FIRE SAFETY FOR MASS TIMBER IN CURTAIN WALL SYSTEMS

Negotiating codes for a sustainable design

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ABSTRACT

With the desire for more sustainable construction and reduced embodied energy, mass timber is being explored for building structures. For medium and high-rise buildings, timber has typically not been considered for curtain and window wall mullions and transoms. A curtain wall solution that uses mass timber (glulam) for the mullions and transoms is introduced, developed and analyzed here. While combustible, the inherent fire resistance provided by mass timber building elements, such as glulam, are distinctly different from the minimal fire resistance of light timber frame or aluminum members. Mass timber has flammability criteria that can meet the International Building Code (IBC) without additional topical treatment. The code compliant path to use mass timber as part of a curtain or window wall within a medium or high-rise building is difficult to ascertain, involving IBC Chapters 6, 7, 8, 14 and 23, which indicates the level of complexity of the problem. But there are IBC compliant paths for the use of timber within a curtain or window wall system provided the limits of the Code are followed. A solution is discussed and detailed here to illustrate how timber can be used to reduce a building's embodied carbon and improve aesthetics. The paper also aims to remove some of the confusion regarding required and relevant fire tests for interior timber systems.

KEYWORDS

Wood façade, sustainable facade, fire safe facades, codes standards rating systems, glass, metal, timber, design processes, regulation

INTRODUCTION

Wood is a viable alternative to aluminum in curtain wall framing applications, with the potential for embodied carbon reductions in building skins (Patterson 2017, 161). The development of multi-story buildings utilizing engineered timber ("mass timber") products like glulam and cross laminated timber (CLT) for building construction is growing internationally due to the desire for building sustainability and the push towards embodied carbon reduction and zero carbon buildings. Building codes are changing and starting to embrace the use of mass timber as part of the structural system, with recent approved updates to the 2021 International Building Code (IBC) allowing mass timber for high-rise buildings up to 18 stories (ICC, 2018).

Unfortunately, building codes have struggled to adapt to the desire by developers, architects and engineers wanting to use mass timber as part of the exterior wall system or use timber as part of the interior support for a curtain or window wall glazing system. Mass timber within a curtain or window wall has a number of advantages for designers and building users, given the sustainability benefits over conventional façade materials, including significantly lower embodied energy and superior thermal performance compared to aluminum. By comparison, 1 ton of fabricated glulam timber represents 0.9 tons of embodied $C0_2$, while 1 ton of aluminum extrusions represents 8 to 9 tons of embodied CO_2 (University of Bath, 2011).

Fire resistance is a primary concern with respect to façade materials and products, gaining enhanced scrutiny in the wake of the Grenfell fire in the U.K. in 2017, and wood is obviously a combustible material, However, the inherent fire resistance provided by mass timber building elements such as glulam is distinctly different from the minimal fire resistance of light timber frame members. Sawn and engineered timber has fire resistant properties that have been well researched and understood (AWC, 2018a; AWC 2018b).

An overview of the design options, benefits, fire safety fundamentals, code approval issues and possible solutions for the use of mass timber as part of a curtain or window wall system in mid and high-rise building applications follows. This investigation is exclusive to the use of timber on the interior of the building envelope and does not consider the use of timber or wood on the exterior. (The use of timber and combustible products on the *exterior surface* of a building should be viewed with caution and addressed through appropriate test methods.) The use of timber on the interior and exterior of low-rise buildings is permitted by building codes, typically up to three or four stories. The approach described following and the related interpretations of the pertinent sections of the IBC have been formally reviewed with building officials in a number of North American cities with general agreement on the validity of the approach.

TIMBER AS A MATERIAL OF INTEREST

Timber is among the oldest of building materials and has a long history of use throughout North America. Timber construction peaked during the North American trade expansion in the late 1800s and early 1900s, predominantly for warehouse structures. The term “heavy timber” was used to describe the large sawn timber elements for multi-story buildings, with some of those buildings still in use today (Arup, 2019). By the 1920’s, reinforced concrete entered the market and, apart from residential applications, little has been seen of multi-story timber construction since.

Building materials and construction comprise 11% of global CO_2 emissions. Embodied carbon is over a quarter of current building sector emissions and growing. Between now and 2050 embodied carbon will represent half of carbon emissions from new building construction. Architecture 2030 states, “We cannot meet climate goals without also eliminating embodied carbon emissions by 2050.” (Architecture 2030, n.d.) Moreover, embodied carbon emissions are locked in with the completion of new buildings and major renovations, unlike carbon emissions from building operations, with no opportunity for future mitigation. Material selection is thereby of critical importance in buildings, with the goal of using materials and assemblies with reduced embodied carbon footprints. Timber presents a compelling potential in this context. Cheung and Farnetani (2016) found potential carbon intensity reductions of 17% over conventional aluminum constructs using a composite frame composition with wood as a primary structural member for the curtainwall unit.

Timber is one of the few renewable construction materials and, by its very nature, the growth of wood through photosynthesis removes CO_2 from the atmosphere. This carbon is thereby sequestered for the lifetime of the material (until burned or decomposed). The processing of wood is also less energy intensive than that of steel or aluminum (Petersen and Solberg 2002). Building structures with timber are becoming more prevalent and designers are looking at new ways to integrate timber into their buildings. Mass timber is a general term to describe engineered timber systems with a dimension greater than 6”. This evolved from the term “heavy timber”, which was based on sawn lumber greater than 6”. Both heavy timber and mass timber can develop their own fire resistance through a protective layer of charred material when exposed to fire (AWC, 2018b). The use of glulam as part of the interior curtain or window wall support systems is novel and requires the fundamental properties of the building materials to be considered, especially within high-rise buildings (a high-rise building is defined within the IBC as a building with an occupied floor over 75ft above grade).

BUILDING CODE CHALLENGES AND SOLUTIONS

All 50 states within the US adopt the International Code Council (ICC) International Building Code (IBC) (ICC, 2018), with some states also adopting the National Fire Protection Association (NFPA) Life Safety Code, otherwise known as NFPA 101 (NFPA, 2018). Many states further amend the model codes to provide the basis for construction compliance. The IBC defines five types of construction for buildings, with Construction Types I and II utilizing concrete and steel for their structural elements and Construction Types III, IV and V using concrete, steel or timber. Construction Types III, IV and V are limited to buildings of less than 85 ft to the roof and often referred to as medium or mid-rise construction. Construction Type I is used for high-rise buildings.

The use of mass timber as part of a glazed curtain wall or window wall within a medium rise building differs significantly from how the material is considered within a high-rise building, but in both medium and high-rise buildings, the path for code compliance is difficult and fraught with potential misinterpretation and misunderstandings. As a simple introduction, the use of glulam to the interior of a curtain wall glazing system for a high-rise building involves IBC Chapters 6, 7, 8, 14 and 23, showing the level of complexity of the problem.

The fundamental requirement that exterior walls of Type I and II buildings be constructed of non-combustible materials, the exceptions for minor quantities of water barriers and sealants etc. notwithstanding, leads most architects to assume that timber in quantity greater than the incidental blocking, allowed specifically in the exceptions of Chapter 6, is not permitted. But close reading of the code requirements and intent shows that if the timber is not exposed to the exterior, with a metal and glass enclosure on the outboard surface, and as long as the timber does not exceed the percentage of wall area allowed for window framing on the interior, timber complies with the requirements for a structural mullion component.

FIRE FUNDAMENTALS

Where a building element is load-bearing or separates one area from another and a fire resistance rating (FRR) may be needed, depending on the Building Construction Type, combustible and non-combustible building elements have fire ratings proven through calculation or fire tests, as required by Chapter 7 of the IBC. For timber, light-timber construction is encapsulated within non-combustible gypsum drywall to achieve protection from fire and a FRR. Mass timber is different in that when it is exposed to fire it achieves a FRR through the insulating benefits of charring, a process of inherent protection based on the section size. The process of charring occurs at approximately 300°C (570°F). Mass timber members can be designed to carry applied forces when exposed to fire, given the rate of charring and insulation to the interior ambient temperature, and strong wood is very predictable. Guidance on engineering design for mass timber fire resistance is provided within the National Design Specification (NDS) for Wood Construction (AWC, 2018a).

The inherent temperature resistance of mass timber elements, such as glulam, make them very suitable to support curtain or window wall systems, as they have a greater resistance to the early stages of fire development when compared to the strength of aluminum under fire exposure. A glulam member that forms part of a curtain wall can have a fire resistance of up to 30 minutes, given the protective properties of char; whereas an aluminum section will start to lose strength and stiffness from around 150°C (300°F) and would have a fire resistance rating on the order of 5 to 10 minutes, at most. Thus, even though window frames are not required to achieve any form of fire resistance, the inherent fire resistance of timber allows a glulam element to outperform a similar aluminum section.

CODE APPROACH

Where timber is being used interior to the line of glazing as part of a curtain wall for example, the elements of the curtain wall need to be defined. The issues to be addressed include:

- How is a window frame defined?
- Is a window frame part of an exterior wall?
- Is a window frame a structural element?
- Are there limits on combustibility with construction type and building height?

A building is made up of many differing parts and the allowances and limits are defined within Chapter 6 of the IBC "Type of Construction", where Chapter 6 defines the type of construction and the building elements that are permitted to be used for each type. Section 602.2 defines the building elements and materials that can be used and refers to exterior walls.

Referring to the definitions of "exterior wall", the "exterior wall envelope" provides a suitable description, stating "*A system or assembly of exterior wall components, including exterior wall finish materials, that provides protection of the building structural members, including framing and sheathing materials, and conditioned interior space, from the detrimental effects of the exterior environment*." An exterior wall envelope has requirements stated within Chapter 14 of the IBC (Exterior Walls), with the requirements applying to those parts of the envelope that are exterior to the building.

With curtain wall and window wall not defined within the IBC, the code compliance path becomes more complicated. But window frames are addressed within the IBC, with the term "trim" including window frames – "*Picture molds, chair rails, baseboards, handrails, door and window frames and similar decorative or protective materials used in fixed applications.*" (ref). The definition of window frames as part of "trim" then provides a direction for code compliance, as elements that are defined as trim are addressed within Chapter 8 "Interior Finishes" of the IBC. The Commentary to the Code also clarifies that elements are expected to be combustible, as does Chapter 7 of the IBC. Glass supports and framing are discussed in Chapter 24 "Glass and Glazing", but no definitions are provided.

Load-bearing members of construction are required to achieve a FRR under many Construction Types. Given window frames are defined within "trim", which are not part of the primary or secondary building structure, they are not considered by the IBC as a load-bearing building element and therefore do not require a FRR.

Within Chapter 8, the use of "trim" is determined by the use of Section 806. Section 806.7 "Interior trim" provides the relevant requirements and permits the use of timber as part of the window frame, provided the timber elements used have a Class C flame spread rating to ASTM E84 (ASTM, 2015) and the total face area of window frame is 10% or less of the total wall area that it is attached to. Thus, a glulam curtain wall can be used, provided it meets with the Class C flammability requirement, which nearly all glulam and timber materials will meet, and the overall face area is less than 10% of the wall area. The American Wood Council produces a guide (AWC, 2019) to the inherent flammability properties of a range of timbers and this indicates that nearly all North American species will achieve Class C without any additional topical treatments. To determine the 10% limit, the IBC Commentary provides a useful calculated example. Hence, while there is a limited scope of application, the use of glulam window frames is permitted. These sections apply to all construction types and can be used within Types III, IV and V. But what about high-rise buildings?

Construction Type I allows limited combustible materials as part of the construction and this is stated within Section 603 of the IBC. This section is very clear in the language used and states, no less than three times, that window frames can be combustible (remembering that "trim" includes window frames):

- 603.1 (6) "millwork such as…….. window sashes and frames".
- 603.1 (8) "trim".
- 603.1 (14) "blocking such as for handrails, millwork cabinets and window and door frames".

Thus, within Section 603, the use of combustible materials for window frames is permitted, but again, must meet Section 806.7 with regard to being Class C flammability and being no more than 10% of the wall area. The timber being used as part of the curtain or window wall must remain interior and therefore should be on the inside of the glazing and framing.

FIRE TEST REQUIREMENTS

There are a range of fire tests listed within the IBC, but only one is applicable to timber being used as part of an interior window system: ASTM E84 "Standard Test Method for Surface Burning Characteristics of Building Materials" (ASTM, 2015). This test classifies interior materials for use, typically on walls and ceilings. The test is relatively low-cost and available at many US based testing facilities.

Other fire tests for exterior wall systems are not relevant for curtain or window wall systems and are used to test the flammability and flame spread of exterior walls. These include NFPA 268 "Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source" (NFPA, 2017) and NFPA 285 "Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components" (NFPA, 2019). These tests are often quoted as being needed for interior window frames but are not applicable. Neither are they applicable to systems that are predominantly glazing, being intended for solid wall systems.

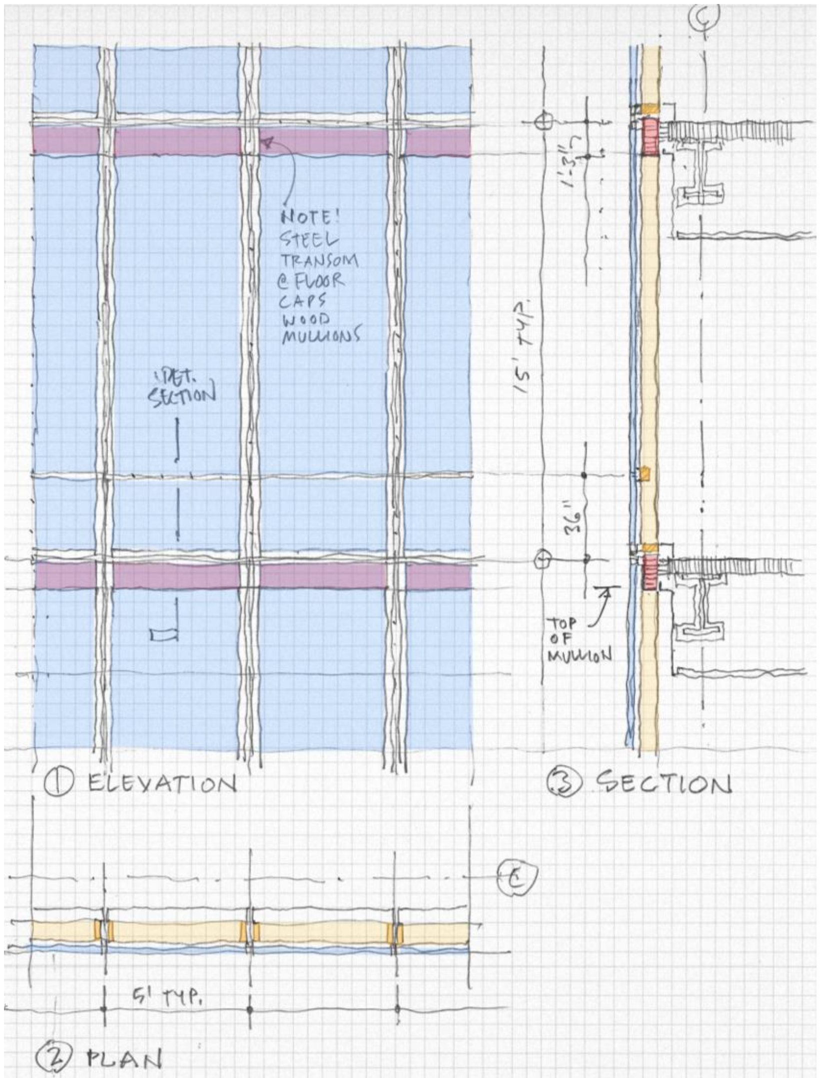

Figure 1: Unitized Wood Curtain Wall, Diagram of Typical Units

OTHER DESIGN CHALLENGES

An area requiring thought and detailing is the slab-edge fire-stopping, required by IBC 715.4, where an assembly will be tested in accordance with ASTM E2307 (ASTM, 2019) or ASTM E119 (ASTM, 2016) to demonstrate an equivalent fire rating to the structural floor assembly. These tests involve timed combustion exposure, although the purpose of the slab-edge firestopping assembly is primarily to prevent migration of smoke between levels as long as the exterior wall remains in place, and to prevent the interior spread of fire.

Using a noncombustible element in the slab-edge area for the fire stopping is a practical solution. It is necessary to maintain consistency with conventional tested assemblies and engineering judgements allowed for by the code, which are based on tested assemblies with noncombustible elements holding the mineral wool insulation, the primary component of typical installed assemblies.

For low and medium rise buildings that are not sprinkler protected the IBC requires a fire resistance rated spandrel creating a 30" vertical or horizontal separation between floors. For a curtain wall incorporating wood mullions, the IBC requirement reinforces the premise for making the nominal spandrel area non-combustible.

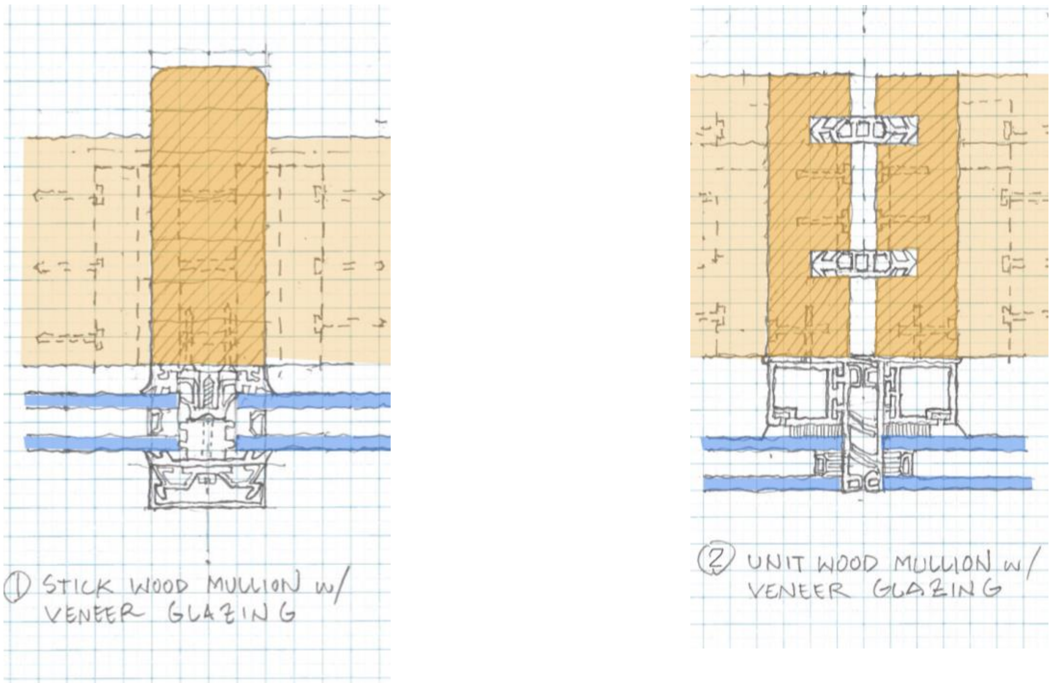

Figure 2: (left) Schematic of aa typical stick mullion curtain wall system with glulam; (right) Plan, Split Mullion

A CONCEPTUAL SOLUTION

The curtain wall system incorporating timber mullions and transoms proposed here takes wind forces and the weight of the wall assembly back to the structural floors. It incorporates an aluminum cassette glazing system holding weather-tight gasketing between units and receiving structurally glazed insulated glass units on the outboard face of the framing. No timber is exposed on the exterior surface of the enclosure. The wall system is unitized, with split mullions and transoms sharing load, and with a spandrel panel element that incorporates the interlocks between levels of the conventional stack joint while also providing the support surface for the tested slab-edge gap firestopping assembly.

The basic relationship and attachment between the aluminum glazing frames and the timber mullions would be essentially the same as in the numerous prefabricated stick frame wood mullion glazing systems which are available for low-rise, store-front applications, which are fairly commonplace. The same limitations that make stick-framed systems of all kinds generally less common than unitized systems, on mid and high-rise facades, account partly for the absence of stick-framed wood mullion systems on mid and high-rise buildings, along with the issue of the nominally combustible assembly. The use of a 'European'-type mitered unit approach to the interlock of the curtain wall units simplifies the connections of the adjacent units to provide load-sharing and also, air-and water-tightness.

There is a system for unitized timber curtain wall in development in Italy. The 'Woody' design by G. Stramandinoli incorporates the veneer glazing system from a major European curtain wall manufacturer into a system of anchoring and sealing adjacent units, comprising a proprietary design. Discussions with the designer of the Woody system about the spandrel concept have yielded a version of this system in concept development that addresses the premise of the firestopping zone discussed above.

Illustrated in figures 3 and 4 is a more generic design concept of a wood mullion unitized system to illustrate how the timber curtain wall could be designed to comply with the IBC requirements for mid-and high-rise buildings in North America. The mullions are nominally 2” on each side of the split vertical and 8” deep, similar to typical aluminum mullion sizing. Dimensions would vary with engineering requirements and unit sizes.

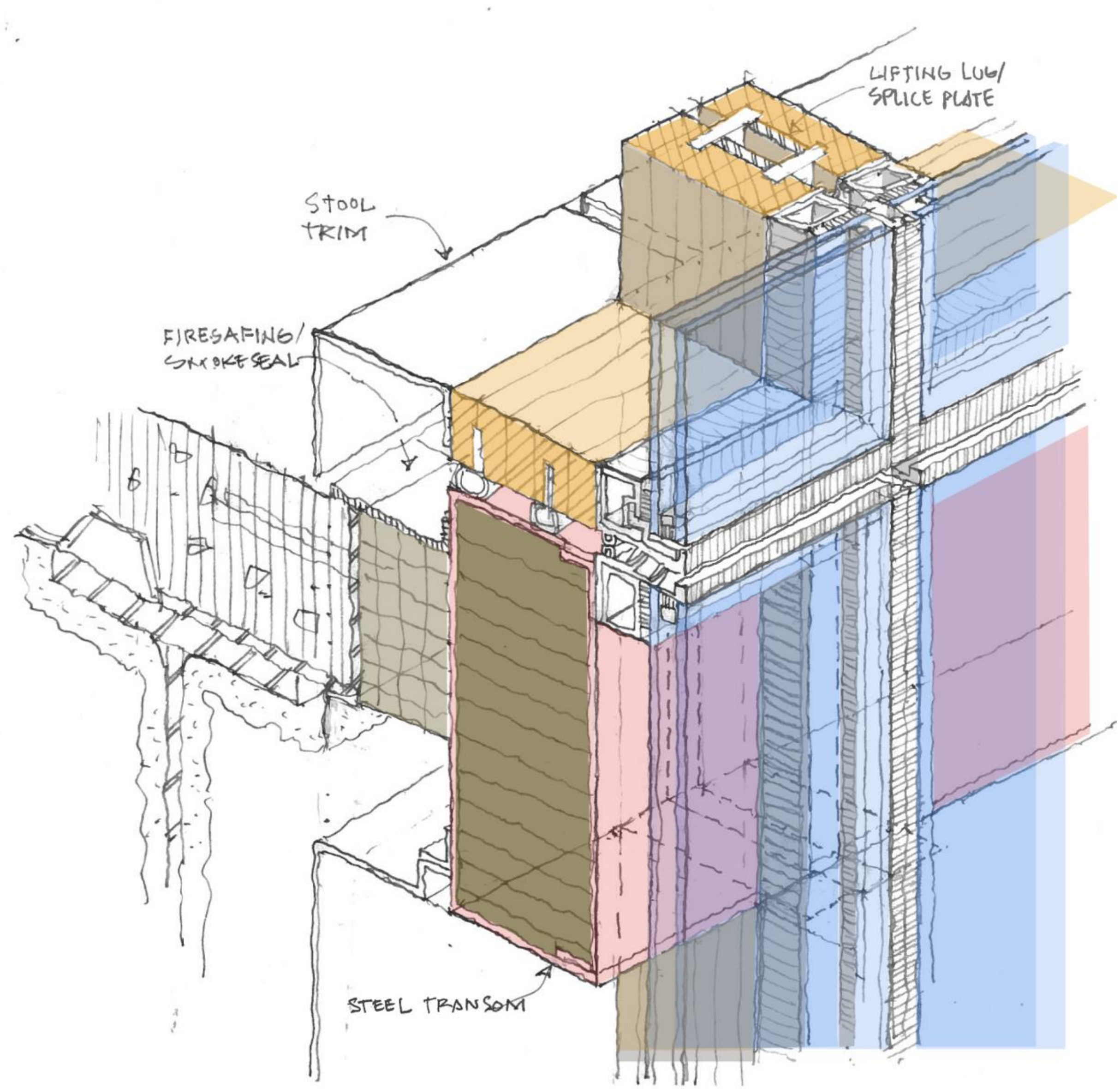

Figure 3: Cutaway View of Unitized Wood Curtain Wall at Insulated Steel Transom and Slab-Edge Firestopping. Transom runs past the mullion which does not occupy the area of the firestopping assembly. No wood is exposed to the exterior, which is clad in glass structurally glazed to aluminum cassette frames.

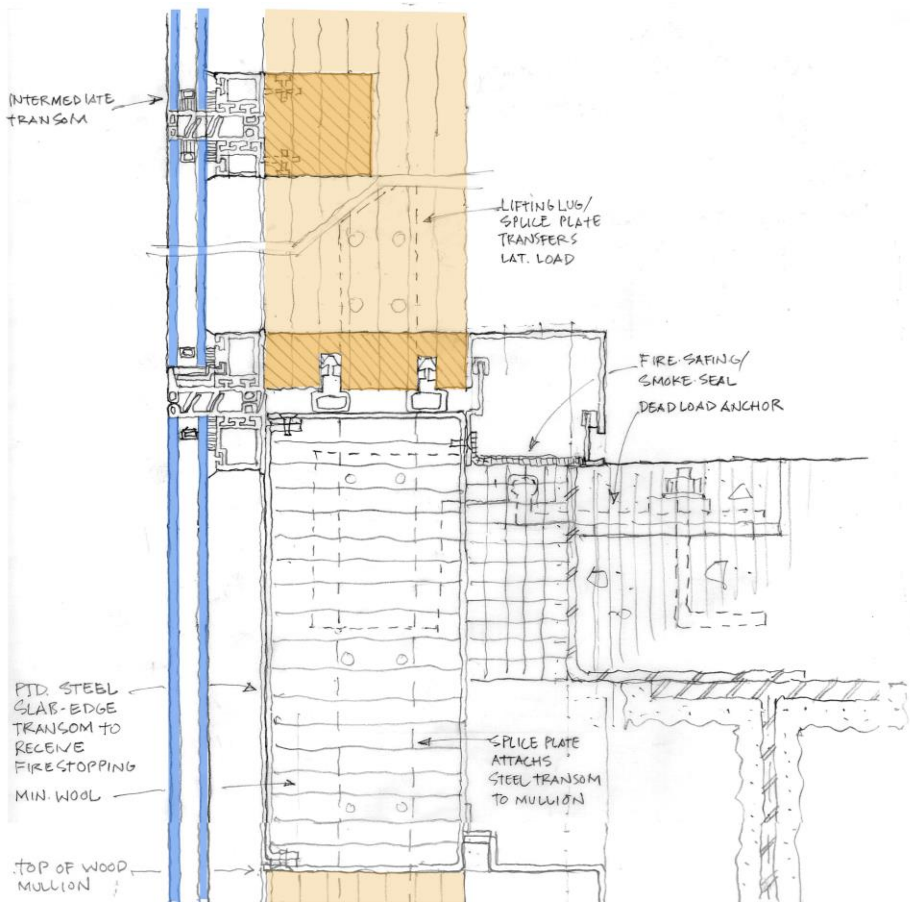

Figure 4 Section at Slab-edge, Unitized Wood Curtain Wall. Insulated steel transom and slab-edge firestopping, similar to 'zero-spandrel' assemblies tested to ASTM E2307.

The spandrel transom assembly would create a discontinuity in the system to provide the totally non-combustible element for firestopping against the slab.

SUMMARY & CONCLUSIONS

The need for buildings to reduce embodied carbon impacts and embrace and use more sustainable building elements has led to greater experimentation with materials. Timber has emerged as a material of interest and is already being used in high-rise structural applications. Extending these applications, the innovative use of mass timber elements such as glulam for curtain and window wall mullions and transoms provides the potential for further embodied carbon reductions in mid and high rise building. But the issue of fire remains a hurdle for the more ambitious use of wood in the building skin.

Mass timber has an inherent flammability and fire resistance that is often misunderstood by designers and authorities alike. The IBC is continually updated to include new and innovative materials and safety solutions. An argument is presented that the use of mass timber elements, such as glulam, within a curtain or window wall system of a medium or high-rise building, is permitted by the IBC, though the compliance pathway is not easy to follow, navigating multiple chapters and requiring some interpretation.

A conceptual basis for timber curtainwall systems and a supporting building code methodology to achieve compliance has been developed here. The fundamental conclusion for the system is:

1. The use of wood in a window or curtain wall system in mid or high-rise buildings is permissible per the IBC if the following conditions are met:

    a. The material must meet Class C flammability requirements (most mass timber elements should comply)

b. The framing elements must encompass no more than 10% of the wall area.

c. The timber components must be inboard of exterior glazing and framing elements.

The fire test applicable to such assemblies is ASTM E84 "Standard Test Method for Surface Burning Characteristics of Building Materials", a relatively low-cost and readily available procedure, which should enhance the adoptability of the strategy developed here for timber-based façade systems. An important opportunity for future work is the continuing education of designers and building officials, who are often keenly interested in the use of mass timber but lack the necessary understanding for implementation.

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