

Structural timber buildings fire safety in use guidance

Volume 6 - Mass timber structures; Building Regulation compliance B3(1)

STA fire safety research and guidance project
Version v1.1 October 2020



Image courtesy of KLH



Publication context

Current good practice and clarification of the applicability of common design guidance 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 within a compartment.

The content only focuses on English Building Regulation B3(1) "*Internal fire spread - structure*", with other Building Regulation requirements to be considered separately.

Who should read this?

Principal designers, architects, engineers, project design co-ordinators, fire engineers, building control bodies and the fire and rescue service.

This guidance is for use by competent persons from the construction industry, who understand the sector they work in.

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Acknowledgements

This guidance has been drafted through members of the STA special interest group (SIG) on fire behaviour of mass timber. The STA would like to acknowledge the contributions of: Dr. Danny Hopkin (OFR), Dr. Michael Spearpoint (OFR), Dr. Carmen Gorska (Stora Enso), Martin Milner (STA) and members of the stakeholder review group.

Thanks are expressed to the research project funders: Stora Enso, Binderholz and KLH, and also to the work of OFR for preparing information in support of the production of this guidance.

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Report made possible with funding from Stora Enso, Binderholz and KLH (images also kindly provided for use)





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1 Introduction

This document details compliance routes for structural stability in the event of fire for timber buildings in England as part of the STA's library of fire-in-use best practice guidance. The STA library of documentation provides guidance, information and recommendations on system specifications and good practice principles when using structural timber building methods.

The current guidance is in six volumes:

- Volume 1 - Pattern book of tested systems
- Volume 2 - Cavity barriers and fire stopping
- Volume 3 - Pattern book of proprietary systems (estimated issue 2021)
- Volume 4 - Service penetration detailing (estimated issue 2021)
- Volume 5 - Good practice drylining to structural timber buildings (estimated issue 2021) and
- Volume 6 - Mass timber structures; Building Regulation compliance B3(1) (this document).

The information may require updates and additional documents as regulations change and knowledge develops. Readers are to be aware of the need to check for updates and use the current issue of guidance from the STA website: www.structuraltimber.co.uk

The work includes key outputs from a mass timber research project, called 'STA Special Interest Group (SIG) - CLT compartment fire behaviour' under the chair of Matthew Linegar of Stora Enso.

1.1 Scope

1.1.1 Regulatory scope

This guidance is focused on Building Regulation compliance routes for structural stability in the event of fire of mass timber buildings of differing uses and sizes.

The guidance is concerned with the life safety requirements for buildings constructed in England, as currently defined by the Regulations (Part B of the Building Regulations 2010, as amended). The scope is Regulation B3 - internal fire spread (structure), specifically, Regulation B3(1) which concerns the performance of the structural system in the event of fire.

Reference to the regulations in Scotland, Wales and Northern Ireland are intended to follow on in future updates of this guidance. However, the principles are similar and the findings relevant to each member country of the UK.

Whilst the scope of this document is structural fire performance, mass timber can introduce hazards impacting all parts of a building's fire strategy, in particular flame spread across internal surfaces, external fire spread and space separation. The implications of building with mass timber and allowing it to contribute as a source of fuel should be fully understood by the design team and considered as at the outset of a project through a qualitative design review (QDR) process, as discussed in Section 3.1.



1.1.2 Timber construction scope

Mass timber is part of the family of material types that are in the structural timber building systems suite of options. As a building method, mass timber offers low carbon benefits and forms part of the offsite construction solution for speed, quality and cost-efficiency.

This guidance concerns large planar panels made from layers of timber, of which the following products are available:

- Cross laminated timber (CLT);
- Glued laminated timber (glulam) in large wall/floor panel form;
- Laminated veneer lumber (LVL) panels;
- Nail/dowelled laminated timber panels; and
- Engineered wood boards in large wall/floor panel form and of minimum 40mm thick.

1.1.3 Designer responsibility scope

This document conveys general guidance. It should be ensured on a case-by-case basis that its application is relevant and that the structural fire safety objectives for the project will be satisfied if this guidance is applied, noting that the purview of this guidance is life safety only.

The document assumes a requisite level of understanding/competence in its application, as discussed further in Section 1.4.



1.2 Why is this guidance needed and intent of guidance

Timber structures are resurgent due to environmental drivers, with an increasing number of tall and complex buildings being conceived that incorporate mass timber, either for the entirety of the structural frame or parts thereof in hybrid structures (often incorporating steel and/or concrete components). Timber is a combustible material. Where it forms large parts of a fire compartment's surface area and can contribute as a source of fuel (either because it is exposed by design or may become exposed prematurely during a fire), it can change the fire dynamics within. Compared to using non-combustible materials this may lead to: higher heat release rates (HRRs), increased compartment gas temperatures, higher incident heat fluxes to structural elements, prolonged fire duration (see Figure 1), more combustion outside of openings causing more severe external flaming. A more exhaustive discussion related to fire hazards and mass timber buildings can be found in refs [1] and [2].

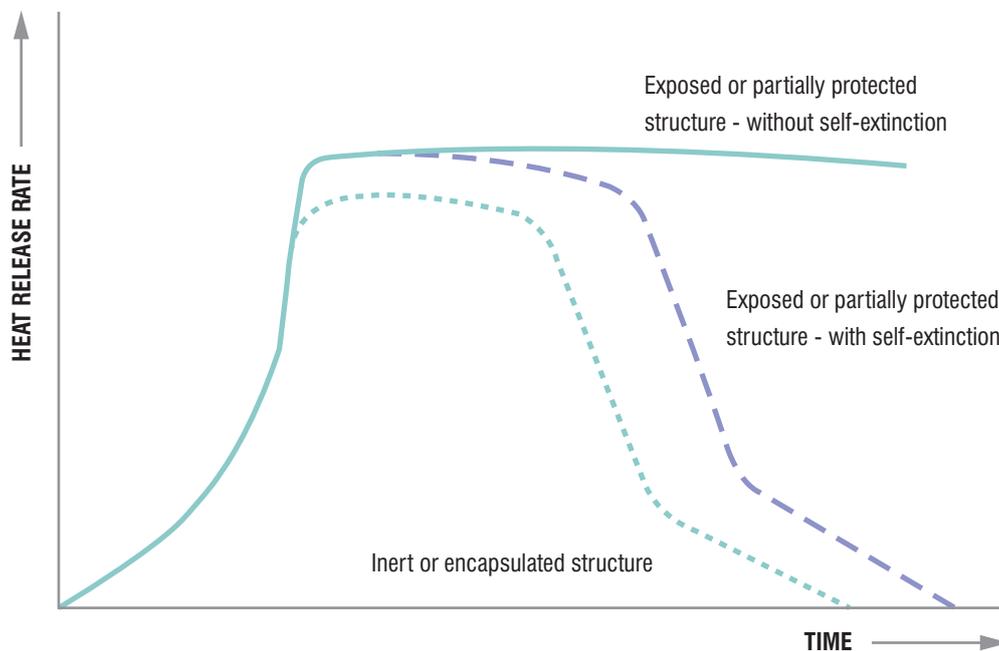


Figure 1: Conceptual illustration of heat release rate vs. time in inert or combustible enclosures, with or without self-extinction

Concerning the performance expected of the structure in the event of fire, the Building Regulations in England set out the minimum expectations under a life safety purview (as discussed in Section 2.1).

For the more common and straightforward building situations, guidance [3], [4] or codes [5], [6] are often applied to satisfy the requirements of the Building Regulations (see Section 2.3). These guidance documents and codes address structural performance in the event of fire through the provision of fire resistance to load-bearing elements of structure. Implicitly, the fire resistance paradigm and the guidance documents/codes that reference fire resistance periods include limitations, which are outlined in the OFR background report included in Appendix A. Discussions which elaborate on fire resistance, its origin and objectives can be found elsewhere, e.g. refs [7]-[9]



For higher consequence buildings, the affording of fire resistance to elements of structure is a proxy for an objective of the structure having a reasonable likelihood of surviving the full duration of a fire (burn-out), as discussed in more detail in Section 2.2. Where structural elements contribute as a source of fuel, the affording of fire resistance to structural elements does not assure that the structural system will have a reasonable likelihood of surviving burn-out. By extension, the application of guidance or codes (which include fire resistance recommendations) does not always assure compliance with the relevant parts of the Building Regulations, with alternative routes to compliance required where a structure burns but must ultimately survive burn-out (see Section 2.4).

This document serves to guide designers towards the most appropriate route for compliance with Building Regulation B3(1) depending upon a project's specific circumstances, considering parameters that include:

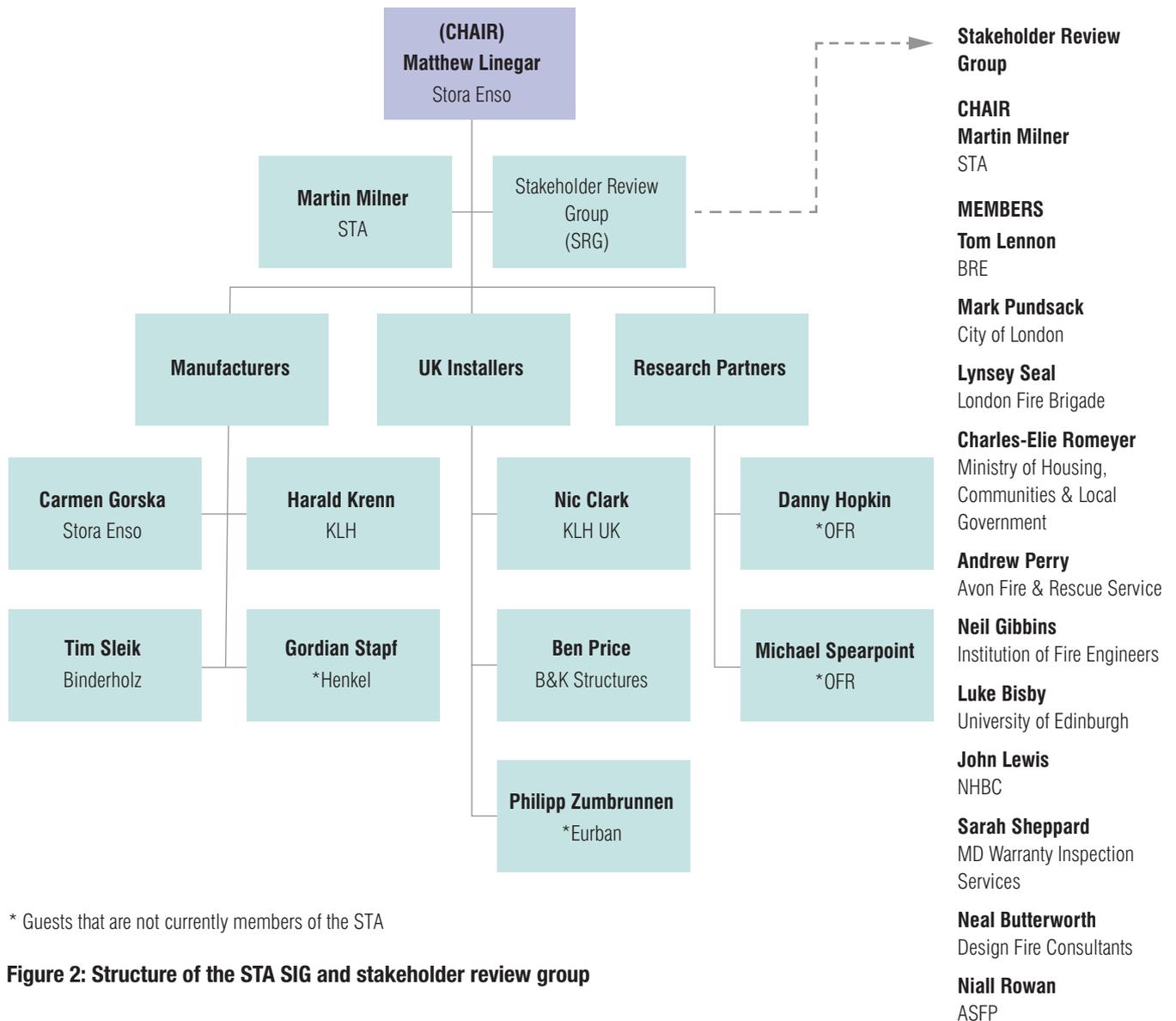
- The structural fire safety objectives;
- The consequences associated with a fire induced structural failure; and
- The ability of the mass timber elements to contribute as a source of fuel.



Image courtesy of Binderholz

1.3 STA special interest group and stakeholder review

This document is an output from the 'STA Special Interest Group (SIG) - CLT compartment fire behaviour'. Outputs are independently reviewed by a stakeholder review group. The project team structure and members are as shown in **Figure 2**.



* Guests that are not currently members of the STA

Figure 2: Structure of the STA SIG and stakeholder review group

1.4 Competency

The fire safety design of mass timber buildings is a specialised area requiring specific knowledge and relevant experience in the fields of, for example, combustion, fire dynamics, heat transfer and structural response. Such expertise is not widely held by a large quantum of fire safety professionals. Where it is established that a more complex fire safety engineering solution is required (e.g. see Section 2.4), only those individuals with demonstrable competence and relevant experience should be engaged to provide support to the project.

Similarly, the competence of the designer should be mirrored in the Building Regulations approvals process to ensure designs are adequately scrutinised by the building control body. This will often necessitate the engagement of third-party peer reviewers to evaluate designs on behalf of the building control body. As per those charged with undertaking design responsibility, this peer review role should be undertaken by those individuals with recognised competence and demonstrable experience in the field of fire safety and mass timber structures.



2 Design considerations for fire performance

This section introduces the statutory Building Regulation requirements in England with respect to structural performance in the event of fire, structural fire safety objectives and how they differ depending upon fire induced failure consequences, and the corresponding implications for the route to Building Regulations compliance for mass timber buildings.

2.1 Fire safety regulatory requirements and intentions

Building Regulation B3(1) in England states that:

“The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period.”

The Secretary of State goes on to clarify the intention of the above functional requirement in Approved Document B as:

“For defined periods, loadbearing elements of structure withstand the effects of fire without loss of stability.”

2.2 Structural fire performance objectives

Whilst speaking to periods of time, neither the wording of Regulation B3(1) nor the Secretary of State’s clarified intention in ADB explicitly define the duration of structural stability required in the event of fire. With reference to the supporting OFR research in Appendix A and parallel research developments in ref [8], the structural fire safety performance objectives for a building can vary in function of the consequences of fire induced collapse. For buildings where the failure consequences are less significant, Regulation B3(1) can be interpreted as likely being satisfied subject to the structure remaining stable for an adequate period to facilitate occupant escape and (predominantly) external fire and rescue service intervention. For buildings where the failure consequences are more significant (e.g. due to what is considered to be prolonged evacuation or (predominantly) internal fire and rescue service intervention), Regulation B3(1) is likely satisfied subject to the structure having a reasonable likelihood of surviving the full duration of a fire (burn-out). This bifurcation of objectives is illustrated schematically in **Figure 3** which goes on to indicate the implications for the compliance route (Section 2.5) and design solutions (Section 2.6).

2.3 Guidance-based routes to compliance

For most common and straightforward building situations, Regulation B3(1) is addressed through the adoption of the statutory guidance in Approved Document B [3], [4], or similar guidance such as BS 9991 [5] and BS 9999 [6]. Therein, fire resistance ratings are recommended for elements of structure in function of building size and use. Subsequently, elements are either designed to inherently achieve or are protected to achieve the recommended fire resistance rating. In the case of mass timber elements, fire resistance would commonly be demonstrated through the calculation methods in BS EN 1995-1-2 [10] or through appropriate test evidence. Once these ‘fire resisting’ elements are formed into a structural system, that structural system can be said to satisfy Regulation B3(1).

Whilst adopted as a common metric of performance, Section 2.2 highlights that structural elements can be afforded fire resistance to satisfy different structural fire safety objectives. With reference to the OFR report in Appendix A and the literature cited therein, fire resistance guidance can likely only serve as an adequate proxy for the objective of a structure having a reasonable likelihood of surviving burn-out where the structure is prevented from contributing as a source of fuel.

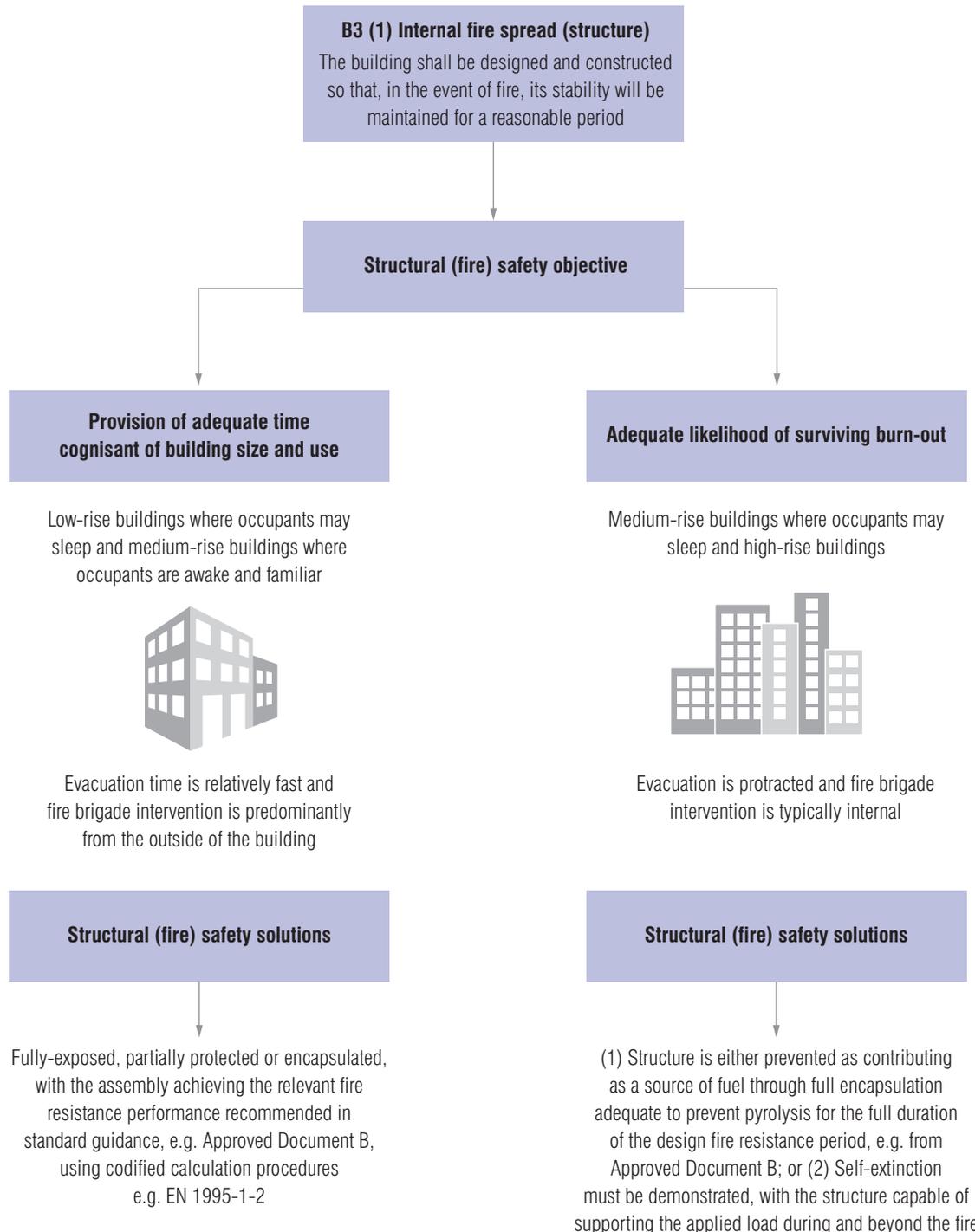


Figure 3: Illustration of the relationship between structural fire safety objectives, compliance routes and design solutions



2.4 Performance-based routes to compliance

Following statutory guidance (ADB) or similar codes (BS 9991, BS 9999) is not the only means of satisfying the requirements of Part B of the Building Regulations. Alternative routes exist and these are discussed in greater detail in BS 7974 [11] and the associated suite of Published Documents (with PD 7974-3 [12] being the most relevant in this case). For some more complex situations, such as those falling outside of the scope of guidance or codes, alternative fire engineering approaches/solutions may be the only means of demonstrating compliance with the Building Regulations and this is recognised in ADB.

BS 7974 notes a performance-based approach to design to constitute consideration of the specific fire hazards and their consequences such that fire safety measures can be introduced, as necessary, to ensure that the functional objectives for the design are met. BS 7974 encourages the inclusion of a qualitative design review (QDR) process, which is discussed further in Section 3.1.

2.5 Mass timber and the impact on route to compliance

It is discussed in Section 1 that combustible structures may increase the severity of fires within building compartments where they are allowed to contribute as a source of fuel. This has implications for a structure's stability, affecting failure time and/or its likelihood of surviving burn-out.

The applicability/relevance of a guidance-based route to compliance, therefore, depends upon the structural fire performance objectives (as discussed in Section 2.2):

- Provision of adequate time: the structure having a reasonable likelihood of surviving the full duration of a fire is not a prerequisite for compliance with Regulation B3(1). Therefore, following the fire resistance guidance in ADB, for example, can likely result in an adequate level of safety and compliance with Regulation B3(1) subject to elements being designed appropriately for the recommended fire resistance rating (e.g. through application of BS EN 1995-1-2 [10]). The design solutions could involve the structure being fully exposed, partially protected or encapsulated (see Section 2.6);
- An adequate likelihood of surviving burn-out: unless the structure is prevented from contributing as a source of fuel, applying the fire resistance guidance in, for example, ADB cannot be said to result in a structure that can satisfy Regulation B3(1). Preventing the structure from contributing as a source of fuel will require encapsulation (see Section 2.6.2). Where the structure is permitted to become involved as a source of fuel, a performance-based route to compliance is likely the only means of demonstrating compliance with Regulation B3(1). Therein, it must be demonstrated that the structure can undergo self-extinction and support the applied load both during and beyond the fire (see Section 2.6.3).

2.6 Mass timber fire safety design solutions

2.6.1 Partial protection

Partial protection implies that the fire resistance classification from BS EN 13501-2 [13] is achieved through a combination of contributions from the lining (often protection) material and substrate (e.g. sheathing or structural element). In a real fire and where this substrate is combustible, e.g. a mass timber structural element, this would infer that additional fuel will contribute to the fire beyond that of contents of the fire compartment at some point (ahead of burn-out). This will alter the fire dynamics within the compartment and will have implications for the structure's ability to potentially withstand the full duration (burn-out) of a fire.

2.6.2 Encapsulation

Encapsulation implies that sufficient protection is provided to the underlying structure/substrate to mitigate the onset of pyrolysis for the full duration of the relevant fire resistance period. This is commonly addressed through the specification of linings achieving demonstrated k2 classifications per BS EN 13501-2 [13]. Where a lining is specified for the purposes of encapsulation, it should be shown that the interface temperature between the combustible substrate and lining (and away from fixings) remains below 200°C [14] (indicating the decomposition of hemicellulose) for the duration of the relevant fire resistance period. For mechanically fixed lining solutions, this is likely demonstrated through lining systems achieving a k2 class but should be subject to review of the specific product test data and associated thermocouple readings.

Where encapsulation is adopted as the design solution, further consideration needs to be given to the overall fire strategy's 'defence-in-depth' to assure that premature failure of any protective lining does not lead to disproportionate damage/collapse of the overall structure. This is particularly relevant when considering Regulation A3, which is discussed further in Section 2.7.

2.6.3 Exposed structures and self-extinction

Self-extinction concerns the cessation of flaming combustion (in this case) of the structural elements either because they have been exposed to a fire from the outset, or have become exposed throughout the duration of a fire due to a partial protection solution. Demonstrating self-extinction is considered a prerequisite for compliance with Regulation B3(1) in cases where the performance objective is an adequate likelihood of surviving burn-out and encapsulation is not proposed. The demonstration of self-extinction would form part of a performance-based route to compliance, as discussed in Section 2.4.

2.6.4 Structural backstop

Irrespective of the solution outlined in Sections 2.6.1 to 2.6.3, the (residual) structural elements must be capable of supporting the load either for the duration of the fire resistance period or for the full duration of a fire, as relevant to the route of compliance. This will typically involve a demonstration that the structure can support the loads for an accidental loading combination, as set out in BS EN 1990 [15] and BS EN 1991-1-2 [16] (including national application documents, e.g. [17], [18]).

2.7 Differentiating failure consequences

Failure consequences caused by fire drive the structural performance objectives discussed in Section 2.2.

Failure consequences are differentiated in guidance addressing general structural design (Approved Document A - ADA [19]) and fire safety design (Approved Document B - ADB).

With respect to disproportionate collapse and Regulation A3 (England), places an obligation to ensure: "the building shall be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause".

ADA provides guidance for designers by grouping buildings into consequence classes, as reflected in **Table 1**. When allowing designers to specify fire resistance to elements of structure, ADB adopts a combination of trigger heights and purpose groups to impose a reducing failure likelihood with increasing failure consequences.



Whilst the two Approved Documents (ADA and ADB) can appear unrelated, it is considered appropriate in the context of this guidance that the ADA consequence class system serves as a boundary on the application for fire resistance guidance. This is clearly reflected in the high consequence buildings, with ADA calling for all consequence class 3 structures to be subject to a systematic risk assessment, taking into account all the normal hazards that may be reasonably foreseen, together with any abnormal hazards. It is seen later in Section 3.2 that a guidance-based route to compliance is not advocated for consequence class 3 structures. For lesser consequence classes, i.e. 1, 2A and 2B, it is shown in Section 3.2 that a guidance-based route to compliance can be applicable, depending upon the structural fire safety objectives and subject to the limiting trigger heights referenced in **Table 2**.

CONSEQUENCE CLASS	CONSEQUENCES OF FAILURE	TYPICAL BUILDING TYPE AND OCCUPANCY - RELEVANT TO MASS TIMBER
CLASS 1¹	Low	<ul style="list-style-type: none"> • Single occupancy houses not exceeding 4 storeys
CLASS 2A¹	Low to medium	<ul style="list-style-type: none"> • 5 storey single occupancy houses • Hotels not exceeding 4 storeys • Flats, apartments and other residential buildings not exceeding 4 storeys • Offices not exceeding 4 storeys • Industrial buildings not exceeding 3 storeys • Retail premises not exceeding 3 storeys of less than 1000 m² floor area in each storey • Single storey educational buildings • All buildings not exceeding two storeys to which the public are admitted and which contain floor areas not exceeding 2000 m² at each storey
CLASS 2B	Upper risk group (medium)	<ul style="list-style-type: none"> • Hotels, flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storeys • Educational buildings greater than single storey but not exceeding 15 storeys • Retail premises greater than 3 storeys but not exceeding 15 storeys • Hospitals not exceeding 3 storeys • Offices greater than 4 storeys but not exceeding 15 storeys • All buildings to which the public are admitted, and which contain floor areas exceeding 2000 m² but not exceeding 5000 m² at each storey
CLASS 3	High	<ul style="list-style-type: none"> • All buildings defined above as Class 2 lower and upper consequences class that exceed the limits on area and number of storeys • All buildings to which members of the public are admitted in significant numbers • Stadia accommodating more than 5000 spectators

Table 1: Consequence class table extracted from Table 11 of Approved Document A (England) and in Annex A of BS EN 1991-1-7¹

¹ Note that consequence classes are further augmented with limiting trigger heights in function of the purpose groups as discussed in Section 3.2 and presented in **Table 2**.

3 Guidance on routes to compliance

The following sections discuss general recommendations in support of ascertaining the most appropriate route to compliance with Regulation B3(1) for mass timber projects of varying scale and use. It should be applied noting the caveats discussed in Section 1.

3.1 The QDR

The most appropriate route to compliance for a mass timber building project should be reviewed at the inception stage. The STA promotes the undertaking of a QDR for all projects involving mass timber construction, albeit acknowledges that this may be more formal and comprehensive for higher consequence versus lesser consequence buildings.

BS 7974 provides a structured process for highlighting and determining fire hazards, fire risks, design actions and mitigation measures. The QDR will typically involve the following main stages [11]:

- a. Review architectural design and selection of materials, including their suitability and fire properties, occupant characteristics and client requirements;
- b. Establish functional objectives for fire;
- c. Identify fire hazards and possible consequences;
- d. Establish trial fire safety engineering designs;
- e. Set acceptance criteria for the designs;
- f. Identify the method of analysis;
- g. Establish fire scenarios for analysis; and
- h. Document outputs of the QDR

3.2 A consequence-based design tool for compliance

The QDR process highlights a need to consider the project objectives, technical design factors, material selection factors and possible fire induced consequences. Adopting these as a foundation and in cognisance of the underpinning research set out by OFR in Appendix A, a general consequence-based design tool to assist in identifying the most appropriate route to compliance for a mass timber building project has been developed and is summarised in **Table 2**.

Section 2.7 discusses the differences in how structural failure consequences are differentiated with respect to Part A and Part B of the Building Regulations (and the associated statutory guidance). As a primary reference point, building consequence classes inform the route to compliance in **Table 2**. Building consequence classes speak in terms of the number of storeys (ground inclusive). Depending upon the floor to ceiling height, this can create a range of building heights of nominally the same number of storeys. The background research reported in Appendix A has highlighted the historical role of trigger heights in differentiating changes in escape duration, operational firefighting practices, etc., and, thus, structural fire safety objectives. In cognisance of the impact of height on such fire strategy considerations, maximum heights for guidance-based routes to compliance are imposed in **Table 2** (through Note 2) for consequence class 2a structures.



CONSEQUENCE CLASS	CONSEQUENCES	PERMISSIBLE COMPLIANCE ROUTE	
		GUIDANCE-BASED ¹	PERFORMANCE-BASED ⁴
1	Low	Yes	Yes
2A	Low to medium	Yes ²	Yes
2B	Medium	Yes ³	Yes
3	High	No ⁵	Yes

NOTE 1: For England the guidance-based approach is documented in, for example, Approved Document B which specifies the recommended fire resistance rating for elements of structure. Elements are then demonstrated as having adequate fire resistance through appropriate testing and/or calculation methods, e.g. BS EN 1995-1-2.

NOTE 2: Subject to the purpose group specific height limitations set out below, otherwise Note³ applies:

BUILDING TYPE AND OCCUPANCY	LIMIT ON UPPER FLOOR LEVEL ABOVE LOWEST GROUND LEVEL
Residential	11m
Hotels and other residential	11m
Offices and mercantile	18m
Assembly and recreation	7.5m
Education/schools	7.5m

NOTE 3: Only applicable to mass timber afforded encapsulation with the lining capable of averting pyrolysis for the full duration of the fire resistance period.

NOTE 4: Demonstration by a competent fire engineer with relevant experience (see Section 1.4) that the structure has a reasonable likelihood of surviving burn-out with due consideration of: the impact of the combusting structure on fire development, the ability of the structure to undergo self-extinction, and the ability of the structure to support the applied loads during and beyond the fire event. A performance-based assessment may be augmented by project specific testing in support of demonstrating that self-extinction is achieved and that the structure subsequently remains stable.

NOTE 5: Consequence class 3 structures should be subject to a project-specific system risk assessment considering fire as an accident, per Approved Document A and in satisfaction of Regulation A3. This necessitates a performance-based assessment in all cases.

Table 2: Consequence-based guidance on route to compliance for mass timber buildings (life safety)

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- [19] HM Government, 'The Building Regulations 2010, Approved Document A (Structure)', London, 2004.

Compliance roadmap for mass timber projects in England Regulation B3(1)

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Project: Research & Development
Project Location: N/A
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Project No: OX19044
Revision: R06
Date: 28/09/2020

Quality Management

Revision	Date	Comment	Author	QA and Technical Review	Approver
D00	24/01/2020	Draft issue covering B3(1) only	Danny Hopkin	Michael Spearpoint	Simon Lay
R00	04/02/2020	Incorporating Stora Enso comments on D00	Danny Hopkin	Michael Spearpoint	Simon Lay
R01	27/02/2020	Incorporating Stora Enso comments on R00	Danny Hopkin	Ben McColl	N/A
R02	16/03/2020	Incorporating STA SIG comments on R01	Danny Hopkin	N/A	Michael Spearpoint
R03	10/06/2020	Updated to support inclusion in STA guidance	Danny Hopkin	N/A	Michael Spearpoint
R04	24/07/2020	Updated for final publication	Danny Hopkin	N/A	Michael Spearpoint
R05	21/09/2020	Updated to include final stakeholder review group comments	Danny Hopkin	N/A	Michael Spearpoint
R06	28/09/2020	Final issue for inclusion with STA Vol. 6 guidance	Danny Hopkin	N/A	Michael Spearpoint

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1 INTRODUCTION

1.1 Context

Mass timber construction has increased in popularity due to environmental drivers, buildability, impact on wellness, etc. Given the declaration of a climate emergency by various jurisdictions [1], the wider adoption of mass timber will be a significant part of construction solutions that seek to reduce impact on climate change in the built environment. Particularly in panelised form, mass timber introduces new fire safety challenges not readily addressed within current regulatory and fire guidance paradigms. This document has been prepared to outline what compliance means in an English regulatory fire context and the differing means through which compliance can / should be demonstrated.

1.2 Appointment

OFR Consultants have been appointed by CLT suppliers Stora Enso, binderholz and KLH to develop a compliance roadmap for mass timber structures in the UK (see scope in Section 1.3), with an emphasis on cross laminated timber (CLT) construction. This issue of the roadmap is written to address specific aspects of Part B of the Building Regulations 2010 (incorporating amendments to 2019) (defined as “the Regulations” henceforth) for England. Differences exist with regard other UK jurisdictions, which should be addressed in a subsequent update of this document or separate jurisdiction specific roadmaps. This issue focuses only on compliance with requirement B3(1) – “*Internal fire spread – structure*”, with other Building Regulation requirements to be considered separately (for example, it should be noted that fuel from a combustible structure can burn outside of openings, presenting an external fire spread hazard that should also be adequately addressed).

The roadmap is intended to provide guidance in relation to satisfying life safety requirements (for people within or the vicinity of a building in the event of fire), with an emphasis on:

Clarifying the legal requirement (as set out in the Regulations) with respect to the fire performance of structures in England (in the first instance);

Documenting the compliance pathway for mass timber structures in terms of satisfying the requirements of Part B of the Regulations;

Outlining what evidence should be provided to support compliance with Part B of Regulations under differing circumstances; and

Clarifying who is ultimately responsible for developing evidence in support of demonstrating compliance with Part B of the Regulations.

In complying with the Regulations, environmental and/or property protection is not assured. Client drivers relating to such objectives may require considerations beyond the scope of this document, see Section 1.4.

1.3 Definitions

For the purposes of this report, the following definitions apply:

- **Building consequence class** – building class grouping, differentiated by the consequences of a structural failure, as defined in Approved Document A [2]. Note: also referred to as reliability class in ISO 2394 [3];
- **Mass timber panelised construction (MTPC)** – large planar panels constructed of cross laminated timber (CLT), glue laminated timber (glulam), laminated veneer lumber (LVL), nail laminated timber (NLT), or similar;
- **Fire resistance** – performance of an isolated construction element in a furnace test, relative to specific performance criteria (integrity, insulation, loadbearing, fire protection) under defined time-temperature

exposure (see: “standard time-temperature curve”) and, where applicable, loading conditions, as defined in EN 1365-1 [4];

- **Reaction-to-fire** – response of a product in contributing by its own decomposition to a fire to which it is exposed, under specified conditions;
- **Exposed** - absence of protection or when protection no longer performs its intended purpose;
- **Standard time-temperature curve** – the time-temperature heating regime adopted in standard fire resistance testing protocols, i.e. as defined in ISO 834 [5];
- **Encapsulation** – lining of the mass timber elements such that pyrolysis is mitigated for the full duration of the fire resistance period when subject to the standard time-temperature curve. Achieved by providing a protective lining capable of averting the onset of pyrolysis (to the extent it may affect enclosure fire development) for the duration of the fire resistance period (Note: the K₂ class as defined in BS EN 13501-1 [6] is often adopted as a means of substantiating the performance of a lining with respect to adequately averting pyrolysis. This document does not explicitly advocate its adoption due to ongoing debates as to conservatism of the temperature thresholds adopted. It is ultimately the responsibility of the designer to defend the performance specification for any encapsulation solutions);
- **Partial protection** – lining of the mass timber elements, where the applied protection material cannot mitigate pyrolysis for the full duration of the fire resistance period when subject to the standard time-temperature curve;
- **Purpose group** – a classification of a building according to the purpose to which it is intended to be put;
- **Auto-extinction** – the cessation of combustion (typically, both smouldering and flaming), without active intervention (e.g. fire fighting);
- **Pyrolyse or Pyrolysis** – process by which a material or compound decomposes by heat in the absence of oxygen; and
- **The Regulations** – the Building Regulations 2010 (incorporating amendments to 2019) as applied to building projects in England.

1.4 Relevant legislation

The compliance roadmap documented herein addresses the requirements set out in the Regulations. It does not address other project objectives, e.g. property protection, business continuity, etc., which should be discussed separately with relevant stakeholders at the outset of a project as part of a qualitative design review (QDR), as defined in BS 7974 [7].

The choice of MTPC as a structural solution can introduce fire safety challenges during the construction phase. These challenges are not unique to MTPC and apply to all forms of timber construction. The safety of construction site staff and those in proximity falls within the remit of several pieces of legislation, e.g.:

- The Construction & Design Management (CDM) Regulations (2015);
- The Fire Safety (Employees’ Capabilities) (England) Regulations (2010); and
- Dangerous Substances and Explosive Regulations (DSEAR).

It is not within the scope of this document to address the hazards and risks associated with timber during the construction phase. However, attention is brought to associated guidance, e.g. HSG 168 [8], the STA 16 step plan [9] and the STA guide to separating distances [10].

1.5 Scope

The scope of this document can be split into two areas: (1) the types of timber construction; and (2) the types of buildings intended to be covered. In the case of the former, the types of timber construction is wholly consistent with the draft Building Control Alliance (BCA) technical guidance note (GN) 29 [11].

1.5.1 Types of timber construction within / outside of document scope

This compliance roadmap addresses mass timber panelised construction (MTPC), which concerns large planar panels constructed of:

- Cross laminated timber (CLT) - see Figure 1-1;
- Glue laminated timber (glulam) - Figure 1-2;
- Laminated veneer lumber (LVL) - Figure 1-3; and
- Nail laminated timber (NLT).

MTPC is differentiated from traditional framed mass timber forms and light timber construction, as the surface area of combustible elements is substantial, e.g. an entire ceiling or walls and ceiling. MTPC typical also involves engineered timber versus solid timber. MTPC might include a combination of timber components, e.g. a glulam frame supporting CLT floors.

1.5.2 Types of buildings within / outside of document scope

Purpose groups are as defined within Approved Document B [12]. The scope of buildings falling within this document are as follows: (a) residential; (b) office; (c) mercantile; (d) assembly and recreation; (e) education facilities. This document does not cover: (i) industrial; (ii) storage; (iii) healthcare; (iv) care homes; (v) those purpose groups not explicitly identified in (a) to (e) above.

1.6 Application of the compliance roadmap / process

The compliance roadmap presented herein should be applied in cognisance of the scope given in Section 1.5. It assumes, sans the factors influenced by the choice of MTPC as the framing solution, that buildings are straightforward / common as it directs users towards aspects of the guidance in, for example, Approved Document B.

The compliance roadmap should not be applied in isolation. It should form part of a wider QDR, with process as defined in BS 7974 [7], to establish if the building can be considered straightforward from a broad fire strategy perspective, with a particular emphasis on the nature of the fire hazards and the fire induced failure consequences.

The scope of the guidance herein predominantly concerns structures falling within consequence classes 1, 2a and 2b, as defined in Approved Document A [2] (i.e. those typically constructed of MTPC). Whilst this roadmap gives general guidance for buildings greater than 18 m in height (measured from lowest ground level to top qualifying storey) without defining an upper height threshold, specific consideration should be given to the failure consequences associated with tall buildings in the event of fire.

Part A of the Regulations places an obligation on the structural engineer through requirement A3 to ensure:

“the building shall be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause”.

The corresponding guidance in Approved Document A [2] states that for building consequence class 3 buildings:

“A systematic risk assessment of the building should be undertaken taking into account all normal hazards that may reasonable be foreseen, together with any abnormal hazards”.

This effectively places an obligation on the structural designer to explicitly consider the impact of the specific fire hazards from a disproportionate collapse perspective for all:

- Hotels, blocks of flats, apartments and other residential buildings greater than 15 storeys in height;
- Educational buildings greater than 15 storeys in height;
- Retail premises greater than 15 storeys in height;
- Hospitals exceeding 3 storeys in height;
- Offices greater than 15 storeys in height;
- All buildings to which members of the public are admitted which contain floors areas exceeding 5,000 m² at each storey; and
- Grandstands accommodating more than 5,000 spectators.

That is, generic fire resistance-based guidance should not be applied without significant interrogation for all building consequence class 3 buildings. This includes those cases where encapsulation is the proposed solution.



Figure 1-1 – Cross laminated timber panel (courtesy of Stora Enso)



Figure 1-2 – Glulam (courtesy of binderholz)



Figure 1-3 – LVL (courtesy of Stora Enso)

1.7 Relationship with guidance and EN 1995-1-2

BS EN 1995-1-2 [13] provides the means / tool to design structural timber elements such that they achieve a predetermined fire resistance rating and sits within a hierarchy of broader considerations (see Figure 1-4). The application of EN 1995-1-2 in isolation does not guarantee that the requirements of the Regulations are met as a prescribed fire resistance rating for mass timber elements does not ensure a reasonable likelihood of the structural system surviving burnout (discussed further in Section 3.1).

In the context of this document, EN 1995-1-2 provides a means to:

- Demonstrate how exposed MTPC elements achieve fire resistance where it has, in advance, been shown that the structural fire design objective(s) can be achieved through a prescribed fire resistance rating (i.e. exposed elements where burn-out need not explicitly be addressed);
- Demonstrate how encapsulated MTPC elements achieve fire resistance where it has, in advance, been shown that the structural fire design objective(s) can be achieved through a prescribed fire resistance rating (i.e. the design of the section below a tested lining solution capable of adequately averting pyrolysis for the duration of the fire resistance period); and
- As a support tool in demonstrating that heated MTPC elements can sustain the accidental loading combination (as defined in BS EN 1990 [14], BS EN 1991-1-2 [15] and the National Annex (NA) to BS EN 1995-1-2 [16]) when either: (1) fully encapsulated (see definitions in Section 1.5) for the duration of the fire resistance period; or (2) exposed or partially protected for the duration (and beyond) of an adequately severe fire scenario. In this regard, the application of EN 1995-1-2 sits alongside a wider and more comprehensive fire modelling or large-scale testing study.

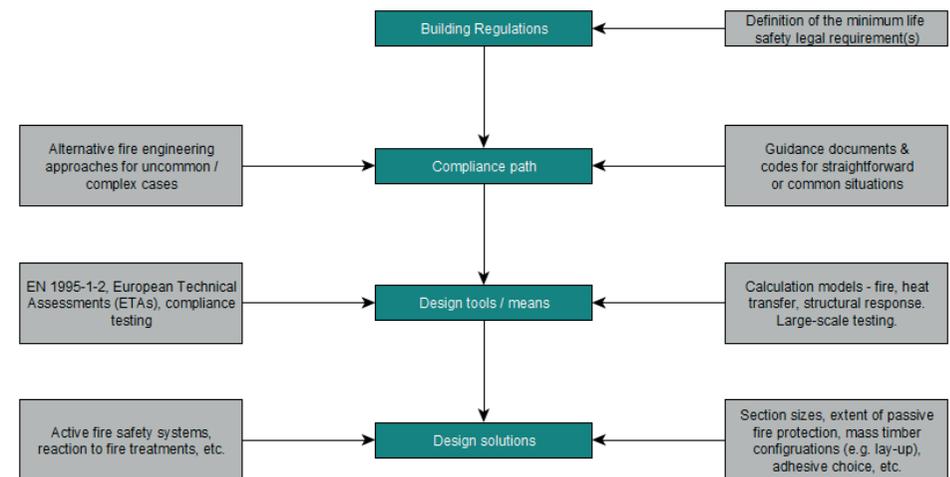


Figure 1-4 – Hierarchy of legislation, tools and design solutions for MTPC

1.8 Competency and peer review

As with all designs, these must be developed by competent individuals, with relevant (demonstrable) education, knowledge and experience. The fire safety design of mass timber structures is a specialist area, with a limited number of individuals with the prerequisite competence, both in respect of the design and approval of such buildings.

For cases where burn-out must be explicitly addressed (see Section 4), it is expected that designs will be developed in collaboration with (structural) fire safety engineers with relevant and demonstrable mass timber design education, knowledge and experience. Note: the level of expertise required for cases where self-extinction is to be demonstrated is significantly greater than encapsulated MTPC approaches. Designers should be vetted accordingly.

Where an approval authority does not have relevant and demonstrable education, knowledge and experience of the fire safety design of mass timber buildings, it is expected that a third-party peer review will be undertaken of the fire strategy and the structural fire safety design. This third-party review should be undertaken by a (structural) fire safety engineer with relevant and demonstrable mass timber design education, knowledge and experience.

2 BUILDING REGULATION REQUIREMENTS (ENGLAND)

The below sections set out the relevant life safety mandatory requirements with respect to fire for buildings constructed in England, as defined by the Regulations. The intentions of the requirements are also clarified adopting the wording in Approved Document B [12]. The Regulations constitute multiple functional requirements (i.e. performance-based regulations – B1 to B5), alongside prescriptive requirements (Regulation 7) introduced post-Grenfell Tower. All must be satisfied and are interrelated, e.g. what constitutes a “reasonable period” under B3(1) is informed by the strategies relating to means of escape (B1), mitigating fire spread (B3 and B4) and fire brigade intervention (B5).

2.1 B1 – Means of warning and escape

2.1.1 Functional requirement

The Building Regulations requirement B1 states:

“The building shall be designed and constructed so that there are appropriate provisions for the early warning of fire, and appropriate means of escape in case of fire from the building to a place of safety outside the building capable of being safely and effectively used at all material times.”

2.1.2 Intention

“In the Secretary of State’s view, requirement B1 is met by achieving all of the following.

- a) There are sufficient means for giving early warning of fire to people in the building.*
- b) All people can escape to a place of safety without external assistance.*
- c) Escape routes are suitably located, sufficient in number and of adequate capacity.*
- d) Where necessary, escape routes are sufficiently protected from the effects of fire and smoke.*
- e) Escape routes are adequately lit and exits are suitably signed.*
- f) There are appropriate provisions to limit the ingress of smoke to the escape routes, or to restrict the spread of fire and remove smoke.*
- g) For buildings containing flats, there are appropriate provisions to support a stay put evacuation strategy.*

The extent to which any of these measures are necessary is dependent on the use of the building, its size and its height.”

2.2 B2 – Internal fire spread (linings)

2.2.1 Functional requirement

The Building Regulations requirement B2 states:

“(1) To inhibit the spread of fire within the building, the internal linings shall—

- a) adequately resist the spread of flame over their surfaces; and*
- b) have, if ignited, either a rate of heat release or a rate of fire growth, which is reasonable in the circumstances.*

(2) In this paragraph “internal linings” means the materials or products used in lining any partition, wall, ceiling or other internal structure. ”

2.2.2 Intention

“In the Secretary of State’s view, requirement B2 is met by achieving a restricted spread of flame over internal linings. The building fabric should make a limited contribution to fire growth, including a low rate of heat release.

It is particularly important in circulation spaces, where linings may offer the main means by which fire spreads and where rapid spread is most likely to prevent occupants from escaping.”

2.3 B3 – Internal fire spread (structure)

2.3.1 Functional requirement

The Building Regulations requirement B3 states:

“(1) The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period

(2) A wall common to two or more buildings shall be designed and constructed so that it adequately resists the spread of fire between those buildings. For the purposes of this sub-paragraph a house in a terrace and a semi-detached house are each to be treated as a separate building.

(3) Where reasonably necessary to inhibit the spread of fire within the building, measures shall be taken, to an extent appropriate to the size and intended use of the building, comprising either or both of the following—

- a) sub-division of the building with fire-resisting construction;*
- b) installation of suitable automatic fire suppression systems.*

(4) The building shall be designed and constructed so that the unseen spread of fire and smoke within concealed spaces in its structure and fabric is inhibited.”

2.3.2 Intention

“In the Secretary of State’s view, requirement B3 is met by achieving all of the following.

- a) For defined periods, loadbearing elements of structure withstand the effects of fire without loss of stability.*
- b) Compartmentation of buildings by fire resisting construction elements.*
- c) Automatic fire suppression is provided where it is necessary.*
- d) Protection of openings in fire-separating elements to maintain continuity of the fire separation.*
- e) Inhibition of the unseen spread of fire and smoke in cavities, in order to reduce the risk of structural failure and spread of fire and smoke, where they pose a threat to the safety of people in and around the building.*

The extent to which any of these measures are necessary is dependent on the use of the building and, in some cases, its size, and on the location of the elements of construction.”

2.4 B4 – External fire spread

2.4.1 Functional requirement

The Building Regulations requirement B4 states:

“(1) The external walls of the building shall adequately resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building.

“(2) The roof of the building shall adequately resist the spread of fire over the roof and from one building to another, having regard to the use and position of the building.”

2.4.2 Intention

“Resisting fire spread over external walls

The external envelope of a building should not contribute to undue fire spread from one part of a building to another part. This intention can be met by constructing external walls so that both of the following are satisfied.

- a) The risk of ignition by an external source to the outside surface of the building and spread of fire over the outside surface is restricted.*
- b) The materials used to construct external walls, and attachments to them, and how they are assembled do not contribute to the rate of fire spread up the outside of the building.*

The extent to which this is necessary depends on the height and use of the building.

Resisting fire spread from one building to another

The external envelope of a building should not provide a medium for undue fire spread to adjacent buildings or be readily ignited by fires in adjacent buildings. This intention can be met by constructing external walls so that all of the following are satisfied.

- a) The risk of ignition by an external source to the outside surface of the building is restricted.*
- b) The amount of thermal radiation that falls on a neighbouring building from window openings and other unprotected areas in the building on fire is not enough to start a fire in the other building.*
- c) Flame spread over the roof and/or fire penetration from external sources through the roof is restricted.*

The extent to which this is necessary depends on the use of the building and its position in relation to adjacent buildings and therefore the site boundary.”

2.5 B5 – Means of warning and escape

2.5.1 Functional requirement

The Building Regulations requirement B5 states:

“(1) The building shall be designed and constructed so as to provide reasonable facilities to assist fire fighters in the protection of life.

“(2) Reasonable provision shall be made within the site of the building to enable fire appliances to gain access to the building.”

2.5.2 Intention

“Provisions covering access and facilities for the fire service are to safeguard the health and safety of people in and around the building. Their extent depends on the size and use of the building. Most firefighting is carried out within the building. In the Secretary of State’s view, requirement B5 is met by achieving all of the following.

- a) External access enabling fire appliances to be used near the building.*
- b) Access into and within the building for firefighting personnel to both:

 - i) search for and rescue people*
 - ii) fight fire.**
- c) Provision for internal fire facilities for firefighters to complete their tasks.*
- d) Ventilation of heat and smoke from a fire in a basement.*

If an alternative approach is taken to providing the means of escape, outside the scope of this approved document, additional provisions for firefighting access may be required. Where deviating from the general guidance, it is advisable to seek advice from the fire and rescue service as early as possible (even if there is no statutory duty to consult).”

2.6 Regulation 7

Regulation 7 states:

“(1) Building work shall be carried out—

- a) with adequate and proper materials which—*
 - i) are appropriate for the circumstances in which they are used,*
 - ii) are adequately mixed or prepared, and*
 - iii) are applied, used or fixed so as adequately to perform the functions for which they are designed; and*
- b) in a workmanlike manner.*

(2) Subject to paragraph (3), building work shall be carried out so that materials which become part of an external wall, or specified attachment, of a relevant building are of European Classification A2-s1, d0 or A1, classified in accordance with BS EN 13501-1:2007+A1:2009 entitled “Fire classification of construction products and building elements. Classification using test data from reaction to fire tests” (ISBN 978 0 580 59861 6) published by the British Standards Institution on 30th March 2007 and amended in November 2009.

(3) Paragraph (2) does not apply to—

- a) cavity trays when used between two leaves of masonry;*
- b) any part of a roof (other than any part of a roof which falls within paragraph (iv) of regulation 2(6)) if that part is connected to an external wall;*
- c) door frames and doors;*
- d) electrical installations;*
- e) insulation and water proofing materials used below ground level;*
- f) intumescent and fire stopping materials where the inclusion of the materials is necessary to meet the requirements of Part B of Schedule 1;*
- g) membranes;*
- h) seals, gaskets, fixings, sealants and backer rods;*
- i) thermal break materials where the inclusion of the materials is necessary to meet the thermal bridging requirements of Part L of Schedule 1; or*
- j) window frames and glass.*

(4) In this regulation—

- a. a “relevant building” means a building with a storey (not including roof-top plant areas or any storey consisting exclusively of plant rooms) at least 18 metres above ground level and which—*
 - i. contains one or more dwellings;*
 - ii. contains an institution; or*
 - iii. contains a room for residential purposes (excluding any room in a hostel, hotel or boarding house); and*
- b. “above ground level” in relation to a storey means above ground level when measured from the lowest ground level adjoining the outside of a building to the top of the floor surface of the storey.*

3 TRADITIONAL ROUTES TO COMPLIANCE AND POTENTIAL CHALLENGES ASSOCIATED WITH MTPC

The choice of MTPC as a structural solution can introduce fire safety challenges beyond those traditionally foreseen by typical routes to compliance, e.g. through the application of standard guidance such as: Approved Document B [12]; BS 9991 [17] and BS 9999 [18].

3.1 Structural performance in the event of fire

The traditional means of satisfying the functional requirement B3(1) for most common building situations is the adoption of fire resistance periods and the design / protection of structural elements to ensure they achieve the recommended fire resistance. The fire resistive principle, both in terms of the demand (the fire resistance period) and what is achieved (the fire resistance rating), is grounded in several historical and fundamental principles which impacts upon its applicability to MTPC.

3.1.1 Fire resistance periods as a proxy for surviving burnout

The origins of the standard fire test stem from early attempts to make a fire resistive comparison of different building materials and systems to assess claims of “fireproof” construction in the late 19th century [19].

The fire resistive principle, originally studied by Ira Woolson, was not meant to be a ultimate ‘solution’ to the structural fire design and regulatory problems that were being encountered at the turn of the 20th century [20]; rather it was meant to serve as a practice correction at that time, specifically in the wake of the Baltimore and San Francisco conflagrations [21]. The standard fire test thus emerged as a test for comparative performance of predominantly non-combustible elements in the most severe possible fire.

In the late 1920s it was widely known that the standard fire was by no means representative of reality, and efforts principally by Simon Ingberg [22] began to correlate a fire severity – using measurements from real burn out compartment tests – to the standard fire curve based on the equal area concept (EAC).

The EAC developed by Ingberg posited that fire severity could be directly correlated with the variable / movable fire load (furniture, etc.), leading to relationships between (variable) fire load energy density and periods of standard fire exposure. As is evident in Figure 3-1, resulting fire resistance periods were intended to be a proxy for elements having sufficient performance / protection to have a reasonable likelihood of surviving burnout. Importantly, in Ingberg’s experiments, the fire enclosure was non-combustible, i.e. the fire severity and thus fire resistance period was expressed solely as a function of the energy contents of the enclosure.

Where the structure / enclosure is allowed to contribute as a source of fuel, the required fire resistance of the elements in terms of having a reasonable likelihood of surviving burnout cannot be known in advance, i.e. see Figure 3-2. This can be further complicated by material fall-off (be that delamination of the char layer or detachment of the internal protective lining). The EAC and its subsequent implications for fire safety design guidance, e.g. through fire resistance ratings in e.g. Approved Document B, can only be reasonably said to apply where the structure is prevented from contributing as a significant source of fuel [23].

3.1.2 Fire resistance periods and objectives – prerequisites

Section 3.1.1 has introduced the concept that fire resistance periods were originally a proxy for estimating what performance in a furnace was required of elements to have a reasonable likelihood of surviving burn-out in a realistic fire condition (in function of the fire load density).

Section 3.2 will discuss the historical evolution of fire regulation and guidance with specific emphasis on structural performance in the event of fire. In the historical evolution of fire regulation and guidance, it is important to note that the fire resistive principle is generally applied to universally address the challenge of achieving adequate structural performance in the event of fire.

However, the objective for providing structural elements with fire resistance differed between building types and heights, and can be broadly differentiated as:

- **Non-fire resisting structural elements** – for cases where the inherent performance of construction was deemed adequate to meet the statutory objectives, but with an acceptance that the structure may fail prior to the fire ‘burning out’;
- **Partially fire resisting elements** – for cases where the construction required demonstrable fire resistance to meet the statutory objectives, but with an acceptance that the structure may fail prior to the fire ‘burning out’; and
- **Fully fire resisting elements** - for cases where the construction required demonstrable fire resistance to meet the statutory objectives and there was an explicit expectation that the structure had a reasonable likelihood of surviving burn-out.

In transitioning between non-fire resisting, partially fire resisting and fully fire resisting construction, the fire resistance demands placed on elements generally increased. Similarly, construction forms that were combustible were increasingly less permissible.

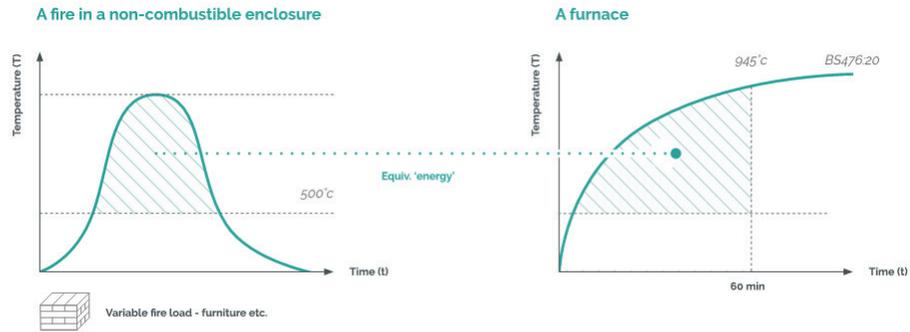


Figure 3-1 – Equal area concept for fire severity after Ingberg [22]

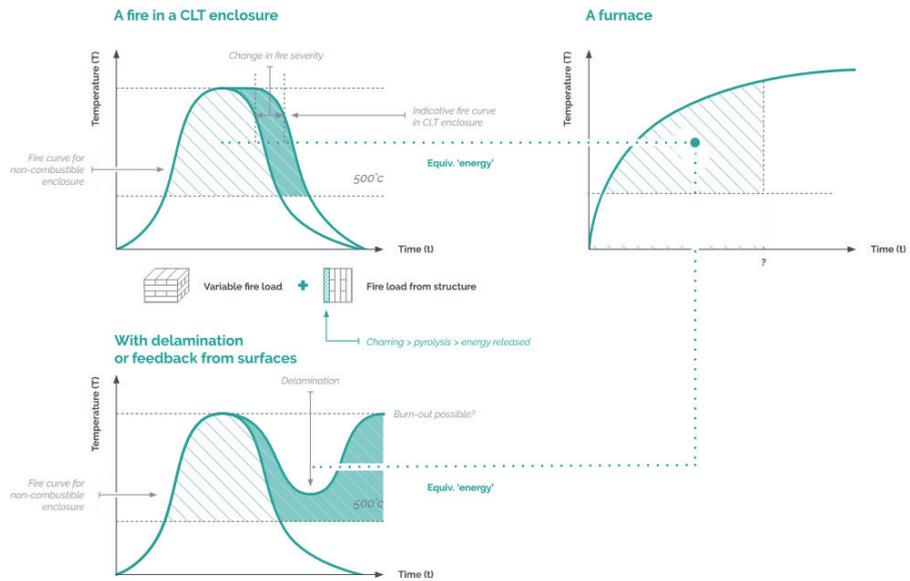


Figure 3-2 – Illustrative implications for the EAC where the enclosure is a source of fuel [DRAFT: figure to be updated]

3.2 Historical review of regulation and guidance – implications for MTPC

A more exhaustive review of fire resistance periods and their evolution is available in the parallel work of Law and Bisby [24], with the below sections providing a summary of key milestones in the development of guidance as it exists today.

3.2.1 Fire design guidance & regulation: Fire gradings of buildings – part I

The post-war [25] building studies (PWBS) have set the foundations for fire guidance as it exists today in England and elsewhere in the UK. They provide some clarity on situations where the structure surviving burn-out was an explicit expectation versus not.

Part I of the PWBS sets out three fire load groupings: low; moderate and high. These are elaborated in Table 3-1 and have been converted from British thermal (Btu / ft²) to SI units (MJ / m²).

Table 3-1 – Fire load groups, occupancies and metrics from PWBS

Fire load type	Occupancy types	Fire load [MJ/m ²]
Low	Domestic buildings, hotels, offices, etc	1,136
Moderate	Trade and factory buildings	2,271
High	Bulk storage buildings	4,542

Alongside fire load grouping, construction types are introduced as per Table 3-2:

Table 3-2 – Construction types, definitions and examples from PWBS

Construction type	Fire resistance [hours]	Definition	Construction examples
Type 1	4	Non-combustible fire resisting construction: fully or partially protected	Protected steel, brickwork, concrete
Type 2	2	according to the fire load of the occupancy (type 1 – high; type 2 – moderate and type 3 – low).	
Type 3	1		
Type 4	0.5	Fire resisting construction: internal construction not necessarily non-combustible and may therefore include combustible floors and roof. Partially protected relative to fire load.	Brick walls, timber floors and roof protected by linings, e.g. plaster.
Type 5	N/A	Externally protected construction.	Brick walls, unprotected timber floors and roof
Type 6	N/A	Non-combustible non fire resisting construction.	Unprotected steel frames
Type 7	N/A	Combustible non fire resisting construction.	Unprotected timber frames.

The PWBS speak to building height in terms of the distance from the lowest ground level to the ceiling of the topmost storey.

The PWBS proposed no height restriction on buildings in which the individual compartments are designed to resist a “complete burn-out except in the case of abnormal fire loads”, where abnormal was defined as that outside the summary in Table 3-1.

For most typical built environment occupancy types considered within the scope of this roadmap (i.e. of the “low” fire load category defined in Table 3-1), construction Types 1 to 3 would all be deemed (by the PWBS) as cases capable of withstanding complete burn-out. For these cases, it is said that fire fighting is from within, given “no risk of collapse”, with special equipment for internal attack provided in buildings exceeding 100 ft in height (c. 30.5 m to topmost ceiling or 27 m to topmost storey relative to ground) due to limitations associated with turntable ladders at the time.

The PWBS further note that cases where non-combustible elements of structure are one grade lower than that required to resist a complete burn-out, a height limit of 75 ft be imposed (c. 22.9 m to topmost ceiling or 19.4 m to topmost storey relative to ground), e.g. Type 2 structures combined with a “high” fire load would be limited in height to 75 ft, but a Type 2 structure combined with a “moderate” fire load would have no limitation in height. A height limitation of 50 ft (c. 15.2 m to topmost ceiling or 11.7 m to topmost storey relative to ground) was recommended for Type 4 construction containing “low” fire loads. Height limits are said to be imposed “having due regard to the risk of collapse and the resulting hindrance to fire fighting within the building”.

The above differentiation could be interpreted as follows:

- **Case A** – buildings exceeding 75 ft in height were expected to be formed of a construction type that was non-combustible and could survive a complete burn-out;
- **Case B** – buildings up to and including 75 ft in height could be formed of non-combustible elements that may not survive a complete burn-out, but achieve an adequate level of fire resistance; and
- **Case C** – buildings up to and including 50 ft in height could be formed of combustible elements that may not survive a complete burn-out but achieve an adequate level of fire resistance.

Similarly, Case A could be said to be an instance where fire fighting is predominantly internal vs. Case B and C relying upon external fire fighting.

3.2.2 Fire design guidance & regulation: The Building Regulations (1965)

The Building Regulations (1965) imposed limitations on the use of combustible materials through requirements for compartmentation, external walls, protected shafts, etc. Regarding compartmentation, it is stated that [26]:

“(7)(a) Any compartment wall or compartment floor which is required by regulation E5 to have fire resistance of 1 hour or more, shall be constructed wholly of non-combustible materials...”

Compartment floors and walls were required as follows:

- To satisfy storey area or building cubic capacity limitations;
- Any floor separating one storey from another in buildings of height exceeding 90 ft;
- Any floor in an institutional (purpose group II building);
- Any wall or floor separating a flat or maisonette from any other part of the same building;
- To separate purpose groups; and
- Floors above basements.

With reference to the fire resistance requirements of Regulation E5, and as an example, apartment buildings (purpose group III – needing compartment walls and floors between accommodation) were required to have 1 hour of structural fire resistance once the building height exceeded 50 ft (or 11.7 m to topmost storey relative to ground), meaning combustible framing solutions were not permissible for apartment buildings taller than c. 15 m. The 50 ft height limitation is consistent with that imposed for Type 4 construction in the PWBS. Like the PWBS, building height refers to the distance from the lowest ground level to the ceiling of the topmost storey.

Conceivably, an office (purpose group IV) could be constructed to a height of up to 90 ft without compartmentation, meaning a combustible frame being permitted up to c. 27 m in building height.

Unlike the PWBS, the Building Regulations (1965) introduced a form of ‘failure consequence differentiation’, whereby fire resistance requirements varied with building height (25, 50, 90 and + 90 ft) and not solely as a function of purpose group / fire load.

3.2.3 Fire design guidance & regulation: The Building Regulations (1985)

The Building Regulations (1985) [27] transitioned to performance-based requirements, where no prescriptive requirements were placed on material choice and / or height. The functional requirement B3. (1) stated:

“The building shall be so constructed that, in the event of fire, its stability will be maintained for a reasonable period.”

That is, if a combustible structure could be shown to remain stable for a “reasonable period”, it would be permissible.

The guidance to the Building Regulations (1985), i.e. the 1985 edition of Approved Document B [28], recommended that any compartment wall or floor requiring 60 min fire resistance should be formed of materials of limited combustibility (defined in BS 476-11 [29]), i.e. precluding the use of timber in situations, such as apartment buildings greater than 2 storeys in height.

3.2.4 The TF2000 and the emergence of medium and high-rise timber construction

Despite changes to the Building Regulations (i.e. a transition to a performance-based framework), there remained some scepticism that combustible structural solutions could satisfy the functional requirements, in particular those concerned with B3 – Internal Fire Spread (Structure). To this end, the Building Research Establishment (BRE) and Chiltern International Fire (CIF) embarked on a large-scale experimental programme, named the Timber Frame (TF) 2000 project. It is not the intention to exhaustively discuss the TF2000 project, with more detailed information available via Lennon, et al. [30], and Lennon and Hopkin [31] (with the latter covering a cavity fire incident that occurred overnight). However, it is generally accepted that the genesis of the project was to exploit the UK’s potential to become world leader in the provision of medium-rise timber frame buildings [32], and that ultimately the conclusions reported opened the door for the medium and high-rise light timber frame buildings witnessed today through some assuaging of concerns relating to fire performance and disproportionate collapse.

3.2.5 Current Regulations, guidance and posited objectives for structural fire performance

The Building Regulations (2010, incorporating amendments to 2018) remain performance-based with respect to structural fire performance [33], with Regulation B3(1) as per the 1985 regulations, with the TF2000 project proving to be a key enabler of medium and high-rise light timber frame construction.

For most common building situations, compliance with the Regulations can be through the application of Approved Document B (2019, Vol. 1 or 2, as relevant [34] [12]). Therein, and within other recognised codes (e.g. BS 9991, BS 9999, etc.) the means of satisfying Regulation B3(1) is by ensuring that structural elements achieve sufficient fire resistance.

Current guidance has been shaped by historical practices, as summarised in Sections 3.1.1 to 3.2.3. From these practices, the following factors can be said to have had a significant influence on the (historical) performance objectives of structures in the event of fire and today’s guidance:

- **Occupant responsiveness** – the cognition of alarms and the timeframe in which the occupants are likely to respond, e.g. sleeping accommodation should be differentiated from non-sleeping accommodation;
- **Evacuation mode and time** – occupants of buildings may not immediately evacuate or could remain in place indefinitely. Depending upon building height or complexity, occupants who receive an immediate evacuation signal could have protracted evacuation times. The objectives should be differentiated for buildings where evacuation is quick vs. protracted;

- **Fire brigade intervention strategy** – depending upon the height and size of the building, fire brigade intervention might be predominantly from an external location or internal location. In the fire resistance guidance in the PWBS, a key differentiator in whether a structure was expected to survive burnout vs. be “partially protected” was whether fire fighters needed to commit internally to intervene (which was likely slower) vs. external intervention.

3.2.5.1 Posited objectives for structural fire design in current guidance

Given the (historical) factors influencing the performance objectives of structures in the event of fire and considering fire brigade intervention approaches (and associated guidance), the following simplified objectives in Table 3-3 are proposed as being an adequate means of demonstrating compliance with Regulation B3(1) under differing circumstances (in today’s regulatory environment).

Trigger heights (measured per Figure 3-3) are adopted that conform historically with differentiation in structures expected to survive burnout vs. provide some (adequate) level of fire resistance (see Sections 3.1.1 to 3.2.3). These heights are adapted to align with current trigger heights given in Approved Document B (2019) [34] [12].

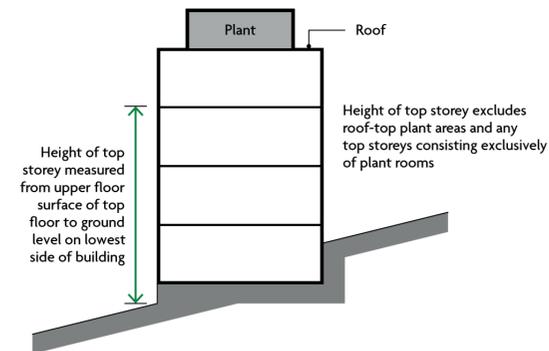


Figure 3-3 – Definition of height as adopted in roadmap (taken from [12])

Section 4 provides a simplified compliance flow chart which seeks to demonstrate, depending upon the building’s purpose group, height and design approach (e.g. exposed vs. encapsulated), how compliance with B3(1) can be achieved. Example applications are summarised in Section 5.

Table 3-3 – Simplified performance objectives for structures in fire to meet B3(1)

Height [m]*	Occupancy type	Evacuation mode	Objective	Indicative means
Up to & including 7.5 m	All within scope of this document	Simultaneous, phased, defend in place	Structure should remain stable for enough time to support escape and predominantly external fire brigade activities.	Elements afforded structural fire resistance per relevant standard guidance, with elements tested or designed to achieve fire resistance (e.g. per EN 1995-1-2).
Up to & including 11 m	Sleeping accommodation	Simultaneous, phased, defend in place	Structure should remain stable for enough time to support escape and predominantly external fire brigade activities.	Elements afforded structural fire resistance per relevant standard guidance, with elements tested or designed to achieve fire resistance (e.g. per EN 1995-1-2).
	Assembly and recreation, institutional	Simultaneous, phased, defend in place	Structure should have a reasonable likelihood of surviving burnout.	Elements afforded encapsulation to avert pyrolysis for the duration of the fire resistance period, as defined in standard guidance or Auto-extinction demonstrated through fire engineering analysis and structural elements demonstrated as being able to support the actions arising from the accidental load combination both during and after the fire.
Up to & including 18 m	Sleeping accommodation, assembly and recreation, institutional	Simultaneous, phased, defend in place	Structure should have a reasonable likelihood of surviving burnout.	Elements afforded encapsulation to avert pyrolysis for the duration of the fire resistance period, as defined in standard guidance or Auto-extinction demonstrated through fire engineering analysis and structural elements demonstrated as being able to support the actions arising from the accidental load combination both during and after the fire.
	Offices and mercantile	Simultaneous	Structure should remain stable for enough time to support escape and predominantly external fire brigade activities.	Elements afforded structural fire resistance per relevant standard guidance.
Above 18 m	All within scope of this document	Simultaneous, phased, defend in place	Structure should have a reasonable likelihood of surviving burnout.	Elements afforded encapsulation to avert pyrolysis for the duration of the fire resistance period, as defined in standard guidance or Auto-extinction demonstrated through fire engineering analysis and structural elements demonstrated as being able to support the actions arising from the accidental load combination both during and after the fire.

* Height is measured to the topmost storey (not including roofs, roof-top plant areas or any storey consisting exclusively of plant rooms) relative to lowest ground level – see Table 3-3. Where conversions are made from the PWBS, a top storey height of c. 3.5 m is subtracted to give the height to the topmost storey.

4 COMPLIANCE FLOW CHART FOR BUILDING REGULATION B3(1)

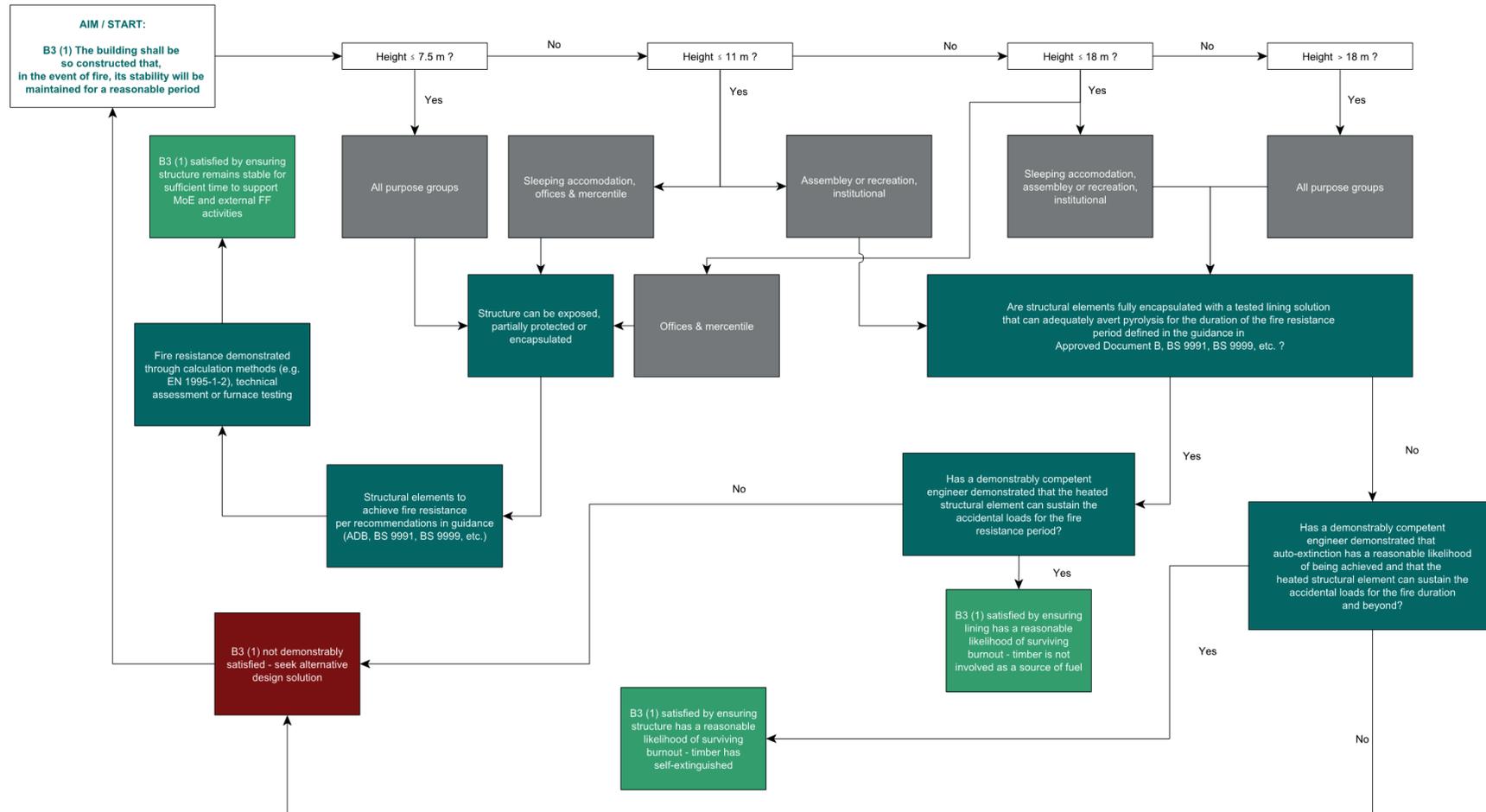


Figure 4-1 – Compliance roadmap flow chart for MTPC in England

5 EXAMPLE APPLICATIONS

In support of the compliance roadmap given in Figure 4-1 for Regulation B3(1), example applications are given to assist in its application.

The cases are for illustrative purposes. The applications should be read alongside Figure 5-2 which has been annotated with different coloured regions to reflect each case and is extracted from the amendments to ADB Vol. 2. Figure 5-3 presents the application of the roadmap and is similarly annotated using the corresponding coloured pathways.

5.1 Dwelling-house [red]

Construction of a 7.4 m high dwelling-house formed with primary load-bearing elements of CLT.

With reference to Figure 4-1, the height of the building to the topmost qualifying storey relative to the lowest ground level is under 7.5 m. The MTPC elements can be: exposed, partially protected or encapsulated whilst satisfying Regulation B3(1). Per Table B4 of ADB Vol. 1, elements of load-bearing structure should achieve 60 min fire resistance for dwelling-houses in the height range of 5 to 11 m. CLT element design can adopt charring rates in the manufacturer's European Technical Assessment (ETA) to arrive at a residual cross section capable of supporting the applied actions on the structure (for the relevant accidental loading combination) considering 60 min of standard fire exposure.

5.2 Medium-rise office building [blue]

Construction of a 15 m high office formed with primary load-bearing elements: glulam frame, with CLT floors.

With reference to Figure 4-1, the height of the building to the topmost qualifying storey relative to the lowest ground level is under 18 m. The MTPC and glulam elements can be: exposed, partially protected or encapsulated whilst satisfying Regulation B3(1). Per Table B4 of ADB Vol. 2, elements of load-bearing structure should achieve 60 min fire resistance for offices in the height range of 11 to 18 m. CLT elements adopt charring rates in the manufacturer's ETA to arrive at a residual cross section capable of supporting the applied actions on the structure (for the relevant accidental loading combination) considering 60 min of standard fire exposure. Glulam elements are designed to achieve 60 min fire resistance using the calculation tools given in EN 1995-1-2.

5.3 Medium-rise apartment building [black]

Construction of a 21 m high apartment building with primary load-bearing elements of CLT (walls and floors).

The building is a relevant building as defined within Regulation 7 of the Regulations. Therefore, MTPC would not be permitted as part of the external wall construction, as discussed in Section 2.6. Remaining internal walls and floors could be formed of MTPC, subject to not entering the external wall zone (tentatively indicated in Figure 5-1).

Viable design solutions are:

- Per Table B4 of ADB Vol. 1, elements of load-bearing structure should achieve 90 min fire resistance for apartment buildings in the height range of 18 to 30 m. Automatic sprinkler protection should also be provided. MTPC elements should be fully encapsulated with a tested lining solution capable of averting pyrolysis for 90 min under standard time-temperature heating conditions. The heat affected zone below the lining should be evaluated, e.g. via the means in EN 1995-1-2, with the residual section checked under actions (for the relevant accidental loading combination) after 90 min of standard fire exposure; or
- A demonstrably competent fire engineer should be engaged to demonstrate that exposed or partially protected MTPC elements have a reasonable likelihood of surviving the burn-out of a fire scenario commensurate with the intended / target residual risk. A structural engineer should be engaged to

demonstrate that the MTPC elements have sufficient load-bearing capacity to support the actions (for the relevant accidental loading combination) both during and beyond the design fire scenario(s).

5.4 Tall office building [green]

Construction of 33 m high office formed with primary load-bearing elements: glulam frame, with CLT floors.

With reference to Figure 4-1, the height of the building to the topmost qualifying storey relative to the lowest ground level is over 18 m.

Viable design solutions are:

- Per Table B4 of ADB Vol. 2, elements of load-bearing structure should achieve 120 min fire resistance for offices in the height range of more than 30 m. Automatic sprinkler protection should also be provided. MTPC elements should be fully encapsulated with a tested lining solution capable of averting pyrolysis for 120 min under standard time temperature heating conditions. The heat affected zone below the lining should be evaluated, e.g. via the means in EN 1995-1-2, with the residual section checked under actions (for the relevant accidental loading combination) after 120 min of standard fire exposure; or
- A demonstrably competent fire engineer should be engaged to demonstrate that exposed or partially protected MTPC elements have a reasonable likelihood of surviving the burn-out of a fire scenario commensurate with the intended / target residual risk. A structural engineer should be engaged to demonstrate that the MTPC elements have sufficient load-bearing capacity to support the actions (for the relevant accidental loading combination) both during and beyond the design fire scenario(s).

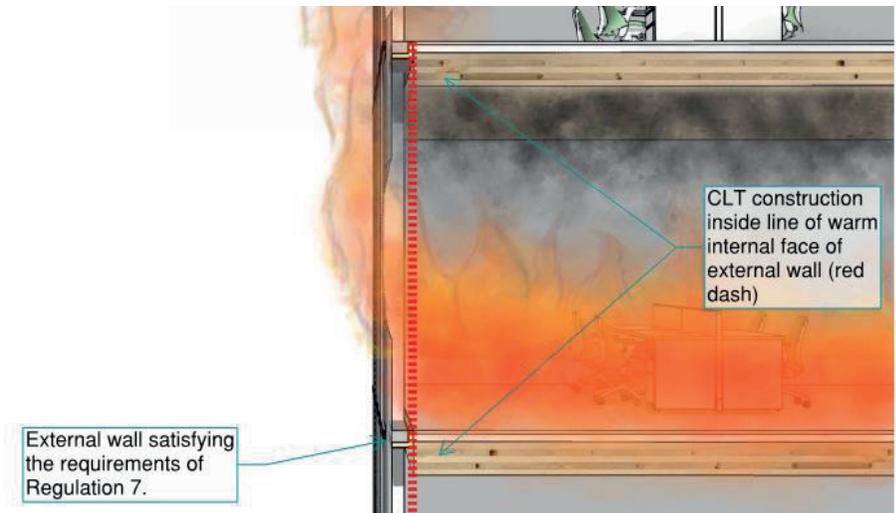


Figure 5-1 – Illustrative application of CLT to a relevant building as defined under Regulation 7

Purpose group of building	Minimum periods of fire resistance ⁽¹⁾ (minutes) in a:						
	Basement storey* including floor over			Ground or upper storey			
	Depth (m) of the lowest basement			Height (m) of top floor above ground, in a building or separated part of a building			
	More than 10	Up to 10	Up to 5	Up to 11	Up to 18	Up to 30	More than 30
1. Residential:							
a. Block of flats							
– without sprinkler system	90 min	60 min	30 min ¹	60 min ^{4,5}	Not permitted ⁽²⁾	Not permitted ⁽²⁾	Not permitted ⁽²⁾
– with sprinkler system ⁽³⁾	90 min	60 min	30 min ¹	60 min ^{4,5}	60 min ^{4,5}	90 min ⁴	120 min ⁴
b. and c. Dwellinghouse	Not applicable ⁽⁴⁾	30 min ¹	30 min ¹	60 min ⁽⁵⁾	60 min ⁽⁵⁾	Not applicable ⁽⁴⁾	Not applicable ⁽⁴⁾
2. Residential							
a. Institutional	90 min	60 min	30 min ¹	60 min	60 min	90 min	120 min ¹
b. Other residential	90 min	60 min	30 min ¹	60 min	60 min	90 min	120 min ¹
3. Office:							
– without sprinkler system	90 min	60 min	30 min ¹	60 min	60 min	90 min	Not permitted ⁽⁶⁾
– with sprinkler system ⁽³⁾	60 min	60 min	30 min ¹	30 min ¹	30 min ¹	60 min	120 min ¹

Figure 5-2 – Extract from amendments to Table B4 of ADB Vol. 2 [12], annotated to reflect the application cases

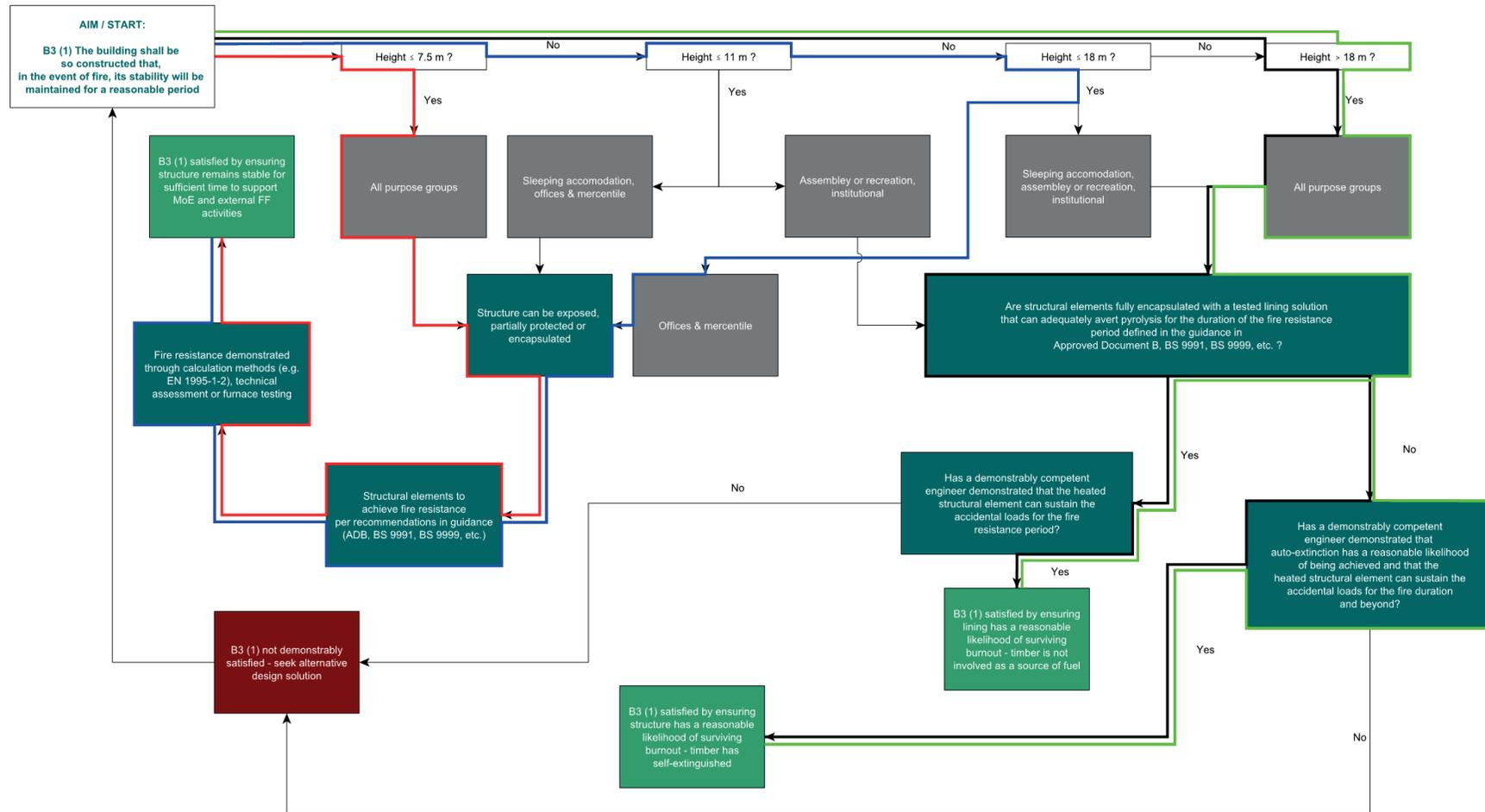


Figure 5-3 - Application of the roadmap to idealised cases

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