Expert Tips

Design for Two-Way Spanning Cross-Laminated Timber

Considerations for building designers seeking to utilize CLT's two-way span capabilities in point-supported floor systems and double-cantilever overhangs to eliminate beams and achieve thin structure depth

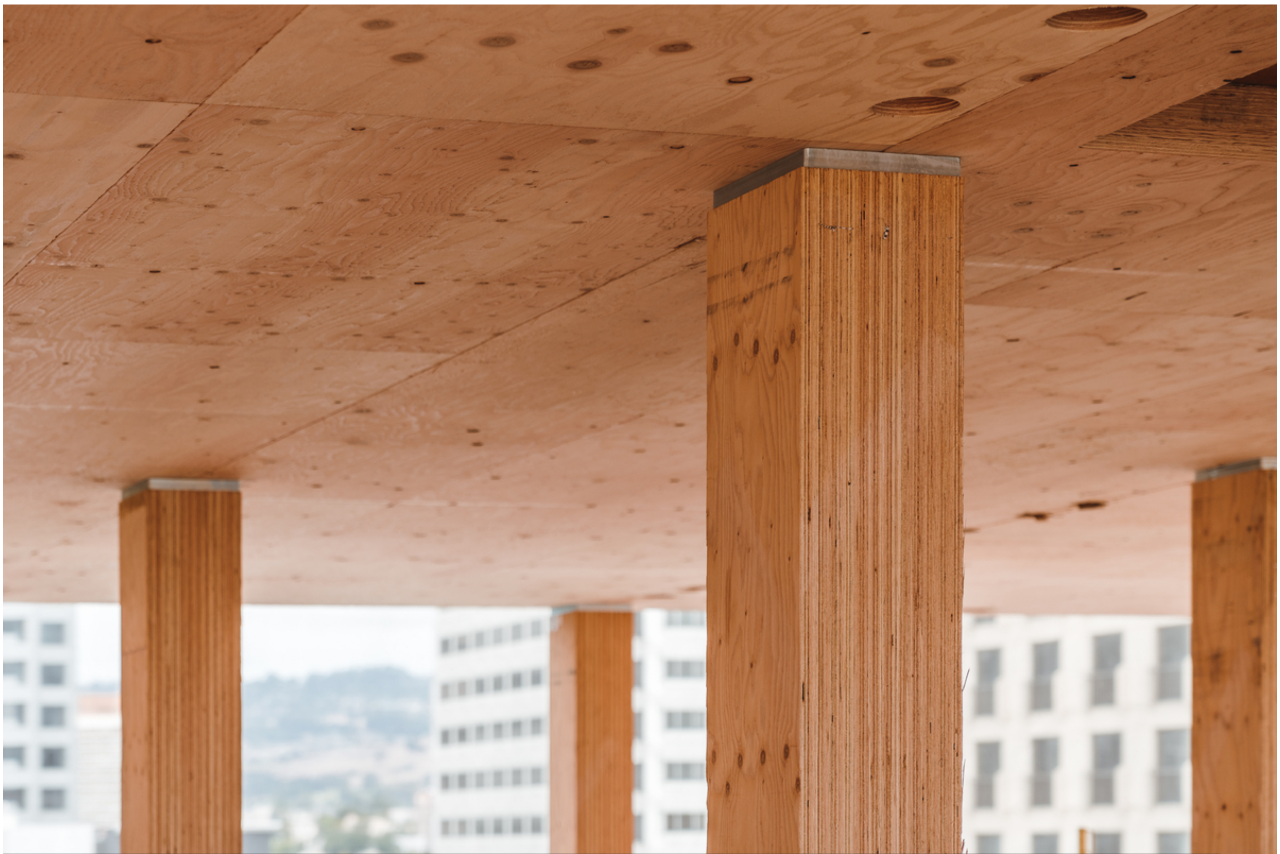
CLT panels span two ways at Brock Commons Tallwood House in Vancouver, BC / Photo Acton Ostry Architects

Mass timber panels are commonly used in single-span floor and roof systems where support beams or walls are perpendicular to the strong axis spans of the panels.

However, a unique attribute of cross-laminated timber (CLT) is that panels have structural capacity in both the major and minor strength directions. Capacity in the minor strength direction is typically less than in the major strength direction, which makes CLT orthotropic. Nonetheless, the capacity of CLT in the minor strength direction can be utilized to create a two-way or flat-plate style of construction. This allows for framing systems with no support beams, where the CLT panels span in both directions between columns. One of the most notable examples in North America is Brock Commons Tallwood House, a student residence at the University of British Columbia with 17 stories of mass timber over a concrete podium. Designers of the Brock Commons project used 5-ply CLT panels spanning over a grid of columns spaced approximately 9 ft x 13 ft apart.

As this structural configuration is uncommon, the project team undertook several extraordinary tasks to be confident in the design. First, the engineering team at Fast + Epp developed a custom CLT layup with the appropriate shear and minor direction bending strengths. The team then worked with researchers at FPInnovations to perform structural testing of the CLT and connections to verify the two-way panel and connection behavior. The column and panel joints were detailed with steel components to directly transfer column axial forces between levels and prevent loading floor panels in compression perpendicular to grain. Further information on this process can be found on the Fast + Epp website here.[1]

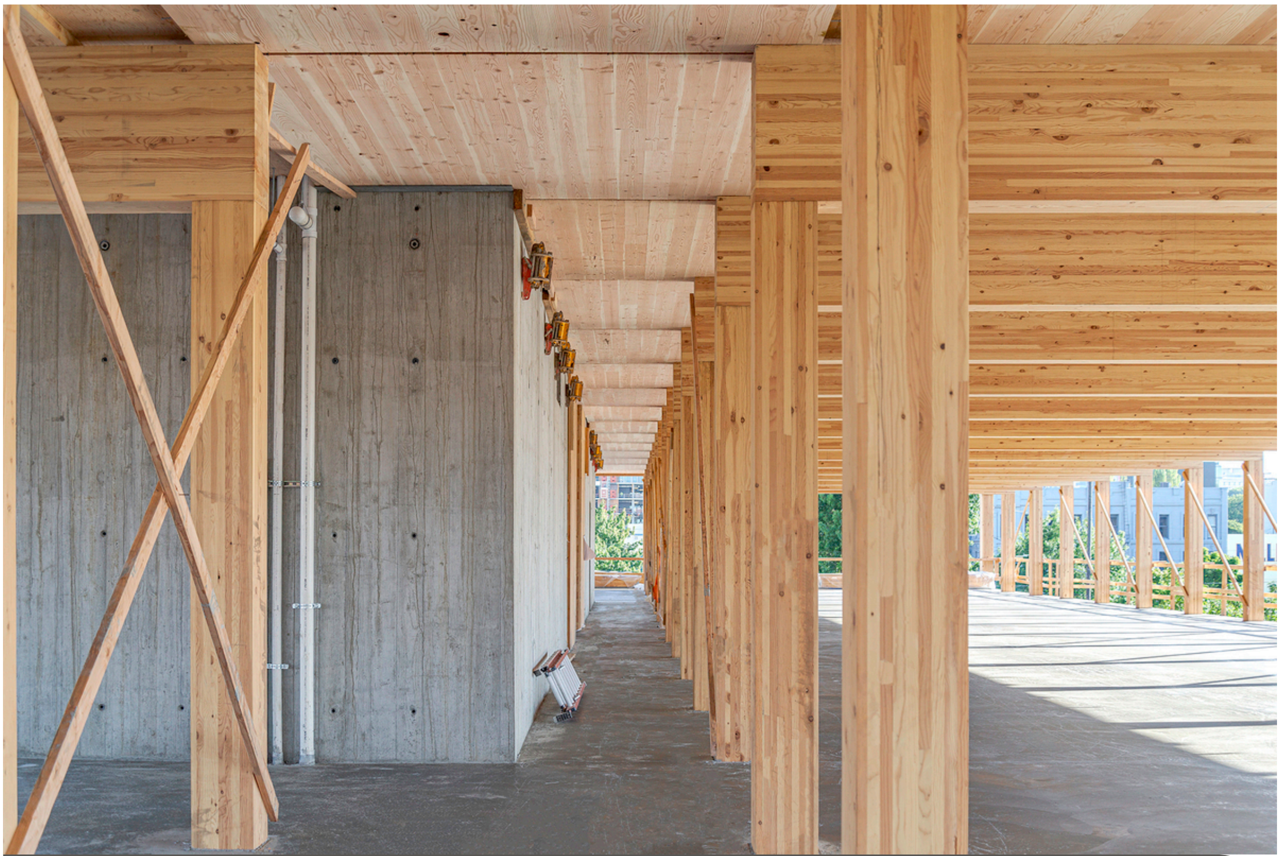
Similarly, the 1510 Webster project in Oakland uses two-way CLT with structural composite lumber laminations over a grid of columns set 12 ft x 15 ft apart.



CLT panels made from SCL laminations span two ways at 1510 Webster in Oakland, CA / Photo WoodWorks

A more common structural configuration that uses the two-way strength capacities of CLT is to have panels cantilever in two directions off the corner of a building, creating beamless eaves. Another is to use CLT over corridors in a multi-family building. In a traditional double-loaded corridor, mass timber floor panels span over the dwelling units from unit demising wall to unit demising wall, parallel to the corridor. At the corridor, one option is to turn the CLT panels so they span from corridor wall to corridor wall. However, to create a more uniform panel layout, an alternative is for the long direction of the panels to be parallel to the corridor. Depending on the width of the corridor and minor axis strength, it may be possible to achieve a beamless support condition, where panels span from corridor wall to corridor wall in their minor axis. A similar configuration in more open floor plans, such as offices, is to have a colonnade of point-supported CLT panels in a central position of a floor plan, creating a beamless zone through which MEP trunk lines and fire sprinkler mains can traverse the building without needing to penetrate dropped beams.

Panels cantilever in two directions at the Andy Quattlebaum Outdoor Education Center in Seneca, SC / Cooper Carry / Photo Jonathan Hillyer



Two-way CLT is used for a beamless zone adjacent to the core at District Office in Portland, OR / Photo Hacker

When looking at two-way spanning CLT construction, at least three potential capacity limits may need to be considered:

1. Bending and shear capacity of the panels
2. Bearing capacity at supports
3. Local punching shear at supports

Bending and Shear Capacity of the Panels

Manufacturers of CLT panels compliant with ANSI/APA PRG 320: Standard for Performance-Rated Cross-Laminated Timber provide third-party certified flexural and shear strength (and stiffness) of their panels in both the major and minor flatwise bending directions. Design of wood structures in jurisdictions of the International Building Code should generally follow the American Wood Council’s National Design Specification® (NDS®) for Wood Construction. Chapter 10 of the NDS includes provisions to calculate ASD and LRFD design capacities to be compared against the building code-defined loads. For two-way behavior, however, the NDS does not address interaction effects between the major strength and minor strength bending and shear checks of CLT panels. Designers must therefore rationalize the interaction effects based on engineering fundamentals, such as those described in NDS 2015 C3.9.2-2. A common design approach in Europe apportions load to the major and minor strength directions based on relative stiffness of the orthogonal layup and then conducts the respective flexural and shear design checks. This common state of practice in European design is described in Section

5.11 of *Cross-Laminated Timber Structural Design: Basic Design and Engineering Principles According to Eurocode*.[2]

Bearing Capacity at Supports

NDS Chapter 10 includes design provisions for the bearing capacity of CLT panels loaded on the CLT panel face. The underlying reference design stress for the CLT panel for compression perpendicular to the grain, $F_{c\perp}$, is based on the constitutive lumber in the panel. These values are sometimes omitted in third-party CLT product evaluation reports aside from references to the species group and grade of lumber used in the CLT. In such cases, the perpendicular-to-grain reference design stress may be obtained from the NDS Supplement for the species and grade of lumber in the surface layer of the CLT or from the manufacturer. Example connection details of CLT supported on columns can be found in Table 3 of the WoodWorks Index of Mass Timber Connections.[3] There are reinforcing detailing strategies that have been used to strengthen the face bearing capacity of CLT panels. While outside the scope of the NDS, such reinforcing strategies use fully-threaded self-tapping screws to distribute stresses into the CLT panel. For an example, see *Technical Engineering Bulletin SDCF Timber-CF as a Compression Reinforcement*.[4]

Local Punching Shear at Supports

At the support in a two-way CLT panel, the shear capacity around the perimeter of the support point needs to be verified. This check is performed using the reference flatwise shear capacities $V_{s,0}$ and $V_{s,90}$ developed in accordance with ANSI/APA PRG 320. While not explicitly addressed in the NDS, a European approach has been developed by Bogensperger et al. (2016).[5] A controlling perimeter line is found by projecting into the panel from the edge of the support at 35 degrees from vertical to the center of the panel. The shear capacity of the panel around this perimeter line is then checked against the applied design loads. More recent information on punching shear research can be found in Slotsboom et al. (2023).[6] and Shahnewaz et al. (2023).[7]

Since two-way bending interaction effects and punching shear are not explicitly covered, careful engineering should be used. Acceptability of the approach is at the discretion of the designer, building official, and jurisdiction. Until design methods consistent with U.S. standards are developed and verified for CLT punching shear, it is recommended that punching shear design verification be based on test results, peer review by qualified experts, or both.

Modeling and Analysis of Two-Way Bending Behavior

A robust method to evaluate CLT panels for two-way bending behavior is though finite element method (FEM) plate analysis of the CLT and support system coupled with experimental validation of the model. While there are many ways to do this through structural analysis packages, it is important to keep in mind that CLT is not an isotropic plate, meaning that flexural and shear stiffness is different in the major and minor strength axis of the panel and these properties can very across and within manufacturers. Adequate FEM analysis packages need to support orthotropic plate analysis, ideally with shear effects as in “thick plate analysis” using Mindlin plate analysis or similar. Such modeling can be found in the examples in WoodWorks’ *U.S. Mass Timber Floor Vibration Design Guide*.[8]

[1] Fast + Epp. Point Supported CLT Testing.

[2] Wallner-Novak, M., Koppelhuber, J., Pock, K. proHolz Austria. (2014). *Cross-Laminated Timber Structural Design: Basic Design and Engineering Principles According to Eurocode*.

[3] WoodWorks – Wood Products Council. (2021). *WoodWorks Index of Mass Timber Connections*.

[4] Simpson Strong-Tie. (2023). *Technical Engineering Bulletin: SCDF TIMBER-CF as Compression Reinforcement*.

[5] Bogensperger, T., Joebstl, R., Augustin, M. (2016). *Concentrated Load Introduction in CLT Elements Perpendicular to Plane – Experimental and Numerical Investigations*. World Conference on Timber Engineering. Vienna, Austria.

[6] Slotsboom, C., Dickof, C., Jackson, R. (2023). *A Comparison of Punching Shear Design Approaches for Point Supported CLT Panels*. World Conference on Timber Engineering. Oslo, Norway.

[7] Shahnewaz, Md., Dickof, C., Ganjali, H., Slotboom, C., Tam, M., Jackson, R., Popovski, M., Tannert, T. (2023). *Experimental Research on Point-Supported CLT Panels: Phase 1: Rolling Shear Strength*. World Conference on Timber Engineering. Oslo, Norway.

[8] Breneman, S., Zimmerman, R., Gerber, A., Epp, L., Dickof, C., Taylor, A., Loasby, W., McDonnell, E., Slotboom, C., McCutcheon, J., Visscher, R. WoodWorks – Wood Products Council. (2023). *U.S. Mass timber Floor Vibration Design Guide*.

