Compliance Road-map for the Structural Fire Safety Design of Mass Timber Buildings in England

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Introduction

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 in parts of hybrid structures (often incorporating steel and/or concrete components). Timber structures are being designed and delivered at a pace that can potentially go beyond current levels of knowledge and the competency of fire safety engineers. In a project funded by three major European cross-laminated-timber (CLT) suppliers (Stora Enso, Binderholz and KLH) through the Structural Timber Association (STA), the need for clarity on how mass timber buildings can satisfy the requirements of building regulations across the UK has been identified. OFR Consultants (OFR) have been engaged as the lead research consultant on the project, with the support of an independent stakeholder review group. A compliance road-map [1] has been developed which serves to guide designers towards the most appropriate route for compliance with English regulatory requirements concerning structural performance in the event of fire. This article summarises the context and background to the development of a consequence-based compliance design tool developed in support of the rational design of mass timber buildings.

The problem and need

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, it can change the fire dynamics within. Relative to using non-combustible materials this may lead to: higher heat release rates, increased compartment gas temperatures, higher incident heat fluxes to structural elements, prolonged fire duration (Figure 1 – Conceptual illustration of heat release rate vs. time in inert or combustible enclosures, with or without self-extinction), more severe external flaming, etc. [2].
The fire dynamics implications can undermine assumptions underpinning fire resistance paradigms for cases where the structure must survive burn-out and the structure is not prevented from contributing as a source of fuel [3]. This places a challenge with the designer to consider how regulations pertaining to structural performance in the event of fire can be satisfied, and what design evidence must ultimately be produced.

![Figure 1](image.png)

Figure 1 – Conceptual illustration of heat release rate vs. time in inert or combustible enclosures, with or with-out self-extinction.

**Structural fire performance objectives**

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, with Regulation B3(1) stating:

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

Whilst speaking to periods of time, the wording of Regulation B3(1) does not explicitly define the duration of structural stability required in the event of fire. With respect to ref [4], the structural fire safety performance objectives for a building can vary in function of the consequences of fire induced collapse. This is elaborated through a bifurcation of objectives as illustrated schematically in Figure 2.
Figure 2 – Illustration of the relationship between structural fire safety objectives, compliance routes and design solutions.

Guidance- and performance-based routes to compliance

For most common and straightforward building situations, Regulation B3(1) is addressed through the adoption of ADB [5], [6], or similar codes [7] [8]. 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 [9] 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).

Following ADB or similar is not the only means of satisfying the relevant requirements of the Building Regulations. Alternative routes exist and these are discussed in BS 7974 [10] and the associated suite of Published Documents. For some more complex situations, such as those falling outside of the scope of guidance, alternative fire engineering approaches may be the only means of demonstrating compliance with the Building Regulations.

Mass timber and the route to structural fire safety compliance

The proposed STA compliance road-map posits that the relevance of a guidance-based route to compliance depends upon the structural fire performance objectives (per Figure 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 [9]);

- **An adequate likelihood of surviving burn-out:** unless the structure is prevented from contributing as a source of fuel, applying the fire resistance approach (for example in ADB) cannot guarantee that Regulation B3(1) is satisfied. Preventing the structure from contributing as a source of fuel will require encapsulation. 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).

Mass timber fire safety design solutions

Differing design solutions exist for mass timber buildings which will have implications for the route to compliance. These can broadly be grouped into three categories:

- Exposed – the structural elements are exposed from the outset of the fire by design;
- Partial protection - the structural elements are behind a protective lining. However, this lining does not avert pyrolysis for the full duration of the fire;
- Encapsulation - sufficient protection is provided to the underlying structure / substrate to mitigate the onset of pyrolysis until burn-out.

In both the case of “exposed” and “partial protection”, it should be assumed that the structure will become involved as a source of fuel at some point in a fire. Application of these routes requires demonstration by a competent fire engineer with relevant experience 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.

Irrespective of the solution presented, 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.

A consequence-based design tool for compliance

Failure consequences due to fire drive the structural performance objectives, and are differentiated in guidance addressing general structural design (Approved Document A – ADA [11]) and fire safety design (Approved Document B - ADB) through the use of consequence classes (Table 1) and trigger heights, respectively. Whilst the two Approved Documents (ADA and ADB) can appear unrelated, it is considered appropriate in the context of this work that the ADA consequence class system serves as a boundary on the application for fire resistance guidance. However, trigger heights cannot be disregarded altogether as history highlights their role in signifying transitions in means of escape, fire fighting, etc. [12].

Considering failure consequences as the primary factor (and trigger heights as a relevant factor), a general design tool has been adopted as per Table 1 to assist designers in identifying the most appropriate route to compliance for a mass timber building project.

Table 1 - Consequence classes per Annex A of BS EN 1991-1-7 [13] and consequence-based guidance on route to compliance for mass timber buildings (life safety).

<table>
<thead>
<tr>
<th>Consequence Class</th>
<th>Consequences of failure</th>
<th>Typical building type and occupancy relevant to mass timber⁶</th>
<th>Permissible compliance route</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Single occupancy houses not exceeding 4 storeys</td>
<td>Guidance-based¹ Performance-based</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td></td>
<td>Yes⁵</td>
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<tr>
<td></td>
<td></td>
<td>• 5 storey single occupancy houses</td>
<td></td>
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<td></td>
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<td>• Hotels not exceeding 4 storeys</td>
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<td></td>
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<td>• Flats, apartments and other residential buildings not exceeding 4 storeys</td>
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<td></td>
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<td>• Retail premises not exceeding 3 storeys of less than 1000 m² floor area in each storey</td>
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<td>• Single storey educational buildings</td>
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<td>• All buildings not exceeding 2 storeys to which the public are admitted, and</td>
<td></td>
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<tr>
<td>2A</td>
<td>Low to medium</td>
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<tr>
<td></td>
<td></td>
<td>• 5 storey single occupancy houses</td>
<td>Yes², ⁵</td>
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<td>• Hotels not exceeding 4 storeys</td>
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<td>• Single storey educational buildings</td>
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<td>• All buildings not exceeding 2 storeys to which the public are admitted, and</td>
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<tr>
<td>Building type and occupancy</td>
<td>Limit on upper floor level above lowest ground level</td>
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<td>----------------------------</td>
<td>-----------------------------------------------------</td>
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<td></td>
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<tr>
<td>Residential</td>
<td>11 m</td>
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</tbody>
</table>

**Note 1** – for England, the guidance-based approach is documented in, for example, ADB 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 Note 3 applies:
Hotels and other residential | 11 m |
Offices & mercantile | 18 m |
Assembly and recreation | 7.5 m |
Education / schools | 7.5 m |

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 - Consequence Class 3 structures should be subject to a project-specific system risk assessment considering all relevant hazards, per ADA and in satisfaction of Regulation A3. This necessitates a performance-based assessment in all cases.

Note 5 – No limitation is placed on the design solution, i.e. exposed, partially protected or encapsulated structures are permissible.

Note 6 – Number of storeys includes ground floor.

Conclusions

The compliance road-map [1] summarised in this article enables those involved in the design of mass timber structures in England to assess the likely most appropriate compliance pathway to meet Building Regulation B3(1) in function of the failure consequences and the preferred design solution. It will ensure consistency in how mass timber building design is approached and will assist approval authorities in the scrutiny of designs. It should be stressed that other hazards exist when building with mass timber, in particular those concerning internal and external fire spread, as discussed in more detail elsewhere [14], [15]. The developed road-map should, therefore, be applied in support of a holistic fire strategy, developed by competent individuals with relevant experience, which captures all relevant implications of building with mass timber.

The next stage of the project is to collate data on the performance of CLT in enclosure fires. Small-scale experimental work is on-going to gain a more thorough understanding of the comparative performance of different CLT lamella and glue arrangements from the sponsoring suppliers. This will be followed-up by large-scale experiments that will investigate how these arrangements affect the dynamics of fire development in larger enclosures such as open-plan offices where a ceiling is constructed of exposed CLT panels. This work has been delivered as part of a collaborative project run by the STA, with all project outputs and background research being made available via the STA website (http://www.structuraltimber.co.uk/sectors/clt-special-interest-group).

Acknowledgements

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References