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Structural Design of Timber Columns in Realistic Fires

Cameron Douglas[1], Dennis Pau[2], Daniel Moroder[3], Andy Buchanan[4]

ABSTRACT:

This paper presents a numerical modelling approach to predict the strength of glued laminated (glulam) timber columns during and after fire exposure. During the decay phase of a fire, the thermal wave penetrates beyond the charred depth, elevating temperatures within the column and reducing its strength and stiffness, potentially leading to buckling under compressive loads. Existing literature highlights the importance of numerical models in simulating heat transfer and evaluating residual structural capacity. This study focuses on the simulated fire performance of non-encapsulated, free-standing glulam timber columns using finite element software SAFIR, with sensitivity analysis on variables related to the growth and decay phases of a parametric fire. This modelling approach provides a potential pathway for compliance with Clause B1 of the New Zealand Building Code, guided by the New Zealand Commentary on the *Fire Safe Use of Wood in Buildings* Global Design Guide. The findings emphasise the critical role of accurately capturing the decay phase of real fires and conducting appropriate sensitivity analyses during the design process. A simplified method is proposed to help designers quickly assess column adequacy, with recommendations for further refinement to improve precision.

KEYWORDS: timber, fire, columns, thermal wave, buckling

1 – INTRODUCTION

Engineered mass timber has gained popularity as a building material for its carbon sequestration capabilities, strong structural performance, rapid on-site assembly, and aesthetic appeal. In fire conditions, mass timber forms a protective char layer, insulating the core and significantly slowing combustion. Depending on the member size, this behaviour helps maintain structural stability for extended periods.

Charring behaviour in an ISO 834 Standard Fire is predictable without delamination, as it follows a rising time-temperature curve to benchmark Fire Resistance Ratings (FRR) of structural elements. Real fires have both heating and cooling phases, with prolonged heat transfer during decay degrading timber's mechanical properties even after the fire appears extinguished. Consequently, the fire performance of mass timber columns during the decay phase is critical, especially for tall timber buildings.

The objective of this paper is to propose a structural fire engineering design for timber columns that ensures compliance with realistic fire scenarios in New Zealand.

2 – BACKGROUND

2.1 ENGINEERED WOOD PRODUCTS

Timber has been used as a construction material for thousands of years. However, by the 20th century, concrete and steel emerged as the preferred materials, driven by technological advancements that enabled the design of taller buildings and long-span structures.

Over the past 30 years, significant research and development in timber engineering have led to the rise of Engineered Wood Products (EWP) as competitive alternatives to concrete and steel. Common EWPs include Cross-Laminated Timber (CLT), which features alternating perpendicular laminates to create plate panels often used for floors, roofs, and walls, and glued-laminated timber (glulam or GL), which is primarily used in beam and column structures, see Figure 1. Other EWPs include Laminated Veneer Lumber (LVL) and plywood, which are created from thin veneers and glued together.

Figure 1. CLT (left) and glulam timber (right).

[1] Cameron Douglas. PTL | Structural & Fire, Christchurch, New Zealand, c.douglas@ptlnz.com

[2] Dennis Pau. PTL | Structural & Fire, Christchurch, New Zealand, d.pau@ptlnz.com

[3] Daniel Moroder. PTL Structural & Fire, Christchurch, New Zealand. d.moroder@ptlnz.com

[4] Andy Buchanan. PTL Structural & Fire, Christchurch, New Zealand. a.buchanan@ptlnz.com

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2.2 NEW ZEALAND BUILDING CODE

The fire safety design process for a building in New Zealand involves developing fire safety measures that comply with the objectives set forth in the New Zealand Building Code (NZBC) C Clauses [14]. The three primary objectives 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.

To secure building consent, the fire engineer must demonstrate compliance through either the deemed-to-comply documents, acceptable solution (C/AS2) and the verification method (C/VM2), or using an alternative solution. Refer to Figure 2 below for a representation of the New Zealand building regulatory framework.

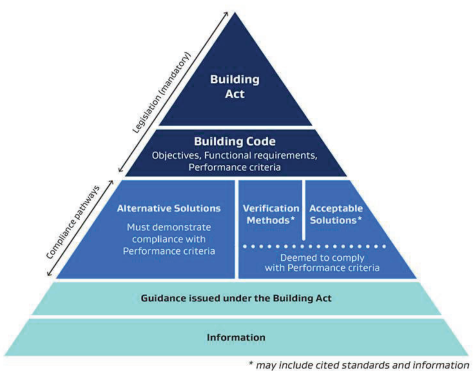

Figure 2. New Zealand Building regulation framework [13].

In recent years, timber has become increasingly popular in various building types across New Zealand, with clients and architects often opting to expose as much timber as possible for aesthetic appeal. However, the design of mass timber structures is currently considered an alternative solution pathway, as the C/AS2 and C/VM2 compliance documents lack provisions specific to mass timber construction. Key fire safety concerns with mass timber include:

- Large, exposed areas of structural timber that can significantly contribute to the overall fire load.
- Delamination (separation of wood layers) in EWP can lead to secondary flashover occurring.
- More fuel causes higher radiation heat flux and extensive flame projection from windows, which could threaten upper storeys or nearby property.
- Smouldering, which can cause timber to continue charring even after the fire is extinguished.
- Degradation of timber's mechanical properties at temperatures above 100°C.

To address these challenges, Timber Unlimited (TU) released the *Fire Safety in Multi-Storey Mass Timber Structures* document in 2023 [22]. This document was developed in consultation with industry experts, councils, and Fire and Emergency New Zealand (FENZ). Additionally, a New Zealand-specific commentary was created to supplement the global design guide, *Fire Safe Use of Wood in Buildings* [2], providing guidance for building designers to meet the NZBC requirements effectively [23].

For a prescriptive fire safety design, the TU guidance addresses the risks associated with exposed timber by prescribing maximum allowable areas of exposed mass timber and minimum fire resistance ratings based on the building's activity, escape height, and presence of sprinkler protection. Beyond the limits of the prescriptive fire safety design, a Specific Engineering Design (SED) is required to account for the additional fuel load contributed by the exposed timber. Figure 3 illustrates a structure with a prescribed level of encapsulation for its associated risk class. Encapsulation is a fire protection measure used to achieve an FRR equivalent to that of a non-combustible material.

Figure 3. Schematic of exposed timber for a building, credit to Studio Gang Architects, U.S.A [21].

According to the TU guidance, the supporting structural elements of the building must maintain structural stability during and after a fire, facilitate firefighter operations, and prevent disproportionate collapse. For buildings with escape heights exceeding 18 metres (if sprinklered) or 10 metres (if unsprinklered), the guidance requires full encapsulation of exposed free-standing timber columns. Alternatively, specialist structural fire engineering must be employed, as such scenarios fall outside the scope of AS/NZS 1720.4. The reason for this consideration is discussed further below.

3 – LITERATURE REVIEW

3.1 THERMOPHYSICAL PROPERTIES

When timber pyrolyzes, it undergoes a chemical transformation into char, a phase change that nullifies the material's load-bearing capacity, typically occurring around 300°C. The char layer acts as a protective barrier,

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insulating the core and slowing the heat flux, which helps maintain structural stability, refer to Figure 4.

However, even before charring occurs, the mechanical properties of timber begin to degrade as the temperature increases. As illustrated in Figure 5, the compressive strength of a structural timber element at 100°C is reduced to just one-quarter of its capacity at ambient conditions. This highlights the importance of accounting for thermal effects in structural fire design.

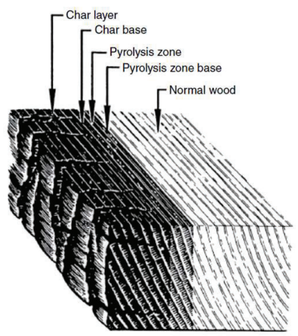

Figure 4. Char layer and pyrolysis zone in a timber beam [17].

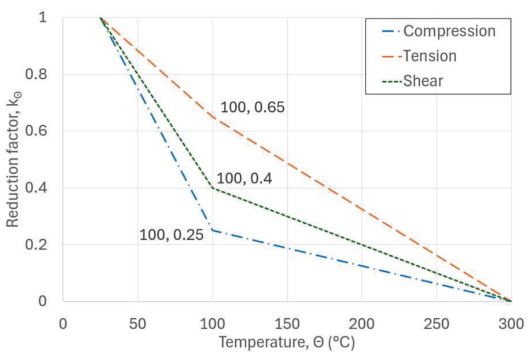

Figure 5. Reduction factor for strength, parallel to the grain of softwood reproduced from Appendix A of EN 1995-1-2 [7].

3.2 BURNOUT RESISTANCE

Burnout resistance refers to a compartment's ability to withstand a fully developed fire without collapse, allowing the fire to self-extinguish once the fuel is depleted. Thermal degradation of columns in tall buildings presents a major challenge to structural stability. In a realistic fire scenario with growth and decay phases, the thermal wave continues to penetrate the column cross-section even after the fire is extinguished. This ongoing heat transfer reduces the strength and stiffness of the timber, increasing the risk of column failure under compressive loads, possibly in a brittle and sudden manner. Such failure presents a life safety risk, particularly if evacuation or search and rescue operations are still in progress.

Recently, several experimental tests have been conducted to better understand the burnout resistance of structural timber columns in realistic fires [11]. Findings from the research include the following:

Gernay [10] analysed 49 glulam columns using SAFIR to study both the ISO 834 Standard Fire with and without decay phase. With decay phase, the simulated burnout resistance of the columns is 20% to 50% of the experimental standard fire resistance which indicated a tendency of premature failure during the decay phase caused by the reduction in the mechanical properties of timber at low temperatures.

A series of 7 full-scale fire experiments, conducted by Gernay et al. [12], with varying heating duration were conducted on loaded glulam columns to measure the structural response in the decay phase of a fire. The sections were 280x280mm GL 24 h and 3.7m in height. The experimental results show that after exposure to 25% of the ISO 834 Standard Fire resistance duration, failure may occur in the decay phase.

Research by Renard et al. [16] detailed five full-scale fire tests that investigate variations in timber column sizes, alternative wood crib fuels, and the impact of water intervention by firefighters. Notably, intense localised charring was observed at the base of the columns, emphasising the critical need to extinguish localised burning on exposed timber columns to mitigate further structural degradation.

This research emphasises the importance of analysing timber structures for realistic fire scenarios. The application of the ISO 834 Standard Fire for design is not appropriate, as it does not account for thermal wave propagation in non-encapsulated, free-standing mass timber columns during the decay phase.

4 – STRUCTURAL FIRE ANALYSES

The structural fire analysis must evaluate the structural adequacy of a timber section, using one of two primary methods: (1) the reduced cross-section approach or (2) the reduced properties approach.

4.1 REDUCED CROSS-SECTION METHOD

This approach assumes the design fire follows the ISO 834 Standard Fire, with a constant charring rate multiplied by the specified FRR provided by the fire engineer. The char rate is relatively predictable and is typically used as 0.65 mm/min to the ISO 834 Standard fire in New Zealand (d_{char}) [19]. Noting that for members exposed to fire on two or more surfaces, this should be amplified by 1.07 [23]. With the publication of AS/NZS 1720.1:2019, engineers in New Zealand have used a zero-strength layer of 7.0 mm for structural analysis [19], whereas the draft Eurocode 5 prescribes 10 mm for bending or tension members and 14 mm for compression members [8]. This is to account for the pyrolysis zone, where the timber's strength is diminished (d_0). The residual internal core of the structural member is then used to assess its structural adequacy, refer to Figure 6 for a representation of a typical beam assessment using the reduced cross-section method.

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While this method enables quick computation based on the standard fire, it is limited by its inability to accurately capture thermal gradient movement and compartment fire dynamics, potentially underpredicting capacity in realistic fire scenarios due to the absence of alternate charring rates and burn durations. Therefore, this method is most suitable for simple, low-rise structures with exposed timber columns.

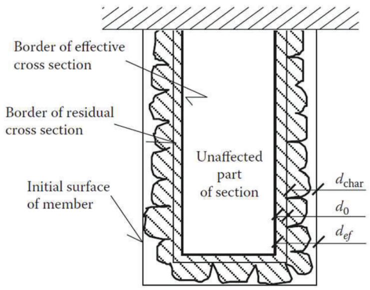

Figure 6. Reduced cross-section method for a beam [25].

4.2 REDUCED PROPERTIES METHOD

An alternative method involves the reduced properties approach, which divides the section into several fibres, allowing for the evaluation of strength and stiffness under any design fire scenario using finite element modelling (FEM). See Figure 7 for a representation of thermal gradients. If the inputs are accurate, the designer can assess the structural elements for failure during the fire decay phase, ensuring a more realistic evaluation than the reduced cross-section method. While this method offers greater accuracy, it is more computationally demanding and typically requires numerical software, such as SAFIR, ABAQUS, or VULCAN. The software must have capability to use the thermophysical properties of timber.

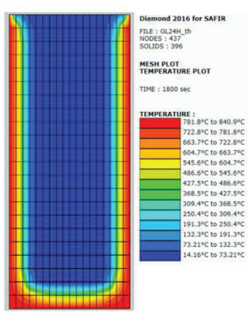

Figure 7. Temperature gradient in a timber beam section [4].

5 – SAFIR NUMERICAL MODELLING

The reduced properties method, as outlined in Section 4.2, was used with SAFIR FEM software to assess thermal wave propagation in the free-standing columns. Developed at the University of Liège, Belgium, SAFIR is capable of simulating the thermomechanical behaviour of timber exposed to elevated fire temperatures [24]. For this study, version 2024.b.6 was used, which introduced a new timber material with irreversible properties. GmSAFIR, the pre-processor for generating input files for SAFIR, was utilised in its 2024-11-11 version. DIAMOND, the post-processor for visualizing the results from SAFIR, was used in its 2025 version.

5.1 GENERAL SAFIR INPUTS

The first step in analysing a structural element exposed to elevated temperatures is to establish the thermal gradients over the cross-section. For this study, an ambient temperature of 20°C with a relative humidity level of 65% was assumed. The timber was considered to be dry, with a moisture content of 12.0%.

The convection coefficients were set as 35 W/m²K for heating and 4.0 W/m²K for cooling. The relative emissivity of the timber material was defined as 0.80. The thermophysical properties of timber, including thermal inertia, specific heat capacity, and density, were specified in accordance with Annex B of EN 1995-1-2:2004 [7].

The SAFIR model employed in this study utilised a two-dimensional conductive solid element analysis on a beam element. A non-linear implicit dynamic analysis was conducted to evaluate the column buckling performance.

In SAFIR, the "WOODPRBWE" material was selected for its ability to account for irreversible properties, ensuring that the load-bearing capacity is not restored from charred sections upon cooling. This material is similar to "WOODEC5" but incorporates probabilistic, temperature-dependent reduction factors for compressive and tensile strengths [9].

5.2 SAFIR MODEL VALIDATION

A key challenge of any numerical modelling software is its ability to accurately replicate real-world effects observed during experimental testing, enabling designers to reliably predict the performance of proposed structural elements.

To address this, a validation study was conducted to assess the suitability of using SAFIR to model the temperature profile of timber. Experimental data collected by Gernay et al. [12] served as the basis for comparison. Specifically, Test 3 was analysed, involving a 3.65 m tall, 280 × 280 mm² GL24h glulam column with pin-pin boundary conditions under a structural compression load of 322 kN. Fire exposure followed the modified ISO 834 standard fire curve for 15 minutes of heating, transitioning to a linear decay phase lasting 71 minutes (at 10.4°C/min). Thermocouples were installed at 10 mm depth increments from the column surface to capture temperature data.

Figure 8 compares our thermal numerical results with their experimental data. The simulated nodal temperatures showed a tendency to overpredict during the heating phase and underpredict during the decay phase, particularly near the surface. However, at greater depths within the column, the variation between simulated and experimental temperatures was reduced. Overall, the maximum temperatures and temperature profiles demonstrated reasonable agreement. This validation is crucial because the key design assumption is that timber's strength and stiffness both degrade irreversibly with increasing temperature during fire exposure. Mechanical analyses were run and tended to show good agreement between tested data. Note that these results are not shown in this paper.

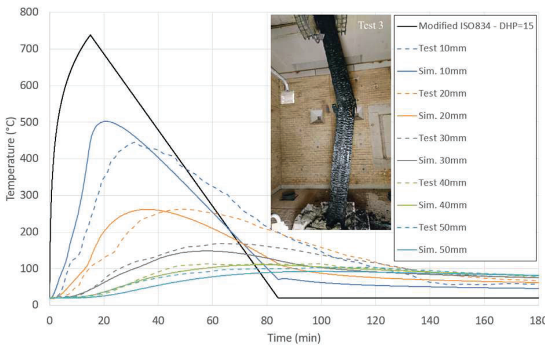

Figure 8. Comparison of the numerical and experimental results for a fire with a decay phase.

5.3 SAFIR MESH SENSITIVY

FEM is highly sensitive to mesh size, which governs numerical integration accuracy. A mesh that is coarse can lead to inaccurate results, while one that is fine can significantly increase computational time. Therefore, it is essential for result accuracy and computation resources that mesh size optimisation is critical. Based on literature, an initial mesh size of 3.0 mm is recommended for modelling timber members exposed to fire [26].

To evaluate thermal gradient convergence, a mesh sensitivity analysis was performed. Figure 9 illustrates the maximum temperature across a timber section for mesh sizes of 1.5 mm, 3.0 mm, 6.0 mm, and 12.0 mm after a simulated fire duration of 6 hours. The analysis shows that finer mesh sizes yield a larger residual section, with the difference between 1.5 mm and 3.0 mm being less than 1%. This indicates that mesh sizes within this range achieve reasonable accuracy and convergence.

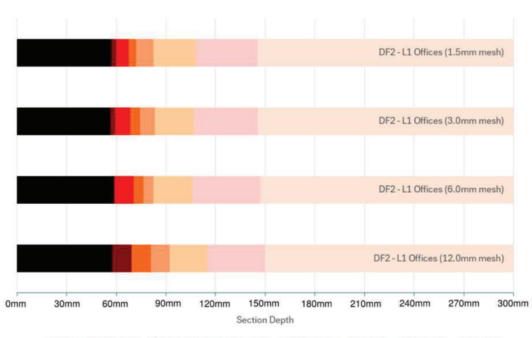

Figure 9. Comparison of maximum temperatures from the timber surface to the section centroid for various mesh sizes.

6 – NEW ZEALAND CASE STUDY

6.1 EXEMPLAR BUILDING

The methodology outlined in Section 4 for designing timber glulam columns for fire was applied to a 10-storey timber frame commercial office structure in New Zealand. The Lateral Load-Resisting System (LLRS) was assumed to function independently of the glulam gravity system and was therefore not considered in this analysis.

The structure features a glulam post-and-beam assembly with CLT flooring, a storey height of 4.0 m, and a bay width of 8.0 m. Refer to Figure 10 for a representation of the building elevation and typical floor plan. The floor plan area is 500 m^2 (A_f), excluding the stair shaft. The section sizes are detailed below.

Sprinklers are provided throughout the building to enhance fire safety. A Fire Load Energy Density (FLED) of 800 MJ/m^2 was assumed for the building. According to the NZBC, a sprinkler concession of 0.5 can be applied, reducing the design FLED to 400 MJ/m².

A superimposed dead load of 1.0 kPa was included to account for services and other permanent fixtures, while a floor live load of 3.0 kPa was applied. The timber was assumed to have a design density of 500 kg/m^3. Refer to Table 1 for a comparison of structural member sizes and dead weights.

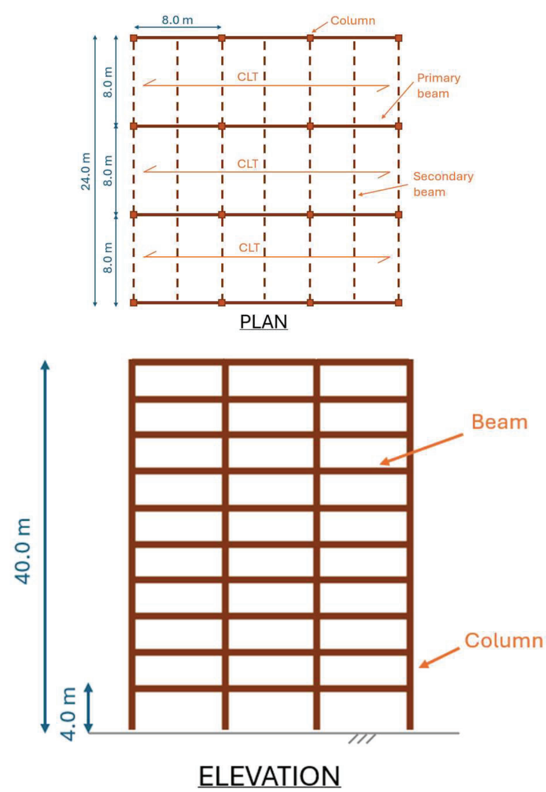

Figure 10. Case study building plan (top) and elevation (bottom).

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Table 1. Structural section sizes, grades, and element unit weight.

Element:	Size:	Weight:
CLT flooring:	140 mm thick, 5 layers	70 kg/m^2 0.70 kPa
Primary beams:	640x520 GL10	166 kg/m 1.66 kN/m
Secondary beams:	640x240 GL10	76.8 kg/m 0.77 kN/m
Columns:	450x450 GL10	101 kg/m 1.01 kN/m

6.2 DESIGN FIRE – PARAMETRIC TIME-TEMPERATURE CURVE

In mass timber structures, it is preferable to maximise exposed timber while maintaining sufficient structural integrity. Accordingly, the iterative fire severity analysis approach for compartment burning was referenced to guide the design [2].

Iterative Fire Severity Analysis

The iterative fire severity analysis method was developed by Brandon [1] to determine the fire resistance of mass timber structures. It involves a step-by-step process that considers fire exposure, material properties, and the structure's geometry to predict a realistic design fire, extending the Eurocode parametric time-temperature curve [5] by incorporating a growth and decay phase. A critical input for this model is the heating rate factor Γ, a dimensionless factor that is a function of the compartments opening factor at flashover, O [m$^{1/2}$], and the thermal inertia of the surface linings, b_{eff} [J^{2}s^{2}m^{4}K^2]. A fast fire growth rate was also assumed, t_{lim}= 15 mins, where t_{lim} is the lower limit of the duration of the heating phase. Refer to Chapter 3.8 of *Fire Safe Use of Wood in Buildings* [2] for further information.

However, it is important to note that the iterative char method is only applicable when glue line integrity is maintained. If the char depth exceeds the bottom lamella thickness of the CLT, there is a risk that the lamella may detach, exposing fresh timber to the fire, potentially preventing the fire from being extinguished.

Additionally, for further comparison, the FRR must be reported. The equivalent exposure time for the iterative fire severity analysis, relative to the ISO 834 Standard Fire, can be approximated using the following equation:

$$t_e = \frac{d_{0,char}}{\beta} \quad (1)$$

Where: t_e is the equivalent time to the ISO834 fire [min] for compartment burnout based on the converged char depth, $d_{0,char}$ [mm], and β is the charring rate in the ISO834 Standard Fire [0.65 mm/min], in AS/NZS 1720.4:2019 [19]. Refer to Pau et al. [15] for further information on the application of the iterative fire severity method on a multi-storey building with varying fuel load and opening factors.

Opening Factor

For a given fire, the opening factor has been identified as a significant influence on both the size and duration of the fire, as detailed by Buchanan and Abu [3]. However, it is challenging for designers to accurately predict how many windows will fail during flashover in a compartment. To address this uncertainty, a range of opening factors were investigated based on a typical building survey discussed below. It is also worth noting that lower ventilation ratios tend to result in long-duration, cooler fires, which can lead to deeper thermal penetration into massive structural timber elements.

A survey of various architectural designs for New Zealand residential buildings, including bedroom and apartment typologies in retirement villages and suburban apartments, as well as commercial buildings such as open-plan offices and retail spaces was carried out by PTL | Structural & Fire (Christchurch, New Zealand), giving the O_{max} and A_f relationship shown in Figure 11. O_{max} represents the maximum opening factor of a fire cell or compartment, assuming 100% breakage of non-fire-rated glazed partitions.

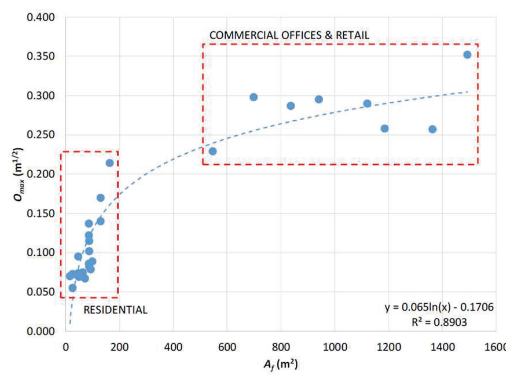

Figure 11. O_{max} vs. A_f for New Zealand Residential and Commercial Buildings.

Based on the above study and the geometry of the building, an opening factor of 0.10 m$^{1/2}$ was selected, assuming 50% window breakage and an A_f of 500 m^2, to evaluate the fire exposure on a column in a commercial office fire compartment.

Thermal Inertia

The thermal inertia of a material represents its ability to resist temperature changes when exposed to elevated heat. This parameter is applied to the bounding materials of a compartment to quantify the amount of energy released into the surrounding environment. A thermal inertia of 600 J^{2}s^{2}m^{4}K^2 (b_{eff}) was assumed.

Resulting Parameters

Based on the above inputs, the design fire assumptions are shown in Table 2 and Figure 12. The area of exposed wood $A_{exposed}$ [m^2] was varied in order to achieve a maximum value of t_e = 90 minutes using equation (1). The resulting area of exposed wood is 500m^2 which, by coincidence, happens to be the same as the floor area of the typical floor (W100 in the TU guide [22]). Encapsulation was then provided to ensure that the remaining exposed surfaces of CLT floors, glulam beams, columns and braces, did not exceed this limiting area. It is important to note that the decay phase of a parametric fire significantly impacts the amount of energy absorbed by the timber column. To assess the model's sensitivity, decay rates of 50% and 200% of the predicted rate were applied. Note that a comparison between the structural performance of a typical ISO834 charring assessment assuming the equivalent time to the Standard ISO834 fire is discussed in Section 7.

Table 2. Results of the iterative fire severity analysis.

O (m$^{1/2}$)	Γ (-)	$d_{0,char}$ (mm)	$A_{exposed}$ (m^2)	t_e (min)
0.10	23.6	58.5	500	90.0

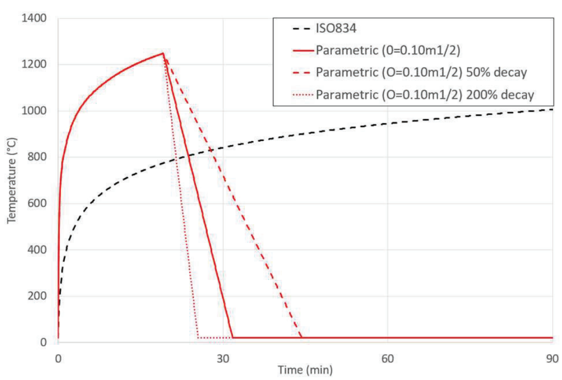

Figure 12. Eurocode Parametric time-temperature design fires

6.3 STRUCTURAL MODEL

With the design fires established, the thermal gradients within the proposed section can be determined for the structural analysis. Buckling behaviour is a second-order phenomenon that is challenging to accurately capture without numerical modelling software. Typically, engineers apply a conservative empirical factor to account for the unbraced length and Euler's buckling load, such as k_{12} in AS 1720.1:2010 [18] or k_8 in NZS 3603 [20] that are applied to the member's capacity in axial compression.

Incorporating thermal gradients within a timber section significantly complicates the accurate prediction of the structural response of the member, which is where FEM becomes essential. FEM analysis of a column requires the inclusion of initial imperfections to trigger buckling behaviour. Either the designer could use an initial displaced shape as noted in EN 1995-1-1 [6], or assume an eccentric load to induce a moment. For this analysis an initial horizontal mid-height deflection was set to H/400 (10 mm at mid-height) in a sinusoidal shape as per EN 1995-1-1.

When elements buckle, they introduce P-Δ effects, leading to potential instability. The slenderness and stiffness of the section play critical roles in resisting these effects and ensuring structural stability. For these simulations, a pin-pin boundary condition was used. Some fixity at the ends of the column would increase the buckling capacity, which should be considered for more accurate design.

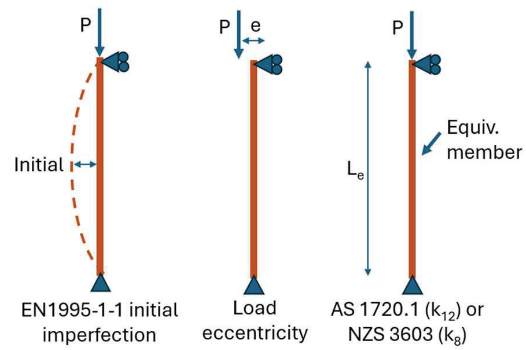

Figure 13. Comparing different buckling methods of columns.

For the simulation, a mesh size of 5.0 mm was used, as determined by the mesh sensitivity study discussed earlier. The time step was set at 1.0 s, with a total model simulation time of 6 hours. This duration was chosen to ensure that thermal gradients within the core had reached steady state. A vertical axial load of 1830 kN was applied to the top of the column to simulate loading from the floors above according to an Accidental Limit State (ALS) load case of 1.0G + 0.4Q. Additionally, for fire design, the material strength and stiffness are converted to the 20th percentile with a k_{fi} factor of 1.15 [23]. Noting that the load was applied to the column incrementally until 20 seconds to achieve numerical stability.

7 – RESULTS & DISCUSSION

Based on the numerical set up described above and the case study building, the resulting depths of the thermal wave throughout a half column cross-section are shown in Figure 15. Noting that these temperatures are the maximum experienced by the numerical nodes throughout the section during the full duration of the simulation. This is because the thermophysical properties of timber have not been calibrated for the cooling phase.

A hand calculation using AS/NZS 1720.4 (19) shows that the ISO 834 standard fire over 90 minutes results in a greater charred depth than the real fire simulation. However, it is evident that for the much shorter duration real fire exposure, the thermal wave penetrates deeply into the section, which could significantly impact the column's buckling capacity.

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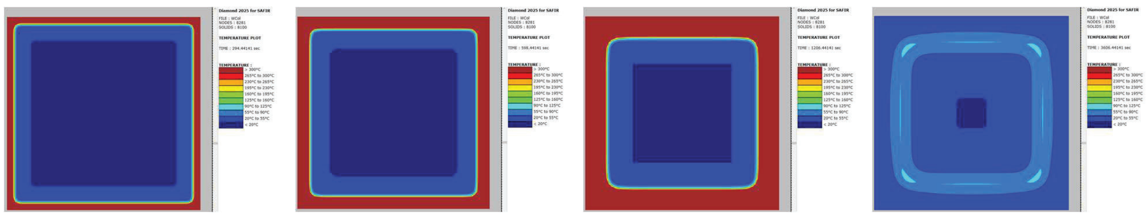
Figure 14 further shows the thermal wave continuing to penetrate further into the column section even after the fire was extinguished at the end of the decay phase. This can be noticed by tracking the dark blue central core of the cross-section, which is the cool residual section of the column. It should be noted that the outer edges of the column appear cool in Figure 14 (d), but these areas have no load bearing capacity because they have become charcoal, highlighting a graphical limitation.



(a) 5 mins *(b) 10 mins* *(c) 20 mins* *(d) 60 mins*

Figure 14. Thermal gradients in the column section over time for the parametric O = 0.10 $m^{1/2}$ scenario.

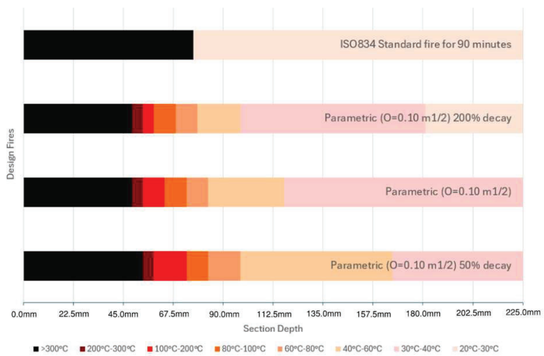


Figure 15. Comparing the maximum temperature in a half section for the ISO834 fire and simulations.

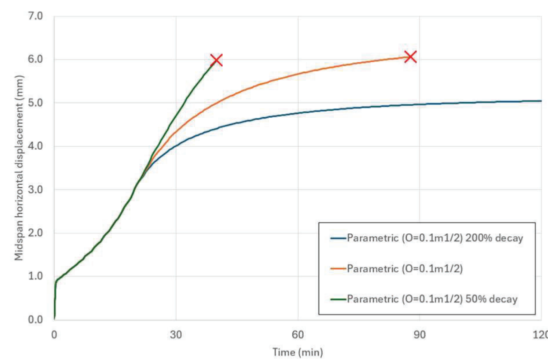


Figure 16. Comparing mid-height horizontal displacement between the simulated fire models.

For the numerical modelling approach, buckling failure was defined as the point at which the mid-height of the column exhibits runaway deflections or exceeds reasonable limits, leading to numerical instability, see Figure 16 illustrating these results. The numerical results indicate that the structural model is sensitive to the decay rate of the parametric fire as the shallower decay rate showed numerical instability as the mid-height horizontal displacement began to run away. These deflections are in addition to the initial imposed displacement of 10 mm. This emphasises the need for caution when designing slender members. Further checks should also consider localised charring at the column base, which may cause premature failure due to shear. However, additional research is required to address this issue.

The structural adequacy of the ISO 834 hand calculation approach is determined by exceeding the compressive capacity, with failure assessed through modifications to the k_{12} or k_8 factor. Structural analysis results for the standard fire charring assessment, including the proposed simplified approach, are presented in Table 3.

8 – FUTURE RESEARCH

8.1 PROPOSED SIMPLIFIED APPROACH

Designing freestanding, non-encapsulated glulam columns for fire resistance is a complex process that demands close interdisciplinary collaboration. Introducing a preliminary indicator of section size adequacy could streamline the process, minimising the risk of rework during the detailed design phase.

The proposed simplified approach utilises a one-dimensional explicit finite difference method, implemented in Excel, to account for reduced section properties based on temperature variations. An equivalent square section can be calculated, reflecting the reduction in strength and stiffness. Using this, simplified buckling factors (k_{12} or k_8) can be applied to assess structural adequacy. However, this method requires further refinement and validation through experimental results. Some limitations of this approach include:

- A one-dimensional model lacks the capability to capture variations along the member length.
- Computations are based on a square section, with no consideration for corner rounding.

- Uncertainty about applicability of buckling factors for structural fire design as these have been derived for ambient conditions.
- Differences in buckling factors between timber material standards in different countries.

Table 3 compares the results of the ISO834 Standard fire for 90 minutes, the numerical approach, and the proposed simplified model with the k_8 buckling factor from NZS 3603, where A_{res} [m^2] is the residual area of the column after the fire was extinguished and the thermal wave has stabilised. These results show a similar trend to the simulation results, although the simplified model indicates higher section capacity, which may be unconservative. The load ratio η gives the applied load as a proportion of the calculated axial capacity. Note that the simplified approach assumes that the axial load is applied with an eccentricity of 10% of the section depth.

Table 3. Comparing the structural adequacy of the timber columns for the design fires based on the simplified approach.

Design fire *		A_{res} **(m^2)**	**Structural adequacy**
Standard fire for 90min		0.083 (41%) 288x288mm	OK ($\eta = 0.87$)
Numerical Approach	Parametric 200% decay	0.089 (44%) 299x299mm	OK ($\eta = n/a$)
	Parametric normal decay	0.080 (39%) 282x282mm	BUCKLED ($\eta = n/a$)
	Parametric 50% decay	0.069 (34%) 262x262mm	BUCKLED ($\eta = n/a$)
Simplified Approach	Parametric 200% decay	0.086 (42%) 293x293mm	OK ($\eta = 0.83$)
	Parametric normal decay	0.079 (39%) 281x281mm	OK ($\eta = 0.92$)
	Parametric 50% decay	0.070 (35%) 264x264mm	BUCKLED ($\eta = 1.09$)

* Refer to Figure 12 for a comparison of the design fires.

The simplified approach will be refined, and a separate paper will be prepared to document the method for designers in due course.

8.2 UNCERTAINTIES

Understanding the limitations of inputs to numerical models is essential for assessing the structural fire capacity of timber columns. Key uncertainties include:

NZBC timber fire design: Currently, timber structures in New Zealand are designed using the ISO 834 Standard Fire, which does not account for thermal wave propagation in realistic fire scenarios.

Decay phase variability: The rate of the decay phase influences the energy absorbed by the section. A range of decay rates should be considered during analysis.

Fire dynamics in large spaces: Mass timber in large open-plan spaces may alter fire dynamics within the compartment, potentially impacting structural performance.

Localised burning effects: Literature suggests localised severe burning can occur at the column base, affecting the mechanical response. Until further research is available, a pin-pin system with no column continuity is advisable.

Assumed mechanical integrity: The models assume no mechanical defects, such as glue-line failure, which may not reflect real-world conditions, depending on the type of adhesive.

Thermophysical property calibration: The thermophysical properties of timber, as defined in EN 1995-1-2, are calibrated for the heating phase but do not consider cooling. Therefore, it is necessary to assume the reduced strength and stiffness properties of timber are irreversible after exposure to fire.

9 – CONCLUSION

To conclude, the aim of this paper was to propose a structural fire engineering design assessment worthy of compliance in New Zealand for timber columns exposed to realistic fires. Key takeaways from this study are noted as follows:

- Structural fire design of timber columns can be done for realistic fire exposure, and it is essential to consider the effects of the thermal wave in the column after the fire has decayed.
- This analysis and design procedure can be carried out using finite element modelling (FEM), with the potential to use a simplified Excel-/code-based calculations (with further refinement).
- The design process is highly sensitive to various inputs, such as fire severity and decay rate. Therefore, incorporating sensitivity analyses of these variables is essential to ensure robustness and accuracy.
- A simplified method offers the potential to design timber columns efficiently without relying on FEM numerical modelling. With further refinement of input parameters, this approach could become a practical and reliable design tool.

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