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Screw Over-tightening in Mass Timber: A Laser-Based Approach for Enhanced Quality Control

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ABSTRACT

Mass timber construction, incorporating materials such as glue-laminated (glulam) and cross-laminated timber (CLT), necessitates the development of innovative connection methods due to their ability to support significant loads. These methods often involve the use of elongated screws. However, the challenge lies in ensuring the mechanical integrity of these connections, particularly safeguarding against overtightening, which is crucial for maintaining structural safety. Traditional approaches for evaluating the integrity of screw connections are manual and thus subject to limitations. In response to this, the present research utilizes laser scanning technology to automate the assessment of screw penetration in wood-aluminum interfaces. The study investigates the relationship between applied torque and penetration depth, with torque values ranging from 10 to 50 Nm in increments of 5 Nm. This investigation revealed a critical torque range, particularly between 35-40 Nm, where minor deviations in overtightening could compromise the connection's integrity. The findings of this study highlight the effectiveness of laser scanning in identifying screws that have been improperly torqued, thereby offering a significant advancement in quality control within the realm of mass timber construction. Furthermore, the research proposes a threshold-based detection method capable of identifying overtightened screws in an experimental setup. This method is particularly effective when the distance between two interfacing surfaces exceeds 3.2 mm, thereby providing a quantitative basis for assessing the screw connection. This methodology holds promise for enhancing the safety and reliability of mass timber construction by enabling more precise control over connection quality.

Keywords: robotic inspection, mass timber construction, automated defect measurement, overtightening detection

ITRODUCTION

Mass timber construction, utilizing materials like glue-laminated timber (glulam) and cross-laminated timber (CLT), is increasingly recognized for its sustainability compared to traditional materials like steel and concrete [1, 2]. As the use of mass timber, particularly CLT, grows in high-rise and high-occupancy buildings, the reliability of connections becomes crucial. Screws, often elongated for larger timber elements, are commonly used connectors. Despite current automated methods for nondestructive evaluation, methods for assessing screw over-tightening are predominantly manual, time-consuming, error-prone and limited studies have investigated connection methodologies [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. Ensuring correct torque application on screws is essential to maintain a secured connection without damaging the screw or mass timber. This study introduces a novel approach by applying laser scanning technology to automate the evaluation of screw penetration depth in wood-aluminum interfaces within CLT structures. This method addresses the limitations of manual assessment by offering a more efficient, accurate, and less labor-intensive evaluation. To our knowledge, this is the first study to integrate laser scanning technology with screw penetration depth measurements in CLT, marking a significant advancement in connection quality control in mass timber construction. The research focuses on validating the effectiveness of laser scanning technology in assessing

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screw integrity in CLT interfaces, particularly using Vgs9180 screws with wood-aluminum connections. By examining the relationship between torque application and penetration depth, a critical torque range is identified. This study aims to enhance quality control in mass timber construction, leveraging laser technology to improve precision and reliability in connection assessments.

METHODOLOGY

In this study, we employed a methodical approach to examine the interface between aluminum plates and cross-laminated timber (CLT) using Vgs9180 fully threaded screws. A robotic arm equipped with a laser scanner was utilized to ensure precise and controlled scanning of the joint interface. This setup enabled the application of a 2 kHz laser scan across the surface at a consistent speed of 10mm/s. The robotic arm's design provided comprehensive coverage and efficient data collection over the wood-aluminum joints. We varied the torque applied to the screws inserted into the CLT panels, setting it in a range from 10 to 40 Nm and incrementing by 5 Nm intervals. Concurrently, the distance between the interfacing materials was meticulously monitored and recorded to establish a correlation between the applied torque and the screw penetration depth into the CLT. Figure 1 in the paper illustrates the methodology used for the scanning process. The experiment involved applying torque to the screws within a range of 10 to 50 Nm, in 5 Nm increments. This range was strategically chosen to encompass typical real-world scenarios and to explore potential critical thresholds where material penetration might be adversely affected. Data from the laser scans was processed to construct a torque-penetration curve. Density-Based Spatial Clustering of Applications with Noise (DBSAN) statistical analyses were performed to clean the outliers and confirm the reliability of the observed patterns [16, 17].

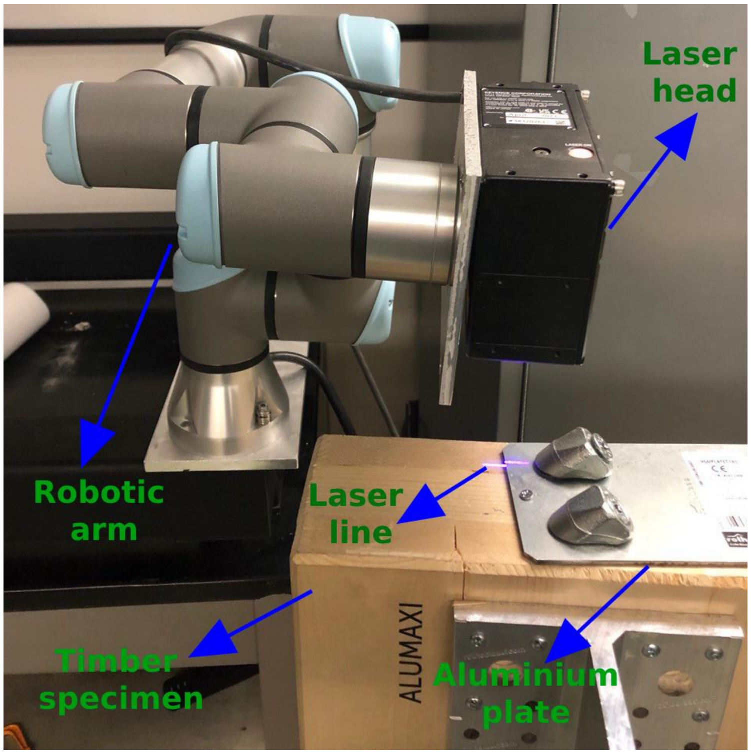

Figure 1: Experimental setup for depth penetration measurement of aluminum in the timber specimen.

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RESULTS

The study revealed a notable shift in the torque-penetration curve, particularly within the 30-40 Nm torque range. This finding indicates a critical zone where even slight variations in torque can substantially influence the depth of screw penetration into the cross-laminated timber (CLT). It was determined that a penetration depth exceeding 3.2 mm is indicative of overtightening. This threshold is pivotal in setting benchmarks for screw installation in mass timber construction, ensuring structural integrity. Figure 2 depicts the results obtained from the experimental setup. Furthermore, the incorporation of a robotic arm equipped with a laser scanner signifies an innovative leap in automating the quality assurance process in mass timber construction. The ability to accurately detect and analyze screw penetration depths through this automated system has significant implications. It offers a pathway to enhance the reliability and safety of timber connections, transforming the standard practices for conducting inspections in timber construction projects. This approach aligns with the industry's evolving needs for precision and efficiency in construction quality control.

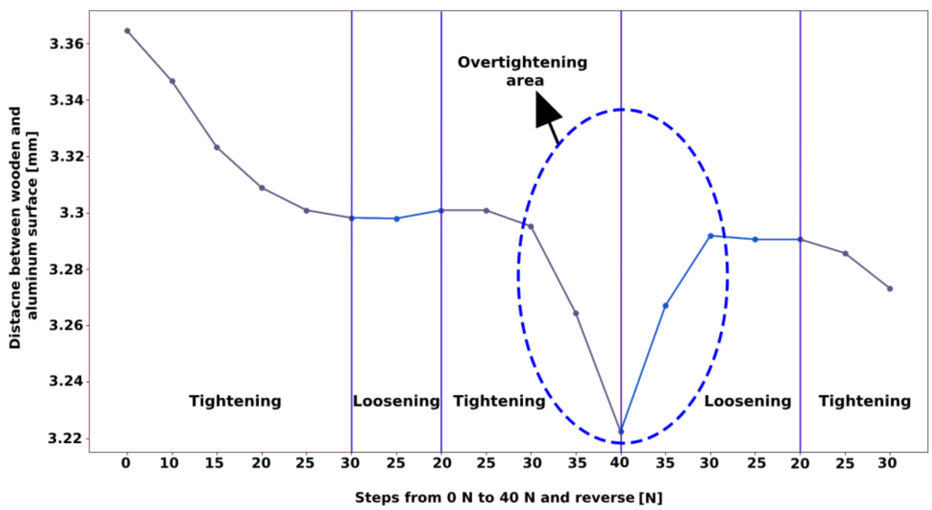

Figure 2: Distance between aluminum and mass timber surface to torque applied at each step curve.

CONCLUSION

This research offers a practical approach to addressing the challenges posed by overtightening in screw connections, a critical element in mass timber buildings. The findings of this study contribute to the domain of structural maintenance and construction technology, particularly in enhancing quality control and safety standards in mass timber construction. The integration of automated laser scanning in evaluating connection integrity not only streamlines the inspection process but also ensures greater accuracy and reliability. This advancement aligns with the industry's ongoing efforts to adopt more efficient methods in construction practices, especially in the realm of sustainable building materials like mass timber.

REFERENCES

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[1] Kremer, PD and Symmons, MA. "Mass timber construction as an alternative to concrete and steel in the Australia building industry: a PESTEL evaluation of the potential." International Wood Products Journal Vol. 6 No. 3 (2015): pp. 138–147.

[2] Crawford, Robert H and Cadorel, Xavier. "A framework for assessing the environmental benefits of mass timber construction." Procedia engineering Vol. 196 (2017): pp. 838–846.

[3] Hashemi, Ashkan, Zarnani, Pouyan and Quenneville, Pierre. "Seismic assessment of rocking timber walls with energy dissipation devices." Engineering Structures Vol. 221 (2020): p. 111053.

[4] Leijten, AJM. "Requirements for moment connections in statically indeterminate timber structures." Engineering Structures Vol. 33 No. 11 (2011): pp. 3027–3032.

[5] Nguyen, Anh Chi, Vestartas, Petras and Weinand, Yves. "Design framework for the structural analysis of free-form timber plate structures using wood-wood connections." Automation in Construction Vol. 107 (2019): p. 102948.

[6] Gamerro, Julien, Robeller, Christopher and Weinand, Yves. "Rotational mechanical behaviour of wood-wood connections with application to double-layered folded timber-plate structure." Construction and Building Materials Vol. 165 (2018): pp. 434–442.

[7] Zhang, Lei, Chui, Ying Hei and Tomlinson, Douglas. "Experimental investigation on the shear properties of notched connections in mass timber panel-concrete composite floors." Construction and Building Materials Vol. 234 (2020): p. 117375.

[8] Ghadimzadeh Alamdari, Ali and Ebrahimkhanlou, Arvin. "A multi-scale robotic approach for precise crack measurement in concrete structures." Automation in Construction Vol. 158 (2024): p. 105215. DOI https://doi.org/10.1016/j.autcon.2023.105215.

[9] Alamdari, Ali Ghadimzadeh and Ebrahimkhanlou, Arvin. "A robotic approach for crack detection through the integration of cameras and LiDARs." Su, Zhongqing, Glisic, Branko and Limongelli, Maria Pina (eds.). Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2023, Vol. 12486: p. 1248606. 2023. International Society for Optics and Photonics, SPIE. DOI 10.1117/12.2658110. URL https://doi.org/10.1117/12.2658110.

[10] Bazrafshan, Pedram, On, Thinh, Basereh, Sina, Okumus, Pinar and Ebrahimkhanlou, Arvin. "A graph-based method for quantifying crack patterns on reinforced concrete shear walls." Computer-Aided Civil and Infrastructure Engineering Vol. 39 No. 4 (2024): pp. 498–517. DOI https://doi.org/10.1111/mice.13009. URL https://onlinelibrary.wiley.com/ doi/pdf/10.1111/mice.13009

[11] Asjodi, Amir Hossein, Dolatshahi, Kiarash M. and Ebrahimkhanlou, Arvin. "Spatial analysis of damage evolution in cyclic-loaded reinforced concrete shear walls." Journal of Building Engineering Vol. 49 (2022): p. 104032. DOI https://doi.org/10.1016/j.jobe.2022. 104032.

[12] Momeni, Hamed and Ebrahimkhanlou, Arvin. "High-dimensional data analytics in structural health monitoring and non-destructive evaluation: a review paper." Smart Materials and Structures Vol. 31 No. 4 (2022): p. 043001. DOI 10.1088/1361-665X/ac50f4. URL https://dx.doi.org/10.1088/1361-665X/ac50f4.

[13] Hamidia, Mohammadjavad, Mansourdehghan, Sina, Asjodi, Amir Hossein and Dolatshahi, Kiarash M. "Machine learning-based seismic damage assessment of non-ductile RC beam-column joints using visual damage indices of surface crack patterns." Structures Vol. 45 (2022): pp. 2038–2050. DOI https://doi.org/10.1016/j.istruc.2022.09.010.

[14] Spencer, Billie F., Hoskere, Vedhus and Narazaki, Yasutaka. "Advances in Computer Vision-Based Civil Infrastructure Inspection and Monitoring." Engineering Vol. 5 No. 2 (2019): pp. 199–222. DOI https://doi.org/10.1016/j.eng.2018.11.030.

[15] Yeum, Chul Min, Dyke, Shirley J. and Ramirez, Julio. "Visual data classification in post-event building reconnaissance." Engineering Structures Vol. 155 (2018): pp. 16–24. DOI https://doi.org/10.1016/j.engstruct.2017.10.057.

[16] Deng, Dingsheng. "DBSCAN clustering algorithm based on density." 2020 7th international forum on electrical engineering and automation (IFEEA): pp. 949–953. 2020. IEEE.

© 2024. This work is licensed under a **CC BY-ND 4.0 license**.

[17] Shen, Jianbing, Hao, Xiaopeng, Liang, Zhiyuan, Liu, Yu, Wang, Wenguan and Shao, Ling. "Real-time superpixel segmentation by DBSCAN clustering algorithm." IEEE transactions on image processing Vol. 25 No. 12 (2016): pp. 5933–5942.

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