Article citation info:
Alpaslan S., Karatay H., Eren O., Uysal M. 2026. Experimental and Numerical Analysis of Screw Withdrawal Strength of Cross-Laminated Timbers. *Drewno. Prace naukowe. Doniesienia. Komunikaty.* https://doi.org/10.53502/wood-217911

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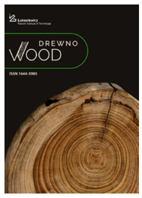

Experimental and Numerical Analysis of Screw Withdrawal Strength of Cross-Laminated Timbers

Seyma Alpaslan
Halil Karatay
Orhan Eren
Mesut Uysal*

Forest Industry Engineering, Bursa Technical University, Bursa, Turkey

Article info

Received: 11 October 2025
Accepted: 9 February 2026
Published: 23 September 2026

Keywords

screw withdrawal strength
cross-laminated timber
finite element analysis
Uludağ fir
black pine

This study examines the impact of screw penetration depth and wood species on the SWS of CLT panels, utilizing a combination of experimental testing and FEA to assess performance. CLT panels were fabricated from Uludağ fir and black pine, and screw withdrawal tests were performed at two penetration depths corresponding to two and three layers. The average densities of CLTs were 0.44 g/cm3 for Uludağ fir and 0.52 g/cm3 for black pine, with respective moisture contents of 11.37% and 11.08%. The average SWS for Uludağ fir CLTs increased from 9.73 N/mm2 (two layers) to 11.27 N/mm2 (three layers), representing a 15.83% enhancement, while black pine CLTs improved from 13.85 N/mm2 to 14.72 N/mm2 (6.28% increase) with an increase in penetration depth from two to three layers. Statistical analysis confirmed significant effects of both wood species and penetration depth. FEA simulations predicted withdrawal resistances of 2950.41–3115.94 N for Uludağ fir and 3339.19–3969.73 N for black pine, with two- and three-layer penetration depths, respectively. The differences between the experimental and numerical results ranged from 3.69% to 50.10%. Approximately 62.50% of comparisons were within an acceptable 24% deviation range for wood materials. The results indicate that denser species and greater penetration depth enhance withdrawal performance, while FEA provides reasonably accurate yet conservative estimates. The developed experimental-numerical framework provides a reliable predictive basis for designing and optimizing screw connections in wooden constructions, contributing to safer, more efficient, and sustainable CLT-based building systems.

DOI: 10.53502/wood-217911

Introduction

The screw withdrawal strength (SWS) is a critical factor in the application of cross-laminated timber (CLT) materials, influencing both structural integrity and construction efficiency. This importance stems from how screws are used to join CLT panels, which consist of layers of timber bonded at right angles to enhance strength and stability. The connection properties of screws directly impact the withdrawal resistance and overall load-bearing capabilities of CLT structures, which are essential for their performance, particularly in applications such as walls, roofs, and floors.

The exploration of SWS in CLTs has garnered substantial attention in recent literature, particularly concerning the interplay of penetration depth, wood

* Corresponding author: mesut.uysal@btu.edu.tr

species, and the comparison of experimental and numerical results. Screws are a primary joinery method in CLT structures, offering advantages in terms of speed of installation and structural performance. Besides, they provided higher strength capacity compared to dowel-type joints (Eini et al., 2022). The penetration depth at which screws are embedded in CLT panels significantly affects their withdrawal resistance and overall load-bearing capacity. The optimal penetration depth may vary depending on the wood species and configuration. Larger penetration depths generally improve withdrawal resistance in CLTs (Dong et al., 2020). In timber-to-timber screw joints, changes in penetration depth had a significant effect on joint performance (Schiro et al., 2018).

Although previous studies have explored various factors impacting screw holding capacity, the specific effects of screw penetration depth in CLTs may differ due to the nature of wood, screw size, lamination technique, and drilling installation. The penetration depth significantly influences withdrawal resistance; however, the optimal depth for various applications and loading scenarios remains unclear (Pang et al., 2020). Therefore, various screw penetration depths should be taken into consideration for each CLT panel, as variations in screw and timber design may alter the outcomes regarding load transfer capabilities; accordingly, penetration depth as applied in timber materials and their direct correlation with withdrawal resistance come into prominence to establish a robust framework for CLTs (Masroor et al., 2023). Furthermore, the specific interaction among screw size, penetration depth, layer thickness, number of layers, and wood species in CLTs requires more targeted exploration. Therefore, diversion in CLT construction could be optimized by joint solutions that interplay the aforementioned factors (Ruggeri et al., 2023). Moreover, the existing body of knowledge often presents empirical findings without corresponding numerical analysis, leading to a fragmented understanding of SWS in CLTs. Experimental studies have documented various joint behaviours under different loading conditions, but they often lack numerical validation, which is crucial for creating predictive models for design (Gavric et al., 2015; Pan et al., 2023). While some studies have attempted to correlate experimental and numerical results, differences between them suggest a need for further rigorous comparisons to develop more accurate computational models (Shahnewaz et al., 2018).

Exploring parameters to alter the screw holding capacity of the CLTs is crucial for optimizing CLT applications in construction, ensuring durability, reliability, and performance under various loading conditions. Understanding the impact of screw penetration depth on the holding capacity is integral to enhancing the performance of CLT applications. Given the complex nature of wood, characterized by its orthotropic properties, screw withdrawal resistance was significantly influenced due to variations in grain orientation within the lumber (Cavus & Ersin, 2023). By investigating and establishing best practices for penetration depth across different scenarios, higher performance in CLT structures can be achieved, thereby reducing the risk of joint failure in situ (Pang et al., 2020). Additionally, anatomical diversity in wood results in significant variations in withdrawal resistance (Abdoli et al., 2022). Thus, integrating a broader range of wood species into research can provide a comprehensive understanding of how species-specific properties affect screw holding capacities, ultimately leading to more informed decisions when selecting materials for CLT construction, because fir and black pine are the native wood species in Turkey, which have been recently under consideration for strength grades according to Eurocode 5 (OGM, 2023). Moreover, a rigorous understanding of how well numerical models predict the behaviour of CLT is essential for safe, economical, and code-compliant design in timber construction. Studies that compare experimental results with numerical simulations provide the evidence base for model validation, calibration, and potential code updates (Jalilifar et al., 2021; Teixeira et al., 2024). Such work supports confidence in FEA or other computational tools to capture the anisotropy of CLTs, their layer interactions, and connection behaviour, particularly under monotonic and cyclic loading as observed in CLT walls, floors, and joints (Jalilifar et al., 2021; Teixeira et al., 2024). Comparative studies help identify which constitutive models, material anisotropy representations, and boundary condition implementations yield the closest agreement with observed behaviour, thereby guiding researchers toward more physically faithful simulations for CLT panels and assemblies (Akter et al., 2021; Jalilifar et al., 2021).

The primary aim of this research is to investigate the influence of screw penetration depth and wood species on the SWS of CLT panels, and to validate the experimental findings through finite element simulations. By integrating experimental testing and numerical modelling, the study aims to provide a more comprehensive understanding of screw-timber interactions and establish a reliable computational framework for predicting connection behaviour in CLT systems. To achieve this aim, the study pursued the following objectives that (i) conducting screw withdrawal tests at two different penetration depths (two-layer and three-layer penetration) and determining the corresponding withdrawal resistance of CLTs made of Uludağ fir and black pine, (ii) developing finite element models replicating the experimental setup to simulate screw-wood interaction, and (iii) benchmarking the experimental and numerical results in terms of ultimate withdrawal load.

Materials and methods

In this study, Uludağ fir (*Abies bornmülleriana* Mattf.) and black pine (*Pinus nigra* Arnold), grown in northwest Turkey and obtained from a local sawmill in Bursa, Turkey, were used to fabricate CLT panels. The fabrication of CLT panels was previously reported by Uysal et al. (2022). Specimens measuring 50 × 50 mm were cut from the CLT panels. Screws with a dimension of 3.5 mm and a length of 45 mm were used. The pilot holes were drilled 80% of the screw diameter. The screws were embedded with lengths of two- and three-layer thicknesses, featuring protruding screw tips (Fig. 1).

The density and moisture content of the CLT specimens were measured from 50 × 50 mm blocks before drilling and screwing specimens. All specimens were acclimatized at 20 ± 2 °C and 65 ± 5% relative humidity. They were then weighed using a scale with a precision of 0.0001g and measured using a calliper with a precision of 0.01 mm. The density (ρ_{12}, g/cm^3) and moisture content (*MC*, %) of CLTs were calculated by using equations 1 and 2, respectively:

$$\rho_{12} = \frac{\omega_{12}}{V_{12}} \qquad (1)$$

where $\boldsymbol{\omega}_{12}$ is the air-dry weight of specimens (g), and V_{12} is the air-dry volume of specimens (cm^3).

$$MC = \frac{\omega_{12}-\omega_0}{\omega_0} \qquad (2)$$

where ω_0 is the oven-dry weight of specimens (g).

All tests for the SWS of CLTs were conducted on the SHIMADZU universal test machine according to TS EN 13446 (2002). Withdrawal load capacities were obtained by applying a withdrawal load parallel to the screw axis from the face of specimens with a rate of 2 mm/min and continued until the ultimate load was reached (Fig. 2). SWS (σ, N/mm^2) of the CLTs was calculated by equation 3.

$$\sigma = \frac{F_{ult}}{2 \times \pi \times r \times d} \qquad (3)$$

where F_{ult} is the ultimate failure load (N), *r* is the radius of the screw (mm), and *d* is the penetration depth of the screw (mm).

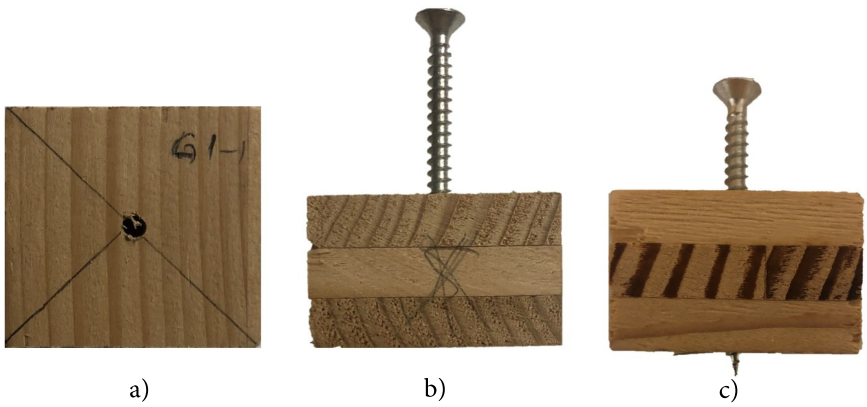

Fig. 1. a. Pilot hole for screws, b. Two-layer penetration depth and c. Three-layer penetration depth

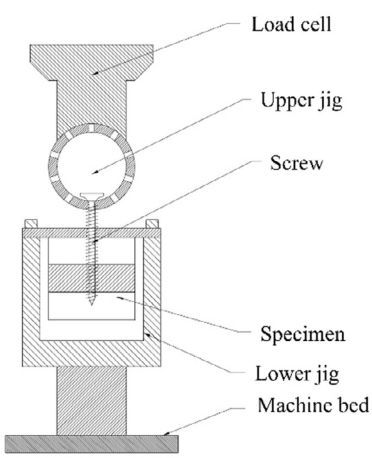

Fig. 2. Screw withdrawal test configuration

Finite element analysis (FEA) was simulated on Autodesk Fusion 360. The experimental setup was modelled, and screws were embedded with a thickness of two and three layers. Linear models were simulated by describing the material properties given in Table 1. The mesh was created with a parabolic element order and a size of 0.50 mm. The prescribed displacement was defined as 2 mm at the neck of the screw, as observed in the experiments.

Data collected to determine the presence of statistical significance among all sample groups were examined using one-way ANOVA and Tukey pair-wise comparisons in SPSS.

Results and discussion

Table 2 gives the results of the density and moisture content of the CLT specimens. According to the results, the average densities of CLTs made of Uludağ fir and black pine were 0.44 g/cm^3 with a coefficient of variation of 3.53% and 0.52 g/cm^3 with a coefficient of variation of 3.41%. In addition, the moisture contents were 11.37% and 11.08%, respectively.

Fig. 3 gives the average SWS of CLTs. According to the results, the average SWS of CLTs made of Uludağ fir was 9.73 N/mm^2 with a standard deviation of 1.05 N/mm^2 in the case that the penetration depth was two-layered. Increasing the penetration depth to three layers enhanced the SWS by 15.83%. In the case of black pine, the average SWS was 13.85 N/mm^2 with a standard deviation of 0.76 N/mm^2 for two-layer penetration depth. In the case of the three-layer one, the average SWS was 14.72 N/mm^2 with a standard deviation of 0.75 N/mm^2. The increase was 6.28% for the CLT made of black pine. As the contact area with wood fibres increases when screws are embedded in more layers of CLTs, CLT materials result in greater resistance to withdrawal force, thereby increasing friction and mechanical interlocking between screw threads and wood fibres (Pang et al., 2020).

Moreover, the density of the wood species plays a vital role in the SWS of CLTs. In here, the black pine was denser by 17.71% compared to Uludağ fir. (Xu et al., 2021) stated that denser wood material resulted in higher SWS due to its denser cellular structure and greater resistance to deformation under the load. According to the results, CLTs made of black pine had higher SWS by 42.34% and 29.45% than Uludağ fir with penetration depths of two- and three-layer, respectively.

According to the statistical analysis, the wood species (p-value < 0.001) had a greater impact on the SWS of CLTs than the penetration depth (p-value < 0.001), and both parameters were statistically significant. On the other hand, the interaction of wood species and penetration depth (p-value = 0.528) was not statistically significant on the SWS of CLTs (Table 3). Variation in wood species and penetration depth explained 90.9% of changes in the SWS of the specimens. Furthermore, the results of Tukey's mean pairwise comparison showed that the SWS of the CLTs made of black pine with three penetration depths were significantly different from those of other sample groups, but there

Table 1. Material properties used in FEA for CLTs made of Uludağ fir and black pine

Parameters	Uludağ fir	Black pine	Screw***
Young's modulus (GPa)*	5.27	8.66	85.00
Possion's ratio	0.30	0.30	0.25
Density (g/cm^3)*	0.44	0.57	7.00
Yield strength (MPa)**	40.00	55.00	150.00
Tensile strength (MPa)**	62.00	67.76	259.00

*Values from Uysal et al. (2023), ** Values from Cetin & Gündüz (2017), and ***Values from Autodesk Fusion 360 (2025)

Table 2. Density and moisture content of the CLT panels made of Uludağ fir and black pine

Wood Species	Density (g/cm^3)		Moisture Content (%)	
	Average	Std. Dev.	Average	Std. Dev.
Uludağ fir	0.44	0.02	11.37	0.17
Black pine	0.52	0.02	11.08	0.17

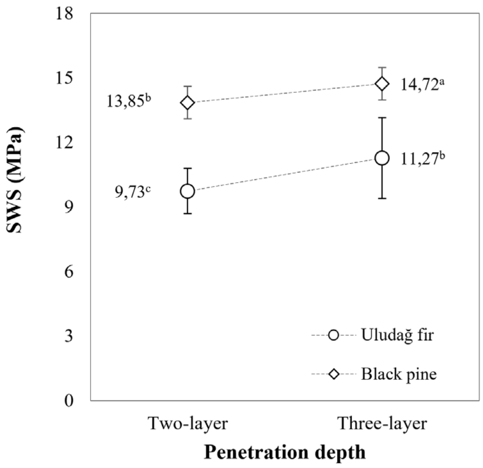

Fig. 3. SWS of the specimens (Same letters indicate that the results were not statistically different from each other, α = 0.05)

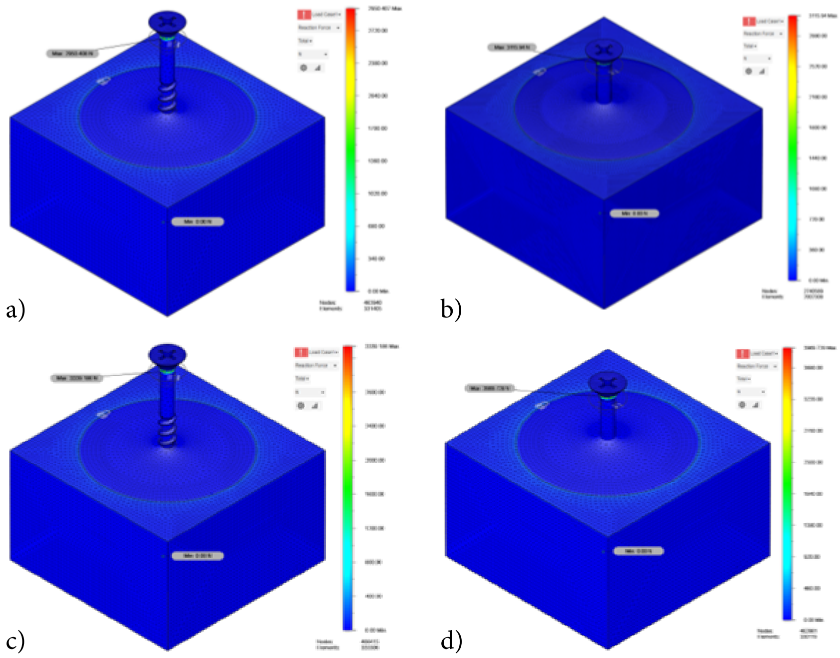

Fig. 4. FEA results: a. Uludağ fir with two-layer penetration depth, b. Uludağ fir with three-layer penetration depth, c. Black pine with two-layer penetration depth and d. Black pine with three-layer penetration depth

was no statistical difference between the SWS of CLTs made of black pine with two-layer penetration depth and Uludağ fir with three-layer penetration (Fig. 3).

Fig. 4 shows the results of FEA. According to the results, the screw withdrawal resistance of CLT was 2950.41 N and 3115.94 N with penetration depths of two- and three-layer, respectively. The increase in resistance was 5.61%, whereas the penetration depth increased. On the other hand, the withdrawal resistance of black pine was 3339.19 N and 3969.73 N, respectively. Similarly, an increase in penetration depth enhanced the withdrawal resistance by 18.88%. The change in mechanical properties of CLTs in FEA resulted in various incremental rates in the withdrawal resistance, as discussed earlier; thereby, an increase in contact area between screw and material provided higher friction and more self-interlocking points in the numerical solution, too.

Table 4 shows the difference between experimental and numerical results. The highest difference observed was 50.10% in the sample group of CLT made of Uludağ fir with a penetration depth of two layers. On the contrary, the lowest difference was 3.69% for CLT made of black pine with a penetration depth of two layers. The high variation may occur owing to model assumptions and simplifications, orthotropic properties of wood, boundary conditions and load cases, and variability in material properties. FEA often relies on certain assumptions to simplify complex physical

Table 3. Two-way ANOVA for the SWS of the CLTs

Source	Sum of Squares	df	Mean Square	F-value	Sig.
Wood species (A)	11480458.30	1	11480458.30	87.47	<0.001
Penetration depth (B)	55299.05	1	55299.05	31.80	<0.001
A*B	55299.05	1	55299.05	0.42	0.528

*R2= 0.909

Table 4. Results of the experimental and numerical studies of screw withdrawal resistance in CLTs

Wood species	Two-layer penetration depth				Three-layer penetration depth			
	No. of specimens	Ultimate load in the experiment	Ultimate load in the FEA	Difference	No. of specimens	Ultimate load in the experiment	Ultimate load in the FEA	Difference
Uludağ Fir	1	1915.63		-54.02%	1	4184.38		25.53%
	2	2332.81		-26.47%	2	4079.69		23.62%
	3	1965.63	2950.41	-50.10%	3	3773.44	3115.94	17.42%
	4	2343.75		-25.88%	4	2826.56		-10.24%
	Average	2139.46		-37.90%	Average	3716.02		16.15%
	Std. Dev.	230.53 (10.77%)			Std. Dev.	618.07 (16.63%)		
Black pine	1	3109.38		-7.39%	1	4609.38		13.88%
	2	3017.19		-10.67%	2	5198.44		23.64%
	3	3220.31	3339.19	-3.69%	3	4845.31	3969.73	18.07%
	4	2826.56		-18.14%	4	4767.19		16.73%
	Average	3043.36		-9.72%	Average	4855.08		18.24%
	Std. Dev.	166.69 (5.48%)			Std. Dev.	249.06 (5.13%)		

* Values in parentheses are the coefficient of variation (CoV)

behaviours. The importance of accurately capturing the material behaviour of CLT, which includes both elastic and inelastic properties. For instance, Albostami et al. (2019) emphasised the necessity of recognizing the limitations of linear elastic models in modelling CLT behaviour under varied loading conditions, particularly in capturing real-world factors such as mechanical interlocking and material degradation over time. Without considering these complexities, FEA results might diverge significantly from experimental observations. In this study, an isotropic model was simulated, which may increase variation due to the simple assumptions made. Additionally, when FEA models assume isotropic properties, the predicted performance may differ significantly from experimental results. Although Boggian et al. (2022) illustrated how connection details and the directional properties of wood influence the behaviour of CLT panels, demonstrating the importance of accurately capturing these characteristics to minimise modelling errors, basic isotropic properties were defined for the modelled CLTs made of Uludağ fir and black pine. Therefore, the experimental results may differ significantly from numerical results. Hu et al. (2019) also stated that localised defects or variations in wood structure in experimental setups can result in outcomes that differ from predictions based on averaged values used in the FEA. Furthermore, if boundary conditions are rigidly defined in the numerical model compared to the actual conditions experienced in experimental tests, variations of up to 24% can occur in wood science (Pichler et al., 2018). The difference between experimental and numerical results for screw withdrawal resistance of CLTs was lower than 24%, except for the sample group of CLTs made of Uludağ fir with a two-layer penetration depth. Specifically, 10 of 16 experimental results for withdrawal resistance were below 24%. This indicates that 62.50% of the results fell below the acceptable level of 24%, with three slightly above it. However, 18.75% of the experimental results exceeded the acceptable level. The study showed that FEA was somewhat successful at predicting screw withdrawal resistance in CLTs across various penetration depths and wood species. The purpose of the FEA was therefore not to replicate the full mechanical complexity of CLT connections, but to evaluate the capability and limitations of a simplified, linear-isotropic modelling approach in estimating screw withdrawal resistance owing to the limitations of Fusion 360, deliberately selected FEM software, in defining fully orthotropic and layered wood materials.

A larger sample size could improve the estimation, but the statistical analyses in this study are intended to identify comparative trends between wood species and penetration depths rather than to provide population-wide estimations. Besides, the CoV of the sample groups was acceptable; namely, the highest CoV was 16.63% for the Uludağ Fir with a penetration depth of 3 layers.

Conclusions

This study investigated the effects of screw penetration depth and wood species on the SWS of CLT panels through combined experimental and numerical analyses. The results confirmed that both parameters significantly affect withdrawal strength, with denser species and greater penetration depths providing higher withdrawal resistance. The benchmarking between experimental and numerical results validates the somewhat successful development of the model, even under simple assumptions and modelling, providing a practical foundation for the predictive design of screw-based joints. The study highlights that the availability of wood materials can be utilized in CLTs, which recently considered the stress grade of wood species according to Eurocode 5.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

References

Abdoli, F., Rashidi, M., Rostampour-Haftkhani, A., Layeghi, M., & Ebrahimi, G. (2022). withdrawal performance of nails and screws in cross-laminated timber (CLT) made of poplar (*Populus alba*) and fir (*Abies alba*). Polymers, 14, 3129. https://doi.org/10.3390/polym14153129.

Akter, S. T., Schweigler, M., Sabaa, S., & Bader, T. K. (2021). An experimental study of the stiffness and strength of cross-laminated timber wall-to-floor connections under compression perpendicular to the grain. Engineering Structures, 11, 442. https://doi.org/10.3390/buildings 11100442.

Albostami, A. S., Wu, Z., & Cunningham, L. S. (2019). Assessment of cross-laminated timber panels by the state-space approach. Advances in Structural Engineering, 22(11), 2375–2391. https://doi.org/10.1177/1369433219841504.

Boggian, F., Aloisio, A., & Tomasi, R. (2022). Experimental and analytical study of friction connection for seismic retrofit with Cross-Laminated Timber (CLT) panels. Earthquake Engineering and Structural Dynamics, 51(14), 3304–3326. https://doi.org/10.1002/eqe.3724.

Cavus, V., & Ersin, I. (2023). Determination of physical and mechanical properties of parallel strand lumber manufactured from bamboo. BioResources, 18(4), 6802–6814. https://doi.org/10.15376/biores.18.4.6802-6814.

Cetin, F., & Gunduz, E. (2017). Evaluation of research studies about mechanical properties of some wood species in Turkey. Journal of Bartin Faculty of Forestry, 19 (1): 161-181. https://doi.org/10.24011/barofd.306723.

Dong, W., Li, M., Ottenhaus, L. M., & Lim, H. (2020). Ductility and overstrength of nailed CLT hold-down connections. Engineering Structures, 215, 110667. https://doi.org/10.1016/j.engstruct.2020.110667.

Eini, A., Zhou, L., & Ni, C. (2022). Behavior of self-tapping screws used in hybrid light wood frame structures connected to a CLT core. Buildings, 12(1018). https://doi.org/10.3390/buildings12071018.

Gavric, I., Fragiacomo, M., & Ceccotti, A. (2015). Cyclic behavior of typical screwed connections for cross-laminated (CLT) structures. European Journal of Wood and Wood Products, 73, 179–191. https://doi.org/10.1007/s00107-014-0877-6

Hu, W., Wan, H., & Guan, H. (2019). Size effect on the elastic mechanical properties of beech and its application in finite element analysis of wood structures. Forests, 10, 783. https://doi.org/10.3390/f10090783.

Jalilifar, E., Koliou, M., & Pang, W. (2021). Experimental and numerical characterization of monotonic and cyclic performance of cross-laminated timber dowel-type connections. Journal of Structural Engineering, 147(7), 04021102. https://doi.org/10.1061/(asce)st.1943-541x.0003059.

Masroor, M., Doudak, G., & Casagrande, D. (2023). Experimental validation of proposed capacity-based design approaches for multi-panel CLT shear walls. 13th World Conference on Timber Engineering, WCTE 2023, 1224–1230. https://doi.org/10.52202/069179-0167.

OGM (2023). Yerli iğne yapraklı ağaç türlerimizden karaçam, göknar, sarıçam ,kızılçam, sedir ve ladin ağaç türlerimize uluslararası standart alınması (in Turkish). Available on: https://www.ogm.gov.tr/marmaraarastirma/haberler/yerli-igne-yaprakli-agac-turlerimizden-karacam-goknar-saricam-kizilcam-sedir-ve-ladin-agac-turlerimize-uluslararasi-standart-alinmasi-38.

Pan, Y., Teflissi, T., & Tannert, T. (2023). Experimental parameter study on CLT shear walls with high-performance self-tapping screw connections. 13th World Conference on Timber Engineering, WCTE 2023, 2040–2045. https://doi.org/10.52202/069179-0270

Pang, S. J., Ahn, K. S., Kang, S. G., & Oh, J. K. (2020). Prediction of withdrawal resistance for a screw in hybrid cross-laminated timber. Journal of Wood Science, 66(1). https://doi.org/10.1186/s10086-020-01926-8.

Pichler, P., Leitner, M., Grün, F., & Guster, C. (2018). Evaluation of wood material models for the numerical assessment of cutting forces in chipping processes. Wood Science and Technology, 52, 281–294. https://doi.org/10.1007/s00226-017-0962-1.

Ruggeri, E. M., D'Arenzo, G., Li Cavoli, D., Casiraro, I., & Fossetti, M. (2023). Experimental characterization of CLT shear walls connected to perpendicular walls. 13th World Conference on Timber Engineering, WCTE 2023, 3423–3429. https://doi.org/10.52202/069179-0446.

Schiro, G., Giongo, I., Sebastian, W., Riccadonna, D., & Piazza, M. (2018). Testing of timber-to-timber screw-connections in hybrid configurations. Construction and Building Materials, 171, 170–186. https://doi.org/10.1016/j.conbuildmat.2018.03.078

Shahnewaz, M., Alam, S., & Tannert, T. (2018). In-plane strength and stiffness of cross-laminated timber shear walls. Buildings, 8, 100. https://doi.org/10.3390/buildings8080100.

Teixeira, M. Z., Terezo, R. F., da Cunha, A. B., Tomio, G. F., Coelho, H. B., & Corrêa, C. A. (2024). Validation of the Physical and mechanical properties of *Eucalyptus benthamii* Maiden & Cambage wood and cross laminated timber panels using the finite element Method. Forests, 15, 881. https://doi.org/10.3390/f15050881.

TS EN 13446 (2002). Wood-based panels - Determination of withdrawal capacity of fasteners. TSE, Ankara, Turkey.

Uysal, M., Eren, O., Karatay, H., & Memiş, D. (2022). Investigation of bending properties of cross laminated timber made of Uludağ fir and black pine. Turkish Journal of Forestry, 23(4), 313–319. https://doi.org/10.18182/tjf.1166361.

Xu, J., Zhang, S., Wu, G., Gong, Y., & Ren, H. (2021). Withdrawal properties of self-tapping screws in Japanese larch (*Larix kaempferi* (Lamb.) Carr.) cross-laminated timber. Forests, 12, 524. https://doi.org/10.3390/f12050524.