FPInnovations™

Creating forest sector solutions

www.fpinnovations.ca

Connections in CLT Assemblies

M. Mohammad

Building Systems
Wood Products Division

2011 UMass Wood Structures Symposium
Amherst, Massachusetts
September 8-9, 2011

Overview

- Importance of connections in CLT assemblies
- Common connection details/techniques in CLT assemblies: European experience
- Summary of recent research on CLT connections
- Proposed European approach for connections design in CLT
- Adoption of European approach in NA design procedure
- Concluding remarks

FPInnovations

CLT Assemblies

- A series of prefabricated CLT panels connected together on site to form an assembly or a building
- Quick on-site erection due to
  - High degree of prefab.
  - Ease of assembly using conventional & innovative fasteners

FPInnovations

Outcome…

Remarkable low, mid & high-rise timber buildings that are pushing the envelope..

FPInnovations

Mixed CLT & Other Wood Based Products

Open Academy, Norwich, UK

Source: http://www.klhuk.com/media

Performance Demands in Timber Connections

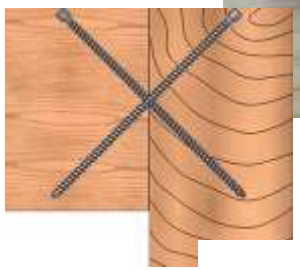
- Easy to design
- Structurally efficient
- Fire resistant
- Aesthetically attractive
- Good serviceability (e.g., shrinkage, stiffness, acoustic)
- Cost-effective & availability
- Easy to assemble (i.e., do not require specialized tools or heavy equipments)

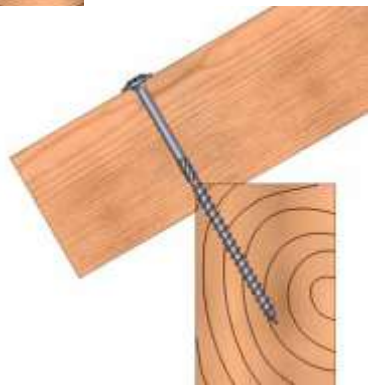
Competitiveness of a timber structure, relative to other building materials, may be determined by the efficiency of the connections, particularly for CLT assemblies

FPInnovations

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)





Source: Log &Timber Connections

FPInnovations

Current CLT Connections Practice in Europe

- Carpentry

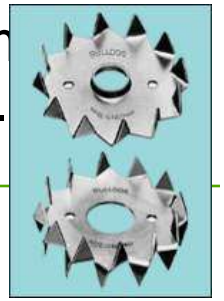
  Using CNC technology to create various types of interlocking profiles (Dovetail connections)

- 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

FPInnovations

Wood and Self-Tapping Screws

- **Extensively used in Europe**
- Easy to install & provide high lateral & withdrawal capacity
- Come in a variety of sizes and features
  - Diameters from **4mm to 12mm**
  - Lengths up to **600mm**
- 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

FPInnovations

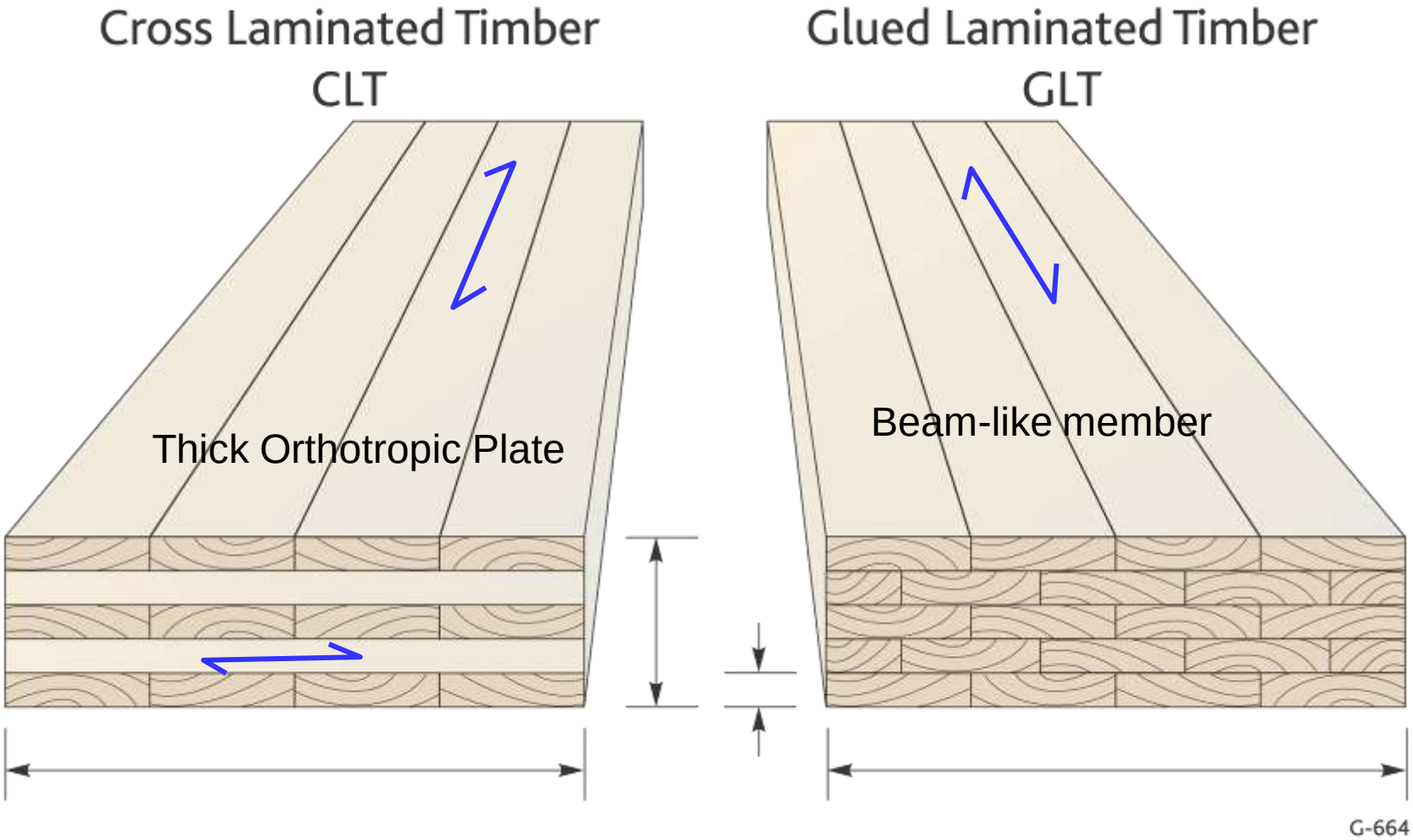
Traditional Fasteners in CLT

Nails and Rivets

- **Not as commonly used** as self tapping screws in CLT
- Nails with specific shank features such as grooved or helically threaded nails are the most commonly used
- Typically used in combination with metal plates and brackets

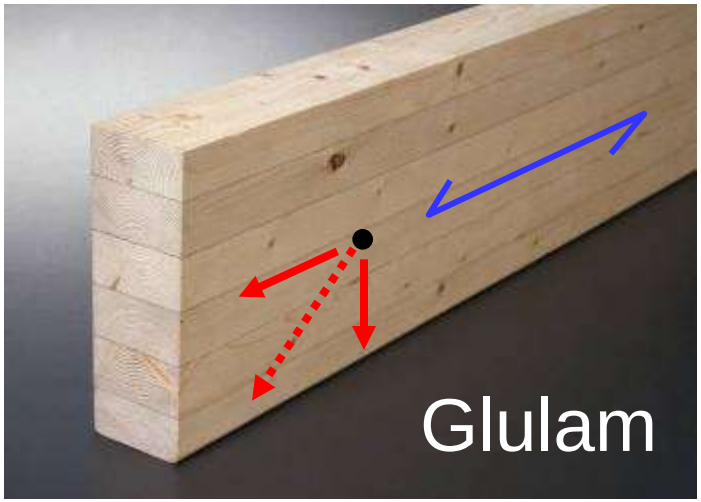
FPInnovations

Why CLT is Different than Glulam?!

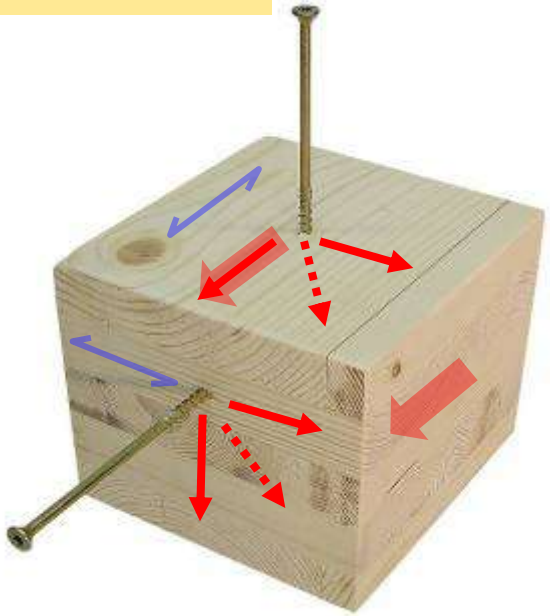


Why Connections in CLT are Different than those in Solid Timber or Glulam?!

Cross Lamination Effect



All laminates are aligned & loaded in the same direction ..



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

FPInnovations

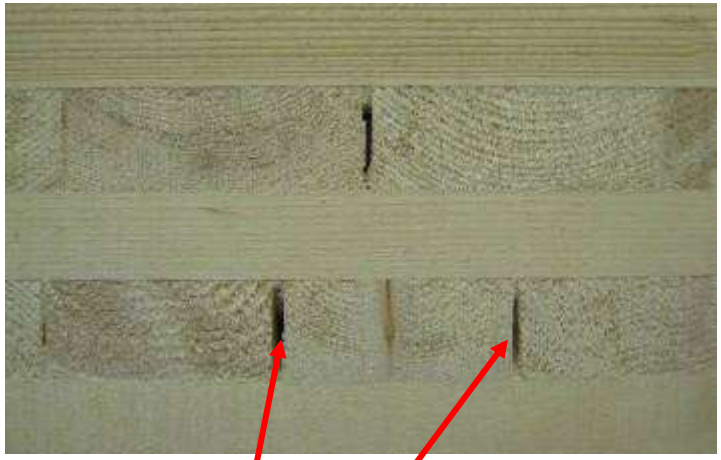
Why Connections in CLT are Different than those in Solid Timber or Glulam?!

Moreover…

Presence of specific CLT panel features such as:

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

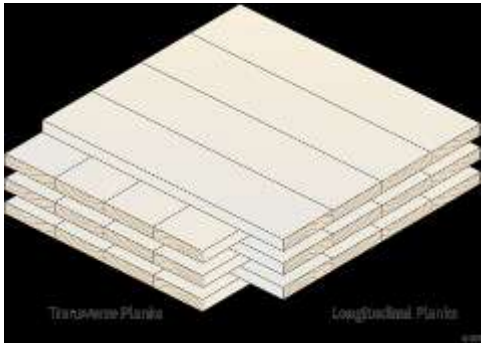
Not common to all CLT products as many products have edge-glued x-lamination



Gaps and grooves

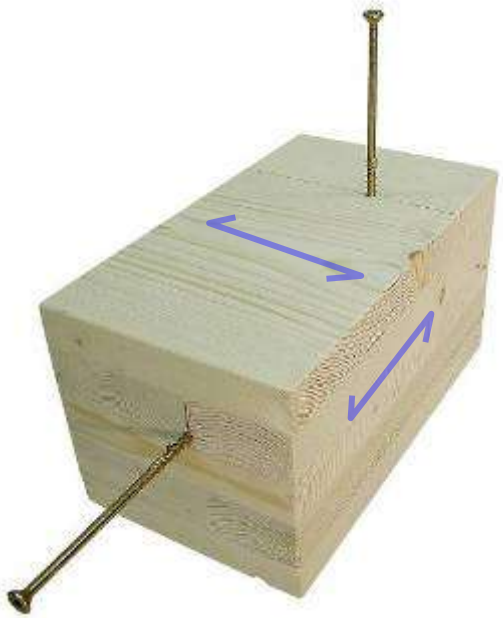
Does that Make Connections Design in CLT more Challenging?

Absolutely NOT!!



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

- However, need to take into account some of the specific features of panels at the design stage (e.g., unglued edges)

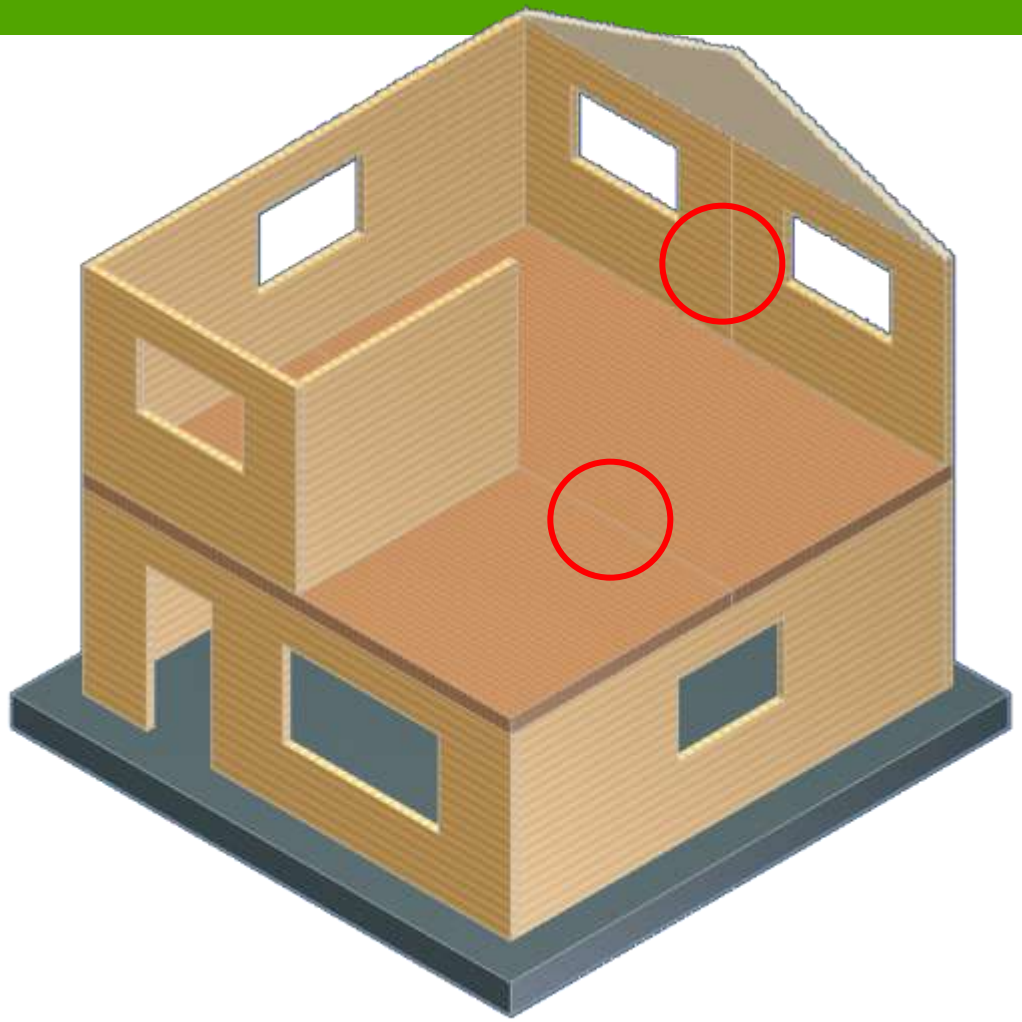


FPInnovations

Connection Details in CLT Assemblies

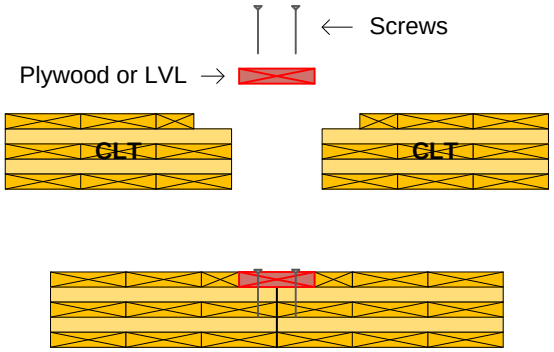
Panel to Panel

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

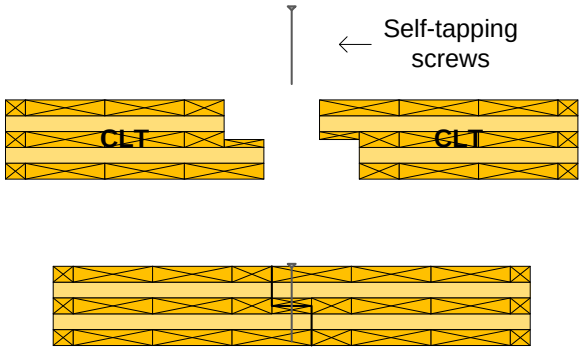


FPInnovations

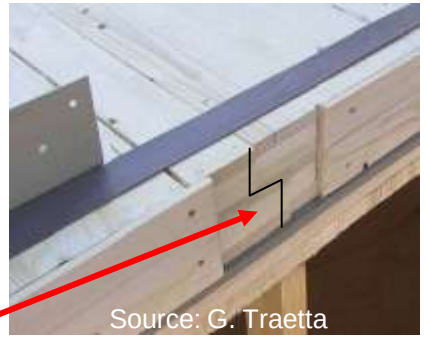
CLT Panel to Panel Connection Details
Traditional Fasteners (Screws, Nails)

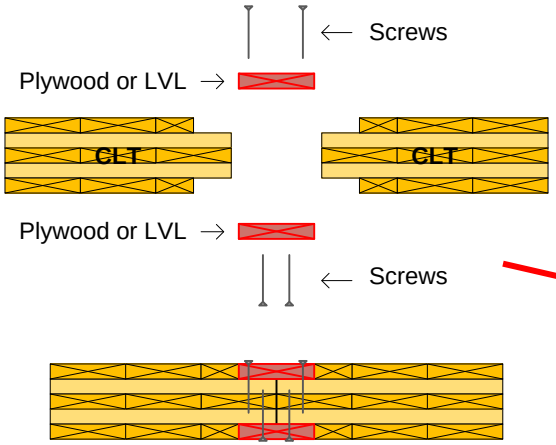


Single surface spline

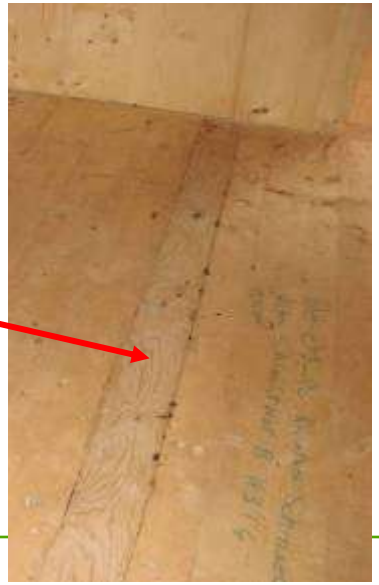


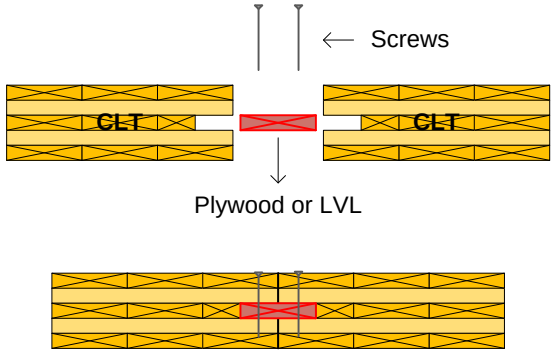
Half-lapped





Double surface spline





Single Internal spline

FPInnovations

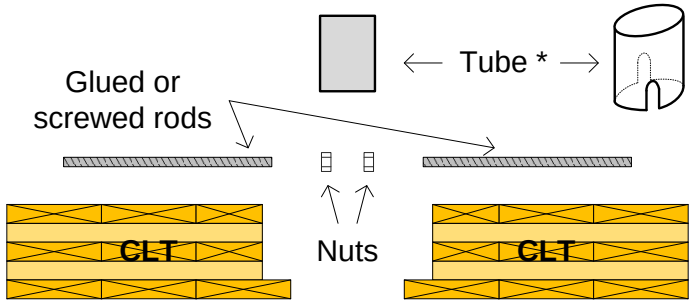
CLT Panel to Panel Connection Details
Traditional Fasteners (Screws, Nails)

Double internal spline

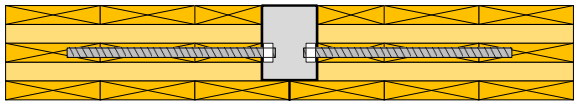
Source: Kevin Meechan
Courtesy WoodWorks

FPInnovations

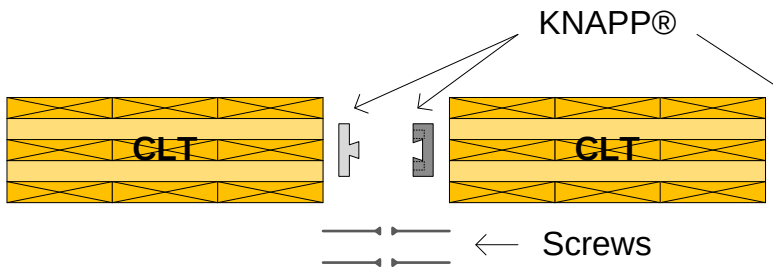
Innovative Systems for CLT Panel to Panel Connections



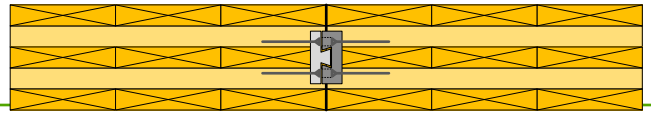
Tube connection system



(Source:Traetta & Schickhofer)



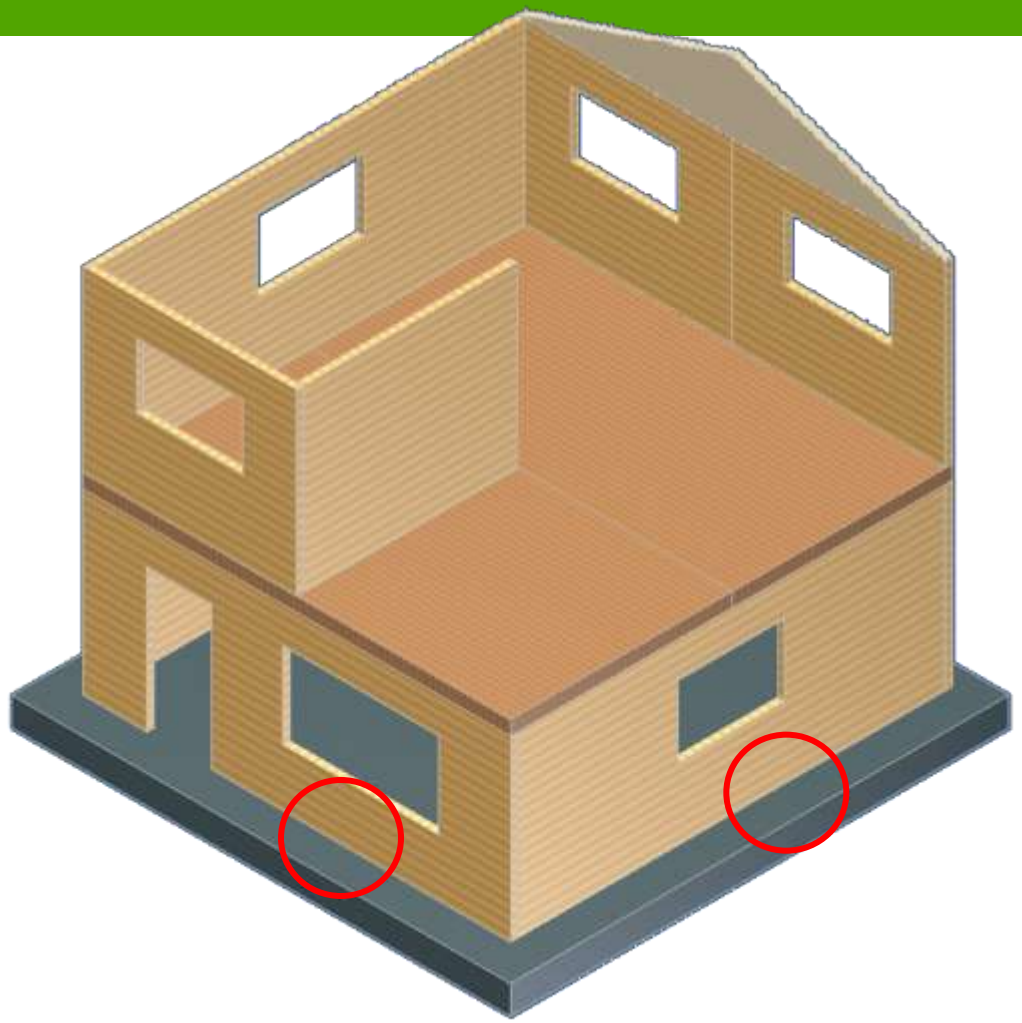
Knapp® connection system



FPInnovations

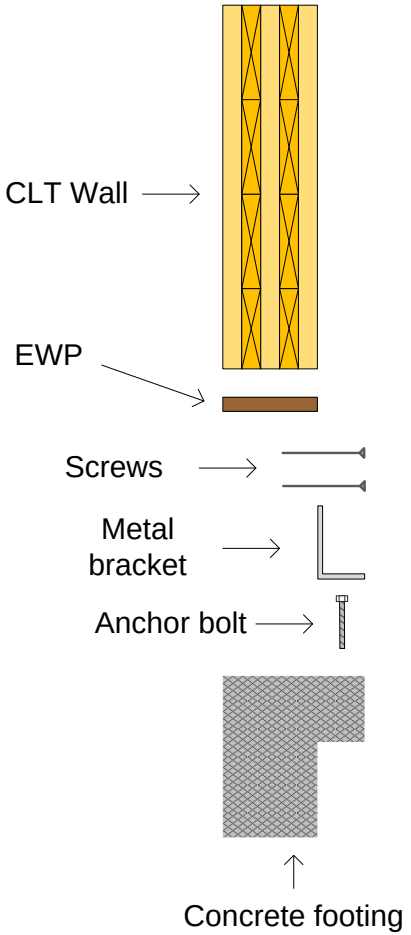
Connection Details in CLT Assemblies

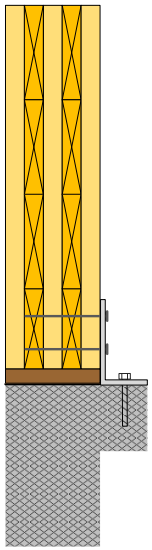
CLT wall to concrete foundation

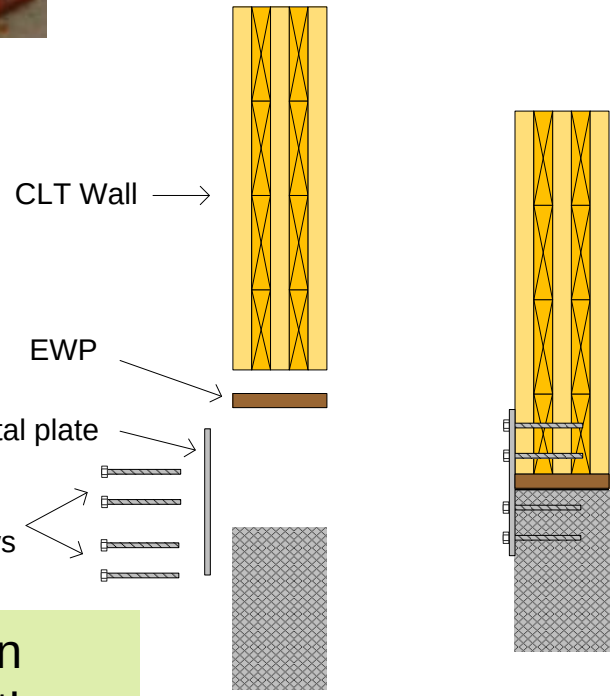


FPInnovations

CLT Wall to Concrete Foundation



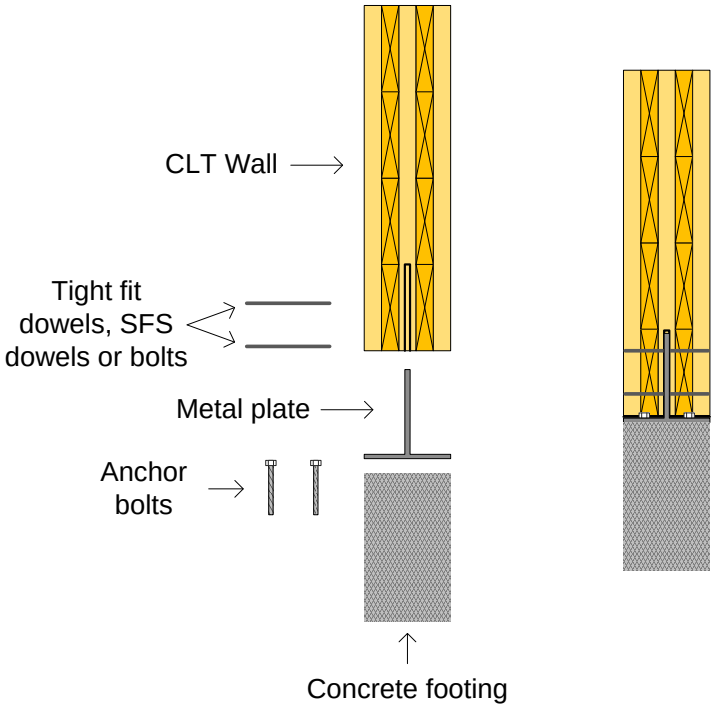




CLT wall to concrete wall or foundation slab using metal brackets or plates with anchor bolts & self tapping screws/lag bolts

FPInnovations

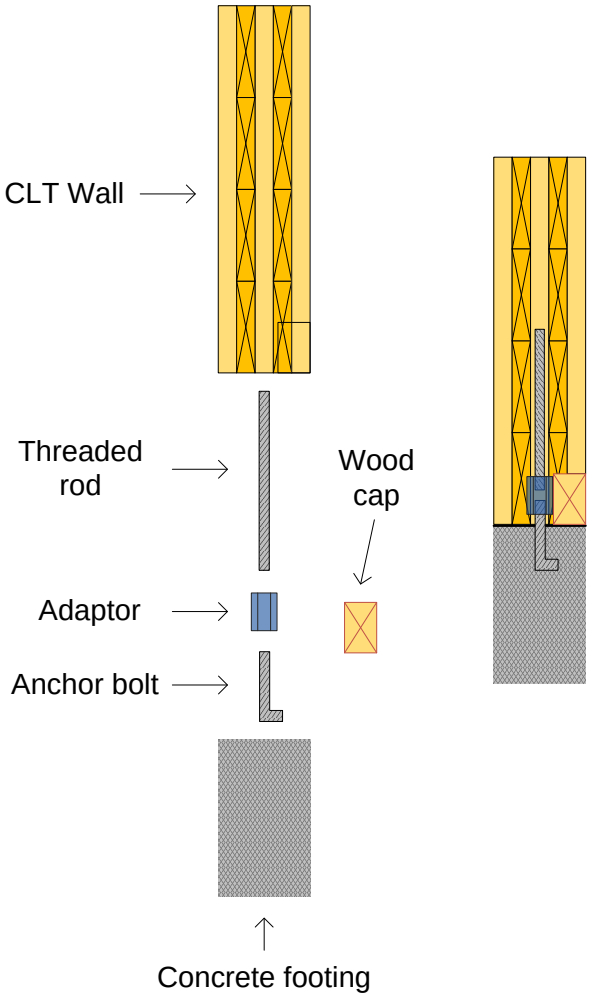
CLT Wall to Foundation: Internal/concealed Metal Plates



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

FPInnovations

CLT Wall to Foundation Connection Details



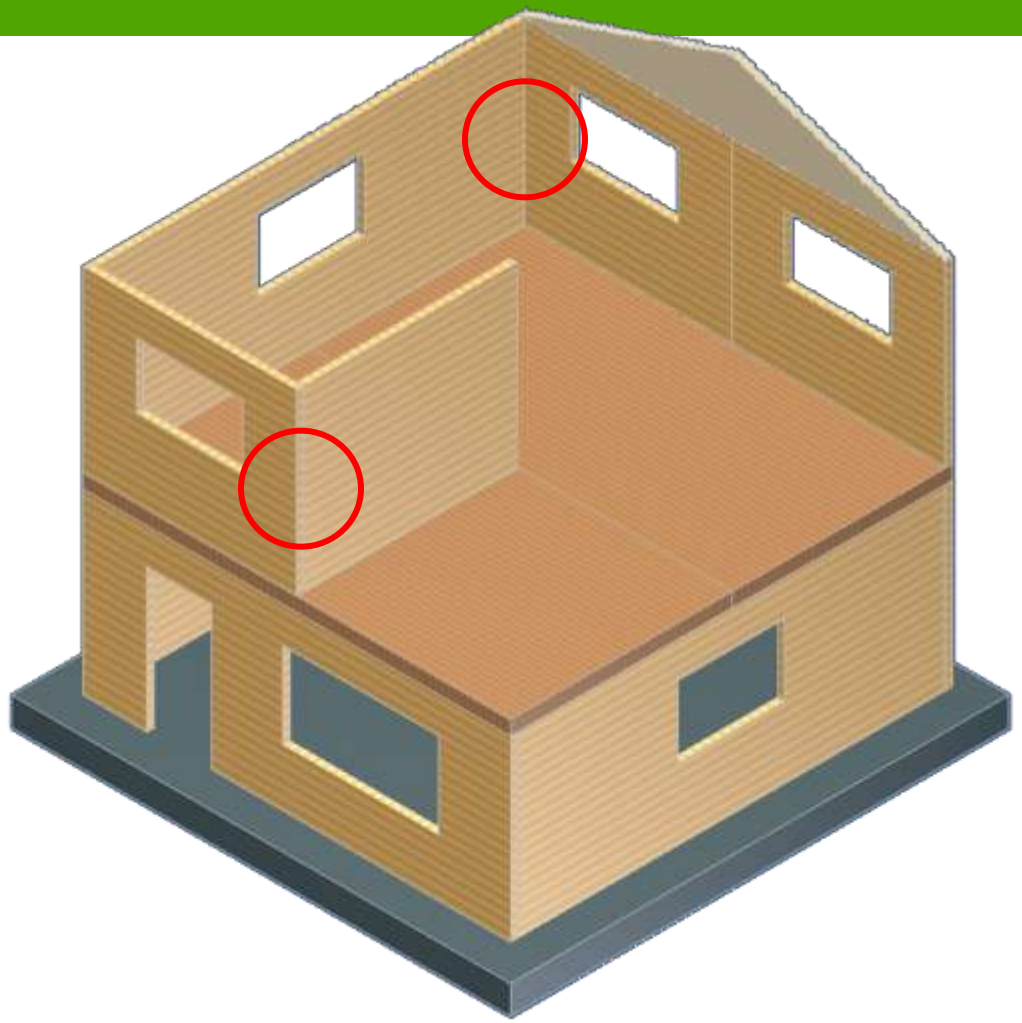
Threaded rod/screw connection system

FPInnovations

Connection Details in CLT Assemblies

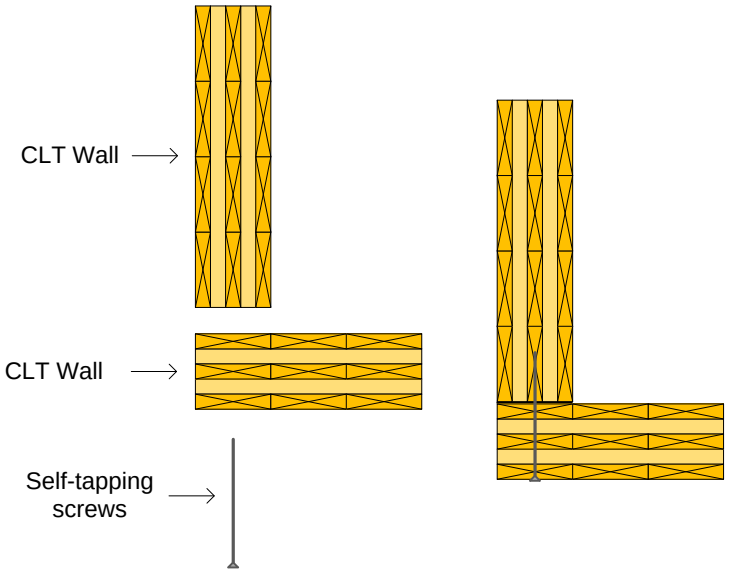
Wall to Wall

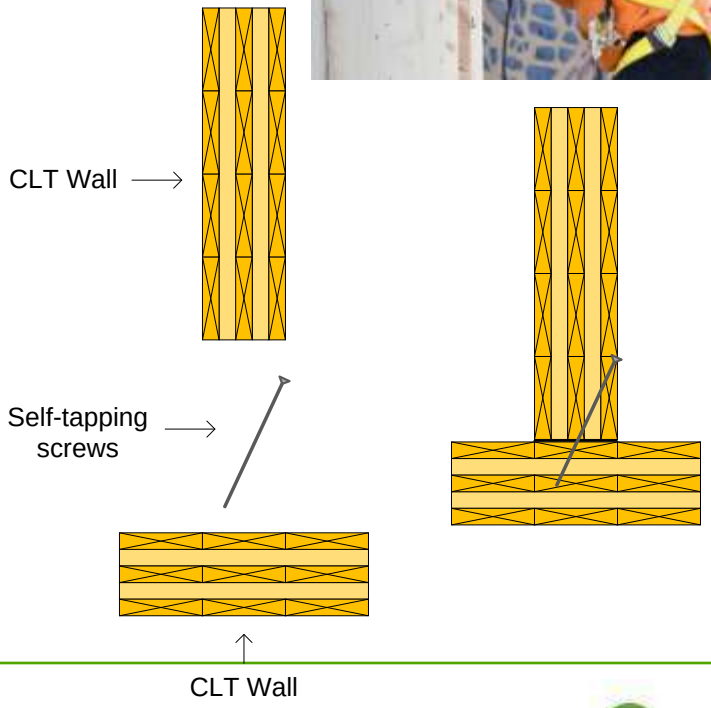
(i.e., exterior & interior walls intersections)



FPInnovations

Wall to Wall Connections in CLT – Self Tapping Screws

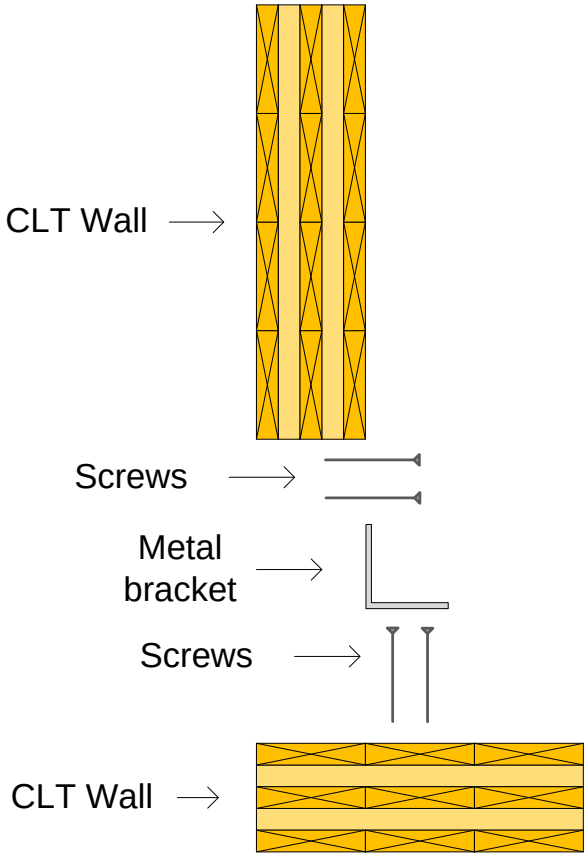


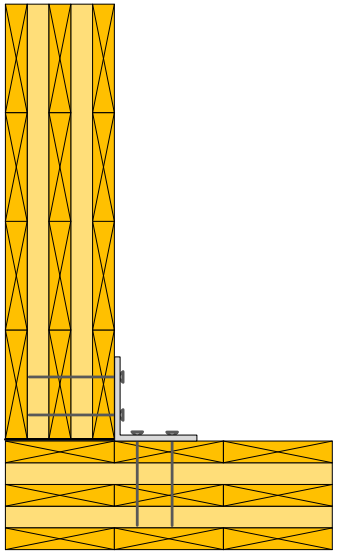


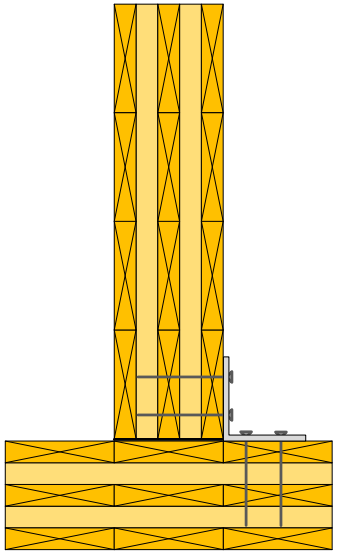
Self tapping driven perp. to panel or @ an angle
(Simplest form of connecting walls to walls)

FPInnovations

Wall to Wall Connections in CLT – Metal Brackets



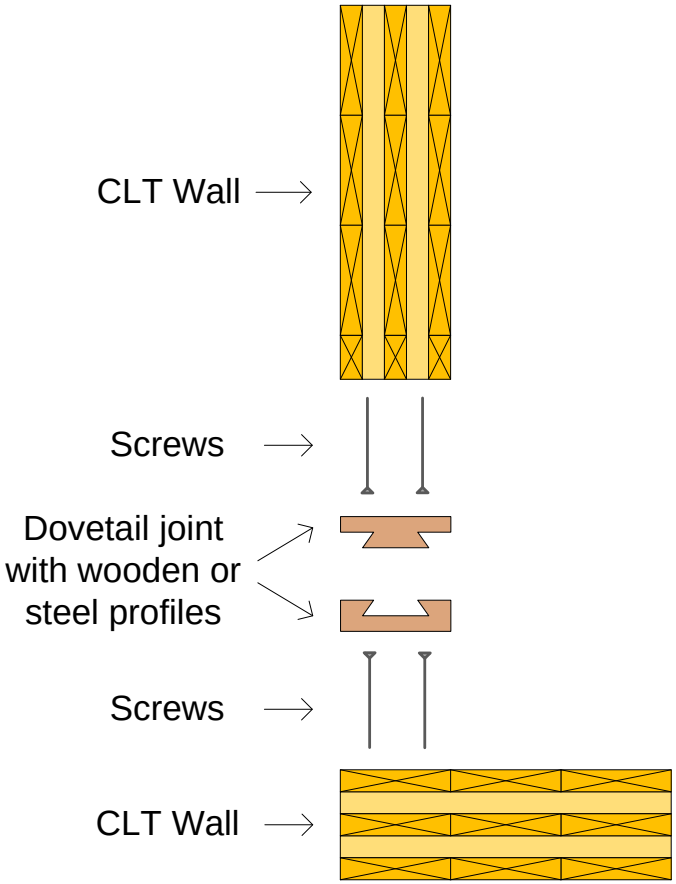




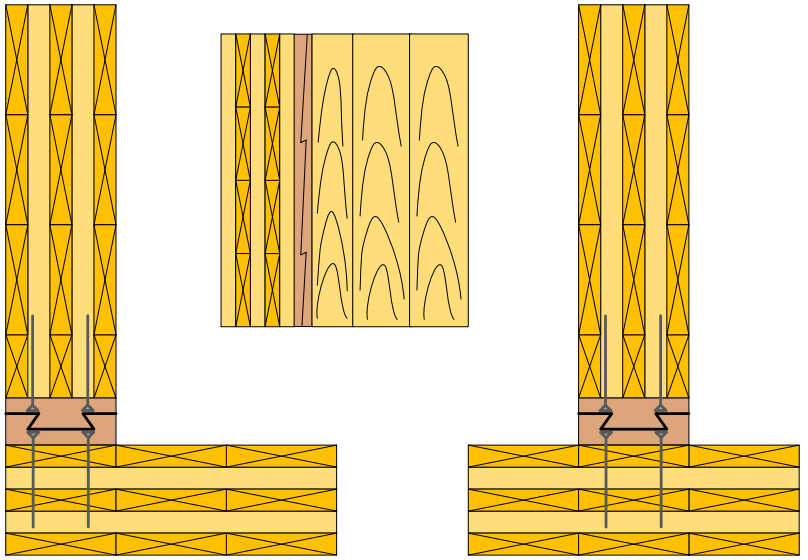
A combination of nails or self drilling screws and metal brackets

FPInnovations

Wall to Wall Connections in CLT – Alternative/ Innovative Systems

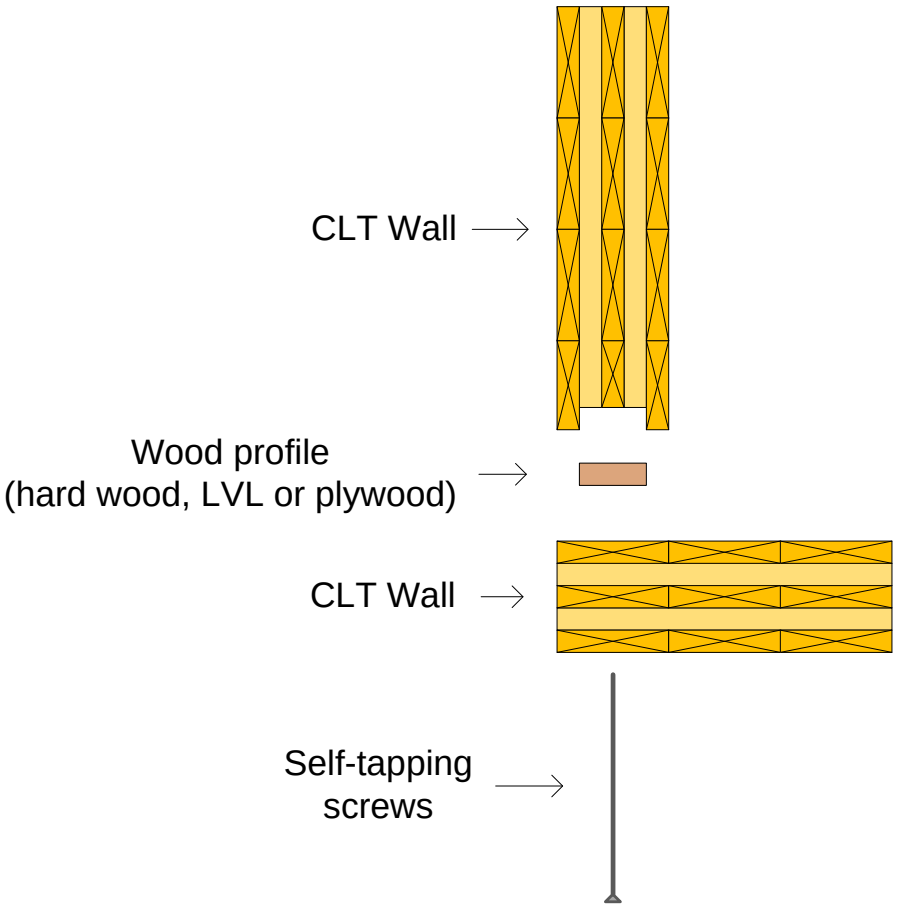


Dovetail connection system

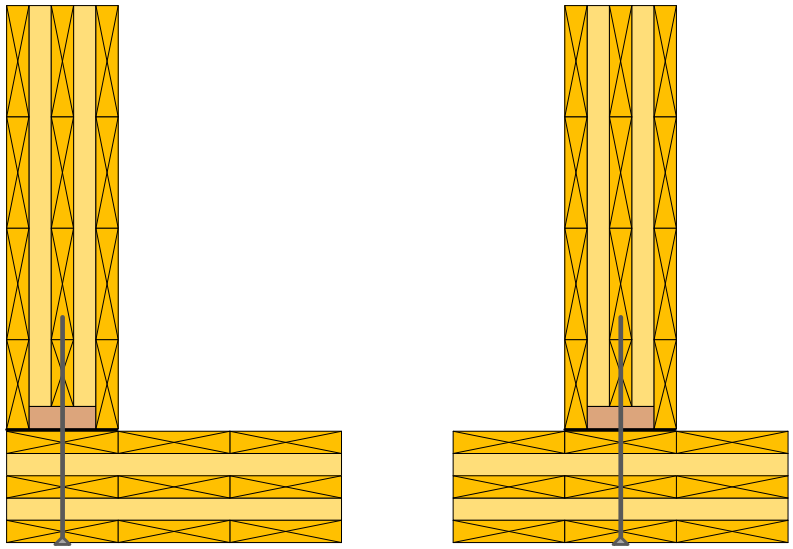


FPInnovations

Wall to Wall Connections in CLT – Alternative/ Systems



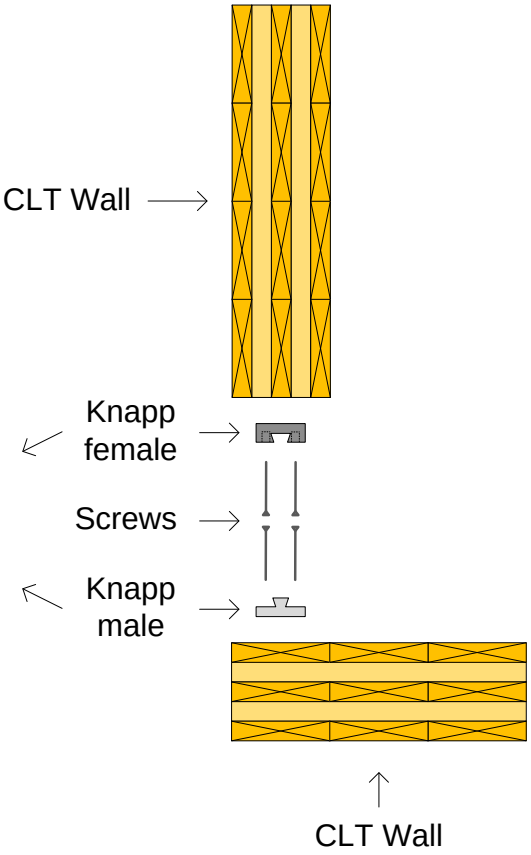
Dovetail connection system

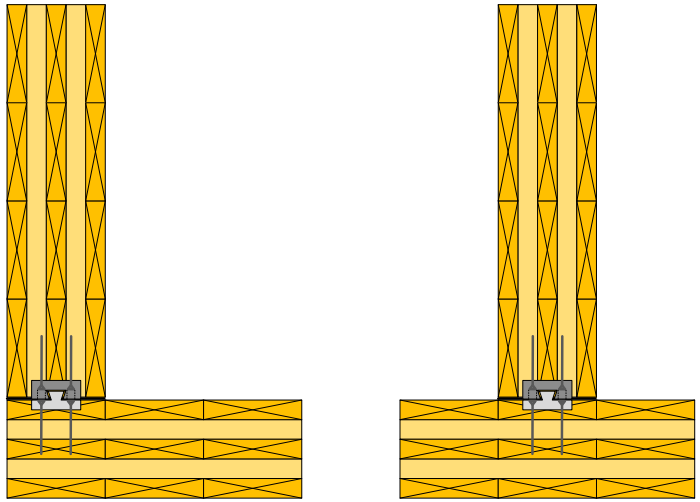


FPInnovations

Wall to Wall Connections in CLT – Alternative/ Innovative Systems

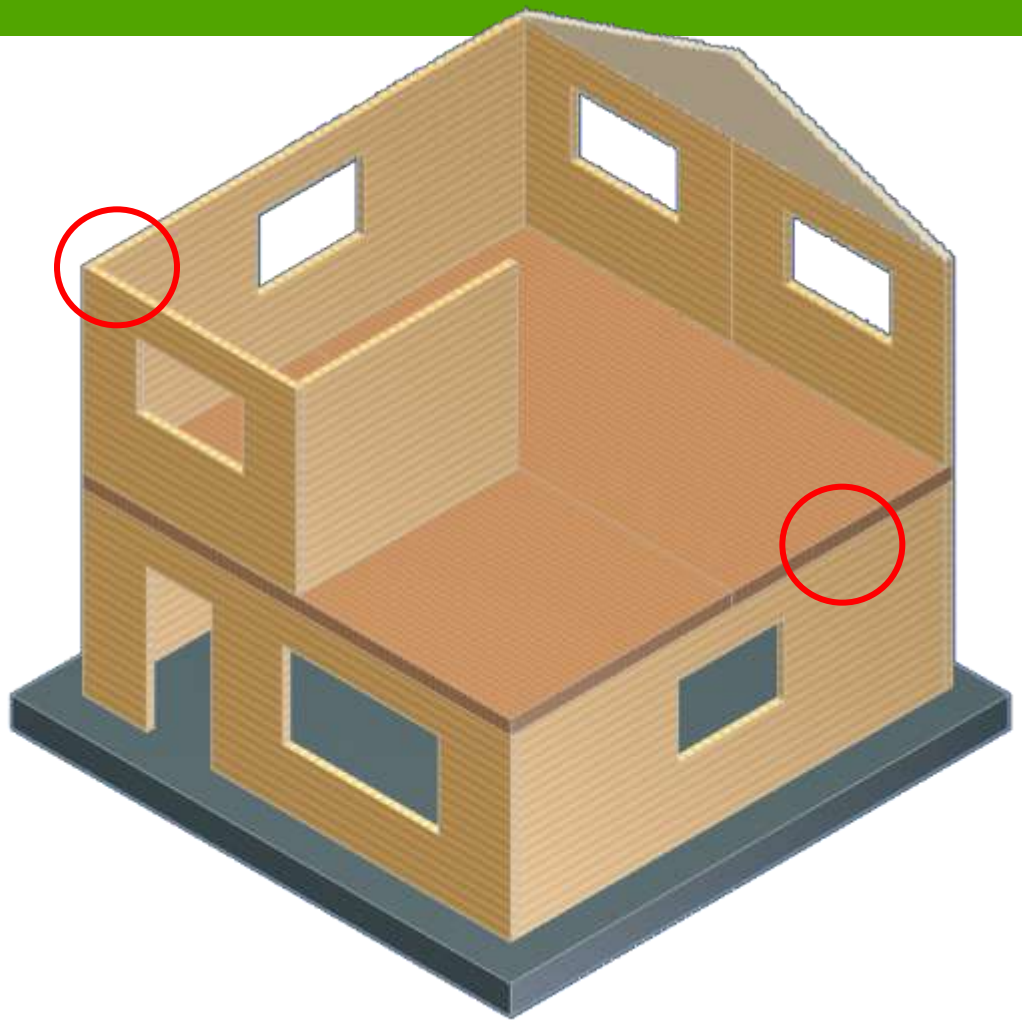
Knapp® connection system





FPInnovations

Connection Details in CLT Assemblies

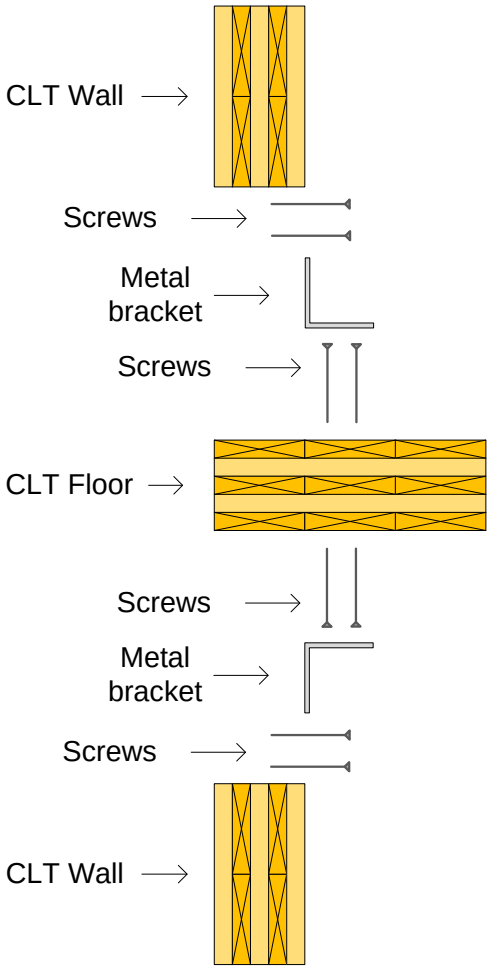


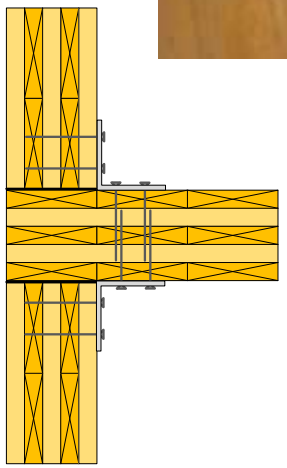
Wall to Floor/Roof

Platform or Balloon type

FPInnovations

CLT Wall to Floor/Roof Connection Details - Platform

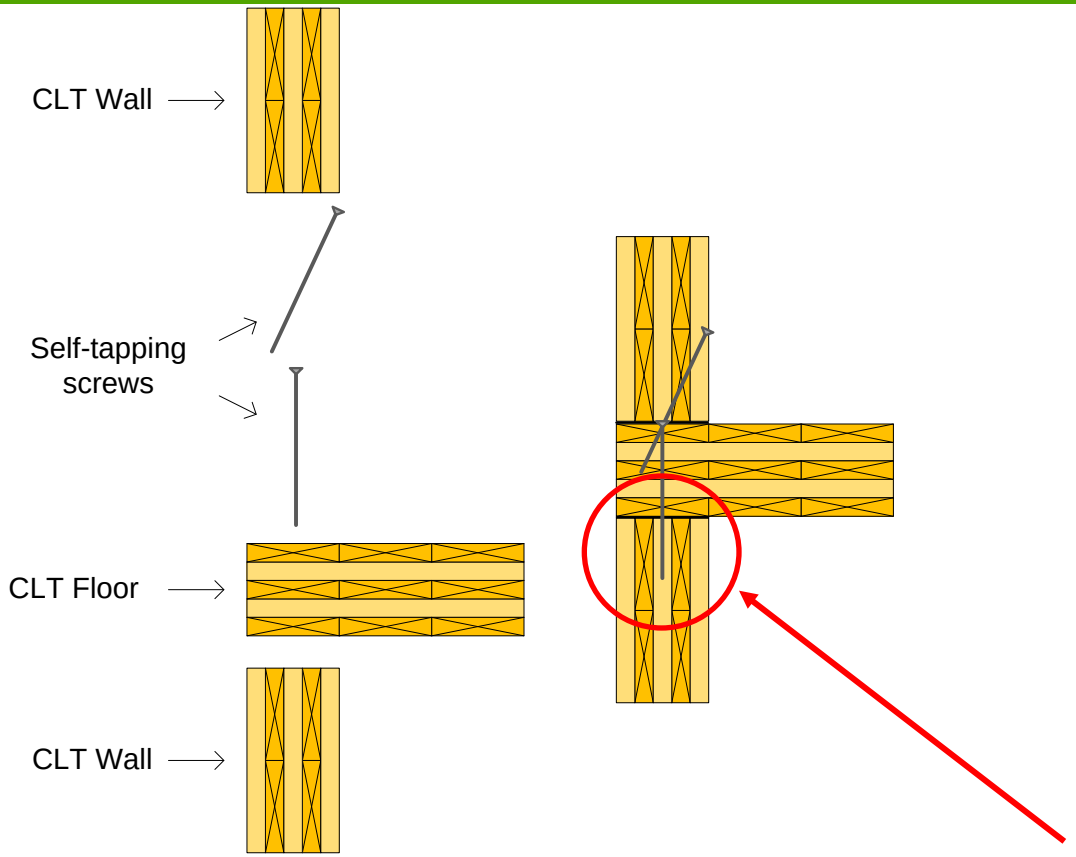




Most commonly used connection system in CLT assemblies in Europe

FPInnovations

CLT Wall to Floor/Roof Connections: Platform

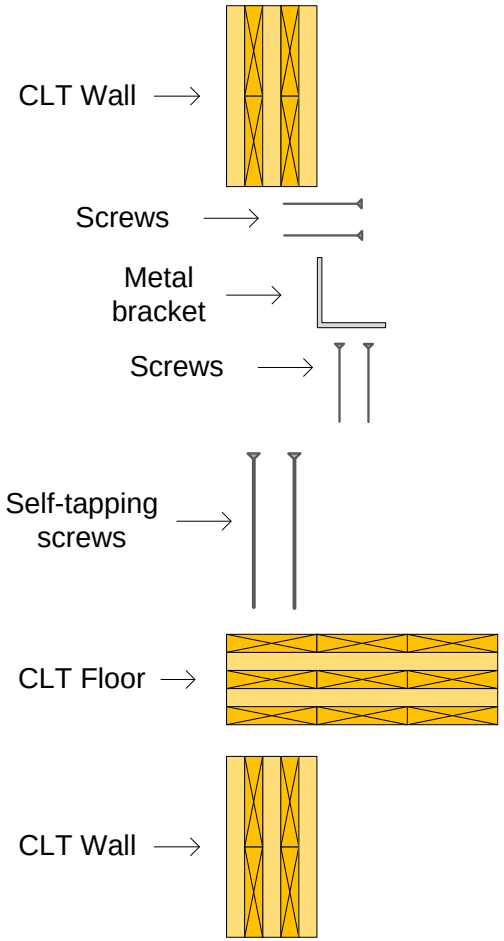


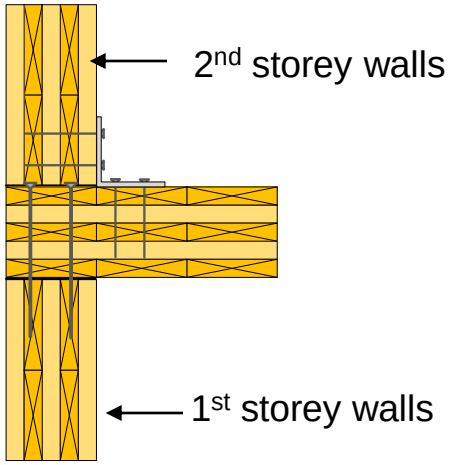
Use of self-tapping screws (Simplest form of connection)

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

FPInnovations

CLT Wall to Floor/Roof: Combination of Several Systems



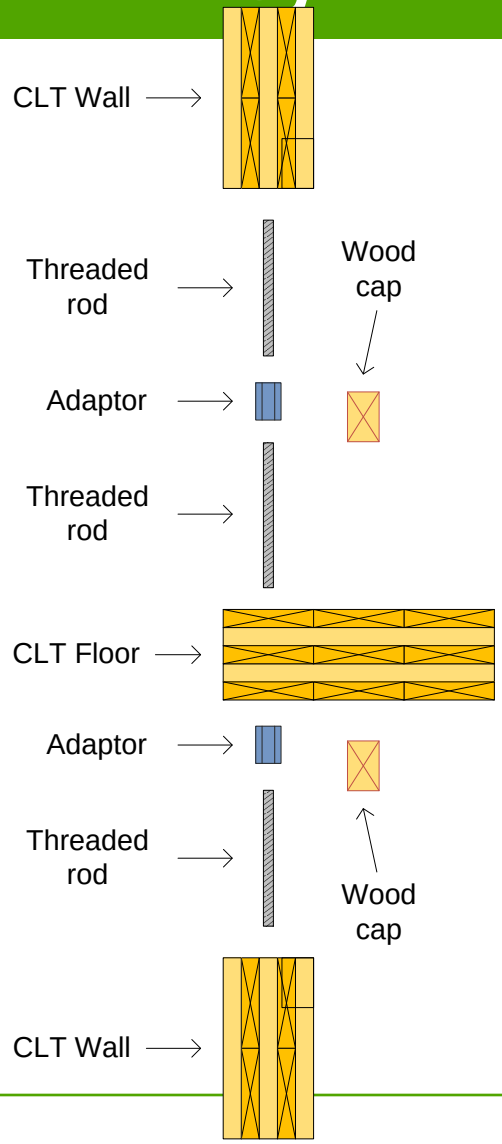


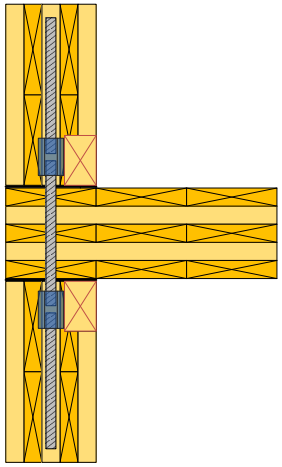
1st storey wall to floor/roof → self tapping screws

2nd storey wall to floor → combination of metal brackets and nails or screws

FPInnovations

CLT Wall to Floor/Roof Connections - Alternative / Innovative Systems



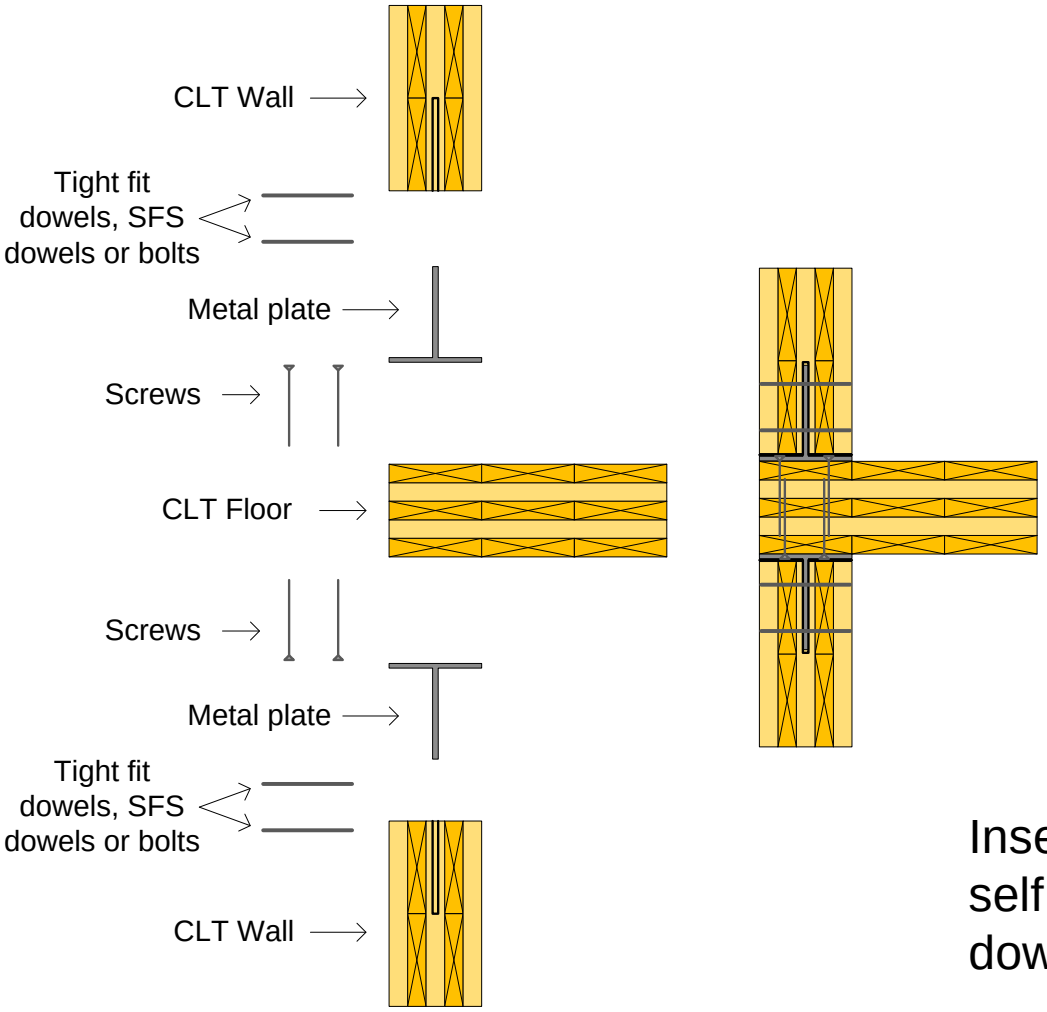


Source: SFSIntec

Innovative long threaded rod with adopters

FPInnovations

CLT Wall to Floor/Roof Connections - Alternative Systems



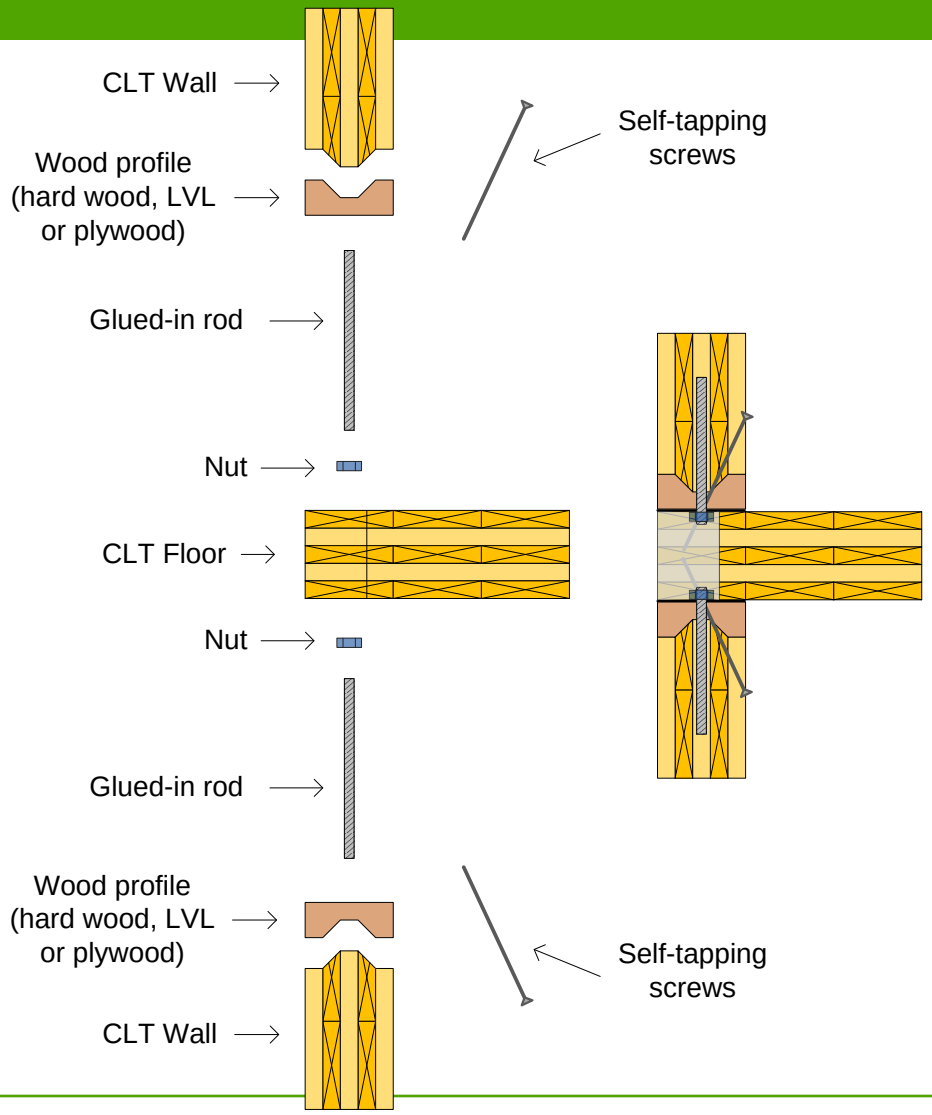
Source: M. Augustin /ITE

Inserted/concealed metal plates with self drilling dowels or traditional dowels and screws

FPInnovations

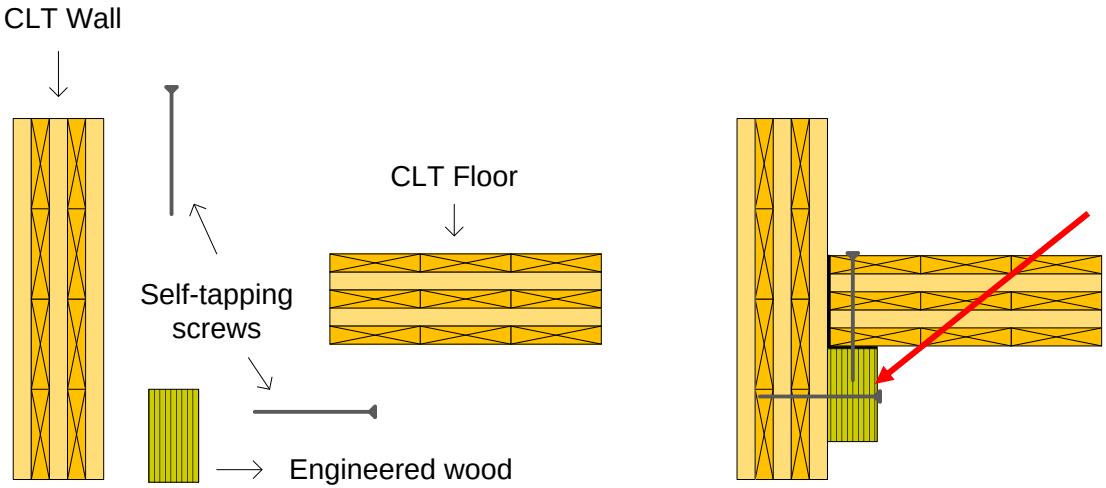
CLT Wall to Floor/Roof Connections – Alternative Systems

Glued-in rods



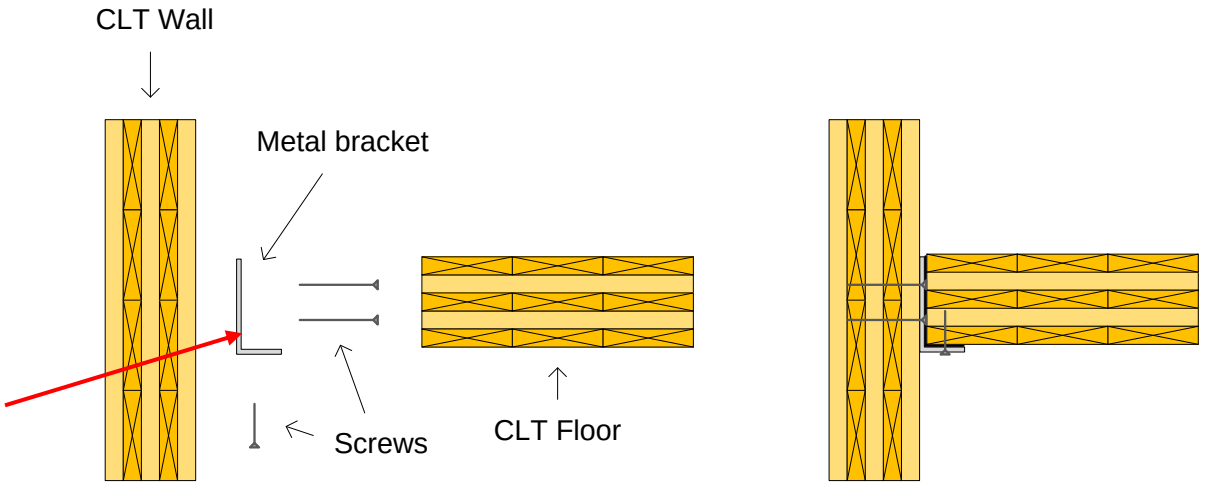
FPInnovations

CLT Wall to Floor/Roof Connections- Balloon Type



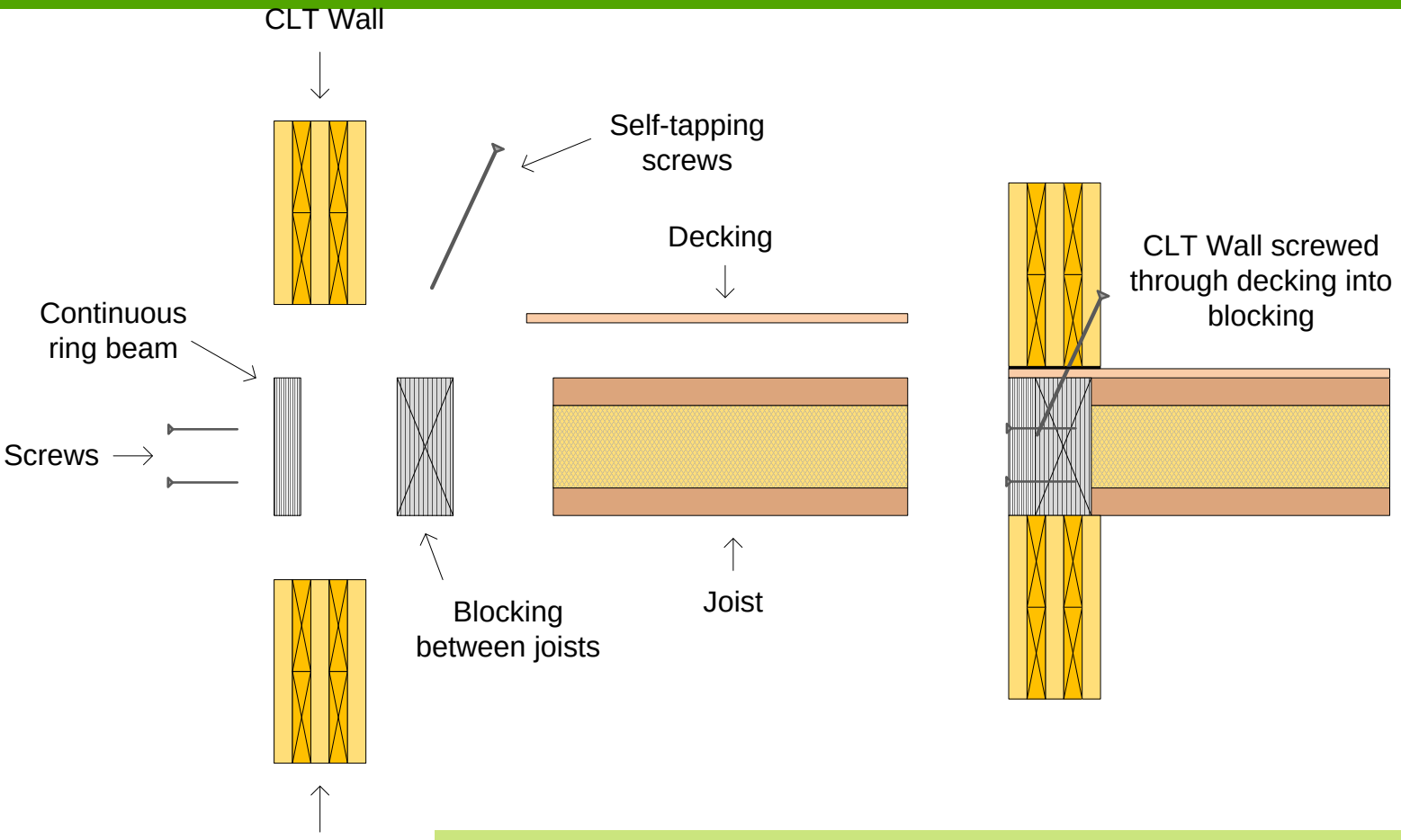
Use of EWP ledger with lag or self tapping screws (e.g., mezzanine, wall parapets, etc.)

Metal bracket with lag or self tapping screws



FPInnovations

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

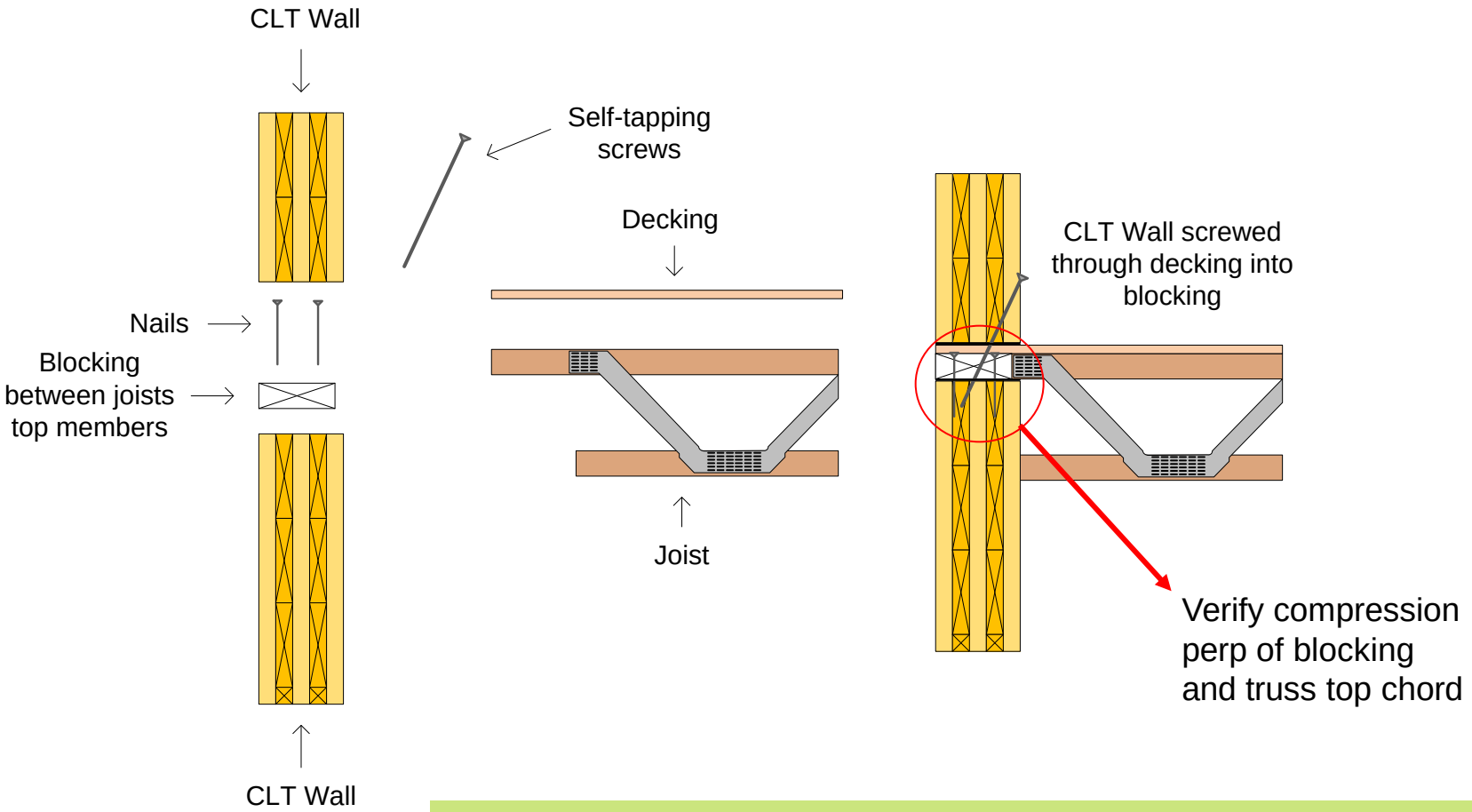


CLT Wall & I-joisted floor with EWP rim board and blocking. Self tapping screws are used

Adopted from TRADA

FPInnovations

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

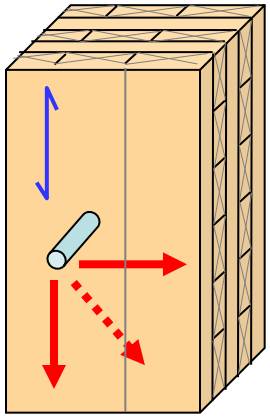
FPInnovations

Designing Connections in CLT – Challenges and Complications…

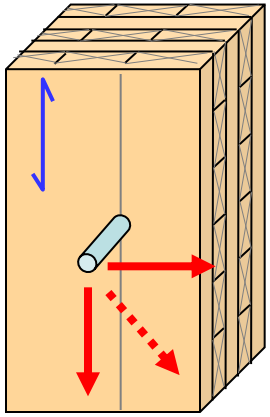
Fastener driven perp. to the CLT panel

Different positions relative to edge gaps between lamina:

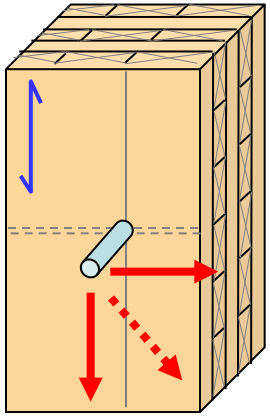
Some possible scenarios



Outside gaps



In outer layer gap



In both outer and X-layers gaps

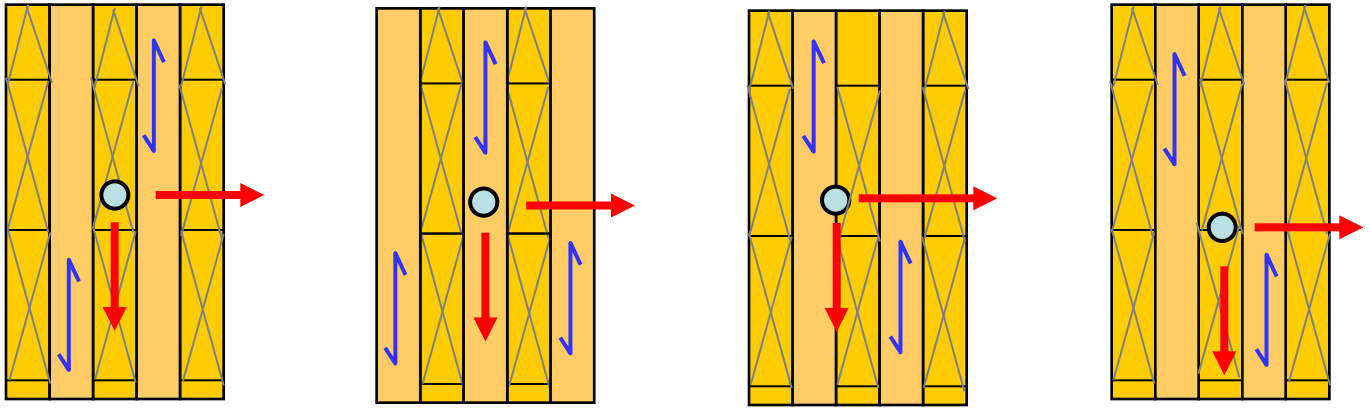
- Not an issue for slender fasteners
- May need to consider in design of large diameter fasteners (i.e., bolts, dowels)

Fastener Driven on Edge…….. Challenges and Complications…

Small fasteners

d ≤ lamina thickness

Some possible scenarios..



Driven // to grain

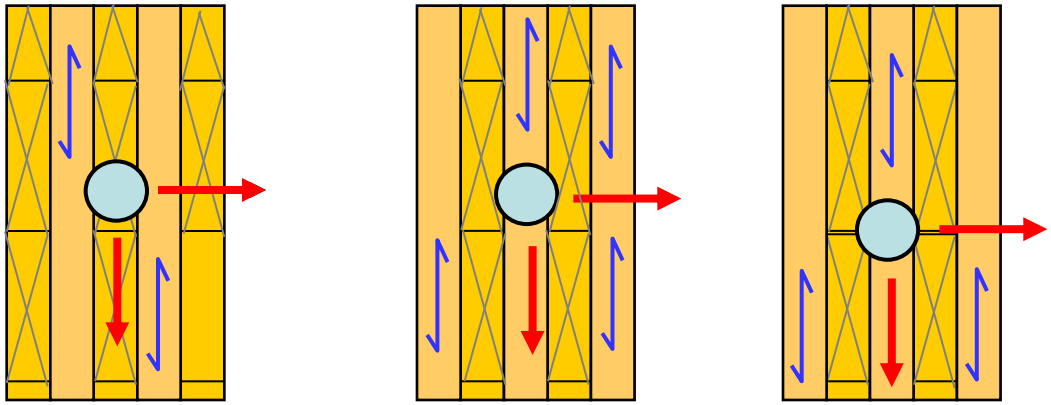
Perp. to grain

Between 2 lamina

// & in gap

Large fastener

d > lamina thickness



// to grain

Perp. to grain

// & in gap

// & in gap

FPInnovations

Research on CLT Connections – European Experience

- Extensive research in Germany, Austria & Norway 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

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

Source: Uibel and Blass (2006)

- A simplified calculation methodology developed to establish the fastening capacity with screws, nails and dowels based on the embedment strength

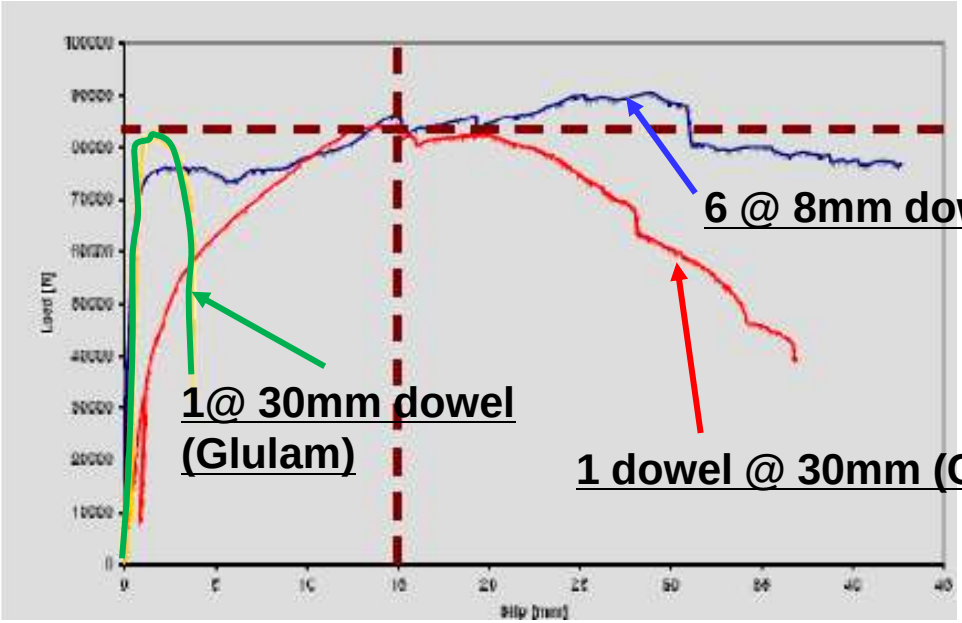
  (Uibel & Blass 2006, 2007)

Source: M. Augustin /ITE

FPInnovations

Behavior of Connections in CLT: European Tests

5-layered CLT to steel connections: Comparison with glulam



High ductility

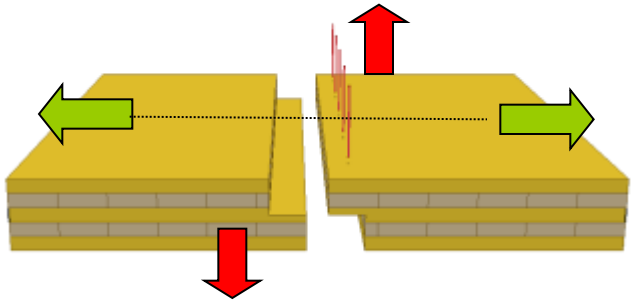
Source: Traetta 2007

FPInnovations

Connections Research Activities @ FPInnovations
Exploratory Study

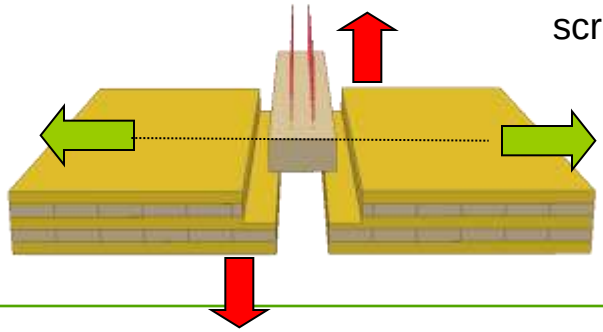
Half-lapped (step) joint

Self tapping screws

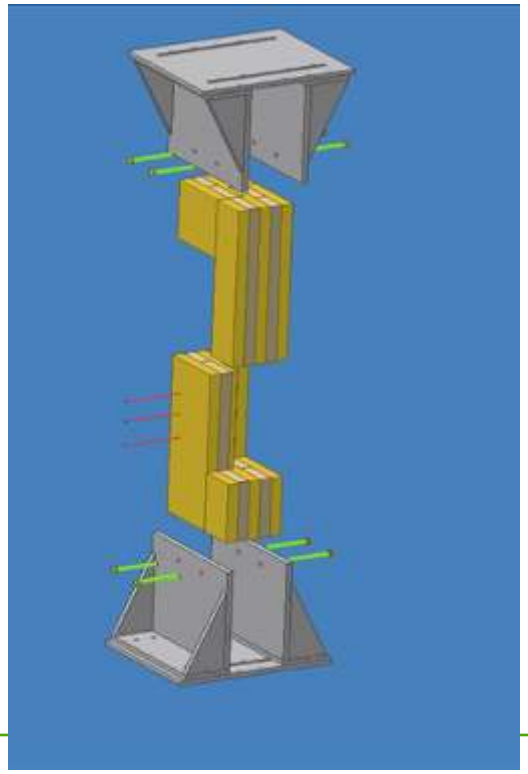


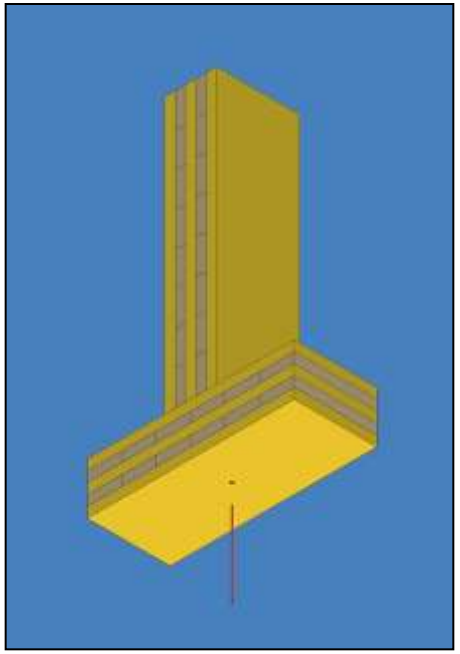
Single Spline joint

Wood screws



-Lateral and withdrawal tests using European CLT
- Screws in CLT with 2 panel-to-panel profiles

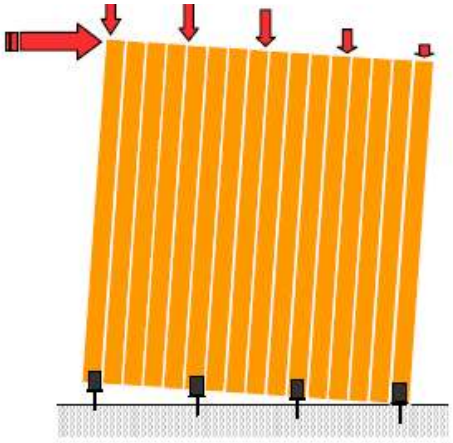




FPInnovations

Testing of Connections in CLT (CLT walls) FPInnovations

Seismic performance of CLT walls is governed by connections

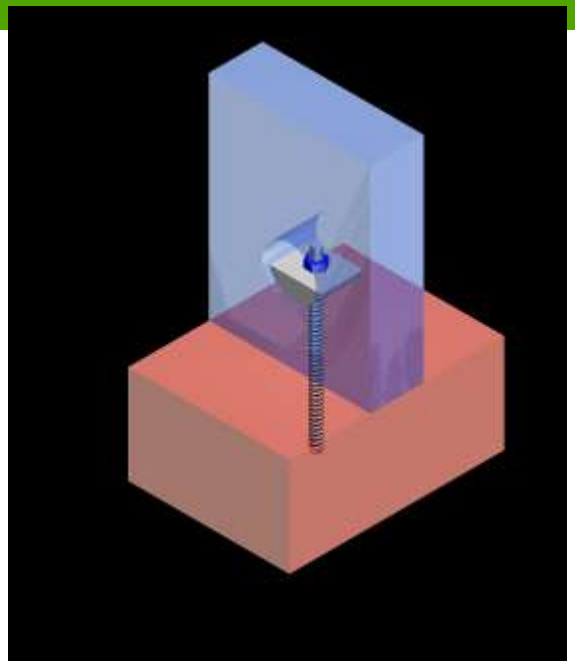


FPInnovations

Development of Innovative Connection Systems Concepts in CLT @ FPInnovations

Design concepts developed..

Testing is underway..

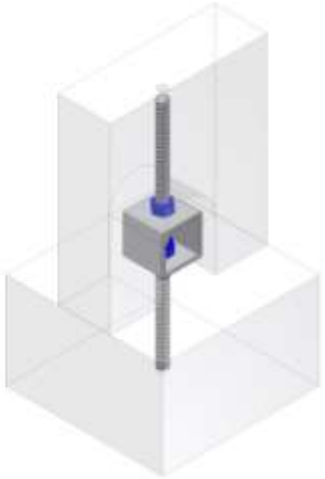


Concept 1: Bearing washer (Prototype)

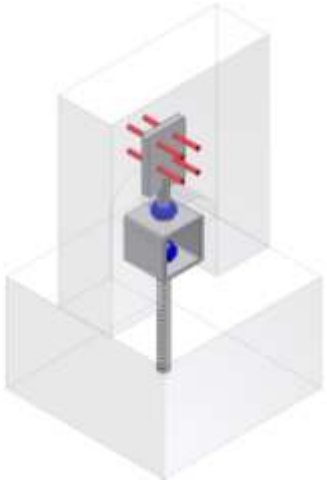
Capitalize on the high bearing resistance of wood

FPInnovations

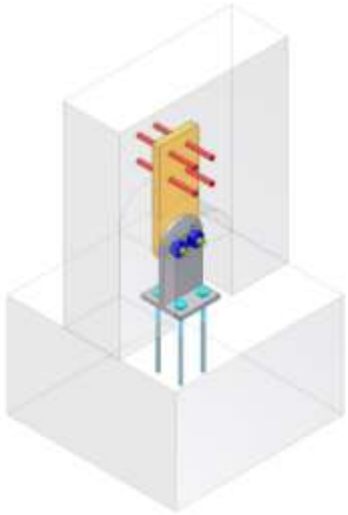
Development of Innovative Connection Systems Concepts in CLT @ FPInnovations



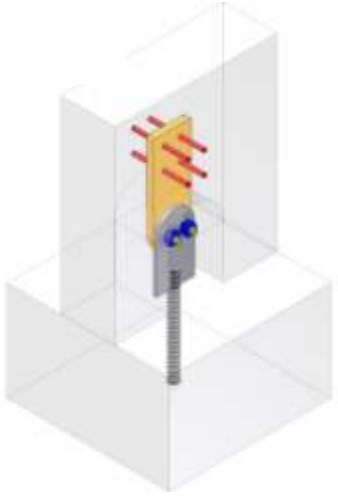
Concept 2



Concept 3



Concept 4



Concept 5

Adopting CNC technology & allowing for quick assembly/disassembly

Reduce to steel-to-steel connections

FPInnovations

Proposed 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..
- Use the embedment eqs. in EC5 (EYM) to determine the resistance of connections (i.e., similar to those used for solid timber/glulam)
- Min. spacing & edge and end distances are specified to minimize brittle failure mode in CLT

Withdrawal Resistance

- Derive withdrawal resistance eqs. empirically by tests.

FPInnovations

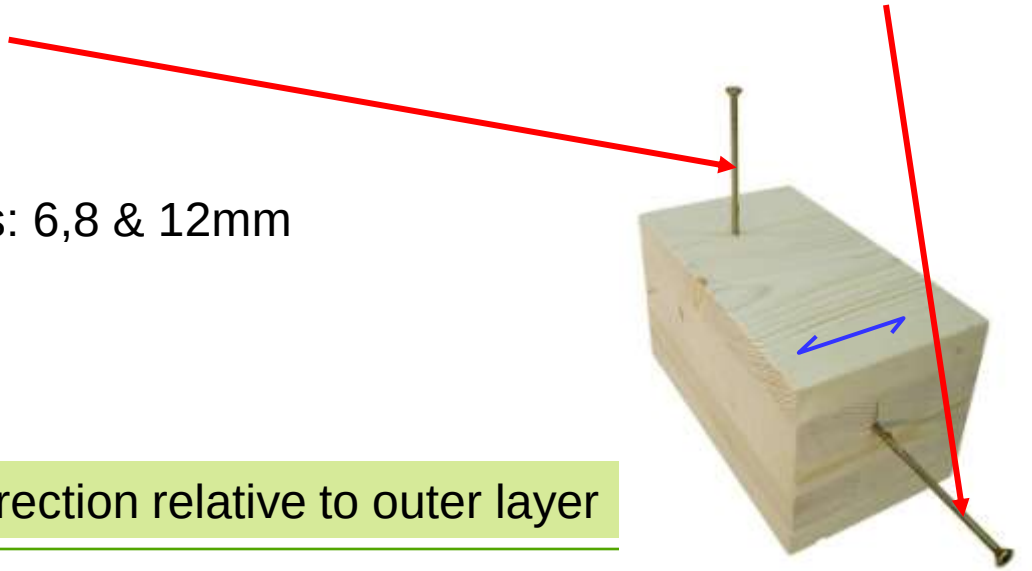
Proposed Calculation Methodology for Embedment Strength – Europe Over 1300 Tests

Nails & Screws – Generalized Approach

Perp. To Plane	On Edge
$f_{h,k} = 0.112\, d^{-0.5}\ \rho_k^{1.05} \quad (N/mm^2)$	$f_{h,k} = 0.862\, d^{-0.5}\ \rho_{ply,k}^{0.56} \quad (N/mm^2)$

Validity

- Nails: 4.2mm, Screws: 6,8 & 12mm
- ≤ 7mm thick lamina



Independent of loading direction relative to outer layer

FPInnovations

Proposed Empirical Models for Characteristic Embedment Strength - Europe

Bolts & Dowels

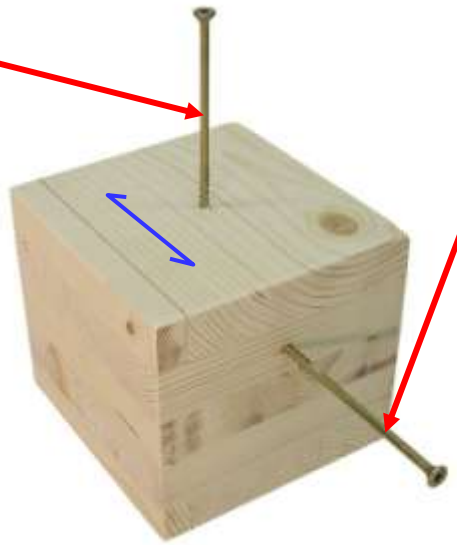
Perp. To Plane

$$f_{h,k} = \frac{0.031(1-0.015\,d)\,\rho_k^{1.16}}{1.1\sin^2\alpha+\cos^2\alpha} \quad (N/mm^2)$$

On Edge

$$f_{h,k} = 0.0435(1-0.017\,d)\,\rho_{ply,k}^{0.91} \quad (N/mm^2)$$

Independent of panel build-up, but function of loading direction relative to outer layer



Validity

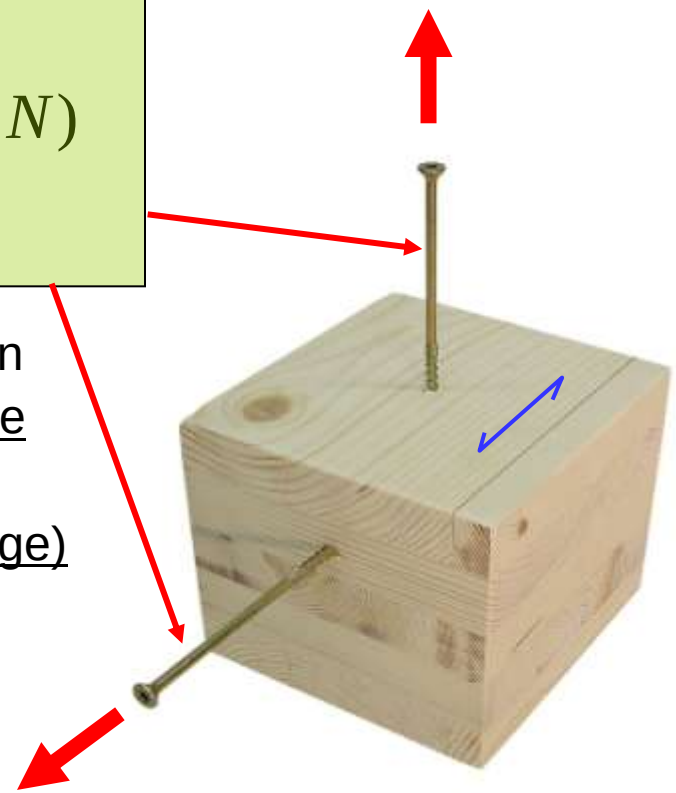
- 40mm thick lamina or less
- $0.94<t_1/t_2<2.1$
- Min. penetration 3 layers

FPInnovations

Proposed Withdrawal Resistance of Self-tapping Screws in CLT – Over 380 tests

Driven Perp. to Plane or on Edge

$$R_{ax,s,k} = \frac{0.35\, d^{0.8}\, l_{ef}^{0.9}\, \rho_k^{0.75}}{1.5\cos^2\varepsilon + \sin^2\varepsilon} \quad (N)$$



Where

ϵ = angle between screw axis and CLT grain direction

ρ_k= density of CLT panel (fasteners driven perp. to the plane of the panel); Or

density of relevant layers (fasteners driven on edge)

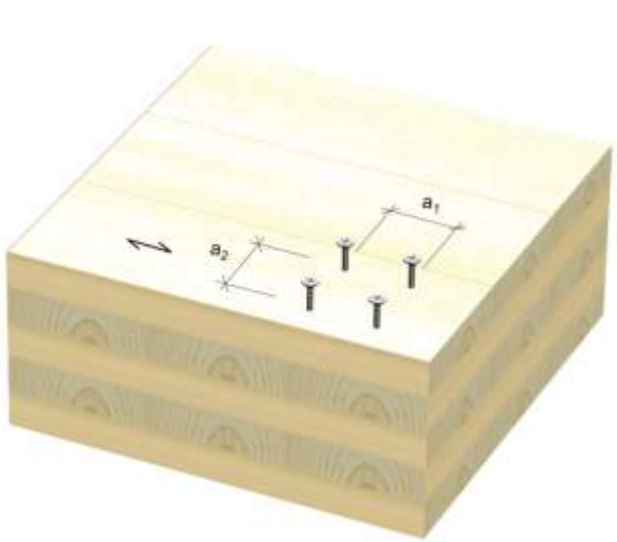
Validity

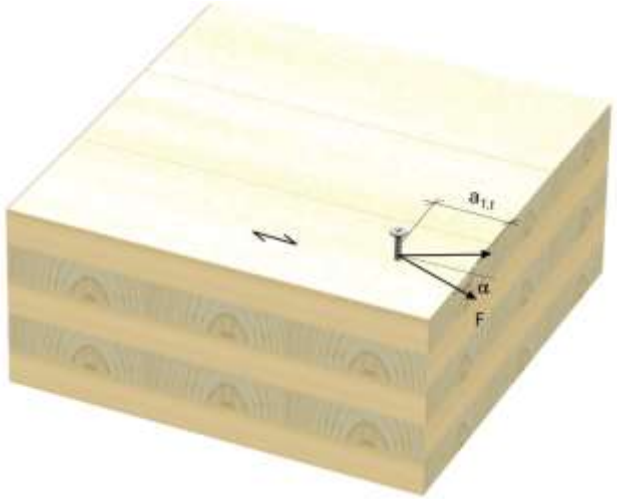
Withdrawal resistance in solid wood exceeds

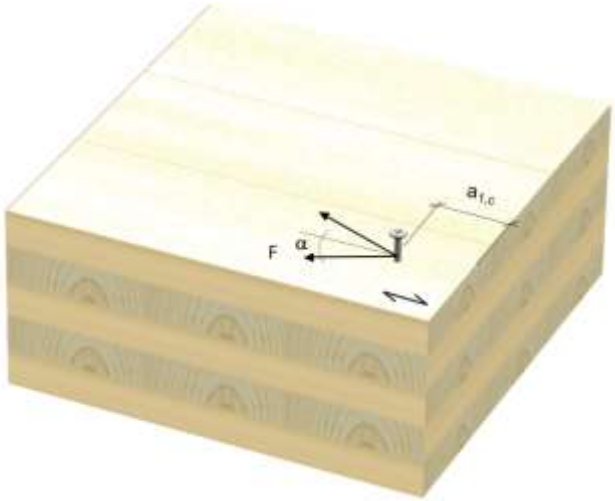
$$f_{ax,k} = 80\, \rho_k^{\,2}\, 10^{-6} \quad (N/mm^2)$$

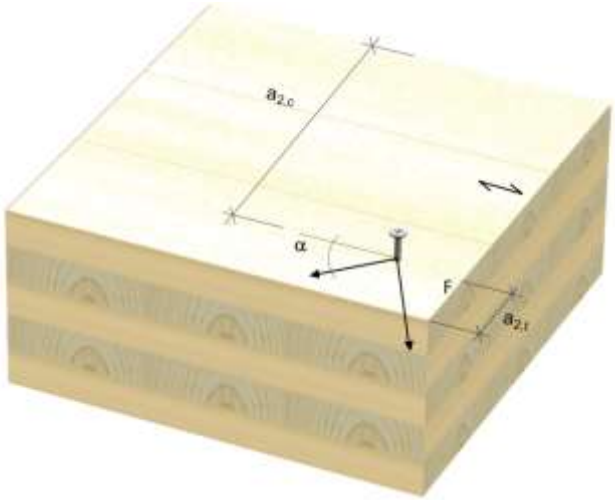
FPInnovations

Min. End & Edge Distances & Spacings in CLT Panel Plane for Dowel-type *(Annex J of CEN Draft)*









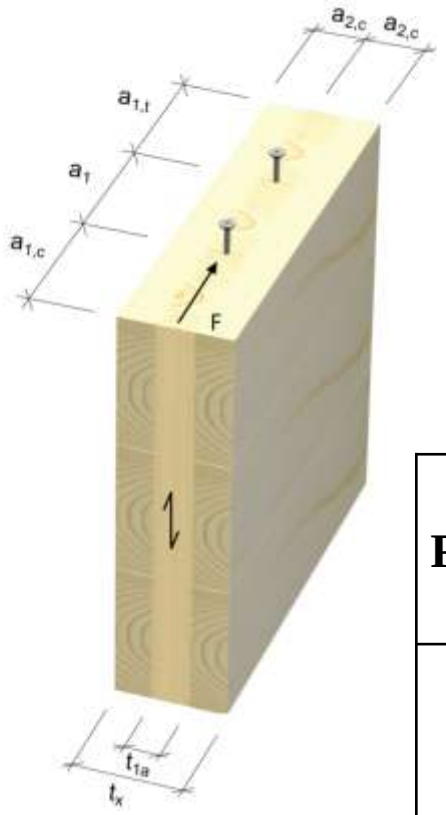
FPInnovations

Min. End & Edge Distances & Spacings in CLT
Plane side *(Annex J of CEN CLT Draft)*

Fastener	$a_{1,t}$	$a_{1,c}$	a_1	$a_{2,t}$	$a_{2,c}$	a_2
Self-tapping screws	6 *d*	6 *d*	4 *d*	6 *d*	2,5 *d*	2,5 *d*
nails	$(7 + 3 \cdot \cos \alpha)$ *d*	6 *d*	$(3 + 3 \cos \alpha)$ *d*	$(3 + 4 \sin \alpha)$ *d*	3 *d*	3 *d*
dowels	5 *d*		$(3 + 2 \cos \alpha)$ *d*	3 *d*	3 *d*	3 *d*
bolts	5 *d*	4 *d*		3 *d*	3 *d*	4 *d*

FPInnovations

Placement of Fasteners in CLT Joints
(*Narrow Side - Annex J of CEN CLT Draft*)



Recommended min. end & edge distances and spacings for dowel-type fasteners

(Adopted from Uibel and Blass 2007 & Annex J of CEN CLT Standard)

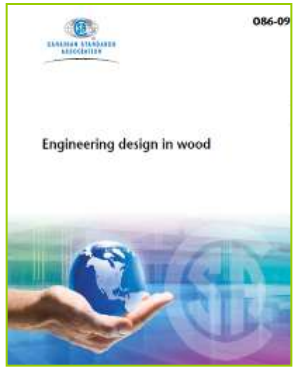
Fastener	$a_{1,t}$	$a_{1,c}$	a_1 **(In plane)**	$a_{2,c}$	a_2 **(Perp. to plane)**
Self-tapping screws	12 *d*	7 *d*	10 *d*	5 *d*	3 *d*
Dowels	5 *d*	3 *d*	4 *d*	3 *d*	3 *d*
Bolts	5 *d*	4 *d*	4 *d*	3 *d*	4 *d*

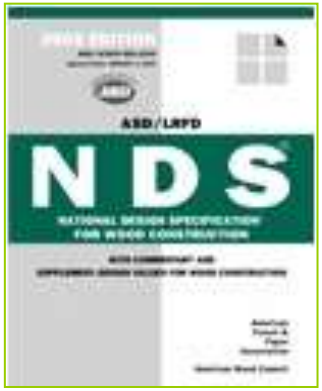
FPInnovations

Design of CLT Connections in CSA O86-09 & NDS

Current design roles in CSA O86-09 for dowel-type fasteners in solid wood and glulam cover:

- Nails & spikes
- Wood screws (up to ¼" in CSA O86)
- Lag screws
- Bolts & dowels
- Drift pins
- Timber rivets
- Self tapping screws?! Not yet!!!

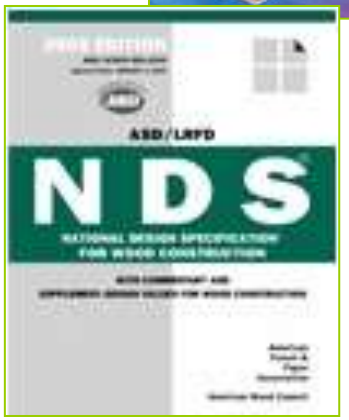




No guidance is given on joints made with proprietary self-tapping screws.. typically used in Europe for CLT connections

FPInnovations

CLT Connections Design & Timber Design Standards in NA (CSA O86 & NDS)



- Based on limited verification testing & analysis @ FPInnovations, European design approach could be adopted in the NDS & CSA O86 provided that:

- **Brittle failure** modes are established in CLT (e.g., large diameters or closely spaced fasteners)
- Min. spacing and edge & end distances are specified as per NA standards

a)

b)

FPInnovations

Current & Planned Research Activities on CLT Connections @ FPInnovations & Partners

Joint FPInnovations and Universities Research under Federal and Provincial programs:

- To investigate connections performance in CLT and develop technical information to support the development of design procedure
- Ultimately, introduce design provisions for connections in NA timber design standards (i.e., CSA O86, NDS)

Detailing of Connections in CLT.. Important!!

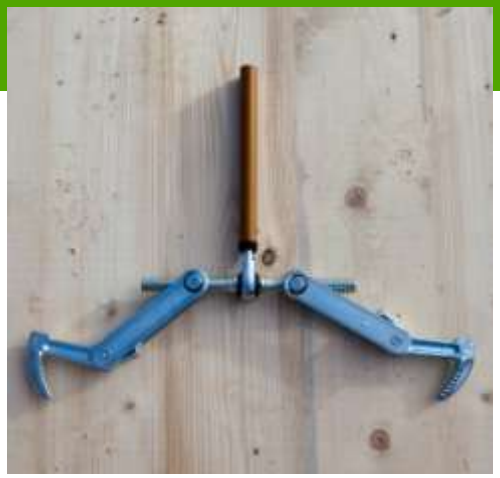
In detailing Connections in CLT, other performance attributes need to be addressed:

- Fire performance
- Acoustic & vibration
- Differential shrinkage
- Building envelope and durability
- Etc.

Need a Multi-disciplinary Approach

FPInnovations

Detailing of Connections in CLT



Important!!

Ensure tight fit between individual CLT panels!!

This is **Key** for:

- Structural integrity
- Improved fire resistance
- Sound insulation
- Air tightness

Source: Kevin Meechan
Courtesy WoodWorks

FPInnovations

In Summary

- European experience and R&D activities and test results @ FPInnovations & elsewhere indicate that traditional connections in CLT are:

  - *Simple*
  - *Structurally efficient*
  - *Cost-competitive*

- Proposed European design methodology could be adopted in NA. However, need to account for potential CLT brittle failure modes & panel specific features

- Need to introduce self-tapping screws and CLT in NA timber standards to assist designers

FPInnovations