion and contraction.

3. External insulation preserves the thermal mass capacity of the panels exposed to internal thermal conditions.

(Greenspec)

The following figures show some of the possible CLT wall assemblies as well as their U values. U value is the overall heat transfer coefficient that describes how well a building element conducts heat or the rate of transfer of heat through one square metre of a structure divided by the difference in temperature across the structure.

In other words, it is the measure of how easily heat flows through a specific type of material, independent of the thickess of the material in question. The lower the thermal conductivity of a material, the better the thermal performance. (The Green Age)

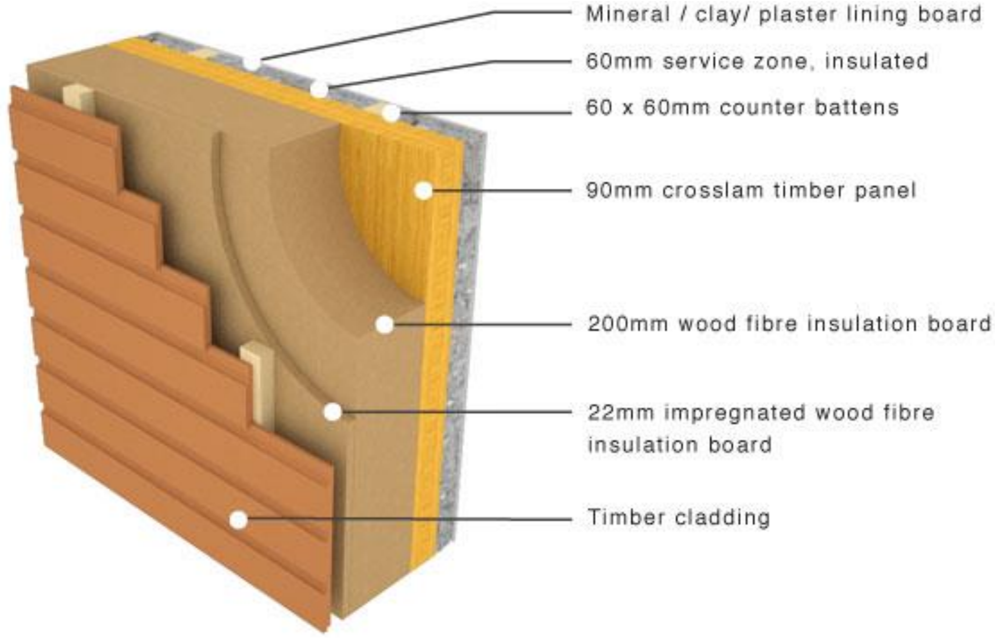

Figure 2. Panel with rigid insulation and timber cladding. U value is approximately 0.13. (Adapted from Greenspec)

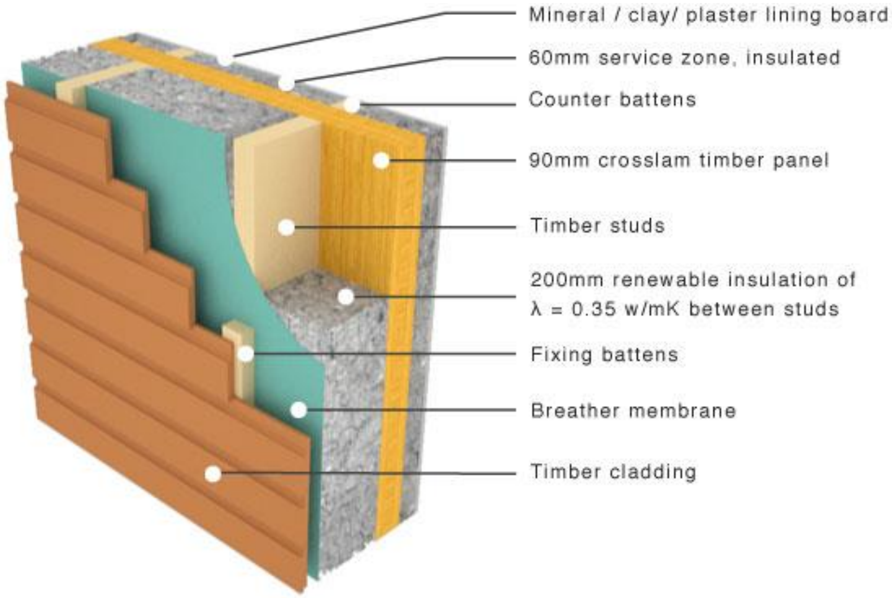

Figure 3. Panel with flexible insulation and timber cladding. U value is approximately 0.14. (Adapted from Greenspec)

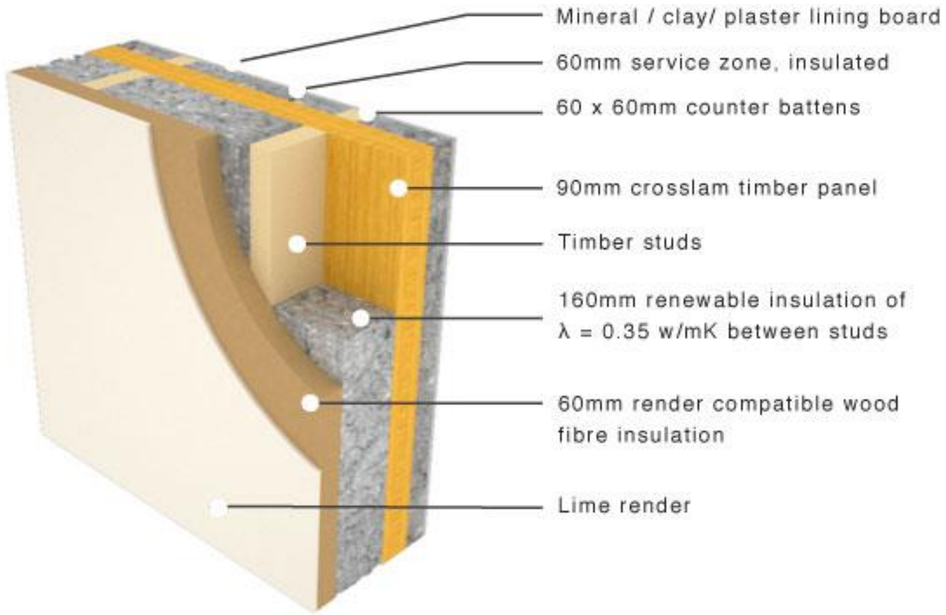

Figure 4. Panel with flexible insulation and lime render. U value is approximately 0.13. (Adapted from Greenspec)

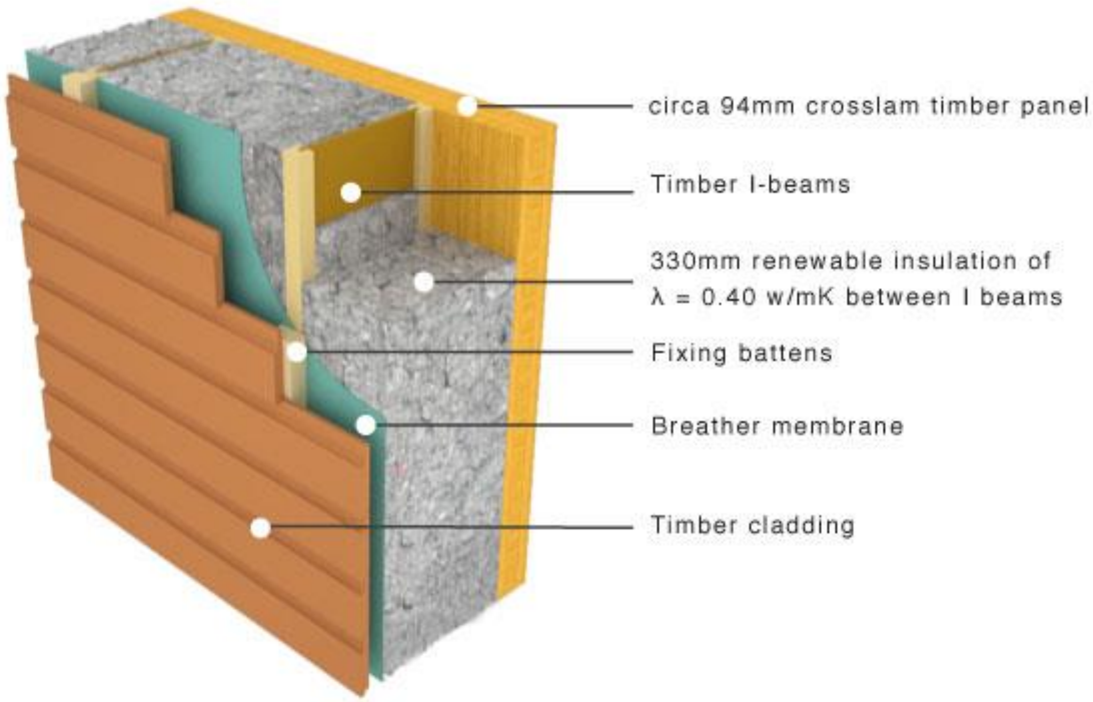

Figure 5. Panel with exposed inner face and flexible insulation. U value is approximately 0.13. (Adapted from Greenspec)

Another aspect that needs to be taken into consideration when designing or selecting the proper insulation is heat flow control. Heat flow control is achieved using insulation to minimize space heat loss or gain through the building enclosure. Air leakage control is also a key element of heat flow control. (CLT Handbook 2011)

Unlike stick-built wood-frame wall assemblies, where fibreglass batt insulation is traditionally placed between the studs, CLT panels are solid and therefore require insulation, placed appropriately, on one side of the panel. (CLT Handbook 2011)

The placement of the insulation may significantly affect the moisture levels and durability of the wood panel in service. In all climate zones, most types of insulation should be placed on the exterior side of the CLT panels. This will keep the wood in a relatively constant warm and dry indoor environment and recue the risk of moisture damage. The use of vapour permeable insulation materials such as mineral or wood fibreboards are recommended instead of less vapour permeable foam plastics. Where wood fibre insulation boards are used outside the weather resistant barrier, the wood should be treated to minimize water uptake and possible fungal growth, and wall penetrations properly detailed to prevent wetting of the insulation. (CLT Handbook 2011)

CLT panels themselves may offer aesthetic benefits and may be left exposed on the interior side to showcase the solid wood finish if the fire safety and acoustic requirements allow. This is another reason why thermal insulation should be placed on the exterior side of the panel. When used in certain building types, some jurisdictions may require that the interior exposed wood surface be covered with gypsum drywall or other non-combustible finish to meet fire safety requirements. In this scenario, it might be seen as desirable to place insulation on the interior side of the panel; however, this wall assembly is not recommended as the CLT panel will be more vulnerable to wetting caused by vapour diffusion from the interior or wetting from rainwater or solar driven moisture from the exterior. (CLT Handbook 2011)

Combination of CLT with other materials & connections

CLT elements can also be combined with other building materials, enabling flexibility in design, style and finish architecture. When field modifications are needed, one of the advantages of CLT over materials such as precast concrete is that changes can be made on site with simple tools, pending approval by the engineer of record. (Evans 2)

In many cases, CLT has been used in combination with other wood based products such as glulam or with other construction materials such as concrete or steel to form hybrid building systems. (Mohammad et al. 12)

The traditional way in designing floor system of tall buildings is to apply composite action between reinforced concrete slab and steel frame that supports it (Fig. 6a)

For non-traditional floor system with ultra-lightweight materials such as CLT, connections between the slab and steel frame is important to achieve intended rigidity or flexibility of the diaphragm (Fig. 6b). Partial composite action is normally considered in the design due to flexible mechanical connectors that leads to slip between the slab and steel frame. CLT thickness ranging from 150 to 300mm can be designed for this type of floor system. (Asiz & Ahmed 2013)

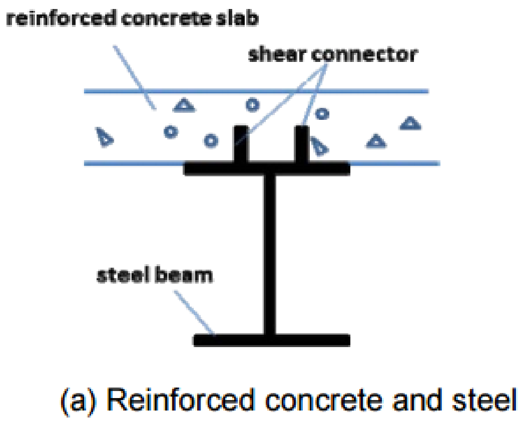

Figure 6. Connections between slab and steel frame. (Adapted from Asiz & Ahmed 2013)

CLT is combined with other materials especially in higher building application, where it is utilized in combination with other common structural materials such as concrete and steel (Asiz & Ahmed 2013 [Gagnon and Pirvu, 2011]). Using case studies of multi-storey building with steel main skeletons, it was shown that the demand for the steel materials of the buildings are much reduced using CLT slab relative to RC slab without sacrificing the important structural performance such as lateral deflection (drift) due to external lateral loads. Also, the reaction loads imposed to the structural supports are significantly reduced due to much lighter CLT slab used without compromising its strength. (Asiz & Ahmed 2013)

Some factors to take into consideration when combining CLT with other materials:

- Particularly in large buildings, a combination of CLT with other derived timber materials, steel and concrete is essential to bridge the required large spans and to transfer the generally high loads into the ground.
- Layer structures must be adapted to the structural-physical requirements resulting from the different intended uses of the building.
- The proper dimensioning of the connectors is very important as connectors play an essential role in civil engineering structural analysis.

(Stora Enso Wood Products 2015)

As for details regarding connections in mixed hybrid CLT construction. Mixed systems using CLT with other types of wood-based materials such as glued-laminated timber (glulam) are common. Those mixed systems are becoming increasingly popular in Europe as a way to optimize the overall design by capitalizing on the positive attributes of the various products. Mixing CLT with other types of construction materials such as concrete and masonry or mixing different types of structural forms is also common. (CLT Handbook 2011)

In CLT assemblies, mixing different wood-based materials and structural systems is done in such a way to optimize the design and to meet certain performance requirements. Therefore, it is not unusual to combine CLT wall assemblies with joisted floor systems using glulam, wood I-joists, metal plated wood trusses or other types of engineered wood elements as the main floor support system, with either wood-based decking such as wood boards, or structural panels.

Important part of combining CLT with other materials is connections. When it comes to structural design, in general there are a number of simple details that can be used to establish roof/wall, wall/floor, and inter-story connections in CLT assemblies, to connect CLT panels to other wood-based elements, or to connect CLT panels to concrete or steel for a hybrid assembly. The type of hardware depends on the assemblies to be connected, on the panel configuration, and on the type of structural system used in the building. Some of the more common lateral load transfer connectors include metal 'L' brackets for shear or traditional strap hold-downs used for overturning. (Evans 7)

Proprietary self-tapping screws or a variety of commodity nails can be used to connect panels in plane or at intersections. Ease of installation along with high lateral and withdrawal capacity make self-tapping screws especially popular because they can take combined axial and lateral loads. (Evans 7)

CNC technology is also driving the development of new and innovative fastening systems. For example, glued-in rods can be used for connections under high longitudinal and transverse loads, and epoxied shear connectors can be used to create composite floors with structural concrete over CLT. (Evans 7)

Some other factors that are important when designing CLT connections are that firstly, they should adhere to the particular specifications and rules that apply in the area where the CLT structure will be constructed, just like other wood connections. (WoodWorks 2012)

As for recommended CLT connections, self-tapping screws will likely be the most common connector used in CLT construction. These are proprietary connectors and design values and requirements would be specified by the manufacturer. The manufacturer will be responsible for providing lateral and withdrawal connection values. (WoodWorks 2012)

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, 2010)

There are some performance demands for CLT connections, and those are:

● Easy to design
● Structurally efficient
● Fire resistant
● Aesthetically attractive
● Good serviceability (e.g., shrinkage, stiffness, acoustic)
● Cost-effective & availability
● Easy to assemble (i.e., do not require specialized tools or heavy equipment)

Performance Demands in Timber Connections Competitiveness of a timber structure, relative to other building materials, may be determined by the efficiency of the connections, particularly for CLT assemblies. (Mohammad 2011)

The following bullet points outline why specifically the connections in CLT are important:

● Maintain structural integrity
● Provide ductility for lateral load design (e.g., seismic & wind)
● Affect the serviceability design (vibration, acoustics, etc.)
● May affect the fire safety design
● Interior and exterior finishing & building envelope
● Could control the level of prefabrication at the mill
● Facilitate a quick assembly and disassembly (i.e., cost-competitiveness)

As far as Europe goes, the common practices in CLT connections are:

● Carpentry Using CNC technology to create various types of interlocking profiles (Dovetail connections) (Source: G. Traetta)
● Traditional Fasteners Bearing or dowel type fasteners, i.e., nails, wood screws, lag screws & bolts, in combination with metal plates, brackets and ties.

● Innovative/Proprietary Self-tapping/drilling screws & dowels, glued in rods, bearing-type systems, metal hooks, etc.

As for self-tapping screws, they are used extensively in Europe. That is mostly because they are easy to install and provide high lateral and withdrawal capacity. Another advantage is their variety – they come in variety of sizes and features, in different diameters and lengths. Unlike traditional lag screws, they do not require predrilling. (Mohammad 2011)

Traditional fasteners in CLT are nails and rivets. They are not as commonly used as self-tapping screws in CLT. When they are used, nails with specific shank features such as grooved or helically threaded nails are the most commonly used. They are typically used in combination with metal plates and brackets. (Mohammad 2011)

One of the most common connection of CLT to other materials is wall to concrete foundation. CLT wall to concrete wall or foundation slab using metal brackets or plates with anchor bolts & self-tapping screws or lag bolts.

In connecting CLT wall panels to concrete foundations (common for the first storey in a CLT building, with concrete footing or with multi-storey CLT building with the first storey made of concrete) or to steel beams, several fastening systems are available to establish such a connection. Exterior metal plates and brackets are commonly used in such applications as there is a variety of such metal hardware readily available on the market. Exposed steel plates are probably the most commonly used in Europe due to their simplicity in terms of installation. When connections are established from outside, then a typical metal plate is used. However, when access is provided from inside the building and where a concrete slab exists, concealed/internal metal brackets are used. Lag screws or powder-actuated fasteners can be used to connect the metal plate to the concrete footing/slab, while lag screws or self-drilling screws are used to connect the plate to the CLT panel. (CLT Handbook 2011)

Typically, metal plates or brackets are placed at a 1219mm interval. But that all depends on the level of load the connection is supposed to resist and its ductility. Different types of metal plates or brackets can be used, depending on whether the CLT panel is attached to a concrete wall/footing or a slab and whether the plate is attached from the outside or the inside of the wall panel. (CLT Handbook 2011)

To protect wood and improve the durability of CLT panels, a SCL sill plate [or bottom plate] is installed between the concrete foundation and the CLT panels. This also simplifies assembly. (CLT Handbook 2011)

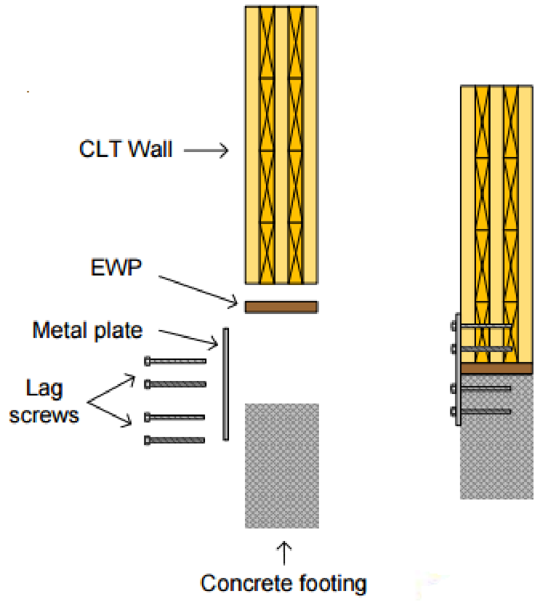

Figure 7. Wall to concrete connection using metal plate and lag screws. (Adapted from Mohammad 2011)

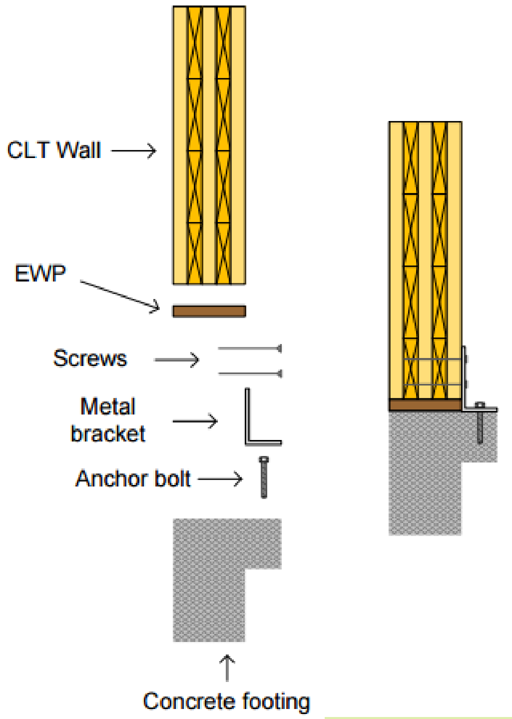

Figure 8. Wall to concrete connection using exterior metal bracket and anchor bolt and screws. (Adapted from Mohammad 2011)

Another method of connection CLT wall to foundation is using internal (concealed) metal brackets and internal metal plates. The use of threaded rod and anchor bolt is possible as well.

To achieve better fire performance and improve aesthetics, designers prefer to conceal connection systems. Hidden metal plates similar to those shown in Figure 9 can be used, but they require some machining to produce the grooves in the CLT panel to conceal the metal plates. Tight dowels or bolts could be used to attach the plates of the CLT panel. However, precise CNC machining is required in some cases. Some innovative types of fasteners that can be drilled through metal and wood or other types of screws that can penetrate through both materials can also be used for this purpose.

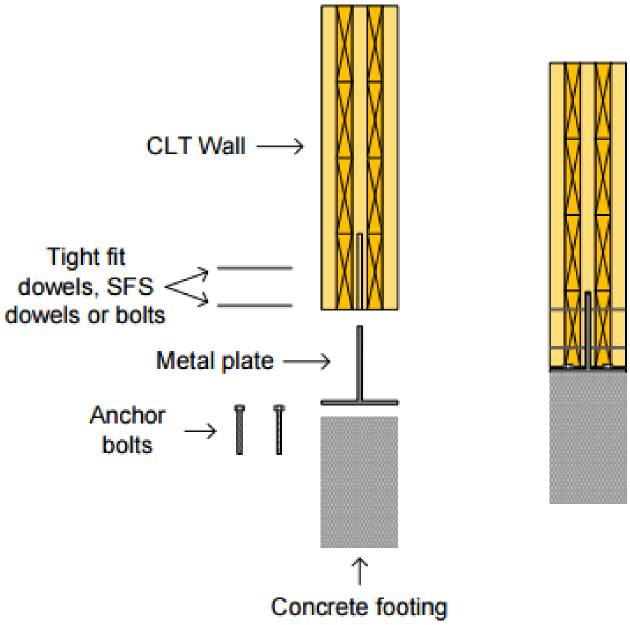

Figure 9. Internal/concealed metal plates wall to foundation connection. (Adapted from Mohammad 2011)

Lie the metal shaft connection system, this system utilizes long threaded rods/screws are used. One particular threaded rod/screw produced by SFSIntec, called ‘’Wood Bar’’, is suitable for this application. The long threaded rod is screwed in the end grain of the panel element. The panels arrive on site equipped with an adaptor.

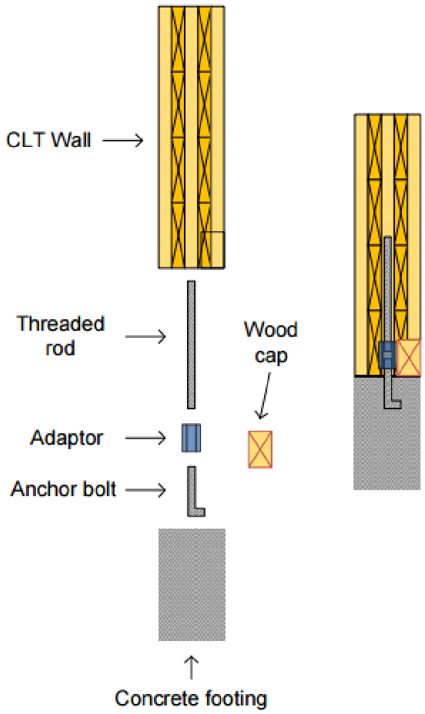

Figure 10. Wall to foundation connection using threaded rod and anchor bolt. (Adapted from Mohammad 2011)

Another option for connecting CLT wall panels to concrete foundations is to use a hollow small diameter metal tube/shaft with threaded ends. Holes are predrilled in the edge (narrow side) of the panel element to accommodate the metal shaft, which is fixed inside the panel using small diameter dowels or bolts. Epoxy could also be used to attach the metal shafts to the panel in the plant. The panels arrive at the construction site already equipped with the shafts to minimize work on site. Threaded anchor bolts cast in the concrete foundations are connected to the shaft's threaded end using a nut adaptor. Usually, a small access hole in the panel is drilled to enable connection between the adaptor and the threaded anchor bolt. A wooden cap is used to cover the access hole and the shafts, making this a completely concealed, fire protected connection. The actual detail depends on the magnitude of design service loads that the wall panel will resist and the panel configurations (such as window and door openings).

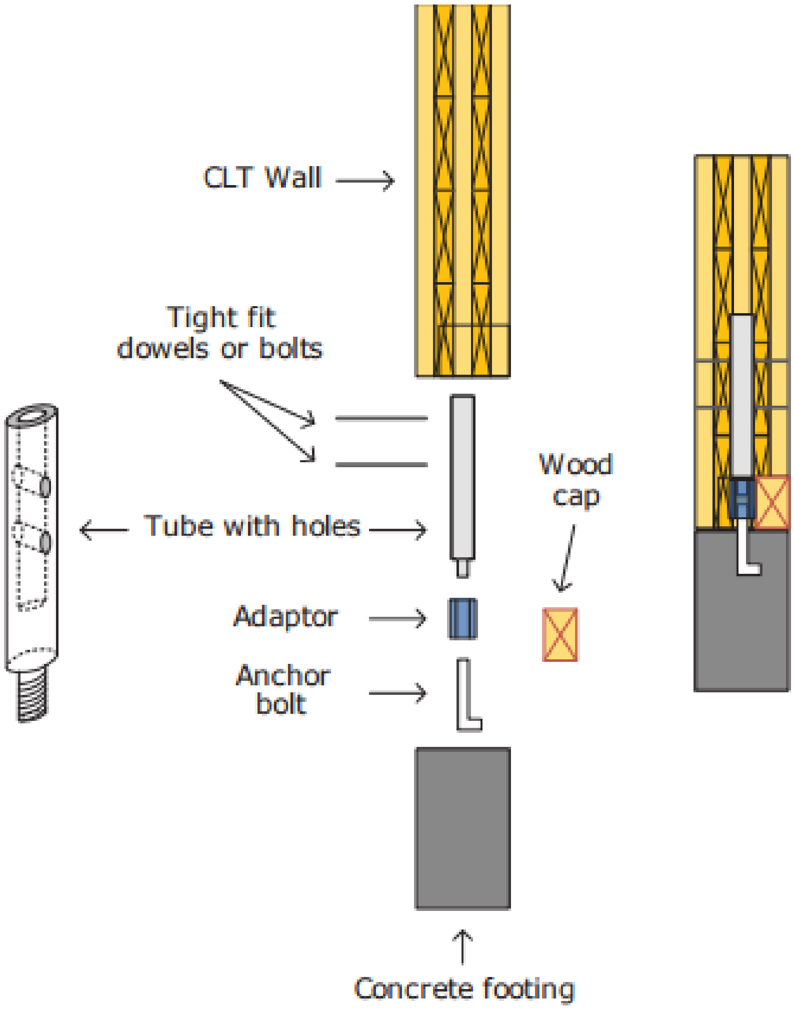

Figure 11. CLT wall to foundation connection using hollow small diameter metal tube/shaft with threaded ends. (Adapted from CLT Handbook)

CLT can be also combined with other wood-based systems. Such systems are called hybrid systems. The figure below depicts a connection between CLT wall and i-joisted floor. Self-tapping screws are used in this connection.

A combination of rimboard and blocking elements made of SCL such as PSL, LVL, or LSL between joists is generally used to ensure transfer of vertical loads from storeys above to the CLT wall below. Differential shrinkage is not an issue here as next storey CLT walls are resting completely on the rimboard and the blocking elements. Typical solid sawn lumber or SCL such as wood I-joists could be used as the main structural systems supporting the subfloor.

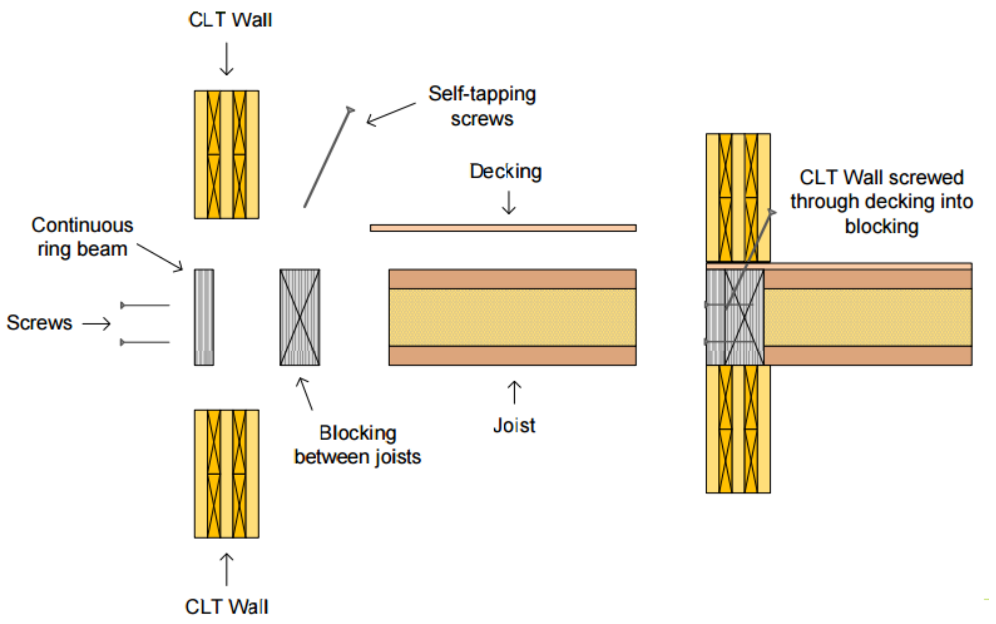

Figure 12. CLT wall and i-joisted floor with EWP rim board and blocking. (Adapted from Mohammad 2011)

Other type of hybrid systems is CLT wall and metal plated floor truss. Self-tapping screws are used in this connection. CLT Wall & metal plated floor trusses. Self-tapping screws are used.

In the case of wood floor trusses, it is necessary to provide wood-based blocking to prevent localized crushing of truss top chords and to have a uniform stress distribution along the wall perimeter. The wood blocking should be made of SCL for better deformation properties and for dimensional stability.

Connection between walls above and below can be established using self-tapping screws driven at an angle or through one of the alternative methods of fastening described above.

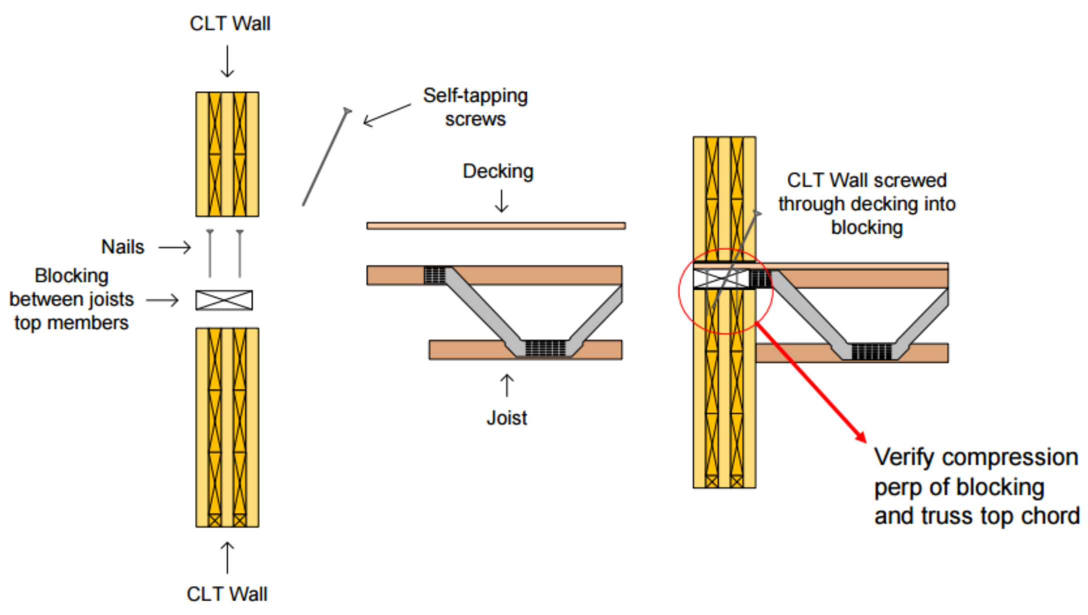

Figure 13. CLT wall and metal plated floor truss. (Adapted from Mohammad 2011)

The following section describes in more details connection systems commonly used in CLT assemblies. Currently, there is a wide variety of fasteners and many different types of joint details that can be used to established roof/wall, wall/floor and inter-storey connections in CLT assemblies or to connect CLT panels to other wood-based elements or to concrete or steel in hybrid constructions. While long self-tapping screws are typically recommended by CLT manufacturers and are commonly used for connecting panels to panels in floors and floor-to-wall assemblies, traditional dowel-type fasteners such as wood screws, nails, lag screws, rivets, bolts and dowels can also be effectively used in connecting panel elements. Other types of traditional fasteners, including bearing type fasteners such as split rings and shear plates, and tooth plates, may have some potential; however, their use is expected to be limited to applications where high loads are involved. Some interesting innovative connection systems are finding their way to the CLT construction market. These include glued-in rods, Geka connectors, the KNAPP system and other systems that adopt similar concepts. Such systems have good potential for use in Celt applications, especially those that employ a high degree of prefabrication using CNC machining technology. Fortunately, major CLT panel and glulam manufacturing facilities are equipped with CNC technology which could facilitate the rapid adoption of such connection systems. The choice of the type of connection to use depends largely on the type of assemblies to be connected (i.e. panel-to-panel, floor-to-wall, etc.), panel configurations and the type of structural system used in the building.

Mixed CLT construction could also be used in buildings with a balloon structural form. In this type of construction, the joisted floor system which incorporates a variety of joist products such as sawn lumber, wood I-joists and SCL can be attached to the CLT walls using traditional metal hangers commonly used in light-frame and heavy post-and-beam timber construction (Figure 13). The wall panels are continuous at the connection between the floor system and the wall and it provides support to the floor system.

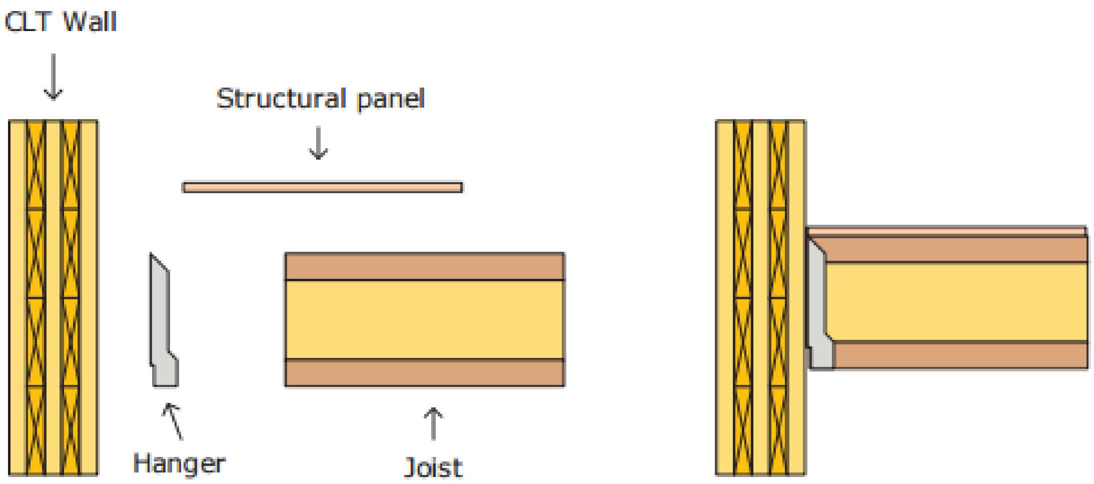

Figure 14. CLT Wall I-joist. (CLT Handbook 2011 [adapted from TRADA 2009])

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