Timber Unlimited

DRAFT FOR PUBLIC COMMENT

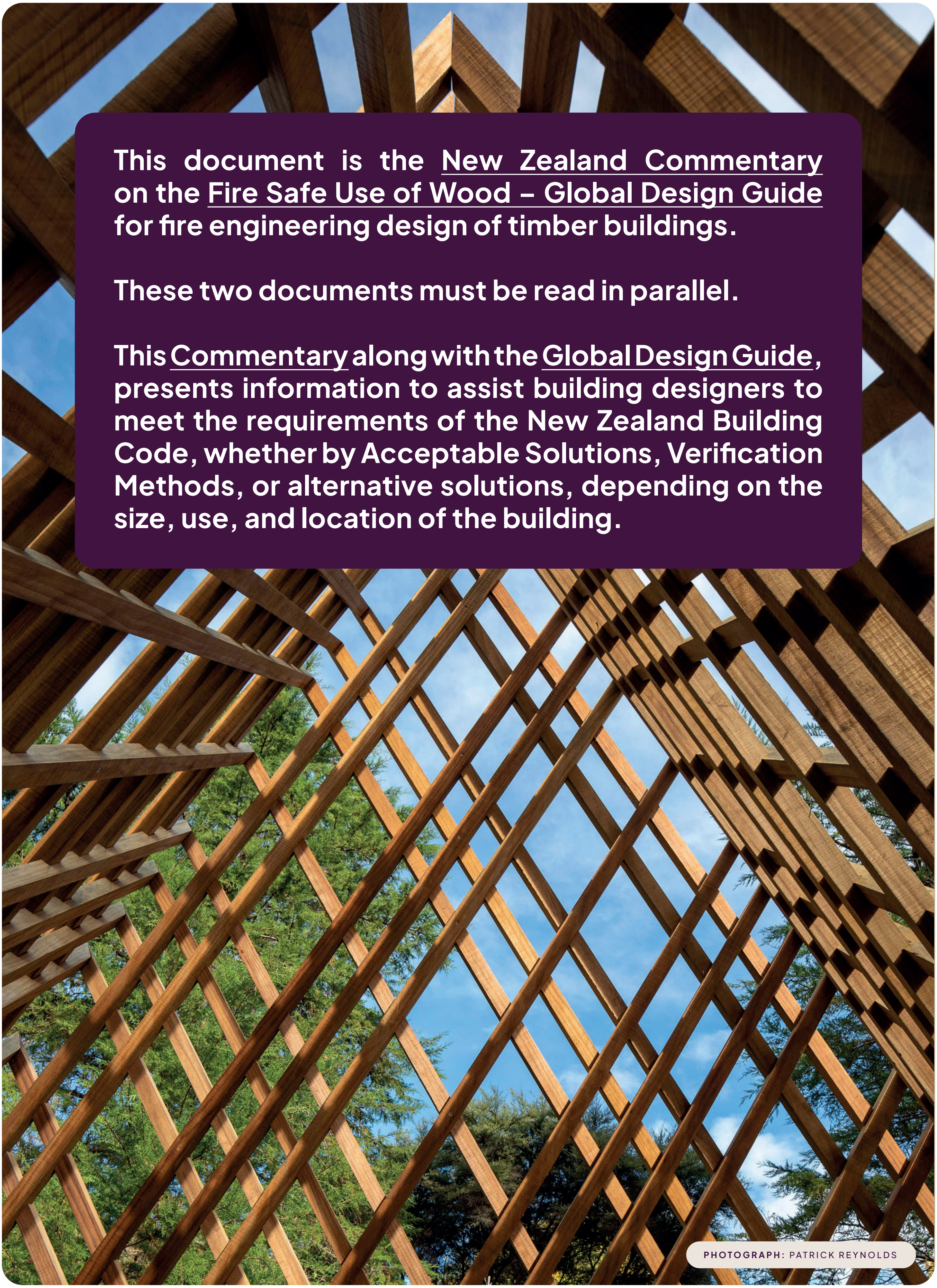
Fire safety in multi-storey mass timber structures

NEW ZEALAND COMMENTARY TO THE GLOBAL DESIGN GUIDE • AUGUST 2024

This document is the New Zealand Commentary on the Fire Safe Use of Wood – Global Design Guide for fire engineering design of timber buildings.

These two documents must be read in parallel.

This Commentary along with the Global Design Guide, presents information to assist building designers to meet the requirements of the New Zealand Building Code, whether by Acceptable Solutions, Verification Methods, or alternative solutions, depending on the size, use, and location of the building.



PHOTOGRAPH: PATRICK REYNOLDS

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Introduction

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0. Introduction

Scope of chapter

This Commentary presents a summary of current methods of providing fire safety in timber buildings in conformance with the New Zealand Building Code.

The numbering of headings and sub-headings in this Commentary follows the numbering in the Global Design Guide, (see 0.2 below) with some additions where necessary.

0.1 Background

Fire safety is becoming a significant obstacle to the greater uptake of mass timber buildings in New Zealand, at a time when the timber industry is investing in production and promotion of timber buildings, and central government is moving rapidly towards lowering carbon emissions in the building and construction industry. Utilising mass timber components in buildings is an effective method for lowering carbon emissions, because timber has lower embodied energy than traditional materials, and carbon remains in the wood for the lifetime of the building, and during any subsequent re-use or re-purposing of the building.

0.2 What is this commentary?

This document is a New Zealand Commentary on the international Fire Safe Use of Wood – Global Design Guide, published in 2022 with contributions from many kiwi authors. A free PDF download is available here. It is called the Global Design Guide in this Commentary.

This Commentary is not a full review of fire safety in timber buildings, but rather aims to provide guidance for designers, builders, building officials and fire engineers to better understand the issues and assist with designs to meet the requirements of the New Zealand Building Code. It will be of immediate use to fire design engineers, structural engineers, architects, suppliers of fire protection equipment, fire engineering staff at FENZ (Fire and Emergency New Zealand) and Building Consent Authorities.

0.3 New Zealand Building Code

The New Zealand Building Code and its supporting documents C/AS1, C/AS2 and C/VM2 were not written with large timber buildings in mind. If these Building Code documents are applied without modification to large timber frame structures or mass timber structures, some buildings may not meet the performance requirements of the New Zealand Building Code. This document is intended to represent industry consensus until such time as the C/AS1, C/AS2 and C/VM2 documents are revised.

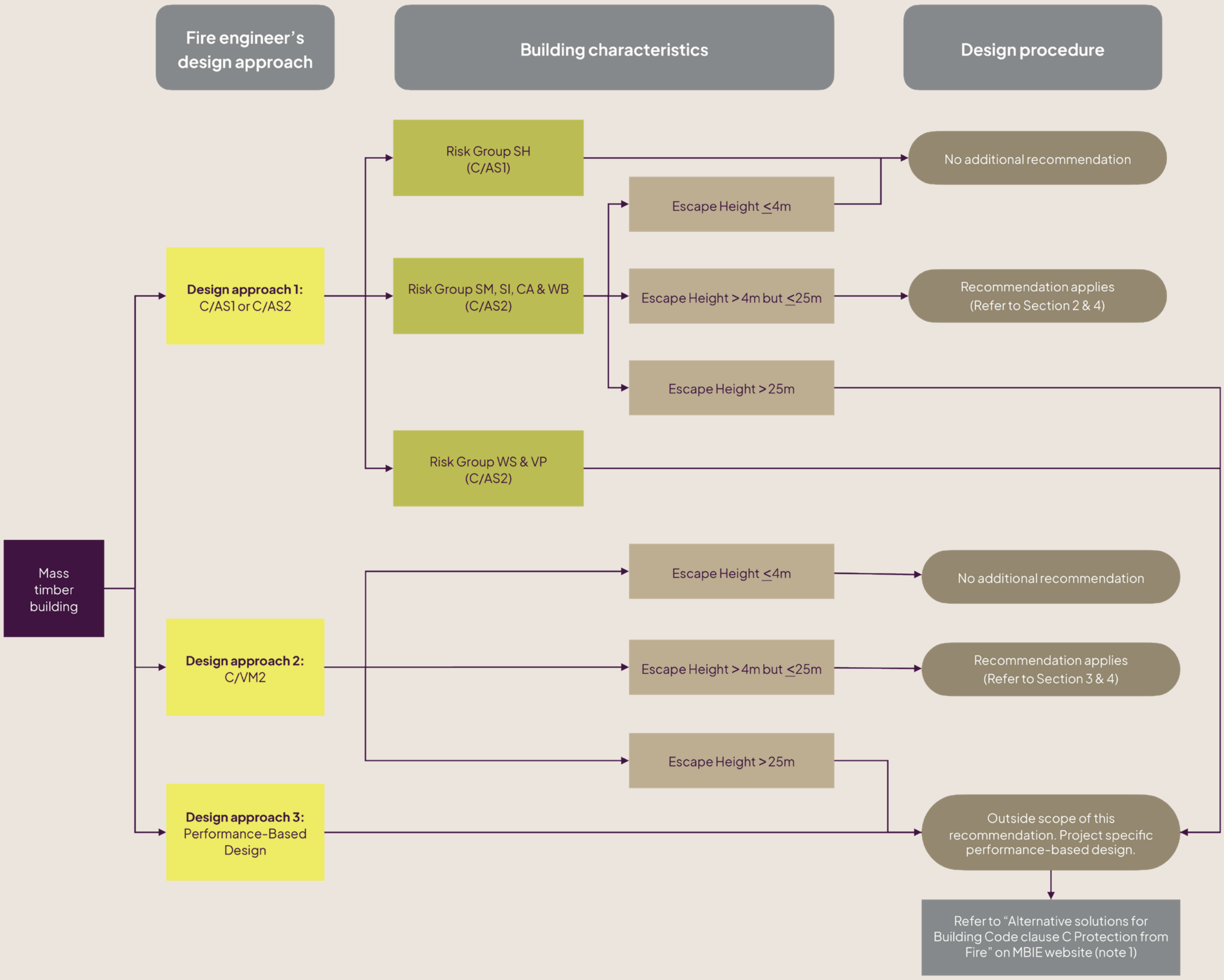
0.4 How to use this commentary

This Commentary is not a stand-alone guide. It should be used alongside the Global Design Guide and the Supplement in Appendix A (see 0.5 below). This Commentary refers to the Global Design Guide chapter-by-chapter and clause-by-clause, so you need both documents.

0.5 The Supplement in Appendix A

The interim recommendations from this Commentary are summarised in a guidance document produced by Timber Unlimited: Fire Safety in Multi-Storey Mass Timber Structures – Recommendations to Supplement C/AS2 & C/VM2, which forms Appendix A to this Commentary. The supplement was produced by the authors of the Commentary during the writing process, to be used as an interim supplement to the use of New Zealand Building Code documents C/AS2 and C/VM2. It is referred to throughout this Commentary as the Supplement in Appendix A.

The guidance in this Commentary applies to all timber buildings of any size or shape, but the Supplement in Appendix A only applies to a subset of timber buildings, as shown in the flowchart below, which appears elsewhere in this document.



0.6 Feedback

Feedback on this Commentary is welcome. Please reach out to Timber Unlimited at enquiries@timberunlimited.co.nz.

Chapter 1
Timber structures and wood products

Author: Andy Buchanan

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1. Timber structures and wood products

Scope of chapter

This Chapter presents an overview of various types of timber buildings commonly used in New Zealand, as an extension to Chapter 1 of the Global Design Guide, which should be read alongside this document.

A description of engineered wood products is also provided, summarising the manufacturing processes and typical end uses. This Chapter is not an exhaustive review of timber constructions and wood products, but rather aims to provide sufficient information for designers, builders, building officials and fire engineers to better understand and differentiate the various wood products and timber building systems available in New Zealand.

The numbering of headings and sub-headings in this Commentary follows the numbering in the Global Design Guide, with some additions where necessary (see Chapter 0 for reference and access details).

The principles of this section are applicable in New Zealand, although structural fire design of light timber structures is most often carried out using literature provided by the manufacturers of lining materials.

1.1 Types of building occupancy

The Global Design Guide and this Commentary apply to most types of building used in New Zealand. The main occupancy groups are residential buildings, office buildings, educational buildings, public buildings and industrial buildings of any size or shape.

This commentary is mostly concerned with multi-storey timber buildings. There is a large range of possible single storey timber buildings, but it is assumed that the overall fire safety risks in single storey buildings will be acceptable if they are designed to meet or exceed the minimum requirements of the Acceptable Solutions of the New Zealand Building Code.

1.1.1 Residential buildings

[Nothing to add to the Global Design Guide]

1.1.2 Office buildings

[Nothing to add]

1.1.3 Educational buildings

[Nothing to add]

1.1.4 Public buildings

[Nothing to add]

1.1.5 Industrial buildings

[Nothing to add]

1.2 Types of timber structure

This guide refers to all buildings which contain significant amounts of timber. All timber buildings have mixes of materials, usually including steel and concrete. Differences between the fire safety in timber buildings compared with steel and concrete buildings are explained in Chapter 2. The biggest differences are where charring of wood can add significantly to the fuel load, buildings where charring will reduce the load capacity of structural timber members, or buildings with exposed timber in the façade system.

1.2.1 Light timber frame construction

Traditional light timber buildings consist of structural studs and joists made from sawn timber, as shown in Figure 1.6 of the Global Design Guide. Most domestic construction in New Zealand is light timber frame. One variation from other countries is that New Zealand studs and joists are often made from Laminated Veneer Lumber (LVL) rather than sawn timber, which provides some additional strength and straightness.

Compared with fire safety in mass timber buildings, most light timber frame buildings do not have large areas of timber which could add to the fuel load. In addition, the structural timber framing is protected with non-combustible lining materials which will prevent charring for a considerable time.

In a severe fire, charring under the protective layer will reduce the structural capacity of the timber members as the fire progresses. The structural fire resistance of light timber frame buildings is addressed in Chapter 7. Non-structural fire safety aspects of light timber frame buildings are addressed in other chapters.

1.2.2 Post-and-beam construction

[Nothing to add]

1.2.3 Mass timber construction

Mass timber buildings include the following types of structures:

- Mass timber buildings where most of the structural frames, walls and floors are constructed of mass timber (either exposed or covered). Lateral loads are resisted by timber shear walls, timber moment-frames or braced frames. Gravity loads are resisted by mass timber floors supported on timber walls or post-and-beam timber frames.
- Buildings with a mix of reinforced concrete and mass timber. Such buildings often have a reinforced concrete staircore to resist lateral loads and a timber gravity structure consisting of mass timber floors supported by timber walls or post-and-beam timber frames.
- Buildings with a mix of structural steel and mass timber. These buildings often consist of structural steel braced frames designed to resist all lateral loads and gravity loads, supporting solid mass timber floor panels.
- Buildings with timber-concrete composite (TCC) floors (with vertical structure of any material). Most TCC floors have a structural concrete topping over timber joists or a timber box-beam assembly.
- Buildings with a combination of mass timber and light timber frames. An economical solution for mid-rise timber buildings is the use of light timber walls supporting mass timber floors.
- Post-tensioned mass timber buildings. This sub-set of mass timber buildings is described separately below.

The structural fire resistance of mass timber elements is addressed in Chapter 7 and the fire resistance of connections in Chapter 8. Non-structural fire safety items are addressed in other chapters.

1.2.4 Long-span structures

Long-span timber structures in New Zealand are usually single storey buildings for industrial, recreational or commercial occupancy. These buildings can use structural timber as arches, trusses or portal frames. Such buildings are not covered in depth because the New Zealand Building Code does not generally require roof structures to have any fire resistance.

1.2.5 Hybrid structures

Many of the building systems listed above in 1.2.3 Mass timber construction, are “hybrid structures”, including mixes of materials, often structural steel and reinforced concrete in addition to timber components.

1.2.6 Prefabricated elements and modules

Most of the fire safety principles in this commentary apply equally to prefabricated and in-situ timber construction.

Two additional sections not covered in the Global Design Guide are 1.2.7 Post-tensioned timber buildings and 1.2.8 Buildings with timber façades.

1.2.7 Post-tensioned timber buildings

Pres-Lam post-tensioned timber buildings have been added to this section because they are not well covered in Chapter 1 of the Global Design Guide.

Post-tensioned timber buildings are a special class of mass timber buildings. The Pres-Lam technology for post-tensioned timber buildings was developed at the University of Canterbury, and the New Zealand and Australian patents are held by PTL Structural & Fire. Pres-Lam buildings use vertical post-tensioning in structural timber walls or horizontal post-tensioning in the beams of structural timber frames. This post-tensioning, often combined with seismic energy dissipaters, enhances the flexural capacity of structural connections, and greatly reduces the number of steel connection brackets required in the building.

1.2.8 Buildings with timber façades

The use of combustible material in external façades of tall buildings raises concerns about vertical floor-to-floor fire spread. This concern increased dramatically after the Grenfell Tower fire disaster in London in 2017. Buildings with timber façades include mass timber or light timber frame buildings which have structural or non-structural timber in the exterior façade. The concern also applies to non-combustible steel or concrete structures with timber in the exterior façade.

The fire performance of timber façades is covered in Chapter 5 while vertical fire spread in exterior façade cavities is covered in Chapter 9.

1.3 Structural timber products

There is nothing in the Global Design Guide about the sources or species of timber. Nearly all the timber used in New Zealand buildings is locally-grown radiata pine. Radiata pine is used as sawn timber and a wide range of engineered wood products including glulam, LVL and CLT. The second most common locally-grown timber species is Douglas fir. A number of imported mass timber products include European spruce and North American Douglas fir, among others. All of these species have similar mechanical properties and exhibit similar fire performance.

For more information on structural timber products in New Zealand, see Buchanan (2019) and WPMA (2020a).

1.3.1 Sawn timber

Most sawn timber available in New Zealand consists of radiata pine boards with nominal thickness of 50 mm (actual thickness approximately 45 mm). The width of the boards is most often nominal 100 mm, 150 mm or 200 mm (actual size being about 90 mm, 140 mm or 190 mm respectively).

Large cross section sawn timber has excellent fire resistance due to a predictable rate of charring. Small cross section sawn timber may have low fire resistance unless it is protected with gypsum plasterboard as part of a fire-rated floor or wall system.

1.3.2 Wood I-joists

Wood I-joists are made in New Zealand by several manufacturers, using sawn timber or LVL radiata pine for the top and bottom chords, and plywood or composite board for the webs. Because of the thin cross section, wood I-joists have very low fire resistance unless they are protected with gypsum plasterboard as part of a fire-rated floor system.

1.3.3 Metal plate timber trusses

Pressed metal plate timber trusses are widely used in New Zealand, most often in roof structures which do not require any fire resistance. Background material in Section 1.3.3 of the Global Design Guide applies.

1.3.4 Structural composite lumber

Section 1.3.4 of the Global Design Guide describes structural composite lumber, referring to a number of glued products manufactured from small wood chips, strands, or fibres. Most of these products are not widely available in New Zealand.

This section also includes laminated veneer lumber (LVL) made from peeled veneers. LVL is made in New Zealand by three manufacturers; Nelson Pine Industries, Carter Holt Harvey, and Juken New Zealand, all using veneers peeled from radiata pine logs. LVL is generally manufactured in panels 1.2 m wide, in a continuous process producing lengths up to 10 metres or more. The adhesive is most often a thermosetting adhesive such as resorcinol formaldehyde which has excellent fire resisting properties, so the fire performance of LVL is similar or better than the fire performance of solid sawn timber.

1.3.5 Glued laminated timber (glulam)

In New Zealand, glulam is manufactured by a large number of separate companies including Techlam, Prolam, and Red Stag Timberlab. The timber species is almost exclusively radiata pine. Section 1.3.5 of the Global Design Guide applies, except that the special North American layups shown in Figure 1.16 are not used in New Zealand.

1.3.6 Mass timber panels

Section 1.3.6 of the Global Design Guide describes a range of mass timber panels, including Cross Laminated Timber (CLT), nail-laminated timber (NLT) and dowel-laminated timber (DLT). Of these three, only CLT is widely used in New Zealand. The major CLT manufacturer in New Zealand is Red Stag Timberlab in Rotorua. CLT is also imported from XLam in Australia, and other overseas manufacturers. CLT panels may be 3 metres wide and up to 15 metres long, with common thicknesses being from 90 mm (3–ply) to 200 mm or more (5–ply or 7–ply) with typical lamella thickness usually being 42 mm or 45 mm.

Section 1.3.6 does not mention glue laminated (glulam) timber panels which are widely used for floor panels in New Zealand, sometimes referred to as Parallel-Laminated Timber (PLT), described in more detail in 1.3.8.

1.3.7 Wood-based panels

Section 1.3.7 of the Global Design Guide describes thin wood-based panels such as plywood, Oriented Strand Board (OSB), Medium Density Fibre boards (MDF) and High Density Fibre boards (HDF), and several types of particleboards, all of which are widely available in New Zealand.

1.3.8 Mass timber floor systems

This new section describes a number of mass timber floor systems widely used in New Zealand:

CLT floor panels

CLT is often used as flooring panels. Although CLT has two-way flexural strength, it is usually used as a one-way spanning system between supporting walls or beams. It is possible to use CLT panels as two-way point-supported floors, supported only on columns with no beams, but this is not often done in New Zealand. Long length panels are often used over two or more spans to reduce deflections and vibrations in one-way systems.

Glulam floor panels

Glue laminated (glulam) timber panels are often used for one-way-spanning floors in New Zealand. These are sometimes marketed as Parallel-Laminated-Timber (PLT) floors. The length of panels can be 10 metres or more, allowing double spans where appropriate. The width of glulam floor panels is usually about 900 mm, which requires a larger number of inter-panel splices than in CLT floors, requiring detailing for both diaphragm action and fire resistance.

LVL floor systems

There are many different possibilities for manufacturing long-span floor panels from LVL. See WPMA (2020b). The most well-known proprietary system is the Potius floor system of T-beam or Box-beam LVL panels which have been used in many buildings throughout New Zealand.

1.3.9 Timber-concrete composite floors

There are many options for Timber-Concrete Composite (TCC) floor systems, mostly using reinforced concrete as a compressive top flange above structural timber tensile components. For example, TCC floors can be flat slabs with concrete topping on CLT panels, or T-beam or Box-beam assemblies using concrete topping over LVL joists or other engineered wood products. A big benefit of concrete topping is the improvement of acoustic performance due to the increased mass. A major disadvantage is the introduction of a wet trade requiring additional propping and time for curing. It is possible to prefabricate pre-cambered TCC slabs off site, but this can introduce transport difficulties.

1.3.10 Mass timber roof panels

Some mass timber buildings have roofs constructed from CLT or other mass timber panels. Most roof structures in New Zealand are not required to be fire rated, but fire engineers need to consider the extra fire load from any exposed timber in the ceiling above the top floor of a building (the underside of the roof).

1.3.11 Structural adhesives

Questions are often asked about the fire performance of structural adhesives in engineered wood products, following some failures in experimental fire tests. Thermally resistive adhesives specified in Clause 1.4.2 of AS/NZS 1720.4:2019 are “thermosetting adhesives including phenol, resorcinol, phenol-resorcinol, or poly-phenolic adhesives”. Most plywood and LVL in New Zealand is manufactured with such adhesives, but most CLT and glulam is manufactured with polyurethane or melamine adhesives which are not on this list.

The fire performance of adhesives is covered in Chapter 2, Section 2.10.5 of this Commentary.

1.4 Conclusion

This chapter has described the range of timber materials and timber structural systems available in New Zealand, complementing the background material in the Global Design Guide.

References

Buchanan A.H. (2019). Timber Design Guide. NZ Timber Industry Federation, Wellington. Available here.

WPMA (2020a). Trees, Timber, Species & Properties. NZ Wood Design Guides, Chapter 1.2. Wood Processors and Manufacturers Association, Wellington. Available here.

WPMA (2020b). Floor and Roof Cassette Systems. NZ Wood Design Guides, Chapter 9.8. Wood Processors and Manufacturers Association, Wellington. Available here.

Chapter 2
Fire safety in timber buildings

Authors: Andy Buchanan, Colleen Wade, Martin Feeney

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2. Fire safety in timber structures

Scope of chapter

This chapter is a commentary on the most important clauses in Chapter 2 of the Global Design Guide, with reference to the New Zealand Building Code and other local conditions. Reference is made to New Zealand recommendations in the Supplement in Appendix A. This chapter is complementary to Chapter 2 of the Global Design Guide, which should be read alongside this document.

This chapter begins with a summary of fire safety topics which make timber buildings different from traditional non-combustible buildings. This list of differences has been discussed with the timber industry and the wider fire engineering community in New Zealand.

2.1 Fire safety goals

Section 2.1 of the Global Design Guide is relevant to New Zealand without modification.

2.1.1 Life safety

[Nothing to add to the Global Design Guide]

2.1.2 Property protection

[Nothing to add]

2.1.3 Insurance views

[Nothing to add]

2.2 Special considerations for timber buildings

2.2.1 Influence of exposed timber surfaces

See 2.2.3.

2.2.2 Exposed timber

See 2.2.3.

2.2.3 Recent reports and guidance on fire safety in timber buildings

The listed reports and guidance on fire safety in timber buildings in the Global Design Guide are recommended reading.

With recent advances in mass timber and CLT production technology mass timber is being considered for more ambitious and more complex buildings than have been constructed historically. There has been recent international concern about fire safety in mass timber buildings (for example, Law and Hadden, 2020).

Section 2.2 of the Global Design Guide, especially the clauses on exposed timber surfaces and recent international reports, are relevant to New Zealand. The authors of this Commentary have identified the following topics on the fire safety of timber buildings in New Zealand, which highlight differences between timber and traditional non-combustible building materials, especially for tall or very tall buildings.

The fire safety differences are:

Early fire hazard:

- Rapid flame spread on exposed internal timber surfaces, whether structural or non-structural (covered by Group numbers in the current NZBC).
- Vertical fire spread on timber in exterior façade systems, whether structural or non-structural (covered by MBIE design guidance, and subject to on-going research).

Large post-flashover fires:
(Note that these fires are far less likely in sprinklered buildings, but they are still possible and need to be accounted for in both sprinklered and unsprinklered buildings)

- Increased fuel load:
  - Burning of exposed timber adds to the fuel load, hence increasing the energy released in a fire and the duration of burning.
  - Charring of timber under protective linings, after some time, can add to the fuel load, depending on the fire severity and the protective material.
- Fire spread between firecells:
  - The additional energy released can lead to larger flames out windows, increasing the risks of fire spread horizontally to other buildings, vertically to other firecells in the same building and up the façade.
  - There is risk of fire spread on timber surfaces in cavities or concealed spaces, especially in modular light timber frame construction.
- Reduced structural performance:
  - Charring and heating of exposed timber reduces the load capacity of structural timber members.
  - Charring and heating under protective linings also reduces load capacity, after some time.
  - The reduction of load capacity can often be greatest during the decay phase of the fire (not covered by current codes or the standard testing regimes).
- Design for burnout
  - The charring rate and total char depth may be greater than measured in standard fire tests.
  - Charring can continue after the moveable fuel has been consumed, if there is no intervention by firefighters.
  - Structural failure of timber elements may occur a considerable time after the fire appears to be out.
- Firefighting challenges:
  - Fire in a mass timber building may present increased challenges for firefighters in determining the fire location and fighting the fire safely from inside the building.
  - Fire in a mass timber building can reignite and this risk extends for a much longer time than in other buildings, even when the fire appears to be fully extinguished.
  - Difficulty in assessing structural adequacy after the fire has been brought under control.
- Fire during construction
  - Additional precautions may be warranted to reduce fire risk on construction sites.

2.3 Fire development

2.3.1 Time-temperature curve

The summary of fire development in Section 2.3.1 of the Global Design Guide is valid for New Zealand. More detail is given in Chapter 3.

2.4 Designing for fire safety

The sections on human behaviour, access for firefighters, fire detection, and active and passive fire protection in Section 2.4 are all valid for New Zealand conditions. See Chapter 14 for more on firefighting.

2.5 Controlling spread of fire

The sections on controlling the spread of fire within buildings and between buildings are all valid for New Zealand conditions. More detail is given in Chapter 6 Fire-separating Assemblies and Chapter 9 Prevention of Fire Spread.

2.6 Fire safety design methods

The description of prescriptive and performance-based codes in Section 2.6 of the Global Design Guide is relevant for New Zealand. The New Zealand Building Code was intentionally written to apply independently to all structural materials, so the performance provisions do not include material-specific advice, based on materials commonly used up to the time of publication. Following the concerns outlined above in Section 2.2, there may be situations where some timber buildings designed to meet the current compliance documents do not meet the performance requirements of the New Zealand Building Code.

More details of the NZ Building Code requirements and possible alternative solutions are given in Chapter 4.

If a Building Consent Authority (BCA) considers a tall timber building to have “complex features”, the building will fall outside the scope of Acceptable Solution C/AS2 (Clause 1.1.2). It is essential for building designers and their clients to have certainty about what types of building designs are likely to be issued with building consents in accordance with the Acceptable Solution C/AS2 and what types of building designs may be regarded as outside the scope because they have “complex features”.

2.7 Fire severity

The description of fire severity in Section 2.7 of the Global Design Guide is relevant for New Zealand. More details of fire dynamics in timber buildings are given in Chapter 3.

2.8 Fire resistance

The components of fire resistance in Section 2.8 of the Global Design Guide are all relevant for New Zealand. More information can be found in Buchanan and Abu (2017). Detailed methods of structural design of timber building elements and connections for fire resistance are given in Chapters 7 and 8.

2.9 Timber protection

The generic descriptions of encapsulation and partial encapsulation in Section 2.9 are relevant for New Zealand. Details of New Zealand materials available for full and partial encapsulation are given in Chapter 6 of this commentary.

The Supplement in Appendix A defines encapsulation as protection which will limit the surface temperature of the wood to 300 °C during the fire design time (or the FRR period).

For the top surface of mass timber floors, a softer definition of encapsulation is used:

> *“The top surface of a structural timber floor is considered to be encapsulated if it is protected by a layer of non-combustible material at least 15 mm in thickness. A layer of combustible floor covering is permitted over the non-combustible protective layer.”*

This definition recognises that many mass timber building designers use a floating floor to control the acoustic performance, allowing that floor to be a layer of non-combustible board such as fibre-cement or magnesium oxide board with a thickness of at least 15 mm.

As an overseas comparison, North America codes require a 38 mm concrete topping on timber floors in mass timber construction. This addition of a wet trade is not attractive to the New Zealand construction industry.

2.10 Design for the full duration of the fire

2.10.1 Burnout

In Section 2.10.1 of the Global Design Guide, the term burnout is defined as:

> *“burnout is … the end of an uncontrolled fire in a compartment after all the available fuel has been consumed, and the room temperatures drop to allow firefighters safe access to carry out fire suppression activities.”*

This recognises that charred wood may continue to smoulder slowly after all other fuel is consumed at the end of the decay stage, so final extinguishment will need intervention by firefighters and application of water, as described in Chapter 14 of this Commentary.

This definition is different from the definition in Clause A2 of the New Zealand Building Code (NZBC):

> *“Burnout means exposure to fire for a time that includes fire growth, full development, and decay in the absence of intervention or automatic suppression, beyond which the fire is no longer a threat to building elements intended to perform loadbearing or fire separation functions, or both.”*

One of the key differences between the two definitions depends on whether the fire is “no longer a threat” when some slow smouldering is continuing.

The difference is important because in New Zealand certain buildings are allowed to have places of safety inside a building.

FENZ’s interpretation of the requirement in relation to internal place of safety is the reason for the recommendation in the Supplement in Appendix A (Section 4.7) for evacuation zone boundary fire separations constructed from mass timber to be fully encapsulated.

The brief background is that:

- The owner of a building must provide an evacuation procedure, for the safe prompt and efficient evacuation of a building’s occupants in the event of a fire emergency requiring evacuation (per regulation 7 of the Fire and Emergency New Zealand (Fire Safety, Evacuation Procedures, and Evacuation Schemes) Regulations 2018).
- The place or places of safety for a building that is a relevant building must meet the requirements of regulation 26 of the Regulations (per regulation 7 (6) of the Regulations).
- The places of safety designated in an evacuation scheme must (per regulation 26 (1) of the Regulations):
  - Be inside or outside of a building, if the building has an automatic sprinkler system; or
  - Be outside the building in any other case.
- A place of safety inside a building must (per regulation 26 (2) of the Regulations):
  - Meet the requirements set out in paragraph (b) of the definition of places of safety in clause A2 of the Building Code; and
  - Be a place from which occupants are able to safely exit the building.
- Paragraph (b) of the definition of places of safety in clause A2 of the Building Code says a place of safety means either:
  “*(a) a safe place*; or
  (b) a place of safety that is inside a building and meets the following requirements:
  (i) the place is constructed with *fire separations* that have fire resistance to withstand *burnout* at the point of the fire source; and
  (ii) the place is in a *building* that is protected by an automatic fire sprinkler system that complies with NZS 4541 or NZ 4515 as appropriate to the *building’s* use; and
  (iii) the place is designed to accommodate the intended number of persons; and
  (iv) the place is provided with sufficient means of escape to enable the intended number of persons to escape to a *safe place* that is outside a *building*”

  (Note that words in italics are further defined in the Building Code.)
- “Burnout” is defined in clause A2 of the Building Code (see above)

According to the above – all internal places of safety must meet the definition of burnout. As timber is combustible and may not self-extinguish without intervention, a pure mass timber building cannot meet the burnout definition and therefore will not comply with the Regulations to permit place of safety inside a building. The only way to address this issue in a mass timber building with place of safety inside a building is therefore to build the evacuation zone boundaries with “full encapsulation” (or another building method) that is able to meet the burnout definition. Such evacuation zone boundaries (i.e. “fire separations” would likely include the designated walls, floors and their supporting structures.

2.10.2 Design to withstand burnout

Design to withstand burnout is covered in this Section 2.10.2 of the Global Design Guide. The interpretation in this section may depend on the definition of burnout given above.

2.10.3 Self-extinguishment

As in the Global Design Guide, the term “self-extinguishment” is not used in this Commentary because it can have contradictory meanings.

2.10.4 Structural design to withstand burnout

Structural design of timber elements and connections to resist any specified fire exposure, including burnout, are described in Chapters 7 and 8 respectively.

2.10.5 Glueline failure

In addition to the statements in 2.10.5 of the Global Design Guide, mass timber elements with fire-resistant adhesives have excellent fire performance, similar to solid wood. Traditional fire-resistant adhesives include "phenol, resorcinol, phenol-resorcinol, or poly-phenolic adhesives" as listed in Clause 1.4.2 of AS/NZS 1720.4:2019, also some melamine and melamine-urea adhesives. Many wood processors prefer to use polyurethane adhesives, some of which lose strength at temperatures as low as 100 °C, which can cause problems for some structures.

Products

Plywood and **LVL** used in New Zealand is generally manufactured with fire-resistant adhesives.

Glue laminated timber (glulam) is manufactured in New Zealand with a variety of adhesives, some being fire-resistant and others with poorer fire performance. Possible glueline failure in glulam elements is of less concern than in large flat timber plates, because failure is less likely to expose large wood surfaces to the fire. In glulam floors, for example, the gluelines are perpendicular, not parallel to the fire-exposed surface.

Cross-laminated timber (CLT) adhesives are more of a concern, following observed delamination in some fire tests. The main New Zealand suppliers of CLT are Red Stag in Rotorua, and XLam in Australia. At the time of publication, it is understood that both these manufacturers generally use Henkel HB-S adhesive which is not considered to be fire-resistant.

Overseas requirements for CLT adhesives

In North America, firefighter concerns arose from full-scale compartment fire tests where exposed layers of CLT fell off, leading to repeated flashover and continued burning. As a result of these concerns, the 2019 version of the CLT manufacturing standard PRG 320 (ANSI, 2018) requires fire-resistant adhesives to be used.

Adhesive testing in PRG 320 requires a full-scale compartment fire test (Annex B) and a small-scale flame test in accordance with Canadian Standard CSA O177. Adhesive suppliers have produced new adhesives which pass these tests. An example is the Henkel HB-X adhesive which is used in North America, and is recently available in New Zealand and Australia.

In Europe, Annex B of the draft Eurocode 5 specifies a small-scale 120–minute furnace test with two samples side by side. This is the so-called GLIF test (Glue Line Integrity Failure test). The test specimen is the CLT test panel, and the adjacent reference specimen is a glulam panel with vertically-oriented gluelines. The CLT specimen, and its adhesive, pass the test if the charring rate is not 5% more than the charring rate in the reference specimen. This new test is not yet covered by an EN specification, but that is expected in due course. This test was developed with the support of major European CLT manufacturers. Another option in the draft Eurocode 5 is to carry out a 120–minute fire resistance test of a full-scale floor panel, demonstrating that the rate of charring is no more than that specified for solid timber.

New Zealand recommendations for CLT adhesives

To address the concerns about possible delamination, the Supplement in Appendix A suggests that:

> *"For buildings with escape heights > 18 m (sprinklered) or > 10 m (unsprinklered), CLT floor panels must be manufactured with fire-resistant adhesive tested in accordance with Annex B of ANSI/APA PRG 320, or Annex B of prEN 1995–1–2:2025, unless it is demonstrated that the effective depth of charring will not reach the first glueline."*

This recommendation is restricted to tall buildings, to recognise that fire-resistant adhesives are not economically available to local CLT manufacturers at this time. It is expected that this situation will change as fire-resistant adhesives become more widely available.

2.11 Special provisions for tall timber buildings

As noted in the Global Design Guide, Section 2.11, fire safety becomes much more important in tall or very tall buildings, regardless of the building materials. This is especially true for multi-storey timber buildings. Additional fire safety precautions for tall timber buildings, anywhere in the world, include automatic fire sprinkler systems and increasing reductions in the areas of exposed wood surfaces for taller buildings, with additional layers of plasterboard to meet FRR requirements.

2.12 Fire safety during construction

See Chapter 13 Building Execution and Control, for management strategies to control the risk of fire during construction in timber buildings.

2.13 Research needs

The research needs in Section 2.13 of the Global Design Guide are all relevant for New Zealand.

Reference

Fire and Emergency New Zealand (Fire Safety, Evacuation Procedures, and Evacuation Schemes) Regulations 2018, Version as at 20 April 2023.

Chapter 3
Fire dynamics

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3. Fire dynamics

Scope of chapter

This chapter is complementary to Chapter 3 of the Global Design Guide, which should be read alongside this document. The additional content included here either highlights more recent research or published reviews of fire behaviour in mass timber compartments or provides additional context, recommendations, and examples for application in New Zealand.

3.1 Introduction

[Nothing to add to the Global Design Guide]

3.2 Combustion of wood products

[Nothing to add]

3.3 Compartment fires

3.3.1 Fire development stages

[Nothing to add]

3.3.2 Fire growth

[Nothing to add]

3.3.3 Flashover

[Nothing to add]

3.3.4 Fully developed fire

[Nothing to add]

3.3.5 External flame protection

Exposing large areas of mass timber within a compartment introduces additional fuel. Fire compartment experiments have shown this to lead to bigger external flames and increased heat fluxes to the building façade as well as increased heat fluxes to neighbouring buildings (Glew et al., 2023).

Recent experiments in larger CLT compartments provides further data on external flaming. For example, the CodeRed #1 experiment (Kotsovinos, Rackauskaite, et al., 2023) in a 352 m^2 open plan compartment with an exposed timber ceiling and columns demonstrated extensive external flaming through all openings of the compartment in the order of 2.5 to 3 m in height. In this compartment 20.5% of the compartment wall surface area constituted openings resulting in an opening factor of 0.071 $m^{1/2}$. This compared to smaller, localised flaming experienced in a similar non-combustible compartment.

In the CodeRed #02 experiment (Kotsovinos, Christensen, Rackauskaite, et al., 2023) the ventilation area was almost halved, with other variables unchanged. The external flames were higher than in CodeRed #01 (3–3.5 m compared to 2.5–3 m) and protruded further laterally. The external flaming was also pulsating between visible flames and dark soot caused by the limited ventilation and incomplete combustion in CodeRed #02.

Furthermore, based on a series of full-scale mass timber compartment tests to quantify the exposure to the external façade, Sjöström et al (2023) concluded:

- There is an increase in plume duration, height, and temperatures when increasing the areas of exposed timber, but that this increase is less for normal- to large-opening compartments, than was previously seen in small-opening compartments.
- Normal variations in external wind speed have a larger influence on plume heights than the effect of doubling exposed timber surfaces.
- The BS 8414 fire test method exhibits exposures on par with the severe end of what could be expected from mass timber compartments.

At the current time, recommendations to modify existing requirements of C/AS2 for unprotected areas and boundary separation distances for mass timber buildings compared to other buildings have not been added to the Supplement in Appendix A. With additional research, they may be in the future.

However, it is recommended that the potential for increased external flaming be considered in the performance-based design of mass timber buildings where timber is exposed including for C/VM2 design. For radiation calculations from compartment openings to a relevant boundary or neighbouring building, one way to better represent the higher heat fluxes is to increase the assumed emitter temperature to 1200 °C as suggested by Glew et al (2023).

See also Commentary Chapters 9, 11 and 14.

3.4 Compartment fire temperatures

The amount of exposed timber tends to have a minimal impact on the peak gas temperature, although the total HRR may be significantly higher than predicted for a similar compartment with no exposed timber. Cessation of flaming during the decay period will typically happen before the compartment temperature decays to ambient levels. This means that during the fire decay period there is continued degradation of the timber, after any flaming on the timber has ceased, that needs to be considered when determining the structural impact (Mitchell et al., 2023).

Based on 24 small-scale exposed timber compartment fire experiments where the percentage of exposed timber area and ventilation were varied Gorska et al (2020) proposed an alternative or modified framework for the opening factor expression developed by Thomas and Heselden, where the area of exposed CLT was deducted from the total internal compartment area (excluding openings and the floor). This was to account for burning timber surfaces where there were no heat losses through the CLT. Mitchell et al (2023) applied this modified form of the opening factor to calculate the maximum average temperature in a wider range of compartment experiments but found that the agreement was inconclusive with most peak average temperatures from the other reviewed experiments reaching a peak temperature (mostly in the 1000–1300 °C region) that did not follow the proposed framework.

3.5 Fire experiments in CLT compartments

[Nothing to add]

3.6 Other factors for timber compartments

3.6.1 Effect of location of exposed timber on charring rates

The Mitchell (Mitchell et al., 2023) review of 64 experiments concluded that:

> *"the location of mass timber elements within a compartment was found to have a significant impact on the charring behaviour. Exposed timber ceilings were found to have charring rates on average 16% lower than exposed timber walls in the same experiment. Furthermore, charring rate is predominantly driven by ventilation conditions and movable fuel load density, with average charring rate decreasing as the proportion of timber surface area to opening surface area increases. However, the influence of key compartment design parameters on timber charring rate requires further understanding to progress the current understanding of compartment fire dynamics."*

It is recommended that in mass timber buildings with escape height more than 18 m and with exposed timber surfaces, that adjacent vertical facing timber surfaces (e.g. in a wall-corner) be no closer than 3 m apart.

3.6.2 Use of fire-resistant adhesives in CLT

Given the current lack of availability of fire-resistant adhesives for CLT manufactured in New Zealand, it is necessary when using the iterative design method described in Chapter 3 Section 3.8.1, for the maximum char depth in CLT manufactured using a non-fire-resistant adhesive to be:

- No greater than the thickness of the surface lamella exposed to the fire, and
- For loading bearing elements, the remaining uncharred cross section has adequate structural capacity to prevent collapse

It is understood the maximum lamella thickness currently available in New Zealand is 45 mm. Refer to manufacturers technical data for information.

3.6.3 Large compartments and traveling fires

Traveling fires have complex temperature fields and existing methodologies developed for traveling fires in non-combustible compartments cannot be assumed to apply to timber compartments. Alternative widely accepted methods for timber compartments are not yet available.

Recent research of interest includes the CodeRed series of experiments carried out inside a large, purpose-built, open-plan compartment with a floor area of 352 m^2. The CLT ceiling and glue laminated timber (glulam) columns were made with adhesives that have been tested to not exhibit char fall-off in fire.

- In CodeRed #01 (Kotsovinos, Rackauskaite, et al., 2023), the impact of a timber ceiling on the fire dynamics was investigated that showed the presence of the timber structure approximately doubled the heat release rate (HRR) compared to the value expected from the wood crib alone. There was rapid flame spread across the timber ceiling and large external flames in the order of 3 m in height. The weighted average depth of charred timber across the entire ceiling was 25 mm.
- In CodeRed #02 (Kotsovinos, Christensen, Rackauskaite, et al., 2023), the impact of ventilation was examined by halving the available ventilation. The reduced ventilation led to an increased fire duration of 20% longer compared to CodeRed #01. The peak heat release rate was estimated to be 16.5% lower than CodeRed #01, and the average char depth in the ceiling, as measured at the end of the experiment was 28 mm.
- In CodeRed #04 (Kotsovinos, Christensen, Glew, et al., 2023), the impact of an exposed surface of the timber ceiling was investigated by encapsulating 50% of the ceiling. The peak heat release rate (HRR) was estimated to be approximately 100 MW, a 17% decrease from CodeRed #01. The average charring depth of the exposed CLT panels was about 25 mm.
- CodeRed #03 (Kotsovinos et al., 2022) investigated the effectiveness of a standard water mist suppression system in both limiting fire growth as well as preventing the ignition of an exposed CLT ceiling. The water mist system was installed such that it achieved the minimum water density to meet the criteria of Ordinary Hazard category 1 (OH1) of FM 5560 Appendix G, considered suitable for an office occupancy. It was concluded that a low-pressure water mist system installed in this compartment with a combustible CLT ceiling can adequately control fire growth, even with open windows. However, it is important to appreciate that while these systems can be effective, they do not negate the need to demonstrate adequate fire resistance in all buildings in which they may be installed. See Commentary Chapter 12.

Two large-scale CLT compartment fire experiments (95 m^2) representing a modern office building have been performed, namely #FRIC-01 (A. Bøe et al., 2023a) and #FRIC-02 (A. Bøe et al., 2023b).

- #FRIC-01, in this experiment the ceiling was exposed. The wood crib fire developed slowly and travelled approximately 1.5 m before the ceiling ignited at 32.5 min. Thereafter the fire spread rapidly across the ceiling and wood crib before it retracted. Three such cycles of rapid spread followed by a retraction occurred within 13 min, with the wood crib fire growing larger for each cycle. After a short period of intense burning, the CLT then ceased burning while the wood crib fire was still burning. The compartment withstood full burnout, and no reignition occurred despite some delamination of the CLT.
- #FRIC-02, with exposed CLT on the back wall and the ceiling. The fire developed fast and spread across the room in less than 3.5 min from ignition of the wood crib fire on the floor and in 1.5 min after the ignition of the ceiling. Large external flames were observed, despite the compartment being well-ventilated. The 5–layer CLT, which comprised a 40 mm thick exposed outer layer and was face-bonded using a common European polyurethane adhesive, exhibited glue-line integrity failure leading to a second flashover after a significant period of decay. Subsequent layers of 20 mm also delaminated before the fire was manually extinguished after 3 h.
- #FRIC-02 compared to #FRIC-01 exhibited a faster fire spread rate, and temperatures, charring rates, heat release rates and external flames that were higher.

The Mass Timber Demonstration Fire Test Program (MTDFTP) (Su et al., 2023) recently carried out in Canada included five large scale fire tests conducted in a two-storey, four-bay mass timber structure. The structure had a total floor area of 334 m^2 with layouts and contents intended to represent business and residential occupancies as well as construction sites in different tests. Findings included:

- The average char depth was well within the depth expected in a standard 2–hour fire resistance test.
- Some exposed CLT ceiling experienced localised delamination in the cooling period during the tests but this did not cause any re-ignition or fire regrowth.
- Since deep-seated hot spots and smouldering remained after the tests, extended firefighting operations were required in order to ensure the hot spots were fully extinguished.
- The conditions in the stairwell were not adversely affected in any test.
- The test structure remained stable and solid after enduring the five severe fire tests.

These findings apply to the particular size, ventilation and configuration of the mass timber structure used and may not necessarily apply to other configurations of compartment.

Performance-based design on a case-by-case basis may be appropriate or a prescriptive solution may be adopted. Alternative Solutions might be based on a comparison with actual full-scale tests if the compartment parameters are sufficiently similar. Also refer to Section 3.1 of the Supplement in Appendix A of this document for a relaxation for buildings with escape height up to 10 m using a prescriptive solution.

3.7 Design to withstand burnout

An understanding of the fire dynamics is particularly important when considering a performance-based design or a C/VM2 design approach (MBIE, 2023a), where there is likely a need to demonstrate burnout in a firecell. If burnout is a design objective or requirement, then it is necessary to achieve a reliable and continuing decay (and therefore burnout) of the compartment temperature in a natural fire (i.e., no regrowth and temperature cycling). This requires a design where char fall-off is minimised either by use of a fire-resistant adhesive or by ensuring the thickness of the surface lamella is greater than the final char depth. The residual construction may be required to provide loadbearing capacity or fire separation functionality. Figure 1 is a photograph of char fall off during a fire test of a CLT floor.

Figure 1. **Example of char fall off during AS1530.4 fire testing of a CLT floor slab in New Zealand (Credit: E. Claridge)**

3.8 Calculation methods for compartments with exposed timber

The following guidance applies to calculations using the iterative design method as described in Chapter 3 of the Global Design Guide.

3.8.1 Proposed thermal parameters for use in calculations

In the absence of any justification for alternative values, it is recommended that the thermal parameters (b) in Table 1 should be used for the firecell bounding surfaces. An area weighted "b" value for the firecell should be determined considering the ceiling, floor and wall area excluding openings, where $b = \sqrt{k\rho c}$.

Table 1. **Thermal parameter (b) for bounding surfaces**

Material	b (J/m²s$^{0.5}$ K)
Plasterboard (MBIE, 2023a)	700
Timber, CLT (MBIE, 2023a)	290
Lightweight concrete (MBIE, 2023a)	1100
Normal weight concrete (MBIE, 2023a)	1700
Fibre cement board for floating floor system (FSRI, undated)	600
Magnesium oxide board for floating floor system (Steau and Mahendran, 2021)	750

The area-weighted "b" value for the firecell can also be used to determine an effective k_b factor for use in equation 2.1 of C/VM2 Section 2.4.4 based on a linear interpolation of the k_b factors given in C/VM2 Table 2.4.

3.8.2 Limits on opening factor and window breakage

The range limits of the compartment opening factor as stated in Chapter 3 Section 3.8.1 is 0.03 to 0.10 m$^{0.5}$ corresponding to the experimental range shown in Chapter 3 Figure 3.9. This is a narrow range restricting design and may unfairly penalise well-ventilated compartments. Until experimental data with a wider range of opening factors is available, it is proposed to allow the iterative design method described in Chapter 3 Section 3.8.1 to be used with a wider range of opening factors in the range from 0.02 to 0.15 m$^{0.5}$ slightly less than that permitted in EN 1991–1–2:2002 Annex A for parametric fires generally and that proposed for the design model in the draft EN 1995–1–2:2025 Annex A4.4. If the actual opening factor is larger than 0.15 then 0.15 should be used in the calculations.

The Fire Engineer should ensure the ventilation chosen for use in fire severity analysis is consistent throughout the assessment and within the recommended limits of the various sub-calculations. Some common considerations are:

- For buildings with an escape height > 18 m, maximum 50% of the opening areas in external walls which can dependably provide airflow to the fire shall be used in calculation unless 100% of the opening area leads to a greater calculated char depth. This is intended to account for some of the uncertainty that is associated with the proportion of window breakage that would actually occur and that is most likely a stochastic variable. The designer should also consider the type of glazing in use, such as double, triple and strengthened glazing units such that assuming 100% breakage may not be conservative. Therefore it is recommended the additional case of 50% breakage is also included in calculations.
- Opening factor and A_v/A_f values should remain within their respective limits in iterative fire severity calculations and should be consistent with the time-equivalence formula limits as per C/VM2 (if used) when determining suitable fire resistance rating for the firecell. i.e.

$$0.02 \leq \frac{A_v}{A_t}\sqrt{h_v} \leq 0.15 \text{ (iterative design method in Ch 3 of the Global Design Guide)}$$

$$0.025 \leq \frac{A_v}{A_f} \leq 0.25 \text{ (time equivalence formula C/VM2)}$$

- A specific room height limit is not proposed here. Generally, the larger the ceiling height, the longer it will take to ignite any exposed timber on the ceiling. This is expected to be beneficial to safety in the building.
- Ensure $d^{i}_{char} - 0.7\beta_{par}t^{1}_{\max} > 0$

For fire scenarios where the compartment is unlikely to experience flashover as a result of well-ventilated fire in a large firecell with interconnected floors, other means of fire severity analysis should be considered. Refer to section 3.1 of the New Zealand recommendations in the Supplement in Appendix A of this document for a prescriptive relaxation for buildings with escape height up to 10 m.

3.8.3 Alternative methods

See 2025 Draft Eurocode 5 Annex A [15] for a description of an alternative method.

3.9 Worked examples

3.9.1 Worked example 1 for office building following C/VM2 compliance pathway

This worked example follows the guidance provided in the Supplement in Appendix A. Section references given here refer to those in the Supplement in Appendix A.

Building description:

Five storey office building, escape height 15 m, no storage above 3 m, Type 6 automatic fire sprinkler system, total occupant load of 250 people and a single stair.

Firecell parameters are:

- Dimensions 16 m long x 9 m wide x 3 m high.
- Multiple windows 2 m high with total width 21 m. h_v = 2 m A_v = 42 m² (total).
- CLT 200 mm thick with 5 layers.
- Thickness of the exposed lamella 40 mm.
- 95% of ceiling CLT to be exposed (136.8 m²) and 10% of walls exposed (10.8 m² excluding openings).
- A floating floor system with a fibre cement topping is used.
- Gypsum plasterboard is used to encapsulate the non-exposed parts of the CLT ceiling and walls. It is assumed that protection boards do not fail, and glue line integrity is maintained in exposed CLT. Fire-resistant adhesive is not used.
- A_t = 438 m² (total surface area including walls, ceiling, floor including openings).

C/VM2 Design Scenarios UT, CS, VS, IS and SF are not considered in this example.

Section 3.1 Relaxation for buildings with escape height up to 10 metres

- Not applicable

Section 3.2 All mass timber buildings (encapsulated or exposed timber)

- Where fire resistance for burnout is required (see design scenarios below), the fire severity calculation must take into account the ventilation and the thermal properties of the firecell boundaries and calculate the depth of charring of exposed timber during the full fire exposure, including the decay period.
- Thermal properties for the bounding surfaces of the firecell must be consistent with the thermal properties of encapsulation materials and in proportion to the surface area of encapsulation.
- The fire load energy density (FLED) is 800 MJ/m² (C/VM2 Table 2.2) and after applying the F_m factor for the sprinklered case (=0.5 from C/VM2 Table 2.3) the design fire load energy density becomes 400 MJ/m².

C/VM2 Section 4.8 Design scenario (FO): Firefighting operations requires (for escape height > 10 m):

- Stairway to be designed as an exitway fire separated from all other parts of the building and designed to resist fire spread until burnout.
- Load-carrying structure and floor systems to resist collapse and prevent fire spread between floor levels until burnout.

C/VM2 Section 4.5 Design scenario (HS):

- Areas of the external wall that are not designated as unprotected area shall have a fire resistance rating sufficient to resist the full burnout design fire. A radiation temperature of 1200 °C will be assumed for any calculations of the received radiation at or beyond the relevant boundary.

Section 3.3 Fully encapsulated mass timber buildings

- In this example, it is not intended to fully encapsulate all the CLT, so this section does not apply.

Section 3.4 Buildings with partially encapsulated timber or with some exposed timber surfaces

- Since fire resistance for burnout is required, the design FLED will include the additional fuel load due to charring of exposed timber floors, walls, ceiling, columns, beams and diagonal bracing.
- Where encapsulation is required, the thickness and fixing of the encapsulation will be sufficient to prevent charring beneath the encapsulation.
- The F_m factor is applied only to the introduced (movable) fuel load (design FLED in Table 2.2 in C/VM2).
- All mass timber not included in charring calculations will be fully encapsulated for the calculated FRR period.

Section 3.5 Notes for C/VM2 design

- The time-equivalent formula in C/VM2 (including any modification to the design FLED proposed in this document) may be used to calculate the equivalent time of exposure to the standard fire, for fire resistance ratings of non-structural elements such as fire doors, penetrations etc.

Section 4 Additional considerations for the fire design of mass timber buildings using C/AS2 or C/VM2

- **Section 4.1 Fire protected (safe path) stairwells and lift shafts with firefighter lift control** – inside surfaces of the lift shaft and stairwell may be exposed as these spaces will be sprinklered. The outside surfaces around the stairwell are not required to be encapsulated as, while the building has a single stair, the escape height does not exceed 18 m.
- **Section 4.2 Penetrations and fire-stopping** – Designers must check that penetrations and fire stopping solutions are suitable for use with mass timber construction. Refer to Chapter 9 on fire spread via building service installations and penetrations.
- **Section 4.3 Gaps in construction** – Gaps at joints and in exposed areas of timber should be minimised to prevent spread of fire through assemblies and to prevent increased charring and challenges to firefighting. Gaps of any size passing through a fire-rated assembly, or surface gaps more than 5 mm wide must be filled with an intumescent mastic or other recognised fire stopping sealant. Refer to Chapter 9 on fire spread via separating elements, joints and junctions.
- **Section 4.4 Vertical Services** – Non-encapsulated service risers and vertical shafts containing building services should be fire stopped at every floor level.
- **Section 4.5 Structural fire resistance** – Structural fire resistance must be demonstrated (by calculation or test results) to show that all structural members and connections have the capacity to resist the applied loads when the cross-section is reduced by the calculated char depth plus a zero-strength layer, as described in Chapter 7.
- Structural calculations must consider increased local charring of timber in contact with metal fixings.
- Free-standing columns and load-bearing walls inside firecells may be exposed (if surface area included in char depth calculations).
- **Section 4.6 Fire-resistant adhesive** – This is not required as the escape height does not exceed 18 m, however the maximum char depth calculated should be less than the maximum thickness of the exposed lamella to prevent falloff.
- **Section 4.7 Buildings with a place of safety inside the building** – There is no “place of safety” inside this building.
- **Section 4.8 Fires during construction** – a comprehensive plan to manage the risks and consequences of fires during construction is required.

Char Depth Calculation:

This example assumes exposure to a fire described using the EN 1991–2 Annex A parametric fire equations where the fire load density also includes the contribution from the exposed mass timber using the method given in the Global Design Guide Chapter 3 Section 3.8.1.

Fire parameters:

- As per EN 1991–1–2 Annex A Parametric fire curve.
- Fire growth rate: fast with t_{lim} = 15 min.
- Design fire load density per unit floor area (FLED) excluding CLT is 400 MJ/m² (see above).
- Thermal parameter, $\sqrt{k\rho c}$ for the compartment boundaries:
  - Wood (147.6 m²), $\sqrt{k\rho c} = 290$ Js^{-1}m^{-2} K^{-1}
  - Fibre cement board for floating floor system (144 m²), $\sqrt{k\rho c} = 600$ Js^{-1}m^{-2} K^{-1}
  - Plasterboard (At – Av – 147.6 – 144 = 104.4 m²), $\sqrt{k\rho c} = 700$ Js^{-1}m^{-2} K^{-1}
  - Weighted average $\sqrt{k\rho c} = \frac{290 \times 147.6 + 600 \times 144 + 700 \times 104.4}{438 - 42} = 511$ Js^{-1}m^{-2} K^{-1} (surface area weighted between plasterboard, fibre cement and timber assuming 95% of ceiling is exposed and 10% of walls are exposed wood.)

Procedure:

First iteration (Steps 1 to 8) for non-combustible or fully protected compartment.

Step	Parameter	Equation and notes	Eq	Value
1	Opening factor	$O = \frac{A_v}{A_t}\sqrt{h_v}$ O must be in range 0.02 to 0.15 m0.5	3.29	0.136 m$^{1/2}$
2	Heating rate factor	$\Gamma = \frac{\left(\frac{O}{\sqrt{k\rho c}}\right)^2}{\left(\frac{0.04}{1160}\right)^2}$ $\sqrt{k\rho c}$ is assumed to be constant during the fire.	3.28	59.3
3	Surface area of compartment boundaries	A_t = 2 (L.W + H(L+W))		438 m²
4	Moveable fire load per surface area of boundaries	q_{mfl} = FLED × LW / At q_{mfl} must be in the range 50 to 1000 MJ/m²		132 MJ/m²
5	Start time of gas temperature decay (1st iteration)	$t^1_{\max} = \max\left[0.0002q_{t,d}/O;\ t_{lim}\right]$ $t^1_{\max}$ is a parameter applying to non-combustible compartments and does not change for subsequent iterations.	3.33	0.25 hr
6	Initial charring rate	$\beta_{par} = \beta\Gamma^{0.25}$ assuming β = 0.65 mm/min	3.30	1.8 mm/min
7	Time at which char rate reduces	$t_o = 0.009\,\frac{q_{t,d}}{O}$ For iteration 1, $q_{t,d} = q_{mfl}$	3.31	8.73 min
8	Final char depth (1st iteration)	$d_{char} = 2\beta_{par}t_o$	3.32	31.5 mm

For the second (Steps 9 to 12), and subsequent iterations, the following steps are repeated to account for the additional fire load from the charring timber, until the final char depth estimate converges to a value e.g., when the difference between successive final char depth estimates are below a specified tolerance such as 0.1 %.

Step	Parameter	Equation and notes	Eq	Value
9	Total fire load per surface area of boundaries	$q_{td}^{i+1} = q_{mfl} + \frac{A_{CLT}\alpha_1 \left(d_{char}^{i} - 0.7\beta_{par}t_{\max}^{1}\right)}{A_t}$ $t_{\max}^{1}$ is constant between iterations Check $d_{char}^{i} - 0.7\beta_{par}t_{\max}^{1} > 0$	3.34	154.3 MJ/m^2 (iteration 2)
10	Initial charring rate	$\beta_{par} = \beta\Gamma^{0.25}$	3.30	Etc.
11	Time at which char rate reduces	$t_o = 0.009\,\frac{q_{t,d}}{O}$	3.31	Etc.
12	Final char depth	$d_{char} = 2\beta_{par}t_o$	3.32	Etc.
Repeat for as many iterations as required				
	Final char depth (10th iteration)	$d_{char} = 2\beta_{par}t_o$	3.32	41.1 mm
	Final total fire load per unit surface area of boundaries	$q_{t,d}^{i+1} = q_{mfl} + \frac{A_{CLT}\alpha_1 \left(d_{char}^{i} - 0.7\beta_{par}t_{\max}^{1}\right)}{A_f}$	3.34	172 MJ/m^2
	Final fire load density per unit floor area	$FLED = \frac{A_t}{A_f}q_{t,d}^{i+1}$		523 MJ/m^2

Following convergence of the char depth calculation to a stable value (~41 mm), the designer can assume this to be an estimate of the maximum char depth within the exposed wood surfaces within the compartment. Note that this char depth has exceeded the first glueline given the lamella thickness is 40 mm in this case. Where non-fire rated adhesive is utilised, the Fire Engineer would need to revisit the extent of encapsulation i.e. increasing the encapsulated area of the walls or ceiling to reduce the maximum char depth. Another option could be to use an alternative mass timber product with a thicker exposed lamella to provide greater glue line protection.

It should also be noted that the opening factor falls outside of the range that the methodology has been validated against experiments as discussed in the Global Design Guide, and therefore additional considerations may be warranted. An example would be that with a very low margin of difference between the predicted char depth and glue line location, further verification may be warranted that the input **β** parameter representing the charring rate corresponding to a standard fire resistance test exposure is accurate for the mass timber product used in construction. The Fire Engineer would also need to supply the maximum char depth to the Structural Fire Engineer for further analysis to determine the structural capacity if the CLT element has load bearing function, refer to Chapter 7 for further details.

Time equivalence calculated by C/VM2 2.4.4 gives 41 minutes with FLED = 523 MJ/m^2, k_m=1, w_f = 0.819 and k_b = 0.096. This can be used to inform the selection of any fire-rated doors, and fire-stopping systems etc that may be required.

3.9.2 Worked Example 2 for apartment building following C/AS2 compliance pathway

Three storey building (SM risk group) without sprinklers, escape height 7 m, Type 1 domestic smoke alarm, Type 2 manual fire alarm system and single stair.

The life and property ratings for an unsprinklered SM risk group according to C/AS2 Table 2.4 are 60 minutes (MBIE, 2023b).

Applying the recommendations in the Supplement in Appendix A of this document for a C/AS2 compliance pathway requires:

- **Section 2.1** – Table 1 recommends exposed wood category W100 and minimum FRR of 90 minutes for this building configuration (i.e. if no NZS 4512 automatic fire alarm system with full building smoke detection coverage is installed). It is proposed to:

  (1) Upgrade the Type 1 and 2 fire alarm systems to a Type 5 modified smoke detection system to accommodate an FRR of 60 minutes, and

  (2) Expose the mass timber of the ceiling and to encapsulate all walls which results in an exposed mass timber area equivalent to 100% of floor area.

  Where C/AS2 requires building elements to be fire rated, the life and property ratings should be taken from Table 1 of Appendix A but not be less than those given in Table 2.4 of C/AS2. For this building, the life and property ratings will remain 60 min from Table 1 (by applying Table 1 note 2).
- **Section 2.2 Exposed mass timber categories** – Category W100 allows all of the ceiling to be exposed with other mass timber encapsulated for the required periods of fire resistance.
  - The top surface of a structural timber floor is required to be protected by a layer of non-combustible material at least 15 mm in thickness.
  - Fire doors to stairwell requires -/60/30 sm as per C/AS2 Table 4.2.
- **Section 3** is not applicable to a C/AS2 compliance pathway.
- **Section 4.1 Fire protected (safe path) stairwells and lift shafts with firefighter lift control** – inside surfaces of the lift shaft and vertical safe path are recommended to be encapsulated. All surface finishes will need to comply with Building Code Clause C3.4 as required. The outside surfaces around the stairwell may not be encapsulated as, while the building will have a single stairway, the escape height does not exceed 10 m.
- **Section 4.2 Penetrations and fire-stopping** – Designers must check that penetrations and fire stopping solutions are suitable for use with mass timber construction. Refer to Chapter 9 on fire spread via building service installations and penetrations.
- **Section 4.3 Gaps in construction** – Gaps at joints and in exposed areas of timber should be minimised to prevent spread of fire through assemblies and to prevent increased charring and challenges to firefighting. Gaps of any size passing through a fire-rated assembly, or surface gaps more than 5 mm wide must be filled with an intumescent mastic or other recognised fire stopping sealant. Refer to Chapter 9 on fire spread via separating elements, joints and junctions.
- **Section 4.4 Vertical Services** – Non-encapsulated service risers and vertical shafts containing building services should be fire stopped at every floor level.
- **Section 4.5 Structural fire resistance** – Structural fire resistance must be demonstrated (by calculation or test results) to show that all structural members that require a fire rating and their connections have the capacity to resist the applied loads for 60 minutes.
- **Section 4.6 Fire-resistant adhesive** – is not required as the escape height does not exceed 10 m and it is not necessary to demonstrate avoidance of falloff of lamella.
- **Section 4.7 Buildings with a place of safety inside the building** – There is no "place of safety" inside this building.
- **Section 4.8 Fires during construction** – a comprehensive plan to manage the risks and consequences of fires during construction is required.

[Note - Optional use of fire sprinklers would allow all timber to be exposed (Category WU) including the top surface of a structural timber floor, and both the life and property rating would be 60 minutes. It would also allow the inside face of stairwells and lift shafts to be exposed provided the surface finishes (e.g. Group Number) are compliant – see Chapter 5 of the FSUW book and this commentary.]

3.10 Further reading

There have been several recent reviews of mass timber experiments published in the literature that readers are referred to e.g. (Ronquillo, Hopkin and Spearpoint, 2021; Liu and Fischer, 2022; Mitchell et al., 2023)

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Chapter 4
Fire safety requirements in different regions

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4. Fire safety requirements in different regions

Scope of chapter

This Chapter presents an overview of the New Zealand Building Code for protection from fire and expands upon the details provided in Chapter 4 of the Global Design Guide. It provides an overview of the current compliance pathways for buildings and highlights specific challenges with timber buildings for compliance with the existing regulatory requirements relating to fire performance.

This Chapter is not intended to outline all the processes required to gain a building consent or a code compliance certificate. It focuses on the performance of the building and the compliance pathways to meet Building Code requirements.

New sections have been added to expand upon the requirements for New Zealand.

4.1 Regulatory control systems for fire safety in buildings

4.1.1 Europe

[Nothing to add to the Global Design Guide]

4.1.2 Canada

[Nothing to add]

4.1.3 USA

[Nothing to add]

4.1.4 China

[Nothing to add]

4.1.5 Japan

[Nothing to add]

4.1.6 Russian Federation

[Nothing to add]

4.1.7 Australia

[Nothing to add]

4.1.8 New Zealand

The Global Design Guide discusses the components of the performance-based New Zealand Building Code. Further information about how the Building Code works in New Zealand can be found on building.govt.nz and the Building Performance Learning Centre.

Measures for fire safety in the Building Code are primarily contained in Clauses C1 to C6 Protection from Fire. Clause C1 contains the objectives of Clauses C2 to C6 which are to:

(a) safeguard people from an unacceptable risk of injury or illness caused by fire.

(b) protect other property from damage caused by fire, and

(c) facilitate firefighting and rescue operations.

Clauses C2 to C6 provide the functional requirements and performance criteria. They are formulated to follow the process of fire ignition to growth and the responses by occupants, firefighters, and the building structure. These clauses are:

C2 – Prevention of fire occurring

C3 – Fire affecting areas beyond the fire source

C4 – Movement to place of safety

C5 – Access and safety for firefighting operations

C6 – Structural stability

Within these clauses, there are 20 performance sub-clauses that are split between quantitative and qualitative criteria as listed in Table 1. The quantified performance clauses were introduced in 2012 as part of an overhaul of the fire safety regulatory system in New Zealand which also saw the introduction of new acceptable solutions and verification methods.

Table 1. **Quantitative and qualitative performance criteria in the NZBC**

Quantitative performance clauses	Qualitative performance clauses
C2.2 Max surface temperature of combustibles C3.4 Materials used as surface linings C3.5 External vertical fire spread C3.6 External horizontal fire spread C3.7 External wall materials C3.8 Large fuel loads C4.3 & C4.4 Tenability during evacuation C5.3 & C5.4 Firefighting vehicle access	C2.3 Explosive or hazardous conditions C3.9 Risk of system failure on fire spread C4.5 Risk of system failure for means of escape C5.5 Means of delivering firefighting water C5.6 Firefighter access within a building C5.7 Information for firefighters C5.8 Risk of system failure for firefighter safety C6.2, C6.3, C6.4 Structural system performance

The discussion in the remainder of this chapter focuses on compliance with these clauses. However, in addition to Clauses C1 to C6, there are two other clauses that are directly relevant for the structural fire design of buildings. Clause B1 Structure contains requirements for the loads that buildings are likely to experience during construction, alteration and throughout their lives. Clause B1.3.3 includes fire and explosions as physical conditions to be considered for the stability of the building. As well, Clause B2 Durability contains provisions that apply to the durability of materials and building elements including timber products and fire protective materials or coatings. Designers must be aware of how these requirements affect the fire design of the building.

Compliance with the New Zealand Building Code is outlined in Section 19 of the Building Act 2004. All buildings are required to comply with the performance requirements of the New Zealand Building Code. In demonstrating compliance with the Building Code requirements for Protection from Fire, a designer can demonstrate compliance through various means. The Global Design Guide outlines various compliance pathways that are discussed in further detail here along with additional mechanisms provided by the Building Act 2004.

Acceptable solutions and verification methods

Compliance with the New Zealand Building Code can be demonstrated in three different ways; by using an acceptable solution, a verification method, or an alternative solution. The most recent published versions of acceptable solutions and verification methods for Protection from Fire include:

- Acceptable Solution C/AS1 Protection from Fire for buildings with sleeping (residential) and outbuildings (risk group SH), Second Edition, issued 2 November 2023
- Acceptable Solution C/AS2 Buildings other than Risk Group SH, First Edition, Amendment 3, issued 2 November 2023
- Verification Method C/VM1 Solid fuel appliances, Second Edition, issued 2 November 2023
- Verification Method C/VM2 Framework for Fire Safety Design, First Edition, Amendment 7, issued 2 November 2023

Verification Method C/VM1 is limited in use for compliance with C2 Prevention of fire occurring for solid fuel appliances and is not discussed further.

Fire engineering design for the majority of buildings in New Zealand is based on compliance with the prescriptive requirements of the Acceptable Solution C/AS1 or C/AS2 as this pathway represents a lower consent risk and generally faster consent processing times. Acceptable Solutions C/AS1 and C/AS2 apply to specific types of buildings (risk groups) which are defined within the documents. C/AS1 is used for risk group SH which primarily includes single family homes but can be used for some low-rise multi-unit dwellings such as townhouses. C/AS2 is used for the following risk groups:

- SM Sleeping (non-institutional),
- SI Care or detention,
- CA Public access and educational facilities,
- WB Business, commercial and low level storage,
- WS High level storage or potential for fast fire growth, and
- VP Vehicle storage and parking.

The Verification Method C/VM2 is not limited to specific risk groups. However, both C/AS2 and C/VM2 have additional limits on the scope of the buildings that they can be used for, so these documents cannot be used for tall buildings (above 20 storeys in height) and buildings with complex evacuation strategies, for example. C/AS2 does permit a certain level of managed evacuation strategies for hospitals, rest homes, and detention facilities.

The minimum fire safety systems required for compliance with C/AS1 and C/AS2 are established in "Part 2. Firecells, fire safety systems and fire resistance ratings". For C/AS1, this includes interconnected smoke alarms in household units and modest fire resistance ratings where building elements separate household units or are in close proximity to property boundaries.

The minimum fire safety systems required by C/AS2 vary by risk groups representing different types of occupants and fire hazards within each risk group. In general, buildings where people sleep require smoke detection throughout, with some, such as care facilities, also requiring sprinkler protection. Some storage activities also require sprinkler protection because of the higher fuel loads and higher fire risks. The minimum fire safety features required by C/AS2 can also increase with the occupant type, occupant load, and escape height, to reflect the higher risks and/or limitations to firefighting response. Risk groups with over 1000 people or over 25 m in escape height all require sprinkler protection. There are other requirements within C/AS2 which may warrant sprinkler protection as sprinklers provide trade-offs for other fire safety requirements.

The minimum fire resistance ratings in C/AS2 are specified for individual risk groups and are split into two categories: life ratings (the fire rating that applies to protect people during evacuation) and the property rating (the fire rating that applies to protect other property). The required life rating and the property rating for a sprinklered building is generally half that required for an unsprinklered building.

C/VM2 contains 10 design scenarios for determining the minimum fire safety features in a building. Some of these scenarios may require smoke detection, sprinkler protection, or fire rated construction to demonstrate compliance for a given building. The minimum fire resistance rating of a compartment can be determined in C/VM2 using the time-equivalence method.

Selection of design method

The decision whether to follow the Acceptable Solution C/AS2 or the Verification Method C/VM2 for fire design is likely to be made early in the design process. A design to C/VM2 (or a full performance-based alternative solution design) takes more design effort and cost than a C/AS2 design. The main reasons for adopting a C/VM2 design pathway are usually to get more freedom in the building design than when using the acceptable solutions. This freedom can include specific designs for interconnected floor areas, means of escape, and fire resistance, for example.

The Building Code documents C/AS1, C/AS2, and C/VM2 do not contain separate requirements for timber structural members versus steel or concrete members. However, the scope of C/AS2 and C/VM2 is limited in some cases, depending on the fire hazards and fire safety features present in the building. For example:

C/AS2 Paragraph 1.1.2 states that:

> 1.1.2 Buildings with complex features are outside the scope of this Acceptable Solution.
>
> …
>
> Buildings that have features for which solutions are not provided within this Acceptable Solution are also deemed to be complex.

C/VM2 Paragraph 1.2.1 states that:

> 1.2.1 This Verification Method is for fire designs for all buildings except those buildings that:
>
> …
>
> c) Contain fire hazards that are not defined by Part 2 of this Verification Method "The rules and parameters for the Design Scenarios".

These considerations are especially important for mass timber buildings which were not envisioned when the documents were originally published. Certain types of mass timber buildings may present complex building features and unique fire hazards that make them out of scope for use with C/AS2 and C/VM2. Further information on these fire hazards is provided in other chapters. In these instances, further analysis of the mass timber surfaces may be necessary and building performance may be better assessed using an alternative solution approach to demonstrate compliance with the Building Code.

Alternative solutions

Not all building work is provided for in the Acceptable Solutions and Verification Methods. In these situations, or in any building design, the designer can choose to demonstrate compliance with the requirements of the Building Code directly as an alternative solution.

MBIE has published guidance on Alternative Solutions For Building Code Clause C Protection From Fire. This guide discusses alternative solutions for the Building Code clauses on Protection from Fire, where they fit into the building regulatory system, what the clauses require, types of alternative solution suitable for fire design, and safety margins.

When undertaking an alternative solution, it is up to the designer to collate sufficient evidence in the fire safety documentation to demonstrate to the building consent authority that the relevant performance criteria in the New Zealand Building Code are met. This evidence may include:

- Calculation or test methods – Calculations, test results, models, simulations not contained in the acceptable solutions or verification methods.
- Comparison with acceptable solutions or verification methods – In many cases, acceptable solutions and verification methods can be used a starting point for assessing an alternative solution.
- Trade literature – For proprietary products, the manufacturer's literature may contain technical data that supports the proposal.
- Expert evidence – This could be peer review of the proposed solution or expert opinions obtained from credible organisations.

Fire Engineering Brief (FEB)

For alternative solutions, it is usually beneficial to discuss the type of analysis to be undertaken and the acceptance criteria with key stakeholders early in the design process. This process, using a report known as the Fire Engineering Brief (FEB), helps to minimise risks and delays in consenting the design. Stakeholders involved in the FEB process generally include the building owner, building consent authority/territorial authority, Fire and Emergency New Zealand (FENZ), peer reviewers, and others with specific involvement in the design. This process is outlined in paragraph 1.3 of C/VM2.

Determinations

Determinations are decisions made by the Ministry of Business, Innovation and Employment (MBIE) on matters related to building work under the Building Act and the New Zealand Building Code. A determination may decide whether a design complies with the Building Code, and may review decisions to grant or refuse building consents. A determination can confirm or reverse a decision made by a building consent authority, and, alongside designs complying with an acceptable solution or verification method, building consent authorities must accept a determination as a means of demonstrating compliance with the Building Code.

Only certain people can apply for a determination, usually the building owner or the building consent authority. The determination process can be fairly rigorous as MBIE has to collect and analyse all the facts before making a legally binding decision.
Determinations are usually the last step to be undertaken when trying to resolve disputes on whether something complies with the Building Act or the Building Code. It is recommended to first try to resolve disagreements by talking to the people involved. For fire engineering designs, gaining agreement in the FEB process can help minimise the chance of later disagreements, especially when working on more complex buildings.

Previous determinations can also be useful. MBIE posts each determination decision online and clearly explains why it was made. A previous determination can be used as part of the supporting evidence for a building consent application. MBIE is not required to follow past decisions like a court has to follow higher court rulings, but previous determinations are considered where the situations are alike.

Product assurance and certification schemes

There are three voluntary certification schemes under the Building Act that work together to provide more options for compliance with the New Zealand Building Code.

- CodeMark is used to certify building products for use with the New Zealand Building Code.
- BuiltReady applies to the quality assurance of manufacturers of modular components.
- MultiProof is used for standardised, repeatable designs to be built multiple times across the country (at least 10 times in 2 years).

These schemes differ from third-party product appraisals because building consent authorities must accept CodeMark, BuiltReady, or MultiProof when these are used to demonstrate that the building complies with the Building Code (subject to the limitations and use of individual approvals).

Waivers and modifications of the Building Code

Territorial authorities can grant building consents subject to a waiver or modification of the Building Code. Waivers and modifications allow territorial authorities to address unique circumstances or uncommon situations that are particular to their local region.

A waiver means that a specific portion of the Building Code is not required to be followed. This is usually applied to a specific performance criterion but can also apply to an entire code clause. A modification still requires a clause to be complied with but may alter the performance criteria while still maintaining the functional requirements and objectives of the Building Code.
As an example, determination 2015/010 stated that the following criteria were reasonable to consider when deciding to grant a modification of the Building Code:

- The extent and possible consequence of the non-compliance with the specific performance clause.
- The availability of other reasonably practicable solutions that would result in the building work fully complying with the Building Code, and associated costs.
- Any special and unique circumstances of the building work subject to the waiver or modification.
- The extent to which the modification will still be consistent with the purposes and principles of the Building Act.
- The modification complying with the relevant objective and functional requirement of the specific clause of the Building Code.

Other factors to be considered include the location and use of a building and the design features present in the building.

Fire and Emergency New Zealand

Fire and Emergency New Zealand (FENZ) is the national provider of firefighting services in New Zealand. Under sections 46 and 47 of the Building Act 2004, FENZ is entitled to provide advice to building consent authorities on certain building consent applications. This function was added to the Building Act in order to:

a. Minimise the risk of Determinations being taken, thereby improving certainty for the building industry;
b. Ensure alternative solutions complying with the Building Code affecting firefighting operations were reviewed by Fire and Emergency New Zealand in addition to the building consent authority or territorial authority; and
c. Minimise potential issues being raised after a building has been constructed which often proved difficult and very costly to re-mediate.

The full list of types of building consent applications that must be sent to FENZ for review are outlined in the New Zealand Gazette in notice 2012-go2694. Among other criteria, this includes buildings that demonstrate compliance through an alternative solution for Clauses C1–C6 D1, F6, or F8 of the Building Code or where there are waivers and modifications of these clauses. FENZ's role in this review is generally provided by the FENZ Fire Engineering Unit with input as required from others in the organisation and is limited to advice on means of escape from fire and firefighting provisions. This advice must not set performance criteria that exceed those in the Building Code. General firefighting considerations for mass timber are discussed further in Chapter 14.

Beyond the requirements of the Building Act, FENZ may offer additional recommendations to enhance the fire safety of buildings as part of its broader objectives and functions under the Fire and Emergency Act 2017. FENZ will generally be included as stakeholder in a fire engineering brief process and will normally issue a letter upon satisfactory review of the FEB and assessment methodologies stated within it. This feedback will form the basis for subsequent FENZ reviews of the design during a building consent application.

Furthermore, Fire and Emergency New Zealand is responsible for approving evacuation schemes in accordance with the Fire and Emergency New Zealand (Fire Safety, Evacuation Procedures, and Evacuation Schemes) Regulations 2018, which outline requirements for safe evacuation procedures. These regulations reference the Building Code defined terms "place of safety" and, through subsequent references, "safe place", and "burnout". This can create additional challenges for mass timber buildings incorporating a place of safety within a building as it must withstand burnout which, as defined, does not consider any intervention or automatic suppression.

4.1.9 Other regions

[Nothing to add]

4.2 International guides and standards

4.2.1 International Fire Engineering Guide (IFEG)

In New Zealand, the IFEG has been published as guidance under Section 175 of the Building Act 2004. As a guidance document, its use is not mandatory under the Building Act. However, it can be used to assist people in complying with the Building Act and can be used by a building consent authority when considering if something complies with the New Zealand Building Code. In a similar fashion, the IFEG is referenced in a comment box in C/VM2 in relation to the fire engineering brief process.

4.2.2 International standards

The report Densified Housing: Analysis of Fire Resistance Requirements (Wade, C. and Baker, G (2022). External Research Report ER69 Densified Housing: Analysis of Fire Resistance Requirements. Porirua, New Zealand) provides a detailed discussion and analysis of the fire resistance requirements prescribed in New Zealand, for buildings of all materials, with no special attention to mass timber. The report includes a comparison of international requirements identifying that those in New Zealand are lower compared with other jurisdictions.

Storeys	New Zealand		USA		Australia		Canada		England**	
	With sprinklers	Without sprinklers	With sprinklers	Without sprinklers	With sprinklers	Without sprinklers	With sprinklers	Without sprinklers	With sprinklers	Without sprinklers
20	30		180		90		120		120	
19	30		180		90		120		120	
18	30		180		90		120		120	
17	30		180		90		120		120	
16	30		180		90		120		120	
15	30		180		90		120		120	
14	30		180		90		120		120	
13	30		180		90		120		120	
12	30		120		90		120		120	
11	30		120		90		120		120	
10	30		120		90		120		120	
9	30	60	120		90		120		90	
8	30	60	120		90		120		90	
7	30	60	120		90		120		90	
6	30	60	60		90		60		60	
5	30	60	60		90		60		60	
4	30	60	60		90		60		60	60
3	30	60	0*		90	90	45	45	60	60
2	30	60	0*		90	90	45	45	30	30
1	0*	0*	0*	§	0*	0*	0*	0*	0*	0*
	FRR	FRR	FRR	FRR	FRR	FRR	FRR	FRR	FRR	FRR

§ International Residential Code can be used for one and two-family dwellings and townhouses up to 3 storeys without fire sprinklers.
* FRR may be required to protect tenancies and egress routes, or to limit fire spread across boundaries.
** Approved Document B only applies to 'common building situations' and may not apply to some buildings with a combustible structure.

Key:

- Combustible materials generally permitted.
- Fire-protected timber (typically requires two layers of fire grade plasterboard).
- Fire-protected timber (limited areas of wood can be exposed on walls and ceiling).
- Non-combustible materials required.
- Primary structure can be combustible, except external wall (unless proven by test).
- Primary structure can be combustible except external wall.

Figure 2. Fire resistance requirements for New Zealand and four other countries (Wade, C and Frank, K. (2021). Fire safety in multi-storey apartments. BUILD 186)

4.2.3 European guideline

[Nothing to add]

4.3 National and regional differences for the use of wood

This section in the Global Design Guide focuses on residential buildings. Based on the use of timber in New Zealand, the commentary here on surface finishes and structural members is applicable to many other building types.

In New Zealand, Timber Unlimited publishes additional guides with information on things like:

- Trees, Timber, Species & Properties
- Timber, Carbon & the Environment

Radiata pine is the most common used type of timber in New Zealand making up 90% of all sawn timber products. This is followed by Douglas fir at 5% and all other hardwood and softwood species that make up the remaining 5%.

Radiata pine is valued for its versatility and can be used for framing, flooring, decking, cladding, and other structural elements in buildings including mass timber elements. Radiata pine typically has a straight grain which makes it easier to work with and contributes to its stability and uniform appearance when used for structural purposes. Radiata pine requires treatment to enhance its durability and resistance to decay and insects for outdoor use.

The burning characteristics of radiata pine are similar to other softwoods: it is relatively easy to ignite and burns at a moderate rate with a moderate amount of smoke. The density of the timber product influences its burning behaviour, including the rate at which it chars. Higher densities lead to lower charring rates. Some design standards and textbooks contain single published values to be used for the density of softwoods with certain equations. Care must be taken when applying these values outside of the applications they were intended for as they may not consider all factors.

BRANZ previously conducted a study looking at the volume of timber content in a typical building and forecasts for 2030. This study found that, across all building types, stand-alone houses, townhouses, and apartments had the largest amount of timber used per floor area of the building and that this is projected to increase by 50% for these buildings between 2020 and 2030. If the timber members were also exposed to a fire in the building, this would comprise a significant portion of the fuel load.

4.3.1 Residential buildings

All buildings have mixes of materials including timber, steel, and concrete. However, approximately 90% of all residential housing in New Zealand is constructed primarily using light timber structural framing. These buildings are typical designed and constructed in accordance with NZS 3604 “Timber-framed buildings”. This standard is widely used in New Zealand’s construction industry. It provides specifications and guidelines for timber-framed houses and small buildings and is cited as part of Acceptable Solution B1/AS1. This standard does not contain any specific requirements for addressing fire safety (or many other aspects of compliance with the Building Code) and there are no specific requirements for the fire protection of timber elements. As a consequence, the standard is generally read in combination with both B1/AS1 and the acceptable solutions for Protection from Fire C/AS1 and C/AS2.

Load-bearing timber elements

This section is a brief summary of the information in Chapter 1 and Chapter 7. Radiata pine has good strength properties with tensile, compressive, and bending strength suitable for structural applications. Structural timber is graded according to its stiffness and strength to meet the performance requirements in the Building Code. The most common type of structural timber is solid timber products such as framing components, rafters and floor joists. Structural load-bearing members can also be engineered wood products such as glue-laminated timber (glulam), laminated veneer lumber (LVL), and cross laminated timber (CLT).

For the structural design of larger buildings outside the scope of NZS 3604, Verification Method B1/VM1 currently cites NZS 3603 “Timber structures standard”. This standard is intended to be replaced by both NZS AS 1720.1 “Timber Structures” and AS/NZS 1720.4 “Timber structures – Part 4: Fire resistance of timber elements”.

Structural timber may be protected with non-combustible or limited combustible materials that delay or prevent heating and the onset of charring in the wood. The structural elements, along with the protective linings, combine to form a building element that has a fire resistance rating. The Acceptable Solutions C/AS1 and C/AS2 and Verification Method C/VM2 all contain requirements for the minimum fire resistance rating of different building elements in different applications.

The fire resistance rating is generally specified in New Zealand with three numbers (i.e. 60/60/60) which indicate the overall performance of the system in terms of structural adequacy, integrity, and insulation, respectively. AS/NZS 1720.4 contains specific fire design requirements for calculating the structural adequacy and insulation components of the fire resistance rating for various timber members using a charring rate and depth of char. It should be noted that AS/NZS 1720.4: 2019 does not permit the full specification of a fire resistance rating by calculation (i.e. an integrity rating). This rating would need to be supplemented by data from other sources such fire testing to AS 1530.4 "Methods for fire tests on building materials, components and structures — Part 4 Fire resistance tests of elements of construction".

Visible wood surfaces

This section is a brief summary of the information in Chapter 5. Timber can be used as internal decorative linings or part of an external cladding system. Clause C3.4 of the Building Code contains limitations on the surface finish for different building elements which primarily address the risk of fire spread from a fire source to other parts of a building. This clause contains a table of material group numbers required for walls and floors along with additional restrictions on floor coverings and flexible fabrics and membranes. Material group numbers can be determined through fire testing. The stringency of the requirement varies depending on the use of the building along with whether the building is protected with sprinklers or not. There are limited requirements for surface finishes in some parts of residential buildings.

The requirements for surface finishes have been similarly provided in the acceptable solutions and verification methods for Protection from fire with some additional considerations in these documents of the test standards and circumstances that can be treated as complying with these requirements.

There are additional performance criteria (C3.5 and C3.7) that relate to external vertical and horizontal fire spread. These may dictate the type of materials that can be included as part of the external cladding system of a building. C/AS2 and C/VM2 contain options for demonstrating compliance through fire testing of external cladding systems and MBIE also published guidance on the fire performance of external wall cladding systems. The use of timber as a cladding material is generally limited to low-risk weather-tightness applications, which are permitted under Acceptable Solution E2/AS1.

For existing heritage, cultural, or historic buildings, it may be challenging to demonstrate compliance with the requirements in C3.4, C3.5 or C3.7. In these circumstances, it may be appropriate to consider a waiver or modification of the Building Code as a special dispensation for the use of timber interior or exterior linings, wood carvings, or exposed timber structural members. These would need to be reviewed on a case-by-case basis by the territorial authority. The application for a waiver or modification and fire design documentation would still have to address how the Building Act purposes and principles and how the building design enables people to escape if it is on fire, protect firefighters, and limits the spread of fire.

4.3.2 Office buildings

[Nothing to add]

4.3.3 Differences between European countries

[Nothing to add]

4.4 Conclusions

[Nothing to add]

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Chapter 5
Reaction to fire performance

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5. Reaction to fire performance

Scope of chapter

This Chapter presents further information for New Zealand practitioners to supplement the content of Chapter 5 of the Global Design Guide. It presents an overview of the relevant reaction to fire test methods and elaborates on their application in New Zealand.

This chapter is complementary to Chapter 5 of the Global Design Guide, which should be read alongside this document.

5.1 Wood products used as interior finish to a wall, ceiling or floor

Important – where areas of exposed wood are included in a building design and are assessed for their contribution to the fuel load as described in Chapter 3 of the Global Design Guide or in the Supplement in Appendix A (for example by following the prescriptive recommendations of Table 1 of the Supplement in Appendix A) it is also necessary for that exposed wood to satisfy the surface finish requirements of the New Zealand Building Code (NZBC) Clause C3.4.

This means complying with the NZBC maximum group number requirement for surfaces of ceilings and walls, or a minimum critical radiant flux for exposed flooring material. In some circumstances, for example where a Group Number 1 or 2 is required, it may be necessary to use a coating, protection or fire-retardant treatment on the exposed wood to achieve the required Group Number, regardless of the provisions of Table 1 of the Supplement or the outcome of engineering char depth calculations.

While Chapter 5 of the Global Design Guide (and this commentary) is primarily concerned with the reaction to fire performance of wood products, there are two other reasons why protective materials or coatings might be applied to wood products to improve fire performance. They are:

1. To reduce the amount of char contributing to the fuel load (see Chapter 3 "Fire dynamics"); and
2. To increase the fire resistance rating (see Chapter 6 "Fire-separating assemblies" and Chapter 7 "Load-bearing timber structures").

5.1.1 Sawn timber

[Nothing to add to the Global Design Guide]

5.1.2 Panel products

[Nothing to add]

5.1.3 Engineered structural wood products

See Chapter 1 for a description of the types of timber products and timber structures used in New Zealand.

5.2 Assessing reaction to fire performance of wood products for compliance with prescriptive regulations

5.2.1 Wall and ceiling linings

Required Group Numbers in NZBC

The Performance requirements for wall and ceiling linings are given in Clause 3.4(a) of the NZBC, and also in Table 4.3 of C/AS2 (MBIE, 2023a). Group Numbers are specified to limit the potential for rapid surface flame spread over the combustible surface of lining materials. Group Numbers range from 1 (best) to 4 (worst). The required maximum Group Number depends on the use of the space in the building and if fire sprinklers are installed.

Because the Group Number requirements are in Clause 3.4 (a) of the NZBC, rather than in supporting documents, they are mandatory requirements and cannot be varied using performance-based design.

In some cases, there also may be a smoke production limitation indicated where "-S" is appended to the Group Number. This is only a requirement when sprinklers are not installed and a Group Number less than 3 is required as shown in Table 1 (reproduced from C/AS2 Table 4.3).

Table 1. **C/AS2 Table 4.3 – Internal surface finishes** (© Ministry of Business, Innovation and Employment 2023. This table is protected by Crown copyright and reproduced from building.govt.nz under the Creative Commons Attribution (CC-BY) 4.0 International Licence)

Table 4.3	**Internal surface finishes** Paragraph 4.17				
Fire protection	**Maximum permitted Group Number**				
	Exitways and Importance Level 4 buildings: walls and ceilings	**Sleeping spaces where care or detention is provided: walls and ceilings**	**Other sleeping spaces (excluding within household units) and crowd spaces: ceiling surfaces**	**Other sleeping spaces (excluding within household units) and crowd spaces: wall surfaces**	**All other occupied spaces: walls and ceilings**
Unsprinklered	1-S	1-S	2-S	2-S	3
Sprinklered	2	2	2	3	3

Group Number requirements do not apply to the following items (see C/AS2 Paragraph 4.17.6 for a complete list):

- Handrails and general decorative trim of any material such as architraves, skirtings and window components, including reveals, provided these do not exceed 5% of the surface area of the wall or ceiling they are part of
- Timber joinery and structural timber building elements constructed from solid wood, glulam or laminated veneer lumber. This exception includes heavy timber columns, beams, portals and shear walls not more than 3.0 m wide, but does not include exposed timber panels or permanent formwork exposed on the underside of floor/ ceiling systems
- Individual doorsets
- Small areas of non-conforming product within a firecell with a total aggregate surface area not more than 5.0 m².

Most wood products are not able to achieve a Group Number 1 or 2 unless they have a fire-retardant treatment or coating (see photograph in Figure 1).

Figure 1. **Exposed timber wall linings in non-sprinklered crowd use spaces may require a fire-retardant treatment (Credit: E. Claridge)**

Figure 2. **Timber wall and ceiling linings within safe path stairwells may require a fire-retardant treatment (Credit: E. Claridge)**

Additional recommendations for safe path stair enclosures and lift shafts with firefighter lift control

To provide additional robustness to single vertical escape routes and for fire fighter protection, the following additional recommendations apply:

- If mass timber is exposed on the inside surfaces of lift shafts and stairwells, it is recommended that spaces are sprinkler-protected, even when not explicitly required by C/AS2. The surface finish materials are required to comply with NZBC Clause C3.4(a). See photograph in Figure 2.
- For single-stairway buildings with an escape heights > 18 m (sprinklered) or > 10 m (unsprinklered) it is recommended that the outside surface of mass timber walls around the stairwell be encapsulated.

Determining Group Numbers – deemed-to-comply solution

Solid wood or wood products can be deemed to have a Group Number 3 in accordance with C/AS2 Table C1.2 provided that:

- The wood or wood product is not less than 9 mm thick; and
- The density is not less than 400 kg/m³ (or not less than 600 kg/m³ in the case of particle boards).

Most wood products used in New Zealand meet these requirements.

Water-borne or solvent-borne coatings, varnish or stain can be applied to wood or wood products with a deemed-to-comply Group Number 3, provided the applied coating is not more than 0.4 mm thick and not more than 100 g/m², and the wood or wood products satisfy the thickness and density limitations given above.

These provisions can also be assumed to apply to CLT, plywood and similar wood products provided that glue lines are not exposed at the surface.

If the above provisions are not met, then the Group Number must be determined based on fire testing. Product supplier literature should be consulted for the appropriate Group Number and associated documentation or certification.

Approved test methods include:

- ISO 5660 Part 1 and 2 (ISO, 2002a, 2002b)
- ISO 9705 (ISO, 1993)

Determining Group Numbers – using AS ISO 9705 or EN 13501–1

Following the advice in Table C1.1 of C/AS2, wood products (including coatings if any) that have received certification in accordance with the Australian National Construction Code (NCC) Specification C1.10 Clause 4 using AS ISO 9705, or a European classification according to BS EN 13501–1 (BSI, 2018) can be assigned a deemed-to-comply New Zealand Group Number, by equivalent, as follows:

European classification to EN 13501–1	NCC Spec. Group Number	NZ Group Number
Class A1, Class A2	1 and SMOGRA ≤ 100	1–S
Class B-s1–d0, Class B-s2–d0	1 and SMOGRA ≤ 100	1–S
Class B-s3–d0	1	1
Class C-s1–d0, Class C-s2–d0	2 and SMOGRA ≤ 100	2–S
Class C-s3–d0	2	2
Class D	3	3

It is noted that in NCC 2022, Specification C1.10 Clause 4 has been revised to become Specification 7 (Fire hazard properties), Clause S7C4 (Wall and ceiling linings) which references a Group Number determined in accordance with AS 5637.1:2015 Determination of fire hazard properties—Wall and ceiling linings (Standards Australia, 2015).

Determining Group Numbers – using AS/NZS 3837

Group Numbers for wood products (incorporating any coatings) determined by testing to AS/NZS 3837 can be assigned Group Numbers for New Zealand use by an Accredited Test Laboratory or other qualified expert following the procedures and equations in AS 5637.1 or in C/VM2 Appendix A (MBIE, 2023b). There is a difference in the end of test criteria in AS/NZS 3837 and ISO 5660.1 that may affect the Group Number assignment.

5.2.2 Floor coverings

Required Critical Radiant Flux as per NZBC

The Performance requirements for floor surface materials are given in Clause 3.4(b) of the NZBC, and also in Table 4.5 of C/AS2. Reaction to fire properties of flooring are based on the fire test ISO 9239–1:2010 (ISO, 2010) where a Critical Radiant Flux (CRF) is determined. The smaller the CRF value (in kW/m²) the easier the flooring can be ignited and the faster is the potential rate of flame spread.

The minimum permitted CRF for a given risk group and location within the building is summarised in Table 2 (C/AS2 Table 4.5). Therefore, a flooring material that has the CRF value shown or a higher CRF value is permitted for the specified risk group and location.

Table 2. C/AS2 Table 4.5 – Critical radiant flux requirements for flooring (© Ministry of Business, Innovation and Employment 2023. This table is protected by Crown copyright and reproduced from building.govt.nz under the Creative Commons Attribution (CC-BY) 4.0 International Licence)

Table 4.5	Critical radiant flux requirements for flooring (kW/m²) Paragraph 4.17.3					
Risk group	Area of building					
	Exitways in all buildings and sleeping areas and treatment rooms in risk group SM, SI		Non-sleeping firecells accommodating more than 50 people		All other occupied spaces, other than household units	
	Sprinklered	Unsprinklered	Sprinklered	Unsprinklered	Sprinklered	Unsprinklered
SM	2.2	2.2	1.2	2.2	1.2	1.2
SI	2.2	4.5	1.2		1.2	
CA	2.2	2.2	1.2	2.2	1.2	1.2
WB	2.2	2.2	1.2	2.2	1.2	1.2
WS	2.2		1.2		1.2	
VP	2.2	2.2	1.2	2.2	1.2	1.2

Determining CRF – deemed-to-comply solution

Wood products, plywood or solid timber can be deemed to have a CRF of 2.2 kW/m² in accordance with C/VM2 Appendix B Table B1 provided that:

- The wood or wood product is not less than 12 mm thick; and
- The density is not less than 400kg/m³
- Applied surface coatings (if any) are not more than 0.4 mm thick and not more than 100g/m².

If the above provisions are not met, then the CRF must be determined based on approved testing, and product supplier literature should be consulted for the CRF achieved and associated documentation or certification. The approved test method is ISO 9239–1:2010.

It is also important to be cognisant of the floor covering/substrate combination that proprietary testing is based on, to ensure it is applicable to the building being assessed. Specifically, the thickness of the substrate can affect ignition and fire growth.

5.2.3 Roofing

There is currently no reaction to fire requirement in New Zealand for the exterior surfaces of roof coverings.

An internally exposed mass timber roof should be treated the same as a ceiling in terms of applying the relevant ceiling surface finish requirement.

5.2.4 Façade Claddings

Timber products used as an external wall cladding material located less than 1 m from a relevant boundary or in a multi-level building with a building height of 10 m to 25 m are required to achieve a Type A classification when tested as described in C/AS2 Appendix C, C7.1. The fire test method specified is ISO 5660-1 or AS/NZS 3837. To achieve this performance timber cladding will typically require a fire-retardant treatment. See Section 5.4 below.

In addition to the external wall cladding material, consideration should also be given to other external surfaces such as soffits, balustrade materials and components of the external wall system such as rigid air barriers, building wraps and insulation. It is advisable to ensure that these materials also meet the same fire performance as required for the external wall cladding material – refer to MBIE guidance (MBIE, 2020).

Where timber products are used as part of an external wall cladding system for a multi-level building with a building height ≥ 25 m, a large-scale façade fire test such as BS 8414 is required as described in C/AS2 Paragraph 5.8.4.

Discussion on use of cavity barriers within external wall systems is covered in Chapter 9.

5.3 Reaction to fire characteristics of wood products for performance-based design

While Section 5.3 of the Global Design Guide provides typical reaction to fire characteristics that can be used to predict time to ignition, rate of surface spread of flame, heat release rate, mass loss rate and generation rate of smoke and toxic combustion products, designers should be aware that performance-based design undertaken with the purpose of demonstrating compliance with Clause 3.4 (a) and (b) of the NZBC requires a Group Number or CRF assessment in accordance with standard fire test methods and flame spread calculations from first principles are likely to have very limited application.

5.3.1 Ignitability

[Nothing to add]

5.3.2 Surface spread of flame

[Nothing to add]

5.3.3 Burning rate

[Nothing to add]

5.3.4 Production rate of smoke and toxic products of combustion

[Nothing to add]

5.4 Methods for improving the reaction to fire performance of wood products

5.4.1 Fire retardant treatments including surface coatings

Methods to improve the reaction to fire performance of a wood product without adding a protective or encapsulation board include:

a. Surface coatings, and
b. Impregnated treatments.

The appropriate solution may depend on where the product is located (e.g. interior or exterior use with the associated durability requirements) and whether a transparent or opaque finish is desired.

Surface coatings used for the purpose of reducing the Group Number of a wall or ceiling lining are most commonly intumescent coatings and can be either a clear or an opaque coating. Intumescent coating solutions for interior timber surfaces are available from several suppliers to provide a Group Number 1 or Group Number 2 performance. There are also surface coatings solutions for exterior cladding products to meet performance for Cladding Type A as given in Table 5.5 of C/AS2. These typically require a specific topcoat and the use of approved applicators to ensure compliance.

Impregnated treatments are increasing in popularity due to their lower maintenance and ability to retain the natural appearance of the timber. These are typically factory-applied or involve off-site treatments. Traditional solutions include use of fire-retardant chemicals which are pressure impregnated into the timber product after manufacture. These products may degrade with time especially in outdoor environments due to migration and leaching of the fire-retardant chemical toward the surface. This is less of a concern for dry, interior environments. Alternative non-hydroscopic polymer fire-retardant treatments provide durable solutions for exterior as well as interior use.

Fire-retardant products based on impregnated treatments are available that include:

- Polymer fire-retardant treatments for interior and external use
- Wood composite cladding with the inclusion of a fire retardant in the extrusion process

Care is required to make sure the product is suitable for the location and environment (e.g., exterior/interior, humidity levels, etc.) where it is to be used.

It is important to note that fire retardant timber treatments to improve reaction to fire properties do not make the product non-combustible. While the fire performance in growing and developing fires can be improved, and in some cases a slower charring rate in larger fires, fire retardant timber is still a combustible material and is a potential source of additional fire load and toxic fumes.

5.4.2 Durability of reaction to fire performance

Methods for determining the reaction to fire properties of external wall cladding systems for New Zealand are given in C/AS2 – Appendix C – Test Methods, Clause C7.1. Where a Type A or B classification is required, Clause C7.1.3 requires timber claddings which have a fire-retardant treatment incorporated in or applied to them to be subjected to the regime of accelerated weathering described in ASTM D 2898 Method B with the water flow rate from Method A. This is to be done before fire testing (C7.1.1) to determine the Type classification (C7.1.2).

It should not be assumed that compliance with the fire testing protocols set out in C/AS2 and C/VM2 is necessarily sufficient to satisfy NZBC Clause B2 for the minimum durability periods building elements must meet in relation to their fire performance. The product suppliers should be consulted for further advice.

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Chapter 6
Fire-separating assemblies

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6. Fire-separating assemblies

Scope of chapter

This chapter discusses the background to fire-separating assemblies and application of protective materials for mass timber construction currently available in New Zealand. Fire-separating assemblies provide essential compartmentation, which limits fire spread, contributing to both life safety and property protection in any building type. The chapter discusses design recommendations for providing fire resistance to timber- and wood-based separating assemblies, including walls, floors and roofs including considerations specific to the use of combustible building materials that can also provide resistance to fire spread.

Chapter 9 deals with fire spread mechanisms and includes specific detail on penetrations and the prevention of fire spread within timber structures and externally.

This chapter is complementary to Chapter 6 of the Global Design Guide, which should be read alongside this document.

6.1 Introduction

Fire-separating assemblies and the concept of firecell separation (or fire compartmentation) are intended to prevent the spread of fire from the firecell of fire origin, to another firecell within the building, or to neighbouring buildings. Typically, the fire safety strategy for any building will include the provision of fire-separating assemblies to reduce the probability of fires spreading to other floors in the building, to protect the means of occupant egress and fire fighter ingress and to protect other property. Fire-separating assemblies are also typically used to separate areas of higher fire hazard and to provide protection to other areas in a building for the purposes of property protection and for example, the protection of hazardous substances. Insurance and other requirements such as business continuity requirements may also stipulate that fire-separating assemblies be provided.

Clause C3 of the Building Code provides for *Fire Affecting Areas Beyond The Fire Source* and includes specific Functional Requirements that amongst other things include that:

> C3.1 *Buildings must be designed and constructed so that there is a low probability of injury or illness to persons not in close proximity to a fire source.*

A Fire Resistance Rating (FRR) as used within the New Zealand acceptable solutions is defined as:

> *The term used to describe the minimum fire resistance required of primary and secondary elements as determined in the standard test for fire resistance, or in accordance with a specific calculation method verified by experimental data from standard fire resistance tests. It comprises three numbers giving the time in minutes for which each of the criteria structural adequacy, integrity and insulation are satisfied, and is presented always in that order. There are two types of FRR: life rating and property rating.*

A Life Rating is defined as:

> *The fire resistance rating to be applied to elements of construction that allows movement of people from their location in a building to a safe place.*

A Property Rating is defined as:

> *The fire resistance rating to be applied to elements of construction that allows for protection of other property.*

The three criteria are expressed as X/X/X, where the X is time given in minutes with examples such as 30/30/30 or 60/60/60.

6.2 Basic requirements for fire-separating assemblies

[Nothing to add to the Global Design Guide]

6.3 Encapsulation

There are no specific standards in New Zealand which define encapsulation of timber for the purposes of fire protection or testing procedures. For the purposes of this commentary encapsulation is defined as either full or partial encapsulation as follows:

Full encapsulation

> *Full encapsulation will ensure that there is no significant charring which could add to the fuel load or reduce structural performance for the full duration of the design fire.*

Partial encapsulation

> *Partial encapsulation is protection not sufficient to provide full encapsulation. Partial encapsulation will mitigate surface flame spread and provide a delay to the onset of charring, but it may not prevent charring of the underlying timber later in the fire.*

Manufacturers of timber products publish fire resistance ratings based on standard fire resistance testing for both bare timber, and timber protected with various products such as gypsum plasterboard or intumescent coatings.

A number of fire system manufacturers have also published test results for systems used to encapsulate and protect timber substrates for various time periods, using the standard fire resistance test. Test results may show a limiting interface temperature between the protective material and timber surface, or no charring at cessation of the test.

Figure 1 shows the result of a fire test on a CLT sample protected by fire rated gypsum plasterboard. After 60 minutes of exposure to the standard fire resistance test, no charring was observed when protected by two layers of 13 mm plasterboard, with substantive charring observed when only a single 13 mm layer of plasterboard was used.

Figure 2 shows the behaviour of a CLT panel, viewed from inside the furnace, with the left section of the panel protected with an intumescent coating compared to the flaming bare timber surface.

Figure 1. **Encapsulated CLT tested for 60 minutes with 2 layers of 13 mm FR plasterboard (left) and 1 layer of 13 mm FR Plasterboard (right) (Credit: Fire TS Laboratory)**

Figure 2. **Inside the furnace of a CLT test, Intumescent coating (left) and non-encapsulated (right) (Credit: Fire TS Laboratory)**

Charring of timber occurs over a range of temperatures typically accepted to be between 250°C to 380°C. Guidelines published by FPInnovations (Ranger et al., 2019) describes the Canadian testing standard CAN/ULC-S146 (SCC, 2019) which limits the average temperature increase of the timber surface to no more than 250 °C, or 270 °C at any individual point after 50 minutes of standard fire exposure. European standards typically recognise a 300 °C criterion. Testing in New Zealand and Australia typically adopts a maximum temperature criterion of 300°C for the period of the fire resistance rating.

Figure 3 shows an example of an encapsulation system for a CLT floor with topside and underside protection (NZ Wood Design Guide, Acoustics, 2020).

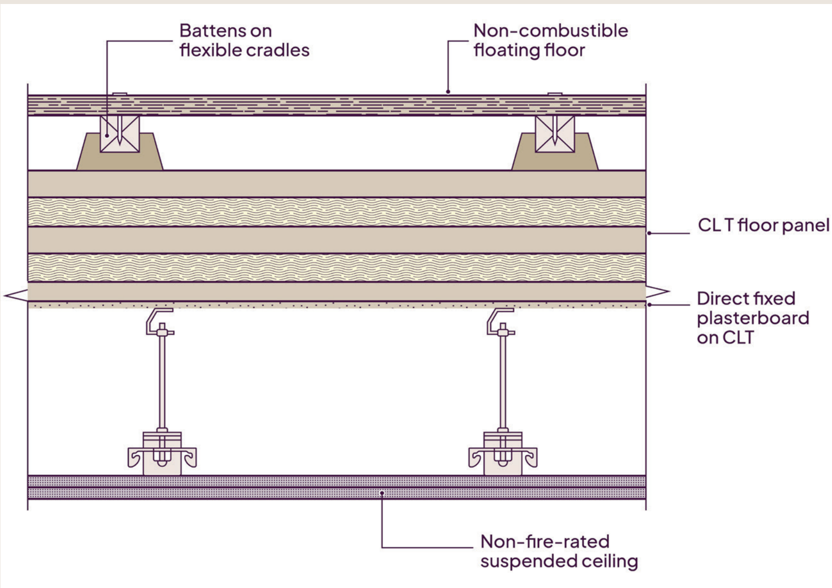

Figure 3. **Encapsulation system for CLT floor showing topside protection using non-combustible floating floor system and underside protection using both direct fix and battened plasterboard ceiling systems**

Section 6.3 of the Global Design Guide provides specific discussion on the various methods adopted, and some of which are discussed further below.

Some manufacturers of lining materials refer to "one-way" and "two-way" fire resistance ratings of light timber frame walls, which can be confusing. In most cases, a "two-way" rating refers to a symmetrical wall assembly which can be exposed to fire from either of the two sides, but not at the same time. A "one-way" rating refers to a wall which is only designed for fire exposure from one side only, such that there is sufficient thickness of lining to prevent any charring of the surface of the timber studs for the fire resistance period. If used in this way, the "one-way" rating becomes an encapsulation rating.

6.4 Fire-separating assemblies

New Zealand shares a number of fire testing standards with Australia and also has specific test standards that include New Zealand specific requirements that may differ from those in Australia and other parts of the world. There are no fire test standards referenced directly within the New Zealand Building Code with the exception of surface lining classification standards. New Zealand currently cites fire test standards within both the BS 476 and AS 1530 series for the determination of fire resistance, as listed in Section 6.4.1.

6.4.1 Methods for determining the fire resistance of separating assemblies

AS 1530.4 [Standards Australia, 2005a] is the primary fire resistance testing standard in the fire safety acceptable solutions C/AS1, C/AS2 (MBIE, 2023a) and Verification Method C/VM2 (MBIE 2023b). NZS/BS 476 parts 21 (Load-bearing structures) and 22 (Non-load-bearing structures) are also currently cited (SNZ, 1987), however, part 20 (General principles) is not directly cited.

6.4.2 Classifications based on fire testing

AS 1530.4

AS 1530.4 provides methods for determining the fire resistance of various elements of construction when subjected to standard fire exposure. It provides a set of uniform requirements for heating conditions, test procedures, and failure criteria. It is based on a representative specimen of an element of construction being exposed to heat under controlled conditions in a furnace, which is operated with a specified time-temperature curve. Observations are made on the performance of the specimen while it is subjected to thermal and, where applicable, physical loading. The standard includes specific sections for different elements of construction such as walls, floors, columns, doorsets and service penetrations. Figure 4 shows a fire resistance test of a timber floor in progress, and Figure 6 shows structural collapse, some time after the failure criteria have been met.

The current NZBC acceptable solutions and verification method reference the 2005 version of AS 1530.4 although the 2014 version has been in use for some time. Whilst there are differences between the two standards, the 2014 version is generally accepted for compliance purposes, with all recent testing using this version.

AS 1530.4 Failure Criteria

Failure criteria are defined in section 2 of AS 1530.4.

The structural adequacy criterion (X/-/-) is reached when collapse has occurred or specific contraction or deflection limits have been exceeded. Load-bearing timber assemblies and further discussion relating to structural adequacy are presented in Chapters 7 and 8.

In some countries, specific criteria or visual observations are required to assess smoke leakage through assemblies. In New Zealand, AS 1530.4 provides no failure criteria for smoke leakage, specifically referring to tests specified in AS 1530.7 which are not cited in the acceptable solutions and verification method.

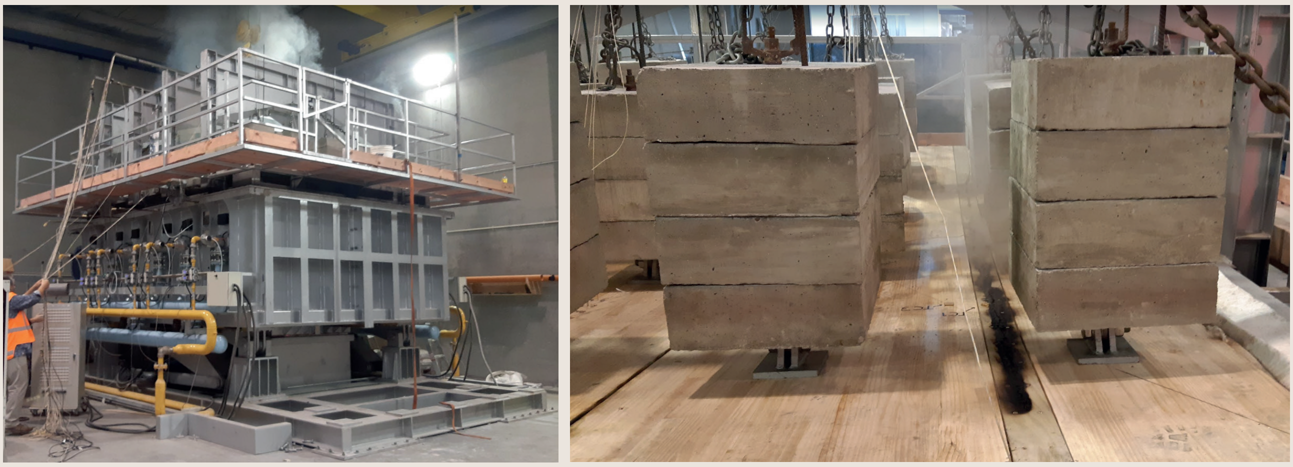

Figure 4. **AS1530.4 Fire test of a loaded timber floor. Concrete blocks used for loading the floor during the test (Credit: Fire TS Laboratory)**

In AS 1530.4, the integrity criterion (-/X/-) is measured using a cotton pad, gap gauges or where sustained flaming occurs. Integrity failure is deemed to have occurred upon ignition (glowing or flaming) of the cotton pad.

The photos in Figure 5 show integrity failures in a CLT slab subjected to standard fire testing. Note that these failures occurred in locations away from thermocouples.

Figure 5. **Integrity failures in an encapsulated 105 mm thick CLT non-loaded slab at 110 minutes (Credit: Fire TS Laboratory / E. Claridge)**

For uninsulated assemblies, integrity failure is deemed to occur when a 6 mm gap gauge can be passed through the specimen so that the gap gauge projects into the furnace and can be moved a distance of 150 mm along the gap; or a 25 mm gap gauge can be passed through the specimen so that the gap gauge projects into the furnace. Sustained flaming is considered as failure when it is observed on the unexposed surface for 10 seconds or longer.

The insulation criterion (-/-/X) is met where the average temperature rise, as measured by standard thermocouples placed on the non-exposed surface, is limited to 140 °C, and the maximum temperature rise at any point (or thermocouple) on that surface does not exceed 180 °C.

Timber has a low conductive heat transfer and as such insulates well. Thermocouples embedded within timber may not provide a good indication of temperature profiles through the timber if char fall off and delamination occur remote from the thermocouples. Because charring and burn through can be affected by gaps, joints and inconsistencies within the timber assembly, burn through and increased charring in these locations may not be found if thermocouples are not located close to these points of interest or if average temperatures are used.

AS 1530.4 notes that the radiant heat transfer from uninsulated specimens is likely to be sufficient to cause unpiloted ignition of the cotton pad and, therefore, the cotton pad use is not considered appropriate, and that fire spread due to radiant heat transfer could occur prior to the stated integrity period for uninsulated specimens.

It is noted that Australia has additional insulation criteria for floors and ceilings referred to as "Resistance to the incipient spread of fire" which requires a higher standard of heat insulation, applicable in those configurations where the ceiling is the primary separating element between firecells. This is in recognition that is certain situations such as within roof spaces and within cavities, the temperature rise of materials in these spaces needs to be limited to a level which will not permit fire spread. The failure criterion adopted for these applications is a maximum rise of 250°C.

Figure 6. **Structural collapse of a timber floor during testing, after failure criteria have been met (Credit: Fire TS Laboratory)**

Equivalence to overseas testing methods

There are many similarities and a few differences between the main standards used in different countries.

Reference to NZS/BS 476 series of standards still remain in the NZBC acceptable solutions, but these have been considered for removal in future editions. BS 476 has not been updated since 1987 and has been replaced with more modern equivalents internationally, such as European Standard EN 1365.

Minor differences exist between BS 476, EN 1365, and AS 1530.4, but all three testing standards are essentially the same, so that testing in accordance with one is accepted in most other jurisdictions.

Standard Heating Conditions

AS 1530.4, as with many international fire resistance testing standards (BS 476–20, EN 1363–1, ISO 834–1) uses standard heating conditions also known as the standard time-temperature fire curve as defined by:

$$T = 345 \log_{10}(8t + 1) + 20$$

where

T = furnace temperature at time (t), in degrees centigrade

t = time into the test, measured from the ignition of the furnace, in minutes

This time-temperature curve is shown in Figure 7 along with the hydrocarbon fire and the external fire, neither of which are often used in New Zealand. Figure 7 also shows the slightly different ASTM E119 time-temperature curve which is used in North America.

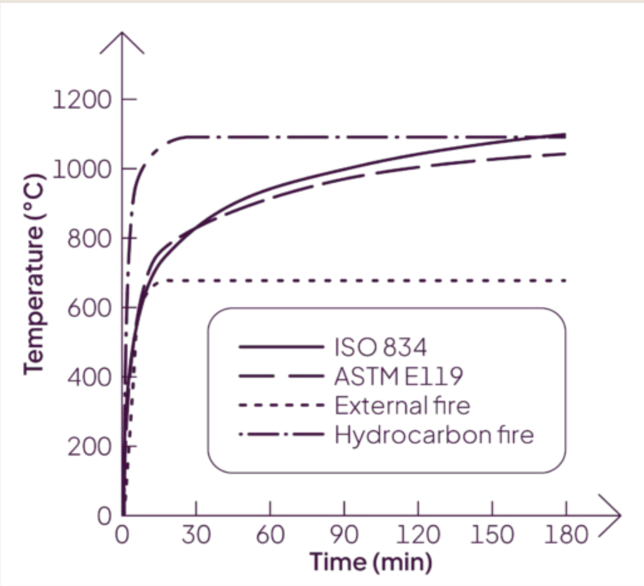

Figure 7. **Time temperature curves for fire resistance testing**

6.4.3 Tabulated design data

The NZBC Acceptable Solutions C/AS1 (MBIE 2023c) and C/AS2 (MBIE, 2023a) prescribe fire resistance ratings (FRRs) whereas the Verification Method C/VM2 provides different approaches for calculating the required fire resistance rating.

C/AS1 only applies to stand-alone houses, townhouses of not more than one household unit located above another with a maximum escape height of 4 m. In C/AS1, the prescribed FRR is 30 minutes for both life and property ratings. This value does not change with the size or complexity of the building or if a sprinkler system is provided. The good historical performance of light timber frame construction means that there are currently no additional requirements for these low-rise buildings if they are constructed using mass timber.

C/AS2 prescribes FRR for buildings up to 20 storeys high. The required FRR depends on various factors such as the building risk group and whether the building is protected with a sprinkler system. Table 1 sets out the prescribed ratings. These values assume, amongst other factors, that there is no intervention from firefighters or sprinklers, and no additional fuel from combustible structural elements.

Table 1. Life and property ratings (Table 2.4 from C/AS2). (© Ministry of Business, Innovation and Employment 2023. This table is protected by Crown copyright and reproduced from building.govt.nz under the Creative Commons Attribution (CC-BY) 4.0 International Licence)

Table 2.4 Life and property ratings in minutes

Risk group	Unsprinklered		Sprinklered	
	Life	Property	Life	Property
SM	60	60	30	30
SI	n/a	n/a	60	60
CA	60[1]	120	30[1]	60
WB	60[1]	120 (180[2])	30[1]	60 (90[2])
WS	n/a	n/a	60[1]	180
VP	60[1]	60	30[3]	30[3]

Notes:

1. When the *escape height* is greater than 10 m the *exitways* shall have *fire separations* with an *FRR* meeting the *property rating* (refer to Paragraph 4.9.2).
2. Where the *building* is less than 15 m to the *relevant boundary* and the storage height is greater than 3.0 m the *FRR* shall be 90 minutes where sprinklered and 180 minutes where unsprinklered.
3. The sprinkler system can be substituted for cross ventilation in accordance with Paragraph 4.1.3.

6.4.4 Simplified calculation methods

[Nothing to add]

6.4.5 Advanced calculation methods

The fire safety verification method C/VM2 MBIE (2023b) is limited to buildings up to 20 storeys high. This design method did not contemplate exposed mass timber construction when it was written. It provides three options for modelling the full burnout design fire:

- Use of a time-equivalence formula
- Using a parametric time versus gas temperature formula, or
- Constructing a Heat Release Rate versus time structural design fire

The first of these three methods is most commonly used. The second is used occasionally in performance-based design, but the third method is seldom used.

For all three methods, Section 2.4 of C/VM2 states that;

> *The 'full burnout design fire' for structural design and for assessing fire resistance of separating elements shall be based on complete burnout of the firecell with no intervention. However, the maximum fire resistance rating for an unsprinklered firecell need not exceed 240/240/240 and 180/180/180 for a sprinklered firecell, determined using AS 1530.4.*
> *The minimum FRR value when using the time-equivalence formula is 20 minutes.*

Table 2.2 of C/VM2 prescribes the Fire Load Energy Density (FLED), which is the fuel load per unit area (MJ/m²), for use in modelling fires, based on fuel load surveys in non-combustible buildings. The method for calculating the FRR assumes, amongst other factors, that complete burnout of the firecell occurs with no intervention from firefighters or sprinklers, and no additional fuel from combustible structural elements. A method to calculate the additional fuel load from a combustible structure is given in Chapter 3.

For buildings outside the scope of the NZBC compliance documents an alternative approach must be used to determine fire resistance ratings. The Fire Engineering Brief (FEB) process as described in the IFEG (ABCB, 2005) is often used to agree proposed approaches and to support an alternative solution to meet the requirements of the Building Code.

6.5 Design of assemblies for compartmentation

Refer to the Global Design Guide for most of these items.

6.5.1 Light timber frame walls and floors

See the Global Design Guide. Almost everything is this section is relevant for New Zealand. A few additions are given here:

Void spaces

Voids and cavities within timber construction present a number of challenges. It is important to be clear which parts of any assembly are part of the fire-separating system. Additional construction not included in the fire resistance test may provide additional shielding of the main construction and present a positive addition to the fire resistance. An example of raised timber flooring over a mass timber floor is shown in Figure 8, provided for additional acoustic performance. In this case the extra layer may increase the fire resistance, but the void may provide a path for unseen spread of fire. The additional timber in the floating floor would also provide further fuel load, which could increase the fire duration. For this reason, floating floors should be constructed with non-combustible flooring panels or be explicitly considered within the fire assessment. Refer also to section 6.5.7.

Consult Chapter 9 for dealing with voids during construction and Chapter 14 for fire fighting challenges.

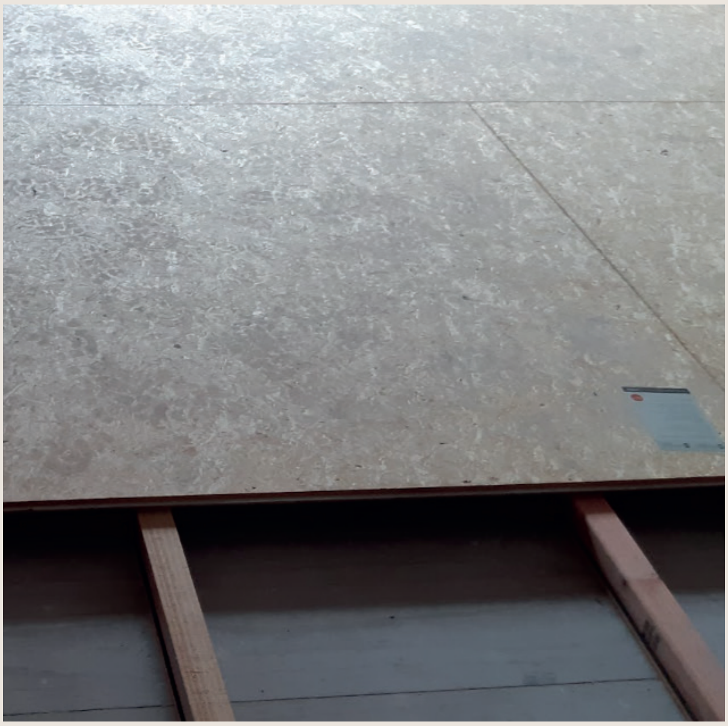

Figure 8. **Raised timber acoustic flooring above a CLT floor**

Figure 9. **Damage to gypsum boards used for encapsulation**

Mechanical impact

Figure 9 shows physical damage to gypsum plasterboard wall lining which could reduce the fire resistance of a light timber framed wall assembly. Mass timber can have benefits of robustness and resistance to such mechanical impact damage, especially where encapsulation is directly fixed to the mass timber element rather than being fastened onto a frame.

Cavity insulation

Most cavity insulation in New Zealand consists of polyester or fibreglass batts, which do not perform as well as mineral wool batts in fire. Polyester batts may contribute to the fuel load whereas fibreglass batts are non-combustible, but glass melts at temperatures around 600 °C, so fibreglass batts provide almost no protection after protective linings fall off. Batts made from organic material such as wood fibre or sheep wool may have similar problems. The best fire performance is from mineral fibre or stone wool batts, as described in Section 6.5.1 of the Global Design Guide.

6.5.2 Mass timber wall and floor panels

[Nothing to add]

6.5.3 Hollow core timber elements

[Nothing to add]

6.5.4 Timber T-beam floors

[Nothing to add]

6.5.5 Gaps during manufacturing and for construction tolerances and shrinkage

Gaps are common in mass timber construction and must be allowed for. There are several different reasons for gaps. They may be gaps within elements due to the manufacturing process of laminated timber products, they may be provided for construction tolerances, or they may occur due to shrinkage movement as the timber dries out. Typically, specimens subjected to fire testing may not have any gaps and may not be representative of those used on site. Increased charring and integrity failures can occur at joints and gaps between lamellae.

Large gaps can be sealed using intumescent or fire-rated acrylic sealants, foam or compressed fire-resistant insulation. The design of joints between timber panels will typically be supported by fire resistance test results, with manufacturers providing standard design approaches to their materials. However, gaps observed on site caused by the construction techniques, formed during the manufacturing process, or due to shrinkage, may need specific consideration, as shown in Figure 10. Refer to Chapter 9 for further information.

Figure 10. **Gaps observed within premanufactured CLT panels after delivery to site (Credit: E. Claridge)**

6.5.6 Hybrid Timber-Concrete-Composite floors

[Nothing to add]

6.5.7 Protection of floors to prevent fire spreading downwards from a fire above

The NZBC fire safety compliance documents only consider fire protection to floors and ceilings from fires occurring below the floor. This concept is shown in Figure 11, reproduced from C/AS2 figure 4.3.

In a BRANZ report, Whiting (2003) considered the impact of fires from above, noting that typical residential construction in New Zealand consisted of 20 mm thick reconstituted wood particleboard on the top surface of timber joists with a paper-faced gypsum plasterboard ceiling on the underside of the joists. Conclusions from this research indicated that for fire resistance ratings of 60 minutes and above fire spread in the downward direction becomes an issue and needs to be explicitly considered, because after 30 minutes of fire exposure a 20 mm particleboard flooring would likely be entirely consumed with the joists being exposed. For mass timber floors, the Supplement in Appendix A requires that the top surface of the floors be protected with non-combustible board material at least 15 mm thick with the aim of delaying the time when the CLT floor might contribute to the fire load.

6.5.8 Openings and penetrations in separating assemblies

[Nothing to add]

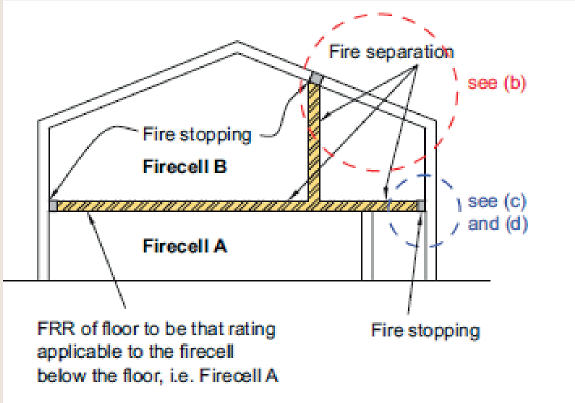

Figure 11. Fire separation of junctions as taken from C/AS2 figure 4.3 (© Ministry of Business, Innovation and Employment 2023. This image is protected by Crown copyright and reproduced from building.govt.nz under the Creative Commons Attribution (CC-BY) 4.0 International Licence)

6.6 Burnout and prescriptive fire resistance ratings

The concept of burnout, application of prescriptive fire resistance ratings and standard fire resistance testing needs careful consideration when applied to the design of timber components. Law and Hadden (2017) identify that '…when combustible structural materials are used, the resulting fire dynamics are no longer independent of the structural design; there is a coupled interaction between the structural and fire engineering design.'. They identify three main concerns which arise when applying the existing building code framework to mass timber designs, including;

1. Current fire-resistance rating requirements do not account for the contribution that a combustible structure makes to the intensity and duration of a fire; consequently, existing fire-resistance requirements do not guarantee structural survival.
2. Current fire-resistance ratings do not guarantee that combustible structural elements will cease to burn once the furnishings are consumed; consequently, existing fire-resistance ratings do not guarantee structural survival.
3. During the standard fire test, the sample properties and contribution of combustion gasses from exposed CLT linings mean that the test does not guarantee equivalent thermal exposure between different construction types.

These concerns are relevant to the New Zealand acceptable solutions and verification method and need to be explicitly dealt with if a timber design includes exposed timber surfaces and an acceptable solution or verification method is to be used as the basis of the design.

As identified in point 3, standard fire resistance testing of timber also poses some concerns with the use of standard time-temperature curves and control of the environment inside of the furnace. Concerns have been raised that the charring rate of timber is lower within a furnace test compared to free burning conditions for a number of reasons including under a pressure controlled and oxygenated environment and control of temperatures that are lower than would otherwise be experienced within a timber lined compartment. As such the use of the hydrocarbon curve in standard fire resistance tests has been proposed to mitigate some of these concerns. However, as the results of larger scale natural fire experiments become available, data from such tests should be able to overcome these concerns.

6.7 Fire-rated suspended ceilings

Many mass timber buildings have suspended ceilings below structural timber floor systems. In most cases, suspended ceilings are not fire-rated, hence they are considered to be non-existent when calculating the separating function or the structural fire resistance of the floor, or when calculating the exposed area of timber contributing to the fire load. It is possible to design and install a fully fire-rated suspended ceiling, but these are expensive and difficult to maintain with penetrations for down-lights, mechanical ventilation or other services. Some providers of fire-resistant lining materials use fire test results to justify the fire performance of suspended ceilings with certain limitations on the number and size of openings.

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Chapter 7
Load-bearing timber structures

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7. Load-bearing timber structures

Scope of chapter

This chapter is complementary to Chapter 7 of the Global Design Guide, which should be read alongside this Commentary.

7.1 General

[Nothing to add to the Global Design Guide]

7.2 Estimation of structural loads

Gravity loads and load combinations for New Zealand design are specified in the New Zealand Building Code document B1/VM1, which refers to the AS/NZS 1170 series. Load combinations for fire conditions are given in in Clause 2.2.4 of B1/VM1 which replaces Clauses 4.2.4 and 6.2.2 of AS/NZS 1170.0.

Clause 2.2.4 of B1/VM1 also specifies a minimum level of lateral load resistance to maintain overall structural stability during and after fire. The lateral load resisting systems that are designed for wind and seismic forces are normally relied on for maintaining structural stability during fire. For most buildings, lateral load resistance after a fire will be greater than during the fire, so no extra checks are required.

Structural stability for lateral loads during fire can be maintained by verification in several different ways, not all giving the same result, by:

1. Ensuring that all elements of the lateral load resisting systems (e.g. as designed for wind and seismic forces) are provided with a fire resistance equal to the highest specified fire resistance rating that applies to the firecell in which they are located, or
2. Arranging lateral load resisting systems and firecell fire separations so that there is always one or more lateral load resisting system located outside of the firecell to provide the minimum level of lateral load resistance. This requires fire separations to provide fire resistance equal to the highest fire resistance rating that applies for each firecell on either side, in order to protect the structure from fire exposure, or
3. Verifying that all elements of lateral load resisting systems can provide the level of lateral load resistance in Clause 2.2.4 of B1/VM1 when exposed to the full effects of a fire. (This type of assessment is carried out in the limiting temperature domain or strength domain, depending on the structural material for the individual element.)

Any external walls that remain free-standing after a fire, whose collapse could endanger firefighters or other property, should be designed for a horizontal face load of 0.5 kPa in accordance with Clause 2.2.4 (b), (iii) of B1/VM1.

7.3 Assessment of fire resistance by testing

[Nothing to add]

7.4 Assessment of fire resistance by calculation

The assessment of structural fire resistance of mass timber in New Zealand depends on the type of timber material being used and the method of calculating the fire severity for the building being designed.

7.4.1 Solid timber, glulam and LVL

Rate of charring

For solid timber, glulam and LVL structural members using New Zealand-grown radiata pine, AS/NZS 1720.4 gives the notional charring rate as 0.65 mm/min. There is some evidence that higher rates have been observed in fire resistance tests, but this document recommends using the rate of 0.65 mm/min until more test results become available.

The notional charring rate in AS/NZS 1720.4 makes no allowance for the reduction in cross-section caused by corner-rounding which was specified in NZS 3603. Following the requirements of Eurocode 5, it is recommended that the notional charring rate of 0.65 mm/min is used directly for plane surfaces, and increased by a factor of 1.07 for members exposed to fire on two or more surfaces with corners, such as timber beams and columns with two or more adjacent exposed surfaces.

Effective residual section

The structural fire resistance is assessed by calculation using the generic methods described in AS/NZS 1720.4, assuming that the effective residual section has ambient-temperature strength properties.

The effective residual section depends on which fire engineering approach is used. There are two possible ways of calculating the effective residual section:

1. For an Acceptable Solution design using C/AS2, the design fire resistance rating is usually specified as 30 or 60 minutes. The effective residual section is the original cross section reduced by the effective depth of charring, which is the product of the notional charring rate and the design fire resistance rating, plus a zero-strength layer.
2. For a Verification Method C/VM2 design using the iterative method from Chapter 3, the output of the calculation is the final char depth for the full burnout design fire. The effective residual section is the original cross section reduced by the final char depth plus a zero-strength layer.

Note that the char depths calculated using these two methods are not equivalent: the final char depth for the full burnout design fire accounts for charring that occurs during the fire decay phase, whereas the char depth time for the equivalent fire resistance rating (Acceptable Solution design) accounts only for charring during the heating phase.

Equivalent fire resistance time

Regardless of the fire engineering method, an equivalent fire resistance rating is often needed for comparison with the standard fire, as used in the standard fire resistance test. There are several different ways of calculating the equivalent fire resistance rating, not all giving the same result:

- For an Acceptable Solution design, the equivalent fire resistance time is the same as the specified design time of 30 or 60 minutes, as applicable.
- The equivalent fire resistance time for timber charring can be calculated by dividing the final char depth from the iterative method by the notional charring rate of 0.65 mm/min.
- The equivalent fire resistance time for design of non-combustible structure (e.g. steel and concrete structural elements) and non-structural elements such as fire doors, partitions, and penetrations can be calculated using the C/VM2 time-equivalence formula, including the additional fuel from burning of exposed wood. This will usually give a lower fire resistance rating than the equivalent value predicted from the char depth.

Details of the iterative method for calculating the char depth are given in Chapter 3. Note that the notional charring rate is needed as an input value. The iterative method requires that internal timber surfaces not exposed to fire are fully encapsulated, because it does not allow for surfaces with partial encapsulation.

Thickness of zero-strength layer

There was no zero-strength layer in NZS 3603. The thickness of the zero-strength layer in AS/NZS 1720.4 is 7.0 mm. It is recommended that this thickness should be increased to the values in the Global Design Guide, Chapter 7, and in Eurocode 5 (prEN 1995–1–2,2023), which prescribe a zero-strength layer of 10 mm for members subjected to bending or tension, and 14 mm for members subjected to compression.

Modification factor for strength and stiffness

For structural fire design, it is recommended that the strength and stiffness of timber be increased by the k_{fi} factor in Table 4.1 of Eurocode 5. This factor is to increase the 5th percentile strength used for ambient temperature design to the 20th percentile strength for fire design. The value of k_{fi} is shown below in Table 1:

Table 1. **Modification factor for strength and stiffness in fire design**

Material	k_{fi}
Structural sawn timber, structural finger-jointed timber	1.25
Glue laminated timber, CLT, wood-based panels	1.15
LVL, block-glued LVL	1.10

7.4.2 Cross-Laminated Timber (CLT)

The above design methods do not generally apply directly to CLT produced in New Zealand and Australia for several reasons:

- CLT manufacturers provide load-span tables for walls and floors, based on the results of full-scale fire resistance tests.
- CLT manufacturers in Australia and New Zealand do not publish char depths from their standard fire resistance tests. This may change in the future.
- For long-duration fires, there may be some falling-off of outer laminations which will increase the rate of charring during fire exposure, depending on the adhesive.

AS/NZS 1720.4 does not refer to CLT, and even if it did, that standard does not allow the use of PUR or melamine-based adhesives which are used for manufacturing most CLT in Australia and New Zealand.

For structural fire design of CLT floors and walls, structural engineers most often use the CLT manufacturer's load-span tables, depending on the fire engineering approach:

- For design using the Acceptable Solution C/AS2, the fire resistance rating is usually specified as 30, 60 or 90 minutes. The published CLT load-span tables can be used directly.
- For design using the full burnout design fire in the Verification Method C/VM2 with the iterative method from Chapter 3, the output of the fire calculation is the final char depth. For structural design using CLT load-span tables, the equivalent fire resistance time for timber charring can be calculated by dividing the calculated final char depth by the notional charring rate. This equivalent fire resistance time can be used to select the appropriate 30, 60, or 90–minute load-span tables.

Note that the iterative method is based on the assumption that no delamination of CLT will occur. This requires that either fire-resistant glue is used, or the glueline temperature is checked to ensure that a critical value (often 200 °C) is not exceeded. The glueline temperature can be calculated using Equation 8.1 in Chapter 8 of the Global Design Guide.

Until load-span tables are published in terms of effective depth of char, for intermediate values of equivalent fire resistance time, CLT manufacturers can expect questions from structural engineers who need to assess the structural performance of CLT walls or floors which are outside the scope or between the values published in the load-span tables.

Some structural engineers choose to make their own calculations using the basic structural engineering principles of the proHolz Guide for Cross-Laminated Timber (proholz, 2014) or the Canadian CLT Handbook (FPInovations, 2019). The structural calculations must take into account two important factors:

1. The zero-strength properties of transverse layers perpendicular to the loaded direction when the charring depth reaches these layers.
2. The possibility of glue failure when the temperature at the glueline exceeds a threshold value.

If non-fire-resistant adhesive is used, the structural engineer can:

- Check the timber temperature at the depth of the glueline as described above, or,
- Follow the requirements in AS/NZS 1720.4 for protected timber, using a charring rate of 0.65 mm/min until the temperature at first glueline reaches a limiting value, after which the charring rate doubles to 1.3 mm/min until the char thickness reaches 25 mm. This is described in Section 7.5.5 of the Global Design Guide.

Another option is to use the higher nominal rate of charring for non-fire-resistant adhesives from the Canadian CLT Handbook (FPInovations, 2019), but note that this charring rate is not published by CLT manufacturers using radiata pine in New Zealand or Australia.

Structural calculations for CLT walls can be challenging in some situations such as:

- Three-ply CLT walls, which have significantly reduced vertical load capacity when charring consumes one of the surface layers.
- CLT walls within firecells which are exposed to fire on both sides simultaneously.

Both of these situations require careful analysis and design by the structural engineer.

7.4.3 Isolated columns and walls

Most proprietary timber wall systems (both light timber frame and mass timber systems) have only been tested with fire exposure on one side. In scenarios where exposure could be from more than one side e.g. isolated load-bearing mass timber walls within a firecell, additional structural fire engineering analysis and design may be necessary. The structural engineer should consult with the CLT manufacturer, or the supplier of linings for light timber frame walls, as necessary.

There is increasing concern about the structural fire resistance of isolated timber columns and walls in tall buildings after a fire has gone out, because of the delayed propagation of a thermal wave into the timber, coupled with the reduction of compressive strength at temperatures more than about 50 °C. This concern applies to all mass timber materials. This topic is covered later in this Commentary, Chapter 12 Robustness in Fire.

7.5 Charring of timber and wood-based panels

7.5.1 Charring of unprotected timber

This section gives the tabulated charring rates in Eurocode 5.
[Nothing more to add]

7.5.2 Charring of protected timber

[Nothing to add]

7.5.3 One-dimensional charring

[Nothing to add]

7.5.4 Two-dimensional charring

[Nothing to add]

7.5.5 European charring model

[Not relevant, except that Figure 7.2 shows graphs of the progressive charring rates for protected timber as specified in AS/NZS 1720.4]

7.5.6 European charring model for light timber

[Not relevant]

7.5.7 Charring model in the United States

[Not relevant]

7.5.8 Charring model in Canada

[Not relevant]

7.5.9 Charring model in New Zealand and Australia

This section of the Global Design Guide summarises the current requirements of AS/NZS 1720.4. For more recent recommendations on the New Zealand charring model for structural design of timber members, see Section 7.4 of this Commentary, above.

7.6 Materials for protection of timber structures

Figure 7.12 (in Section 7.6 of the Global Design Guide) shows Harmathy's 10 rules for fire resistance. These "rules", which are still considered to be applicable, are useful when assessing assemblies similar to but different from tested assemblies.

7.6.1 Wood-based protection materials

[Nothing to add]

7.6.2 Gypsum boards

This section of the Global Design Guide gives detailed information on gypsum plasterboards available in Europe, and some information on North American boards. Similar information for New Zealand gypsum boards is available from local manufacturers or importers.

7.6.3 Clay plasters

[Not relevant]

7.6.4 Cement-based boards

A number of cement-based boards are available in New Zealand. These are often used as non-combustible encapsulation on the top of mass timber floors. Other non-combustible boards with similar properties include magnesium sulphate or magnesium oxide boards.

7.6.5 Intumescent coatings

Clear intumescent coatings are most often used in New Zealand to comply with restrictions on the Material Group Number to reduce the early fire hazard. However, these coatings typically do not increase the fire resistance rating of structural timber. Some intumescent coatings can delay the start of charring, which can be used in structural calculations, but only if certified evidence from testing is available which demonstrates an enhanced fire resistance .

7.7 Effect of glueline failure

The information in Section 7.7 of the Global Design Guide is generally applicable, except that the European GLIF test for glue line integrity failure will be replaced in the draft version of Eurocode 5 (prEN 1995-1-2, 2024). The new test is expected to be a 120 minute standard fire resistance test to compare the charring depth in a CLT panel (gluelines parallel to the exposed surface) with the charring depth in a solid glulam panel (gluelines perpendicular to the exposed surface).

7.8 Calculation methods for standard fire exposure

7.8.1 Effective cross-section in Eurocode 5

[Not relevant]

7.8.2 Effective cross-section in Australia and New Zealand

The calculation methods for Australia and New Zealand have been described in Section 7.4 above.

7.8.3 Effective cross-section in the United States

[Not relevant]

7.8.4 Effective cross-section in Canada

[Not relevant]

7.9 Advanced calculation methods

Section 7.9 of the Global Design Guide is all relevant for New Zealand designers. Advanced calculation methods may need to be used in special situations where the standard calculation methods are inadequate. Advanced calculation methods will require finite element analysis to predict the thermal gradient, leading to loss of strength and decomposition of the wood material in a structural cross-section. Mechanical properties at elevated temperatures are given in the Global Design Guide Section 7.9, and in Structural Design for Fire Safety (Buchanan and Abu, 2017).

Additional information on possible loss of strength during the decay and burnout phases of a fire is covered in this Commentary, Chapter 12 Robustness in Fire.

The draft of Eurocode 5 (prEN 1995-1-2,2024) gives a design method for loss of strength in the decay phase, using larger values of the zero-strength-layer.

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AS/NZS 1170.0:2002 Structural Design Actions. Part 0 – General Principles. Standards New Zealand, Wellington.

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Chapter 8
Timber connections

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8. Timber connections

Scope of chapter

This chapter provides complementary information to Chapter 8 – Timber Connections of the Global Design Guide. The Global Design Guide contains the core information, so must be read along with this complementary chapter. Since the performance of timber connections in fire requires fundamental knowledge of fire exposures, and the interdependence of the thermal and mechanical behaviour of timber in fire, this chapter should be read in conjunction with other chapters of the Global Design Guide.

This chapter is limited to assessing the fire resistance of timber connections as quantified by the standard fire resistance test. This is the fire resistance under particular test conditions (specified in AS 1530.4) in which the furnace is heated to follow the time-temperature curve known as the Standard Fire curve. As discussed in Chapter 3, a real compartment fire, depends on many factors including the fuel, compartment geometry, linings, and the available ventilation. Designers should bear in mind that the standard fire will not occur, but rather a real fire may be more or less severe than the standard fire (by a small or large margin).

8.1 Introduction

Connections are critical parts of load paths, so they are of paramount importance for maintaining structural stability under all types of actions. Timber connections are given significant attention as they contain concentrated stresses and are optimised for constructability, scheduling, and cost. In New Zealand, connections have seismic requirements in addition to fire requirements (either as part of the lateral load resisting system or for deformation compatibility). Although seismic design results in superior ambient-temperature connection performance, this does not automatically translate to improved behaviour in fire. Rather, some connection features that improve seismic performance may enhance or degrade connection behaviour in fire. Therefore, connection performance in fire should be explicitly verified in design and not simply discounted if it is not perceived to be the critical load case. It is not always simple to design timber connections for both fire and seismic performance.

8.2 Overview of timber connection typologies

Figure 1 shows a range of different types of connection considered in this chapter. For the purposes of fire resistance, timber connections can be separated into two broad categories (examples of these types are given in the following section):

- **Linear element connections**, e.g. beam-column connections and splice connections.
  These connections must maintain their load-bearing capacity but do not generally form part of a fire separation so they are not required to resist the passage of fire. These connections are required to achieve a Fire Resistance Rating (FRR) of X/-/- (i.e. "structural adequacy" only).
- **Panel Connections**, e.g. wall or floor panel-panel connections.
  These connections join panels which are often fire separations (e.g. floors and walls). These connections are required to both maintain load-bearing capacity and prevent the spread of fire. These connections are required to achieve a Fire Resistance Rating of X/X/X or in some cases X/X/- (refer to the project Fire Engineer).

The behaviour of timber connections in fire is complex as a result of the different heating rates, conductivity and strength-temperature relationships of steel and timber. Exposed steel surfaces will be heated by the fire and will conduct heat into the connection. Therefore, unless demonstrated otherwise (by comprehensive tests or advanced design methods):

- For FRR ≤ 30 minutes – some well-proportioned connections with partially concealed connectors can achieve 30/-/- without additional protection. Other connections should be protected (either by sacrificial timber or other system).
- For FRR > 30 minutes – connectors should be protected (either by sacrificial timber or other system e.g. boards).

As always, designers should err on the side of conservatism as any real fire will not be a standard fire and there is uncertainty in the underlying models and parameters. Regardless of the required FRR, steel items should be protected from direct fire exposure wherever possible.

Proprietary connectors are becoming increasing popular as they provide efficient, compact and design-simple solutions. As with ambient-temperature design, their fire resistance ratings are best established through testing. Often the failure mode is too complex to model and testing allows their efficiency to be maximised.

8.2.1 Timber to timber connections

[Nothing to add to the Global Design Guide]

8.2.2 External metal plates

[Nothing to add]

8.2.3 Embedded metal plates

[Nothing to add]

8.2.4 Fully concealed connections

[Nothing to add. See Figures 8.5 and 8.6 in the Global Design Guide for examples of fully concealed connections.]

8.3 Mass timber panel connection typologies

8.3.1 Panel-to-panel spline, half-lap

At the time of writing, all CLT products supplied in New Zealand are proprietary products so have their fire resistance determined through standard fire resistance testing. As proprietary systems, manufacturers test and supply construction details including connections (e.g. panel-to-panel floor joints).

In standard fire resistance tests, floor panel-panel joints have been observed to often fail the integrity criterion at the panel joint (i.e. passage of flame). Integrity failure is typically difficult to predict with calculations, so test evidence is required.
Since char contracts there is greater charring at panel joint interfaces as the small gaps between panels widen near the fire exposed surface. AWC TR10 (2021) estimates the local charring depth at interface joints (perpendicular to the fire exposure) to be twice the depth of charring of the element away from the gap (see Figure 2).

(a) Steel gusset for beam to column connection. Test specimen before testing (Credit: David Barber)

(b) Steel beam supported on CLT wall with intumescent-painted plate and screws.

(c) Steel beams supported in rebates on top of CLT wall.

(d) Slotted steel connection to exposed steel (Beatrice Tinsley Building, University of Canterbury)

(e) Interior beam-column connection of a Pres-Lam frame. The bottom left brackets are only for energy dissipation. All exposed steel is painted with intumescent paint. (Credit: Paul Horne)

(f) Exterior beam-column connection of a Pres-Lam frame (Credit: Paul Horne)

Figure 1. **Typical timber connections to be design for fire resistance**

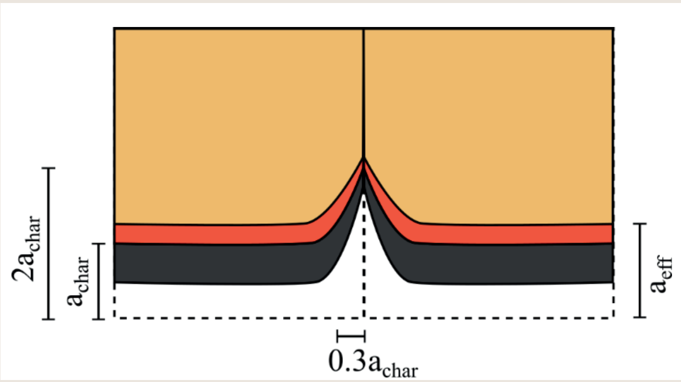

Figure 2. **Char penetration at abutting wood elements that are unbonded (adapted from AWC, 2021)**

8.3.2 Panel-to panel hold-down connections

[Nothing to add]

8.3.3 CLT wall-to-floor connections

[Nothing to add]

8.3.4 Hybrid Structures – CLT elements and structural steel frame

Steel elements, when protected from fire, are typically designed to reach a critical temperature between 500 and 600 °C to maintain sufficient strength during the fire. However, heated steel will conduct heat into any timber it is in contact with. There is little research about heated steel in contact with timber in load-bearing applications, so the most common approach is to use a board protection to limit the temperature of the steel element (and therefore of the timber element) to less than the charring temperature (normally considered to be 300 °C).

If the steel element is not protected to control its maximum temperature when exposed to fire, design of the timber element should explicitly consider the additional charring and the heated layer resulting from the steel in contact with the timber.

8.4 Response of elevated temperatures in timber connections

8.4.1 Review of fire testing results

Experimental research on the behaviour of timber connections in fire is expensive and difficult so only a limited number of types of connection have been tested. Due to the challenges of simultaneously applying representative forces, restraint and thermal exposure, many experiments have been undertaken on smaller elements, under smaller loads than in real buildings, and the majority have been exposed to the standard fire. Despite their limitations, these experiments revealed valuable information about the fundamental behaviour of the connection types and their failure modes. Experiments comparing connections with and without unprotected steel elements have repeatedly shown that connections with exposed unprotected steel perform poorer than equivalent connections without any exposed steel.

8.4.2 Charring in connections

When a connection is exposed to fire, any exposed steel components will be heated, and they will conduct heat along their length and into the surrounding timber, resulting in increased temperatures and reduced mechanical properties of the adjacent wood. This occurs at all scales from accelerated localised charring around small fasteners (e.g. screws and nails) to corner rounding and interface charring around steel plates. Heating of the connection interior results in accelerated charring and reduced strength of the timber embedment and fasteners. Connections with internal knife plates perform much better than connections with external steel plates. Bolts have a greater heated surface area than dowels and so conduct more heat along their length. The fire resistance of connections decreases as the utilisation ratio (ratio of effect to resistance) increases.

The thermal and mechanical responses of timber connections are interdependent. A temperature criterion does not capture any deformations that degrade the connection performance further (e.g. gaps opening, plate deformation, char crushing and other deformations that must be compatible with the surrounding structure). Therefore, it is not sufficient to evaluate the fire resistance of a timber connection based on a temperature criterion alone (e.g. 300 °C isotherm position).

8.4.3 Influence of applied load

[Nothing to add]

8.4.4 Loss of strength behind the char layer – thermal penetration depth

[Nothing to add]

8.4.5 Fire severity

The majority of design methods apply only to a Standard Fire exposure (a fire resistance rating implies a standard fire exposure). If the design fire exposure is not a standard fire, the assessment of connection fire resistance will necessarily have to consider the different thermal field and mechanical response resulting from the non-standard fire exposure. In all cases it is essential to account for the reduced strength and stiffness in the heated timber beneath the char layer. The thermal gradient beneath the char-layer and the thickness of the equivalent zero-strength layer thickness depends on the fire exposure and material properties.

For designs to C/AS2, the fire severity will be 30 minutes or 60 minutes as prescribed. For designs to C/VM2, an equivalent fire severity must be determined, including the additional fuel from exposed wood surfaces. If a connection failure is likely to result from charring of exposed wood, the calculated char depth should be used. If the failure is more likely to result from heating of steel or failure of protective boards, the time-equivalent formula from C/VM2 can be used. See Section 7.4.1 in Chapter 7.

8.5 Design for fire resistance

8.5.1 Failure modes

The failure modes of connections in fire are often different to those at ambient-temperature and currently the only way to confirm the failure modes in fire is through experiments. Deformations at connections occur not only in the direction of the applied load but can also occur in other directions. For example, a connection that supports vertical loads at ambient temperature may develop horizontal displacements or rotations when exposed to a fire.

8.5.2 Beam-to-column bearing connections

Steel plates including bearing plates and the edges of embedded plates should not be exposed to fire unless the additional heating from these surfaces is included in the analysis. Steel brackets should be buried within the effective cross-section of the timber wherever possible. The bearing stress must remain below the bearing strength, considering the temperature at this surface (the bearing strength can be estimated from the reduced compressive strength based on the thermal profile).

8.5.3 Beam-to-column knife-plate connections

[Nothing to add]

8.5.4 Charring localised to screws

[Nothing to add]

8.5.5 Glued-in dowels and rods

Unless they are protected against elevated temperatures, glued-in dowels and rods should be avoided because epoxies generally have a lower strength than timber at the same temperatures. If glued-in rods are used, no steel should be exposed to the fire and steel surfaces should be contained well within the residual section. When glued-in rods are protected, the temperature of the rod should be verified to ensure that it remains below the failure temperature of the epoxy. Some epoxy manufacturers publish a "glass transition temperature" which gives an indication of the failure temperature (the glass transition temperature is correlated with the greatest reduction in strength although there is some decrease in strength occurs before this temperature).

Unless specifically designed and analysed otherwise, epoxy should not be relied on to provide resistance after the heating phase of the fire due to the propagation of the thermal wave in the cooling phase (and the low-temperatures at which epoxies can lose strength). See Chapter 12.

8.6 CLT panel-to-panel connections

8.6.1 Design for fire resistance

[Nothing to add]

8.7 Connections with additional fire protection

Fire protection materials are thermal insulation to slow down the temperature rise of the timber substrate; they do not prevent damage from occurring. Given enough heating, a thermal field will develop in the timber substrate under the protective material. There are two common methods of protecting timber connections: boards and sacrificial timber. Other proprietary systems are available but outside the scope of this commentary as their fire resistance is determined through testing.

For protection to be effective throughout the fire exposure it should:

1. Remain in place for as long as possible (i.e. the "fall-off" time must be known),
2. Be thick enough to ensure a low temperature rise on the unexposed face of the protection (i.e. the temperature rise on the unexposed face must be known), and
3. Be detailed to provide effective protection throughout the fire exposure (see Figure 3):
   a. As gaps open due to contractions of char layer or protective material,
   b. As charring spreads behind the edges of protection, and
   c. To prevent failure of the fasteners holding the protective board in place.

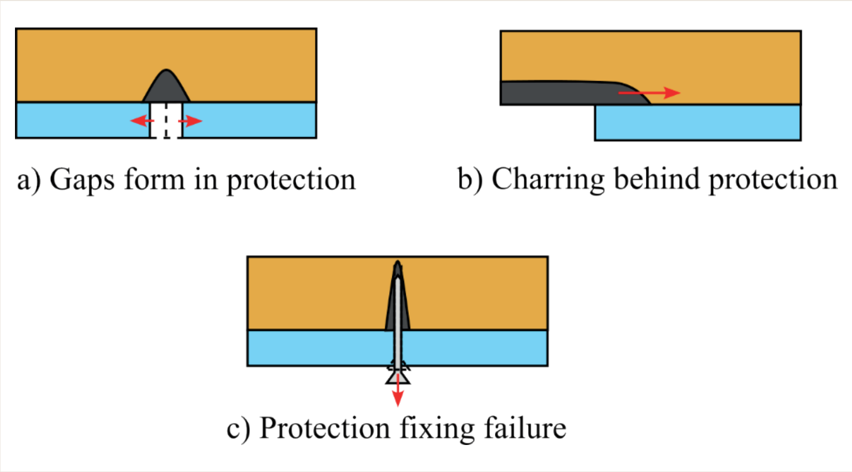

Figure 3. **Possible modes of charring behind fire-protective boards**

The boards typically used in New Zealand for board fire protection are:

- Fire resistant gypsum plasterboards,
- Specialist fire protection boards (calcium silicate, magnesium oxide, magnesium sulphate, etc),
- More recently, lighter specialist encapsulation boards (e.g. rock fibre boards).

The ability of a board to resist fire depends on more than the board material, but also on other factors including, the fixing details, jointing or sealing of edges, gaps, etc. For this reason, these products are specified as "systems" which cover all the aspects, with installation methods to ensure the specified performance is achieved.

Fire-protective boards on the New Zealand market are almost all proprietary systems. They must be specially designed and certified for timber structures. Some manufacturers provide details of protective boards for "one-way" fire resisting systems, based on testing to show that no charring occurs on timber beneath the protection after 30 minutes or 60 minutes of standard fire exposure. Timber members and connections protected with such boards are deemed to have 30 minutes or 60 minutes of fire resistance.

Fire-protective board systems for steel elements are typically designed to limit the steel temperature to 500–600 °C so they do not necessarily provide the same FRR when used on timber which chars at 300 °C.

Protective boards must be extended some distance beyond from the protected connection to avoid charring behind the protective layer close to the connection (see Figure 4). Ideally this edge distance is detailed by the board manufacturer. As an indication and where no other guidance is available, if the board is in uniform direct contact with the timber, an edge distance of 100 mm for FRR 30 minutes and 200 mm for FRR 60 minutes is likely to be sufficient provided the board fixings remain embedded in solid timber. This is based on a lateral char rate behind the board rather than extensive experimental evidence and therefore should be verified for each situation.

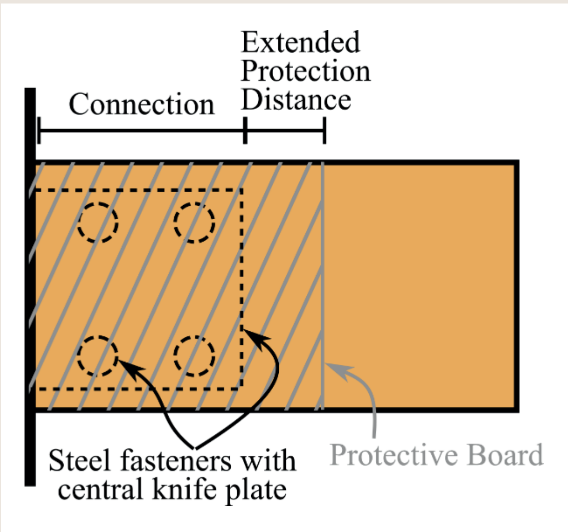

Figure 4. **Protective board extended beyond the connection**

8.7.2 Protection with sacrificial timber

Sacrificial timber can be used to provide protection which maintains the timber aesthetic. This can be achieved by embedding the fasteners within an enlarged timber cross-section or by fixing additional timber onto the outside of the connection. Methods to calculate the required increased element cross-section or thickness of sacrificial timber are already provided within AS/NZS 1720.4. See Figure 8.19 in the Global Design Guide (from AS/NZS 1720.4).

Where additional layers of timber are attached to be sacrificial timber for the structural element, they must be carefully detailed, so the timber remains fixed to the timber element and accelerated charring does not occur at interfaces. Where particleboard, fibreboard, OSB and plywood are used, the appropriate char rate is to be factored by $\sqrt{(\rho_k/450)}$(ρ_k is characteristic density, kg/m³) to account for the density and have a minimum thickness of 19 mm.

8.7.3 Use of intumescent coatings

Currently intumescent coatings are commonly used for two different purposes:

1. An intumescent coating (usually transparent) applied to exposed timber surfaces where a Group 1 or 1S surface finish is required (i.e. control surface spread of flame). When exposed to a fire, this coating forms a thin char layer to prevent rapid spread of flame over the timber surface early in the fire growth phase of the fire development. These coatings do not have any recognised contribution to fire resistance rating (unless a particular application is supported by test evidence). See Chapter 5 for Reaction to Fire.
2. An opaque paint (commonly referred to as "intumescent paint") applied as part of a paint system to protect structural steelwork. This paint is applied to steelwork at a specific thickness to achieve the limiting temperature at the fire resistance time specified by the structural engineer.

Intumescent paints contain carbon and acid sources which react to produce the carbon which is foamed as the blowing agent reacts and releases gases. These reactions take place at a similar temperature range to form the thermally insulating "char" layer. This resulting char is delicate (like a burnt marshmallow) and can be easily damaged by deformations or contact.

Applying intumescent paint to steel items in a timber connection may not provide the FRR expected. If intumescent paint is to be used then the issues raised in the Section 8.7.3 of the Global Design Guide must be addressed. Using other protection methods (boards, sacrificial timber) will invariably result in more reliable performance than intumescent paint.

Some suppliers are trialling steelwork intumescent paints on timber substrates to delay the onset of charring. Paints in this application must be supported by fire resistance test results. Intumescent paints have construction constraints (such as environmental conditions during and after application). Poor application methods can degrade adhesion to the timber and reduce fire performance. Fire resistance tests to support the use of these products must be conducted under representative conditions to capture both the thermal and mechanical response, including applied loads and resulting deformations.

8.7.4 Timber-to-steel connections

Many mass timber buildings in New Zealand include steel beams which are fire-protected with intumescent paint, such as those shown in Figure 1 (c). If the steel beam is protected with intumescent paint to a limiting temperature of, say, 600 °C, all timber in contact with the steel will be subject to charring. This includes the underside of the CLT floor panels and the top of the CLT walls which are supporting the beam. Ideally, the thickness of the intumescent paint should limit the maximum temperature to 300 °C but this is not economically feasible.

A practical design suggestion is to provide intumescent paint which limits the maximum steel temperature to 450 °C, and accept that there will be some charring of all timber in contact with the heated steel. This is considered acceptable provided that any charring will only cause local vertical deformations, with no possibility of catastrophic structural failure.

The deformation rate of heated steel in contact with charring timber is currently unknown. If the charring rate of adjacent bare timber exposed to fire is 0.65 mm/min, it can be assumed that the contact deformation will be similar. Although the rate of deformation will be increased by the bearing pressure and reduced compressive strength, it may be decreased by the local cooling effect on contact between steel and cooler wood. This topic urgently requires research investigation.

8.8 Connection design methods

8.8.1 Char-rate methods

[Nothing to add]

8.8.2 Acceptance criteria

AS/NZS 1720.4 uses temperature-based acceptance criteria for connections. The temperature of steel protected beneath applied insulation is limited to a conservative figure of 120 °C, which can be increased to 300 °C where dowels are used. Considering the typical load ratios of timber connections in the fire limit state and the reduced strength of timber at these temperatures, this code requirement generally results in conservative designs. Therefore, Section 8.11 of this chapter proposes alternative methods for fire resistive connections.

8.8.3 Worked examples

The worked examples in the Global Design Guide are simple examples based on first principles. They are satisfactory for simple designs. Additional design methods recommended for New Zealand are given in Section 8.12.

8.8.4 Connection detailing

At time of writing all timber panel products supplied to the New Zealand market are proprietary. Therefore, the easiest method of demonstrating that connections comply with the required fire resistance rating is to use the details provided by the panel manufacturer. These have generally been determined through standard fire resistance testing or expert opinion, and they cover a range of options to achieve satisfactory FRRs.

If a test result is not available for a particular detail, a new solution may have to be developed with the panel manufacturer. This may involve testing, or an expert opinion based on engineering judgement. Expert opinions are rare, undertaken by expert structural fire engineers and supported by substantial evidence. The principles from this commentary and the Global Design Guide can be used to inform development of a new detail.

Refer to technical literature and technical support of the panel manufacturer for specific information.

8.8.5 Guidance documents

[Nothing to add]

8.9 Advanced calculation methods

There are few analytical models of timber connections exposed to fire that are simple, comprehensive and sufficiently validated for design purposes. While in some cases the thermal field within connections can be modelled acceptably, capturing the mechanical response of these connections in fire is much more challenging. To correctly model the behaviour of timber connections in fire, the thermal and mechanical interaction must be included but this involves complex behaviour, for example, heating through a crushing char layer and softening wood. There are many pitfalls in advanced analyses, therefore, they should only be undertaken by expert structural fire engineers with specialist skills and experience. Caution should be exercised as finite element models may not capture all the failure modes observed in experiments.

8.9.1 Modelling of timber connections

[Nothing to add]

8.9.2 Uncoupled models

[Nothing to add]

8.9.3 Coupled thermo-mechanical models

[Nothing to add]

8.10 Further research

The range of timber materials available in New Zealand (CLT, Glulam, LVL, PLT etc) and many ways of connecting elements (screws, bolts, coach screws, rivets, dowels etc) result in a wide range of connection types which may all behave differently when exposed to fire. Few connection types have been studied extensively experimentally and even fewer have analytical models. Hybrid steel-timber structures have different types of connection and potential further complexities considering the thermal and mechanical interaction between the different materials at connections.

Connections will perform differently in non-standard fires, which can be which can be hotter or cooler than the standard fire, but this has received only a little research attention. For structures which are required to withstand the full duration of a fire including burnout, there are questions about the performance of connections in the cooling phase where the thermal wave continues to propagate into the timber connection. The research that has been done on timber members indicates that a long slow cooling phase is more severe than a short hot one. There is very little information on the residual strength of timber connections after severe fires.

8.11 Alternative design methods

[Sections 8.11 and 8.12 are not in the Global Design Guide. These new sections provide additional material for New Zealand designers.]

The New Zealand Building Code (NZBC) verification method for "Structure", B1/VM1, currently cites NZS 3603 as the timber structures design standard. However, the provisions in NZS 3603 do not align well with modern mass timber construction and the replacement standard, AS/NZS 1720.4 (2019), is not yet cited.

AS/NZS 1720.4 only contains design provisions for protected connections and requires unprotected connections to have their FRR determined through standard fire resistance testing. For protected connections, this standard imposes a temperature limit of 120 °C underneath thermal insulation or the connection must be located within the effective cross-section. Considering typical load ratios of timber connections in the fire limit state and the reduced strength of timber at this temperature, these requirements generally result in conservative designs, especially when 30 minute FRR is required.

8.11.1 Proposed new design methods

For more economical and comprehensive connection design, designers can refer to international design standards and engineering methods. The use of these methods will change the NZBC compliance pathway from a Verification Method to an Alternative Solution.

This Commentary recommends that:

For FRR ≤ 30 minutes: Simple design guidance for generously-proportioned unprotected connections is provided in Section 8.11.2. This guidance is based on the current version of Eurocode 5–1–2:2004 with some modifications based on the latest draft version.
Connections which fall outside the scope of this guidance should be fully protected.

For FRR > 30 minutes: Connections should be protected, either by applied protection or sacrificial timber.
The guidance here is based on AS/NZS 1720.4 and Eurocode 5–1–2 with modifications to incorporate new findings since these standards were written.

When the next generation of the Eurocodes is published, this section should be reviewed and amended as appropriate.

There is little published information on proprietary connections as they have their fire resistance evaluated through standard fire resistance tests. The following design guidance applies to common non-proprietary connection typologies exposed to the standard fire. For proprietary products, refer to the manufacturers' literature.

8.11.2 30 minutes FRR

A generously-proportioned unprotected splice type connection, such as that shown in Figure 5, loaded in tension and/or shear, can be considered to achieve a FRR 30 when:

1. The load ratio (under the fire combination of actions and ambient-temperature resistance) ≤ 0.3, and
2. The outer side members are both timber and are thicker than the minimum thickness in Table 1 (middle member(s) can be timber or steel), and
3. The edge and end distances are increased from those required for ambient-temperature resistance by the distance a_{fi} in Table 1. Slotted-in steel plates must also be recessed by distance a_{fi}. a_{fi} (shown in Figure 5) is a notional distance so that the connections achieves FRR 30, it is not the char depth.
4. The ends of the steel dowels and the heads of the bolts may be exposed.

Unprotected external steel plates are not permitted, instead they must be fully protected.

The dark shading in Figure 5 indicates the size of beam which would be needed for non-fire conditions. Alternatively, to achieve a 30–minute FRR for protected connections, the methods in 8.11.3 may be used.

Table 1. **Minimum thickness and edge distances for various connection configurations**

Fasteners	Configuration	Minimum outer side member thickness (mm)	Increase in edge and end distances, a_{fi} (mm)
Dowels Dowels may project no more than 3 mm. Dowels may be replaced by no more than 2 bolts per fastening group.	Timber-to-timber	70	25
	Timber-to-steel with 1 slotted-in steel plate	90	35
	Timber-to-steel with 2 slotted-in steel plates	60	35
	Timber-to-steel with 3 or more slotted-in steel plates	50	35
Bolts	Timber-to-timber	90	30
	Timber-to-steel (one or more slotted-in plates)	120	40
Laterally loaded nails or screws	Timber-to-timber	100	40

Table 1 is based on a conservative simplification of the current draft Eurocode 5 for FRR 30 in a wide range of applications. For more specific detail refer to Eurocode 5. Table 1 should be updated to reflect any future changes to Eurocode 5.

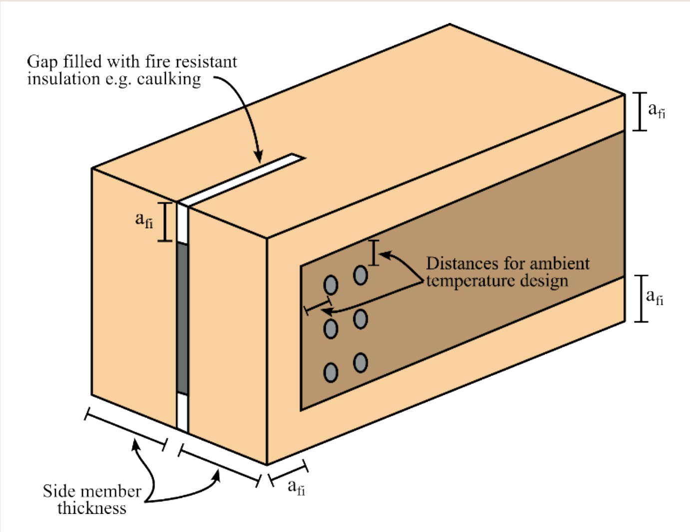

Figure 5. **Dimensions for the case of a single slotted-in steel plate**

8.11.3 60 minutes FRR

For fire resistance of more than 30 minutes for the connection typology shown in Figure 4, or for any FRR for any other typology, refer to the existing method in AS/NZS 1720.4 which requires the thickness of protective timber to be equal to, or more than, the calculated depth of charring, provided that the residual timber has sufficient cross section to carry the fire-reduced loads.

To achieve a 60 minute FRR using protective boards, this Commentary proposes two alternative pathways:

1. For protection systems not specifically fire tested, refer to the existing method in AS/NZS 1720.4, except that the temperature of steel brackets or fasteners underneath the protection is relaxed from 120 °C to 140 °C (in line with AWC TR10, 2021). 140 °C is the upper limit of the average temperature rise for the insulation criterion in the standard fire resistance test (see AS 1530.4). This allows many fire protection systems that achieve an insulation and integrity rating to be used to protect timber connections.
2. Protection systems specially tested in accordance with EN 13381-7 can be designed using the parameters determined from the test results. This standard "specifies test methods for determining the contribution of fire protection kits to the fire resistance of structural timber members." The parameters from this testing allow the optimised use of protection (boards, sprayed fire protection and reactive coatings) based on quantified performance in a test.

8.11.4 Additional requirements for all connections

1. Gaps should be minimised. If they are unavoidable then fire resistant sealant, intumescent sealants or intumescent strips should be installed.
2. Internal steel plates should be contained within the effective cross section for the duration of the fire exposure.

8.12 Additional worked examples

8.12.1 Example 1: Internal knife plate to achieve FRR 30/-/-

The connection consists of a 10 mm steel knife plate connecting a 600×260 mm LVL beam to a LVL column with group of 10 mm diameter steel dowels (similar to Figure 4 or Figure 5). The load ratio (the ratio of the shear demand from the combination of actions for the fire design scenario to the ambient temperature load capacity of the joint) is 0.27 (i.e. < 0.3). Therefore, based on Table 1 the minimum permitted outside thickness is 90 mm (actual is 124 mm) and the a_{fi} is 35 mm.

8.12.2 Example 2: Internal knife plate to achieve FRR 60/-/- with proprietary system

Same connection as in Example 1 excelpt that it is required to achieve a FRR 60/-/- . With this approach, a much greater load ratio is possible, up to a maximum value of 100%.

The connection shown in Figure 5 is protected with a proprietary board system which is designed to protect the timber from reaching a temperature of 300 °C after 60 minutes of standard fire exposure (see 8.7.1). The protective board should be extended beyond the joint by 100 mm, as shown in Figure 4. No increase in fastener edge or end distances is required.

8.12.3 Example 3: Steel bracket bearing connection to achieve FRR 30/-/-

A steel bracket is used to connect a 600×260 mm LVL beam to a LVL column (see Figure 5) and is required to achieve a FRR of 30/-/-. The bearing stress on the bracket under the fire design situation is 5 MPa. Experimental testing on the LVL has shown a charring rate of 0.7 mm/min in a standard fire resistance test.

The bearing stress must be less than the compressive strength of the timber (f_{perp} = 10 MPa). The bracket will be protected by a layer of sacrificial timber which includes the expected char depth and a distance until timber of sufficient strength is present, i.e.

$$total\ depth = char\ depth + \ sound\ timber\ depth$$

The char depth is 30 minutes x 0.7 mm/min = 21 mm.

In the absence of better information the reduction in compressive strength parallel to the grain given in Figure 7.17 of the Global Design Guide (from Eurocode 5–1–2) is applied perpendicular to the grain. For a load factor of 5 MPa/10 MPa = 0.5, the limiting temperature for this reduction in compressive strength is 70 °C. Based on the temperature profile beneath the char front given in Section 9.2.1 of Structural Design for Fire Safety (Buchanan and Abu, 2017), the depth at which this temperature is reached is calculated from:

$$T = 20 + 280\left(1 - \frac{x}{35}\right)^2 = 70$$

giving a value of $x = \ 20\ mm$

Therefore,

$$total\ depth = 21 + 20 = 41\ mm$$

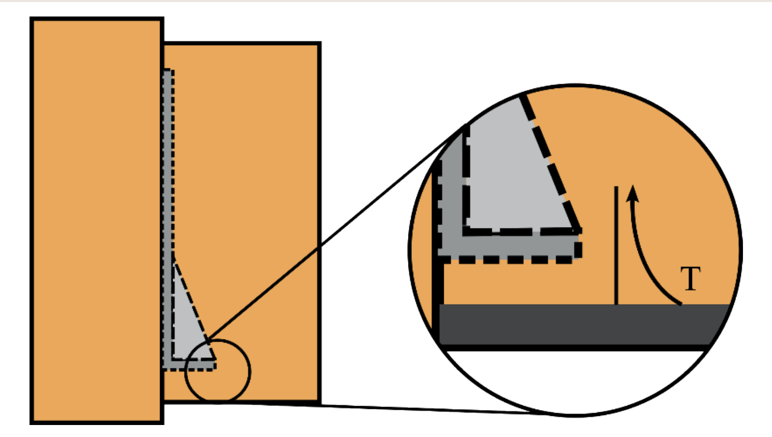

Figure 6. **Illustration of connection and char layer and temperature profile beneath**

Reference

AWC (2021) Calculating the fire resistance of wood members and assemblies. Technical Report No. 10. American Wood Council, USA. Available here.

Chapter 9
Prevention of fire spread within structures

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9. Prevention of fire spread within structures

Scope of chapter

This chapter is complementary to Chapter 9 of the Global Design Guide, which should be read alongside this document.

This chapter elaborates on the four fire spread mechanisms encountered in mass timber building design and the relevant fire safety solutions. It begins with a high-level discussion on the relationship between performance criteria of New Zealand Building Code (NZBC) C-Clauses with respect to major fire spread mechanisms.

For each fire spread mechanism, the chapter assesses the current fire engineering literature and proposes feasible design solutions to mitigate the fire spread risks, in accordance with New Zealand recommended practice and international guidelines.

Refer to Chapter 5 for surface flame spread on interior surface finishes. While this Chapter discusses vertical external fire spread, the understanding of this fire risk is rapidly evolving and new knowledge is under development, so the current chapter is not comprehensive in this regard. Some guidance from the current literature is provided and explained in Section 9.7 of this Commentary.

9.1 Introduction

Fire spread remains a complex and dynamic phenomenon which cannot be predicted accurately by existing numerical analyses. The current fire spread mitigation strategy is qualitative and preventative in nature, involving the application of fire spread barriers and standard tested solutions. Note that each building design is unique and has specific design objectives which might introduce additional fire spread risks due to the utilisation of mass timber construction.

Fire protection to mitigate fire spread in mass timber buildings is complex, so the fire engineer should consult with relevant experts and the wider design team to ensure a coordinated design approach.

9.1.1. New Zealand Building Code (NZBC) requirements

The prevention of fire spread within structures relates closely to the functional and performance requirements outlined in NZBC Clause C3 – 'Fire affecting areas beyond the fire source' (New Zealand Government, 2012). A more comprehensive explanation of the NZBC C-clauses and the fire safety requirements in New Zealand is covered in Chapter 4 of the Commentary. Table 1 presents selected C3 requirements having a direct relationship to mitigating the four major fire spread mechanisms:

(1) Fire spread via separating elements, joints and junctions,

(2) Fire spread via building service installations and penetrations,

(3) Fire spread via building cavities and ventilation gaps, and

(4) Vertical fire spread via exterior façade cavities.

Table 1. **NZBC C-Clauses relevant to prevention of fire spread within structures**

C3 Requirements	Design solutions
Functional C3.1: Buildings must be designed and constructed so that there is a low probability of injury or illness to persons not in close proximity to a fire source.	Design solutions to ensure occupants remote from fire are not adversely affected by **fire spread mechanisms (1) to (4)** e.g. complete fire separation between firecells using mass timber wall and floor assemblies achieving a specific Fire Resistance Rating (FRR).
Functional C3.2: Buildings with a building height greater than 10 m where upper floors contain sleeping uses or other property must be designed and constructed so that there is a low probability of external vertical fire spread to upper floors in the building.	Design solutions to prevent excessive **external fire spread mechanisms (3) to (4)** vertically up the building e.g. fire rated aprons or spandrels between floors or having sprinkler protection.
Functional C3.3: Buildings must be designed and constructed so that there is a low probability of fire spread to other property vertically or horizontally across a relevant boundary.	Design solutions to prevent excessive **fire spread mechanisms (1) to (4)** affecting properties under different ownership e.g. complete fire separation between apartments under different ownership.
Performance C3.5: Buildings must be designed and constructed so that fire does not spread more than 3.5 m vertically from the fire source over the external cladding of multi-level buildings.	Design solutions to prevent excessive **external fire spread mechanisms (3) to (4)** vertically up the building, specifically involving external cladding systems e.g. cavity barriers within external wall cavities.
Performance C3.7: External walls of buildings that are located closer than 1 m to the relevant boundary of the property on which the building stands must either: a. be constructed from materials which are not combustible building materials, or b. for buildings in importance levels 3 and 4, be constructed from materials that, when subjected to a radiant flux of 30 kW/m², do not ignite for 30 minutes, or c. for buildings in Importance Levels 1 and 2, be constructed from materials that, when subjected to a radiant flux of 30 kW/m², do not ignite for 15 minutes.	Design solutions to prevent excessive external **fire spread mechanisms (3) to (4)** due to the selection of building façade materials e.g. use of non-combustible or limited-combustible building elements constituting the external cladding system.
Performance C3.9: Buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety system intended to control fire spread.	Design solutions to ensure there is adequate design robustness to mitigate **fire spread mechanisms (1) to (4)** e.g. a combination of sprinkler protection and encapsulation for mass timber design to achieve specific fire resisting performance.

Note that the NZBC C-Clauses are considered as the minimum societally accepted fire safety requirements and certain building designs might have additional design objectives in order to fulfil functionality or owner/insurer requirements.

9.2 Preventing fire spread by detailed design

Detailed design of timber elements is important. Specific consideration needs to be given to service penetrations, possible gaps between structural elements, and interfaces between timber and thermally conductive metal components that may lead to heat transfer into the timber causing localised charring.

9.2.1 Different types of timber constructions

Chapter 1 provides a description of different types of timber structures.

9.2.2 Typical fire spread paths and principles to prevent fire spread

The two main NZBC compliance pathways for fire safety, the Acceptable Solution C/AS2 (MBIE, 2020a) and the Verification Method C/VM2 (MBIE, 2020b) have traditionally been developed for non-combustible building materials such as steel and concrete with light weight timber framing typically fire protected by plasterboard systems. The fire safety requirements within these documents do not explicitly account for the additional fire risks involving mass timber construction. Nevertheless, C/AS2 and C/VM2 offer some fundamental mitigation principles which fire engineers should also adopt for mass timber construction.

Table 2 correlates the four main fire spread mechanisms listed in 9.1.1 to the different paths described in Figure 9.1 and Section 9.2.2 of the Global Design Guide with the relevant methods to demonstrate that fire spread has been mitigated sufficiently to meet the requirements of the Building Code in C/AS2 and C/VM2. The different fire spread mechanisms address the different NZBC C-Clauses, as discussed above in section 9.1.1.

Table 2: **C/AS2 and C/VM2 common design solutions to mitigate fire spread within structures**

Mechanism	Paths described in Figure 9.1 of Global Design Guide	Design solutions from compliance pathways (C/AS2 and C/VM2)
1. Fire spread via separating elements, joints and junctions	Path I, II and III	C/AS2, paragraph 4.5 • Junctions of fire separations, including those to external walls, to be bonded together or fire stopped over the full length. • Junctions of vertical fire separations to terminate as close as possible to the external roof cladding and primary elements providing roof support, with any gaps fully fire stopped.
2. Fire spread via building service installations and penetrations	Path IV	C/AS2, paragraph 4.5 • Services penetrations through fire separations to be fire stopped to maintain the continuity and effectiveness of the fire separations. • All gaps around services penetrations to be fire stopped. C/AS2, paragraph 4.4 • Fire stopping systems to be tested to AS 1530.4 or NZS/BS 476-21 and 22, and AS 4072.1. • Fire stopping systems to be compatible in relation to the type of penetration, the size of gap and the material and construction of the fire separation.
3. Fire spread via building cavities and ventilation gaps	Path V	C/AS2, paragraph 4.15 • Pathways for fire spread within fire separations (wall and floor) and external walls (e.g. curtain wall construction) to contain cavity barrier or be fire stopped. • Cavity barrier to be tightly fitted and mechanically fixed to rigid construction to avoid premature failure due to building movement or failure of fixings during fire. • Concealed ceiling spaces without sprinkler protection to be subdivided with fire separations. C/VM2, paragraph 4.3 Design fire scenario (CS) • Concealed spaces without automatic fire detection system to contain cavity barrier with appropriate FRR and be limited to specific dimensions. • Suppression system (e.g. sprinkler protection) to confine the fire starting in a concealed space and reduce the likelihood of a severe fire occurring. • Automatic fire detection system to provide early warning of fire starting in a concealed space.
4. Vertical fire spread via exterior façade cavities	Path V	C/AS2, paragraph 5.8 and C/VM2, paragraph 4.6 Design fire scenario (VS) • Cavity barrier fitted at each floor level within external wall cavities. • External wall cladding materials to be non-combustible, limited combustibility or achieve specific fire performance tested to ISO 5660.1 or AS/NZS 3837 (if appropriate for building height/occupancy). • Entire external wall cladding system to be tested in full-scale façade fire test to BS 8414-1, 2, or NFPA 285 (not recommended due to lesser severity) to achieve specific fire performance (BR 135 or EW classification in accordance with AS 5113).

Besides the common design solutions outlined in Table 9.2, when designing fire safety of mass timber buildings, the fire engineer should consider additional fire spread risks due to:

- The extent of non-encapsulated timber surfaces when the fire engineer adopts the limited area encapsulation strategy or partial encapsulation strategy. Significant, continuous timber surfaces exposed from the start of fire, or after the fall-off of encapsulation, will contribute towards fire severity which affects the design and construction of fire separations.
- The orientation of exposed timber surfaces. Closely spaced exposed timber surfaces e.g. corner configuration might exacerbate the adverse impacts of fire spread.
- The location of exposed timber surfaces e.g. in occupied spaces, safe paths, protected services shafts, or behind battened ceilings or walls etc. Certain locations might introduce additional fire safety challenges for fire detection and firefighting.
- The delamination of cross laminated timber (CLT) during fire if non-fire rated adhesive is used. Delamination of CLT can provide additional fuel to a fully-developed fire which will exacerbate internal and external fire spread as well as prolong the fire duration.
- The interface of timber with metallic building elements. Metal in contact with timber will accelerate the thermal wave propagation into the timber thus enhancing charring and reducing timber structural capacity.
- Extended façade exposure (temperature and heat flux) from compartment fires containing significant, continuous exposed timber surfaces, due to the prolonged fully-developed burning phase.

9.2.3 Construction tolerances

[Nothing to add]

9.3 Fire spread via separating elements, joints and junctions

9.3.1 Fire resistance of separating elements

Depending on the chosen compliance pathway according to the Design Flowchart in Appendix A, the fire engineer should evaluate the suitable FRR for mass timber separating elements and determine the suitable type (full or partial) and extent (complete or limited area) of encapsulation for mass timber fire separations. The following notes are important design information for post-flashover fire severity analysis:

- New Zealand and Australian mass timber manufacturers have product literature which demonstrates the FRR achieved by mass timber walls and floors during a standard ISO 834 fire test, in accordance with AS 1530.4 or NZS/BS 476-21 and 22 (XLam, 2020; Red Stag Wood Solutions, 2022).
- For floors, the fire stopping is normally detailed to mitigate fire threat from the underside. For exposure from above the floor, the prescriptive approach in the Supplement in Appendix A and BRANZ Study Report 117 (Whiting, 2003) are recommended.

9.3.2 Fire resistance of joints between structural elements

Some gaps will occur at joints between elements during construction, often related to construction tolerances. Even with tight-fitting elements, a gap could grow in width after installation due to timber shrinkage or building movement.

Regarding fire resistance of joints and gaps between timber elements, it is essential to distinguish between “open gaps” and “closed gaps”. Open gaps must never be present in a fire resisting wall or floor, because an open gap will cause an immediate integrity failure, rapid fire spread through the gap, and charring of exposed timber surfaces.

Closed gaps are those where there is no path for spread of flames or hot gases. If closed gaps are less than 5 mm wide there will be no flow of hot gases into the gap, hence no extensive charring. For example, Figure 1 shows charring patterns after fire resistance tests on glulam beams with gaps larger and smaller than 5 mm.

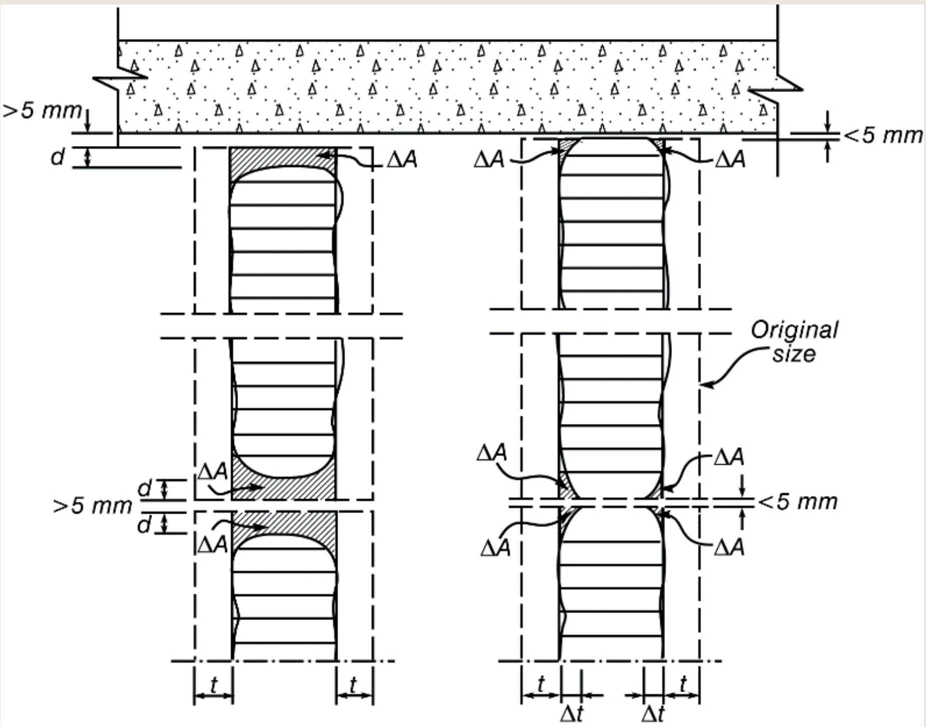


Figure 1. **Effect of gap width on charring of glulam beams (from Carling, 1989)**

See the Global Design Guide, Section 9.3.2, Figures 9.2 and 9.3, also Table 9.1 for details of fire stopping of several types of joints between structural elements.

Figure 2 below is similar to Figure 9.3 (a) in the Global Design Guide, showing a plywood spline between two mass timber floor panels. If the width of the gap (w) is less than 5 mm, charring is not expected in the gap or on the underside of the plywood spline.

If the gap width (w) is greater than 5 mm, or becomes greater than 5 mm, charring will occur in the gap and on the underside of the spline. If such a gap is not sealed, the minimum thickness (t) of the spline should be at least the calculated char depth d_{char} + 20 mm. Gaps can grow in width due to shrinkage during fire exposure, as internal moisture evaporates. This shrinkage can be more pronounced for parallel-laminated timber elements compared with cross-laminated elements because most shrinkage is perpendicular to the grain of the wood.

All gaps which are greater than 5 mm, or may become greater than 5 mm, wide should be filled with fire-resistant material which will retain its performance even if the gap width increases during the fire.

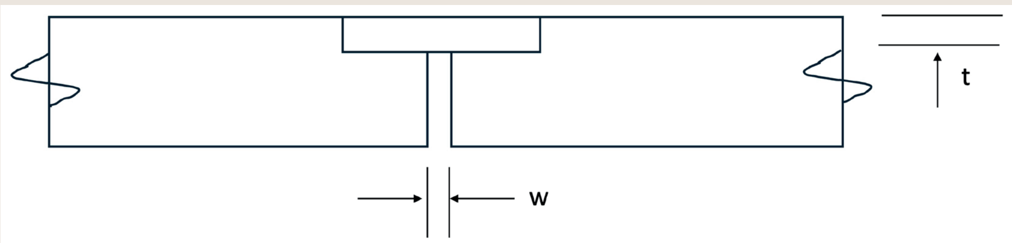


Figure 2. **Construction joint between two mass timber floor panels**

Even for tight-fitting surfaces, it is recommended to apply an intumescent sealant during construction. Figure 3 (a) shows construction of a joint between two mass timber panels using a rebated spline and intumescent sealant. Figure 3 (b) shows an integrity (burn-through) failure of a plywood spline in a fire resistance test.

(a)

(b)

Figure 3. **(a) example of a spline joint showing intumescent sealant. (b) an integrity failure in a plywood spline, observed during testing**

9.3.3 Seismic gaps

The protection of seismic gaps in construction may need consideration of specific materials and systems that have been tested to allow for sufficient movement and also allow for detailing with mass timber construction. Figure 4 shows a possible detail of a seismic gap.

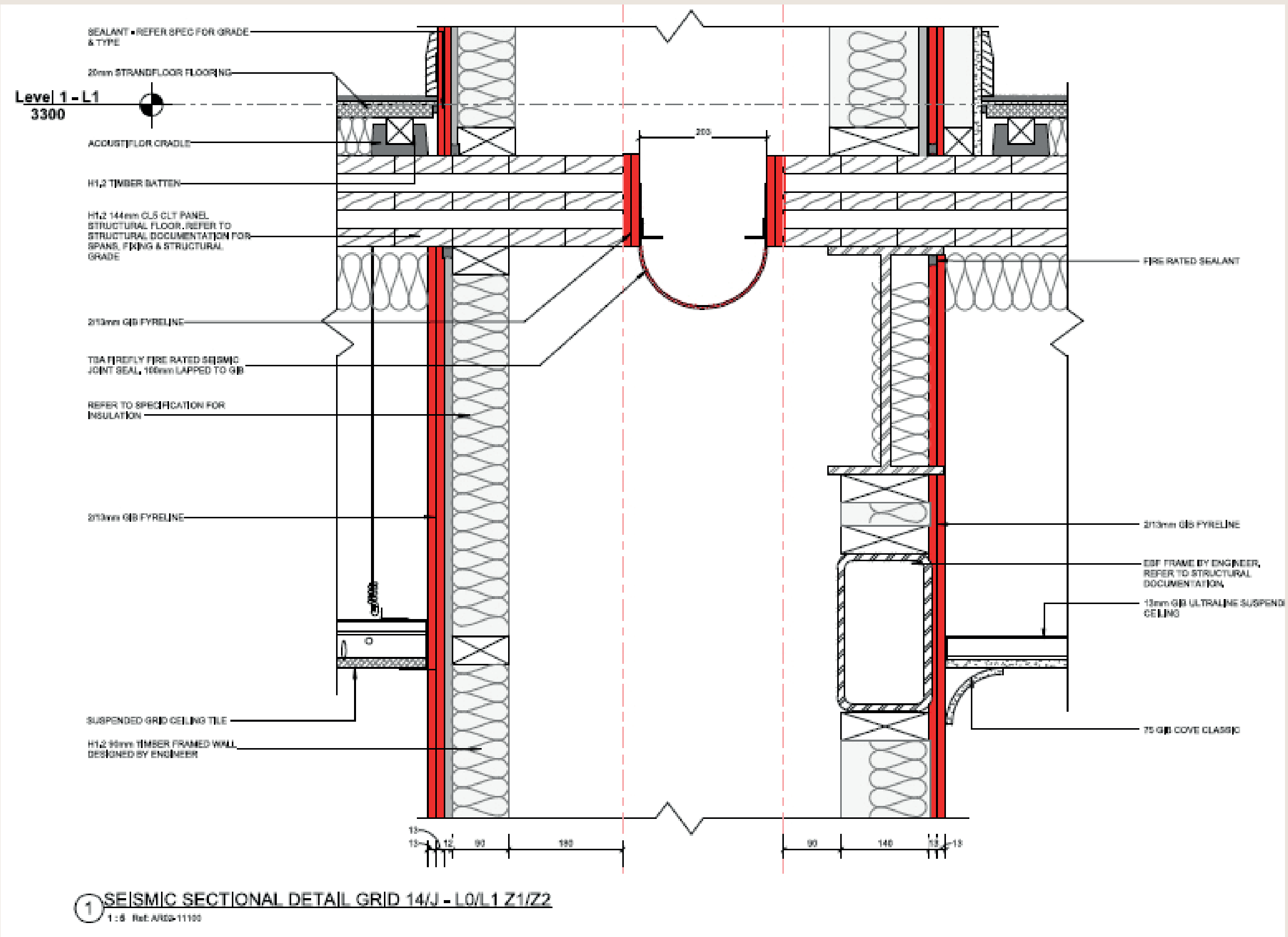


Figure 4. **Example of a fire separation allowing for seismic movement whilst maintaining the fire separation across a CLT floor**
Note: Illustrations of proprietary fire-stopping solutions do not endorse their use in this or any other situation.

9.3.4 Smouldering combustion in construction joints

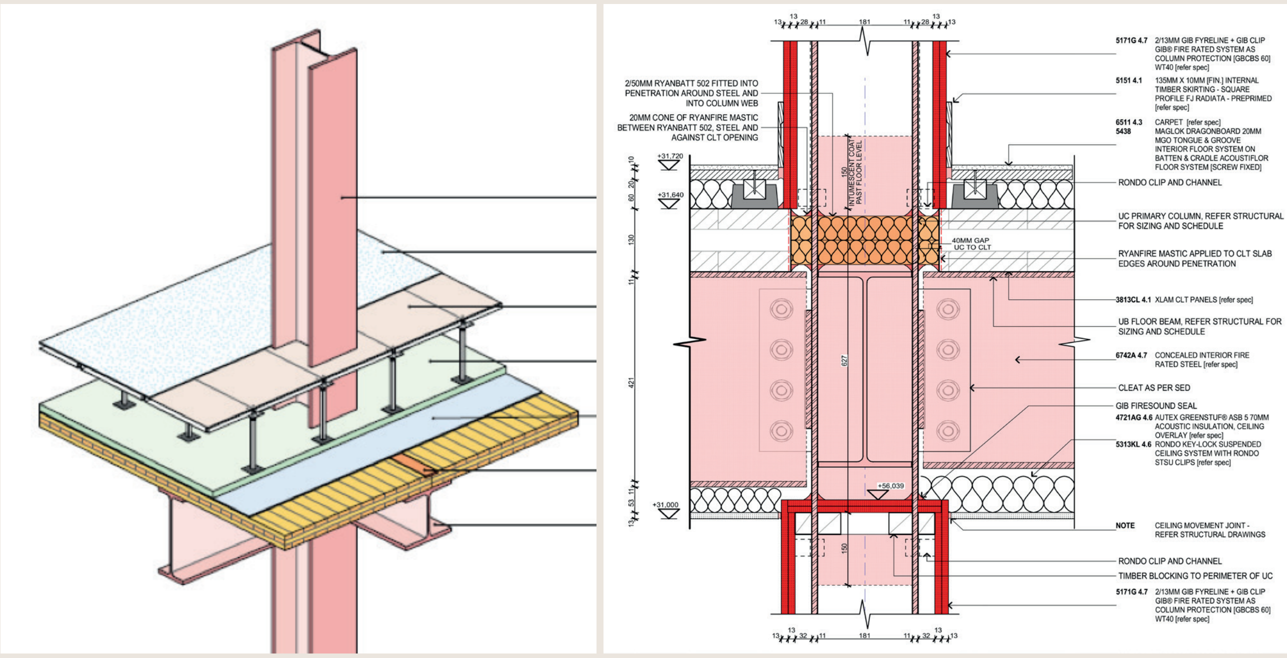
This is a new section, not included in the Global Design Guide. Inadequate firestopping can lead to fire spread inside construction joints, resulting in long-lasting smouldering combustion that is difficult to extinguish. A series of experiments conducted in Canada in 2022 (Su et al., 2023) involved the burning of a large two-storey structure constructed using mass timber elements. After one of the experiments, smouldering combustion was observed to continue for almost 3 hours in one of the beam-to-column connections. The smouldering combustion was not able to be extinguished even with hose water.

Therefore, an incomplete sealing of the construction joints can lead to smouldering occurring in hidden places that are difficult for suppression agents including water to reach. Smouldering combustion can lead to the weakening of structural members and pose serious life safety concerns for fire fighters and post-fire investigators. Thus, it is essential to mitigate against smouldering combustion by providing adequate firestopping, ensuring good installation and construction practices and facilitating fire service operations during and after the fire.

Complex junction details where different materials and structural elements intersect one another should be avoided where possible. Complex junctions require careful consideration and coordination to ensure the pathways for fire spread and heat transfer are fire stopped and the passive fire protection systems are compatible.

For example, Figure 5 shows a complex junction detail comprising a steel column penetrating a CLT floor supported by steel beams attached to the steel column. The CLT floor has been designed to remain non-encapsulated i.e. the suspended ceiling is non-fire-rated (not shown in Figure 3 (a)). A generic design solution involves a selection of passive fire protection products:

- Fire rated plasterboard system to protect the steel column below the suspended ceiling and above the floating floor, to maintain the required FRR (stability). This plasterboard is not shown in Figure 5(a).
- Fire rated intumescent paint system to protect the portion of the steel column within the ceiling space, and the steel beams, to maintain the required FRR (stability).
- Fire rated mineral batts as a cavity barrier to fire stop the irregular gaps within the CLT floor as a result of steel column penetration, to maintain the required FRR (integrity & insulation).
- Fire rated intumescent mastic to fire stop linear gaps between the different passive fire protection systems and fire rated elements, to maintain the required FRR (integrity & insulation).
- Overlapping of the key passive fire protection systems e.g. fire rated plasterboard system and fire rated intumescent paint system to ensure adequate protection against fire spread.
- Non-combustible floating floor on top of the CLT floor panels.



(a) (b)

Figure 5. **Design considerations for fire stopping of a complex construction junction; (a) junction comprising a through-floor steel column, steel beams and CLT floor panels (AISC, 2022) (b) generic design solution involving different fire stopping products and passive fire protection systems**

Note: Illustrations of proprietary fire-stopping solutions do not endorse their use in this or any other situation.

9.4 Fire spread via building service installations and penetrations

9.4.1 General requirements of fire-stopping building services

Fire stopping of services penetrations is vital in maintaining the continuity and effectiveness of fire separations. Due to the complexity of modern buildings, adequate design coordination between the fire engineer and other design disciplines is necessary to develop the design solution, and the early engagement of a passive fire protection engineer who is a suitably qualified expert on passive fire protection is necessary to ensure the practicality of the developed solutions.

Acceptable Solution C/AS2 Clause 4.4 presents the general requirements relating to fire stopping of service penetrations which are applicable for mass timber building design:

- FRR of the fire stopping system including the penetrations shall be no less than the FRR of the fire separation.
- FRR shall be ascertained by standard fire testing in accordance with AS 1530.4 or NZS/BS 476–21 and 22 and AS 4072.1.
- The installed fire stopping system shall be identical to the tested solution, in terms of penetration materials, penetration gaps and construction substrate.

For service penetrations through the encapsulation layer of mass timber assemblies, FPInnovation (Ranger et al., 2019) provides useful guidelines, including Figure 6, where fire stopping is required for:

a) Through penetration i.e. services penetrating the fire rated mass timber elements and the encapsulation layer (Figure 6(a), and
b) Partial penetration i.e. services penetrating the encapsulation layer, only where the encapsulation layer is contributing to the FRR of the overall mass timber assembly (Figure 9(b).

No fire stopping is required to the partial penetration of the encapsulation layer which does not contribute to the FRR of the overall mass timber assembly because the area occupied by the services penetrations are relatively small thus the limited charring of timber around the vicinity of non-fire stopped services penetrations is not expected to contribute excessively towards the fuel load and fire severity.

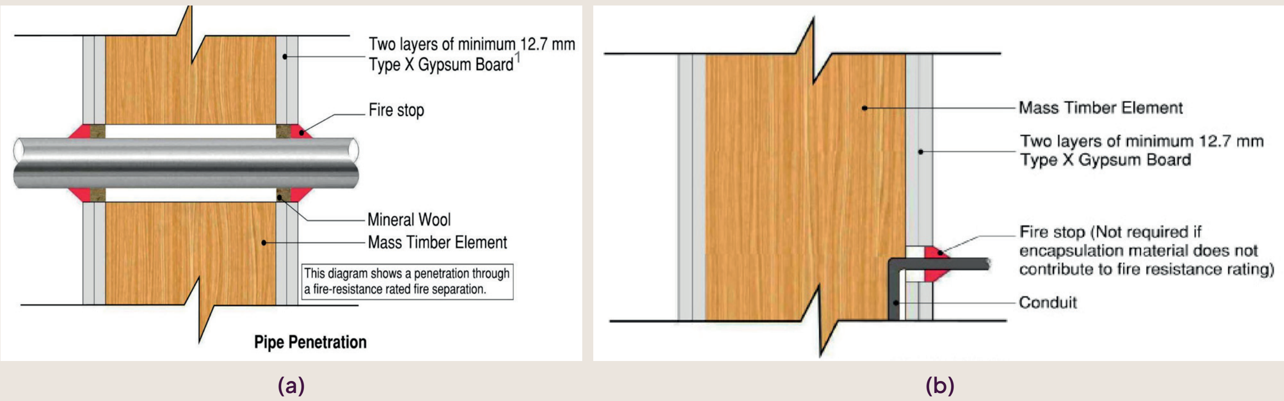


Figure 6. **Fire stopping to services penetrations involving CLT elements; (a) through penetration, (b) partial penetration**

Due to the similarities between various engineered wood products, the fire stopping products tested for a mass timber type could potentially be applicable for another, given the fire stopping products are able to perform similarly in event of a fire. The scope for interchanging applications should be clearly documented within product certification or be attained following technical consultation with relevant product suppliers (mass timber, fire stopping etc.). An accredited testing laboratory or a suitably qualified expert should be involved to ascertain the fire performance and to provide formal engineering justification.

While service penetrations through a complete fire rated mass timber floor require fire stopping to maintain the fire separation, the design solutions for a mass timber intermediate floor might be different depending on the chosen compliance pathway and the building risk profile i.e. escape height, building use e.g. care, sleeping, business etc. Some recommendations are provided below based on compliance pathway:

- Acceptable Solution C/AS2: Service penetrations through mass timber intermediate floors should remain fire stopped, unless sufficient engineering analysis could demonstrate that these penetrations do not compromise the load bearing capability of the intermediate floor, including its supporting structure.
- Verification Method C/VM2 and Alternative Solution: Services penetrations through mass timber intermediate floors must be fire stopped.

9.4.2. Concepts of fire protection to building services in multi-storey buildings

[Nothing to add]

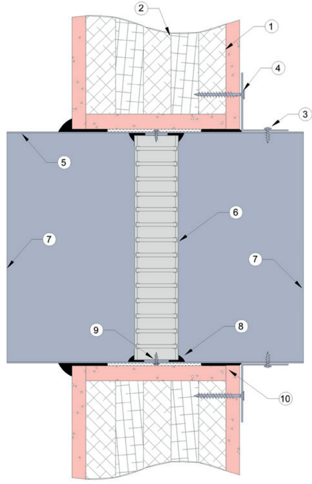
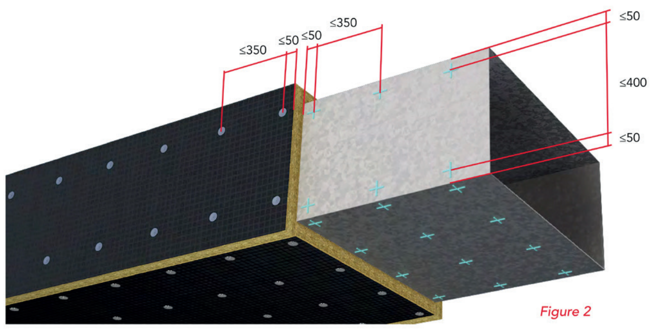
9.4.3. Types of building service installations

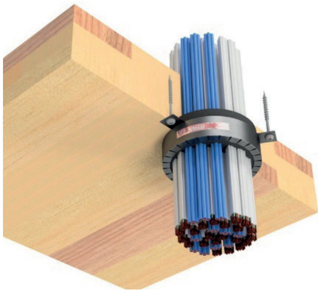
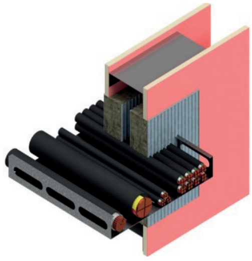
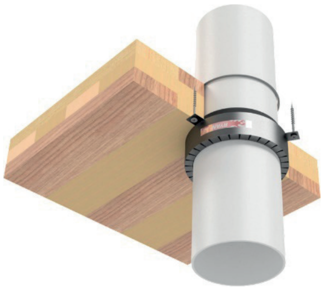
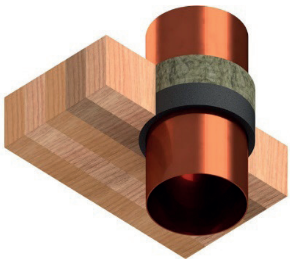
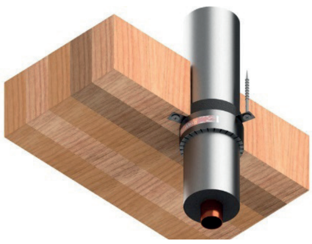
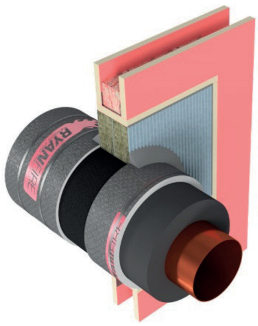
Many common fire stopping solutions for building services have been developed and tested for plasterboard and concrete substrates, so for their application in mass timber, early consultation with relevant experts is required to ensure suitability of the design solutions. Below are a few mass timber specific considerations:

- Ensure that the embedment of a fire stop's fasteners (e.g. fire rated collar, screws etc.) in mass timber are not detrimentally affected by charring of timber.
- Ensure a friction fitted fire stop (e.g. fire rated batt) will stay in place and not be affected by weakening and delamination of mass timber.
- Ensure an intumescing fire stop (e.g. fire rated intumescent sealant) will cope with movement due to surface shrinkage when mass timber chars and burns.

Table 3 outlines the generic fire stopping solutions for a few types of common services penetrations (Lorient, 2023; FIREPRO DuctRock Slab, 2023; Ryanfire, 2023).

Table 3. **Generic fire stopping solutions of different services penetrations, substrates, and wall or floor scenarios (Credit: Ryanfire (2023).**
Note: Illustrations of proprietary fire-stopping solutions do not endorse their use in this or any other situation.
[1]Refer to Section 9.4.4 of this Commentary for further details on cut-out fire stopping systems.

Type of service	Type of penetrations	Generic fire stopping solutions	Illustrations
Mechanical	Air handling systems	• Fire and smoke dampers • Refer to AS 1668.1:2015 for guidance	DESCRIPTION 1 13mm or 16mm fire rated plasterboard fixed to wall and aperture. 2 XLam CLT panel. Thickness: 85mm to 315mm. 3 Angles fixed to damper casing with steel fasteners at 150mm centres or at least 2 per side. 4 0.6mm (min) Z275 galvanised steel angles to all four sides. Angles shall be continuous and at least 2 x the dimension of the gap between the damper casing and the wall. Angles fixed to wall with 50mm long coarse thread screws at 150mm centres or at least 2 per side. 5 Z275 galvanised steel casing min thickness 0.6mm. 6 Lorient LVH44 intumescent fire damper. 7 Casing terminates with breakaway joints as per AS1682.2. 8 Fire damper perimeter sealed with Lorient intumescent sealant. 9 Fire damper fixed to casing with steel screws. 10 Gap between damper and aperture filled with Lorient Intumescent sealant.  Fire and smoke damper/encapsulated
	Kitchen exhaust system	• Fire rated encasement • Refer to AS 1668.1:2015 for guidance	 Fire rated encasement

Type of service	Type of penetrations	Generic fire stopping solutions	Illustrations
Electrical	Single cable/ cable bundles	• Fire rated collar with fire rated intumescent sealant (floor) • Mineral wool backing with fire rated intumescent sealant (floor) • Designated cut-out fire stopping system[1]	 Fire rated collar/cable bundle/ CLT floor
	Cable tray/ conduit	• Fire rated encasement • Refer to AS 1668.1:2015 for guidance	 Fire rated encasement
Hydraulic	Plastic (PVC, PB, PP, HDPE, PEX etc.)	• Fire rated collar with fire rated intumescent sealant (floor) • Mineral wool backing with fire rated intumescent sealant (floor) • Designated cut-out fire stopping system[1]	 Fire rated collar/PVC pipe/CLT floor
	Metal (copper, steel etc.)	• Mineral wool backing with fire rated intumescent sealant (floor) • Designated cut-out fire stopping system[1]	 Fire rated intumescent sealant/metal pipe/PLT floor
	Insulated metal	• Fire rated collar with fire rated intumescent sealant (floor) • Designated cut-out fire stopping system[1]	 Fire rated collar/insulated metal pipe/ PLT floor  Designated cut-out fire stop/ insulated metal pipe/plasterboard wall

9.4.4. Penetration fire-stopping systems for walls and floors

If penetrations through a mass timber substrate are yet to be tested or where there are multiple services penetrations of different types and materials e.g. electrical and hydraulic, metal and plastic etc., passing through a fire rated construction, some of the individually tested solutions in Table 3 might not be applicable.

Under these circumstances, a designated cut-out within the fire rated wall or floor is often formed, which is replaced by a tested, non-combustible substrate that would contain all the services penetrations protected by relevant fire stopping products, as shown in Figure 9.6 of the Global Design Guide. A list of solutions for services penetrations passing through fire rated construction can be found in the NZFPA passive fire protection register (NZFPA, 2021).

Insulation ratings are intended to limit the transmission of heat through a specimen and are one component of the FRR of containment elements. However, C/AS2 requires no insulation ratings in certain circumstances, such as for sprinkler protected buildings where only the integrity rating applies, for non-load-bearing assemblies. The insulation criterion is also not required by C/AS2 for fire stopped penetrations if means are provided to keep combustible materials at a distance of 300 mm away from the penetration.

This can create a hazardous situation for mass timber buildings. Depending on the nature of the service penetration and type of fire stopping system used, thermal transmission through the fire-stopped penetration can cause accelerated charring and increased damage to the timber adjacent to the penetration, as shown in the photos below.

Figures 6 and 7 show increased local charring adjacent to pipe penetrations through a CLT floor panel, after a standard fire test in accordance with AS 1530.4. The floor panels have been inverted after the test. The pipe penetrations were protected by metal fire collars fixed in place by metal screws. The metal collar in Figure 6 has dropped out of the floor panel, and the collar in Figure 7 has remained in place; in both cases there is severe charring adjacent to the collar, caused by heat conduction through the metal collar.

Figure 6. **(Credit: E.Claridge)**

Figure 7. **(Credit: E. Claridge)**

Figure 8 shows ongoing burning behind a service penetration through a CLT wall panel at the end of a fire resistance test. Once a test is concluded the test specimen is usually removed from the furnace and any ongoing burning is extinguished manually. It is concerning that fire resistance testing does not consider whether combustible specimens will continue burning after the test has concluded, because timber substrates typically require application of water to extinguish the burning to prevent further charring.

Figure 8. **Ongoing burning behind a service penetration at the end of a fire test (Credit: E. Claridge)**

Figures 9 and 10 show damage caused by a metal plate and screw fixings compared with bare timber. The unprotected steel plate attracted heat from the fire and the screws provided increased temperatures inside the timber accelerating the charring. See Chapter 8 for more information on the fire resistance of timber connections.

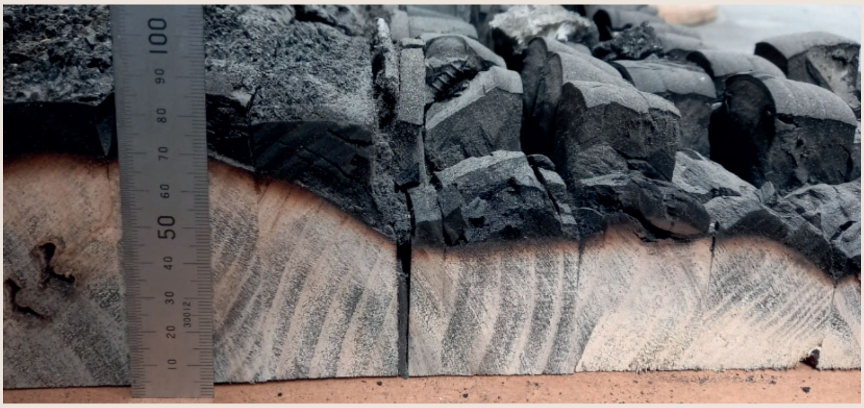


Figure 9. **Increased charring below a metal plate (cross section showing more charring on the right hand side where the steel plate was located). (Credit: E. Claridge)**

Figure 10. **Increased charring below a metal plate (plan view showing screw holes on right hand side). (Credit: E. Claridge)**

The testing of service penetrations using standard fire resistance testing does not consider the impact of increased charring due to the nature of the penetration or the substrate being tested. The condition of the substrate and its ability to perform after the test is also not considered with only the failure criterion of the testing regime being considered on the non-exposed side of the specimen. To mitigate these effects in the design of penetrations, the additional heat transmission impacts that may occur should be considered. Based on experimental performance, Ranger et al. (2018) provided the following general recommendations for service penetrations through mass timber construction:

- Ensure that annular width is no more than 25 mm as a larger offset is likely to dislodge fire stopping products during firefighting.
- Avoid spacing service penetrations closer than 100 mm together, due to enhanced lateral charring.
- Avoid service penetrations butting against timber which is vulnerable to charring.
- Apply adequate FR intumescent sealant at joints, corners, and where fire resisting door frames are inserted into mass timber walls.

9.4.5. Service installations embedded within building elements

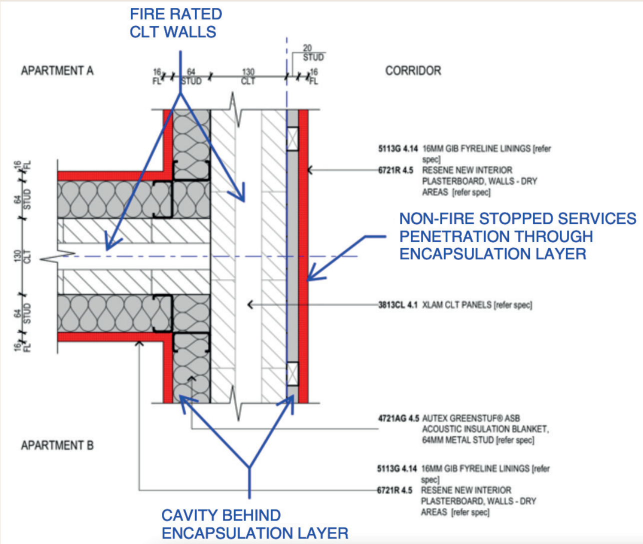
Building services can also be embedded within fire rated construction, and there are two design principles,

(1) Services passing through a cavity outside the fire-separating element, and

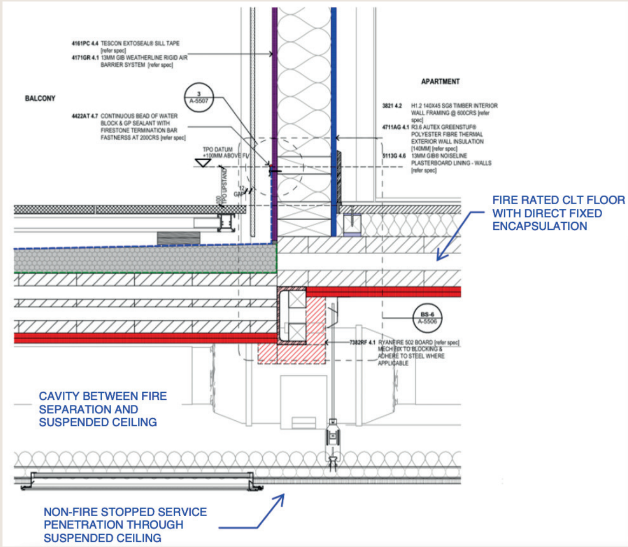
(2) Services embedded within the fire-separating element.

Option (1) is commonly encountered in mass timber residential building where wall or ceiling cavities provide thermal, acoustic and encapsulation performance. This cavity option results in a thicker assembly i.e. fire rated mass timber wall followed by cavity covered with a non-fire rated wall lining, replicated on both sides. See Figure 11.

In accordance with FPInnovation recommendations on partial penetration in Section 9.4.1 commentary, fire stopping is not required to service penetrations through a lining that does not contribute to the FRR. Common service penetrations include sprinkler heads, light fittings etc. within a suspended ceiling, and shower mixers and electrical fittings within a wall.



(a)

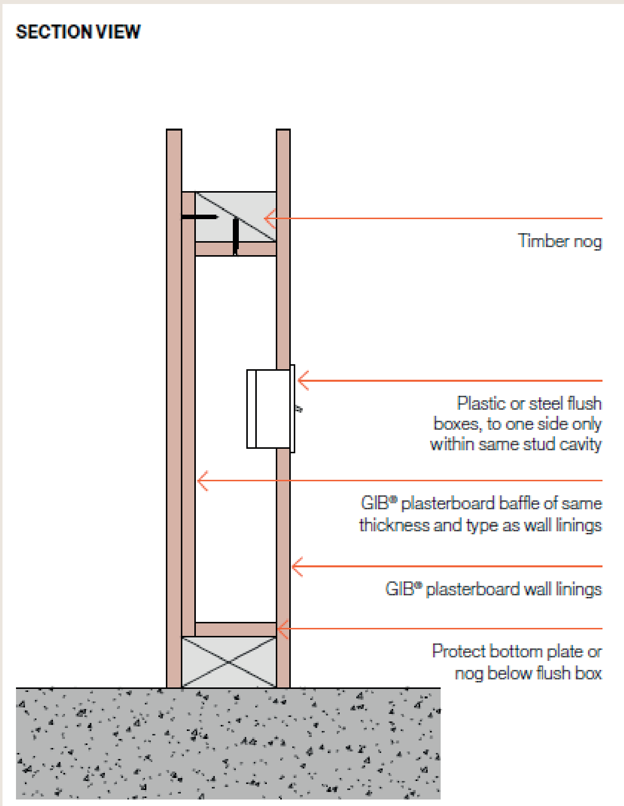


(b)

Figure 11. **Services passing through false cavity outside the fire-separating element; (a) wall scenario, (b) floor scenario**
Note: Illustrations of proprietary fire-stopping solutions do not endorse their use in this or any other situation.

Option (2) is commonly encountered in light timber-framed plasterboard construction and this requires fire stopping of all the service penetrations embedded within the fire separation. Common examples include electrical flush boxes within a fire rated wall, and recessed light fittings within a fire rated ceiling etc. Figure 12 shows traditional fire stopping solutions are applicable for these scenarios, including the application of steel flush box containing a fire-rated intumescent pad (Ryanfire, 2023), a fire-rated cover over light fittings, and a recessed fire-rated plasterboard box (GIB Fire Rated Systems, 2018) to receive a non-fire rated plastic electrical flush box.

(a)



(b)

Figure 12. **Services embedded within the fire-separating element; (a) fire rated intumescent pad involving electrical flush box, (b) fire rated boxing approach for large recessed electrical appliance (Credit: Winstone Wallboards Ltd.)**

9.4.6. Service installations within protected shafts and ducts

[Nothing to add]

9.4.7. Air ventilation ducts through walls and floors

AS/NZS 1668.1 (2015) provides some guidance on the application of fire dampers and smoke dampers (fire rated) for common air handling systems and the general design requirements for smoke control systems i.e. smoke exhaust systems, pressurisation systems etc. in a building. A brief non-comprehensive summary of requirements from the standard are provided below:

- Fire damper required on mechanical air handling ductwork penetrating fire separation; refer to Clause 3.2.1.
- Fire and smoke damper required on mechanical air handling ductwork penetrating fire separation, where the aggregate opening area exceeds 0.1 m^2 (classified as 'Major' exhaust or supply air systems); refer to Clause 7.2.3.
- The exhaust duct of a smoke exhaust system to be fire separated when passing through adjacent firecells; refer to Clause 3.7.1.
- Kitchen exhaust duct to be fire separated when passing through adjacent firecells; refer to Clause 6.2.4 and note that fire damper is not suitable for kitchen exhaust application.
- Air handling systems not required for fire safety is required to shut down on fire alarm; refer to Clause 7.2.

When installing fire and smoke dampers within a fire rated mass timber construction, direct thermal contact of the damper's metal casing on exposed timber surfaces could promote charring, and this should be avoided by having adequate insulation e.g. plasterboard and intumescent sealant, between the metal casing and timber, refer to the example in Table 3.

9.4.8. Elevated temperature exhaust system penetrations through walls and floors

[Nothing to add]

9.5 FIRE SPREAD VIA BUILDING CAVITIES AND VENTILATION GAPS

9.5.1. Main principles to prevent spread of fire and smoke

The NZBC Acceptable Solution C/AS2 and Verification Method C/VM2 and other guidance documents introduce a selection of traditional approaches for mitigating concealed space or cavity fire risks, including:

- Minimising combustibles and ignition sources within cavities (protected light timber framing is traditionally acceptable).
- 'Protect framing' requirements for external wall according to MBIE guidance document 'Fire performance of external wall cladding systems – Revision 2: 2020' (MBIE, 2020) to ensure that combustible framing and building insulation in cavities are adequately protected from fire with suitable lining materials.
- Passive fire stopping or cavity barriers to contain the fire spread in cavities where the fire stopping product should be:
  (1) Non-shrinking material to complete the fire separation or in a ventilated façade scenario. The use of a tested proprietary intumescent product which only expands during fire is acceptable, as seen in Figure 13; and
  (2) Compatible with mass timber, including the fixing method which will not cause premature failure i.e. avoid direct thermal contact between metal and timber.
- Sprinkler system to contain the fire spread in cavities.
- Providing early warning of fire using automatic heat detection in cavities.

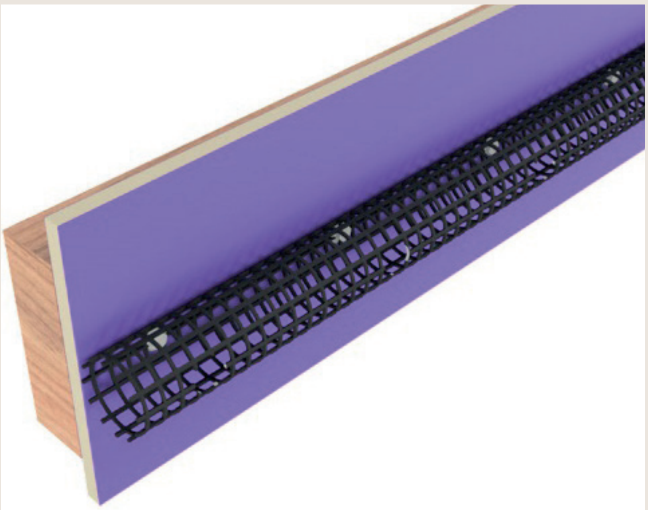


Figure 13. **Intumescent cavity barrier – A fire rated intumescent mesh fixed onto rigid air barrier in a ventilated cavity at the level of a timber floor (Courtesy Ryanfire, 2023)**

9.5.2. External and internal wall cavities and suspended ceiling spaces

This section of the Global Design Guide refers to hidden voids in construction which could provide vertical or horizontal pathways for spread of smoke and fire. Wall cavities are normally protected by passive fire protection linings, as the cavities are unlikely to have sprinkler-protection, even in a sprinklered building.

Suspended ceiling cavities must never extend through a fire separation into another firecell. Ceiling cavities in New Zealand are often subdivided into smaller spaces to prevent uncontrolled fire spread. Sprinkler protection in a concealed ceiling space is typically only provided when required by the sprinkler standard.

Encapsulation in suspended ceiling cavities is covered in Section 6.9 of this Commentary.

9.5.3. Cavities between elements of modular construction

[Nothing to add]

9.6 Vertical fire spread in exterior façade cavities

Externally exposed timber cladding is uncommon in multi-storey buildings in New Zealand due to difficulties achieving the required 50-year durability. In addition, it can generally be assumed that non-coated/treated timber products will ignite within 15 minutes if exposed to a radiant flux of 30 kW/m² thus exposed timber products would typically not meet the performance criteria in Clause C3.7 of the NZBC for external walls located closer than 1 m to the relevant boundary.

In New Zealand, multi-storey mass timber buildings often have a non-timber external cladding system over the timber surfaces to achieve acceptable fire performance, and to 'protect framing' as per reference needed to MBIE 2020. A mass timber exterior wall surface is typically covered by a non-combustible rigid air barrier (RAB) or similar, and the ventilation cavity protected by either tested fire-rated intumescent bar-type or mesh-type fire stopping products (as discussed above in Section 9.5.1) to allow for air flow and moisture migration under normal circumstances. For ease of installation, timber battens are typically fixed through the RAB to the mass timber wall system to receive the cladding materials. These battens constitute a limited amount of combustible fuel and are not expected to contribute significantly towards vertical fire spread.

9.7 Vertical fire spread between unprotected openings

This section has been added to the Commentary. It does not appear in the Global Design Guide.

Re-radiation between parallel surfaces and the channelling effect of hot smoke within an exterior façade cavity are the primary factors driving vertical fire spread via a façade cavity. Besides possible vertical fire spread in a façade cavity, vertical fire spread can also occur by failure of 'unprotected areas' of the external wall e.g. leap-frog effect from non-fire rated windows to the floor above, which is mitigated by other means such as fire-rated aprons or spandrel construction, or provision of a suppression system etc.

9.7.1. Effect of sprinklers

The installation of a sprinkler system is commonly considered reasonable protection to mitigate vertical fire spread via unprotected external areas of a multi-storey building. The use of a suppression system is often preferred over fire rated construction involving aprons and spandrels due to the latter's notable impacts on the building's appearance and functionality. While an internal sprinkler system may have limited effect on an external fire, it is expected to reduce the probability of a severe fire developing within the building that could contribute to external fire spread.

9.7.2. Estimating flame height

Hopkin and Spearpoint (2021) have developed an empirical approach to estimate the flame height from a partially encapsulated mass timber compartment based on compartment fire experiments investigating (1) burning rate versus combustible surface area, and (2) flame height versus total heat release rate for different ventilation area. Based on the calculated flame height, suitable apron and spandrel size to mitigate vertical fire spread could be designed as illustrated in the subsequent Worked Example.

Research on façade fires involving mass timber compartments is relatively new and some general findings from the current literature are summarised below:

- More intense external flaming due to additional unburned pyrolysis gases combusting outside the compartment (Maag and Fontana, 2000; Hakkarainen, 2002; Épernon Fire Test 2020).
- Increased heat release rate of fire both inside and outside of the compartment, and increased gas temperature and heat flux on façade (Hakkarainen, 2002; Su and Lougheed, 2014; Hadden et al., 2017; Épernon Fire Test, 2020; Kotsovinos et al., 2022; Sjöström et al., 2023; Engel and Werther, 2023).
- Extended fully-developed phase of the compartment fire (Hadden et al., 2017; Su and Lafrance, 2018; Sjöström et al., 2023; Engel and Werther, 2023).

9.7.3. Summary

Currently, the overall impact of a mass timber compartment on vertical fire spread risk remains inconclusive given the limited findings and on-going research. The benefits of sprinklers and encapsulation which are frequently adopted in fire safety design have also not been thoroughly investigated or quantified as the reported compartment fire experiments involved mostly exposed timber surfaces without suppression. Lastly, recent research outcomes from Engel and Werther (2023) and Sjöström et al. (2023) suggested that external fire spread, specifically plume height, is influenced more by external variables such as wind rather than the exposed mass timber area within the compartment. However, other factors such as compartment geometry and asymmetry may also be factors.

9.7.4. Worked examples

Worked example 1 – Determination of flame height above ventilation openings

Building Description

3–storey office compartment with concrete floor/walls and CLT ceiling. The building description was taken from an experiment undertaken in a large purpose-built facility in 2021, known as CodeRed #01 (Kotsovinos et al., 2022). However, a few modifications were made to the original CodeRed #01 building such as the number of storeys, the number of windows, and the window dimensions.

Firecell parameters are:

- Firecell of interest located on Level 1 i.e. above ground floor.
- Firecell is non-sprinkler protected.
- Firecell dimension, 34.3 m length × 10.3 m width × 3.1 m height.
- Multiple windows of 2.2 m height and combined 7.2 m total width.
- 100% CLT ceiling (353 m²) and 2 Glulam columns (10 m²) are non-encapsulated.

Procedure:

Refer to Hopkin and Spearpoint (2021) for a full description of the procedure including limitations.

Evaluate the pyrolysis rate of the CLT compartment fire $(\dot{m}_p)$, which is a function of the non-encapsulated CLT area (A_{CLT} = 363 m²), total compartment surface area (A_t = 983.1 m²) and ventilation characteristics i.e. ventilation area (A_v = 15.8 m²) and height (h_v = 2.2 m).

$$\dot{m}_p = 0.1\left(1 - \frac{A_{CLT}}{A_t}\right)e^{\left(\frac{8}{3}\right)\left(\frac{A_{CLT}}{A_t}\right)}A_v\sqrt{h_v}$$

$$\dot{m}_p = 0.1\left(1 - \frac{363}{983.1}\right)e^{\left(\frac{8}{3}\right)\left(\frac{363}{983.1}\right)}15.8\sqrt{2.2} = 4.0\ kg/s$$

Evaluate the global equivalence ratio (Φ), which is a function of A_{CLT} and A_t.

$$\emptyset = 1.14\left(1 - \frac{A_{CLT}}{A_t}\right)e^{\left(\frac{8}{3}\right)\left(\frac{A_{CLT}}{A_t}\right)}$$

$$\emptyset = 1.14\left(1 - \frac{363}{983.1}\right)e^{\left(\frac{8}{3}\right)\left(\frac{363}{983.1}\right)} = 1.9$$

Evaluate the external pyrolysis rate of the CLT compartment fire ($\dot{m}_{p,ext}$) i.e. burning outside of compartment, which is a function of Φ and $\dot{m}_p$.

Evaluate the dimensionless flame height from the compartment openings (Z^*), which is a function of the complete heat of combustion of fuel (ΔH_c = 19,000 kJ/kg) i.e. mostly wood, ambient air characteristics i.e. density (ρ_∞ = 1.2 kg/m³), specific heat (c_p = 1.0 kJ/kgK) and temperature (T_∞ = 293 K), gravitational acceleration (g), and characteristic length ($\ell = \left(A_v\sqrt{h_v}\right)^{2/5}$) i.e. a function of ventilation characteristics.

$$Z^* = \frac{Z_f}{\ell} = 2.0\left(\frac{\dot{m}_{p,ext}\,\Delta H_c}{\rho_\infty c_p T_\infty \sqrt{g}l^{5/2}}\right)^{3/5}$$

$$Z^* = 2.0\left(\frac{1.9 \times 19000}{1.2 \times 1.0 \times 293 \times \sqrt{9.81} \times 15.8\sqrt{2.2}}\right)^{3/5} = 2.5$$

Based on Equation (9–4), the flame height relative to neutral plane (*Zf*) can be evaluated from *Z** and *ℓ*. For this worked example, $Z_f = 2.5 \times \left(15.8\sqrt{2.2}\right)^{2/5} = 8.8\ m$. Assuming the neutral plane is at half-height of the windows, the flame height relative to the top of the windows is $Z_{op} = 8.8 - 1.1 = 7.7\ m$.

In absence of sprinkler protection to control or suppress the fire, the estimated flame height above the opening, 7.7 m is significant and unlikely to meet the performance outlined in NZBC C-Clauses. The Fire Engineer could consider a number of design options to reduce the flame height which includes:

- Without implementing sprinklers, size an apron (horizontal fire rated projection) to limit flame height to no more than 3.5 m, and provide additional spandrel protection if required based on the reduced flame height.
- Increasing the extent of encapsulation for CLT ceiling and columns, to lower ACLT.
- Include sprinkler protection to control vertical fire spread.

Worked example 2 – Determination of horizontal fire spread to relevant boundary

Building Description

Same building as the building used in 9.7.4 worked example 1 with the following additional information:

- The objective is to determine if the NZBC Clause C3.6 requirement for radiation received in relation to the relevant boundary is met for the intended design.
- The relevant boundary is located 7 m from the south external wall of the building.
- The south side, level 1 of the building has multiple windows with an enclosing rectangle area of 20 m² (10 m width x 2 m height). Refer to Verification Method, C/VM2 on guidance on how to determine the enclosing rectangle dimensions.

(Note: the information mentioned here is not according to the CodeRed #01 experiment)

Procedure:

Using the Chapter 3 recommendation based on Glew et al (2023), an emitted radiation heat flux of 267 kW/m² (based on an emitter temperature of 1200 °C) is applied to the enclosing rectangle area.

Evaluate the configuration factor (F_{12}) and the received radiation flux ($\dot{q}''_{received}$) at the relevant boundary. F_{12} is a function of the height (a = 2 m) and the width (b = 10 m) of the enclosing area, and the distance to the relevant boundary (c = 7 m). $\dot{q}''_{received}$ is a function of F_{12} and the emitted radiation flux at the window ($\dot{q}''_{emitted}$=267 kW/m²).

$$X = \frac{a}{2c} = \frac{2}{2(7)} = 0.14$$

$$Y = \frac{b}{2c} = \frac{10}{2(7)} = 0.71$$

$$F_{12} = \frac{2}{\pi}\left[\frac{X}{\sqrt{1+X^2}} tan^{-1}\frac{Y}{\sqrt{1+X^2}} + \frac{Y}{\sqrt{1+Y^2}} tan^{-1}\frac{X}{\sqrt{1+Y^2}}\right] = 0.10$$

$$\dot{q}''_{received} = F_{12} \times \dot{q}''_{emitted}$$

$$\dot{q}''_{received} = 0.10 \times 267 = 26\frac{kW}{m^2}$$

Evaluate the configuration factor and the radiation received at 1 m beyond the relevant boundary (c = 8 m).

$$X = \frac{a}{2c} = \frac{2}{2(8)} = 0.13$$

$$Y = \frac{b}{2c} = \frac{10}{2(8)} = 0.63$$

$$F_{12} = \frac{2}{\pi}\left[\frac{X}{\sqrt{1+X^2}} tan^{-1}\frac{Y}{\sqrt{1+X^2}} + \frac{Y}{\sqrt{1+Y^2}} tan^{-1}\frac{X}{\sqrt{1+Y^2}}\right] = 0.08$$

$$\dot{q}''_{received} = F_{12} \times \dot{q}''_{emitted}$$

$$\dot{q}''_{received} = 0.08 \times 267 = 21\frac{kW}{m^2}$$

The current configuration of the apartment building does not meet the performance requirements outlined in NZBC C-clauses. A Fire Engineer could consider a number of design options to limit the radiation flux received at the relevant boundary, which includes:

- Limit the area of the unprotected opening on the south side of the building on level 1 by fire rating the external glazing to reduce the enclosing rectangle area (C/VM2).
- Fully encapsulate the entire CLT ceiling and all the Glulam columns on level 1.
- Install sprinklers to reduce the subsequent emitted radiation from the external windows of level 1.

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Chapter 10
Active fire protection by sprinklers

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10. Active fire protection by sprinklers

Scope of chapter

This chapter is complementary to Chapter 10 of the Global Design Guide, which should be read alongside this Commentary.

This chapter discusses the role of sprinklers for active fire protection in mass timber buildings, with reference to the New Zealand Building Code (NZBC) and New Zealand Standards, as an extension to Chapter 10 in the Global Design Guide. As mass timber buildings become larger, taller and more complex, it is essential to improve sprinkler system effectiveness as far as possible. Possible solutions are described in this chapter.

10.1 General concepts of active fire protection

In New Zealand the term 'fire protection systems' normally refers to the:

- Fire detection and warning system (the fire alarm system)
- Fire sprinkler system (and other fire suppression systems)
- Fire hydrant systems

These systems are normally installed in accordance with the respective New Zealand standards NZS 4512, NZS 4541, and NZS 4510.

Smoke control systems for stairwell pressurisation and smoke exhaust systems are other active fire safety systems, but these are not covered in this chapter.

For buildings designed in accordance with the Acceptable Solution C/AS2, the standards for fire protection systems are prescribed by that Acceptable Solution and specific versions are cited (referenced by date of publication).

For buildings designed in accordance with the Verification Method C/VM2, NZS 4541 or NZS 4515 are prescribed as a specific standard for protection of a place of safety inside a building. Elsewhere, the Verification Method refers to automatic sprinkler systems to be installed to an appropriate standard without prescribing a specific version. The New Zealand Standards NZS 4541 or NZS 4515 are acknowledged to be appropriate standards in this context.

For some buildings NFPA standards are used for automatic sprinklers and other fire suppression systems. However, for most building designs the fire sprinkler systems are installed in accordance with NZS 4541.

Hydrant systems need to be installed in accordance with NZS 4510 for compatibility with FENZ firefighting equipment. Fire hydrant systems are not discussed further in this Chapter.

10.2 Detection, alarm and smoke management systems

The New Zealand fire alarm Standard NZS4512 is specified for almost all buildings requiring a fire detection and alarm system in New Zealand.

10.3 Sprinkler systems

10.3.1 Objectives of sprinkler systems

Sprinkler systems for most building installations in New Zealand have a universal objective to activate and control fire growth while a fire is small, minimising the damaging effects of the heat and smoke generated by the fire. In many cases, the sprinkler system may be effective in suppressing and extinguishing a fire, although this is not usually stated as a primary objective.

Some sprinkler systems, such as sprinkler systems for limited area sleeping occupancies installed in accordance with NZS 4515 and sprinkler systems for houses installed in accordance with NZS 4517, are installed with a specific objective to control a fire to allow increased time for evacuation. These systems may have reduced water supply requirements, less extensive sprinkler coverage requirements and less expensive maintenance requirements to encourage installation in the appropriate buildings. These design and operation differences can result in an increased likelihood of subsequent property damage if the fire is not controlled effectively by sprinkler operation and is able to grow in spite of sprinkler operation.

10.3.2 Components of sprinkler systems

[Nothing to add to the Global Design Guide]

10.3.3 Wet-pipe and dry-pipe fire sprinkler systems

[Nothing to add]

10.3.4 Residential fire sprinkler systems

[Nothing to add]

10.3.5 Water mist systems

[Nothing to add]

10.3.6 Sprinklers in earthquake areas

It is essential that sprinkler systems are designed so that there is no mechanical failure due to earthquake shaking. Sprinkler systems in New Zealand buildings, like all building services, are required to be braced to the building structure to resist serviceability design level earthquake forces without damage. The design forces for seismic restraint are linked to the building Importance Level.

A signficant risk in earthquake areas is possible loss of the city water supply due to pipe damage. This can be overcome in some cases by providing an independent on-site water supply, possibly a swimming pool or a suitable supplementary water tank.

10.4 Sprinkler effects on fire safety

There is little doubt that when sprinklers operate, they are highly effective in controlling fire growth, limiting fire spread and in many cases suppressing and extinguishing fires rapidly, substantially reducing the fire threat to people inside the building. Even in cases where the sprinkler system operation results in localised reduced visibility due to production of steam or smoke logging due to entrainment of soot in sprinkler water spray, these effects do not adversely influence the performance of mass timber elements in buildings.

Any concerns about the effectiveness of sprinkler operation following an outbreak of fire are almost always focussed on sprinkler reliability rather than sprinkler efficacy. See Section 10.5 below.

10.4.1 Effects on fire development

[Nothing to add]

10.4.2 Property protection by sprinklers

[Nothing to add]

10.4.3 Life safety by sprinklers

[Nothing to add]

10.4.4 Cost-benefit analysis

[Nothing to add]

10.5 Sprinkler system effectiveness

The effectiveness of any fire protection system is a function of two inputs: reliability and efficacy.

1. Reliability is the probability that it operates as intended to, when required to do so.
2. Efficacy is the probability that it achieves its performance objective when it operates (hence efficacy is a function of performance objectives).

Effectiveness is the product of reliability and efficacy. The effectiveness of a sprinkler system is therefore directly related to specific performance objectives. Enhancing the system reliability (such as improving the reliability of sprinkler water supply) does not improve the efficacy (although it does improve overall effectiveness).

For sprinkler systems, efficacy can be defined for a range of possible design objectives, including:

- On sprinkler operation, fire is controlled to an extent that conditions in the enclosure of fire origin remain tenable.
- On sprinkler operation, fire is controlled to an extent that conditions beyond the enclosure of origin remain tenable (i.e. the control of fire temperature and toxicity is such that even with smoke spread, the conditions remain tenable in immediately adjacent firecells e.g. fire protected stairways or corridors.
- On sprinkler operation, fire is controlled to an extent that internal vertical fire spread is prevented (regardless of tenability conditions in the floor of fire origin).
- On sprinkler operation, fire is controlled to an extent that external horizontal and/or vertical fire spread is prevented (regardless of tenability conditions in building).
- On sprinkler operation, fire is controlled to an extent that fire temperature and heat transfer to structure are controlled to levels below threshold values above which structural material strength or stiffness reduces (regardless of tenability conditions in the building).

Consideration of sprinkler system effectiveness for the last design objective in this list depends on the type of structural material and the relevant threshold values above which structural material strength or stiffness reduces.

10.5.1 Sprinkler system reliability

Although the basic components of wet-pipe automatic sprinkler systems are more or less the same around the world, specific details of system design, operation and maintenance vary in different countries. In New Zealand, there are several aspects of sprinkler system design, operation and maintenance which significantly improve the system reliability (Feeney, 2001). Some of these differences are unique to New Zealand sprinkler systems. They impact on both sprinkler system reliability and effectiveness.

Sprinkler systems in buildings where the pressure in a reticulated main water supply is sufficient to operate the sprinkler system without needing a booster pump have very few moving parts. This applies to buildings up to around 20 metres high. The network of sprinkler pipes, valves and sprinkler heads, the continuous automatic monitoring of system water pressure and valve open status, and the simple operation in event of fire is collectively a very reliable system. The parts of the system that have most potential to reduce system reliability are reductions in pressure of the city water supply system, lack of available water due to supply network impairment, temporary sprinkler isolation to allow for system alterations, or inattention to the consequences of building alterations on sprinkler system performance.

For taller buildings where sprinkler booster pumps are needed, or where system design or operation is more complex (e.g. the system has more valves or covers a large area and is therefore more vulnerable to increased frequency of isolation for alteration) sprinkler system reliability reduces.

The performance requirement of NZBC Clause C3.9 requires buildings to be designed with regard to the likelihood and consequence of failure of any fire system intended to control fire spread. Code Clause C6.2 requires building to be designed taking into account the likelihood and consequence of failure of any fire system that affects fire severity and its impact on structural stability. These clauses apply to automatic sprinkler systems. For this reason, the high probability that a sprinkler system will be effective in controlling the consequence of a fire in a building can be factored into the building fire design.

However, the possibility (a low probability) of a sprinkler system failing to operate as designed must also be considered. The NZBC documents C/AS2 and C/VM2 account for this possibility by requiring certain minimum fire safety features even where these are needed only in the event of an uncontrolled fire (i.e. consistent with accounting for a sprinkler system failure in sprinkler-protected buildings). This need to consider an unlikely scenario applies regardless of whether a building is constructed with non-combustible or combustible materials.

10.5.2 Sprinkler system efficacy

The effect of sprinkler operation on fire heat release rate and fire temperature has been measured in various full-scale fire experiments. For example, six fire tests were conducted in an open-plan office setup (Proe et al; Thomas, et al) to evaluate the response and suppression capability of sprinklers. The test set-ups were organised to maximise the effect of shielding, and pressure at the sprinkler was controlled to the minimum pressure prescribed by the sprinkler design standard. In all test cases the fire was extinguished and there was a rapid drop-off of several hundred degrees in air temperature within a period of a few minutes after sprinkler activation.

Where mass timber elements in buildings are part of a load-bearing structural system or provide a fire separation function, the performance of mass timber elements usually remains highly effective if the fire temperature does not exceed the temperature at which charring occurs (around 250 °C to 300 °C).

For a performance objective of controlling the effects of fire on the structural performance of mass timber elements, the efficacy of sprinklers is very high when the sprinkler system controls fire growth (heat release rate), fire spread (area involved) and temperature of the fire gases such that the wood surface temperature does not exceed 300 °C.

10.5.3 Sprinkler system management procedures

Sprinkler system management procedures influence sprinkler system effectiveness. The sprinkler system commissioning and maintenance requirements in NZS 4541 are specific to New Zealand and are generally more onerous than in other countries. Sprinkler system design in New Zealand is audited by an independent third party (Sprinkler System Certifier) and the installation is also verified independently for compliance with the sprinkler standard. Sprinkler system installation contractors and maintenance contractors are required to be approved and listed. Tests are conducted periodically for water flow, pump starting and pump operation. Key system components such as system standing pressure and closing of valves that impede water flow are continuously monitored electronically, with defect warnings appearing automatically on the national fire brigade monitoring system. Although these regular maintenance and compliance auditing requirements add cost to the commissioning and maintenance of the sprinkler system, they contribute substantially to the high level of reliability of sprinkler systems complying with NZS 4541.

Maintenance and compliance auditing requirements add cost to the commissioning and maintenance of the sprinkler system, they contribute substantially to the high level of reliability of sprinkler systems complying with NZS 4541.

The consequences of water damage to timber (durability, swelling, reduction in structural stiffness) in multi-level buildings may be greater in mass timber buildings than for buildings constructed without mass timber. Sprinkler system design should consider the benefits of installing monitored sprinkler isolation valves (installed at each floor level). After a fire is controlled firefighters can close these valves to reduce the length of time that water discharges from sprinklers and therefore limit the amount of collateral water damage in event of sprinkler operation. This benefit is achieved without needing to isolate the sprinkler protection to other floors in the building.

The consequences of water damage from the use of fire hydrants for firefighting operations is likely to be far more extensive than consequential sprinkler water damage, so it is always a better strategy to install sprinklers than to rely on manual firefighting if potential water damage is of concern.

10.6 Fire safety design with sprinklers

For buildings protected with an automatic sprinkler system the NZBC explicitly modifies the performance requirements for internal surface linings, the acceptance criteria for demonstrating adequate evacuation time for building occupants and access requirements for firefighters, regardless of structural material.

The installation of an automatic sprinkler system offers a number of other design and safety benefits as permitted by the NZBC and compliance documents, also regardless of structural material. The design and construction benefits in the NZBC documents include:

- Reduced requirements for structural fire resistance
- Lower fire resistance ratings for fire separations
- Relaxation of controls on horizontal external fire spread
- Less stringent acceptance criteria for assessing the impact of fire on occupants during their escape
- Less onerous controls on internal surface finishes
- Less onerous controls on vertical external fire spread

These benefits recognise the role that sprinkler systems play in achieving the NZBC functional requirements and the effectiveness of sprinkler systems to reduce the severity and likelihood of fires spreading beyond the enclosure of fire origin. Nevertheless, the risk and impact of potential system failure must be taken into account.

The NZBC explicitly recognises the positive influence of an automatic sprinkler system when designing a structure to remain stable during fire. The justification for reducing fire resistance ratings in buildings protected with an automatic sprinkler system is described in Chapter 12 of this Commentary .

10.6.1 Countries with sprinkler requirements for taller timber buildings

[Nothing to add]

10.6.2 Countries with alternative fire safety design with sprinklers

[Nothing to add]

10.6.3 Examples of reduced fire precautions with sprinklers

[Nothing to add]

10.7 Justification for reduced fire precautions with sprinklers

This section of the Global Design Guide gives justification for reducing the moveable fire load when sprinklers are installed in a building. See Chapter 12 of this Commentary for more discussion of the F_m factor in the NZBC document C/VM2.

10.8 Enhancements to improve sprinkler system effectiveness in mass timber buildings

As mass timber buildings become larger, taller and more complex, it is essential to improve sprinkler system effectiveness as far as possible. As discussed above, this can be done by improving the reliability and the efficacy of the sprinkler system, which is described below.

10.8.1 Enhancements to improve sprinkler system reliability

Routine sprinkler system surveys and reports on sprinkler system performance in actual fires give some insight into potential causes for sprinkler system unreliability. These include:

- Insufficient water flowrate available at source
- A sprinkler head is not present at the specific location of fire origin
- The sprinkler system has been disabled or isolated

Some of these causes relate to specific occupancy types (e.g. buildings in which frequent sprinkler alterations occur, such as for changes to tenancy fitout), or specific management practices (e.g. inadequate system maintenance). Addressing the most common reported system vulnerabilities does not necessarily result in a measurable improvement in performance in all buildings. Careful choice of appropriate measures to improve sprinkler reliability is required.

Options to improve sprinkler system reliability and resilience include:

- Require the sprinkler maintenance contractors to provide a clearly visible 'sprinklers isolated' tag to hang on the fire panel to indicate system shut-down for alteration or maintenance; the tag should identify the date when system isolation started and when it is expected to end; the tag needs to be hung in a location which minimises the likelihood of the system being left unnoticed in an impaired state for longer than necessary (similar to the 'remove before flight' tags used on aircraft).
- Carry out end-of-line testing as part of sprinkler system commissioning (at first installation).
- Install a 'life-safety' valve set for the main sprinkler valve set; this allows the principal valve set to be bypassed for maintenance without compromising water supply to the whole sprinkler system.
- Provide a source of supplementary water supply (e.g. water tank) as a back-up option to allow firefighter sprinkler boost; this improves system resilience in the event of loss of adequate water flow or water pressure, or failure of a booster pump to start when needed; this requires appropriate inlets, signs and coordination with firefighter access.

10.8.2 Enhancements to improve sprinkler system efficacy

Routine sprinkler system surveys and reports on sprinkler system performance in actual fires also provide some insight into potential causes for poor sprinkler system efficacy. These include:

- Insufficient water pressure
- Booster pump fails to start on demand
- Sprinkler type is not appropriate for the fire location (e.g. the sprinkler RTI or temperature rating)
- Sprinkler spray coverage is compromised (shielded sprinkler heads)
- Sprinkler is obstructed (storage of goods too close to sprinkler head)
- Sprinkler spacing or flowrate is inappropriate for the design hazard category in the fire location (e.g. change in use of the building)

Some of these causes relate to specific management practices (e.g. lack of sprinkler maintenance; excessive quantity of stored goods; storage too close to sprinkler heads, or changes in occupancy or classified use). In almost all cases, addressing inadequate management practices is one of the most cost-effective ways of improving sprinkler efficacy.

10.8.3 Options to improve both efficacy and resilience of sprinkler systems

Options to improve both efficacy and resilience of sprinkler systems include:

- Specify a minimum additional margin of at least 100 kPa for the sprinkler hydraulic design pressure (additional to the minimum margins already prescribed in NZS4541 between design pressure and measured available pressure at design flow). This is easier to implement for new installations than for retrofits, and it provides a margin over design optimisation which can leave almost no margin for supply pressure fluctuations over time and deterioration of system losses over time.
- Require the sprinkler system designer and installer to supply full and complete as-built documents at the end of system installation and commissioning. Require the main contractor to submit these and sign-off on audited as-built drawings and the Operation & Maintenance Manual as a record of as-built construction; this provides the building owner and future maintenance contractors with an accurate record of sprinkler design and installation which reduces the likelihood that alterations and maintenance to the system over its design life will drop below design threshold values.

Specific choices for sprinkler system enhancement to improve resilience of mass timber buildings in fire are discussed in more detail in Chapter 12.

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Chapter 11
Performance-based design and risk assessment

Authors: Colleen Wade, Ed Claridge, Martin Feeney, Greg Baker

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11. Performance-based design and risk assessment

Scope of chapter

This chapter is complementary to Chapter 11 of the Global Design Guide, which should be read alongside this Commentary. This chapter presents further information intended for New Zealand practitioners to supplement the content of Chapter 11 of the Global Design Guide. It gives an overview of the application of performance-based fire design in New Zealand.

11.1 Introduction

11.1.1 Performance-based design

MBIE has published a guide (MBIE, 2018) to help with developing alternative solutions for complying with the performance requirements of New Zealand Building Code (NZBC) clauses C1–C6 Protection from Fire (the fire clauses). The MBIE guide emphasises that it is essential to identify the relevant Building Code clauses, what approach will be used i.e. whether it is a departure from the Acceptable Solutions or Verification Method, or performance-based design, and to provide evidence that the relevant performance criteria are met.

For the purposes of the present document, performance-based design can be considered to be an alternative solution as discussed in the MBIE guide i.e. being all or part of a building design that demonstrates compliance with the Building Code but differs partially or completely from the relevant Acceptable Solutions (C/AS1, C/AS2) or Verification Method (C/VM2), as modified by the Supplement in Appendix A of this document.

Performance-based design is therefore considered to be those designs which are out of scope of the Supplement in Appendix A but which could nonetheless draw upon the guidance provided in the Global Design Guide and the associated chapter commentaries provided in this document.

The flowchart in Figure 1 gives a graphical representation of the major steps in deciding how to use the Supplement in Appendix A and to identify where a performance-based design solution will apply. The risk groups and the term 'escape height' are as defined in the Acceptable Solutions, i.e.

> *"The height between the floor level in the firecell being considered and the floor level of the required final exit which is the greatest vertical distance above or below that firecell. Where the firecell contains intermediate floors, or upper floors within household units the escape height shall be measured from the floor having the greatest vertical separation from the final exit."*

To use the flowchart in Figure 1 for a particular building, the fire engineer must decide which design approach is likely to be used for the fire design of the building. The occupancy and the escape height of the building will then indicate whether the Acceptable Solution C/AS2 or the Verification Method C/VM2 can be used with no change, or which recommendations of the Supplement in Appendix A can be used. Buildings which are out-of-scope will need to be designed with an alternative solution using performance-based design.

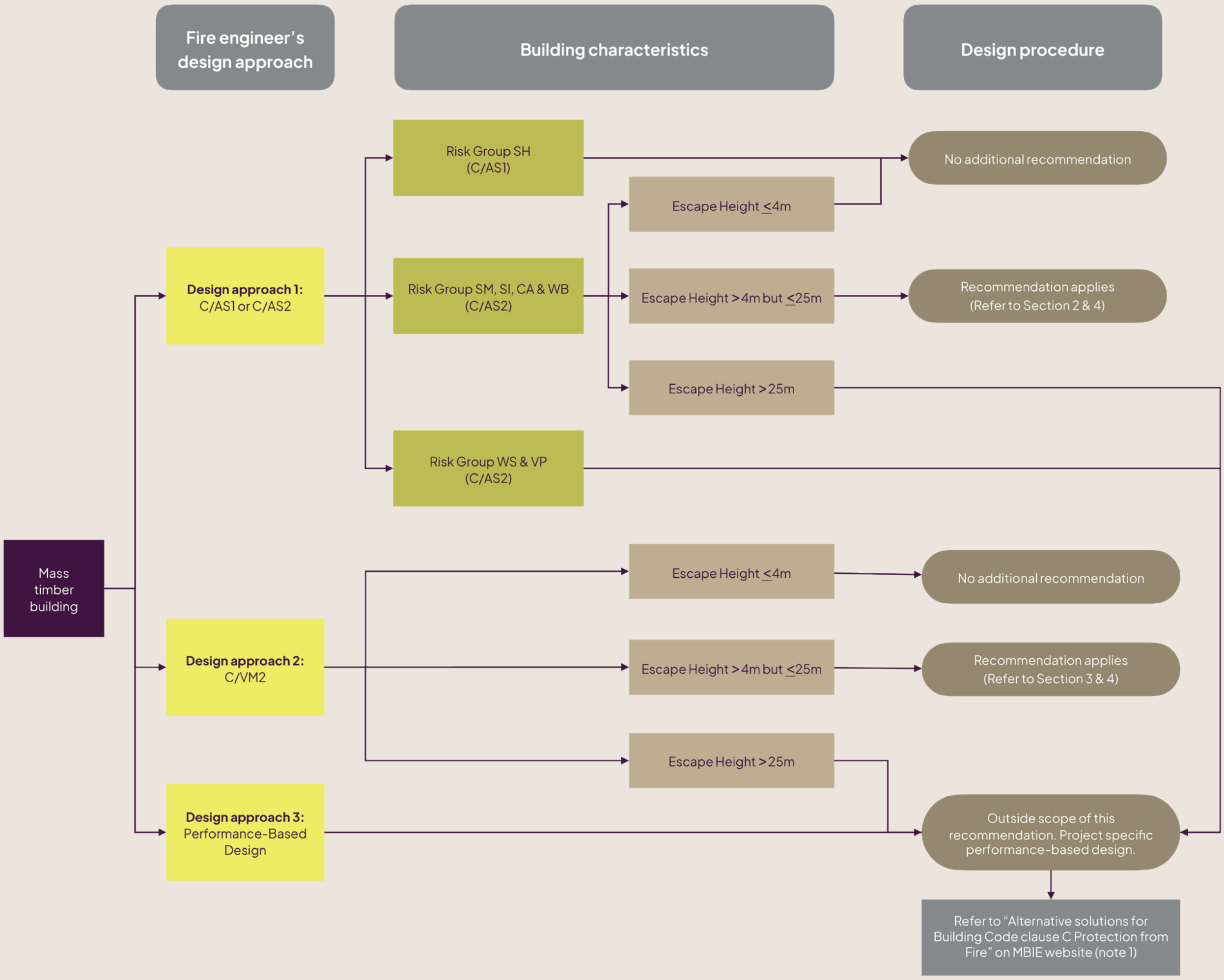

Figure 1. **Flowchart showing alternative fire design approaches to multi-storey mass timber buildings in New Zealand**

11.1.2 Early developments

[Nothing to add to the Global Design Guide]

11.1.3 Overview of the fire safety design process

The New Zealand Building Act and related New Zealand legislation are discussed in Chapter 4 of this Commentary.

To assist in minimising risk associated with design and approval of a performance-based design, the Fire Engineering Brief (FEB) process is recommended. The FEB process engages relevant stakeholders at an early stage in the fire design of a project to encourage input and discussion on the design methodology, acceptance criteria and any specific requirements stakeholders may have, including the design review process to be applied.

SFPE New Zealand has published guidance (SFPE New Zealand, 2018) outlining good practice when considering the content that might be included in the FEB document.

11.1.4 Pathways for demonstrating compliance:

As shown above in Figure 1, three design approaches are identified. They are:

1. Design Approach 1: Follow C/AS1 or C/AS2 as applicable, including recommendations from Sections 2 and 4 of the Supplement in Appendix A. This approach provides prescriptive solutions for mass timber buildings and no calculation is required.
2. Design Approach 2: Follow C/VM2, including recommendations from Sections 3 and 4 of the Supplement in Appendix A. This approach may include engineering calculations to quantify the contribution of mass timber to the fire temperature history and fire duration (i.e. fire severity).
3. Design Approach 3: Adopt a performance-based design approach. This can be used for any building but will be necessary if the proposed building is out of scope of the preceding two options. It may or may not include engineering calculations depending on the specific methodologies applied.

With respect to Design Approach 1 and Design Approach 2, compliance documents C/AS1, C/AS2 and C/VM2 were not written with mass timber structures specifically in mind and therefore the additional considerations and recommendations as set out in this document and the Supplement in Appendix A are recommended.

As described in Chapter 11 of the Global Design Guide, the performance criteria used for performance-based design, Design Approach 3 could be comparative or absolute, with quantitative, qualitative or deterministic methods employed. Given the state of knowledge of fire design for mass timber buildings, caution must be applied when selecting methods of analysis to ensure that up-to-date knowledge, experimental evidence and the various technical guidance available internationally are considered.

11.1.5 Sources of further information

In addition to the references provided in Chapter 11 of the Global Design Guide, readers are referred to:

- The Fire Engineering Brief (FEB) Content Guidelines (SFPE New Zealand, 2018)
- International Fire Engineering Guidelines (IFEG) (Australian Building Codes Board, 2005)
- Alternative solutions for Building Code clause C Protection from Fire | Building Performance (MBIE, 2018)
- The SFPE Guide to Performance-Based Fire Safety Design (SFPE, 2015)

In the UK, the Structural Timber Association (STA) has published guidance aimed at clarifying the routes for structural fire design compliance, applicable to mass timber buildings: Structural Timber Buildings Fire Safety in Use Guidance. Volume 6 - Mass Timber Structures (Structural Timber Association, 2023).

This guide is intended for use by design professionals to support competent fire safety strategy decisions, specifically relating to the structural stability of a building in the event of a fire. Although the content of the STA guide primarily focuses on Building Regulations in the UK, it may provide useful background for New Zealand engineers contemplating a performance-based design outside the scope of the Supplement in Appendix A.

The international consulting firm Arup has also developed a guide primarily aimed at fire safety engineers, but also providing practical guidance for others involved in the design and construction of mass timber buildings, such as architects, clients, and contractors. This guide, Fire Safe Design of Mass Timber Buildings (Ove Arup & Partners Limited, 2024), draws on Arup's collective experience through the development of mass timber building solutions worldwide, navigating sometimes complicated approvals processes. The Arup guide is written for business and residential occupancy buildings up to 50 m high and educational occupancy buildings up to 25 m high, but it does not cover other risk groups such as crowd/assembly, healthcare and homes for aged people. It describes a risk-informed qualitative approach with recommendations given for the evacuation strategy, means of egress, fire suppression, compartmentation and firefighting measures as well as the type and location of the mass timber structure. It is useful for New Zealand designers contemplating a performance-based fire design which is outside the scope of the Supplement in Appendix A.

The risk-based methodology framework described in the Arup guide provides solution-oriented risk-informed recommendations and advice but is not strictly performance-based design. However, it could be referred to as part of a performance-based design.

11.2 Hazard analysis and fire scenarios

[Nothing to add]

11.3 Application of analysis methods to timber construction

11.3.1 Hazard identification

[Nothing to add]

11.3.2 Preliminary qualitative and quantitative analysis

[Nothing to add]

11.3.3 Fire scenarios for quantitative risk assessment

This subsection of Chapter 11 gives a general overview of the process for selecting fire scenarios for deterministic analysis noting that an estimate of the probability of flashover fires can aid the selection of credible worst-case scenarios.

Caution is needed when there is a significant amount of exposed timber within a compartment, as the frequency and severity of flashover fires may be greater than for an equivalent compartment without exposed mass timber. In cases where a non-fire-resistant adhesive is used in CLT, potential scenarios of char fall-off including lamella delamination leading to fire regrowth will need to be considered, not currently shown in Figure 11.4 of the Global Design Guide.

Char fall-off is the delamination of the char developed during the burning of the mass timber, exposing more timber to burning. It can be caused by cracking and fall-off of char or complete failure of the adhesive glue line between the lamellae that form CLT (Mitchell et al, 2023). Figure 2 shows a view of the underside of a CLT slab after a fire resistance test where fall-off of the char has occurred.

Figure 2. **Example of char fall-off on the underside of a CLT slab during a fire resistance test (Credit: E. Claridge)**

Similarly, if encapsulation does not remain in place throughout the fire duration, fire regrowth may occur. These phenomena are illustrated in Figure 3 where the fire could follow multiple paths, from simple decay to single- or multiple-char fall-off with repeated flashover, leading to eventual smouldering. Curve (B) is representative of a compartment without exposed mass timber (Mitchell et al, 2023).

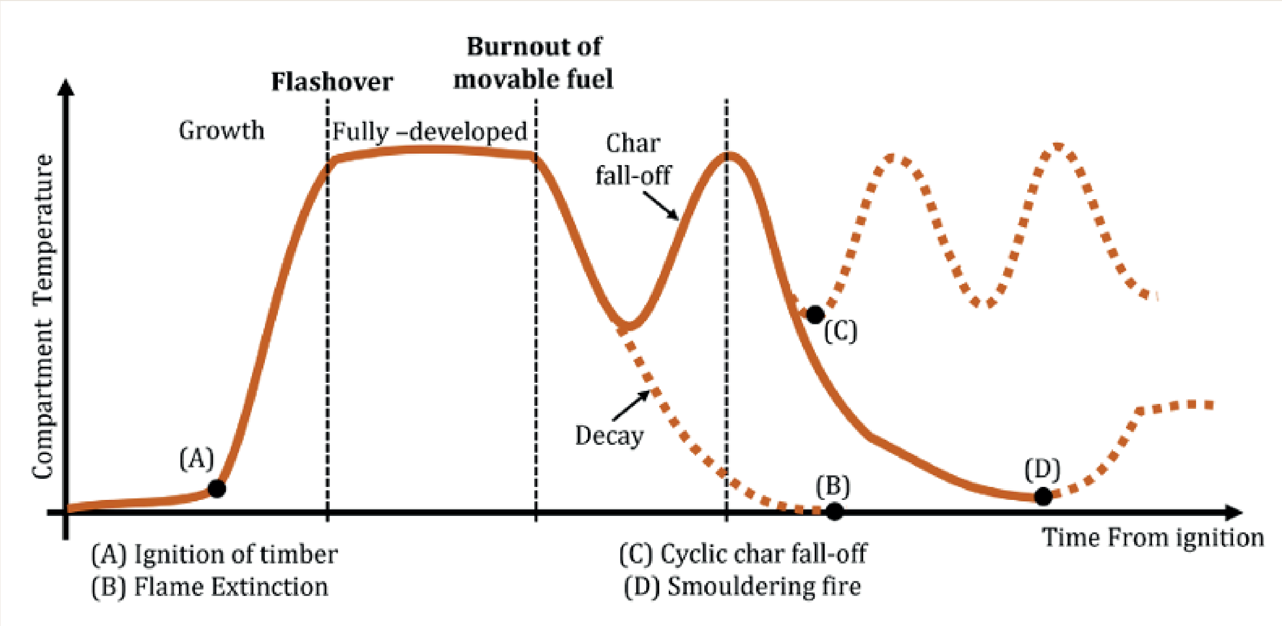

Figure 3. **Illustration of fire phenomena during a timber compartment fire (© 2022 Mitchell et al. Fire and Materials published by John Wiley & Sons Ltd. Reproduced under terms of the Creative Commons Attribution License)**

It is also recommended that the potential for increased external flaming be considered in the performance-based design of mass timber buildings where significant amount of timber is exposed, as discussed in Chapter 9 of this Commentary. For radiation calculations from external wall openings with exposure to a relevant boundary or neighbouring building, one way to represent higher heat fluxes is to increase the temperature of the assumed emitter to 1200 °C, as suggested by Glew et al (2023).

11.3.4 Quantitative risk assessment of structure and barrier performance

Quantitative risk analysis should only be carried by experienced and competent engineers on a case-by-case basis. Due to the current state of knowledge and uncertainties concerning fires in mass timber compartments, caution is required in performance-based design especially when the possible consequences of failure are high.

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Chapter 12
Robustness in fire

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12. Robustness in fire

Scope of chapter

This chapter is complementary to Chapter 12 of the Global Design Guide, which should be read alongside this Commentary.

This Chapter refers to the most important sections in Chapter 12 of the Global Design Guide. Focussing on structural performance, it discusses assessing and improving the resilience and robustness of mass timber buildings when involved in fire, with reference to the New Zealand Building Code and New Zealand Standards.

The material in this chapter of the Commentary relates specifically to New Zealand.

12.1 Basics of structural robustness

This section of the Global Design Guide describes the probabilistic basis of structural robustness, related to fire safety.

In more practical terms, structural resilience and robustness are important characteristics of structures that are exposed to loads and forces whose magnitude cannot be well defined. Examples of loads where the upper limit design forces cannot be defined with high confidence include seismic loads, effects of tsunami inundation, effects of fire and wind forces. For some of these load types, the structural response to the load is predictable even if the magnitude of load is uncertain. For example, we might not know with very high certainty what the maximum magnitude of wind forces will be, but we are confident about our understanding of how we expect the structure to resist those forces.

For some types of loading the structural response itself is complex and uncertain because of the dynamic or time-dependent nature of the load or structural response. Earthquakes and the effects of fire both generate structural responses which are complex more or less regardless of the magnitude of the loads. There are two separate but related design approaches for dealing with this uncertainty in structural response:

1. The first approach is to design the structure for a cautious, pessimistic, high design load, to compensate for uncertainty in the magnitude of the maximum load. This is a way of providing a structure with high load capacity. This provides structural robustness in the sense that the structure is capable of resisting high design forces, in order to provide a margin of safety to our uncertain prediction of maximum loads. This approach is effective where there is reasonable certainty in quantifying an upper bound to the maximum loads (e.g. wind forces, snow loading, hydrostatic pressure).
2. The second approach is to design and detail the structure so it is highly capable of absorbing overload and damage in a predictable way, without collapse. This provides structural resilience: the structure resists the impact of design forces by allowing damage and energy absorption in those parts of the structure which are designed to dependably withstand this. The structure is insensitive to any localised structural member failure and has capacity to absorb energy and redistribute internal stresses, such as using alternative load-carrying mechanisms. This approach does not rely on accurate prediction of the maximum loads. Instead the structure is able to respond predictably to the uncertain magnitude of overload. This approach is appropriate only for infrequent and uncertain events such as severe earthquake, tsunami effects and severe fire, which are not expected to occur more than once or twice during the lifetime of a building.

In practice, structural design often employs a mix of both approaches, providing varying degrees of resilience and robustness depending on the structure, the type of event causing the extreme design loads and societal tolerance to the consequences of structural damage or failure.

All structural engineering is fundamentally risk-based, founded on a probabilistic framework which is a function of building design life, structural loading magnitude and frequency (return periods), load factors and load combinations. Structural fire engineering is similarly probability-based, taking into account the influence of fire exposure on structural stiffness and material strength, and the frequency and severity of large fires.

12.2 Basics of robustness and fire safety engineering

[Section 12.2 of the Global Design Guide applies in general. New sections 12.2.1 through 12.2.6 have been added to this Commentary for use in New Zealand].

12.2.1 Improved structural robustness

Buildings need increased structural robustness when the consequences of failure during fire are high and therefore the probability of failure needs to be reduced. In other words, the tolerable level of risk is low. Characteristic risk factors include:

- Buildings containing occupants who are evacuated to a place of safety inside the building (i.e. not evacuated immediately to an external place of safety).
- Buildings containing occupants who need assistance to evacuate and are therefore very slow to move or respond to a fire emergency.
- Buildings in which the evacuation time is long (compared with the time it may take for fire to grow and spread); this includes buildings where the combination of occupant load and escape route capacity results in long queuing time or slow evacuation movement due to height (e.g. large occupant load buildings; tall escape height).
- Buildings containing sleeping occupants, or occupants who may not be alert, responsive, motivated and able to evacuate promptly; (i.e. occupancies for which timely response and purposeful movement may be delayed).
- Buildings where the height or other design features require firefighters to commit to internal rather than external firefighting and the internal commitment time is long (tall escape height; long escape routes).
- Buildings for which the probability of loss of structural stability caused by fire needs to be reduced to a level as low as reasonably practicable.

A taller escape height increases the time occupants of upper storeys are in the stair, increases the number of occupants in the stair (although this is related more strongly to the occupancy type and area of each floor in the building), decreases the likelihood that firefighters can effectively fight a fire or rescue occupants from outside the building, and increases the time and effort required for firefighters to reach the upper levels.

Buildings which present high fire risk need higher levels of structural fire resistance and/or greater structural robustness in order to comply with the functional requirements of the performance-based NZ Building Code. The greater the risk factors, the higher the expected level of structural robustness.

For buildings designed to withstand the effects of fire, structural robustness can include an additional component. Unlike structural design for environmental effects such as wind forces, seismic loads and tsunamis, effective fire safety systems are available which reduce the frequency and severity of a large fire. The most obvious of these is an automatic sprinkler system. This introduces an additional option to the design solutions available for providing structural robustness.

Buildings which present high fire risk to occupants are more likely to need sprinklers for life safety reasons. Because sprinklers are very effective in controlling the effects of fire to the immediate area of fire origin they provide a substantial life safety benefit, as well as controlling the impact of fire on structures. Note however, that the performance requirements of NZBC Clauses C3.9, C4.5, C5.8 and C6.2 all require buildings to be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems.

12.2.2 Design for burnout

The need for consideration of burnout has been discussed in Chapter 2 of this Commentary. At a fundamental level, (e.g. Building Code functional requirements) structural systems in buildings are provided with fire resistance for one or more reasons (a summary of NZBC Clause C6.1):

1. To protect occupants while they are escaping from fire.
2. To protect firefighters who enter the building for firefighting or rescue operations.
3. To protect other property

This protection is achieved by maintaining structural stability with a low probability of collapse, so that the escape routes and fire separations which protect them remain in place for the time it takes for all occupants to leave the building, and the firefighter access routes are similarly protected for buildings where firefighting operations require entry.

For most common structural systems and materials designed in accordance with current New Zealand structural materials standards (reinforced concrete, reinforced masonry, steel and composite steel/concrete elements, mass timber), structural strength and stiffness, hence structural stability is not affected until the structural material has been exposed to a severe fire for some time. Fires which do not reach flashover do not typically threaten structural stability.

For buildings with any of the risk factors in Section 12.2.1 above, and for buildings which contain property under different ownership, the structural fire resistance needs to be adequate to withstand burnout. Burnout is defined in Clause A2 of NZBC. C/VM2 Paragraph 2.4 describes '*full burnout design fires*' for structural design and offers three choices for modelling the effects of that full burnout design fire.

12.2.3 Maintaining structural stability for life safety

For buildings where the evacuation time is short (short escape height and distance, relatively few occupants, occupants are awake, alert, motivated and capable evacuating quickly to a place of safety outside the building, the time structure is exposed to post-flashover fire conditions is relatively short, and consequently does not require high fire resistance levels in order to confidently remain stable for the required time.

Protection of other property requires those elements which control fire spread (to other property) to remain in place, which implies that the structural systems providing this support also need to remain stable for as long as the fire threatens other property.

Where a full building evacuation can reasonably be completed within a short time (say approximately 10 minutes after receiving notification from an automatic fire detection system), structural fire resistance is often prescribed at a nominal value (e.g. 20 minutes or 30 minutes fire resistance rating as determined by exposure to the standard fire test). There is nothing highly significant about this time value – it is merely an estimated time frame which is likely to result in most or all occupants leaving the building before the structural system is adversely affected by a fire reaching flashover. This evacuation time frame is likely to apply to building uses where occupants are awake, alert, responsive and in most cases able to evacuate without assistance. Total building evacuation time is influenced by a number of factors, including number of occupants and capacity of escape routes, occupant response time and motivation to evacuate promptly, and total travel distance (building height) to a place of safety outside the building.

Where full building evacuation times are approximately in the range 10 to 30 minutes (after receiving notification to evacuate from an automatic fire detection system) occupants are still likely to be evacuating from the building after a fire reaches flashover elsewhere in the building, but the length of exposure of the structure to post flashover fire conditions is modest. Factors that may result in longer evacuation times may include one or more of the following:

- Occupants who are slightly delayed (e.g. typical residential/accommodation sleeping occupancies, where initial response time is longer than if awake and alert, but occupants are able to evacuate promptly once they are progressing towards the final exit) or
- Because of longer travel distance (e.g. higher escape height) or high occupant load or limited escape route capacity.

The probability of the fire affecting structural stability for buildings during the evacuation time is influenced more directly by the level of fire resistance provided and by the presence of sprinklers (which reduce the likelihood of the structure being exposed to severe fire).

Where full building evacuation times are longer than about 30 minutes, it is quite likely that occupants will still be in the building (evacuating to a place of safety either inside or outside the building) within the time when the structure's stability could be challenged by exposure to a post-flashover fire. In these cases, fire resistance needs to be assessed more carefully and sprinklers play a much more important role in reducing the probability that the strength of the structural system is reduced to a critical level by the fire. In these buildings, the structural system needs fire resistance appropriate for withstanding the full duration of fire (i.e. design for burnout).

The same applies to design of buildings where evacuation procedures include evacuation to a place of safety inside the building. Typically, the structural engineer is the appropriate party to identify the load paths and key structural elements which are required to maintain the stability of the structure. Adequate fire resistance is required for these structural elements, including the connections and fixings and secondary structure that stabilises or braces the structural elements.

12.2.4 Firefighting considerations

For buildings where the overall height of the building (and access) is such that firefighting activities to control external fire spread could be accomplished from outside the building (i.e. without having to commit firefighters to entry), the consequence of loss of structural stability is less than for taller building heights. The likelihood of firefighters needing to control a large fire is also strongly influenced by the presence of sprinklers.

Above the low-rise building height threshold where external firefighting operations are not effective, firefighters will need to enter the building. Where firefighters need to commit to an internal attack (e.g. because of building height), their access route needs to be protected long enough to ensure that a safe retreat can be made, which requires the structural system to have adequate fire-resistance to protect the firefighter access route.

For buildings where firefighters need to commit to an internal attack (e.g. because of building height), and the firefighter access route distance to the most remote area within the building is long, the risk and consequence of loss of structural stability caused by fire is high. This risk is significantly increased if the building is not sprinkler protected. In this case, the structural system needs fire resistance adequate to withstand the full burnout design fire.

For buildings where the distance is 'short' to the most remote area within the building such that firefighter retreat time is comparatively short, the risk associated with loss of structural stability caused by fire is less, particularly if the building is sprinkler protected. Structural fire resistance that is close to but not necessarily equal to that required by the full burnout design fire may be acceptable for sprinkler protected buildings.

FENZ firefighting capability varies significantly across New Zealand, with areas outside of major city centres heavily relying on volunteer brigades. These volunteer brigades are not 24-hour staffed and may not possess the same level of experience, training or appliances as career firefighters, especially for tall buildings. This will lead to differences in response times and the ability for certain types of responses which in turn may fundamentally impact the options available when undertaking firefighting operations. See Chapter 14 for further information.

12.2.5 Controls on fire spread to protect other property

Protection of other property requires those building elements which control fire spread (to other property) to remain in place for as long as the fire threatens other property (i.e. to withstand exposure to the full burnout design fire). This implies that the structural systems providing this support to these building elements also need to remain stable for as long as the fire threatens other property.

Controls on fire spread to protect other property are usually a function of horizontal distance from external walls to relevant boundaries or the presence of 'other property' boundary elements inside a building (i.e. not influenced by building escape height, external or internal firefighting strategies or full building evacuation time). For buildings where there are no parts of the building which need to control fire spread (internal or external) to other property, then collapse of the building during or at the end of a fire does not affect Building Code compliance. There is no requirement to provide structural fire resistance for that specific purpose.

For buildings where external or internal walls or floors or similar are needed to control fire spread to other property, the structure providing (vertical and horizontal) support to these building elements needs fire resistance which corresponds to withstanding the full duration of fire (burnout).

12.2.6 Structural failure in the decay phase

Structures which are required to have any level (even the lowest level) of fire resistance are unlikely to suffer structural failure during the fire growth phase, prior to a fire reaching full development or flashover. There is a time lag from the maximum fire temperature to the maximum structural material temperature and strength reduction in the decay phase. The magnitude of this time lag depends on the fire duration (e.g. short hot fires compared with longer, less hot fires), the thermal conductivity of the structural material, exposed surface area and massivity of the structure and the thickness and thermal properties of any insulative structural fire protection. This is why it is important to design structural fire resistance taking account of the decay phase (i.e. for the full burnout design fire).

For mass timber structures, the particular combination of relatively low thermal conductivity and relatively low density (compared with steel and concrete) usually extends this time lag between peak fire temperature and peak structural temperatures until well into the decay phase. This phenomenon is aggravated where the influence of the added fuel load from charring exposed mass timber is most pronounced after the fire reaches peak temperature. The greatest reduction in structural strength – corresponding to the highest structural temperature and deepest penetration into the mass timber cross section – may occur at some considerable time after the peak fire temperature. Therefore, mass timber structural failure will almost always occur in the decay phase, and at a time much later than expected for structures of non-combustible materials.

A 'thermal wave' of increased temperature penetrating slowly into the cross section produces a reduction in timber strength which can result in unexpected structural failure long after the fire temperatures have decayed. Refer to Gernay (2021) and Gernay et al (2022) for a more detailed description of this phenomenon. The July 2024 draft of Eurocode 5 gives a design method for calculating the effect of the thermal wave.

For buildings which are taller than 18 metres, firefighting is more challenging than for shorter buildings because it is much less likely to be effective from outside the building. If occupant evacuation time is longer than 30 minutes, that is more likely to overlap with the time frame for firefighters using the stairs for access. Hence the consequence of structural failure increases, with a correspondingly lower tolerable level of risk.

Therefore, designers of these mass timber buildings are encouraged to consider this decay-phase influence of temperature on the strength of columns and other critical structural members. Mass timber structural members supporting gravity loads in axial compression or tension are most vulnerable, since insufficient strength during a fire is less likely to result in a ductile failure or occur with warning of imminent failure evident by a noticeable increase in deflection. See section 12.11.4 of this Commentary for more detailed recommendations.

12.3 Normative framework and robustness

[Nothing to add]

12.4 Exposure types

[Nothing to add]

12.5 Consequences resulting from a fire event

[Nothing to add]

12.6 Evaluation of improvements

12.6.1 Prevention of progressive collapse for the fire situation

This section of the Global Design Guide is a description of design for alternative load paths to prevent structural collapse when one or more critical structural elements lose load capacity during a fire.

12.6.2 Approaches for improved robustness for timber buildings

[Nothing to add]

12.6.3 Improvement of the robustness for structural timber buildings

[Nothing to add]

12.7 Design of timber buildings for reuse after a fire

[Nothing to add]

12.8 Discussion and conclusion

[Useful discussion; nothing to add. This is the last section in Chapter 12 of the Global Design Guide]

12.9 Justification for reduced fire resistance in buildings protected with a sprinkler system

[This section 12.9 and following sections 12.10. 12.11, and 12.12 have been added as important new contributions to the robustness of New Zealand mass timber buildings in fire]

The New Zealand Building Code explicitly permits the influence of an automatic sprinkler system to be taken into account when designing a structure to remain stable during fire. The compliance documents implicitly (C/AS2) or explicitly (C/VM2) modify the performance required in fire of structural systems necessary for structural stability by adjusting the prescribed fire resistance rating or the calculation of fire severity (as a way of accounting for the likelihood of failure of sprinkler systems).

The Verification Method C/VM2 offers choices for modelling a full burnout design fire, for structural design and for assessing fire resistance of fire-separating elements (C/VM2 Paragraph 2.4). Fire duration calculations are permitted to use the F_m factor in C/VM2 Table 2.3 to modify the design FLED from Table 2.2. The design FLED in Table 2.2 applies to the fuel load introduced into the building by the occupant activity. The design FLED does not include the additional fuel load present where the building itself is constructed of large areas of mass timber that are not effectively protected from exposure to fire. The equivalent effect of the F_m factor is applied in Acceptable Solution C/AS2 Table 2.4, where different values of prescribed fire resistance ratings apply to unsprinklered and sprinklered firecells.

The F_m factor accounts for a range of factors including:

- Acknowledging that the likelihood of a severe fire occurring in a sprinkler protected building is very low.
- The FLED nominated for a particular activity (e.g. in C/VM2 Table 2.2) is not a single constant value; it is a variable load that changes with time and with distribution within a firecell.
- The design FLED is a nominally high percentile value obtained from surveys of fuel load with an expected low probability of occurrence (which is appropriate for achieving a high level of fire safety).
- The likelihood of a severe fire occurring in a sprinkler protected building simultaneous with and at the same location as an unlikely high percentile fuel load is highly improbable. Accordingly, to maintain consistency in tolerable failure probabilities, a reduction factor is applied to the design FLED which is consistent with the 'accidental' live load combination factor applied to represent the load likely to be supported by a structure in the event of a severe fire.
- The influence of non-uniform fire load and/or ventilation in a firecell.
- The consequence of a more severe fire occurring than that accounted for by design. This is reflected in a different value for the F_m factor depending on whether the structural system is likely to have dependable resilience to accommodate variations from the calculated fire severity. For this purpose, the structural system comprises the individual members and the connections between these members. Most of the common structural systems and materials designed in accordance with current New Zealand structural materials standards are controlled by design and detailing to develop a minimum level of dependable deformation capacity under overload. This expectation also applies to fire conditions as long as structural elements are not susceptible to brittle or non-ductile material failure.
- Construction material types which typically develop dependable deformation capacity include reinforced concrete, reinforced masonry, steel and composite steel/concrete elements. The capacity for mass timber structures to develop dependable deformation under overload is a function of the structural system (ability to redistribute internal forces via alternate load paths) and the structural detailing (e.g. steel connectors or similar which have a ductile response to overload). The dependable deformation of composite mass timber/steel structural systems is influenced by the extent and reliability of lateral restraint provided during a fire to prevent buckling of steel members.

The F_m factor (k factor) = 0.5 for assessing time equivalent fire resistance ratings in sprinklered buildings has been included in versions of the Acceptable Solution for Fire Safety since December 1993.

The F_m factor does not apply to the additional fire load present in unprotected mass timber members, as this is permanent fuel load of more or less a constant value that does not vary with time or location in the firecell.

Note that the F_m factor does not account for the wide range of FLED values observed for some occupancies in other parts of the world. There are concerns that the design values selected for the New Zealand compliance documents (i.e. Table2.2 of C/VM2) are based on historical data that may not be comprehensive, sometimes conflict with more recent surveys (e.g. FLED for New Zealand residential occupancies are low compared to Canadian surveys of living rooms, and highlight large discrepancies with European and Australian design values).

Structural designers should be mindful of elements in structural systems whose stability is critical to the stability of the whole system. Where a structure response hierarchy during fire is desired (e.g. to protect selected critical members) the key elements of the structural system should be provided with greater fire resistance.

12.10 Risk matrix approach for improved resilience of timber buildings

For those buildings where the total building evacuation time is longest (the design time required for the last person to leave the building), or where firefighters are most vulnerable because of long access and retreat times, structural fire resistance needs to be assessed more cautiously so that the probability of structure instability caused by fire is low and structural resilience is high, improving the reliability of the structure to support the design loads for the full burnout design fire. The level of caution that should be applied when assessing the full burnout design fire and associated structural fire resistance provided in order to protect occupants escaping from fire or to protect firefighters who are inside the building for firefighting operations can be ranked according to the following risk factors (ranked from most important, in descending order; see also Section 12.2):

1. Buildings containing occupants who need assistance to evacuate (evacuation time is very long and/or involves evacuation to a place of safety inside the building)
2. Buildings where evacuation time is very long duration (a function of occupant load, escape route details, evacuation procedures); often consistent with very long evacuation routes, including tall buildings and including buildings with occupants who are slow to respond to notification of fire such as sleeping occupancies
3. Buildings where firefighters need to commit to an internal attack because of building height, and the firefighter access route in the building is long (lengthy firefighter retreat time); often related to building height
4. Buildings where evacuation time is of medium length duration (as in item 2 above, but total building evacuation time is shorter)
5. Buildings where firefighters need to commit to an internal attack because of building height, and the firefighter access route in the building is not long (moderate length firefighter retreat time)
6. Buildings where occupant evacuation time is only slightly delayed (e.g. typical residential or accommodation sleeping occupancy where response might be delayed but where the occupants are willing and able to evacuate promptly once they are progressing towards the final exit
7. Buildings where occupant evacuation is of short duration (occupants are awake, alert, responsive and building evacuation times are short)
8. Buildings where firefighting can be conducted from outside the building and occupants typically can evacuate promptly without needing assistance

The ranges for total building evacuation time are:

- Short = 10 minutes; this evacuation time is likely to result in most or all occupants leaving the building either before or very soon after a fire reaches flashover and full development
- Long = greater than 30 minutes; structure in the building is likely to be subjected to fully developed fire for an exposure time which is non-trivial
- Medium = between 10 and 30 minutes; occupants are likely still in the process of evacuating from the building after a fire reaches flashover somewhere in the building, but the length of exposure of structure to severe fire conditions is modest; a nominal level of fire resistance achieves a high probability that structure can support design loads without collapse.

These factors can be distilled to:

- Three categories of total building evacuation time (short duration - up to 10 minutes; medium duration - between 10 and 30 minutes; long duration - more than 30 minutes)
- Three categories of building escape height (up to 10 metres; between 10 and 25 metres; taller than 25 metres) – related to firefighting vulnerability and retreat time

These risk factors are also influenced by occupancy type and number of occupants at risk (in particular, whether occupants are likely or not to be awake, alert, familiar with the building and the fire emergency procedures).

The relevant building heights related to firefighting operations were provided to MBIE in 2011 by the New Zealand Fire Service National Fire Risk Manager, which formed the basis of Design Scenario FO (Firefighting Options) in Paragraph 4.68 of C/VM2.

Putting these risk factors into a series of matrices for different occupancy risk factors (relating to occupancy – the ability for occupants to react to a fire emergency and evacuate quickly without assistance) generates a risk ranking system as shown in Table 1.

In the following risk matrix, the Occupancy risk factors are intended to classify occupancy as follows:

- Occupancy Risk A is characterised by buildings where occupants are awake and alert, or where the total number of sleeping occupants in the building is not more than 250 and none of the occupants (awake or sleeping) need assistance to evacuate.
- Occupancy Risk B is characterised by buildings where occupancies are not covered by Risk A, where the total number of sleeping occupants in the building is more than 250 provided that the number of occupants in the building who need assistance to evacuate is not more than 10.
- Occupancy Risk C is characterised by buildings where occupancies are not covered by Risk A or B and where the number of occupants in the building who need assistance to evacuate is more than 10.

Table 1. **Risk matrix for different building heights and evacuation times**

Escape height he:	Total building evacuation movement time (duration):		short evac < 10mins	medium 10 < evac < 30	long 30 < evac
			Occupancy risk A (awake, alert)		
he < 10	firefighting	low	[green]	[green]	[yellow]
10 < he < 25	vulnerability:	moderate	[green]	[yellow]	[yellow]
25 < he	external/internal	high	[yellow]	[yellow]	[red]
			Occupancy risk B (# sleeping > 250)		
he < 10	firefighting	low	[green]	[yellow]	[red]
10 < he < 25	vulnerability:	moderate	[yellow]	[yellow]	[red]
25 < he	external/internal	high	[yellow]	[red]	[red]
			Occupancy risk C (# needing assisted evac > 10)		
he < 10	firefighting	low	[yellow]	[red]	[purple]
10 < he < 25	vulnerability:	moderate	[yellow]	[red]	[purple]
25 < he	external/internal	high	[red]	[purple]	[purple]

Suggested risk ranking

[green] **Low risk**: no particular need to ensure stability for entire duration of fire hence no need to assess burnout fire severity explicitly or account for contribution of mass timber fire load

[yellow] **Medium risk**: design for burnout required; apply limits for extent of exposed area of mass timber or install sprinklers; sprinkler system encouraged and sometimes required but no special sprinkler robustness needed

[red] **High risk**: sprinkler system with enhanced robustness and maintenance is recommended; limits apply for extent of exposed area of mass timber; encapsulation system designed for burnout fire severity

[purple] **Very high risk**: sprinkler system with enhanced robustness and maintenance is required; timber structure encapsulated where practicable; encapsulation system designed for robust assessment of burnout (or superior adhesive used for CLT)

The lowest risk category applies to combinations of risk factors for which exposed mass timber has little effect on fire safety. The highest risk category applies to risk factor combinations where more sophisticated design approaches are needed and/or more fire safety features are needed in the building to compensate for the challenges introduced by exposed mass timber.

12.11 Improving resilience of timber structures

12.11.1 Approaches for improving resilience

There are several ways to improve timber structure resilience to fire exposure. Some approaches are described in the following section. The increase in resilience and the cost to do so is not the same for each approach. The extent to which the reliability and efficacy of sprinklers is solely relied on to improve resilience is also dependent on the risk level. As the level of risk ranking increases, it is necessary to improve resilience using more than one approach. For example, structural resilience could be increased by a combination of providing increased coverage or performance of encapsulation when the design is based on calculating structural capacity and providing for a slightly greater effective depth of charring than that calculated when the design is time-based or structural capacity based.

Where the consequences of failure are highest, structural resilience does not rely totally on the effective operation of sprinklers.

12.11.2 Encapsulation system enhancements to improve structure resilience in fire

Structural resilience is increased for mass timber buildings by adding or extending the coverage of encapsulation systems to conceal and protect the mass timber from exposure to fire. For buildings with a high or very-high risk ranking, the confidence in ensuring adequate structural strength is maintained for the full burnout design fire needs to increase. Currently, there is uncertainty in preventing smouldering combustion of exposed mass timber after the introduced fire load has been consumed and in the reliability of fire models to predict when this would occur. Providing more extensive coverage of encapsulation and improving the performance of the encapsulation system are approaches which can be adopted to compensate for uncertainty in structural fire resistance.

Note however, that encapsulation systems do not necessarily prevent charring of the protected mass timber (the extent to which this occurs depends on the specification of the encapsulation system). Increasing the extent of protected mass timber also has the effect of increasing the effort required to determine (visually or with thermal imaging equipment) whether the concealed mass timber is continuing to char behind the protection layer after the fire has been controlled.

The expected improvement in resilience from providing or enhancing an encapsulation system is also related to:

- The likelihood and magnitude of fire severity that could actually occur in a firecell
- Whether the fire severity is a nominal FRR value from a prescriptive design approach
- The accuracy of our calculation to quantify the required fire resistance

Increasing the coverage and/or performance of an encapsulation system can be relatively cost-effective. It is often used in conjunction with other approaches to increase resilience as a supplementary improvement in high risk and very-high risk buildings (e.g. for sprinklered buildings) or as the principal approach for increasing resilience in medium risk buildings. It is also effective as an approach to improve structural resilience for critical structural members (e.g. highly loaded, high exposed surface area).

In some buildings, or parts of buildings, encapsulation is strongly recommended to address the uncertainty in expecting self-extinction of exposed mass timber and the consequence of extended fire duration when timber continues to char after the fire has been controlled. This includes:

- Buildings with only one stairway (for fire egress or firefighter access) with mass timber walls protecting the stair. In such buildings, the outside surface of the timber wall should be encapsulated (the wall surface potentially exposed to the fire) where the risk is moderate or higher (e.g. for escape height greater than 10 metres in unsprinklered buildings or escape height more than 18 metres in sprinklered buildings).
- Firecells with exposed timber at internal corners. Structural collapse or loss of fire separation integrity can occur from the damaging effects of interactive burning of exposed timber at corners or on adjacent facing surfaces. Potential for interactive burning can be mitigated by installing encapsulation on one adjacent surface. This improvement should be considered in locations where one of the surfaces is a critical structural member or is a fire-separating element protecting an escape route in a high or very-high risk building.
- Riser shafts enclosed with exposed timber internal surfaces and which contain building services or other non-negligible ignition source. The effects of interactive burning are increased as the distance between exposed timber surfaces reduces. To mitigate the potential for fire to spread vertically over multiple levels within a concealed space, encapsulation should be provided to the internal timber surfaces if the shaft is not fire separated at each floor level.
- Buildings with firecell ventilation ratio (ratio of ventilation area to floor area) less than around 15% and design fire load energy density (FLED) of more than 400 MJ/m² with large, exposed timber surface area. In these firecells, the influence of fuel load increase due to the exposed timber surface area may require a minimum level of encapsulation in order to achieve convergence when calculating the depth of charring.

- Buildings with long evacuation time (more than say 30 minutes after instruction to evacuate) or tall escape height requiring long duration firefighter access and retreat time (more than say 50 metres) or mass timber buildings with evacuation procedures relying on evacuation to internal places of safety. Resilience for structural stability is increasingly important for these buildings. A more cautious design approach to determine encapsulation coverage and/or performance is recommended, depending on whether other approaches are used to improve fire safety resilience.
- Buildings with open connections between levels (some buildings with atria) in which fire spread between levels could occur relatively quickly resulting in severe fire exposing the underside and topside of floors, it may be appropriate to increase encapsulation system coverage to reduce the consequences of mass timber floors exposed to fire simultaneously on two surfaces.

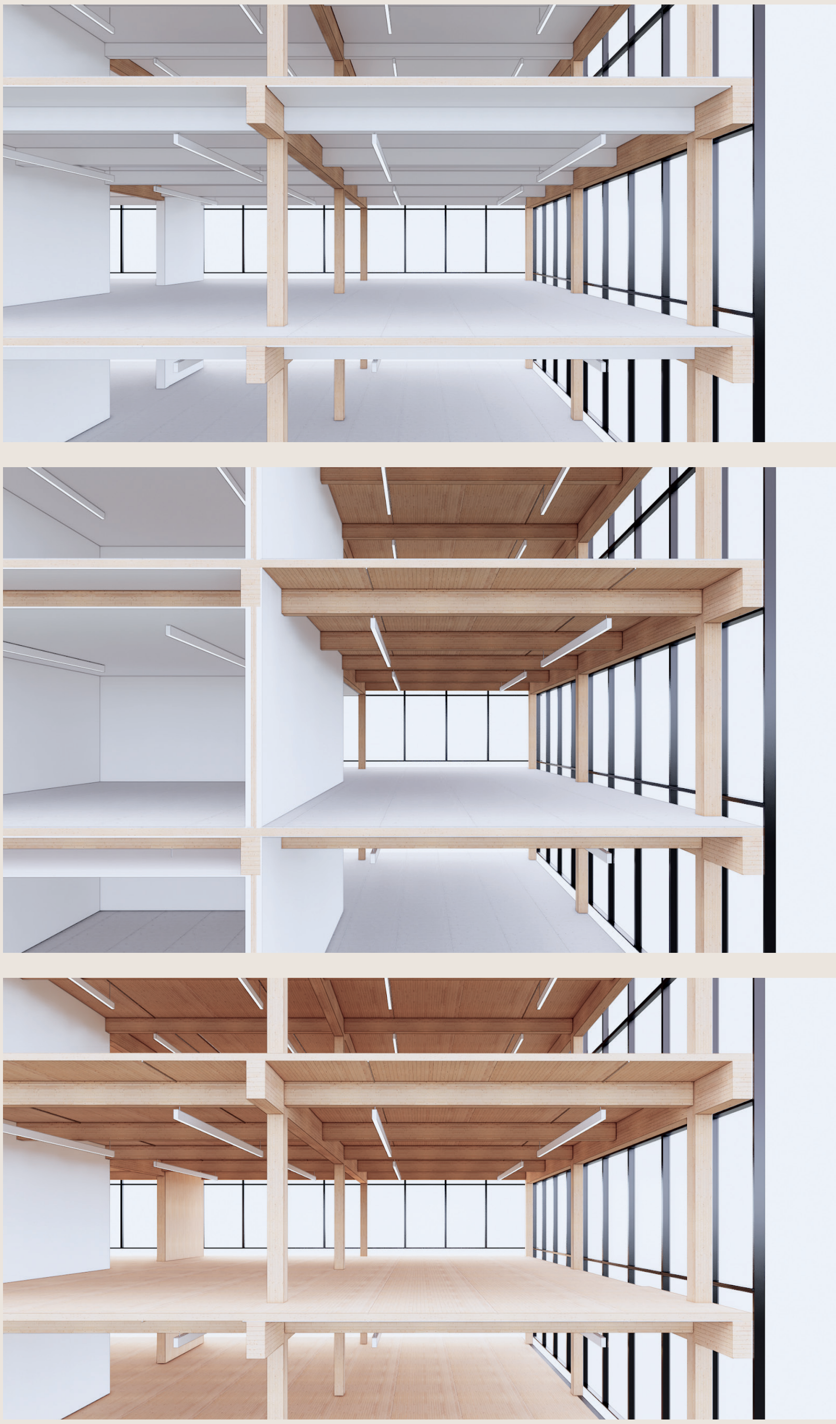

Figure 1. **Decreasing levels of encapsulation, from top image to bottom image (Credit: Studio Gang Architects, San Francisco, USA)**

The level of protection provided by encapsulation can also be improved (where appropriate) by designing the encapsulation system to limit the surface temperature of the timber to 250 °C rather than 300 °C.

Methods to improve structural resilience using encapsulation systems include using a more insulative system and improving the attachment performance (screw spacing or other connectors to hold the encapsulation system in place). Refer to the encapsulation system supplier for specific advice.

Increasing the coverage and specification of the encapsulation system improves the resilience of the structure when exposed to severe fire, but it does not reduce the likelihood of this occurring or reduce other consequential effects of a severe fire. Installing encapsulation systems as early as possible during construction reduces the risk of fire spread in mass timber buildings.

12.11.3 Calculating structural fire resistance to improve structure resilience in fire

The calculation of fire severity makes some assumptions which influence the level of structural fire resistance required. Where the fire resistance of mass timber structure relies on calculation of effective depth of charring further assumptions are made for parameters such as average charring rate, influence of timber temperature on material strength, duration of and temperature during the fire decay phase. The sensitivity of the calculated structural fire resistance varies for different input parameters.

Resilience for structural stability is increasingly important for buildings with long evacuation time (more than say 30 minutes after instruction to evacuate) or tall escape height requiring long duration firefighter access and retreat time (more than say 50 m escape height) or mass timber buildings with evacuation procedures relying on evacuation to internal places of safety. These buildings require a more cautious design approach.

A more accurate assessment of fire severity is needed when calculating the effective depth of charring to determine the structural fire resistance. This gives greater confidence that the uncertainties in the calculation methods and the limited knowledge from research and testing might lead to a fire performance failure. The calculation for the full burnout design fire should include a sensitivity study of the key input parameters, which are:

- Fire load (the design value for moveable fire load, usually expressed as FLED; and also the additional fire load contributed by the surface area of exposed mass timber).
- Area of openings for ventilation (usually a function of the area of glazing in windows)
- Duration of the fire for the full burnout design fire including the decay period (this is a function of both the fire load and the ventilation).

For this reason, a minimum value of the moveable fire load (FLED) is recommended in the design equations for buildings above a threshold escape height. The current guidance in this Commentary cautiously adopts a threshold escape height of 18 metres, because of uncertainty around performance of mass timber columns in fire and consequence of failure when supporting more than about five or six levels. The lower bound limit on FLED is a compensation to account for the uncertainty of estimating the actual likely value of fire load, and also the uncertainty in quantifying fire dynamics with large areas of exposed mass timber, the actual likely duration of severe fire exposure and the influence this has on the rate of charring rate and total effective depth of charring.

Similarly, the full burnout design fire should also consider the fire severity with only partial area (50% is suggested) of window glass breaking and fallout, within the limits of the ventilation factor in Equation 2.2 in C/VM2, and when calculating fire duration using models for natural fires.

The lower value suggested for partial (not full) glass breaking and fallout of windows compensates for uncertainty and underestimation when quantifying the fire severity. It also highlights the level of sensitivity to one of the most influential assumptions used when calculating the ventilation factor and fire duration.

Figure 2 is a graphical illustration of the relationship between ventilation and fire severity for a given level of fuel load, showing the increasing level of fire resistance required for firecells with small ventilation openings. The relationship is not linear. The fire resistance increases more quickly with reducing firecell ventilation at lower ventilation ratios. This means that the fire resistance rating becomes increasingly more onerous when less firecell ventilation is provided.

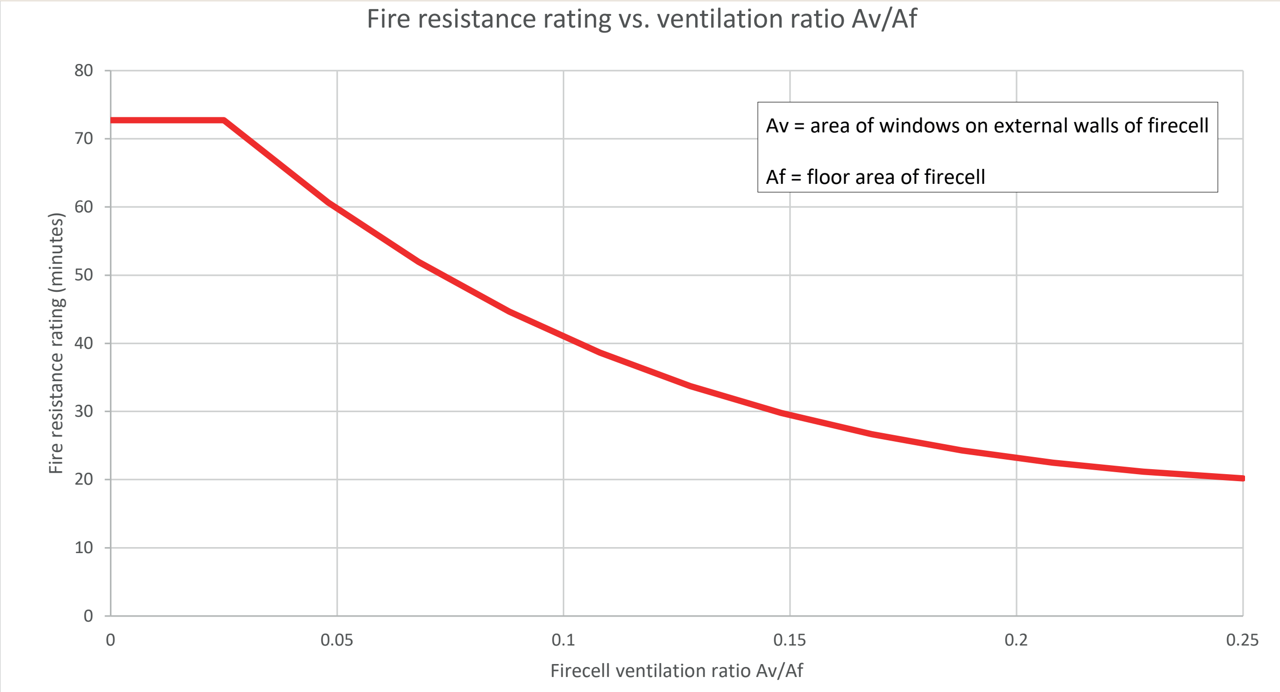

Figure 2. **Graphical illustration of the relationship between ventilation and fire severity**

12.11.4 Isolated columns and walls

Free standing columns, and structural walls inside firecells, are potentially exposed to fire on two or more surfaces. The exposed surface on more than one surface makes these structural elements susceptible to an increased penetration depth of internal timber temperatures with a corresponding reduction in the percentage of cross-section area that is not heated. An example of this cross-section reduction due to charring is shown in Figure 3.

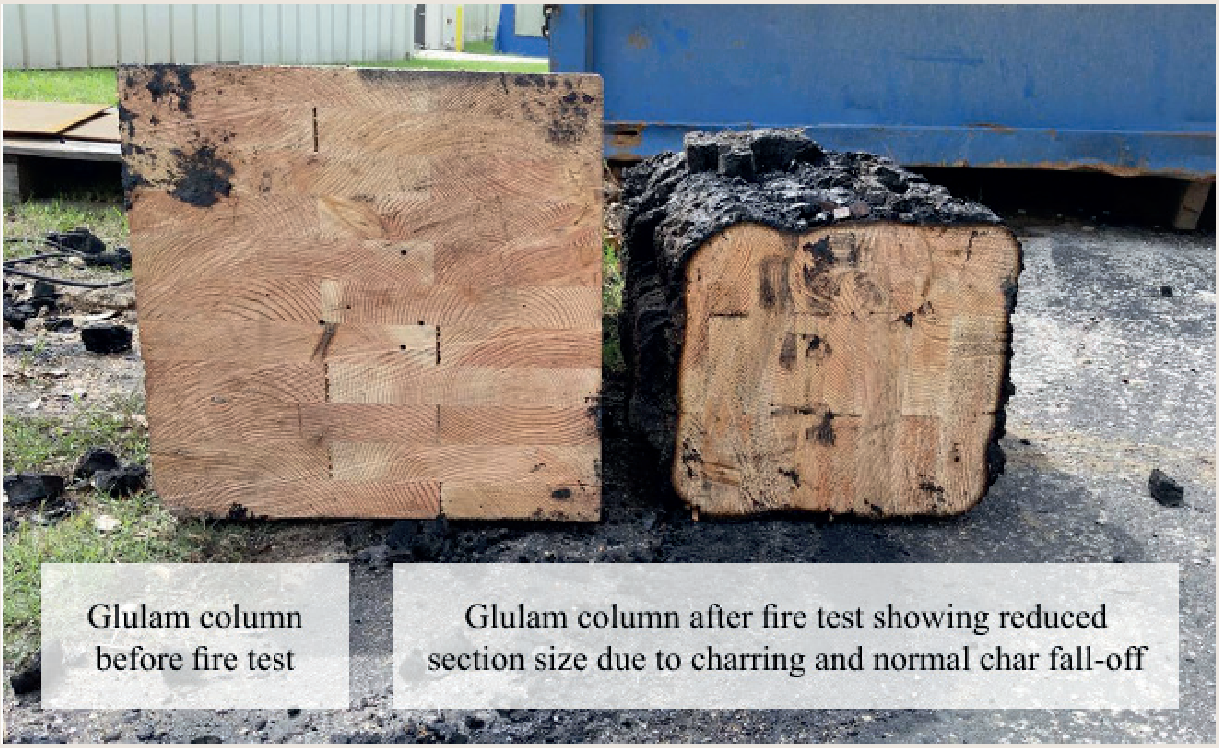

Figure 3. **Cross section through glulam column following fire experiments showing char layer and reduced cross sectional area (© Dave Barber (Arup, 2024))**

In addition to the effect of surface charring, the influence of thermal diffusivity, thermal inertia and delayed heating on the temperature distribution through a column cross-section is shown in Figure 4. The material strength loss for relatively low temperature increase compounds this effect. For structural members subjected to axial force, this effect can appreciably reduce strength. The structural design of critical structural members (e.g. highly loaded columns with large exposed surface area) needs to account directly for this significantly reduced strength resulting from fire exposure. As an alternative, the critical structural members should be fully encapsulated.

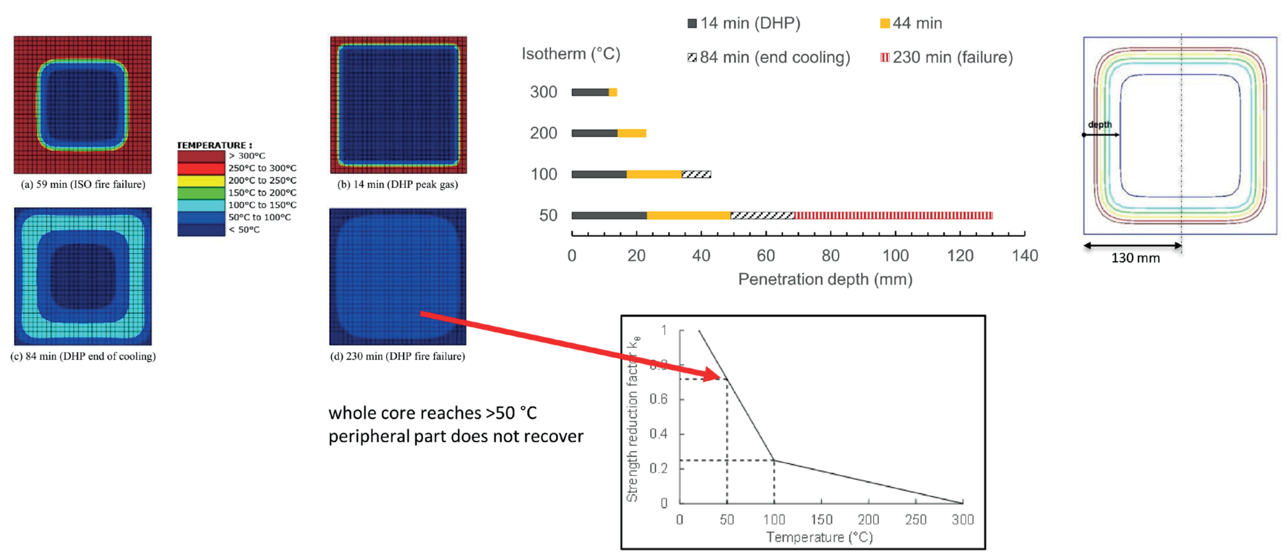

Figure 4. **Temperature distribution in the cross-section of a timber column throughout a fire event and thereafter due to delayed heat transfer (Gernay, 2021)**

The structural design calculations are not routine (they fall outside of the requirements of AS/NZS 1720.4) and require specialist structural fire engineering input. More information is included in Gernay, T. et al. (2022) and Gernay, T. (2021). See section 12.2.6 of this Commentary for discussion on structural failure of isolated walls and columns in the decay phase.

12.11.5 Enhancements to improve sprinkler system effectiveness

When a sprinkler system operates in the event of fire, it provides a range of functional benefits in addition to protecting the structure from exposure to fire. Refer to Section 10.5 in this Commentary for some examples. The presence of a sprinkler system does not directly alter the frequency of fire starts (because sprinklers do not operate until after a fire has started and grown to a size which activates the sprinkler) but by suppressing or preventing fire growth in a significant proportion of the small fires that do occur, sprinklers reduce the frequency of large fires. The other options discussed in this section for improving fire resilience of timber structures, such as more effective encapsulation or more reliable assessment of fire resistance levels also do not reduce the frequency of fire starts. But none of these enhancements, apart from sprinklers, reduce the frequency of large fires.

In doing so sprinklers reduce the consequences of large fires: reduced occupant tenability in the firecell of fire origin, reduced smoke spread within and beyond the enclosure of fire origin, reduced likelihood of fire spread beyond the room of origin, reduced impact of smoke and fire on building services, internal finishes, and structure. Accordingly, improving sprinkler system effectiveness usually provides a range of consequential benefits for other fire protection objectives.

Enhancing the performance of encapsulation systems and improving the estimate of the structural fire resistance required both improve timber structure resilience when exposed to severe fires, but they provide limited benefits until a severe fire occurs, and in general those particular enhancements only benefit the structural system. Enhancements to improve sprinkler system effectiveness, which provide other direct fire protection benefits should be prioritised when the costs for other enhancements are similar.

The fire design solutions to satisfy Building Code Clauses and associated provisions for fire safety performance and other project or building owner requirements often dictate when sprinkler systems are installed in buildings. For mass timber buildings that present a high or very-high fire safety risk, enhancing the sprinkler system effectiveness provides a high value improvement in fire safety resilience.

For buildings with long evacuation time (more than say 30 minutes after instruction to evacuate) or tall escape height requiring long duration firefighter access and retreat time (more than say 50 metres) or mass timber buildings with evacuation procedures relying on evacuation to internal places of safety, the following options for enhancing sprinkler system effectiveness should be considered (the likely most effective options listed first). Refer to Section 10.8 in this Commentary for more detail):

1. Specify a minimum additional margin of at least 100 kPa for the sprinkler hydraulic design pressure (additional to the minimum margins already prescribed in NZS4541 between design pressure and measured available pressure at design flow).
2. Require the sprinkler system designer and installer to supply full and complete as-built documents at the end of system installation and commissioning. Require the main contractor to submit these and sign-off on audited as-built drawings and the Operation & Maintenance Manual as a record of as-built construction.
3. Install a 'life-safety' valve set for the main sprinkler valve set; this allows the principal valve set to be bypassed for maintenance without compromising water supply to the whole sprinkler system.
4. Carry out end-of-line testing as part of sprinkler system commissioning (at first installation).
5. Require the sprinkler maintenance contractors to provide a clearly visible 'sprinklers isolated' tag to hang on the fire panel to indicate system shutdown for alteration or maintenance.
6. Implement systems for more reliable building management and operation practices as a voluntary addition to the Compliance Schedule/annual Building Warrant of Fitness maintenance processes to address potential causes for poor sprinkler system efficacy: lack of sprinkler maintenance; excessive quantity of stored goods; storage too close to sprinkler heads; changes in occupancy (refer Section 10.8.2 in this Commentary).

The enhancements listed above are likely to provide greater overall building fire safety resilience in preference to increased encapsulation coverage or increased mass timber structural fire resistance.

Depending on the building occupancy and the vulnerability of structure to fire exposure in a specific mass timber building and the building escape height, enhancing structural performance through increased encapsulation coverage and/or performance and/or increasing mass timber column sizes for more resilient structural fire resistance should be considered next in the priority list. This is more important when the building escape height exceeds around 60 metres.
Further sprinkler system enhancements provide relatively modest enhancements to structural performance when they increase sprinkler system efficacy to compensate for a failure elsewhere in the sprinkler system. The additional sprinkler system enhancements provide a diminishing return because the likelihood of benefitting from the improvement reduces.

These further enhancements can include the following:

7. Provide a source of supplementary water supply (e.g. water tank) as a back-up option to allow firefighter sprinkler boost; this improves system resilience in the event of loss of adequate water flow or water pressure
8. Provide a system for continuous automatic monitoring of incoming water supply pressure
9. In very tall mass timber buildings (escape height exceeding around 100 metres), provide a series of gravity supply water tanks to reduce reliance on booster pumps operating with appropriate pressure and flowrate. These tanks can also supply water for firefighting purposes.

12.12 C/VM2 Robustness check

The Design Scenario (RC) Robustness Check in Paragraph 4.10 of C/VM2 assesses robustness of a fire safety design in a general sense by revealing any high dependency on a single key fire safety system. This design scenario applies generally to fire safety designs, regardless of structural material. It focusses principally on design for life safety for pre-flashover fire conditions. It applies to key operable or openable fire safety systems such as fire/smoke control doors or similar closures and any other feature that relies on mechanical or electronic components to activate during a fire. The Robustness Check focusses on the deterministic ASET/RSET calculations required to satisfy the CF Challenging Fire scenario rather than any sort of quantitative or qualitative risk assessment.

This (RC) Robustness Check design scenario does not consider structural robustness or consequence of failure of structure during fire for any structural material. For the reasons outlined in the previous sections of this Commentary, structural robustness and resilience need to be considered in addition to any C/VM2 Robustness Check evaluation.

The Design Scenario (FO) Firefighting Operations in Paragraph 4.8 of C/VM2 tests for safe operation of firefighters. Depending on the building escape height, structure fire resistance is derived using either the full burnout design fire (escape height > 10 metres) or for a specified time period after ignition (escape height not more than 10 metres). For buildings with escape height > 10 metres, the structure fire resistance for the full burnout design fire is more challenging for mass timber buildings than for other structural materials for the reasons outlined in this Commentary.

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Chapter 13
Building execution and control

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13. Building execution and control

Scope of chapter

This chapter is complementary to Chapter 13 of the Global Design Guide, which should be read alongside this Commentary.

The chapter starts with discussion on documentation and workmanship for fire safety in mass timber construction, the scope of construction monitoring for the project Fire Engineer, and the role of other personnel including the Fire Protection Engineer. The chapter focuses on the risks of fire during construction, and recommends preventative measures specifically related to mass timber buildings which are summarised in the Fire in Construction Checklist in Section 13.9.

This chapter also includes fire safety during building alterations or refurbishment, but it does not apply directly to the deconstruction or demolition of mass timber buildings.

13.1 Introduction

The life of a building involves multiple stages, from the design phase, through the construction phase, and the commissioning phase, to the eventual operation of the building. The design phase is where the fire safety design is agreed by the stakeholders and the proposed design solutions are implemented on site in the construction and commissioning phases.

13.2 Control of workmanship

For a mass timber building project, the adopted construction approach could be either:

- Off-site prefabrication of mass timber assemblies, or
- On-site installation of mass timber structural elements, including encapsulation and fire stopping etc.

In the former, mass timber could arrive on site with limited exposed timber surfaces, ready for immediate erection, especially if encapsulation is factory-installed. In the latter, planned site management will require storage for construction materials, and weather protection of exposed timber surfaces etc. The project's Fire Safety Coordinator needs to ensure that the Fire Safety Plan adequately accounts for the specific construction approach adopted.

13.2.1 Installation of fire protection measures

Chapters 6 and 9 of this Commentary provide further details on passive fire protection systems suitable for mass timber construction. Chapter 10 provides information on the application of fire sprinkler systems in mass timber buildings, and Chapter 14 covers aspects of firefighter response.

13.2.2 Installation of fire stops and cavity barriers

[No addition to the Global Design Guide]

13.3 Inspection during construction

In New Zealand, project-specific fire engineering construction monitoring is normally performed by the Fire Engineer who was responsible for the fire engineering design. Typically fire engineers would not be monitoring or overseeing the construction of timber elements but would be focusing on confirming that the key elements of the fire design have been incorporated into the building.

Building construction, especially on large and complex sites, proceeds in stages, varying across parts of a building, both horizontally and vertically. Construction monitoring needs to accommodate this staging challenge.

Based on the size, importance and complexity of the building and the capability of the contractor, the BCA will assign a level of expected construction monitoring service, when issuing the building consent. The Engineering New Zealand document Construction Monitoring Services (SFPE NZ, 2021) gives definitions for a range of construction monitoring (CM) levels from CM1 (infrequent monitoring) to CM5 (continuous monitoring). The most commonly used level is CM2 for simple buildings and CM3 for more complex buildings.

Typically, the Fire Engineer will inspect active and passive fire protection systems, as well as relevant means of escape. The Fire Inspection Schedule submitted by the Fire Engineer as part of the building consent application contains the details of recommended inspections over different stages of the construction, including pre-lining, partial lining, first fix of services, second fix of services, commissioning and completion.

Both active and passive fire systems are specified systems on the Compliance Schedule for the building, managed through the Building Warrant of Fitness (BWOF) process, for the life of the building. The inspection work will be undertaken by an Independent Qualified Person (IQP). The IQP will carry out visual inspection and report on any noticeable defects and ensure that scheduled maintenance is carried out to ensure the systems' functionality during construction and for the life of the building.

13.3.1 Inspection of passive fire protection measures

The Fire Engineer will normally inspect passive fire protection systems as they are installed over different stages of construction, from the pre-lining stage through the partial lining stage to building envelope closure.

A mass timber firecell may be designed to have selected wall or ceiling surfaces encapsulated, partially encapsulated and/or non-encapsulated, depending on the compliance pathway illustrated in the Design Flowchart of Appendix A. The encapsulated surfaces need to be monitored for extent and quality as construction proceeds. Typically fire separations are a Specified System on the Building Compliance Schedule (SS15/3), so these also need to be inspected by the IQP as part of the ongoing Building Warrant of Fitness (BWoF) requirement during the operational life of the building.

13.3.2 Inspection of active fire protection systems

The design and construction monitoring of fire detection, sprinkler and alarm systems are normally undertaken by the Fire Protection Engineer. However, the Fire Engineer will commonly co-inspect active fire protection systems and liaise with the Fire Protection Engineer. As with passive fire protections, the active fire protection systems are installed over different stages of construction, and need to be inspected at relevant times.

An Accredited Inspection Company is normally engaged at commissioning to independently certify that the active fire protection systems satisfy the respective design standards, in addition to inspection by an IQP to follow the building's Compliance Schedule.

13.3.3 Coordination of interacting trades

Design coordination of the fire safety design of a complex mass timber building should begin at the start of the design stage. This should be documented using the latest version of Practice Note 22 published by Engineering New Zealand (ENZ, 2011). This document is currently under review.

The application of Building Information Modelling (BIM) tools can often simplify the design coordination and minimise construction clashes, providing the contractor with clear construction details.

13.3.4 Documentation

Typical documentation for fire safety is described in Construction Monitoring Guide, A Guide to Monitoring Construction of Building Design Features Relating to Fire Engineering (SFPE NZ, 2021), also in Engineering NZ Practice Note PN22.

During construction, other documents are used to communicate and present relevant information, to enable building sign-off by the contractor and designer at completion of the project, including the following:

- Consultant Advice Notice (CAN):
  - The Fire Engineer provides a CAN (a written notice to communicate fire safety advice) to record work-in-progress, or to raise fire safety queries, with the contractor and Contract Engineer of the project.
  - The collation of CANs at project completion becomes a record of the construction monitoring carried out. Note that the primary construction record on fire safety should be kept independently by the contractor because the Fire Engineer is only responsible for spot checks of site scenarios.
- Producer statements (PS):
  - A Producer Statement PS1 will have been provided by the fire engineer at the start of the project.
  - A Producer Statement PS2 will have been provided by the fire engineering peer reviewer at the start of the project, if a peer review has been requested.
  - Producer statements PS3 and PS4 are supplied at project completion, to demonstrate that the relevant building works constructed are in accordance with manufacturers' instructions or relevant standards, meeting the NZBC requirements.
    - » Producer Statements PS3 for the active and passive fire protection systems are supplied by the relevant contractors and, where required by standards, supported by independent certification provided by an accredited inspection company.
    - » A Producer Statement PS4 for fire safety is supplied by the Fire Engineer once all fire safety queries raised in CANs are satisfactorily resolved, and the review of construction completion documents has concluded.

When a building is in use, the building warrant of fitness (BWOF) system becomes effective, which is an annual statement supplied by the building owner to confirm that the specified systems in the Building Compliance Schedule have been maintained and checked in accordance with recommended current best practice or relevant standards (MBIE, 2016). BWOF inspection, maintenance and reporting is performed by an independent qualified person (IQP) in line with specified fire safety features and fire protection systems outlined in the Compliance Schedule. When the BCA reviews the BWOF submission, including any feedback made by the IQP, the Fire Engineer may need to amend the building's Compliance Schedule if necessary to align with any evolving current best practices.

There are a number of excellent international documents giving guidance on fire safety during construction, including those by Ranger et al (2019), STA (2014), STA (2017), and Swedish Wood, TDUK & STA (2023).

13.4 Fire safety during construction

Construction is a short but important phase of a building's life where the specified fire protection systems are often incomplete or non-functional, thus a fire occurring during construction could become uncontrollable causing total building loss and life safety concerns.

Fires during construction are a challenge for firefighters. The main challenges and some recommendations are identified in the FENZ Designers' Guide to Firefighting Operations (FENZ, 2022).

Fire during construction is mostly initiated by arson, or accidents involving hot works, thus the likelihood of these two primary events should be proactively mitigated with reasonable site and security management, as described in NFPA documents 51B and 241 (NFPA 2022, 2024).

13.4.1 Recommended fire precautions during construction

In New Zealand, the Safety in Design (SID) process is managed and administered by the design and construction team. It is described in Safety in Design in Construction: An Introduction (Site Safe, 2019). This is a systematic risk mitigation framework that is produced at the start of the design process and maintained until construction completion. The SID framework ensures that fire safety risks are proactively identified and mitigated during design, construction and at completion, by having feasible mitigation provisions in place, as part of responsibilities under the New Zealand Health and Safety at Work Act 2015.

To develop a feasible fire safety risk management strategy, a typical SID framework involves:

- Utilise a risk assessment matrix to rank the identified fire hazards.
- Determine the initial fire risks without any mitigation provisions in place.
- Re-evaluate the residual risks after feasible implementation of fire safety risk management in accordance with the hierarchy of controls, and continue until an acceptable risk level is achieved.

A generic SID scenario for fire safety in a multi-storey mass timber building design might include mitigation provisions during construction such as:

- Ensure timely encapsulation of light timber frame construction, and encapsulated surfaces of mass timber panels.
- Provide sequentially functional detection and suppression system e.g. building fire hydrant and sprinkler systems, in line with the progression of building levels.
- At completion, the building should have fully-commissioned fire alarm, sprinkler and hydrant systems with specified encapsulation systems fully in place.

13.5 Responsibility and enforcement

New Zealand Health and Safety at Work Act 2015 defines a 'Person Conducting a Business or Undertaking' (PCBU) as personnel with primary responsibilities to mitigate health and safety risks as far as is reasonably practicable, including the fire risks for a construction site which is a workplace (MBIE, 2023).

Table 1 illustrates the generic role and responsibility of various PCBUs typically involved in fire safety on a building project.

Table 1. **Role and responsibility of 'Person Conducting a Business or Undertaking' involved in building construction**

Personnel	Description
Building Owner/Project Manager	• Client or client representative • Primary decision maker on the implementation of design and construction of the building • Could act as the Contract Engineer
Architect	• Responsible for architectural design of the building • Responsible for coordinating the overall building design • Could act as the Contract Engineer
Structural Engineer	• Responsible for structural design, including the structural fire design of the building
Fire Engineer	• Responsible for fire safety design i.e. adequacy of means of escape, suitable FRR, prevention of internal and external fire spread etc.
Fire Protection Engineer	• Responsible for specific design and construction details of active and passive fire protection i.e. fire alarm system, fire sprinkler system, fire stopping system etc.
Services Engineer	• Responsible for mechanical, hydraulic, electrical, acoustic, security designs etc. of the building
Contractor	• Responsible for constructing the entire building, with assistance from sub-contractors as necessary • Responsible for managing the construction programme • Appoints the Fire Safety Coordinator for the construction site • Responsible for liaising with BCA, design team and relevant parties for required site activities during construction

Besides the PCBUs listed above, a few other personnel also have a notable influence on fire safety during construction as described in Table 2.

Table 2. **Role and responsibility of other personnel involved in building construction**

Personnel	Description
Local Council, acting as Building Consent Authority (BCA)	• Responsible for approving building consent, certificate of public use, certificate of code compliance etc. • Responsible for requesting independent peer review for complex fire safety designs • Responsible for regulating the on-going compliance of buildings in use via the BWOF process
FENZ	• Responsible for firefighting • Responsible for providing fire safety advice during design of certain buildings • Responsible for approving final location for fire alarm panel and sprinkler, fire hydrants, and/or hydrant inlets • Conducting building familiarisation surveys as appropriate • Responsible for approving the evacuation scheme, if applicable
Accredited Inspection Company	• Responsible for conducting independent certification of specific fire protection systems of the building
IQP	• Responsible for on-going checks and maintenance of specific fire protection systems listed in the building's Compliance Schedule via the BWOF process

13.5.1 Responsible parties

[Nothing to add]

13.5.2 Adoption and application

[Nothing to add]

13.6 Preventative measures

The following sections focus on the recommended precautions for fire safety during construction, as presented in Figure 13.1 of the Global Design Guide.

In 2012, the Structural Timber Innovation Company (STIC) proposed a brief overall fire safety management strategy (STIC, 2012) to mitigate fire in mass timber construction, with six main items including:

1. Prevention of after-hour access to the construction site,
2. Undertaking fire risk assessment,
3. Planning for emergencies,
4. Preventing ignition,
5. Identifying and managing potential fuel sources, and
6. Implementing early installation of fire safety measures

This is expanded in the Fire In Construction Checklist described in Section 13.9. It is important to recognise that each building site will have its unique challenges which require specific fire safety considerations.

13.6.1 Fire Safety Plan

The Fire Safety Plan forms an important part of the strategy to mitigate fire during construction. The main activities are likely to include management of hot works, use of electrical equipment, storage of combustible materials, waste management and site access, as well as incomplete fire protection systems, both active and passive, as described in Section 13.6.1 of the Global Design Guide.

The Fire Safety Plan will require constant updating to ensure that adequate and timely provisions are implemented on site and these are made clear to all people involved. On-site contractors and any visitors need to undergo formal induction to ensure familiarity with:

1. Emergency procedures including fire safety,
2. Emergency assembly points, especially for large developments, and
3. Any new site-keeping practices and personal protective measures.

Site Safe will normally assist the design and construction team with developing a suitable Fire Safety Plan.

13.6.2 Fire Safety Coordinator

The Fire Safety Coordinator is the person responsible for managing the risks of fire during construction. The Fire Safety Coordinator will perform on-going fire risk assessments, developing and maintaining the Fire Safety Plan, and liaising with other stakeholders such as BCA, FENZ, relevant experts etc.

The Fire Safety Coordinator may be the construction site manager, the Health & Safety Officer, or a nominated experienced on-site supervisor. It is important for this individual to possess in-depth knowledge of the construction in terms of programme, upcoming site works, relevant trades coordination, and evolving hazards across various part of the site.

13.6.3 Control of ignition sources

This section of the Global Design Guide is essential reading.
Nothing more to add.

13.6.4 Control of combustible materials

[Nothing to add]

13.6.5 Prevention against arson

[Nothing to add]

13.6.6 Liaison with fire authority

It is essential for the Fire Engineer and the Fire Safety Coordinator to liaise continually with FENZ during construction of mass timber buildings especially where the project is very tall or large, or contains complex features or intricate details etc.

The Fire Safety Coordinator will liaise with FENZ to identify potential fire risks and to discuss site specific circumstances relating to firefighting e.g. arrival times, access for vehicle and personnel, site topography, availability of water supply etc. Such discussions will ensure that the identified fire risks are mitigated adequately with consideration of the firefighting capability, and will assist the development of the Fire Safety Plan.

For multi-storey building sites that occupy a large floor area i.e. more than 5000 m², on-going FENZ consultation will be necessary, as the fire risks will evolve over the stages of construction. Any new feedback from FENZ should be incorporated into the Fire Safety Plan. To understand firefighting challenges during construction, refer to the Designers' Guide to Firefighting Operations (FENZ, 2022).

13.6.7 Water supplies

Firefighting water supply is essential for a construction site, especially when automatic suppression system is not likely to be fully functional. Firefighting water supply should be readily available as soon as mass timber assemblies arrive on site. This may be street water mains, in-ground hydrant systems or static water supplies. No hot works are to be permitted without the agreed firefighting water supply being available.

The Fire Safety Coordinator should ensure that strategic and operational building fire hydrant systems are maintained throughout construction, in line with the construction's vertical progression. Maintaining a functional building hydrant during construction is also the standard requirement (FENZ, 2020) where Clause 8.1.2 of NZS 4510:2022 requires a hydrant riser to be progressively made functional as close as practicable and no more than 8 m below the highest floor under construction. For multi-storey timber buildings, the hydrant riser should be made functional right up to the highest floor, to allow a rapid start to firefighting activities.

13.6.8 Staff training and human activities

[Nothing to add]

13.7 Fire detection and suppression

This section discusses the importance of active and passive fire protection systems in mitigating fire during construction, the means of escape provisions for construction site evacuation, and the firefighting access requirements.

13.7.1 Alarm and detection

Fire alarm systems are typically isolated during construction and are not fully commissioned until nearing completion (FENZ, 2020). As such, appropriate security or closed-circuit television (CCTV) systems should be put in place to detect any small fire, and robust means of alerting the entire site to an emergency should be implemented, preferably electrically operated fire warning devices or where suitable, manual alerting devices such as air horns. It is essential to ensure rapid means of contacting FENZ i.e. arranged contact with the local FENZ representative, and a phone for 111 emergency calls.

13.7.2 Active fire protection

Hand-held firefighting equipment if used appropriately and timely, can prevent an accidental fire on site from escalating. The common recommendations for fire extinguishers on site as follows:

- At least one fire extinguisher per floor or maximum coverage area of up to 500 m² per fire extinguisher.
- Provide a mobile fire point with content and location designed per NZS 4503:2005
- Ensure that on-site contractors are adequately trained and familiar in using fire extinguishers.
- Any hot work should have its dedicated fire extinguisher and designated fire watch.
- Locations of fire extinguishers are indicated on the construction site plan and discussed at site meetings to improve awareness.

Note that hand-held firefighting is a first-aid approach with limited capacity, and it may not be sufficient if a large accidental fire is detected when no one is on site. For this reason, well planned security and early fire detection systems are essential to allow rapid access by firefighters.

It is clear that the presence of an automatic fire sprinkler system would offer protection to the construction site. If the building is more than 4–storeys, it is desirable that the automatic fire sprinkler system be progressively commissioned to limit non-sprinkler protected levels to no more than 2–storeys below the current construction level, but this is unlikely in most cases because the sprinklers will not be installed and commissioned until the building is nearly complete. Sprinkler protection to stairs and areas with extensive exposed timber surfaces etc. should be made operational as soon as possible.

13.7.3 Compartmentation of the building

[Nothing to add]

13.7.4 Protection of combustible construction

Early protection of combustible construction is important. This is especially important with light timber frame construction, which is much more vulnerable to construction fires compared with large mass timber elements.

Early installation of many encapsulation products may not be desirable because they are susceptible to water damage, and they can be damaged due to shrinkage and swelling of wood with changes of moisture content. For this reason, most contractors will not want to install any linings until the roof is on, the building is weather-tight, and the moisture content has reached acceptable levels.

13.7.5 Protection of neighbouring buildings

[Nothing to add]

13.7.6 Means of egress – Escape routes

[Nothing to add]

13.7.7 Fire service access

In New Zealand, the NZBC Acceptable Solution C/AS2 provides a few building code requirements in terms of FENZ vehicular access to building sites (C/AS2, 2023). Sufficient access width and a hard packed surface are also recommended for a construction site, to be made available at the start of construction and maintained throughout. Any restrictions, permanent or temporary should be discussed with FENZ to ensure firefighting operation will not be adversely hampered. Additional challenges related to fire service access are discussed in the Designers' Guide to Firefighting Operations (Designers' Guide, 2022).

13.8 Emergency procedures

[Nothing to add]

13.9 Fire in construction checklist

A generic Fire in Construction Checklist with items of interest and descriptions is presented in Table 3 for reference. Further modifications to this checklist are needed to suit specific construction sites. If any items cannot be implemented satisfactorily, the Fire Safety Coordinator should ensure that alternative options continue to adequately mitigate the fire safety risks.

Table 3. **Fire in Construction Checklist**

Item	Description	Implemented (Y, N or N/A)
Fire Safety Plan	Fire Safety Coordinator	
	Evacuation drills	
	Basic firefighting training for contractors	
	Location of fire extinguishers	
	Fire evacuation plan for the construction site	
	Fire assembly points	
	General house-keeping practices to mitigate fire risks from site activities e.g. hot works, storage of combustibles, waste disposal etc.	
	Site Safe consultation	
	FENZ consultation	
Means of egress	Minimum two escape routes (via completed fire rated stairs)	
	Maximum travel distance 35 m to ground level or to completed fire rated stair	
	Meet recommendations in STA Advice notes, Robustness against fire, Part 5 – *Design of escape routes during the construction process*	
FENZ provisions	Firefighter site access in accordance with NZBC Compliance Documents	
	Building access for firefighters	
	Water supply	
	Building fire hydrant system progressively commissioned, consult Section 13.6.7 for details	
Arson mitigation	Community arson information	
	Controlled site access	
	Security systems	
	Secure the perimeter of the building site	
Hot work	Dedicated fire extinguishers	
	10 m separation distance from adjacent combustibles	
	Adequate shielding to immovable combustibles	
	Monitor heat transfer from hot work, especially through steel elements	
	Minimum 30 or 60–minutes continuous watch after completion	
	Final inspection at 4–hours after completion	
Storage of combustible items	15 m separation distance between the building and combustible storage area, including mass timber	
	6 m separation distance between the building and containers/drums	
	10 m separation distance between the building and open-topped rubbish skips	
	NZS 4512 fire alarm system progressively commissioned, consult Section 13.7.1 for details	
	Security or CCTV system	
	Electrically operated fire warning devices	
	Manual alerting devices	
	Telephone for 111 emergency calls, and calls to local FENZ liaison person.	
Fire detection and alarm	Fire sprinkler system and fire hydrant system progressively commissioned, consult Section 13.7.2 for details	
	Early sprinkler protection to stairs and areas with greatest fire risk	
	Fire extinguishers (maximum 500 m² floor coverage per fire extinguisher)	
	Provide mobile fire point with content and location designed per NZS 4503:2005	
Timber encapsulation	Specified encapsulation progressively installed, as much as possible.	

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Chapter 14
Firefighting considerations for timber buildings

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14. Firefighting considerations for timber buildings

Scope of chapter

This chapter discusses fire service considerations relevant to timber buildings as an extension to Chapter 14 in the Global Design Guide. It focusses on firefighting tactics and capability in New Zealand.

This chapter is complementary to Chapter 14 of the Global Design Guide, which should be read alongside this document.

14.1 Introduction

New Zealand has a long and established building history involving timber construction including many large and significant fires involving timber buildings. To date these losses have typically involved low-rise light timber frame structures leading to limited firefighting experience with mass timber buildings. This chapter discusses firefighting capability in New Zealand and its relevance to some of the challenges of undertaking firefighting in and around timber buildings, as well as potential measures that can be implemented to facilitate firefighting operations.

As identified in chapter 2, the use of mass timber presents a number of concerns, some of which specifically concern firefighting response and additional challenges during the construction stages, during a fire incident and after fires have been extinguished. In particular, designers need to be aware of the performance of timber structures if there is no intervention by firefighters. Further information specific to fire fighting and timber building design can be found within Chapter 14 of the Fire Safe Use of Wood in Buildings – Global Design Guide.

14.1.1 Fire and Emergency New Zealand

The Fire and Emergency New Zealand Act 2017 combined urban and rural fire services into a single, integrated fire and emergency services organisation – Fire and Emergency New Zealand (FENZ). The principal objectives of FENZ are reducing the incidence of unwanted fires and the associated risk to life and property. These include protecting and preserving life, preventing or limiting injury, damage to property, land and the environment.

There are approximately 1800 career firefighters with 1140 management and support staff, as well as approximately 11840 volunteer firefighters and support staff, over 640 station sites and 1278 fire appliances covering all of New Zealand.

In complying with the requirements of the Building Code it should be recognised that, among other purposes, the Building Act is intended to facilitate firefighting operations. Anyone performing functions or duties or exercising powers under the Building Act is required by law to take account of the reasonable health and safety expectations of firefighters when firefighting or undertaking rescue operations in a building. Building Act Section 4(2)(h) includes for;

> *the reasonable expectations of a person who is authorised by law to enter a building to undertake rescue operations or firefighting to be protected from injury or illness when doing so;*

Building Code Clause C5 provides the requirements specific to Access and safety for firefighting operations. Of specific relevance are the Functional requirements which include;

> *C5.1 Buildings must be designed and constructed so that there is a low probability of firefighters or other emergency services personnel being delayed in or impeded from assisting in rescue operations and performing firefighting operations.*
>
> *C5.2 Buildings must be designed and constructed so that there is a low probability of illness or injury to firefighters or other emergency services personnel during rescue and firefighting operations. Refer to clause C5.3 to C5.8 for specific Performance requirements.*

14.1.2 Firefighting capability in New Zealand

Understanding the operational capabilities of FENZ and the relevant local fire brigades that would be attending any incident is crucial for fire engineering designers. Building design requirements internationally often consider local firefighting capability, specifically with regards to the types of buildings that can be built in certain areas. Such restrictions include limiting the building height and provisions for external access and separation distances between adjacent buildings. For example, Section A-3, Application of Part 3 (Fire Protection, Occupant Safety and Accessibility) of the 2020 National Building Code of Canada explains as follows (Canadian Commission on Building and Fire Codes, 2022):

> *Firefighting capability can vary from municipality to municipality… …The level of municipal fire protection considered to be adequate will normally depend on both the size of the municipality (i.e., the number of buildings to be protected) and the size of the buildings within that municipality. Since larger buildings tend to be located in larger municipalities they are generally, but not always, favoured with a higher level of municipal protection.*
>
> *Although it is reasonable to consider that some level of municipal firefighting capability was assumed in developing the fire safety provisions in Part 3, this was not done on a consistent or defined basis. The requirements in the Code, while developed in the light of commonly prevailing municipal fire protection levels, do not attempt to relate the size of building to the level of municipal protection. The responsibility for controlling the maximum size of building to be permitted in a municipality in relation to local firefighting capability rests with the municipality. If a proposed building is too large, either in terms of floor area or building height, to receive reasonable protection from the municipal fire department, fire protection requirements in addition to those prescribed in this Code, may be necessary to compensate for this deficiency. Automatic sprinkler protection may be one option to be considered.*

In New Zealand there are no similar limitations with the only relationship historically being the reach of ladders and aerial appliances relevant to the thresholds contained in the relevant building fire safety design regulatory documents.

Fire brigade capability across New Zealand varies significantly, with areas outside of major city centres heavily relying on volunteer brigades. These brigades are not 24-hour staffed and may not possess the same level of experience and training as career fire firefighters. Also, each station is equipped with different appliances that may have different firefighting capability. This will lead to differences in response times and the ability for certain types of responses which may fundamentally impact the options available when undertaking firefighting operations. Firefighting water supply quality and quantity also varies throughout New Zealand. Understanding these capabilities and their limitations is vital for efficient and effective fire safety and design planning, especially in taller and more complex buildings.

Figure 1 shows the Fire and Emergency regions across New Zealand, with an indication of the number of fire stations and fire appliances in each region.

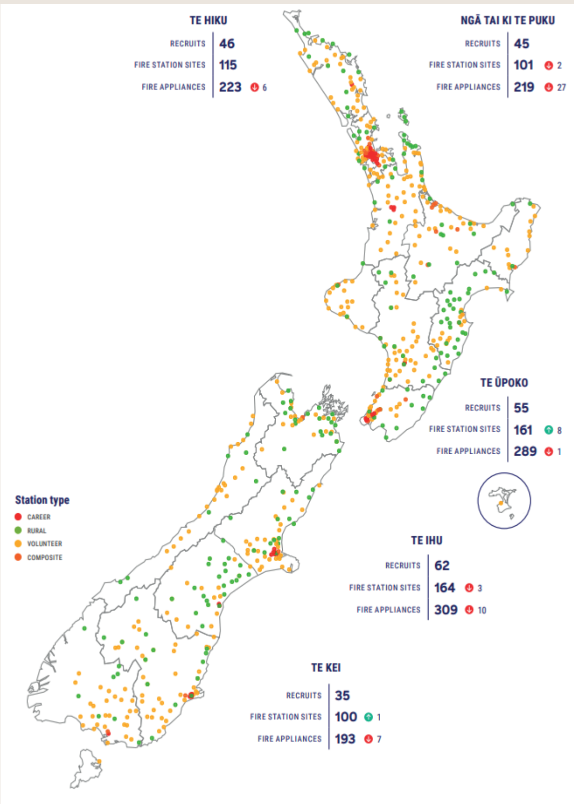

Figure 1. **Fire and Emergency regions and associated resources (2023)**

The Fire and Emergency fleet currently includes Type 1 to Type 3 pumping appliances, Type 4 to Type 6 aerial appliances, smoke chaser, rural appliances, water tanker and other special vehicles such as Hazmat/Command Unit etc. There are a limited numbers of aerial appliances that are available for taller buildings. Information about each type of aerial appliance currently available and their location are shown in Table 1 (note that location of appliance may be adjusted/changed from time to time according to operational needs).

Table 1. **Fire and Emergency aerial appliance types, reach capability, and allocated locations across New Zealand**

Aerial appliance	Image	Max. reach height	Total fleet	Locations
Type 4		Up to 17 m	18 (16 + 2 reliefs)	Te Hiku: Whangarei, Ellerslie, Te Atatu, Papatoetoe Ngā Tai ki te Puku: Mount Maunganui, Rotorua, Gisborne Te Ūpoko: Avalon, New Plymouth, Whanganui, Napier, Palmerston North Te Ihu: Christchurch city, Timaru, Nelson Te Kei: Invercargill
Type 5		22 m	6 (4 + 2 reliefs)	Te Hiku: Parnell Te Ūpoko: Newtown, Thorndon Te Ihu: Christchurch city
Type 6		25 m	3	Te Hiku: Auckland city Ngā Tai ki te Puku: Hamilton Te Kei: Dunedin city

Figure 2 illustrates FENZ aerial appliance types and their operational reach envelopes. Height capability will decrease if the appliance cannot be sited close to the building. A number of factors can influence siting location including suitable hard-standing location, the location of other buildings and potential hazards such as structural collapse or falling debris generated by the fire.

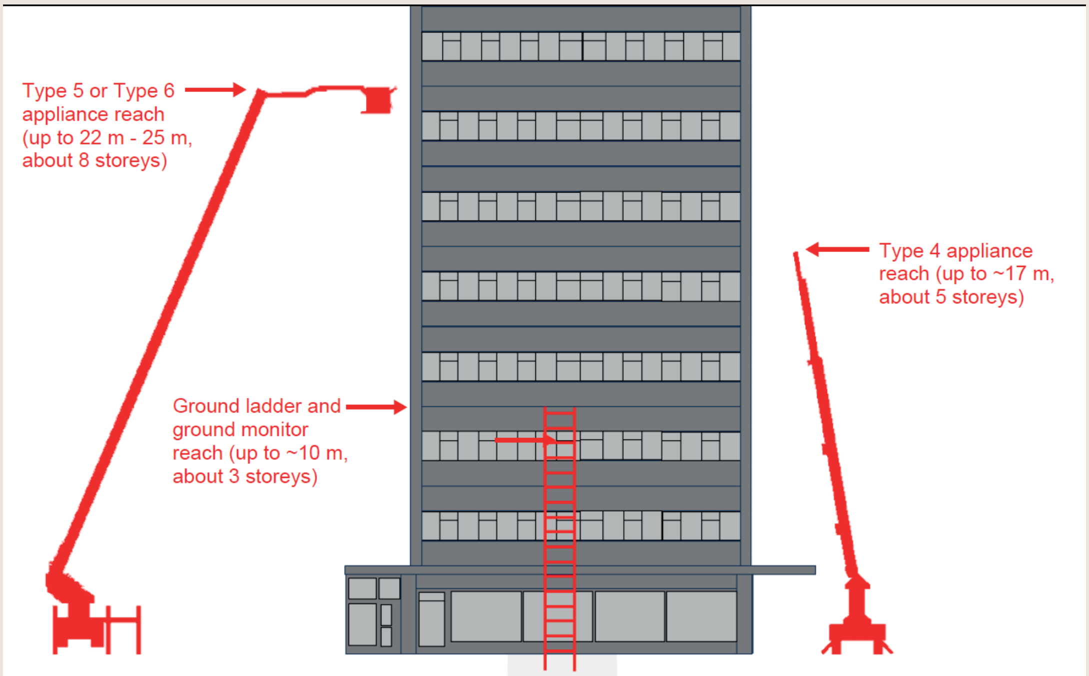

Figure 2. **FENZ aerial appliance types and their maximum operational reach envelopes**

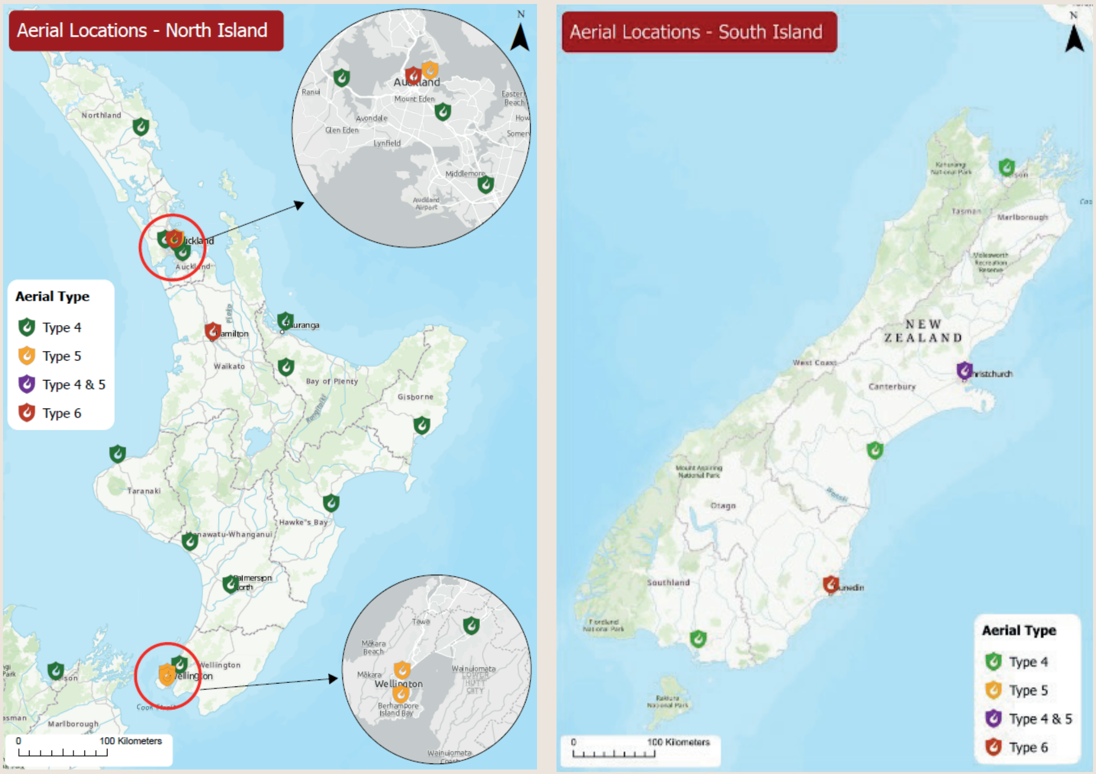

Figure 3. **Location of Aerial Appliances across New Zealand (single appliance in each indicated location)**

A location summary for different aerial types is shown in Figure 3. Type 4 appliances are the only aerials equipped with firefighting water pumps. Type 5 and 6 appliances must be supplied from other pumping appliances.

The nominal rated water flow capacity of Type 1 through Type 4 appliances is shown in Table 2. These rated flow rates are based on drafting from a static water supply at the maximum rated suction head. Higher flow rates may be achieved from other water supplies such as pressurised reticulation systems. Volunteer stations located in smaller population centres are generally resourced with Type 1 and 2 pumping appliances. Career stations in larger population centres are generally resourced with Type 3 pumping appliances and aerial appliances as shown above.

Table 2. **Fire and Emergency pumping appliance nominal rated water flow rate (Source: Pump Operation Technical Manual)**

Appliance type	Nominal rated water flow rate (lpm)
1	1800 - 1900
2	1900 - 2800
3	Up to 3785
4	Up to 4680

14.2 Traditional fire knowledge

Section 14.2 of the Global Design Guide provides relevant discussion which is also relevant to New Zealand. Similar traditional timber construction methods have been prevalent in New Zealand as described in the Global Design Guide, and as such fire service knowledge is comparable.

14.3 Fire service concerns related to mass timber buildings

Specific concerns by Fire and Emergency include the following:

- Faster fire growth and greater total heat release rates
- Earlier flashover, including the possibility of multiple flashovers (i.e. regrowth following a decay phase). Risk of glueline failure also may contribute to potential secondary flashover.
- Increase in fuel load producing longer duration fires
- Increased firefighting water demands
- Greater requirements for resources inside the building, including access above the fire floor
- Hidden fire spread in voids and ongoing combustion behind encapsulation
- Increased severity of external flaming from windows and openings and chance of fire spread to adjacent buildings
- Greater reliance on fixed fire protection systems
- Increased production of carbon monoxide due to ongoing smouldering combustion
- Increased influence of wind-driven fires
- Greater requirements on overhaul procedure and rekindling risk
- Risk of structural failure due to the weight of water pooling on floors and collecting in void spaces.
- Risk of delayed structural failure due to smouldering and continued heat propagation continuing to weaken timber as the fire decays
- More pre-incident planning required for these buildings

Most of these concerns are similar to those listed in the Global Design Guide. They are all considered in this Commentary. A number of these concerns can apply to any type of construction, especially exceptional fuel loads and other issues outside the normal management of the building. However, when comparing similar buildings, the use of combustible construction when compared to non-combustible construction will inherently present a greater fuel load and additional challenges to fire safety design and potential firefighting responses.

14.3.1 Internal compartment fire dynamics

Large experiments such as the CodeRed (Kotsovinos, Rackauskaite, et al., 2023) (Kotsovinos, Christensen, Rackauskaite, et al., 2023) experiments and FRIC have demonstrated that once the ceiling is ignited mainly as a result of direct impingement of the flames from the seat of the fire, or through a combination of radiation and convection as observed in FRIC 01 [4], the flames rapidly spread across the compartment. The rate of spread can be accelerated when both the wall and ceiling are exposed as was observed in the FRIC experiment compared to when only the ceiling is exposed as observed in the CodeRed experiments #01 and #02. The fire had travelled across the compartment in the CodeRed #01 and #02 experiments in 5 and 8 minutes respectively in comparison to the 25 and 32 minutes observed in the identically constructed but non-combustible compartments.

The CodeRed experiments demonstrated higher temperatures near ground level due to the thermal feedback from the ceiling compared to non-combustible buildings. In addition to the increased compartment temperatures observed with mass timber compartments, this can be partly due to the fact that in non-combustible buildings it is mainly only hot gases accumulating in the upper layer, whereas in building with exposed CLT ceiling the flames can spread across exposed mass timber well beyond the seat of the fire which will be radiating down onto occupants and firefighters. Hence, this also places a higher risk to firefighters entering the compartment attempting to reach the seat of the fire.

14.4 Light timber frame construction

Refer to section 14.4 of the Global Design Guide.

14.5 Mass timber structures

While modern mass timber elements, such as CLT panels, can be designed (and tested) to provide fire resistance ratings based on standardised fire testing of isolated elements, these results need to be carefully considered in the context of the remaining structural capacity of the element and ongoing heating effects, once the test has been terminated. The temperature data from both CodeRed #01 and #02 indicate that the cessation of flaming cannot be used as a reliable point to determine structural capacity for exposed timber members. Hence, in a real fire situation, while the thermal imaging cameras may be used to determine the locations of potential hotspots, monitoring the surface temperatures and trying to establish thermal degradation and temperatures inside the structural members will not be practical.

This transient thermal lag has also been studied in other experiments e.g. Gernay (2021), which showed consideration of the temperatures within the decay phase is critical for the design of columns to avoid their failure well after flames within the compartment have ceased. Gernay's experiment showed that structural failure can occur many hours after flames have ceased within the compartment. Current design methods in Standards such as AS/NZS 1720.4 are unlikely to be suitable to capture the structural degradation of mass timber elements in the decay. Refer to Chapter 7 and Chapter 12 for further details on the structural performance of mass timber elements in a fire.

Many experiments have shown that extensive overhaul procedures are necessary to fully extinguish the fire and smouldering in the building that would otherwise continue to weaken the structure. Fires in mass timber structures can become deep-seated in thick timber sections. This phenomenon was observed in a series of experiments conducted in 2022 in Canada (J. Su et al, 2023). These experiments involved five fire scenarios in a large two-storey, four-bay structure constructed of mass timber elements including glued-laminated timber, cross-laminated timber and dowel-laminated timber. Two scenarios simulated completed residential apartments, two simulated construction site fires and one simulated an open plan office floor. One of the residential apartment experiments was used as a control with no exposed mass timber.

Particularly in the open plan office test, deep-seated smouldering combustion was observed at mass timber joints. The report indicates:

> *"In the junction of the beam-to-column connection B203–C103–C202 and CLT ceiling panel butt joint between Bay 2 and Bay 3, smouldering continued for nearly three hours after the test. After several attempts to extinguish it with hose stream from below, this beam-column-ceiling junction still persisted smouldering. In the end, the smouldering had to be extinguished from the top on the second floor by removing the fire caulking from the floor butt joints and pouring a bucket of water into the junction.*
>
> *The main reason for deep charring in some joints and connections such as described above was believed to be that the firestop installation was compromised by the rainy weather during the construction – some firestop caulking was washed away by the rain during installation, compounded by the absence of normally used concrete topping on the floor/ceiling assemblies. The manually installed connection hardware and various mass timber products from different manufacturers/ suppliers could not achieve the fit as good as those typically produced using the CNC technology with high precision. These negatively impacted the fire separation continuity of the floor/ceiling assemblies. Also, the perimeter walls of the test structure were not built as airtight as normal buildings. Although steps were taken to remedy the issues after the construction, physical obstruction by the finished building elements prevented some joints from getting a complete seal. These incomplete seals would likely have allowed hot fire gases to move through and caused continuous smouldering at the joints, in addition to the absence of firefighting intervention during the four-hour long test. However, the issues were unique to the test structure only. For normal buildings, the CNC technology would be used in the production of the mass timber structural elements and the installation of connection hardware to provide tight fits, concrete topping would be poured on the floor assemblies and their building envelope would be airtight to limit air leakage and thermal transfer in order to meet the NECB."*

Construction defects such as those described above have been routinely observed in actual buildings. Also, the use of features such as concrete toppings on mass timber floors is considered undesirable by the New Zealand building industry, as discussed in Section 2.9 of this commentary.

Attempting to detect and address smouldering in mass timber buildings presents a difficult task for firefighters. Therefore, it is very important to consider the impact of the thermal wave on the load bearing capacity of critical load bearing structural elements to ensure the safety of firefighters and others who will be within the vicinity of the building. Overhaul procedures may be further complicated where the pyrolysis of timber is occurring behind protected linings or beneath floating floors due to construction defects, inadequate protection, inadequate detailing (particularly in compartments with partial encapsulation as observed in CodeRed #04 experiment (P. Kotsovinoa et al, 2023).

The continual degradation of the load capacity of structural elements well after flames have ceased increases the risk of building collapse. The difficulty in predicting the structural performance of mass timber elements, particularly load bearing columns, can pose a significant threat on the life safety of the firefighters during the fire, and post-fire investigators as well as others who may be located within or adjacent to the building after the fire. Therefore, it is recommended that critical elements such as mass timber load bearing columns are well protected so that they do not contribute to the fire severity, and fire safety systems such as sprinklers are installed.

14.6 Tall timber buildings

14.6.1 Sprinkler & fire safety system

Over a building's lifespan, its fire support features will inevitably need maintenance and replacement. Active fire safety systems also need regular maintenance with various reasons needing them to be isolated and unavailable. For mass timber buildings the impact of fire safety systems not being available may significantly increase the fire safety risk to the building during that time. Standards often mandate notifying the fire service of any impairments, especially when essential facilities like hydrant systems might not be accessible. Such situations should be anticipated, allowing Fire and Emergency to enhance operational responses.

It's crucial for Fire and Emergency to understand the extent of timber construction and the relevant fire safety strategy of the building. When a timber building undergoes renovations affecting multiple systems for example, temporary compensating features may be necessary to ensure effective firefighting. Such risk factors and mitigating features may need to be established and set out as part of the fire safety strategy, especially for tall timber buildings.

The above is particularly important for sprinkler systems which may be isolated when the building is undergoing alterations or are yet to be operable as the building is being constructed. (Refer to Chapter 13 for fire safety during construction.) Sprinklers when operating effectively significantly limit the impact of the fire severity on the structure by limiting fire growth and fire spread. Sprinklers also significantly increase the level of firefighter safety and enable successful extinguishment of the fire if not already extinguished by the sprinkler system. The concessions for sprinkler protected buildings that typically are allowed , such as larger compartment sizes and lower fire resistance ratings compared to non-sprinklered buildings may not be appropriate to mass timber buildings without specific consideration of the origins of the basis for the concession. While sprinklers are reported to have a high degree of reliability in suppressing fires there remains the possibility that they may not control the fire. The New Zealand Building Code requires designers to consider the likelihood and consequence of failure of fire safety systems such as sprinklers on the structural fire severity. Naturally the consequences of failure in combustible construction would be higher than for non-combustible construction.

14.6.2 Firefighter access

For buildings with an escape height ranging between 10 m and 18 m most aerial appliances, when available and provided with appropriate access to the exterior of the building, can reach the top floor for external attack or rescue. Internal firefighting approaches are feasible with additional resource allocation where the design of the building provides for protected means of access and egress routes for firefighters. For buildings with an escape height between 18 m and 25 m, external attacks are only viable in specific regions equipped with Type 5 or Type 6 appliances (refer Section 14.1.2). Internal attacks are possible, albeit demanding higher resource allocation again. Buildings with an escape height exceeding 25 m are especially resource-intensive, necessitating comprehensive planning and efficient resource allocation for effective fire control and management.

14.6.3 Burnout

In New Zealand, the term “burnout” is defined in Clause A2 of the New Zealand Building Code (NZBC):

> *“Burnout means exposure to fire for a time that includes fire growth, full development, and decay in the absence of intervention or automatic suppression, beyond which the fire is no longer a threat to building elements intended to perform loadbearing or fire separation functions, or both.”*

Such burnout phenomenon is likely in non-combustible buildings but may never occur in massive timber structures without sprinkler and/or firefighter intervention, because smouldering combustion of large timber members could continue indefinitely until the structure collapses.

Therefore, provision of firefighting facilities should be carefully considered when designing a mass timber building. The actual operational requirement may be above and beyond what’s stated in the current compliance documents that were designed for non-combustible constructions, especially for tall mass timber buildings.

Refer to Chapter 2 regarding further discussion of Burnout and designing timber structures to meet the relevant Code requirements.

14.7 Firefighting considerations

14.7.1 Firefighting water supplies

For timber construction, it may be useful to consider increased heat release rates and therefore larger water demands. (Ni and Gernay, 2022) for a specific scenario as part of a case study estimated additional firefighting water requirements when all visibly exposed surfaces consisted of Cross-Laminated Timber (CLT) panels within a compartment. They estimated that the additional fire heat release rate and duration might lead to a potential escalation of approximately 47% of additional firefighting water flow and an increase in the total firefighting water required of 91%. This contrast was drawn when compared to a scenario involving non-combustible linings.

Other factors related to fire behaviour in mass timber structures that may contribute to greater firefighting water needs include extended overhaul activities and greater potential for fire spread beyond the compartment of fire origin. As noted previously, deep seated fires in mass timber can be difficult to achieve final extinguishment and therefore may need additional water supply for long duration cooling, however the flow rate during these activities would not be as great as for initial fire knockdown or exposure protection prior to direct suppression. More severe and longer duration external flaming may increase exposure protection and/or extinguishment water flow and total supply needs for adjacent compartments.

As such, prudent consideration of the potential augmentation in water supply prerequisites is imperative when devising firefighting systems tailored to the distinctive challenges posed by mass timber buildings.

14.7.2 External fire exposure to surrounding buildings

The risk of external fire spread to adjacent properties and other floors is a concern in mass timber buildings due to the combustibility of timber and the consequential increased external flame projection and compartment temperatures.

A simple assessment presented in a technical report by Gernay et al (2020) assumes the worst-case scenario where the mass timber building is completely engulfed in a fire, and evaluates radiative heat exchange toward the neighbouring building from a virtual solid flame. For a 10-story case study, the critical distance for ignition of a neighbouring building is 23 m if all the timber is protected and does not get involved in the fire, but this distance increases to 30 m if 100% of the timber is exposed.

The CodeRed experiment #01 showed the presence of an exposed CLT ceiling significantly impacts fire behaviour when compared to non-combustible structures. Buildings with exposed CLT ceilings experience longer fire durations, nearly double the peak Heat Release Rate (HRR), and substantial external flaming, with flames reaching heights of 2.5 to 3 meters for most openings. In contrast, non-combustible buildings exhibit smaller, more localized external flaming with less significant flame heights. This comparison underscores the heightened fire risks associated with exposed CLT ceilings, including the potential for vertical flame spread up external walls and to adjacent properties.

Additional debris and fire brands, especially under wind-driven conditions may also be experienced in timber buildings that do not feature encapsulation or non-combustible protective linings.

The increased risk of external fire spread will place additional strain on firefighting resources and the exposure risk to firefighters. For additional information on external fire spread in mass timber buildings, please refer to Chapter 3 of this mass timber guidance commentary. However, it is important to note that the provisions proposed in the mass timber guidance do not explicitly address this risk at this stage. It is recommended for the fire designers to take the additional mass timber fuel load into account when assessing the risk and separation distance required.

14.7.3 Combustible cores and vertical enclosures

In low-rise structures, external firefighting tactics can be used to contain and dampen down the fire, as well as prevent the fire's spread to neighbouring properties. However, when dealing with taller buildings, regardless of their construction materials, internal firefighting approaches are the only effective method.

In the case of tall timber buildings, especially those accommodating vulnerable occupants, the fire engineering design centres on robust compartmentation measures. These measures are strategically designed to halt fire propagation, allowing the fire to self-extinguish while preserving the building's structural stability. This compartmentation is critical to enable occupants' safe egress and fire service firefighting and rescue operations.

Regardless of structure height, if the fire is in the initial stages and contained to one compartment/floor, then firefighters may choose to attempt to extinguish the fire by an internal attack. The need for an internal attack becomes greater as the building's height increases due to external attack being less feasible.

CVM2 explicitly requires structural protection for durations exceeding the 'burnout' time for some buildings/building elements such as buildings with an escape height (EH) above 10 m and building elements providing property protection. The C/VM2 commentary states the following regarding buildings with an EH > 10 m:

> *"In taller buildings (with an escape height above 10 m) where it will take longer and be more challenging for firefighters to reach the upper floors and where external ladder access is usually unlikely, then fire protected routes (i.e., safe paths) are required to enable the firefighters to reach all upper full floors. The safe paths do not need to extend to the level of all intermediate floors (see below). However, all the load carrying structure and floor systems (for intermediate floors see below) must be designed to resist collapse for the burnout period. Depending on any other functions required for these building elements, at least structural adequacy is required. Integrity and/or insulation may or may not be required."*

It is not acceptable for these taller buildings to collapse catastrophically during or following fire, even if the occupants have safely evacuated, due to the potential endangerment of persons outside the building at ground level.

It is important to note that fire safety strategies should not rely on external firefighting attack for taller buildings due to several reasons including:

- Availability of appliances due to the appliance attending another event or being out of service.
- Some of the larger aerial appliances have a delay in response and require some time to set-up.
- The available local aerial appliance (if any) may not have the capability of reaching the floor of fire origin. Refer Figures 1 and 2 for height capability of different appliances and to for the distribution of the aerial appliances across NZ.
- The surrounding environment of the building may not be suitable for an appliance to set-up.
- Multiple appliances would be required to effectively put out a fire which may not be feasible. Reaching the seat of the fire may also be difficult.

The complex fire dynamics behaviour and associated risks in buildings with exposed mass timber (such as the increased risk of rapid flashover, higher near-floor temperatures, and potential for secondary flashover) pose a risk to firefighters carrying out an internal fire attack if sprinklers do not control the fire. For buildings up to escape height of 25m, see the requirements in Section 4.1 of the Supplement in Appendix A.

For buildings over 25m escape height where the stairway is a single means of escape, it is important to have non-combustible core walls and stairs (including stair treads, risers, and landings) due to the reliance on internal firefighting.

Such design supports the importance of these parts of the buildings for firefighting intervention and provides greater confidence to firefighters in the robustness and resilience of tall mass timber construction. As reported in Chapter 4, the FRR requirements for tall mass timber buildings in New Zealand are less than those in many other countries.

14.7.4 Void spaces and cavities

Section 14.7.4 of the Global Design Guide is relevant to New Zealand without modification.

14.7.5 Identifying voids and fires within voids

Section 14.7.5 of the Global Design Guide is relevant to New Zealand without modification.

14.7.6 Extinguishing fires within a void

Section 14.7.6 of the Global Design Guide is relevant to New Zealand without modification.

14.7.7 Extinguishing fires in wood-based materials

Section 14.7.7 of the Global Design Guide is relevant to New Zealand without modification.

14.7.8 Extinguishing agents

Water is the primary extinguishing agent available to Fire and Emergency. Most pumping fire appliances also have built in Class A foam capability. Class A foam agents can either be added to water in lower proportions as a wetting agent to reduce the surface tension of the water (which can assist with penetration into fuel packages to enhance cooling) or in higher proportions to produce foam, which can be used as a blanket to isolate burning fuel from the oxidizer source, i.e. air. Foam blankets do break down over time which mean that they may be less beneficial for deep seated fires. With deep seated fires, heat may continue to be produced in sufficient quantity that reignition or rekindling can occur after the foam blanket has degraded and oxygen and fuel are again able to mix.

Fire and Emergency has run trials with using compressed air foam systems (CAFS) from time to time in the past, and there are some appliances that have this capability. However, at present this capability is not generally provided on Fire and Emergency pumping appliances.

14.7.9 Non-direct attack

At present, it is not standard practice for New Zealand fire appliances to carry special equipment such as piercing nozzles or cutting extinguishers for non-direct attack.

14.7.10 Comparison of extinguishing equipment

Section 14.7.9 of the Global Design Guide is relevant to New Zealand without modification.

14.7.11 Overhaul procedure

The overhaul procedures will need to be more thorough to deal with smouldering and address hidden fires such as in joints or behind fire protection material. During and after a fire, the timber concealed by fire protection might be affected, necessitating the removal of the protection by firefighters to prevent ongoing charring and potential for reignition. The ongoing smouldering may cause a delayed collapse of the structure without proper overhaul procedure.

There are various examples of re-ignition of timber structures occurring in the literature, one occurred when FENZ experienced the loss of a large timber house in 2021, Figure 4. Following a localised chimney fire which was thought to have been fully extinguished firefighting crews had to return to the scene the early following day after the fire re-ignited, destroying most of the building.

Figure 4. **Image from Stuff, available here (FENZ, 2021)**

14.8 Wind-driven fires

Many areas of New Zealand are particularly susceptible to high winds. Some councils may have wind maps available. Wind data may also be obtained from MetService. In combination with increased external flaming expected from compartments with exposed mass timber, wind may affect where fire appliances, personnel and external hose streams can be located.

14.9 Design stage and fire service involvement

Fire and Emergency should be involved with tall or complex timber building design, including in the design process as well as during construction (refer to Chapter 13 for detail). It should be incumbent on the design engineer to under¬stand and ascertain what resources are available locally, especially where tall buildings are being considered in an area that does not have extensive tall building resource and experience. Early engagement with Fire and Emergency is strongly encouraged.

14.10 Pre-incident planning

Firefighting tactics during the early growth phase of a fire are not likely to significantly differ in a mass timber building compared to an equivalent non-combustible building. Rather firefighters need to be more cautious of the changing conditions occurring as a fire in a mass timber compartment develops to the point where the compartment itself becomes involved in the fire. The fire dynamics unique to a mass timber compartment (rapid flashovers, increased external flaming and potential for secondary flashovers) become important if an internal attack was to be carried out. These differences may lead to the need to change in tactics required to address fundamental differences in building behaviour when dealing with timber lined compartments compared to traditional non-combustible construction. Therefore, it is very important that Fire and Emergency are aware of such buildings and undertake the necessary planning and awareness at each of the building stages, including during construction and when the building is occupied.

14.11 Post-earthquake fires and fire service response

Section 14.11 of the Global Design Guide is relevant to New Zealand without modification.

14.12 Future needs

Like the majority of fire service organisations around the world, Fire and Emergency has little experience with fire incidents or other interactions with mass timber buildings at present. As time progresses experience with mass timber will increase, leading to more knowledge generated about the most effective and safe methods for firefighting operations and building features necessary to achieve societally acceptable fire safety with this new type of construction. There will also be ongoing efforts to increase the building scale, complexity and reduce costs where mass timber construction is used.

There is a risk if the use of mass timber construction expands rapidly before the associated fire safety ramifications are well known, that insufficient built-in fire safety measures could result in significant societal cost to retrofit, abandon or replace large numbers of buildings before they have reached their natural lifespan. As discussed in general terms in the Global Design Guide, Fire and Emergency intends to continue to learn and evolve our interaction with mass timber construction and other stakeholders to attempt to achieve the most favourable outcomes for all stakeholders.

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Appendix A

Contents

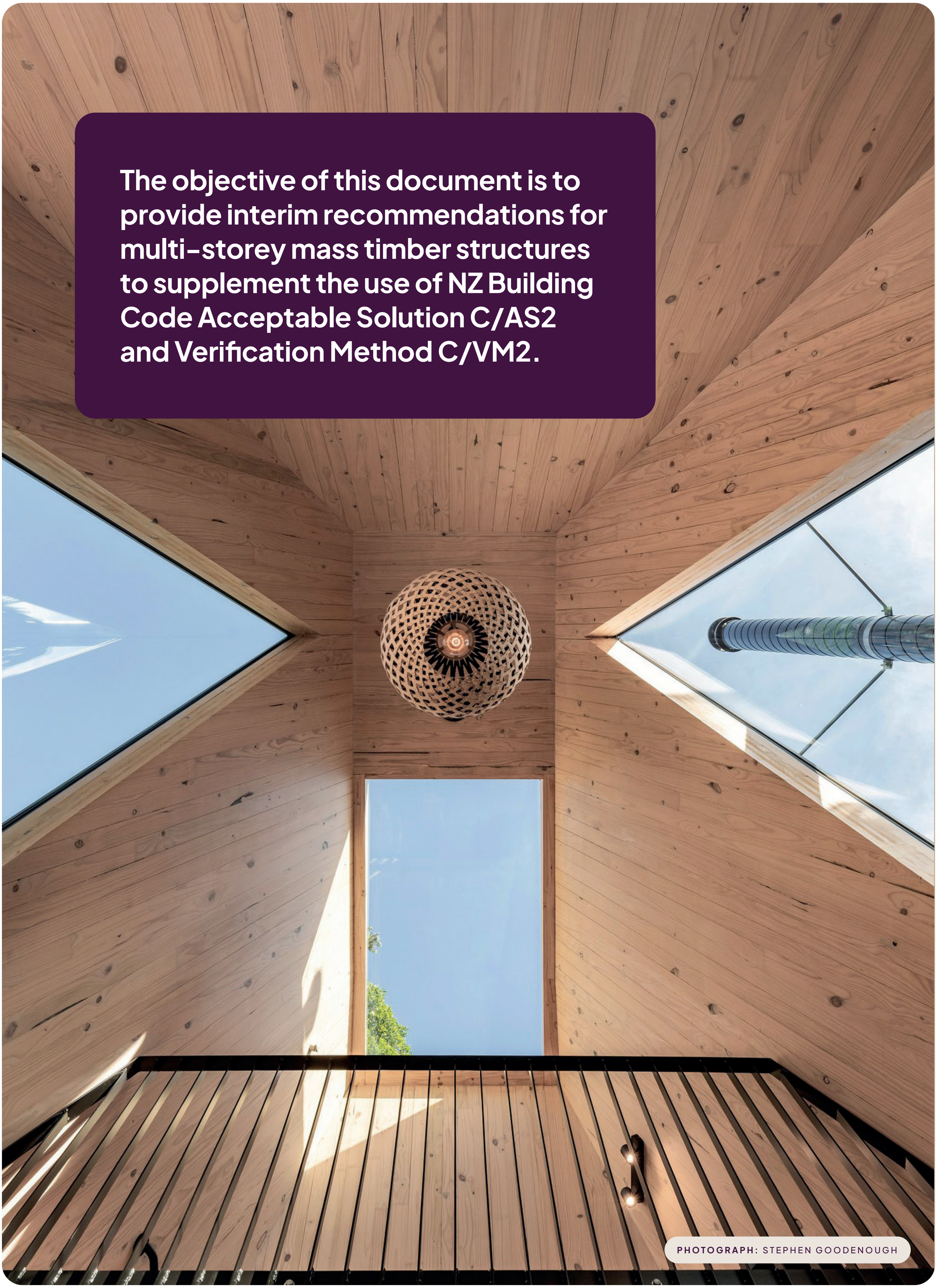
Supplement (Version 1, October 2023)	Fire safety in multi-storey mass timber structures *Recommendations to supplement C/AS2 & C/VM2*

Timber Unlimited

Version 1
27 October 2023

Fire safety in multi-storey mass timber structures

RECOMMENDATIONS TO SUPPLEMENT C/AS2 & C/VM2



The objective of this document is to provide interim recommendations for multi-storey mass timber structures to supplement the use of NZ Building Code Acceptable Solution C/AS2 and Verification Method C/VM2.

PHOTOGRAPH: STEPHEN GOODENOUGH

1. Introduction

Rationale

- The reason for this proposal is to address three principal concerns regarding fire safety in mass timber buildings, in the unlikely event that firefighter access is delayed, and sprinklers (if installed) are ineffective:

  1. Large areas of exposed structural timber can add significantly to the fire load.
  2. Charring may continue after a severe fire appears to be extinguished.
  3. The strength of wood decreases with temperature, starting at temperatures below 100°C.

- Recent advances in timber materials, including Cross Laminated Timber (CLT), have resulted in mass timber being considered for a wide range of buildings. New Zealand Building Code (NZBC) documents C/AS2 and C/VM2 do not contemplate the extensive use of mass timber, so using these documents without specific consideration of mass timber may produce fire safety outcomes that do not meet the performance requirements of the NZBC.

Use of this document

- This document provides recommendations for an emerging area of building construction and is published by Timber Unlimited. It is not published as guidance under s175 of the Building Act. It is recommended practice produced by a team of experts after reviewing recent national and international research. The advice is likely to change as more information becomes available. The flowchart in Appendix D may be of assistance to readers.
- Although this document is intended to give guidance to architects, developers, and the building industry, all fire designs submitted for building consent should be carried out by suitably qualified professional fire engineers with recognised qualifications.

Background

- A recent international book, *Fire Safe Use of Wood – Global Design Guide (2022)* provides much information on the design of timber buildings for fire safety. To expand the use of this guide into common practice in New Zealand, Timber Unlimited has commissioned a New Zealand Commentary and these recommendations.
- Further discussion and detailed justification for the recommendations in this document will be provided in the Commentary to be published early 2024.

What buildings do the interim guidance recommendations apply to?

- This document applies to all mass timber buildings with escape heights greater than 4 metres, where charring could significantly add to the fuel load and reduce the structural capacity.
- It is expected that buildings with escape height not more than 4 metres will be subject to normal design procedures, with no additional recommendations. Buildings with escape heights above 25 metres are beyond the scope of this document.

The following types of building are included:

- Buildings with mass timber structural frames, walls or floors (either exposed or protected).
- Buildings with a mix of concrete and mass timber (e.g. concrete core walls and timber gravity structure).
- Buildings with a mix of structural steel and mass timber (e.g. structural steel braced frames with CLT floors).
- Buildings with timber-concrete composite floors (with vertical structure of any material).
- Buildings with a mix of mass timber and light timber frames (e.g. light timber walls and mass timber floors).

This document applies to risk groups SM, SI, CA, and WB as defined by C/AS2.

- Risk groups WS (high rack storage) and VP (vehicle parking) are outside the scope of this document.
- There are no additional recommendations for mass timber residential buildings designed using C/AS1.
- There are no additional recommendations for light timber frame buildings (such as those covered by NZS 3604) provided that there are no large areas of exposed structural mass timber.

2. Prescriptive design of mass timber buildings using Acceptable Solution C/AS2

For mass timber buildings with escape height greater than 4 m, a prescriptive design based on C/AS2 should contain the following supplementary measures in 2.1 to 2.2. Additional items in 4.1 to 4.8 are recommended for buildings designed using C/AS2 or C/VM2.

2.1. FRR and areas of exposed wood

Where CAS2 requires building elements to be fire rated, the life and property ratings should be taken from Table 1 below but not be less than those given in Table 2.4 of C/AS2. The FRR values in Table 1 apply to both life ratings and property ratings. Encapsulation materials provided to limit the fuel load may also contribute to the fire resistance.

Table 1.
Permitted area of exposed mass timber and minimum FRR
For Risk Groups SM, SI, CA, WB[4]

	Unsprinklered building		Sprinkler-protected building[1]	
	Exposed wood	Minimum FRR[5]	Exposed wood	Minimum FRR[5]
Escape Height up to 4 metres (1 and 2 storeys)[6]	WU	As in C/AS2	WU	As in C/AS2
Escape Height more than 4 m and up to 10 metres (3 and 4 storeys)[6]	W100	60[2]	WU	60[3]
Escape Height more than 10 m and up to 18 metres (5 and 6 storeys)[6]	W0	90	W200	60
Escape Height more than 18 m and up to 25 metres (7 and 8 storeys)[6]	Not recommended		W100	60

Notes to Table 1:

1. Sprinklers must be installed to a recognised standard as required by C/AS2 (e.g. NZS 4541).
2. The minimum FRR of 60 minutes in category W100 requires a Type 4 or Type 5 fire alarm system to be installed, otherwise the minimum FRR becomes 90 minutes, unless all wood is encapsulated (category W0).
3. If exposed wood is in category W100, the minimum FRR is specified in C/AS2 Table 2.4.
4. For Risk Group WB, refer to Note 2 in C/AS2 Table 2.4.
5. The minimum FRR applies to all structural and non-structural elements which are required to be fire-rated.
6. The escape height governs over the number of storeys, which are shown only for guidance.

Refer to Section 2.2 for exposed mass timber categories WU, W200, W100 and W0. The permitted amount of exposed timber considers factors such as the expected occupant egress time, risk to firefighting operations and adjacent property, reflecting the increased consequence of failure with increasing building height.

Risk Groups and building types that are not covered by this Guidance Document are not excluded from using mass timber. This document is simply guidance and has no regulatory enforcement status. Designers are free to use mass timber in buildings not within the scope of this document using either C/VM2 or an Alternative Design (or a combination of the two), provided that they achieve the satisfaction of the regulatory authorities.

2.2. Exposed mass timber categories

Category WU

- Unlimited area of exposed mass timber surfaces.

Category W200

- The maximum area of exposed timber in any firecell is 200% of the floor area, shared across multiple surfaces.
- This could be all of the ceiling exposed and some of the walls, or a combination of both.
- In addition, structural timber beams and columns may also be exposed provided that the additional exposed surface area is no more than 10% of the floor area.

Category W100

- The maximum area of exposed timber in any firecell is 100% of the floor area on an elevated horizontal surface (timber floor soffit), OR 40% of the floor area on vertical surfaces (timber walls), OR a pro-rata combination.
- As an example, a pro-rata combination of exposed area could be 75% of the ceiling plus a wall area equal to 10% of the floor area, as permitted in Type IV-B construction in the US International Building Code (IBC).
- In either case structural timber beams and columns may also be exposed provided that the additional exposed surface area is no more than 10% of the floor area.
- In this category there must be a 3 m separation distance (measured parallel to the floor) between exposed timber on adjacent walls to prevent interactive burning of walls in internal corners.

Category W0

- Full encapsulation. No exposed mass timber is permitted, hence no addition to the fire load. FRR should be as per C/AS2, table 2.4 or calculated using C/VM2.

All categories other than WU

- All non-exposed mass timber must be encapsulated to limit the surface temperature of the timber to 300°C for the specified FRR period from C/AS2 Table 2.4 or Table 1.
- The top surface of a structural timber floor is considered to be encapsulated if it is protected by a layer of non-combustible material at least 15mm in thickness. A layer of combustible floor covering is permitted over the non-combustible protective layer.

3. Verification Method design of mass timber buildings using principles of C/VM2

For buildings with escape heights above 4 metres, a design based on the principles of C/VM2 should contain the following supplementary measures in 3.1 to 3.5. Additional consideration should also be given to the items in 4.1 to 4.8 as these are recommended for buildings designed using either C/AS2 or C/VM2.

3.1 Relaxation for buildings with escape height up to 10 metres

For sprinklered buildings with escape height up to 10m, the floors may be inter-connected and the mass timber may be fully exposed without including it in the fuel load calculations provided that:

- The design complies with C/VM2 requirements for a building with no mass timber, and
- Safe paths are encapsulated on the surface exposed to fire threat, and
- The fire resistance is no less than 60–minutes, and
- The following firefighting requirements are met:
  - FENZ hose run distance to any point on the floor is less than 75 m as measured from FENZ vehicular access, or where full building coverage is achieved from a single internal building hydrant, and
  - Where hydrants are required, the safe path stair is provided with a firefighting lobby with the hydrants located in the firefighting lobby, and
  - Vehicular access requirements are agreed with FENZ.

Note: The recommendations in 3.2 to 3.5 do not apply to buildings satisfying the above criteria.

3.2 All mass timber buildings (encapsulated or exposed timber)

- Where fire resistance for burnout is required, the fire severity calculation must take into account the ventilation and the thermal properties of the firecell boundaries, and calculate the depth of charring of exposed timber during the full fire exposure, including the decay period.
- Thermal properties for the bounding surfaces of the firecell must be consistent with the thermal properties of encapsulation materials and in proportion to the surface area of encapsulation.
- For buildings with escape height > 18 m, the minimum fire load energy density (FLED) for the moveable fuel, after applying the F_m factor, is 400 MJ/m^2.
- For buildings with escape height > 18 m, modelling the full design fire must be for the most severe fire exposure considering full and partial (50%) breakage of windows, within the limits of Equation 2.2 of C/VM2.
- The top surface of a structural timber floor is considered to be encapsulated if it is protected by a layer of non-combustible material at least 15mm in thickness. A layer of combustible floor covering is permitted over the non-combustible protective layer.

3.3 Fully encapsulated mass timber buildings

- Buildings with fully encapsulated mass timber may be designed in accordance with C/VM2 Section 2.4 using the time-equivalent method as for non-combustible materials.
- All mass timber must be protected to prevent charring for the calculated FRR period by limiting the surface temperature of the timber to 300°C.

3.4 Buildings with partially encapsulated timber or with some exposed timber surfaces

- Where fire resistance for burnout is required, the design FLED must include the fuel load of charring of exposed timber floors, walls, ceiling, columns, beams and diagonal bracing.
- The fuel load must include calculated charring of mass timber under protective linings (partial encapsulation).
- The F_m factor applies only to the introduced (movable) fuel load (design FLED in Table 2.2 in C/VM2).
- All mass timber not included in charring calculations must be fully encapsulated for the calculated FRR period.
- In normally occupied spaces there must be a 3 m separation distance (measured parallel to the floor) between exposed timber on adjacent walls to prevent interactive burning of walls in internal corners.

3.5 Notes for C/VM2 design

- The lower limit on FLED takes into account the likely fire load and uncertainty about the fire dynamics and possible contribution of charring wood to the fire load, especially important for taller buildings.
- The partial breakage of windows is included here to recognise the consequence of the uncertainty when quantifying fire severity for tall buildings.
- The calculation of fire severity may require an iterative calculation such as that described in Chapter 3 of the *Fire Safe Use of Wood – Global Design Guide*.
- The fire engineer must ensure that the fire load calculations are consistent with the surface areas of timber completely exposed, areas fully encapsulated, and those areas which are only partially encapsulated. The timber surface contributing to additional fire load includes non-structural mass timber elements as well as structural timber elements.
- The time-equivalent formula in C/VM2 (including any modification to the design FLED proposed in this document) may be used to calculate the equivalent time of exposure to the standard fire, for fire resistance ratings of non-timber structural elements, and non-structural elements such as fire doors, penetrations etc.

4. Additional considerations for mass timber buildings using C/AS2 or C/VM2

A design based on C/AS2 or C/VM2 should contain the following supplementary measures in 4.1 to 4.8.

4.1 Fire protected (safe path) stairwells and lift shafts with firefighter lift control

- Mass timber may be exposed on the inside surfaces of lift shafts and stairwells, provided that the spaces are sprinkler-protected and the surface finish materials comply with Building Code Clause C3.4.
- For single-stairway buildings with an escape heights > 18 m (sprinklered) or > 10 m (unsprinklered) the outside surface of mass timber walls around the stairwell must be encapsulated.

4.2 Penetrations and fire-stopping

- Designers must check that penetrations and fire stopping solutions are suitable for use with mass timber construction.

4.3 Gaps in construction

- Gaps at joints and in exposed areas of timber should be minimised to prevent spread of fire through assemblies and to prevent increased charring and challenges to firefighting. Gaps of any size passing through a fire-rated assembly, or surface gaps more than 5mm wide must be filled with an intumescent mastic or other recognised fire stopping sealant.

4.4 Vertical services

- Non-encapsulated service risers and vertical shafts containing building services should be fire stopped at every floor level.

4.5 Structural fire resistance

- Structural fire resistance must be demonstrated (by calculation or test results) to show that all structural members and connections have the capacity to resist the applied loads for the required time of fire resistance as stated in this document.
- Structural calculations must consider increased local charring of timber in contact with metal fixings.
- For buildings with escape heights > 18 m (sprinklered) or > 10 m (unsprinklered), free-standing columns and load-bearing walls inside firecells must be fully encapsulated, or alternatively the structural design calculations must consider the maximum internal temperatures induced by the fire. This recommendation is beyond the requirements of AS/NZS 1720.4 so specialist structural fire engineering input is required. More guidance will be given in the Commentary to the *Fire Safe Use of Wood – Global Design Guide*.

4.6 Fire-resistant adhesive

- For buildings with escape heights > 18 m (sprinklered) or > 10 m (unsprinklered), CLT floor panels must be manufactured with fire-resistant adhesive tested in accordance with Annex B of ANSI/APA PRG 320, or Annex B of prEN 1995-1-2:2025, unless it is demonstrated that the effective depth of charring will not reach the first glueline.

4.7 Buildings with a place of safety inside the building:

- Evacuation zone boundary fire separations constructed from mass timber are required to be fully encapsulated.

4.8 Fires during construction

- Comprehensive plans to manage the risks and consequences of fires during construction are essential for all mass timber buildings taller than two storeys, as described in the *Fire Safe Use of Wood – Global Design Guide.*

Appendix A. Definitions and glossary

Burnout

As defined in Clause A2 of NZBC: "Burnout – Means exposure to fire for a time that includes fire growth, full development, and decay in the absence of intervention or automatic suppression, beyond which the fire is no longer a threat to building elements intended to perform load-bearing or fire separation functions, or both."

Full encapsulation

- Full encapsulation will ensure that there is no significant charring which could add to the fuel load or reduce structural performance for the full duration of the design fire.
- Full encapsulation is required to limit the wood temperature to 300°C.
- Manufacturers of protective lining materials are able to provide information on the encapsulation performance of their materials derived from standard fire resistance tests.
- Test methods and acceptance criteria for encapsulation will be given in the Commentary to the *Fire Safe Use of Wood – Global Design Guide.*
- Encapsulated walls may have small service penetrations which allow some local charring, provided that the fire resistance rating of the assembly is not compromised and there is no significant increase in fuel load.
- Note: It should be recognised that the strength of wood will start to reduce at temperatures below 100°C and pyrolysis will start to occur at temperatures over 200°C, resulting in damage to protected wood well before charring occurs at about 300°C. For this reason, a severe fire may damage the timber behind encapsulation, and encapsulation will likely need removal by firefighters to prevent ongoing charring.

Partial encapsulation

- Partial encapsulation is protection not sufficient to provide full encapsulation. Partial encapsulation will mitigate surface flame spread and provide a delay to the onset of charring, but it may not prevent charring of the underlying timber later in the fire.
- Wood surfaces with partial encapsulation will start charring when the wood temperature under the protective layer reaches about 300°C and will char at an increased rate after the protective material falls off. Any charring under partial encapsulation, or after the protective layers fall off, will add to the available fuel load, increasing the severity and duration of the expected fire.
- The design time for partial encapsulation will depend on the fire design strategy used for the building.

Escape height

(as defined in C/AS2)

Effective depth of charring

(as defined in AS/NZS 1720.4 Clause 2.6)

Fire Resistance Rating

(as defined in C/AS2)

Appendix B. Concerns about fire safety in timber buildings, with possible mitigation measures.

- The recommendations in this document reflect concerns with large, post-flashover fires which may increase the fire risk to life safety and property in buildings. These types of fires are less frequent in sprinklered buildings, but still must be designed for.
- These concerns have mostly been addressed in this document. One item requiring more research is hazard due to larger external flaming where there are no specific mitigation measures currently proposed. This and other items of concern will be covered in more detail in the Commentary to the *Fire Safe Use of Wood – Global Design Guide*, based on the results of recent international research.

Appendix C. Collaboration

For buildings of any material, design for fire safety requires collaboration between the fire engineer, the architect, the structural engineer, other consultants and the approving authorities. The required level of collaboration increases for mass timber buildings because the decisions of one party can greatly affect the requirements of others.

Input from the fire safety engineer:

- The decision whether to follow the Acceptable Solution C/AS2 or the Verification Method C/VM2 for fire design is likely to be made early in the design process. A design to C/VM2 (or a full performance-based design) takes more design effort than a C/AS2 design.
- The main reasons for adopting a C/VM2 design pathway are usually to get more freedom in the building design, such as interconnected floor areas, rationalised means of escape, lower fire resistance provisions and other trade-offs.
- At a later stage of most designs, there will be additional input from a fire protection engineer and a passive fire engineer.

Input from the structural engineer:

- For structural fire design of most mass timber elements, the structural engineer needs to know the effective depth of char in the design fire. For C/AS2 design, this will be a simple calculation based on the standard charring rate for 30, 60, or 90 minutes, with or without a protective layer of gypsum board. Charring calculations are not normally necessary for CLT panels because the manufacturers provide load-span tables for protected and unprotected assemblies.
- Where calculation of fire severity is carried out including exposed timber, as described in Chapter 3 of the *Fire Safe Use of Wood – Global Design Guide*, the fire engineer will provide the structural engineer with the effective depth of char to use in the structural calculations. Note that the effective depth of char may be greater than that obtained from the equivalent fire severity calculations. The structural engineer may need to discuss this with the fire engineer and with CLT providers to assess the structural capacity of CLT.

Input from the architect:

- For most buildings, the architect's drawings show the finishes on all surfaces, including intumescent paint and gypsum plasterboard of various types and thicknesses. Co-ordination is essential because different types of gypsum plasterboard may be required by the fire engineer to control the fuel load, by the structural engineer or CLT provider to achieve structural fire resistance, and/or by the architect to provide a desirable architectural finish, noise control, and reaction to fire requirements.

Input from the builder and QS:

- The builder, the material suppliers, and the quantity surveyor all need to be involved in this decision-making because selected details will greatly affect the buildability and the cost of construction.

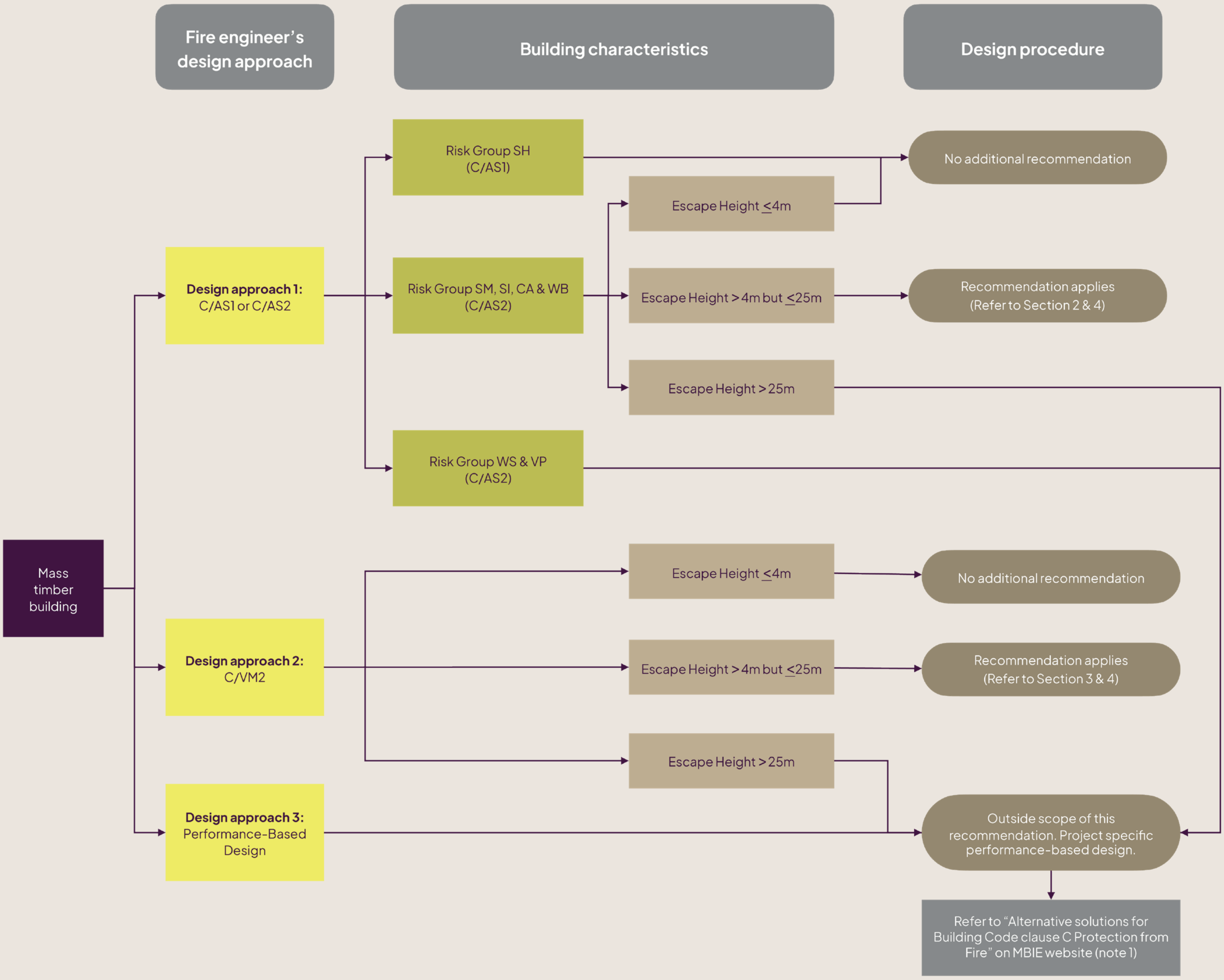
Input from the regulatory authorities:

- A building consent will not be issued by the Building Consent Authority (BCA) unless they are satisfied that the building meets the requirements of the New Zealand Building Code. The lead consultants should be talking to the BCA early in the design process. Discussions with Fire and Emergency New Zealand (FENZ) will also be required for some buildings.

Appendix D. Design flowchart

The flowchart below gives a graphical representation of the major steps in deciding how to use this document.

This document could be used as part of an alternative solution design approach as shown below.



Note 1:
Link to Alternative solutions for Building Code clause C Protection from Fire

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Timber Unlimited is a collaboration between Wood Processors and Manufacturers Association of New Zealand, New Zealand Timber Design Society, BRANZ Limited and Scion, hosted by Scion. We are helping create a future where the benefits of building in wood are widely understood and building owners and property developers commission wooden buildings.

FENZ supports the recommendations in this document. However, each building will be considered in light of its own facts, circumstances and context.

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