TALL WOOD

THE CASE FOR Tall Wood BUILDINGS

How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Building Structures

FEBRUARY 22, 2012

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Funding for this 'Case Study' project was provided to the Canadian Wood Council (CWC) on behalf of the Wood Enterprise Coalition (WEC) by Forestry Innovation Investment (FII). Any results, findings, conclusions or recommendations are those of the author, and do not necessarily represent those of the CWC, WEC - and it's partners, FII or the Province of British Columbia.

Table of Contents

Introduction

We are in a unique moment in architectural and building engineering history when shifting world needs has asked us to question some of the fundamentals of how we have built for the last century and how we will build in the next.

"I'd put my money on solar energy…I hope we don't have to wait till oil and coal run out before we tackle that." Thomas Edison, *In conversation with Henry Ford and Harvey Firestone March 1931*

Wood is the most significant building material we use today that is grown by the sun. When harvested responsibly, wood is arguably one of the best tools architects and engineers have for reducing greenhouse gas emissions and storing carbon in our buildings. The Case for Tall Wood Buildings expands the discussion of where we will see wood and specifically Mass Timber in the future of the world's skylines. As we pursue the solar and green energy solutions that Thomas Edison spoke of over 80 years ago, we must consider that we are surrounded by a building material that is manufactured by nature, a material that is renewable, durable and strong.

This report introduces a major opportunity for systemic change in the building industry. For the last century there has been no reason to challenge steel and concrete as the essential structural materials of large buildings. Climate change now demands that we do. The work of thousands of scientists with the United Nations Intergovernmental Panel on Climate Change (IPCC) has defined one of the most significant challenges of our time. How we address climate change in buildings is a cornerstone in how the world will tackle the need to reduce emissions of green house gases and indeed find ways to store those same gases that are significantly impacting the health of our planet. Just as the automobile industry, energy sector and most other industries will see innovations that challenge the conventions of the way we will live in this century, the building industry must seek innovation in the fundamental materials that we choose to build with. In a rapidly urbanizing world with an enormous demand to house and shelter billions of people in the upcoming decades we must find solutions for our urban environments that have a lighter climate impact than today's incumbent major structural materials. This report is a major step in that direction. Indeed it introduces the first significant challenge to steel and concrete in tall buildings since their adoption more than a century ago.

The work in this report reflects several years of momentum, effort and conviction by many people interested in the issues of climate change, architecture, wood design and innovation. The story the report tells is one of optimism for a progressive new way of building safe and environmentally-friendly large buildings. The report challenges conventions. It attempts to address preconceptions. We have tried to communicate and educate with the full story of why tall and large wood building structures are important to understand from the point of view of broad principles and at a detailed level. This study is the beginning of a path to realizing built projects. More engineering, research and testing will be required to expand on the ideas we discuss. We hope that architects and engineers will join us in pursuing this discussion and in developing increasingly broader approaches to Tall Wood buildings. We also hope that the ideas within the study will gain momentum within the larger building industry and be the precursor to a revolution in the way we build mid-rise and tall buildings around the globe.

The FFTT Approach

This report introduces a new way of constructing tall buildings. The Mass Timber panel approach we have developed is called FFTT.

FFTT stands for Finding the Forest Through the Trees; a non technical acronym with an important story.

The acronym speaks to the idea that much of the sustainable building conversation is focusing on minutia. While even the minutia contributes and is important, the big systemic change ideas are what we believe will be necessary for the built environment to tackle the scale of the climate change and housing demand challenges facing the world. FFTT is a contribution to hopefully many significant shifts in the way we approach buildings in the next decades. The goal is simply to focus on the forest but never forget the trees.

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Acknowledgements

We would like to specifically thank a number of people and organizations that have helped our team learn and share these important ideas. Our special thanks to Erol Karacabeyli of FPInnovations, Mary Tracey and Oscar Faoro of WoodWORKS! BC, and Etienne Lalonde of the Canadian Wood Council who have helped organize our effort with this study. Thank you also to the many people we have interviewed from developers, marketing groups and contractors to building authorities and fire chiefs. Thank you to Andrew Waugh of Waugh Thistleton Architects in London England for his determination to lead by example and show the world what is possible in Tall Wood in his 9 storey Stadthaus project in Murray Grove London. Thanks to FPInnovations, Natural Resource Canada, BC Wood, WoodWORKS! BC and the Canadian Wood Council for their research and dedication to the increased and responsible use of wood. Thanks also to those who have shown considerable interest in helping spread this discussion to the world including TEDxVancouver, the Canadian and US WoodWORKS! programs, the Canadian Green Building Council, the Australian Green Building Council, Forestry and Wood Products Australia, The UN Food and Agriculture Organization and the Province of British Columbia. Most of all, thank you to the Canadian Wood Council (CWC), the Wood Enterprise Coalition (WEC) and Forestry Innovation Investment (FII) who have opened the door to a breadth of important innovation in wood.

Equilibirum's Special Acknowledgements

We would like to thank Dr. Mahmoud Rezai, PhD, StructEng of EQ Engineering for his work on the typical concrete base building details as well as for his concept review comments.

Many other colleagues have also kindly provided comments on the overall structural concept presented in this study. In particular, we would like to thank Dr. Leander Bathon, PhD, Ing from the University of Wiesbaden, Germany, for his comments on the concept of the proposed lateral load resisting system and the use of the HSK system in particular for hold-down connections. We would also like to thank Dr. Andre Filiatrault, PhD, Eng, past chair of Multi-Disciplinary Centre for Earthquake Engineering (MCEER) and professor at Buffalo University, for taking the time to discuss the lateral load resisting system concept with us.

Report Team Acknowledgements

The decision to Creative Commons License the FFTT solution is very important. The aspiration to move the world towards more sustainable structural solutions is the fundamental motivator of all involved in preparing this report. This is about sharing good ideas and choosing not to profit from them. I am very proud of the team that has dedicated an enormous amount of time well beyond what was anticipated. Special thanks for the great work of the architectural team of Tracey Mactavish, Kate Snyder, Seng Tsoi, Laura Radford and Bryan Beca, the structural team from Equilibrium Consulting of Eric Karsh, Robert Malczyk, Benny Neylon, the BTY costing team of Joe Rekab and Sean Durcan and the code team lead by Geoff Triggs of LMDG.

Thank you to our code peer reviewer Andrew Harmsworth of GHL Consultants and our structural peer review team of Grant Newfield and Ron DeVall of Read Jones Christoffersen Consulting Engineers. Thank you to additional peer reviewers Jennifer O'Connor, Pablo Crespell, Marjan Popovski of FPInnovations. Their peer review was a great benefit to the thoughtfulness and rigour of the final report.

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A Note on Intellectual Property

The FFTT [cc] system illustrated in this document is intended for universal use and development with specific Creative Commons copyright conditions. The scale of the opportunity contained in these solutions is enormous, and there will be meaningful opportunities for some organizations, companies and individuals to profit from pursuing these ideas. The decision of the authors and originator of these ideas is to encourage an Attribution Non Commercial Share Alike approach (see below for definition) that encourages adoption of FFTT [cc] into mainstream building practices. This decision underscores our belief that these ideas are stepping stone concepts to the types of systemic change necessary to address climate change issues in the building industry with the increased use of sustainably harvested wood in building structures.

In Brief

THIS REPORT INTRODUCES A NEW WAY OF DESIGNING AND CONSTRUCTING TALL BUILDINGS.

The report describes a new structural system in wood that represents the first significant challenge to concrete and steel structures since their inception in tall building design more than a century ago. The introduction of these ideas is driven by the need to find safe, carbon-neutral and sustainable alternatives to the incumbent structural materials of the urban world. The potential market for these ideas is quite simply enormous. The proposed solutions have the potential to revolutionize the building industry, address the major challenges of climate change, urbanization, and sustainable development and to significantly contribute to world housing needs.

The document introduces a Mass Timber solution for tall buildings called FFTT including;

- A definition of Mass Timber which includes several existing large scale panel products in the current marketplace including Cross Laminated Timber (CLT), Laminated Strand Lumber (LSL) and Laminated Veneer Lumber (LVL).
- A differentiation between Mass Timber and light wood frame.
- The structural details of FFTT as a "strong column – weak beam" balloon-frame approach using large format Mass Timber Panels as vertical structure, lateral shear walls and floor slabs. The "weak beam" component is made of steel beams bolted to the Mass Timber panels to provide ductility in the system. Concrete is used for the foundations up to grade. No further concrete is necessary in the system unless selected for architectural reasons.
- How FFTT is non-proprietary structural solution developed by the authors of this report. Other systems will be possible and introduced as these ideas become more prevalent.
- How FFTT is adaptable to various architectural forms including office and residential uses and has been conceptually engineered to 30 storeys in height for the high seismic areas like Vancouver.

The report details how FFTT addresses;

- The structural characteristics of Mass Timber that enable these solutions including how;
  - a. On a weight to strength ratio, engineered wood products generally match, and in some cases exceed the performance of reinforced concrete;
  - b. Building engineered wood high-rises will be possible once further analysis and testing is carried out ;
  - c. Mass Timber behaves very well in fire and is significantly different in fire performance to that of light wood frame.
- Life safety issues including fire protection and building code compliance;
- Building envelope issues including thermal performance, water ingress protection, building movement;
- Durability and longevity;
- Acoustic and vibration performance;
- Cost effectiveness;
- Constructability and construction schedule;
- Market and consumer expectations.

WHY THIS REPORT IS IMPORTANT

- **Climate Change:** FFTT is a structural solution that has a much lighter carbon footprint than functionally equivalent concrete and steel systems.
- **Cost Competitiveness:** FFTT (Mass Timber) is a cost competitive alternative to concrete for high-rise construction to 30 storeys.
- **Economic Diversification:** The FFTT approach and future alternative Mass Timber approaches offer a Value Added option for the Canadian economy, building on the foundation of our sustainable forestry stock.
- **Rapidly Renewable Resource, Forestry Diversification and Market Opportunities:** Mass Timber includes CLT that can capitalize on our current forest stock. It also includes an LSL alternative to CLT. LSL is made from fast growth species offering a more rapidly renewable alternative to solid engineered wood solutions.
- **National and Global Demand:** The trend of increasing urbanization around the world demands alternative safe techniques to build tall buildings in a carbon neutral manner.

Executive Summary

This study illustrates how Mass Timber products, when used in combination with new structural approaches are significantly different from light wood-frame approaches in their ability to build mid-rise (6-12 storeys) and tall buildings (+/- 30 storeys). The study details how Mass Timber structures can meet relevant structural design criteria and fire and life safety needs, and do so within cost competitive marketplace conditions. We have framed the many preconceptions that exist for consumers, building code authorities, private developers and the construction industry and have addressed how those preconceptions can be answered with science, engineering, design and reference information and testing. Finally we speak to the steps necessary to expand on this research with greater detail, testing and ultimately prototype buildings that will help introduce Tall Wood buildings to urban environments around BC, Canada and elsewhere in the world.

For those new to the subject of building structures, it is important that we offer a context for why this study is so fundamentally important now. For more than a century, mid-rise and tall buildings around the globe have been built predominantly in concrete and steel. These two existing materials have been excellent choices and will continue to be important materials in the construction of all buildings in the future. The questions then arise; why the need for an alternative to concrete and steel for mid-rise and tall buildings, and why now? The answer is simply Climate Change.

Concrete and steel have a large carbon footprint and are highly energy intensive materials to produce. Over the last twenty years, as the world's understanding of anthropogenic climate change has evolved, we have seen the large impact that buildings contribute to the green house gases causing climate change. Concrete production represents roughly 5% of world carbon dioxide emissions, the dominant green house gas. In essence the production and transportation of concrete represents more than 5 times the carbon footprint of the airline industry as a whole. It is clear that the very fundamentals of what materials we build our buildings with are worth re-evaluating.

The essential shift that we will discuss is the unique carbon profile of wood. When harvested sustainably wood systems used as substitutes for other materials typically reduce greenhouse gas emissions. In addition wood's ability to store carbon makes it a very important challenger to steel and concrete as a structural building material. For wood to be a viable alternative it must be cost competitive and safely perform structurally at greater heights than previously envisioned. This is just one motivation for research internationally into Tall Wood buildings.

The study will show that buildings from 10 to 30 storeys can be achieved using new Mass Timber techniques and will discuss how and why these buildings will become important choices in the marketplace of the future.

It is the opinion of the authors of this study that the implementation of the ideas within this document will revolutionize the construction methodologies for mid-rise and tall buildings. It is important for readers to understand that this is a conceptual design solution and that time, additional design and engineering development will be necessary before considerable heights are realized in built form and building regulations embrace the use of such systems.

Historic and Global Context

Tall Wood buildings are not a new concept. 1400 years ago tall pagodas in Japan were built to 19 storeys in wood and still stand today in high seismic, wet climate environments. Several countries around the world have a history of building Tall Wood buildings. In Vancouver's Gastown neighbourhood 7 and 10 storey heavy timber buildings have stood for the last hundred years.

Current innovations worldwide have triggered a race to create taller wood buildings. The 9 storey Stadthaus building in London illustrated how Tall Wood can be a competitive system in the marketplace. Recent initiatives include a proposed 10 to 12 storey building in Melbourne Australia, a 17 storey building in Norway and a 30 storey hybrid timber and concrete building in Austria. Each building design takes a different structural approach to Mass Timber construction. Each illustrates the development and expansion of this important new market.

What is Mass Timber?

The important shift that this report will address is the fundamental difference between small-scale dimensional lumber solutions (light wood frame) and Mass Timber construction. Mass Timber is defined as solid panels of wood engineered for strength through laminations of different layers. The panels vary in size but can range upwards of 64 by 8 feet (20m x 2.4m) and in the case of CLT can be of any thickness from a few inches to 16 inches or more. Ultimately these are very large, very dense solid panels of wood. The three primary Mass Timber products that we will discuss are:

- Cross Laminated Timber (CLT) made from layers of solid wood set at 90 degree orientations.
- Laminated Strand Lumber (LSL) made from a matrix of thin chips.
- Laminated Veneer Lumber (LVL) made from thin laminations of wood similar to plywood but much larger in scale.

These Mass Timber products offer significant benefits over light wood frame techniques in terms of fire, acoustic performance, and structural performance, scale, material stability and construction efficiency. Education of the public on the differences between wood stud and Mass Timber is an important effort in bringing these ideas to the market.

Wood and Climate Change

Wood is typically the best principal material available for building structures with respect to embodied energy use, carbon emissions and water usage.

Sustainable forest management and forest certification are a necessary precursor to the increased use of wood. The ability of the public to embrace an increase in wood buildings comes with a strong understanding of the overall impact on BC, Canada and the world's forests. Deforestation is a critical contributor to anthropogenic climate change. The concept of using more wood will only be fully embraced when the harvesting of wood is understood to be truly sustainable and responsive to the environment.

Diversity of the forest ecosystem will be informed in part by the evolution of LSL solutions in compliment with CLT. Faster growth birch and aspen are used in LSL which becomes a viable Mass Timber option in the proposed FFTT system. The ability to increase forestry diversity may provide net economic and forest security in BC and Canada.

Structural/Height Findings

Mass Timber buildings are changing the scale of what is possible to be built in wood around the world. Different systems will continue to evolve but our proposed FFTT system can efficiently achieve heights of 30 storeys in a predominantly wood solution (with steel beams). The CREE system in Austria has shown that a 30 storey hybrid wood and concrete structure is possible.

The FFTT system has been engineered to address the seismic codes for the Vancouver market. Engineering analysis has shown that in the case of a wood structure it is sometimes wind load on the building that governs the design and in some approaches earthquake forces that govern. This is due to the significantly lighter weight of a wood structure compared to its concrete counterpart. The relative weight difference between a wood structure and a concrete structure results in savings on foundations that are particularly relevant in poor soil areas where foundation costs can be high.

The FFTT system is a predominantly wood system with a solid wood central elevator (and stair) core and wood floor slabs. Steel beams are used to provide ductility in the system to address wind and earthquake forces. Concrete has been used for the below grade areas of the structure.

Wall thicknesses of Mass Timber are comparable or thinner than concrete walls due to the dramatic difference in the fundamental weight of the building. This means that there is no floor area penalty to a developer interested in a FFTT building.

The FFTT system allows for open plans that will accommodate both office and residential uses.

Building Code/Life Safety Findings

The current building height limit for wood buildings in BC is 6 storeys. This height limit was established with light wood-frame (wood-stud) structures in mind. Mass Timber buildings are significantly different from light wood-frame buildings in their fire performance due to the solid nature of the timber panels and their inherent ability to resist fire without the addition of protective membrane barriers. Fire history and recent fire testing in Europe and Canada has demonstrated that solid wood structural elements can be designed to perform to a 2-hour fire-resistance rating as required for high buildings, using one of the two methods as described below. Appropriately-designed Mass Timber buildings will not create the arrangement and volume of combustible concealed spaces that are a possibility with light wood-frame construction, as the solid wood panels form a key part in the fire-rated assemblies between compartments of the building. Wood shaft systems can be protected with non-combustible lining materials and sprinkler systems to resolve issues associated with vertical flame spread. In addition to the typical 'active' fire protection systems (automatic sprinkler systems, fire alarm and detection systems), there are two primary design approaches to assessing acceptable structural passive fire protection measures in a Mass Timber building:

Charring Method

Although wood is considered a combustible material, well designed heavy-timber (large wood column and beam) and Mass Timber (panel product) structures have been recognized as having good performance in fire by North American and International standards. This is due to the fact that in heavy timber and Mass Timber construction there is a sufficient mass of wood that a char layer can form (incomplete combustion) and that in turn, helps to insulate the remaining wood from heat penetration. Once ignited, structures classified as "heavy timber" exhibit excellent performance under actual fire exposure conditions. Due to the ability of wood to form a protective char layer during combustion, the fire-resistance rating of large-sized members can be calculated based on minimum structural thicknesses and the remaining sacrificial thickness available for charring. This fire safety design approach is of particular interest as it is consistent with the technical analysis of Mass Timber structures in Europe and would ultimately facilitate the most sustainable design solution for fire protection in Tall Wood buildings. The charring approach is being used in other international jurisdictions.

Encapsulation Method

The alternate approach to ensuring adequate fire performance of the Mass Timber assemblies is ‘encapsulation’ by method applying 2 layers of fire-rated gypsum board to the underside of floors and generally throughout the building, similar to standard construction techniques used to construct fire-rated floor, roof and wall assemblies in both combustible and non-combustible building types. This technique has been accepted as an alternate solution to enable building code requirements for non-combustible construction.

Architectural Findings

While on the surface this exercise is about defining a universal structural system using FFTT to engineer Tall Wood buildings, it is important to understand a number of architectural issues that are essential to the system’s success. The report has intentionally steered away from illustrating the ‘look’ of a finished building to leave the ideas open to the imagination of all architects.

FFTT allows for flexible tower planning and façade design to the height of 30 storeys currently studied. Flexibility is very important for a number of reasons:

1. An open plan (where there are no interior structural partition walls) allows for a variety of uses including office or residential.

2. Developers typically rely on flexibility in tower structural systems to ensure they can adjust planning layouts to meet their market goals. Open plans give enormous design flexibility to developers and architects.

3. Exterior character and massing are important to adjust to the specifics of a given site, setback requirements, views and view corridors, shadowing conditions or architectural expression.

In addition to understanding the impacts on flexible planning, the report reviews building envelope conditions, acoustic conditions, systems integration and provides typical details to show how various components work in addressing fire and life safety requirements. In general we have found that FFTT is a viable solution from all planning, technical, and aesthetic perspectives to satisfy the typical needs of a tower design.

Industry Perception

Our interviews with contractors and developers resulted in a host of revealing information.

Contractors initially struggled to know who they should bring to our meetings. Is this a wood building where wood-framing trades will be suitable or is this more like a concrete tilt-up building or a steel frame building? The answer certainly proved to be that these solutions warrant the skills of tall building contractors foremost and that FFTT is perhaps most akin to tilt-up concrete in the way it is erected. There was also discussion of the effective speed of erection and how speed affects the overall cost of a project. It was felt that a high efficiency tall concrete building in Vancouver where the industry has honed some exceptional skills would allow a floor to be erected in 4 to 7 days in concrete. It was felt this could be significantly faster in FFTT depending on the level of pre-assembly on the ground and the area for lay down of the material and access to the site for regular panel delivery.

Developers saw a different set of issues and most often wanted to understand the perceived risk. Would consumers buy into these Tall Wood buildings? How would a developer position the building in the market? Would it impact long-term resale? How will the first Tall Wood buildings be best realized? What would it feel like to live in a Tall Wood building? Would it have vibration issues as trucks drive by? To answer this several prototype buildings need to be realized. The feeling was that a public-private partnership or public incentive might be necessary for the first to reach the market. Cost effectiveness of construction and overall project costs would ultimately be the determining factor.

Market Perception

Our interviews with Vancouver real estate marketing groups revealed a number of challenges and opportunities with building Tall Wood projects in the private sector. Many in Vancouver perceive wood buildings as being less durable and enduring than concrete. Vancouver’s “Leaky Condo Crisis”, where many wood frame buildings experienced moisture problems due to envelope failure, has resulted in a strong perception that concrete is a preferable material choice with better long-term value and performance. While these perceptions are perhaps overly simplified and ill informed, they do capture the sound bite often found in certain markets and need to be addressed with education and new approaches.

The recommendations of marketing groups emphasize the need to reposition wood in the market by speaking to the unique qualities of Mass Timber. Suggestions were made to target high-end projects specifically at the outset to benchmark these new structures at the top of the market. It was felt that trickling down to more affordable developments would be easier than starting solely on the basis of affordability and trying to expand into the higher-end market. It was recommended that positioning initial designs as “exceeding the building code” might be a good means of introducing the systems. This is consistent with a performance-based approach to design that suggests that ‘equal or better’ performance to non-combustible buildings is possible.

In general the concepts of Tall Wood, once understood, were received very positively with a sense of ambition that an effective marketing campaign and strategy would successfully deliver the message to consumers. The marketing groups also expressed a need to find ambitious developers interested in showing industry leadership with initial projects but that other developers would follow if the strategy was well executed.

Cost Findings

A cost analysis was conducted to compute the project costs for both 12-storey and 20-storey FFTT options utilizing both the charring and the encapsulation approach to fire protection. Concrete construction was used as a benchmark building to compare costs with wood. Location factors were then applied to these numbers to further understand applications in different regions of BC.

FFTT includes options of using various Mass Timber products. By assuming for CLT, LSL or LVL options we have worked to increase the cost competitiveness of systems in the marketplace. Each Mass Timber product has unique properties and may ultimately be selected for architectural as well as structural reasons. CLT production is just coming on-stream in Canada, and we have assumed that its pricing will stabilize at a competitive rate against LSL in time to compete for these types of applications.

The estimated costs were developed based on preliminary design drawings that are included in this document. The cost estimates offer a Spring 2011 costing that could inform a decision to proceed with the design development of a project. More precise estimates based on more detailed design information would most likely fine-tune this baseline cost. Our research revealed an industry expectation that as the design development of FFTT building advances, there will be significant reduction in the costs of construction for this type of system.

During the Peer Review period of this document several refinements were made and new ideas were generated. These early indications show potential refinements with significant cost reductions in the system and overall building weight. These refinements have not been priced and analyzed in this report and as such will need to be addressed in the next steps.

The future of carbon pricing suggests scenarios beneficial to Mass Timber solutions. BC's carbon tax today impacts the energy costs used in the production of concrete but largely does not impact steel pricing that is imported from other regions. Current conditions imply that low energy use in wood harvest and manufacture may make Mass Timber a lower risk material in the future, one that it is less vulnerable to energy price fluctuation and carbon emission penalties. Future mechanisms to provide owners with carbon sequestration incentives will arguably make Mass Timber even less expensive than concrete as the carbon economy becomes more monetized.

Table II.1

Region		12 Storey Concrete Frame	12 Storey FFTT Charring Method	12 Storey FFTT Encapsulation Method	20 Storey Concrete Frame	20 Storey FFTT Charring Method	20 Storey FFTT Encapsulation Method
Vancouver		$ 17,550,800	$ 17,518,000	$ 17,856,200	$ 30,097,900	$ 30,297,100	$ 30,989,900
	$ / sf	**$283**	**$283**	**$288**	**$292**	**$294**	**$300**
Northern BC		$ 19,832,404	$ 19,269,800	$ 19,641,820	$ 34,010,627	$ 33,326,810	$ 34,088,890
	$ / sf	**$320**	**$311**	**$317**	**$330**	**$323**	**$330**
Interior BC		$ 18,779,356	$ 18,393,900	$ 18,749,010	$ 32,204,753	$ 31,811,955	$ 32,539,395
	$ / sf	**$303**	**$297**	**$303**	**$312**	**$308**	**$315**
Fraser		$ 17,550,800	$ 17,518,000	$ 17,856,200	$ 30,097,900	$ 30,297,100	$ 30,989,900
	$ / sf	**$283**	**$283**	**$288**	**$292**	**$294**	**$300**
Vancouver Island		$ 18,691,602	$ 18,393,900	$ 18,749,010	$ 32,054,264	$ 31,811,955	$ 32,539,395
	$ / sf	**$302**	**$297**	**$303**	**$311**	**$308**	**$315**

Note: The 20 storey FFTT option indicated is based on the Option 2 design.
The prices shown increases by $2 /SF for the Option 3 structural approach.

The cost summary table reflects full project costs not hard construction costs.

Recommended Studies

As part of the continuing research and development phase of the Mass Timber building design, it is recommended that the following studies, physical testing and research/dialogue initiatives be considered to facilitate FFTT acceptance in the future:

1. **Public Campaign and Education**
2. **Structural Analysis**
   a. Advanced dynamic & non-linear analysis of the proposed lateral load resisting systems
   b. Detailed analysis of typical connection options
   c. More detailed construction and erection engineering, in conjunction with industry experts
   d. Detailed cost analysis in conjunction with cost consultants, suppliers and builders
3. **Structural Testing**
   a. Testing of overall moment frame behaviour, with CLT's as well as LSL/LVL panels
   b. Testing of typical connections
   c. Testing of high and low pressure adhesives for the lamination of LSL and LVL panels
4. **Fire and Building Code Research, Fire Risk Assessment/ Testing**
   a. Development of a fire testing program and fire/smoke modeling
   b. Fire testing of Mass Timber panel assemblies, connections, typical service penetration conditions, etc.
   c. Development of future code change proposals for Mass Timber systems
5. **Market Potential Review and Research in National and Global Markets**
6. **Pilot Project**
   a. We believe it would be beneficial to incorporate these studies into the design and construction of an actual pilot project, where costs and construction issues could be tested in real life. We recommend that the height considered exceed that of platform CLT methods already constructed to 9 storeys and proposed upwards of 14 storeys in other countries. An FFTT prototype of 16-20 storeys or higher would illustrate the capacity of the system well beyond the approaches used elsewhere and situate Canada as a leader in this field.
7. **Wood Design, Material Science and Forestry Discussions and Research**
8. **Cost Evaluation with Steel Alternatives and in National and Global Markets**
9. **Tall Wood Conference and Strategic Planning for Industry Evolution**
10. **Symposium in Fire Performance Based Design of Wood Structures**

Goals of the Study

This report asks and addresses the following questions;

1. What heights are technically and economically feasible for tall Mass Timber buildings in real market conditions?

A hypothetical site in Vancouver has been selected that will consider seismic conditions, fire and life safety regulations and competitive marketplace conditions.

2. Why should we pursue Tall Wood building solutions as an alternative to steel and concrete buildings?

a. Rapidly Renewable Resource, Forestry Diversification
b. Climate Change Benefits
c. Urbanization and the related impact on climate
d. Economic Diversification.
e. Cost Competitiveness

3. What unknowns exist for the building of mid-rise and tall mass-timber buildings in the marketplace?

a. Fire and Life Safety
b. Building Code Authority Acceptance
c. Acoustic Performance
d. Building Enclosure
e. System Integration
f. Construction techniques and methods
g. Cost Analysis

4. What options do we have to address the restrictions and open the door to mid-rise and Tall Wood buildings?

a. How will building codes evolve?
b. What new materials, connection components, etc, will be needed?
c. What testing and evaluation will be necessary?
d. How do we get initial prototypes constructed?
e. How do we convey the solutions to the public who may have preconceptions?
f. What are the insurance risk issues during and post construction?

5. Will Tall Wood buildings be viable in the private development marketplace? What are the opportunities for residential construction and office construction?

a. Why will consumers want to buy or rent in Tall Wood buildings over steel or concrete alternatives?
b. Will developers and building owners want to build in wood?
c. What marketplace biases exist and how can we address them?
d. Is the risk of building code acceptance manageable?

6. What recommendations can be made to further pursue the proposed ideas in detail?

a. Peer Review
b. Public Campaign and Education
c. Structural Analysis
d. Structural Testing
e. Code Discussions, Fire and Building Research, Testing and Evolution of Methodologies
f. Market Penetration Review and Research in National and Global Markets
g. Pilot Project
h. Wood Design, Material Science and Forestry Discussions and Research
j. Cost Evaluation with Steel Alternatives in National and Global Markets
k. Tall Wood Conference and Strategic Planning for Industry Evolution
l. Symposium for fire performance of wood structures

Research Team

Funding Organizations

Funding for this 'Case Study' project was provided to the Canadian Wood Council (CWC) on behalf of the Wood Enterprise Coalition (WEC) by Forestry Innovation Investment (FII). Any results, findings, conclusions or recommendations are those of the author, and do not necessarily represent those of the CWC, WEC and it's partners, FII or the Province of British Columbia.

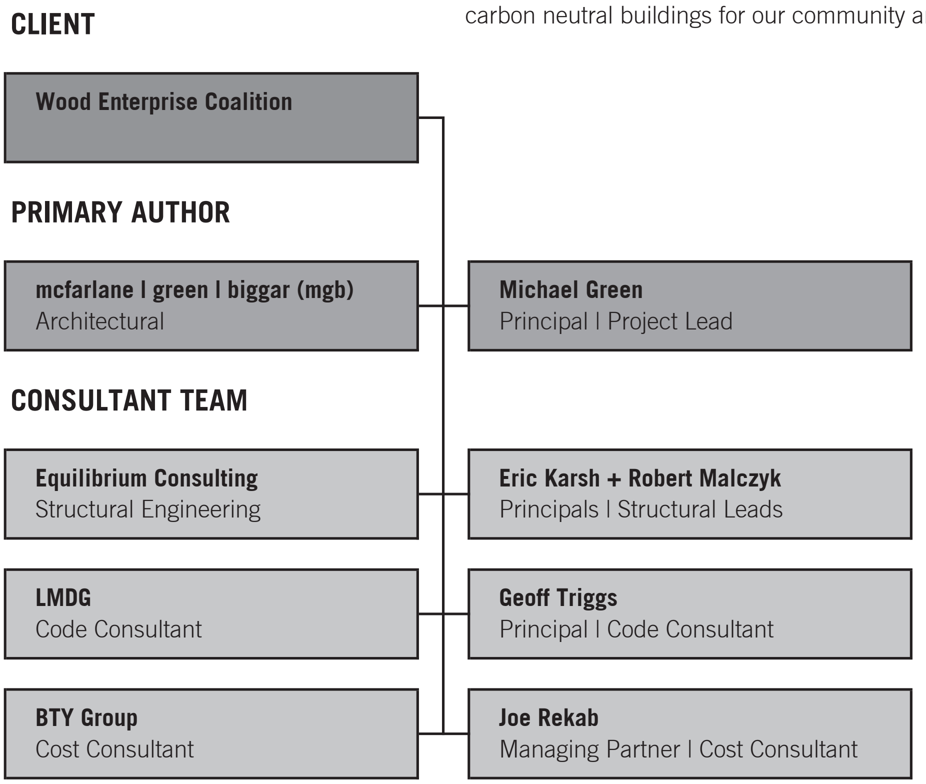
Team

mgb are the project lead for this report and first proposed the need for a study to understand how Tall Wood buildings work and how they can best be introduced into the private sector in particular.

The team has been lead by Michael Green who first introduced the FFTT concept for Tall Wood buildings in 2008. The vehicle for this was a series of public lectures on the benefits of a transition to wood buildings to tackle climate change. The FFTT system has evolved considerably over the last 4 years and this study articulates the engineering challenge involved. The collaboration with Eric Karsh and Robert Malczyk of Equilibrium Consulting has enabled the structural engineering of FFTT buildings to be more fully explored and understood. Equilibrium's unique talent in engineering in wood teamed with the expertise of LMDG and BTY has rounded out a team committed to addressing as much depth as possible in the delivery of these new ideas.

mgb ARCHITECTURE + DESIGN

mgb was founded on the belief that excellence in architecture and design is a product of collaboration, investigation, and vision. The firm strives to be a leader in both architecture and design through innovative uses of wood technology and sustainable practices. mgb is also a champion of a new sustainable aesthetic that utilizes a less-is-more approach. The end result is structures that demand less of the environment while maintaining functional and aesthetic appeal. The firm's work includes a wide array of projects from international airports to skyscrapers, from schools to public institutions, from galleries to libraries and from mixed-use residential to private interiors. The regional and typological diversity of our portfolio teamed with our commitment to shaping the world of architecture and building beyond the boundaries of our specific projects, has lead us to expand our role as researchers, educators and champions of the change necessary in building today; climate change and world housing. These ambitions have lead to extensive public speaking and championing these concepts around the globe. It is part of our quest for learning: to build stronger, healthier, cost effective carbon neutral buildings for our community and beyond.



STRUCTURAL ENGINEERING

Equilibrium Consulting

Eric Karsh MEng, PEng, StructEng, MIStructE, Ing
Robert Malzyk MaSC, PEng, StructEng, MIStructE, MBA
Equilibrium I Principal I Structural Lead

EQ is a full-service, award-winning consulting firm specialized in building structures. The firm is recognized for its creative approach, cost effective designs and commitment to the development of architecturally integrated detailing. The firm has a broad field of expertise and successful experience, including renovation work, upgrades and new construction, on projects with very limited budgets as well as high profile architecturally oriented public projects, large and small. Equilibrium is recognized as a leader in timber engineering in North America. Over the past few years, Equilibrium has pioneered the use of proven, state-of-the-art timber technologies in BC, and has helped raise the local industry's awareness and sophistication through the execution of numerous innovative and architecturally notable timber structures. Technologies such as polyurethane glue glulam, five-axis CNC shaping, state-of-the-art connection systems and cutting edge 3D analysis and CAD modelling, as well as the innovative use of local conventional systems such as gang nailed trusses and wood I-joists are a few examples. Recently, Equilibrium has been a leader in introducing solid wood panel technology to North America.

CODE CONSULTANT

LMDG Ltd.

Geoff W. Triggs ASct, Eng. L, Principal
LMDG I Principal I Code Consultant

LMDG Building Code Consultants Ltd. was founded in 1988. The firm provides building code, fire code and fire protection consulting services to architects, engineers, building owners, developers, insurance adjusters government agencies, lawyers and contractors and is a multi-disciplinary team of professionals with extensive knowledge and experience in fire protection and life safety.

LMDG has extensive experience in the research, development and application of new technologies to facilitate the expanded use of wood products/systems in the residential/commercial construction marketplace. LMDG has worked closely with leading architects/engineers and the CWC/WoodWORKS!BC over the years, and was named as "Wood Champion" in 2009 for our work on such landmark wood design projects as the Richmond Olympic Speed Skating Oval, the LEED Platinum Vancouver Convention & Exhibition Centre Expansion Project, Surrey City Centre and the SkyTrain Millennium Line Stations, which pioneered the first use of wood for modern rapid-transit stations in the world.

COST CONSULTANT

BTY Group

Joe Rekab
BTY Group I Managing Partner I Cost Consultant

BTY Group is one of Canada's most successful and experienced Cost and Project Management consultancies. The firm offers a progressive combination of cost planning, control and project management support services to public and private entities across Canada. In business for over 30 years, BTY Group has earned a reputation for providing clients with professional and practical services of the highest caliber. The diversity of the firms client base attest to BTY Group's ability to adapt critical thinking and analysis to any task at hand. Their integrated approach represents the most progressive method to deliver maximum value and a whole life investment. From offices in Vancouver, Calgary, Edmonton, St. Catherines, Toronto and Montreal they have provided capital investment support to clients in the health, education, research, transportation, leisure, retail, residential and commercial sectors. As the group strives to be Canada's leading and most trusted provider of cost, value and project management services they are continuously positioning themselves at the forefront of the industry's most innovated developments and have recently been involved in presentations across the country on the topic of timber construction in Canada.

TALL

WOOD

RESEARCH PHASE PART 1

1.1 Climate Change, Population Growth and our Forests

Tall Mass Timber Buildings and Climate Change

For more than a century urban skylines around the world have been shaped by tall buildings constructed with the incumbent materials of steel and concrete. These materials have outstanding structural properties and have been historically appropriate choices for tall buildings throughout the modern era. Architects and engineers have explored the potential of concrete and steel extensively and have developed considerable understanding of their performance in a variety of environments including high seismic and high wind load areas. These materials have enabled buildings to stretch to great heights that are continually being pushed around the world. Fire protection of these materials has also developed over the last century with considerable understanding of how to appropriately protect the structure, the occupants and fire fighters in the event of fire. Today we have a new paradigm that calls into question these two incumbent materials and asks if there are other alternatives with less impact on climate change.

Today 50% of the world's population lives in urban environments. UN Habitat estimates that by 2050 roughly 70% of the world will live in urban environments. These environments will continue to demand large building solutions, as urban density becomes an increasingly important part of addressing climate change. UN Habitat also estimates that 3 billion people will need a new affordable home in the next 20 years. In today's building tradition this means that mostly concrete buildings will be built to meet this demand. Concrete's large carbon footprint will continue to be a challenge without alternative structural solutions for the world's major urban environments.. (UN-HABITAT 2008)

As our understanding of anthropogenic climate change evolves we have come to understand that green house gas emissions and in particular the dominant green house gas of carbon dioxide has a direct impact on the green house effect that is impacting overall global warming.

The two ways the world can address climate change will be to:

1. Reduce carbon and other green house gas emissions
2. Find ways to store carbon and other green house gases

Wood can contribute to both of these critical tasks.

Emissions

The building industry represents approximately a third of green house gas emissions worldwide. This is primarily due to fossil fuel consumption in building operations such as heating, cooling, and lighting and, to a lesser extent, the embodied energy consumption in materials and building construction and maintenance. Fundamentally the large carbon footprint of buildings must be reduced for the world to address climate change.

The effects of embodied energy in structures are significant, and they will command our attention more as buildings become increasingly energy efficient (thereby changing the operating versus embodied energy ratio). Numerous publications have highlighted the lighter embodied footprint of wood over other systems. For example, the 2004 Canadian Wood Council document, Energy and the Environment in Residential Construction, presented operating and embodied energy assessment results, based on life cycle assessment. These results were summarized into six categories: primary energy, greenhouse gas emissions, air pollution, water pollution, solid waste production and resource use. This study included assessment of the following building life cycle stages: product manufacturing, on-site construction, maintenance and replacement, and building end-of-life (demolition and final disposition of materials). While a study of single family housing at a much smaller scale to the Mass Timber typology proposed, the results are worth discussing here as base statistics:

> "The steel and concrete designs embody 26% and 57% more energy relative to the wood design, emit 34% and 81% more greenhouse gases, release 24% and 47% more pollutants into the air, discharge 400% and 350% more water pollution, produce 8% and 23% more solid waste, and use 11% and 81% more resources (from a weighted resource use perspective)." (Canadian Wood Council 2004)

Carbon Sequestration

A growing forest removes carbon dioxide from the atmosphere and stores this carbon in vegetation and soil. Some of this carbon is released back into the atmosphere through decaying trees, forest fires, insect outbreaks, and forest management practices. A forest, if managed properly, is a large carbon reservoir. When a tree is manufactured into a lumber product, the carbon accumulated in the tree is stored within that product for its complete life cycle. Wood stores somewhere between 1 to 1.6 tonnes of carbon dioxide per cubic meter of wood depending on species, harvesting methods and secondary manufacturing methods. (FPInnovations 2011) A typical North American timber-frame home captures about 28 tonnes of carbon dioxide, the equivalent of seven years of driving a mid-size car or about 12,500 liters of gasoline. (BREAAM 2010, Naturally wood 2010) The success of carbon sequestration relies on sustainable forestry practices as well as strategies for management of wood products at a building's end of life. If Mass Timber building systems were to become common in the building industry, the amount of carbon stored in buildings would significantly increase.

Until recently there was simply no need to innovate a new structural solution for mid-rise and tall buildings. The impacts of climate change raise the need to look to better solutions than steel and concrete. Wood will be an important part of the solution. This is not to say that concrete and steel will be eliminated from construction. Indeed hybrid solutions of wood, steel and concrete will be necessary. Each has a purpose but in the end increasing wood use in large buildings is a viable approach to carbon-neutral building structures.

Sustainably Managed Forests

The realization of mid-rise and tall wood buildings will, in time, dramatically increase the demand for wood. This raises a valid question of whether the world has enough forest resources to sustainably support such an initiative. A key component to answering this question is understanding the difference between deforestation and sustainable harvesting of our forests.

Deforestation is the permanent conversion of forest to non-forest uses such as agriculture or urban development. Sustainable harvesting is the removal of trees with long term replanting and species diversification inherent in the planning process; the forest remains a forest. Sustainably managed forests are necessary to support the economic and carbon sequestration arguments for mass wood building systems. Mainstream acceptance of increased wood use and tall wood buildings in the market requires a strict adherence to the principals of a sustainably managed forestry sector.

A sustainably managed forest is regulated by provincial governments setting standards to ensure forests are regenerated and that multiple forest values are respected. Common factors that are incorporated into these standards are the composition of species, the density, distribution, age and height of the regenerating trees, and the distribution of various forest types and age classes across the landscape. Sustainable forest management is monitored by applying a set of indicators, which are objective measures that can be supported by data and by certification systems. The three certification systems that are most commonly used and recognized are the Canadian Standards Association (CSA), the Forest Stewardship Council (FSC), and the Sustainable Forestry Initiative (SFI). These sustainability indicators include biological diversity, ecosystem conditions, economic and social benefits and society's responsibility. (NRCAN 2011) Canada has by far the most certified forest in the world; at over 15.1 million hectares, Canada has 42% of the world's third party certified forest. The vast majority of Canada's commercial forests are certified (refer to www.certificationCanada.org).

Basic requirements of credible forest certification programs include:

1. Forest management practices that conform to existing laws.
2. Protection of biodiversity, species at risk and wildlife habitat; sustainable harvest levels; protection of water quality; and prompt regeneration (e.g., replanting and reforestation).
3. Third-party certification audits performed by accredited certification bodies.
4. Publicly available certification audit summaries.
5. Multi-stakeholder involvement in a standards development process.
6. Complaints and appeals process.

Notes on Canadian Forests

Canada has 91% of its original forest cover, and its rate of deforestation has been virtually zero for more than 20 years. (FAO Advisory Committee on Paper and Wood products 2003)

Canada's forests are 94% publicly owned and managed by government on behalf of all Canadians. As a result, the Canadian forest industry operates under some of the toughest environmental laws anywhere in the world, and these laws are strictly enforced.

Canada harvests less than 1% of its forest each year and by law public forests must be regenerated.

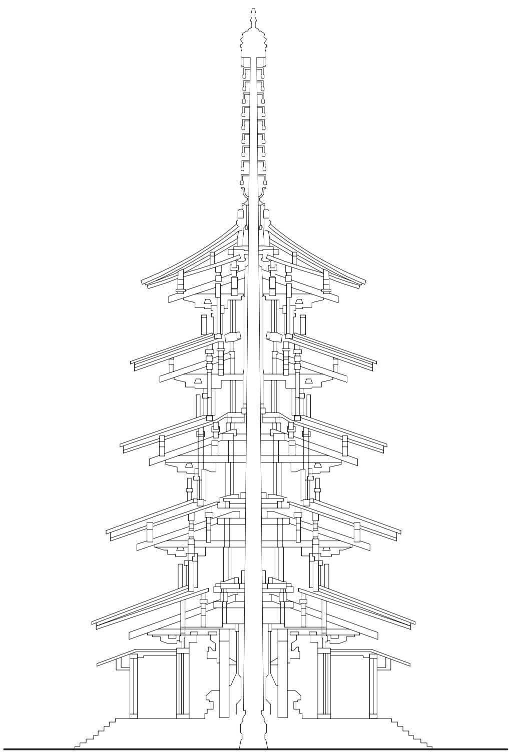
Building Life End

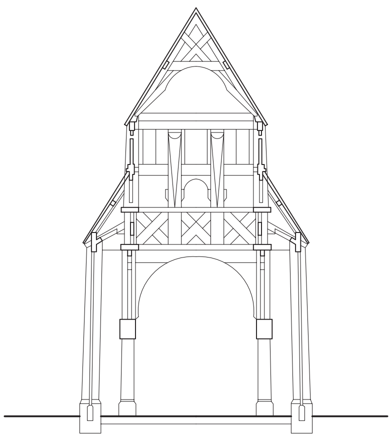
If at the end of a building's life cycle its wood components is not transformed into other uses, we will only have succeeded at delaying climate change (not reversing it) with an extended release of stored carbon into the atmosphere through decomposition or burning. The transformation of structural composite lumber to other uses at a building's life end is a fundamental component of a regenerative approach to sustainability.

1.2 Context for Tall Wood

Wood Structures throughout History

Tall Wood buildings have existed for centuries. 1400 years ago tall pagodas in Japan were built to 19 storeys in wood and still stand today in high seismic and wet climate environments. Several countries around the world have a history of constructing tall wood buildings including examples here in Vancouver of up to 9 storeys. Heavy timber structures have stood for the last hundred years. In 2008, the Stadthaus project in London was the impetus for continued innovation in Mass Timber building - evident in current proposals for bigger and taller buildings in wood up to 30 storeys.

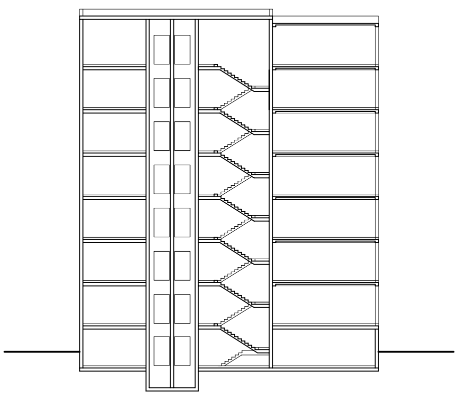




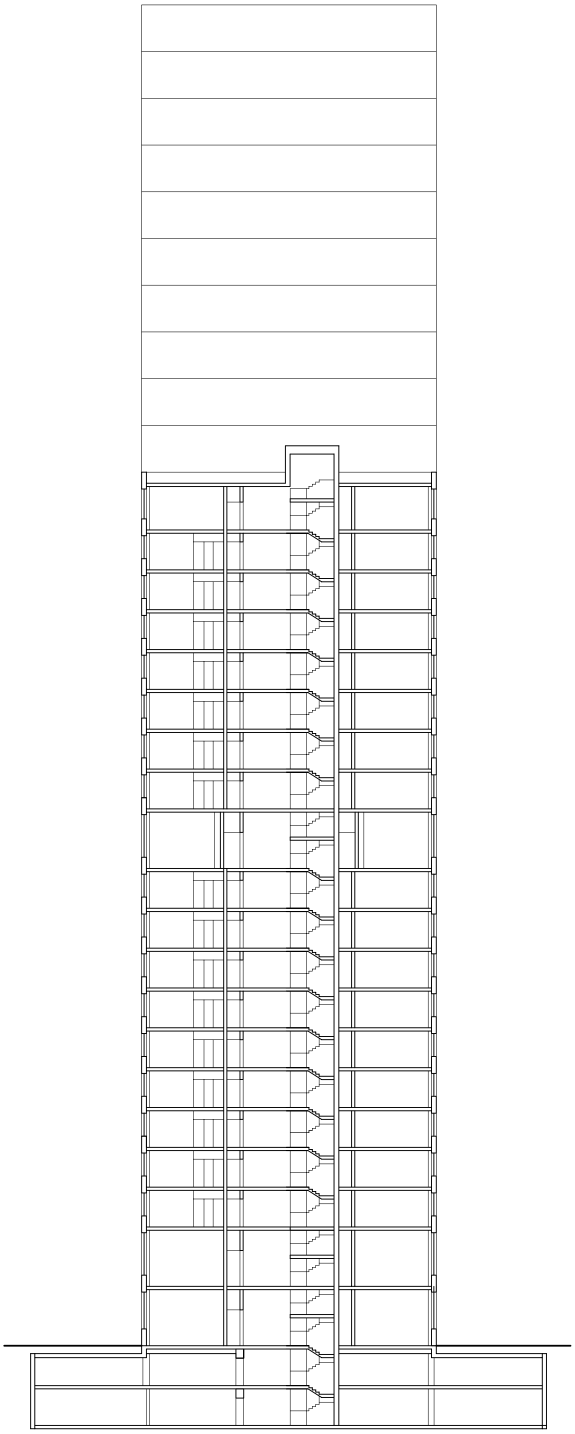
Horyu-ji Temple
Architect: N/A
Date of completion: 603-1603
Location: Nara, Japan
Building type: Temple
Design: 5 Storey pagoda (32.25 Metres / 122 Feet)
Structure: Central wooden pillar; timber; Japanese joinery

Urnes stavkirke Stave Church
Architect: N/A
Date of completion: 1130
Location: Norway
Building type: Medieval Church
Design: 1 Storey
Structure: ; Heavy Timber; Post and Beam

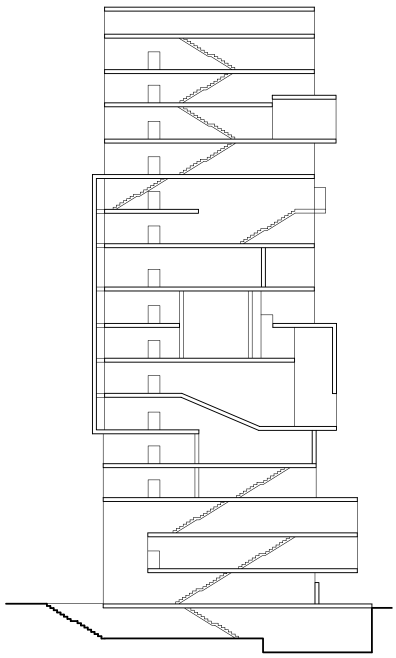
Stadthaus, 24 Murray Grove
Architect: Waugh Thistleton Architects
Date of completion: 2008 Realized
Location: 24 Murray Grove, Hackney, London
Building type: Residential
Design: Nine storey timber tower
Structure: KLH cross-laminated timber panel system



LCT ONE
Architect: CREE (Creative Renewable Energy and Efficiency), Design by Hermann Kaufmann
Date of completion: Construction Start - Sept. 2011
Location: Dornbirn, Austria
Building type: Mixed Use
Design: 8 storey mixed-use tower
Structure: Hybrid glulam beams and reinforced concrete slab; pre-fab construction



LifeCycle Tower
Architect: CREE (Creative Renewable Energy and Efficiency)
Date of completion: Unrealized
Location: Dornbirn, Austria
Building type: Mixed Use
Design: 20-30 storey mixed-use tower
Structure: Hybrid glulam beams and reinforced concrete slab; pre-fab construction



Barentshouse Kirkenes
Architect: Reiulf Ramstad Architects
Date of completion: 2009 Unrealized
Location: Kirkenes, Norway
Building type: A centre for cultural and innovative interchange between Russia and Norway
Design: 16-17 Storey
Structure: Wood / N/A

1.3 World-Wide Reference Projects and Studies

Stadthaus, 24 Murray Grove

Constructed entirely in timber, the nine-storey high-rise in Hackney is the tallest timber residential building in the world. Comprised of both private and affordable housing, Murray Grove provides twenty-nine apartments.

The building has been assembled using a unique cross-laminated structural system pioneered by KLH of Austria. Architect Andrew Waugh worked very closely with KLH to integrate the technology without sacrificing the design principles. The cross laminated solid timber panels form a cellular structure of platform framed, timber load bearing walls, including all stair and lift cores, with timber floor slabs, making it the tallest pure timber building in the world.

Each of the panels is prefabricated including cut-outs for windows and doors. As the panels arrived on site they were immediately craned into position, dramatically reducing the time on site. The entire nine-storey structure was assembled within nine weeks.

The structure of the Murray Grove tower will store over 181 tonnes of carbon. Additionally, by not using a reinforced concrete frame, a further 125 tonnes of carbon are saved from entering the atmosphere. This is equivalent to 21 years of carbon emissions from a building of this size, or 210 years at the current requirement of 10% renewable energy usage.

Regulations in Europe have meant there are no precedents for this scheme. Finland allows only three-storey timber buildings. Austria prohibits timber housing above five floors. However, the engineering methods of timber construction pioneered by Waugh Thistleton and Techniker are now being added to UK Building Regulations in annexe form. For the moment, the UK remains the only country to produce the tallest cross-laminated high-rise across the continent. (Detail 2009)

Image: Waugh Thistleton Architects

Architect: Waugh Thistleton Architects
Date of completion: 2008 (realized)
Location: 24 Murray Grove, Hackney, London
Building type: Residential
Design: Nine storey timber tower
Structure: KLH cross-laminated timber panel system

Barentshouse Kirkenes

Recently the Norwegian Barents Secretariat announced plans for a new cultural centre that is being touted as the world's tallest wood building. The Secretariat hopes that the new structure will serve as a physical symbol of their important role in the High North – a lighthouse of sorts and a beacon of knowledge and development. As part of that role, the new office and cultural centre will also act as a model for sustainable building and carbon neutrality.

The new tower by the Secretariat will be located in Kirkenes, Norway and will be 16-17 storeys tall and constructed from natural materials with innovative and environmental solutions in all parts of the building. Oslo-based Reiulf Ramstad Architects are responsible for the ambitious project, which will be situated in downtown Kirkenes on the historical ground of a multi-ethnic area.

To achieve carbon neutrality, Reiulf Ramstad Architects is relying on integrated systems that also enable it to adapt to the changing seasons and climate. The firm also plans to reuse biodegradable household and industrial waste to produce bio-gas. Recycled materials from the surrounding area will be incorporated into the design, which is based on traditional architecture from Russia, Sweden, Finland and Norway.

The interior of the centre will house energy-efficient offices for the Barents Secretariat as well as a library, a theater and a creative environment for artists, researchers, students and other relevant institutions. Their goal is that the wood structure will serve as an example of sustainable construction for the surrounding region while acting as a centre for cooperation between Russians, Finns, Swedes, Saamis and Norwegians.

The arctic town of Kirkenes is the hub of regional relations between Norway and Russia. This building will mirror the diverse interchange that is taking place between the two nations and symbolize innovation and international cooperation. Wood and timber play an important role in the culture and traditions of both nations. Therefore the concept was to create a single edifice out of wood. The result will be the tallest wood structure in the world: a multi-functional, architecturally innovative structure that constitutes a pilot project regarding the use of wood in the buildings of tomorrow. (Meinhold 2009)

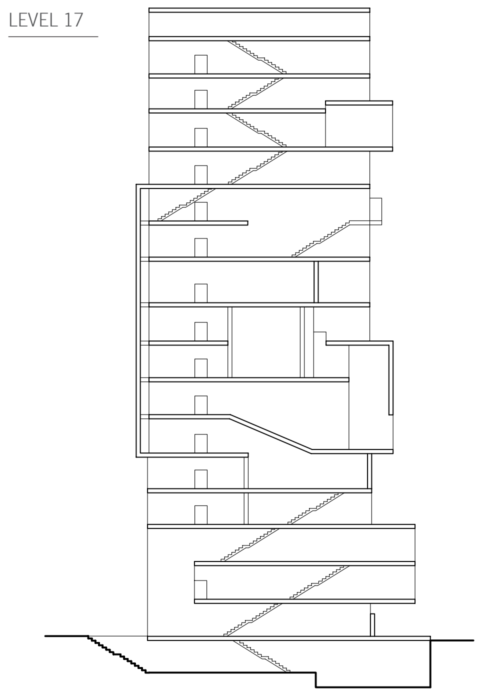


Image: Reiulf Ramstad Architects

Architect: Reiulf Ramstad Architects
Date of completion: 2009 Unrealized
Location: Kirkenes, Norway
Building type: A centre for cultural and innovative interchange between Russia and Norway
Design: 16-17 Storeys
Structure: Wood / N/A

LifeCycle Tower

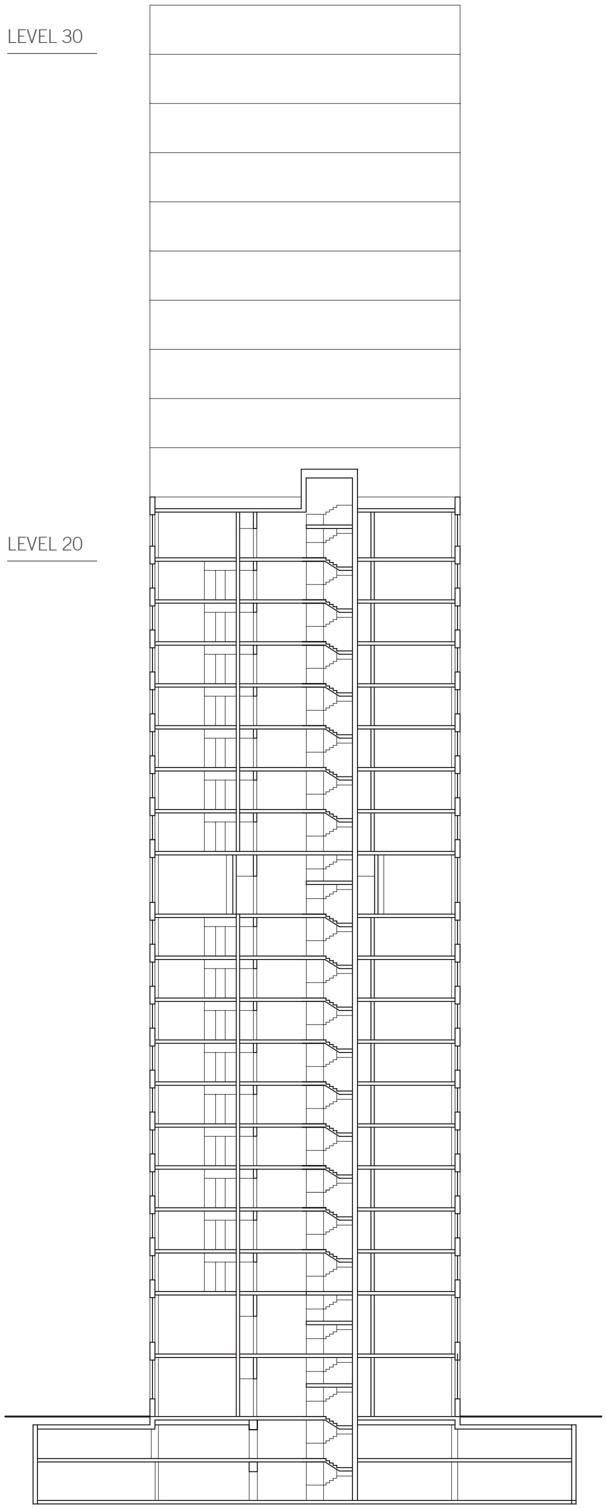
CREE, (Creative Renewable Energy & Efficiency) is in the process of designing one of the most sustainable high-rise building systems ever conceived. Taking into account the entire carbon footprint and lifecycle of a building, the LifeCycle Tower to be built in Dornbirn, Austria uses wood as its primary structural support. When it is completed it will stand 30 storeys tall, competing for the title of the tallest wood structure building in the world. The building is designed to Passivhaus standards and uses prefabricated building modules that can be erected in half the time of a traditional building. An adaptive façade can host solar electric, solar thermal, green panels, or sunscreens, making this a strong candidate for the world's greenest high-rise structure.

The core of the prefab system is a wooden post and beam construction that supports a concrete slab. The utilities and elevator core of the building can be made from either concrete or wood. The exterior shell is engineered to maximize the walls' R-value and reduce thermal bridging. The system has the potential to qualify for the Passivhaus standards which supports, and in fact encourages, larger buildings.

The design is based on a 1.3 metre grid, and can be used for hotels, offices, apartments, or other needs. The façade utilizes a panelized system which can be manipulated for the client's aesthetic preferences and supports a number of technologies. These include a building-integrated photo voltaic (BIPVs) system, green wall system, solar thermal panels or a second glazing curtain. Systems integrations help make best use of energy resources like solar, biomass boilers and passive cooling thanks to the operable windows.

The wood beam post slab configuration is also very earthquake resistant and has excellent fire-resistance without losing as much structural strength as steel. The Glulam beams are set in an interesting horizontal fashion to support the reinforced concrete slab. Utilities and lighting are then run in between the beams. Even the Passivhaus standard windows use wooden frames.

By pushing the limits of one of the most ubiquitous and potentially sustainable building materials and combining it with the benefits of prefab construction and the energy performance of Passivhaus design, the Lifecycle tower comes close to being the ultimate green building. (Michler 2010)



Architect: CREE (Creative Renewable Energy and Efficiency)
Date of completion: Unrealized
Location: Dornbirn, Austria
Building type: Mixed Use
Design: 20-30 storey mixed-use tower
Structure: Hybrid glulam beams and reinforced concrete slab; pre-fab construction

Barsana Monastery

The Barsana Monastery is considered the tallest wooden structure in Europe standing at 56 metres tall (180 feet). Located in the hills of the Maramures Region in Northern Transylvania, the Barsana Monastery stands as the tallest structure in this convent, built in 1720, consisting of multiple orthodox churches. This monastery was created in post-Communist years and has become a significant cultural and religious attraction.

The Barsana Monastery is built of heavy oak beams on a foundation of large blocks of stone. The plan is rectangular with a polygonal chancel apse that is slightly narrower than the main body of the building. On top of the pronaos rises the wooden spire tower which gives the character of these orthodox churches. A two level porch sits on wooden pillars that form rounded arches on the west façade of the church. This porch was added in 1900 along with larger windows to add lighting to the low chancel level. The naos is in the centre of the church which consists of a high barrel vault and two large windows low on the north and south sides. The wooden roof covering the main part of the church is supported by two heavy timber consoles and the ends of the upper beams of the wall.

UNESCO has recently designated this part of the Maramures Region as a World Heritage site to preserve the stylized and vernacular wooden architecture of these monastery churches.

One of the smaller churches under repair showing the type of wood construction used in all of the monastery structures.

Architect: N/A
Date of completion: 1720
Location: Barsana/Maramures, Transylvania
Building type: Monastery
Design: 56 metres (180 feet)
Structure: Heavy timber (oak); stone block foundation

1.4 Canadian Reference Projects and Studies

North Vancouver City Hall

mgb Architecture's design for the expansion and renovation to the City of North Vancouver's City Hall is currently under construction using a Mass Timber structure. The project partially renovates the existing 1970's modern heritage City Hall building and expands the facility into a recently vacated library structure. A new bridging atrium creates a new front door for the building and reorganizes the internal departments of City Hall.

While not a tall building, the North Vancouver City Hall project is an exploration of the use of Mass Timber (LSL) in prefabricated panel form as a new solution for long span floor and roof structures. The Mass Timber roof structure has been pre-fabricated off-site and assembled on site so as to minimize disruptions to the normal operations of the public building. By laminating 4 cross layers of LSL together the panels are 30' long x 12' wide and 14" thick including a 7" void layer between the solid top layer and the intermittent strips of the exposed ceiling layer. The result is a long span panel that allows for services including automatic sprinklers to be integrated within the concealed area of the structure. The structural panel is the finished ceiling eliminating the need for additional finishing of the interior. Equilibrium Consulting completed the structural design for the building.

This solution illustrates how creative paneling solutions can span significant distances in the build up of the FFTT structural solution described in this report.

Architect: mgb ARCHITECTURE + DESIGN
Date of completion: September, 2011
Location: North Vancouver, BC
Building type: City Hall
Design: Renovation and addition
Structure: Free span LSL panels

1.5 Material and System Research

Mass Timber

Mass Timber building systems in this document refer to any of three materials: Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), and Cross Laminated Timber (CLT). These materials each have their own unique properties, but for the purposes of applying them to the FFTT building system, they are essentially interchangeable.

Why Wood?

Mass Timber building systems offer an exciting and innovative solution with possible long term benefits to the building sector, the timber industry and the fight against climate change. Wood is one of the most sustainable means of construction and Mass Timber building systems can offer an efficient solution for large-scale, tall buildings.

In recent years the BC forest industry has been significantly affected by the pine beetle epidemic and mill curtailments. These issues require a shift in the way that we manage and harvest our forests, as well as in the way that we manufacture raw wood into value added product. CLT, LVL, and LSL panels can take advantage of lower grade lumber that otherwise would not be considered for structural uses. After wood is forested, logs are sent to sawmills where it is then sawn into dimensional lumber, broken down into wood chips or planed into veneers. Chips or veneers are either sent to pulp mills or structural composite mills (which could include LSL and LVL). The expanded use of LSL and LVL to take advantage of wood by-products is just one example of how Mass Timber systems would contribute to diversifying the forest and lumber industry.

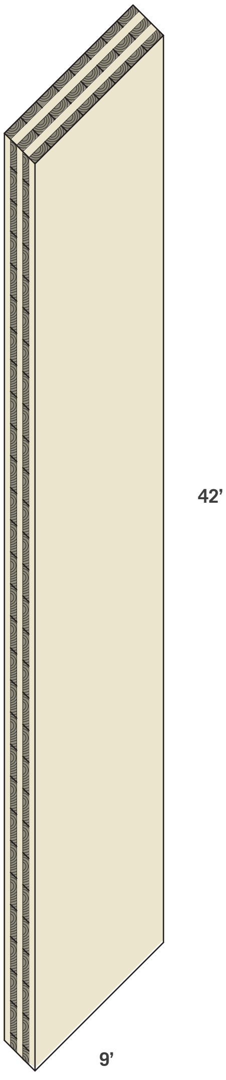
Canadian forests account for 10% of the world's forest cover and 30% of the world's boreal forests. Canada has 397.3 million hectares of forest and other wooded land; annually, less than 1% of Canada's forests are harvested. (NRCAN, 2011) In 2009, the forest industry's contribution to Canada's GDP accounted for approximately 21 billion dollars (1.62%). (Statistics Canada 2009)

Economically, we suggest that the question of relevance should be why **not** wood?

See Section 1.1 for discussion of sustainably managed forests, carbon emissions and carbon sequestration.

Cross Laminated Timber

CLT consists of several layers of boards stacked crosswise (at 90 degrees) and glued together on their wide faces and, sometimes, on the narrow faces as well. A cross-section of a CLT element has at least three glued layers of boards placed in orthogonally alternating orientation to the neighboring layers. In special configurations, consecutive layers may be placed in the same direction, giving a double layer to obtain specific structural capacities. CLT products are usually fabricated with three to seven layers or lamella.



Manufacturing Process:
Selection of lumber, lumber grouping and planing, adhesive application, panel lay-up and pressing, and product cutting, marking and packaging.

Engineering Standards:
Canada and the U.S. refer to APA 320 for engineering standards for CLT. Refer to individual manufacturers for product specifications and standards.

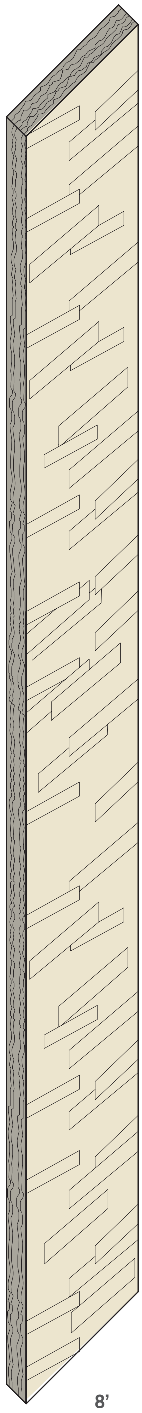
Fire Ratings:
The Canadian Standard for Engineering Design in Wood (BCBC) can be used to calculate the fire-resistance rating of CLT panels along with the same methodology that is currently used for calculating the fire-resistance ratings of glulam and "heavy" timber in the U.S. New Zealand, and Europe.

Adhesives:
Phenol formaldehyde (PF), Phenol-resorcinol formaldehyde (PRF)

Note:
Contact individual manufacturers for specific product information. Adhesives may vary depending on manufacturer.

Laminated Strand Lumber

Laminated strand lumber is a structural composite lumber manufactured from strands of wood species or species combinations blended with an adhesive. The strands are oriented parallel to the length of the member and then pressed into mats using a steam injection press.



Construction:
Strands are oriented parallel to the axis of the member and pressed into solid mats.

Typical Canadian Tree Species Used:
Fast growing species such as aspen or poplar.

Engineering Standards:
Canada and the U.S. refer to LSL as structural composite lumber. Refer to individual manufacturers for product specifications and standards.

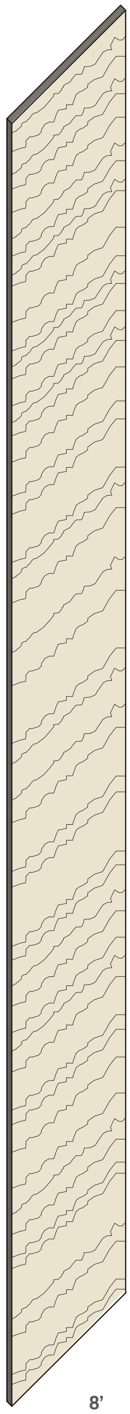
Fire Ratings:
The provisions of IBC Section 721.6.3, design of fire-resistant exposed wood members are applicable to LSL when used as a bending member (beam and header). Fire-rated assemblies are constructed in accordance with the recommendations provided by APA Design/Construction Guide: Fire-Rated Systems, Form W305.

Adhesives:
Phenol formaldehyde (PF), Phenol-resorcinol formaldehyde (PRF), polymeric-diphenylmethane diisocyanate (pMDI)

Note:
Contact individual manufacturers for specific product information. Adhesives may vary depending on manufacturer.

Laminated Veneer Lumber

Laminated veneer lumber is made up of layers of wood veneers laminated together using a waterproof structural adhesive. The manufacturing process consists of rotary peeling a log into veneers that are then dried and graded for strength and stiffness. After the graded veneers are coated with adhesive they are laid-up into a billet that is then fed into a hot press that cures the adhesive under heat and pressure. The cured and compressed billet then leaves the hot press and is ripped into boards.



Construction:
A parallel-lamination process is used where the grain of each layer of veneer runs in the same direction to achieve uniformity and predictability.

Veneer Thickness:
Ranges from 2.5mm to 4.8mm

Typical Canadian Tree Species Used:
Douglas fir, larch, southern yellow pine, poplar, and aspen

Engineering Standards:
Canada and the U.S. refer to LVL as structural composite lumber. Refer to individual manufacturers for product specifications and standards.

Fire Ratings:
The provisions of IBC Section 721.6.3, design of fire-resistant exposed wood members are applicable to LVL when used as a bending member (beam and header). Fire-rated assemblies are constructed in accordance with the recommendations provided by APA Design/Construction Guide: Fire-Rated Systems, Form W305.

Adhesives:
Phenol formaldehyde (PF), Phenol-resorcinol formaldehyde (PRF)

Note:
Contact individual manufacturers for specific product information. Adhesives may vary depending on manufacturer.

(Department of Housing and Urban Development 2010)
(National Research Council Canada 2007)
(APA The Engineered Wood Association 2010)
(Vacca, LP SolidStart Engineered Wood Products and Formaldehyde Emissions 2009)
(FPInnovations 2011)

Adhesives used in Structural Composite Lumber

Adhesives are used in structural composite lumber for lamination purposes and to transfer stresses between adjoining wood fibers. The adhesives used for Structural Composite Lumber products in Canada vary slightly depending on the manufacturer but most panels are composed of phenol-formaldehyde (PF), phenol resorcinol-formaldehyde (PFR) or polymeric methylene diphenyl diisocyanate pMDI adhesives.

The selection, application, and curing of adhesives are controlled at the point of manufacture with extensive testing of physical properties, reliability of bond, performance under environmental factors and emission of VOCs (volatile organic compounds).

Understanding Formaldehyde

While formaldehyde is commonly known to be an irritant and potential carcinogen, it is important to understand the different formaldehyde based products: UF, PF, PRF and pMDI. Formaldehyde is a naturally occurring chemical that is present in the atmosphere, our bodies and even some vegetables we consume. Exposure to formaldehyde happens on a daily basis because of its presence in the atmosphere and in manufactured products.

Manufactured formaldehydes bind formaldehyde with other chemicals and are used in many products from carpets, upholstery, furniture, and computers to medicines, and vaccines. Different types of formaldehyde compounds have different levels of chemical stability that reduce (high stability) or increase (low stability) their emissions of VOCs under different environmental conditions - impacting human health and comfort.

Urea-formaldehyde (UF) is found in many interior and non-structural wood products and is the focus of the LEED Indoor Environmental quality credit 4.4 for Low-Emitting Materials: Composite Wood and Laminate Adhesives. The intent of this credit is to reduce the quantity of indoor air contaminants that are odorous, potentially irritating and / or harmful to the comfort and well-being of installers and occupants. UF is more economical than PF, PFR and pMDI but more readily releases VOCs into the environment when it is sawn or when it is exposed to moisture. UF is not used in Structural Composite Lumber, nor in CLT. (Emery 2002)

Phenol Formaldehyde (PF) is an adhesive derived from the chemical reaction between phenolics and formaldehyde which create a strong bond that is necessary for the composition of any exterior wood adhesive application and eliminates the possibility of VOC emissions.

Phenol Resorcinol Formaldehyde (PRF) has similar properties, but is more reactive than phenol-formaldehyde meaning that curing is faster and takes place at room temperature. LVL and LSL manufacturers typically use a blend of PF and PRF because of the higher cost of resorcinols.

Polymeric Methylene Diphenyl Diisocyanate (pMDI) is an isocyanate based adhesive. As is the case with PF and PRF, cured pMDI forms a strong bond that is not susceptible to the hydrolysis reaction that would cause the adhesive to release VOCs. Properly hardened pMDI is inert and is proven to be well below any emissions standard. pMDI is limited in use due to higher costs and its unique handling procedures. (Vacca, LP SolidStart Engineered Wood Products and Formaldehyde Emissions 2009)

Emissions

Emission levels in products that do emit formaldehyde are highest in a new product and decrease over time. Breathing air containing low levels of formaldehyde can cause burning and watering eyes. As levels increase, it can cause burning of the nose and throat, coughing, and difficulty in breathing. Some people may be more sensitive to formaldehyde and have effects at levels lower than expected.

Although formaldehyde in adhesives would be difficult to replace without losing the performance of the product and increasing costs, alternatives to formaldehyde in adhesives are being tested such as soybean based products and other organic materials.

The emissions from PF, PRF, and pMDI are well below the standard levels that are considered harmful.

LVL and LSL testing has shown that formaldehyde emissions from these products range from 0.02 ppm to 0.04 ppm. (NRC-CNRC Institute for Research in Construction 2009). Recent testing conducted by FPInnovations has shown that a CLT panel emits between 0.015 ppm to 0.05 ppm. (FPInnovations 2011)

The Environmental Protection Agency considers 0.10 parts per million as elevated (elevated meaning the exposure level that can cause side effects in people). The Housing and Urban Development (HUD) has also set limits on the amount of allowable formaldehyde which may be emitted for building materials and contents at 0.3 parts per million. (U.S. Department of Housing and Urban Development 2007)

The newest formaldehyde limits are being implicated by the California government and are known as the CARB Phase I and Phase II for wood composite products, particleboard, MDF, thin MDF, and hardwood plywood (HWPW) with composite core (HWPW-CC) or veneer core (HWPW-VC). By July 2012, phase II will be enforced and formaldehyde emission limits will vary from 0.13 ppm for thin MDF to 0.05 ppm for HWPD-CC.

All available scientific data indicates that the maximum formaldehyde emissions associated with structural composite lumber panels are equivalent to levels present in outdoor air urban environments. Such low levels of formaldehyde are not proven to cause health concerns and problems.

1.6 Evolution of the Building Code

Historical Summary- Current Developments

Historically, buildings of "combustible construction" have been categorized differently than other "non-combustible" building types, and this has been reflected in the usage of wood-framing/wood products for typically small residential projects, and smaller "low-rise" type commercial buildings only. The history of fire losses in buildings has tended to show that buildings of combustible construction are more vulnerable to the effects of fire than the non-combustible alternative, and this is primarily regulated through limitations of building area and building height in either Part 3 or Part 9 of the applicable building codes in Canada. Although the "Building Size and Construction Relative to Occupancy" requirements of Part 3 have not significantly changed over time, more recent changes to the National Building Code of Canada to permit 4-storey wood-frame construction for Residential buildings, and the B.C. Building Code, to permit 6-storey wood-frame construction, indicate that acceptable levels of safety have been recognized with higher wood-frame structures. This is partially due to the benefits of automatic sprinkler protection and further advances in fire separation/firestopping system testing and technology, which are integrated into these building types as part of the required construction and fire safety measures prescribed by the Code.

One of the shortcomings of the current construction classification systems used in the Canadian building codes is that "combustible construction" as a defined term, and as it is applied in the various construction categories (or Articles of Subsection 3.2.2.), is a general term that is used to describe all construction of combustible or wood materials (i.e., light wood-frame, engineered lumber, TJI's, heavy timber structure or other Mass Timber systems). Heavy timber construction is defined separately and is prescribed with minimum dimensional criteria (per Article 3.1.4.6.) to achieve a "45-minute fire-resistance rating", however it is noted that fire engineering analysis have been conducted on historical heavy timber buildings incorporating laminated wood stud floor decking, and massive solid timber beam and column structures. The conclusions of these studies have shown that timber elements greater than the minimum dimensions referenced in the NBC or "heavy timber", can provide a FRR greater than 45 minutes and between 1-2 hours depending on structural loading. In many cases, the structural "weak point" for the building in the event of fire becomes the exposed steel connectors and plates at structural joints, as opposed to the timber elements themselves.

The User's Guide to the NBC 1995 states that the NBC "deals with three principal types of construction: combustible, which has little inherent fire-resistance unless protected; heavy timber construction, which although combustible has a degree of resistance to structural failure when exposed to fire, and non-combustible construction. Even non-combustible construction may require protection to prevent its' collapse when exposed to fire because structural steel or reinforcing steel has its' load carrying capacity reduced at elevated temperatures. The primary difference between combustible and non-combustible construction is that non-combustible materials do not burn and contribute fuel to a fire. Thus, a basic non-combustible structural frame, if adequately protected from thermal effects of a fire, should remain in place throughout a fire and offer some degree of safety to occupants and firefighters. From the foregoing intent statements of the NBC structural fire protection requirements, it is clear that the fundamental Code issue associated with the Mass Timber approach, is that while these solid panel materials can be designed to meet the "fire performance" criteria (2-hour FRR), the system is still made up of combustible construction by definition. Any proposed design approaches and alternative solutions that are developed to utilize these materials beyond the prescriptive Code limit of 6-storeys, must ultimately identify, define and satisfy the intended level of safety that is prescribed by a reference "non-combustible" building (i.e., concrete benchmark building), in delivering a tall building incorporating wood as the primary structural material.

It is important to note that Mass Timber systems such as those described in this report are not directly addressed or contemplated in the current building code requirements of the National or Provincial building codes. Mass Timber systems are an important and unique type of robust solid wood panel design that is not reflected and does not 'fit' within the current building code definitions and classification systems. Although made of combustible materials, the Mass Timber panels are a structural system that has the ability to resist the effects of fire, either in an exposed unprotected condition, or with protection by common thermal membranes such as gypsum board. Technical fire-engineering analysis of timber charring methods and fire performance has been conducted extensively in many international locations. Currently, the existing body of research, testing and documentation that has been developed in EU nations, is being expanded by Canadian research scientists and industry members at FPI in Ottawa, Ontario. New construction assemblies for various solid wood systems including Cross-Laminated Timber (CLT) in both exposed and protected conditions, are being subjected to laboratory testing for fire, acoustics and other material properties, with the objective of developing recognized fire-rated assemblies up to 2-hour FRR. This will increase the technical knowledge base and confidence level with Authorities towards the greater application of Mass Timber systems on large or high buildings in the future.

The intentions of this study from a building code perspective is to break down the barriers between the combustible/non-combustible classifications of building codes, and to ultimately demonstrate that a tall building can effectively and affordably be constructed of mass wood materials, without compromising the fundamental principles of the Code; that is, fire safety, structural safety, environmental separation (envelope performance) and other associated health/accessibility objectives. From a fire protection and life safety perspective, the main intention of the study will be to show that material assemblies and structural systems incorporating Mass Timber systems, will provide an equal level of performance and safety when exposed to conceivable fire scenarios within the interior building spaces (in terms of fire durability of assemblies and fire separation of compartments). Further, this study will examine the occupant safety (both in-situ occupants and emergency responders) parameters that will need to be integrated in the building design, such that the ultimate goal of "life safety" is achieved in the event of a possible fire emergency condition.

From a building code perspective, the primary challenge to be addressed is that a residential building over 6-storeys in building height (and exceeding a limited building area) is required to be of non-combustible construction. The immediate perception from an "Authority Having Jurisdiction" perspective is that a building of 20-storeys, or even 12-storeys in building height and of "combustible construction" will be severely pushing the envelope relative to the fundamental Code principles outlined above. The proposed Project location is in the City of Vancouver and it is noted that the COV Licenses & inspections Department is accustomed to and favourable towards reviewing well-developed technically supported "performance-based" alternative solution proposals for building designs. The Tall Wood Building concept will be carving new territory for this AHJ, and will require early/frequent engagement in order to be successful. It is also anticipated that Vancouver Fire Rescue Services (as the Fire Department AHJ), will have a conservative and concerned regard to the Tall Wood Building design, as the operation and safety of firefighters and other emergency responders will not be permitted to be compromised during an emergency incident in the building.

In early 2011, the National Research Council, the Canadian Wood Council and FPInnovations joined to establish a new consultation group to discuss code changes required to allow taller wood buildings. The group consisted of researchers from the above mentioned groups, design professionals, fire experts, representatives of the concrete, steel and masonry institutes and others.

After a one day meeting held in March in Ottawa, several members of the group concluded that there is a need to change the current height requirements in the code to allow taller wood structures. The main reason was the introduction of new engineered wood materials such as cross laminated timber (CLT) to the Canadian market by several local companies in 2010.

Design professionals, fire experts and researchers noted that the behaviour of solid wood systems such as CLT is completely different than that of light wood frame, which currently dominates the multi-storey wood construction market in Canada. It was noted that structural behaviour of solid wood includes much higher strength and stiffness and superior dimensional stability. Fire experts explained the charring effect that differentiates solid wood from light wood systems, which burn much faster.

The group plans to meet again later this year. In the meantime several CLT research projects are being conducted at FPInnovations and several Canadian universities. The summary of this research will be presented to the group at the next meeting. The ultimate goal of this consultation group is to prepare recommendations for NRC enabling changes to the current height limits for solid wood building systems. In the meantime several CLT and Mass Timber research projects, including small and full-scale testing of Mass Timber panels in different configurations, have been conducted at FPInnovations in Ottawa. This testing has continued from previous research studies conducted in Europe, and will publish fire-performance information relative to solid wood panel systems for future reference by design and industry professionals.

A "design brief and objective-definition" meeting with key COV officials was held early in the design development process to identity such that these potential challenges/obstacles can be understood and addressed as the concept design moves forward. The other main challenge that is anticipated for the Tall Wood Building study is the identification of documented and/or recognized fire-tested building assemblies for the various manufactured wood products that are proposed to be incorporated, since most of these assemblies and products will not have any North American test results.

Building Height and Building Area Regulations

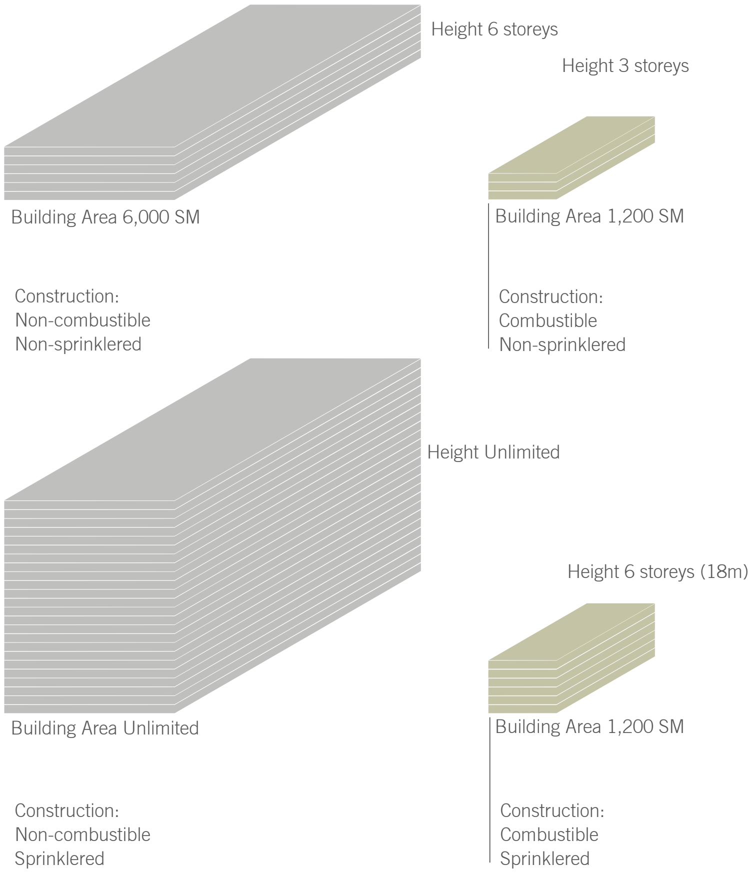
One of the principal roles of the model building code (National Building Code) of Canada is to regulate the size/height of built structures relative to fire safety, and this is primarily achieved by limiting the area/height of buildings incorporating combustible construction, and by requiring incrementally higher fire-resistance ratings for mid-rise to high buildings of non-combustible construction. At the same time, one of the other purposes of the continued development of the NBC, is to incorporate new technologies, materials and methods into the adopted Code requirements, such that they can be readily utilized in the design and construction industry.

Much of the building height and building area regulation in today's building codes are based on historical references and information, which have been perhaps "lost in translation" and are not as critical towards ultimate fire safety within a building as they used to be. For instance, building heights for combustible construction were often linked to the maximum height that a fireman and ladder could reach or the ability of the fire department apparatus/ equipment to cover the building relative to water hose stream pressures. With the advent of automatic sprinkler protection in modern-day buildings, these building height limit considerations are not as important relative to fire fighting and fire safety within the building.

Building heights for combustible construction have been limited to 2-3 storeys for most occupancy classifications up until the 1990's at which time the National and Provincial building codes were changed to allow 4 storey wood-frame construction for Residential and Office type occupancies. This fundamental change was made recognizing the benefits of automatic sprinkler systems towards controlling fires within interior compartments of a building as well as protection of occupants evacuating the building during a fire condition. Similar considerations were utilized in developing the recent 2009 change in the Province of B.C. to 6-storey Residential wood-frame construction. It is important to note that the recent changes discussed above contemplate the use of standard light wood-frame construction methods/materials which is a fundamentally different construction system than the Mass Timber system design that has been developed for this project.

Relative to "building area" limitations, the historical references of building code development again point towards the reduction of large undivided areas of combustible construction, with the objective of minimizing the damage resulting from severe fire conditions and to aid in fire department manual suppression activities towards extinguishment of a fire condition. Several large conflagration events occurred in built-up urban areas during the late 1800's due to the uncontrolled and undivided (i.e., no firewalls) construction of wood-frame buildings. The resulting building area limitations of the building codes have been intended to control the ultimate "fire risk" in conjunction with other factors such as the presence of automatic sprinkler protection, level of fire-resistance provided, building height and number of streets the building is facing. For the subject of the Tall Wood Building design, the building area considerations mentioned above are not as critical with respect to the use of wood materials, in that the building will have a small footprint area (of approximately 500 m^2) and will be a "standalone" tower design that will be spatially separated from adjoining properties.

However, it is noted that Mass Timber systems have also been successfully used for larger footprint buildings (i.e., office, retail and warehouse type buildings) in Europe. Therefore, it is noted that this construction type should not be limited in building area, height, or occupancy classification, provided an acceptable level of building performance can be demonstrated for the site-specific building design condition, including adequate protection of adjacent building or property fire exposure in the case of buildings that may maximize the available site coverage.



References:
Stage 1 Report
Building Code provisions for Residential Buildings and identification of Technical and Process Risks, GHL Consultants
October 29, 2008

www.housing.gov.bc.ca/building/wood_frame/6storey_form.htm

British Columbia Building Code 2006
(3.2.2.42 and 3.2.2.43)
(3.2.2.45 and 3.2.2.46)

Maximum Building Height and Maximum Building Area by Regulation: Non-combustible vs. Combustible

Building Height and the BC Building Code

The regulated building height for combustible buildings in British Columbia has not changed significantly over time, up until the past 20 years as further discussed below. Initially unregulated, height and size restrictions were implemented in North American building codes in reaction to major devastating fires that destroyed large built-up city centres such as San Francisco and Vancouver in 1886.

With the technical advances of fire resistant building materials and the implementation of automatic sprinkler systems, taller wood buildings were deemed feasible and this is reflected in the modern day evolution of Building Code requirements. In 2009, the province of British Columbia made significant changes to its Building Code to allow 6 storey wood frame construction. All of the study and analysis that was done to implement this change was based on the assumption of “stick-frame” platform systems - and many believe that this is the economical maximum achievable with this construction system.

Mass Timber systems, which structurally behave more like concrete systems, are very different from stick-frame wood structures in every aspect. For instance, light-wood frame construction typically requires membrane type protection (GWB) which will create multiple void spaces, whereas Mass Timber designs rely on the solid nature of the wood panels to carry a high degree of inherent fire-resistance in the structure. Their use in modern day construction will change the way we evaluate the safety of wood in buildings. It is noted that the proposed Tall Wood Building design will push the ultimate building height beyond 18 m, which is the benchmark used in the building code to determine if a building qualifies as a “high building”, in accordance with Subsection 3.2.6. A high building is defined as a building with the uppermost floor level exceeding 18 m above grade and containing a Group C (Residential) occupancy. In the City of Vancouver (where the Vancouver Building By-law applies), any building with a floor level higher than 18 m is classified as a high building, and as such, additional measures are required to provide an acceptable level of safety.

The User’s Guide to the NBC 1995 states, “A high building has a specific group of criteria that distinguishes it from lower buildings. Although the criteria are predominantly established on the basis of height, the real concern is that the occupants may not have enough time to evacuate before smoke contamination reaches lethal levels in some parts of the building.” The purpose of Subsection 3.2.6. for high buildings is threefold:

› To provide for the safety of the occupants of a building, by maintaining the tenability of occupied floor spaces during a fire emergency, and by providing a means for all occupants of the fire floor to leave that floor quickly;

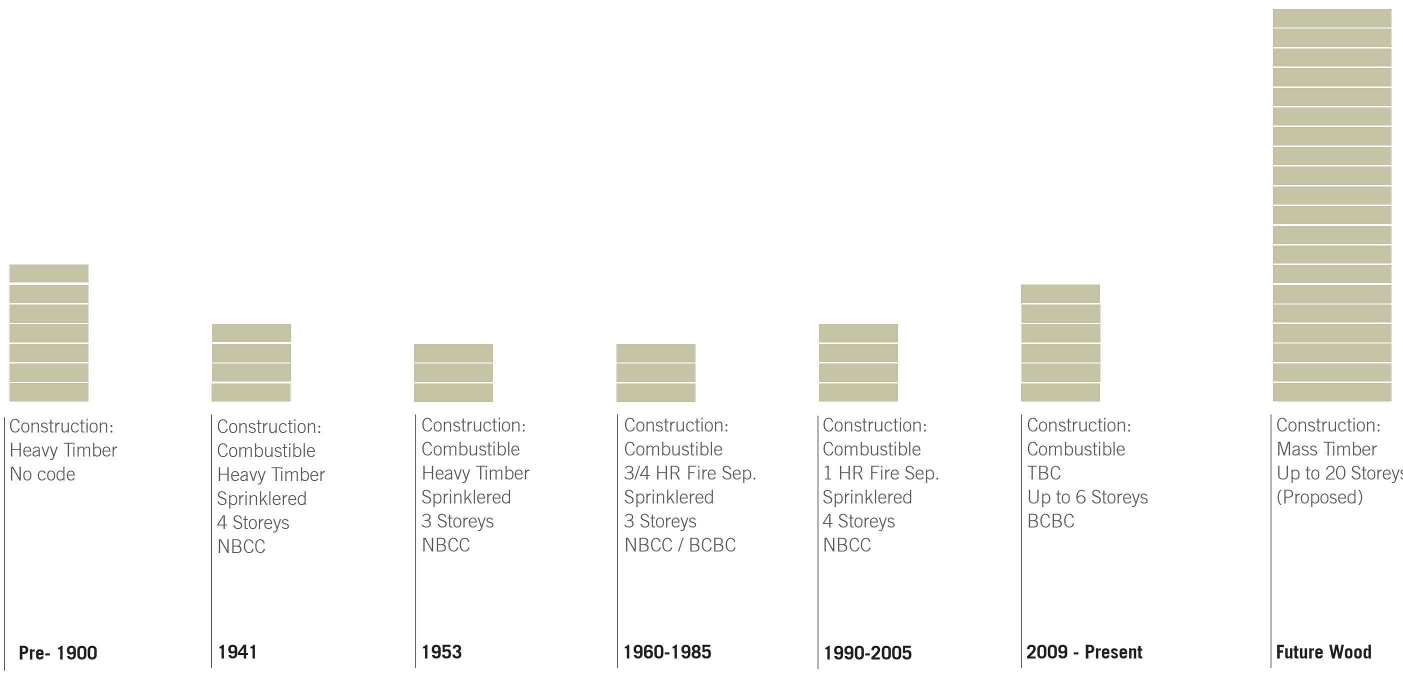
› To maintain tenable conditions in exit stairs leading from floor spaces to the outdoors, and in spaces through which occupants have to pass or in which they remain while waiting for assistance to evacuate;

› To maintain tenable conditions in elevators that are used to transport fire fighters and their equipment from the street floor to the floor immediately below the fire floor and for the evacuation of injured persons or persons with disabilities.

It is noted that in modern-day buildings, the above-noted objectives for occupancy safety and tenability of building floor areas is normally achieved with the installation of automatic sprinkler systems throughout the building (formerly known as smoke-control “Measure A”). This is based on the ability of automatic sprinklers to rapidly detect, activate and suppress a fire condition at the early stages of development, thereby providing fire control and reduction in smoke production which could ultimately affect occupants in the adjoining “non-fire” compartments of the building. The proposed TWB design will incorporate a complete and enhanced automatic sprinkler system design, as well as other applicable high building measures, to maintain an equal level of safety for the building occupants, to that required by the applicable requirements of Subsection 3.2.6.

The User’s Guide to the NBC also references that, “in high buildings, the smoke that is generated from a burning surface is an additional concern. Since evacuation of a high building takes considerable time to complete, the occupants must be protected from the effects of smoke until they have left the building, or the fire has been extinguished and there is no further hazard. In high buildings, the smoke emission characteristics of wall, ceiling, and floor surfaces are regulated through the imposition of maximum smoke developed classifications. In these buildings, additional restrictions are placed on flame-spread ratings of interior finish materials, in comparison to lower buildings. These additional restrictions apply primarily if the building is not sprinklered.” Therefore, in a sprinklered building the flame spread ratings and smoke developed characteristics are relaxed by the building code, based on the ability of sprinkler systems to detect, control and suppress a fire condition prior to significant burning of surface materials and flashover within a fire compartment. It is also noted that under the prescriptive requirements of the NBC for a sprinklered building, the interior surfaces of the building would be permitted to be lined with significant combustible fuel loading within the building. This would be similar to the use of exposed Mass Timber as a final finish treatment within the interior of the building, and would also be fully protected with automatic sprinklers to effectively limit surface burning characteristics in the interior compartments.

Timeline: Building Height by Regulation in British Columbia (Wood Frame Structures)



References:
A Historical Perspective on building Heights and Areas in the British Columbia Building Code. Table 1: Building Height Limitations in the NBC

Building Code Provisions for Residential Buildings and Identification of Technical and Process Risks. Page 5.

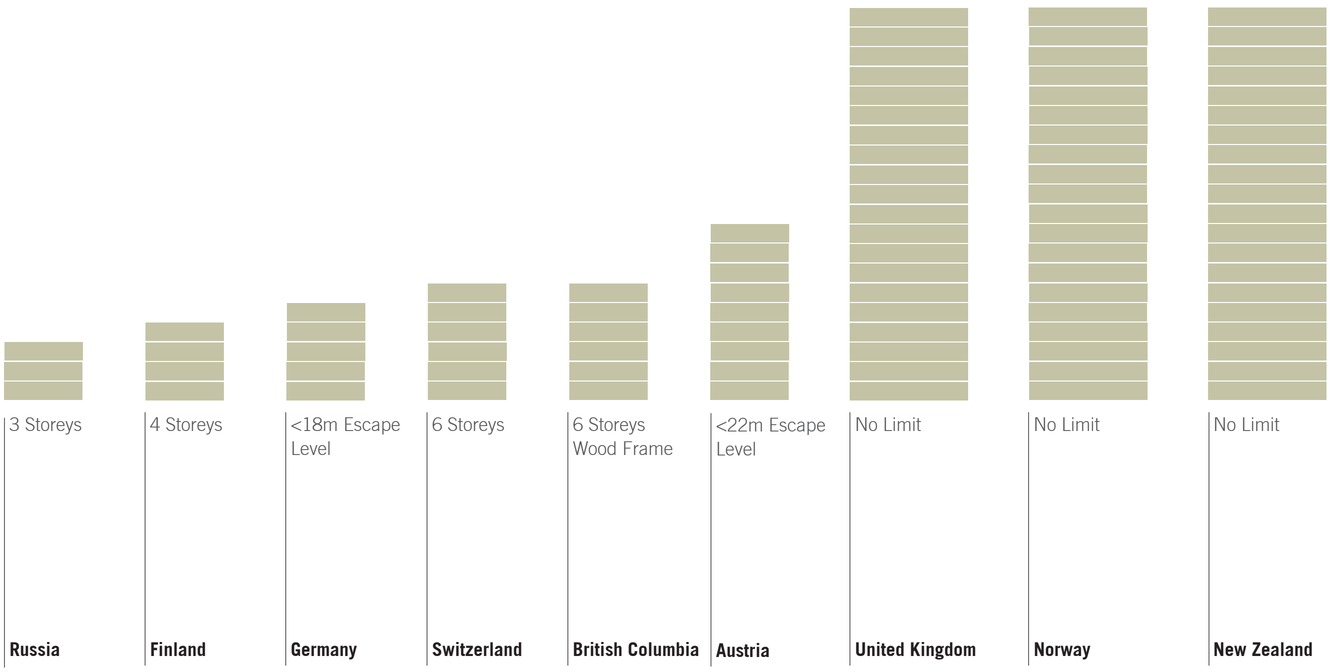
International Perspective on Building Height Regulation

The regulated building height for combustible buildings varies widely across the world. Extremes include Russia, with a limitation of 3 storeys, and the United Kingdom that has no specific height limit, provided that a minimum level of safety performance can be demonstrated (i.e., "performance-based" building code regulation), evaluating each project on its specific engineered merits.

As illustrated in Section 1.2 of this report, there are numerous examples of completed/realized or in-design/unrealized mass wood system buildings around the world, with most of the design and manufacturing technology originating in EU nations (i.e., Austria, Germany, Italy, Sweden and the UK). An often referenced example of a completed mass wood building, using "cross-laminated timber" (CLT) panel systems, is the Stadthuas/Murray Grove Project located in London, England. This 9-storey (> 18 m high) residential building incorporates a 1-storey concrete podium with 8-storeys of gypsum-board lined CLT panels for the horizontal and vertical structural systems (including vertical shafts) for the building structural system. The gypsum-board membrane protection installed directly to the CLT panels exceeded the required 90-minute fire-resistance rating required by the local building code regulations, as the gypsum board was primarily installed for marketing/purchaser perception reasons only. That is, the gypsum-board membrane was not required to be installed to achieve the necessary fire-resistance rating for the building, as the exposed CLT panels were of sufficient thickness to achieve the 90-minute fire duration required by the local building code regulations. It is also interesting to note that the Stadthaus Project achieves the required level of safety and fire protection for the local building regulations, without the installation of automatic sprinkler systems in the building floor areas. This is a significant contrast to the Canadian building code requirements, where a building of this height would be required to be fully sprinklered.

Other high building designs utilizing Mass Timber systems and/or hybrid mass wood/concrete/steel structural systems are currently in development around the world (e.g., Austria, Norway, Australia), and this Tall Wood Building design intended for Vancouver, B.C. is intended to set the standard for Canadian design, construction and manufacturing technology, for the delivery of an economical, safe and durable residential structure of primarily wood materials.

Maximum Building Height by Regulation (Wood Frame Structures)



References:

(Rhomberg 2010)

TALL WOOD

IDENTIFYING CHALLENGES PART 2

2.1 Preliminary Survey of Industry Preconceptions

We have tried to track common preconceptions to building tall with wood throughout the study - whether that be through discussions within the industry or with the common public. While we have attempted to address each of these preconceptions at a basic level, Part 5 outlines further work required to fully develop the following to make Tall Wood a built reality.

COST

- A Tall Wood structure cannot compete with the economics of a slip form concrete structure.
- Wood is fundamentally more expensive than concrete.
- The detailing of a Tall Wood structure will add more cost to construction.
- The cost of fire protection will make these structures more expensive.
- There is not enough competition in the Mass Timber market to ensure competitive pricing.
- Who will bear the cost and risk of introducing these ideas in the built form?

DESIGN

- A Tall Wood structure will limit the design freedom possible in concrete construction because it will require more walls and more structure and shorter structural spans.
- A Tall Wood structure will have thicker walls than its concrete counter part. Walls would be thicker in wood, requiring more floor area.

CODE

- The fire-resistance of a Tall Wood structure can not replicate the performance of concrete.
- A Tall Wood structure is more dangerous than a concrete building (i.e., wood structures are seen as more vulnerable to fire).
- If there is a fire in a wood building, the entire building/ structure will contribute to the fire and burn to the ground.
- From a fire department perspective, a Tall Wood building will not provide an adequate level of safety for firefighters' or emergency responders who must enter the building to rescue persons or suppress fires.

STRUCTURAL

- › Wood is weaker than concrete.
- › A Tall Wood building will not withstand an earthquake.
- › A Tall Wood building will not be as safe in an earthquake as a concrete or steel building.
- › A Tall Wood building will be vulnerable to building envelope failure/leaky condo syndrome - compromising the structure.
- › A Tall Wood building will deflect excessively in strong wind storms causing discomfort and damage to finishes.

PUBLIC OPINION

- › Wood shrinks.
- › Wood rots.
- › Wood burns.
- › Glued wood off-gasses.

ECONOMIES I VALUATION I MARKETABILITY I INSURANCE

- › A wood building is exposed to more risk during construction; exposed to moisture and to fire hazard.
- › Wood buildings are valued less than concrete buildings.
- › Insurance premiums are higher for wood buildings than for concrete buildings.
- › Wood cannot compete with the steel and concrete industries.
- › We do not have enough wood supply, impact on forest industry; sustainably managed forests.

SCHEDULE

- › A Tall Wood structure can not compete with the ability to pour a “floor per week” in concrete construction.

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CASE STUDY DESIGN PART 3

3.1 Prototype Site and Market Conditions

Why use a specific example in Vancouver?

Vancouver currently harbours a cluster of wood construction and design professionals, wood researchers, and fabricators that are on the leading edge of innovative wood design. All of the resources to develop the first Tall Wood prototype are within a very tight radius of collaboration. If it could happen anywhere; it could happen here. For the purposes of this study a theoretical site was selected in Vancouver's West End neighbourhood.

This location was selected in Vancouver specifically due to the following real-world constraints and opportunities:

1. An urban site within a tight urban grid for construction lay-down area and site access.
2. An appropriate density with residential towers typically ranging from 10 to 20 storeys.
3. A highly competitive developer and market atmosphere
4. An insightful consumer profile
5. A high seismic region of BC
6. City zoning that requires efficient design to maximize floor space ratio for competitive developers.
7. Wood construction and design cluster consisting of leading wood researchers, designers, and fabricators.

These parameters establish a challenging context that will allow similar solutions to be applied elsewhere in the province where arguably fewer constraints will exist.

West End
Vancouver, BC

3.2 FFTT Solution

FFTT is a unique tilt-up system that effectively balloon-frames Mass Timber panels in a cost effective and simple manner to build Tall Wood buildings. The system uses a strong column – weak beam structural approach that is described in detail later in the report. FFTT was first developed by Michael Green and Eric Karsh in 2008 and has evolved to the current approach described here. Mass Timber panels are used for floors, walls and the building core with engineered wood columns (up to 12 storeys) and steel beams and ledger beams (12 storeys and up) integrated into the Mass Timber panels supporting floors. The introduction of steel allows for the 'weak beam' solution and great flexibility for the system to achieve heights with a predominantly all-wood solution.

FFTT uses the integral strength of CLT (available up to 42' x 9' in North America), LSL (up to 64' x 8') or LVL (up to 64' x 8') panel products. These products are manufactured in Canada and use Canadian wood products that can be of a lesser grade than solid timber solutions.

The FFTT system is adaptable to many building types, scales and locations and allows for the fast erection of very simple and structurally sound buildings. mgb and Equilibrium have introduced an example of the use of the LSL panels in the roof structure of the atrium space of the new City of North Vancouver City Hall project currently under construction. The City Hall project illustrates how large panel products can be used in cross lamination to make long span, thin and architectural structures. In the case of City Hall the application is quite specific to the building's overall architecture but the structural solution is a clear indication of the practical viability of these panel solutions in today's market conditions.

The diagrams in section 3.16 Constructability, illustrate the assembly concept of FFTT. It is intended to drive the cost of building erection down to make wood solutions cost competitive with steel and concrete and allow wood solutions to achieve significantly greater heights. Its success will be in its ultimate simplicity and the solutions we are developing are driven by the economics and practical realities of building as well as the inherent potential of under utilized Mass Timber products on the market today.

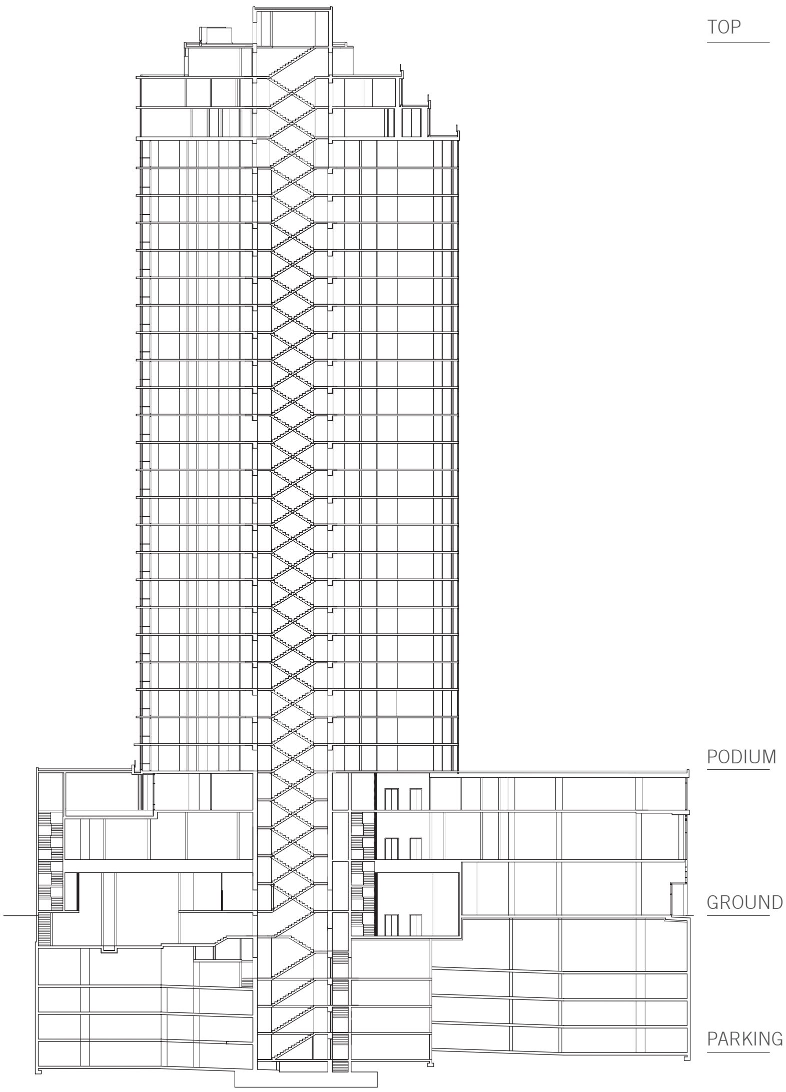
The solution is also intended to address the reality that wood frame is a solution specific to North America and only a few other markets in the world. Wood frame requires the retooling and teaching of the building industries in foreign markets in order to increase the use of our wood resources. This solution is driven towards a universal system of building that is easily understood and requires little training. It is driven to open a wider market for our wood products by working with international building cultures rather than highly specific North American solutions. We believe it will offer an exportable building industry in time as the panels can be designed, engineered, pre-cut, pre-assembled and then flat packed to become an exportable building structural system.

This solution will move BC from a resource-based wood economy to a value added wood economy benefiting the entire building sector in addition to the timber industry.

3.3 Concrete Benchmark

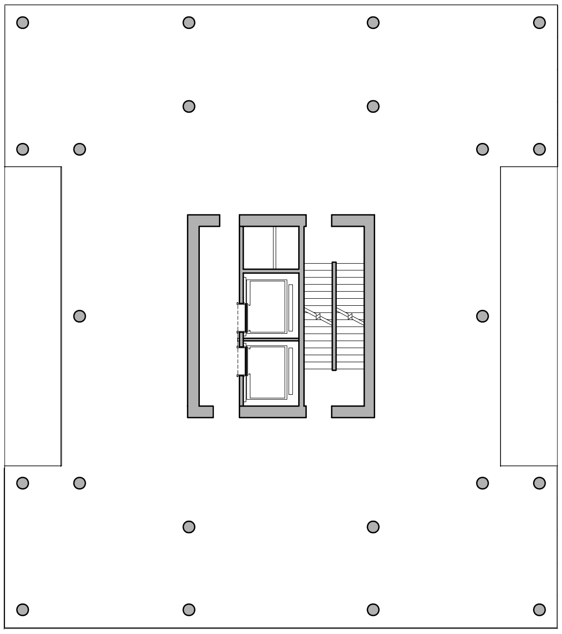
Benchmark Solution

In order to fully understand the characteristics of a Mass Timber building system for tall structures, we have created a concrete base case or benchmark. This enables us to compare solutions back to a building system that is commonly known amongst professionals, the construction industry as well as the marketplace and is a valuable tool in quantifying the magnitude of change, whether it be in detailing, fabrication sequence, or cost of construction.

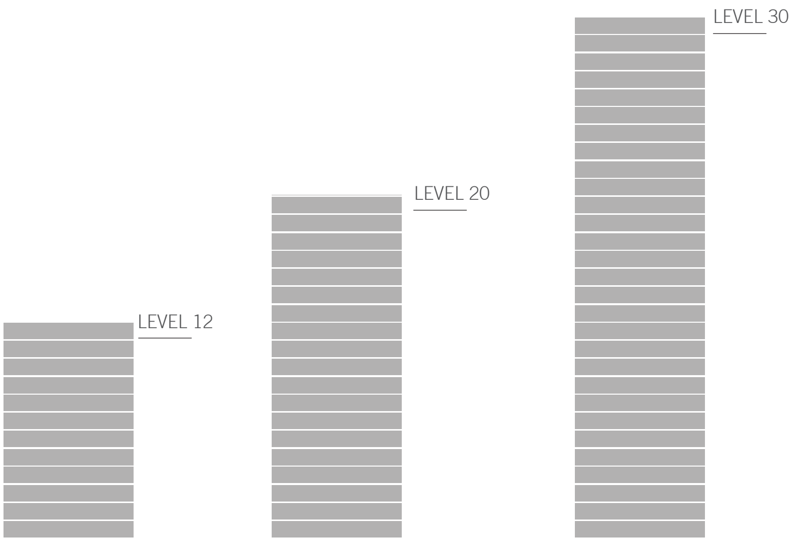


Typical Vancouver Podium Tower Section

Benchmark Solution Structural Diagram

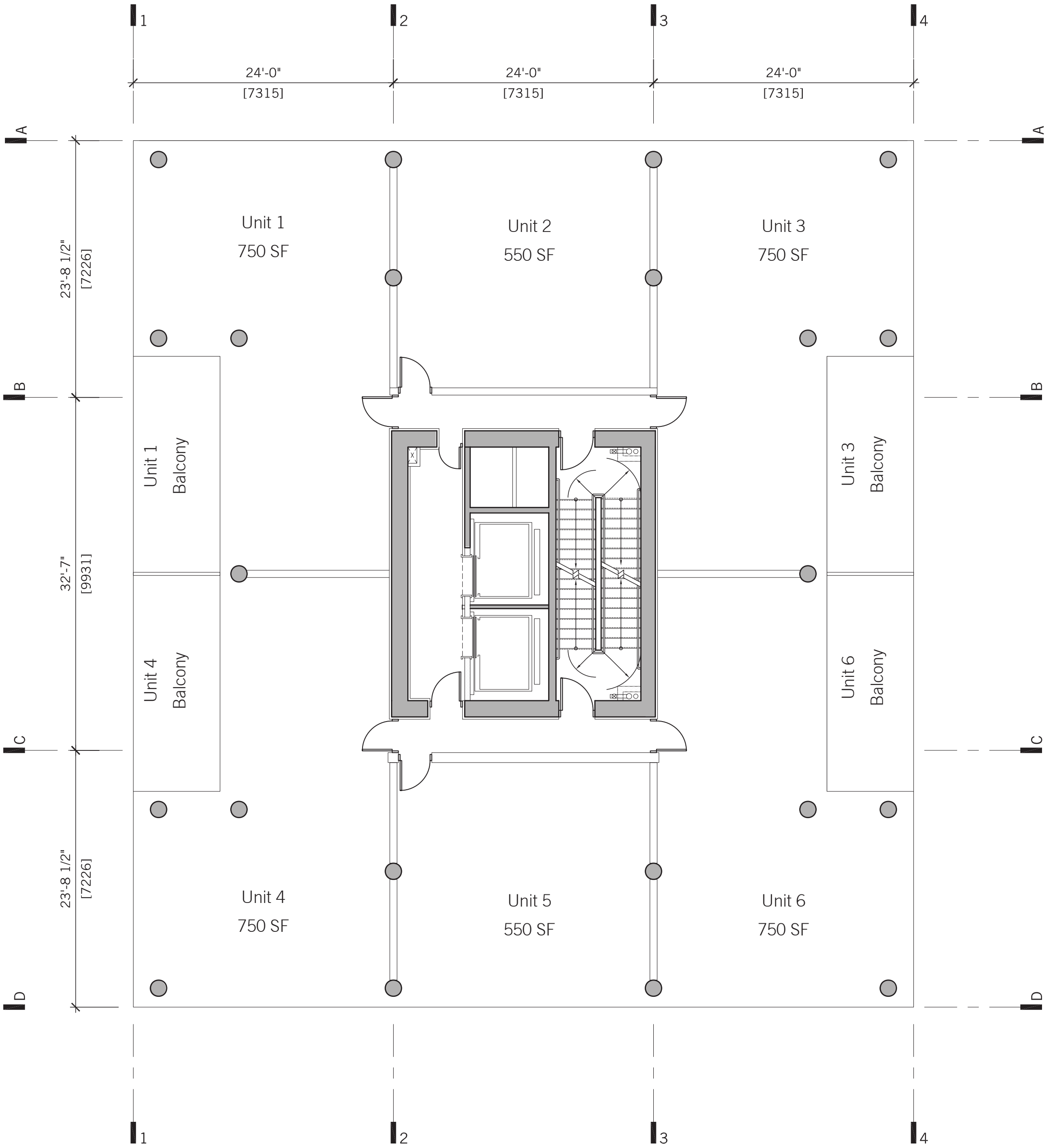


12, 20, 30 storeys in height
Concrete structure
Refer to Appendix A for structural details

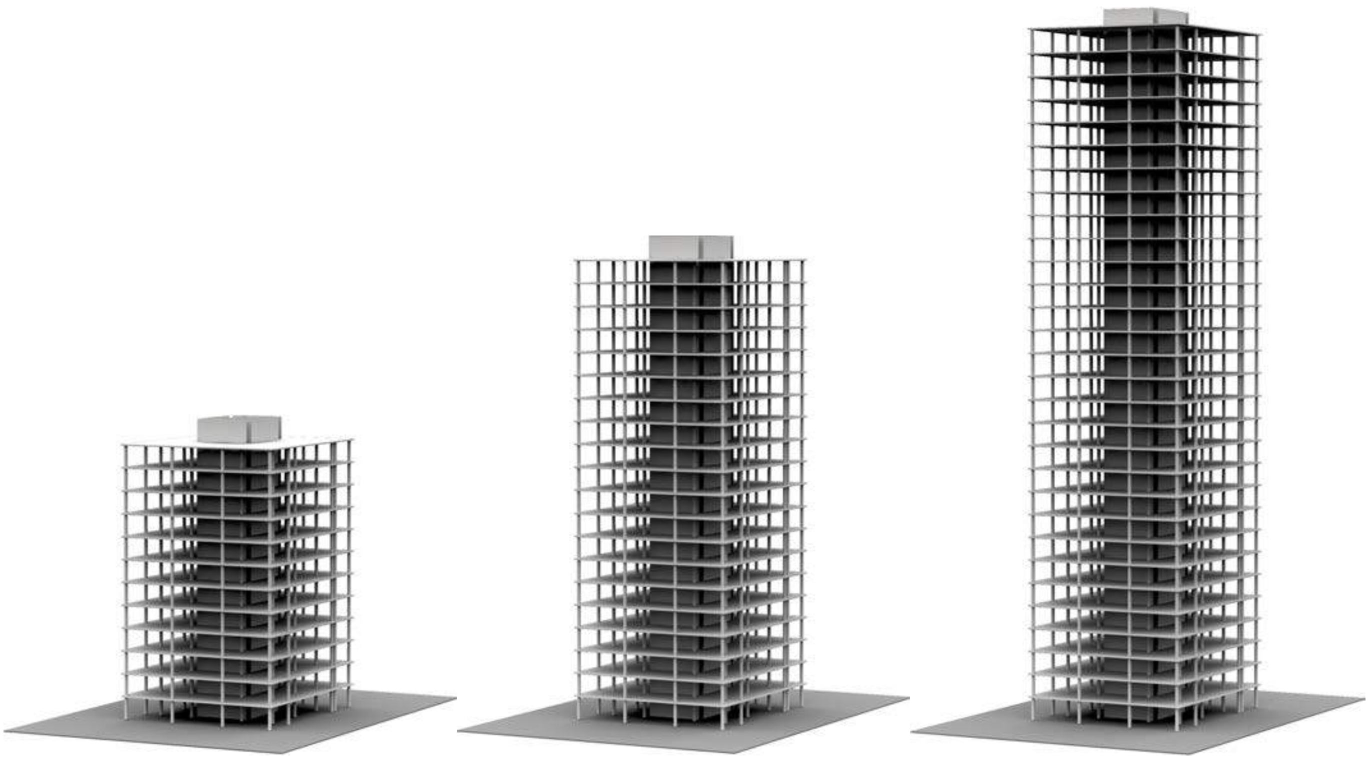


Building heights

Concrete Tower Benchmark



12, 20, 30 storeys in height
Concrete structure
Refer to Appendix A for structural details

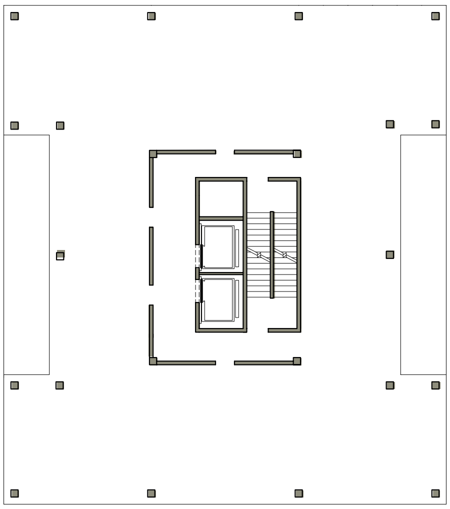


12, 20, 30 storeys in height
Concrete structure
Refer to Appendix A for structural details

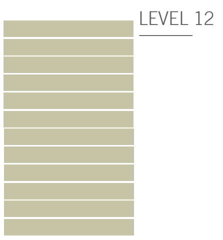
3.4 Proposed Tower Solutions - Applied and Theoretical Plans

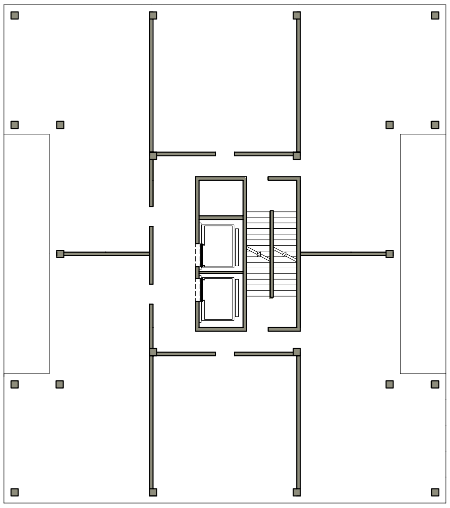
FFTT Structural Diagrams

The following diagrams illustrate 4 possible structural configurations utilizing the FFTT system. With each option, the structural capacity principally determines the possible building heights. For instance, in Option 1, a building height up to 12 storeys is achievable employing structural core walls and glulam columns at the perimeter as the supporting structure. In options 2 and 3, which achieve greater building heights up to 20 storeys, additional structure is required. Structural interior walls and structural exterior walls provide this additional support in options 2 and 3 respectively. For option 4, as in option 2 and 3, structural interior walls and structural exterior walls provide additional support.

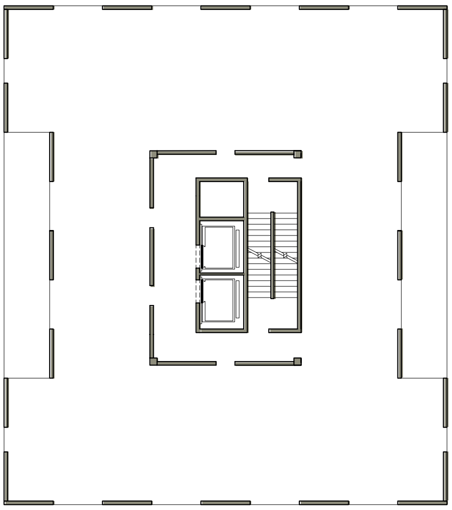


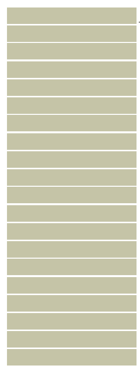
OPTION 1
Up to 12 storeys in height
Structural core
Glulam columns at curtain wall



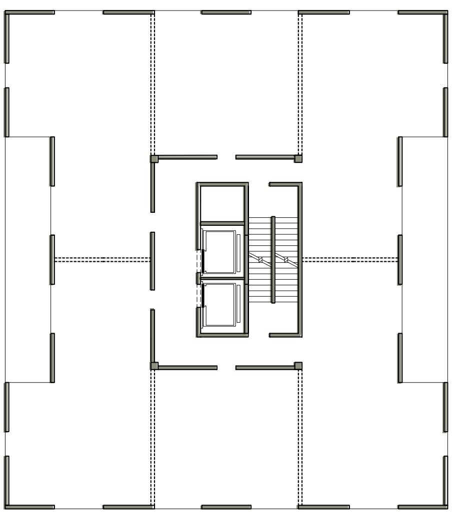


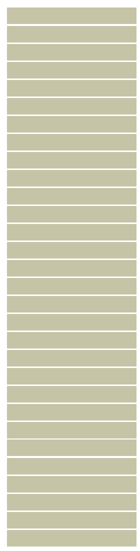
OPTION 2
Up to 20 storeys in height
Structural core and interior walls
Glulam columns at curtain wall





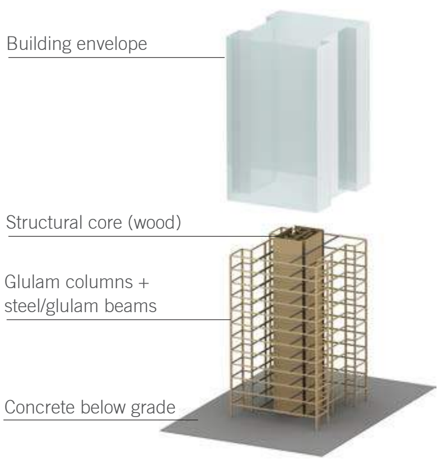
OPTION 3
Up to 20 storeys in height
Structural core and exterior walls



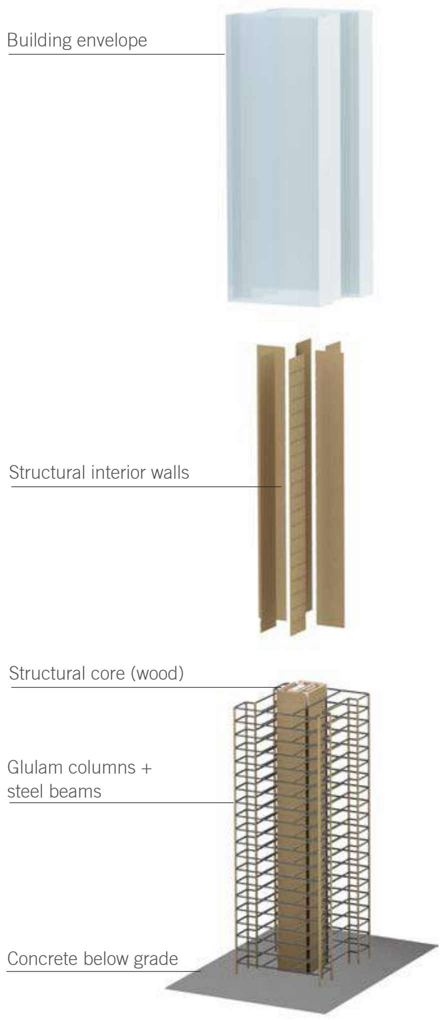


OPTION 4
Up to 30 storeys in height
Structural core, interior walls or
exterior walls

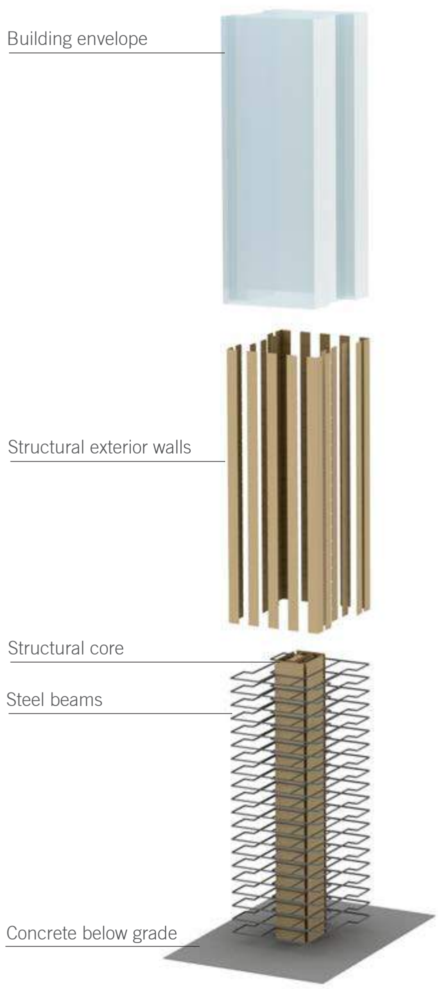
FFTT Axonometric Diagrams



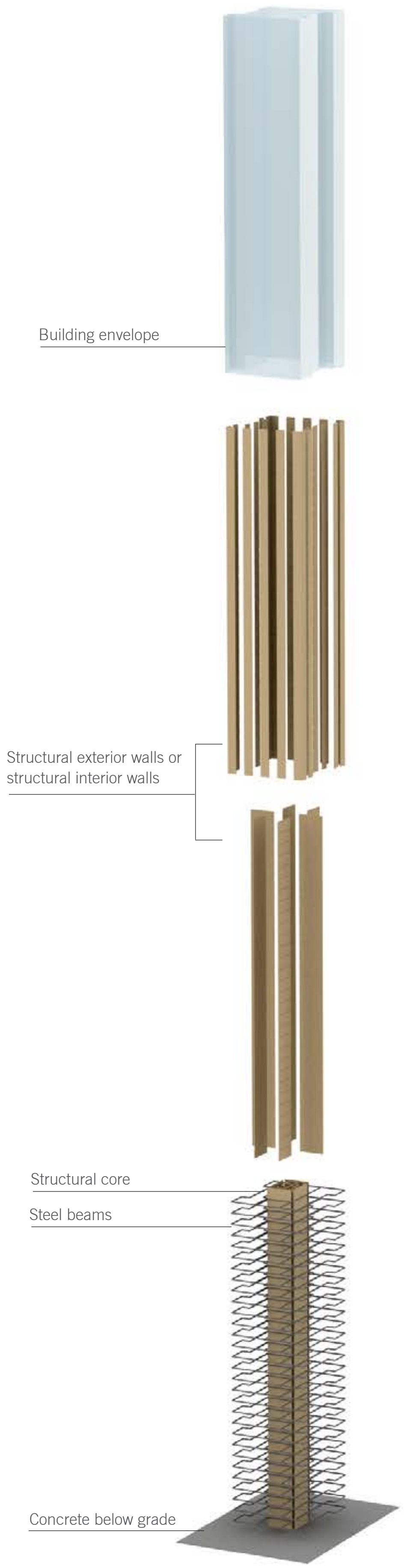
OPTION 1 - Up to 12 Storeys



OPTION 2 - Up to 20 Storeys



OPTION 3 - Up to 20 Storeys



OPTION 4 - Up to 30 Storeys

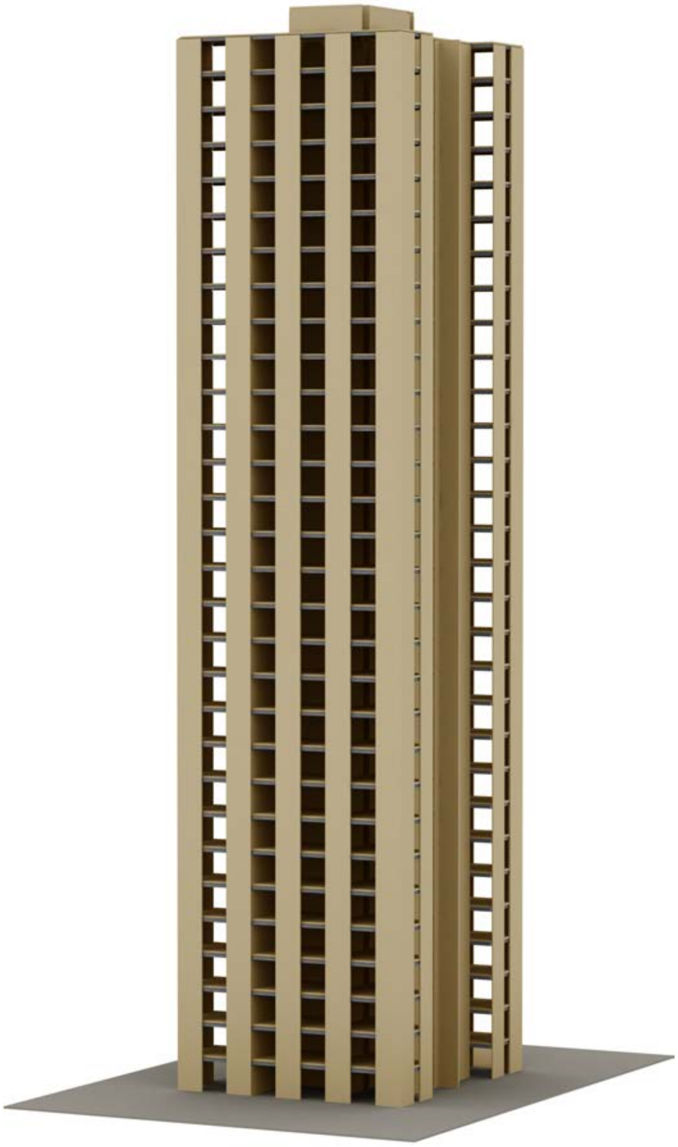
Implied Architectural Impact as Result of the Structure

The structural configurations, in addition to determining the achievable building heights will impact both the design of the envelope and floor plan of the building. For example, Option 1 offers the greatest amount of flexibility in the design of its interior partitioning. This structural configuration bears closest resemblance to the typical concrete benchmark in that it utilizes a structural core and perimeter columns that affords it a free-plan. In options 3 and 4, where additional structure is required for the increase in building height, constraints are placed on the design of either the interior partitions or envelope. As a result, these configurations can be more advantageously applied to specific uses. For instance, where interior walls are utilized as structure, a residential application would be appropriate where these structural walls could double as unit demising walls.

OPTION 1 - Up to 12 Storeys

OPTION 2 - Up to 20 Storeys

OPTION 3 - Up to 20 Storeys



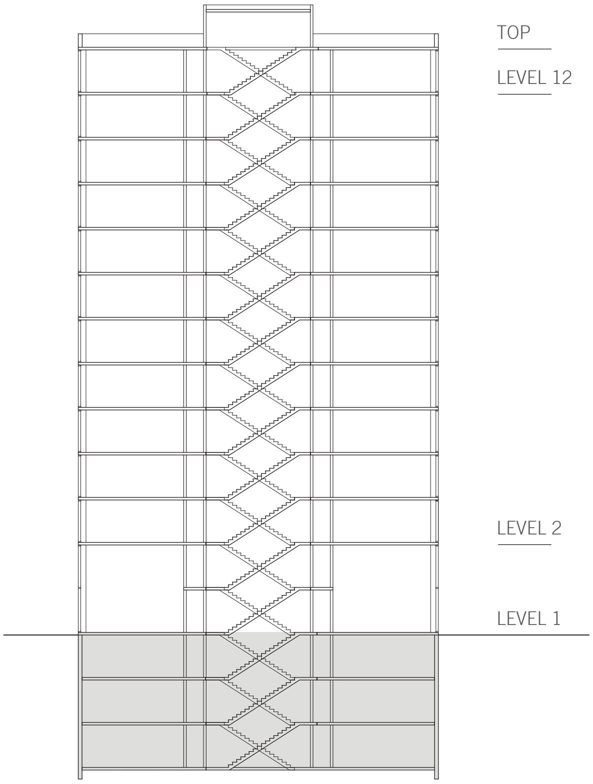
OPTION 4 - Up to 30 Storeys

CASE STUDY - OPTION 1

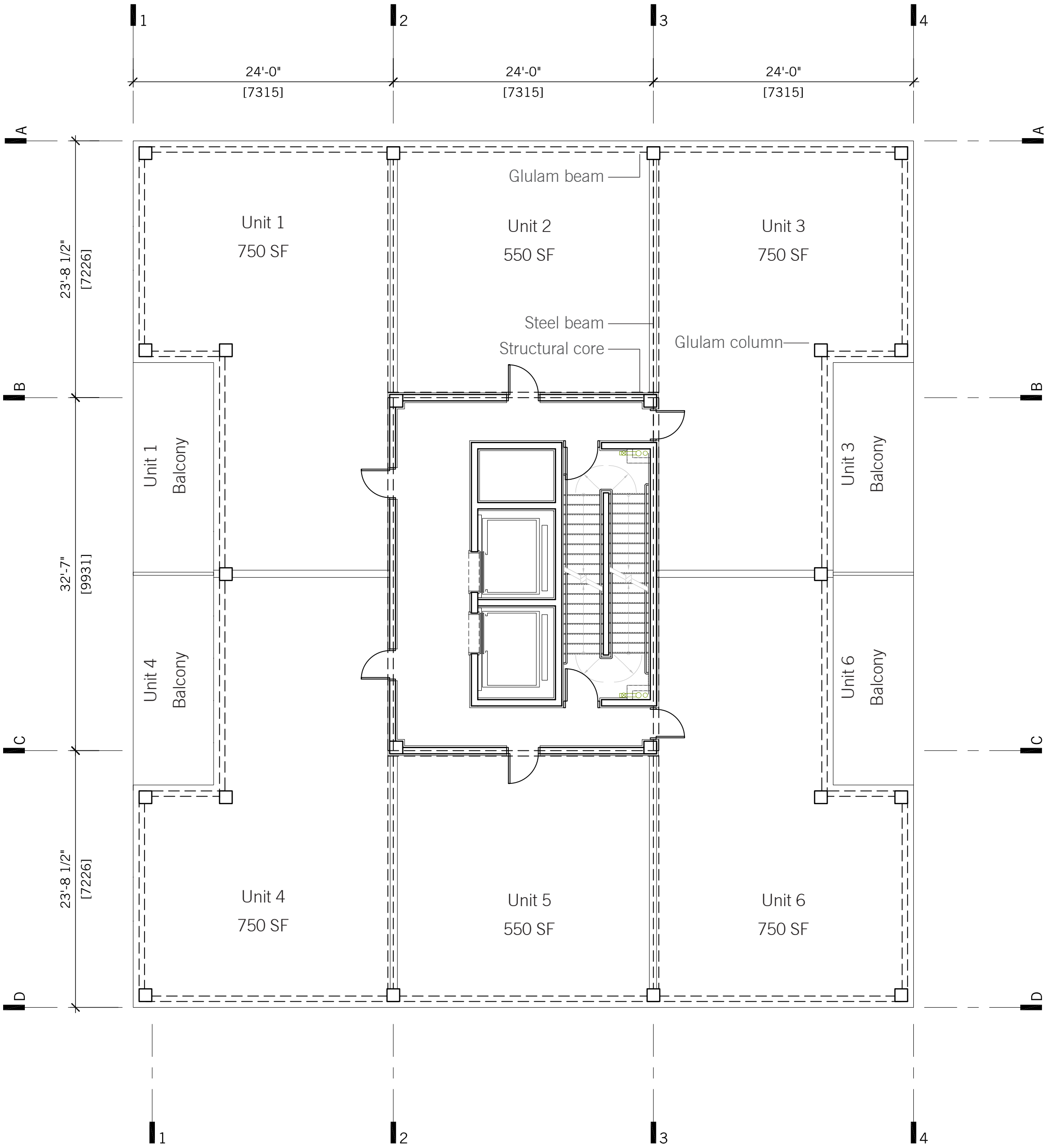
Up to 12 storeys in height
Structural core
Glulam columns at curtain wall

In this option, which allows up to 12 storeys in building height, the wood core walls and glulam perimeter columns are deployed as the supporting structure. Since none of the interior walls are required to have a load bearing function, a great amount of flexibility is afforded in terms of floor plan layout. As well, in the absence of exterior load bearing walls, this option allows flexibility in the design of its façade, including the ability to support an entire curtain wall envelope if desired.

Additionally, like many buildings with such open spaces, interior modifications are easily made to allow for future changes in occupancy or use. Its open floor plan and ability to easily accommodate future changes positions this option quite competitively in terms of use and planning to its concrete benchmark, particularly in the office market.



SECTION



PLAN OPTION 1

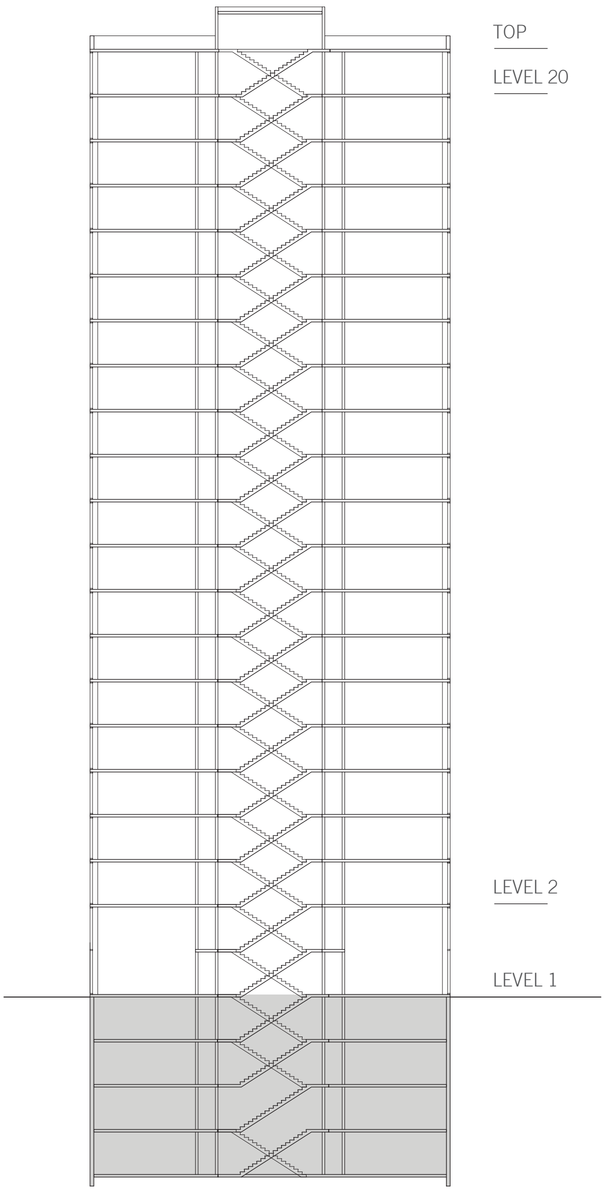
Refer to Section 3.6 Structural Intent for structural information

CASE STUDY - OPTION 2

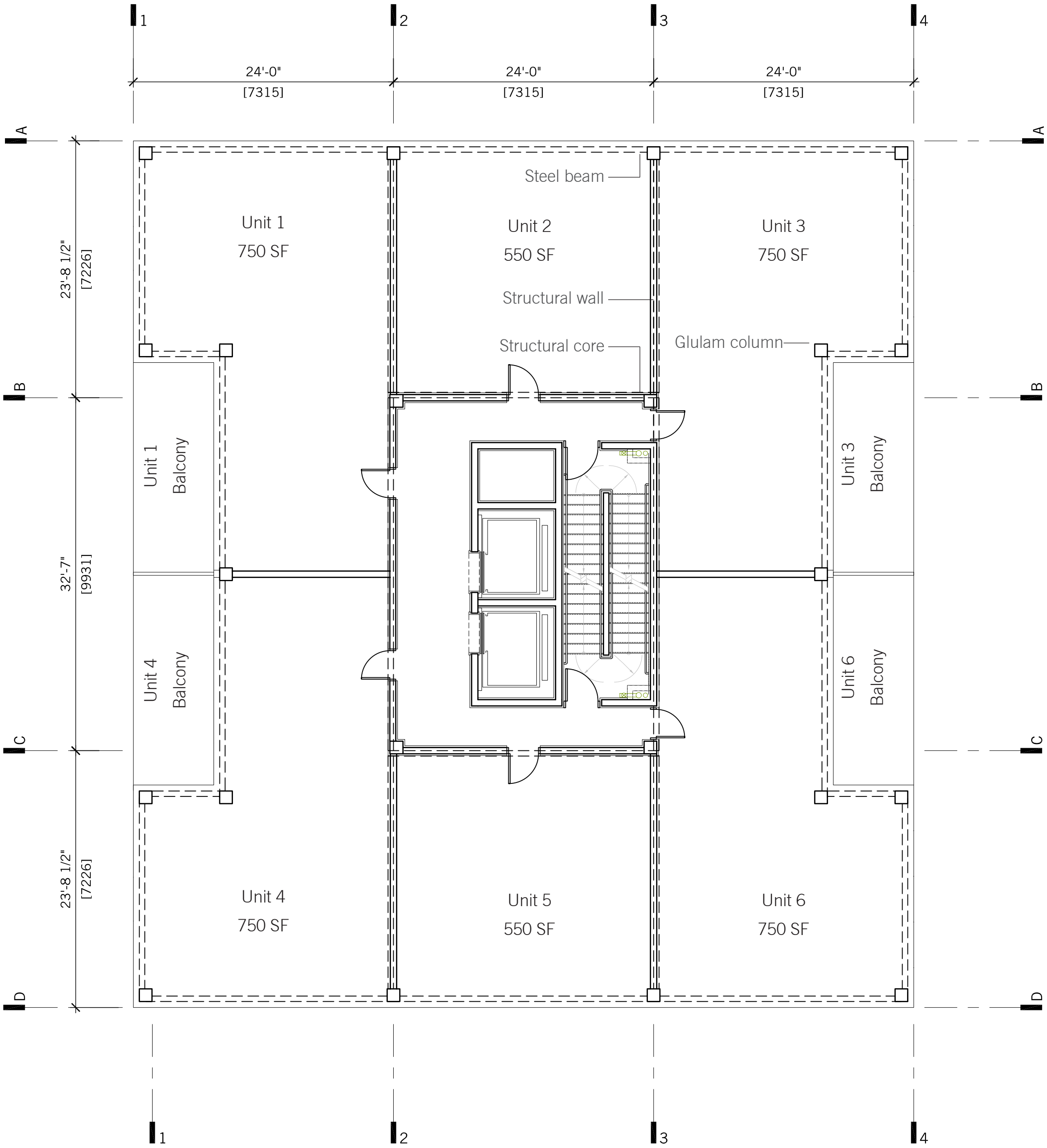
Up to 20 storeys in height
Structural core and interior walls
Glulam columns at curtain wall

Here, in addition to the structural wood core walls and glulam perimeter columns, interior structural walls are introduced in order to increase the possible building height up to 20 Storeys. Similarly to Option 1, in the absence of exterior structural walls, this option also allows great flexibility in the design of its facade, supporting an entire curtain wall if desired. In terms of interior planning, the introduction of interior load bearing walls diminishes some flexibility in floor plan layout and future changes as optimized in Option 1. However, these interior structural walls can be located accordingly, for specific uses such as demising walls between units.

This structure lends itself to being more suitable for a residential application, as it does not offer the open plans desirable of office layouts. However, because of its structure, it offers a competitive building height, pushing it from a mid-rise to a high-rise structure.



SECTION



PLAN OPTION 2

Refer to Section 3.6 Structural Intent for structural information.

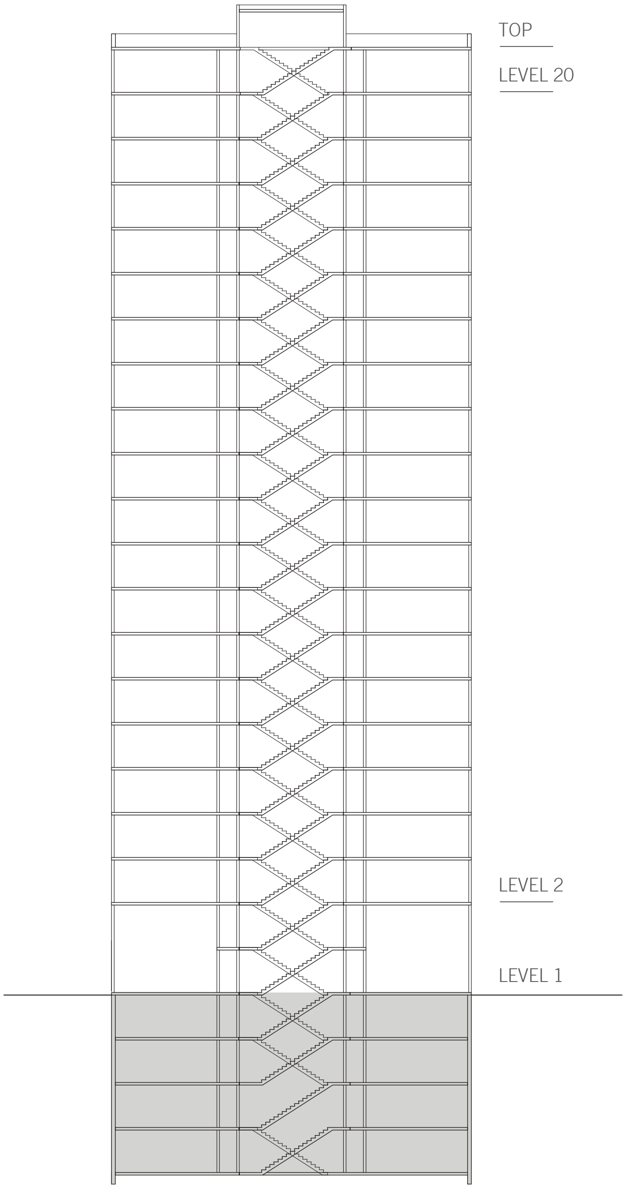
CASE STUDY - OPTION 3

Up to 20 storeys in height
Structural core and exterior walls

This option is similar to Option 2, with a maximum achievable building height of 20 storeys. This is accomplished utilizing structural wood core walls and introducing exterior structural wood walls. Here, the exterior structural walls have replaced the interior structural walls and perimeter glulam columns in Option 2.

The impact of this is that the plan is now structure free, again allowing flexibility in terms of interior partitioning and allowing future interior modifications. On the other hand, the presence of the exterior structural walls now limits the flexibility of the facade. For example, where solid structural walls occur, it would not be possible to have vision glass. As a result of this structure, punched or bay windows would be most suitable. Additionally, from a thermal performance point, these exterior walls provide opportunities for greater insulating assemblies.

This structure would be particularly suitable for residential applications in consideration of its exterior structure and facade composition. While, its open interior plan would be suitable for an office arrangement, it would be challenged in the office market because of its obstructed views and amount of daylight the interior receives relative to its concrete benchmark which can utilize a completely glazed curtain wall. Again, like Option 2, it offers a competitive building height at 20 storeys.



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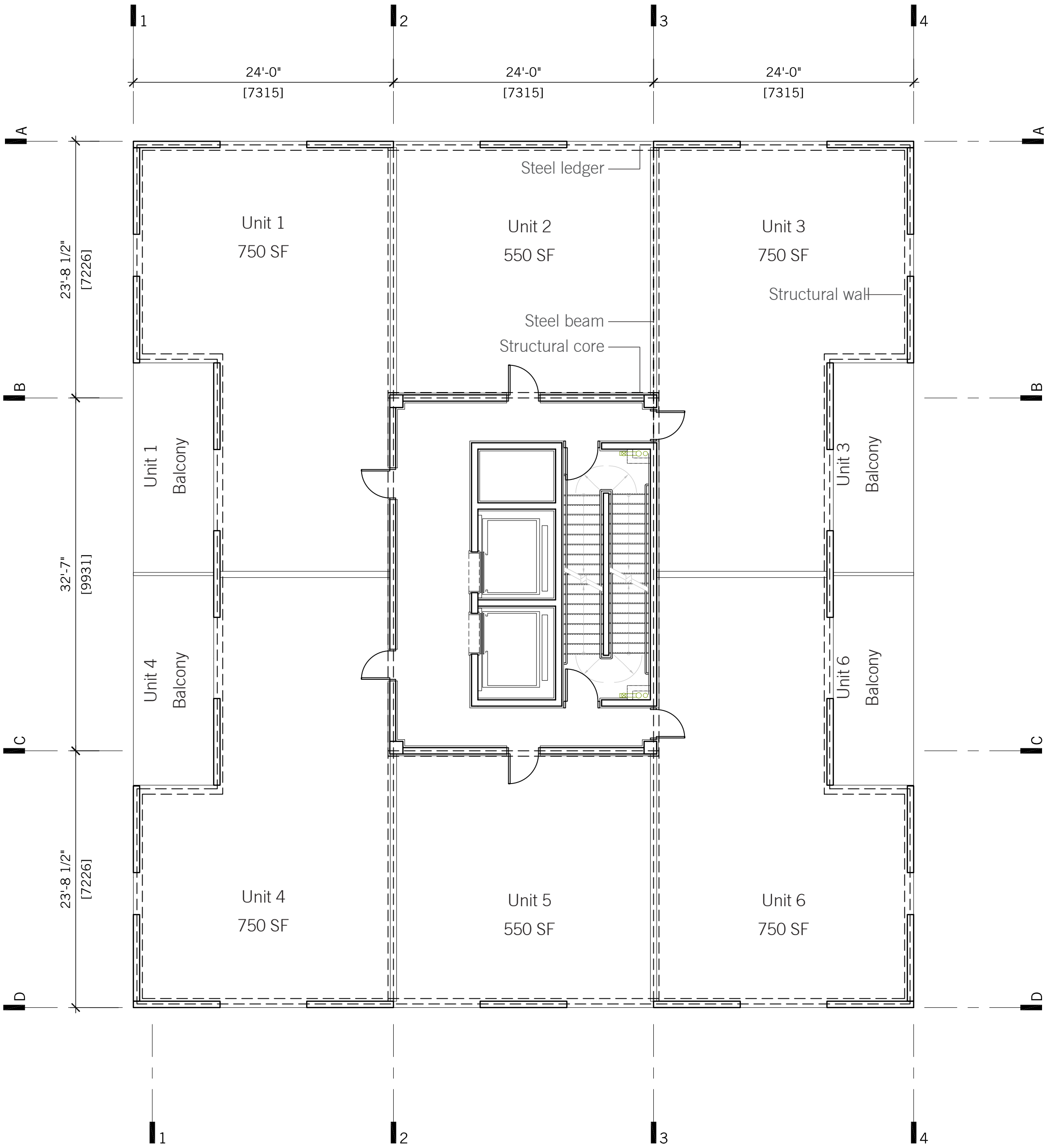


PLAN OPTION 3

Refer to Section 3.6 Structural Intent for structural information

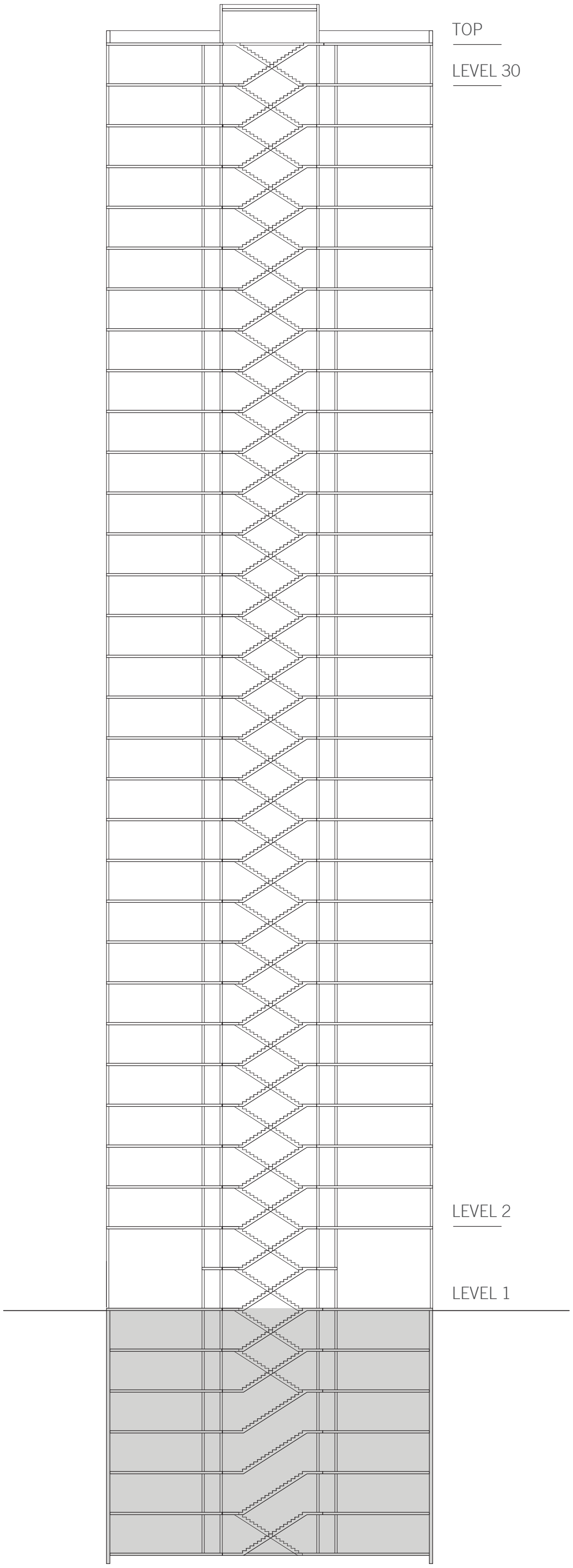
Note: Our analysis has shown that a 30 storey model performed adequately with either the interior partition walls or perimeter frame.

CASE STUDY - OPTION 4

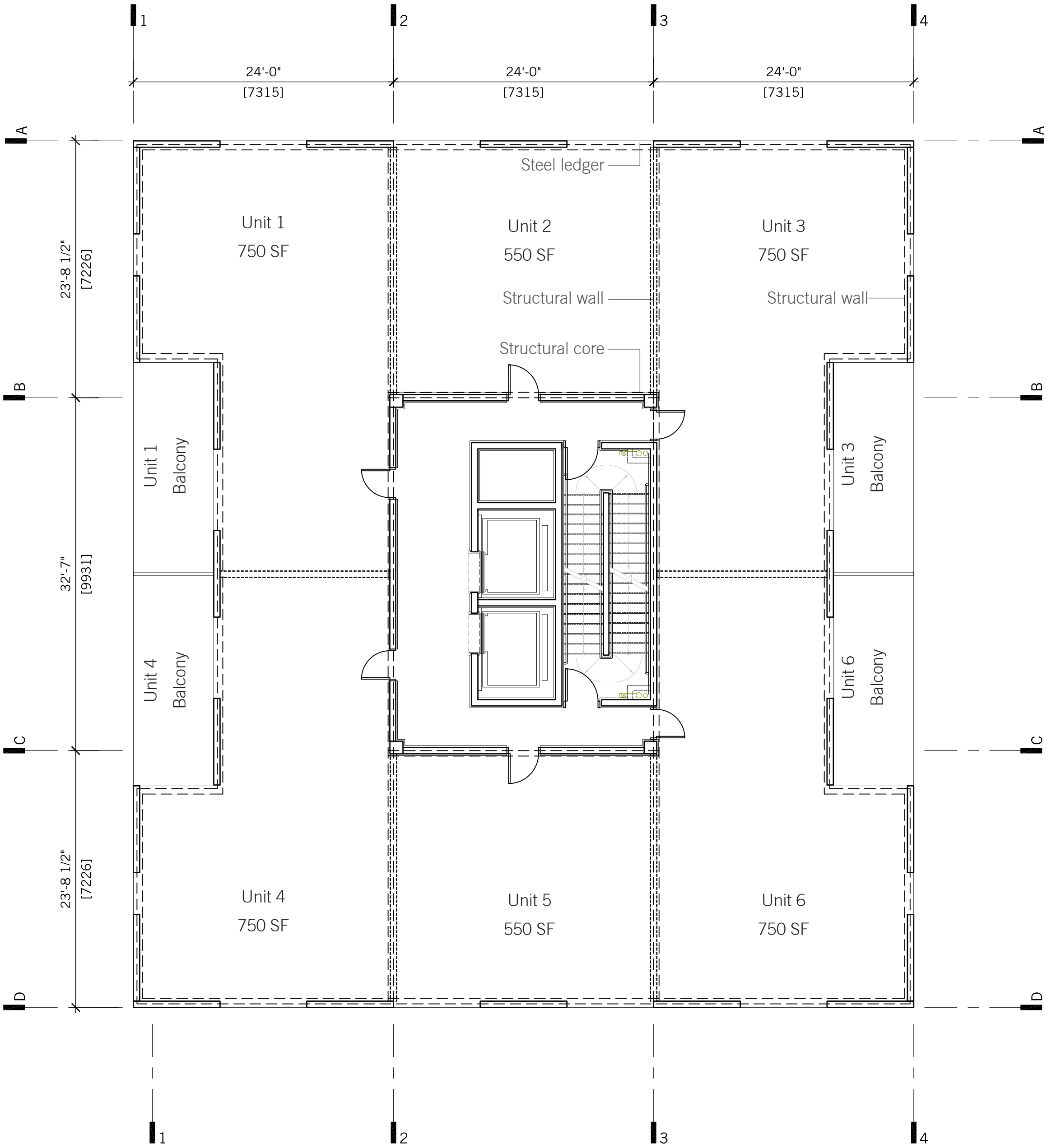
Up to 30 storeys in height
Structural core, interior walls and exterior walls

This option pushes the maximum building height to 30 storeys. To do so, it utilizes structural core walls, structural interior walls and structural exterior walls. As a result, it offers the least flexibility of the four options. Its interior structural walls would limit it to residential use, as in Option 2, its exterior structural walls would limit the envelope options as discussed in earlier in Option 3.

The primary advantage of this option is its building height. However, the structure that is required to achieve this height becomes disadvantageous to its planning and design flexibility. As a result, this option is limited in its flexibility and use.



SECTION



PLAN OPTION 4

Refer to <u>Section 3.6 Structural Intent</u> for structural information.

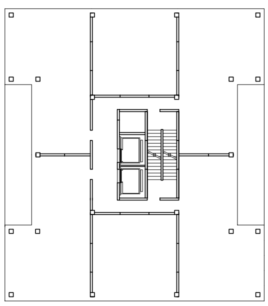
Note: Our analysis has shown a 30 storey model performed adequately with either the interior partition walls or exterior frame.

3.5 Architectural Application of an Idea

The FFTT system is designed and considered as a universal structural system to engineer Tall Wood buildings. However, it is important to understand that it has also been driven by a number of architectural issues pertinent to tall buildings that are crucial to the system's success. The FFTT system allows for flexibility in tower planning and facade design with some decrease in flexibility once the system is utilized in applications above 20 storeys. Above this height, an FFTT tower would likely be limited to residential use. The flexibility in tower planning is important for a number of reasons:

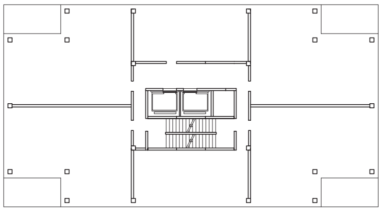
1. An open plan (where there are no interior structural partition walls) allows for a variety of uses including office or residential.
2. An open plan (where there are no interior structural partition walls) allows for future modifications as uses and tenants change.
3. Developers typically look to flexibility in the structural system to ensure they can manipulate the solution to meet their market goals. Open plans give enormous design flexibility to the developers and architects.
4. Exterior character and massing are important to adjust to the specifics of a given site, setback requirements, views and view corridors, shadowing conditions or architectural expression.

In addition to these considerations, a review of acoustic and vibration conditions, systems integration, life safety, fire and finishing relevant to tower construction follow in subsequent sections. In summary, what we have found is that there are no obstacles with FFTT to satisfying the typical needs of a tower design leaving possibilities open to the imagination of all architects.



OPTION 2 - Illustrated with a glulam curtain wall

1 Structural core
2 Structural unit partition walls
3 Glulam columns
4 Protective envelope



OPTION 2 - Illustrated with a glulam curtain wall and corner balconies

1 Structural core
2 Structural unit partition walls
3 Glulam columns
4 Protective envelope
5 Corner balcony

Interior perspective illustrating a glulam curtain wall

Interior perspective illustrating structure as finishing

Option 2 illustrated with a glulam curtain wall and podium base

3.6 Structural Intent

Introduction

The history of Tall Wood structures is 15 centuries old or more. The Horyu-ji temple in Japan, a post and beam timber structure dating back to the 7th century, still stands today at 32.5 metres in height in one of the highest seismic zones in the world. Similar European examples, and our own Canadian record of century-old post and beam buildings reaching 8 or 9 storeys, are also testaments to the natural strength and resilience of wood as a structural material.

The shift from heavy timber to light wood frame over the past century has led to lower limits on the height of wood structures in codes around the world. The recent increase to a six-storey limit in the BC building code only constitutes progress in the context of light framing. Light wood frame certainly remains an economical and versatile structural option, but has probably reached its natural limit at six storeys.

In the larger context of heavy timber and engineered wood construction however, the limits of scale and height potentially lie in order of magnitude beyond. The introduction of solid engineered wood panel products in particular, offers the possibility to capture this untapped potential. Structurally, one would think we should ultimately be able to build timber structures that are at least as tall as the trees that grace the forests of our beautiful province.

Finally, this report builds on the efforts of other designers around the world. We hope our work makes a contribution to the overall effort, and look forward to others building upon the concepts presented herein.

Scope

The purpose of this feasibility study is to explore the possibility to build mid and high-rise buildings with a primarily wood structure. For the purpose of this feasibility study, an innovative structural solution has been developed and modelled for a typical 12, 20 and 30-storey residential tower in Vancouver, British Columbia. The proposed system consists of large engineered wood wall and floor panels such as CLT (Cross Laminated Timber), LSL (Laminated Strand Lumber) or LVL (Laminated Veneer Lumber), linked together with ductile wide flange steel beams, designed to yield and provide plastic hinges in a seismic event.

The specifics of our model are based on an arbitrary residential solution, however the concepts would be equally applicable to high-rise office construction or the construction of large-scale, low-rise buildings such as airports, museums or commercial complexes. The study presents a structural system which we believe makes the design of truly large scale timber structures technically possible, whether they reach high towards the sky or wide across the horizon. But it also aims to present a construction system that is simple, flexible and economically viable.

While the study included preliminary calculations and computer modelling, the results remain primarily conceptual in nature. More detailed analysis as well as laboratory testing will be required to advance this effort to the implementation stage.

Solid Wood Panel Construction

Widely used in Europe, particularly in low-energy construction, solid wood panels are dubbed the “concrete of the 21st Century”. Solid wood construction refers to all solid wood panel types, including side and cross-laminated panels; glued, dowelled or nailed. In the North-American context, they also include engineered wood panel products such as LSL and LVL, which are originally produced in large billets before they subsequently are cut into smaller elements.

One particular panel type, called CLTs (Cross Laminated Timber), the glued version, has recently attracted a lot of attention in Canada. Three Canadian Universities as well as FPInnovations (the largest timber research organization in the world) have been carrying out significant research in Vancouver and Québec City on CLTs over the last five years. This research has been aimed at numerous aspects of CLT design and construction, including fabrication and quality control, mechanical properties, seismic behaviour and connections, vibration and sound transmission, environmental impact and cost comparisons.

The first North-American CLT conference took place in Vancouver in early 2011, at which FPInnovation’s excellent CLT design handbook was released. Other conferences have since taken place in Montreal, Toronto and Moncton, NB. The next conferences are scheduled to take place in Calgary and Edmonton in April 2012. A joint Canada-US task force, under the tutelage of the American Plywood Association, also released a CLT production standard in late 2011. Most significantly, three Canadian timber suppliers have entered the market in 2011 with their own brand of CLT panel products.

Qualifying as heavy timber under the current BC Building Code, solid wood panels display many of the qualities found in cast-in-place concrete construction, including strength and stiffness, efficient thermal mass, soundproofing and vibration control, and good fire-resistance. Solid wood panels offer a lighter and economical alternative to concrete construction with the potential for faster erection due to CNC pre-fabrication, with all the environmental and architectural qualities we know about wood, including a reduction in the carbon footprint embodied in the building.

For the purposes of this study, three basic panel types have been considered: glued CLTs, LSL (Laminated Strand Lumber) and LVL (Laminated Veneer Lumber) panels. These engineered wood products have different characteristics and offer different advantages and limitations, and may be more advantageous for use in certain parts of the structure than others.

Glued CLT panels are now available from Canadian suppliers in sizes up to 400mm thick, 3m wide and 13m long. LSL and LVL are typically produced in Canada in billets up to 89mm thick, 2.44m wide and 19.5m long.

Can Solid Timber Panel Construction Go Tall?

A building structure consists of individual elements connected together to form a system. The first step in assessing this system, is the assessment of the material proposed for the fabrication of its components. All other issues set aside (connections, ductility, erection, weather protection etc.) the key question is: does engineered wood in itself have the inherent strength required to practically reach 30 storeys or more?

A simple comparison of material properties, based on gross area, between LSL, LVL and CLT and that of a typical reinforced concrete core wall (such as the one shown in our base case in Appendix A for example), would show that solid wood panel products have resistances which are roughly in the same order of magnitude as reinforced concrete in all critical aspects. This includes axial capacity, flexure in and out of plane, shear and stiffness.

Considering that timber weighs a quarter of the weight of reinforced concrete, resulting in much lower gravity and seismic loads on the structure, one can conclude, in a simplified manner, that from a material standpoint, solid wood panel construction would be able to do the job quite efficiently. The potential savings in foundation costs can expected to be significant, particularly in poor soil conditions.

Structurally, the challenge then resides in the ability to achieve efficient and reliable connections and develop systems with sufficient ductility to achieve good performance in high seismic zones. We believe this report presents workable solutions addressing these issues. We believe that as more work is done and more minds focus their attention on this potential new way to build, more solutions will emerge, making tall timber construction increasingly efficient and competitive.

CLT vs LSL (or LVL) panels

You will note that CLT and LSL panels have been used interchangeably in the typical details and discussions throughout the report. Our analysis has shown that ultimately, all panel types can be used either for core construction or floor systems, with relatively minor variations in the overall dimensioning of the respective elements. This said, panel type will have an impact on specific details of the design. As an example, the bearing of steel beams on panel ends will be affected by grain orientation and will be lower in CLTs, which have a mixture of vertical and horizontal layers. The published shear capacity of LSL and LVL panels at this time is higher than that of CLTs. CLTs on the other hand can be readily produced in thicker panels.

For the purposes of this report, which aims to be primarily conceptual in nature, element sizes were often matched to the closest panel thickness currently available in the Canadian market. Wall panel thicknesses for instance were increased in increments of 3 ½ inches to match the thickest common LSL or LVL panel thicknesses available. More refined and efficient dimensioning would of course be considered in an actual design and will become increasingly possible as the industry sees the market potential of panel products and offers a wider variety of panel dimensions. Ultimately, the optimization and specific detailing of the system is left to the individual engineer.

Design Data

The following design values are based on Appendix C of the British Columbia Building Code 2006 for Vancouver. This data constituted the basis of our preliminary design and the preliminary dimensioning of structural elements upon which the cost analysis was based.

Table 3.6.1

Importance Category	Normal
Climatic Design Data (per BCBC 2006)	
ULS importance factor for snow	Is = 1.00
Ground Snow Load	Ss = 1.80 kPa Sr= 0.20 kPa Plus snow built up where applicable
ULS importance factor for wind	I_w = 1.00
Hourly Wind Pressure	(1/10) 0.36 kPa
Hourly Wind Pressure	(1/50) 0.48 kPa
Seismic Design Data	
ULS importance factor for earthquakes	I_Q = 1.00
5% damped spectral accelerations	Sa(0.2)= 0.94 Sa(0.5)= 0.64 Sa(1.0)= 0.33 Sa(2.0)= 0.17
Peaked ground acceleration	PGA= 0.46
Assumed Site Class	C
Rd	2.0
Ro	1.5
Design Live Loads	
All floor and patio areas	1.90 kPa
Roofs	1.82 kPa Plus snow built up where applicable
Design Dead Load	(including partitions and 40 mm concrete topping)
Floors	4.00 kPa + perimeter wall weight
Roofs (includes allowance for rooftop units and screens)	3.00 kPa
Lateral Interstorey Drift Limit	
Wind	h_n/500
Seismic	h_n/40

Code Analysis

Based on BCBC 2006 and the Canadian Standards Association codes for material design (latest editions).

Upcoming Revisions to the Building Code

Early in 2011, the National Research Council, the Canadian Wood Council and FPInnovations joined to initiate the formation of a new consultation group to discuss code changes required to allow taller wood buildings. The group consisted of researchers from the above mentioned groups, design professionals, fire experts, representatives of the concrete, steel and masonry institutes and others.

Following meetings in March 2011 and December 2011 in Ottawa, several members of the group concluded that there is a need to change the current height requirements in the code to allow taller wood structures. This recommendation is in response to the introduction of cross laminated timber (CLT) and solid wood panel construction in general to the Canadian market.

Light wood frame currently dominates the multi-storey wood construction market in Canada, and clearly constitutes the basis of the current building code. The group noted however that the structural and fire performance of solid wood panel systems such as CLT is significantly different than that of light wood frame, and that this should be reflected appropriately in the building code.

CLT and solid wood panel research projects are ongoing at FPInnovations and several Canadian Universities, the results of which will constitute the basis of upcoming recommendations to NRC to enable changes to the current height limits for solid wood building systems.

Structural Concept - Case Study Analysis

Initially, the scope of the study was to review the feasibility to build up to 12 storeys in wood. As the study progressed and analysis results started to come in, the study was expanded to 20, and then 30 storeys. Ultimately, we limited our efforts to four case study options, based on the typical residential tower floor layout provided by mgb, and various building heights (see architectural report). These consist of:

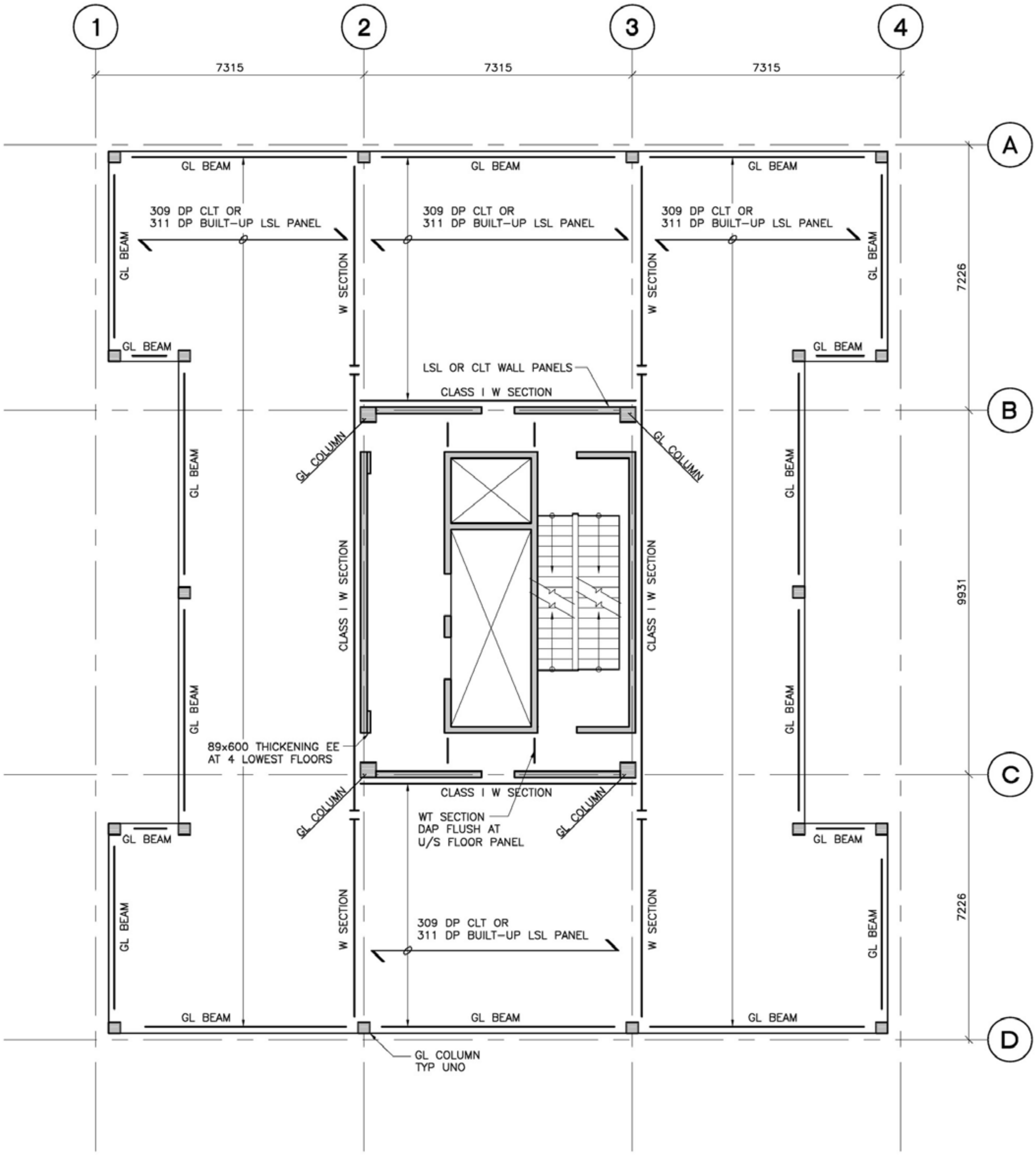
- Option 1: 12 Storey building with core only
- Option 2: 20 Storey building with core and interior shear walls
- Option 3: 20 Storey building with core and perimeter moment frames
- Option 4: 30 Storey building with core and perimeter moment frames and interior walls

Structural concept plans have been included for each option below, and the associated architectural floor plans, elevations and exploded 3D models can be found in the architectural report. While we originally anticipated that both interior shear walls and perimeter frames would be required to achieve sufficient stiffness for the 30-storey case (Option 4), this did not prove necessary, as the layouts for Options 1 and 2 met the strength and serviceability criteria for 30 storeys.

The structural options we have chosen are for demonstration purposes. Numerous other arrangements are certainly possible and may be required for different building geometries. The intent is to demonstrate that the innovative concepts of lateral load resisting systems in solid wood construction that we are proposing have the ability to meet the requirements of the code for various building heights, and are expected to display safe and reliable ductile behaviour under seismic loading. These concepts, we believe, provide a new workable structural solution for buildings of all types and sizes.

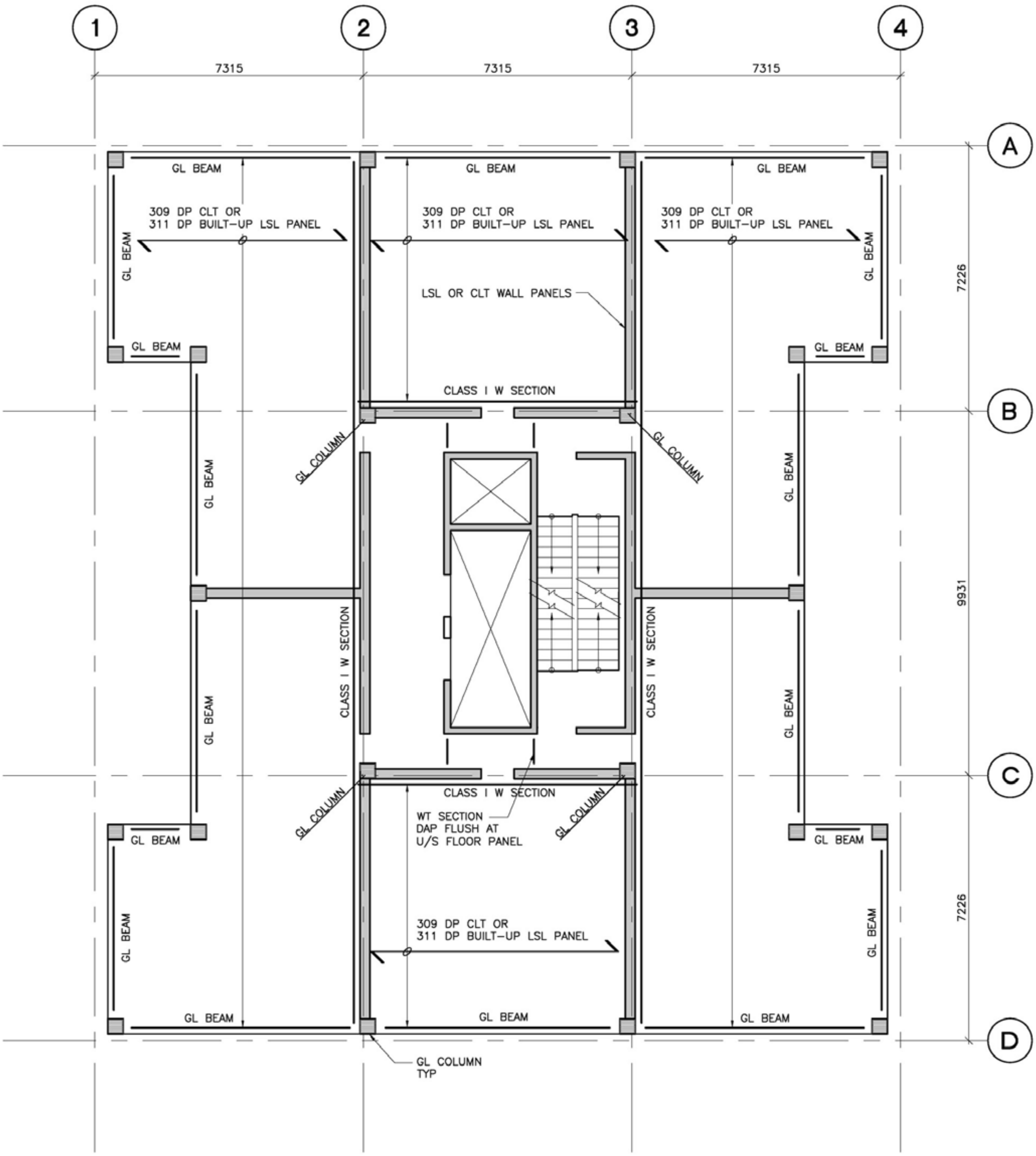
Please refer to Appendix A for sample output from the preliminary analysis of our study. Appendix A also provides typical details and reinforcing requirements for concrete structures of equal height and identical floor plates.

Plans



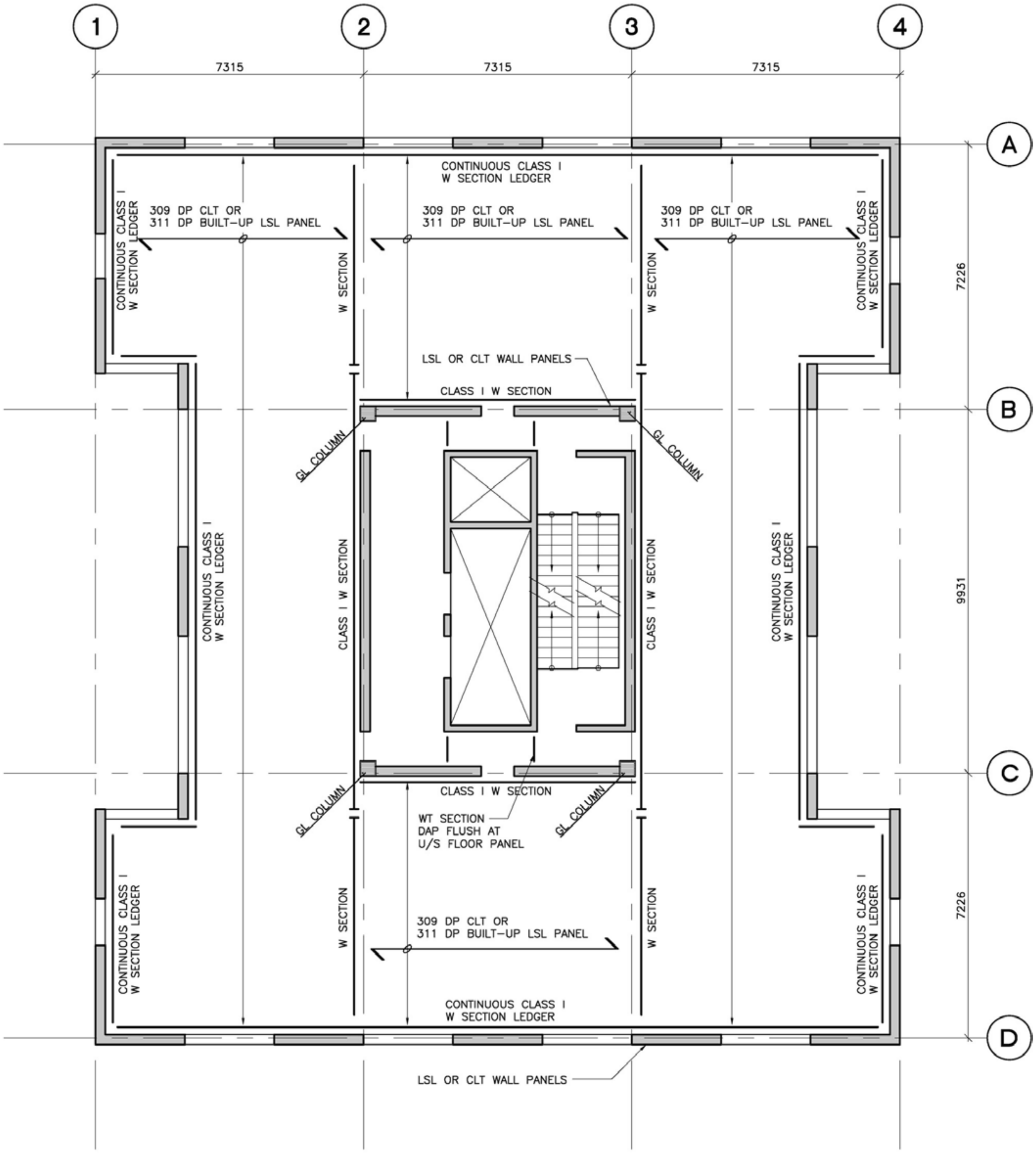
Option 1 - 12 Storey

NTS



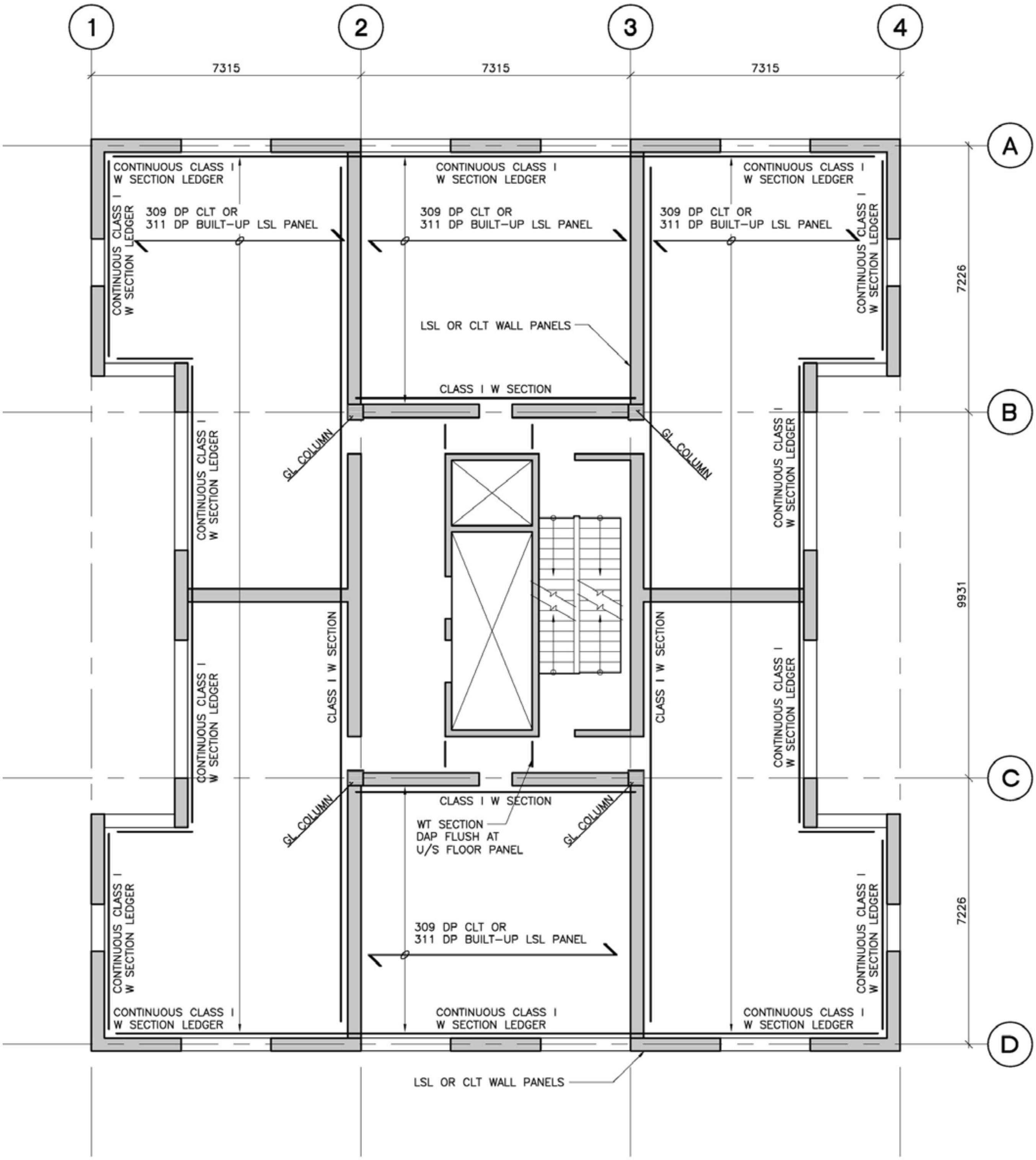
Option 2 - 20 Storey
NTS

Note: Our analysis has shown that a 30 storey model of option 2 performed adequately.



Option 3 - 20 Storey
NTS

Note: Our analysis has shown that a 30 storey model of option 3 performed adequately.



Option 4 - 30 Storey

NTS

Note: Our analysis has shown that a 30 storey model performed adequately with either the interior partition walls or perimeter frames.

Gravity Load Resisting System

The floor and roof structure may be of CLT, laminated LSL panels or glue-laminated engineered wood panel construction, with or without concrete topping. The topping provided can be either composite or non-composite. In the examples under consideration, the panels are assumed to span one-way east-west over interior steel beams which also act as core headers or link beams. A CLT panel thickness of 255mm is shown, and an LSL panel depth of 267mm has been assumed, using 3 layers of 89mm LSL, assumed to be glue-laminated together in the shop.

The perimeter structure consists of glulam post and beam for Options 1 and 2, and moment frames of solid wood panels and steel link beams for Options 3 and 4. Typical columns would consist of glue-laminated timber which could be installed in multiple lifts to limit the number of elements and simplify connections from floor to floor.

While it is assumed at this time that dropped ceilings and wall finishes will be used in locations to provide fire protection and/or acoustic treatment and the concealment of services, spaces can be built into the panel assemblies to provide chases for services. In the case where charring is used as a strategy for fire protection, all member sizes would need to be checked and adjusted to meet the post-fire load case. Our preliminary analysis has shown that the charring design approach minimally impacts the sizing of the structural members in most cases (see section on fire-resistance below as well as the architectural and code consultant reports).

Alternate Floor Framing

For the purposes of this study, large free spans and deeper floor panels have been assumed to minimize the number of dropped beams and maximize flexibility in laying out services. In an actual design, options should be available to shorten spans and reduce panel thicknesses, thereby achieving a more efficient and lighter floor system. The addition of a few dropped beams would allow for the use of 5 ply or 169mm deep panels instead of the 9 ply or 309mm used in the study. This would potentially result in an estimated saving of $7 to $8 per square foot, and would reduce the weight and the resulting seismic loads on the building by as much as 15%, adding further savings.

Floor Vibration

Floor vibration often governs the design of solid wood panel construction. Careful analysis of floor vibration must be included in the design of solid wood panel floors, particularly where concrete topping is omitted.

This said, the stiffness and feel of a properly designed solid wood panel floor will be much closer to that of a concrete slab than a light frame structure, often with a shallower depth, and can be nearly indiscernible from a concrete floor structure where concrete-wood composite is used.

Lateral Load Resisting Systems

Using the inherent vertical strength of solid wood panel construction, the approach is to achieve “strong column / weak beam” shear wall and moment frame systems with good ductility and sufficient strength and stiffness to resist all required loading conditions.

The “strong columns” in this instance, would therefore be large CLT panels or LSL/LVL panels glue-laminated to the required thicknesses. The “weak beams” would be ductile (class 1) wide flange beams, proportioned to develop plastic hinges at or near design load levels (as per the principles of capacity design), while providing the required stiffness, contributing to the overall ductility of the system. Reduced beam sections (RBS) can be used to achieve the desired hinge locations and capacities while retaining the majority of the beam stiffness. Wide flange beams are chosen as they typically have more reliable over-strength than hollow structural sections.

Based on the typical residential tower floor plan illustrated in the architectural report, three lateral load resisting systems (LLRS) have been explored: 1) the core, 2) perimeter moment frames which would be integrated into the building facades, and 3) interior demising walls. These can be used individually or in combination, provided of course that code requirements regarding the combination of different lateral load resisting systems are followed.

Our preliminary analysis shows that the ductility level of the lateral load resisting system may not impact the final design significantly. Stiffness appears to govern in most cases, and wind loading will govern for higher buildings even in higher seismic zones, particularly if concrete topping is omitted and the building mass is relatively low.

Readers familiar with the intricacies of structural design will note a number of particularities with the proposed system which may cause concern or debate. These may include the eccentricity of the steel elements and the walls panels, the sudden localized reduction in wall cross section at the link beam locations and the potential prying action of the tight-fit beams within the wall length. It goes without saying that all such issues need to be carefully assessed in the course of a detailed design for load combinations which include the requirements of capacity design. Our preliminary review of these secondary effects has shown that they are quite manageable.

The diaphragm will be provided by the solid wood floor panels, which will be connected together to transfer the required shear forces.

1. Core walls and headers (moderate to high ductility)

- Core walls would consist of “strong”, glue-laminated LSL or LVL panels or CLTs installed vertically and connected together to create larger wall panels forming the core. “Weak” ductile wide-flange steel beam headers, partially embedded into the panel face would connect individual core wall panels together over doors and other openings. The system’s ductility will vary with the design.
- The steel headers would be proportioned to develop plastic hinges at or near design load levels (as per the principles of capacity design), Reduced Beam Sections (RBS) can be used to achieve the correct plastic moment capacity and adequate beam stiffness, contributing to the overall ductility of the system.
- The header moments will be developed by direct end grain bearing of the header beam on the solid wood panel edges. No mechanical fasteners would usually be required, other than to torsionally restrain the header beam into place.
- Particular attention will be required in heavily loaded cores with eccentric opening arrangements. Localized modifications to the system may be required in such instances.
- Alternative link beam and associated connection arrangements can also be considered, such as back-to-back ductile channels connected directly to the panel face rather than embedded. Research and testing of various connection details will determine the most appropriate solutions for particular building arrangements.
- The vertical joints between adjacent panels or between panel ends and glulam columns could consist of lapped joints (say ±150mm wide) connected with a large number of self-tapping mechanical fasteners over the full height of the core. This has been shown in CLT testing at UBC to provide significant additional ductility over single, homogeneous panel walls connected at the base only. Further testing of the combined system may allow for lower recommended R_d and R_o values, further reducing the lateral forces experienced by the structure.
- The horizontal joints can also consist of lapped joints (say 600mm wide), connected with numerous mechanical fasteners and/or keyed as required for higher shear loads. Tension ties will be required at each end.
- Ductile hold downs (or dampers) and shear connections will be developed to anchor the core at the base. Numerous options are available for this purpose.

2. Perimeter wall moment frames (high ductility)

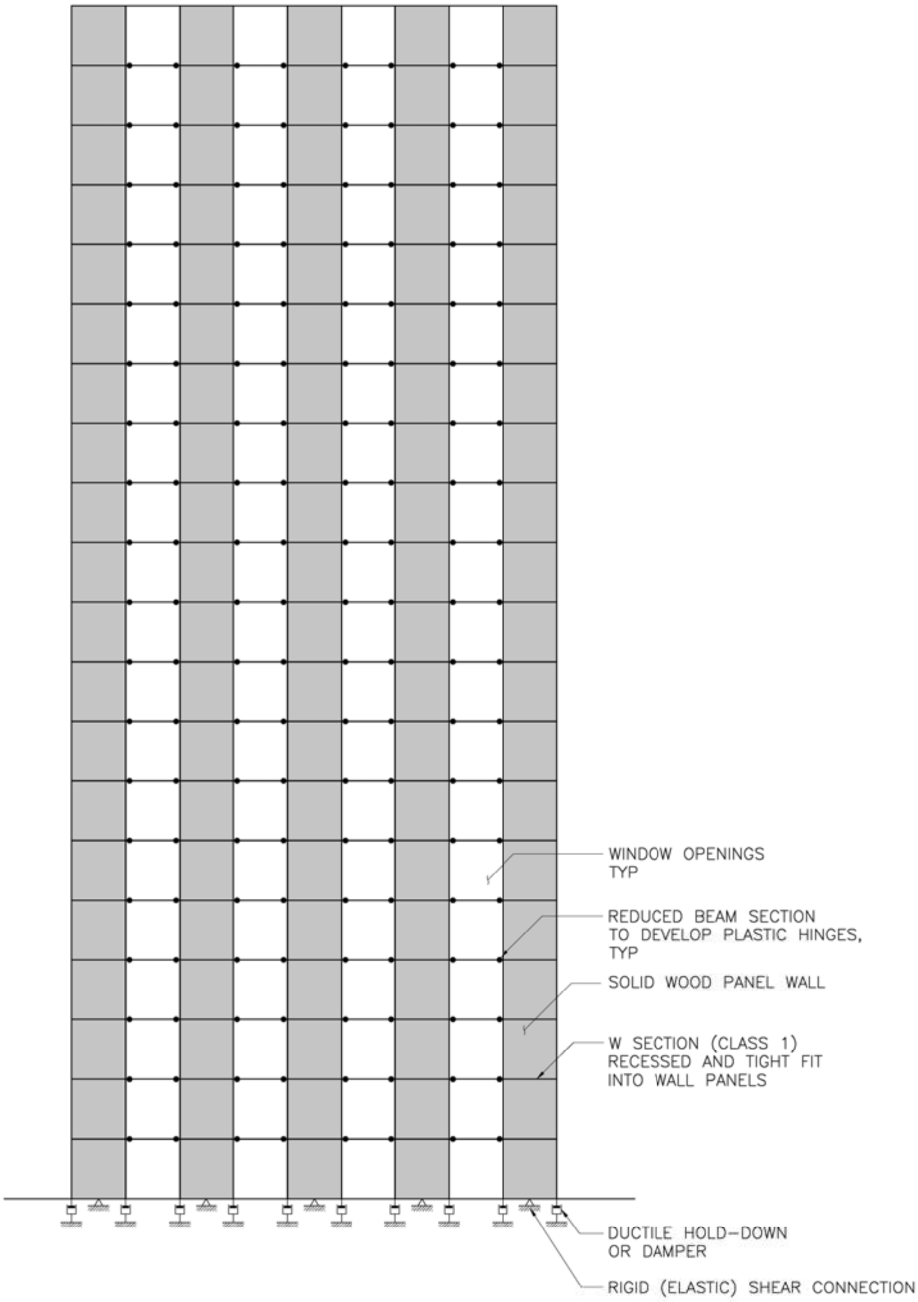
- Perimeter moment frames will consist of “strong” glue-laminated LSL, LVL or CLT vertical panel elements, linked by “weak” ductile (class 1) wide flange steel headers connecting the vertical panel elements to create ductile strong column / weak beam moment frames which can be integrated in the building façades.
- The headers would be proportioned and detailed to develop plastic hinges near the edge of the wall panels at or near design load levels (as per the principles of capacity design), contributing to the overall ductility of the system. Reduced Beam Sections (RBS) can be used to achieve the correct plastic moment capacity and adequate beam stiffness.
- The header moments will be developed by direct end grain bearing of the header beam on the solid wood panel edges. No mechanical fasteners would usually be required, other than to torsionally restrain the header beam into place.
- This will provide flexible and reliable high-ductility moment frames with very simple connections, without the risk of brittle weld failures.

3. Interior partitions/load-bearing walls (moderate to high ductility)

- Interior walls can be made to be continuous and load-bearing from foundation to roof, and can be used as an integral part of the primary LLRS. However, this may be more appropriate for the purpose of achieving adequate stiffness under wind loading, and may not be desirable in high seismic zones, depending on the particular wall arrangements.
- Alternatively (and more likely), they could be used to complement the primary LLRS (lateral load resisting system), if required, much as drywall sheathing is used in combination with engineered wood panel shear-walls (OSB and plywood), to add stiffness to the primary lateral load resisting system and help control drift. This strategy would allow the partitions to remain non load-bearing, but would require that the interior walls be connected to the floor diaphragms with connections sufficiently ductile to provide stiffness under wind loading while accommodating the drift of the primary LLRS under ultimate seismic loading conditions.

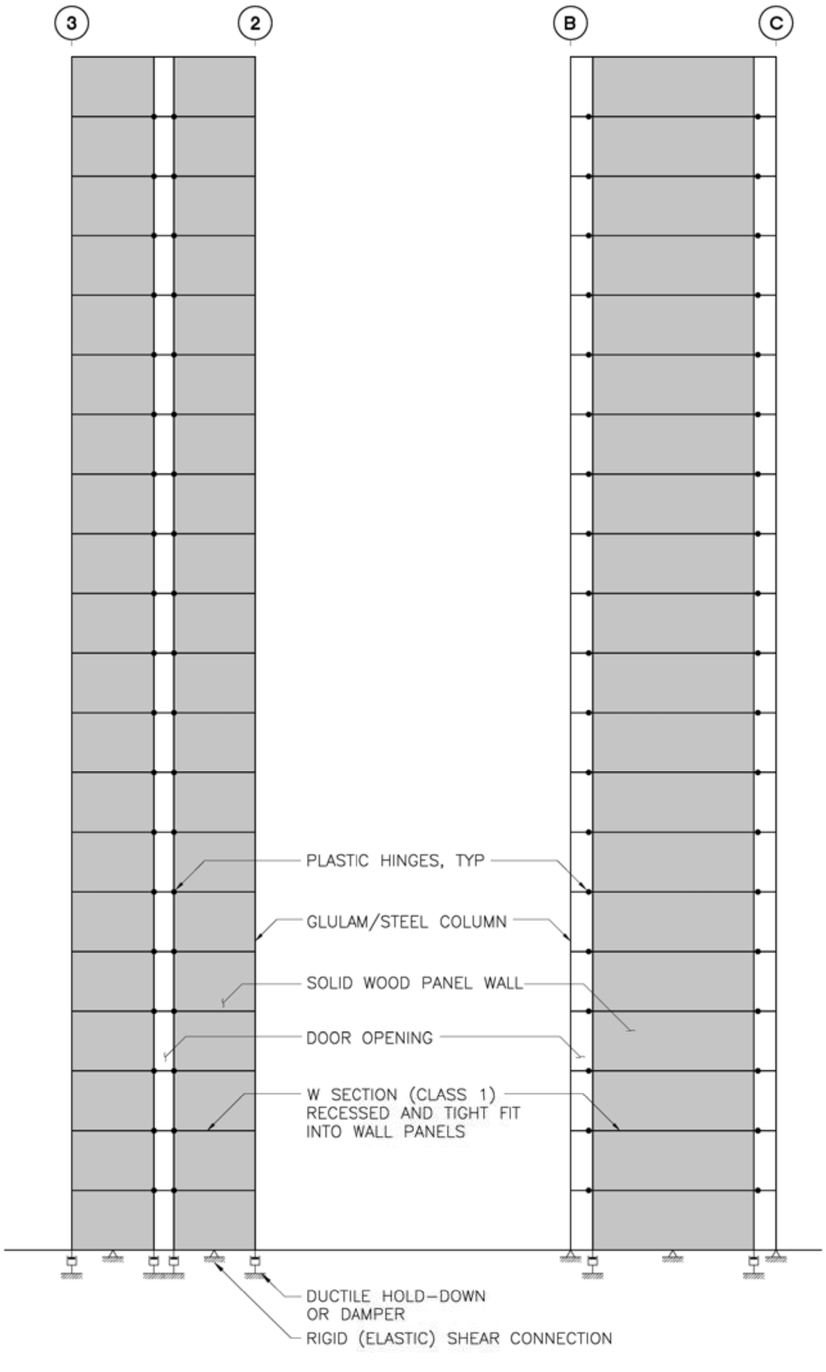
Refer to the typical details further in the report for specifics of interior partitions built through and between floors.

Lateral Load Models



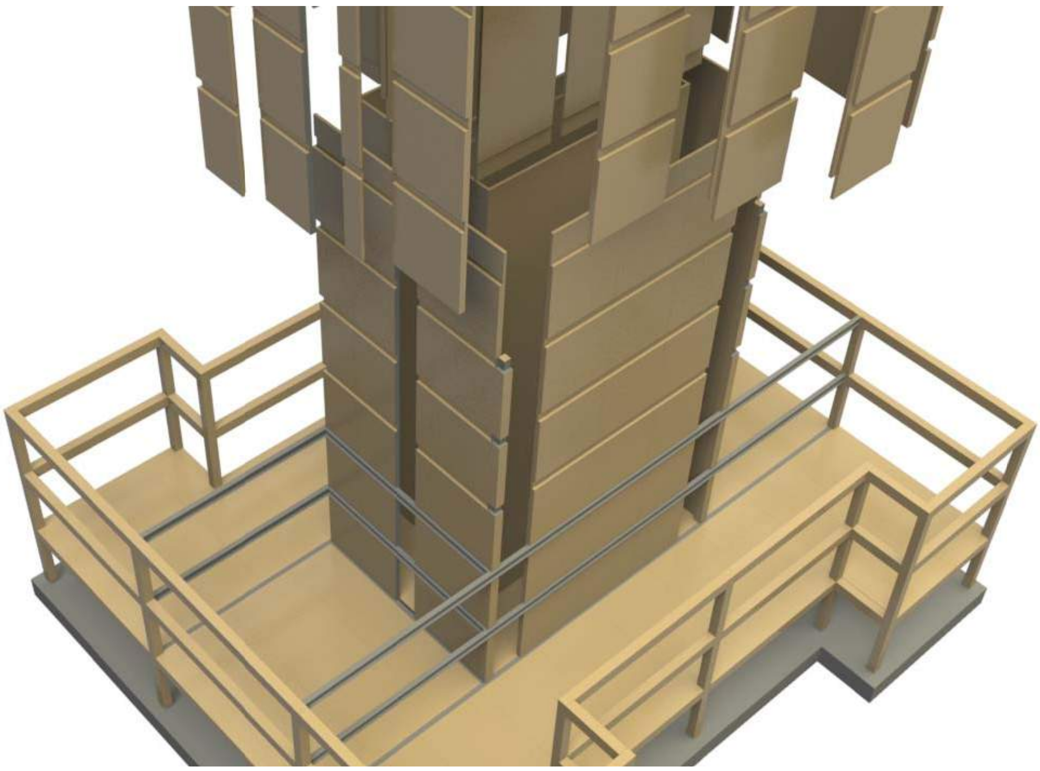
Lateral Load Model - Typical Perimeter Moment Frame Model

1:250



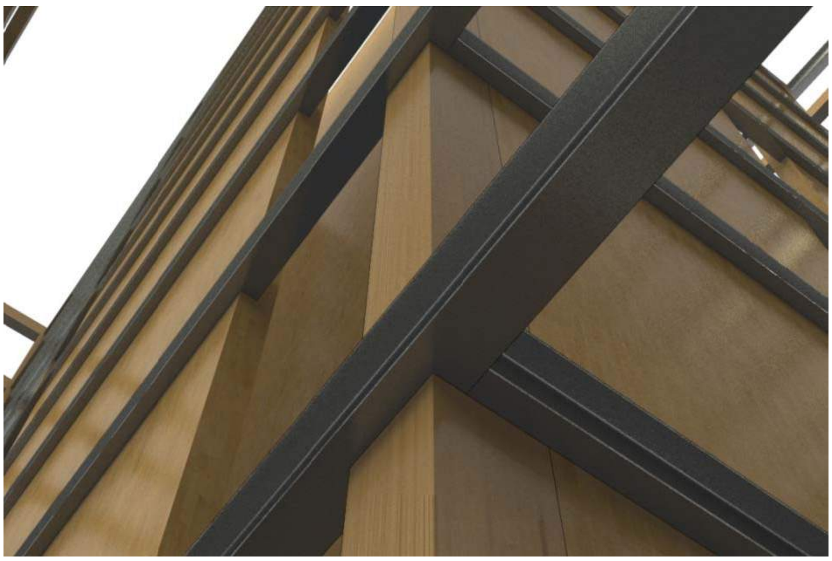
Typical Core Wall Model

NTS



Option 1 - 12 Storey with core

Exploded view



Close-up Views

Solid panel core and intersecting ductile steel link beams

R Values for Seismic Design

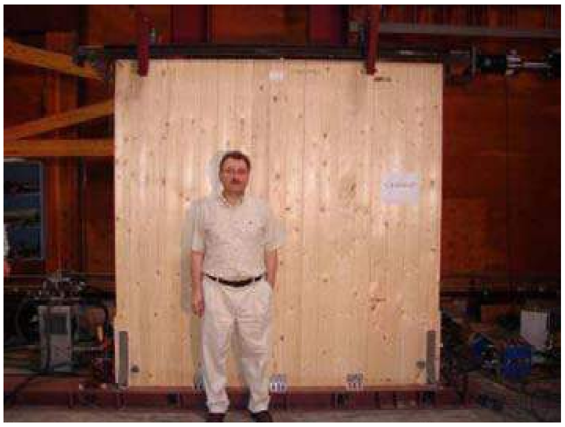
The “R” factors referenced in Section 4 of the National Building Code represent the level of ductility of a lateral load resisting system and are critical to the design of seismically resistant structures. All commonly used lateral load resisting systems are assigned an R_d and R_o value in the National Building Code. The higher the ductility of a system, the higher the associated “R” factors, and as a result, the lower the required seismic design forces. “R” values have yet to be assigned for solid wood panel construction in the building code but educated assumptions have been made for the purposes of this study.

Preliminary results of CLT shear wall panel tests conducted by FPInnovations laboratory at the University of British Columbia have shown good behaviour and ductility, for panels connected at the base with standard hold down anchors and “L” shaped shear connectors and screws. These displayed well-shaped hysteresis curves over 20 cycles or more. Because solid wood panels are proportionally extremely strong and rigid, the ductility must be provided by the connections.

The CLT Handbook published by FPInnovations in March of 2011 is recommending preliminary “R” values for CLT panels with simple, standard connections of $R_d = 2.0$ and $R_o = 1.5$. These values are primarily based on single panel assemblies with standard light framing anchorage. The panel connections in our case will of course be substantially larger. The goal however will be to develop base anchorage details that are of similar or higher ductility.

Given that the testing was based on single and double panel walls, FPInnovations has also recognized that these initial values are necessarily conservative. The presence of screwed vertical and horizontal lap joints in the panel assembly for example adds ductility to the system. The presence of ductile link beams in our case could alone justify much higher R values. The behaviour of our system is likely closer to moderately ductile or ductile steel moment frames or moderately ductile or ductile partially coupled walls, with “R” values of say $R_d = 3.5$ and $R_o = 1.5$ or higher.

Testing and comprehensive analysis (such as is suggested in the ATC 63 document), and comparative analysis against other systems is of course required to confirm appropriate values for code adoption for the design of various solid wood panel based lateral load resisting systems. For the purposes of this study, we conservatively chose values of $R_d = 2.0$ and $R_o = 1.5$.



CLT Shearwall Test
FPInnovations

2 Storey CLT Structure Testing
FPInnovations

Lateral Loads

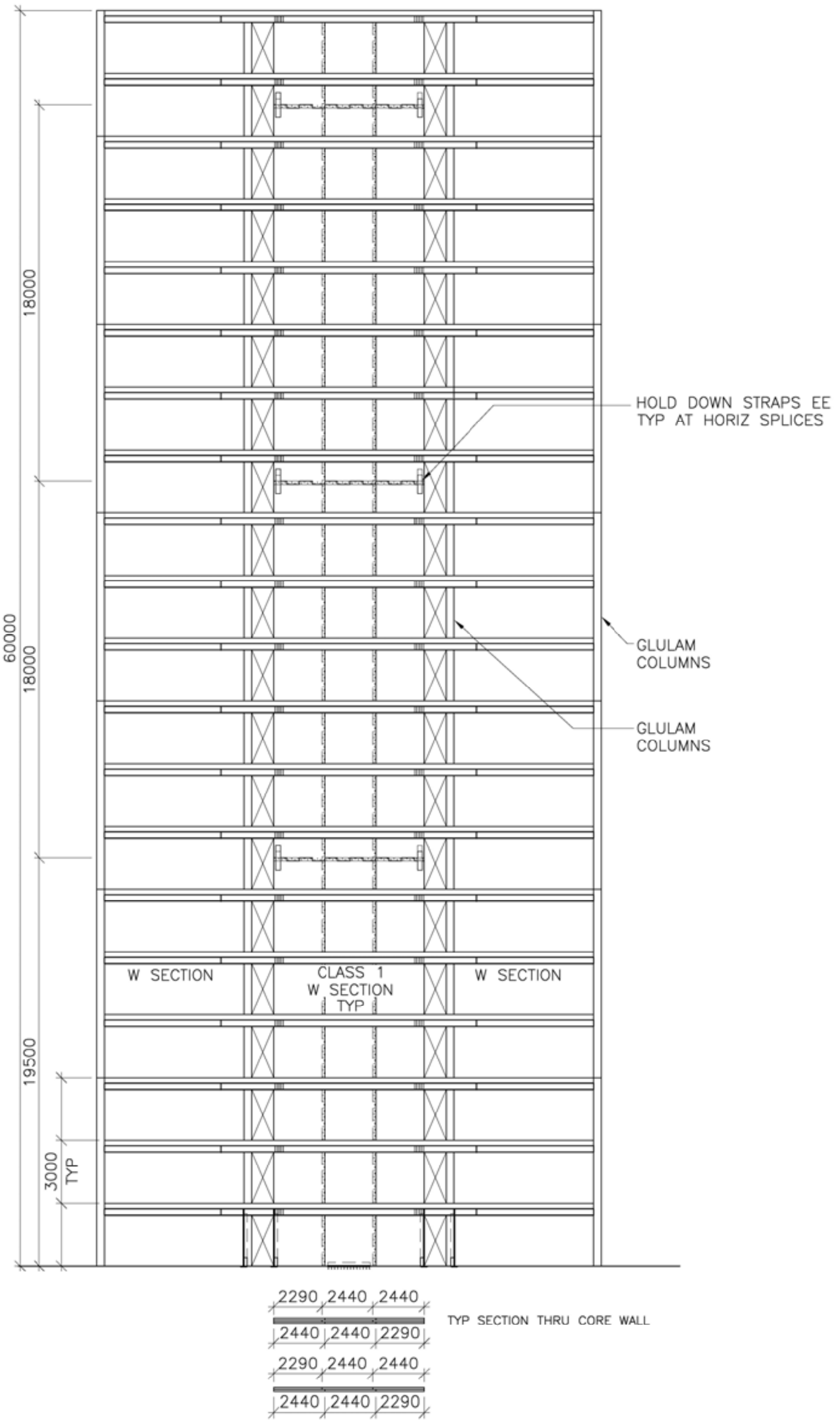
In summary, the seismic forces used for the preliminary analysis of our building prototypes were based on 3 metre storey heights and R_d = 2.0 and R_o = 1.5. Soil factors were based on an assumed site class “C”, and a “Normal” importance building category was used. Wind loading is based on q 1/50 = 0.48 kPa as summarized in the design data provided above.

The lateral seismic forces used were based on behaviour approximating that of moderately-ductile timber moment frames. The true behaviour would be expected to be somewhere between ductile linked walls and a steel moment frame, where wall or column elements themselves display additional ductility (through vertical and horizontal lap joints between panels). Therefore, the forces derived from the preliminary analysis are quite conservative – it is expected that further testing and more detailed analysis will realize greater R values.

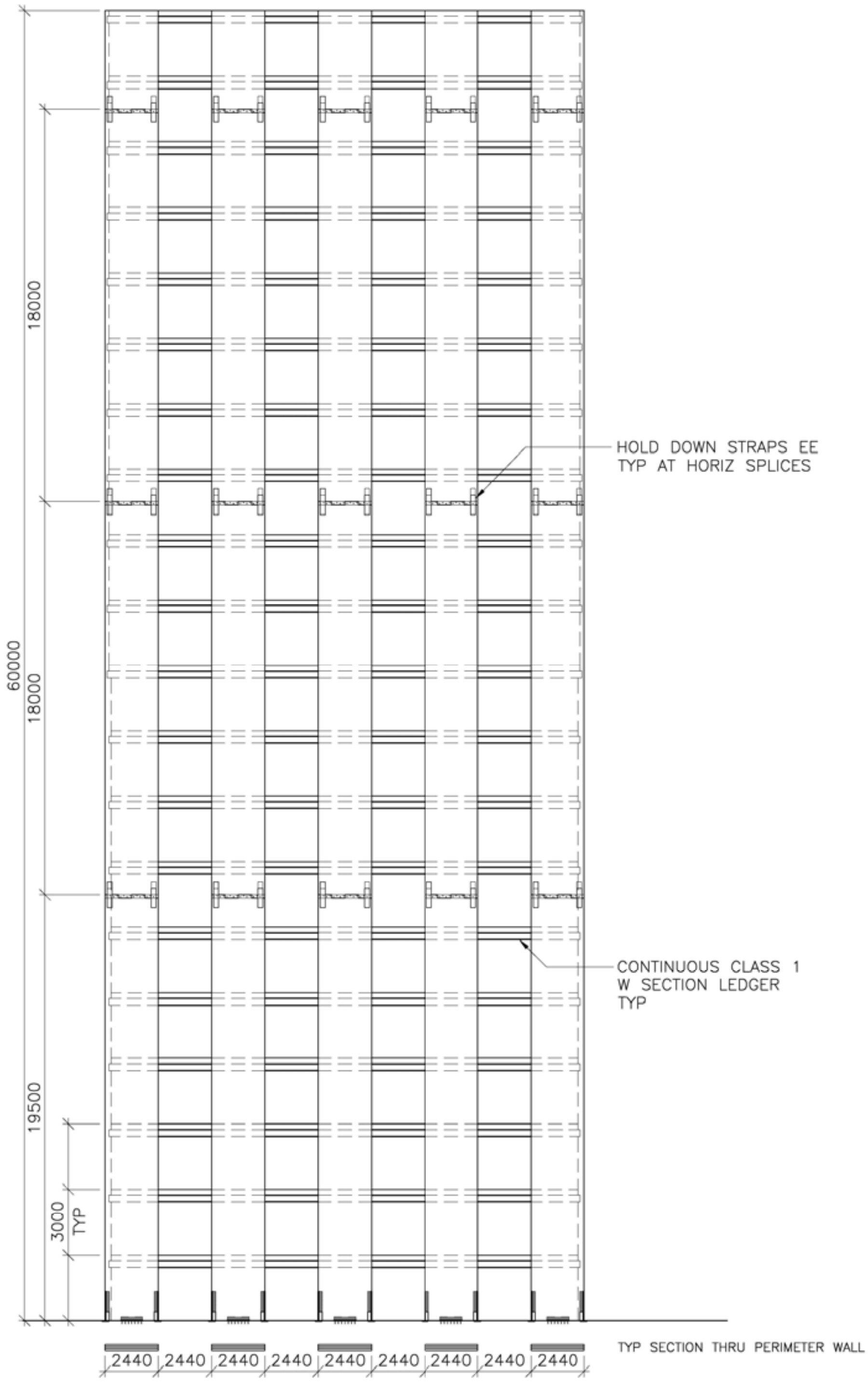
Wind Induced Vibration

Given the light weight of solid wood construction, wind induced vibration must be considered in the analysis. The use of permanent internal solid wood panel partitions (commonly used in residential buildings but usually absent in commercial construction) could be used to mitigate vibrations.

Sample Details



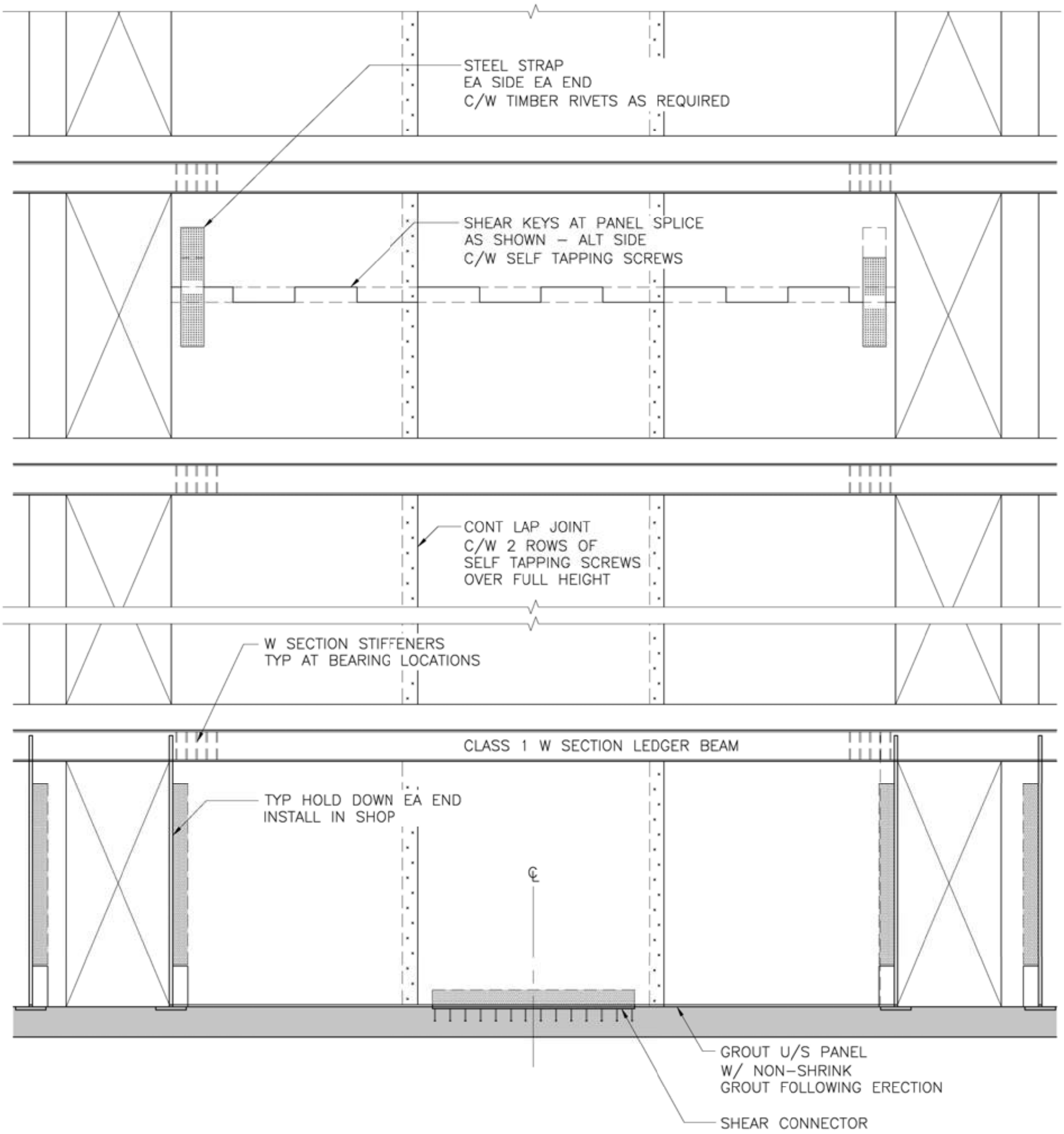
Core Wall
20 Storey
NTS



Typical Perimeter Moment Frame

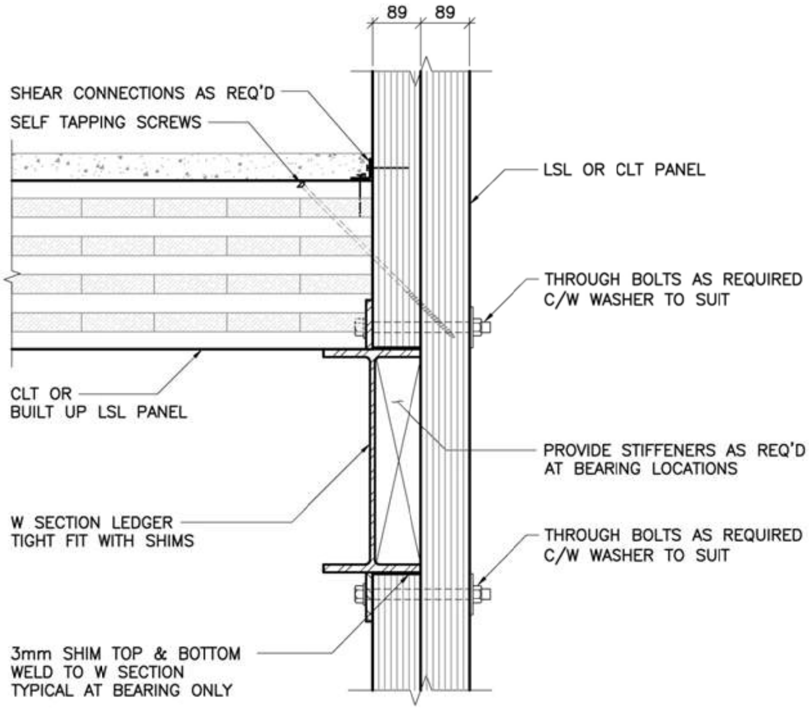
20 Storey

NTS



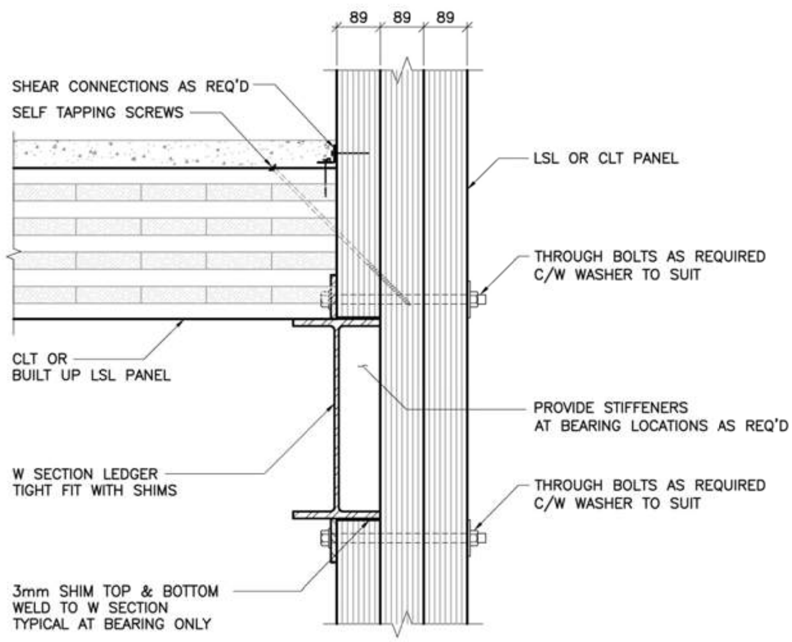
Conceptual Panel Connection Details

NTS



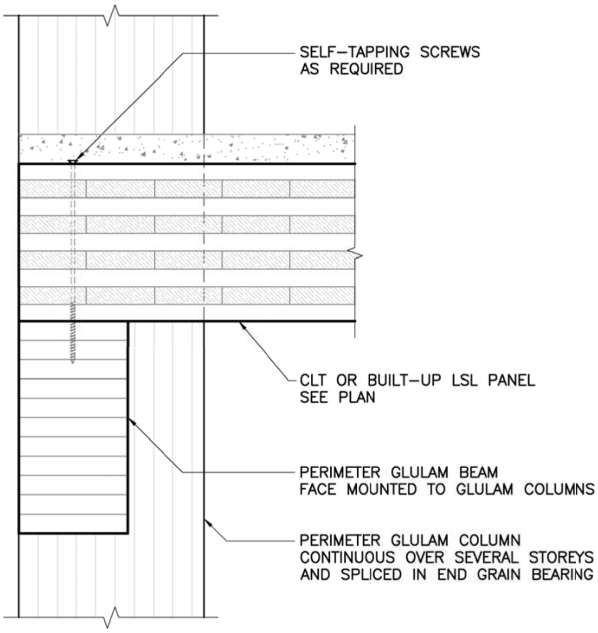
Section Detail - Ledger Connection to Double LSL (178) Panel or 205 CLT

NTS Typical at core or at moment frames



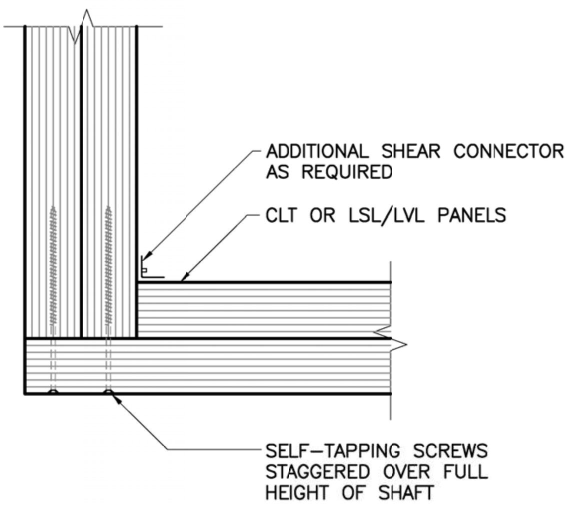
Section Detail - Ledger Connection Triple LSL (267) Panel or 274 CLT

NTS Typical at core or at moment frames



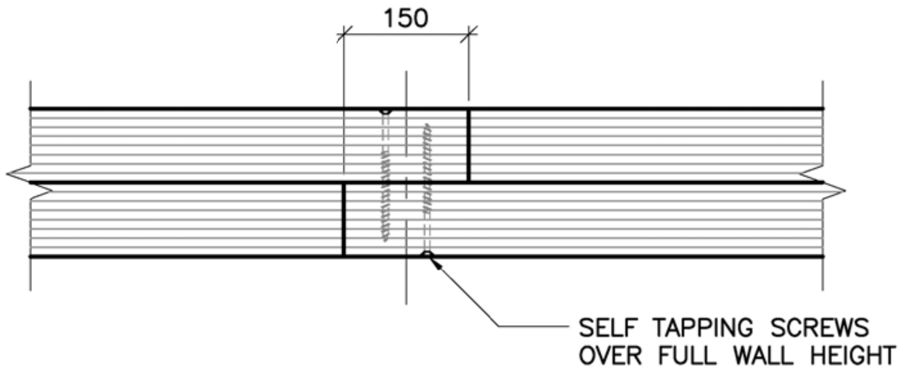
Section Detail - Typical Perimeter at Post and Beam

NTS Options 1 and 2

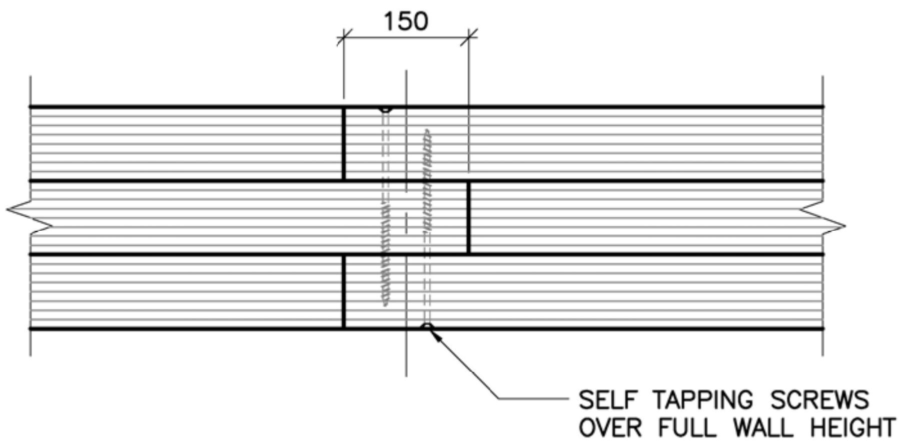


Plan Detail - Typical Wall Intersection

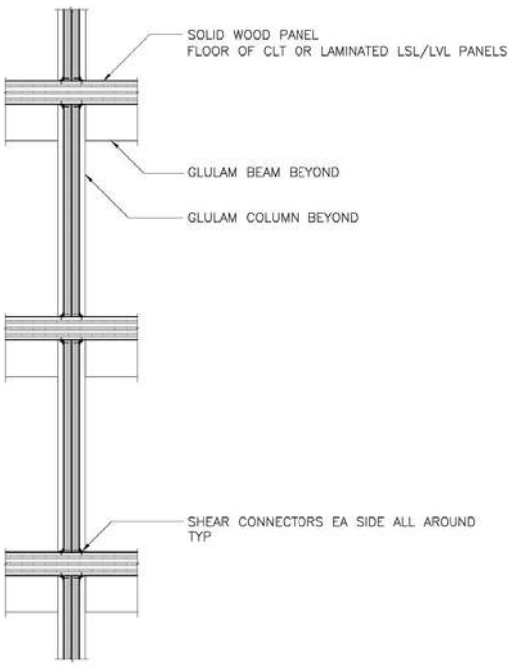
NTS



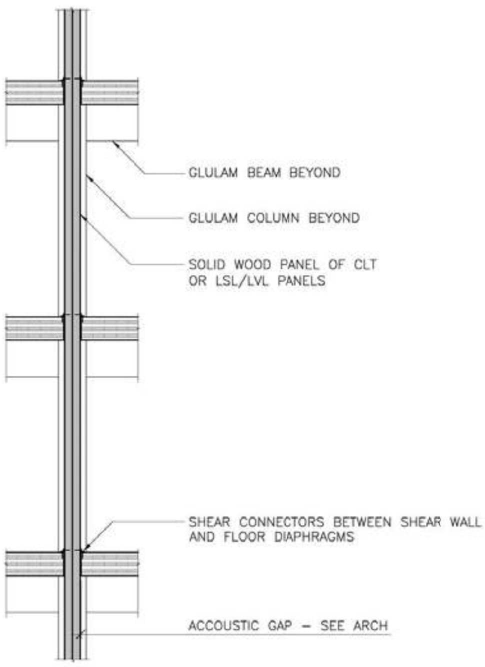
Plan Detail
Typical Vertical Joint
Double Panel (178 mm)
NTS



Plan Detail
Typical Vertical Joint
Triple Panel (267 mm)
NTS



Section - Intermittent Demising Wall
NTS



Section - Continuous Demising Wall
NTS

Erection

All timber elements will be pre-fabricated to sizes designed to optimize speed and ease of erection. The header to panel connections will be simple and can be made on the ground to connect several panels together. These can then be "tilted up" several storeys at a time. It is envisaged that the core would be erected first and used to brace other walls and columns, which can be erected in lengths as high as 12m (for CLTs) or 19.5m (for LSL and LVL).

Alternatively, the core can be pre-assembled on the ground and erected in 3 or 6 storey lifts, and the perimeter structure can be prefabricated in a shop with the envelope on and erected in one storey lifts.

Refer to the architectural report for a summary of contractor feedback, erection diagrams and additional construction related commentaries.

Fire-resistance

Encapsulation is typically used to provide fire-resistance rating to timber structures; however, charring is increasingly accepted around the world as a valid means of achieving reliable and safe structural performance in fire. Current testing at FPInnovations/NRC in Ottawa and other wood research facilities around the world, are demonstrating 1 to 2-hour FRR for load-bearing solid wood assemblies when subjected to representative fire exposure curves. The fire performance of load-bearing solid wood systems is a function of the factored loads applied to the structural element, in combination with the sacrificial or protective layers of wood that is incorporated in the panel design to obtain the degree of fire-resistance necessary for the application. Laboratory empirical testing of various structural wood assemblies incorporating Mass Timber will assist to reinforce the first-principles calculation methodologies that have successfully been used in the past for timber structures.

Combined with modern fire suppression systems and compartmentalization, structures can be detailed to safely resist fire without encapsulation, using charring calculation methods. This eliminates the need for encapsulation, reducing building weight and cost while showcasing the natural beauty of the exposed timber.

Design Loads

BCBC 2006 addresses fire loading in Paragraph 25 of Structural Commentary A, where the loading is:

$D + T_s + (aL$ or $0.25S)$
$a = 0.5$ for typical live load (or 1.0 where storage or equipment occurs)

Eurocode 5 EN1995-2-1 provides a simplified method, whereby:

$E_{d,fi} = n_{fi} E_d$
(n_{fi} can be taken as 0.6) i.e. fire loading is 60% of the factored dead and imposed loading

For the design loads in this study (D = 4.0 kPa and L = 1.9 kPa) the fire loading is essentially the same irrespective of the design approach used (3.96 vs 3.95 kPa).

Material Strength Factor

Typically, material strength is multiplied by a factor of safety to account for variations in the strength of materials. In Canada, the typical factors used are 0.9 for steel, 0.65 for concrete and 0.8 – 0.9 for timber, reducing the strength of the material that can be assumed in design. As a result, the material actually used is very often stronger than that assumed for design; however, a small fraction will be of lower strength than that assumed in design.

For the low probability event of a fire, Eurocode 5 contains a factor that effectively increases the strength that can be assumed for the material. This is because a fire occurring during the lifetime of a modern building is very unlikely and the strength of the material is unlikely to be below that assumed. The possibility these two events in combination is very unlikely (a fire occurring in a compartment or building where the material strength is less than the assumed strength). This factor is 1.15 for glulam members (and CLT) and 1.1 for LVL and LSL members.

A similar, comprehensive and rational design approach needs to be developed for the design of tall timber buildings in Canada, where charring is used as the primary means of fire-resistance for structures. For conservative results at this stage, we have not allowed for any material strength increases in our computations.

Structural Element Area Reduction

Timber elements exposed to a fire char at measured rates of 0.65mm/min (for CLT and LSL panels) and 0.635mm/min (for glulam elements). An additional 'heated zone' is assumed to provide negligible resistance to load – this is taken as 7mm, 10mm and 16mm for glulam, floor panels and wall panels, respectively.

In the analysis, column elements were exposed to fire on 3 sides; walls and floors to fire on 1 side. Based on the reduced load (60% of factored dead and live load), the capacity of the reduced-area structural elements was verified to determine what increases, if any, were necessary to carry the structural loads for a fire event. The tables below illustrate the thickness of structure removed by a 120-minute fire and the changes in section size necessary to safely accommodate this approach to fire safety design. It will be seen that minor increases to some column sizes were necessary; however, as a whole, the changes are minimal.

Refer to the charring diagrams for floor panels, wall panels and columns below. CLT panels have been used for the illustration as they are the worst case scenario due to the cross laminations, which are assumed to have zero cross grain capacity.

Changes to structural elements for 120-minute exposed fire rating

Typically, accounting for fire protection by charring resulted in 1-2 additional laminations for glulam columns at lower levels (Levels 1- 8). No changes to solid wood panels were required, as other factors – acoustic, lateral loading – determined the minimum size required for these elements. Similarly, glulam beams did not increase in size, as their size was governed by other gravity loadcases.

Char Depth and Heat Zone

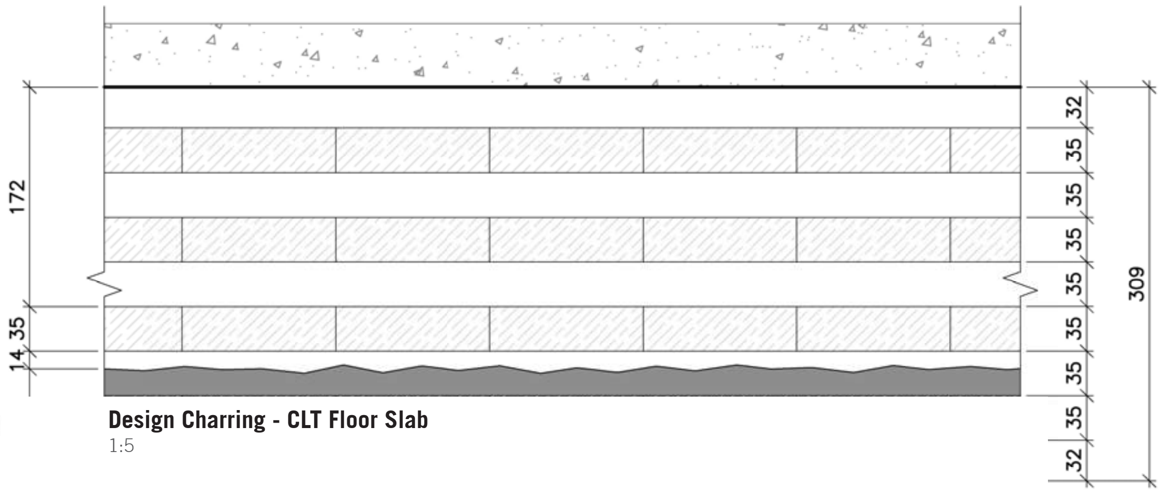
Table 3.6.2

	d_{heat} mm	t min	β mm/min	d_{char} mm	total mm
CLT Floor Panel [1]	10	120	0.65	78	88
CLT Wall Panel [1]	16	120	0.65	78	94

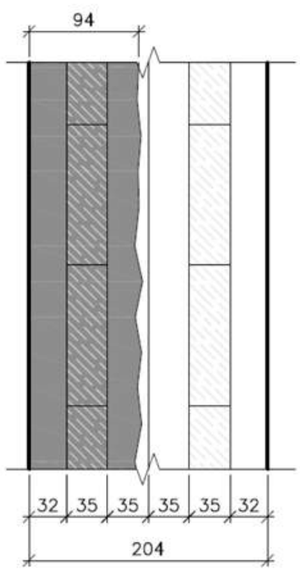
	k_0	d_0 mm	t min	β_n mm/min	$d_{char,n}$ mm	d_{ef} mm
Glulam Element [2]	1.0	7	120	0.635	76	83

[1] Based on FPInnovations CLT Handbook 2011, Chapter 8 – Fire

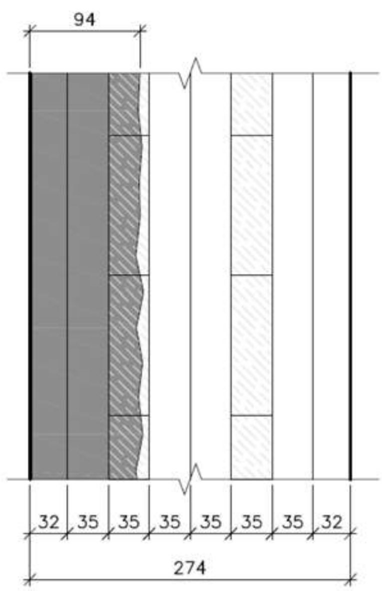
[2] Based on Eurocode 5 - EN1995-2-1, Design of Timber Structures, General Rules - Structural Fire Design



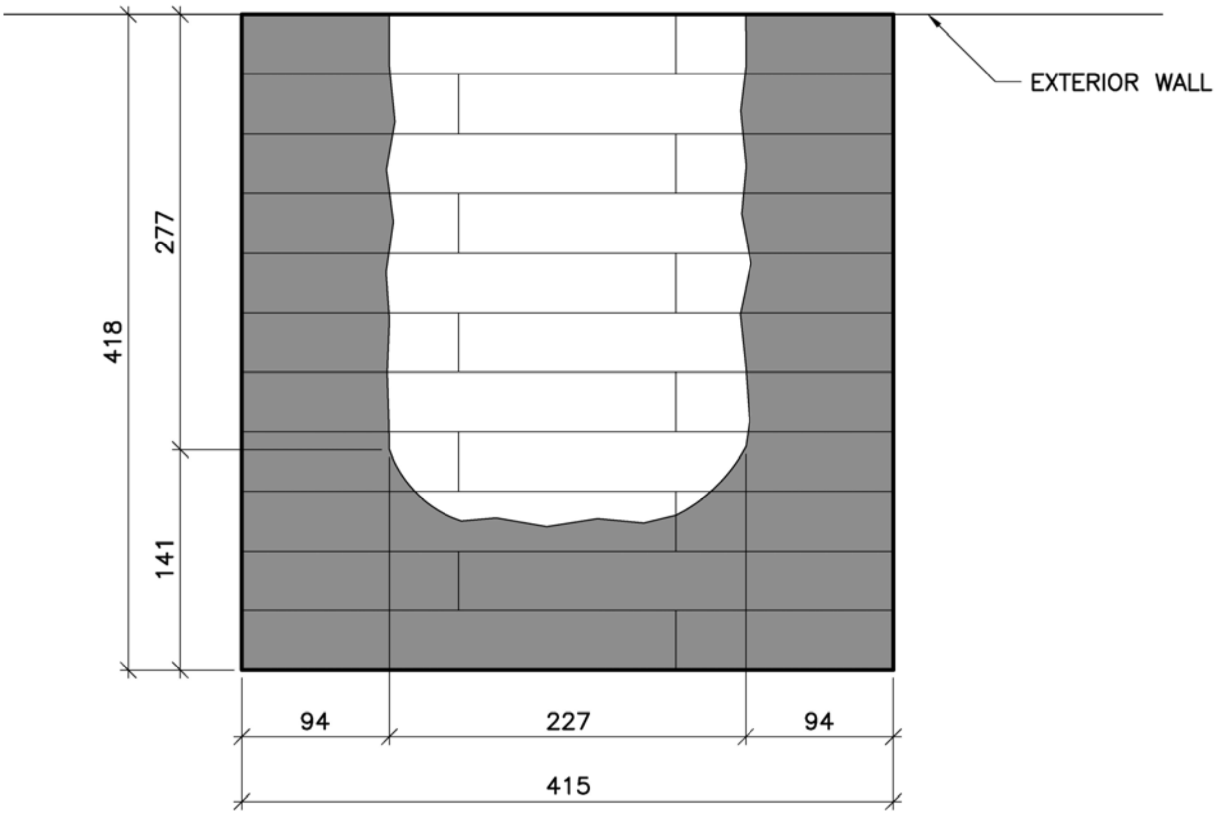
Design Charring - CLT Floor Slab
1:5



Design Charring - 204mm Shear Wall
1:5



Design Charring - 274mm Shear Wall
1:5



Design Charring - Glulam Column
Exposed on 3 sides
1:5

List of Next Steps

The purpose of this study was to explore the performance of an innovative structural solution as it applies to the construction of a mid to high-rise residential tower construction in Vancouver, British Columbia.

Following this study, we conclude that, structurally, buildings in excess of 30 storeys can be built in a practical and economical manner using the proposed method. This is made possible with the introduction of solid wood panel construction in Canada, and the development of a safe and efficient lateral load resisting system which combines the reliable strength and efficiency of solid wood panels and the reliable ductility and stiffness of structural steel sections.

While we are confident that the concepts put forth in this report are sound on first engineering principle, more sophisticated analysis and much testing is required to arrive at a point when code recommendations can be made. We see this as the ultimate goal in making the use of wood in tall building possible.

As a starting point, we would recommend the following list of next steps from a structural engineering standpoint, which we hope will lead to the construction of the first timber high-rise in Canada.

The analysis carried out as part of this study is preliminary and aimed at establishing the feasibility of our concepts. More detailed analysis, peer review and testing will be required to ensure that such structures perform satisfactorily and meet code requirements.

Non-Conventional Seismic Systems

While we have not had the chance to explore the use of viscous dampers, self centering systems and other leading edge seismic resistance methods, we believe that there is great potential for such approaches in solid wood construction and hope to investigate them in the near future.

Self-centered systems are gaining popularity with building Owners who want to further protect their capital investment, and with Owners of post-disaster facilities. We believe this would be a worthwhile topic for further research.

Conclusion

Based on our case study and preliminary analysis, using the Vancouver load case, it is our opinion that solid wood panel structures of 12 to 15 storeys can be practically and economically constructed with wood core construction alone and that structures of 30 storeys or more can be achieved practically and economically with a combination of lateral load resisting systems.

Appendix A

See Appendix A for structural details including the concrete benchmark details, option frame layouts, deflection outputs and analysis report.

PEER REVIEW

As requested, Read Jones Christoffersen Ltd. (RJC) has completed a peer review for Section 3.6 “Structural Analysis” as provided in the report, “The Case for Tall Wood Buildings” dated December 22, 2011. The overall purpose of this section was to study and present in concept, a structural system suitable for constructing tall wood buildings and to provide the framework for further studies, research, and testing required to demonstrate the performance of such a system.

Four hybrid structural systems identified as Options 1 to 4 are presented. Our peer review was primarily focused on reviewing the gravity and lateral concepts presented in Options 1 and 3. The “hybrid” systems generally include Engineered and Proprietary wood products including Cross-Laminated Timber (CLT), Laminated Strand Lumber (LSL), and wood Glulam members utilized for floor, column and wall components, combined with steel beams which form an essential part of the lateral load resisting system.

In general, the details provided in the report include a unique hybrid system composed primarily of wood-based products supplemented with structural steel beams used as a part of the lateral load resisting system. Wood products are strategically used for their strong attributes as required for both the gravity and lateral systems. Steel beams are used interchangeably with wood as a part of the gravity system, but more importantly, for the lateral system where they can be well proportioned to resist lateral forces as well as contribute to the building stiffness. In addition, the steel beams can be easily detailed to provide the necessary ductility and suitably proportioned (as reduced beam sections) to limit the potential amount of loading under a seismic event.

Based on our peer review of the structural concepts, it is our opinion that the systems outlined in the report provide one method worthy of consideration for constructing taller wood buildings. However, as noted in the report, it will be critically important that additional work, including nonlinear modeling, static and cyclic testing of assemblies, studies on ductility as well as further research be conducted to fully demonstrate that such concepts can meet all code requirements.

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3.7 Fire Performance

The following is a summary of the building code requirements for the proposed Mass Timber system approaches being considered. It is noted that the proposed building design will be primarily of Residential (Group C) major occupancy with an assumed building height of between 12-30 storeys. Therefore, the subject building designs will be classified under the "high building" requirements of Subsection 3.2.6., with the additional measures for high buildings considered to be incorporated in the project design. This would include complete automatic sprinkler protection with fire booster pump, firefighter's elevator, emergency generator for 2-hour back-up power supply, full fire alarm system with CACF & voice communication systems, 2-hour protection of emergency electrical conductors and other provisions including smoke control and venting. In all respects, the proposed Tall Wood Building as a prototype model, will comply with the applicable requirements of the local building code within the jurisdiction of the City of Vancouver (VBBL 2007), with the exception that Mass Timber systems will be utilized as the structural framework for the building. In essence, the principal Code deviation or variation from the prescriptive building code requirements for "high buildings", will be that the prototype building will consist of "combustible construction" in the form of solid Mass Timber structural systems and other related architectural elements, whereas the applicable code requirements prescribe non-combustible construction.

Project Characteristics Summary Table 3.7.1

Project Characteristics Summary Table	
Applicable Part of Division B:	3
Number of Buildings:	1; no firewalls
Building Area:	Approx. 500 m^2
Building Height:	12-30 storeys
Number of Streets Facing:	1
Sprinklered:	Yes - per NFPA 13 (and additional sprinkler criteria outlined in this report)
Major Occupancies:	Group C residential (above-grade dwelling units) Group F3 Industrial (below-grade parking)
Article:	3.2.2.42. (Group C), Any Height, Any Area, Sprinklered) - see below for details
Construction Type:	Non-combustible prescribed (Mass Timber system "alternative" proposed) Fire assemblies and supporting structures to have 2-hour fire-resistance rating (floors constructed as "fire separations")
Highrise Requirements:	Applicable - > 18 m and therefore, in accordance with Sentence 3.2.6.1.(1), the Project is a "high building"

Intent of Applicable Building Code Requirements

Relative to the fundamental structural fire protection and construction requirements of the building code, the objectives and functional statements from Division B - Table 3.9.1.1. that are applicable to the code requirements noted above are as follows:

Table 3.7.2

Code Requirement	Objectives and Functional Statements
3.1.5.1.(1) Non-combustible materials	[F02-OP1.2], [F02-OS1.2]
3.2.2.42. (2) Group C, Any Height, Any Area	[F02-OP1.2], [F02-OS1.2] applies to the portion of the Code text:"...the building referred to in Sentence (1) shall be of non-combustible construction..."

Objective and Functional Statements

Based on the breakdown of the applicable objective and functional statements applicable to the non-combustible requirements of the applicable building code sections, it is noted that the important statements relative to "non-combustibility" of building construction are [F02-OP1.2] and [F02-OS1.2]. The detailed descriptions of the applicable objective and functional statements from Division A are as follows:

Table 3.7.3

Objectives and Functional Statements	Description
F02	To limit the severity and effects of fire and explosions
OP1.2	To limit the probability that, as a result of it's design or construction, the building will be exposed to an unacceptable risk of damage due to fire addressed in this Code are those caused by fire or explosion impacting area beyond its point of origin.
OS1.2	To limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire. The risks of injury due to fire addressed in this Code are those caused by fire or explosion impacting areas beyond its point of origin.

Analysis of Objective and Functional Statements

The functional and objective statements noted above are intended to limit the probability that construction materials will contribute to the growth and spread of fire, which could lead to significant damage to the building and/or unacceptable harm to persons. Also the functional and objective statements noted state that materials, assemblies of materials and structural members required to have a fire-resistance rating are intended to protect people and the building from fire or explosion progressing through the building, and prevent collapse of structural and non-structural members which could injure people or damage the building beyond the area of origin.

The prescriptive criteria of Subsection 3.2.2. require non-combustible construction and specific fire-resistance ratings for various occupancies within buildings of varying heights and areas (i.e., 2-hour ratings and non-combustible construction for this project). These requirements relate the anticipated fire load in the various occupancies to the size of the building (area and building height), location of the building (relative to streets/principal entrances) and type of occupants expected in the building. The intent of the structural fire protection requirements outlined in Subsection 3.2.2. is to minimize the possibility of collapse, due to fire exposure, of floor or roof assemblies, for a sufficient time to allow occupants to move to a place of safety and to allow fire fighting operations to commence within the building. This is consistent with the objective statement of OP1.2 as previously referenced. In addition, the related objective of OS1.2 relative to "life safety" can be attributed to limiting the effects of fire (both flame/heat damage and smoke from the fire source) on areas beyond the point of fire origin (i.e. outside the boundary of the compartment of origin).

The above-noted objective and functional statements provide the starting point for identifying and defining the minimum level of performance that must be provided in the Tall Wood Building design, such that it can be considered "equal" to non-combustible construction and representative of the minimum building code criteria for buildings greater than 18 m in height. At the same time, key questions and specifics relative to fire ignition/development within a structure of Mass Timber need to be answered, including the potential contribution of timber elements to fire, impact of possible smoke development/spread in a high building as well as flame spread characteristics of materials to compare against the prescribed "non-combustible" level of performance.

It is the objective of this study to demonstrate in principle, that a high building constructed of Mass Timber systems, can not only provide the required 2-hour fire-resistance rating for a building of this height and occupancy, but also achieve the level of fire safety and performance that stem from the above-referenced functional and objective statements. That is, although the building is required to be of "non-combustible construction" in accordance with the applicable building code requirements, an equal level of fire performance and occupant safety can be provided, utilizing Mass Timber systems as the principal structural system. These construction systems and other active/passive protection measures to be incorporated in the building, will be designed to meet the appropriate functional and objective statements of the applicable building code requirements (as referenced above), in order to deliver a Tall Wood building design that will provide an equal level of performance to that outlined in the acceptable solutions in the Building Code.

Review of Fire Performance Methodologies

There are fundamentally two different approaches that can be taken towards demonstrating sufficient fire performance of a Mass Timber structural system; first, a “charring” approach where the Mass Timber panels or systems may be exposed within the building, and second, an “encapsulation” approach where the Mass Timber panels are covered with conventional membrane systems (gypsum board). It is technically feasible to incorporate exposed wood timber panels in the building design based on analysis of char rates. This approach, is currently undergoing further research and development in Canada (i.e. fire testing of Mass Timber panels and connection details) and until such time that testing is completed/documented, a comprehensive “alternative solution” approach (including peer reviews) will be necessary before it is permitted with confidence on any high building designs. A strategy for performance based design is outlined in the section on regulatory compliance. In the long term, as sustainability objectives for building designs increase, exposed Mass Timber systems will gain momentum and recognition as a “green” and safe building system; in the short term, it is felt that exposed timber systems will be used to a lesser extent.
The majority of the Mass Timber panel systems (and associated structural elements) are likely to be encapsulated or protected with conventional fire-rated gypsum board or equivalent systems. This situation will change as new technology, that enables building performance to be quantified, becomes more available.

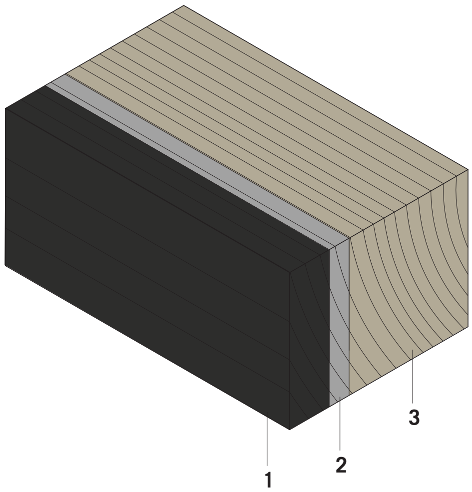
Light Frame Construction vs Heavy Timber Construction Under Fire Exposure

In light wood frame construction, the structural components are typically composed of dimensional lumber such as 2x4’s, 2x6’s etc. The relatively small size of these wood members makes them extremely susceptible to ignition and early collapse in a fire. For this reason, light wood construction is normally protected from fire by a fire resistant membrane such as gypsum board, which creates natural concealed spaces and interconnections with combustible voids in this type of construction.

Although timber is considered a combustible material, heavy timber structures have been recognized as having enhanced performance under fire conditions due to the fact that there is a sufficient mass of wood that a char layer can form (as a result of incomplete combustion) that helps retard heat penetration and further pyrolysis. Mass Timber panels and plank systems can be used to form floor/ceiling assemblies, load-bearing wall or column elements and continuous vertical shafts as part of the base building construction, without creating void spaces as part of a fire-rating membrane application. Vertical shaft construction in Mass Timber will not result in unprotected concealed spaces, as these shafts will typically be lined with non-combustible (GWB) or FR treated materials, and provided with sprinkler protection over the vertical extent of the shaft.

Charring of Heavy Timber

Charring is a process in which the outer layer of wood reaches its ignition temperature, ignites and burns continuously. In this chemical reaction, the heat removes hydrogen and oxygen from the solid wood, leaving a layer of char that is now mainly composed of carbon. This char layer has low conductivity which results in a sharp thermal gradient across the char layer. Beyond the char layer, a layer known as the pyrolysis zone forms, where the rise in temperature of the char layer causes decomposition of the wood in this zone. The inner core is only slightly affected by the temperature rise resulting mainly in moisture loss.



Charring Diagram

1 Char layer
2 Pyrolysis zone
3 Normal wood

Charring Rates

Timber elements exposed to a fire char at measured rates of 0.65mm/min (for CLT and LSL panels) and 0.635mm/min (for glulam elements). An additional ‘pyrolysis zone’ is assumed to provide negligible resistance to load – this is taken as 7mm, 10mm and 16mm for glulam, floor panels and wall panels, respectively.
Source: FPInnovations CLT Handbook 2011

Char depth + heat zone

	d_{heat} mm	t min	β mm/min	d_{char} mm	total mm
CLT Floor Panel [1]	10	120	0.65	78	88
CLT Wall Panel [1]	16	120	0.65	78	94

	k_0	d_0 mm	t min	β_n mm/min	$d_{char,n}$ mm	d_{ef} mm
Glulam Element [2]	1.0	7	120	0.635	76	83

[1] Based on FPInnovations CLT Handbook 2011, Chapter 8 – Fire

[2] Based on Eurocode 5 - EN1995-2-1, Design of Timber Structures, General Rules - Structural Fire Design

The fire-resistance rating of large-sized members can be calculated, based on minimum structural thicknesses and the remaining sacrificial thickness available for charring. This fire safety design approach is of particular interest as it is consistent with the technical analysis of Mass Timber structures being done in Europe and would ultimately facilitate a truly expressed/ exposed wood design in a Tall Wood building. It is noted that a Mass Timber high building design would require a comprehensive Building Code Analysis/Alternative Solution in order to define and document the design approach from a building code perspective. This would utilize fire engineering techniques supported by international fire research (including fire modelling, Canadian and other fire tests). It is expected that this approach may encounter more stringent levels of review by approving Authorities Having Jurisdiction (including the need for peer review of the Alternate Solution due to the "performance-based" nature of the fire safety design and reliance on detailed calculation methods, fire modelling and other factors). Planned fire tests of Mass Timber assemblies will assist in growing the confidence level of authorities relative to the use of these systems in larger and higher buildings.

The above approach, using analysis of char rates, is the method utilized in the CLT manual published by FPInnovations. Fire tests are planned to validate the char calculation model used to determine fire-resistance.

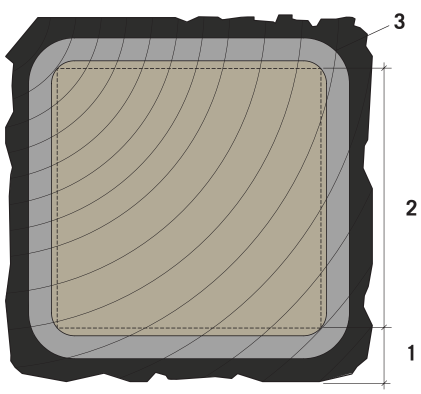
Mass Timber construction is good from a fire performance perspective since the mass wood elements can provide the necessary fire-resistance to support the imposed dead/live loads on the structural assemblies both during and after a fire condition; fundamentally they do not have to rely on additional membrane protection to achieve this. It is noted that where Mass Timber panels are used for floor assemblies, and "drop-ceilings" are installed below, a combustible "concealed space" will result. The fire risk associated with these concealed spaces can be reduced by the application of gypsum-board protection to the wood surfaces within the void spaces, or alternatively, the installation of automatic sprinklers as required by NFPA 13. In general, it is recommended that combustible void spaces be avoided to the greatest extent possible in Tall Wood Building designs, by using the inherent mass and thickness of the solid wood panels to maintain acceptable fire and acoustic separations between compartments.

Charring Rate

The charring rate is the rate at which a wood member will burn away when exposed to fire over time. This charring rate depends on numerous factors such as timber type, its density, tree species, adhesives, moisture content and structural forces acting upon it, as well as the characters of the fire itself.

Timber elements exposed to a fire char at measured rates of 0.65mm/min (for CLT and LSL panels) and 0.65mm/min (for glulam elements). An additional 'pyrolysis zone' is assumed to provide negligible resistance to load – this is taken as 7mm, 10mm and 16mm for glulam, floor panels and wall panels, respectively. See section 3.6 for design specific structural analysis of charring and impact on material thickness specification.

The measured rates of potential fire exposure are considered a "worst-case" scenario, as in most fire conditions, the automatic sprinkler system would operate to control temperatures/fire development within the compartment of origin; this would further minimize the fire impact on the underside of the Mass Timber floor assembly. Recent fire testing programs have demonstrated that in "sprinkler controlled" fire scenarios, temperatures will be effectively controlled by the sprinkler discharge (i.e. fire suppression through cooling and wetting of the fire and surrounding surfaces). The result is that minimal damage or charring of the wood panel materials will occur. However, in the event of sprinkler malfunction or certain fires that are not controlled by sprinklers, the Mass Timber systems will need to meet the structural fire protection criteria applicable to the 2-hour fire test exposure under the CAN/ULC-S101 fire test standard. In addition, it is expected that in standard fire scenarios (i.e. non-'postseismic' event) the fire department resources would be dispatched and able to suppress the fire condition before the 2-hour fire duration is achieved. An area of further research should be the investigation of the performance of tall Mass Timber buildings, relative to the reliability of built-in fire protection systems and their reliability in post-earthquake fire scenarios. Further fire testing should be conducted to confirm that heavy timber will not contribute substantial fuel to a sprinklered fire. The reliability of sprinkler systems – and in fact the entire holistic safety system – becomes an important factor in controlling fire risk.



Charring Structural Design Diagram

1 Sacrificial layer (char layer and pyrolysis zone; no structural capacity)
2 Residual section (structural capacity retained)
3 Rounded corner

Structural Design and Capacity of Charring Heavy Timber

It is widely recognized that heavy timber members that have been damaged by fire still retain structural capacity in the non-charred section. It is accepted that the charred portion itself has no structural strength. However, using this principle as a basis for design, heavy timber structural members can be designed to have a sacrificial layer of wood that would act as a fire protective layer. Using tested charring rates derived from fire tests, the thickness of this sacrificial layer can be determined in order to derive the appropriate fire-resistance rating necessary to protect the structure from collapse.

Assuming that the sacrificial layer of wood is burned away but the remaining wood is of sufficient capacity to support the imposed dead/live loads of the floor assembly above, the Mass Timber floor assembly would meet the performance objectives for fire safety and structural stability. Schaffer indicates that fire-resistance testing of heavy timber type construction of specified minimum dimensions, is considered "equivalent to or better than other types of construction having a 1-hour fire endurance." (Schaffer 1984) The protective char layer of wood exposed to fire can be compared to other sacrificial protective coatings used on non-combustible materials, such as spray-applied fire-resistive material (SFRM) typically used on steel structures to achieve the necessary fire-resistance rating. Although both fire-protective systems can be designed to provide an equal level of fire performance, the fire-resistive character of Mass Timber can be seen as more reliable since it is inherent with the material property of the timber elements. On the other hand, spray-applied fire-resistive materials typically have on-going concerns and maintenance issues associated with the permanence and reliability of the coating, due to poor adhesion or dislodgement of the materials over time. Studies of material properties have also shown that at the piloted ignition temperature of wood timber (approximately 350°C), exposed structural steel would begin to lose strength (Schaffer 1984). By comparison, at a critical temperature of 550°C, the steel will be reduced to approximately 60% of its original strength, with further reductions in strength as the temperature rises. In fact, Schaffer draws a comparison between the critical temperature for loss of strength in steel (550°C) and the temperature at which the demarcation between charred and uncharred wood occurs as a result of fire exposure. (Schaffer 1984) Consequently, it is concluded that in cases when automatic fire suppression is compromised, mass wood timber elements will perform as well under fire conditions as protected steel or better if fire protection to the steel becomes dislodged or damaged. This means that while wood will ignite at relatively low temperatures (around 350°C) the effect on large members is such that steel will collapse more quickly as fire temperatures rise. The result is that a typical heavy timber beam may have a fire-resistance of 45-60 minutes (see below) compared with 10 minutes for unprotected steel.

Fire-resistance Rating and Compartmentalization

Fire-resistance is a measure of a building assembly's ability to resist the effects of heat and fire when exposed to fire under specified fire test conditions of test for a pre-determined fire duration. Load bearing structures should continue to carry loads without collapse or excessive deflection when exposed to fire. In the case of non-load bearing assemblies, the fire-resistance is based on its fire separating function and its ability to maintain integrity (self-supporting). The fire-resistance rating (FRR) of a building assembly has been typically assessed by standardized tests CAN/ULC S101 in Canada and ASTM E119 in the United States and ISO 834 in many other countries. By containing the spread of a fire and protecting the building structure, occupants are given time to exit the building and fire fighters time to prevent further property loss without the risk of building collapse.

Standardized fire testing of Mass Timber material assemblies (currently underway in Ottawa) will be beneficial in gaining further technical confidence in the use of this technology in the future. In the meantime, other analytical calculation techniques including charring rate calculations (in conjunction with dynamic structural analysis during fire conditions) and computerized fire modeling, can be used to determine the structural fire performance of the material assemblies to be used for this project.

It is also noted that one of the positive characteristics of the TWB project design, is the degree of sub-compartments that would exist in the completed project. That is, each floor area would be sub-divided into small residential "fire compartments" that would limit the potential spread of fire beyond the compartment of origin; essentially there would be fire-rated floor/wall construction around each room boundary. In conjunction with automatic "fast-response" residential type sprinkler protection in each fire compartment, the likelihood of a potential fire condition developing beyond the compartment of origin would be negligible. This design arrangement will assist in meeting one of the fundamental Code objectives of Article 3.2.2.42. – OP 1.2/OS 1.2 limiting the probability of damage or injury due to fire spread impacting areas beyond the point of origin.

In practice however, it is necessary to consider the risk or probability of fire spread due to system or sub-system failure. Refer to the section on regulatory compliance for more detail.

Flammability and Interior Finishes: Flame Spread Rating and Smoke Developed Classification

While assemblies possessing a fire-resistance rating prevent the spread of heat and fire from passing from one compartment to another they do not consider flame spread and smoke development. Since heavy timber is a combustible material, there will be a degree of smoke and heat generated when exposed to fire. Of particular concern would be exit corridors and exit shafts where smoke, flames and other toxic gases generated by combustibles can spread and compromise exiting facilities. In addition, other vertical shafts within the building including elevator shafts, service shafts and service chases could be potential conduits for vertical flame or smoke spread and need to be protected accordingly. Consequently, these areas of the building would typically be protected with gypsum board or other non-combustible finish materials to meet the applicable building code requirements, in addition to having sprinkler protection at multiple levels in accordance with NFPA 13 requirements (for vertical shafts of combustible construction).

The potential for material assemblies to spread flames and smoke is also governed by the building code and are referred to as Flame-Spread Rating (FSR) and Smoke Developed Classification (SDC). The flame-spread rating and other surface burning requirements of the code are intended to be applicable to the interior finish materials that form part of the interior surface of a floor, wall, partition or ceiling, including such elements as: interior claddings; surfacing of fabric, paint, veneer, etc.; doors, windows, trim; lighting elements such as light diffusers/lenses; and carpet material that overlay a floor. It is also noted that under the prescriptive requirements of the NBC for a sprinklered building, the interior surfaces of the building would be permitted to be lined with significant combustible (FR or non-treated wood) finishes as well as wood fixtures and millwork, which although technically complying, would contribute to the combustible fuel loading within a non-combustible building. The contribution of mass wood systems to a fire have also to be viewed in the context of the allowable use of combustible elements in a non-combustible building and the fuel associated with building contents.

Generally, these interior finish materials are relatively thin surface or veneer treatments that are applied to or overlaid onto a base substrate material. Such materials, due to their combustibility or other material properties, may represent an increase in the fuel load and fire hazard within an interior compartment of a building. However, owing to the large dimension, solid wood nature of Mass Timber construction, the surface burning characteristics of the solid wood panels and similar Mass Timber systems will be substantially different: these solid materials are more resistant to ignition, and will not sustain surface flaming as easily due to the difficulty in generating sufficient vapours at the surface to sustain flammable mixtures of combustible gases. For these reasons, the surface burning characteristics of Mass Timber elements is expected to be significantly better than standard finishes of limited thickness.

The flame spread of “non-fire retardant treated” light wood finish materials, using various wood products exposed in an interior fire compartment, are shown in the reference table ranging from Douglas Fir plywood (FSR 155), to various lumber products (FSR 75-100) and more massive “engineered wood” products such as PSL or LVL laminated materials (FSR 50). The ease of generating vapours when subject to a fire means that small light members readily generate sufficient vapours for ignition whereas larger members require significant fire exposure to generate the required vapour concentration to enable sustained burning to occur.

Flame Spread and Smoke Developed Indices in High Buildings

Section 3.1.13.7 (1) provides a specific “relaxation” for sprinklered buildings. In effect, the more stringent FSR/SDC ratings of the Code are waived in sprinklered floor areas of high buildings due to the proven benefits of automatic sprinkler protection in detecting, suppressing and controlling interior compartment fires. It is also noted that where Mass Timber systems are proposed to be used in an exposed condition, that the surface burning characteristics of the wood members could be augmented through “fire-retardant treatments” or other chemical applications, since the fire compartments in which they are exposed will be fully sprinklered. Fire testing programs have demonstrated that in “sprinkler controlled” fire scenarios, temperatures will be effectively controlled by the sprinkler discharge (i.e. fire suppression results in the cooling and wetting of the fire and surrounding surfaces) with the result of minimal damage or charring of the wood panel materials. Further, since the exposed wood surfaces will form part of a solid Mass Timber panel system (as opposed to a thin interior finish or lining material that these code requirements are intended to regulate), the wood surfaces will not be as readily ignitable and will not sustain surface combustion in the same manner as thin/low mass interior finish materials.

Table: Flame Spread Indices of Wood Products

Wood Material	Flame Spread Index	
Yellow Poplar Lumber	185	**Class C**
Douglas Fir Plywood	155	
Walnut Lumber	140	
Oriented Strand Board	138	
Yellow Birch Lumber	110	
Southern Pine Plywood	110	
Maple Lumber	104	
Douglas Fir Lumber	100	
Red or White Oak Lumber	100	
Eastern White Pine Lumber	85	
Western White Pine Lumber	75	**Class B**
Red Cedar Lumber	73	
Redwood Lumber	70	
White Fir Lumber	65	
Fire Retardant Treated Lumber Plywood	< 25	**Class A**

(American Wood Council 2006)

Table: Smoke Developed Indices of Wood Products

Wood Material (Lumber 1" Nominal Thickness)	Smoke Developed Index
Red Pine	229
Lodgepole Pine	210
Maple flooring	157
Eastern White Pine	122
Red Oak Flooring	100
Redwood	75-115
Western Red Cedar	98
Douglas Fir (Pseudotsuga menziesii)	54

(USDA, Forest Service 2010)

Applicable Building Code Excerpts for Flame-Spread Rating and Smoke Developed Classification for High Buildings

3.1.13.7. High Buildings

1) Except as permitted by Sentences (2) to (4), the interior wall, ceiling and floor finishes in a building regulated by the provisions of subsection 3.2.6. shall conform to the flame-spread rating requirements in Article 3.1.13.2 and to the flame-spread rating and smoke developed classification values in Table 3.1.13.7.

Table 3.7.4

Table 3.1.13.7
Flame-Spread Rating and Smoke Developed Classification in a High Building

Location or Element	Maximum Flame-Spread Rating			Maximum Smoke Developed		
	Wall Surface	Ceiling Surface(1)	Wall Surface	Wall Surface	Ceiling Surface(1)	Wall Surface
Exit stairways, vestibules to exit stairs and lobbies described in Sentence 3.4.4.2.(2)	25	25	25	50	50	50
Corridors not within suites	(2)	(2)	300	100	50	500
Elevator cars and vestibules	25	25	300	100	100	300
Service spaces and service rooms	25	25	25	50	50	50
Other locations and elements	(2)	(2)	No Limit	300	50	No Limit

Notes to Table 3.1.13.7.
(1) See Article 3.1.13.4. for lighting elements
(2) Other requirements of this Part apply

(British Columbia Building Code 2006) Division B - Part 3

Encapsulation Approach

The alternate and more conservative approach to ensuring adequate fire performance of the Mass Timber assemblies, utilizes an encapsulation system which is similar to standard construction techniques used to construct fire-rated floor, roof and wall assemblies in both combustible and non-combustible building types. For instance, there are standard-tested ULC listed wall and floor assemblies that incorporate 2 layers of gypsum board to achieve a 2-hour fire-resistance rating, in conjunction with wood or steel framing support systems. This approach is acceptable as a means to address the applicable code requirements from a designer's, builder's and code authority's perspective, where the solid wood members are protected with 2 layers of fire-rated gypsum board within each compartment and generally throughout the building.

The encapsulation approach would incorporate the installation of 2-layers of 16 mm type X gypsum board directly to the exposed surfaces of the Mass Timber materials, using positive fastening devices (i.e., screws) of sufficient depth to resist deterioration and pull-out during fire exposure. The resulting floor and wall assemblies are expected to achieve the required 2-hour fire-resistance ratings based on similar ULC listed fire-tested assemblies incorporating gypsum board protection of light wood or steel construction, and the cumulative assembly rating information contained in Appendix D of the BC Building Code. This approach can be used to meet either the full 2-hour criteria (subject to confirmation by on-going fire testing), or partially, as a "hybrid system" where the gypsum board membranes maintain a degree of thermal protection for the wood substrate, until the temperature on the unexposed side of the GWB results in charring of the structural wood panels. In this instance both the contribution of the gypsum board and charring of the wood have to be taken into account in determining the fire-resistance.

As with typical drywall finished construction techniques, gypsum board layers would incorporate staggered, overlapping joints to maintain solid continuous thermal protection of the underlying wood substrates. With this approach there would be no combustible void or concealed spaces in the Mass Timber construction, due to the presence of GWB on all surfaces within ceiling spaces, shaft areas, etc. The finished gypsum board surfaces providing protection of the Mass Timber structural elements of the building, may also perform as the interior room finishes for the individual residential dwelling units (for high ceiling areas with no drops and wall finishes). Therefore, specific instructions and information would need to be distributed to the individual building owners, to caution them on altering or damaging the ceiling/wall finishes in the suite. Other "serviced" areas of the suites would incorporate suspended ceiling "dropped" areas (as per architectural details) with space to house electrical/mechanical/plumbing services within and avoid openings/penetrations of the fire-rated Mass Timber system as a benefit of this design approach. Where these concealed spaces exist, the horizontal timber panel would either be protected with gypsum board membranes or the concealed space would be provided with sprinkler protection. As previously noted, while this approach is seen as a very conservative approach to the use of Mass Timber, it has the advantage that it is more readily accepted by building authorities.

The potential for water damage could be a concern in Mass Timber buildings. A typical concern of owners and developers is the concern that automatic sprinkler systems may operate inadvertently producing significant quantities of water over the fire area and down through the building. While this can be a concern, automatic sprinkler operation is typically monitored so that, in the event of water flow, an alarm will sound. In modern buildings, such alarms are centrally monitored and supervised off- premises. This enables both prompt response to operation of sprinklers in event of fire as well as accidental damage and other potential causes of water leakage. To put this in context, there are other significant sources of water supply in buildings including that for bathrooms, showers, swimming pool and irrigation uses. Such supplies are not typically monitored and are installed to a lower standard than that of automatic sprinkler systems. This means that water damage is more likely to occur from the failure of plumbing systems, typical cleaning and other operations than automatic sprinkler systems. For instance the reported frequency of failure of automatic sprinkler heads is less than one in 10 to the 14th power: rendering accidental operation a very unlikely event. Similarly there is the perception that all sprinklers operate simultaneously and thereby, create massive water damage as a result. In reality only one sprinkler may operate over the fire, restricting any water damage to a relatively small area. By comparison, unsprinklered buildings can expect significantly higher water usage arising from the need for fire department operations to extinguish the fire rather than reliance on automatic sprinkler operation. The extremely high volumes of water at a much later stage of the fire means that, relative to automatic sprinklers, extreme water damage can result. This is often compounded by the difficulty in locating the actual source of the fire due to reduced visibility arising from smoke density and other factors. The amount of water used in sprinklered fires is approximately 4-5% of that in unprotected buildings. For this reason, fears arising from potential sprinkler system operation should not be a concern in Tall Wood buildings. Good practice however, demands that failures be analyzed and flow devices capable of detecting all flow conditions including the failure of main supply lines, be added to minimise potential water damage under normal and emergency conditions.

Exterior Cladding and Balcony Details

The fire-rated Mass Timber system approaches would apply to all of the interior/exterior load-bearing structural elements of the proposed building, including interior floor assemblies, interior/exterior load-bearing walls and other structural columns, beams, posts that are supporting the dead/live loads imposed by the building and it's occupants. One exception to the above will be the exterior balcony assemblies, which are permitted to be "unrated" elements on the exterior of the building by the applicable building code requirements, and due to conflicts with building envelope/ventilation detailing are problematic to provide a fire-rating to the underside. It is noted that the all exterior balcony areas of the building will be sprinkler protected (using dry sidewall type sprinklers) and the underside of the balcony assemblies will be finished with a ventilated non-combustible cladding material (i.e., cementitious panels system). The exterior cladding system providing the building envelope for the Tall Wood Building design, will entail a ventilated "rain-screen" exterior wall system, utilizing non-combustible cladding and components (including exterior insulation materials) in order to minimize the potential for vertical fire spread on the building façade via exterior window openings.

Scissor Stair Design and Protection of Connection Hardware

The proposed building designs incorporate two options for meeting the exiting requirements of the building code; a 2 stair shaft design with separate exit stair facilities located in 2 separate exit shafts constructed of vertical Mass Timber panels, and a 2 stair shaft design with separate exit stair facilities located in a "scissor stair" of hybrid Mass Timber/concrete construction. As this type of exit system is prevalent in mid-to-high-rise buildings in the City of Vancouver, it is important to investigate the constructability and feasibility of a scissor stair design using Mass Timber; this should form both part of this study and future research efforts. Refer to Core Plan and Stair Detail drawings for further details of each configuration. The two separate exit shaft options would be feasible from a constructability and safety perspective; however, the scissor stair option requires further analysis and development relative to connection details, continuity/integrity of fire separations between separate stair compartments, and provision of rated firestopping systems that will prevent the passage of smoke at gaps/joints between the scissor stair components. For the scissor stair design to be acceptable in the City of Vancouver, all of the above factors must be addressed at the design phase of the project, as the City has indicated that scissor stair designs in wood-frame buildings would not be permitted without full resolution of the design details in advance of construction. In addition, the City of Vancouver and most other municipalities require a full "smoke test" of the scissor stair construction prior to occupancy of a building, in order to demonstrate that each exit stair is "smoke tight" from the other.

Another concern and detail that will require further analysis/review relative to fire performance of the Mass Timber systems, is the detailing and protection of the timber connection hardware that is used to tie the building structural panels and systems together. Using the "encapsulation approach" to fire-rating of the Mass Timber structures, the connection plates will typically be protected either behind the protected assemblies or mass wood materials. However, where the connection plates are exposed or vulnerable to the effects of fire, and also perform a critical load-bearing capacity in the structural design of the building, these connectors will need additional fire protection in the form of intumescent coatings or similarly applied fire protection products.

Enhanced Sprinkler System Design – Benefits of Automatic Sprinklers

For either of the fire-rated Mass Timber approaches (exposed charring or encapsulation), an enhanced sprinkler system design based on the requirements of NFPA 13 is proposed. The aim is to provide a complete and highly reliable automatic fire suppression system throughout the building. The following points summarize the proposed enhanced sprinkler system design:

- Installation of fast-response residential type sprinkler heads in all fire compartments, rooms, closets, exterior balconies, spaces, etc. throughout the entire building with no exceptions for unsprinklered compartments. This feature will mitigate the possibility of a fire developing in a small non-sprinklered space and spreading to other areas of the building.
- All exterior occupied spaces such as balconies, ground level patios with building overhangs above, and similar exterior spaces will be sprinkler protected to minimize potential fire ignition and vertical spread on the building exterior.
- In order to provide an improved degree of seismic safety and reliability in the sprinkler/standpipe system design, the building will be typically provided with a 2 vertical standpipe system (one in each exit stair) and this standpipe system will be "looped" within the building such that if one part of the water supply system becomes severed or impaired, the fire department will still have the ability to pump into the system and boost the pressure to the sprinkler/standpipe systems. Manual isolation valves will be installed in strategic, accessible locations for isolation of the overall fire protection system during such an emergency condition as necessary. Other arrangements may be necessary based on a more complex analysis of sprinkler reliability.
- All control and isolation valves serving the entire fire protection system, including the main shut-off valve on the City street supply will be electrically supervised and monitored by the building fire alarm system, in order to avoid the possibility of a critical valve being closed and thus, impairing the water supply to the entire building. This also helps provide an early alarm and judicious response to operation of a sprinkler(s) over a fire.

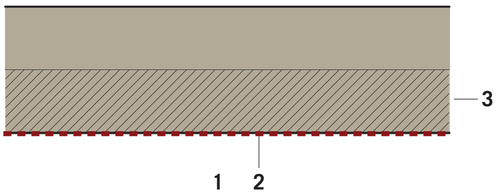
The proposed enhancements to the base sprinkler system for the building are intended to increase reliability of the automatic fire suppression system for the entire building. Further research is needed to quantify reliability as described in the following section. In theory, fire exposure of the Mass Timber systems will be minimal, due to the well documented cooling and suppression benefits of automatic sprinkler protection. Other enhancements proposed for the base fire suppression systems are intended to provide a higher degree of reliability for firefighters operating within the building, during a fire incident or other "post-disaster" scenarios (i.e. seismic event).

The reliability of the sprinkler system in all conditions of service is an essential objective of any design. Further research to document sprinkler reliability and predict overall building performance is necessary.

Enhanced Fire Detection Design – Exposed Timber Applications

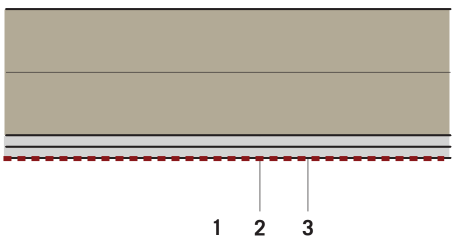
For the potential exposed timber panel designs, using a charring analysis approach for determining the structural fire-resistance rating of the building, there is a concern that fire exposure of the exposed timber panels within an interior fire compartment may result in partial combustion, which in turn could produce quantities of smoke that could jeopardize occupants of the building (i.e. persons evacuating the building). The primary concern would be a developing fire from a dwelling unit area since common areas would have relatively little fuel. The fire alarm technology is available to enable "intelligent" smoke alarm/detector devices to be provided in each residential fire compartment. Detectors would perform a two-fold function: first to activate an audible signal within the dwelling unit only (i.e. to alert/awake the occupants); second to form part of the fire alarm system for the building, with smoke detection devices initiating an "alarm" condition on the building fire alarm panel and throughout the building after a period of 5 minutes should the fire not be acknowledged. The fire alarm system could also be programmed to initiate a fire department response signal after a pre-determined period of time, to investigate the cause of the alarm condition, and initiate manual fire suppression activities as necessary upon arrival. As an "addressable" fire alarm system, the smoke detectors within suites could be utilized to pin-point the location of the fire detection initiation, such that firefighters would know the exact location of the fire alarm condition upon arrival.

Hybrid Charring and Encapsulation Details



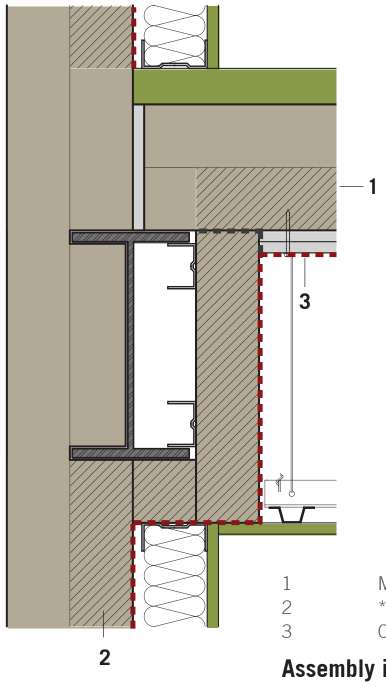
1 Fire exposed side
2 Mass Timber structure
3 **/***Sacrificial Mass Timber layer (2HR FRR)

Assembly illustrating charring only concept



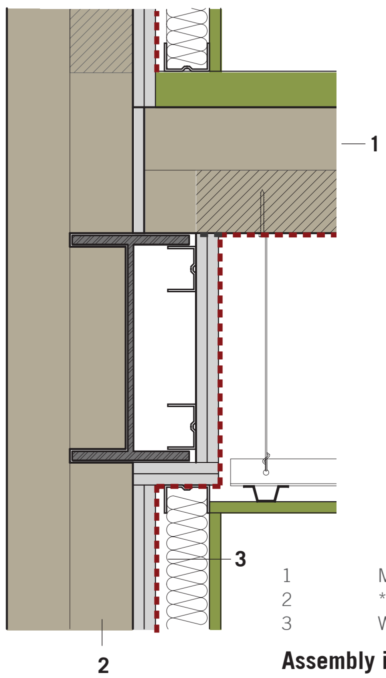
1 Fire exposed side
2 Mass Timber structure
3 2 layer 5/8” type X gypsum board (2HR FRR)

Assembly illustrating encapsulation only concept



1 Mass Timber structure
2 **Wall: sacrificial Mass Timber layer (2HR FRR)
3 Ceiling: 2 layer 5/8” type X gypsum board (2HR FRR)

Assembly illustrating hybrid charring and encapsulation concept



1 Mass Timber structure
2 **Ceiling: sacrificial Mass Timber layer (2HR FRR)
3 Wall: 2 layer 5/8” type X gypsum board (2HR FRR)

Assembly illustrating hybrid charring and encapsulation concept

** Charring rates vary depending on moisture, density, species etc. The charring rate of 0.65mm/min is the generally accepted average. Refer to Section 3.7 Fire Performance for additional information on charring rate.

*** Interior finish: exposed wood paneling subject to flame-spread rating and smoke developed classification code requirements. Refer to section 3.7 for additional information on flamespread, smoke classification and interior finishes.

**** Sprinklers required in ceiling cavity if charring method is used.

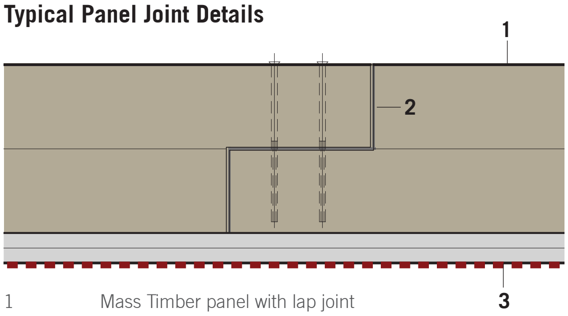
Fire Separation and Panel Joints

Since the study proposes the use of panel products (LVL, LSL, CLT) that are required to be joined at some instances, an important component of a fire protection strategy would be the integrity of the joints. These joints are potential pathways that could allow a fire to penetrate an assembly. Therefore, proper design and firestopping system applications are required to ensure an effective seal.

In the case of fire protection using encapsulation, the gypsum board should be attached directly to the wood panels so that it is tightly butted with no air cavity. For additional integrity and continuity, joints of the gypsum board can be staggered to the joints of the wood panels.

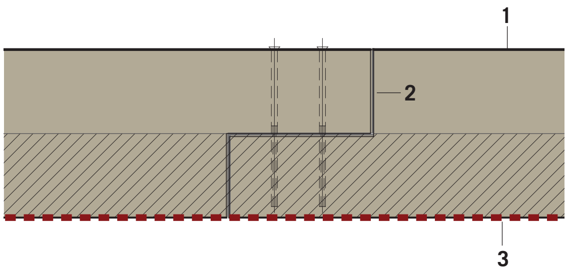
Where wood panels are used as a finished surface, or in the charring fire protection method, it is crucial that joints are sealed properly to prevent fire from breaching the assembly at a faster rate than anticipated during a fire. Some manufacturers provide tested details for such joints. However, further work and collaboration between designers, manufacturers and authorities is required to ensure joint details are sufficient to maintain the integrity of the given fire-rated assemblies. Moreover, these joints must be designed and reviewed in relation to the actual type of timber used, its structural function and required fire protection requirements.

Typical Panel Joint Details



1 Mass Timber panel with lap joint
2 Continuous bead of construction adhesive
3 2 layer 5/8” type X gypsum board

Assembly illustrating encapsulation concept with lap joint



1 Mass Timber panel with lap joint
2 Continuous bead of construction adhesive
3 Sacrificial Mass Timber layer

Assemblies illustrating joints. Refer to Section 3.6 Structural Intent for additional information on joints.

Code Analysis

From a building code perspective, the main focus has been on the determination and delivery of an equivalent level of performance for a Tall Wood building constructed of engineered "Mass Timber" technology (a combustible material), as compared with a typical market apartment building of reinforced concrete construction (the comparable benchmark building in Vancouver). However, it is noted that the Mass Timber systems approach is feasible to use on other high building types typical of the downtown Vancouver area, including office buildings and potentially "mixed-use" type buildings incorporating a variety of live, work and shopping functions in one building. The introduction of other occupancy classifications would not fundamentally change the technical approaches to building code compliance utilizing Mass Timber systems, but would integrate appropriate fire protection and life safety features based on the specific occupancy hazards within each occupied area. There are fundamentally two main approaches to achieving the base-line code requirements for fire-resistance of the Mass Timber structural elements: an "encapsulation" approach where the solid wood members are protected with 2 layers of fire-rated gypsum board within each compartment and generally throughout the building - this approach is seen as a conservative but acceptable means of addressing the applicable code requirements. The other design approach with respect to fire safety and fire-resistance of the structural Mass Timber elements, is that of a "charring rate" analysis, where the Mass Timber panels would be used as fully or partially exposed elements in the building design, and calculation methodologies for determining the rate of charring and subsequent reduction in structural capacity would be applied to determine the effective depth/thickness of wood needed to achieve the required level of performance. This fire safety design approach is of particular interest as it is consistent with the technical analysis of Mass Timber structures being done in Europe and would ultimately facilitate a truly expressed/exposed wood design in a Tall Wood building. It is expected that this approach may encounter less certainty and more stringent levels of review by approving Authorities (including technical peer reviews by qualified professionals with experience in wood design), based on the "performance-based" nature of the fire safety design and reliance on detailed calculation methods, fire modeling analysis and other factors. However, current fire testing of Mass Timber assemblies will certainly assist in building the technical confidence level relative to the use of these systems for larger and higher building types. Moreover, a performance based approach to achieving acceptable reliability of the building on a holistic basis would enable evaluation of individual designs in a systematic manner.

A residential building greater than 18 m high is classified as a "high building" under the applicable code requirements, and therefore is required to have minimum 2-hour rated floor/load-bearing wall assemblies, as well as being fully sprinkler protected. Based on the availability of current fire testing information and analytical calculation methods to determine fire performance of solid or engineered wood structures, it is concluded that the 2-hour fire-resistance rating performance level of the applicable code requirements (Subsection 3.2.2. for "Any Height, Any Area") can be achieved using Mass Timber systems. However, it is noted that the key difference and issue associated with Mass Timber systems is that they are comprised of "combustible" materials, whereas the prescriptive code requirements reference "non-combustible" construction. At the same time, the "objective-based" information of the code that has been outlined in this report (and is used to develop alternative solutions), incorporates a functional statement to "limit the severity of the effects of fire" with "fire safety to occupants" and "fire protection of the building" as the main objectives relative to construction type. Since the required level of structural fire protection performance can be determined and demonstrated using Mass Timber structures, it is critical that any alternative solution approaches for Tall Wood buildings also analyze and address the issues associated with the combustibility of the wood structural elements, and the building as a whole, in order to be successful. This is proposed to be done at the next level of code analysis/development towards the comprehensive formulation of a complete "alternative solution" approach utilizing Mass Timber systems for buildings over 6 storeys in height. In addition, it is noted that a probabilistic risk assessment methodology will also be necessary as part of the code development, alternative solution and fire modelling/testing work, in order to best determine the appropriate fire protection, life safety and structural safety requirements for a Tall Wood building design, from a risk-based perspective. The risk analysis would partially entail the comparison of a typical benchmark concrete high-rise residential building, relative to a similar building type of Mass Timber design, in order to assist in determining the applicable risk factors associated with the use of solid wood structural elements, and how those risk factors would most effectively be dealt with and mitigated in the final building design. The previous section of this report provides some examples of possible fire and life safety "enhancements" or mitigating features to the TWB design, such as the installation of enhanced sprinkler protection with additional seismic resistance to improve reliability, and the provision of intelligent smoke detection technology in compartments where Mass Timber systems may be used as an exposed structural element using a "charring approach".

In the long-term, future code changes are required to enable the further use of Mass Timber on larger/higher buildings. The fundamental performance criteria outlined in the applicable functional and objective statements of the National Building Code, can be used to evolve and re-develop the traditional code classification system (combustible vs. non-combustible construction) into a modern code format that ultimately considers all base construction materials on an even playing field (i.e.

concrete, steel, wood, etc.). Some key work needs to be undertaken to re-engineer the existing classification of buildings as it does not differentiate between different performance of systems, for instance; wood frame relative to a Mass Timber system capable of more than 2-hour fire-resistance. As summarized in this report, the fundamental fire protection and life safety objectives for a residential building greater than 18 m in height (high building classification) can be distilled as follows:

› All floor assemblies and load-bearing elements to have minimum 2-hour fire-resistance rating (based on standard testing, or other analytical methods);

› Building to be designed to limit the severity and effects of fire or explosions;

› Building to be designed to limit the probability of unacceptable risk of injury of occupants caused by fire impacting areas beyond the point of origin;

› Building to be designed to limit the probability of unacceptable risk of damage to building caused by fire impacting areas beyond the point of origin;

› To provide for the safety of the occupants of a building, by maintaining the tenability of occupied floor spaces during a fire emergency, and by providing a means for all occupants of the fire floor to leave that floor quickly;

› To maintain tenable conditions in exit stairs leading from floor spaces to the outdoors, and in spaces through which occupants have to pass or in which they remain while waiting for assistance to evacuate;

› To maintain tenable conditions in elevators that are used to transport fire fighters and their equipment from the street floor to the floor immediately below the fire floor and for the evacuation of injured persons or persons with disabilities.

This type of "objective-based" language could be used as the basis for a future code change proposal to the National Research Council of Canada, in order to permit the use of all materials for a proposed building design, including the possible use of Mass Timber structural systems for high buildings. However, the performance based approach outlined in the following section is more likely to be a long term solution for assessing performance of the building overall rather than its individual elements.

In summary, it is concluded that a high building of residential occupancy can be designed and constructed to meet the above noted functional statements and fundamental safety objectives of the National Building Code of Canada, on a "performance-basis", whether it be of concrete, steel or Mass Timber construction. As part of the technical research and interview process for this project, it is noted that a successful presentation and discussion meeting with the City of Vancouver CBO and other senior technical staff was held on March 11th, 2011. During that meeting, it was concluded that the City staff were generally receptive/positive towards the information and technical details of the proposed Tall Wood building study, and that such a building can be developed to meet the fundamental objectives of the applicable building code (VBBL 2007) on a "performance-basis". It is interesting to note from this meeting, that the CBO indicated the "encapsulation" approach seemed "counter-sustainable" due to extensive use of gypsum board materials in the design, and suggested that more research be done towards exposed Mass Timber designs as an ultimate sustainability objective for the design study. This is further discussed in the following section.

Relative to the constructability of tall buildings using Mass Timber technology, it is noted that the issue of "construction fire safety" must be clearly acknowledged, addressed and implemented as part of a comprehensive Construction Safety Plan that is prepared by the General Contractor/Construction Manager for the project. Due to the fact that wood buildings are typically constructed using combustible materials in an unprotected condition, it is imperative that precautions and procedures be laid out for minimizing ignition hazards, control of heat sources, security presence on-site and sequential installation of fire protection systems, as the building is constructed.

3.8 Regulatory Compliance in British Columbia

Introduction

The design of wood buildings today, relies primarily on the requirements of the National Building Code of Canada which is adopted and modified for use in British Columbia and other provinces and territories. The BC Building Code is an objective-based code that permits alternate solutions to meet the intent of the code but there are significant barriers to wood use embodied in the document. The subject of future research should include a proposal that sets out how the barriers in the code can be systematically reassessed and eventually replaced by a more rational performance-based approach to wood building design. The research documents should set out in brief the technology for enabling most buildings to be constructed of wood except where operational requirements cannot be readily met or where, the user prefers non-combustible construction such as in the secure area of institutional facilities.

Wood Use Matrix

As an objective-based Code, the BC Building Code provides two avenues for Code compliance. One is prescriptive through compliance with the "acceptable solutions" in Division B. The other is through the use of "alternative solutions", which typically require a suitable technical analysis to demonstrate that a proposed design will achieve a level of performance that meets the minimum level intended by the BC Building Code.

The Wood Use Matrix shown on the Wood Enterprise Coalition web site (wecbc.ca) contains appropriate guidance for wood use in accordance with the BC Building Code in terms of "acceptable" and "alternative" solutions.

Matrix Development for Provincially-Funded Government Buildings by the Procurement Working Group

For projects developed or funded directly by the Provincial Government, Wood Use Matrix values were provided by representatives from each area to the Procurement Working Group. The Ministries relied on a combination of internal expertise and their architectural, engineering and code consultants. The results and links to example projects were coordinated by the Wood Enterprise Coalition.

The Matrix is a guideline that shows where:

1. An acceptable solution with wood is permitted;
2. An alternative solution with wood is relatively easy to implement;
3. An alternative solution with wood will require advanced analysis;
4. An alternative solution with wood will require extensive research.

Based on the above, the following values are assigned for Tall Wood buildings of different heights assuming a residential or office use:

Table 3.8.1

Building Height (storeys)	Matrix Classification Level (1-4: relative ease of achievement)
1-6	1- An acceptable solution in wood is permitted
7-9	2- An alternative solution in wood is relatively easy to implement
10-12	3- An alternative solution in wood will require advanced analysis
13 +	4- An alternative solution in wood will require extensive research

Note:
While the matrix gives guidance on the use of wood it is not intended to supersede the judgement of the responsible design professionals.

Performance-Based Approaches

The matrix is a measure of the ease of implementing the use of wood whether wood use is permitted or can be introduced as part of the design process as an alternate solution.

While an acceptable solution can be developed for any one building, systemic change is necessary to enable solutions to be universally available to all designers. Efforts to re-engineer the current code by reintroducing new definitions for different wood systems such as unprotected wood frame, protected wood frame, engineered heavy timber and other systems will enable rationalization of the height and area requirements that currently reflect wood frame rather than more robust systems such as prescriptive and engineered heavy timber. This, in conjunction with the development of tools that enable the relative performance of Tall Wood or large wood buildings to be assessed and documented against non-combustible construction, will support code changes at the provincial level and strengthen the case at the national code level eventually enabling such approaches to be incorporated into the National Building Code of Canada and referenced in new and/or existing standards.

Definitions of Construction types

The classification of construction types into two types: combustible and non-combustible, while simple in its approach, equates combustible construction with light wood frame buildings and ¾ hour prescriptive heavy timber with non-combustible construction: steel or concrete. Traditional heavy timber and brick-joist buildings that are included in building classifications in the US enable relatively different heights and areas to be developed based on the relative fire behaviour of the different systems which have variations in fire-resistance as well as differing records of fire performance over time. Traditional heavy timber construction in Gastown and Yaletown in Vancouver, have a very good record of performance. Most of the buildings fall in the 6-7 storey range depending upon the definition of grade. Many of the buildings have been retroactively sprinklered which may account for the good fire record across the inventory of buildings.

Current Use of Heavy Timber Systems

Although there are definitions of heavy timber construction in the code, the use of heavy timber is restricted to two storeys or where the building is permitted to be of combustible construction. The height and area limits are very restrictive as they are generally felt to equate to wood frame construction. This means that the traditional heavy timber building is no longer permitted, whereas in the US, this represents what is known as Class IV construction which has its own height and area limits for permitted occupancies. In Canadian codes all heavy timber is assigned a fire-resistance of ¾ hour based on minimum dimensions of timber elements. In the US heavy timber is assigned a 1 hour fire-resistance which has significant benefits in terms of height and area.

Different Wood Systems

The development of new building systems using heavy timber elements such as CLT can achieve a fire-resistance of in excess of 2 hours, which is on par with the fire-resistance of floors in a non-combustible high building. Such systems may be termed engineered or Mass Timber. Thus, the fire performance across the spectrum of systems including:

- Unprotected wood frame;
- Gypsum protected wood frame;
- Brick joist construction;
- Prescriptive heavy timber;
- Engineered or Mass Timber is vastly different. For this reason, it is felt that additional research is required to redefine various systems that fall under the definition of combustible construction. This would then enable a comprehensive assessment to be undertaken that would result in new height and area requirements for the different systems. While this is planned at the national level it is likely that the province will undertake its own comprehensive study ahead of the national bodies, enabling the basis for code changes to be established provincially and fed into the national processes.

Increased height and Area

The fire performance of large structures necessitates means of assessing the cumulative fire risk associated with height and increased area. While some jurisdictions do not specify the material that is used to achieve fire-resistance provided it is assigned a fire-resistance based on fire tests. There are challenges in achieving alternate solutions in a way that will be repeatable and that will enable those solutions to qualify as acceptable solutions once building performance is proven on the basis of fire fundamentals. To achieve this it is necessary to assess the holistic performance of buildings rather than to meet a list of prescribed requirements. In reality the measures can be complimentary and the level of reliability that is achieved depends on the overall reliability of all measures in relation to fire events and other failures that may conceivably occur.

Performance Assessment Tools

A probabilistic fire risk assessment could be developed that benchmarks performance of a sprinklered Tall Wood building against the same sprinklered tall non-combustible building. This should not be just a life safety exercise but must include a thorough assessment of reliability to reduce the probability of a total failure of the structural system due to fire, to a very low frequency event. Such approaches have been used by fire protection engineers to demonstrate acceptable performance and risk in other large wood structures. The reliability of systems can be increased significantly, for instance in earthquake areas, through the incorporation of fully mechanical secondary water supplies that have a finite effect on the likelihood of acceptable fire performance.

A suitable probabilistic fire performance method has been outlined by the Wood Enterprise Coalition and could be an important area of research to enable acceptance of a methodology at the national level that mass or engineered heavy timber or other systems can provide robust and reliable solutions in combination with other measures. Such a research programme needs to be supported by other measures including penetrations for wood systems, fire testing of assemblies, connections, use of balloon framing, etc.

It is anticipated that, to a degree, the assumptions in all relevant codes and standards, need to be re-evaluated to assess the adjustments that are necessary to encourage wood and support the use of wood in most buildings. The performance of buildings must be approached holistically and tools that enable us to balance measures rather than consider them individually will provide both flexibility for the designers as well as comfort to regulators that such systems can achieve equivalent and greater performance than non-combustible systems. As such, we urge the construction industry to support the necessary research to enable tall and other wood structures to be designed and constructed to their full potential. This is particularly true of new systems described in this document that have significantly improved fire performance but lack the recognition in the code and the means of assessing their contribution in a holistic strategy for overall building fire safety. Once such an approach becomes accepted it is inevitable that other building systems, such as non-combustible construction would adopt a similar system for measuring performance and, if necessary, increasing building reliability to acceptable levels.

3.9 Acoustic Performance

Sound and Buildings

The passage of sound between units of a residential or commercial building, as well as from the outside in, plays a large role in the comfort level (and general happiness) of its occupants. There are two ways to measure the passage of sound, Sound Transmission Class (STC) and Impact Insulation Class (IIC).

Sound Transmission Class (STC)

Sound transmission can be defined as sound waves hitting one side of a partition causing the face of the partition to vibrate resulting in sound transmission to the other side.

Sound transmission class or STC, is a numerical rating assigned to a wall or floor assembly, used to describe how well it transmits sound. STC classifies the average noise reduction in decibels for sounds that pass through an assembly. A high STC rating for an assembly implies good sound attenuation characteristics. Loud or amplified speech and loud music would still be audible with an assembly that has an STC rating of 45. Whereas, loud music would be inaudible except for very strong bass notes in an assembly with a rating of STC 60. (Canadian Mortgage and Housing Corporation 2009)

The STC rating ignores low-frequency sound transmission below 125 Hz, which is often associated with mechanical systems, transportation noise and amplified music. Low-frequency sounds can be a major cause for complaint in multi-family construction. A heavier assembly with the same STC as a lighter assembly may often outperform the lighter assembly at low frequencies due to the attenuation of sound arising from increased mass.

Impact Insulation Class (IIC)

Impact sound transmission is caused by direct contact or impact that vibrates the wall/floor. This sound then resonates in the cavity of the assembly which is then transmitted into the next space as sound.

The standard test for impact sound resistance results in a rating called “impact insulation class” (IIC). The standard test method uses a tapping machine that consists of a motor and turning shaft that lifts and drops five steel hammers on the floor a total of 10 times per second. Sound pressure levels are measured in the room below at specific frequencies.

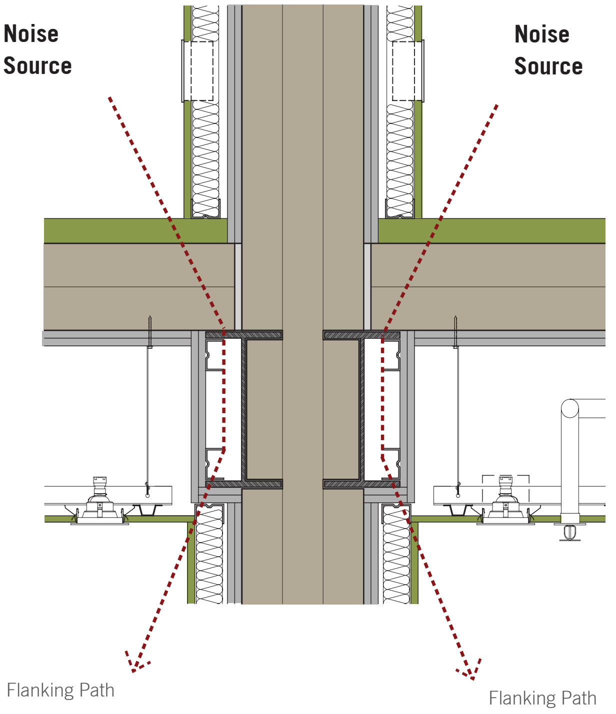
IIC increases as the impact sound insulation improves. The building code does not outline acceptable IIC ratings for walls or floors but recommends an IIC of 55. In practice, this is deemed largely ineffective and levels of IIC 70 are typically necessary for residential applications.

Flanking Sound

Flanking noise refers to situations in which sound vibrations are transmitted through an assembly by moving across its top, bottom or sides and into an adjoining space.

A flanking path transmits sound through paths other than the actual partition between two spaces. Sound can travel considerable distances in a structure because of flanking noise around partitions from space to space. Flanking noise is difficult to control because of the low frequency of the sound waves and the way in which it is transmitted. Typical flanking paths include open plenums that span walls, suspended ceilings, common ductwork, adjacent exterior windows, common floor heaters, open vents and under door openings. The sensitivity to details and materials in a structure will determine the effect of flanking noise which is almost impossible to entirely avoid.

Typical flanking paths through an interior floor and wall assembly



Mass

The weight or thickness of a partition is one of the major factors in its ability to block sound. Mass is commonly added to existing walls by adding layers of gypsum board. When the mass of a barrier is doubled, the STC rating increases by approximately 5 dB, which is clearly noticeable. The more dense a product the better its sound transmission performance will be. (Canadian Mortgage and Housing Corporation 2009)

Discontinuity

When sound vibrations are allowed to move from one wall face to another through a solid internal element, the STC rating significantly decreases. An air space within a partition or floor assembly can also help to increase sound isolation. The airspace can be increased or added to a partition by using components such as resilient channels and layers of gypsum board. An airspace of 1 ½" will improve the STC by approximately 3 dB. An air space of 3" will improve the STC by approximately 6 dB. An airspace of 6" will improve the STC by approximately 8 dB. (Canadian Mortgage and Housing Corporation 2009)

Resilient Connections

Fastening horizontal resilient channels to the structural members of an assembly are common approaches used to break the sound transmission path. Resilient channels installed on both sides of a wall may be beneficial where flanking sound can enter the wall framing from above or below. The position and location of resilient channels are important because if installed wrong, they can actually decrease the STC rating (e.g. ensuring the resilient channels are oriented with their bottom flange attached to the wall stud framing.

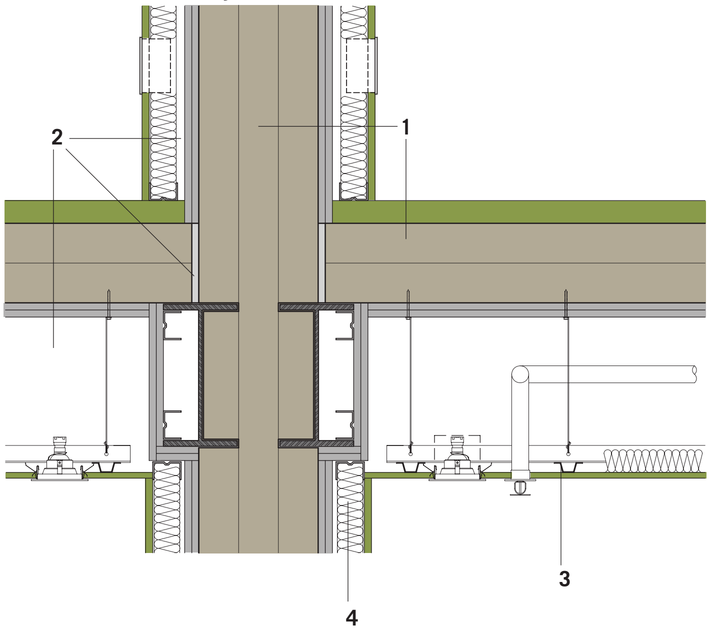
Absorption

Sound absorptive material can be installed in a cavity wall or floor to reduce sound transmission between spaces. These sound absorbing materials are usually porous foams or fibrous layers so that sound passes easily through them. Examples of sound absorbing materials are mineral wool, glass fiber, cellulose fiber, open cell foams, and acoustical tiles. These materials convert sound vibrations into heat as sound repeatedly reflects from the surfaces of an enclosed space, passing through the sound-absorbing material many times and with each pass, decreasing the sound energy.

Assembly Components

A sound rating depends on and is affected by the components in any wall or floor assembly. The construction details play a large role in this, from materials and thickness in the layers (gypsum board or sound absorption material) to spacing of studs and resilient channels in a wall assembly. In a floor assembly, the same principals apply where finishing, topping, sub-floor, ceiling boards, sound absorption material, space between layers, and the size and spacing of joists and resilient channels all affect sound ratings. An ideal assembly to control sound transmission would include an airtight construction (especially at penetrations), two layers that are not connected at any point by a solid material, the heaviest or most dense material that would be practical, and the deepest cavity that is practical filled with a sound-absorbing material.

Addressing sound control issues through assembly components in the Tall Wood case study



1 Mass: density of LVL, LSL, or CLT
2 Discontinuity: use of airspace or isolation pad
3 Resilient Connections
4 Absorption: use of sound absorptive material

3.10 Building Enclosure

The Role of the Building Envelope

The envelope of a building is designed to resist wind and earthquake loads, limit air leakage, control vapour diffusion, prevent rain penetration, surface and cavity condensation, excessive heat loss and heat gain, and also resist noise and fire.

A common preconception with wood buildings is that they are more prone to weathering and failure and therefore are less likely to last as long as concrete or steel structures. The reality is that all buildings must consider how to protect the structure from the effects of weather and climate; therefore a well-designed building envelope will address the concerns of one building structure over another on the basis of its comparative performance. Once protected by an envelope designed to address the environment and particulars of the structure all buildings are effectively equal. It is quite common for example to find wood houses in eastern North America that are 100-200 years old and of wood frame construction. These buildings have endured as the result of suitable envelope design and maintenance over the life of the building.

Each structure will perform differently depending on the variation in performance parameters. By example, lightweight wood frame buildings dry over time and shrink as the moisture content of the wood is removed. This requires consideration in the design of an envelope. Another example in concrete buildings is where penetration of the concrete from interior to exterior exist without a suitable insulation and protection layer. This will cause enormous heat loss through conductivity and connection. This is a common problem seen in the design of concrete buildings around Vancouver. These issues can be addressed in all buildings with proper design detailing.

For the vast majority of conditions the approach to designing an envelope for a tall Mass Timber building will be no different or only very modestly different than designing an envelope for a tall concrete building.

The History of Vancouver's Leaky Condo Crisis

The negative annotations associated with wood buildings in Vancouver are a derivative of envelope failures that caused significant moisture damage in condominiums in Vancouver over the last few decades. The reasons for the envelope failures were numerous but were in part attributable to poor detailing and poor understanding of the movement of wood structures. Light weight wood frame buildings shrink over time as the wood dries to its ultimate stable moisture content. In a typical platform-built wood frame building this means that each floor will see shrinkage over its height. Building envelopes must accommodate this shrinkage to ensure continuity of both the air and vapour barrier layers and the protective exterior building envelope. As a host of problems, including a lack of understanding of the fundamentals of good envelope design contribute to the problem, large retroactive measures were therefore occurring involving insurance/warranty claims and often litigation by owners of their representative parties. This effectively branded wood as a riskier building material than concrete.

This concern is a critical factor to address as wood buildings move into the next generation and specifically as Mass Timber buildings are introduced to the market.

The Principles of Building Envelope Design

Protect the building from degradation due to the impacts of:

1. Water
2. Ice / Snow
3. Solar Radiation
4. Humidity (movement of humidity from inside to outside or vice versa)
5. Temperature variation from inside to outside or vice versa - Heat or Cold
6. Movement (due to wind and seismic effects)
7. Pressure (due to wind – positive and negative forces)
8. Acoustics / Sound
9. Fire / Smoke on the building envelope

These issues pose several key questions:

1. Will the building's movement due to live loads (wind/ seismic/ functional use) put unique stresses on the building's envelope?
2. Will the building's structure change over time? Shrinkage in light frame wood or creep in concrete for example.
3. How will water be repelled by the exterior protective surface?
4. How will the materials on the exterior dry out if they become wet?
5. How will air flow be controlled?
6. How will vapour flow be controlled?
7. How will the building provide insulation from heat and/or cold?

Thermal Performance

Wood, steel and concrete have significant differences in their thermal performance characteristics. These will directly affect the performance of the building envelope. The first is thermal conductivity, which is the material's ability to conduct or transmit heat. Essentially, thermal conductivity is the rate of energy loss cheat through a piece of material. In building science, this is typically referred to as the U-Value. The greater the U-Value, the greater the amount of energy passing through that material.

Thermal conductivities of some common materials and products are indicated below.

Thermal conductivity (k) is measured in Watts per metre Kelvin (W/(m·K)).

Thermal Conductivity - k - W/(m·K)

Material/Substance	**Temperature – 25** ℃
Aluminum	250
Concrete	1.7
Carbon Steel	54
Glass, window	0.96
Glass, wool Insulation	0.04
Wood across the grain, white pine	0.12
Mass Timber	+/- 0.11

As the above chart illustrates, wood performs considerably better than concrete and steel in terms of thermal conductivity. Thermal conductivity is particularly important in building conditions where thermal bridging can occur, for instance, where floor plates project from the interior to the exterior such as in a balcony. These are areas where large amounts of heat can be lost. Thus, wood, with its low thermal conductivity can significantly out-perform materials such as concrete and steel in areas where thermal bridging is a concern.

The reciprocal of thermal conductivity is thermal resistivity. This is typically known as the R-value which measures the thermal resistance or the ability of a material to resist transfer of heat. The greater the R-value the better the insulating properties of that particular material across a thickness.

Thermal Resistance – R-value ft.^{2}·°F·h/(BTU in)

Material/Substance	**R-Value**
Concrete	0.08
Glass, window	0.91
Glass, wool Insulation	3.5
Wood (most soft woods)	1.41
Mass Timber	+/- 1.2

References:

Thermal Conductivity
http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

Thermal Resistance
http://en.wikipedia.org/wiki/R-value_(insulation)

As illustrated, wood drastically out performs concrete in terms of its insulating properties. Concrete which by comparison has a low resistance to heat transfer is often left exposed without additional insulation. By comparison, Mass Timber has significant thermal resistivity; almost a 1/3 that of glass wool insulation. Used as a structural material, Mass Timber products such as CLT can significantly increase the insulation value of an assembly. For instance, a CLT panel of 3 1/2" would have an R-value of 4.2. In the FFTT system, structural panels are deployed in thickness of greater than 7", providing significant baseline insulation for the entire structure.

The result is that wood out performs both steel and concrete in terms of its ability to resist heat transfer and heat loss. Thus, wood has the potential to radically improved the buildings performance from a material point of view, if wood is employed as a structural material.

Curtain Wall

Glass curtain wall systems are very common in tall buildings and are amongst the most weather resistant and airtight exterior wall assemblies on the market today. These systems are characterized by large panels of glass, spandrel panels and a grid of window frames. Properly constructed and designed curtain walls will control air leakage, rain penetration and condensation. Additionally, a rainscreen system at the spandrel panels will facilitate water penetration, venting and drying. A comparison of the FFTT system (Options 1 and 2) against its concrete benchmark reveals that there would be no significant difficulties in employing a curtain wall with the FFTT system (refer to section 3.12 Typical Details).

Rainscreen

A rainscreen wall system typically includes an exterior cladding, a cavity behind the cladding drained and vented to the outside; an inner wall plane incorporating an air barrier; and a set of compartment seals limiting the cavity size. The outer layer of the rain screen is typically made up of a cladding that deflects the kinetic force of the rain, while the inner components remain protected. The vented cavity uses gravity and flashings to drain water that penetrates the outer wall. In the FFTT system (Option 3 and 4) where exterior structural walls are utilized, a pressure equalized rain screen system is recommended.

Detailing at Grade

Mass Timber panels should be well protected from moisture at grade. Tall Wood buildings will have a concrete foundation and foundation walls extending the concrete to timber panel connection to at least 12" above grade. This height should increase in areas prone to high snow drifting, ponding, flooding or termite concerns. In general there will be a moisture barrier between concrete structures and the Mass Timber materials in the structure.

Mass Timber products……" (especially any exposed portions of the panels and parts in contact with foundations) would benefit from wood preservative such as borate or copper based preservatives, particularly in wetter or more humid climates or where termites are prevalent." "In areas of high termite hazard, such as the Southeastern United States, multiple lines of defense should be used to prevent termite damage to CLT panels"– (FPInnovations 2011)

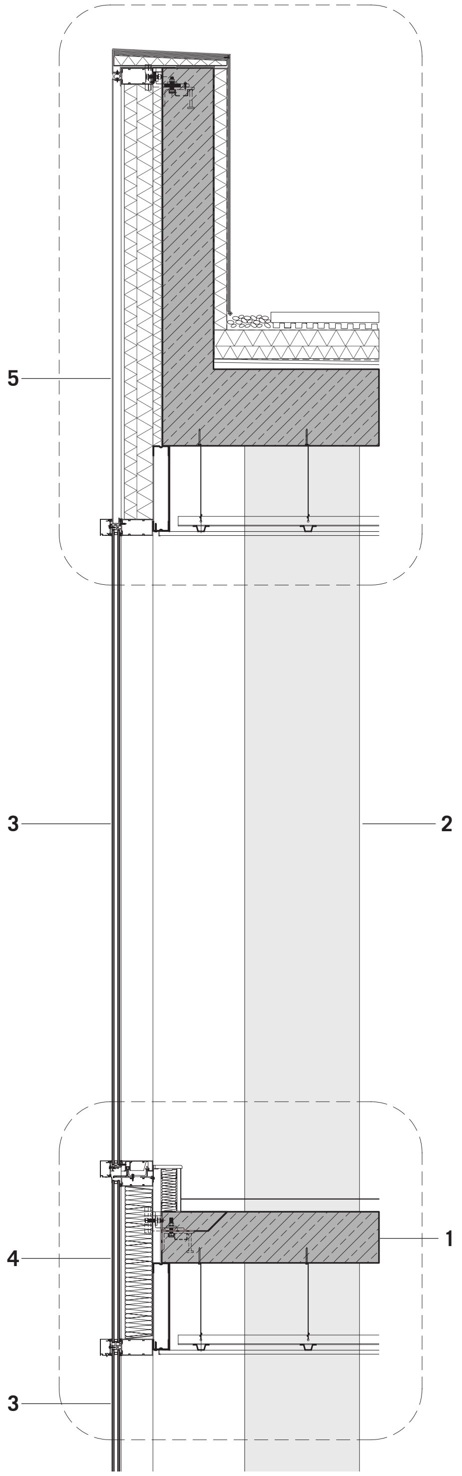
Control of Moisture During Construction

During construction, it is critical to prevent the wood panels from exposure to moisture for prolonged periods. Care and consideration can easily alleviate many of the issues that moisture can cause. These measures include:

1. Pre-fabrication of panels to reduce construction time
2. Scheduling of material deliveries to optimize material usage and minimize on-site storage time
3. Use of preservative treated lamina for panels that are likely to be exposed to moisture for prolonged periods of time particularly edges and end grains
4. Products such as LVL and LSL from certain manufacturers come with standard water-resistant coating on all faces providing additional weather protection
5. On-site protection such as temporary shelters
6. Consideration of season for construction

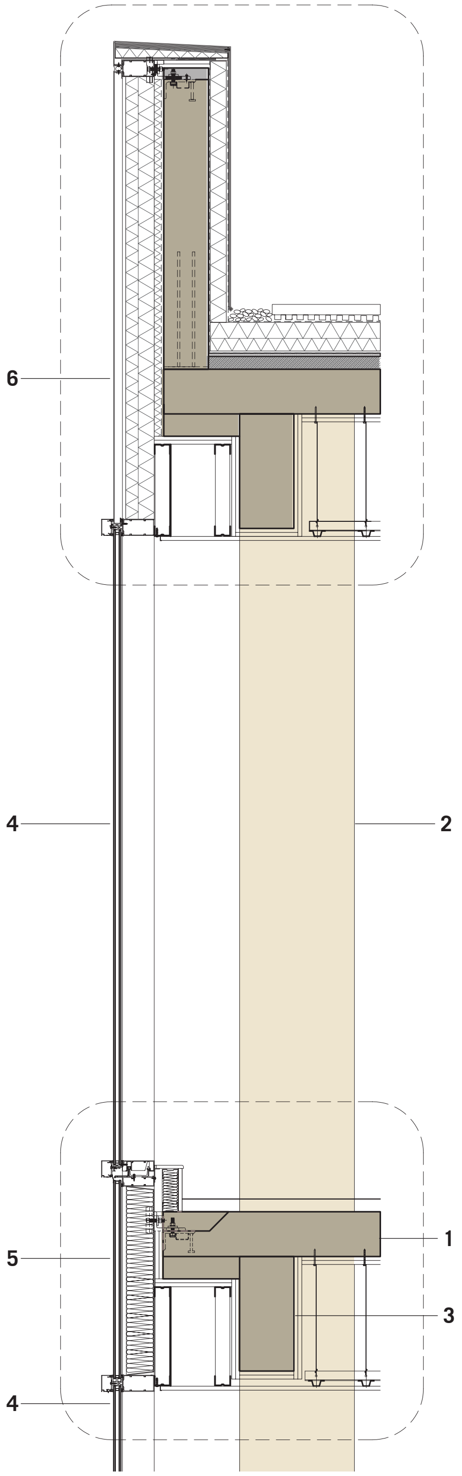
Diagrams

Envelope Comparison



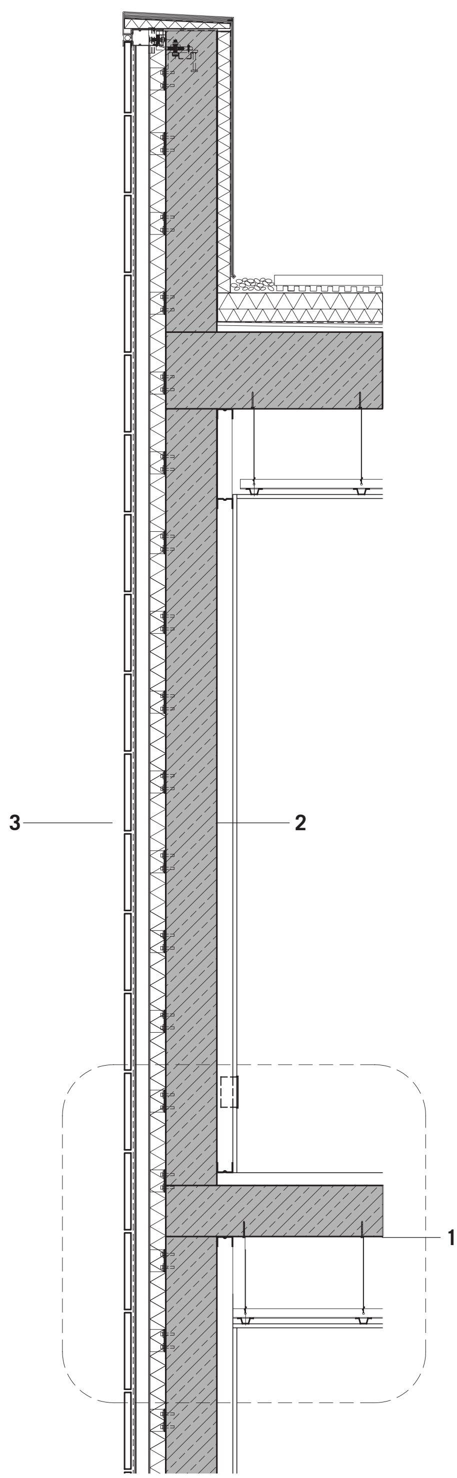
1 Concrete floor slab (2HR FRR)
2 Concrete column beyond (2HR FRR)
3 Vision glass
4 Spandrel glass panel
5 Spandrel glass panel or non-combustible cladding

Typical concrete tower curtain wall facade section



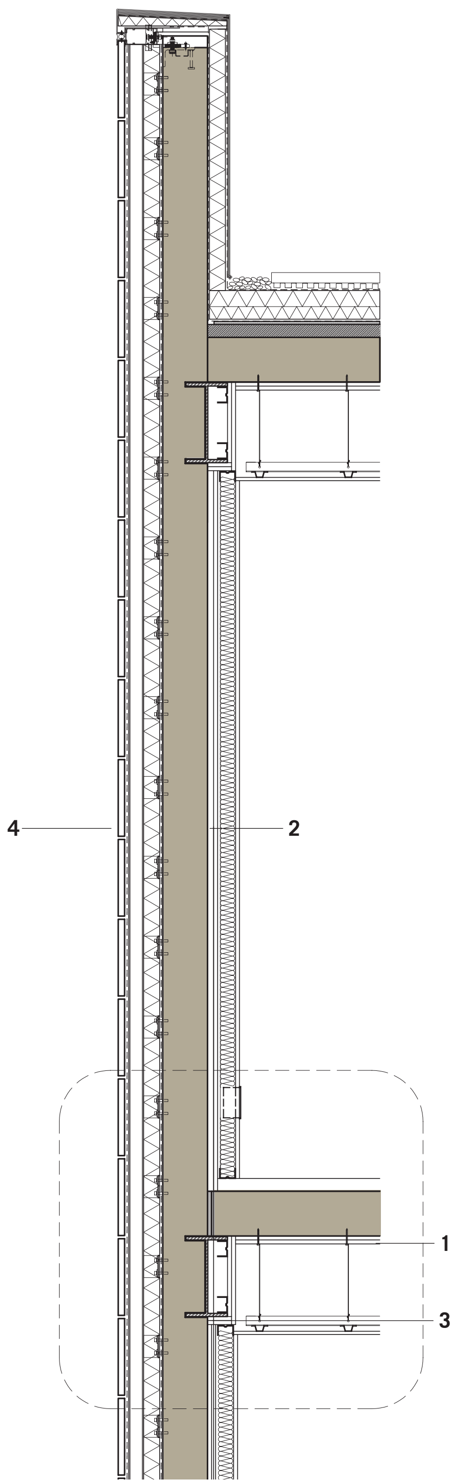
1 2 layer Mass Timber + 2 layer 5/8" type X gypsum board (2HR FRR)
2 Glulam column + 2 layer 5/8" type X gypsum board beyond (2HR FRR)
3 Glulam beam + 2 layer 5/8" type X gypsum board (2HR FRR)
4 Vision glass
5 Spandrel glass panel
6 Spandrel glass panel or non-combustible cladding

Tall Wood case study curtain wall facade section (option 1 + 2)



1 Concrete floor slab (2HR FRR)
2 Concrete wall (2HR FRR)
3 Non-combustible cladding + rainscreen

Typical concrete tower facade section

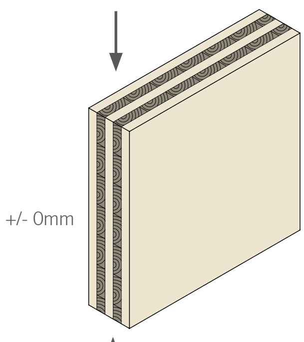


1 Mass Timber structure + 2 layer 5/8” type X gypsum board (2HR FRR)
2 2 layer LVL, LSL or CLT + 2 layer 5/8” type X gypsum board (2HR FRR)
3 Steel beam
4 Non-combustible cladding + rainscreen

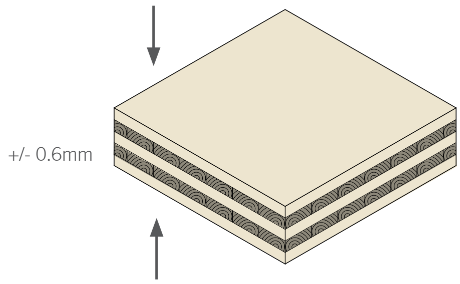
Tall Wood case study facade section (option 3 +4)

Material Moisture Content / Shrinkage

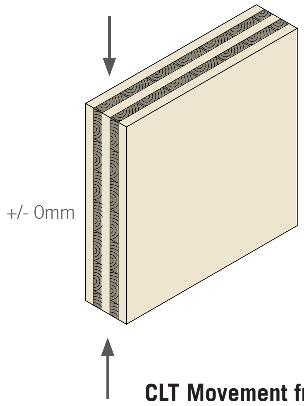
One of the significant differences between light wood-frame buildings and Mass Timber buildings is the difference in shrinkage over time as the wood's moisture content stabilizes to the building's environment. It is typical to see significant shrinkage in light wood-framing where initial wood stud moisture content typically ranges from 15% up to 19% and eventually stabilizes at 8 to 10%. The moisture content in Mass Timber and engineered wood generally starts with a moisture content of 8-10% during fabrication. This results in stable material over fabrication and extremely little shrinkage along the main axis of the material during the life of a building. Slightly more shrinkage will be found across the thickness of CLT material than LSL/LVL due to CLT's solid wood composition. As a result a platform based CLT construction system as was built for the Stadthaus project in London can result in accumulative shrinkage over the height of the building that may require consideration in the detailing of the exterior envelope. The FFTT system which balloon frames using the length of the Mass Timber panels will see extremely little shrinkage and therefore will not require special consideration for shrinkage in the envelope. Shrinkage in FFTT would be similar to that of a concrete building as concrete creep occurs during the initial curing stage of the material.



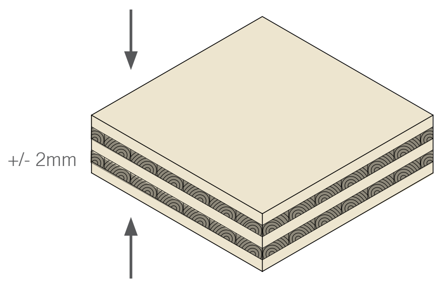
CLT Movement from compression under load



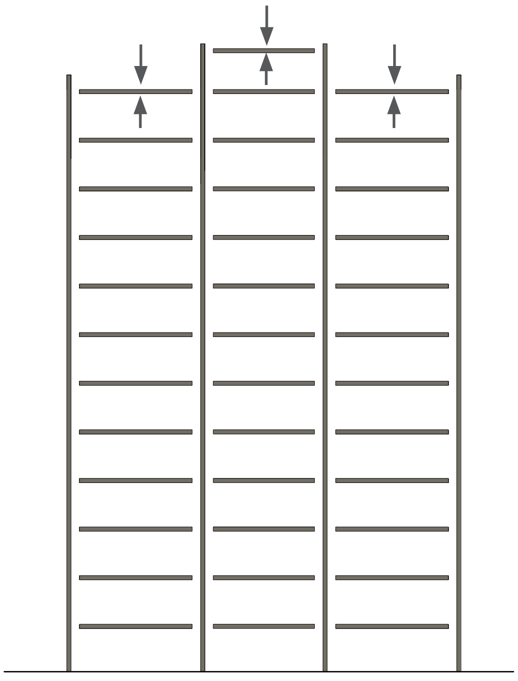
CLT Movement from compression under load



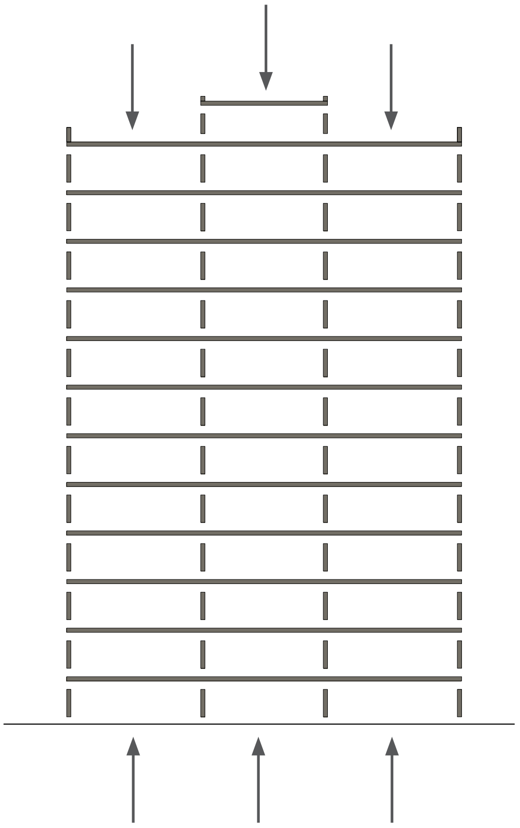
CLT Movement from moisture loss



CLT Movement from moisture loss



FFTT Framing diagram
Cumulative Shrinkage = 0



Platform Framing diagram
Cumulative Shrinkage = 31.2 mm

3.11 Systems Integration

At a building scale, systems have been integrated as they would be in a typical concrete tall building; continuously through vertical rated shafts and locally through fire rated vertical and horizontal penetrations.

Within the units or suites, systems integration can be handled one of three ways, dependant on the method of fire separation and the desired interior finish:

1. **CNC or route out chases within the Mass Timber panels to receive all services.** This method is popular in Europe, but requires a high level of pre-construction coordination (and offers no flexibility during construction) that is not typical of North American construction practice.

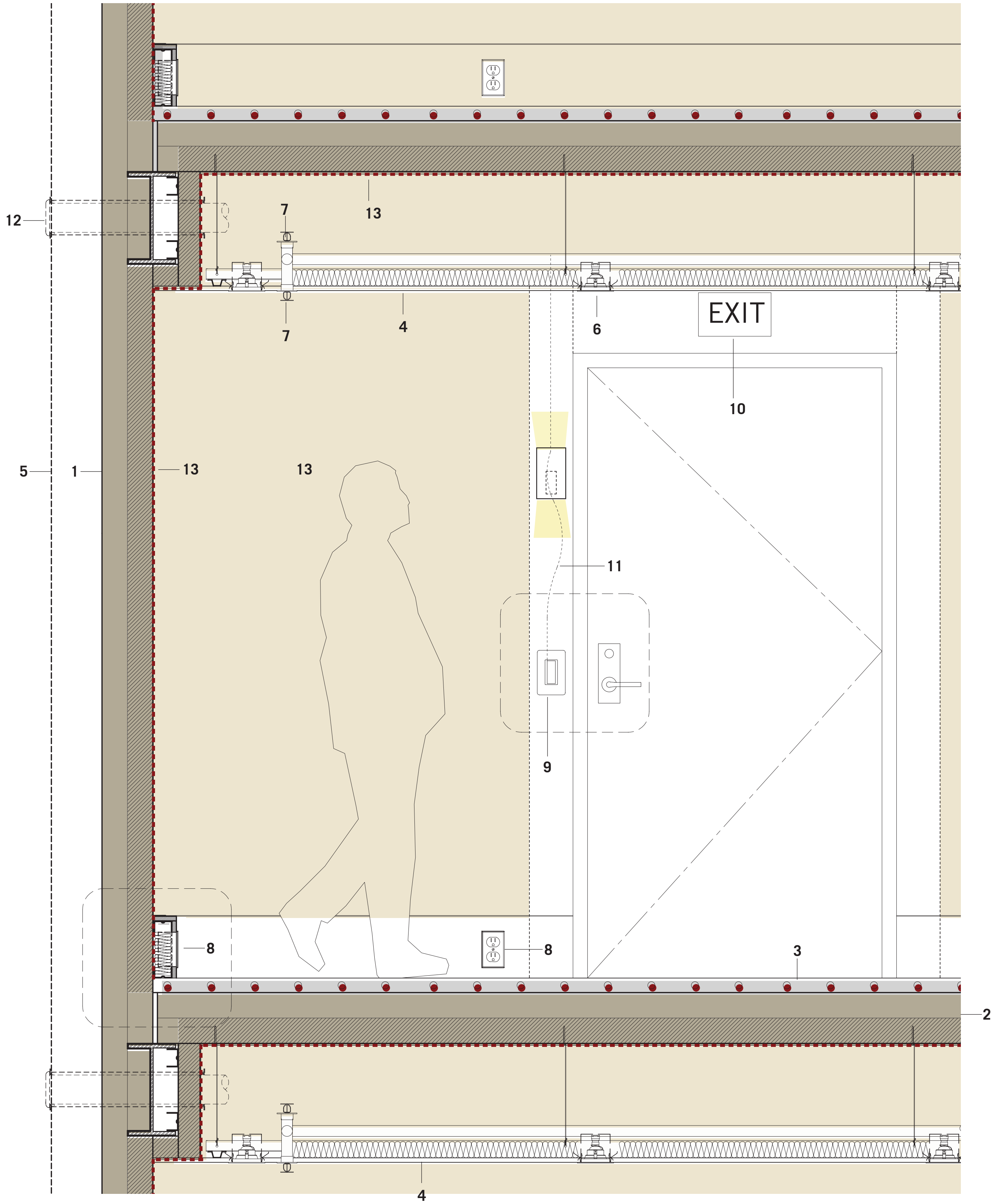
2. **Encapsulation approach to fire separation** - provide chases or cavities (non-combustible) both horizontal and vertical to run services outside of the fire protection layer. This is the most flexible approach and is most akin to current North American construction practice.

3. **Charring approach to fire separation** - provide a zone of services along the suite's floor perimeter in corridors and at doorways to run services and outlets. This requires some pre-construction coordination but retains flexibility during the construction phase. This option could also utilize a sprinklered cavity at the ceiling level which could be localized if services are ganged together.

The diagrams that follow illustrate both options 2 and 3.

1	Mass Timber structure + sacrificial layer
2	Mass Timber structure + sacrificial layer
3	Finish floor. Radiant in light weight gypsum topping or concrete topping. If using baseboard heating refer to floor assemblies page for flooring options
4	Finish ceiling: 1 layer 5/8" type X gypsum board
5	Facade (non-combustible). Refer to envelope section for additional information
6	Pot light
7	Sprinkler (concealed space sprinkler)
8	Base with chase for electrical outlet
9	Light switch or similar control
10	Ceiling mounted exit sign
11	Chase beyond for wiring. 2 Layer 5/8" type X gypsum board (2HR FRR)
12	Exhaust penetration with fire stopping (refer to penetration details)
13	**Ceiling and floor: sacrificial Mass Timber protection layer. On walls, used as a finished layer. CLT Charring rate - 0.65 mm/min. (2HR FRR = 78mm) [3"]
**	Charring rates vary depending on timber type, moisture, density and species. The charring rate of 0.65mm/min is the generally accepted average. Refer to Section 3.7 Fire Performance for additional information on charring rate.

Opposite: Tall Wood case study typical section illustrating systems integration. Charring only concept shown.


12
7
13
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4
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EXIT
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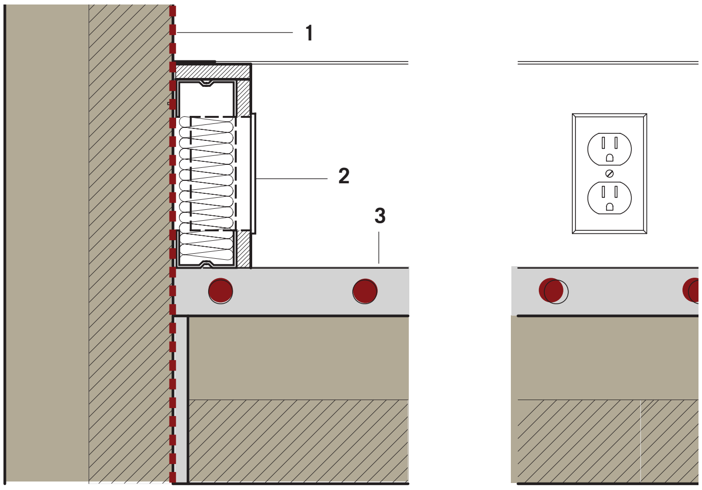
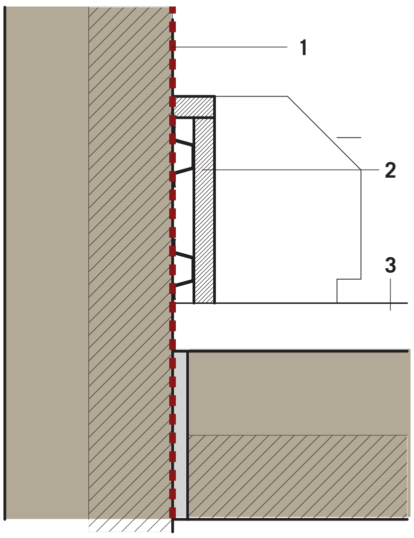
Systems integration typical details



1 **Mass Timber structural panels + sacrificial Mass Timber layer (2HR FRR)
2 Furring, baseboard, chase for wiring and electrical socket
3 Finish floor. Radiant in light weight gypsum topping or concrete topping

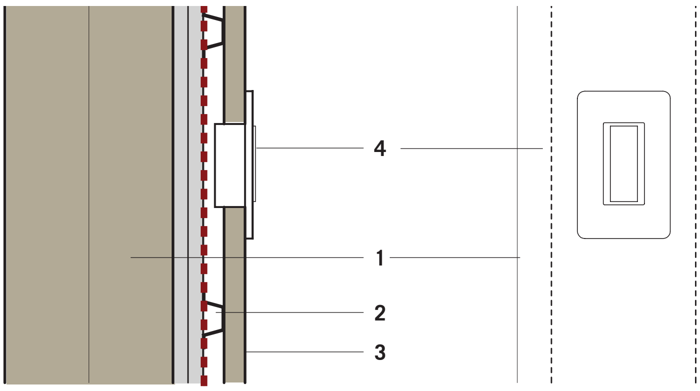
Tall Wood case study typical section illustrating systems integration. Charring only concept shown. Baseboard and chase for electrical sockets, data communications (similar detail for ceiling sprinklers in corridors)



1 **Mass Timber structural panels + sacrificial Mass Timber layer (2HR FRR)
2 Furring, baseboard, chase for wiring and baseboard heater
3 Finish floor. Refer to floor assemblies for various options

** Charring rates vary depending on timber type, moisture, density and species. The charring rate of 0.65mm/min is the generally accepted average. Refer to Section 3.7 Fire Performance for additional information on charring rate.

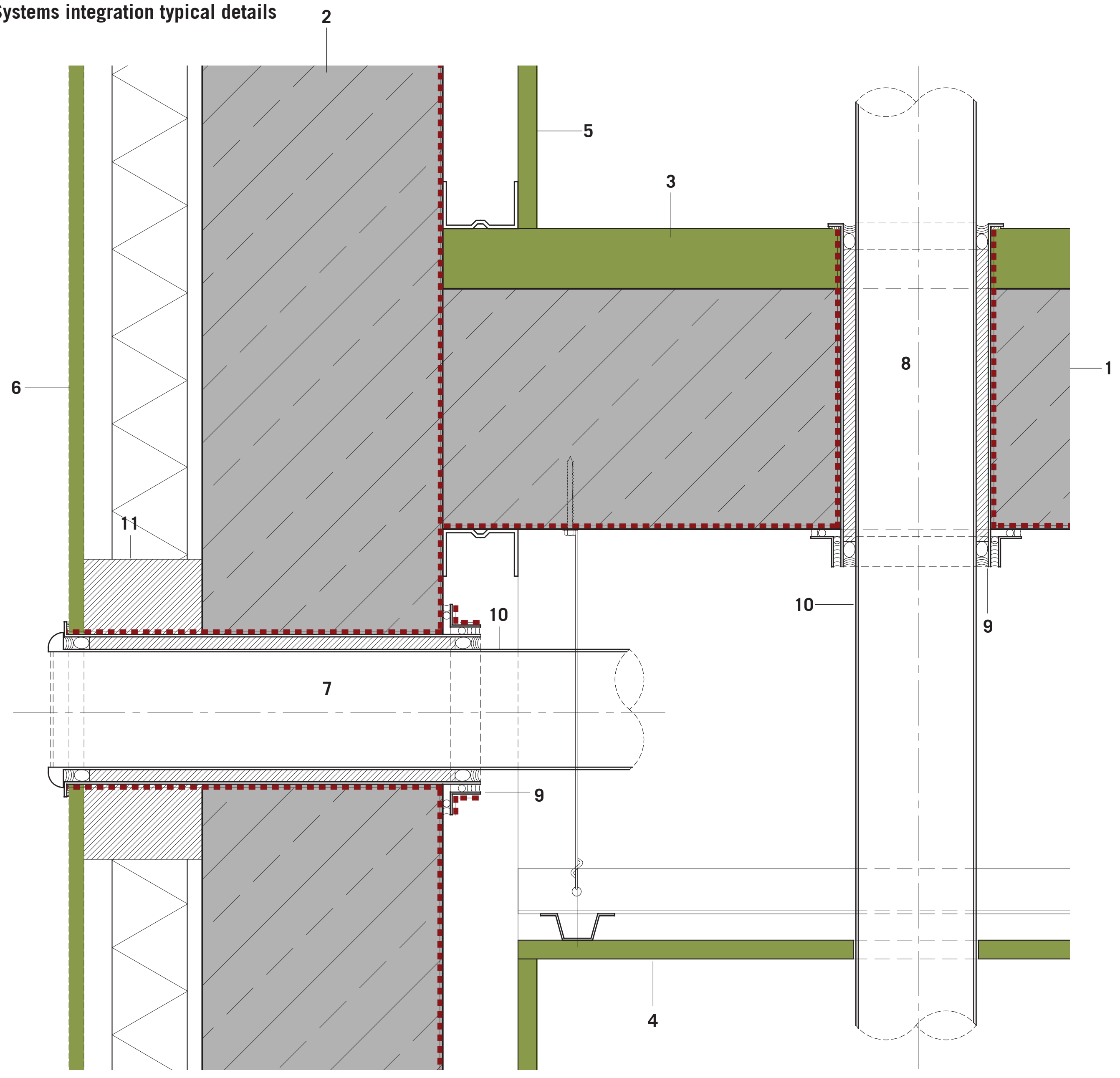
Tall Wood case study typical section illustrating systems integration. Charring only concept shown. Baseboard heater option.



1 Mass Timber structural panels + 2 layer type X gypsum board (2HR FRR)
2 Furring and chase for wiring
3 Finish wall
4 Light switch or similar device

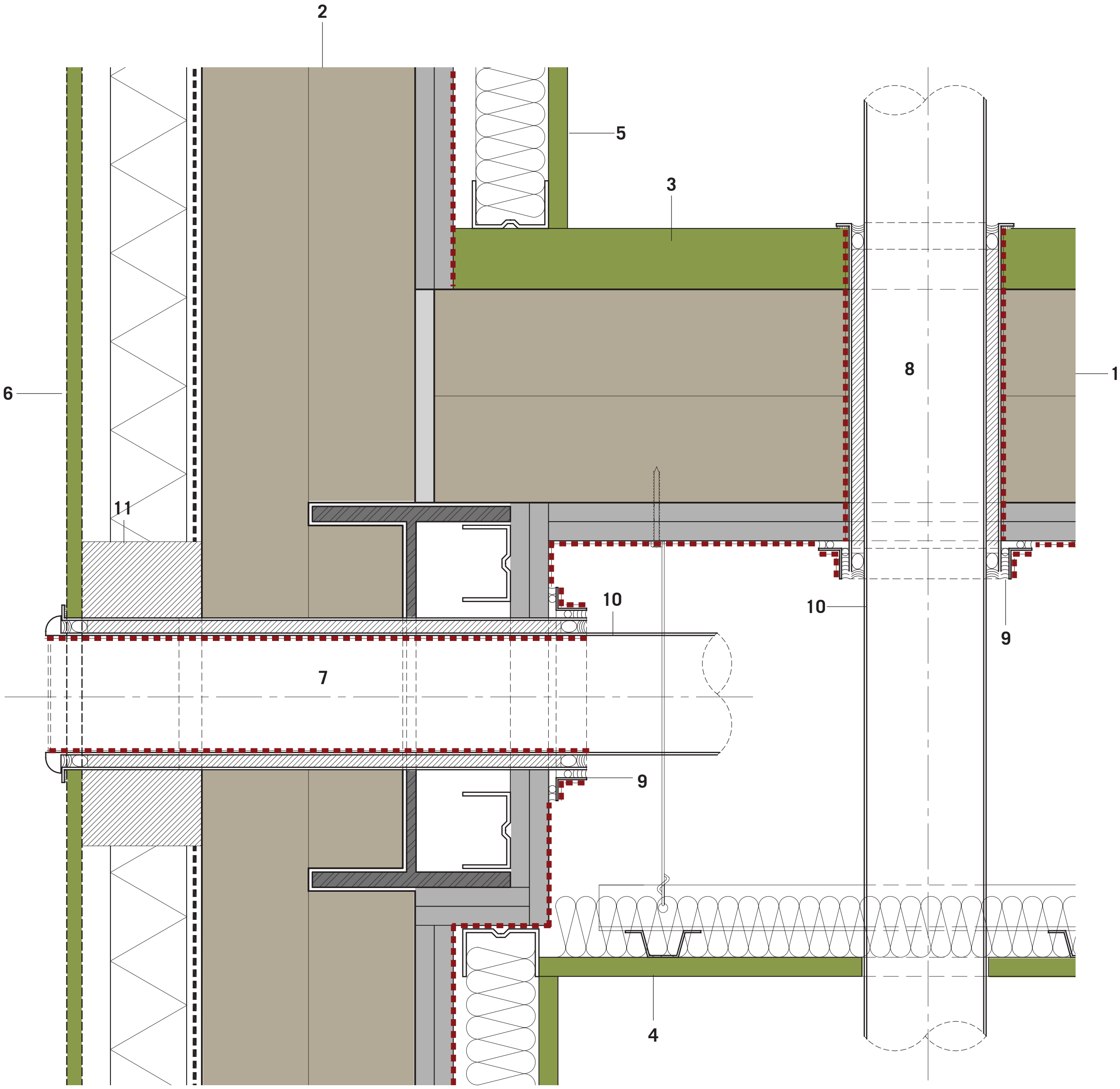
Tall Wood case study typical section illustrating systems integration. Encapsulation only concept. Electrical chase for switches, light sconces, fire pulls, alarms, intercoms and thermostats.

Systems integration typical details



1	Cast in place concrete floor (2HR FRR)	7	Horizontal exhaust penetration with fire stopping
2	Cast in place concrete wall (2HR FRR)	8	Vertical exhaust penetration with fire stopping
3	Finish floor	9	Prefinished metal flange with perimeter fire rated sealant
4	Finish ceiling: 1 layer 5/8" gypsum board	10	Sleeve C/W flange and filled with spray insulation. Fire stop at sleeve location
5	Finish wall: 1 layer 5/8" gypsum board	11	Spray insulation
6	Facade (non-combustible)		

Typical concrete tower penetrations at floor and wall



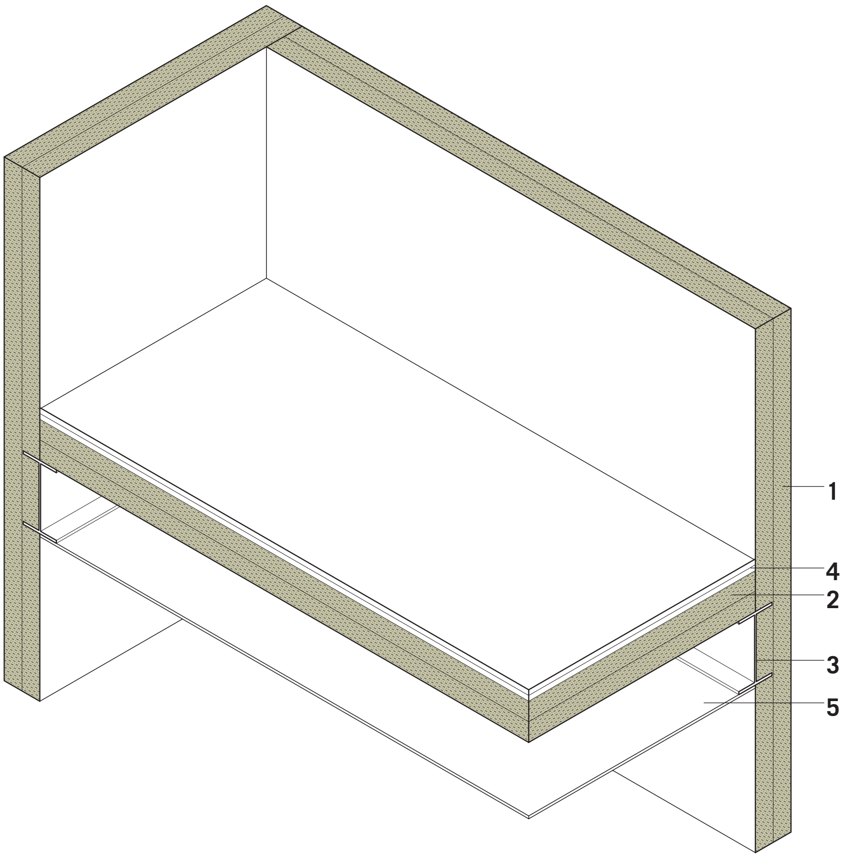
1 Mass Timber structural panels + 2 Layer 5/8” type X gypsum board (2HR FRR)
2 Mass Timber structural panels + 2 Layer 5/8” type X gypsum board (2HR FRR)
3 Finish floor
4 Finish ceiling: 1 layer 5/8”gypsum board
5 Finish wall: 1 layer 5/8” gypsum board
6 Facade (non-combustible)
7 Horizontal exhaust penetration with fire stopping
8 Vertical exhaust penetration with fire stopping
9 Prefinished metal flange with perimeter fire rated sealant
10 Sleeve C/W flange and filled with spray insulation. Fire stop at sleeve location
11 Spray insulation

Typical wood case study tower floor and wall section at exterior wall

3.12 Typical Details

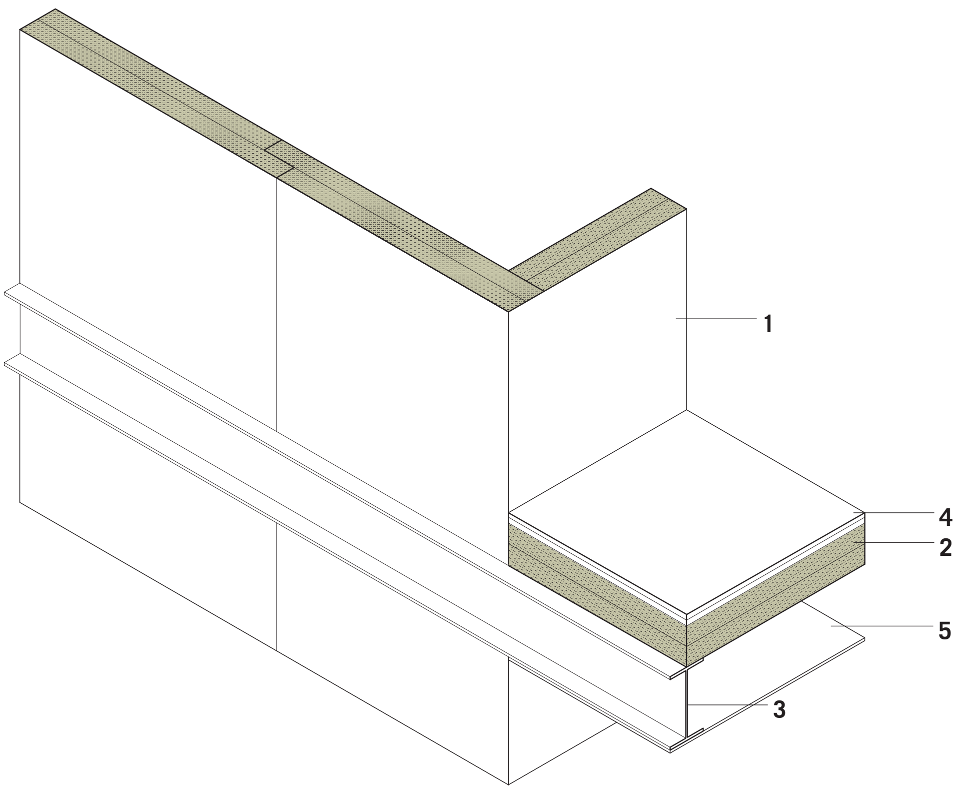
FFTT Typical Details

The following illustrations are a set of generic details developed for the FFTT system. These details investigate pertinent issues such as fire ratings, acoustics, finishing, envelope considerations and systems integration. The departure point for these details are based on a set of typical conditions that would be encountered in the concrete benchmark. Thus, each FFTT detail is compared through these illustrations, to a concrete detail of the same condition. In doing so, the pros and cons of each system can be easily identified and compared. Moreover, as an important component of the FFTT system, details for two fire-protection strategies are included. The first is the encapsulation method, where the required fire-ratings are achieved by encapsulating the assemblies with gypsum board. The second, the charring method, utilizes a sacrificial layer of wood to achieve the required fire ratings. Refer to Section 3.7 on Fire Performance for additional information on encapsulation and charring.



1	Mass Timber structural panels (walls)
2	Mass Timber structural panels (floor)
3	Steel beam
4	Various floor finishes
5	Services

Schematic axonometric view of exterior corner condition



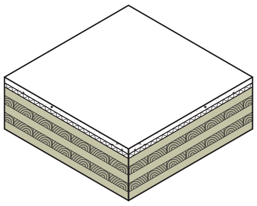
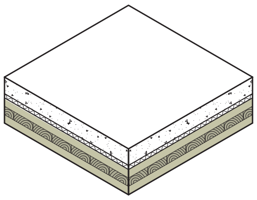
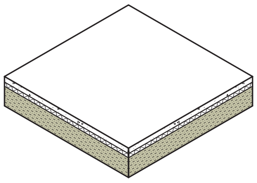
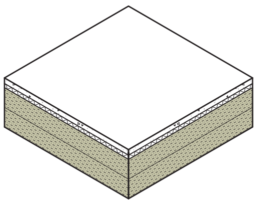
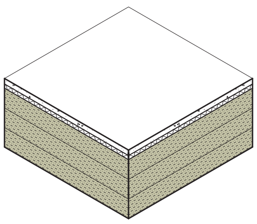
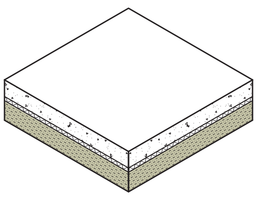
1 Mass Timber structural panels (walls)
2 Mass Timber structural panels (floor)
3 Steel beam
4 Various floor finishes
5 Services

Axonometric view of steel beam at core wall

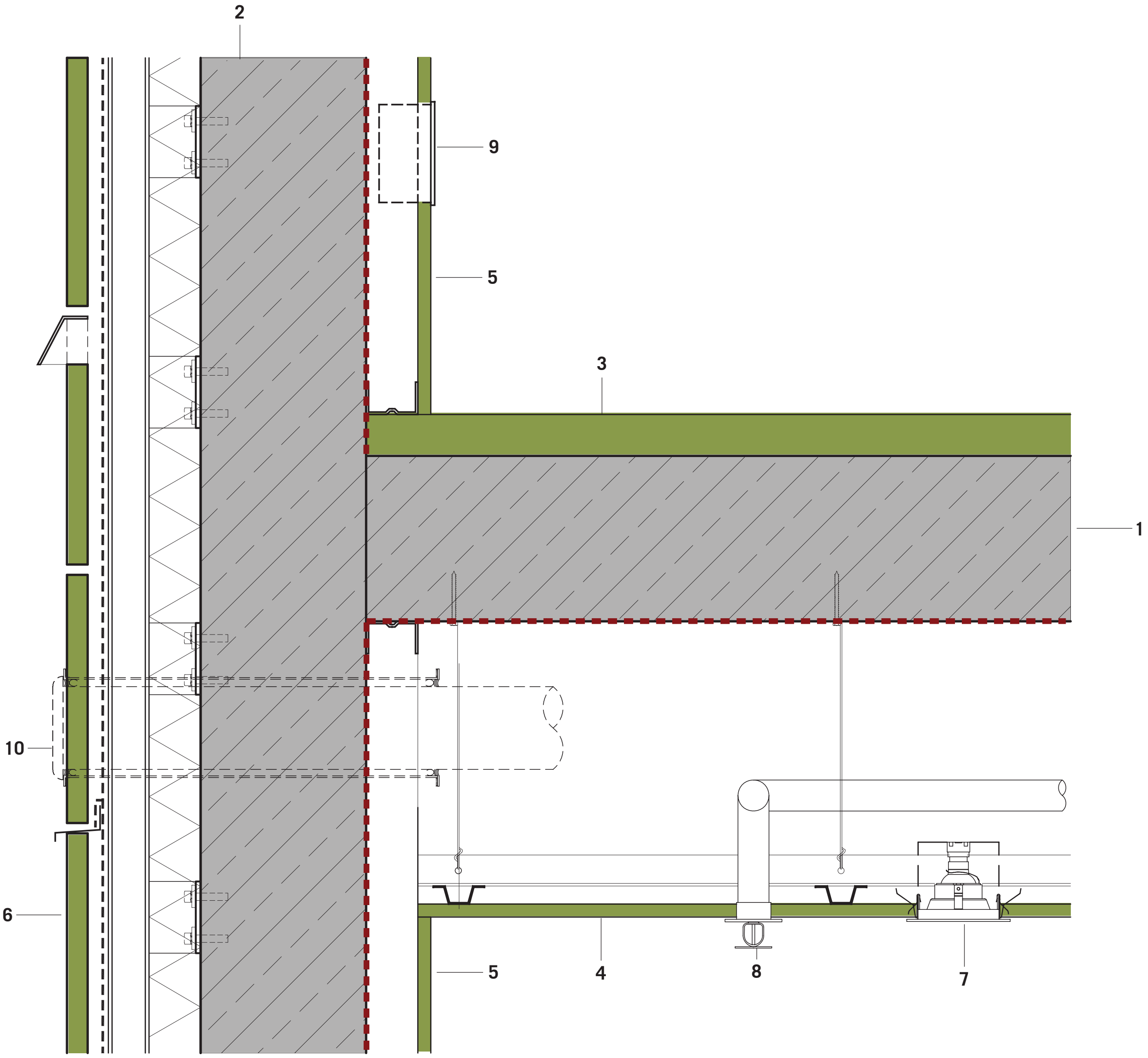
FFTT Floor Assemblies

The following table provides various possibilities for flooring assemblies using the FFTT system. In the FFTT system, the structure is principally independent of the floor system, unlike its concrete counterpart where floors are cast to be integral with the walls and columns. This affords great flexibility in terms of options for floor assemblies. The assemblies illustrated here are only intended as a guideline and should be further designed in regards to structural, acoustic and fire performance considerations.

Floor Assembly Options

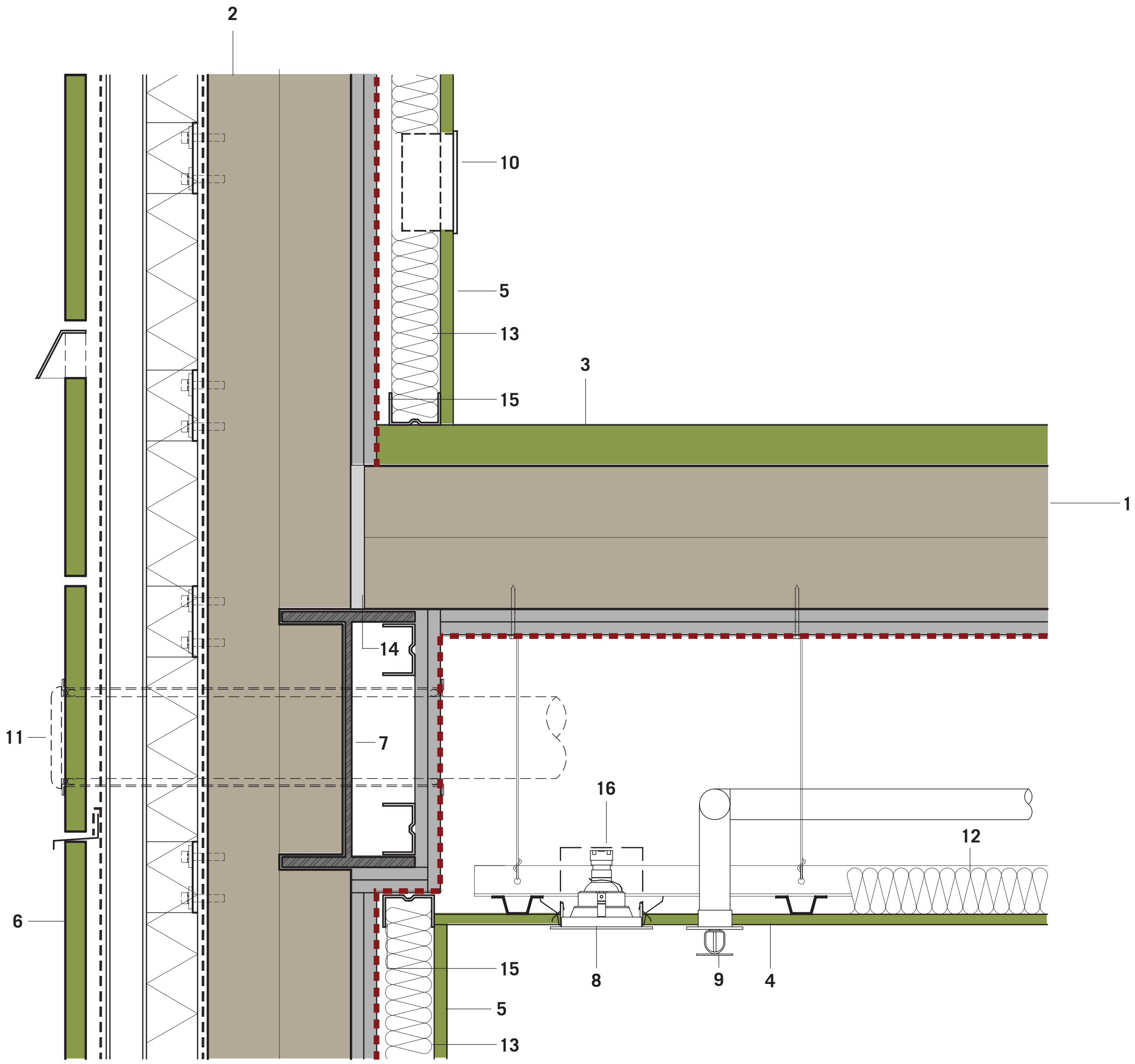
			Assembly	Span	Depth
0	Concrete		130mm concrete	N/A	130mm
1	CLT		55mm concrete topping 25mm rigid insulation 190mm CLT (5 layers)	8000mm	270mm
2	CLT - concrete composite		75mm concrete topping 19mm rigid insulation 114mm CLT (3 layers)	12000mm	208mm
3a	LSL - single layer		38mm concrete topping 19mm rigid insulation 89mm LSL panel	2400mm	146mm
3b	LSL - double layer		38mm concrete topping 19mm rigid insulation 178mm LSL panel	6000mm	235mm
3c	LSL - triple layer		38mm concrete topping 19mm rigid insulation 267mm LSL panel	6000mm +	324mm
4	LSL - concrete composite		75mm concrete topping 19mm rigid insulation 89mm LSL panel	6000mm	183mm

Note: All assemblies meet 2 HR fire rating through charring or encapsulation



1	Cast in place concrete floor (2HR FRR)
2	Cast in place concrete wall (2HR FRR)
3	Finish floor
4	Finish ceiling: 1 layer 5/8” gypsum board
5	Finish wall: 1 layer 5/8” gypsum board
6	Rain screen facade (non-combustible). Refer to typical envelope details.
7	Pot light
8	Sprinkler
9	Electrical outlet
10	Exhaust penetration with fire stopping

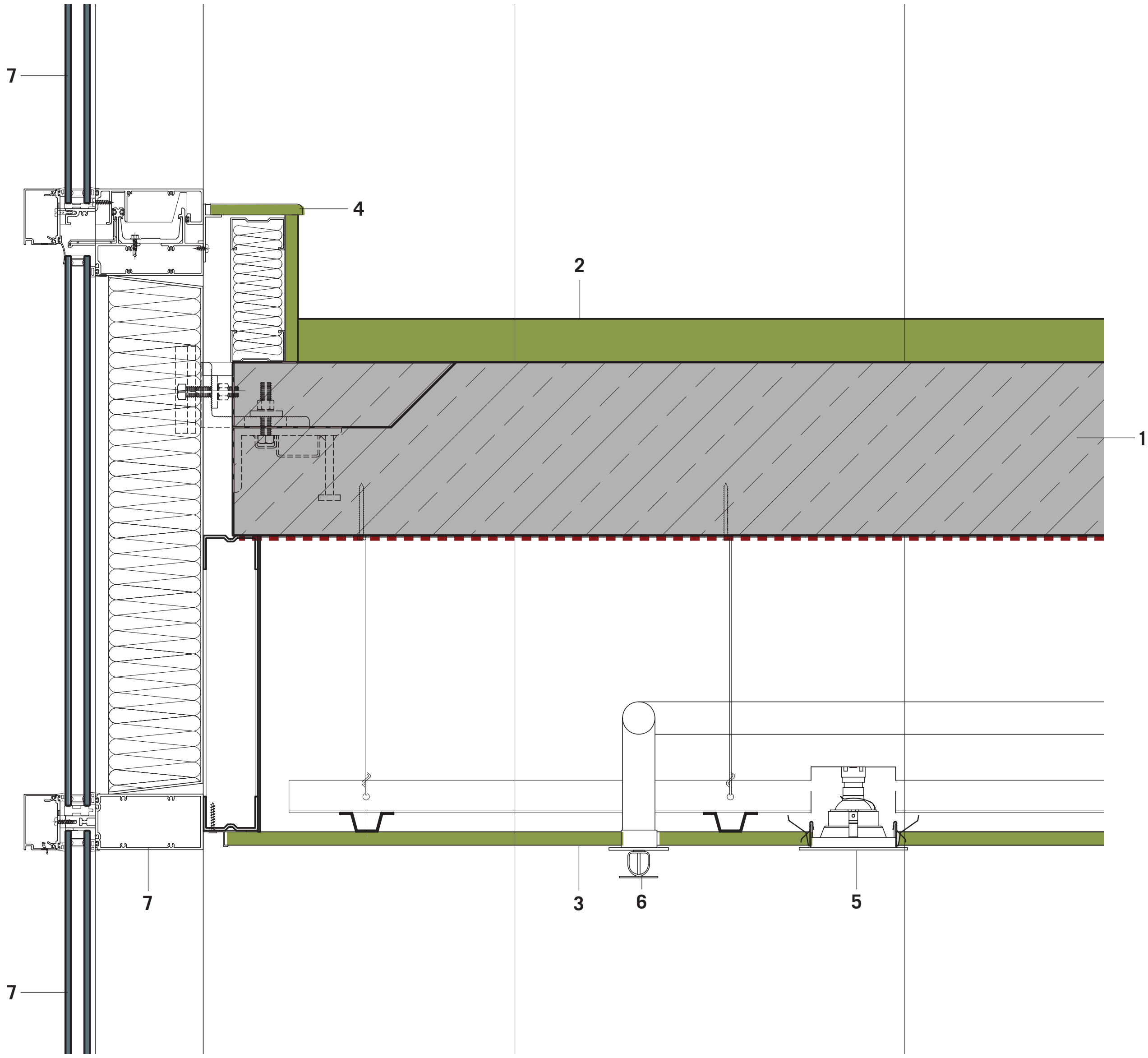
Typical concrete tower floor and wall section at exterior wall



1	Mass Timber structural panels + 2 Layer 5/8" gypsum board underside only (2HR FFR)	9	Sprinkler (plastic pipe)
2	Mass Timber structural panels + 2 Layer 5/8" gypsum board interior side only (2HR FFR)	10	Electrical outlet
3	Finish floor (refer to floor assembly table)	11	Exhaust penetration with fire stopping
4	Finish ceiling: 1 layer 5/8" gypsum board	12	2" loose mineral wool insulation for sound absorption (ceiling)
5	Finish wall: 1 layer 5/8" gypsum board	13	2" loose mineral wool insulation for sound absorption (wall)
6	Rain screen facade (non-combustible). Refer to typical envelope details	14	Gasket to reduce sound transmission between floor and wall
7	Steel beam	15	Gap between drywall and stud to reduce sound transmission
8	Pot light	16	Back boxes for light fixtures to reduce sound transmission

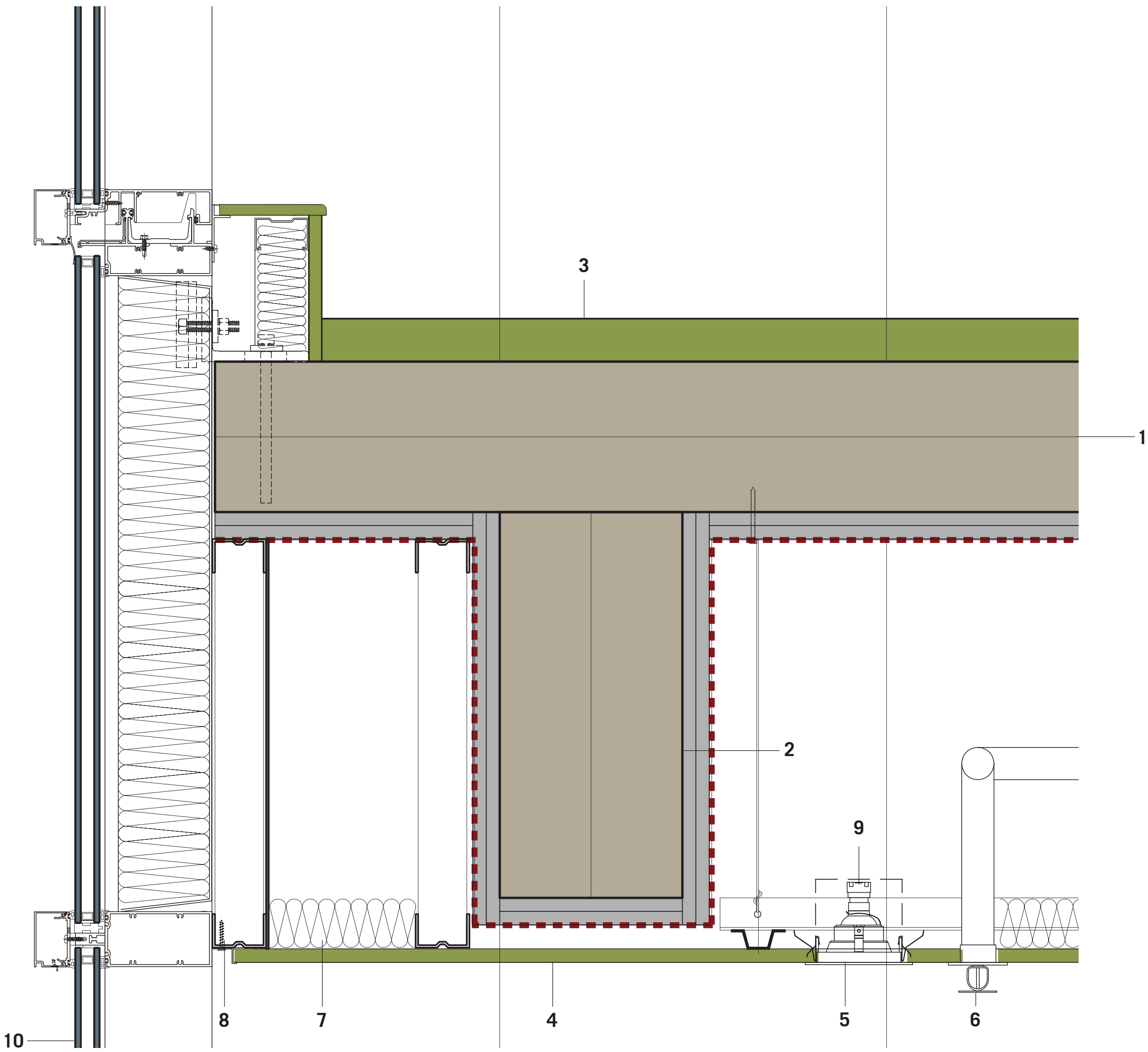
Tall Wood case study floor and wall section at exterior wall

Typical Details



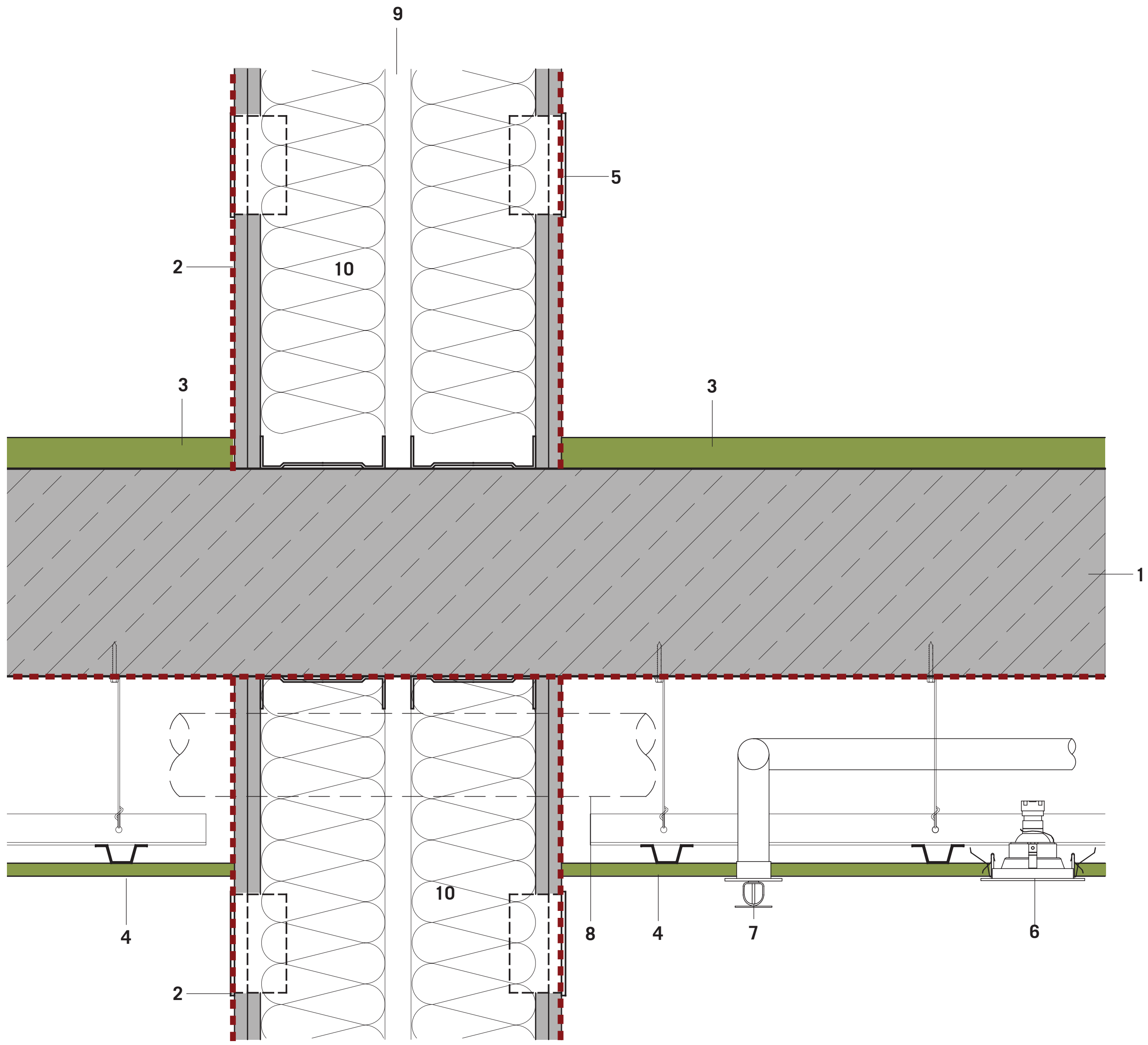
1 Cast in place concrete floor (2HR FRR)
2 Finish floor
3 Finish ceiling: 1 layer 5/8" gypsum board
4 Base
5 Pot light
6 Sprinkler
7 Curtain wall facade system. Refer to typical envelope details.

Typical concrete tower floor and wall section at curtain wall



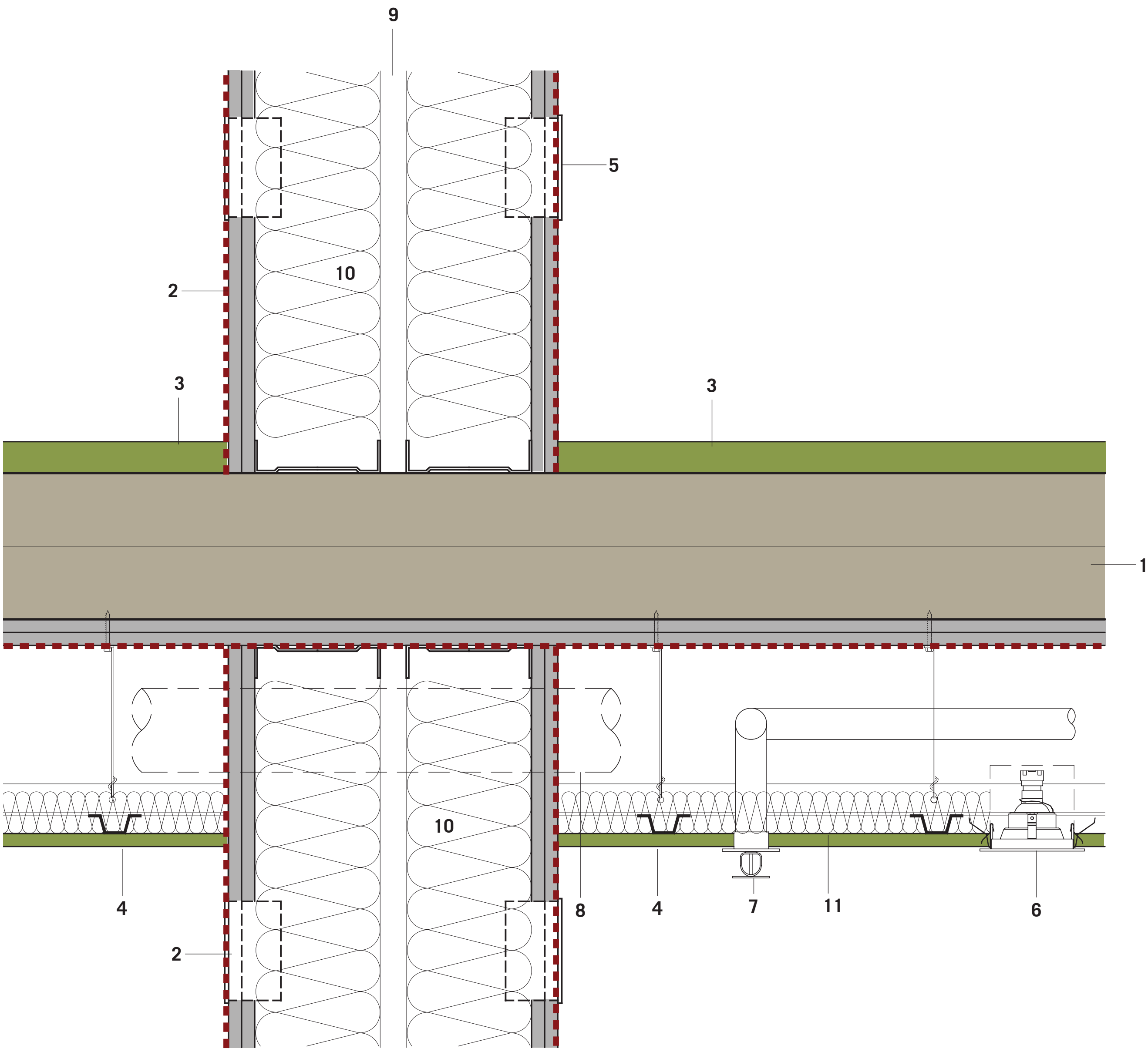
1 Mass Timber structural panels + 2 Layer 5/8” gypsum board underside only (2HR FFR)
2 Glulam beam + 2 Layer 5/8” gypsum board (2HR FFR)
3 Finish floor (refer to floor assembly details)
4 Finish ceiling: 1 layer 5/8” gypsum board
5 Pot light
6 Sprinkler
7 2” loose mineral wool insulation for sound absorption (ceiling)
8 Acoustic seal
9 Back boxes for light fixtures to reduce sound transmission
10 Curtain wall facade system. Refer to typical envelope details.

Tall Wood case study floor and wall section at exterior wall



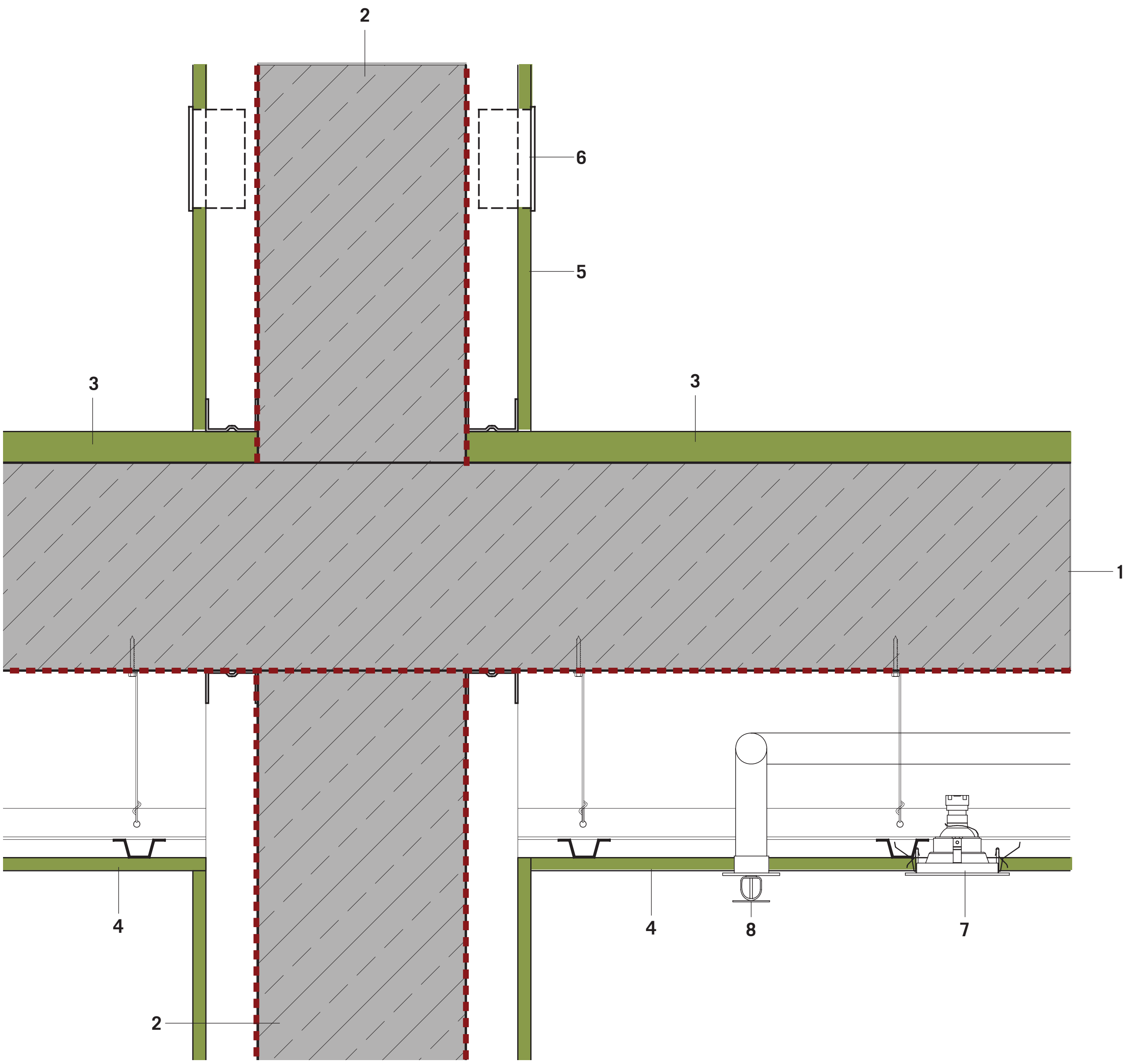
1 Cast in place concrete floor (2HR FRR)
2 Double steel stud wall with 2 layer type x 5/8" gypsum board on both sides
3 Finish floor
4 Finish ceiling: 1 layer 5/8" gypsum board
5 Electrical outlet
6 Pot light
7 Sprinkler
8 Duct with fire stopping
9 Air space between walls to reduce sound transmission
10 Mineral wool insulation for sound absorption

Typical concrete tower typical non-load bearing interior partition between units



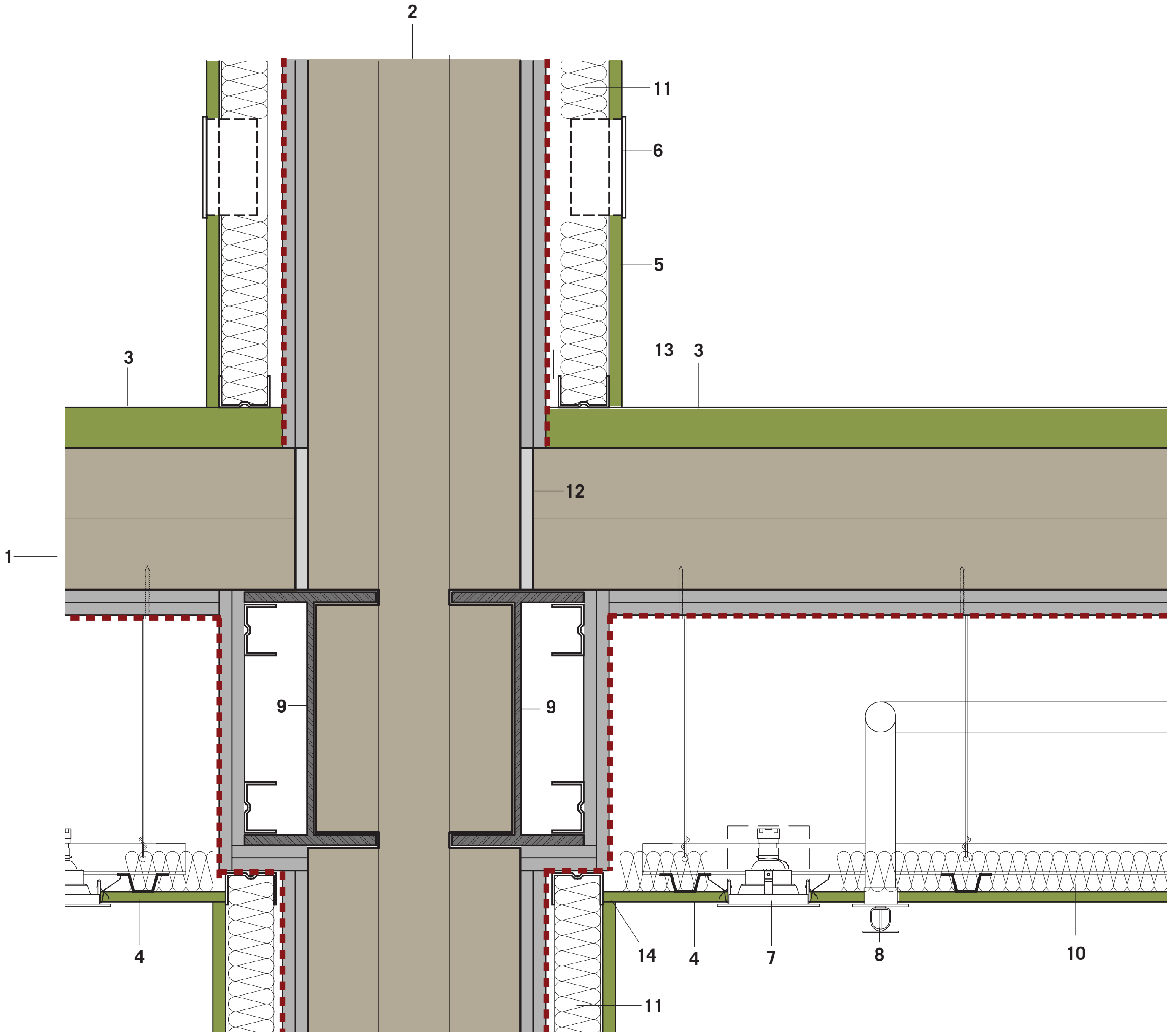
1 Mass Timber structural panels + 2 Layer 5/8" type X gypsum board on underside only (2HR FRR)
2 Double steel stud wall with 2 layer type x 5/8" gypsum board on outer sides only
3 Finish floor (refer to floor assembly details)
4 Finish ceiling: 1 layer 5/8" gypsum board
5 Electrical outlet
6 Pot light
7 Sprinkler
8 Duct with fire stopping
9 Air space between walls to reduce sound transmission
10 Mineral wool insulation for sound absorption
11 2" loose mineral wool insulation for sound absorption

Tall Wood case study typical non-load bearing interior partition between units



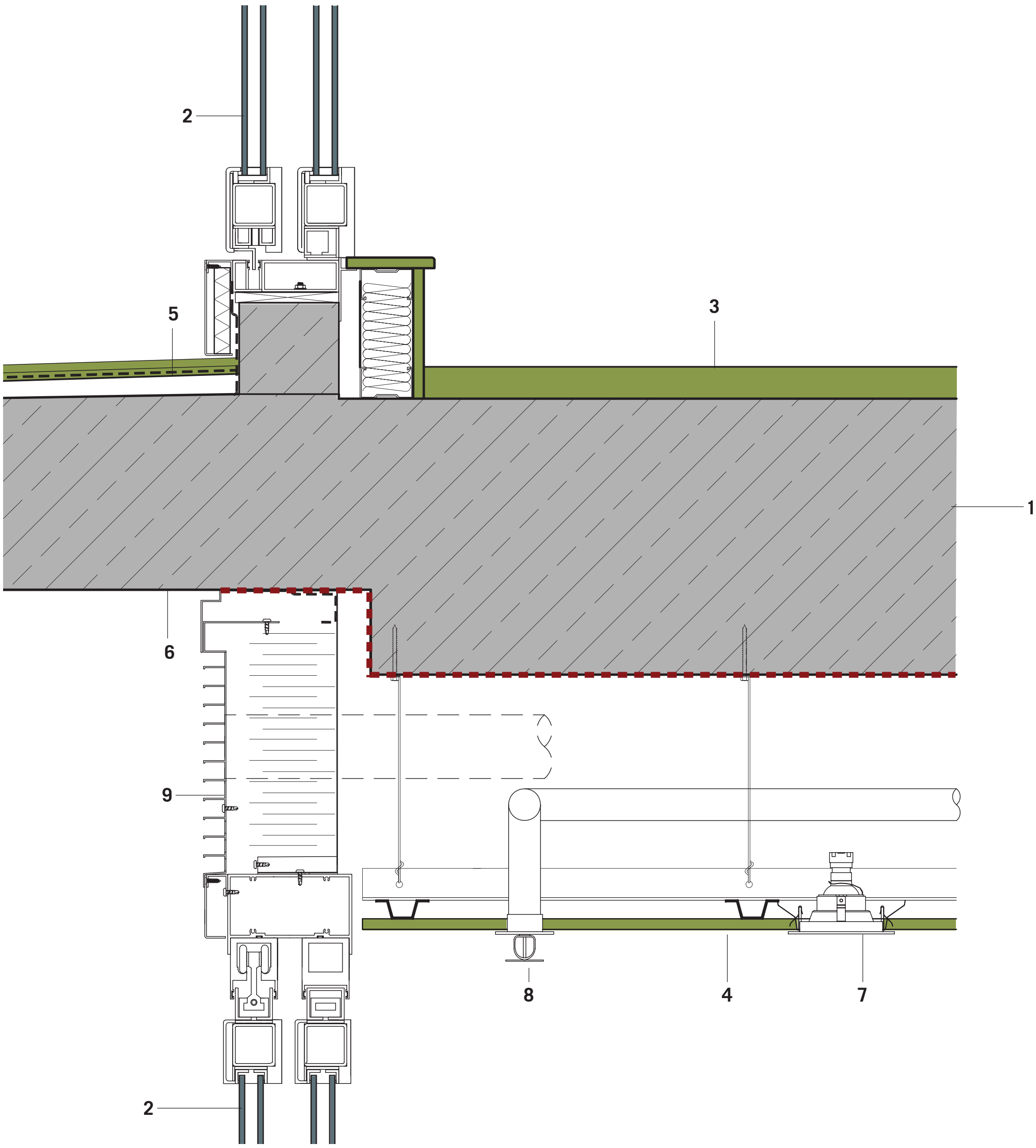
1 Cast in place concrete floor (2HR FRR)
2 Cast in place concrete wall (2HR FRR)
3 Finish floor
4 Finish ceiling: 1 layer 5/8" gypsum board
5 Furring and finish wall: 1 layer 5/8" gypsum board
6 Electrical outlet
7 Pot light
8 Sprinkler

Typical concrete tower typical load bearing interior partition



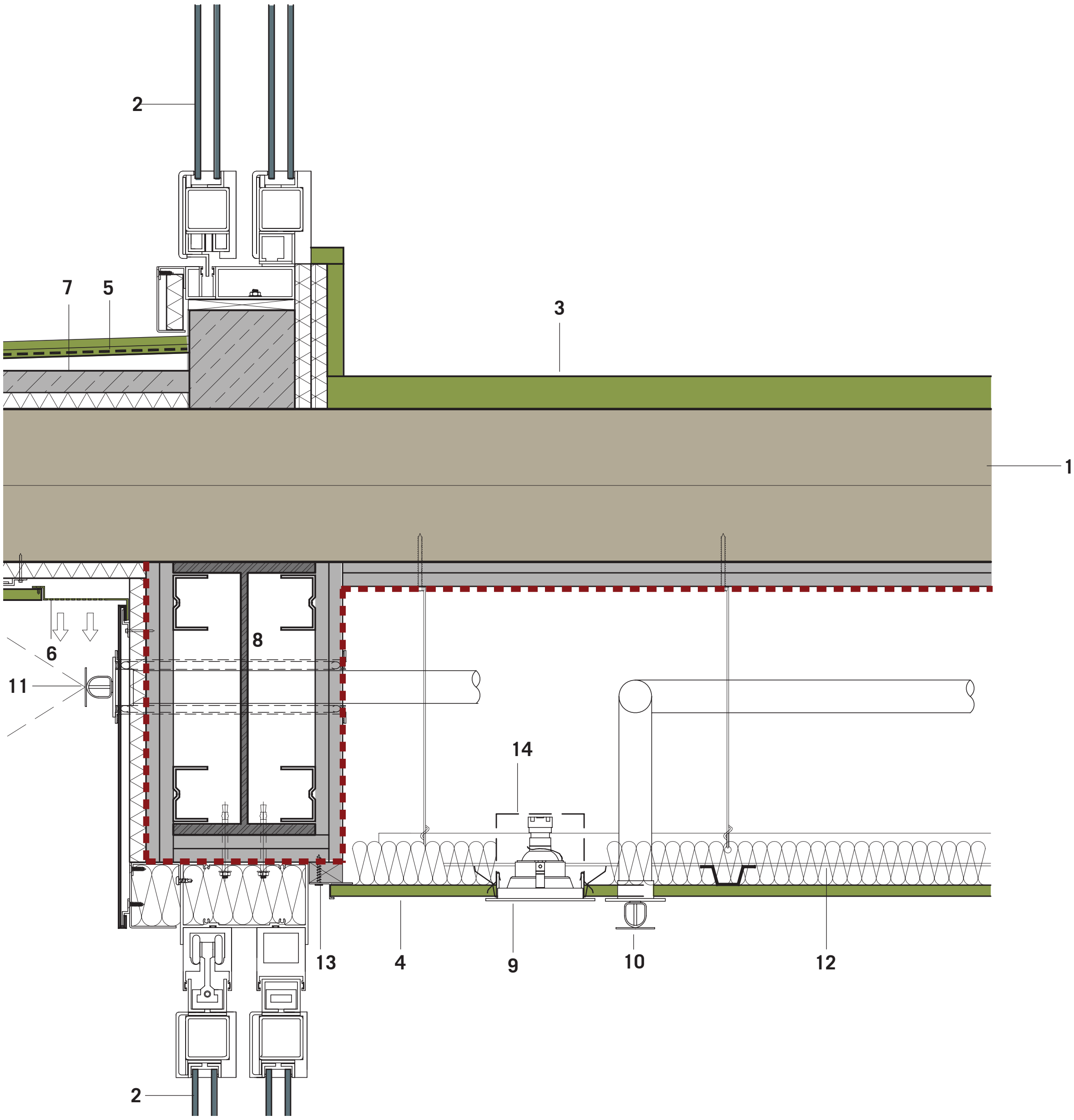
1	Mass Timber structural panels + 2 Layer 5/8" type X gypsum board (2HR FRR)
2	Mass Timber structural panels + 2 Layer 5/8" type X gypsum board (2HR FRR)
3	Finish floor: (refer to floor assembly table)
4	Finish ceiling: 1 layer 5/8" gypsum board
5	Furring and finish wall: 1 layer 5/8" gypsum board
6	Electrical outlet
7	Pot light
8	Sprinkler (plastic pipe)
9	Steel beam
10	2" loose mineral wool insulation for sound absorption (ceiling)
11	2" loose mineral wool insulation for sound absorption (wall)
12	Gasket to reduce sound transmission between floor and wall
13	Gap between drywall and stud to reduce sound transmission
14	Acoustic seal

Tall Wood case study typical load bearing interior partition



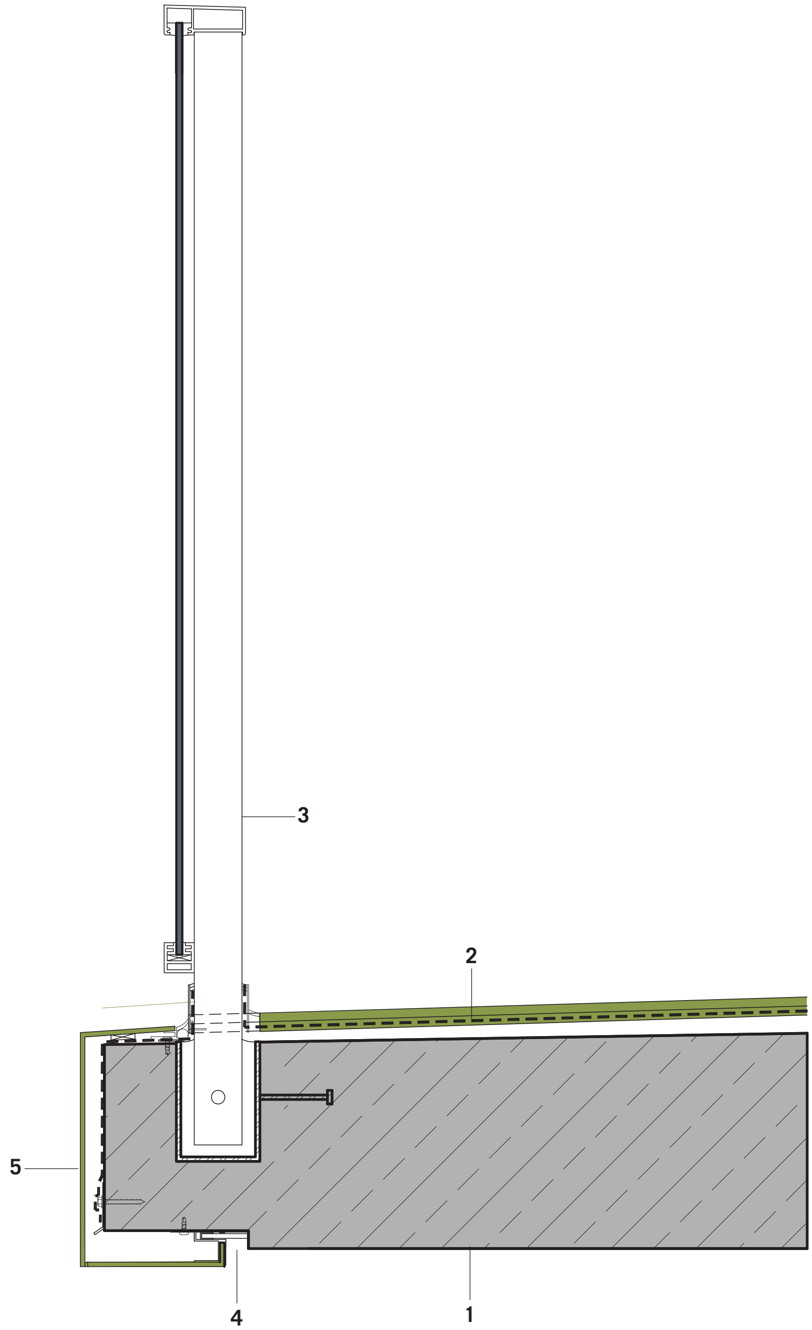
1 Cast in place concrete floor (2HR FRR)
2 Balcony door
3 Finish floor
4 Finish ceiling: 1 layer 5/8” gypsum board
5 Finish floor balcony (sloping with waterproofing)
6 Exposed concrete
7 Pot light
8 Sprinkler
9 Spandrel panel + exhaust

Typical concrete tower sliding door section at balcony



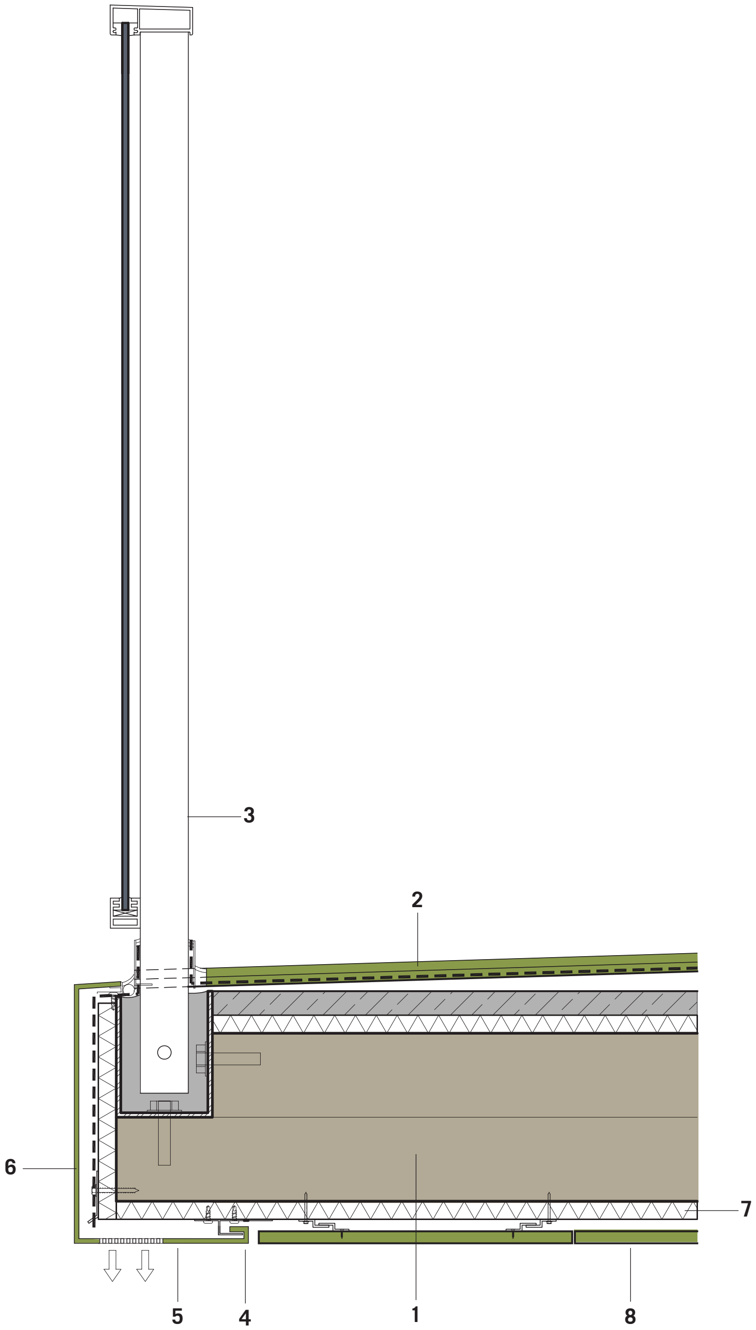
1	Mass Timber structural panels + 2 Layer 5/8” type X gypsum board underside only (2HR FRR)
2	Balcony door
3	Finish floor (refer to floor assembly details)
4	Finish ceiling: 1 layer 5/8” gypsum board
5	Finish floor balcony (sloping waterproofing)
6	Exterior soffit with prefinished perforated vent.
7	Concrete topping and curb (2HR FRR)
8	Steel beam
9	Pot light
10	Sprinkler
11	Dryhead sprinkler with fire stopping (up to 10’ outboard)
12	2” loose mineral wool insulation for sound absorption
13	Acoustic seal
14	Back boxes for light fixtures to reduce sound transmission

Tall Wood case study sliding door section at balcony



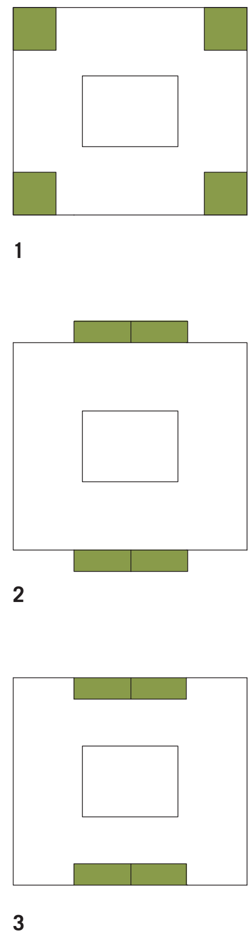
1 Cast in place concrete balcony floor (no FRR required); Painted or exposed surface
2 Finish floor with waterproof membrane
3 Vertical supports with glass guard rail
4 Drip edge
5 Metal fascia

Typical concrete tower typical balcony rail



1 Mass Timber structural panels (no FRR required)
2 Finish floor with waterproof membrane on concrete topping
3 Vertical supports with glass guard rail
4 Drip edge
5 Exterior soffit with prefinished perforated vent.
6 Metal fascia
7 Insulation
8 Non-combustible cladding

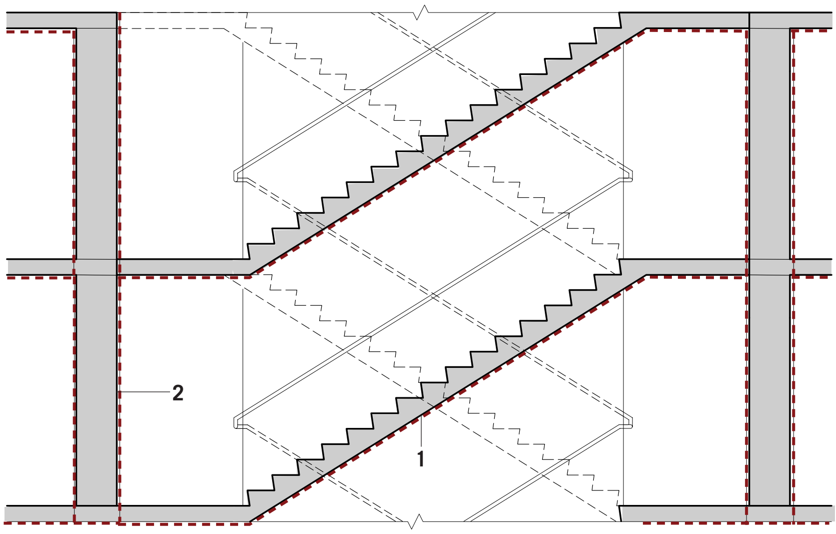
Tall Wood case study typical balcony rail

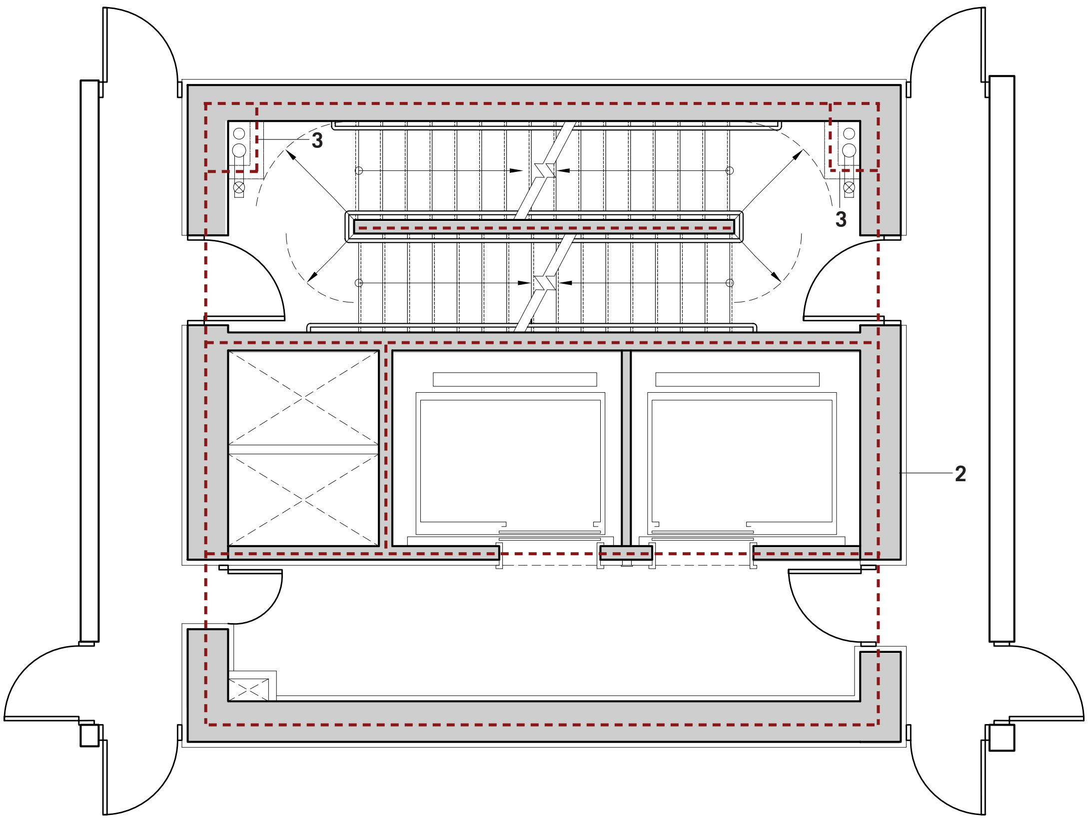


1 Corner balcony configurations
2 Cantilevered balcony
3 Recessed balcony

Possible balcony configurations

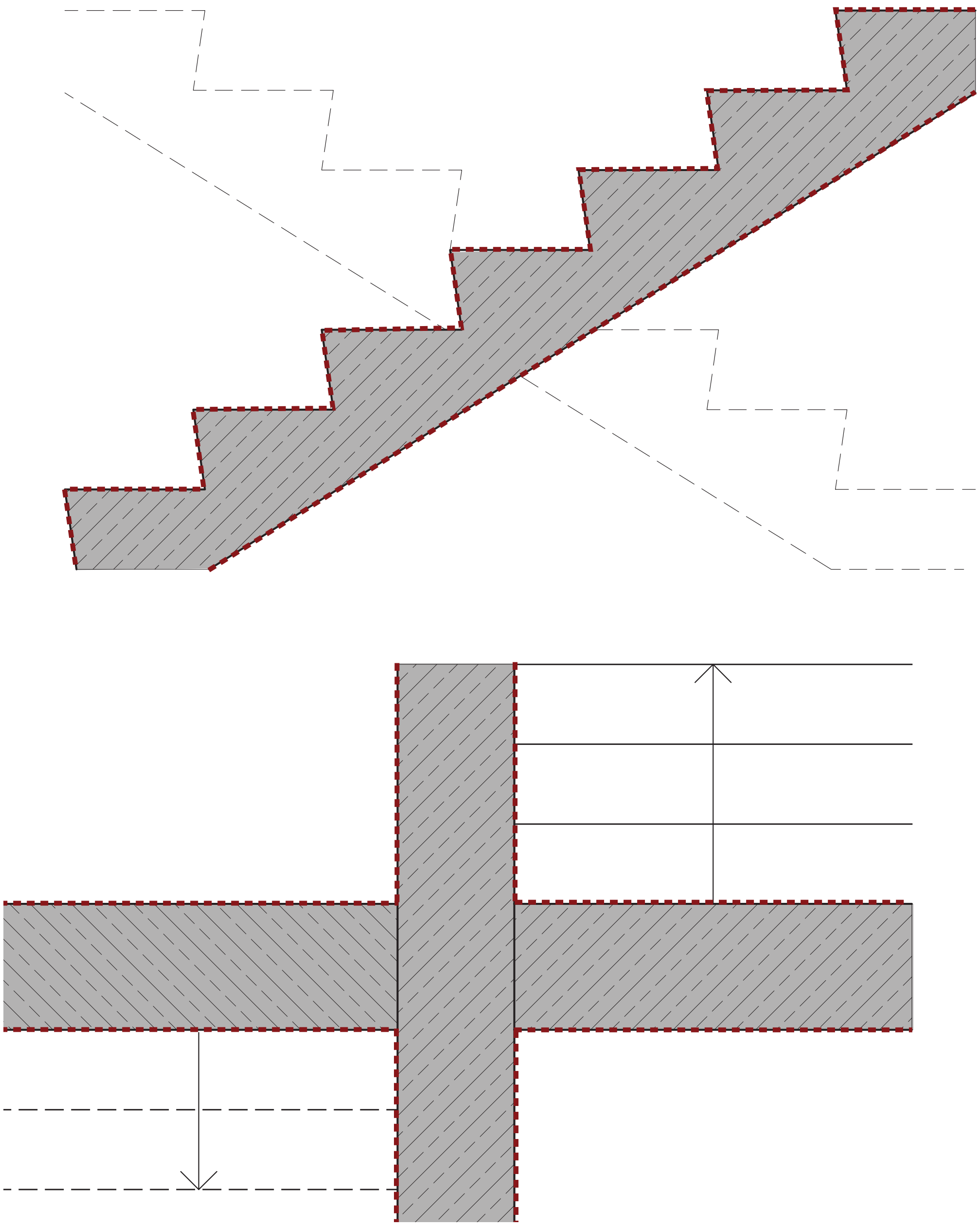
Core Study: Stair





1 Cast in place concrete stair (2HR FRR)
2 Cast in place concrete wall (2HR FRR)
3 Stand pipe enclosed (2HR FRR)

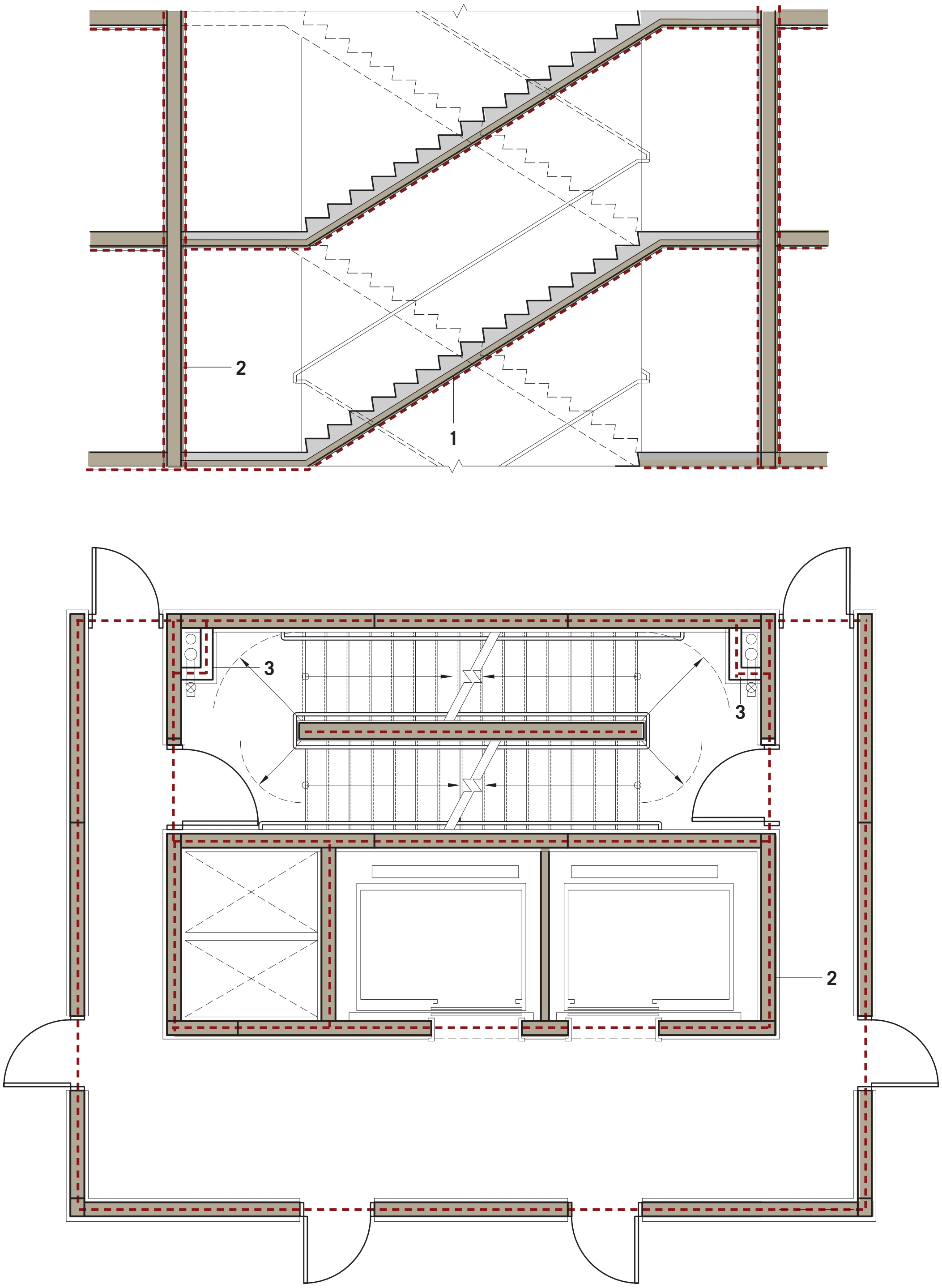
Typical concrete tower typical core with scissor stair



1 Cast in place concrete stair (2HR FRR)
2 Cast in place concrete wall (2HR FRR)

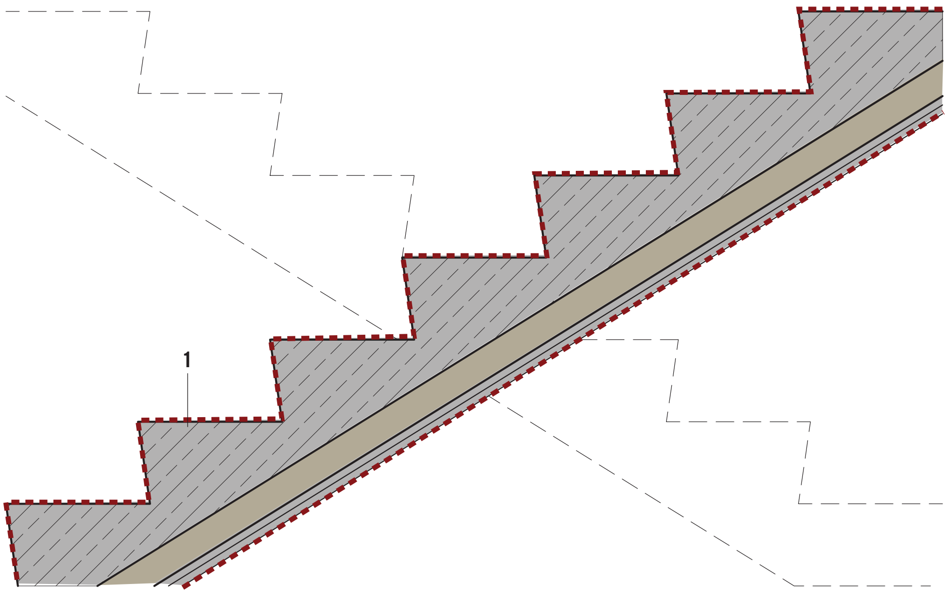
Typical concrete tower typical core scissor stair

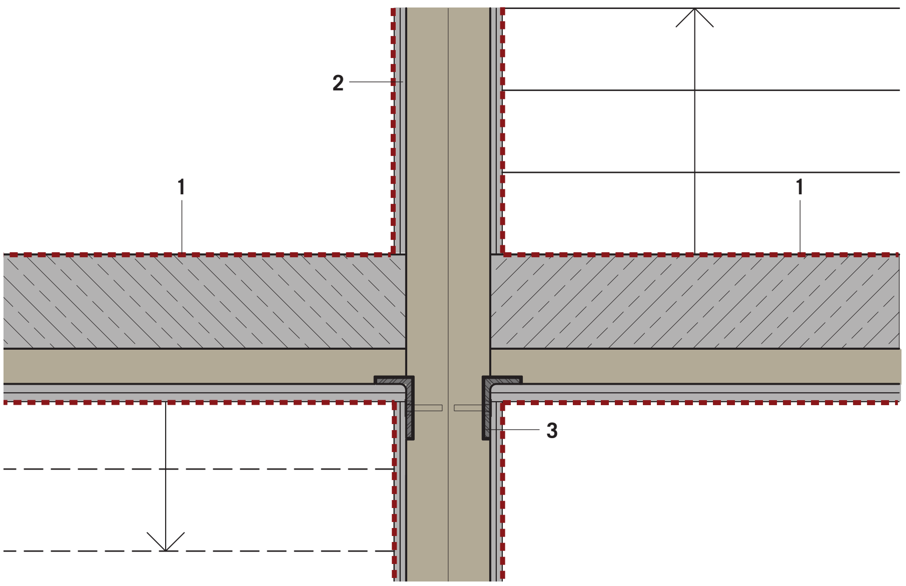
Core Study: Stair



1 Stair: 2 Layer 5/8" type X gypsum board + Mass Timber structural panels + concrete treads (2HR FRR)
2 Wall: 2 Layer 5/8" type X gypsum board + Mass Timber structural panels (2HR FRR)
3 Stand pipe encasement: 2 Layer 5/8" type X gypsum board + steel studs (2HR FRR)

Tall Wood case study tower typical core with scissor stair

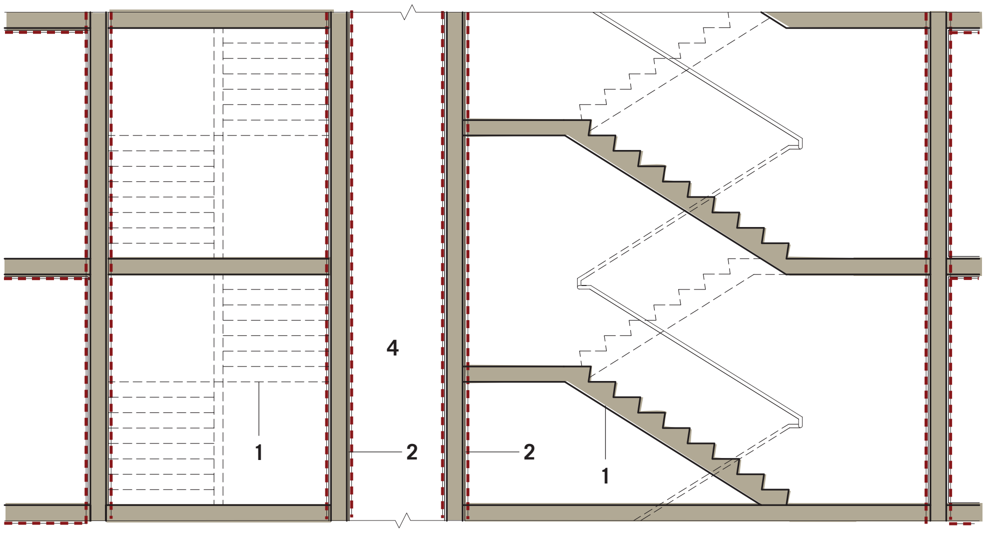


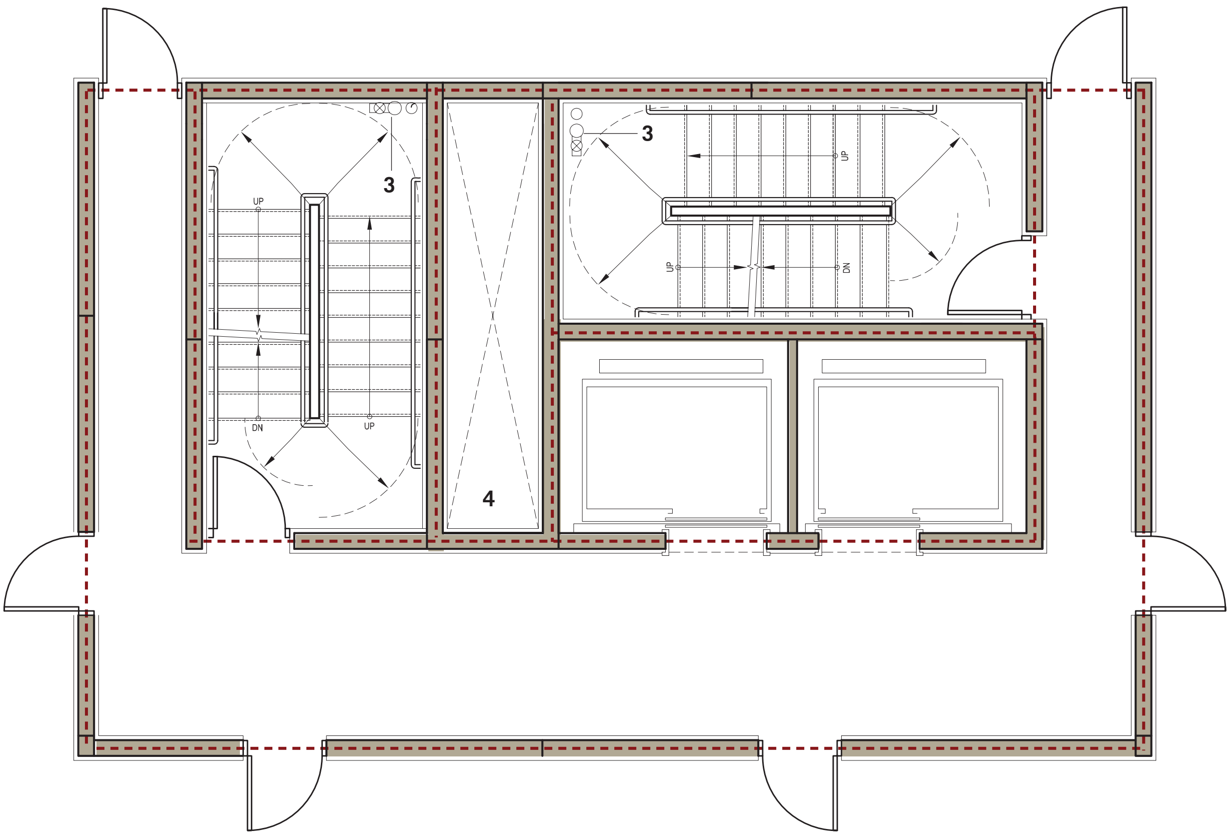


1 Stair: Mass Timber structural panels + 2 Layer 5/8" type X gypsum board + concrete stair form (2HR FRR)
2 Wall: Mass Timber structural panels + 2 Layer 5/8" type X gypsum board + concrete topping (2HR FRR)
3 Recessed steel ledger

Tall Wood case study typical core scissor stair

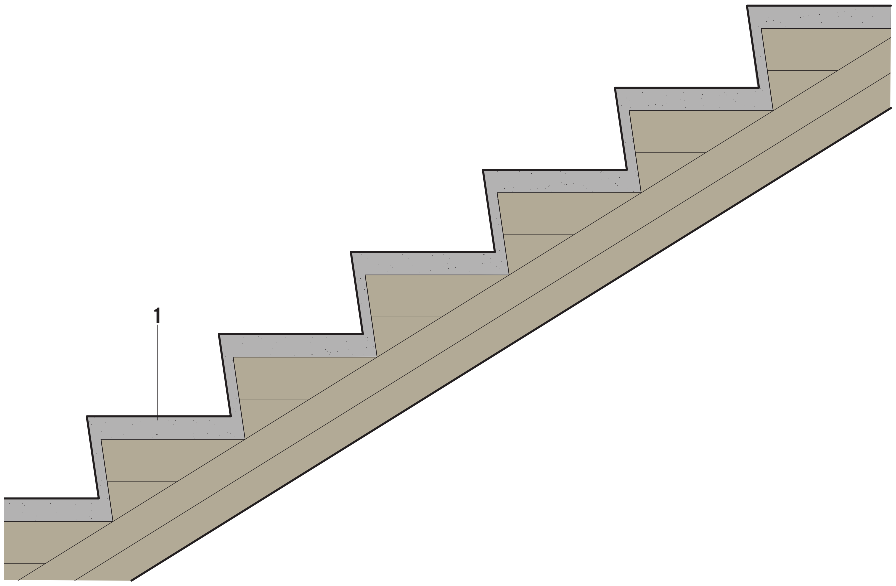
Core Study: Stair

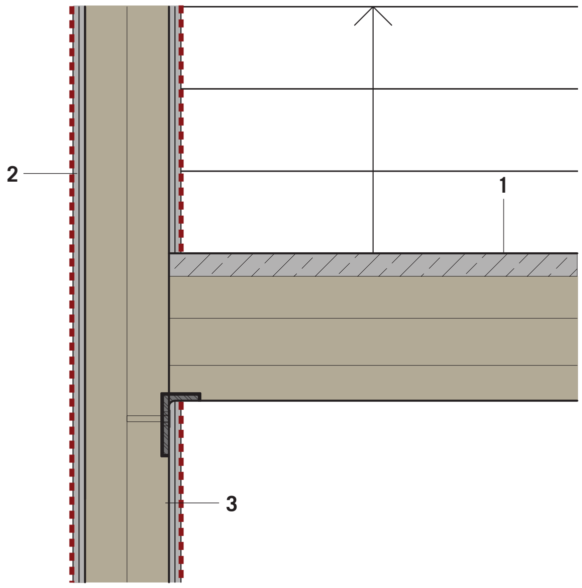




1 Stair: Mass Timber structural panels + concrete topping or equivalent wear surface
2 Wall: 2 Layer 5/8" type X gypsum board + Mass Timber structural panels (2HR FRR)
3 Stand pipe: exposed
4 Elevator shaft and shaft with liner of GWB (2 lyrs) or FRT plywood or cement board

Tall Wood case study tower typical core with two separate exit stairs



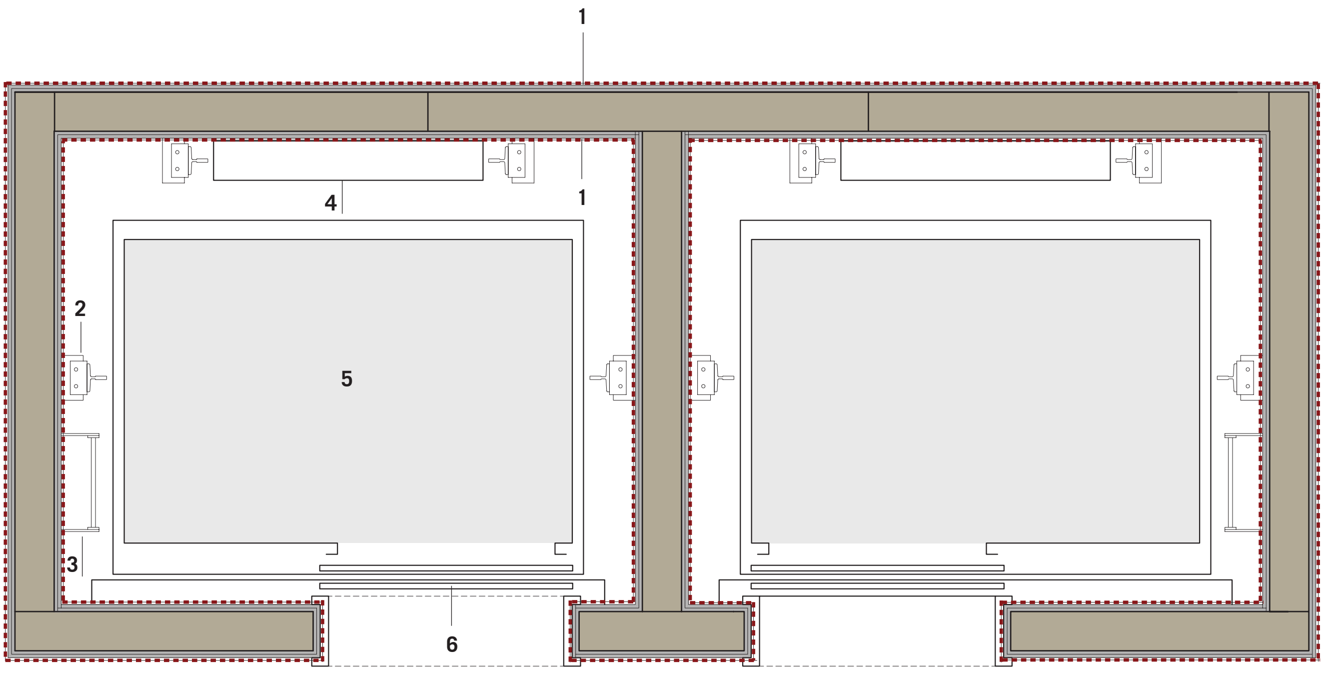


1 Stair: Multi-layer LVL or LSL + concrete topping (No FRR required)
2 Wall: Mass Timber structural panels + 2 Layer 5/8" type X gypsum board both sides (2HR FRR)
3 Recessed steel ledger

Note: Future work and testing required.

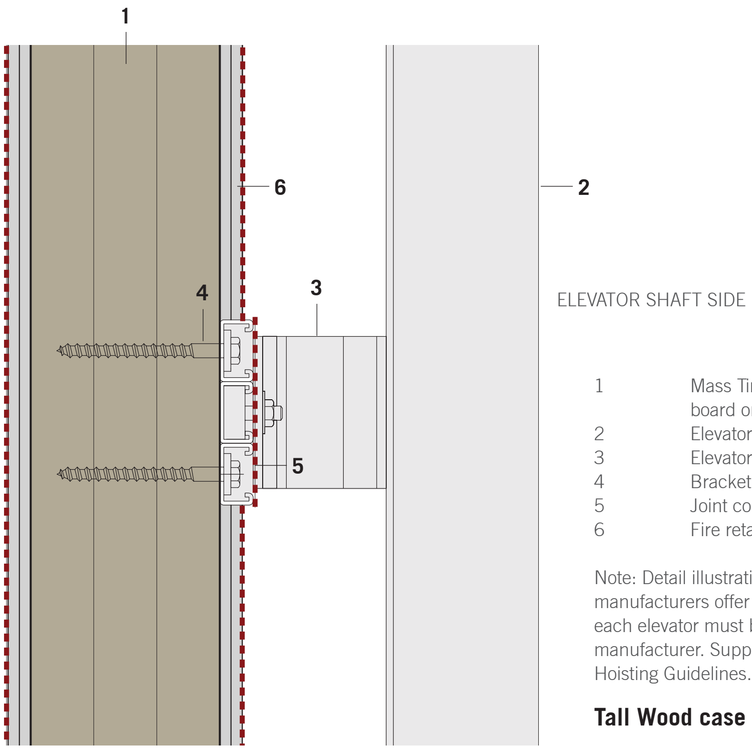
Tall Wood case study typical core single stair

Core Study: Elevator



1 Mass Timber structural panels + 2 Layer 5/8" type X gypsum board on each side of shaft wall (2HR FFR)
2 Elevator rail and bracket
3 Pit ladder
4 Elevator lift
5 Elevator cab
6 Elevator door

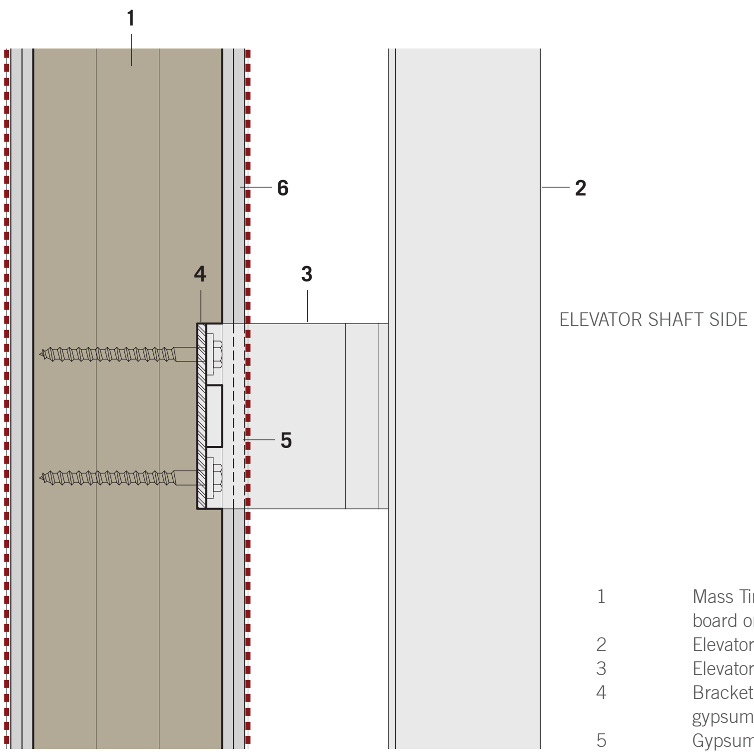
Tall Wood case study elevator plan



1 Mass Timber structural panels + 2 Layer 5/8" type X gypsum board on each side of shaft wall (2HR FRR)
2 Elevator rail
3 Elevator rail support bracket
4 Bracket connection to structural wall
5 Joint compound. Fire-rated.
6 Fire retardant treated plywood or cement board or GWB

Note: Detail illustrating fire protection of shaft wall. Various elevator manufacturers offer proprietary rail support brackets. As with typical practice, each elevator must be designed and engineered with the specified elevator manufacturer. Support bracket in illustration from Schindler Elevator Hydraulic Hoisting Guidelines.

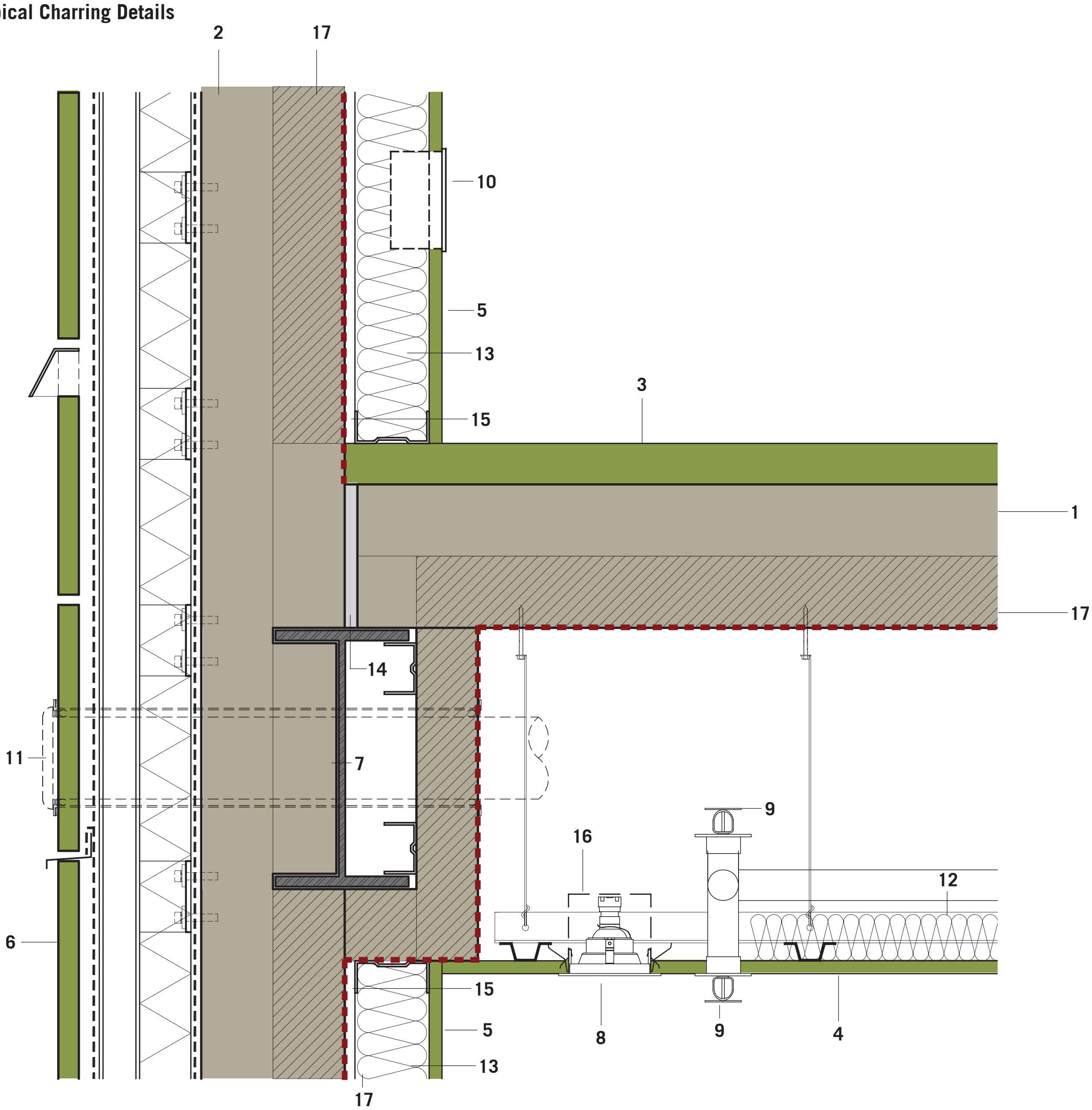
Tall Wood case study elevator rail at shaft wall detail



1 Mass Timber structural panels + 2 Layer 5/8" type X gypsum board on each side of shaft wall (2HR FFR)
2 Elevator rail
3 Elevator rail support bracket
4 Bracket connection to structural wall. Recessed plate to allow gypsum to run continuously over
5 Gypsum board to run over bracket connection. Firestop gaps.
6 Fire retardant treated plywood or cement board or GWB

Tall Wood case study elevator rail at shaft wall alternate detail

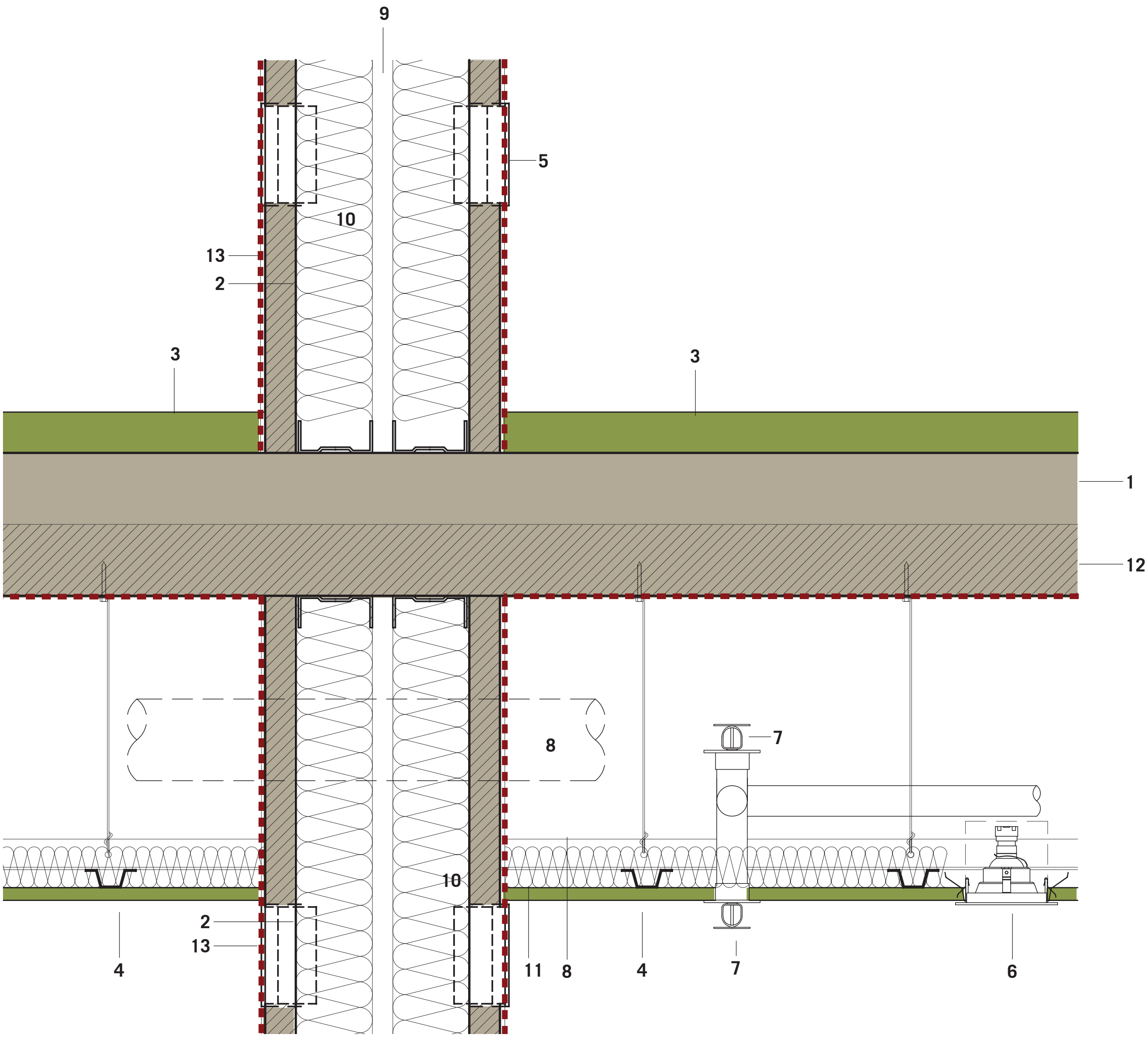
Typical Charring Details



1 ** Mass Timber structural panels + sacrificial layer
2 **Mass Timber structural panels + sacrificial layer
3 Finish floor (refer to floor assembly table)
4 Finish ceiling: 1 layer 5/8" gypsum board
5 Finish wall: 1 layer 5/8" gypsum board
6 Facade (non-combustible)
7 Steel beam
8 Pot light
9 Sprinkler up and down (combustible concealed space)
10 Electrical outlet
11 Exhaust penetration with fire stopping
12 2" loose mineral wool insulation for sound absorption (ceiling)
13 2" loose mineral wool insulation for sound absorption (wall)
14 Gasket to reduce sound transmission between floor and wall
15 Gap between wood and stud to reduce sound transmission
16 Back boxes for light fixtures to reduce sound transmission
17 **Ceiling and floor: sacrificial fire protection layer (LVL, LSL, CLT).

** Charring rates vary depending on timber type, moisture, density and species. The charring rate of 0.65mm/min is the generally accepted average. Refer to Section 3.7 Fire Performance for additional information on charring rate.

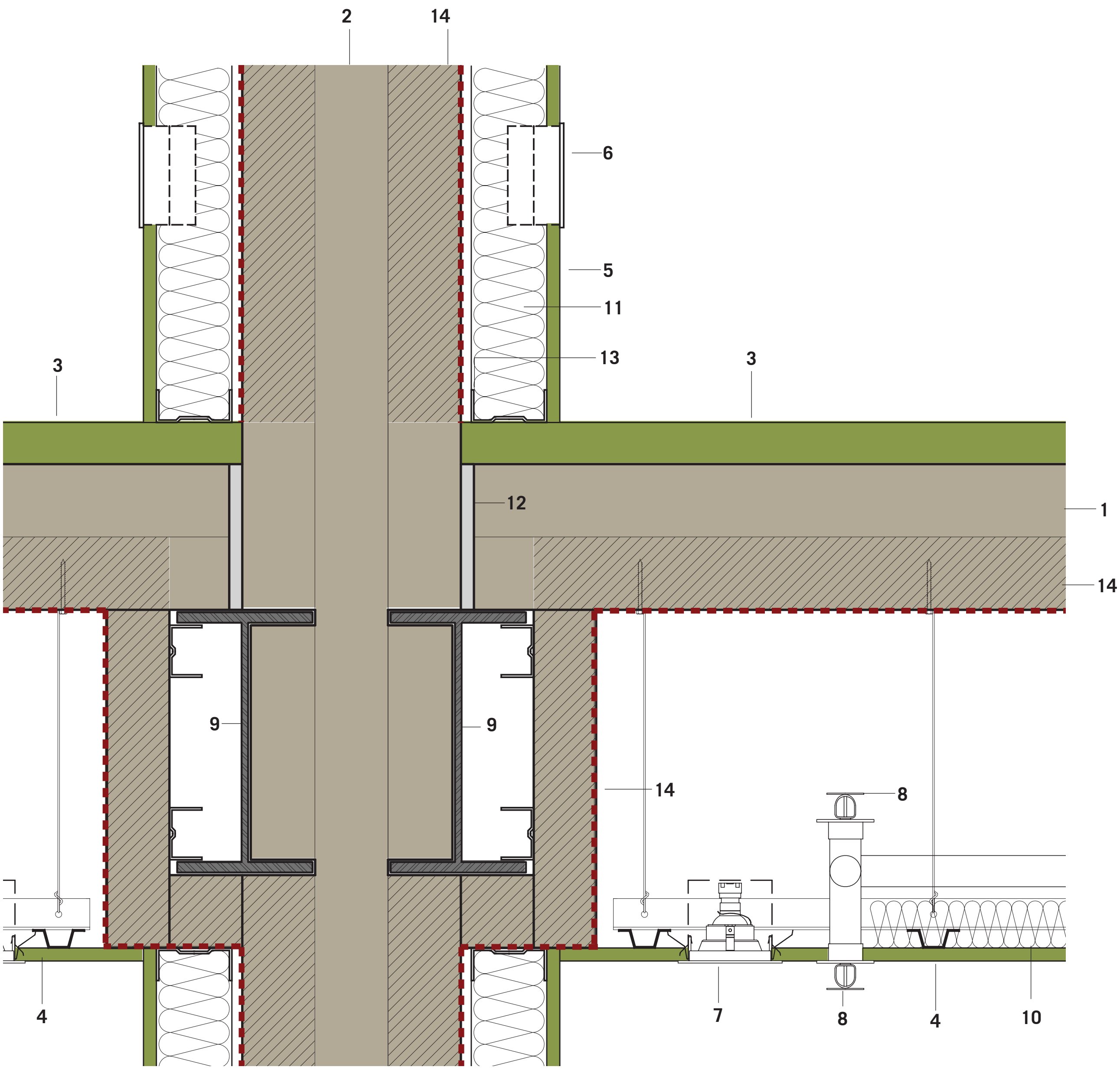
Tall Wood case study floor and wall section at exterior wall illustrating charring concept



1	**Mass Timber structural panels + sacrificial layer
2	**Double steel stud wall + sacrificial layer
3	Finish floor (refer to floor assembly details)
4	Finish ceiling: 1 layer 5/8" gypsum board
5	Electrical outlet
6	Pot light
7	Sprinkler up and down (combustible concealed space)
8	Duct - fire stopped
9	Air space between walls to reduce sound transmission
10	Mineral wool insulation for sound absorption
11	2" loose mineral wool insulation for sound absorption
12	**Ceiling: sacrificial fire protection layer (LVL, LSL, CLT). LVL - 0.65 mm/min. 2HR FRR = 78mm [3"]
13	**/***Wall: sacrificial fire protection layer (LVL, LSL, CLT). 0.65 mm/min. 1HR FRR = 39mm [1 1/2"]
**	Charring rates vary depending on timber type, moisture, density and species. The charring rate of 0.65mm/min is the generally accepted average. Refer to Section 3.7 Fire Performance for additional information on charring rate.
***	Interior finish: exposed wood paneling subject to flame-spread rating and smoke developed classification code requirements. Refer to Section 3.7 Fire Performance for additional information on flamespread, smoke classification and interior finishes.
****	CLT is recommended as finishing if using a sacrificial layer.

Tall Wood case study typical non-load bearing interior partition between units illustrating charring concept

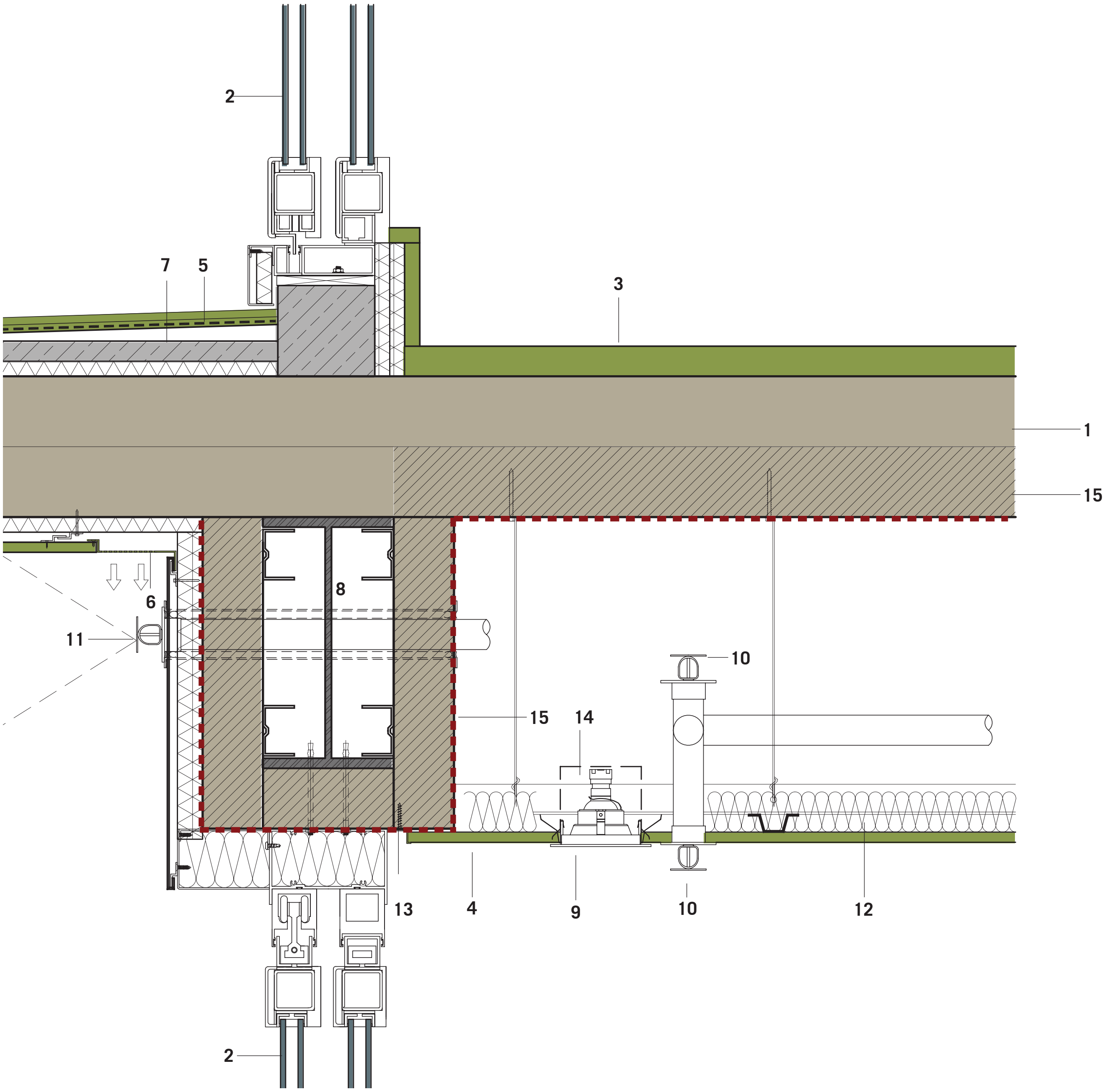
Typical Charring Details



1 **Mass Timber structural panels + sacrificial layer
2 **Mass Timber structural panels + sacrificial layer
3 Finish floor: (refer to floor assembly details)
4 Finish ceiling: 1 layer 5/8" gypsum board
5 Furring and finish wall: 1 layer 5/8" gypsum board
6 Electrical outlet
7 Pot light
8 Sprinkler up and down (combustible concealed space)
9 Steel beam
10 2" loose mineral wool insulation for sound absorption (ceiling)
11 2" loose mineral wool insulation for sound absorption (wall)
12 Gasket to reduce sound transmission between floor and wall
13 Gap between wood and stud to reduce sound transmission
14 **Ceiling and floor: sacrificial fire protection layer (LVL, LSL, CLT).

** Charring rates vary depending on moisture, density, species etc. The charring rate of 0.65mm/min is the generally accepted average. Refer to Section 3.7 Fire Performance for additional information on charring rate.

Tall Wood case study typical load bearing interior partition illustrating charring concept

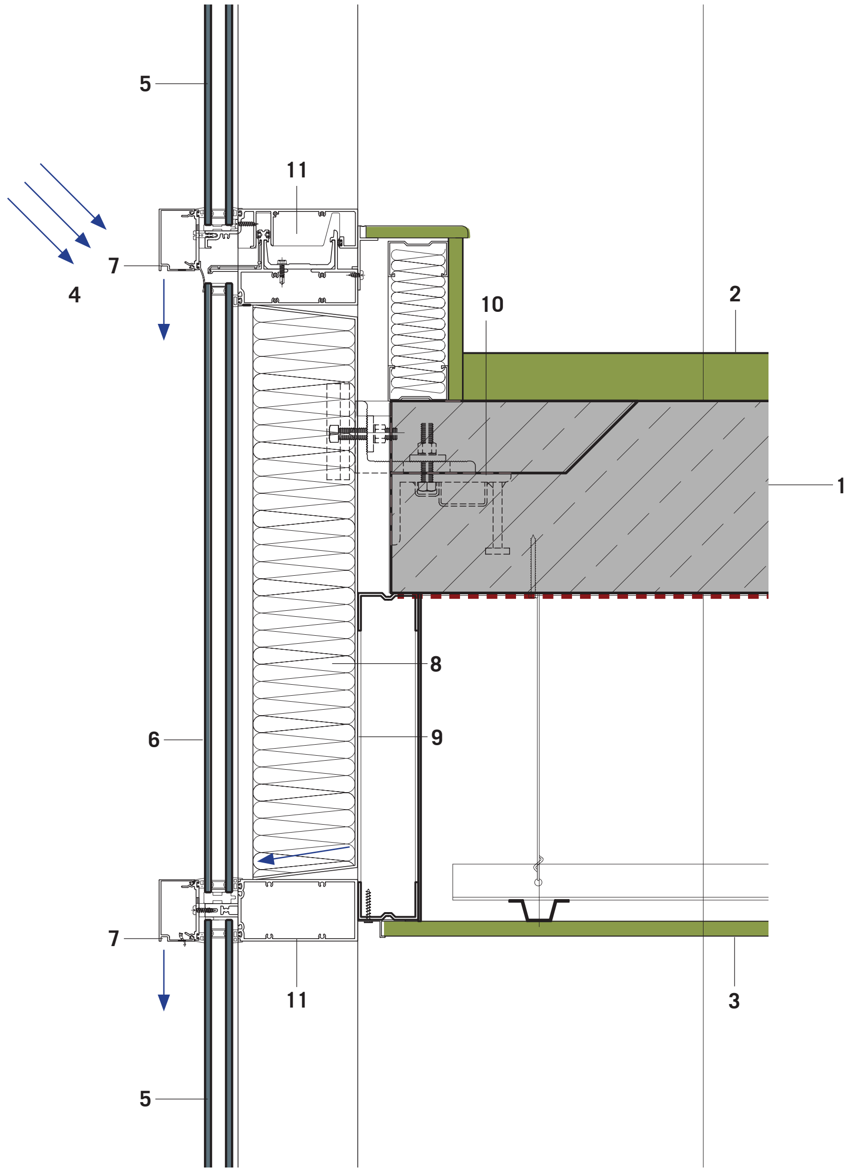


1 **Mass Timber structural panels + sacrificial layer
2 Balcony door
3 Finish floor (refer to floor assembly details)
4 Finish ceiling: 1 layer 5/8" gypsum board
5 Finish floor balcony (sloping waterproofing)
6 Exterior soffit with prefinished perforated vent.
7 Concrete topping and curb
8 Steel beam
9 Pot light
10 Sprinkler up and down (combustible concealed space)
11 Dryhead sprinkler with fire stopping (up to 10' outboard)
12 2" loose mineral wool insulation for sound absorption
13 Acoustic seal
14 Back boxes for light fixtures to reduce sound transmission
15 **Ceiling and floor: sacrificial fire protection layer (LVL, LSL, CLT).

** Charring rates vary depending on moisture, density, species etc. The charring rate of 0.65mm/min is the generally accepted average. Refer to Section 3.7 Fire Performance for additional information on charring rate.

Tall Wood case study sliding door section at balcony illustrating charring concept

Typical Envelope Details

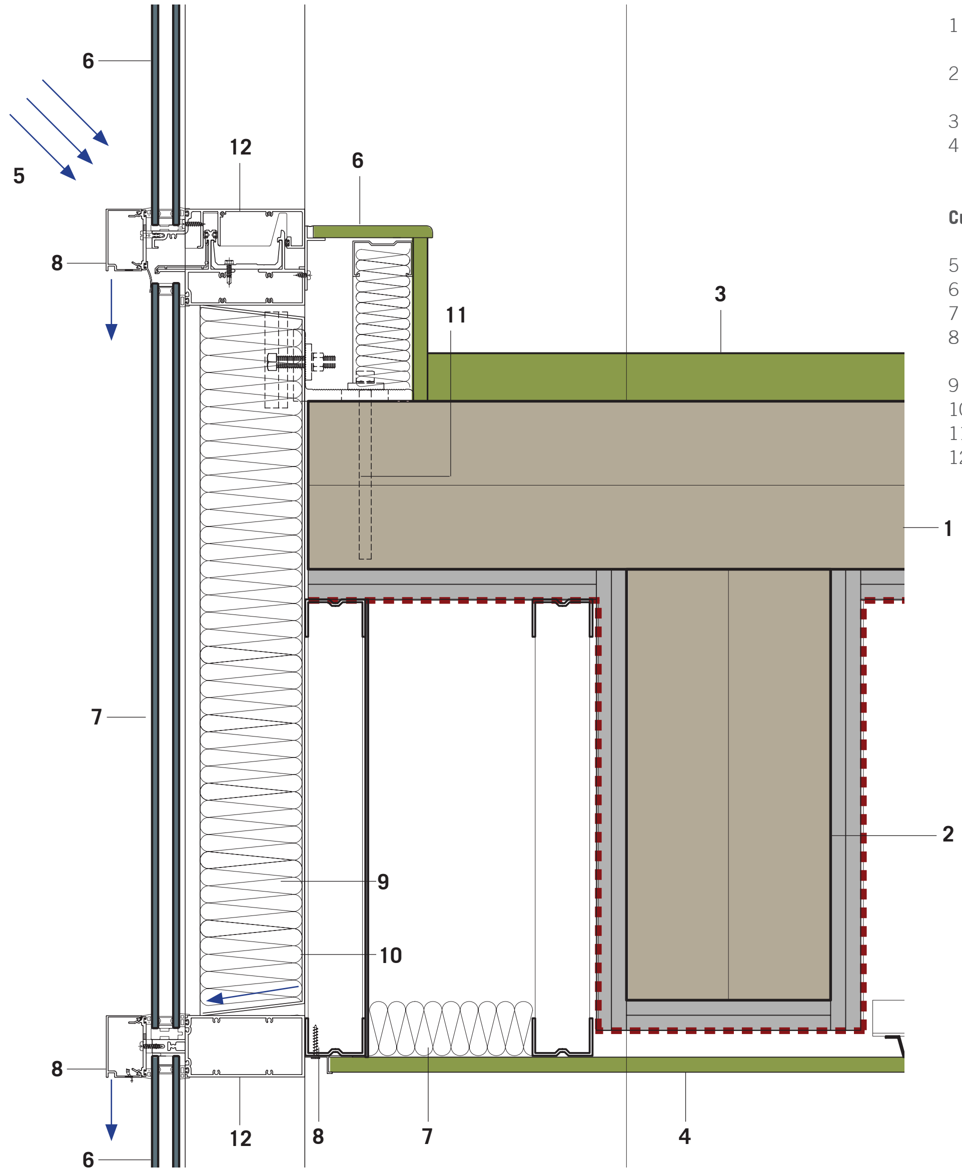


1 Cast in place concrete floor (2HR FRR)
2 Finish floor
3 Finish ceiling: 1 layer 5/8" gypsum board

Curtain Wall

4 Wind driven rain
5 Vision glass (double or triple glazed)
6 Spandrel panel (double glazed)
7 Drainage and pressure equalization opening + drip edge
8 Non-combustible insulation
9 Backpan (air / vapour barrier) + drainage
10 Floor anchor
11 Mullion

Typical concrete tower floor and wall section at curtain wall



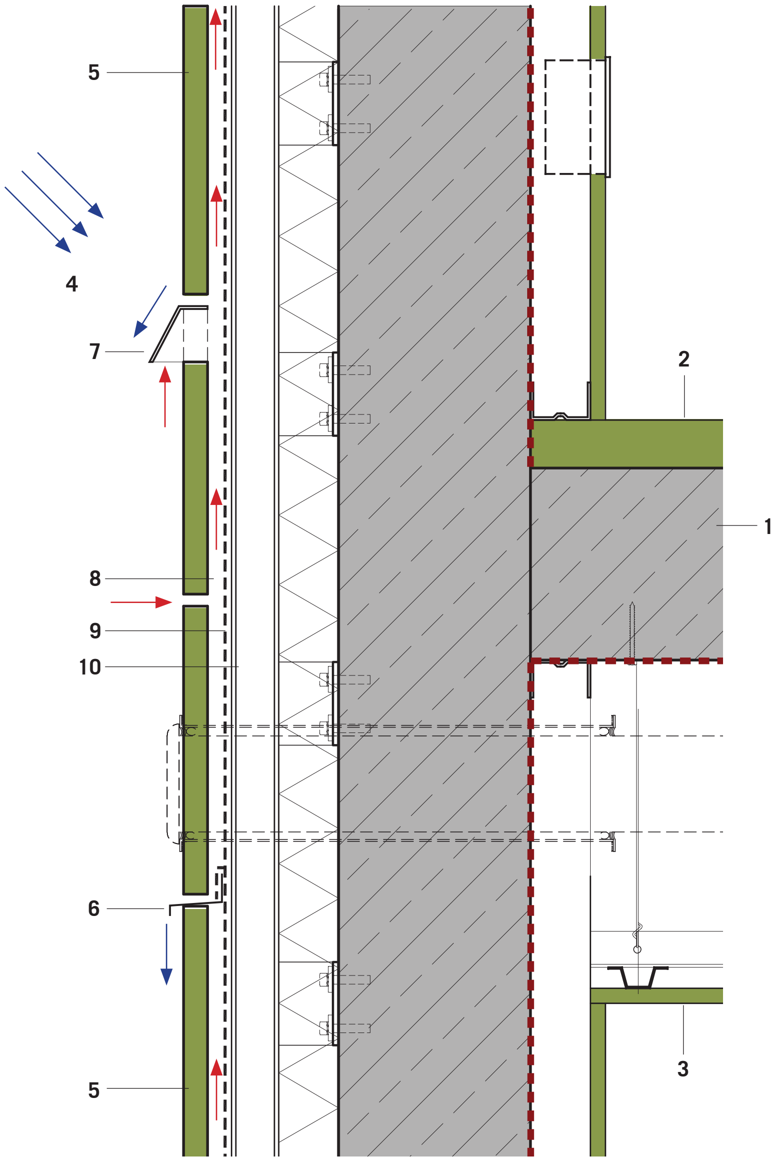
1 Mass Timber structural panels + 2 Layer 5/8" gypsum board underside only (2HR FFR)
2 Glulam beam + 2 Layer 5/8" type X gypsum board (2HR FFR)
3 Finish floor (refer to floor assembly details)
4 Finish ceiling: 1 layer 5/8" gypsum board

Curtain Wall

5 Wind driven rain
6 Vision glass (double or triple glazed)
7 Spandrel panel (double glazed)
8 Drainage and pressure equalization opening + drip edge
9 Non-combustible insulation
10 Backpan (air / vapour barrier)
11 Floor anchor
12 Mullion

Tall Wood case study floor and wall section at exterior wall

Typical Envelope Details



1 Cast in place concrete floor (2HR FRR)
2 Finish floor
3 Finish ceiling: 1 layer 5/8" gypsum board

****Pressure Equalized Rainscreen Wall**

4 Wind driven rain
5 Non-combustible cladding mechanically anchored as required with open joints.
6 Flashing with drip edge. Pressure equalization opening.
7 Protected vent. Pressure equalization opening.
8 Drainage cavity for back venting
9 Drainage plane
10 Non-combustible insulation

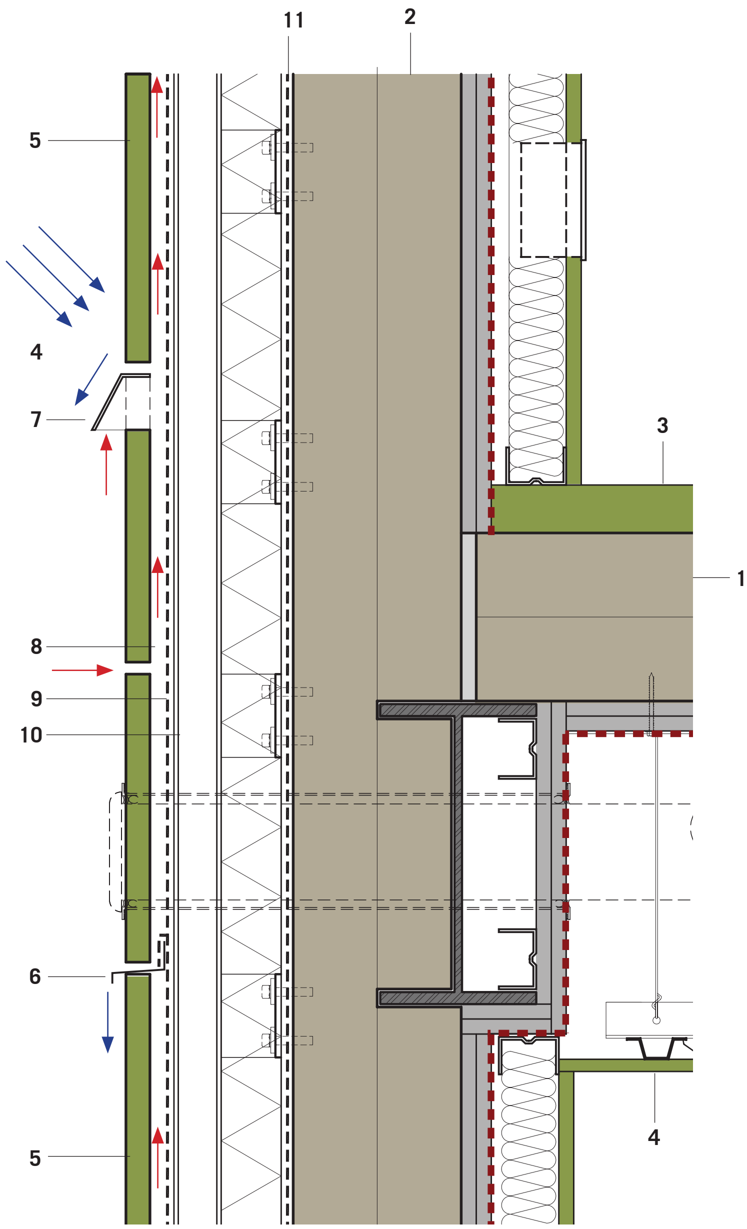
**Notes:

1. Pressure equalization results in reduced incidental water ingress through cladding, collected at drainage plane and returned to exterior

2. Back venting of cladding allows drying by means of air movement and vapour diffusion

3. Open joints and vents at top and bottom combined with compartmentalization reduce pressure difference across cladding

Typical concrete tower floor and wall section at exterior wall



1 Mass Timber structural panels + 2 Layer 5/8” type X gypsum board underside only (2HR FFR)
2 Mass Timber structural panels + 2 Layer 5/8” type X gypsum board inside only (2HR FFR)
3 Finish floor (refer to floor assembly details)
4 Finish ceiling: 1 layer 5/8” gypsum board

Pressure Equalized Rainscreen Wall

4 Wind driven rain
5 Non-combustible cladding mechanically anchored as required with open joints.
6 Flashing with drip edge. Pressure equalization opening.
7 Protected vent. Pressure equalization opening.
8 Drainage cavity for back venting
9 Drainage plane
10 Non-combustible insulation
11 Waterproofing layer

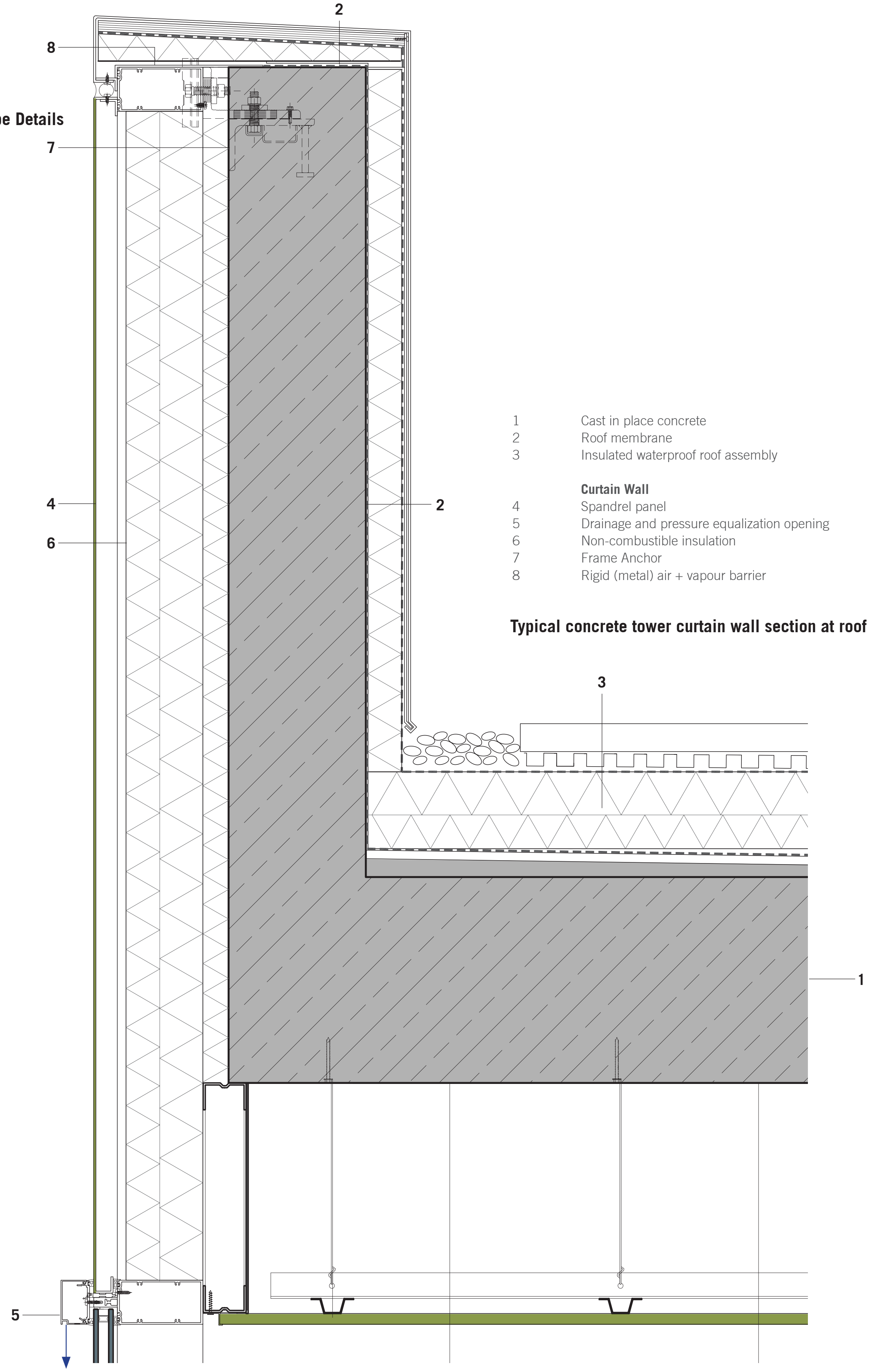
**Notes:

1. Pressure equalization results in reduced incidental water ingress through cladding, collected at drainage plane and returned to exterior

2. Back venting of cladding allows drying by means of air movement and vapour diffusion

3. Open joints and vents at top and bottom combined with compartmentalization reduce pressure difference across cladding

Tall Wood case study floor and wall section at exterior wall

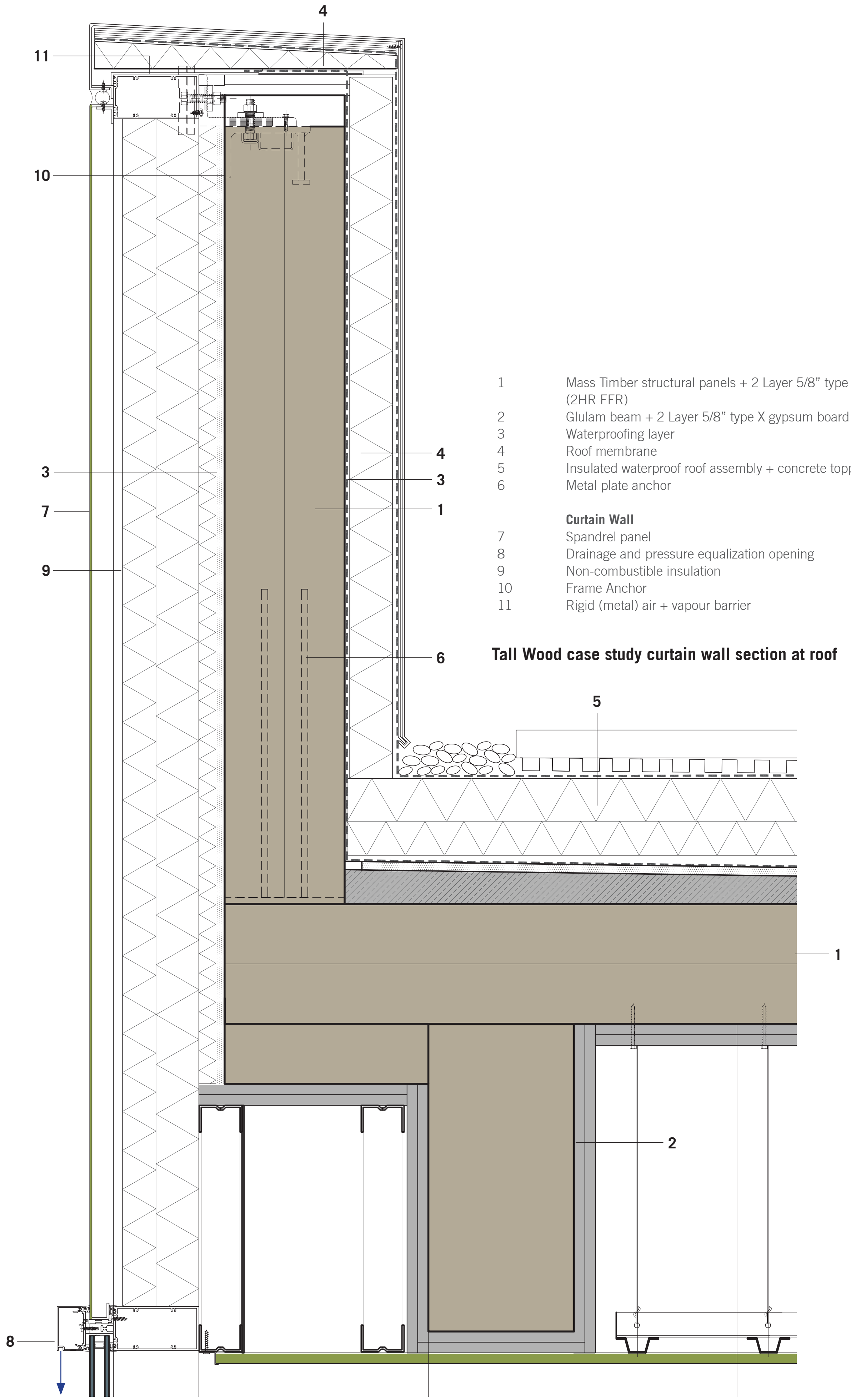


1 Cast in place concrete
2 Roof membrane
3 Insulated waterproof roof assembly

Curtain Wall

4 Spandrel panel
5 Drainage and pressure equalization opening
6 Non-combustible insulation
7 Frame Anchor
8 Rigid (metal) air + vapour barrier

Typical concrete tower curtain wall section at roof



1	Mass Timber structural panels + 2 Layer 5/8” type X gypsum board (2HR FFR)
2	Glulam beam + 2 Layer 5/8” type X gypsum board (2HR FFR)
3	Waterproofing layer
4	Roof membrane
5	Insulated waterproof roof assembly + concrete topping
6	Metal plate anchor
	Curtain Wall
7	Spandrel panel
8	Drainage and pressure equalization opening
9	Non-combustible insulation
10	Frame Anchor
11	Rigid (metal) air + vapour barrier

Tall Wood case study curtain wall section at roof

3.13 Cost Analysis

Project Cost Summary

To develop a comprehensive overview of the cost implications for each design we reviewed all project costs applicable to each option (see Appendix B).

Cost Findings

The cost analysis calculated the project costs for both 12-storey and 20-storey Timber Frame options utilizing both the charring and the encapsulation approach to fire protection. The results were then applied against various locations within BC to further understand applications to different regions and compared them to a benchmark concrete frame building of similar size.

The estimated costs were developed based on preliminary design drawings that are demonstrated in this document. The estimates offer a reasonable current day cost envelope that could form the basis for developing a project design. More precise estimates based on more detailed design information would most likely vary from this baseline.

The table below sets out the comparative costs of the various options we investigated.

Table 3.13.1

Region		12 Storey Concrete Frame	12 Storey FFTT Charring Method	12 Storey FFTT Encapsulation Method	20 Storey Concrete Frame	20 Storey FFTT Charring Method	20 Storey FFTT Encapsulation Method
Vancouver		$ 17,550,800	$ 17,518,000	$ 17,856,200	$ 30,097,900	$ 30,297,100	$ 30,989,900
	$ / sf	**$283**	**$283**	**$288**	**$292**	**$294**	**$300**
Northern BC		$ 19,832,404	$ 19,269,800	$ 19,641,820	$ 34,010,627	$ 33,326,810	$ 34,088,890
	$ / sf	**$320**	**$311**	**$317**	**$330**	**$323**	**$330**
Interior BC		$ 18,779,356	$ 18,393,900	$ 18,749,010	$ 32,204,753	$ 31,811,955	$ 32,539,395
	$ / sf	**$303**	**$297**	**$303**	**$312**	**$308**	**$315**
Fraser		$ 17,550,800	$ 17,518,000	$ 17,856,200	$ 30,097,900	$ 30,297,100	$ 30,989,900
	$ / sf	**$283**	**$283**	**$288**	**$292**	**$294**	**$300**
Vancouver Island		$ 18,691,602	$ 18,393,900	$ 18,749,010	$ 32,054,264	$ 31,811,955	$ 32,539,395
	$ / sf	**$302**	**$297**	**$303**	**$311**	**$308**	**$315**

Note: The 20 storey FFTT option indicated is based on the Option 2 design.
The prices shown increases by $2 /SF for the Option 3 structural approach.

To show a unit like-for-like assessment, we extrapolated costs for the main comparative sections of the different forms of construction. The table below summarizes these cost differences.

Table 3.13.2

Item	Concrete	Timber Panels	Difference
Structural Walls (Including Fire Rating)	$39/Sq.ft	$29/Sq.ft	26%
Upper Floors (Including Columns, Beams + Topping)	$22/Sq.ft	$39/Sq.ft	-43%

Note: Timber Panel Costs from 12 storey FFTT Encapsulated Method.

Project Modelling

Concrete Building

The proposed concrete building model is a concrete frame structure supported by typical footing foundations with a concrete slab on grade. The typical floor and roof structures are suspended slabs supported on concrete columns and beams.

The envelope of the structure is assumed to be 70% glazing with window wall system and 30% wall cladding. The interior construction is drywall partitions; and concrete shear walls with header beams to the elevator shaft and stair core.

Mechanical and electrical works are included. HVAC system includes electric baseboard heating and ventilation only. Air conditioning is not included.

The level of finishes used as the base for this report is mid-range. This is consistently applied across each building design.

Wood Building

The proposed wood building model is a Mass Timber structure supported by typical footing foundations with a concrete slab on grade. The typical floor and roof structures are structural wood decking with non structural concrete topping.

The structural walls/columns combinations differ depending on each option, specifically:

1. Mass Timber Core Walls and Glulam Beams & Columns
2. Mass Timber Core Walls and Demising walls with Glulam Beams & Columns
3. Mass Timber Core Walls and External Wall Panels
4. Mass Timber Core Walls, Demising Walls and External Wall Panels (not in costing)

As previously noted, the architects and engineers details show that structural steel is also used in the FFTT buildings. The use is consistent around the core wall areas for each Mass Timber option with perimeter stud beams for options 3 and 4.

Mechanical and electrical works are included. HVAC system includes electric baseboard heating and ventilation only. Air conditioning is not included.

The level of finishes used as the base for this report is mid-range. This is also consistently applied across each building design.

Areas

The gross floor area of the project measured in accordance with the guidelines established by the Canadian Institute of Quantity Surveyors is as follows:

Option 1

Table 3.13.3

Location	Gross Floor Area	No. of Units
Ground Floor	5,160 sqft	0
Typical Floors 2-12	56,760 sqft	66
Total Gross Floor Area	**61,920 sqft**	**66**

Option 2 and 3

Table 3.13.4

Location	Gross Floor Area	No. of Units
Ground Floor	5,160 sqft	0
Typical Floors 2-20	98,040 sqft	114
Total Gross Floor Area	**103,200 sqft**	**114**

Exclusions

The construction estimate includes all direct and indirect project costs identified in the drawings and other information provided by the Prime Consultant. The estimate specifically excludes the following:

- Land costs;
- Legal fees and expenses;
- Demolition and Removal of hazardous materials;
- Loose furnishings and equipment;
- Unforeseen ground conditions and associated extras;
- Off-site works;
- Phasing of the works and accelerated schedule;
- Erratic market conditions, such as lack of bidders, proprietary specifications;
- Cost escalation.

Taxes

The estimate excludes the Harmonized Sales Tax (H.S.T.).

Project Schedule and Escalation

We have priced this estimate in today's dollars (2011 dollars) and have taken into account current market conditions and quarter competitiveness returning to the marketplace.

Pricing

The estimate has been priced at current rates taking into account the size, location and nature of the project. The unit rates utilized are considered competitive for a project of this type, bid under a stipulated lump-sum form of tender in an open market, with a minimum of five bids, supported by the requisite number of sub-contractors.

The estimate allows for labour, material, equipment and other input costs at current rates and levels of productivity. It does not take into account extraordinary market conditions, where there may be few bidders as well as bidders who may include disproportionate contingencies and profit margins in their tenders.

3.14 Schedule Analysis

As part of our study, we completed a review of the entire project schedule as well as the construction schedules for each building option.

Pre-Construction Schedule

The main design consultants for this study noted that while there may be a slightly longer design period required for these initial FFTT building projects, they also anticipated no additional design time required for this type of building in the future. Accordingly, we did not include any change in pre-construction schedule for the different types of construction options.

Construction Schedule

BTY Group met with representatives of some of Canada's largest construction companies to discuss schedule implications for the various designs. We also interviewed specialist timber installers to identify logistics and scheduling challenges.

One of the salient observations was that no company had any experience in undertaking Mass Timber building on this scale. This led them to err on the side of caution in estimating timing and schedules.

It was evident, however, that the FFTT building will enjoy a distinct advantage over concrete from the start of the construction of any of the building options. Specifically, once a floor in a FFTT building has been completed, it will be available for rough in immediately. On the other hand, concrete frame buildings require back propping under each newly poured floor for approximately five to six weeks after the pour. The other delay inherent in concrete frame building is related to core construction. This was estimated to delay the start of the project by approximately three to four weeks. FFTT construction of the core had no significant delay in floor installation.

As a project progresses, industry experts agreed that the concrete frame building would hit a target schedule of constructing a floor in approximately four to five days. The FFTT design was estimated to have a similar construction time for each floor. It was also noted that the FFTT design would speed the rough-in of carpentry and mechanical and electrical fixtures since no concrete drilling would be required and simple screw fixtures would suffice.

One of the main concerns that held back the FFTT construction on a floor-by-floor basis was the requirement to install a double layer of wallboard to the underside of each floor slab (for the encapsulation method). This would delay the mechanical and electrical rough-in, and add a risk of the wallboard suffering from water penetration since the building would not be watertight at the start of installation, especially on the lower floors.

Overall, we estimated the time-savings on the FFTT options as follows:

- Option 1 (12 Storey): 10 Weeks 15%
- Option 2 & 3 (20 Storey): 10 Weeks 11%

Our Project Cost Summaries show that these schedule savings translate into cost savings both during construction (in the Contractors General Requirements and Fees), and in overall project financing.

Financing

The reduction in construction schedule translates into cost savings at the end of the project in the amount of interest to be paid on the project loan. Earlier completion enables earlier sales, which enable earlier loan repayment in full, saving larger interest payments.

Industry Expectation

Within the industry, we found a reasonable expectation that as the design development of FFTT building advances, there will be significant improvement in savings to be realized for this type of construction. The gains will come primarily from off-site prefabrication of sections, the use of larger panels, and from faster installation as companies develop systems that improve panel placement and securing. Even so, we cannot yet predict precisely how much savings could be achieved through scheduling.

Construction time for Mass Timber buildings is well known in Europe because this type of construction has been systematized there. In Canada, however, it is still in its infancy. There are only a few manufacturers and installers in this sector. High initial start up costs for manufacturers remain a barrier to entry. So currently there is little competition within the market to drive increased supply or lower installation costs.

There are, however, additional market factors that in the long term will have a significant impact on the overall competitiveness of FFTT construction.

3.15 Market Factors

Energy Costs

As energy costs increase manufacturing costs will rise with them. This will have a significant impact on concrete frame construction due to the large number of manufactured components (and their delivery) required, e.g. concrete manufacture, reinforcement, formwork, and on-site finishing. FFTT construction's simplicity and its minimal number of components give it distinct advantages as energy costs rise.

Labour Costs

FFTT construction stands to benefit in the long term from increasing labour costs and labour scarcity, which significantly affected BC's construction market in 2007-2008. With off-site prefabrication and minimal labour requirements on-site during installation, FFTT construction has much less exposure to labour factors than that of concrete frame and steel frame construction.

Material Cost

The FFTT system can use different Mass Timber products to achieve similar results. There will be connection differences and varied technical solutions but the overall concepts will remain the same. Each material, be it CLT or LSL or LVL, has a different set of performance, cost and environmental benefits.

From a cost point of view it is important that there is ample competition in the material marketplace to see that Mass Timber solutions are explored by building owners and designers. While central Europe now has many CLT manufacturers in place, North America still has very few. Currently only 3 CLT manufacturers are organized here in Canada. Over time this will increase with demand but the importance of the competitive marketplace will in part determine if these ideas are realized at all. It is the proverbial chicken and egg scenario.

One might argue that this same phenomenon has been seen in our glulam industry where there are relatively few manufacturers in Canada compared to central Europe. In turn the cost competitiveness of glulam material here is significantly less than in Europe as a direct result of competition. Often the preconception of building owners is that a glulam timber building will be more expensive and therefore less worth exploring.

By developing systems that can use either CLT, or LSL in particular, we are introducing greater material competition at the outset. LSL is produced in abundance in North America primarily for use as beams in light wood frame construction. There appears to be significant room in the LSL industry to grow and provide large panel material to provide a very cost competitive option to CLT. This will in turn keep the CLT industry in check through the competitive pricing that will see a more likely adoption of these new ideas.

Insurance

The impact of insurance and valuation of risk for Mass Timber building structures is difficult to measure without a real prototype design to present to underwriter's for their review and evaluation. Preliminary discussion with insurance providers suggest that of the three types of insurance related to a new building type; Professional Liability Insurance, Builder's Risk (Course of Construction Insurance) and Building Property Insurance, Builder's Risk insurance has the most potential to be elevated compared to concrete structures. Further work is required to fully document analysis and testing of systems to demonstrate the physical properties and performance of Mass Timber structures. This is an important step for Tall Wood structures to reach the competitive market.

Sustainability/Government Policy

As governments worldwide increasingly impose carbon taxes and levy fees based on environmental impacts of products, FFTT construction will enjoy a distinct and growing advantage. As a renewable resource material - and one that sequesters carbon during its lifetime - FFTT construction should benefit significantly from it's relatively benign environmental impact.

In summary, FFTT construction appears to be well positioned to improve its cost competitiveness over time.

Future Carbon Tax Policy

Today's carbon tax in BC reflects an approach to the cost of carbon specifically through emissions. Current strategies do not reflect the benefit of carbon sequestration. The cost of both emissions and storage would become important factors in choosing one building material over another in the future. This is a complex issue that we extract two principles from that will effect costs in the future:

1. **The Rising Cost of Carbon Intensive Materials**
   Choices in the construction market have an embedded cost of emissions in most carbon tax structures. In other words choosing energy intensive structural or building materials like steel or concrete will have an embedded BC carbon tax in the energy used for the material's production. This is of course only applied when the material is produced here in BC or if the material is produced in a region of the world that has its own carbon tax. Steel for example is arguably impacted less by the BC carbon tax than concrete because it is produced outside of the province. As other jurisdictions in the world move to applying a cost to carbon as is recommended by the majority of world economists, it is assumed that the cost of high energy materials like concrete and steel will rise accordingly. The implications of the increased material cost will more dramatically separate competing materials based strictly on carbon footprint.

   In effect it would be expected that the cost of wood would remain stable while concrete and steel prices would continue to rise with rising energy prices and additional costs for carbon (through taxation or other mechanisms). This assumption will make wood solutions that much more cost competitive than steel or concrete.

2. **The Cost Benefit of Carbon Sequestration**
   The second factor in considering today's BC carbon tax is that it does not consider carbon sequestration. In effect, the choice to build with a wood structure that is storing carbon could become a tax benefit to the owners of the building if there is a mechanism in place. We have not found where this concept has been applied in the world to date but clearly this is important in the overall cost comparison exercise and in the overall carbon tax discussion.

3.16 Constructability

The construction methods for an FFTT building will be influenced by the location, size and nature of the construction site in question.

mgb and Equilibrium have devised a construction method that is based on current tilt up methods and is suitable for the proposed site for this project. The following concept was developed with great assistance from Dan Sadler and PCL Constructors Westcoast Inc.

One of the key issues involved in FFTT construction will be the availability of an on site tower crane or the opportunity to increase the number of cranes on any FFTT building site. With all panels requiring lifting into place by a crane it will be essential that the main contractor allows for a full-time crane focused on the panel installation until all panels are installed.

Panel size will also be dictated by manufacturers' pressing capabilities and by transportation limitations. Another factor that requires further analysis is the availability of adequate access routes from storage to site to ensure the delivery of proposed panel sizes. This will be especially important in city centre sites.

One of the prime advantages of FFTT construction is the extensive level of design completed off site. This helps minimize site errors and reduces the amount of site management required. The use of Mass Timber panels also reduces the number of trades on site at any one time compared to concrete frame construction. Contractors can accordingly reduce the number of trade supervisors and increase cost savings.

A major concern of FFTT construction that needs to be addressed is the effect of extended exposure to water on the panels. There are a number of temporary coating products currently available that can be applied to the panels during construction to help waterproof them without affecting the finishing in the long term. There is also a reasonable expectation that FFTT construction systems and waterproofing methods during construction will advance as the industry matures.

While we have already analyzed the speed of construction in the Schedule Review, it bears repeating that the construction industry expects to see major advances in the speed of construction of FFTT buildings as product selection increases and new installation methods are developed and deployed.

FFTT Assembly
Tall Wood Case Study Assembly Diagram: 20 Storey

The following diagrams illustrate a sequencing plan for the construction of the Tall Wood Case Study 20 storey tower option. This concept explores the possibility of using Mass Timber panels in their large sizes, up to 64' feet long and 8' feet wide for LVL and LSL, and up to 42' long and 9' wide for CLT. The approach utilizes typical tilt-up technology along with a tower crane that can also be used for foundation, envelope and the like. The basic premise is to work from the inside out, installing the core walls first and working to the exterior walls.

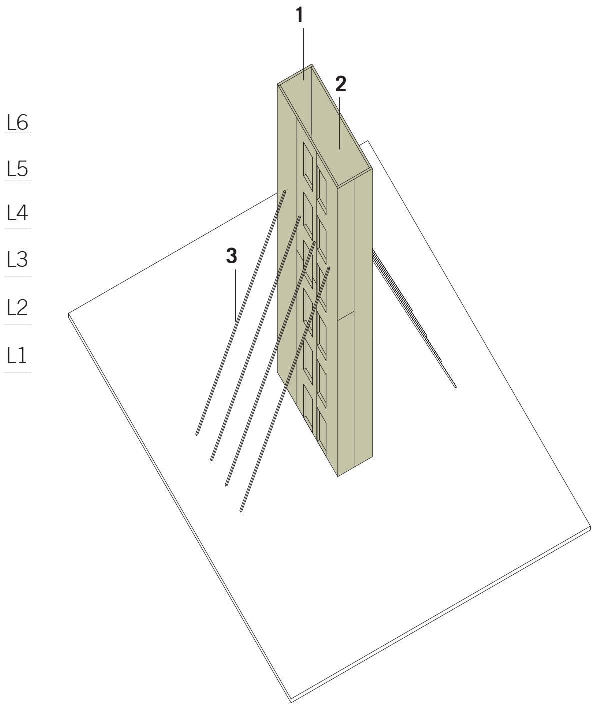
The preferred location of the crane tower would be outside of the building footprint but close to the building's edge. The crane can be configured to be free-standing and sized appropriately for the height and weight requirements of the structure.

Building sites will vary and the room to maneuver with large panels may prove difficult, particularly in urban sites. Additional space is required for the bracing of the panels, principally where panels are required to be braced on the exterior. Accordingly, for sites that are particularly limited in area, panels could be reduced in size to suit the space restrictions.

Furthermore, typical tilt-up braces used for concrete applications may have to be modified in order to make them suitable for the wood panels. Additional considerations include equipment or lifts that would be required to access connection points, material storage and weather protection.

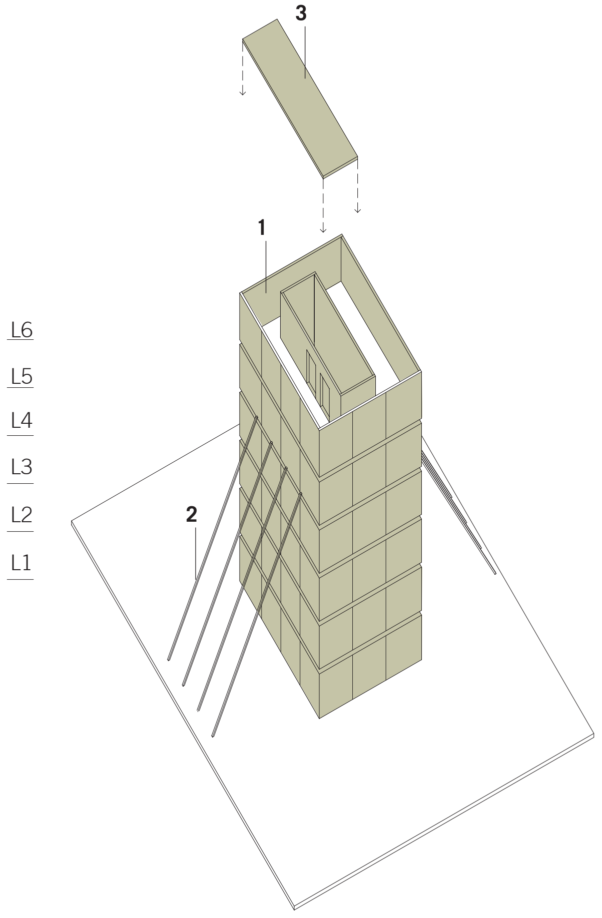
These findings are preliminary in nature and it is recommended that further investigation with engineering and construction plans is required to verify the methodology.

Construction Sequencing (Continued)



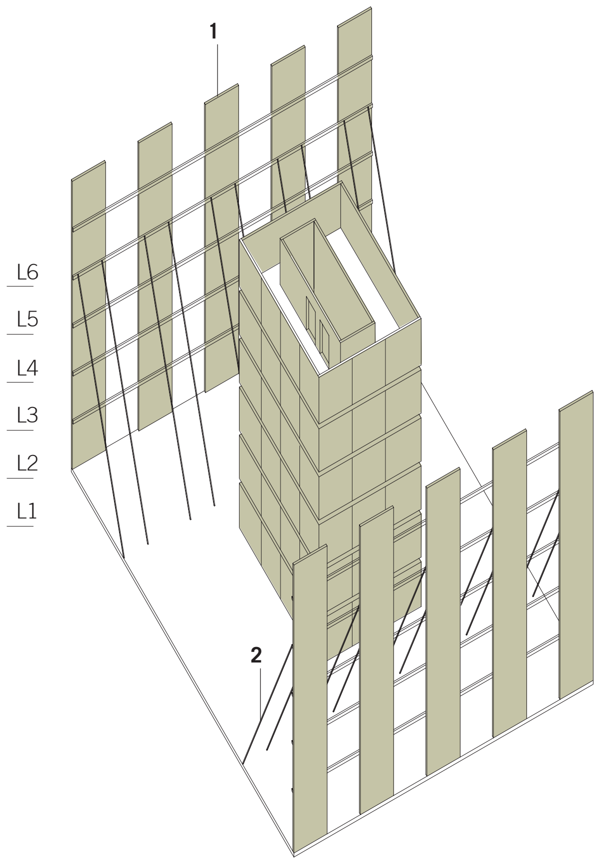
1 Install inner core walls. First lift.
2 Scaffold inner core to access connections (TYP)
Can also be used to install elevator rails
3 Brace inner core walls until core walls are secure

STEP 1



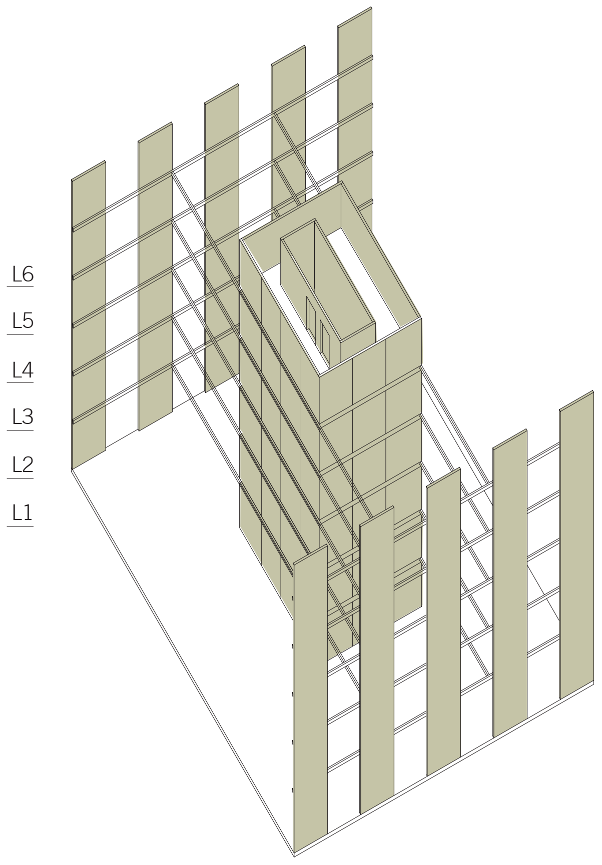
1 Install outer core walls and brace
2 Brace outer core walls until floors are in
3 Install floors and remove braces

STEP 2



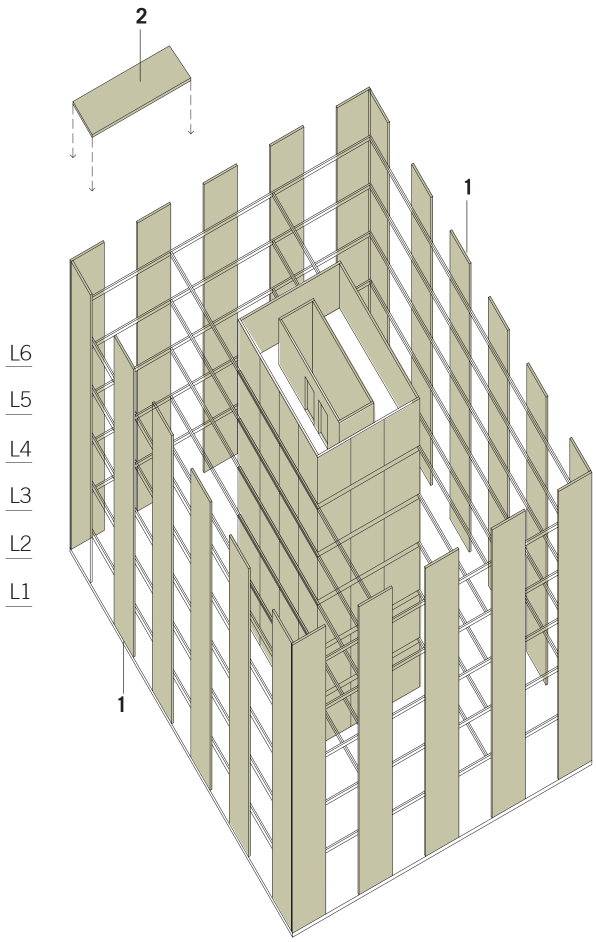
1 Low lift exterior walls
2 Brace exterior walls

STEP 3



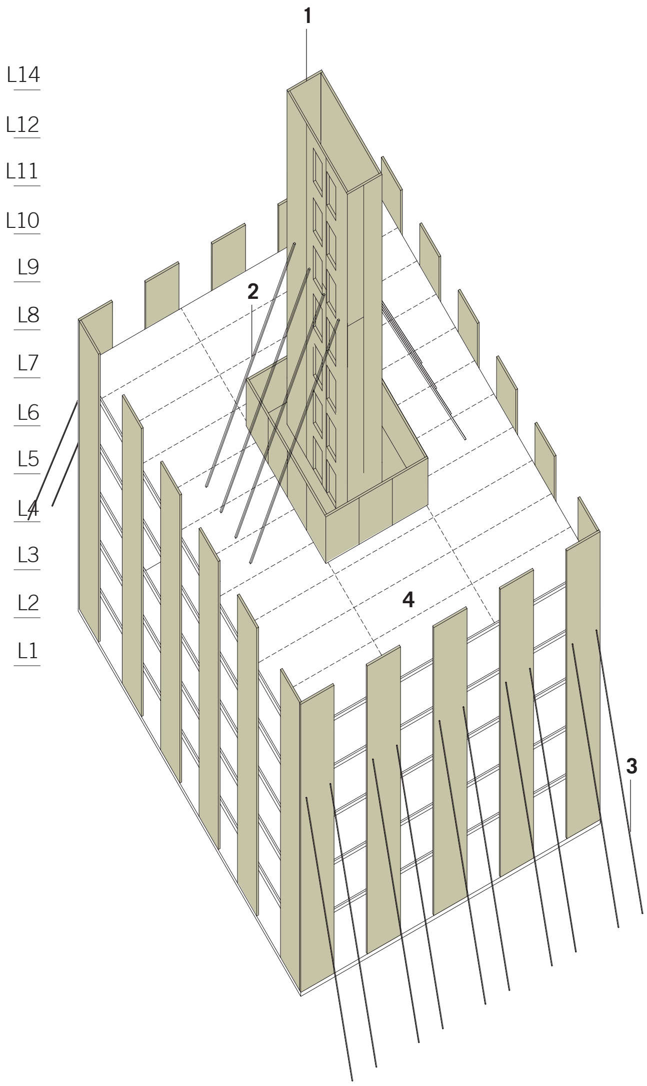
1 Install steel beams connecting core to outer walls
2 Remove braces

STEP 4



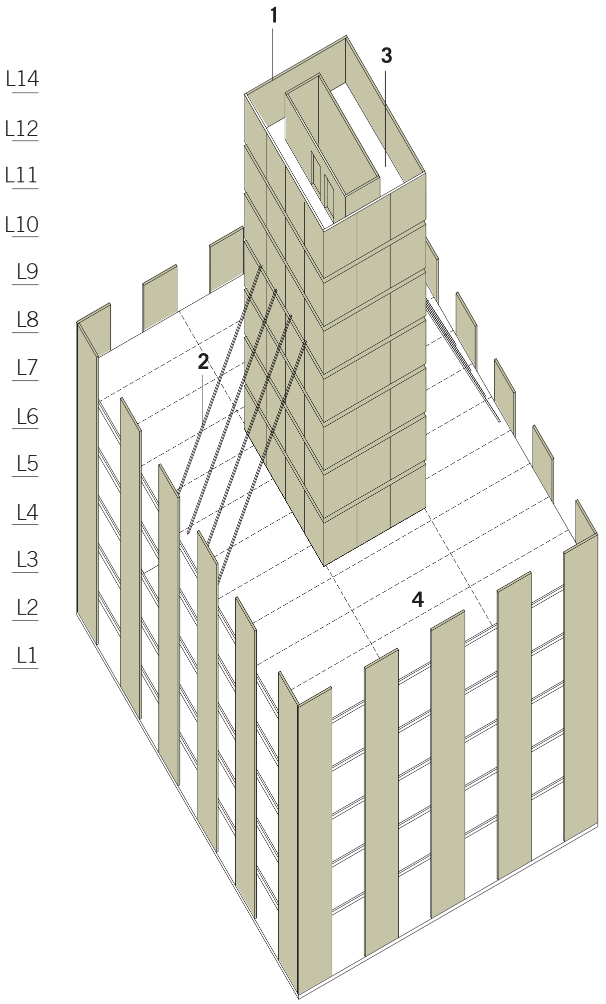
1 Low lift remaining two side exterior walls
2 Install floors
3 Brace until all four exterior walls are connected and floors are in

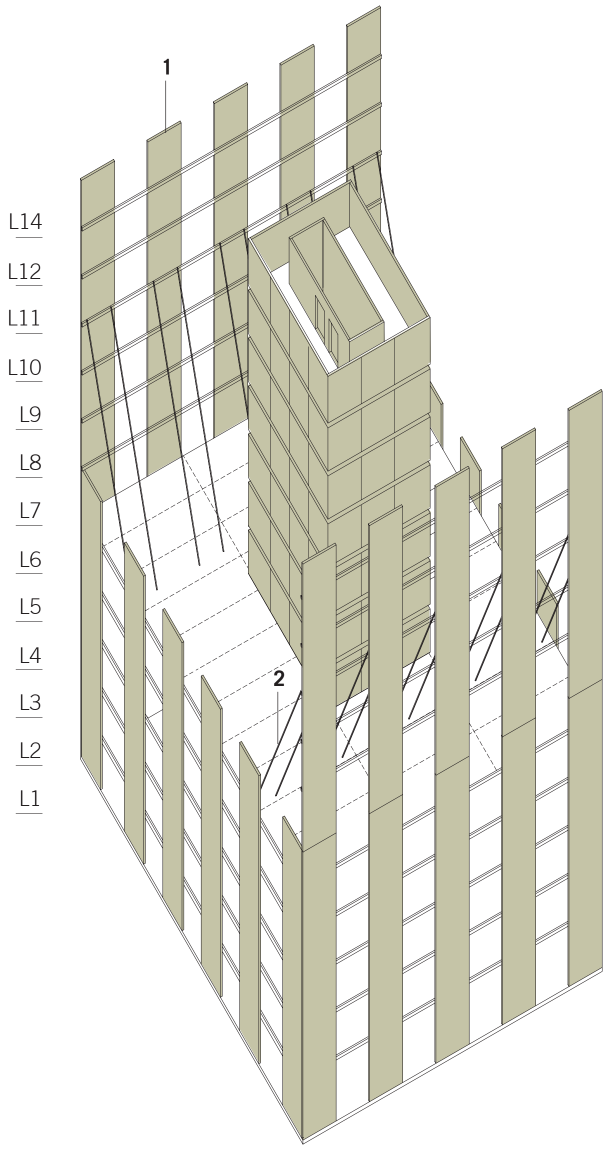
STEP 5



1 Second lift inner core
2 Brace inner core until all inner core walls are secure
3 Brace outer walls
4 Will require lift on floor 6 to access connections

STEP 6



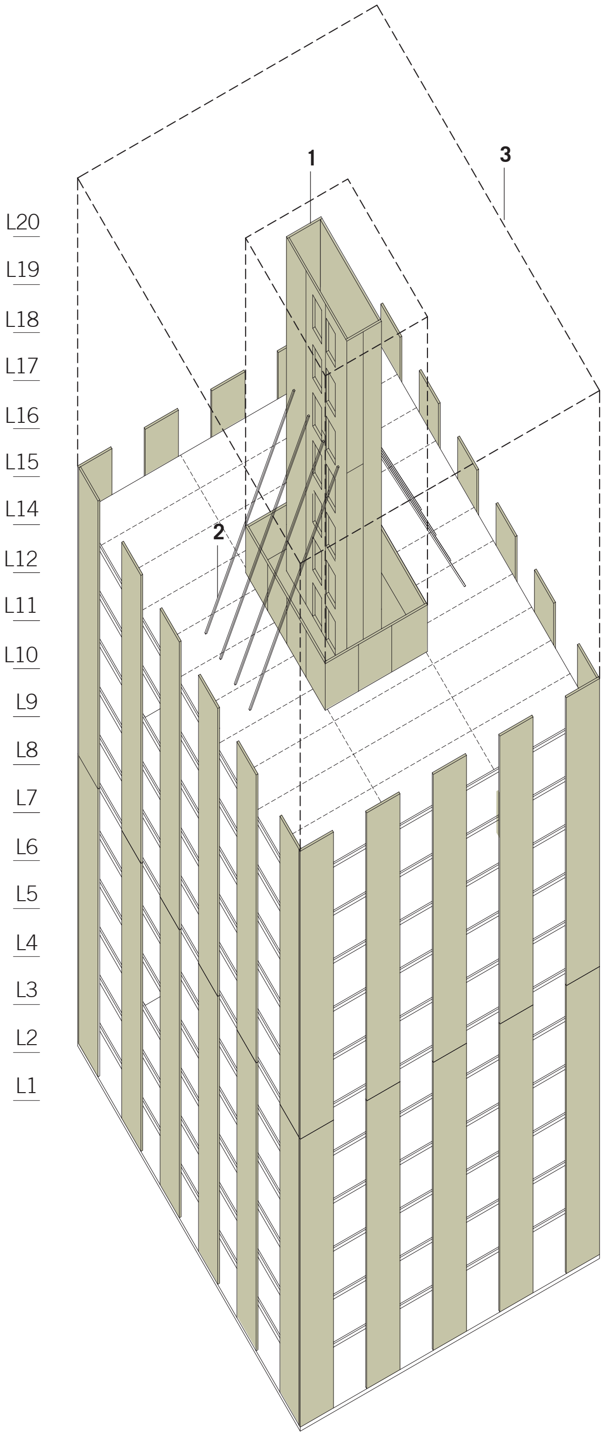


1 Second lift outer core walls and floors
2 Brace outer core
3 Install core floors
4 Will require lift on floor 6 to access connections

STEP 7

1 Second lift outer walls
2 Brace walls
3 Repeat steps 4,5,6

STEP 8



1 Install inner core walls. Third lift.
2 Brace walls
3 Repeat steps 2,3,4,5

STEP 9

TALL WOOD

PERSPECTIVES ON WHERE WE ARE HEADED

INDUSTRY INTERVIEWS PART 4

4.1 Industry Representatives

A large number of organizations and individuals contributed to this study with insight specific to their specialty within the building regulation, construction, development and real estate industries. A large thank you is extended to all who participated. While their input is generally reflected throughout the study, a summary of interviews is captured in the following paragraphs for specific reference. Comments reflect the context of the specific discussions, and are not meant to infer support of the study or its contents.

Contractors

PCL Construction: Attendees

Dan Sadler Senior Project Manager

Comments:

- The typical construction schedule for concrete is one week/ floor. A wood system would have to be faster than that to have a significant advantage. Floor to floor height is a critical element in managing cost – should be carefully considered w/ the service space in the ceilings proposed.
- A number of construction sequences were discussed with a tilt up approach to assembly and a number of different approaches to construction craning. The final sequence proposed has been diagrammed within the document (section 3.16).
- Who would build the first one? This is a question of risk management and is tied to many of the discussions had with others.

Ledcor Construction: Attendees

Andrew Hull, Manager Business Development
Dave Jamieson Senior Superintendant
Roy Vanbeest Operations Manager

Comments:

- Ledcor has explored CLT with BC Housing on two residential towers (12 storey). At that time it was not cost competitive and they did not proceed. Tera Housing may also be a good candidate to build in Mass Timber.
- Access to inner city sites and storage on site are extremely limited. Deliveries would have to be staged to avoid storage issues.
- It is not the traditional timber builders who will understand and install this system, it is more akin to concrete. A re-education and re-training of trades would be part of the widespread implementation of the system.
- There is a loss of efficiency in having to come back again in the construction sequence to clad the building. A more pre-fabricated approach to the complete building assembly would improve its appeal to the developer market.

Fire Professionals

City of Richmond Fire Department: Attendees

Dave Clou Chief Fire Prevention Officer

Comments:

- Many of the issues that are inherent in the 6 storey wood frame building solutions are resolved by the use of Mass Timber solutions. These include shrinkage and the inherent mass of the system that offers fire-resistance by it's nature (ability to char).
- There are three phases of credibility of the proposal; 1. Design 2. Construction and 3. Long term durability and maintenance. The Mass Timber solution can be designed without question. The success of the system relies on the consistent execution of details for penetrations and for connections. Long term success requires education of the end user as to the role of the different components of the assembly in protecting the structure from fire and a strategy for replacement of components in the event of fire or severe water damage. This lead to a discussion of the fire protection being a "sacrificial layer" that could be replaced relatively easily – whether that be a gypsum based membrane or an additional layer of wood easily removed from the base wood structure.
- One of the largest risks in multi-unit residential buildings is the exterior balcony and exposure from barbeque's and fuel fired appliances (such as patio heaters). Without fire detection or sprinkler coverage, flame can burn undetected and spread up and across the face of the building doing significant damage before any control measures can be implemented. Providing sprinkler coverage for these areas would go a long way in eliminating this fire risk.
- Emergency response was discussed in light of recent earthquake events in Japan. Loss of water supply is a major issue and concern. The downtown core of Vancouver currently has a salt water system piped separately from the main system to provide redundancy in an emergency of this nature. LMDG is currently proposing a gridded dual riser sprinkler system that would still provide water if one of the risers was damaged. Other cities (such as Los Angeles) require that buildings have their own water source, such as tanks or pools on the roof for such an event.

Code Authorities

Province of BC Building + Safety Standards Branch: Attendees

Bob Thompson Senior Codes Administrator | BCAB Secretary
Tracey Green Liason Manager
Steven Kuan Seismic Engineer
Roger Lam Manager
Jeff Vasey Executive Director

Comments:

- Building Code stumbling blocks to Tall Wood buildings; Currently 6 storeys is allowed for residential construction and for other occupancies using combustible construction. Also, building area is limited for combustible construction, not just building height. The main argument against taller wood structures (combustible construction) would be the lack of scientific data in regards to fire performance. Currently, the fire performance of taller wood structures is not known/accepted by authorities having jurisdiction even though manufacturer's may have done their own testing. For these new engineered wood systems, further testing for fire performance would be required. Options for further testing include computer modeling and prototyping.
- Market Perception; The current title for "A Case for Tall Wood Buildings" does not give any indication of a new system. The market and public perception is still of platform style framing when associated with wood structures. The Vancouver Sun article was an example that omitted mentioning the structural difference between what is proposed and what is in the public perception. The report should include some material on Mass Timber vs. stick-frame to clarify the difference.
- Charring; The main concern of the "charring" method would be the contribution of the material to the smoke and heat developed by a fire. The areas of particular concern for smoke and heat spread would be the corridors and exits which are treated more conservatively in the code as the primary way of getting out of a building in the event of a fire.
- Fire retardants; more development is needed to fully understand. Deterioration over time. Off gassing, environmental health.
- Structure; Clarify the structural differences between concrete and wood structures. May work numerically but for acceptance would require further testing, prototypes etc. Clarify "weak beam, strong column" and the interaction with the core. Connection details are critical to the structure – for example what is the connection detail at the ground?

City of Vancouver: Attendees

William Johnston Chief Building Official
James Hook Project Coordinator
Patrick Ryan Deputy Chief Building Official
Rick Cheung Building Code Specialist
James Lau Building Policy Engineer

Comments:

- Separating this study from the 6 storey discussion is important.
- Key issues include long term maintenance, durability and perceived envelope issues with wood construction.
- Current discussions with regard to the building code are considering eliminating the combustible I non-combustible designations. How do European model codes compare? This should be discussed in the study.
- What is the embodied energy of this type of building over its lifespan? How would this compare to concrete and steel?
- Tax structures around carbon tax related to embodied energy would change the way that developers think about building with this kind of system.
- The proposal to encapsulate in a gypsum membrane is reducing the sustainability argument for this construction type. A charring approach would support this argument more effectively, but would have to be extensively tested including all proposed connections. A system would need to be developed to rate the connections - heavy timber connections developed in Europe conceal connectors in the wood.
- How does this system impact design freedom? Could the floor plates step back, be curved, etc…
- Insuring the building - the largest fire risk is during construction.
- Termites are an issue that would be a problem in other climates.
- Could CLT be made out of salvaged wood?
- Could existing buildings be retrofitted with engineered products?
- Increased seismic protection of the sprinkler system was discussed in light of recent earthquake events in Japan. A looped system (vertical) is proposed rather than separate risers – similar to what was designed for the new Vancouver Convention Centre.
- The risk from plumbing leaks and overflows needs to be addressed. How is the system retrofitted or repaired?
- Scissor stairs – are currently not permitted in 6 storey wood construction due to shrinkage issues and potential breech of the fire protection membrane– given that shrinkage in a Mass Timber solution is minimal (comparable to concrete) this would have to be reviewed on a detail basis along with the attachment of the elevator carriage to the inner walls of the core structure.

Developers

Westbank Projects Corporation Attendees:

Ian Gillespie Developer | Owner

Comments:

- Resale Value; Office towers made of concrete will have a higher retail value than a steel building (from experience). Concrete is considered to be more comfortable to be in, for reasons of acoustics, vibrations etc. Office buildings are rated based on class. Construction type would play a role in the evaluation of class.
- Can a wood core be sufficient for an elevator?
- There is a perception that concrete buildings last longer than wood buildings.
- The best way to gain acceptance is through building. The first one will be difficult, but the system will gain momentum shortly afterwards, after 10 it may become commonplace?
- Where would an all wood structure be in terms of LEED rating?
- Telus is marketed as a LEED Platinum building. Therefore, it is anticipated to have better marketability in the future, if it were to be sold later on. For residential buildings, environmental ratings have less marketability as consumers are less willing to spend a few extra hundred dollars on a mortgage for a LEED rating.
- Residential market in Vancouver. 70% of our purchasers are from overseas (China) and would have more difficulty accepting a wood structure building. However, there is a market for instance in such areas as SFU and UBC.
- These wood structures should be sold at the high-end of the market. Marketing it as a stronger or equal to concrete might be the way to go.
- Perhaps the starting place for one of these structures is the public sector.
- Developers have a high margin of risk and a low profit margin. The first might be equal or greater in cost to concrete.
- The warmth of wood is appealing.

Marketing Consultants | Consumer Opinion

MAC Marketing: Attendees

Cameron McNeill

Comments:

- The fact that Mass Timber building is a new typology lends itself to getting a start in the public sector – public housing or institutionally driven development such as SFU or UBC. The private market would start to build with this building type most likely only after it was established, with some example structures built.
- The public perception of wood is that it is cheaper than concrete and steel construction. If the Mass Timber typology is to gain widespread acceptance in the private sector it must be developed for and marketed to a high end clientele as being equal to or stronger than concrete.
- The ultimate selling point is cost. The system must be competitive with concrete to be marketable. The Vancouver market is largely Asian and overcoming the perceived value of concrete buildings will be a significant challenge.
- Some characteristics that should be developed to target consumers include – the beauty of wood, the innovation of the system and safety around fire protection and earthquake.

TALL WOOD

NEXT STEPS PART 5

5.1 Recommended Studies

As part of the continuing research and development phase of the Mass Timber building design, it is recommended that the following further studies, physical testing and research/dialogue initiatives be considered to facilitate the project success in the future which we hope will lead to the construction of the first timber high-rise in Canada.

Peer Review

- The analysis carried out as part of this study is preliminary and aimed at establishing the feasibility of our concepts. More detailed analysis testing and peer review are required to satisfy the requirements of due diligence. In order to broaden the appeal of this future study, we would recommend that formal peer reviews be carried out both by Canadian and US experts.

Public Campaign and Education

- A public campaign to "reintroduce wood" and specifically the unique benefits of Mass Timber to the general public. This is very important to overcome the preconceptions that exist and in educating people on why these ideas are important from an environmental, economic and global perspective.
- Unless consumers understand the big picture of why mid-rise and Tall Wood buildings are being explored, how safe they are and how they benefit society, it is unlikely that these ideas will take hold.
- It is also important to continue the BC WoodWorks and Canada Wood Council's structure for encouraging architecture and engineering professionals' understanding and expertise in new approaches to large, medium and Tall Wood buildings.

Structural Analysis

- Advanced dynamic and non-linear analysis of the proposed lateral load resisting systems
- Detailed analysis of typical connection options
- More detailed construction and erection engineering, in conjunction with industry experts
- Detailed cost analysis in conjunction with cost consultants, suppliers and builders

Structural Testing

- Testing of overall moment frame behaviour, with CLT as well as LSL/LVL panels
- Testing of typical connections
- Testing of high and low pressure adhesives for the lamination of LSL and LVL panels

Code Discussions Research and Testing

- Development of a fire testing program for specified FFTT building systems components including encapsulated and exposed timber panel configurations in horizontal and vertical orientations.
- Development of detailed fire and smoke modeling of the project design to assist in facilitating/developing the Mass Timber building design concept further.
- Fire testing of Mass Timber panel assemblies including the fire performance of panel connection hardware details.
- In conjunction with fire modeling activities, a complete "alternative solution" analysis for the Mass Timber building design concept needs to be prepared, as a continuation of this preliminary conceptual study.
- Testing of fire stopping assemblies for typical service penetration conditions through Mass Timber systems (i.e., combustible and non-combustible piping, electrical cables/wiring and similar building services contemplated in Mass Timber buildings).
- Development of future Code change proposals for the deletion of "combustible construction" terminology for Mass Timber systems, such that timber systems will be treated as an equal material to other conventional building construction materials (concrete, steel) that would not be limited in use by building area, height or occupancy.

Pilot project

- It would be beneficial to incorporate these studies into the design and construction of an actual pilot project, where costs and construction issues could be tested in real life. Ultimately pilot projects at various heights should be explored.
- The 2008 Stadthaus project in London illustrated how a platform built CLT solution can achieve 9 storeys (in a less seismically active area than coastal BC). We would suggest that a pilot project at a greater height of 12-16 might be a logical next step that would show BC's and Canada's leadership in these discussions worldwide. A 20 storey option will be arguably more emotionally charged but given the findings of the report and work over time with all stakeholders in these discussions (perhaps most importantly building authorities) we expect to see these scales appear soon somewhere in the world.
- Several developers spoke to the need for a public role in the initial pilot projects to help manage the issues of first to market costs and risk. Public-private partnerships were suggested as a logical approach that would help introduce Tall Wood buildings effectively. Post secondary institutions were also mentioned as logical places for introduction in the market folding into the philosophy for leadership and innovation that is prevalent in BC's universities and colleges.
- Continued Dialogue
- Continued meeting and presentation with key stakeholders to identify and develop critical design/construction details.
- Meetings with the Authorities Having Jurisdiction to discuss the pilot project directions/details and map-out the way forward for the approvals process including Development Permit issues, strategies for Building Code compliance, Alternative Solution development, etc.
- Information sharing and transfer of fire testing data that has been completed to date (by FPInnovations and others) relative to other Mass Timber systems assemblies in Canada.

Market Potential Review and Research in National and Global Markets

- Evaluation of insurance implications and costs during and post construction
- Evaluation of home warranty program implications
- Evaluation of Carbon Tax and incentives of carbon sequestration
- Evaluation of energy costs and material selection - The embedded cost of energy in mass wood versus concrete or steel
- Evaluation of maintenance costs and long term durability

Wood Design, Material Science and Forestry Discussions and Research

- Further development of material science – innovations in LSL manufacturing and rapidly renewable approaches to the material
- Capacity analysis – what is the impact on forestry – economic and environmental – with an increase use of wood

Cost Evaluation with Steel Alternatives in National and Global Markets

- Concrete construction largely dominates tall building construction in Western Canada. In order to expand the ideas of this study and test FFTT's competitiveness in larger markets, it needs to be compared against steel benchmarks.

Tall Wood Conference and Strategic Planning for Industry Evolution

- The ideas of this study and of other Tall Wood studies currently being undertaken around the world need to be presented to a wide audience. Through peer review and collaboration new and more sophisticated solutions will develop. A Tall Wood conference may be a good starting point.
- Given the scale of opportunity that Mass Timber solutions offer, organizations (government and non-government) need to collaborate to create a strategic plan for change within the forestry, lumber and construction industries.

TA
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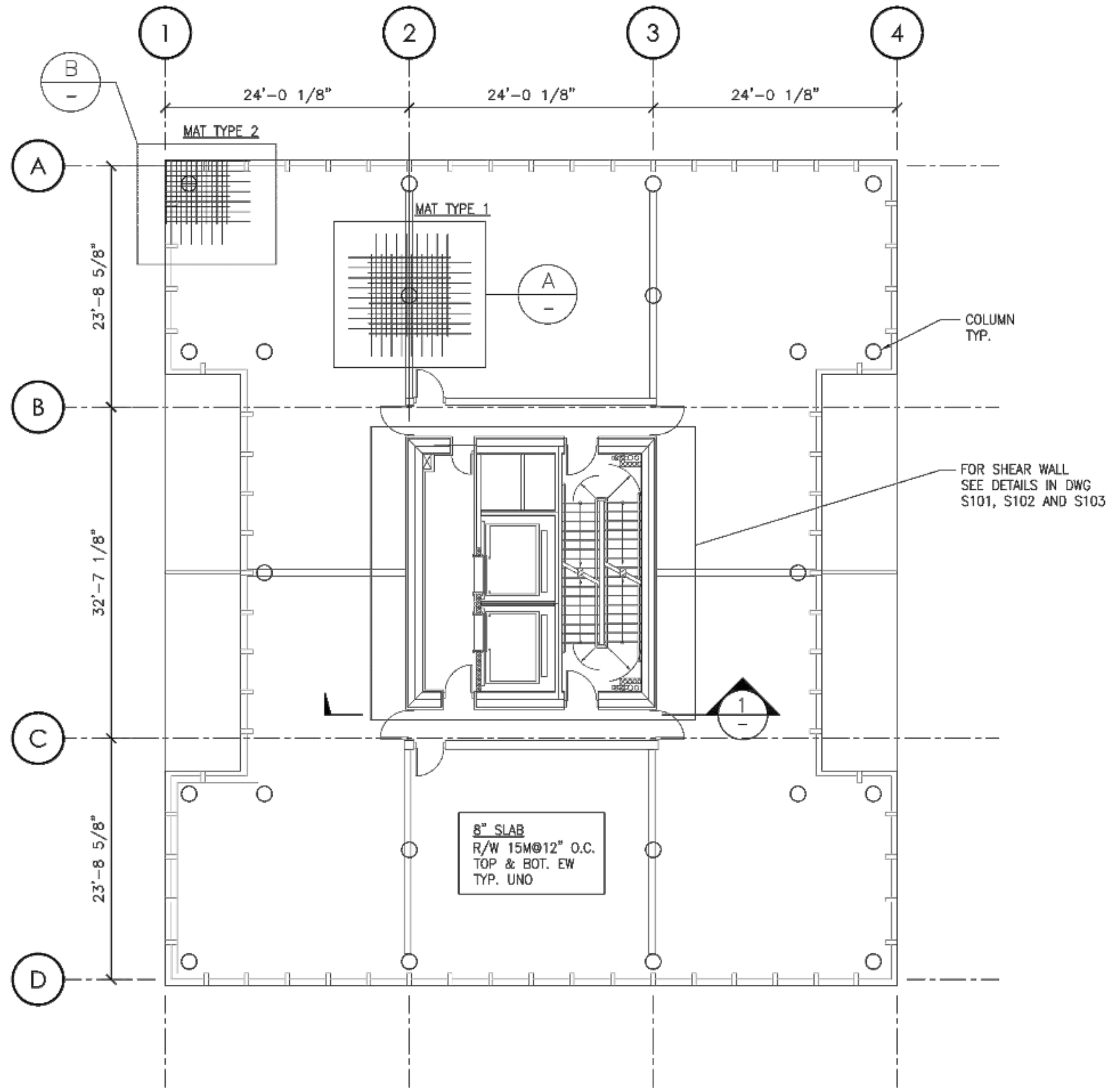
REFERENCE DOCUMENTS PART 6

Appendix A

Appendix A: Concrete Base Building Details



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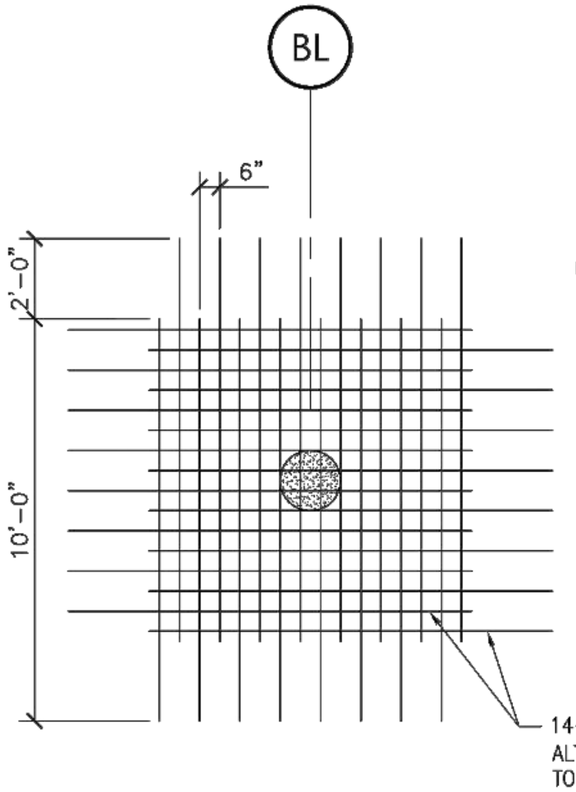

A
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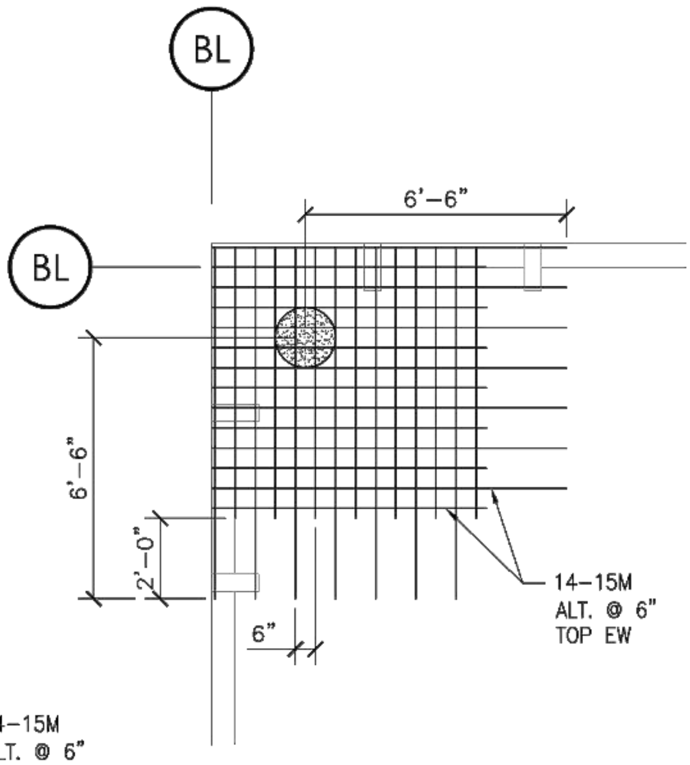

B
–
MAT TYPE 2
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Project: CONCRETE HIGHRISE 12, 20, 30 STOREYS

Project No. 10075

Revisions: –

Title: MAT TYPE 1 / MAT TYPE 2

Date: MAR 09, 2011

SKETCH No. DS-S02

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Checked: JEK

Scale: AS SHOWN

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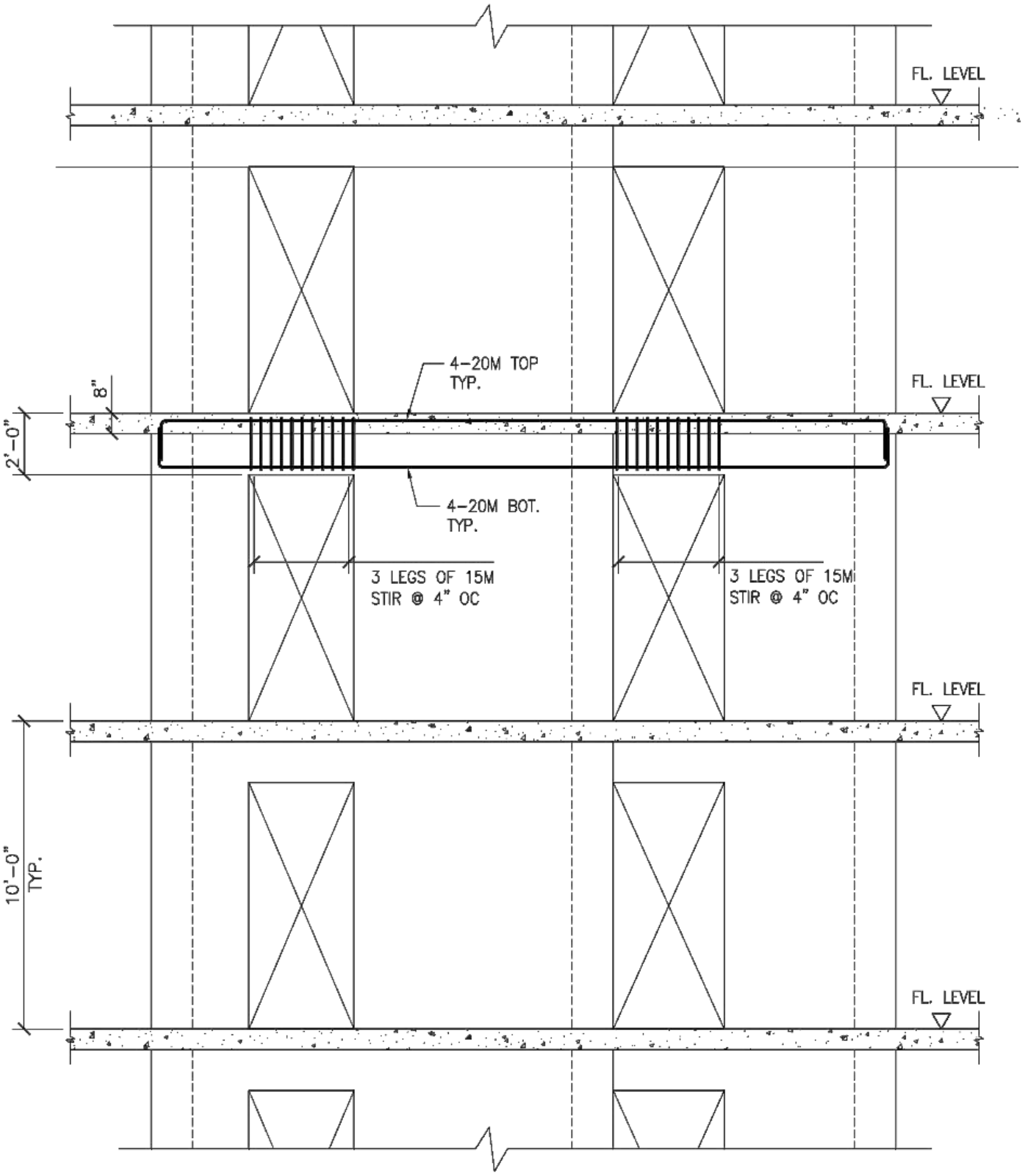

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Project: CONCRETE HIGHRISE 12, 20, 30 STOREYS		Project No. 10075	Revisions: –
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Drawn: RV	Checked: JEK	Scale: NTS	

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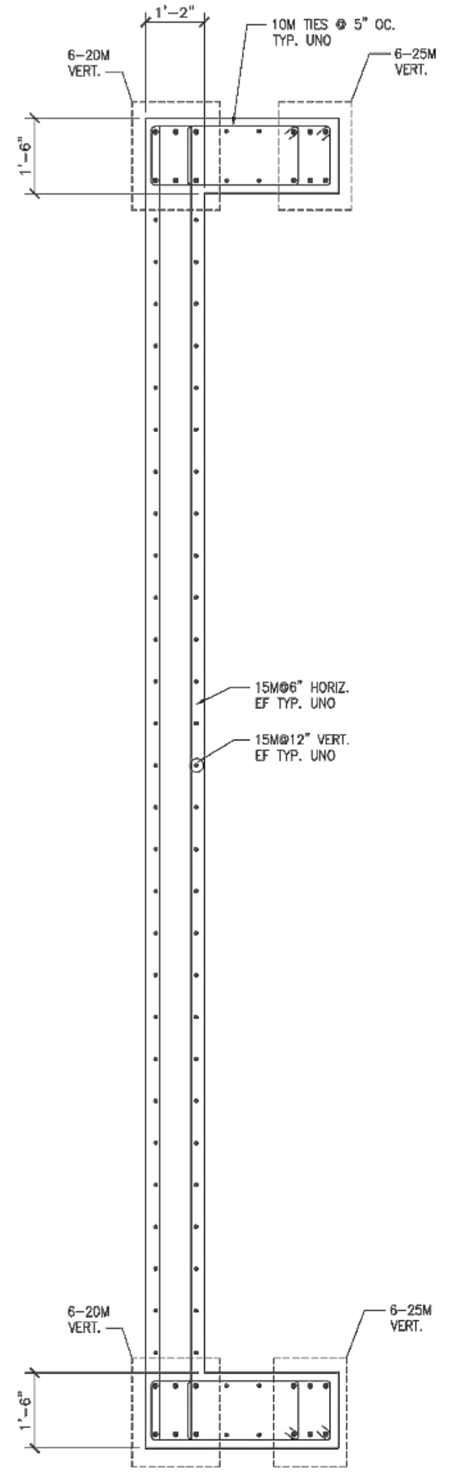

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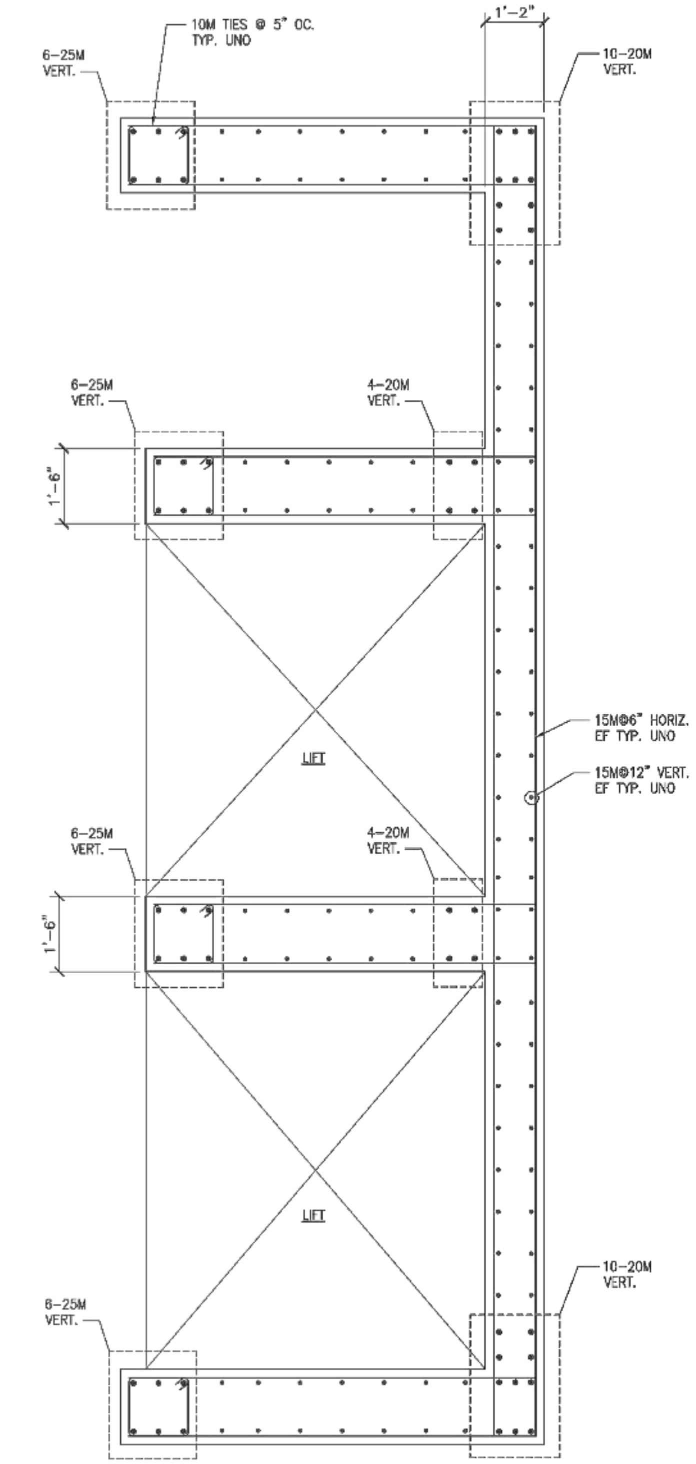

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Project: CONCRETE HIGHRISE 12, 20, 30 STOREYS		Project No. 10075	Revisions: –
Title: SHEAR WALL BTW BAYLINE 2 & 3 SHEAR WALL REINFORCING PLAN UP TO 12 STOREYS		Date: MAR 09, 2011	SKETCH No. DS-S05
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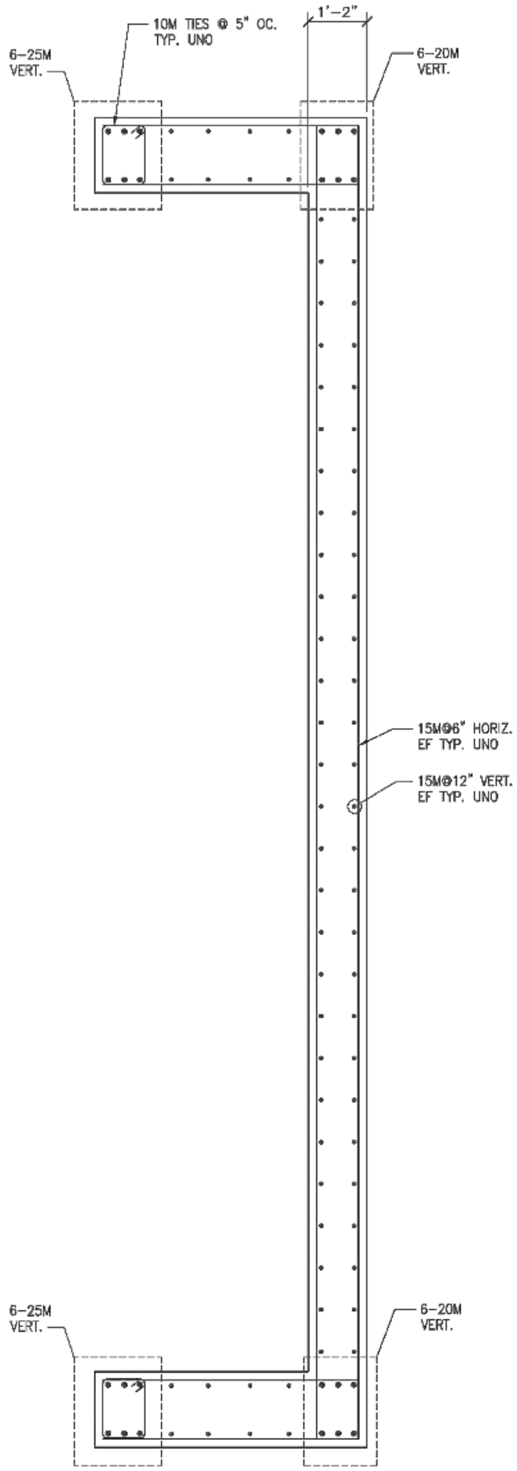

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Project: CONCRETE HIGHRISE 12, 20, 30 STOREYS		Project No. 10075	Revisions: –
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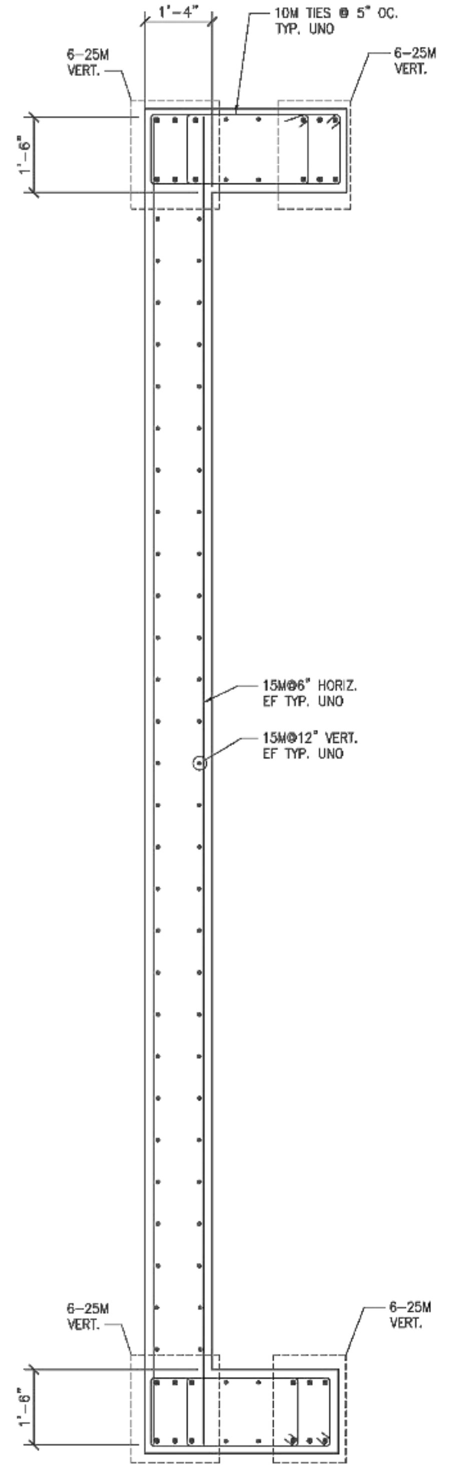

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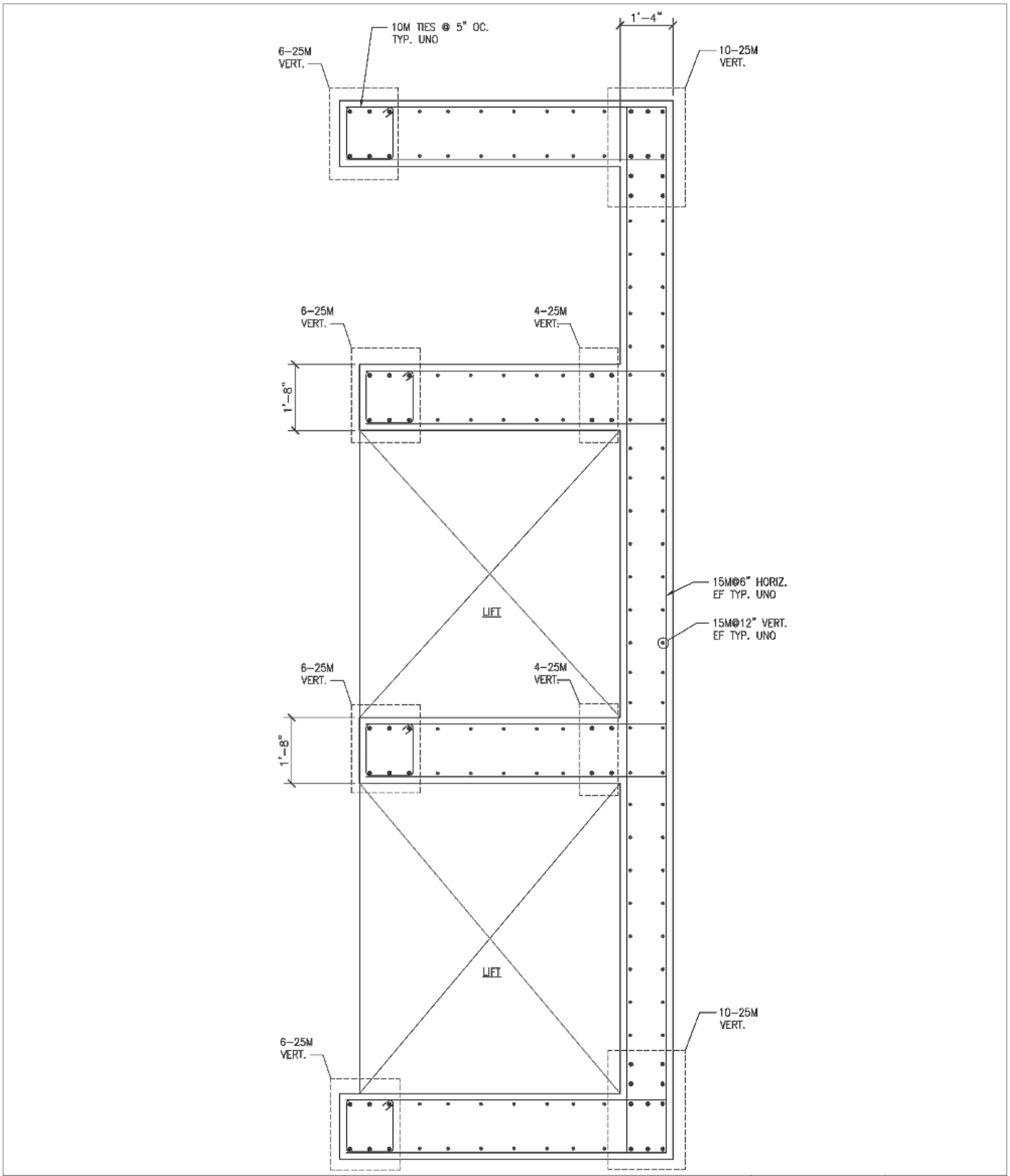

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Title: SHEAR WALL BTW BAYLINE 2 & 3 SHEAR WALL REINFORCING PLAN UP TO 20 STOREYS		Date: MAR 09, 2011	SKETCH No. DS-S08
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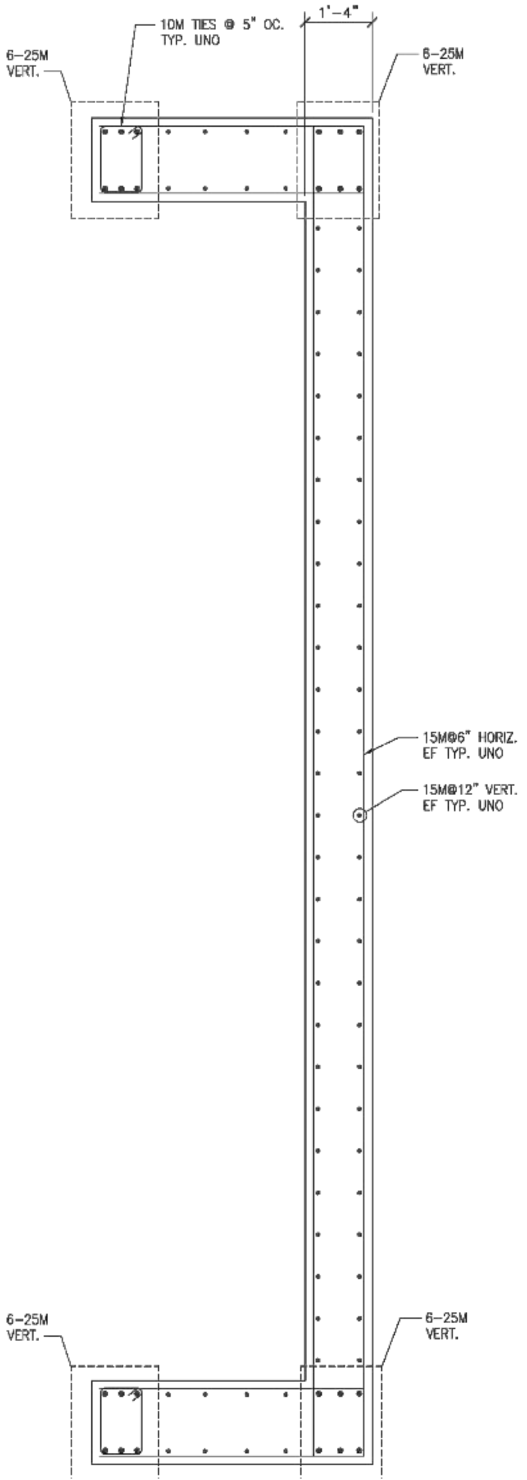

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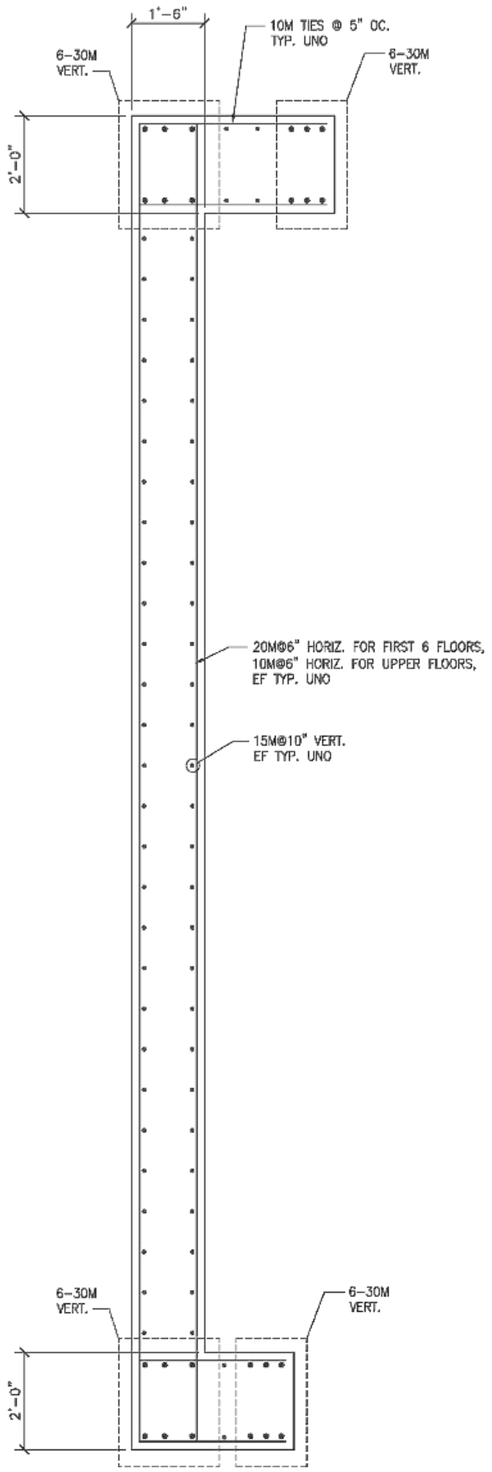

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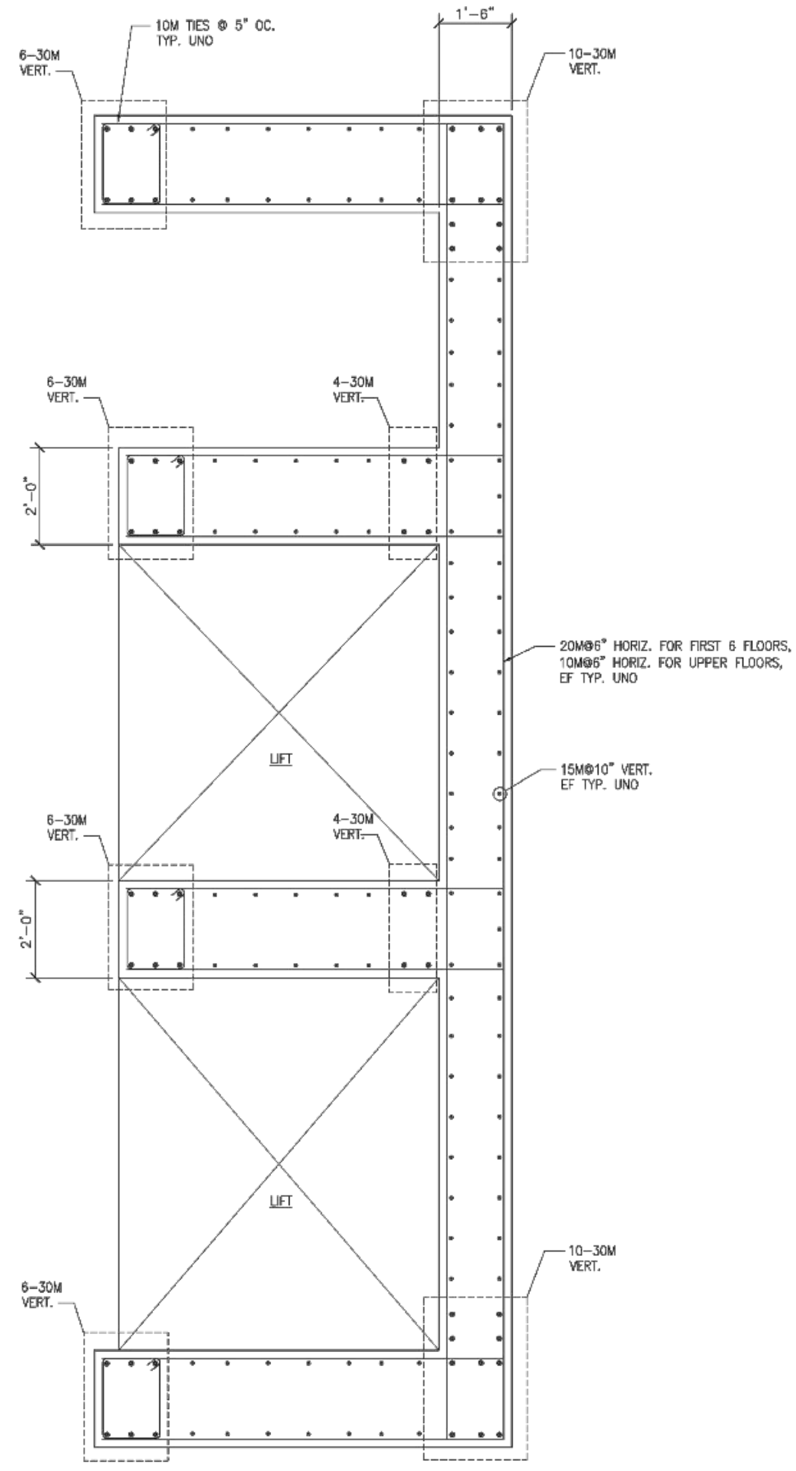

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Project: CONCRETE HIGHRISE 12, 20, 30 STOREYS | Project No. 10075 | Revisions: –

Title: SHEAR WALL BTW BAYLINE 2 & 3
SHEAR WALL REINFORCING PLAN
UP TO 30 STOREYS

Date: MAR 09, 2011

SKETCH No. DS-S11

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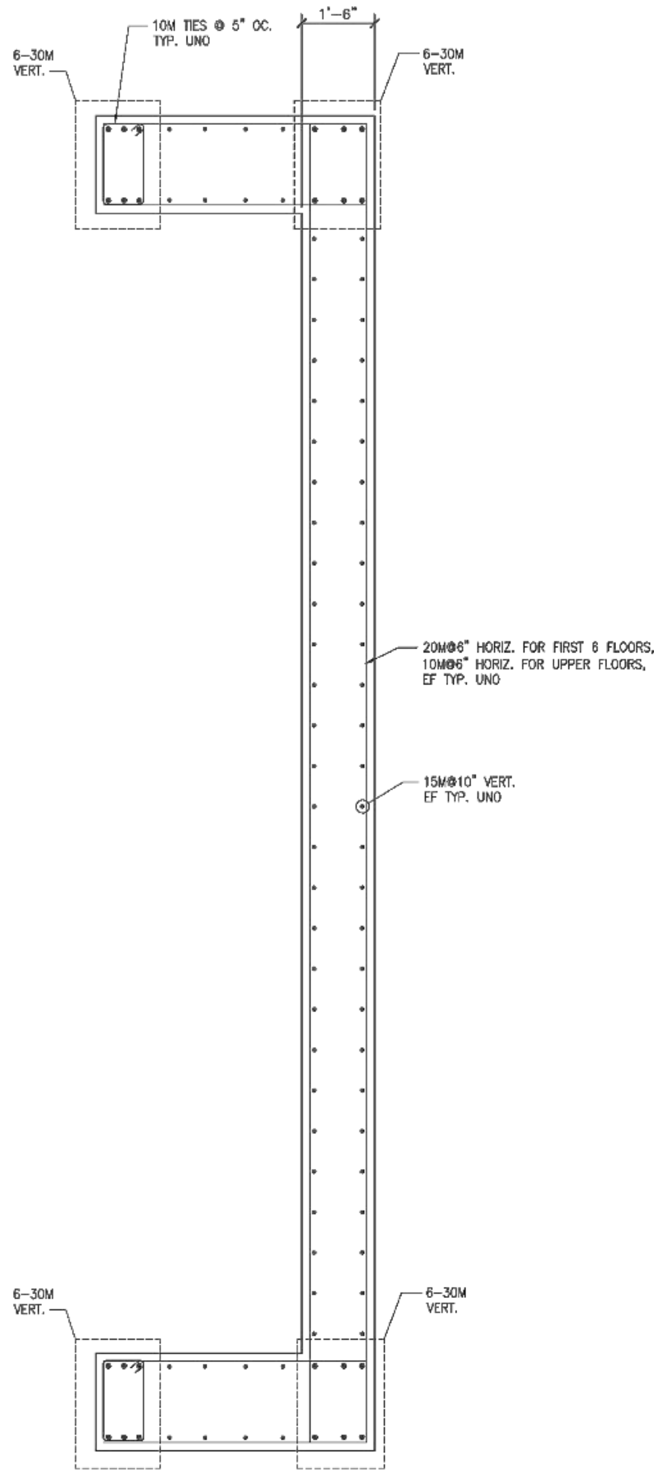

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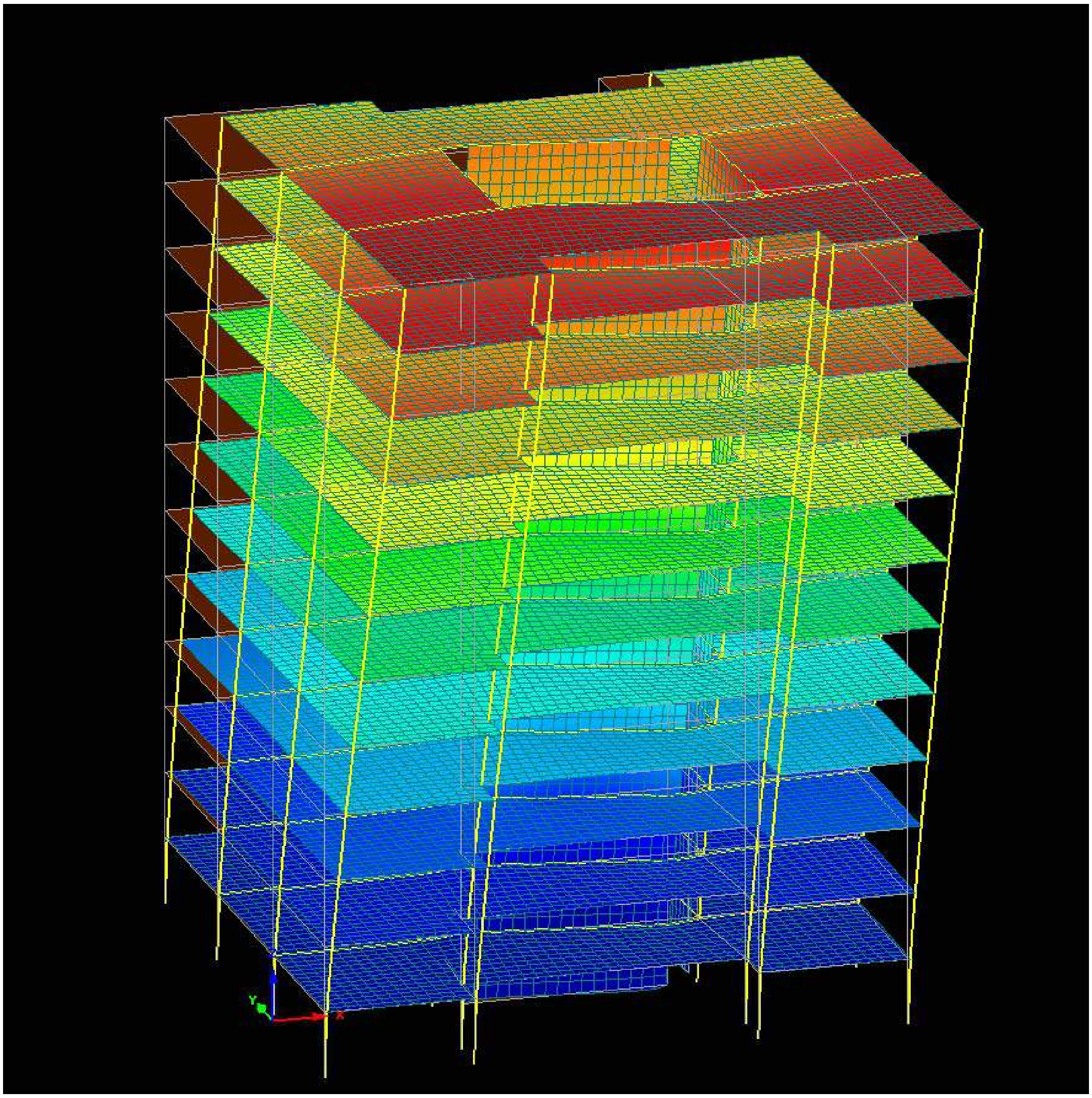
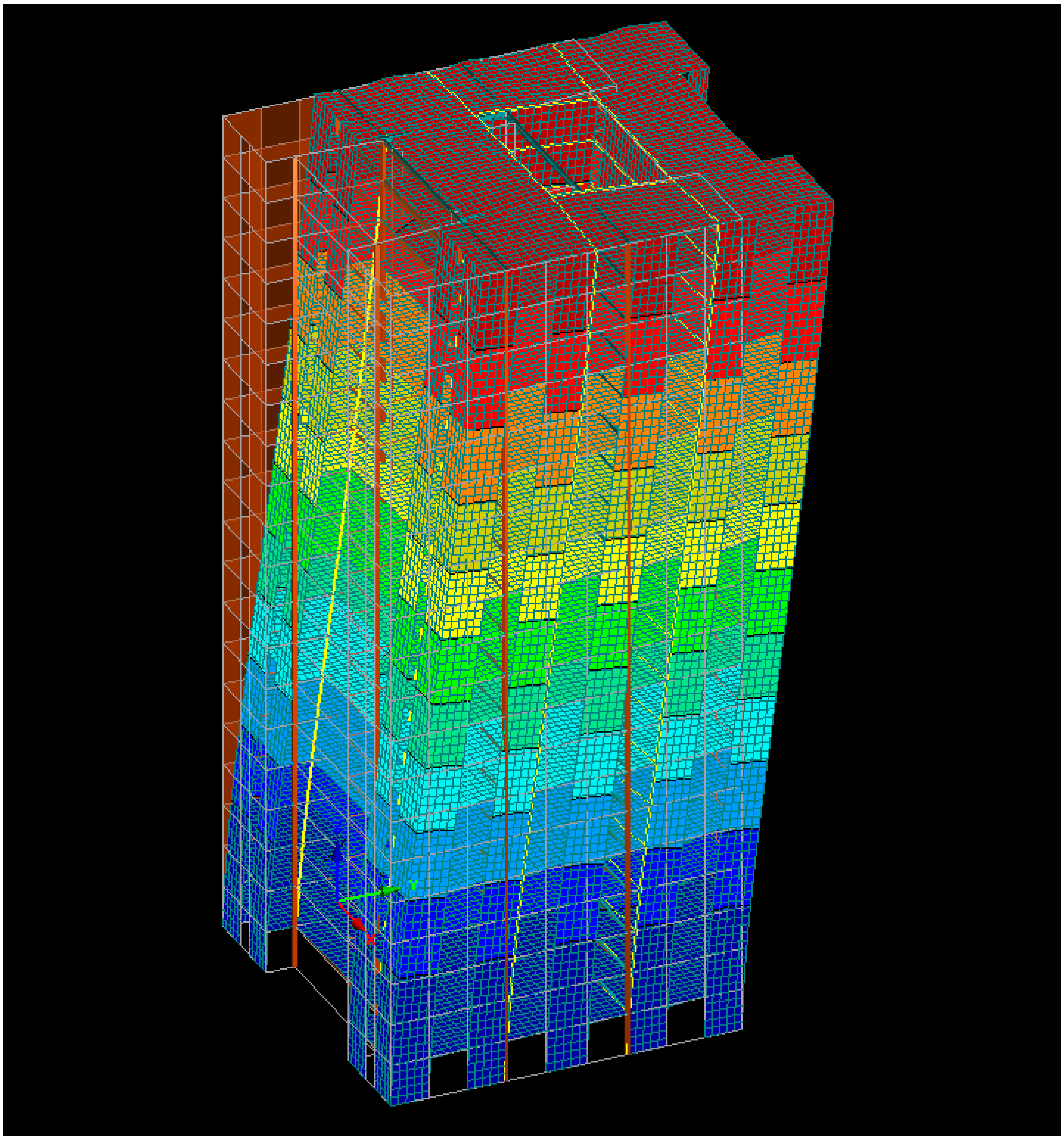
Structural Modeling

Option 1 - 12-Storey Building - Core and Post and Beam Model - Deflected Shape



Option 3 - 20-Storey Building - Core and Outer Moment Frame Model - Deflected Shape



Appendix B

Appendix B: BTY Cost Documentation

The following documentation was used as the basis for preparing the cost estimate:

Table B.1

Drawing	Description	Date
Structural		
DS-S01	Key Plan	March 9, 2011
DS-S02	Mat Type 1/Type 2	March 9, 2011
DS-S03	Shear Wall Header Beam	March 9, 2011
DS-S04	Shear Wall at Bayline 2, Shear Wall Reinforcing Plan Up to 12 Storeys	March 9, 2011
DS-S05	Shear Wall btw Bayline 2 & 3, Shear Wall Reinforcing Plan Up to 12 Storeys	March 9, 2011
DS-S06	Shear Wall at Bayline 3, Shear Wall Reinforcing Plan Up to 12 Storeys	March 9, 2011
DS-S07	Shear Wall at Bayline 2, Shear Wall Reinforcing Plan Up to 20 Storeys	March 9, 2011
DS-S08	Shear Wall btw Bayline 2 & 3, Shear Wall Reinforcing Plan Up to 20 Storeys	March 9, 2011
DS-S09	Shear Wall at Bayline 3, Shear Wall Reinforcing Plan Up to 20 Storeys	March 9, 2011
DS-S10	Shear Wall at Bayline 2, Shear Wall Reinforcing Plan Up to 30 Storeys	March 9, 2011
DS-S11	Shear Wall btw Bayline 2 & 3, Shear Wall Reinforcing Plan Up to 30 Storeys	March 9, 2011
DS-S12	Shear Wall at Bayline 3, Shear Wall Reinforcing Plan Up to 30 Storeys	March 9, 2011
Architectural	Proposed Tower Solutions - Applied & Theoretical Plans (Option 1 to Option 4)	March 2011
	Sequencing plan (from PCL)	March 2011

Option 1-3 Project Cost Comparisons

Option 1 – 12-Storey Building

Table B.2

	Base Case (Concrete)	Study Case (Wood) (Encapsulation Method)	Study Case (Wood) (Charring Method)
A. LAND COST	**$0**	**$0**	**$0**
1 Land (Excluded)	0	0	0
B. CONSTRUCTION	**$13,801,400**	**$14,180,400**	**$13,911,700**
1 Building	13,801,400	14,180,400	13,911,700
2 Site Development & Parking (excluded)	0	0	0
C. PROFESSIONAL FEES (9%)	**$1,242,100**	**$1,276,200**	**$1,252,100**
1 Project Management			
2 Architect / Engineers / Cost Consultant			
3 Other Consultants			
D. PERMITS FEES & TAXES (5%)	**$690,100**	**$709,000**	**$695,600**
1 DCC / DCL / GVRD			
2 Building Permits			
E. FINANCING	**$981,400**	**$840,300**	**$824,400**
1 Financing / Legal / Inspection			
F. PROJECT CONTINGENCY (5%)	**$835,800**	**$850,300**	**$834,200**
SUB-TOTAL	**$17,550,800**	**$17,856,200**	**$17,518,000**
I HARMONIZED SALES TAX (Excluded)	**$0**	**$0**	**$0**
TOTAL PROJECT COST (2011 Dollars)	**$17,550,800**	**$17,856,200**	**$17,518,000**
J ESCALATION	**$0**	**$0**	**$0**
1 Escalation Reserve (excluded)			
ESCALATED PROJECT COST (2011 Dollars)	**$17,550,800**	**$17,856,200**	**$17,518,000**
Gross Floor Area	61,920 sqft	61,920 sqft	61,920 sqft
Total Construction Cost $/sqft	$223 /sqft	$229 /sqft	$225 /sqft
Total Project Cost $/sqft	$283 /sqft	$288 /sqft	$283 /sqft

Option 2 – 20-Storey Building (Alternative Design No. 1)

Table B.3

	Base Case (Concrete)	Study Case (Wood) (Encapsulation Method)	Study Case (Wood) (Charring Method)
A. LAND COST	**$0**	**$0**	**$0**
1 Land (Excluded)	0	0	0
B. CONSTRUCTION	**$23,213,700**	**$24,113,500**	**$23,574,500**
1 Building	23,213,700	24,113,500	23,574,500
2 Site Development & Parking (excluded)	0	0	0
C. PROFESSIONAL FEES (9%)	**$2,089,200**	**$2,170,200**	**$2,121,700**
1 Project Management			
2 Architect / Engineers / Cost Consultant			
3 Other Consultants			
D. PERMITS FEES & TAXES (5%)	**$1,160,700**	**$1,205,700**	**$1,178,700**
1 DCC / DCL / GVRD			
2 Building Permits			
E. FINANCING	**$2,201,100**	**$2,024,800**	**$1,979,500**
1 Financing / Legal / Inspection			
F. PROJECT CONTINGENCY (5%)	**$1,433,200**	**$1,475,700**	**$1,442,700**
SUB-TOTAL	**$30,097,900**	**$30,989,900**	**$30,297,100**
I HARMONIZED SALES TAX (Excluded)	**$0**	**$0**	**$0**
TOTAL PROJECT COST (2011 Dollars)	**$30,097,900**	**$30,989,900**	**$30,297,100**
J ESCALATION	**$0**	**$0**	**$0**
1 Escalation Reserve (excluded)			
ESCALATED PROJECT COST (2011 Dollars)	**$30,097,900**	**$30,989,900**	**$30,297,100**
Gross Floor Area	103,200 sqft	103,200 sqft	103,200 sqft
Total Construction Cost $/sqft	$225 /sqft	$234 /sqft	$228 /sqft
Total Project Cost $/sqft	$292 /sqft	$300 /sqft	$294 /sqft

Option 3 – 20-Storey (Alternative Design No. 2)

Table B.4

	Base Case (Concrete)	Study Case (Wood) (Encapsulation Method)	Study Case (Wood) (Charring Method)
A. LAND COST	**$0**	**$0**	**$0**
1 Land (Excluded)	0	0	0
B. CONSTRUCTION	**$23,213,700**	**$24,271,900**	**$23,757,000**
1 Building	23,213,700	24,271,900	23,757,000
2 Site Development & Parking (excluded)	0	0	0
C. PROFESSIONAL FEES (9%)	**$2,089,200**	**$2,184,500**	**$2,138,100**
1 Project Management			
2 Architect / Engineers / Cost Consultant			
3 Other Consultants			
D. PERMITS FEES & TAXES (5%)	**$1,160,700**	**$1,213,600**	**$1,187,900**
1 DCC / DCL / GVRD			
2 Building Permits			
E. FINANCING	**$2,201,100**	**$2,008,600**	**$1,966,000**
1 Financing / Legal / Inspection			
F. PROJECT CONTINGENCY (5%)	**$1,433,200**	**$1,483,900**	**$1,452,500**
SUB-TOTAL	**$30,097,900**	**$31,162,500**	**$30,501,500**
I HARMONIZED SALES TAX (Excluded)	**$0**	**$0**	**$0**
TOTAL PROJECT COST (2011 Dollars)	**$30,097,900**	**$31,162,500**	**$30,501,500**
J ESCALATION	**$0**	**$0**	**$0**
1 Escalation Reserve (excluded)			
ESCALATED PROJECT COST (2011 Dollars)	**$30,097,900**	**$31,162,500**	**$30,501,500**
Gross Floor Area	103,200 sqft	103,200 sqft	103,200 sqft
Total Construction Cost $/sqft	$225 /sqft	$235 /sqft	$230 /sqft
Total Project Cost $/sqft	$292 /sqft	$302 /sqft	$296 /sqft

Option 1-3 Construction Cost Comparisons

OPTION 1 COMPARISON

NUMBER OF UNITS: 66 Unit
GROSS FLOOR AREA: 61,920 sqft

Table B.5

	Element	Concrete (a)	Wood (Encap) (b)	Variance (a) - (b)		Wood (Charring) (c)	Variance (a) - (c)		Comments
A1	**SUBSTRUCTURE**								
A11.1	Standard Foundations	433,400	309,600	123,800	29%	309,600	123,800	29%	Foundations to Timber Building will be lighter
A11.2	Special Foundations	0	0	0	0%	0	0	0%	
A12	Basement Excavation	1,393,200	1,393,200	0	0%	1,393,200	0	0%	
A2	**STRUCTURE**								
A21	Lowest Floor Construction	41,300	41,300	0	0%	41,300	0	0%	
A22.1	Upper Floor Construction	1,325,200	2,331,500	-1,006,300	-76%	2,375,000	-1,049,800	-79%	250mm thick timber panel floor
A22.2	Stair Construction	96,000	129,600	-33,600	-35%	129,600	-33,600	-35%	Timber Stairs construction with conc topping
A23	Roof Construction	103,200	167,700	-64,500	-63%	169,300	-66,100	-64%	169mm thick timber panel roof deck
A3	**EXTERIOR ENCLOSURE**								
A31	Structural Walls Below Grade	0	0	0	0%	0	0	0%	
A32.1	Walls Above Grade	302,700	302,700	0	0%	302,700	0	0%	
A32.2	Structural Walls Above Grade	0	0	0	0%	0	0	0%	
A32.3	Curtain Walls	1,118,200	1,118,200	0	0%	1,118,200	0	0%	
A33.1	Windows & Louvres	0	0	0	0%	0	0	0%	
A33.2	Glazed Screens	0	0	0	0%	0	0	0%	
A33.3	Doors	100,400	100,400	0	0%	100,400	0	0%	
A34.1	Roof Covering	46,400	46,400	0	0%	46,400	0	0%	
A34.2	Skylights	0	0	0	0%	0	0	0%	
A35	Projections	231,000	231,000	0	0%	231,000	0	0%	
B1	**PARTITIONS & DOORS**								
B11.1	Fixed Partitions	646,800	722,800	-76,000	-12%	646,800	0	0%	Additional wallboard required for Fire-rating
B11.2	Moveable Partitions	0	0	0	0%	0	0	0%	
B11.3	Structural Partitions	1,176,300	661,400	514,900	44%	661,400	514,900	44%	Solid Timber Core walls in lieu of Concrete
B12	Doors	211,200	211,200	0	0%	211,200	0	0%	
B2	**FINISHES**								
B21	Floor Finishes	349,800	349,800	0	0%	349,800	0	0%	
B22	Ceiling Finishes	204,600	434,600	-230,000	-112%	204,600	0	0%	Additional wallboard required for Fire-rating
B23	Wall Finishes	277,200	277,200	0	0%	277,200	0	0%	
B3	**FITTINGS & EQUIPMENT**								
B31.1	Metals	59,400	59,400	0	0%	59,400	0	0%	
B31.2	Millwork	363,000	363,000	0	0%	363,000	0	0%	
B31.3	Specialties	191,400	191,400	0	0%	191,400	0	0%	
B32	Equipment	462,000	462,000	0	0%	462,000	0	0%	
B33.1	Elevators	530,000	530,000	0	0%	530,000	0	0%	
B33.2	Escalators & Moving Walkways	0	0	0	0%	0	0	0%	
B33.3	Material Handling Systems	0	0	0	0%	0	0	0%	
C1	**MECHANICAL**								
C11	Plumbing and Drainage	666,600	666,600	0	0%	666,600	0	0%	
C12	Fire Protection	216,700	216,700	0	0%	216,700	0	0%	
C13	HVAC	495,000	495,000	0	0%	495,000	0	0%	
C14	Controls	19,800	19,800	0	0%	19,800	0	0%	
C2	**ELECTRICAL**								
C21	Service & Distribution	277,200	277,200	0	0%	277,200	0	0%	
C22	Lighting, Devices & Heating	475,200	475,200	0	0%	475,200	0	0%	
C23	Systems & Ancillaries	231,000	231,000	0	0%	231,000	0	0%	
Z1	**GENERAL REQUIREMENTS & FEES**								
Z11	General Requirements	1,155,000	980,000	175,000	15%	980,000	175,000	15%	Timber Construction 2.5 months quicker approx
Z12	Fee	602,200	384,500	217,700	36%	376,700	225,500	37%	Less Management rq'd due to off site detail design
NET BUILDING COST		**13,801,400**	**14,180,400**	**-379,000**	**-3%**	**13,911,700**	**-110,300**	**-1%**	
	Harmonized Sales Tax				**0.0%**			**0.0%**	
TOTAL CONSTRUCTION COST (2011 Dollars)		**13,801,400**	**14,180,400**	**-379,000**	**-3%**	**13,911,700**	**-110,300**	**-1%**	

Unit Cost Analysis							
Cost per sq.ft.:	**223**	**229**	**-6**	**-3%**	**225**	**-2**	**-1%**
Cost per Unit:	**209,112**	**214,855**	**-5,742**	**-3%**	**210,783**	**-1,671**	**-1%**

OPTION 2 COMPARISON

Table B.6

NUMBER OF UNITS: 114 Unit
GROSS FLOOR AREA: 103,200 sqft

	Element	Concrete (a)	Wood (Encap) (b)	Variance (a) - (b)		Wood (Charring) (c)	Variance (a) - (c)		Comments
A1	**SUBSTRUCTURE**								
A11.1	Standard Foundations	928,800	516,000	412,800	44%	516,000	412,800	44%	Foundations to Timber Building will be lighter
A11.2	Special Foundations	0	0	0	0%	0	0	0%	
A12	Basement Excavation	1,857,600	1,857,600	0	0%	1,857,600	0	0%	
A2	**STRUCTURE**								
A21	Lowest Floor Construction	41,300	41,300	0	0%	41,300	0	0%	
A22.1	Upper Floor Construction	2,289,000	3,997,900	-1,708,900	-75%	4,069,900	-1,780,900	-78%	250mm thick timber panel floor
A22.2	Stair Construction	160,000	216,000	-56,000	-35%	216,000	-56,000	-35%	Timber Stairs construction with conc topping
A23	Roof Construction	103,200	178,500	-75,300	-73%	180,900	-77,700	-75%	169mm thick timber panel roof deck
A3	**EXTERIOR ENCLOSURE**								
A31	Structural Walls Below Grade	0	0	0	0%	0	0	0%	
A32.1	Walls Above Grade	497,900	497,900	0	0%	497,900	0	0%	
A32.2	Structural Walls Above Grade	0	0	0	0%	0	0	0%	
A32.3	Curtain Walls	1,839,500	1,839,500	0	0%	1,839,500	0	0%	
A33.1	Windows & Louvres	0	0	0	0%	0	0	0%	
A33.2	Glazed Screens	0	0	0	0%	0	0	0%	
A33.3	Doors	164,400	164,400	0	0%	164,400	0	0%	
A34.1	Roof Covering	46,400	46,400	0	0%	46,400	0	0%	
A34.2	Skylights	0	0	0	0%	0	0	0%	
A35	Projections	399,000	399,000	0	0%	399,000	0	0%	
B1	**PARTITIONS & DOORS**								
B11.1	Fixed Partitions	1,117,200	1,331,600	-214,400	-19%	1,117,200	0	0%	Additional wallboard required for Fire-rating
B11.2	Moveable Partitions	0	0	0	0%	0	0	0%	
B11.3	Structural Partitions	2,604,200	2,095,300	508,900	20%	2,095,300	508,900	20%	Solid Timber Core walls in lieu of Concrete
B12	Doors	364,800	292,200	72,600	20%	292,200	72,600	20%	
B2	**FINISHES**								
B21	Floor Finishes	604,200	604,200	0	0%	604,200	0	0%	
B22	Ceiling Finishes	353,400	736,700	-383,300	-108%	353,400	0	0%	Additional wallboard required for Fire-rating
B23	Wall Finishes	478,800	478,800	0	0%	478,800	0	0%	
B3	**FITTINGS & EQUIPMENT**								
B31.1	Metals	102,600	102,600	0	0%	102,600	0	0%	
B31.2	Millwork	627,000	627,000	0	0%	627,000	0	0%	
B31.3	Specialties	330,600	330,600	0	0%	330,600	0	0%	
B32	Equipment	798,000	798,000	0	0%	798,000	0	0%	
B33.1	Elevators	800,000	800,000	0	0%	800,000	0	0%	
B33.2	Escalators & Moving Walkways	0	0	0	0%	0	0	0%	
B33.3	Material Handling Systems	0	0	0	0%	0	0	0%	
C1	**MECHANICAL**								
C11	Plumbing and Drainage	1,151,400	1,151,400	0	0%	1,151,400	0	0%	
C12	Fire Protection	361,200	361,200	0	0%	361,200	0	0%	
C13	HVAC	855,000	855,000	0	0%	855,000	0	0%	
C14	Controls	34,200	34,200	0	0%	34,200	0	0%	
C2	**ELECTRICAL**								
C21	Service & Distribution	478,800	478,800	0	0%	478,800	0	0%	
C22	Lighting, Devices & Heating	820,800	820,800	0	0%	820,800	0	0%	
C23	Systems & Ancillaries	399,000	399,000	0	0%	399,000	0	0%	
Z1	**GENERAL REQUIREMENTS & FEES**								
Z11	General Requirements	1,575,000	1,400,000	175,000	11%	1,400,000	175,000	11%	Timber Construction 2.5 months quicker approx
Z12	Fee	1,030,400	661,600	368,800	36%	645,900	384,500	37%	Less Management rq'd due to off site detail desigr
NET BUILDING COST		**23,213,700**	**24,113,500**	**-899,800**	**-4%**	**23,574,500**	**-360,800**	**-2%**	
	Harmonized Sales Tax				**0.0%**			**0.0%**	
TOTAL CONSTRUCTION COST (2011 Dollars)		**23,213,700**	**24,113,500**	**-899,800**	**-4%**	**23,574,500**	**-360,800**	**-2%**	

Unit Cost Analysis								
Cost per sq.ft.:	**225**	**234**	**-9**	**-4%**	**228**	**-3**	**-2%**	
Cost per Unit:	**203,629**	**211,522**	**-7,893**	**-4%**	**206,794**	**-3,165**	**-2%**	

OPTION 3 COMPARISON

Table B.7

NUMBER OF UNITS: 114 Unit
GROSS FLOOR AREA: 103,200 sqft

	Element	Concrete (a)	Wood (Encap) (b)	Variance (a) - (b)		Wood (Charring) (c)	Variance (a) - (c)		Comments
A1	**SUBSTRUCTURE**								
A11.1	Standard Foundations	928,800	516,000	412,800	44%	516,000	412,800	44%	Foundations to Timber Building will be lighter
A11.2	Special Foundations	0	0	0	0%	0	0	0%	
A12	Basement Excavation	1,857,600	1,857,600	0	0%	1,857,600	0	0%	
A2	**STRUCTURE**								
A21	Lowest Floor Construction	41,300	41,300	0	0%	41,300	0	0%	
A22.1	Upper Floor Construction	2,289,000	3,817,100	-1,528,100	-67%	3,877,000	-1,588,000	-69%	250mm thick timber panel floor
A22.2	Stair Construction	160,000	216,000	-56,000	-35%	216,000	-56,000	-35%	Timber Stairs construction with conc topping
A23	Roof Construction	103,200	161,500	-58,300	-56%	164,300	-61,100	-59%	169mm thick timber panel roof deck
A3	**EXTERIOR ENCLOSURE**								
A31	Structural Walls Below Grade	0	0	0	0%	0	0	0%	
A32.1	Walls Above Grade	497,900	497,900	0	0%	497,900	0	0%	
A32.2	Structural Walls Above Grade	0	0	0	0%	0	0	0%	
A32.3	Curtain Walls	1,839,500	1,839,500	0	0%	1,839,500	0	0%	
A33.1	Windows & Louvres	0	0	0	0%	0	0	0%	
A33.2	Glazed Screens	0	0	0	0%	0	0	0%	
A33.3	Doors	164,400	164,400	0	0%	164,400	0	0%	
A34.1	Roof Covering	46,400	46,400	0	0%	46,400	0	0%	
A34.2	Skylights	0	0	0	0%	0	0	0%	
A35	Projections	399,000	399,000	0	0%	399,000	0	0%	
B1	**PARTITIONS & DOORS**								
B11.1	Fixed Partitions	1,117,200	1,296,500	-179,300	-16%	1,117,200	0	0%	Additional wallboard required for Fire-rating
B11.2	Moveable Partitions	0	0	0	0%	0	0	0%	
B11.3	Structural Partitions	2,604,200	2,409,400	194,800	7%	2,409,400	194,800	7%	Solid Timber Core walls in lieu of Concrete
B12	Doors	364,800	364,800	0	0%	364,800	0	0%	
B2	**FINISHES**								
B21	Floor Finishes	604,200	604,200	0	0%	604,200	0	0%	
B22	Ceiling Finishes	353,400	736,700	-383,300	-108%	353,400	0	0%	Additional wallboard required for Fire-rating
B23	Wall Finishes	478,800	478,800	0	0%	478,800	0	0%	
B3	**FITTINGS & EQUIPMENT**								
B31.1	Metals	102,600	102,600	0	0%	102,600	0	0%	
B31.2	Millwork	627,000	627,000	0	0%	627,000	0	0%	
B31.3	Specialties	330,600	330,600	0	0%	330,600	0	0%	
B32	Equipment	798,000	798,000	0	0%	798,000	0	0%	
B33.1	Elevators	800,000	800,000	0	0%	800,000	0	0%	
B33.2	Escalators & Moving Walkways	0	0	0	0%	0	0	0%	
B33.3	Material Handling Systems	0	0	0	0%	0	0	0%	
C1	**MECHANICAL**								
C11	Plumbing and Drainage	1,151,400	1,151,400	0	0%	1,151,400	0	0%	
C12	Fire Protection	361,200	361,200	0	0%	361,200	0	0%	
C13	HVAC	855,000	855,000	0	0%	855,000	0	0%	
C14	Controls	34,200	34,200	0	0%	34,200	0	0%	
C2	**ELECTRICAL**								
C21	Service & Distribution	478,800	478,800	0	0%	478,800	0	0%	
C22	Lighting, Devices & Heating	820,800	820,800	0	0%	820,800	0	0%	
C23	Systems & Ancillaries	399,000	399,000	0	0%	399,000	0	0%	
Z1	**GENERAL REQUIREMENTS & FEES**								
Z11	General Requirements	1,575,000	1,400,000	175,000	11%	1,400,000	175,000	11%	Timber Construction 2.5 months quicker approx
Z12	Fee	1,030,400	666,200	364,200	35%	651,200	379,200	37%	Less Management rq'd due to off site detail desig
NET BUILDING COST		**23,213,700**	**24,271,900**	**-1,058,200**	**-5%**	**23,757,000**	**-543,300**	**-2%**	
	Harmonized Sales Tax				**0.0%**			**0.0%**	
TOTAL CONSTRUCTION COST (2011 Dollars)		**23,213,700**	**24,271,900**	**-1,058,200**	**-5%**	**23,757,000**	**-543,300**	**-2%**	
Unit Cost Analysis									
	Cost per sq.ft.:	**225**	**235**	**-10**	**-5%**	**230**	**-5**	**-2%**	
	Cost per Unit:	**203,629**	**212,911**	**-9,282**	**-5%**	**208,395**	**-4,766**	**-2%**	

Glossary

Glossary

Absorption Absorption refers to a materials ability to absorb sound. Sound absorptive material can be installed in a cavity wall or floor to reduce sound transmission between spaces.

AHJ AHJ in this document is an acronym for the Authority Having Jurisdiction.

Anthropogenic Climate Change Anthropogenic Climate Change refers to the man-made production of greenhouse gases with its associated controversial consequences.

Assembly Components Assembly components refer to the individual members that determine the characteristics and qualities of an entire assembly (e.g. floor or wall assemblies). Typical components include gypsum board, sound absorption material, spacing of studs, resilient channels, finishing, topping, sub-floor, ceiling boards, and the size and spacing of joists.

Building Envelope The envelope of a building that is designed to resist wind and earthquake loads, limit air leakage, control vapour diffusion, prevent rain penetration, prevent surface and cavity condensation, limit excessive heat loss and heat gain, and resist noise and the affects of fire.

Carbon Sequestration The ability of a material to store carbon.

Charring Rate Charring rate is the time that a wood member will burn away when exposed to fire.

Combustibility A combustible material or assembly is considered to likely catch fire and burn.

Condensation Control To be resistant to condensation, a building enclosure system must incorporate various features such as thermal continuity and the ability to drain and dry.

COV COV in this document is an acronym for the City of Vancouver.

Cross-Laminated Timber (CLT) A laminated timber panel consisting of several layers of boards stacked crosswise (typically at 90 degrees) and fastened with glue, dowels or nails. CLT products are usually fabricated with three to seven layers.

Curtain Wall An airtight and weather resistant cladding and exterior wall system. This system is usually characterized by a grid of aluminum frames and large panels of glass as well as spandrel panels.

Discontinuity A break or gap in a building assembly that increases sound isolation to aid with sound transmission.

Ductility Ductility refers to a materials ability to mold, shape or bend without failing or breaking.

FFTT FFTT is a unique tilt-up system that effectively balloon frames Mass Timber panels in a cost effective and simple manner to build Tall Wood buildings.

Fire-resistance Rating (FRR) Fire-resistance is a measure of a building assembly's ability to prevent the spread of heat and fire passing through a barrier as well as for a load bearing structure to continue to carry loads without collapsing or experiencing excessive deflection when exposed to fire.

Fire Retardant and Resistant Coatings Fire retardant and resistant coatings are products which are used to improve the fire performance characteristics of a material.

Flame Spread Rating (FSR) Flame spread rating refers to the relative speed in which a flame will spread over the surface of an interior material.

Flanking Sound Flanking noise refers to the situation in which sound vibrations are transmitted through an assembly by moving across its top, bottom or sides and into an adjoining space.

Glue-laminated Lumber (Glulam) This is a structural composite lumber where individual dimensional lumber is end jointed and glued together by a lamination process.

Impact Insulation Class (IIC) Impact sound is caused by a direct contact or impact on a floor or wall that vibrates the partition. This sound is then radiated in the cavity of the assembly which can then be transmitted into the adjacent space as sound.

Laminated Strand Lumber (LSL) Laminated strand lumber is a structural composite lumber manufactured from strands of wood species or species combinations blended with an adhesive. The strands are oriented parallel to the length of the member and then pressed into mats using a steam injection press.

Laminated Veneer Lumber (LVL) Laminated veneer lumber is made up of layers of wood veneers laminated together using an adhesive that are laid-up into a billet that is then fed into a hot press curing the adhesives under heat and pressure.

Mass The mass (weight or thickness) of a partition in a building assembly is one of the major factors in its ability to block sound.

Mass Timber Building System Mass Timber building systems in this document refer to any of three materials: Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), and Cross Laminated Timber (CLT).

Moment Force A moment force is one which causes a rotational effect. This force is a product of a given force multiplied by its perpendicular distance from a determined point.

Phenol Formaldehyde (PF) PF is an adhesive used for structural composite lumber derived from crude oil; crystalline compound for phenol and methanol for formaldehyde.

Phenol Resorcinol Formaldehyde (PRF) PRF is an adhesive used for structural composite lumber with similar properties to PF but is more reactive (because of the resorinol properties), meaning that curing is faster and takes place at room temperature.

Polymeric Methylene Diphenyl Diisocyanate (pMDI) pMDI is an isocyanate based adhesive typically used in combination with PF or PRF in the manufacture of structural composite lumber.

Prefabricated Prefabricated construction refers to shop manufactured components that are transported to a site and assembled in situ.

Rain Penetration Control A rain penetration control is either; face sealed systems and rain screen systems. The principles of a rain screen include the control of capillary action, surface and cavity drainage, pressure equalization, compartmentalization, use of backpans, and ventilated spandrel cavities to allow a path for any water entering the system to exit and for assembly components to dry.

Resilient Connections In the context of this report these are structural members of an assembly used to break the sound transmission path. The also play a key role in the rating of an assembly.

Seismic Force Seismic forces are associated with earthquakes and tremors.

Shear Force A force that acts parallel to a plane of a component or material.

Smoke Developed Classification This is the relative degree that a material will generate smoke when subject to a standard tunnel test.

Sound Transmission Class (STC) Sound transmission can be defined as sound waves hitting one side of a partition causing the face of the partition to vibrate which re-radiates as sound on the other side of the partition.

Structural Composite Lumber Structural composite lumber in this document refers to either Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), or Cross-laminated Timber (CLT).

Sustainability Indicators Sustainable forest management is monitored by applying a set of indicators, which are objective measures that can be supported by data and by certification systems.

Tilt-Up Construction Tilt-up method of construction where panels of a structure are either pre-fabricated or assembled on site and then ‘tilted’ into place by means of large cranes and attached to footings, roof structures and to each other.

TWB TWB in this document is an acronym for a Tall Wood Building (a structure consisting primarily of Mass Timber).

Urea-Formaldehyde (UF) Urea-formaldehyde is a thick, creamy adhesive that dries to a colorless solid. UF is commonly associated with most wood products but is only suitable for interior applications and not for damp conditions. The raw materials for UF adhesives are derived from natural gas; ammonia for urea and methanol for formaldehyde.

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