FIRE + RISK CONSULTANTS

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

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Quality Management

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Contents

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 K_2 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 m^2 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)

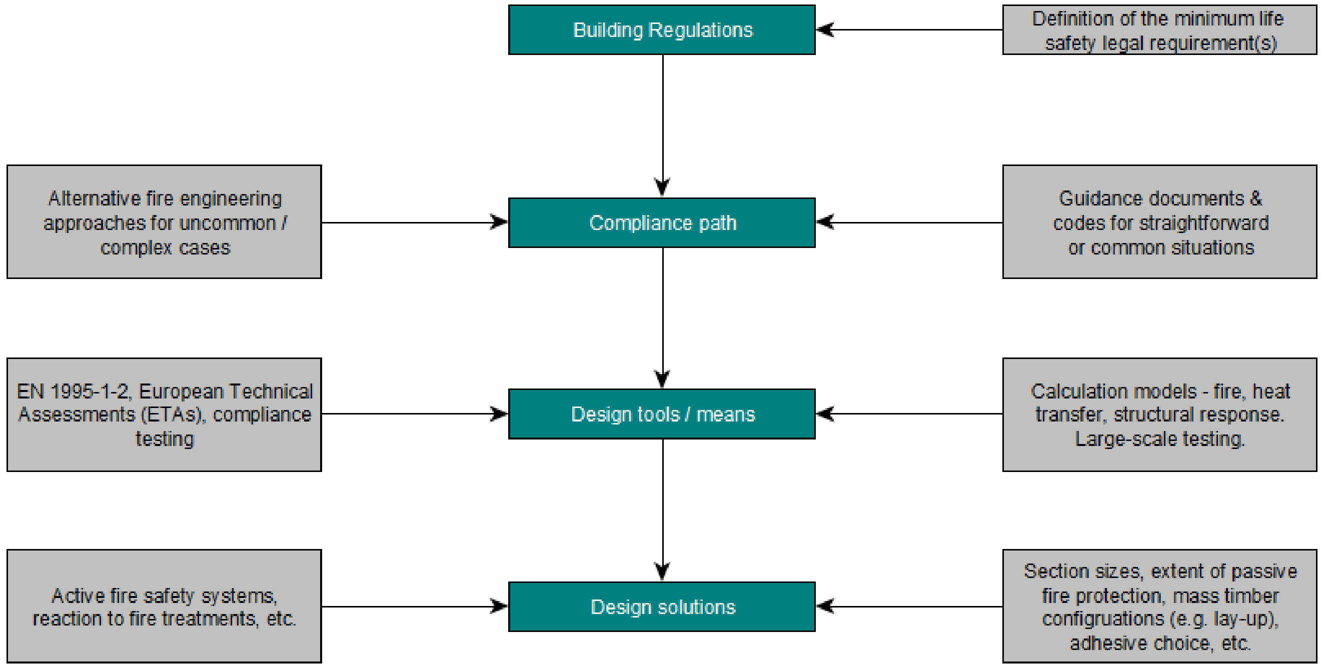

Figure 1-4 – Hierarchy of legislation, tools and design solutions for MTPC

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.

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 Inberg'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.

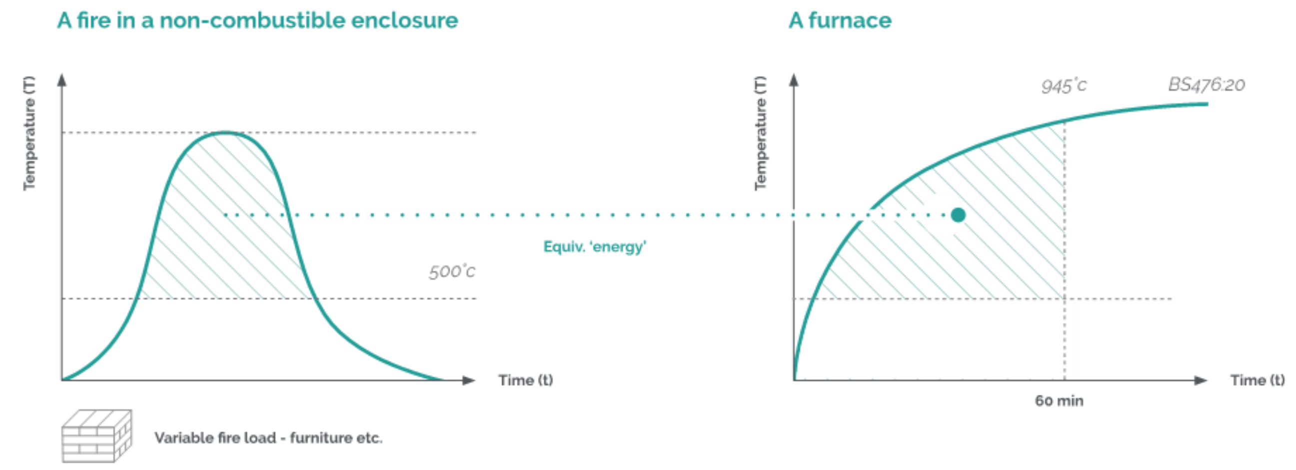

Figure 3-1 – Equal area concept for fire severity after Ingberg [22]

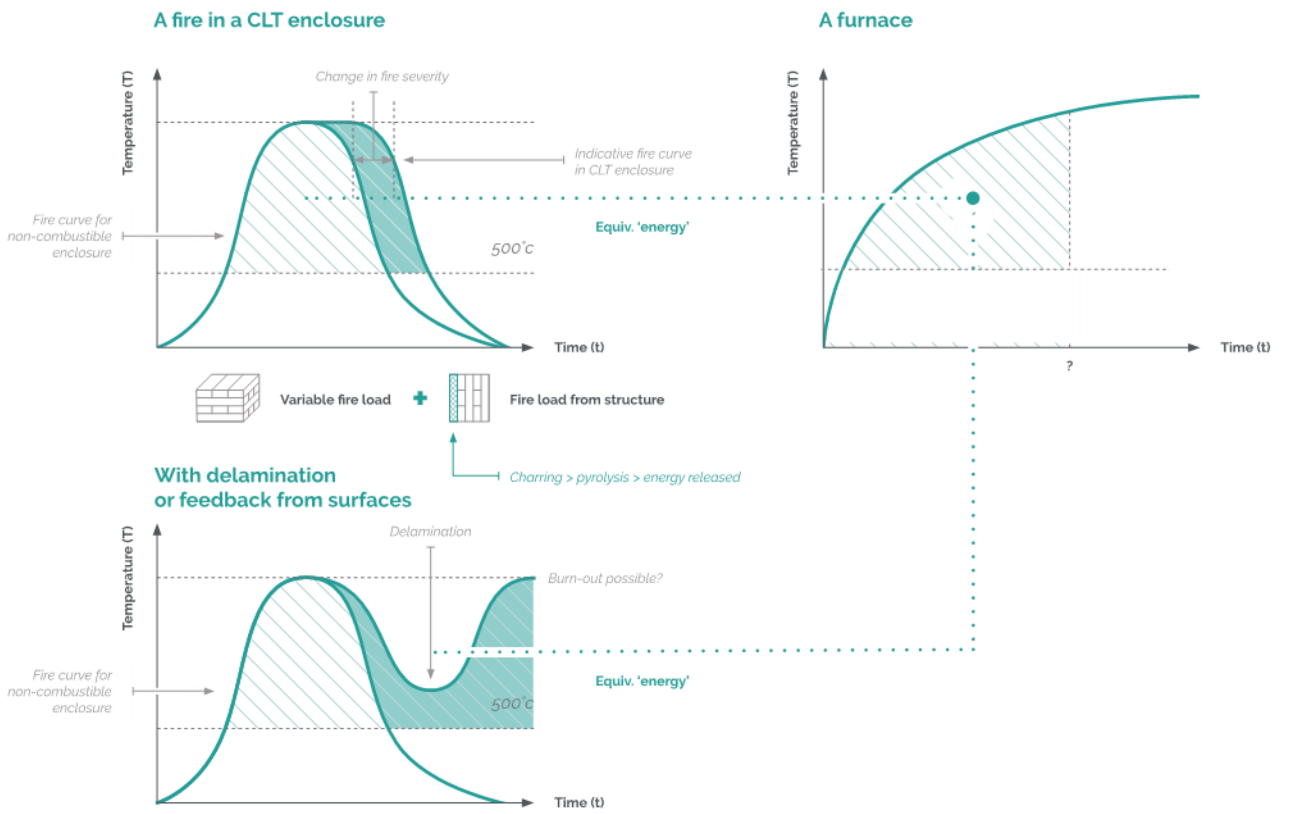

Figure 3-2 – Illustrative implications for the EAC where the enclosure is a source of fuel [DRAFT: figure to be updated]

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 / ft^2) to SI units (MJ / m^2).

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 according to the fire load of the occupancy (type 1 – high; type 2 – moderate and type 3 - low).	Protected steel, brickwork, concrete
Type 2	2		
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 hinderance 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].

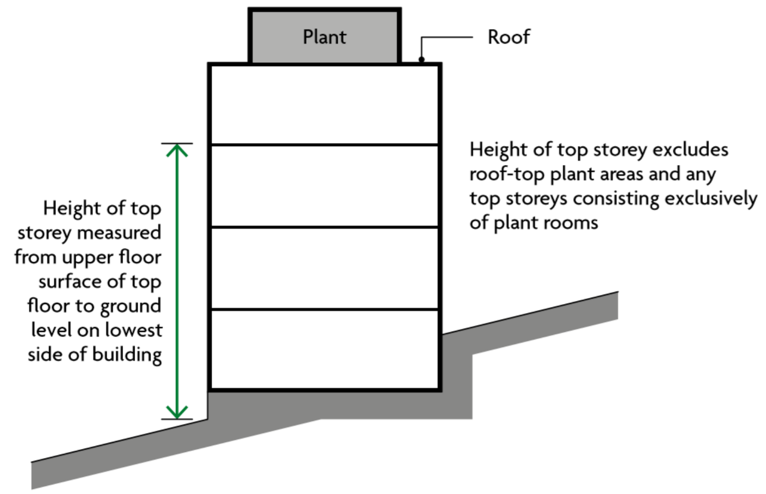

Figure 3-3 – Definition of height as adopted in roadmap (taken from [12])

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)

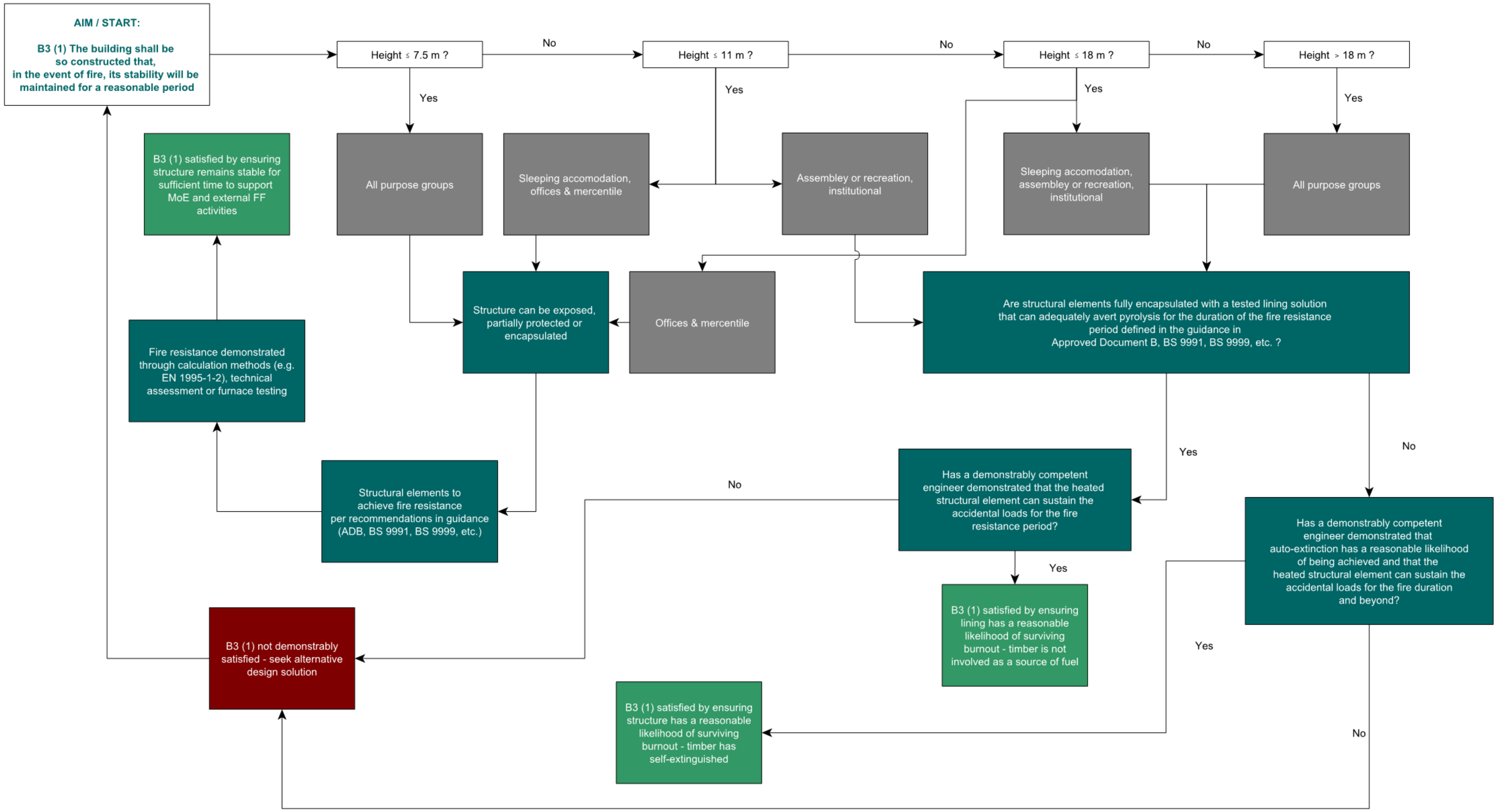

Figure 4-1 – Compliance roadmap flow chart for MTPC in England

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).

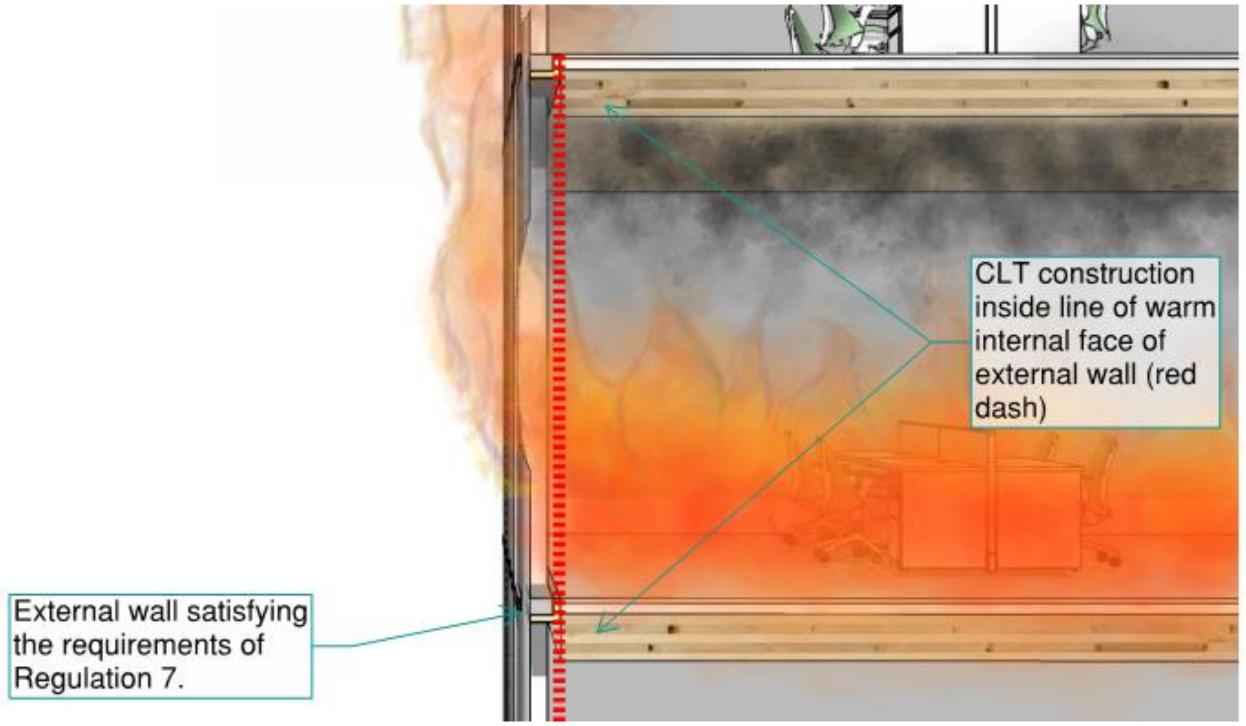

Figure 5-1 – Illustrative application of CLT to a relevant building as defined under Regulation 7

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†	60 min+§	Not permitted[2]	Not permitted[2]	Not permitted[2]
– with sprinkler system[3]	90 min	60 min	30 min†	60 min+§	60 min+§	90 min+	120 min+
b. and c. Dwellinghouse	Not applicable[4]	30 min*†	30 min†	60 min[5]	60 min[5]	Not applicable[4]	Not applicable[4]
2. Residential							
a. Institutional	90 min	60 min	30 min†	60 min	60 min	90 min	120 min‡
b. Other residential	90 min	60 min	30 min†	60 min	60 min	90 min	120 min‡
3. Office:							
– without sprinkler system	90 min	60 min	30 min†	60 min	60 min	90 min	Not permitted[6]
– with sprinkler system[3]	60 min	60 min	30 min†	30 min†	30 min†	60 min	120 min‡

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

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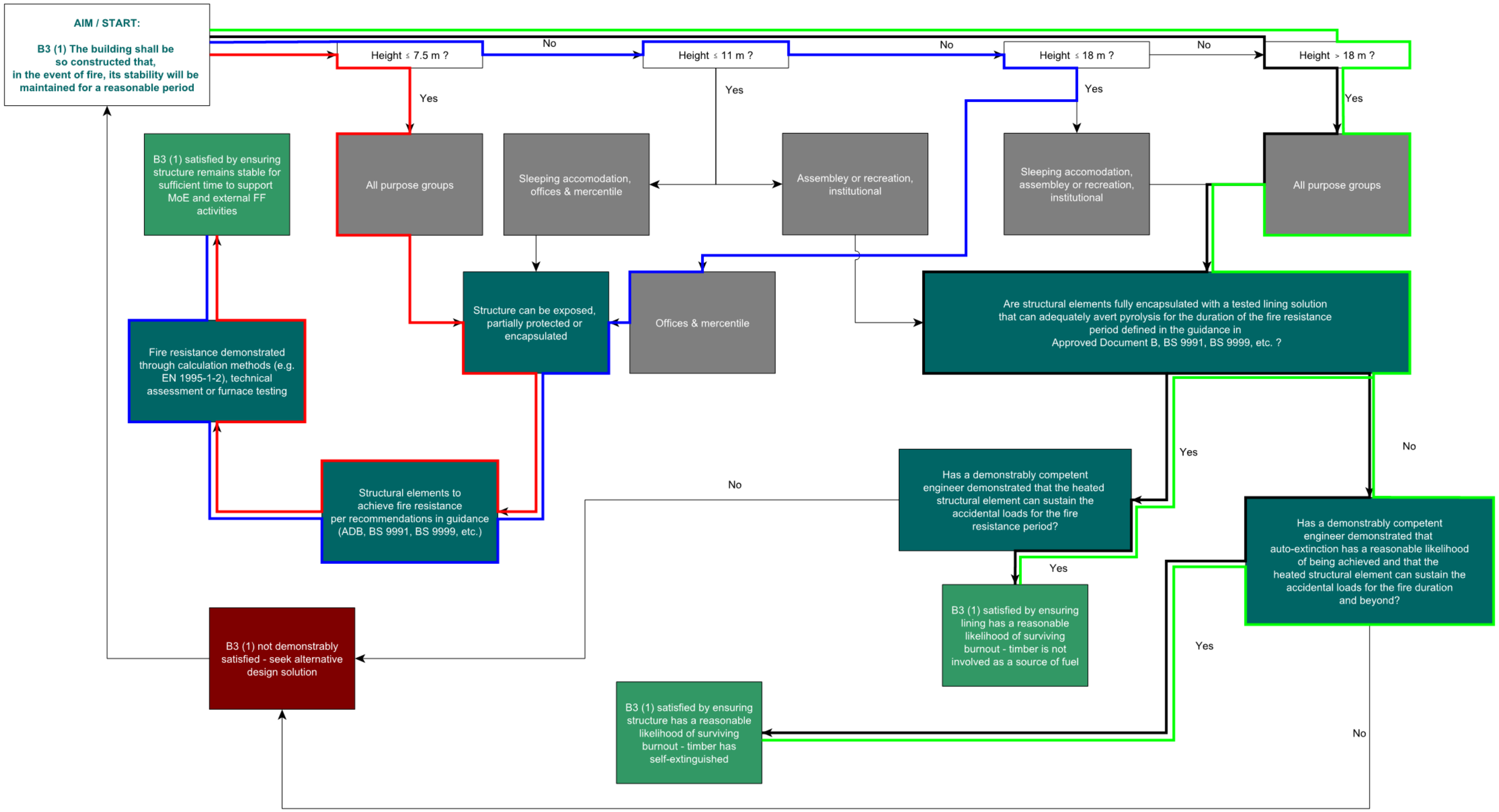

Figure 5-3 - Application of the roadmap to idealised cases

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