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CLT Connections Design

Seminar on CLT Design, including Connections, and Resistance to Lateral and Gravity Loads

Moncton, NB

December 1, 2015

Overview

- Why connections in CLT are different from other EWP
- Types of connection systems in CLT assemblies
- Common connection details/techniques in CLT
- Current R&D activities
- Proposed design approach for fastenings in CLT in the CLT Handbook

Why Connections are Important in CLT Assemblies?!

- 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 prefab. at the mill
- Facilitate a quick assembly and disassembly (i.e., cost-competitiveness)

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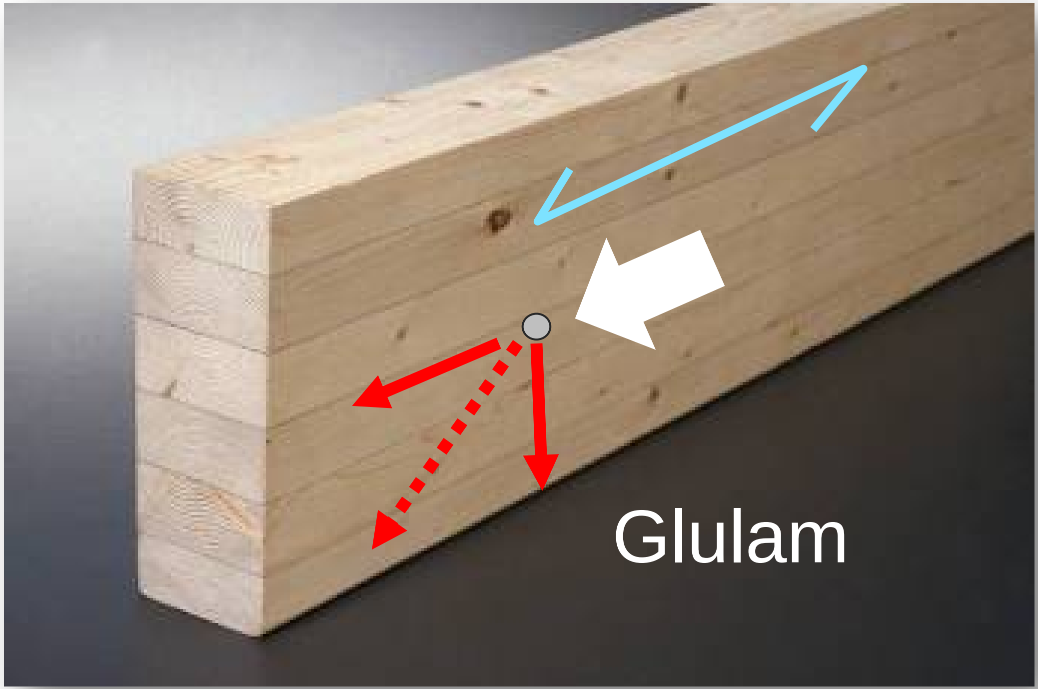
Why Connections in CLT are Different than those in Solid Timber or Glulam?!

- Laminates are aligned & loaded in the same direction (relative to grain)

  - // to Grain

  - Perp. to Grain

  - At an Angle



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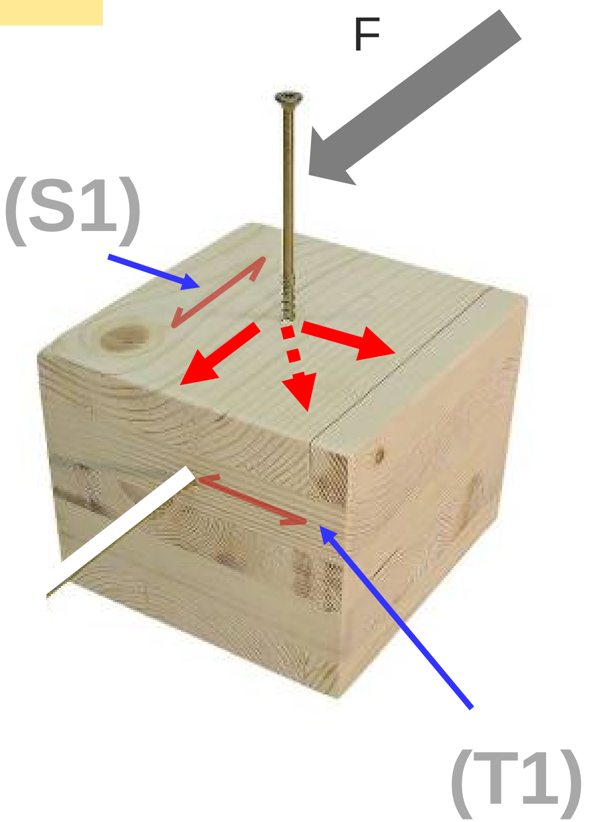
Why Connections in CLT are Different than those in Solid Timber or Glulam?!

Cross Lamination Effect

Different layers are loaded @ different angles due to X-lamination

- Critical for fasteners ≥ ¼” in diameter



For Example

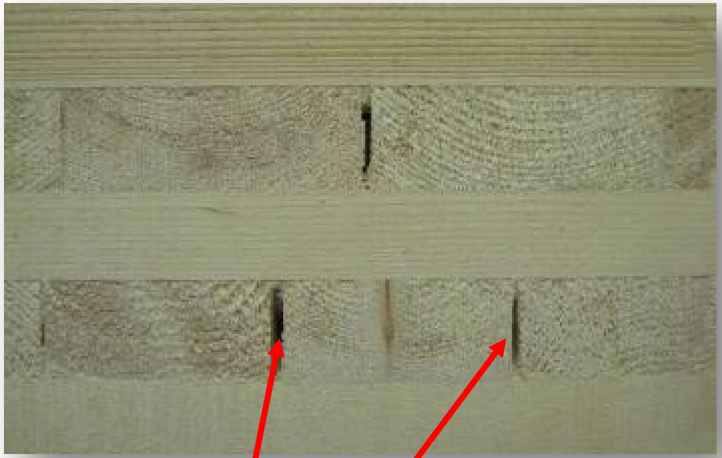
- Outer layer (S1) loaded // to Grain
- Transverse layer (T1) perp. to Grain

Why Connections in CLT are Different than those in Solid Timber or Glulam?!

Moreover…

Presence of specific CLT panel features such as:

- Gaps in unglued X-laminates edges
- Artificially sawn grooves to relieve drying stresses



Gaps and grooves

Not common to all CLT products as many products have edge-glued x-lamination

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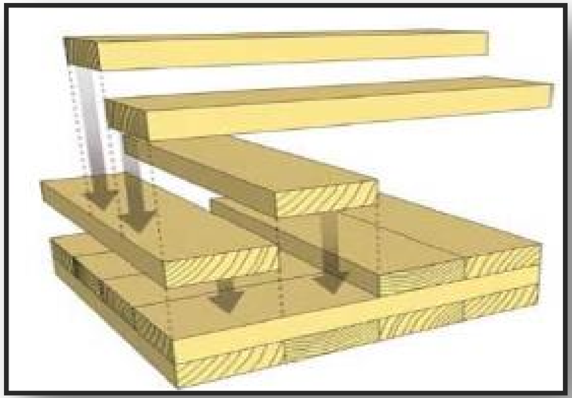
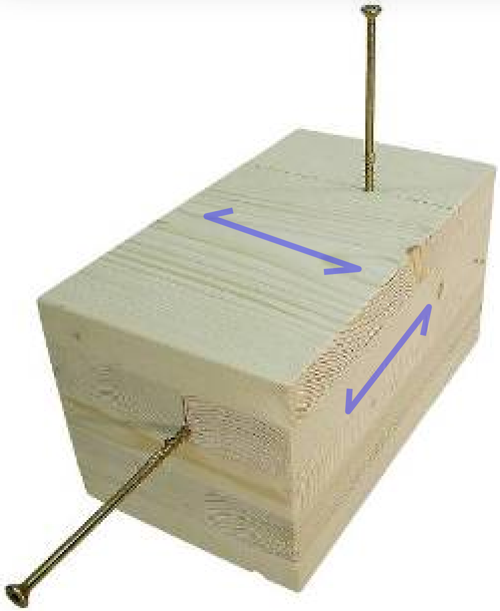
Does that Make Connections Design in CLT more Challenging?

Absolutely NOT!!

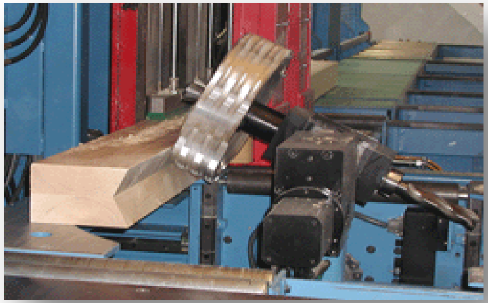


- CLT has a more favourable ability to resist splitting due to X-lamination (i.e., acts like "transverse reinforcement")

- However, need to take into account some of the specific features of panels at the design stage (e.g., gaps, lamination orientation, etc.)



Current CLT Connections Practice (Europe & Canada)



- Carpentry

Using CNC technology to create various types of interlocking profiles (Dovetail connections)

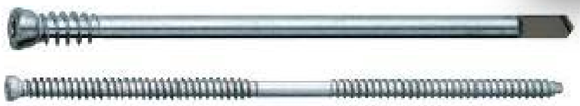
- Traditional Fasteners

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.

Source: Log &Timber Connections



SFS Intec WT/WS

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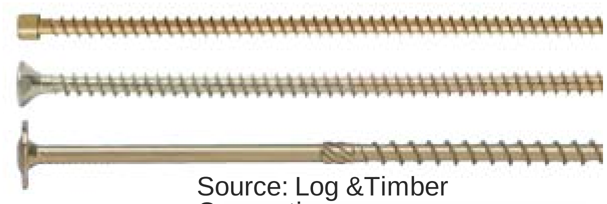
Wood and Self-Tapping Screws

Easy to install & provide high lateral & withdrawal capacity

- Come in a variety of sizes and features
  - Diameters up to **12mm**
  - Lengths up to **600mm** and even longer
- Do not require predrilling in most cases, (unlike traditional lag screws)
- Used for WW or WS connections

Source: SFSIntec



Source: Log &Timber Connections

Source: Kevin Meechan Courtesy WoodWorks

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Traditional Fasteners in CLT

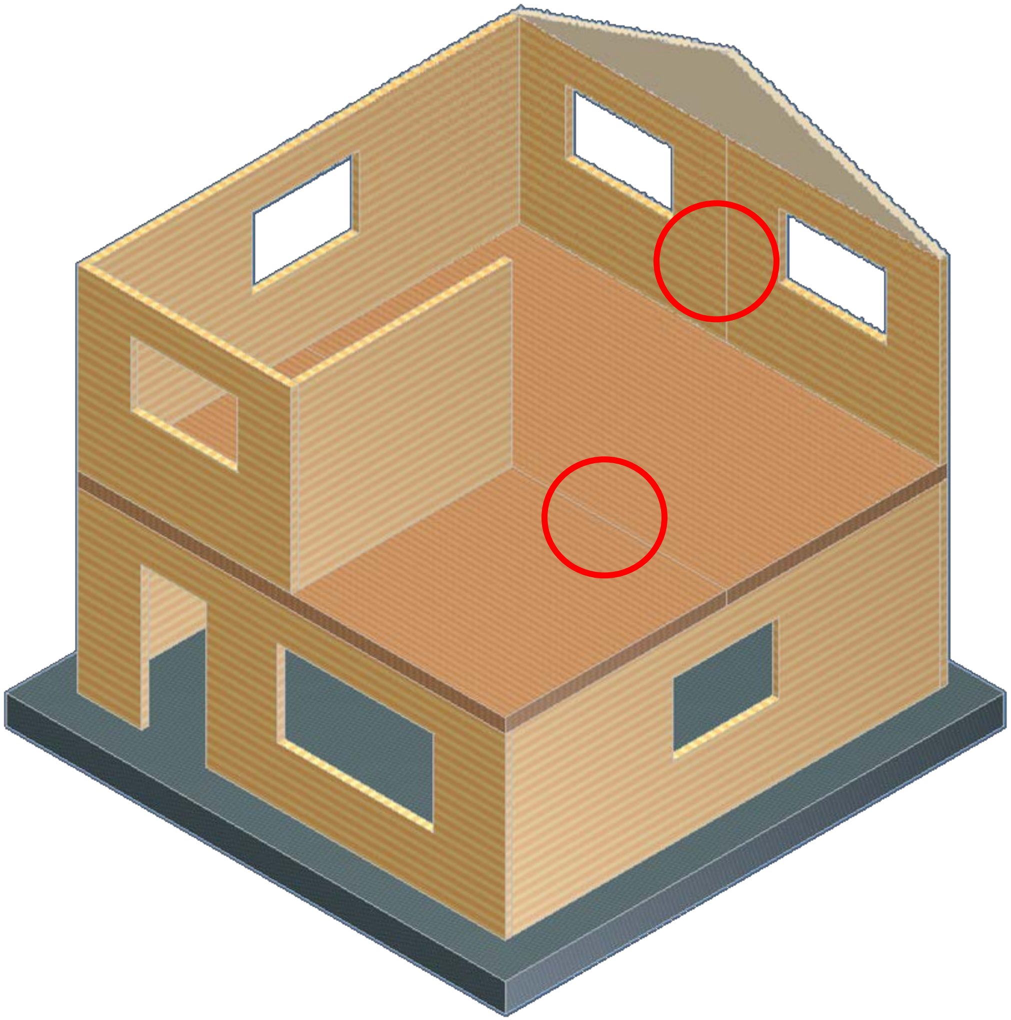
Nails and Rivets

- **Not as commonly used** as self tapping screws in CLT
- Nails with specific shank features such as ring nails are the most commonly used
- Typically used in combination with metal plates and brackets
- Rivets are rarely used (i.e., one project in Ottawa- PlayValue)

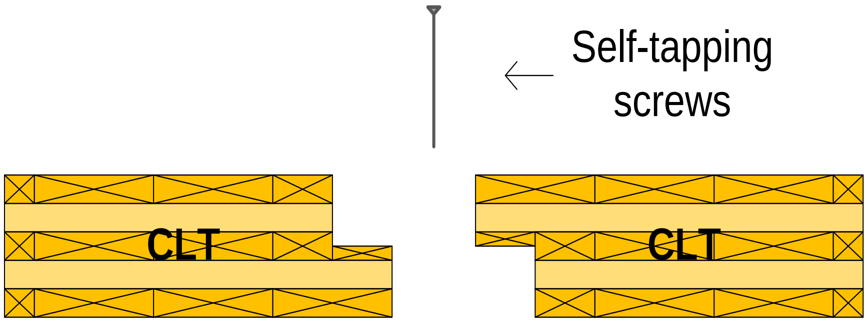
Connection Details in CLT Assemblies

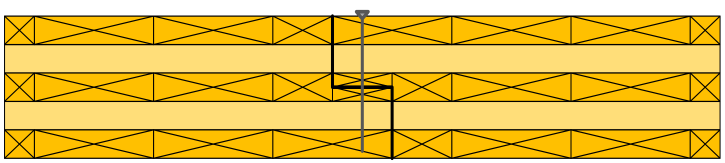
<u>Panel to Panel</u>

(i.e., in wall, floor & roof assemblies)

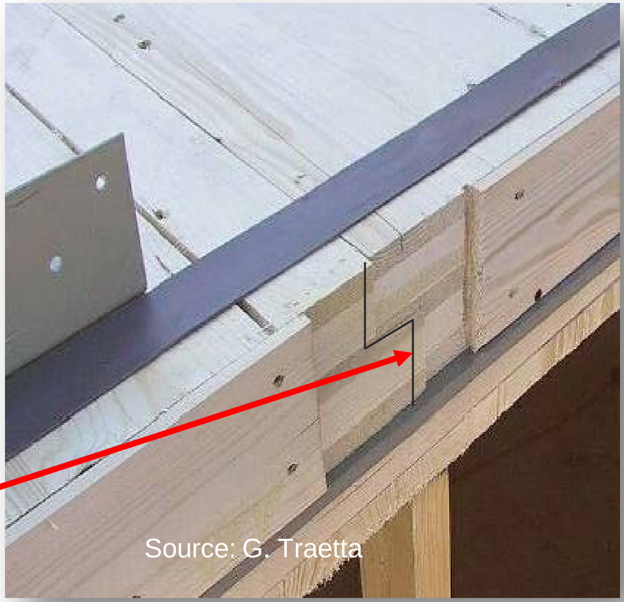


CLT Panel to Panel Connection Details
(Screws, Nails)

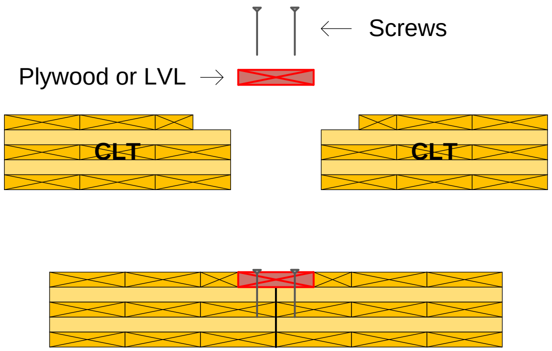




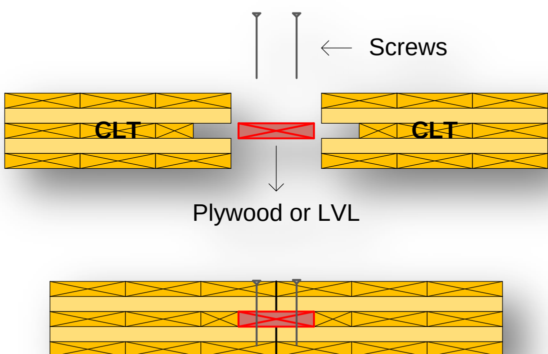
Half-lapped



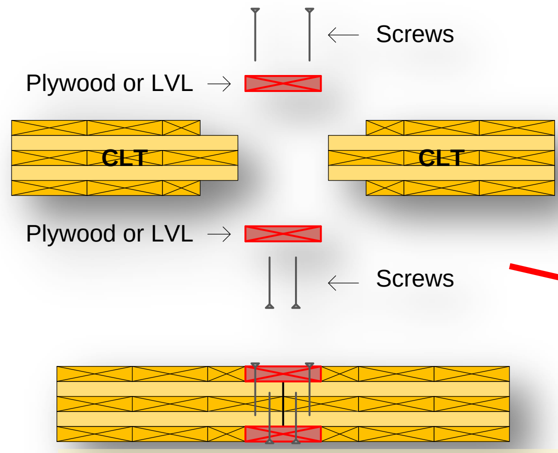
CLT Panel to Panel Connection Details
Traditional Fasteners (Screws, Nails)



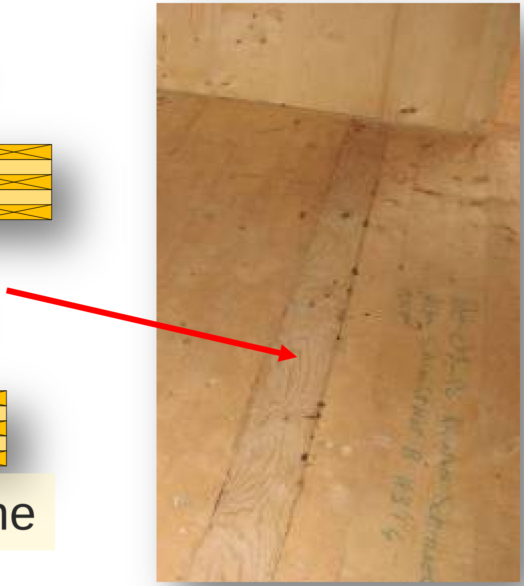
Single surface spline



Single Internal spline



Double surface spline



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CLT Panel to Panel Connection Details

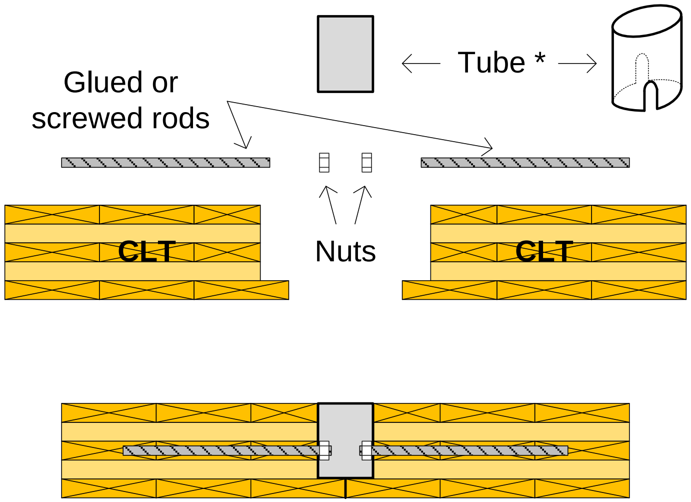
Traditional Fasteners (Screws, Nails)

Double internal spline

(Binderholz)

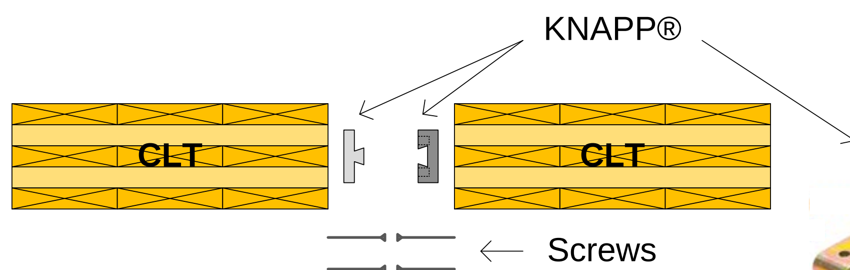
Source: Kevin Meechan
Courtesy WoodWorks

Innovative/Proprietary Systems for CLT Panel to Panel Connections



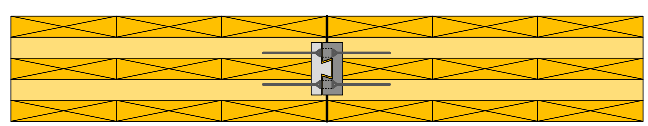
(Source:Traetta & Schickhofer)

Tube connection system



Dovetail

Knapp® connection system



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Innovative Connection Systems in CLT

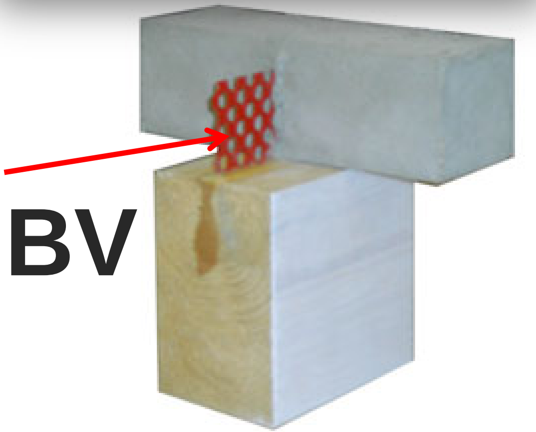
HSK System: UBC Okanagan Fitness Centre

(McFarland Marceau Architects)

Moment resisting connection as part of the portal frame

Photo courtesy of Nicola Logwork – John Boys

Innovative Connection Systems in CLT



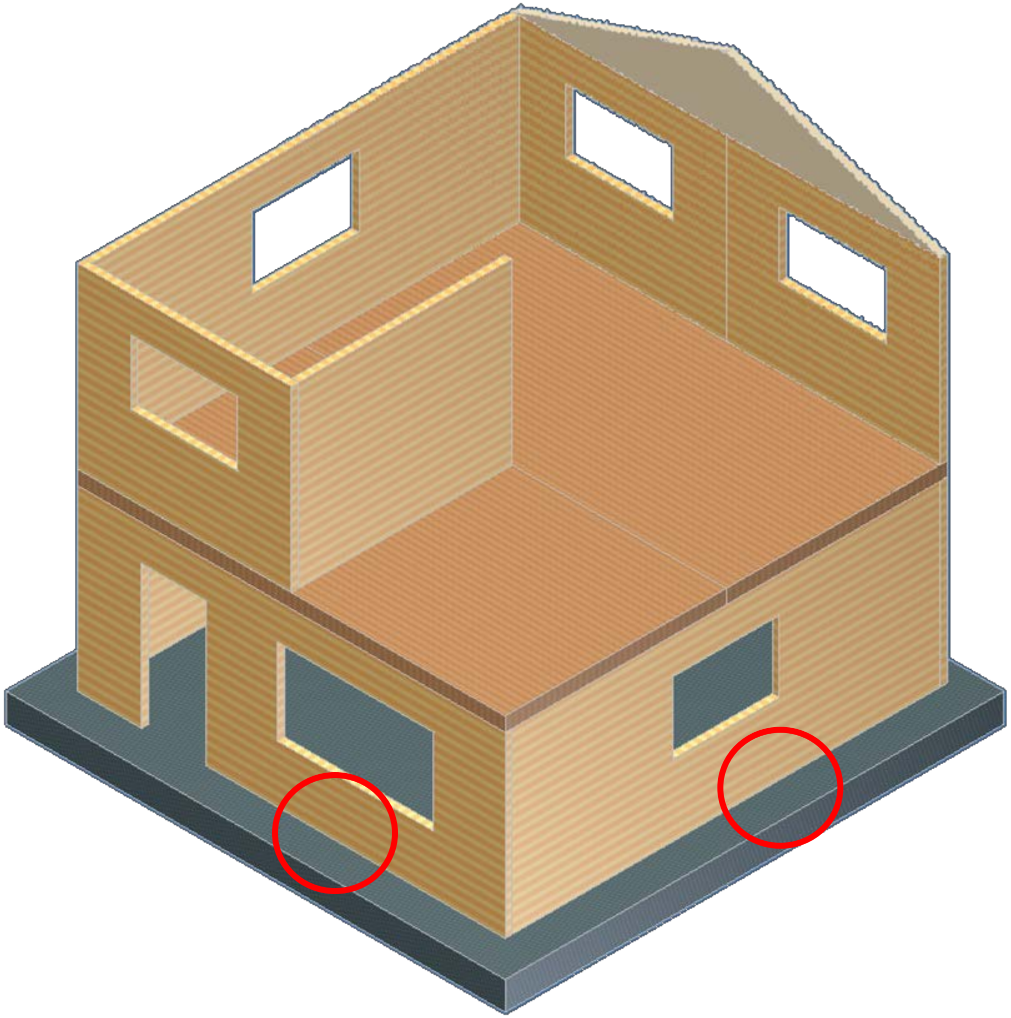
HBV

- HSK systems
- HBV (i.e., hybrid composite CLT/concrete)

Both used in UBC ESB building

Connection Details in CLT Assemblies

CLT wall to concrete foundation



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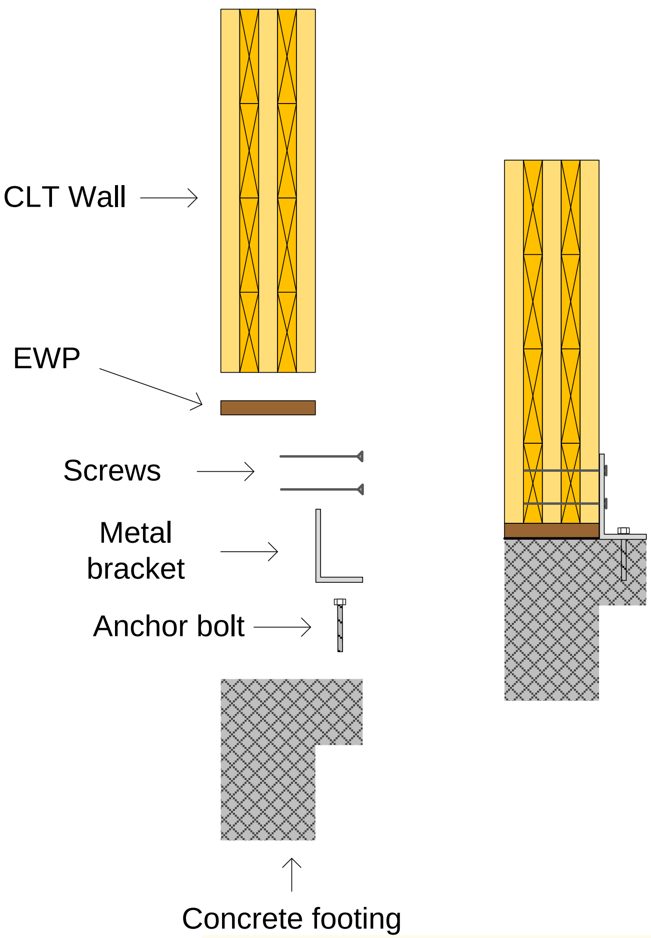
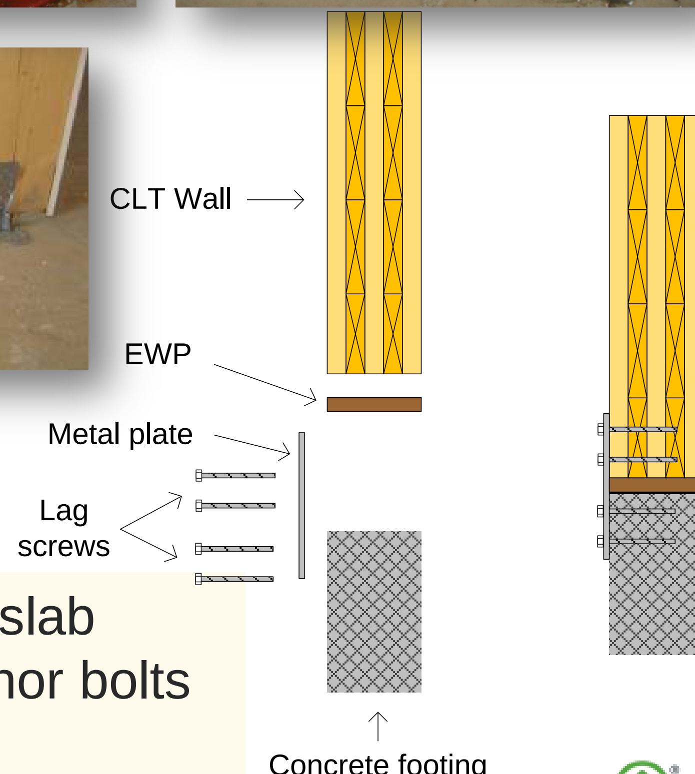
CLT Wall to Concrete Foundation





CLT wall to concrete wall or foundation slab using metal brackets or plates with anchor bolts & self tapping screws/lag bolts

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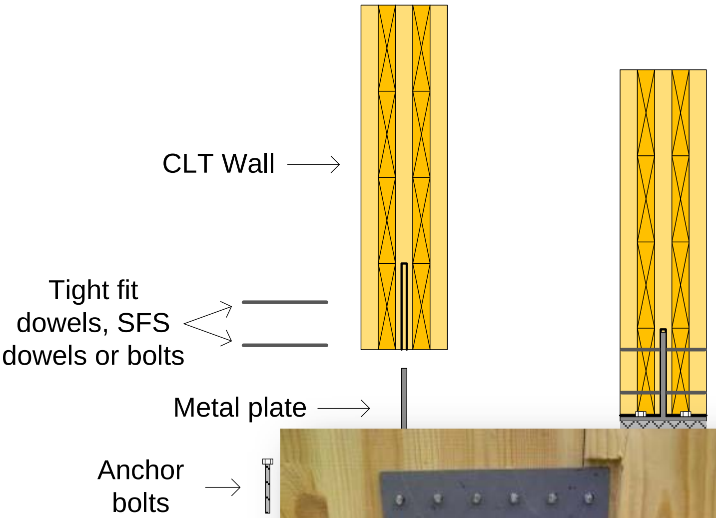
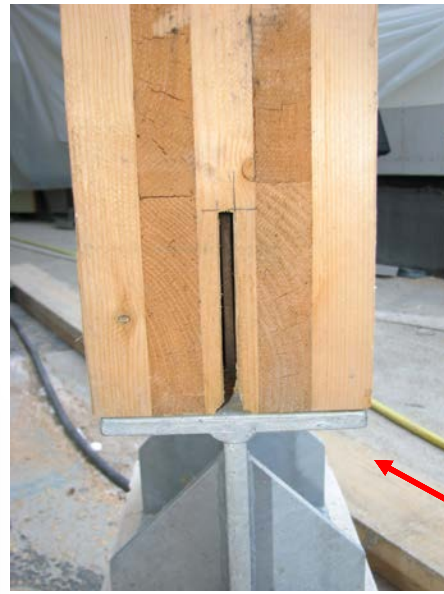
CLT Wall to Foundation: Exterior or Concealed Metal Plates





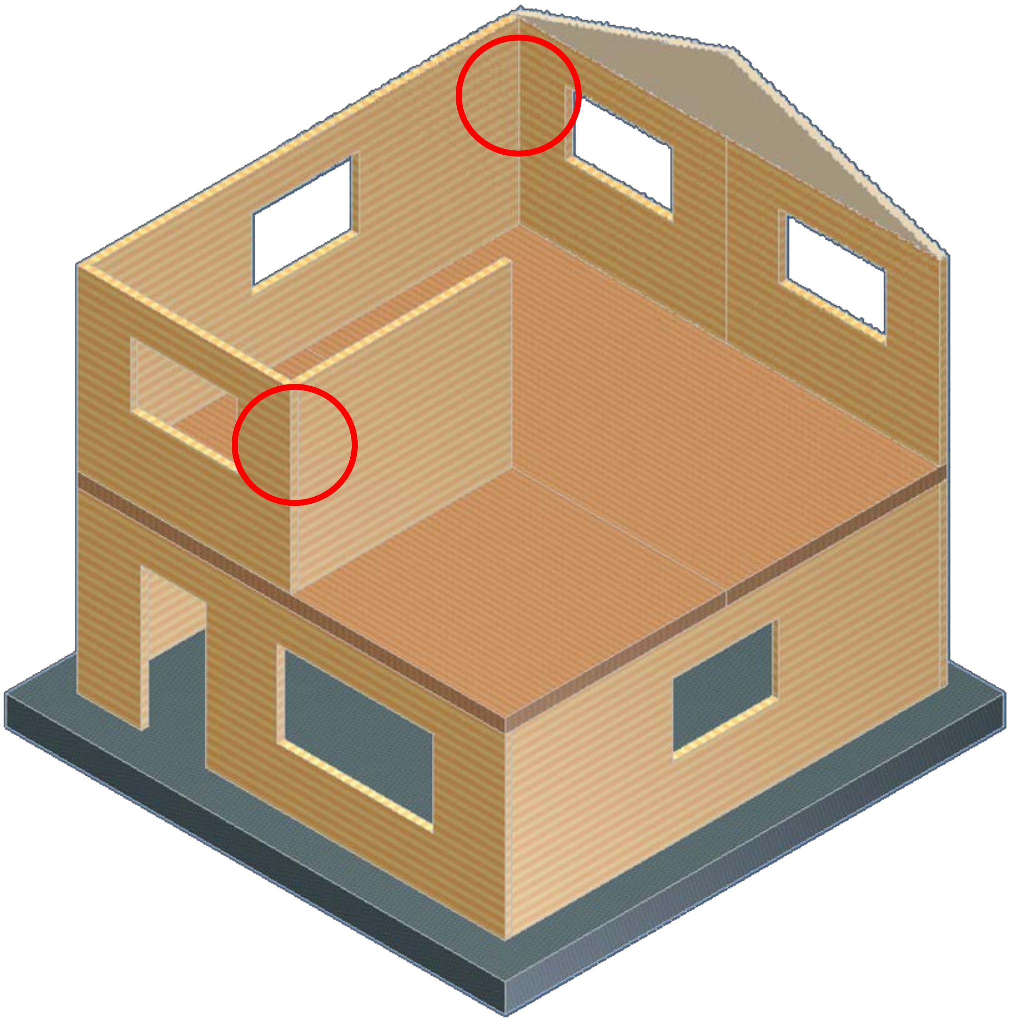
Exposed/exterior metal plates/holddowns

CLT panel/post to concrete pedestal through metal brackets and internal metal plates

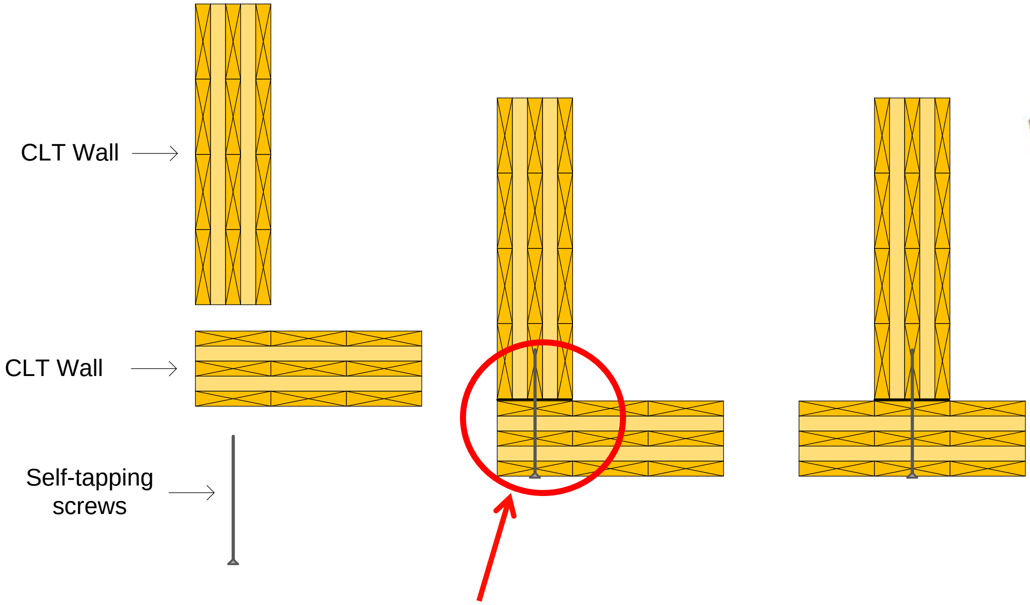
Connection Details in CLT Assemblies

Wall to Wall Intersections

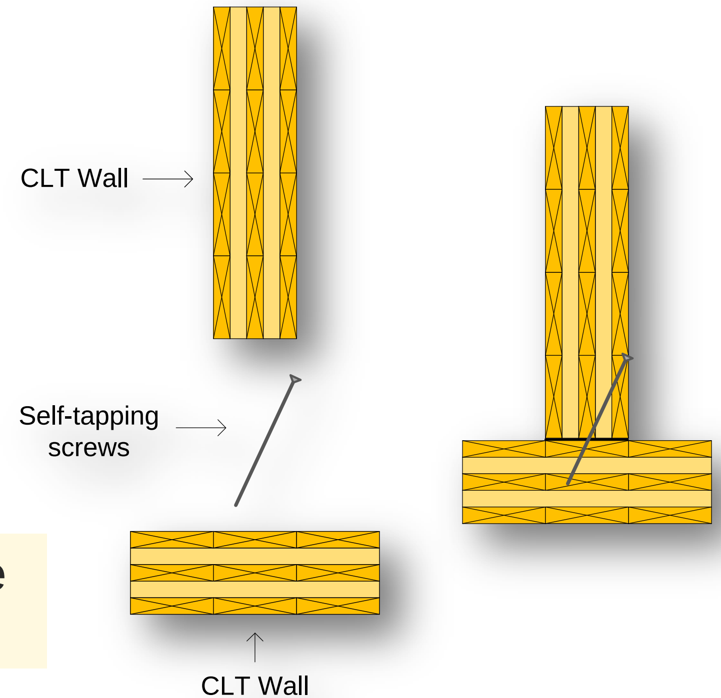
(i.e., Exterior & interior)



Wall to Wall Connections in CLT – Self Tapping Screws



Ensure screws are driven in the side grain!!



Self tapping driven perp. to panel or @ an angle
(Simplest form of connecting walls to walls)

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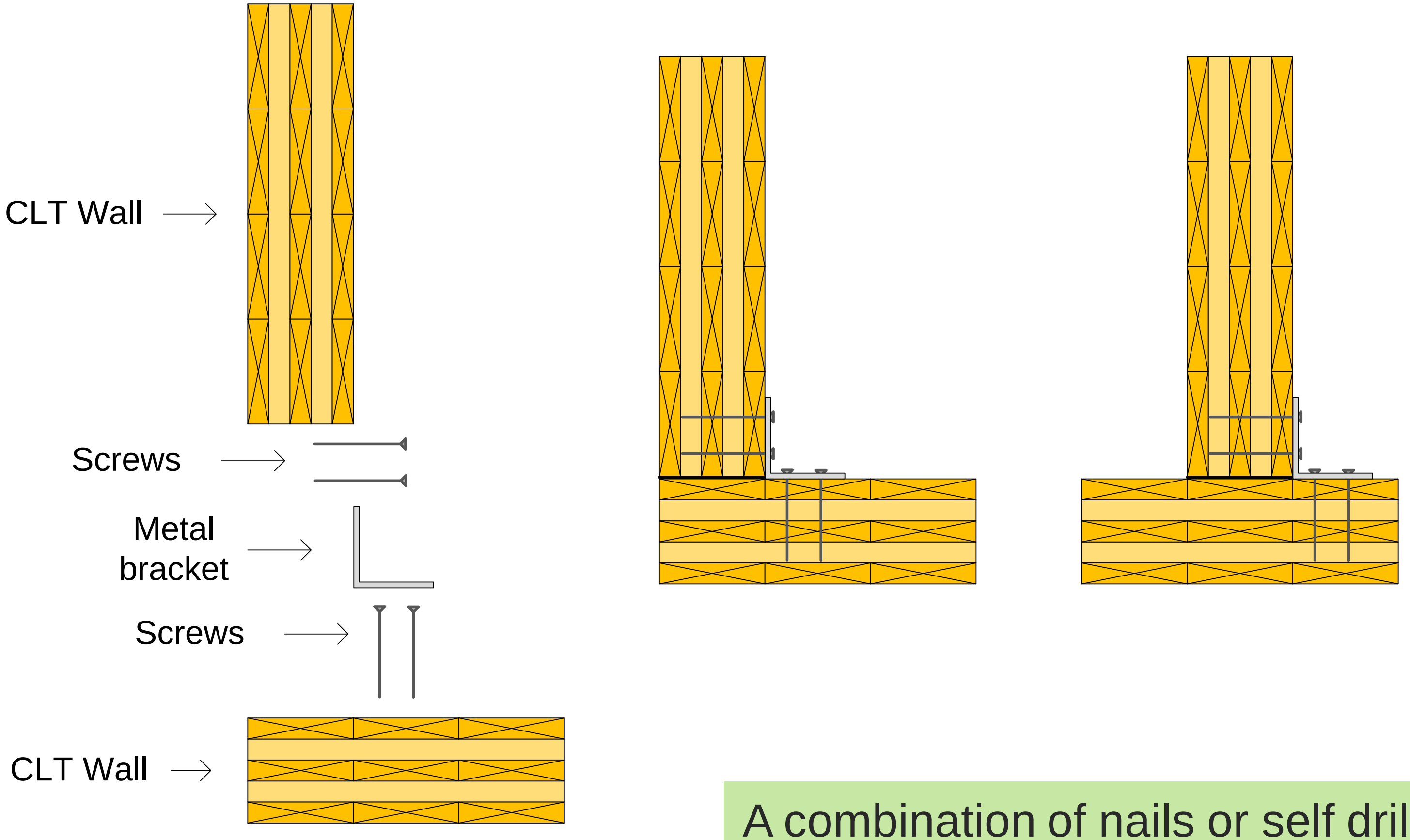
Wall to Wall Connections in CLT – Metal Brackets



A combination of nails or self drilling screws and metal brackets

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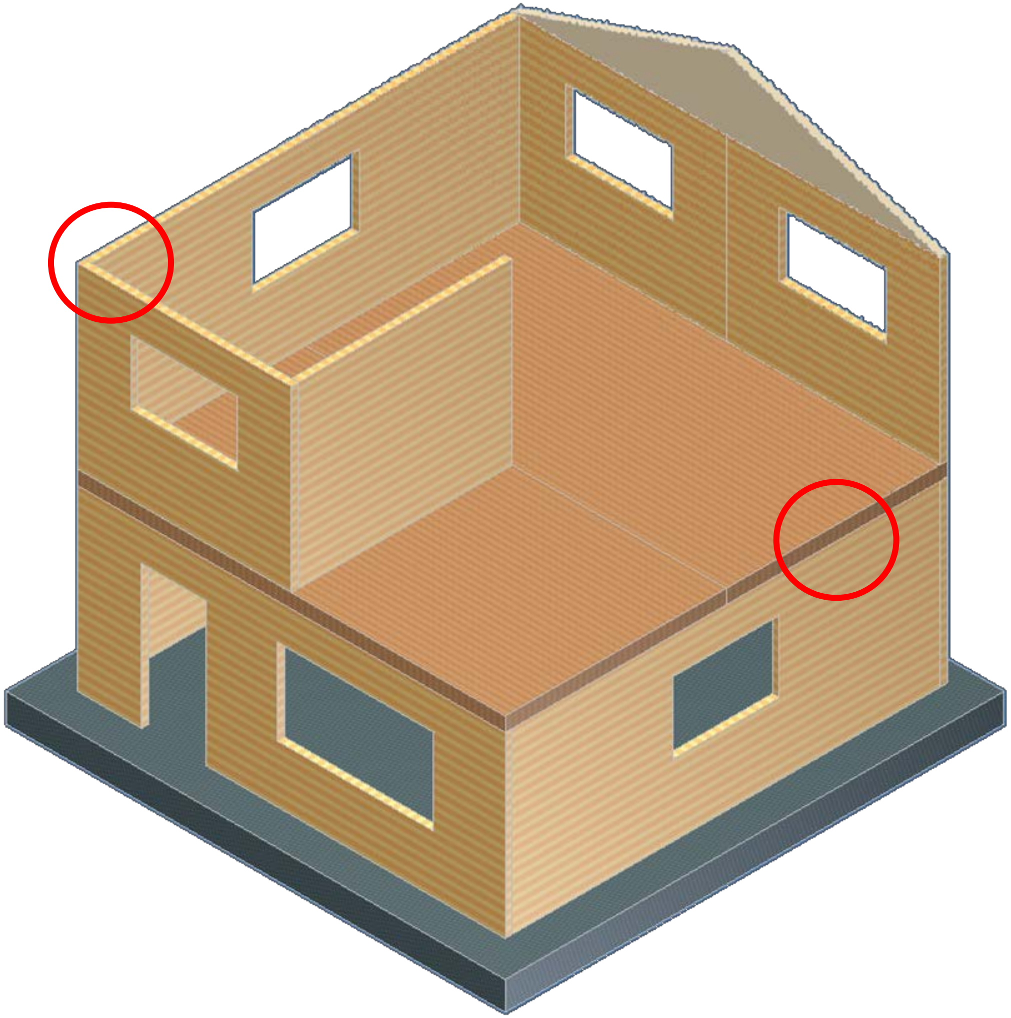
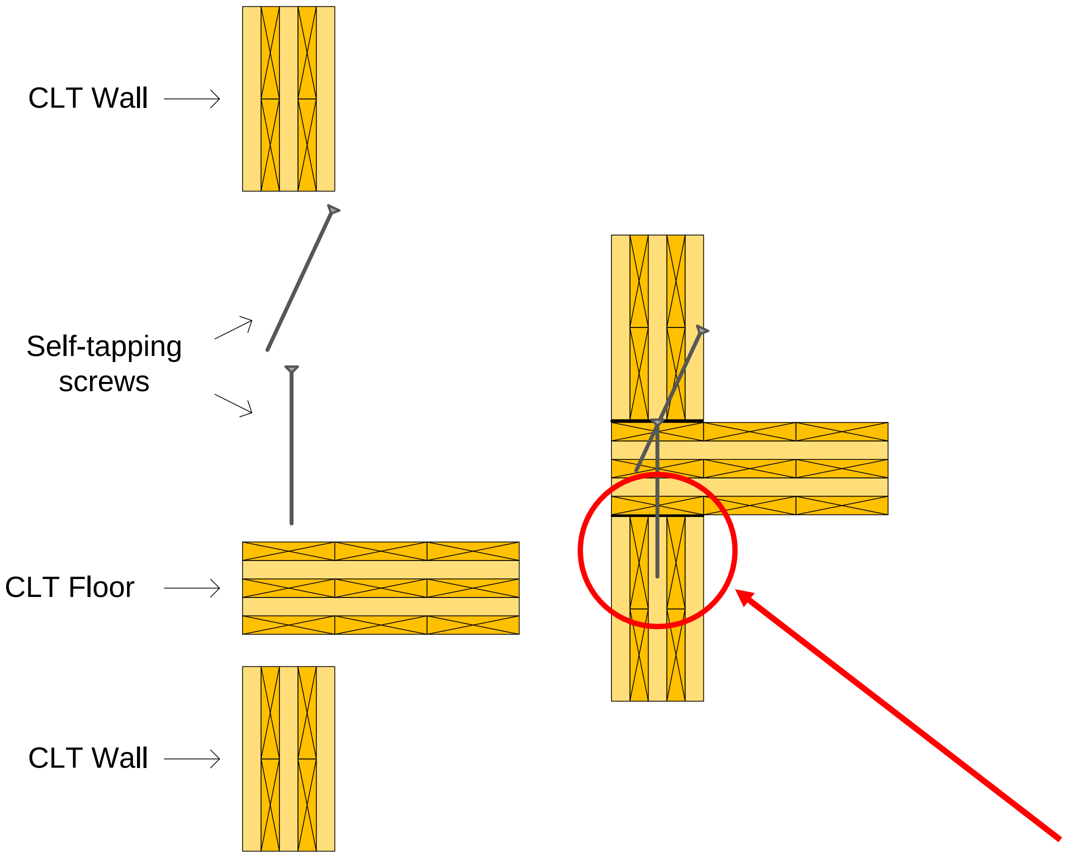
Connection Details in CLT Assemblies

<u>Wall to Floor/Roof</u>

Platform or Balloon type of Construction System



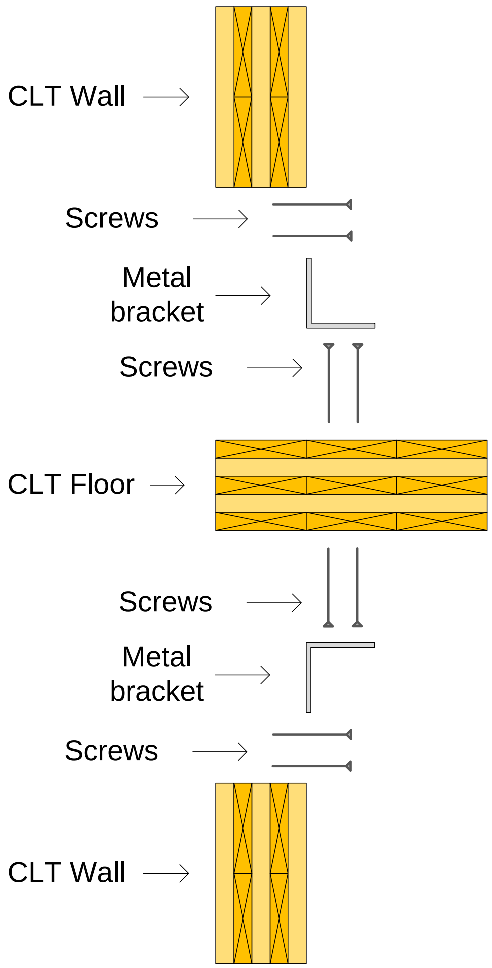
CLT Wall to Floor/Roof Connections: Platform

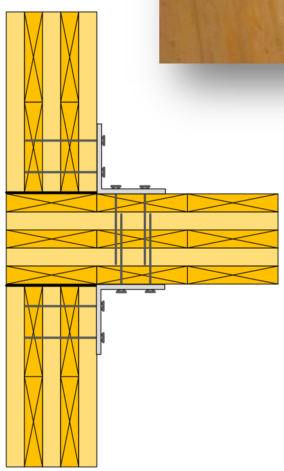


Use of self-tapping screws (Simplest form of connection)

Special attention should be paid in driving screws on edge as they may penetrate through end grain

CLT Wall to Floor/Roof Connection Details - Platform





Most commonly used connection system in CLT assemblies in Europe & Canada

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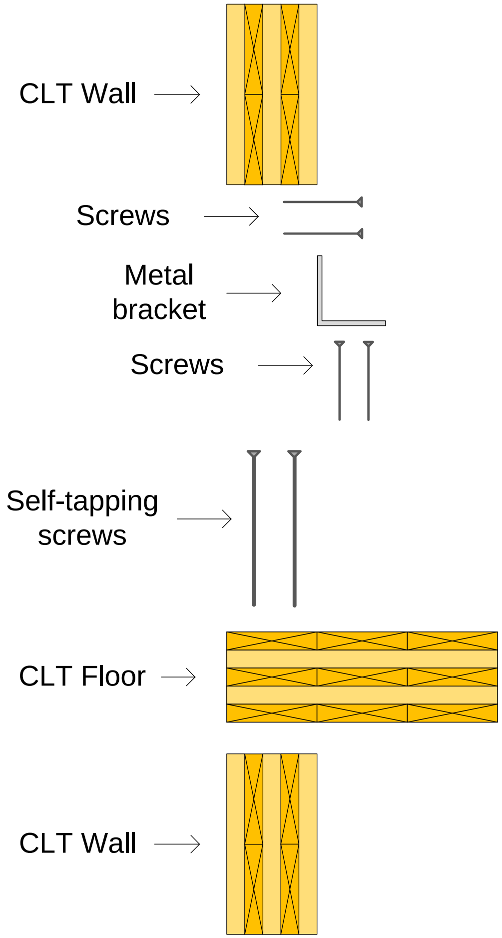
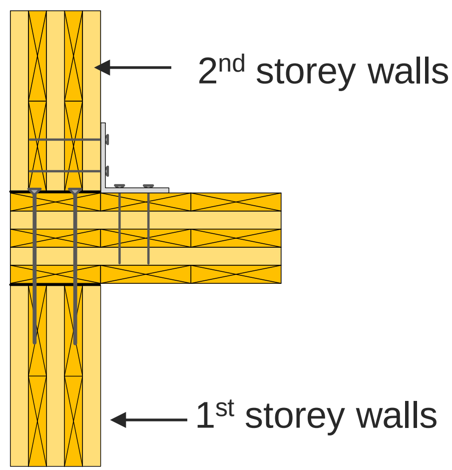
CLT Wall to Floor/Roof: Combination of Several Systems





1st storey wall to floor/roof → self tapping screws
2nd storey wall to floor → combination of metal brackets and nails or screws

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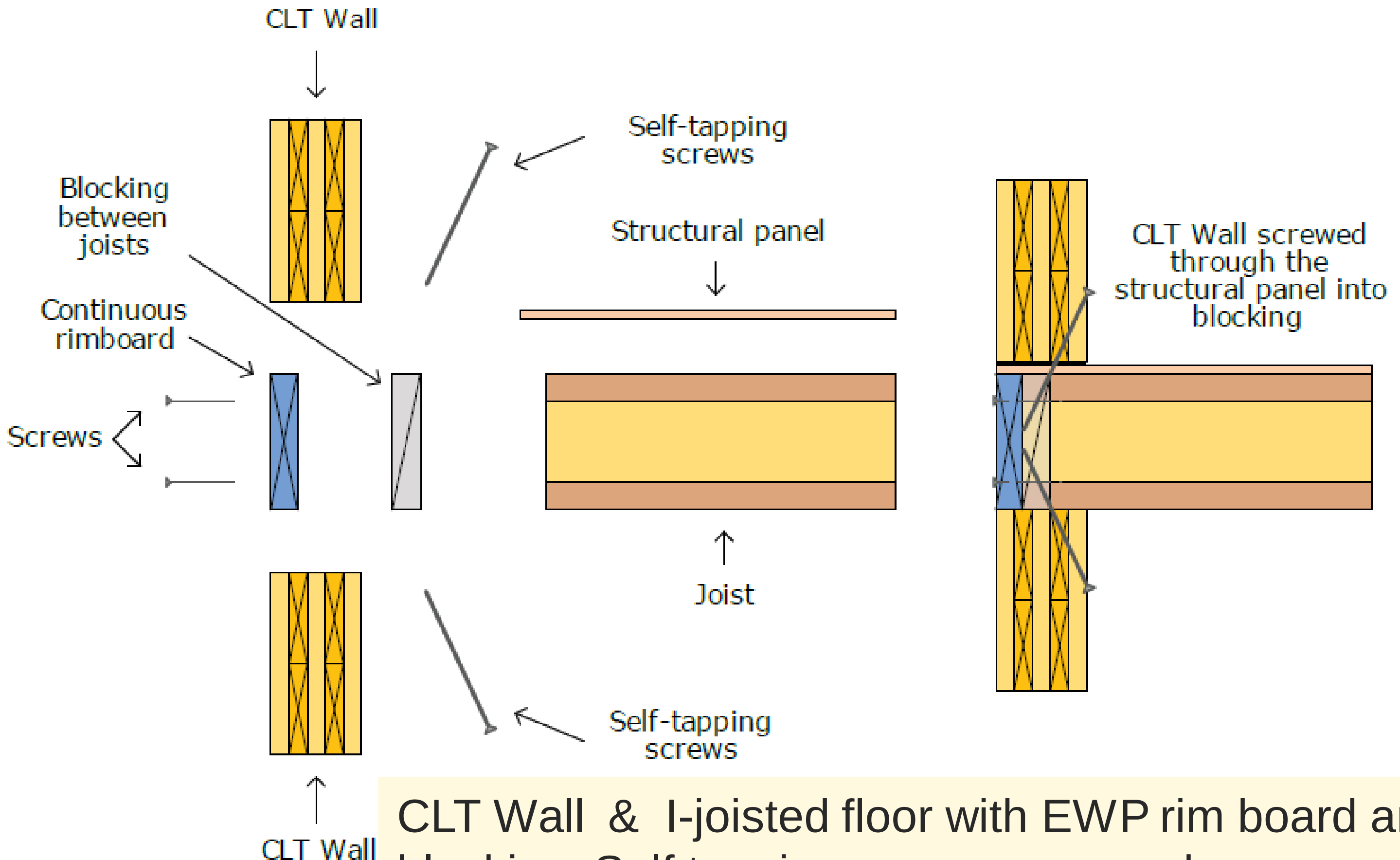
TimberStrand® LSL
Round Hole Zone
See Guidelines

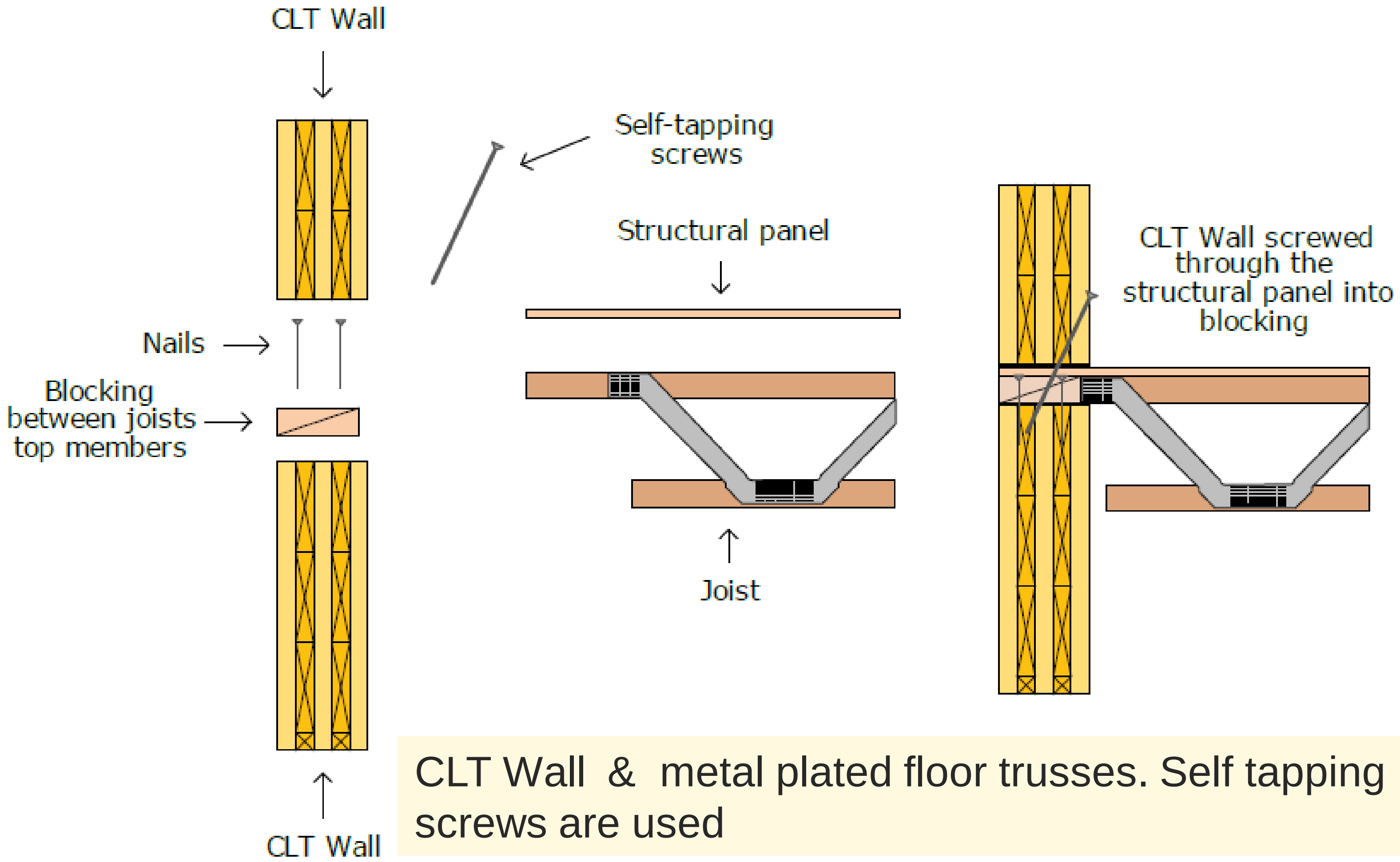
Mixed CLT with other Wood-Based Systems (Hybrid Systems): CLT Wall & I-Joisted Floor



CLT Wall & I-joisted floor with EWP rim board and blocking. Self tapping screws are used

Adopted from TRADA

Mixed CLT with other Wood Based Systems (Hybrid Systems): CLT Walls & Metal Plated Floor Truss



CLT Wall & metal plated floor trusses. Self tapping screws are used

Adopted from TRADA

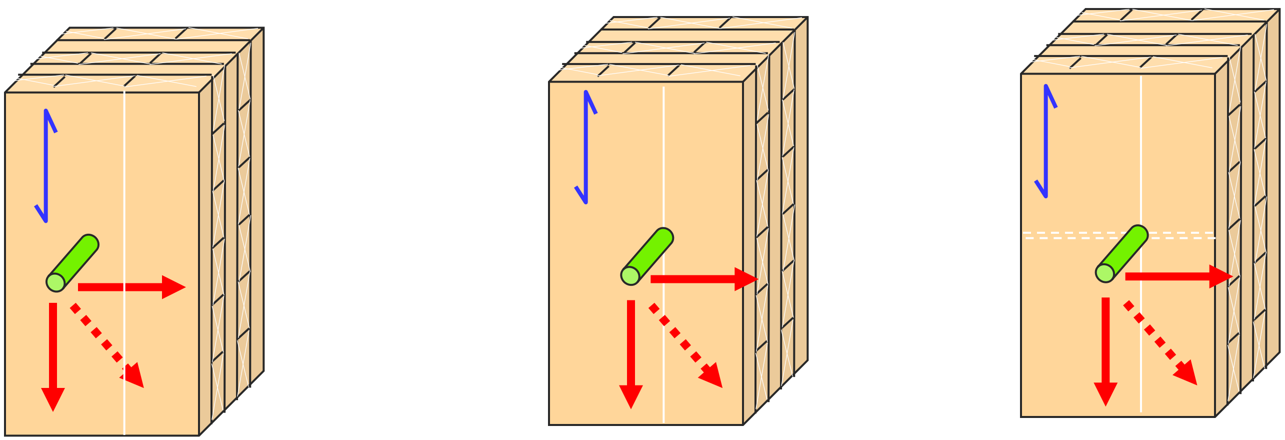

Hybrid CLT Walls and Open web Steel
Joist/deck Roof System

Designing Connections in CLT – Challenges

Fastener driven perp. to the CLT panel

Different positions relative to edge gaps between lamina

Some possible scenarios



Outside gaps

In outer layer gap

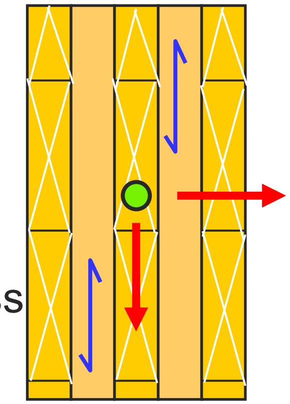
In both outer and X-layers gaps

- Not an issue for slender fasteners
- May need to consider in design of large diameter fasteners (i.e., bolts, dowels)

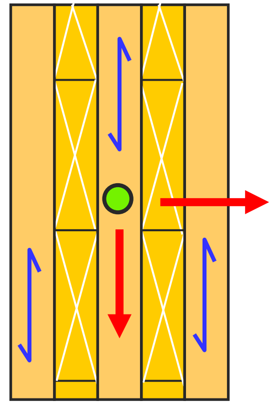
Fastener Driven on Edge…….. Challenges

Small fasteners

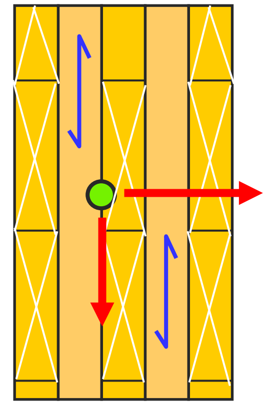
d ≤ lamina thickness



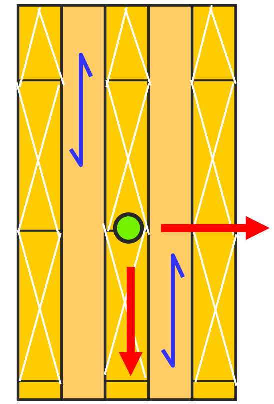
Driven in end grain



side grain



Between 2 lamina

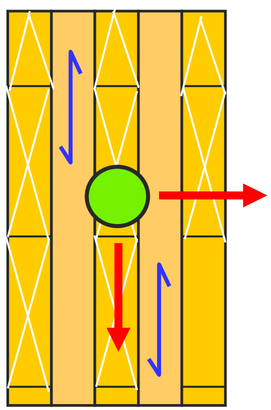


End grain & in gap

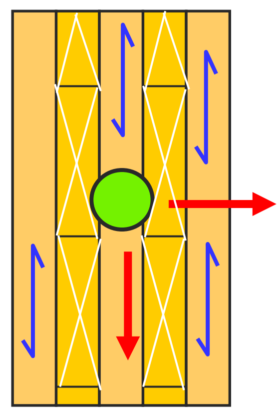
Some possible scenarios..

Large fastener

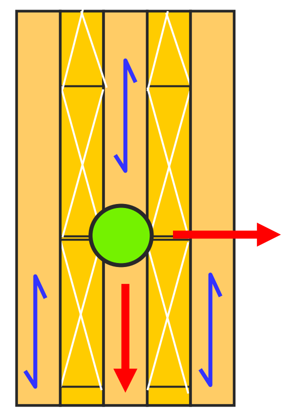
d > lamina thickness



Driven in end grain



Side grain



End grain & in gap

Research on CLT Connections – European Experience

- Extensive research in Germany, Austria & Italy on performance of traditional fasteners in CLT:

  - Different loading directions 0º, 45º, 90º relative to outer layer
  - Different positions relative to edge gaps between lamina
  - Different types of fasteners
  - Long term connection tests
  - Lateral and withdrawal

  (Uibel & Blass 2006, 2007)(Traetta 2007)

- A simplified calculation methodology/formulas developed to establish the fastening lateral & withdrawal capacities with <u>screws</u>, <u>nails</u> and <u>dowels</u>

- *(Uibel & Blass 2006, 2007)*

Source: Uibel and Blass (2006)

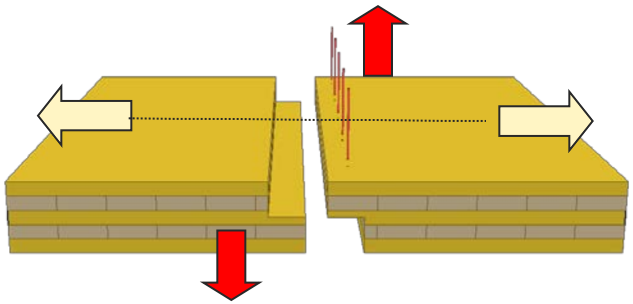
Source: M. Augustin /ITE

R&D Activities in Canada: FPInnovations, UNB, Laval University & UBC

-Embedment, lateral, withdrawal and screw head pull out tests
- Self tapping & lag screws
-Different types of panel-to-panel joints

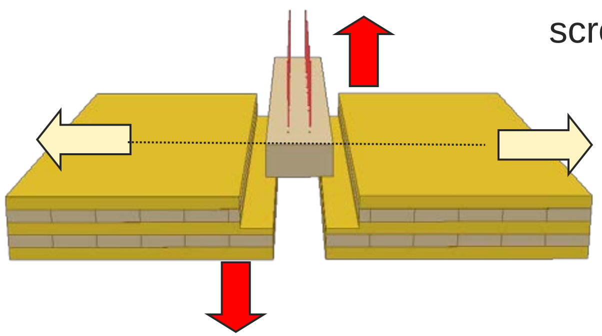
Half-lapped (step) joint

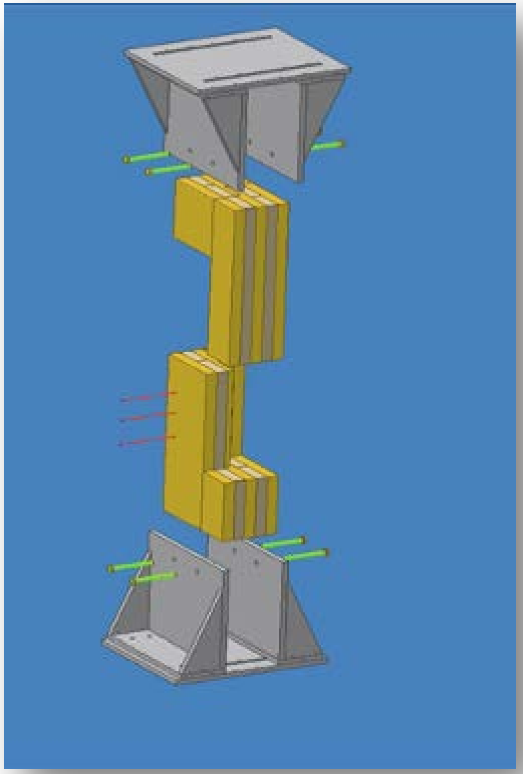
Self tapping screws

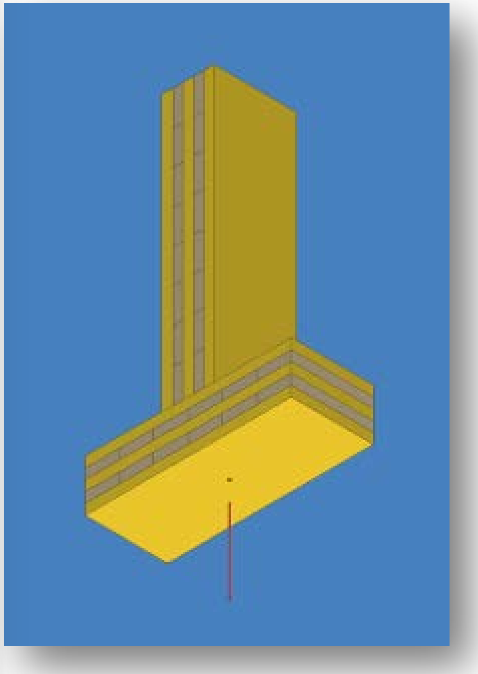


Single Spline joint

Wood screws







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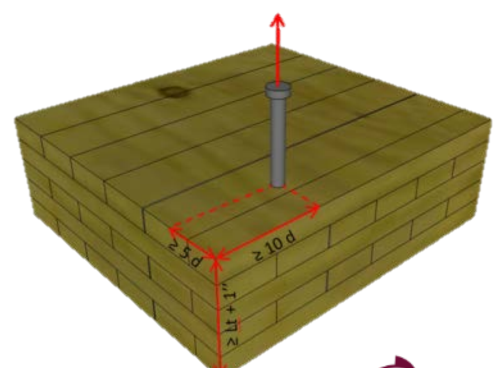
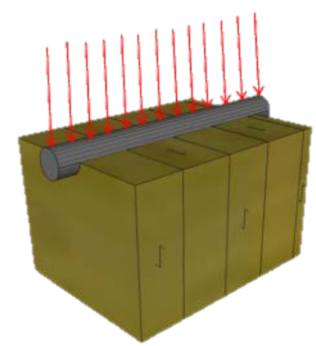
NEWBuildS: Evaluation of Connections Performance in CLT and Hybrid Construction

3 Sub-projects covered under an umbrella project

- Fastener Withdrawal and Embedment Strength in Timber, Glulam and CLT: (UL)- (2014)
- Connections for CLT Diaphragms in Steel-frame Buildings: (UNB) – (2013)
- Continuity Connections for CLT Plates in Hybrid Superstructures: (UNB) – (2015)





NEWBuildS

UNIVERSITÉ LAVAL
Faculté de foresterie, de géographie et de géomatique
Département des sciences du bois et de la forêt

CENTRE DE RECHERCHE SUR LES MATÉRIAUX RENOUVELABLES

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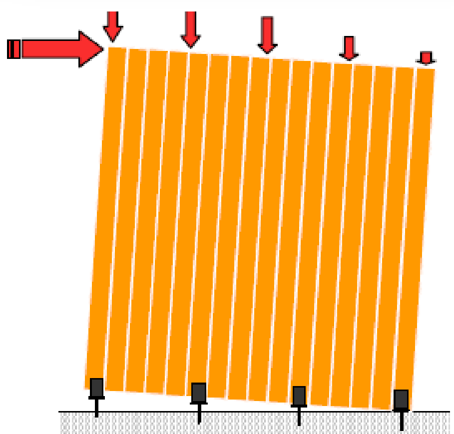
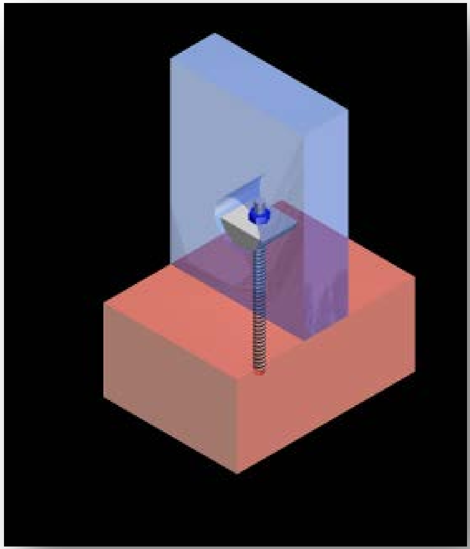
Testing of Connections in CLT (CLT walls) FPInnovations

Seismic performance of CLT walls is governed by connections



Development of Innovative Connection Systems Concepts in CLT @ FPInnovations

Design concepts developed and some limited testing done



Concept 1: Bearing washer (Prototype)

Capitalize on the high bearing resistance of wood

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European Design Approach for Connections in CLT

Laterally Loaded Dowel-type Fasteners

- Establish the embedment strength for each type of fasteners in CLT **(in plane & on edge) –** Empirically (1000s of tests)
- Emb. strength Eqs. are used in the current EC5 design procedure for connections in solid timber & glulam (EYM)
- Min. spacing & edge and end distances are specified to minimize brittle failure mode in CLT

Withdrawal Resistance

- Derive withdrawal resistance Eqs. empirically by tests (100s)

US Design Approach for Connections in CLT (US CLT Handbook)

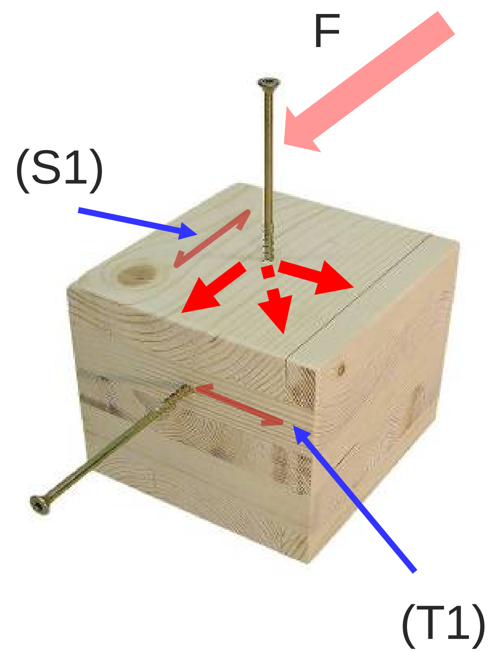
Laterally Loaded Dowel-type Fasteners

Use dowel-bearing strength Eqs. in NDS

- Fasteners < ¼”
  - For fasteners on edge, use 0.67 end grain factor
- Fasteners ≥ ¼”
  - Use **“Effective” Fastener Length** concept due to X-lamination

$$\boldsymbol{Effective\ fastener\ length} = \boldsymbol{l} * \frac{\boldsymbol{Fe}\perp}{\boldsymbol{Fe}\|}$$

  - Apply <u>END GRAIN factor 0.55</u> for fasteners driven on edge



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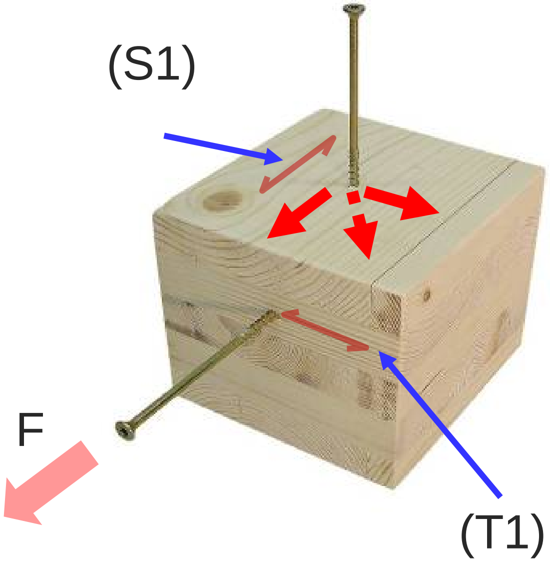
US Design Approach for Connections in CLT (US CLT Handbook)

Withdrawal Resistance

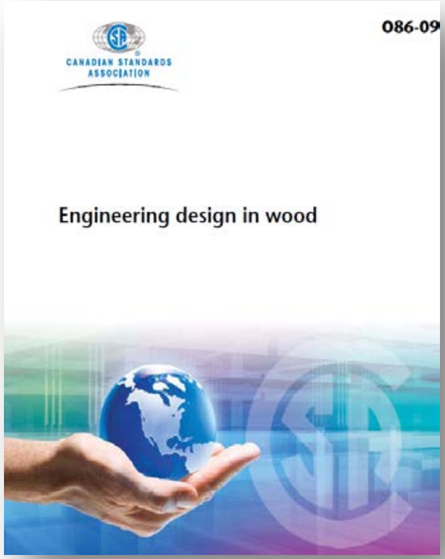
- Use current withdrawal Eqs. in NDS
- Use 0.75 for Lag screws driven on edge (end grain)
- Nails, spikes & wood screws <u>should not be loaded in withdrawal in end grain (on edge)</u>



Design of Timber Connections in CSA O86-09

Current design roles in CSA O86-14 for dowel-type fasteners in solid wood and glulam cover:

- Nails & spikes
- Wood screws (up to ¼" in diameter)
- Lag screws
- Bolts & dowels
- Drift pins
- Timber rivets
- Self-tapping screws?! Not yet!!!



No guidance is given on joints made with proprietary self-tapping screws. Typically used in CLT connections in Canada & elsewhere

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Proposed Approach for Fastenings Design in CLT in Canada

(CLT Handbook)

Fasteninqs Capacity in CLT

Proposed Design Approach Covers

- Bolts and Dowels (*lateral resistance: face & edge*)
- Lag screws (lateral & withdrawal: face & edge)
- Nails and spikes (*lateral: face & edge; withdrawal: face/edge!*)
- Wood screws (lateral: face & edge & withdrawal: face/edge!)

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Lateral Resistance: Approach

- Use existing Emb. Eqs. for fasteners loaded // or perp. to grain but adjust with a CLT reduction factor.
- For fasteners driven on edge, end grain factor (*0.67)* is applied (i.e., similar to existing **CL 10.6.6.2** for lag screws)
- Use current yielding Eqs. to determine ductile capacities based on Emb. strength
- Brittle resistance is beyond scope. Assume doesn't govern (i.e., proposed approach is conservative based on preliminary testing)

Proposed Fastenings Design in CLT

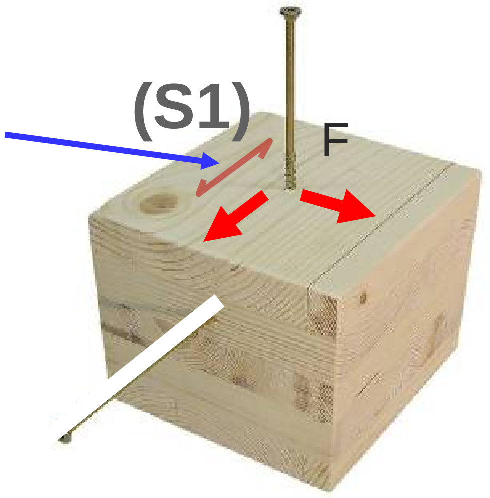
Lateral Resistance in CLT

Dowels, bolts & lag screws installed in the **plane side** of the panel (i.e., perpendicular to the panel)

- Load // to major strength direction (i.e., outer layer)

$$f_{iQ} = 50\,G\,(1 - 0.01 d_F)\,J_X$$

J_X = adjustment factor for connections in CLT
= 0.9 for CLT



- Load perp. to major strength direction

$$f_{iQ} = 22\ G(1 - 0.01 d_F) \quad (N/mm^2)$$

Proposed Fastenings Design in CLT

Lateral Resistance in CLT

- **Dowels, bolts & lag screws** installed in **the edge** of the panel (i.e., on edge)

$$f_{iQ} = 0.67 * 22\ G(1 - 0.01 d_F) \quad (N/mm^2)$$

- *0.67 accounts for bolts, dowels & lag screws installed in end grain (conservative)*
- *Less conservative: Use Jx=0.9 if precautions are taken to ensure dowels are driven in side grain*

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Proposed Fastenings Design in CLT

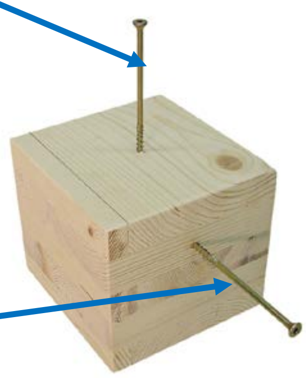
Lateral Resistance in CLT

Nails & wood screws

- **<u>Driven in the plane side</u>** of the panel (i.e., perpendicular to the panel)

$$f_2 = 50\,G\,(1 - 0.01 d_F)\,J_X$$

J_X = 0.9 for CLT



- **<u>Driven on edge</u>**

- <u>Conservative</u>: Apply 0.67 end grain factor;
- <u>Less conservative</u>: Could use same Emb. Eq. for fasteners driven in the plane but ensure side grain penetration occurs on site

Proposed Fastenings Design in CLT

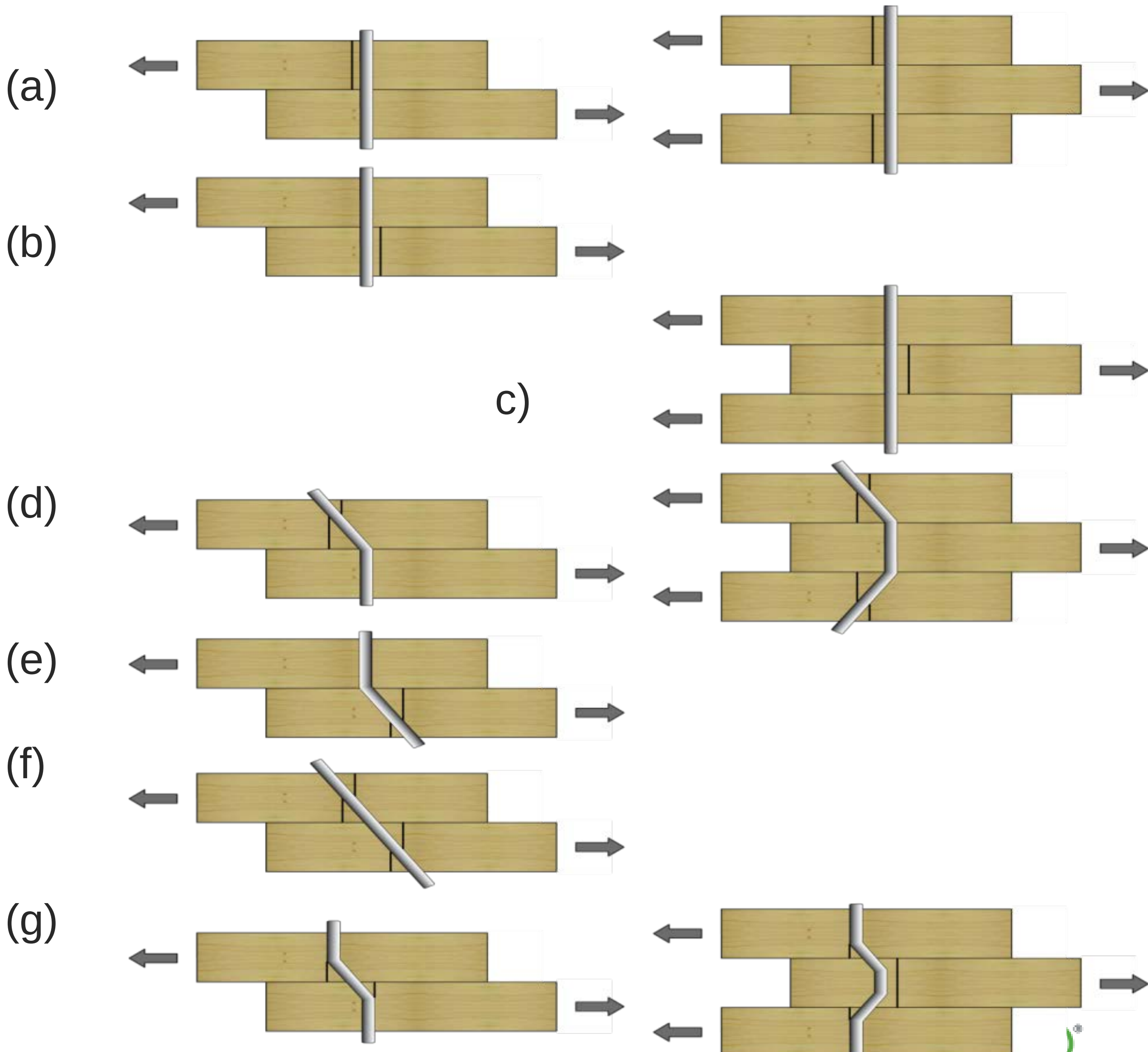
Lateral Resistance in CLT

Timber Rivets: **Beyond Scope**

Could determine capacity based on exterior ply penetration ONLY!

Proposed Fastenings Design in CLT

Use yield Eq. in CSA O86 to determine capacity based on new embedment strength values, f_1 & f_2



Proposed Fastenings Capacity in CLT

Withdrawal Resistance in CLT

- **Lag screws driven <u>per. to the CLT panel</u>**
  - Use current Eq. for withdrawal for lumber & glulam for **<u>face</u>** with an adjustment factor for CLT ($J_X = 0.9$)

$$y_w = 59\, d_F^{\;0.82}\, G^{1.77}\, J_X \;\; N/mm$$

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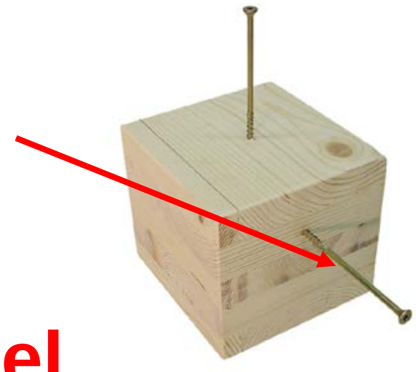
Proposed Fastenings Capacity in CLT

Withdrawal Resistance in CLT



- **Lag screws driven in <u>edge of CLT panel</u>**
  - Use current Eq. for withdrawal for lumber & glulam for **<u>face</u>** with an adjustment factor for CLT ($J_X = 0.9$) & <u>end grain factor</u>

$$y_w = 0.67 * 59\, d_F^{\,0.82}\, G^{1.77} J_X \; N/mm$$

Conservative: Use 0.67 end grain factor
Less conservative: Use same equation for lags screws driven perp. to panel but ensure side grain penetration occurs

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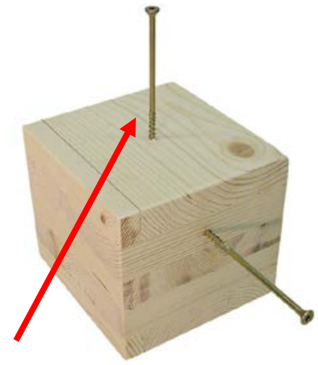
Proposed Fastenings Capacity in CLT

Withdrawal Resistance

- **Nails, spikes and wood screws driven**



$$y_w = 16.4\, G^{2.2}\, d_F^{0.82}\, \boldsymbol{J_X} \quad N/mm$$

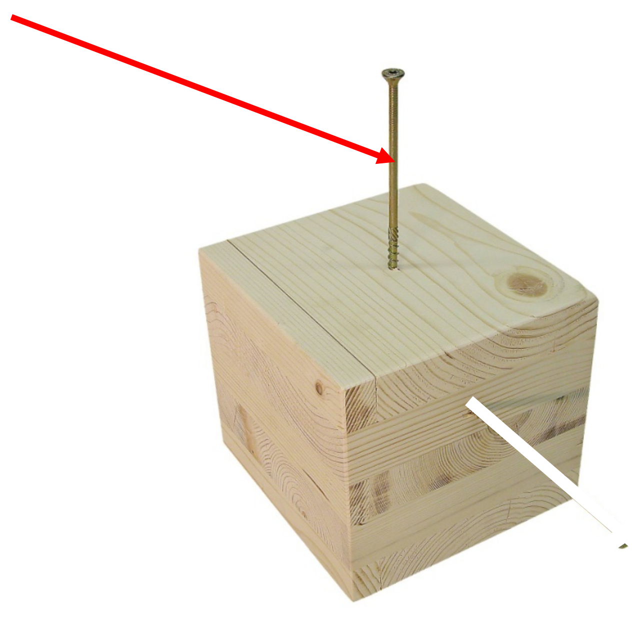
J_X = 0.9 for CLT

- Nails and spikes driven into the end grain shall not be considered to carry load in withdrawal
- Where designs rely on withdrawal resistance of fasteners in panel edge of CLT, precaution shall be taken to ensure that side grain penetration occurs

Fastenings Capacity in CLT

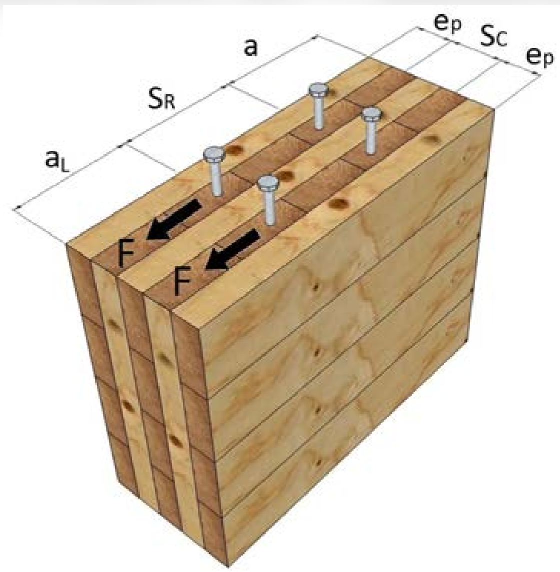
Placement of Fasteners in CLT Panel Face

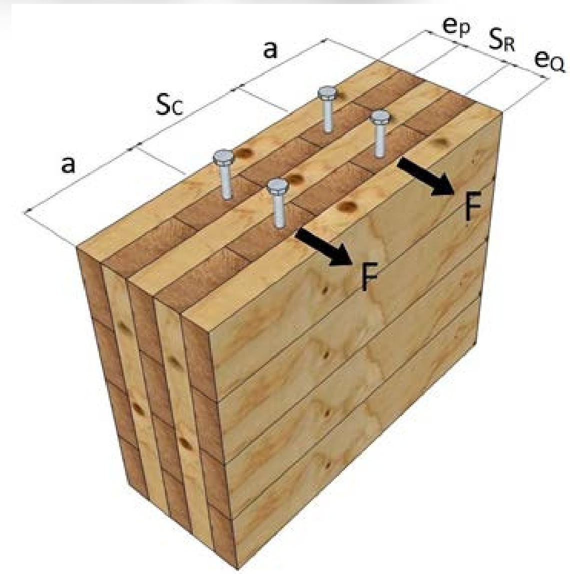
- For all fasteners installed/driven perp. to the panel, <u>current CSA O86 min. spacings and end & edge distances for lumber/glulam apply</u>



Fastenings Capacity in CLT

Placement of Fasteners in Panel Edge





Fastener	S_R	S_C	a_L	a	e_Q	e_P
Nails/ Screws	10d	4d	12d	7d	6d	3d
Bolts	4d	3d	5d/50mm	4d/50mm	5d	1.5d

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In Summary

- Current R&D activities and experience indicate that connections in CLT are:
  - *Simple*
  - *Structurally efficient*
  - *Cost-competitive*
- Proposed design approach for CLT connections is conservative and can be reasonably adopted
- Need to introduce self-tapping screws and CLT in NA timber standards to assist designers

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