

Advancing Timber for the Future Built Environment

## Numerical Study on Timber-Timber Composite (TTC) Floors

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**ABSTRACT:** Timber–timber composite (TTC) floors offer lightweight and sustainable solutions for achieving long spans with enhanced stiffness and vibration performance. However, the influence of key design parameters on their structural behaviour remains insufficiently investigated. This study presents a numerical investigation of TTC floors comprising cross-laminated timber (CLT) panels connected to laminated veneer lumber (LVL) beams. A finite element (FE) model was developed in ETABS and validated against experimental test results, demonstrating good agreement in flexural stiffness. The validated model was then used to assess the applicability of the Gamma method for predicting floor stiffness. Although the Gamma method generally overestimates stiffness—particularly for configurations with thicker CLT panels—it provides reasonable predictions for typical composite floors. A parametric study was conducted to evaluate the effects of CLT thickness, shear connector spacing, and LVL beam dimensions. Results indicate that increasing LVL depth is the most influential factor, followed by LVL breadth, CLT thickness, and connector spacing. Furthermore, as LVL width increased, the discrepancy between FE and analytical predictions decreased. These findings offer valuable insights into the design and optimisation of TTC floors and underscore the need for refined analytical methods to more accurately capture their composite behaviour.

**KEYWORDS:** Timber-timber composite (TTC), Finite element modelling (FE), Cross-laminated timber (CLT), Laminated veneer lumber (LVL), Lightweight construction

## **1 – INTRODUCTION**

In recent decades, there has been a renewed interest in the use of timber in construction to reduce carbon and energy footprints [1]. Advances in chemical treatments, adhesives, and wood processing technologies have enabled the creation of large engineered wood product (EWP) panels such as cross-laminated timber (CLT) and glued laminated timber (GLT), which offer stability [2], durability [3], aesthetics, lightweight, and a high strength-to-weight ratio. These attributes make timber increasingly competitive with traditional materials such as concrete and steel. However, timber's relatively low elastic modulus results in reduced stiffness in long-span floors, leading to concerns regarding serviceability issues such as deflections and vibrations [4-7]. To address these challenges, composite systems combining EWPs with steel, reinforced concrete, or other timber products have been developed to improve structural performance [8-10]. Extensive research has focused on the mechanical behaviour of timber-concrete, steel-timber, and timbertimber composite connections, evaluating their load-slip behaviour, stiffness, and load-carrying capacity [11–14]. For timber-timber composites (TTC), Chiniforush et al. [13] conducted push-out experiments on cross-laminated timber (CLT) panels connected to laminated veneer lumber (LVL) beams. Their study assessed the load-slip response, peak load, and stiffness of TTC joints, and demonstrated that finite element (FE) models could accurately capture the load-deflection behaviour and peak strength of TTC beams using ABAQUS software.

Further investigation by Nie et al. [15] involved longterm sustained load testing of TTC joints, connecting LVL or GLT joists to CLT slab panels, to evaluate the influence of joist type, connector size and type, and CLT slab thickness and orientation. Their findings revealed that over 50% of creep deformation occurs within the first year, with CLT thickness playing a significant role in the creep coefficient. A validated FE model was employed to further examine these effects. Similarly, Chernova et al. [16] studied the bending behaviour of CLT-GLT composite structures, showing that inclined screw

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connections significantly enhance strength, stiffness, and shear capacity. Their work also highlighted that the orientation of the CLT top layer relative to the GLT beam axis affects structural performance. In terms of numerical modelling, Félix Suárez-Riestra [17] proposed a new analytical model to predict the long-term behaviour of timber under varying environmental conditions, improving upon traditional design standards by offering more precise predictions of creep deformation based on humidity and temperature exposure.

In addition to static performance, significant research has highlighted the superior energy dissipation capacity of timber connections under cyclic loads [18], an important feature for seismic applications. Compared to brittle materials, timber joints-especially those incorporating mechanical connectors such as screws or nails-can undergo large deformations while maintaining load resistance, enabling effective hysteretic energy dissipation during earthquake events. Timber-timber composite systems can further benefit from this behaviour, offering enhanced ductility and resilience under repeated lateral loading. Studies have shown that TTC connections, particularly those using inclined fasteners, provide stable hysteresis loops with limited strength degradation under cyclic actions [14,16]. Furthermore, hybrid timber systems, combining different types of EWPs like CLT and LVL, have been shown to exhibit reduced creep deformation compared to traditional timber-only joints [19-22]. The combination of high-strength LVL beams and stiff CLT panels helps distribute stresses more uniformly and limits long-term deflections, particularly when appropriate connection detailing is used [8,10]. By optimizing the geometry and material composition, hybrid TTC floors can better maintain their serviceability performance over time under sustained loading conditions.

Despite these advancements, a comprehensive understanding of the composite action in CLT-LVL floors with varying geometrical configurations remains limited. Specifically, there is a need to investigate the influence of LVL beam arrangement, CLT panel thickness, shear connector spacing, and effective width assumptions across a wide range of spans and design conditions. Additionally, the current analytical methods, such as the Eurocode gamma method, require validation for application to timber-timber composite systems, especially in the absence of extensive experimental data. In this study, a detailed FE model was developed using ETABS software to simulate TTC floor systems and validated against experimental results. The validated model was then employed for a comprehensive parametric study to evaluate the influence of key parameters on the flexural stiffness and serviceability behaviour of TTC floors, providing valuable insights for the design and optimization of sustainable composite timber floors.

### 2 – METHODOLOGY

#### 2.1 FE Modelling

A detailed three-dimensional FE model of the timbertimber composite (TTC) floor system was developed using ETABS software. The composite system consisted of cross-laminated timber (CLT) panels mechanically connected to laminated veneer lumber (LVL) beams. The aim of the FE modelling was to capture the global flexural response and serviceability behaviour of the TTC beams under flexural loading, while also accounting for partial composite action arising from connection slip. The LVL beams were modelled using frame elements that allowed for both axial and flexural deformations. As it is shown in Figure 1, the CLT panels were modelled using layered shell elements capable of representing the orthotropic behaviour of timber across different grain directions. The interaction between the LVL beams and CLT panels was simulated using nonlinear link elements, which were assigned load-slip relationships derived from experimental push-out tests conducted by Chiniforush et al. [13].



Figure 1: 3D FE model representing the Timber-timber composite (TTC) floors

This approach allowed for a realistic representation of the shear connection behaviour under loading. The material properties for both CLT and LVL components, including moduli of elasticity, shear moduli, and Poisson's ratios, were based on experimentally determined values from Chiniforush et al. [13]. The slip modulus and ultimate strength of the shear connectors were obtained directly from the mean load-slip curves of the push-out experiments as reported in [13] (see Figure 2). The developed FE model in this numerical study aimed to balance computational efficiency with sufficient accuracy to enable its use in extensive parametric studies

across a range of geometrical and material configurations.



Figure 2. Mean load-slip of the TTC joints (per shear connector set) obtained from push-out experiment courtesy of Chiniforush et al. [13]

#### 2.2 Model Validation

The developed FE model was validated against experimental results reported by Chiniforush et al. [13] for a 6.0 m long CLT-LVL composite beam tested under four-point bending. The beam consisted of a CLT panel measuring 1200 mm in width and 120 mm in thickness connected to an LVL beam with a cross-section of 300  $mm \times 62 mm$ . In the validation setup, a total vertical load of 120 kN was applied symmetrically through two concentrated point loadings. The mid-span deflection predicted by the FE model was compared with experimental measurements to assess the accuracy of the numerical simulation. The effective flexural stiffness (EI) obtained from the FE model was compared with values calculated using the Eurocode gamma method and experimental results. To ensure the accuracy and reliability of the FE results, a mesh sensitivity analysis was conducted. Several mesh configurations with varying element sizes were tested for the layered shell elements representing the CLT panel. The influence of mesh refinement on the predicted mid-span deflection and overall stiffness was evaluated. It was observed that refining the mesh size beyond 150 mm × 150 mm had a negligible effect on the global response, with changes in predicted deflections of less than 2%. Therefore, a mesh size of approximately 150 mm was selected for the final models to balance computational efficiency and solution accuracy.

Figure 3 illustrates the comparison between the experimental, FE model, and analytical predictions of *EI*. The results showed that while the Eurocode gamma method slightly overestimated the stiffness due to shear deformation effects, the FE model, with the chosen mesh density, accurately captured the nonlinear response and

closely matched the experimental results. This validation confirmed the capability of the FE model to predict the global behaviour of TTC floors, providing a reliable foundation for the subsequent parametric study.



Figure 3: Comparison between the stiffness of the floor from the experiment, FE and design equations (Gamma method)

# 2.3 Analytical Modelling (Eurocode Gamma Method)

In parallel with the FE modelling, an analytical model based on the Eurocode gamma method [23] was used to calculate the effective flexural stiffness of the TTC floor systems. The gamma method is a simplified approach commonly employed to estimate the flexural stiffness of partially composite members, originally developed for timber-concrete systems but here adapted to timber-timber composites. The effective flexural stiffness  $EI_{eff}$  of the composite section was calculated using Eq (1):

$$EI_{eff} = E_L I_L + \gamma_L E_L A_L a_L^2 + E_C I_C + \gamma_C E_C A_C a_C^2 \qquad (1)$$

where,  $E_L$  and  $E_c$  are the moduli of elasticity of the LVL and CLT, respectively,  $I_i$  is the second moments of area,  $A_i$  is the cross-sectional area,  $a_L$  and  $a_c$  is the vertical distance between the centroids of the LVL and CLT, and  $\gamma_c$  is the connection efficiency factor. The connection efficiency factor ( $\gamma_c$ ) accounts for the degree of composite action and is defined as:

$$\gamma_C = \left(1 + \frac{\pi^2 E_C A_C s}{K l^2}\right)^{-1} \tag{2}$$

where K is the slip modulus per unit length of the shear connection. The value of K was obtained based on the load-slip characteristics measured during experimental push-out tests. The analytical calculations provided a baseline to evaluate the accuracy and limitations of simplified design approaches in predicting the stiffness of TTC systems. Comparisons between analytical and FE model results were performed for each variation in the parametric study to assess the applicability of the gamma method across different geometric configurations.

#### 2.4 Parametric Study

After validation, the FE model was used to conduct a systematic parametric study to investigate the influence of key design parameters on the flexural stiffness of TTC floor systems. The variations considered in the study are summarized in Table 1.

Table 1: Parameters and their range used in numerical study

Parameter	Variations
Panel thickness (mm)	3-ply: 72, 5-ply: 120, 7-
	ply:168
Shear Connector Spacing (mm)	200, 350, 500
Width of LVL Beams (mm)	45, 63, 75, 90
Depth of LVL Beams (mm)	300, 400, 600

The parameters examined include different CLT panel thicknesses (3-ply, 5-ply, and 7-ply configurations), shear connector spacings (200 mm, 350 mm, and 500 mm), and variations in the width and depth of LVL beams. The selected ranges cover typical values encountered in practical design and construction. Each parameter was varied individually while keeping the others constant to isolate its effect on the structural response. The aim was to evaluate how changes in geometry and connector layout influence the effective flexural stiffness (EI) and to assess the accuracy and limitations of the Eurocode gamma method across different floor configurations. The material properties remained consistent across all models, based on the experimental data reported by Chiniforush et al. [13]. The load-slip behaviour of the shear connectors was assumed to remain unchanged for different configurations, ensuring consistency in the connection modelling. The flexural stiffness results obtained from the FE analyses were compared with predictions from the Eurocode gamma method for each parametric variation. This allowed for the quantification of discrepancies and identification of trends, providing insights into how different design choices affect both numerical predictions and analytical estimates of TTC floor performance.

#### 2.5 Loading and Boundary Conditions

The TTC beams were modelled under four-point bending with a total vertical load of 120 kN applied symmetrically. Supports were modelled as pinned at one end and roller-supported at the other end to simulate simply supported boundary conditions and allow horizontal translation. The load application points were placed at one-third spans from the supports to generate a constant moment region in the middle portion of the beam. This loading configuration allowed for a clear evaluation of flexural behaviour without introducing shear-dominated failure. Since the focus of the study is on serviceability behaviour, material nonlinearities such as plasticity were not considered, and the models primarily captured elastic and large deformationsdue to slip at the connections..

## 3 - RESULTS & DISCUSSION

#### 3.1 Effect of LVL Beam Depth

Figure 4 presents the variation of flexural stiffness (EI) with different LVL beam depths. As the depth of the LVL beam increased from 300 mm to 600 mm, a significant increase in flexural stiffness was noted. For beams with 300 mm depth, the Gamma method overestimated the stiffness by about 20% compared to the FE model. However, for deeper beams (600 mm), the FE model predicted higher stiffness than the Gamma method, suggesting that the analytical method may underestimate stiffness for larger section depths. This trend highlights that as the flexural rigidity of the LVL member becomes dominant, the contribution of partial composite action becomes less critical, and the assumptions of the gamma method may become conservative. This suggests testing deeper beam may be required in future studies.



Figure 4: Comparison of EI (kN/mm) for the beams with different depth according to FE and code equation (gamma method). The beam width is 63mm



Figure 5: Comparison of EI (kN/mm) for the beams with different breadth according to FE and code equation (gamma method)

#### 3.2.2 Effect of LVL Beam Breadth

The impact of LVL beam width (breadth of the beam) on flexural stiffness is illustrated in Figure 5. The flexural stiffness increased with beam breadth, but the rate of increase was less pronounced compared to depth variations. For narrower beams (45 mm), the gamma method overpredicted stiffness by about 30%. As the breadth increased to 90 mm, the difference between the FE and analytical results reduced to approximately 10%, indicating better agreement for wider sections.

#### 3.2.3 Effect of CLT Panel Thickness

Figure 6 shows the variation of flexural stiffness with different CLT panel thicknesses (3-ply, 5-ply, and 7-ply). Both FE and analytical results demonstrated a consistent increase in stiffness with panel thickness. However, the Gamma method consistently predicted slightly higher stiffness values across all panel configurations. The discrepancy of 10–15%, could be attributed to neglecting shear deformation of the CLT panel in the Gamma method. The results confirm that using thicker CLT panels can improve the flexural stiffness of TTC floors, although the benefit may diminish at higher thicknesses due to the proportional increase in self-weight.



Figure 6: Comparison of EI (kN/mm) for the CLT with different number of Ply according to FE and code equation (gamma method)

#### 3.2.4 Effect of Shear Connector Spacing

The influence of shear connector spacing on flexural stiffness is summarized in Figure 7. Reducing the connector spacing from 500 mm to 200 mm enhanced the stiffness, as closer spacing reduced the amount of relative slip between the CLT panel and LVL beam. However, using Gamma method gives a larger enhancement with smaller connector spacings compare to FE model. Reducing the shear connector spacing from 500 mm to 200 mm increased flexural stiffness by only 10%. At 200 mm spacing, the Gamma method overestimated stiffness by about 20%, whereas at 500 mm, it closely matched the results (within 9%). These findings indicate that denser connector spacing enhances composite action potentially to a limit and beyond that limit adding more fasteners may not be economical. This suggests more cost-benefit analysis by practitioners is needed to come up more efficient designs in the future.



Figure 7: Comparison of EI (kN/mm) for the CLT with different shear connector spacing according to FE and code equation (gamma method)

#### 3.3 Discussion

The results of the parametric study reveal important trends regarding the flexural performance of timbertimber composite (TTC) floors and the applicability of the Eurocode Gamma method. For variation in the LVL beam depth, the Gamma method overestimated flexural stiffness by approximately 21% for 300 mm deep beams, but this discrepancy reduced to around 5% at 400 mm depth. Interestingly, at 600 mm depth, the FE model predicted about 19% higher stiffness compared to the gamma method, indicating that the analytical approach becomes conservative for larger beam depths. This trend highlights that as LVL depth increases, the flexural rigidity dominates the system behaviour, and the influence of partial composite action becomes less critical. Regarding variation of LVL beam width, the Gamma method overpredicted stiffness by about 28% for narrow beams (45 mm breadth), with the difference reducing to 9% for wider beams (90 mm breadth).

The variation in CLT panel thickness showed a consistent trend, where the Gamma method overestimated stiffness by approximately 10–15% across 3-ply, 5-ply, and 7-ply configurations. The increase in panel thickness led to higher flexural stiffness, although the relative difference between FE and analytical predictions remained nearly constant. For shear connector spacing, reducing the spacing from 500 mm to 200 mm resulted in an increase in flexural stiffness by only 10%. This demonstrates that denser connector arrangements significantly improve composite action and reduce relative slip.

Overall, the Eurocode Gamma method provided reasonable stiffness estimates for TTC floors with larger LVL sections and tighter connector spacing but showed noticeable inaccuracies for slender beams or sparsely connected systems. Hence, designers should be cautious when applying simplified analytical methods in serviceability limit state design.

## 4 - CONCLUSION

This study presented a numerical investigation into the flexural performance of timber-timber composite (TTC) floor systems, combining cross-laminated timber (CLT) panels and laminated veneer lumber (LVL) beams connected through mechanical fasteners. A detailed FE model was developed in ETABS and validated against experimental results, accurately capturing the global load–deflection behaviour of TTC beams. The Eurocode gamma method was also evaluated for its ability to predict the effective flexural stiffness of TTC floors. Results showed that while the Gamma method provided reasonable estimates for systems with regular LVL sections and wide connector spacing (500-600 mm), it could overestimate stiffness by 10–30% for deeper section or in floors with tighter fastener spacings.

The parametric study demonstrated that increasing LVL beam depth and breadth, and increasing CLT panel thickness effectively improved the flexural stiffness of TTC floors while reducing shear connector spacing may not be so effective. Findings from this study highlight the importance of detailed numerical modelling in accurately capturing partial composite action in non-conventional systems. Moreover, optimizing TTC floor designs can contribute to enhancing the structural performance while reducing embodied carbon of buildings, offering a viable alternative to traditional concrete or steel composite floor systems.

## 5 – ACKNOWLEDGMENT

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through the Alliance International Catalyst Grant (ALLRP) for the project titled "Progressive Collapse Resilient Beam-to-Column Connections in Tall Timber Buildings." The authors gratefully acknowledge NSERC's continued support of research in structural engineering and timber construction innovation.

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