

Fire Safety Principles for Massive Timber Building Systems



PROCEDURAL

GUIDELINE

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Source of authority

Approved by AFAC Council on 30 April, 2018.

Purpose

The primary objectives of this guideline are to:

- identify principle objectives for the design of buildings using massive timber building systems;
- describe the process of separating the hazards associated with massive timber construction;
- describe a framework that has been used to design a performance-based high-rise massive timber building;
- identify the relationship between fire authorities' guidance and the National Construction Code's (NCC) limitations of deemed-to-satisfy (DTS) clauses in relation to the use of massive timber building systems;
- describe the specific issues relating to occupant life safety and fire brigade intervention in buildings incorporating massive timber building systems;
- facilitate consistent advice from AFAC members to the construction industry; and
- describe the process of developing a fire safety strategy that enables building practitioners to design and construct buildings utilising massive timber building systems.

Scope

This guideline is predicated on establishing principles for the safe design of buildings using massive timber building systems. It is not a prescriptive document. Rather, it seeks to inform fire agencies about the current approaches for fire safety design with engineered timber products. The adoption of the guiding principles detailed herein, coupled with a comprehensive design process should ensure a reliable design outcome in terms of fire safety by the design and construction stakeholders.

Statement of engagement

This guideline was developed through consultation and contribution from members of AFAC's Built Environment Technical Group (BETG) and external bodies, such as Lendlease and the University of Queensland.

Audience

This guideline has been developed predominantly for AFAC and its member agencies as an informative document. The guideline within the AFAC doctrine represents a compendium of the technical advice that has been developed to this point in time.

AFAC holds no objection to the use of this informative document being adopted for industry design purposes where it is used to assist the building approval assessment and building fire safety in general. However, it must be understood that the document seeks to achieve safe design outcomes through the application of these guiding principles foremost. This document is not a prescriptive framework and is not intended to be applied in a method of offsets and concessions that devolve towards minimum standards of compliance.

The expectation of AFAC is that with the correct adoption of this guideline within a professional building design process, a pathway towards agreed outcomes for stakeholders can be facilitated.

Definitions, acronyms and key terms

In this document the following terms have specific meanings.

Combustible: Has the same meaning as Clause A1.1 of the NCC.

Contribution of timber: The explicit emphasis that the timber used in the buildings construction must not contribute additional fuel to any conceivable fire scenario, and the timber must not contribute to any effect that is worse than would occur in a non-combustible compartment.

Deemed-to-satisfy provisions: Has the same meaning as Clause A1.1 of the NCC.

Delamination: The consequence when a layer of laminated engineered timber separates from the parent member due to the heat transfer and or combustion effects in the compartment. Delamination is applicable in exposed timber but may also be applicable in fire protected timber.

Debonding: The effect of lamellae, laminated engineered timber separating at its adhesive layer due to effects of a fire event. It is synonymous with delamination.

Designed containment: The concept of preventing fire spread to adjacent compartments using internal and external containment measures.

Design for compartment burnout: A design period that includes fully developed and decayed fire development of the furnishings fuel load that exists without contributory burning of the CLT element. This design shall include coupled interaction between the structure and the fire and safeguards against the risk of unwanted failures.

Encapsulation: The term applied to the method of protecting timber element with a non-combustible material to avoid the timber becoming involved in a furnishings fire (refer to fire-protected timber).

Engineered wood product: A composite wood product manufactured to achieve specific and consistent performance suitable for engineering design.

Exposed timber: Exposed timber elements have no protection and therefore rely on the properties of the timber section to withstand the effects of fire.

Fire brigade intervention (as per the guide to the NCC): The terminology used in the NCC to determine the time taken by the fire brigade to arrive at the building and any likely action of its officers (e.g. whether they will undertake a search and rescue operation, and the likely time for that operation).

Fire compartment: Any part of a building separated from the remainder by barriers to fire such as walls and / or floors having an appropriate resistance to the spread of fire with any openings adequately protected.

Fire-protected timber: Has the same meaning as Clause A1.1 of the NCC. It is synonymous with the encapsulation.

Fire resistance level: Has the same meaning as Clause A1.1 of the NCC. Fire resistance is not generally applicable in exposed massive timber building systems design, and should be replaced by the concept of designed containment.

Furnishings fire: The furnishings fire establishes a difference between a fire that involves the compartments contents (furnishings) and a fire that may involve the structure. Refer to contribution of timber.

Independent performance: The design of exposed massive timber building systems that comprise of materials (such as CLT) should be a performance-based design where the material exhibits no reliance or protection from any other system of material. This has the meaning that automatic sprinkler systems or protective coverings have no basis in an independent performance assessment.

Massive timber building systems: Engineered wood products manufactured to a size and performance suitable for wall, floor and roof construction in buildings.

Performance solution: Has the same meaning as Clause A1.1 of the NCC.

Self-extinction: This is the phenomenon where flame on the surface of the CLT member ceases to propagate. Extinction is a limit condition and, in this context, it is the limit point where the supply of fuel vapour to the flame from the CLT section falls below the fuel vapour amount needed for flaming.

Sole occupancy unit means: Has the same meaning as Clause A1.1 of the NCC.

Introduction

This guideline is a collection of the current research, terminology and design approaches using massive timber building systems for the built environment. As engineered timber building products are subject to ongoing development, this guideline endeavours to establish the common terminology and the foundation principles. Subsequently, this guideline compiles AFAC agencies' experiences of research and construction approaches for timber buildings. AFAC has endeavoured to describe the products and the design principles that are associated with the construction approaches using those products.

This guideline details the precautions required during the construction phase that is necessary should a fire event occur. The National Construction Code has relevance for any building construction product, and the interface with engineered timber is addressed in this guideline.

The research related to engineered timber and associated products are large and growing. AFAC has listed the foundation research that has informed fire safety approaches to this point. As research about massive timber construction and fire safety continues, AFAC advocates that users of this guideline and fire agencies in general follow this progression in construction material research.

AFAC's guideline

Background

Massive timber building systems refers to a method of construction which utilise engineered wood products that are typically manufactured into very large timber panels (e.g. 3 m wide x 18 m long x 0.3 m thick) which are capable of being loaded in three dimensions, and therefore suitable for structural applications. Massive timber building systems can refer to a variety of different products, and is generally used to distinguish this construction method as different from traditional light-weight timber frame construction methods.

Massive timber building systems panels are claimed to possess an inherent level of fire resistance similar to solid timber, due to the thickness of the panels allowing for charring while maintaining a suitable thickness of unaffected timber capable of supporting the structural loads. This inherent fire resistance is based on the principle of a timber section developing a char layer that insulates the internal timber and supports a process of self-extinction as the energy transfer to overcome the thickening char layer, acts to extinguish the combustion of timber.

AFAC member agencies have evaluated two types or applications for massive timber design and their building systems, generally referred to as: fire protected timber (encapsulation) and exposed timber.

Fire protected timber is effectively a deemed-to-satisfy (DTS) solution as it is referenced in the NCC. Encapsulation is often applied to this fire protection method as the principle acknowledges timber as an additional and available fuel source, and therefore it is shielded by a fire resisting barrier that prevents the timber contributing to a furnishings / base fuel fire event. The exposed timber approach is discussed in section later in this guideline.

Timber products

Massive timber building systems may refer to an evolving range of engineered wood products used for structural purposes. Table 1 provides a summary of common

engineered wood products currently referred to as massive timber building systems.

Common trade name(s)	Description	Example
Cross laminated timber (CLT or XLAM)	A prefabricated solid engineered wood panel made of at least three orthogonally bonded layers of solid-sawn lumber or structural composite lumber (SCL) that are laminated by gluing of longitudinal and transverse layers with structural adhesives to form a solid rectangular-shaped, straight, and plane timber intended for roof, floor, or wall applications.	
Laminated veneer lumber (LVL)	A type of structural composite lumber manufactured by bonding very thin sheets, or veneers, of timber together with adhesives.	
Glue laminated timber (GLT or Glulam)	An engineered wood product composed of individual wood laminations, selected and positioned in the timber, based on their performance characteristics, and bonded together with durable, moisture-resistant adhesives.	
Structural composite lumber (SCL)	An engineered wood product that is intended for structural use and bonded with adhesives	
Laminated bamboo	An engineered product using bamboo timber and bonded with adhesives.	

Table 1: Examples of engineered wood products used in massive timber building systems.

Guiding principles for fire safety design

Building designers may wish to undertake their building designs adopting either encapsulation or exposed timber methods or combinations of both. Within this context of design flexibility, AFAC and its member agencies submit the following principles to be appropriately addressed in the building design, whether the DTS or performance solution approaches are undertaken.

Contribution of timber

The timber is potentially an additional fuel load above that of the buildings furnishings fuel load. The design must therefore prevent the timber from contributing this additional fuel to a fire.

Fire resistance

The conventional approaches to fire resistance are essentially based on the premise that the compartment boundary is non-combustible or inert and does not contribute fuel to the fire. Massive timber construction elements obviously contradict this premise, and therefore a modification to the determination of fire resistance of the boundary needs to be undertaken.

Charring assessment

The assessment of charring through the lamellae of timber provides indication of element behaviour and failure through delamination. Consider multiple approaches using calculation and experimental values for converging around an appropriate time interval for charring.

Failure assessment

Assessing the conditions that lead to failures associated with massive timber building systems: for example, protective layers falling off and delamination of CLT. The failure assessment is also applicable to embedded connections and supported attachments.

Burnout assessment

Assessment of the compartment for burnout of the furnishings fuel load under the most arduous conditions occurring in the compartment.

The two approaches that AFAC and its member agencies supports for massive timber building systems construction are described the following sections.

Encapsulation

The process of preventing massive timber sections from becoming additional fuel for a building fire has been managed in the fire protected timber approach of the *National Construction Code*, otherwise synonymously known as encapsulation. Protecting the surface of massive timber sections is defined by the NCC, specification A1.1. Fundamentally, the protective or encapsulation layer(s) prevents the timber in contributing to the fire event.

Exposed timber

The exposed timber approach is adopting a self-extinction property of the material as it chars. This property needs to be verified by comprehensive technical analysis that adopts a strategy of separating the hazards that the exposed massive timber building systems has introduced. The separation of hazards is ideally formulated within a fire safety strategy for the building. The fire safety strategy is a statement that defines the goals and objectives established for the building.

The fire safety strategy for a building essentially delivers the outcomes we seek: for example, the occupants escape to safety before they may be injured, firefighters are able to intervene and conduct their operations and the building, in part or whole, does not unexpectedly collapse due to fire and whilst occupants are still within the building. For the massive timber building systems, an additional strategy of separating the hazards demonstrates that the building can deliver fire safety outcomes commensurate with a conventional DTS building, and is therefore a fire-safe building through its own performance.

Hazard analysis for fire safety strategy

The IFEG (2005) states that a systematic review should be conducted to establish potential fire hazards (both normal and special) of a building under evaluation. A hazard is the outcome of a particular set of circumstances that has the potential to give rise to unwanted consequences. Regarding building fires, a fire hazard means the danger in terms of potential harm and degree of exposure arising from the start and spread of fire and the smoke and gases that are thereby generated.

The fire related hazards in a building can arise from the layout of the building including its location with respect to adjoining properties, construction materials, activities undertaken in the building, possible ignition sources and fuel sources.

One of the first stages in reviewing potential fire hazards for a project is to examine available fire incident data for facilities having the same or very similar form and usage. This data may be international in origin and therefore

must be used with care in order to establish possible hazards and a realistic measure of the possible unwanted consequences of fire.

Every hazard has a risk associated with it. The risk arising from a hazard is the frequency of an event involving that hazard, times, the expected consequences. A hazard may be eliminated, but there will always be an event frequency of occurrence and therefore always a positive value of risk associated with the hazard.

Fire safety engineering is essentially a risk management process wherein the outcome is to minimize the overall fire risk associated with a facility by mitigating or eliminating serious hazards, or by reducing the frequency of hazardous events.

The risk assessment process, of which hazard analysis forms part, is the means by which those hazardous events with the most serious consequences are identified. This then enables the most appropriate fire scenarios related

to these events to be defined. This process then allows the analyses to be carried out to ensure that the fire safety systems and strategies employed are sufficient to satisfy the performance requirements.

Whilst the frequency of hazardous events (probability) is considered during the hazard analysis, the consequent analyses for the evaluation of the resultant fire scenarios are deterministic.

Hazard analysis for exposed timber

The following figure illustrates the basic hazards for exposed timber. These hazards may combine in a way that threatens the objectives of the fire safety strategy and therefore it is imperative to keep them controlled by separation (separation of hazards). Therein, by controlling each hazard entity and keeping them separated, the design has a pathway for illustrating that the goals and objectives can be attained.

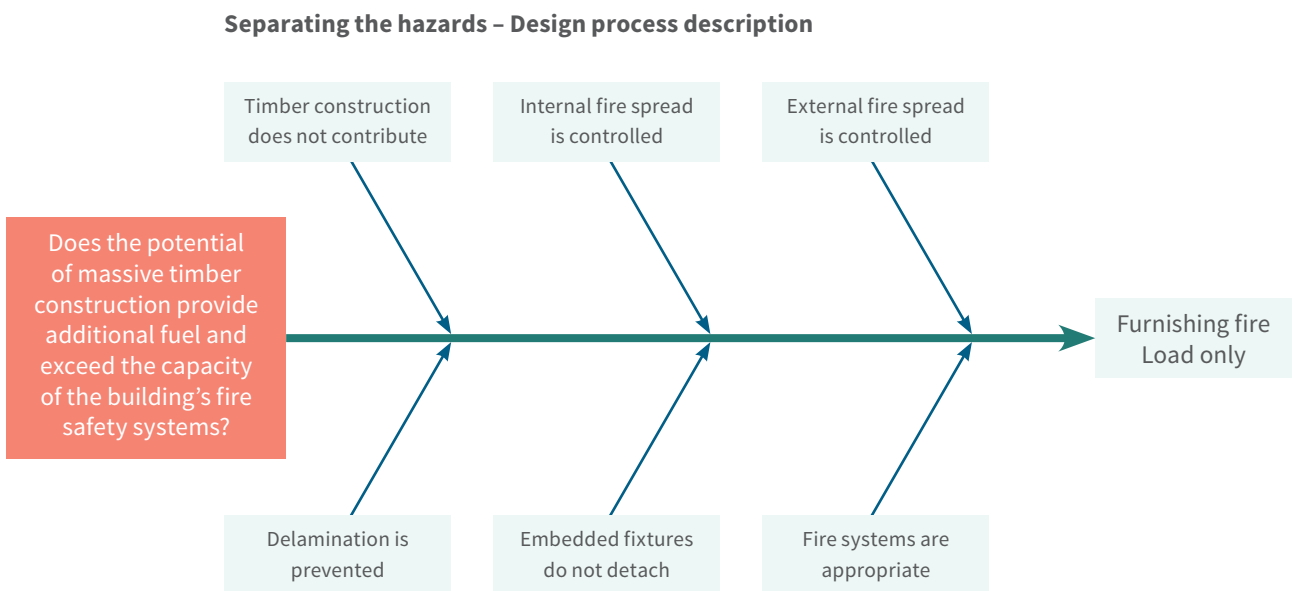


Figure 1: Separating the hazards of massive timber (adapted from Torero, 2016)

Separation of hazards

The following principles define the separation of the hazards introduced by mass timber building systems.

Ignition of a fire is considered as having a probability of unity (1-100%). Thus, a fire will be assumed to ignite and progress according to conventional growth rates appropriate to the buildings use / classification.

Sprinklers are recognized to reduce the probability of a fire event reaching unwanted conditions, nevertheless they do not eliminate all of the probability. Given the potential large consequences of a timber structure fire and the uniqueness that massive timber building systems contain, a purposeful fire safety strategy that manages the consequences is necessary and does not focus on

the reduction of probability. For this reason, sprinklers are therefore deemed to be a redundancy to the core fire safety strategy and, for the purposes of analysis, the sprinklers are assumed to fail.

A failure mode of mass timber products is delamination. Delamination is controlled by fire duration which is determined by ventilation and fuel load. A conservative fuel load is necessary for this analysis in units MJ/m² (background information justifying this is required) will be used. Ventilation conditions need to be selected so that a heat flux that prevents self-extinction of the timber is attained for the longest possible time. This combination of fuel load and ventilation will guarantee a worst-case condition for delamination assessment.

In the presence of a furnishings fire (residual fuel load), exposed timber will ignite and flames will spread on

the surface of the structure. The analysis should display the evolution of the fire with the interaction between the burning of the furnishings and that of the exposed timber structure. The subsequent burning of massive timber sections from a furnishings fire can be identified through separated energy criteria. An ignition criterion of 12.5 kW/m² or 300°C is recommended to monitor flame spread over the timber structure while a self-extinction criterion of ≥6 kW/m² is recommended to establish where the exposed timber structure will cease burning after furnishings fuel load has been fully consumed (burn-out). The separation of hazards can only be done if complete self-extinction is demonstrated in such an approach.

The fire growth rate determines the available safe egress time (ASET) therefore comparative modelling of the fire growth in a building constructed of non-combustible material (e.g. concrete or steel) and of exposed timber need to be conducted. Only if it can be demonstrated that the ASET does not change because of the contributions of structural timber to fire growth separation of hazards can be done for fire growth.

If extended travel distances are a component of the building design, it will be necessary for an ASET vs RSET analysis to be performed for the conventional hazards introduced into the building, and then it needs to be demonstrated that the fire growth with and without exposed timber will remain the same for at least twice the RSET. A factor of two is selected, as it takes into account the variability of egress data within the calculation. Only if it can be demonstrated that the fire growth with and without exposed timber will remain the same for at least twice the RSET then the two hazards are adequately separated.

The delamination of massive timber elements results in timber contributing to the continuation of the fire's duration beyond the burn-out of the furnishings fuel load. This can result in further delamination and the continuation of the fire until structural integrity is lost. This represents a hazard for firefighters and adjacent buildings. Therefore, this scenario needs to be prevented. Only if it can be demonstrated that delamination can be avoided during the entire period between ignition and self-extinction then separation of hazards can be done. The absence of delamination is assessed by conducting a heat transfer analysis into all structural elements affected by the fire to demonstrate that the temperature at the interface between the exposed lamella and the next layer of the mass timber does not reach the critical value of 190°C. This critical value is considered a conservative estimate of the onset of degradation of all the adhesives that are used in the bonding laminated timber sections from the interpretation of various research study findings (e.g. Emberley, 2015; Crielard 2015; Frangi, 2004).

In the absence of delamination, then, the conventional FRL analysis can be applied. For example, the charring rates can be calculated using conventional approaches to guarantee structural integrity according to the member's residual sectional strength for the periods prescribed by DTS solutions.

The presence of exposed timber will inevitably introduce additional fuel to the fire. During the fully developed fire, much of this fuel will burn outside in the spill plume. The spill plume should be modelled for all scenarios (fires at multiple locations) to demonstrate that the additional timber fuel for the external flames, will not result in external fire spread. Typically, a fire safety strategy is governed by the assumption that fire will remain at the floor of fire origin. Therefore, only if it is demonstrated that external spread will not occur, then both hazards (additional fuel and available fire spread pathway) can be separated. An analysis of the spill plume should be conducted to demonstrate that, for all scenarios studied, external elements will be protected with the heat flux from the spill plume. The receiving element should be below 40 kW/m² for any glazed openings to not fracture and fall out and consequently below 12.5 kW/m² for the timber elements (at or around the openings) within the level above to not ignite.

Smoldering represents a hazard, nevertheless, if delamination is prevented then this hazard is minimized and it can be assumed that smoldering of structural timber that has not fallen from the structure will not transition to flaming, and that smoldering on the massive timber element itself is sufficiently slow as to not represent a significant hazard.

A sensitivity analysis with sufficient ignition locations that cover all critical scenarios should be conducted. This sensitivity analysis should include critical conditions for external flames, critical conditions for delamination, critical conditions for charring and critical conditions for structural integrity.

If all eleven conditions are satisfied, then the hazards introduced by the massive timber as a construction material can be separated from the conventional hazards of buildings. Once these eleven points have been demonstrated a fire safety analysis for the building should be conducted under the assumption that massive timber construction has no impact on the fire safety strategy.

Limitations of this guideline

It should be noted that the design considerations and principles provided within this guideline are intended to facilitate the safe building design process with respect to fire safety performance of buildings incorporating massive timber building systems. The incorporation of these design considerations and principles identified within this guideline may not necessarily deliver a compliant design for every building project. The use of this guideline should be carefully considered on a case-by-case basis for building projects.

The use of massive timber building systems in buildings or building parts classified under the NCC has not been specifically addressed in this guideline. It promotes the analysis of hazards, achievement of fire safety outcomes and developing a coherent strategy that delivers the performance irrespective of classification or occupancy types. Discussions of buildings' particular classification have been omitted as at this stage as the fire engineering issues associated with using massive timber building systems and building classification (e.g. special fuel load, special occupancy requirements) warrants further research.

Issues for design consideration, building approval and building operation

The use of massive timber building systems introduces combustible materials into the construction of buildings. The use of combustible construction materials has the potential to introduce a number of issues, including (but not limited to):

- building elements with reduced fire resistance levels (FRLs) with respect to structural adequacy, insulation, and integrity;
- combustible materials within fire-isolated egress paths;
- combustible materials within concealed spaces;
- higher fuel loads within fire compartments;
- combustible materials in balcony areas that may have unprotected penetrations through the floor (e.g. downpipes and floor wastes) and significant ignition sources (e.g. gas, electric, wood or coal barbecues); and
- exposed combustible building elements during construction.

For the reasons identified above, the use of combustible materials within certain structures is limited or prohibited entirely by the BCA based on the type of construction required. Table 2 reproduces the types of construction required for certain buildings as identified by NCC Clause C1.1.

Rise in storeys	Class of building	
	2, 3, 9	5, 6, 7, 8
4 or more	A	A
3	A	B
2	B	C
1	C	C

Table 2: Type of construction required (reproduced from NCC, clause C1.1).

Generally, construction types A and B limit or prohibit the use of combustible materials due to the potential for rapid horizontal and vertical fire spread and the impact on occupant tenability during egress and the impact on the ability for fire brigade intervention. Therefore, if massive timber building systems are used for buildings that require type A or B construction, the entire building, essentially, becomes non-compliant with the DTS provisions of the NCC and will need to be subject to a performance solution.

A performance solution must demonstrate compliance with the NCC performance requirements in accordance with NCC, clause A0.3. In these circumstances, the use of massive timber building systems in buildings must be comprehensively assessed by a fire engineer. It then must show to satisfy the NCC performance requirements to the satisfaction of the authority having jurisdiction before the building may be considered compliant.

Consequently, all of the itemised items of consideration should be incorporated into the fire engineering documentation that is developed in order to demonstrate how the buildings fire safety strategy is achieved.

Fire engineering documentation

In general, the regulatory framework does not permit the use of combustible materials for elements of buildings that require types A and B construction. Therefore, details of the massive timber building system proposed should be provided to the relevant fire service during the fire engineering design phase in addition to the supporting information that the system is appropriate to facilitate occupant egress and fire brigade intervention. This information may include, but should not be limited to;

- panel construction details (including adhesive details) and method of production;
- construction method details (e.g. connections, fixings, penetrations);
- compliance with international standards or codes if applicable (e.g. EuroCodes);
- calculations for fire endurance and containment to validate fire resistance;

- calculations for panel charring rate with consideration to AS 1720.1, AS 1720.4 and published literature; and
- test information identifying that the proposed panel construction can achieve the required FRL.

The fire engineering report should consider building design features associated with the use of the massive timber building system that may have an impact on occupant egress and fire brigade intervention, including (but not limited to);

- the potential for fire spread between combustible building elements and combustible façades;
- the use of appropriate construction joints to limit the spread of fire and maintain required FRLs;
- the use of appropriate penetration sealing systems to limit the spread of fire and maintain required FRLs;
- location and construction of building parts with certain classifications and significant fire loads (e.g. carpark areas which can present a significant fire load should be incorporated into the lowest storeys of the building and constructed of conventional steel and concrete); and
- fire spread through concealed spaces.

Material considerations

Recent research conducted on the fire resistance properties of massive timber building system panels has identified a number of factors that can impact the fire performance, including (but not limited to);

- wood type;
- thickness of layers;
- number of layers;
- orientation of layers;
- orientation of the panel (e.g. wall, ceiling, floor);
- adhesive used between adjoining layers;
- adhesive used between adjacent boards; and
- longitudinal joining of boards.

Where test results are used to demonstrate that a panel construction meets a specific FRL, consideration should be given to the material properties identified above when comparing the tested panel construction and the proposed design panel construction. The panel manufacturer should be consulted for further advice.

Additionally, the methods to be used for connecting the panels require equally rigorous consideration and justification to ensure these areas do not introduce potential weak spots in the structure that may facilitate fire or smoke spread or lead to premature structural failure of one or multiple panels.

Advice should also be sought from the panel manufacturer regarding the impact of large quantities of water on the structural integrity of the panel which may be applied from fire sprinklers or during fire brigade intervention.

Firefighting considerations

The use of massive timber building systems introduces issues that have the potential to detrimentally impact on the ability for fire brigade intervention in the event of fire, including (but not limited to):

- the potential for structural collapse during search and rescue activities and firefighting activities;
- the potential for external fire spread requiring additional resources to control;
- the potential for significant production of smoke and heat reducing the ability to conduct efficient and effective search and rescue and firefighting activities;
- the potential for increased load on automatic suppression systems and hydrants for fire suppression; and
- the potential for fire spread in concealed spaces.

Conditions expected within the building during fire brigade intervention should be clearly demonstrated as part of the fire engineering assessment and discussed with the appropriate fire brigade to determine if their operational requirements are met.

Fire safety systems

In areas where fire sprinklers are not specifically required by the DTS provisions of the NCC, the installation of a sprinkler system in accordance with AS 2118 is considered necessary. Sprinkler protection should be extended to cover all areas of the building, including fire-isolated stairs.

Smoke seals and closers are to be provided to all sole occupancy unit entrance doorways and waste room doors within any residential tower.

Reliable, monitored, early warning detection systems are expected throughout buildings utilising massive timber building systems; the detection system should be designed to minimise the potential for unwanted / false alarms.

For buildings greater than 25 m in effective height, each storey is expected to be provided with not less than two exits in addition to any horizontal exits.

Structural design

Buildings utilising massive timber building systems should include an appropriate level of structural redundancy throughout and particularly in areas that are potentially critical for occupant egress and fire brigade intervention (e.g. stair wells).

The adequacy of all structural panel connections consisting of steel plates or pins are to be verified by a structural engineer as part of the fire safety design.

Connections to be appropriately protected, by means such as timber plugs with appropriate depth into layers of lamellae, or have connections recessed into members such that appropriate depth of timber provides protection to connections.

Concealed spaces

Service penetrations within concealed spaces are to be provided with a suitable penetration sealing system to inhibit the spread of smoke to other fire compartments and maintain the required FRL / containment barrier of the building element penetrated. Any concealed spaces should be provided with smoke detection and sprinkler protection.

Egress and emergency evacuation

Building management needs to formulate, document, and implement an emergency evacuation plan for all occupants, including those with mobility impairment, consistent with the fire engineering report and include occupant / staff training in accordance with the requirements of AS 3745.

Fire precautions during construction

Here, the NCC, clause E1.9 should be complied with in full. A site-specific fire safety risk management plan is to be prepared by the developer in consultation with the fire engineer to identify and address risks that will exist during the construction process. The fire safety risk management plan must include arson prevention measures.

Prior to commencement of construction, an additional report is to be prepared demonstrating effective consideration of the previous two points. The report is to obtain agreement from appropriate stakeholders.

A fully operational fire hydrant system, appropriate to the size and orientation of the building and building site, is to be made available on-site, at ground level, from the commencement of construction.

In the event that any sprinkler, hydrant or fire detection systems are fully isolated, or isolated in part, as a result of staged building work or maintenance, additional fire safety measures and procedures are to be implemented to maintain an appropriate degree of safety. The de-isolation and re-activation of these systems must occur prior to the close of business each day.

Fire Safety Systems Installation and Commissioning

All fire safety measures documented within the fire engineering report are to be installed in accordance with the relevant Australian Standards. Sprinkler systems are to be provided with monitored isolation valves on each level of the building within the emergency egress stairs.

Sprinkler systems are also to be provided with end-of-line testing capacity on each level of the building.

At the commencement of the construction phase and prior to occupation, the building and all fire safety measures are to be inspected by the fire safety engineer to ensure that the fire safety measures have been reasonably implemented in accordance with the fire engineering report.

Prior to occupation of the building, integrated testing and commissioning is to be undertaken on all fire safety systems. Similarly, prior to occupation of the building, the relevant fire service is to inspect the functional operation of the fully installed fire safety systems.

Maintenance and management

All parts of emergency egress paths, including the egress stairs, corridors, lift lobbies, and entry areas, are to be kept free of combustibles (e.g. furniture). Balconies, regardless of floor area, are not to be used for storage or contain combustible or flammable products (e.g. barbecues) unless sprinkler protected.

The management measures identified in the previous two points are to be recorded as essential safety measures for the building, to be maintained regularly in accordance with the fire engineering report or relevant Australian standards.

All fire safety systems are to be maintained in accordance with relevant Australian standards.

Supporting discussion

Research background

The research of Richard Emberley of the University of Queensland examined the external heat fluxes that distinguish self-extinction from flaming combustion in cross laminated timber. Emberley's thesis is titled *Fundamentals for the Fire Design of Cross Laminated Timber Buildings*, and is recommended reading for understanding the process where a high external heat flux (flame) is imposed on a CLT section is needed to continue the conduction and charring for combustion and delamination conditions.

The objectives of Emberley's research were as follows.

- Identify the conditions leading to self-extinction: Identify the limits and the burning rate.
- Profile the In-depth heat losses (conduction).
- Profile the time to self-extinction.
- Establish a critical heat flux and mass loss rate needed for self-extinction.
- Identify conditions preventing self-extinction.

Emberley was able to quantify the external heat flux that identified the self-extinction process occurring in cross laminated timber by way of the variation of external heat flux. The research plotted the variation of external heat flux (cone heater at different radiation fluxes) and monitoring the mass loss of timber occurring with combustion of the timber.



Figure 2: Radiant cone heater on CLT section with multiple thermocouples.

The concise results of the research are presented here, and with simplified conclusions are presented below. The external flux within a range of 30-100 kW/m² indicated the internal flux migrating through the CLT section tended towards a constant value (refer to Figure 3). Furthermore, the research was able to characterise self-extinction:

- Self-extinction occurred after the removal of every heat flux that was applied;
- Self-extinction time Max = 40 seconds.

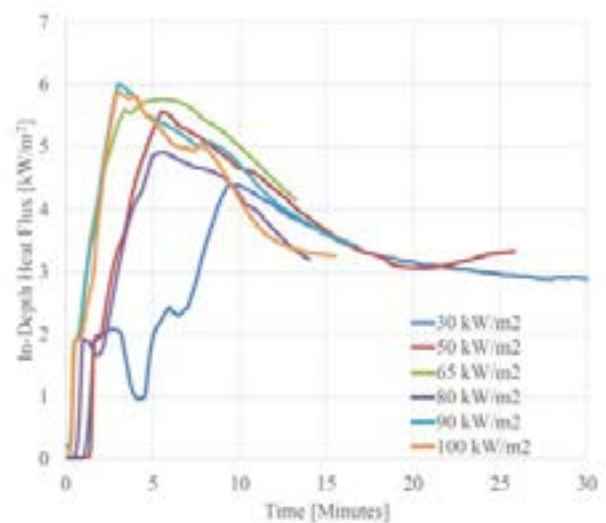


Figure 3: Internal heat fluxes in CLT section.

The research results indicated a separation between the flaming combustion of CLT under an imposed heat flux and the process leading to self-extinction (refer to Figure 4).

There is following research also underway, however the current understanding allowed the use of separating flaming combustion and the process of self-extinction to be analysed for a design purpose.

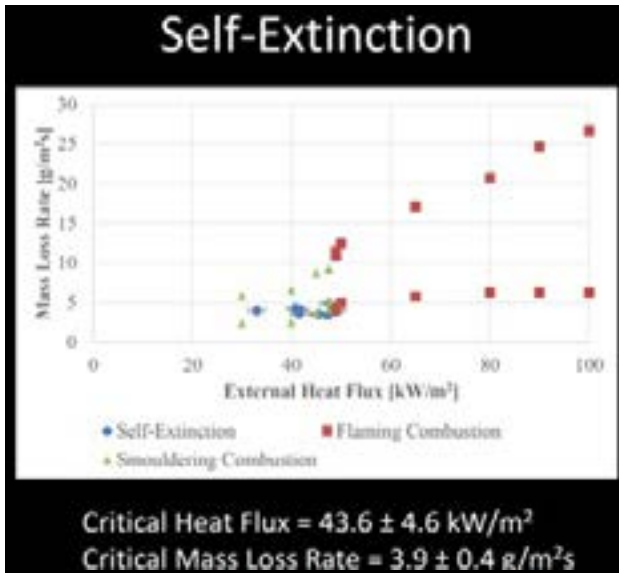


Figure 4: CLT self-extinction.

A Queensland Government research project in 2016 recorded the flux that is created by a furnishing fire (timber crib in this project) and the interaction with the flux that is imposed on the CLT ceiling and wall that supports the CLT burning. The ventilation opening was dimensioned for maximum compartment temperature to be achieved. A façade extension was attached to measure the flame extension and the fire impacts beyond the compartment.

The two fire cribs were ignited and the fire developed and flashed over. The CLT wall and ceiling was involved in fire during the peak burning period. The simplified outcome of this project was as soon as the crib fire started to decay, the fire also started to decay and the CLT did not support prolonged burning additional to the cribs. Delamination was also prevented.



Figure 5: CLT enclosure and facade test.

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