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Fire Safety in Engineered Timber

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A B S T R A C T

The growing popularity of engineered timber in the construction of mid- and high-rise buildings has raised concerns regarding its fire safety performance. This paper delves into the complex dynamics of fire safety in engineered timber construction, critically examining its combustibility, structural performance, and environmental benefits. The study provides a comprehensive analysis of current fire safety practices, international fire codes and regulations, and the behavior of engineered timber in fire scenarios. Factors such as charring behavior, structural robustness, and passive and active fire protection systems are thoroughly explored and evaluated. The paper not only highlights the advantages of engineered timber in fire-safe design but also acknowledges its limitations and potential challenges. Additionally, innovative solutions and approaches to enhance the fire safety of engineered timber structures are investigated, including the use of fire-retardant treatments, advanced structural detailing, and the integration of fire-resistant materials. The research offers valuable insights and practical recommendations for the safe, resilient, and sustainable use of engineered timber in construction, contributing to the ongoing development of this sustainable building material. It concludes with recommendations for improvements in regulatory frameworks and suggestions for future research directions.

Keywords: Engineered Timber, Fire Resistance, Fire Retardant Treatments, Fire Safety, Mass Timber Structures, Structural Design

1. Introduction

Engineered wood, mass timber, or engineered timber is a type of structural wood product that is manufactured by gluing wood veneers, strands, or layers of lumber together. The most commonly used types are cross-laminated timber (CLT), glued laminated timber (glulam), and laminated veneer lumber (LVL). They are all designed to increase strength, stability, and dimensional uniformity compared to traditional solid wood. In recent times, engineered timber has become a material of preference in sustainable architecture due to its low embodied carbon, renewability, and suitability for prefabrication and modular construction.

1.1 Importance of fire safety in engineered timber

Engineered timber, while providing many structural and environmental benefits, poses important challenges with respect to fire safety, especially in the case of multi-story and high-occupancy buildings. Given that wood is naturally combustible, ensuring the fire performance of timber elements is crucial for both, occupant safety and the integrity of the structure. As timber construction becomes more common in urban areas, it is essential to understand how engineered timber reacts to fire exposure and how it can be safely integrated into building designs. Fire codes, material treatments, and structural detailing must all be coordinated to minimize the fire risks of engineered timber and to meet both, code requirements and public expectations of safety.

1.2 Research objectives and questions

The objective of this research is to investigate the fire safety performance of engineered timber and to evaluate the effectiveness of current fire safety measures and technologies for this material. The specific research question for this project is: How can the fire performance of engineered timber be optimized to mitigate the risks associated with its combustible nature?

1.3 Structure of the paper

The paper will be organized into six main sections. This introduction is the first section, followed by Section 2, which will provide a literature review of fire safety measures and regulations applicable to engineered timber. This section will also evaluate the effectiveness of existing measures and standards for the material. In Section 3, the paper will examine fire behavior and performance of engineered timber in fire. This section will consider factors such as charring behavior, material composition, and compartmentation. In Section 4, the study will discuss the benefits, limitations, and challenges associated with using engineered timber in construction that is fire safe, along with case studies. In Section 5, the paper will present strategies for improving the fire resistance of engineered timber, including design solutions, fire retardant treatments, and new materials. The final section of the paper will conclude the study by summarizing the findings, providing recommendations, and identifying future research directions for improving the fire safety performance of engineered timber.

2. Fire safety measures and regulations

Effective fire safety in engineered timber structures depends on a balanced fire protection system. It entails active fire protection systems that include sprinklers, smoke detectors, alarms, and portable firefighting equipment (Kincelova & Boton, 2020). The systems aim at detecting and suppressing fires in the early stages, boosting the safety of the occupants as well as preventing the building structure from damage. Passive fire protection measures in engineered timber buildings are also crucial for fire safety and include fire-resistance assemblies, compartmentation, protective cladding, and the charring response of engineered timber (Law & Hadden, 2020). They help to prevent the spread of fire and smoke, maintain the building's integrity, and gain time for evacuation. Both active and passive fire protection measures must be brought together in order to achieve the desired level of fire safety for engineered timber structures.

2.1 Fire codes and legislation relating to engineered timber

Fire codes and building laws are of prime significance in ensuring engineered timber buildings' safety. Different international and national fire codes and laws have been formulated to provide comprehensive data regarding the design, construction, and use of engineered timber in buildings. The International Code Council (ICC), National Fire Protection Association (NFPA), and European Committee for Standardization (CEN) are some of the most prominent organizations to have established fire safety codes and standards that include provisions requiring engineered timber.

The International Building Code (IBC) allows for the construction of high timber buildings up to a specified height using cross-laminated timber (CLT) and glulam as supporting elements as part of Type IV construction if some prerequisites are fulfilled related to fire resistance, hidden space protection, and height/area limitations (Barber, 2018). The NFPA 5000 and the European Eurocode 5 also provide some guidelines regarding the fire design of wood structures, such as acceptable char rates, fire resistance periods to be delivered, and how the fire design is to be carried out. Fire codes are expected to provide a minimum standard of acceptability in terms of safety and discuss a wide range of issues, including:

- Minimum fire resistance required for building elements
- Egress and evacuation features
- Compartmentation and protection of load-bearing elements
- Fire detection and suppression system requirements.

2.2 Evaluation of current regulations

Although current fire regulations provide a basic framework for designing safe timber buildings, there are several limitations in the way that they address the behavior of engineered timber products under fire conditions. Gales and McNamee (2023) note that many existing building codes were developed with steel and concrete structures in mind. As a result, they may not fully capture the charring behavior and fire endurance of newer timber products. Kotsovinos and Rackauskaite (2022) found that large open-plan spaces with exposed timber are not fully understood and therefore difficult to incorporate into existing modeling, including flame spread dynamics and complex smoke movement. Furthermore, there is significant variation in the fire performance of different timber types, moisture content, and construction details that can lead to deviations from standardized assumptions. Therefore, there is a need to comprehensively re-evaluate the existing fire safety codes and regulations for engineered timber products. Regulatory bodies and organizations need to consider new empirical data, simulation results, and full-scale fire tests to refine fire resistance classifications and design methodologies specific to engineered timber systems.

2.3 Potential improvements in fire safety measures

A more effective fire safety strategy for engineered timber structures must be a multi-faceted approach. It should incorporate the latest material science innovations, system design improvements, and regulatory reforms. Acker and Li (2023) highlight the benefits of using a combination of fire-retardant treatments and physical barriers. Fire retardants can be applied to timber elements to delay ignition, while physical barriers, such as intumescent coatings and protective cladding, can be used to prevent or slow down fire spread in timber assemblies. Newer structural systems have also been developed to improve the fire resistance of timber structures. Trummer and Schneider (2022) found that hybrid timber-concrete slabs have shown promising fire resistance due to the combined thermal properties and strength of both materials. This suggests that the future of fire safety in engineered timber may lie in an integrated approach where the material properties and structural design work together to achieve the required fire performance. Potential improvements in regulations should include the following:

- Encourage the use of performance-based fire engineering, which allows for more flexibility and innovation while still achieving the same safety goals.
- Require full-scale fire testing of new timber systems before they are approved for use.

- Update the guidance on the detailing and protection of critical connections in timber structures, which are often the weak points during a fire.

3. Performance of engineered timber in fire conditions

3.1 Fire resistance properties of engineered timber materials

One of the advantages of engineered timber, as noted by Kincelova and Boton (2020), is its enhanced fire resistance. Engineered timber materials, like cross-laminated timber (CLT) and glued laminated timber (glulam), are designed to char under fire exposure. The charring creates an insulating layer that minimizes heat transfer and allows the structure to remain intact for an extended period. Thus, it has a self-insulating property that reduces fire spread and structural collapse (Kincelova & Boton, 2020). In addition to charring, Law and Hadden (2020) highlight another important fire resistance property of engineered timber, which is its low thermal conductivity. Engineered timber has significantly lower thermal conductivity compared to conventional building materials like steel and concrete. These characteristic limits the passage of heat, giving occupants a longer time to evacuate in case of a fire (Law & Hadden, 2020).

3.2 Behavior of engineered timber structures during fire

Engineered timber structures exhibit certain behavior in the presence of fire that is important to understand for the purpose of design and construction of fire-safe buildings. In their paper on the analysis of the behavior of engineered timber structures in fire, Luo and Shi (2020) state that this behavior is determined by a number of factors, including compartmentation, moisture content, connections, and protective measures. Compartmentation is important for the fire behavior of timber structures since it can help to contain the fire within a certain area, reducing the speed of the fire spread and making the evacuation of the building occupants easier and safer. The moisture content of the wood also has a direct effect on the ignition and burning rates, so it is important to have proper measures to control it during the construction (Luo & Shi, 2020). Connections between the engineered timber elements, such as beams, columns, and connections to other building elements, play a crucial role in the fire behavior of timber structures. A failure of these connections can lead to a collapse of the structure during a fire event, which is why they should be given due attention during the design and construction process (Acker & Li, 2023). Finally, there are also various protective measures that can be applied to engineered timber structures in order to improve their fire resistance, such as fire-resistant coatings and fire barriers (White, 1986).

3.3 The factors affecting the fire performance of engineered timber

Various parameters affect the fire performance of engineered timber, and understanding these parameters is crucial to ensuring the safety and resilience of structures. Kotsovinos and Rackauskaite (2022) highlight the role of fire dynamics in building compartments, particularly in large open-plan spaces with exposed timber structures. An understanding of flame behavior, heat release rates, and smoke movement is required in order to design effective fire safety measures and to optimize the performance of engineered timber products (Kotsovinos & Rackauskaite, 2022). The remaining parameters that affect the fire performance of engineered timber are the quality of the timber material, its density, and if there is any protection treatment applied. According to Trummer and Schneider (2022), the structural behavior of hybrid timber-earth floor slabs can be influenced by factors such as timber density, connection details, and interaction of timber and earth layers. Therefore, detailed research and investigation are required to investigate these factors and develop effective fire safety solutions for engineered timber buildings.

3.4 Comparative analysis of different types of engineered timber

There are different types of engineered timber products that have been developed and used in the construction of buildings such as cross-laminated timber (CLT), glulam, and LVL. The fire performance characteristics of these different types of engineered timber are worth understanding so that one can make fully informed decisions during the designing and building process. For instance, Zhou and Lu (2023) suggest that the fire resistance of timber-concrete composite boards can be enhanced by adding partial protection, i.e., a gypsum layer plasterboard or concrete to the exposed timber surfaces. This indicates the merit of considering the specific characteristics and behavior of different kinds of engineered timber in order to maximize fire performance in buildings. By comparative analysis of various kinds of engineered timber, valuable information can be gathered on their individual fire resistance characteristics, structural performance, and advantages under different construction conditions. Architects, engineers, and researchers can make make informed choices for the optimization and choice of engineered timber products, thereby ensuring the fire safety and building resilience.

4. Advantages, Limitations, and Challenges

In terms of fire safety, there are a number of advantages to using engineered timber. First, engineered timber is known to provide excellent fire resistance in some cases. The layered structure of engineered timber, along with its charring behaviour, is often better than that of conventional solid timber. This can effectively slow down the spread of fire and maintain the structural integrity of the material by charring the outer layers (Luo & Shi, 2020). Secondly, the lightweight nature of engineered timber reduces the overall load of a structure in a fire event in comparison with other construction materials, such as concrete and steel (Kincelova & Boton, 2020). Another advantage is that the use of engineered timber in construction can support sustainability and reduce the carbon footprint of buildings. Timber is a renewable material with a lower embodied carbon than concrete and steel, which makes engineered timber a sustainable choice that can contribute to the carbon sequestration potential of a structure (Taghiyari & Morrell, 2021). Also, engineered timber offers great design flexibility and new possibilities for architects. Engineered timber components can be prefabricated off-site for more efficient and faster construction processes. Engineered timber's dimensional stability also means there is less chance of damage occurring during a fire, contributing to better fire performance (Trummer & Schneider, 2022).

On the other hand, there are also some limitations to using engineered timber in terms of fire safety. Moisture sensitivity can be one of the main limitations of using engineered timber for fire safety. Exposure to high moisture levels can result in degradation and loss of fire performance properties, potentially weakening the engineered timber's structural integrity and fire resistance (White, 1986). Another common limitation is that the fire resistance of engineered timber is often improved by the application of special fire retardant treatments. While effective, these treatments do make the construction process more complex, expensive and need to be repeated (Acker & Li, 2023). In addition, when it comes to larger engineered timber structures, their compartmentation, fire-rated assemblies, and occupant safety must be considered. These things can be more difficult in open-plan spaces where the lack of compartmentation may need to be compensated with other design considerations and protective measures to achieve sufficient fire resistance (Gales & McNamee, 2023).

There are also various challenges that come with incorporating engineered timber into a fire-safe structure. One challenge relates to the development of guidelines and standards. There are general fire safety codes and regulations that are relevant to engineered timber structures. However, they must be updated to account for recent materials and construction practice developments (Mcnamee & Janssens, 2021). In addition, fire-rated assemblies for engineered timber structures must be designed and constructed with special consideration, meaning that more advanced modeling techniques need to be used. Simulating the behaviour of engineered timber structures in complex fire scenarios, accounting for varying parameters such as temperature distribution and moisture movement, can help to arrive at a more accurate fire safety design process (Zhou & Lu, 2023). Lastly, there is a need to raise the awareness of industry professionals about the fire safety aspects of engineered timber. Architects, engineers, and contractors need to have an up-to-date knowledge about the best practices, design principles, and research on engineered timber to be able to incorporate it into construction projects safely and responsibly (Law & Hadden, 2020).

To provide real-life examples of some of the advantages, limitations and challenges of using engineered timber in fire-safe environments, a number of case studies have been published in the literature. A case study on a tall timber building project in Australia is an example of a successful use of engineered timber as part of a fire-safe structure. The case study detailed the fire resistance and sustainable features of the building (Kincelova & Boton, 2020). However, there are also case studies that show the challenges of using engineered timber in a fire-safe environment. One such case study on a large open-plan compartment with exposed timber elements revealed some of the difficulties in achieving the required fire resistance (Kotsovinos & Rackauskaite, 2022). These and many other case studies provide real-life insights and examples of the advantages, limitations, and challenges of using engineered timber in fire-safe structures. As such, architects, engineers, and policymakers now have access to the information they need to make informed decisions about using engineered timber in their projects.

5. Strategies to improve fire resistance

In terms of enhancing the fire resistance of engineered timber, there are a number of strategies that can be employed. One such strategy is the application of fire retardant treatments, which plays a fundamental role. These treatments involve the application of chemical agents on the surface of the timber, and they function by reducing the fire spread rate while increasing the ignition and burning time of the material. Some of the most prevalent fire retardant treatments applied to engineered timber are intumescent coatings, fire-resistant varnishes, and fire-retardant impregnation. Intumescent coatings are especially intriguing as they possess the ability to expand when exposed to heat. It is this expansion that forms a protective char layer, which insulates the wood and decelerates its ignition. Fire-resistant varnishes also function effectively by forming a protective film on the wood surface. This film reduces the possibility of ignition and also retards the spread of flames. Fire-retardant impregnation is the application of chemicals to the wood so that they penetrate the material and create a fire barrier. Aside from fire retardant treatments, there are also other extremely crucial factors to consider when attempting to enhance the fire resistance of engineered timber. Structural design is one such consideration and it plays a basic role in minimizing the risk of fire spread and collapse. Some of the main considerations include:

- Compartmentation: This is a design strategy that involves dividing a building into multiple separate fire compartments, each of which is surrounded by fire-resistant barriers. This can be an effective way of containing the spread of fire and smoke within a building.
- Fire-resistant cladding: It is also important to use fire-resistant cladding, such as gypsum boards or cementitious panels, in engineered timber buildings. This can provide an additional layer of protection against fire.
- Fire-resistant joints: In addition, it is also important to design engineered timber structures with appropriate fire-resistant joints and connections. This can help to prevent premature failure of the structure during a fire.
- Fire-rated assemblies: Finally, the use of fire-rated assemblies, such as fire doors and fire-rated glazing, can be very important in engineered timber buildings. These assemblies can be designed to help prevent the spread of fire and smoke, while also ensuring the safe evacuation of building occupants.

There are many other innovative technologies and materials that are being developed and researched to provide further improvements in the fire safety of engineered timber. One such approach involves the use of fire-resistant adhesives in the production process of engineered wood products like cross-laminated timber (CLT). Another promising avenue of research is the investigation of new fire-resistant coatings, including intumescent nano-coatings, that ensure improved fire protection compared to traditional coatings. Also, there is growing interest in the development of fire-resistant timber composites through the inclusion of non-combustible materials or fire-resistant additives.

6. Conclusion

In this article, the intricate issue of fire safety in engineered timber construction has been addressed offering a comprehensive look at the current measures, materials, behaviors, and innovations in the field. Engineered timber products like CLT, glulam, and LVL bring impressive benefits in sustainability, structural performance, and construction efficiency. Its inherent combustibility requires robust fire safety measures. The current codes and regulations for engineered timber construction, while improving, often lag behind the pace of innovation and practical experience in the field. They may require updates or enhancements to adequately address the fire behavior of mass timber elements. Engineered timber can provide inherent fire resistance due to its charring behavior, low thermal conductivity, and structural integrity. When combined with passive and active fire protection systems, it can meet or exceed current fire safety standards. Factors such as moisture content, connection detailing, compartmentation strategies, and protective treatments significantly affect the fire performance of engineered timber. These factors must be considered in an integrated manner during both the design and construction phases. This research contributes to the growing literature on fire safety in engineered timber construction by providing a comprehensive overview of the challenges and opportunities in this field. It will aid in informed decision-making by architects, engineers, builders, and policymakers.

6.1 Recommendations for architects, engineers, policymakers, and researchers

To ensure confidence in using engineered timber in modern construction, the following are recommended:

- Engineers and architects must take fire safety into account in early planning stages. This includes implementing compartmentation, selecting appropriate fire-retardant treatments, and detailing connections that will be durable when subjected to fire.
- Regulatory agencies must update and harmonize the fire safety provisions with empirical data from large-scale fire testing and offer performance-based design solutions applicable to engineered timber.
- Researchers are encouraged to develop novel fire-resistance composite materials and explore mass timber's long-term performance under varying environmental conditions. Simulations and fire modeling must be more accurate and accessible to practitioners.
- Academia, industry, and code authorities from all sectors will need to collaborate to improve standardized fire testing techniques and design guidelines specific to mass timber.

6.2 Future research directions

In order to improve the practices for fire safety in engineered timber construction, future research should focus on the following topics:

- Advanced fire modeling to predict the behavior of complex timber assemblies in realistic fire scenarios, including time-dependent factors such as heat flux, relative humidity, and structural deformation.
- Durability studies on the long-term performance of fire-retardant treatments under different environmental stressors, including moisture, UV exposure, and mechanical wear.
- Development of new composite systems that incorporate non-combustible materials with timber to achieve improved fire ratings, without compromising sustainability.
- Case studies documenting both successful and problematic implementations of engineered timber in fire-safe construction, to serve as real-world references for best practices and lessons learned.

Addressing these areas of research will enable the building industry to continue to improve the safe and innovative use of engineered timber, while ensuring that fire safety remains a core consideration in this evolution toward sustainable construction.

7. References

Barber, D. (2018). Fire Safety of Mass timber Buildings with CLT in USA. *Wood and Fiber Science*, *50*(Special), 83–95. https://doi.org/10.22382/wfs-2018-042

Cachim, P. B., & Franssen, J. (2008). Comparison between the charring rate model and the conductive model of Eurocode 5. *Fire and Materials*, *33*(3), 129–143. https://doi.org/10.1002/fam.985

Gales, J., & McNamee, R. (2023). Fire research for timber structures. *Fire and Materials*, *47*(4), 413–414. https://doi.org/10.1002/fam.3140

Joris, V. A., Li, W., Jiang, X., Durimel, M., Liselotte, D. L., Parakhonskiy, B., Skirtach, A., & Jan, V. D. B. (2023). *Combining wood protection options to enhance resistance against decay and improve fire safety of engineered wood products like CLT*. https://biblio.ugent.be/publication/01HRYRY9CS558GK1WW4BHDJRZZ

Kincelova, K., Boton, C., Blanchet, P., & Dagenais, C. (2020). Fire safety in tall timber building: A BIM-Based Automated Code-Checking approach. *Buildings*, *10*(7), 121. https://doi.org/10.3390/buildings10070121

Kotsovinos, P., Rackauskaite, E., Christensen, E., Glew, A., O'Loughlin, E., Mitchell, H., Amin, R., Robert, F., Heidari, M., Barber, D., Rein, G., & Schulz, J. (2022). Fire dynamics inside a large and open-plan compartment with exposed timber ceiling and columns: CodeRed #01. *Fire and Materials*, *47*(4), 542–568. https://doi.org/10.1002/fam.3049

Law, A., & Hadden, R. (2020). We need to talk about timber: fire safety design in tall buildings. *The Structural Engineer*, *98*(3), 10–15. https://doi.org/10.56330/xjps1661

Luo, L., Shi, B., Liu, W., Yang, H., & Ling, Z. (2020). Experimental Investigation on the Fire Resistance of Glued-In Rod Timber Joints with Heat Resistant Modified Epoxy Resin. *Materials*, *13*(12), 2731. https://doi.org/10.3390/ma13122731

McNamee, R., Janssens, M., & Gales, J. A. (2021). Editorial for special issue on Interflam 2019: Mass timber and fire resistance. *Fire and Materials*, *45*(7), 845–846. https://doi.org/10.1002/fam.3032

OpenAI. (2025). ChatGPT (June 28 version) [Large language model]. https://chat.openai.com/chat

Taghiyari, H. R., Morrell, J. J., & Papadopoulos, A. N. (2021). Wollastonite to Improve Fire Properties in Medium-Density Fiberboard Made from Wood and Chicken Feather Fibers. *Applied Sciences*, *11*(7), 3070. https://doi.org/10.3390/app11073070

Trummer, J., Schneider, M., Lechner, M., Jarmer, T., Demoulin, T., Landrou, G., Nagler, F., Winter, S., & Dörfler, K. (2022). Digital design and fabrication strategy of a hybrid Timber-Earth floor slab. *IOP Conference Series Earth and Environmental Science*, *1078*(1), 012062. https://doi.org/10.1088/1755-1315/1078/1/012062

White, R. (1986). An Empirical model for predicting performance of Fire-Resistive coatings in wood construction. *Journal of Testing and Evaluation*, *14*(2), 97–108. https://doi.org/10.1520/jte10327j

Zhou, H., Lu, W., Lu, B., Wang, L., Bao, Y., Zhang, J., & Chen, Z. (2023). Experimental and numerical analyses on the fire resistance of Timber–Concrete composite boards using an innovative form of partial protection. *Buildings*, *13*(3), 725. https://doi.org/10.3390/buildings13030725