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Ascent – Challenges and Advances of Tall Mass Timber Construction

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Abstract

Ascent, a 25 story residential tower located in Milwaukee, WI (USA), will become the tallest timber building in the world upon completion. This paper discusses the project's structural system, permit process, groundbreaking project specific testing, and several of the challenges the team overcame, all of which open the door to future Mass Timber projects; particularly in the United States.

Keywords: Mass Timber, Glulam, Crosslaminated Timber, CLT

1. Introduction

Wisconsin, a state in which over 40% of the total land area is composed of forestland has historically provided timber for construction throughout the US Midwest, including their neighbor city to the south, Chicago, one of the birthplaces of the skyscraper. In a state with a storied tradition of timber construction, Ascent was envisioned as a tall mass timber tower through a partnership between a local developer (Newland Enterprises), architect (Korb + Associates), and Thornton Tomasetti as the structural engineer of record. The Ascent site offers "magnificent lake and city views" and, in the developers own words, Ascent was born with the desire to "offer an unparalleled balance of natural elements, comfort and luxury". This vision, culminating in the 25-story residential tower Ascent, is set to develop a new market throughout the Midwest, while breaking the record for height of mass timber construction, currently held by Mjøstårnet in Brumunddal, Norway, at 85.4m (as ratified by CTBUH).

The popularity of mass timber has unquestionably increased over the past decade. While mass timber construction is commonplace throughout Europe (in some cases dates back hundreds of years) its utilization in high-rise construction has been somewhat non-existent. In an effort to explore the viability of tall mass timber construction, Thornton Tomasetti was engaged in an ambitious research project with Perkins and Will and the University of Cambridge, to design an 80-story, 800-foot (333m) residential tower, located in Chicago, IL (USA), fully utilizing mass timber construction.

The goal of the River Beech project was to identify the current limitations of tall mass timber construction and to propose areas that need further research to open the door for future projects; additional information can be found in a previous CTBUH research paper (Snapp et al, 2017). From a structural standpoint, the study concluded that the current limitations in the height of timber buildings are not a question of the structural capacity of the material, but rather other factors such as fire engineering, current code limitations, or lack of existing research - for example wind engineering for tall mass timber buildings.

The knowledge gained by this previous research informed the design and development of Ascent, a building where mass timber high-rise construction has taken shape. This paper explores the structural system of Ascent, the building permitting process, the groundbreaking research specific to the project, as well as some of the challenges related to mass timber construction.

2. Background in Tall Mass Timber Construction

From an owner (developer) and architectural standpoint, one of the primary drivers for developing Ascent as a mass timber structure, was to show off the "intrinsic beauty" of the material/structure. As will be discussed throughout the paper, mass timber design and construction require reconciling the desire to expose the structure, while also acknowledging that the material is inherently combustible. As such, in addition to structural engineering, fire engineering becomes a critical component of any mass timber high-rise.

For frame of reference, current prescriptive ("by right") designs throughout the United States (IBC) limit the height of exposed timber construction to approximately 6-7 stories. While future editions of the code will allow

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Figure 1. Ascent. (Image courtesy of Korb + Associates)

Figure 2. River Beech Tower. (Image courtesy of Perkins and Will)

for slightly increased building heights, they typically come with the caveat that all (or portions) of the structure must be concealed.

Currently, the tallest mass timber building in North America is the Brock Commons dormitory building in the University of British Columbia (Vancouver, Canada), which raises 18 levels above ground. The building was a significant milestone in tall mass timber construction, and temporarily held the world record for tallest mass timber structure. However, as a stipulation of the permitting process, nearly all the timber elements were required to be concealed from a fire protection/life safety standpoint.

While mass timber construction has a multitude of benefits beyond visually exposing the structure (which are not a focus of this paper but include sustainability,

Figure 3. Early interior rendering of Ascent unit. (courtesy of Korb + Associates)

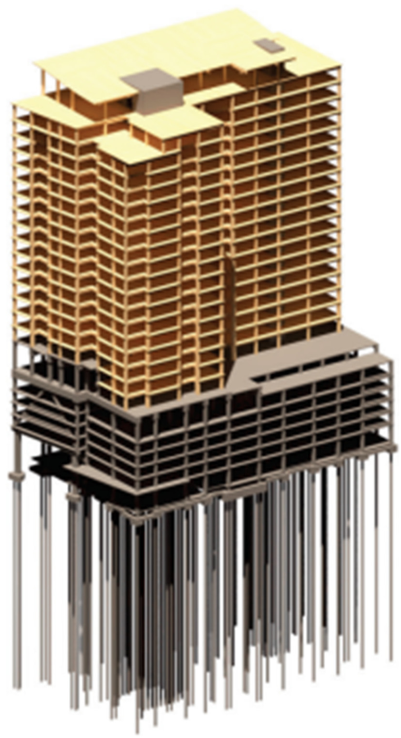

Figure 4. Ascent Structural System. (© Thornton Tomasetti)

reduced foundations due to the lightweight of the material/structure, and simplified construction/rapid erection of the structure thanks to its proclivity to prefabrication), from an owner standpoint the exposed structure becomes a key market differentiator when developing a high end property.

That said, the Ascent team quickly realized the architectural function of many of the spaces throughout the structure would require concealment of large areas of the building: restrooms, kitchens, corridors, etc. Assuming a cost premium for exposing mass timber construction (increased member sizes in accordance with the char method), there is a clear cost-benefit analysis required. While outside the scope of this paper, material/construction cost in the above mentioned cost-benefit analysis lead to an interesting discussion on the idea of a "hybrid structure". In the case of Ascent, this means utilizing reinforced concrete core walls for the structural lateral system and PT parking decks throughout the podium.

In examining the Ascent structure, reinforced concrete core walls were utilized as part of an agreement with city officials throughout the permitting process; as opposed to any structural or economical limitation on mass timber lateral systems. However, as mass timber is typically a more expensive source material (as opposed to reinforced concrete), there would appear to be potential economic benefits to considering hybrid structures, integrating various construction materials (timber, steel, concrete, etc.) to take full advantage of their individual strengths. As Ascent was located in a city with a history of efficient/economical PT construction, the team reviewed multiple structural systems (including standard PT construction, mass timber construction, and partial PT floor plates with perimeter mass timber elements) before finalizing the system described in the next section.

3. Ascent Structural System

3.1. Gravity System

The Ascent structure is composed of a 7 level parking podium, with 18 residential levels, including an amenity level roof deck. In a city known for very long and harsh winters (including great amounts of snow), the podium was designed utilizing reinforced concrete columns and 7.5 inches (190mm) thick post-tensioned flat plate slabs. The system was selected to accommodate the required parking level clear spans, while providing additional resilience to the snow, salts and waters associated with winter (in addition to utilizing the very economical/familiar construction option for the city).

The mass timber gravity super-structure, comprised of glulam beams and columns and one-way spanning Cross-Laminated Timber (CLT) slabs (all of Austrian spruce),

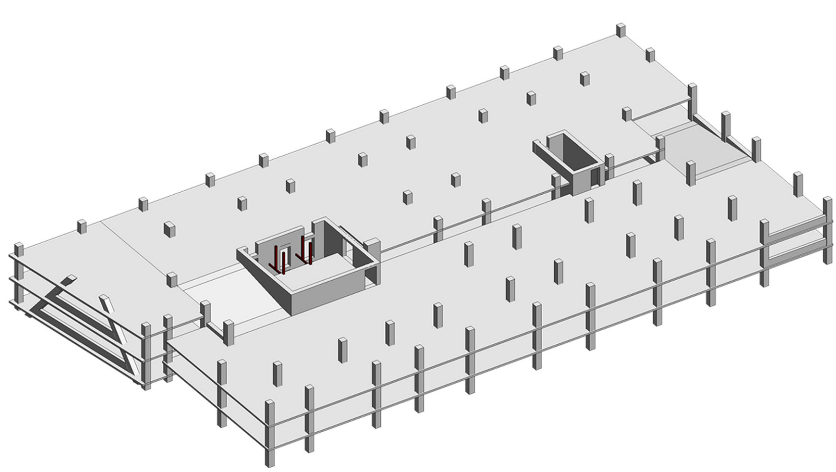

Figure 5. Typical PT Parking Floor. (© Thornton Tomasetti)

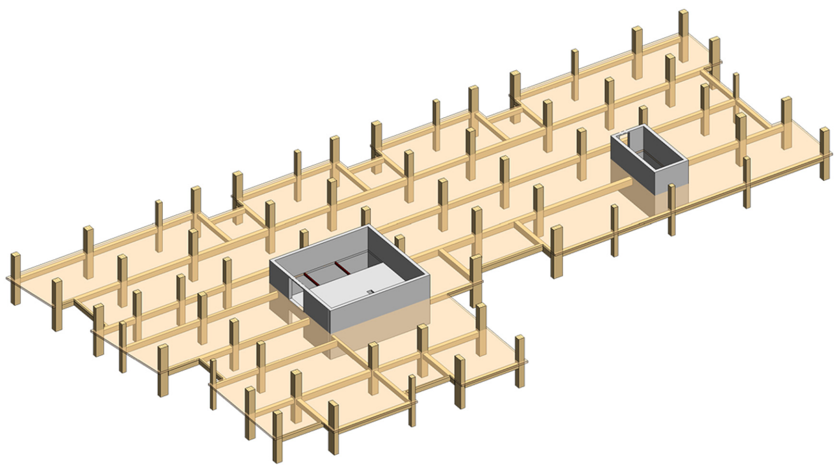

Figure 6. Typical Mass Timber Floor. (© Thornton Tomasetti)

rises above the reinforced concrete podium at level 7. While mass timber is capable of spanning large distances (as showcased in the Lisbon Olympic Stadium, one of many examples throughout the world), a key to any high-rise project is to create an efficient structural system which can be replicated over multiple floors, resulting in an overall economical design. In the case of mass timber construction, one-way spanning framing systems typically require column grids on the order of 15'-20' x 20'-25' to create an economical system. While the material itself is capable of larger spans, it was found that beyond the ranges above, not only did the structure become larger (deeper beams and thicker floor panels), but substantially more expensive.

As a result, Ascent utilized a typical residential column grid of approximately 17 feet wide by an alternating 20'-0" to 25'-0" length, minimizing the one-way slab span to maintain an efficient floor assembly (specifically 5-ply CLT floor panels).

Preliminary concept designs considered multiple options for the mass timber floor system, including the use of Nail Laminated Timber (NLT), a very North-American product consisting of timber laminations (2xX boards) supported on their short side and nailed in succession. In a state with a tradition on timber construction, this system had multiple advantages, including increasing the number of local suppliers and materials (species). However, due to the pure size and magnitude of the project, the large floor areas required a level of pre-fabrication/manufacturing and QAQC that would have been difficult to

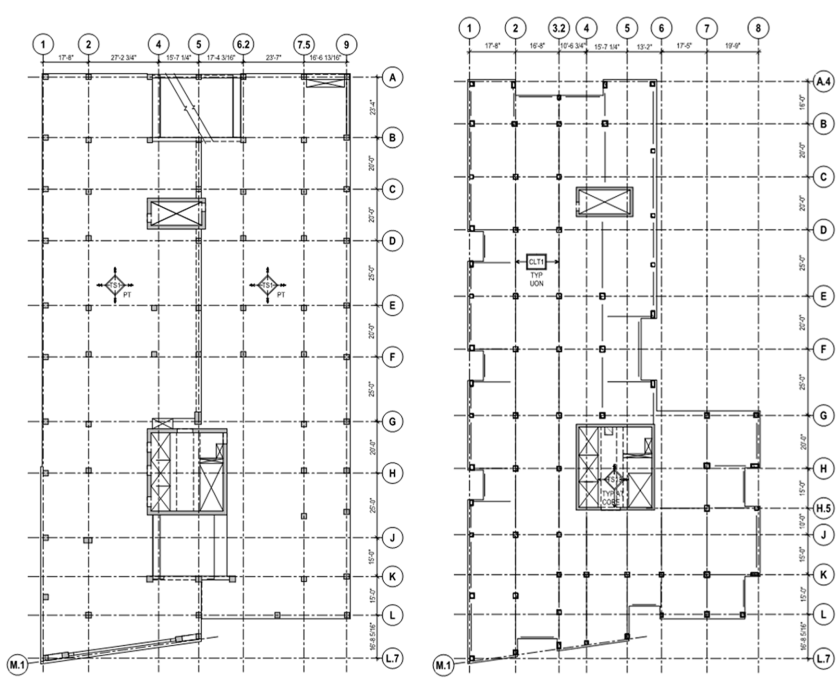

Figure 7. PT Framing Plan (left) and Timber Framing Plan (right). (© Thornton Tomasetti)

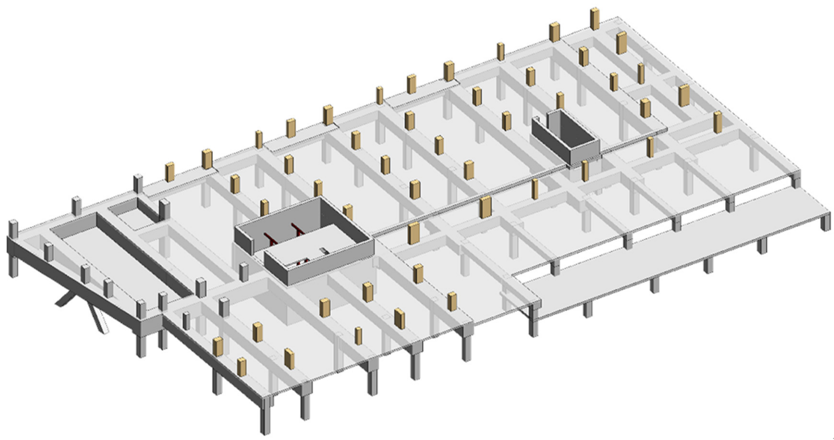

Figure 8. Transfer beams at level 7. (© Thornton Tomasetti)

achieve with NLT. Dowel Laminated Timber (DLT) (similar to NLT, but a more manufactured product utilizing wood dowels in-lieu of nails) was also considered; however, in the final analysis it was found that Cross-Laminated Timber (boards of glued timber stacked cross-wise) provided the optimal combination of aesthetics and economical efficiency, utilizing the following a 5-ply 180mm CLT slabs at the typical residential plans, and a 7-ply 240mm CLT slab at the amenity/roof levels (with the increased thickness accounting for the higher amenity loading requirements).

Additionally, a 2 inch (50 mm) gypcrete (non-structural) topping slab was incorporated (along with an acoustical sound mat) above the typical residential CLT slabs. In addition to providing acoustical separation, the topping slab acts as a form of fire protection for the top of the CLT slab, while also allowing for an in-floor radiant heating system throughout the slab.

While the column grid above created an efficient residential floor plan, the relatively tight column spacing did not allow for efficient parking layout or adequate drive lanes below. Therefore, at the transition between the typical parking and residential floors, a transfer level was developed to integrate the typical parking and residential column grids. By taking advantage of the relatively light weight of the mass timber structure above, and a staged/sequenced stressing of the concrete beams below, the team was able to minimize the depth of the transfer elements (4’-0” to 6’-0”post-tensioned transfer beams, 1200 mm to 1800 mm), supporting 19+ floors of structure, while also providing comfortable drive lanes and an efficient parking layout below.

3.2. Lateral System

From the start of the project, the team understood that Ascent would be pushing the limits of timber construction in many aspects. By pushing its height far beyond the prescriptive limits of the current code (or any existing mass timber building in the United States), the team worked very closely with city officials during the design process. As part of this process (discussed in greater detail throughout the paper), it was requested to utilize reinforced concrete core walls for the structural lateral system; providing a safe mean of egress for the occupants and a safe path of access for the fight fighters both during construction and for the life of the structure. The two cores shown in the image below correspond to an elevator and stair main core in the south and a smaller stair core to the north.

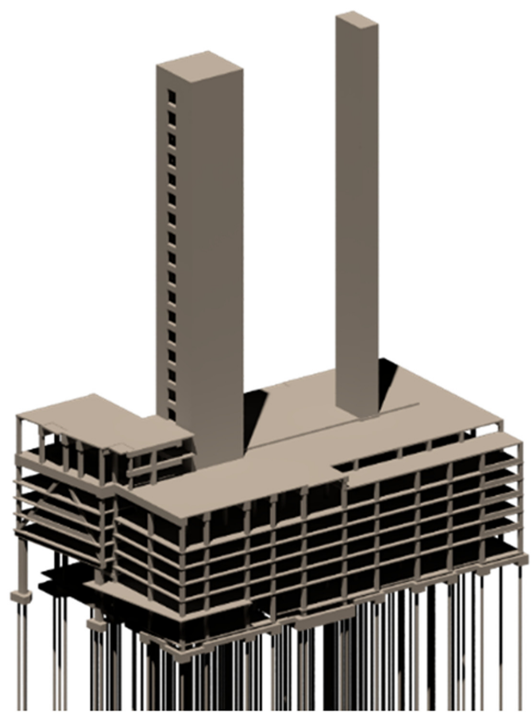

Figure 9. Ascent Lateral System(© Thornton Tomasetti)

3.3. Foundation System

Unlike its counterparts in New York or Chicago, the city of Milwaukee does not have the luxury of a shallow

Figure 10. Pile Static Load Testing. (© Thornton Tomasetti)

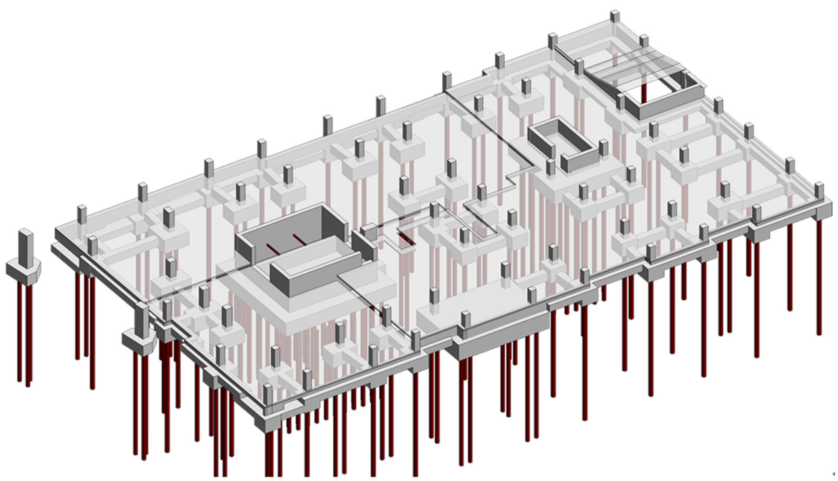

Figure 11. Ascent Foundation System. (© Thornton Tomasetti)

rock layer. Throughout Milwaukee, particularly adjacent to Lake Michigan, finding competent bearing strata for high-rise construction can typically require driving deep foundations 120-150 feet (36.5-45 m) to reach rock or refusal. In an effort to create an efficient foundation system, the team decided to once again push the boundaries of conventional design, including statically load testing concrete filled steel pipe piles.

As a result of the testing, the team was able to confirm the highest capacity piles in the state, at over 450 tons per pile (~816 tonnes), for a system that is conventionally rated for approximately half that capacity. By combining the high capacity piles with the lightweight mass timber structure above, the team was able to significantly reduce the number of deep foundation elements, resulting in substantial savings to the overall project

4. Permit

4.1. City Variance

Due to the unique nature of the project, engaging the city and ensuring their support from the very early stages of the project was crucial. While not typically required as part of the permitting process, the Milwaukee Fire Department was also invited to join the design conversations early on, and have been consistently engaged, in an effort to not only understand their concerns, but to directly address them from the start of the project.

Throughout the United States, American codes (typically IBC or in this case the Wisconsin Commercial Building Code) rely on a prescriptive design methodology (as opposed to other areas, such as Europe that more frequently incorporate performance based design). In practice, this can result in the code providing multiple limits for construction and design (for example the previously referenced 6-7 story limit on timber construction). However, the International Building Code (upon which the Wisconsin Commercial Building Code is based) allows designers to utilize a more performance-based design approach, within a clause titled “Alternative materials, design and methods of construction and equipment”. This opens the door for authorities having jurisdiction (AHJ’s)

Figure 12. Interior Render of the Amenity Spaces (courtesy of Korb + Associates)

to approve non-prescriptive systems through a variance process; contingent on the project team verifying the design "is satisfactory and complies with the intent of the provisions of this code" (ICC, 2015). In the case of Ascent, this meant (among other things) confirming the fire performance of the timber elements through calculation, product certifications, and/or additional fire testing.

A crucial precedent for the Ascent project was the Framework project, in Portland (Oregon, USA), which received approval for exposed timber elements under the same code (IBC 2015), utilizing the provision above.

With the roadmap just described, the Milwaukee AHJ and Ascent project team agreed upon a variance approach in which the project would receive a variance for a Type IV Construction on the height of the structure, while requiring the design to maintain the most stringent fire ratings (Type 1A), appropriate for typical high-rise construction. Practically speaking, this required the floor framing elements to achieve a standard 2-hour fire rating, with an increased rating of 3-hours for the column elements.

4.2. Fire Rating

While all wood is combustible, it is important to differential the behavior of mass timber vs. traditional "stick framing" in the presence of fire. In the case of mass timber, when exposed to fires and high temperatures, the larger size (volume) of material allows the element to develop a char layer around its perimeter, protecting the interior material and maintaining the core structural integrity. Conversely, in traditional stick timber construction (for example individual houses, which are frequency constructed from 2 × 4, 2 × 6 small timber elements, around 50 mm by 100-150 mm) the char quickly encompasses the totality of the member, eliminating the structural integrity.

For mass timber construction, the progression of char up to two hours is a well-known (and well-tested) phenomena, allowing designers to explicitly calculate the rate of charring, and therefore oversize the elements as required to ensure that at a given time the structural member will retain a specific structural capacity.

Previous timber fire tests were typically limited to two hours, as would be sufficient for most (if not all) timber design/considerations. However, to obtain a permit for Ascent it was incumbent on the design team to verify a Type 1A structure, and therefore confirm a 3-hour fire rating for the columns. Limited existing test data, extrapolation of existing prescriptive code requirements, and mechanics of material all agreed that the rate of char decreases over time, and therefore it would be conservative to utilize the existing test data and char calculations; which would result in an estimated char thickness of 4.2 inches (100 mm), for a 3-hour event.

However, to confirm this value the Ascent project engaged the USDA Forest Products Laboratory (FPL) in

Figure 13. 3-Hour Fire Test. (courtesy of Korb + Associates)

Madison, Wisconsin (U.S.A), which in working with the design team developed a testing procedure to confirm the required 3-hour char rate. Several specimens of two American species (Douglas fir and Black Spruce), and one European specie (Austrian spruce) where tested, resulting in similar char rates and confirming that the char thickness referenced above was conservative. The results of this test, which will be released in the near future as public information, open a very important door for future projects following a similar path, particularly throughout North America.

In addition to the column fire testing referenced above, existing CLT fire-test product certificates were reviewed for multiple manufacturers and grades/species of lumber. Initial (past) fire testing indicated an increase in CLT char rates, due to delamination of the bottom layer of the panel during a fire event. After further testing, the American standard PRG-320 18 established a number of guidelines to prevent this phenomenon. The team specified all suppliers should comply with this latest version of the standard, including potential European manufacturers. This is a noteworthy clarification, not only as it is critical to the performance of the CLT panels, but also because while most American mass timber standards lag behind their European counterparts, this is an example of an American mass timber standard pushing the industry.

As part of the permitting process, in addition to the fire testing, char calculations, and product certificates, and reinforced concrete cores, the project team provided multiple (non-structural) fire mitigation measures including: a fully sprinklered building with redundancies, 2-hour elevator/stair shafts, redundant water main hookups, standpipes typical at each stair, stair pressurization, and system smoke detectors (vs. smoke alarms).

5. Challenges

As anticipated in any boundary pushing project, the design of Ascent was not without a number of unique challenges. These challenges encompassed a variety of technical, logistical, and financial considerations; which were magnified due to the scale of the project, and lack of existing precedents. Solving these challenges required a high degree of coordination between multiple trades/specialties, and a willingness to collaborate beyond what is standard in the construction industry. In addition to this coordination, the team relied on (limited) existing and new research, while developing multiple iterations of the structural design to refine and optimize the system.

5.1. Material Sourcing

While mass timber is a well-established product throughout most of Europe, particularly since the early 90s, in the United States it is still considered as an innovative product (which over the past decade is just gaining traction/popularity). The relatively young U.S. market and sudden increase in demand inherently result in additional challenges to any mass timber project throughout the United States. While current code and economic limitations throughout the U.S. drastically reduce the number of projects that are completed/constructed, North American manufacturers are frequently inundated with requests for their time/resources. This can make it difficult for a project team to receive necessary feedback from manufacturers, as they have limited resources and need to determine what they consider to be a “realistic” project. Proposing a 25-story tower, currently 3-4 times the code prescriptive limit and nearly 20 stories taller than the next tallest timber building in the United States, made it difficult for manufacturers to initially see the Ascent project as realistic/feasible.

As a result, in the team’s research of European manufacturers (both CLT and glulam), it was discovered that it is feasible and cost competitive to source and ship materials from European manufacturers to North America; partially thanks to the reduced cost of boat transportation and smaller price fluctuations in European timber. (Additionally, some believe European manufacturers tend to provide a higher quality product due to their additional experience and resources.)

However, sourcing from a different country across an ocean is not without its challenges and considerations, including the following: additional difficulty in timely replacement of elements in the case of a defective/damaged product, various industry standards (with limited literature on how to reconcile differences in philosophical approaches), variations in dimensions and standard units, and multiple materials/species (which in the case of wood inherently can result in a change in the appearance of the final product).

5.2. Connection Design

As previously discussed, the goal of the Ascent project was to show off the “intrinsic beauty” of the structure, and without the exposed timber, it was difficult to confirm the financial viability of the project. While this paper previously referenced the fire protection of the timber elements themselves, it is equally as important to consider the fire performance of the connections between the timber elements. Frequently connections in mass timber projects utilize exposed steel connectors. From a fire protection standpoint, it can be problematic to expose the steel and there is very little research on the use of intumescent paint in mass timber applications. This typically leaves designers with two options: utilize a pre-engineered connection “product” that has already been tested and certified, or design a custom concealed connection.

Unfortunately, for the Ascent project both items above resulted in their own unique challenges. Due to the required 2-hour floor framing fire rating, when considering commercially available pre-engineered connections on the market throughout North American, there was not a

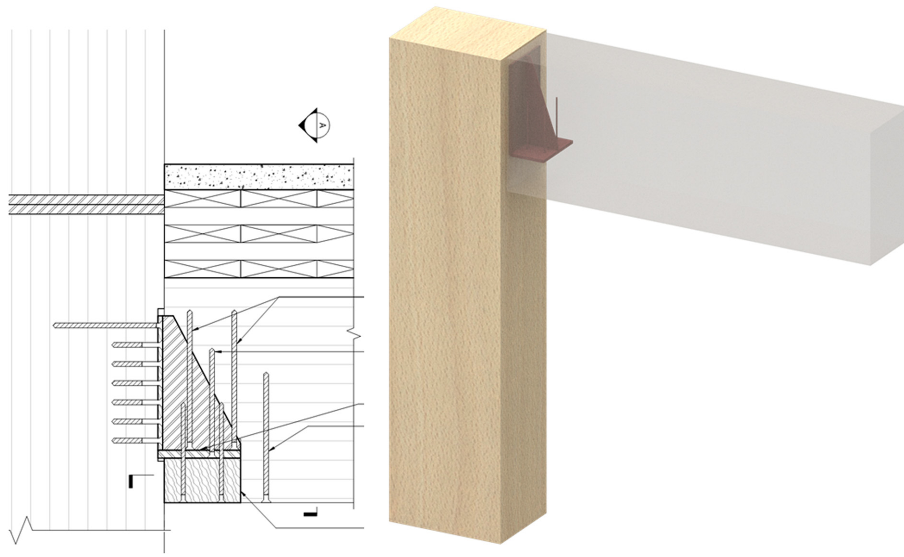

Figure 14. Column to Beam Exposed Connection. (© Thornton Tomasetti)

single product that had been tested (and obtained) the necessary 2-hour rating. While a custom concealed connection could be engineering and would technically be protected by the charring of the adjacent exposed timber, technically the custom connection would require additional (costly and lengthy) fire testing, in addition to the larger cost typically associated with custom concealed connections.

While Framework (the previous project in Portland, Oregon, following a similar permitting path to Ascent) unfortunately never completed construction (due to financial challenges), it was granted funding from the US Department of Agriculture, which the team invested in researching a number of exposed (steel concealed) connections. Among them was a specific exposed timber beam - timber column connection rated for two-hours. This connection and associated test data served as the basis for the typical exposed beam-column connection throughout Ascent. While Ascent optimized the connection (both for structural and fire engineering efficiency), the connection fundamentally consists of a metal ledger that is screwed to the column, and that provides a simple bearing seat for the beam. The connection is routed into the glulam beam and the bottom is covered with a wood block, as show in the image below.

To offset the cost of the relatively expensive custom connection, where possible the team incorporated multiple timber-to-timber connections, minimizing the utilization of expensive steel connectors. However, it should be noted that the Austrian Spruce species exhibits a lower than average bearing capacity, requiring a large quantity of screw reinforcement for typical timber-to-timber bearing connections.

5.3. United States vs European Codes

Currently there are a number of philosophical discrepancies between timber design codes in Europe and the United States, complicating the usage of the materials across the Atlantic. The differences typically result from the fundamental principles of how the materials are tested, including the size of the tested samples, which can result in large variations in design parameters. The literature on how to relate one to another is limited (a comparison can be found in Yeh, Chen, Skaggs, 2017), and typically the analysis is run multiple times for each set of codes/standards. This is clearly an area where consensus among the industry, and further research, is required.

5.4. Penetrations Through Exposed Glulam Elements

There are many unique considerations for mass timber structures, but systems are fundamentally similar either in timber or other traditional construction material buildings, and inherent to them are mechanical and electrical systems. Despite hours and hours of early and frequent coordination, it is inevitable that conduits and pipes will necessarily penetrate structural floors, ceilings, beams, and walls to adequately service the building.

There are a number of rated products that allow for penetrations of cross-laminated panels, however, as far as the design team is aware there are no products currently rated for fire sealing a penetration through an exposed glulam beam. From a structural standpoint, this implies that if there is a penetration through an exposed beam, the beam would have to be designed for a penetration the size of the conduit plus the size of the char all around the penetration. Therefore, when considering an exposed 2-hour rated element, even the smallest of penetrations would result in a significant (and in some cases undesignable) opening. As such, all beam penetrations throughout Ascent were concealed.

Once again, there is very little research/literature regarding the reinforcing of glulam beams with large penetrations, primarily limited to several national annexes in the Eurocode, which still contain somewhat limited information (see the German National annex to Eurocode 5); and is therefore another area where further research is required

6. Conclusions

As mass timber becomes more enticing and a common material in the design team's palette, future projects (like Ascent) will continue to push the boundaries of existing codes and research. This paper has examined Ascent's structural system, but also emphasized existing challenges and what was required to overcome current code and research limitations. As the Ascent team learned from past projects and research, future projects will undoubtedly utilize Ascent as a benchmark and frame of reference. Ascent's development was not the product of one person or team, but the result of a collaboration across multiple disciplines, with a common goal of making a tall mass timber project a reality. By highlighting a number of challenges and items requiring further research, the authors hope to utilize Ascent as a springboard to continually develop the (international) industry's (including universities, research centers, code officials, designers, developers, and contractors) understanding of mass timber construction.

Acknowledgments

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