TALL WITH TIMBER

A SEATTLE MASS TIMBER TOWER CASE STUDY

DLR Group

DLR Group presents our conceptual design of a 12-story mixed-use, mass timber tower for Seattle. This design and cost feasibility study is the result of a tight collaboration of DLR Group, Martha Schwartz Partners, Fast+Epp, Swinerton, WoodWorks and Heartland.

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FOREWORD

From a Seattle Developer

Trees. When I think of Seattle and the Pacific Northwest, I think of many things, but the one that stands tall in my mind are our green forests. Forests that inspire our mental and physical well-being -- both consciously and subconsciously.

Our trees provide the very foundation and backdrop for what makes Seattle the truly magical and creative city it is. And it’s time to use these trees in the construction of high-rise buildings.

Why? Trees are an abundant, renewable, natural resource — and much more sustainable than using concrete and steel. Structural engineering methods and life-safety technologies have progressed to a point that make building high-rise buildings using wood products safe and cost effective. Many local industries and jobs revolve around timber as well.

The City of Seattle has the opportunity to once again be a leader in addressing climate change as well as supporting regional and local industries that create jobs that depend on trees.

Developers, architects, engineers, contractors, etc. are eager to build high-rise buildings using wood products such as cross-laminated timber (CLT) made from trees. Our trees. Grown and harvested by our communities. The will is more than here. The time is NOW and all that is remaining to make this a reality is for our governmental bodies to pass legislation to kick off the next Seattle green wave.

Seattle is called the Emerald City not for the stone, but for its trees. Let’s start building with them!

Greg Smith, CEO
Urban Visions

Fig. 7 | Pacific Northwest Forest

FOREWORD

From the Industry

The timing of this book coincides with an inflection point that mass timber development is experiencing throughout the United States. Until now, developers and designers of mass timber buildings have been comprised of groups referred to as early adopters. Fueled by inspiration sourced from the characteristics of the products themselves, such as cross-laminated timber—including their performance capabilities, sustainability and natural aesthetic—these dedicated professionals have positioned themselves at the forefront of a building revolution.

While manufacturers bring innovative products to the market, these early adopters create the demand by challenging standard practices, perceptions and, in this case, by exploring the structural and creative potential provided by a new class of building products. Beyond these important beginnings, a fundamental shift in the overall development, regulatory and design community is now taking place. The momentum behind mass timber across the industry is transitioning from the curious and conversational to the designed and allowable.

The results have been profound. Interest from land owners, developers and designers has driven an unprecedented amount of research and testing from leading organizations such as the Oregon State College of Forestry and Washington State University. Much of this work has focused on the ability of mass timber materials to comply with fire testing standards, seismic codes and structural requirements, and they have excelled in these areas. The resulting data has led to the construction of mass timber buildings across the country, including an eight-story condominium in Portland and two seven-story offices in Minneapolis and Atlanta. Various jurisdictions are now even encouraging construction with innovative mass timber products as a means to improve forest health, reduce wildfire severity and create jobs in rural communities. Furthermore, construction with mass timber is now widely appreciated as a sustainable alternative to more carbon-intensive traditional building materials such as concrete and steel.

This broad base of support has created tremendous momentum toward increased building height and accommodation of mass timber buildings to be written into the next iterations of state and local building codes. Based on proposals of the International Code Council's Ad Hoc Committee on Tall Wood Buildings, Oregon has already introduced a statewide code path for tall wood buildings of mass timber construction, and other states, including Washington, are following suit.

This report is a product of the effort of a team of industry professionals: DLR Group, Martha Schwartz Partners, Fast + Epp, Swinerton, Heartland, and WoodWorks, whose efforts catalyze the next phase of mass timber development. The goal is to share key insights about tall wood buildings with the developer community.

From forest to frame.

Seattle's first foray into the realm of tall wood buildings is something to celebrate. Please join us!

Ethan Martin
WoodWorks – Wood Products Council

Carson Bowlin
Heartland, LLC

EXECUTIVE SUMMARY

Climate change, difficult to predict steel and concrete prices, and new levels of health consciousness are factors contributing to industry momentum and subsequent market recalibration in support of renewable and locally available resources in North America. Structural components of engineered wood are the center-piece of the discussion in building design, and the growth of mass timber.

Buildings up to 18 stories tall, constructed with mass timber, are now within reach in the U.S. after having been common in European markets for several decades. They are near or within cost brackets that are competitive with conventional construction in concrete or steel. In 2018, the City of Seattle began accepting permit application for tall mass timber developments.

This report was undertaken to establish design parameters and requirements, and to provide a cost comparison between mass timber (design case) and cast-in-place post-tension concrete (baseline) as structural framing systems for a 12-story, hypothetical mixed-use building in Seattle, Washington, USA. The focus is the design potential, with primary efforts on system design, structural cost, and constructibility. Consideration was also given to environmental performance and compliance with the requirements of fire and life safety. The Tower is 214 feet tall with the roof of the highest occupied floor at 180 feet height. The mixed-use program includes street level retail, five floors of commercial offices, and a 192-key hotel. The building is crowned by a roof top garden and bar that is operated by the hotel and accessible to the public. The landscape design program of the building includes a newly created nearby park extension. The substructure of the building includes five levels of ramped parking, internal loading docks and utilities infrastructure.

The form and massing of our Seattle Mass Timber Tower (SMTT) accentuates and juxtaposes soft, curvilinear shapes and culminating, pointed forms. The formal language of dovetail and interlocking shapes of the enclosure is a subtle reference to the timber aesthetic of the finger and dovetail joinery.

The tower maximizes opportunities for exposed wood surfaces on the interior beams, columns, walls and ceilings. These elements are clearly visible from the exterior. The exterior enclosure consists of a state-of-the-art curtain wall system. The seemingly delicate but robust exterior shading devices are an integral part of the south-west elevation featuring gently curving pairs of steel branches.

A full-height stack of three and four level atria face Denny Park, Lake Union and Mount Baker. These “Tech Rooms” provide informal meeting and lounge areas for the office and hotel floors and serve as an organizing element for the tower.

A structural column grid of 12.5 feet x 42 feet was chosen to reduce the dimensions of primary mass timber structure components, maximizing the number of local manufacturers that will have the capability to bid for this project. Mass timber connections such as beam-to-column and column-to-column transitions are steel embeds that are concealed by the glue-laminated timber geometry for fire protection. The typical floor-to-floor heights are 14 feet, with 18 feet at street level and level 12. The typical office floor plates average at 25,800 gross square feet at a total of 135,000 gross square feet.

Our mass timber design follows a new building classification of Type IV-B. The primary frame, bearing walls and floors require a 2-hour fire-resistant rating (FRR), and the roof requires 1-hour FRR. Unprotected portions of mass timber ceilings, including integral beams, are permitted and limited to an area equal to 20 percent of the floor area or unprotected portions of mass timber walls, including integral columns are permitted and limited to an area equal to 40 percent of the floor area.

The key objective of the high-performance lighting and HVAC design is to highlight a minimally intrusive and concise distribution design, preserving both the aesthetics and structural integrity of a mass timber design. Each floor of the building will be zoned independently and served by dedicated outside air and a radiant floor system for heating and cooling.

Cross-laminated timber was chosen over other floor assembly products such as dowel-laminated timber (DLT) or mass plywood panel (MPP) because of the higher number of available manufacturers and our interest to not negatively affect our cost model by material availability and limitations in the supply chain.

This report is the result of a collaboration by a team of architects, engineers, landscape designers, contractors, and industry experts who came together to imagine the best possible path and solution for the design of a taller mass timber mixed-use building. The design team consists of DLR Group for architecture, environmental engineering, and MEP design, Fast+Epp for structural systems; Martha Schwartz Partners for landscape design; Swinerton for constructibility and cost; WoodWorks for industry consultancy; and Heartland for real estate development analysis.

The team objective was to conceive a compelling and elegant design that would reflect innovative spirit, cost-effectiveness, resource-efficiency, and technological rigor. The team based the design parameters and constraints on real-life assumptions relative to the assumed jurisdiction and site, environmental, economic, and socio-cultural criteria. Using 2018 metrics, the result of the cost estimate produced a 0.5 percent savings of the mass timber design case as compared to the baseline post-tension concrete system.

For tall mass timber, the time is now, and the place is here. The legislative framework is in place, it is cost competitive, and the product superior.

Fig. 11 | SMTT | Street View of Southwest Facade

ABSTRACT

In North America, new manufacturing and construction methods for taller buildings constructed with engineered wood, referred to as mass timber multi-story developments are now price competitive with conventional construction in concrete or steel. This report explores the design potential and opportunities of this new typology in the context of the authority having jurisdiction of the 2021 International Building Code (IBC).

Climate change, international trade disputes, and new levels of health consciousness contribute to an industry momentum in support of renewable and locally available resources. In 2016, the Board of the International Code Council (ICC) approved the creation of an ad hoc committee to explore the building science of tall wood buildings with the scope being to investigate the feasibility of and act on developing code changes for tall wood buildings. The City of Seattle began accepting permit applications for developments that use mass timber in heavy timber building types up to 18-stories tall. In 2018 the 14 proposals presented by the ad-hoc committee were approved by the ICC membership.

A team of internationally recognized industry leaders developed a design, engineering and cost feasibility study to serve as an example for the design of a 12-story mixed-use mass timber tower in Seattle.

Mass timber construction carries many advantages including higher levels of quality, a reduced construction schedule, cost competitiveness, and a more stable model of long-term labor distribution. Challenges include a more front-loaded, manufacturing-oriented approach to integrated design that requires teams of architects, engineers, contractors, and manufacturers to work closely together and at higher levels of detail resolution, starting on day one.

INTRODUCTION

Trees

Mass timber, more specifically trees, grow from sunlight, carbon dioxide and water. They sequester carbon and produce oxygen. The carbon cycle, together with the nitrogen and the water cycle, comprises a sequence of events that are key to making earth capable of sustaining life. The environmental cost impact of using concrete and steel in construction is well documented and considered significant while the use of a variety of forest products can economically support sustainable management of forest lands.[1]

Contemporary architectural design language, engineering, and market potential of mass timber design in North America is in the beginning stages and offers an opportunity to define a new design aesthetic. In addition to contributing to health and wellness in terms of ambient climate and human physiology. New code provisions by the International Code Council now enable the construction of tall structures based on new technology driven by scientific advances. Mass timber technology is part of a materials revolution that does not require space-science funding to reform the design field and achieve sustainable heights on earth.

Fig. 12 | Pacific Northwest Forest

The Task

This report was undertaken to establish design parameters and requirements, and to provide a cost comparison between mass timber and cast-in-place post-tension concrete as structural framing systems for a 12-story, hypothetical mixed-use building in Seattle, Washington, USA. The focus was how to maximize the design potential with primary efforts on system design, structural cost, and constructibility. Consideration was also given to environmental performance and compliance with the requirements of fire and life safety. In 2018, the ICC Committee Action Hearings concluded the IBC must be updated to include the use of mass timber in the construction of buildings as tall as 18 stories. The ICC members will now vote on the changes, with the results expected to be revealed in December 2018.

Code Compliance

Aligning with the proposals for the 2021 IBC, the City of Seattle began accepting permit applications for developments that use mass timber in heavy timber building types of up to 18-stories tall. According to Jon Siu of the Seattle Department of Construction and Inspections, a critical component of those proposals is a requirement for cross-laminated timber (CLT) panels to comply with the 2018 version of ANSI/APA PRG 320, the Standard for Performance Rated Cross-Laminated Timber.

Fig. 13 | UBC Brock Commons under construction | Vancouver, BC

Three new building classifications were introduced: Type IV-A, timber buildings permitted up to 18 stories and 270 feet tall; Type IV-B, timber buildings with a maximum height of 12 stories and 180 feet; and Type IV-C, which is permitted to rise nine stories and 85 feet tall at maximum. The tallest, Type A, must protect all mass timber surfaces and include a 3-hour fire-resistance rating for the primary structural frame and load bearing exterior walls. The shortest of the timber typologies is allowed to use exposed structural timber as an interior finish.

For our design, a building classification of Type IV-B, we are following a prescriptive approach for reasons of cost control and market readiness. The building is fully sprinklered. The primary frame, bearing walls and floors require a 2-hour fire-resistant rating (FRR), and the roof requires 1-hour FRR. Unprotected portions of mass timber ceilings, including integral beams, are permitted and limited to an area equal to 20 percent of the floor area. Or unprotected portions of mass timber walls, including integral columns, are permitted and limited to an area equal to 40 percent of the floor area. The outside face of exterior walls of mass timber construction requires non-combustible protection with a minimum assigned time of 40 minutes. Where interior protection is required, mass timber assemblies need to be covered with two layers of 5/8” type X gypsum board, or equivalent, on each side of the enclosure. For our typical floor assemblies, we accomplish this with gypsum wall boards on the underside of CLT panels and concrete topping slabs above the CLT. The topping slabs are embedded with a continuous, closed loop PE-tube system for radiant heating and cooling of the interiors. A continuous rubber mat separates the CLT floor panels from the concrete topping and will provide the required sound isolation and acoustic control.

Site, Program and Statistics

The hypothetical site for this project is a parcel within Seattle’s zoning of Downtown Mixed Commercial, a location near Denny Park, in walking distance to the South Lake Union neighborhood, downtown Seattle, and Seattle Center. Standing 214 feet tall with the roof of the highest occupied floor at 180 feet height. The mixed-use program includes street-level retail, five floors of commercial offices, and a 192-key hotel. The building is crowned by a roof top garden and bar that is operated by the hotel and accessible to the public. The landscape design program of the building includes a newly created nearby park extension. The substructure of the building includes four levels of ramped parking, internal loading docks and utilities infrastructure. At 12 stories and 305,000 gross square feet of total area, our program maximizes the development potential in a combination of applicable parameters including anticipated zoning provisions, floor-area-ratio limitations, building type classification, and occupancy types.

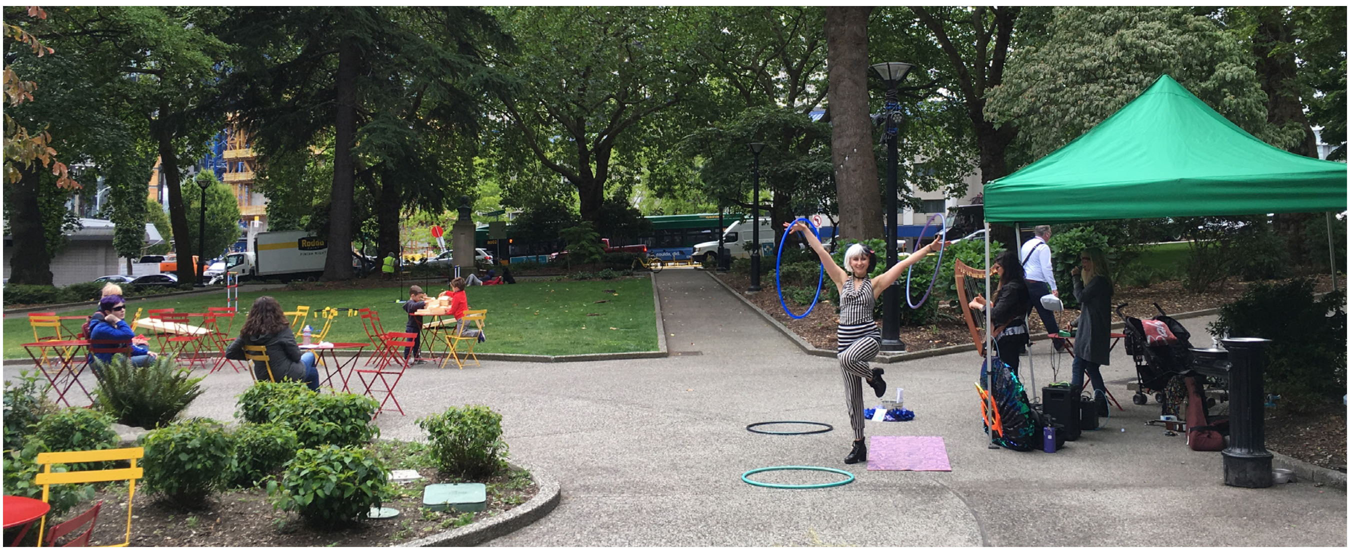


Fig. 14 | Denny Park | Seattle, WA | 2018

The target users for the building are tech tenants (offices) and short-term visitors (hotel). The building has two separate service cores that are associated with the separate street level entrance lobbies and functions of office and hotel. The continuous shear walls in the two cores and the substructure are engineered in concrete and perform lateral load transfer from the mass timber primary structure consisting of CLT wall and floor assemblies, glulam beams, and columns. A structural column grid of 12.5 feet x 42 feet was chosen to reduce the dimensions of primary mass timber structure components, maximizing the number of local manufacturers that will have the current capability to bid for this project. Mass timber connections such as beam-to-column and column-to-column transitions are steel embeds that are concealed by the glulam geometry for fire protection. The typical floor-to-floor heights are 14 feet, with 18 feet at street level and level 12. The typical office floor plates average at 25,800 gross square feet at a total of 135,000 gross square feet. Multi-tenant lease corridors connect to the two egress stairways of the cores and straddle the four-story multi-use atria of the tower at each level.

For the primary structure, the use of tree columns, in lieu of glulam columns, was considered and analyzed but ultimately aborted due to concerns over dimensional consistency and moisture content control relative to shrinkage and creep. The issue of dimensional consistency is not a technical challenge; assumptions can be made that address this variability. The challenge lies primarily with carrying out the Computer Numerical Control (CNC)/prefabrication work that can be achieved with mass timber with these irregular, organic shapes. Bespoke columns will add significant cost of prefabrication and ultimately impact speed of erection, which factors heavily into mass timber's competitiveness. Regarding the issue of moisture content control: significant wood checking (cracking) in columns would be expected, which in turn would introduce a layer of complexity when detailing concealed timber connections.

Cost Analysis

Mass timber construction follows different economic drivers, from design and manufacturing to phasing and construction. A concrete baseline structural and cost

Fig. 15 | SMTT | Model

model was established for the same overall footprint of the design, using a structural system and grid that is conducive to post-tension concrete construction. The substructure is identical in both our mass timber design case and the baseline, however the baseline accounts for a premium due to higher material weight of the foundation.

The Ultimate Value

Trees and our relationship to trees is deeply embedded in our existence. Humans breath in oxygen and breath out carbon dioxide, in return, trees absorb carbon dioxide and supply oxygen.

The effects of trees and plants on human behavior is occurring in more ways than one and is well documented. Humans have a subconscious need to be near nature and spend more time in an area when trees and plants are present. Mood levels improve.[2] Views of trees and plants and exposure to wood surfaces improve concentration, alertness and overall wellbeing, and reduce stress levels.[3] The exposure to plants, trees and natural materials has the potential to control aggression and anger [4] and alleviate pain. Imagine, plant, harvest, build and repeat!

Knowing is not enough, we must apply.
Willing is not enough, we must do.

Johann Wolfgang von Goethe

MASS TIMBER STATE OF THE INDUSTRY

'Mass timber' refers to a class of materials that share three characteristics: they are wood-based, solid, and of a certain dimension. It is easy to confuse mass timber (a material type) with heavy timber (a construction type) as there is some overlap. But for the purposes of this discussion, we are talking about the materials: their manufacture, their inherent qualities, and their extrinsic potential. Because of their strength and dimensional stability, mass timber products offer a renewable, sustainable and carbon-friendly alternative for building applications where wood has not always been considered.

Perhaps the most exciting aspect of mass timber manufacturing is that it is enabled by, and dependent upon, a generation of technology that is elevating the entire industry: 3D computer modeling and CNC machining. Wood geeks and computer geeks unite to bring forth a new way of building that is driving innovation. The icing on the cake is that this movement is rooted in a renewable material with the potential to mitigate the impacts of climate change.

Mass timber has moved well beyond a few project teams inspired by the use of innovative products in non-traditional applications, and is quickly becoming an established — if extraordinary — option for building developers and designers across the U.S.

Product Innovation and Supply

As interest in mass timber has increased, so has the availability of products. For CLT manufacturers, an important nuance is whether a plant has been certified to the ANSI/APA PRG-320 Standard for Performance-Rated Cross-Laminated Timber, which provides a basis for standardization of CLT quality, manufacturing, and structural properties for structural building applications in North America. This standard covers panel dimensions and dimensional tolerances, component requirements for lumber and adhesives, performance criteria, qualification and product marking, and quality assurance requirements for CLT. PRG-320 defines how the structural properties

Fig. 16 | Installation of Glue-Laminated Columns | Vancouver, BC of the CLT panels are to be determined through a qualification process. It also defines, as examples, seven stress grades of CLT panels based on commonly available visually-graded and machine-rated lumber species groups and grades. CLT grades E1 through E4 use machine stress-rated lumber for layers parallel to the major axis. CLT grades V1 through V4 use visually-graded lumber for layers parallel to the major axis. The predefined structural capacities of the CLT example grades are found in the PRG-320 standard and can be useful as a reference; however, not all of the example grades and layups in the standard are being manufactured at this time. Manufacturers also have additional CLT grades and layups with structural properties certified through the PRG-320 qualification process — i.e., there are many more layups available than just those suggested. Due to this, consideration of the CLT products being manufactured is recommended in order to see what specific grades and layups are available. Most recently updated in 2018, PRG-320 serves as the basis of CLT code compliance in the International Building Code. For CLT to meet the requirements of the IBC, it must be certified to the PRG-320 standard.

The below snapshot of manufacturers (as of October 2018), shows significant and expanding North American supply.

Cross-Laminated Timber

Though CLT appears to be just a big block of wood, it is not a commodity product. CLT can be fabricated to meet a variety of structural performance requirements by using different grades and species of lumber. Like precast concrete, CLT is specifically designed for each building and the different geometric and structural requirements of that building. CLT is ripe for building efficient prefabricated buildings, which is the key to safe, efficient, and fast construction in the field by a small installation crew. Most of the CLT produced in North America and Europe is manufactured for a specific project. In other words, CLT exemplifies mass customization. Each building, with its unique geometry and structural grid, requires panels of a certain stress grade, thickness, width, and length, and it would be economically unviable to expect a manufacturer to have the exact shape, size, and quantity of panels required for a project in stock at all times.

Nail-Laminated Timber

NLT has been used for more than a century, but is undergoing a resurgence as part of the modern mass timber movement. It is created from dimension lumber members (2-by-4, 2-by-6, 2-by-8, etc.), stacked on edge and fastened with nails or screws to create larger structural panels. Panels can be fabricated in 8- to 10-foot widths and required lengths by finger-jointing lumber to the spans needed for the project. NLT is highly accessible and can be made by many manufacturers. Those who want to learn the system and/or create panels can download the Nail-Laminated Timber: U.S. Design & Construction Guide from the Think Wood website (www.thinkwood.com/products-and-systems/nltguide).

Dowel-Laminated Timber

DLT is created from dimension lumber members (2-by-4, 2-by-6, 2-by-8, etc.), stacked on edge and fastened with wooden dowels to create larger structural panels. Panels can be fabricated to the required lengths by finger-jointing lumber to the spans needed for the project. It is available from StructureCraft in British Columbia.

Company	Plant Location	Product	Certifications
D.R. Johnson Wood Innovators.	Riddle, OR	CLT	APA PR-L320
Freres Lumber Co.	Lyons, OR	MPP	APA PR-L325
SmartLam	Columbia Falls, MT	CLT	APA PR-L319
StructureCraft	Delta, BC, Canada	DLT	
Structurlam Mass Timber Corp.	Pentiction, BC, Canada	CLT	ICC ES-Report 3631 APA PR-L314

Fig. 17 | Regional Panel Manufacturers

Glue-Laminated Timber (Glulam)

Integral to a mass timber structure are the glulam columns and beams that often serve as the load-bearing elements in a building. Glulam is an engineered wood product, comprised of many layers of dimension lumber bonded together along the face of the boards, using a durable, moisture-resistant, structural adhesive.

In the Pacific Northwest, where coniferous trees produce over one-third of the softwood lumber used in the nation[5], standard APA certified glulam is fabricated primarily from Douglas Fir lamstock. This species of lumber is a hard and dense softwood, which correlates to higher strength values in the beams.

Glulam beams and columns are a simple process of gluing 2-by material to form the necessary sizes and lengths. Jigs are used to form curves, bends, and a variety of radii. Glulam can be sourced from a wide variety of U.S. manufacturers.

As the majority of glulam made in the Pacific Northwest is manufactured to a standard size for structural use. The product is typically sold as a

Company	Plant Location
Boise Cascade Co.	Homedale, ID
Calvert Company Inc.	Vancouver & Washougal, WA
Structurlam Mass Timber Corp.	Pentiction, BC, Canada
American Laminators	Swisshome, OR
QB Corp.	Salmon, ID
Fraserwood	Squamish, BC, Canada
D.R. Johnson Wood Innovators	Riddle, OR
Rosboro	Springfield & Vaughn, OR
Shelton Lam & Deck	Chehalis, WA
Western Archrib	Edmonton, AB, Canada
Western Structures	Eugene, OR
GR Plumbe Co.	Ferndale, WA
Terminal Forest Products	Everson, WA
Zip-O-Laminators	Eugene, OR

Fig. 18.1 | Regional Glulam Manufacturers

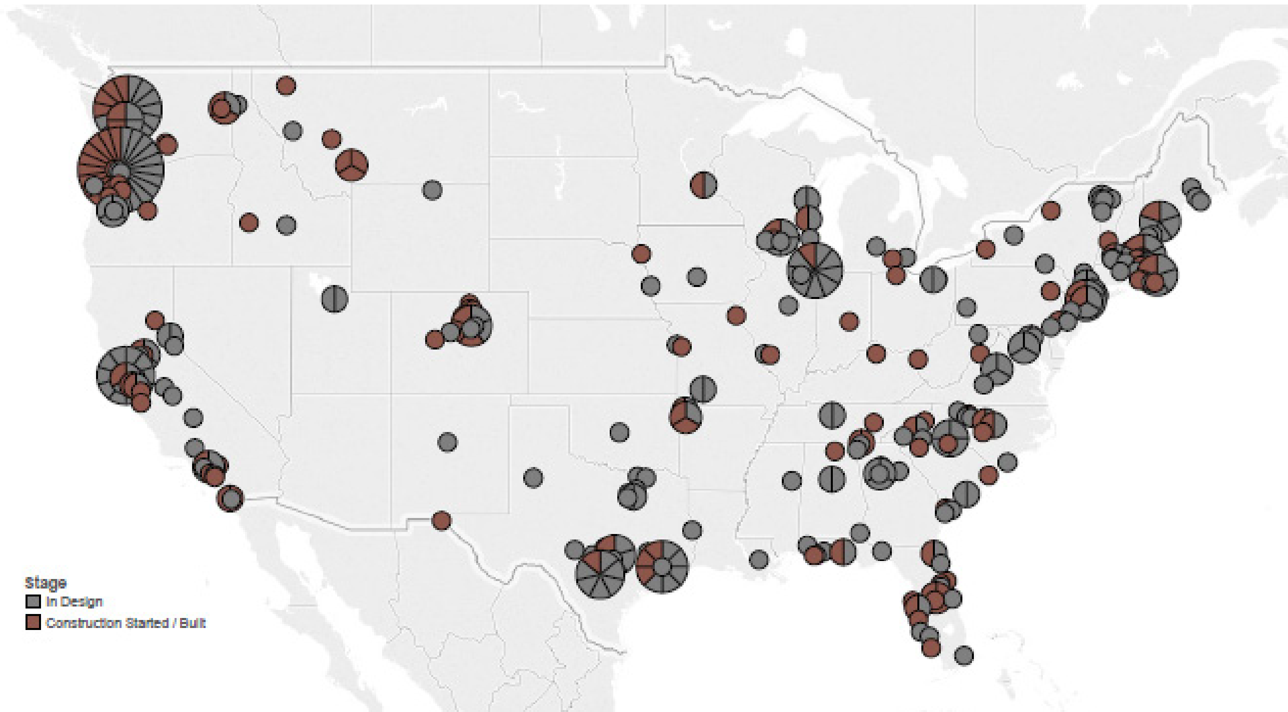


Fig. 18.2 | Mass Timber Projects in Design and Construction in the U.S. | Woodworks | September 2018

commodity by distributors to sub-contractors who perform the construction. Since the advent of 3D modeling and CNC machining in the 1990s, however, certain manufacturers have experienced success supplying custom, architectural glulam framed for steel connections that can often be installed (or at least test-fit) in the production facility. Thus, the region is home to a wide spectrum of glulam products, ranging from standard “sticks” that must be cut to exact size and shape on-site, to custom, fully-prefabricated kit-of-parts components that are ready for assembly upon delivery.

Mass Plywood Panels

Freres Lumber has developed a veneer-based structural composite product, which it is using as lamella within its Mass Plywood Panels (MPP) product. Also certified to the PRG-320 standard, Freres’ MPP product consists of layers of veneer instead of lumber.

Structural Composites

Laminated veneer lumber (LVL) and laminated strand lumber (LSL), are relevant to the mass timber discussion because they can be manufactured as panels in sizes up to 8’ wide with varying thicknesses and lengths depending on the manufacturer. LVL producers are too numerous to count, and LSL is produced by both LP Building Products and Weyerhaeuser. Parallel strand lumber (PSL) columns are also commonly used in combination with other mass timber products. PSL columns have higher strength than glulam columns, and a different aesthetic. It can be helpful to use these on the lower floors of a tall building. PSL is produced by Weyerhaeuser.

For wood high-rises, very long spans or other specific requirements such as acoustic separation, some designers choose wood-concrete composites. Most of the products described above can be made into a composite by applying a concrete topping in such a way that the two materials act as one.

Computer Numerical Control Machining

CNC machining has advanced the mass timber products industry to a level of precision typically not associated with wood construction. This advancement utilizes the drawings produced by the practicing professional and translates this into a machine language where the CNC machine reads the drawings and cuts the material within extremely tight tolerances. A basic, ‘what-is-drawn’ becomes ‘what-is-cut.’ This has forced designers to take a harder look at what they draw to ensure items such as welds, bolt heads, sprinkler pipes, conduit, junction boxes, and the like are drawn precisely to ensure accurate results.

Fig. 19 | CNC Machining of Glue-Laminated Beam

Mass Timber Projects

There is no question that some parts of the country have been quicker to embrace mass timber than others. The Pacific Northwest continues to be a leader; Washington and Oregon are both poised to have 12-story mass timber buildings soon — potentially including the one featured in this book. However, mass timber buildings are being constructed nationwide, including offices, corporate headquarters, university buildings, elementary schools, student housing, hotels, distribution centers, and a museum of fine arts. These are real, buildings and the list goes on. Projects cover the gamut of construction types and occupancies, though there is a definite trend toward the use of mass timber in offices and commercial buildings as developers seek to leverage the unique aesthetic to attract and retain quality tenants.

WoodWorks, which provides technical assistance for commercial and multi-family wood buildings, has seen its technical support for mass timber projects grow exponentially. In 2015, the organization provided assistance on a handful of projects where the developer, architect or engineer had an interest in using mass or heavy timber. In 2017, the number of projects had grown to 158, and they expect to support close to 200 projects this year.

WoodWorks also tracks mass timber projects they aren't involved with and, as of October 2018, had more than 400 multi-family, commercial or institutional mass timber projects in their database, either constructed or in design.

Governing Influences

While the SMTT is among the first timber high-rises in the U.S., credit must be given to the many forward-thinking industry and research organizations, government agencies, and design firms whose work set the stage for this milestone. This includes the ICC Ad Hoc Committee on Tall Wood Buildings, which has proposed changes to the 2021 IBC, and efforts throughout the Pacific Northwest by Forterra and others, that led Oregon to become the first state to adopt the Ad Hoc Committee proposals. Comprehensive information can be found at the Think Wood Research Library [6].

Fig. 20 | Wilson School of Design under construction | Richmond, BC

MARKET ACCEPTANCE

Now is the opportune time for Seattle to test the mass timber technology on a taller building type. Data collection is crucial to the success of this venture and new outlook for development in the city. Teams are looking to gather information relating to comparable leases, building sales and proven material, construction, and operating cost information to underwrite the economics of a proposed project in Seattle. These data points are crucial in the underwriting process of future projects as they justify the construction, design and financing costs of a project by forecasting the future lease revenues and disposition values of the development.

Potential Challenges

A distinct component to the burgeoning opportunity of mass timber development is the ability for groups to navigate unique challenges relating to the adoption of new building materials. Historically, groups of participants within the development community have not had to address such a significant change and can be cautious when adopting new practices as a consequence. One specific example of this applies to insurance coverage for projects using mass timber. During the lifecycle of a development project there are typically three distinct areas in which insurance is needed. The first is a property insurance policy that will cover the project through the construction period of the development with coverage not to exceed the hard cost budget of the project. The second is a liability policy that will cover the job site itself and contain specific provisions that are negotiated with the general contractor. The third need is for the building itself upon completion and stabilization of the project. Working with an insurance broker that understands these specific needs and the unique characteristics of mass timber is vital to securing adequately priced policies that provide the right level of coverage. There is risk in the possibility of receiving policies that reflect higher insurance premiums and a greater cost burden on the project if the presence of wood is associated with traditional wood-frame construction as opposed to mass timber. This is because products such as cross-laminated timber have been proven through rigorous testing to externally char and maintain their structural integrity in a fire situation.

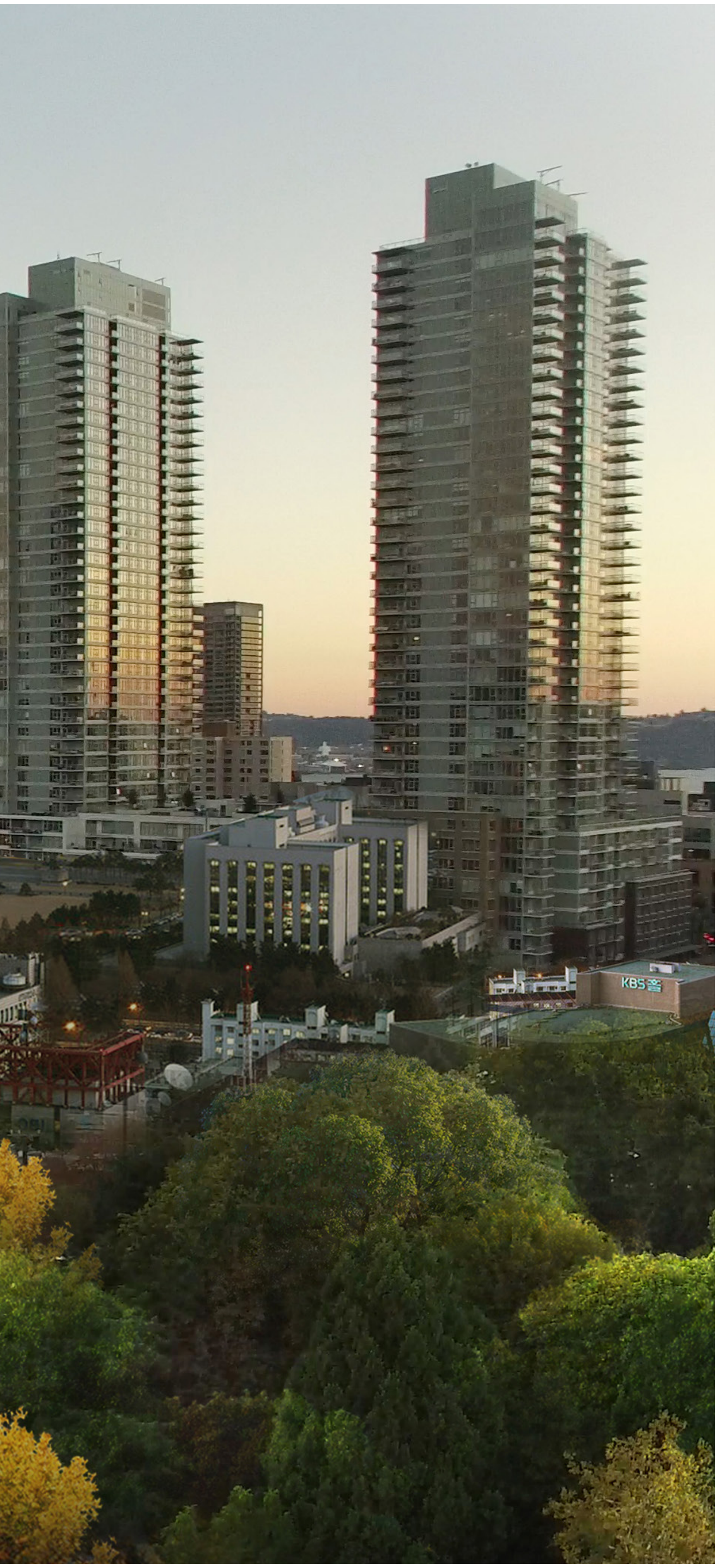
The question of operating costs of completed mass timber buildings is key for developers and owners to consider and work to better understand. As is the case with emerging technologies, the data available around building operation of mass timber projects is minimal. The working hypothesis is that mass timber constructed buildings will be more efficiently operated and maintained, offering a cost savings over traditional materials. For example, the current operating expense (OPEX) that a tenant bears within a traditionally constructed concrete and steel office space on a net lease in the Seattle market is $15 per rentable square foot. If a mass timber constructed building can offer a lower OPEX of $10 to $12 per square foot, the economic advantages will make the space more attractive to users. The task at hand is gathering data to prove this premise for the benefit of the broader market.

Competitive Advantages

Connor McClain of Colliers in Seattle, recognizes the competitive advantage presented by office space constructed from Mass Timber. Even with limited market data available, he believes that the initial advantage of Mass Timber office projects in Seattle will come through the leasing velocity that developers will experience. The industry term, leasing velocity, refers to the overall interest that is experienced from potential tenants and the number of leases that a developer secures on behalf of their project. Organizations and companies seeking newly constructed office space will be drawn to the positive environmental attributes, the improved aesthetics, the unique characteristics, and sense of innovation that is embodied in the space through the use of Mass Timber materials. These dynamics may translate to higher lease rates for Mass Timber developments as compared to those constructed from traditional materials of concrete and steel which in the current end of 2018 market lease for $45.00 - $49.00 per square foot “NNN”. Connor McClain frames the potential for Mass Timber constructed office space stating, “it is highly likely there will be a premium for Mass Timber constructed office space within the leasing market. The unique nature of the product has the ability to generate additional value within the lease rate on a dollar per square foot basis. From a tenant perspective, there are environmental benefits from the use of natural materials, employee health advantages and a perceived sense of leadership on behalf of the company through a new cutting-edge material and design.”

Fig. 23 | SMTT | Street View of the Northeast Elevation

Fig. 24 | SMTT | Seattle Skyline View



ARCHITECTURAL DESIGN

Change in Climate and Climate Change

Trees are one of the longest standing resources for building material in existence, with evidence pointing to structures built over 10,000 years ago that used timber as a primary source for construction. European and Asian civilizations were extremely advanced in their knowledge and use of different types of wood and developed a full range of methods for interlocking wooden components according to the type of wood, function and application, replacement cycles, and the system of the structure. An example is the nine-story, 220-foot tall wooden pagoda of Yingxian, Shanxi, in China. The octagonal structure is made from 54 different types of wood joints; not a single piece of metal was used in the joinery of the structure.

Climate change is creating new levels of awareness and urgency for change in the way we assign value, pursue opportunities, conduct business, and design for clients. In contemporary design and construction, many traditional wood components and joinery systems have been replaced with engineered wood composites and joinery of concealed metal fasteners to facilitate post-industrial economies of scale, manufacture and fire and life safety. The excitement of mass timber design and construction is fueled by the emerging economic advantages, a shift in manufacturing and supply chains and new code legislation that now render engineered wood as cost competitive with more conventional types of construction such as concrete and steel. The underlying health benefits of exposed timber surroundings have been scientifically proven in physiological and psychological dimensions. Sustainable design is design that's good for the earth and the people, or, as Dr. Tracy Brower, author of *Bring Work to Life by Bringing Life to Work*, said in an article earlier this year. "There's an opportunity to shift the conversation from space as a cost versus space as an investment," Bower commented. "When we do the right things for people, we get amazing outcomes for the organization, and space is one of the levers we can pull to create the right experience for people."

A New Design Aesthetic

In North America, mass timber materials and assemblies of engineered wood systems are creating an opportunity to rethink form and function, maybe even to develop a new design language. New words can be "invented", and a new vocabulary applied in its process. A new design aesthetic can be explored, one that speaks to experimentation, lightness, beauty of natural, high-performing materials and the grace of authenticity.

The form and massing of our Seattle Mass Timber Tower result from the proportion of our site parcel, accentuating and juxtaposing soft, curvilinear shapes and culminating, pointed forms. The tower maximizes opportunities for exposed wood surfaces on the interior beams, columns, walls and ceilings, and expresses these components through transparent and translucent expanses of the enclosure system. The formal language of dovetail and interlocking shapes of the enclosure is a subtle reference to the formal timber aesthetic of finger and dovetail joinery.

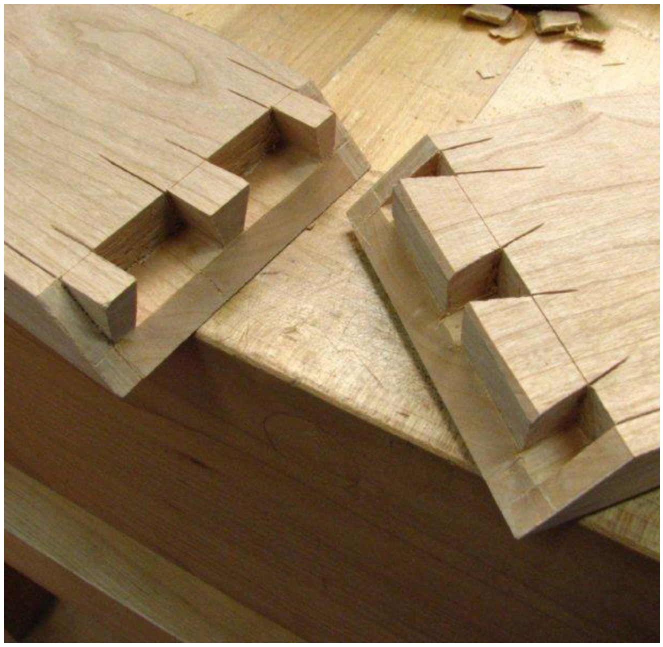


Fig. 26.1 | Jointing Concept

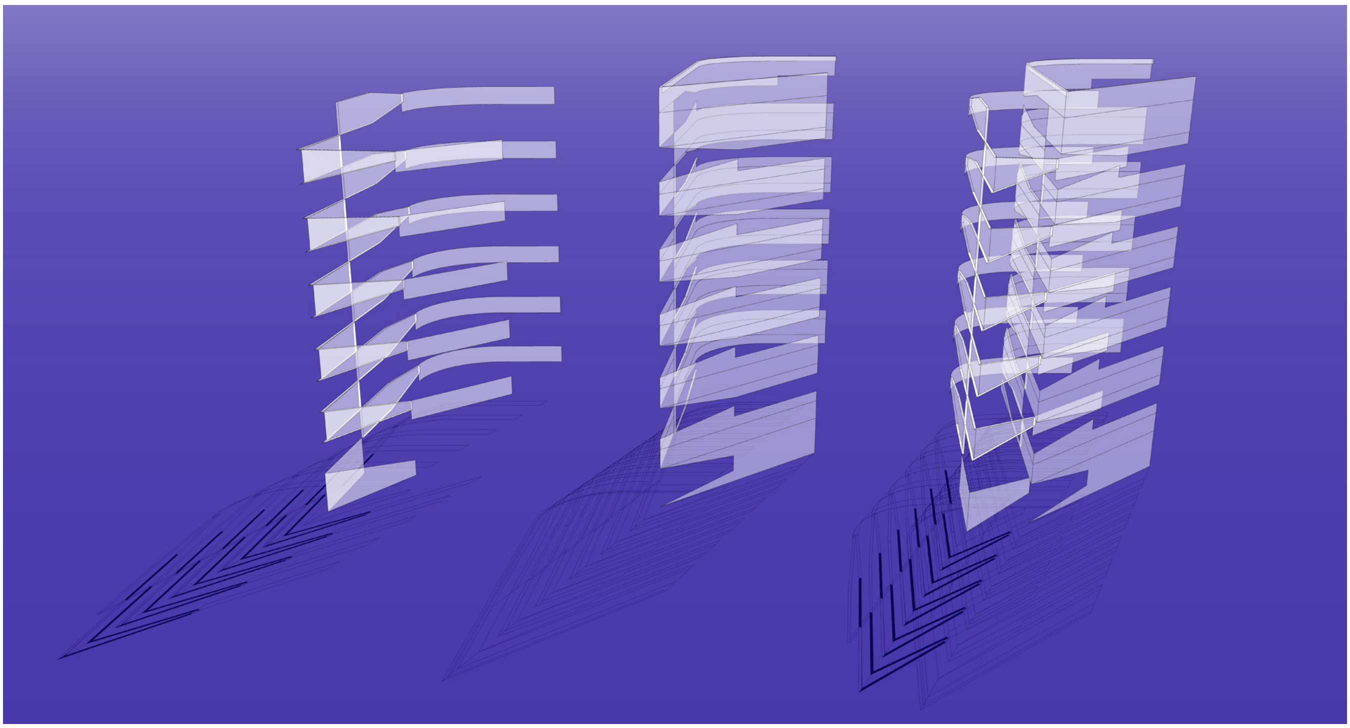


Fig. 26.2 | SMTT | Exterior Enclosure Concept

Fig. 27 | SMTT | Model Close-up of Jointing Expression

Street, Roof Top and Atria

The streetscape has been carefully designed to maximize pedestrian activities and safety, and to increase the visibility of street level retail. An adjacent, vacant parcel is proposed as a park, an extension of Denny Park. The park anchors the memory of the place as manifested by a shimmering red pine cone sculpture surrounded by a small formation of trees. The roof top garden and bar of the building offers expansive views. It is a vertical extension of the park and is publicly accessible.

Facing Denny Park, Lake Union and Mount Baker, a series of three- and four-level atria, “Tech Rooms”, provide informal meeting and lounge areas for the office and hotel floors, and serve an organizing element for the tower. The character of the atria emphasizes the natural beauty and seemingly arbitrariness of tree configurations in a forest. Slanted tree columns create a relationship with the horizon line to the north and serve as support structure for the atria decks.

Fig. 28 | SMTT | View of Activated Street Level

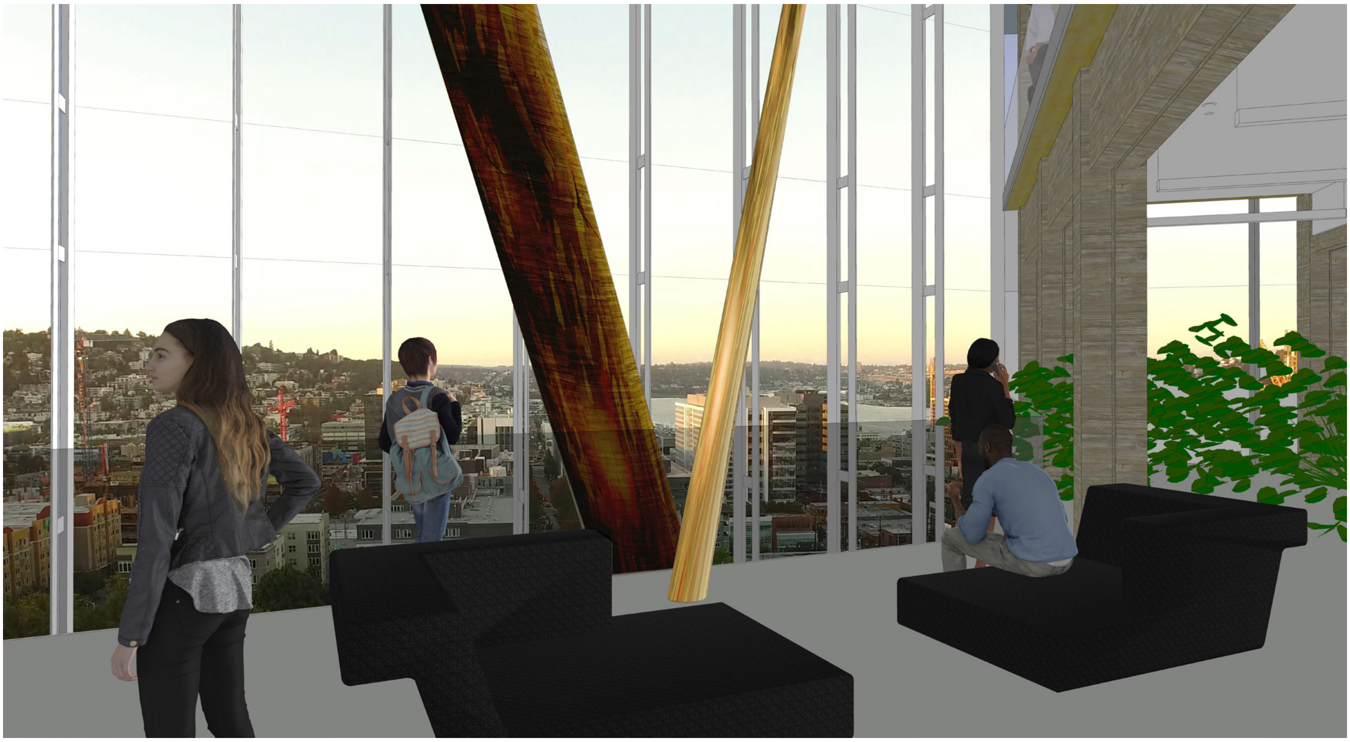


Fig. 29.1 | SMTT | Interior Atrium with Scenic Views

Fig. 29.2 | SMTT | Interior Atrium View

Exterior Enclosure and Shading

The exterior enclosure consists of a curtain wall system. The cost model reflects a standard, thermally-broken aluminum system. Alternatively, the panels could be fabricated with high-performance, composite wood-aluminum framing. Two types of vision glazing are proposed, a) transparent, charcoal-tinted glazing and b), translucent, frosted glazing. For energy-code compliance of the enclosure we are targeting a performance-based window-to-wall ratio of 40 percent.

The south-west elevation of the building experiences significant solar heat gain and associated solar glare from the westerly sun path across the Puget Sound. Both the potential for heat gain and glare are mitigated with a seemingly delicate but robust system of exterior shading devices; a lattice work of suspended, cedarwood-type extrusions that are mounted to the curtain wall with gently curving pairs of steel branches.

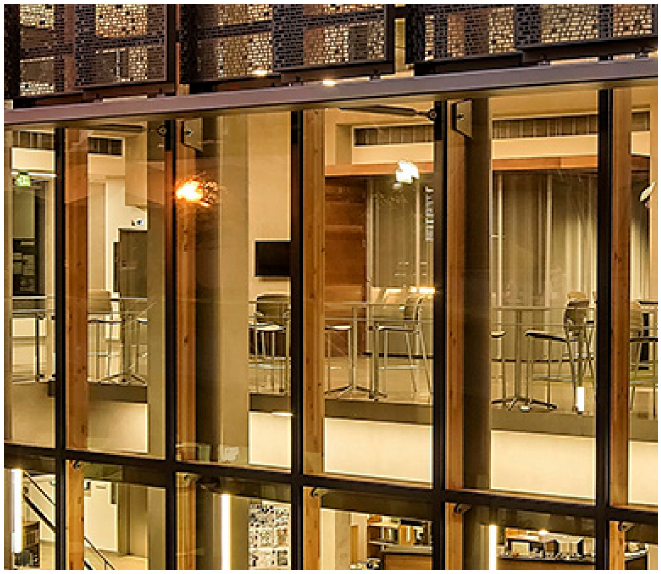


Fig. 30.1 | Expressive Wood Framing for Glazing

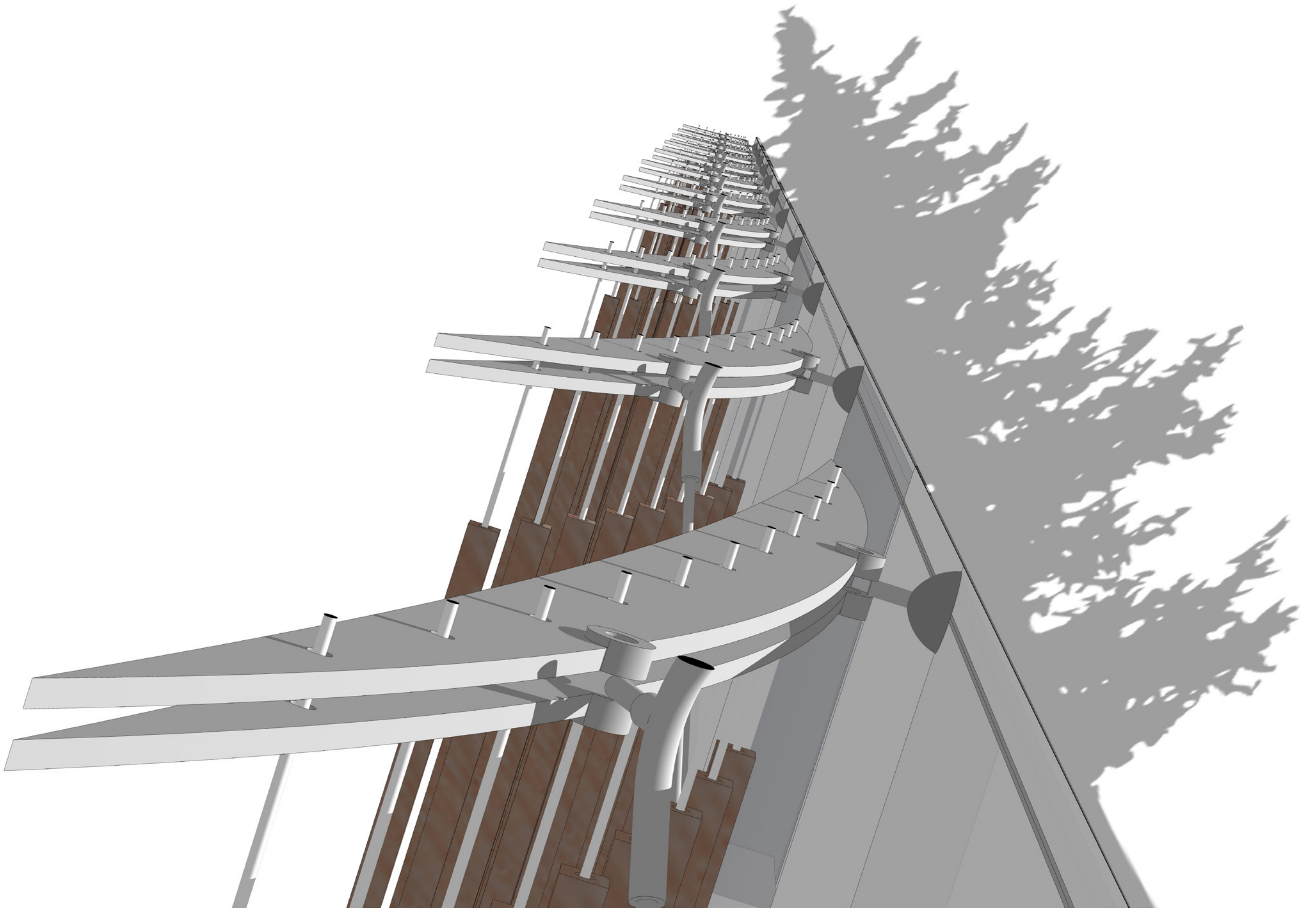


Fig. 30.2 | SMTT | Exterior Shading Design Concept

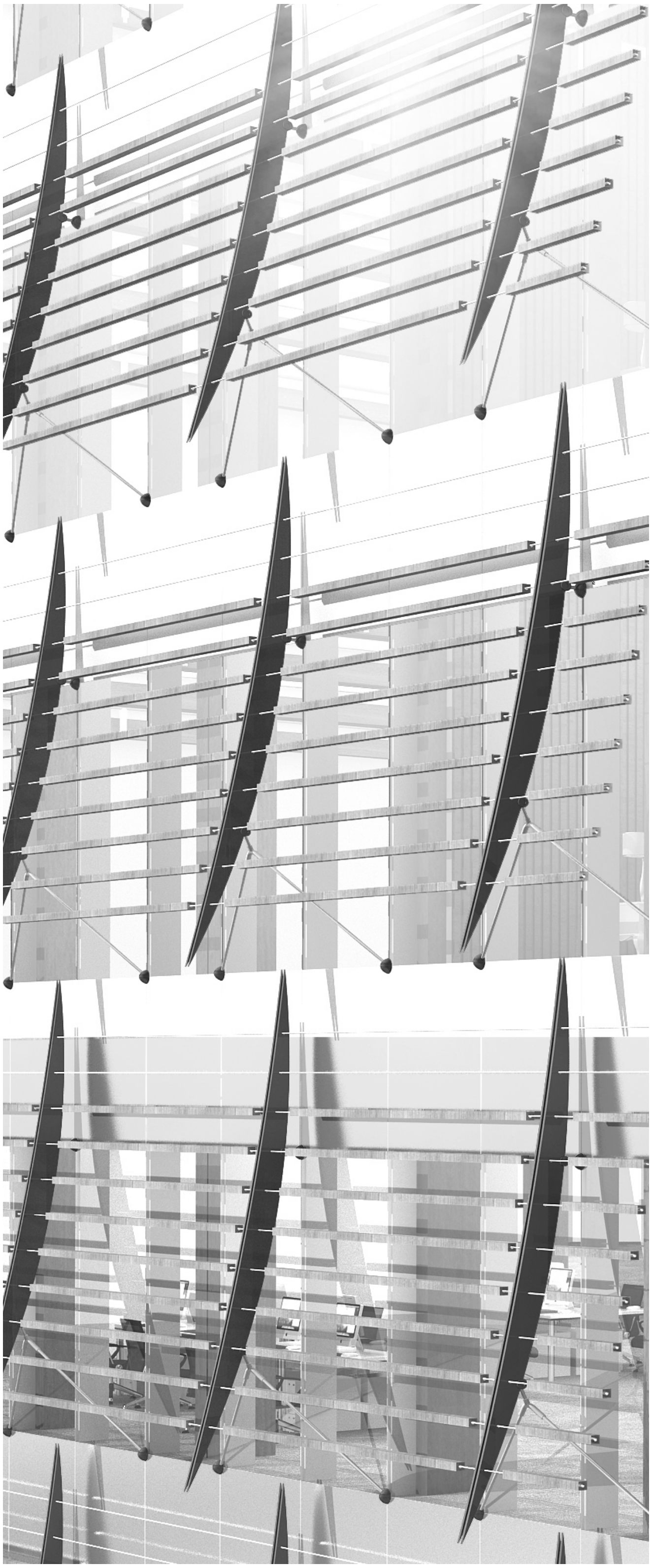


Fig. 31.1 | SMTT | Exterior Shading Close-Up

System Design

The system design for structure and MEP follows a tight rational path to ensure both maximum standardization that allows for economy of scale in various applications and a building form that is adaptable to irregular site parcel configurations and/or design aspirations of individualized proportion and formal expression. For example, the curvilinear form of the building is designed to work in concert with structural standardization, economies of manufacture, program requirements and architectural fit.

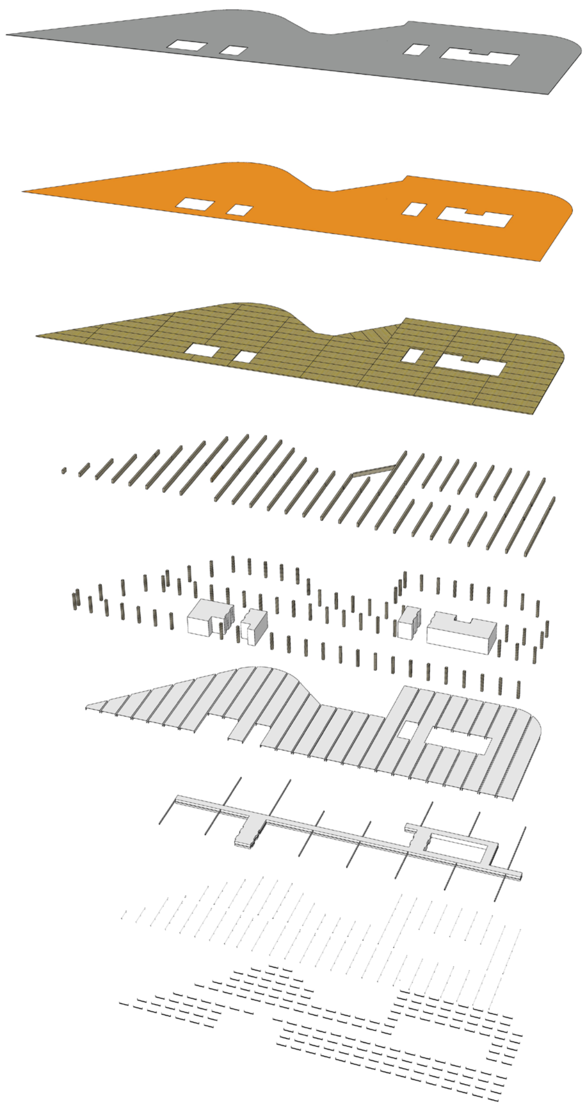


Fig. 31.2 | SMTT | Systems Diagram

ARCHITECTURAL DRAWINGS & STATISTICS

Fig. 32.1 | SMTT | View Section A

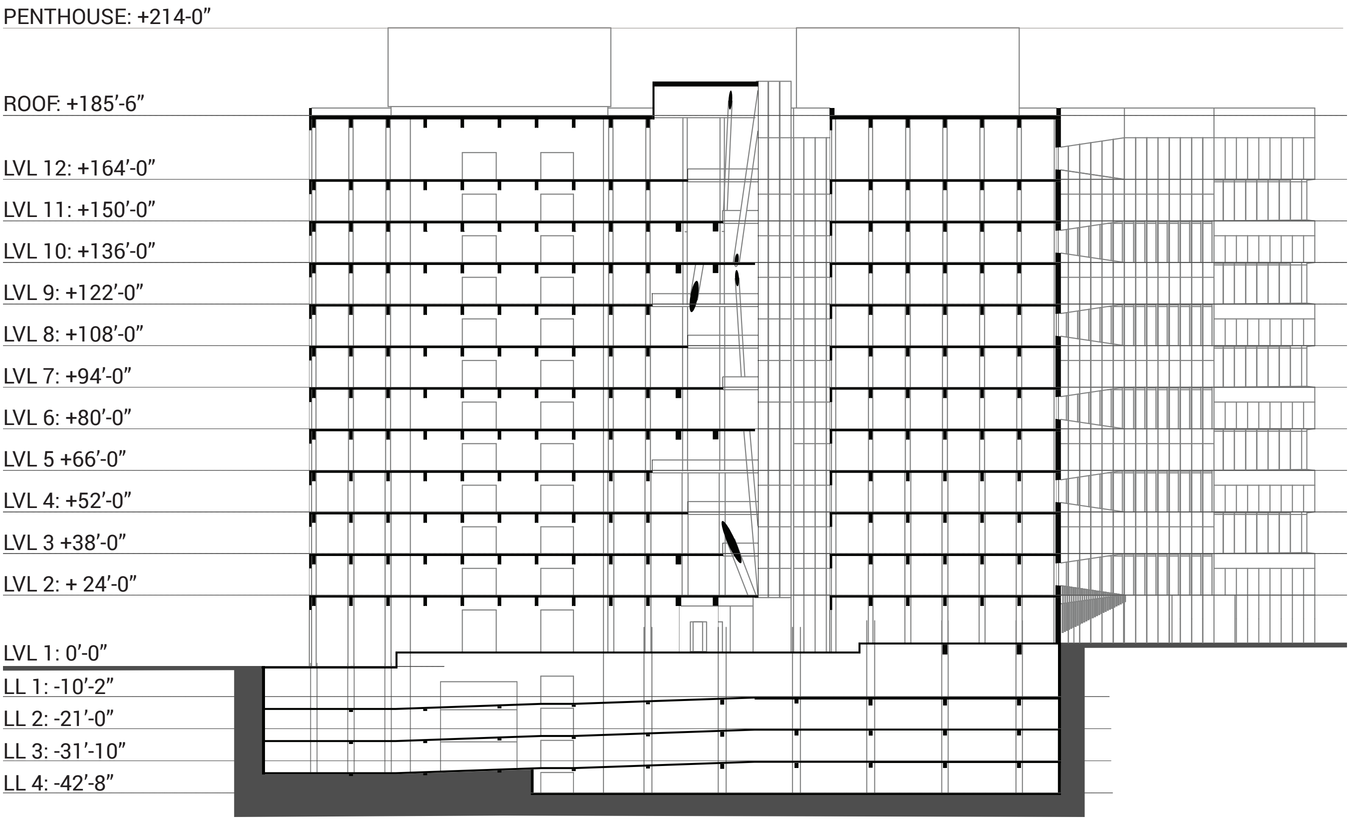


Fig. 32.2 | SMTT | Section B | 1”=60’ scale

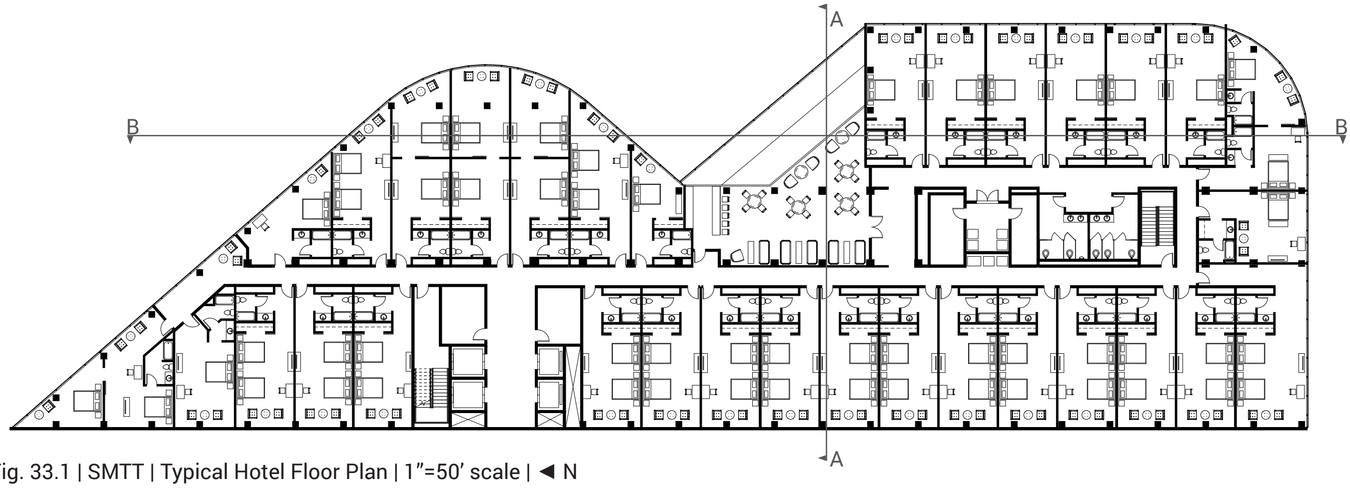


Fig. 33.1 | SMTT | Typical Hotel Floor Plan | 1″=50′ scale | ◄ N

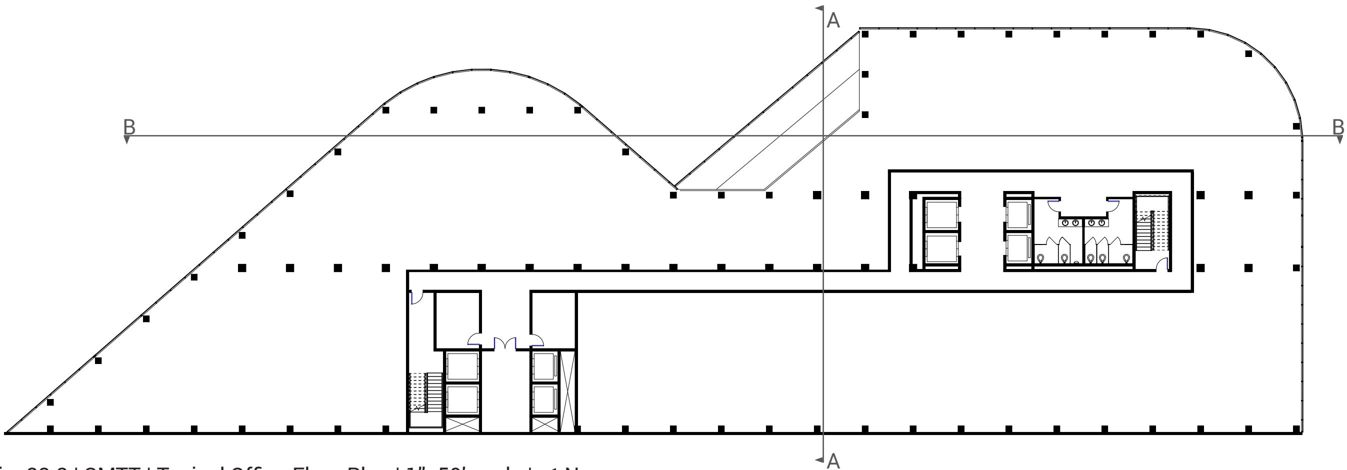


Fig. 33.2 | SMTT | Typical Office Floor Plan | 1″=50′ scale | ◄ N

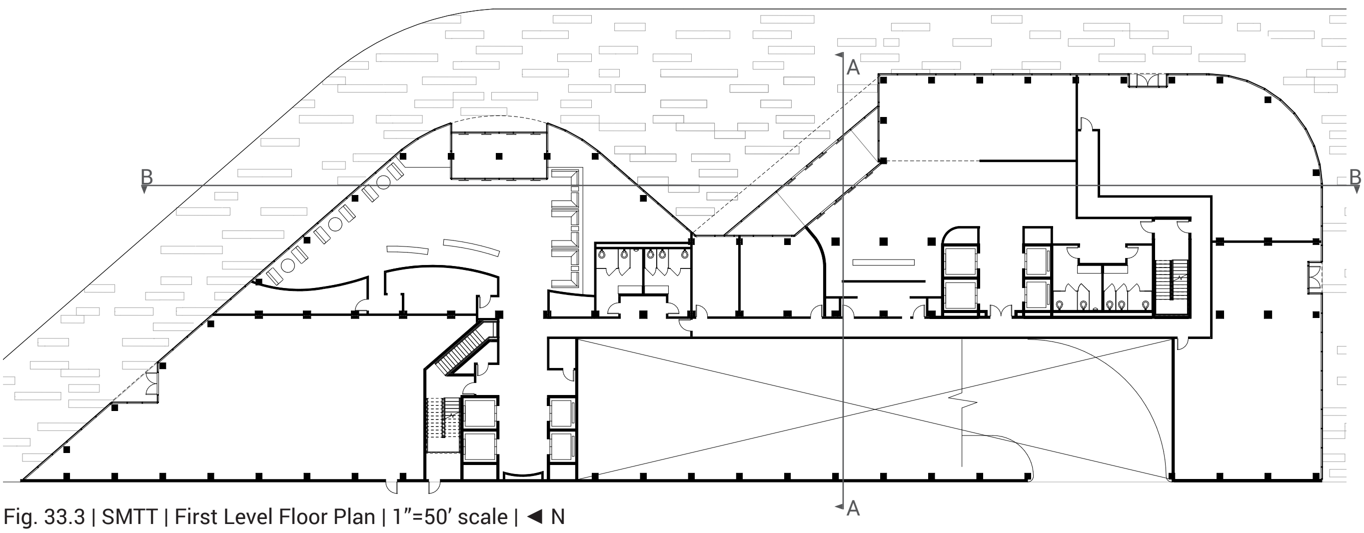


Fig. 33.3 | SMTT | First Level Floor Plan | 1″=50′ scale | ◄ N

Site Area: 34,960 SF
FAR Allowed: 8

Floor	Program	Total GSF	Common Program Space Deduction	Rentable Square Footage
12	Hotel	25,800	9.19%	23,429
11	Hotel	25,800	9.19%	23,429
10	Hotel	25,800	9.19%	23,429
9	Hotel	25,800	9.19%	23,429
8	Hotel	25,800	9.19%	23,429
7	Hotel	25,800	9.19%	23,429
6	Office	25,800	9.19%	23,429
5	Office	25,800	9.19%	23,429
4	Office	25,800	9.19%	23,429
3	Office	25,800	9.19%	23,429
2	Office	25,800	9.19%	23,429
1	Retail/Office & Hotel Lobby	20,811	6.07%	8,595 Retail (19,548 total)
		304,611		**277,267**

Stall Count Calculation	Stall Count
Hotel Stalls @ 1.0/4 Rooms:	48
Retail Stalls @ 2.00/1000 GSF:	42
Office Stalls @ 1.0/1000 GSF:	103
Total Minimum Stall Count:	**193**
Required Bike Parking:	**24**

Floor	TOTAL GSF	Stall Count
P-1	32,330	46
P-2	32,330	80
P-3	32,330	82
P-4	22,574	55
	119,564	**263 Actual**

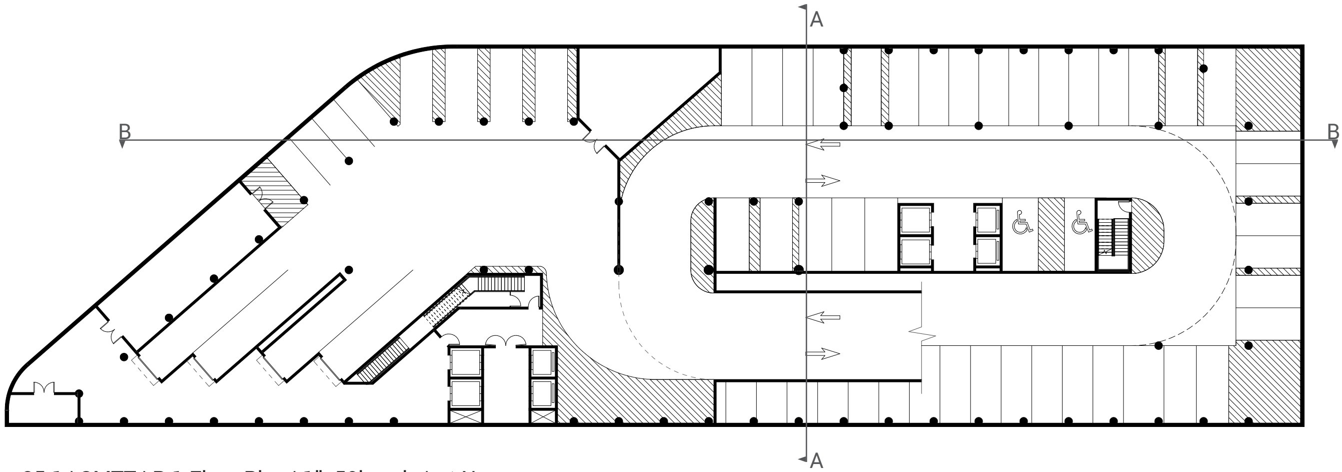


Fig. 35.1 | SMTT | P-1 Floor Plan | 1″=50′ scale | ◄ N

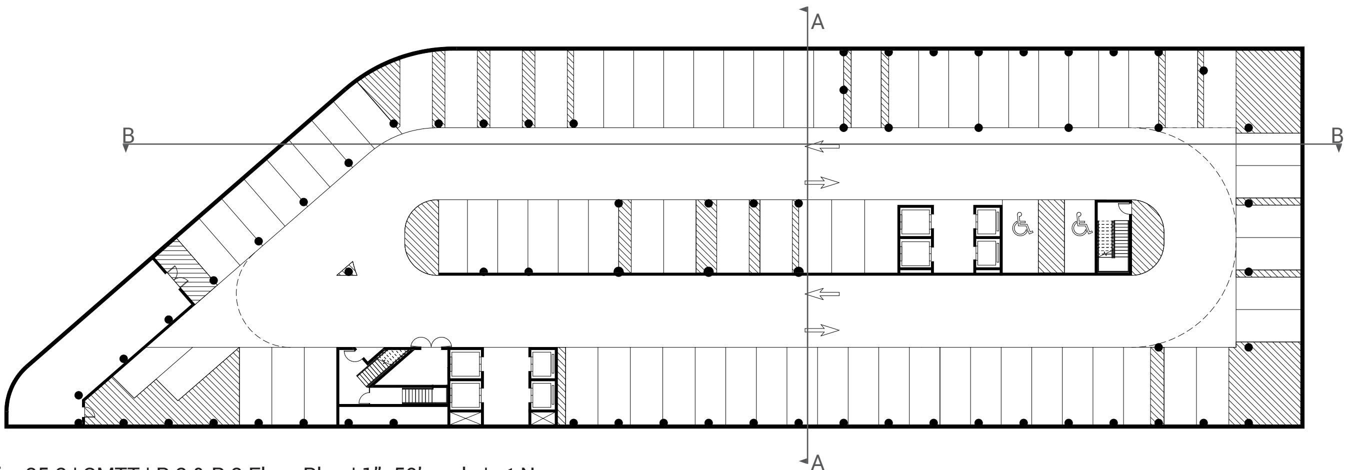


Fig. 35.2 | SMTT | P-2 & P-3 Floor Plan | 1″=50′ scale | ◄ N

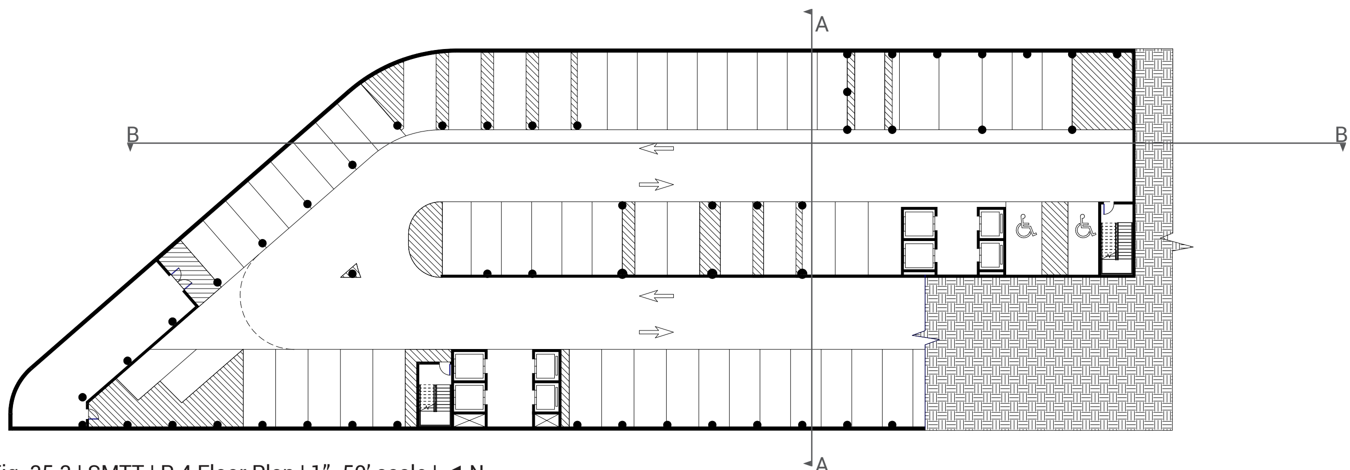


Fig. 35.3 | SMTT | P-4 Floor Plan | 1″=50′ scale | ◄ N

MODEL PHOTOS

Fig. 36.1 | SMTT | Model | View from the Park

Fig. 36.2 | SMTT | Model | Aerial View of Southwest Facade

Fig. 37 | SMTT | Model | Corner Detail

STRUCTURAL SYSTEMS, COMPONENTS & PERFORMANCE DESIGN

Structural Design

The Seattle Mass Timber Tower structure consists of a logical, restrained response to the building massing and floor plate geometry that also integrates well with architectural requirements, MEP systems, and constructibility considerations. Our team's primary goal is to create a tall timber building that is efficient, simple, and therefore cost-competitive.

A concrete baseline structure, more traditional and more common in Seattle, is used as a baseline comparison with the timber tower. Both buildings are approached with an open mind and the goal of material optimization to ensure a healthy comparison between timber and concrete for this building.

Design Criteria

Since the SMTT falls under the proposed IBC Type IV-B construction type, the entire project, including the structural systems, must fall under 2018 code versions to meet the current code modification requirements set forth by the City of Seattle. Therefore all structural studies, analysis, and design are carried out using this material to ensure the design meets these future code requirements, and more specifically, the increased lateral seismic loading in the latest version of ASCE 7, which will impact lateral system costs. A preliminary lateral analysis indicates that the seismicity will govern over wind for the lateral design.

Foundations

While no geotechnical report is currently available for the site in question, our process includes examining two relatively recent reports from nearby construction sites and extrapolating their findings to obtain some reasonable first-pass assumptions.

At the expected footing elevation and based on the reports used, we anticipate very dense sand and gravel to be encountered, and for this material we assume an allowable bearing capacity of 8ksf. Our expectation is that the liquefaction potential at this site is low, as is lateral spreading and vertical differential movement.

Therefore, we expect the seismic Site Class to be C, though given the high-level nature of this study we assumed Site Class D for both the timber and concrete structures. If it is determined with a site-specific Geotechnical report that the site is in fact C, this will result in concrete material savings for both the timber and concrete schemes.

Superstructure

The superstructure for the timber building is composed of 5-ply CLT floor plates forming the roof and floors over dropped glulam beams and glulam columns.

One of the best ways to achieve material efficiency with CLT is to use as much of a standard off-the-press panel (which is approximately 10'x40' in the Pacific Northwest) as possible and ensure the layout grid does not depend on the panels being exactly 10'-0" wide, since different suppliers have slightly different overall panel sizes.

This approach is used by our team, and further, the panels typically span three-span continuous, resulting in enhanced deflection, strength, and vibration performance compared to a simple single span arrangement. The multi-span approach also reduces the number of crane picks required on site, further enhancing speed of erection.

The grid spacing used also ties directly into this conversation. A 12'-6" bay allows us to use a single panel that is 37'-6" long to span three bays. Had we used a larger or tighter grid spacing, material efficiency would have been lost. By starting with fundamental, simple parameters like standard panel sizes at the beginning of the design, we can fully optimize the use of mass timber.

At the outside portions of the floorplate, the columns are spaced at 42' with 14-1/4"x34" glulam beams spanning in between. Supporting columns vary in size from 16"x16" at the upper levels to 24"x24" at the lower levels down to grade.

Typically, a high performance steel beam hanger system is used throughout the structure to connect the beams to the columns. The hangers used create a sliding dovetail joint between the columns and beams with installer-friendly tolerances. They feature a simple and repetitive installation with drop-in assembly on site. The other benefit of these connectors is that they are not visible once the installation is complete, so they perform well from an appearance standpoint, and with the wood surrounding them they are naturally fire-rated.

The atria framing is achieved with long-spanning diagonal drop beams and stiffening steel struts arranged in a repetitive manner. The atrium glazing itself is hung from a deep joist girder at the roof level, with the floor plates every 4th floor controlling out-of-plane movement. Another option that currently exists is the integration of the oblique atria tree columns as part of the load-bearing system of the atria floors. Since the columns are there it is reasonable to explore the feasibility of their use in this manner, with the potential benefits including reduced beam sizes and improved floor vibration performance.

The concrete baseline structure is imposed on the same overall floor footprint as the timber structure, but instead of forcing the same column spacing (which would result in a relatively uneconomical PT design), additional columns are added to allow for flat plate construction on all elevated levels. The PT slab is 8" thick on all floors, and generally spans a 21' x 25' grid, so it is relatively highly utilized and has been priced accordingly. The columns range from 14" Ø at the upper floors to 22" Ø at the lower levels down to grade.

For both the timber and concrete structures, transfer beams are employed at grade and in select locations on the first upper level and first lower level to resolve the vertical load path and transition the grid to accommodate the parking. Below grade, both structures feature mild-reinforced concrete slab with drop beams and columns.

Based on the foundation assumptions presented above, shallow strip and raft footings are used for the timber and concrete structures, with the latter featuring footings that are 20-30 percent larger due to material weight.

Seismic Resistance

As with any building in this region, seismicity and lateral resistance is a significant consideration during design. Earthquake forces are unique in that they are derived not only from the horizontal movement of the building, but also the weight of the building itself.

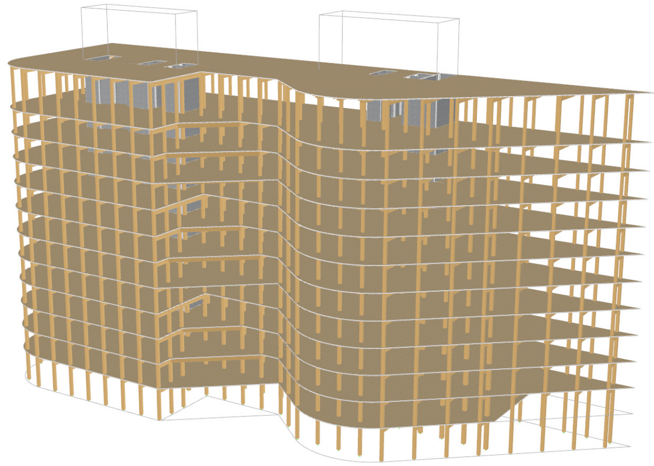


Fig. 39.1 | SMTT | Global Structure

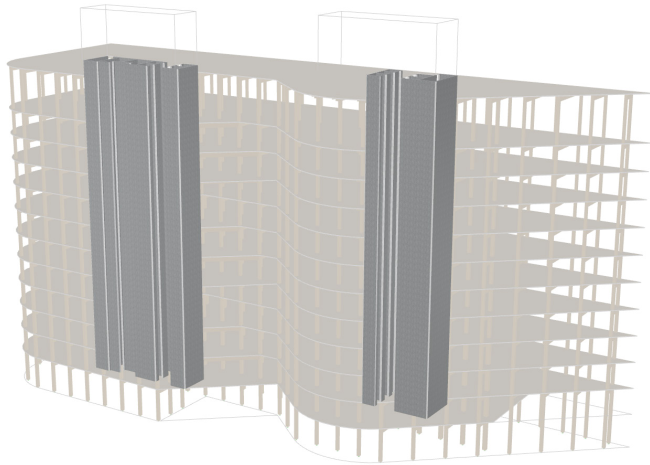


Fig. 39.2 | SMTT | Concrete Cores

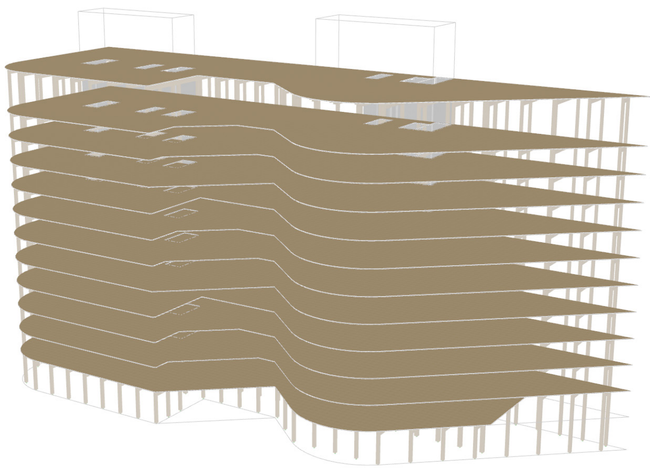


Fig. 39.3 | SMTT | CLT Floor & Roof Components

Therefore, there is significant incentive to reduce a building's weight if one wants to reduce the amount of seismic forces that need to be resisted, since this in turn reduces the amount of shear wall required, size of the footings, and amount of onerous detailing.

Since timber is much lighter than concrete, the Seattle Mass Timber Tower imposes a relatively small load on the lateral force-resisting system, which in turn results in measurable material savings.

The lateral capacity of timber and concrete buildings is primarily achieved with concrete shear walls that run continuously from the footings to the penthouse.

A primary objective of this project is to create a timber building that takes advantage of local and national code development around mass timber while not exceeding prescriptive requirements to trigger time consuming peer reviews under alternate methods and materials provisions of the building code.

Therefore, and in part due to the building geometry and shear wall layout, CLT shear walls are not used. While steel brace bays offered an enticing alternative to concrete shear walls (for one because they could in theory be installed in parallel to the mass timber, perhaps by the same crew), the stiffness that they provide for this floor plate geometry and vertical lateral force-resisting system layout is not adequate.

The main difference between the timber and concrete structures in terms of shear walls is the thickness: for the relatively lightweight timber structure, on average 14 inches thick concrete shear walls are adequate, and for the more robust concrete structure on average 16 inches thick concrete shear walls are required. This comparison was carried out using a concrete compressive strength of 5000 psi.

A unique aspect of the timber structure is the diaphragm that is used at the roof and elevated floor levels: the 5-ply CLT has plenty of capacity to resist the in-plane forces that will develop due to seismic loading and transfer these forces to the concrete shear walls. A simple plywood spline is employed to connect the panels and achieve the required global behavior.

However, an existing limit set forth in the Special Design Provisions for Wind & Seismic by the American Wood Council, a document that governs the design of timber elements under wind and seismic loading, limits the distance a horizontal floor or roof wood structure panel sheathed diaphragm may extend out beyond a shear wall to 35 feet.

While this is written with plywood and OSB sheathed diaphragms in mind, and is likely inappropriate to apply to mass timber CLT diaphragms, in order to not trigger the previously-mentioned peer review of the structure, simple steel plate is specified to be installed on top of the CLT at key locations to act as horizontal trusses and effectively limit the maximum CLT diaphragm cantilever length to less than 35 feet.

It could be that the authority having jurisdiction will not demand the plywood geometry limit be applied to CLT, but in the meantime while we wait for the codes to catch up with all the possibilities of mass timber, our

Fig. 40 | Integration of Mass Timber and Steel | The Library at the Dock | Docklands, Australia team has opted to include steel plate cross bracing in exchange for a longer and more costly design phase.

Fire Safety

There are two main materials present in the primary structure that could be exposed to flame in the event of a fire: concrete and timber.

As discussed previously, concrete shear wall cores are used in the SMTT to provide the required stiffness and strength to resist lateral loading, and they also simplify the fire-protection strategies required at the cores due to concrete's inherent fire resistance.

Beyond the cores, however, the rest of the above-grade structure is timber, so careful consideration is given to fire safety and code conformance in these areas.

With the City of Seattle's acceptance through code modification of the new tall timber construction types ahead of the national code cycle, our team has clearly defined fire safety requirements that are to be met in terms of protecting the primary timber structure.

The Seattle Mass Timber Tower falls under the Type IV-B category, so all primary structural elements must meet a 2-hour fire resistance rating except the roof, which has a 1-hour requirement. In addition, an area of the ceiling equivalent to 20 percent of the floor area may be left exposed while the remaining area must be protected with a non-combustible material.

To achieve this requirement, a large portion of the ceiling structure is covered with gypsum board. The bottom portion of the glulam beams, a strip of CLT floor plate around the building perimeter, the timber framing in the atrium space on all levels left exposed.

While mass timber has an inherent capability to resist fire by covering it with gypsum as the prescriptive code language dictates, we are eliminating the need for a performance-based, alternate method fire safety approach which would include more costly, drawn-out design process.

The timber columns throughout the structure have been designed to resist a 2-hour fire rating. This is achieved by oversizing the members to provide what is essentially a sacrificial wood layer that can safely ignite in a fire event, form a char layer, and protect the structural core of the column to maintain life safety and structural integrity in a rare case where the sprinkler system does not activate for a fire event.

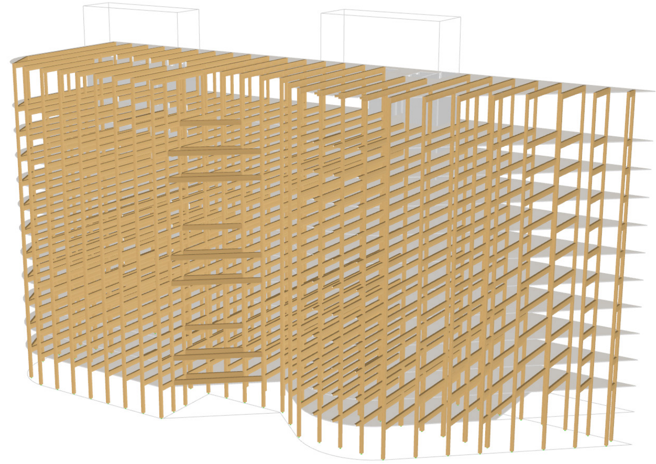


Fig. 41.1 | SMTT | Beams & Columns

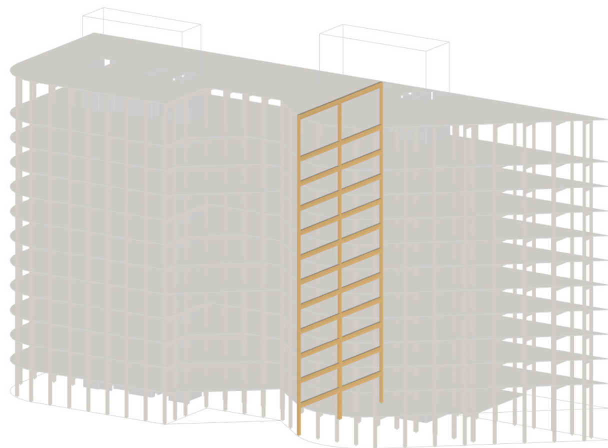


Fig. 41.2 | SMTT | Typical Beam & Column Bay

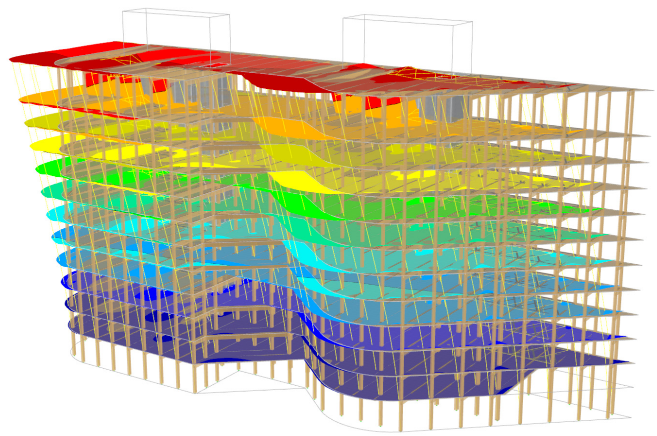


Fig. 41.3 | SMTT | Seismic Loading Lateral Deformation

STRUCTURAL DRAWINGS

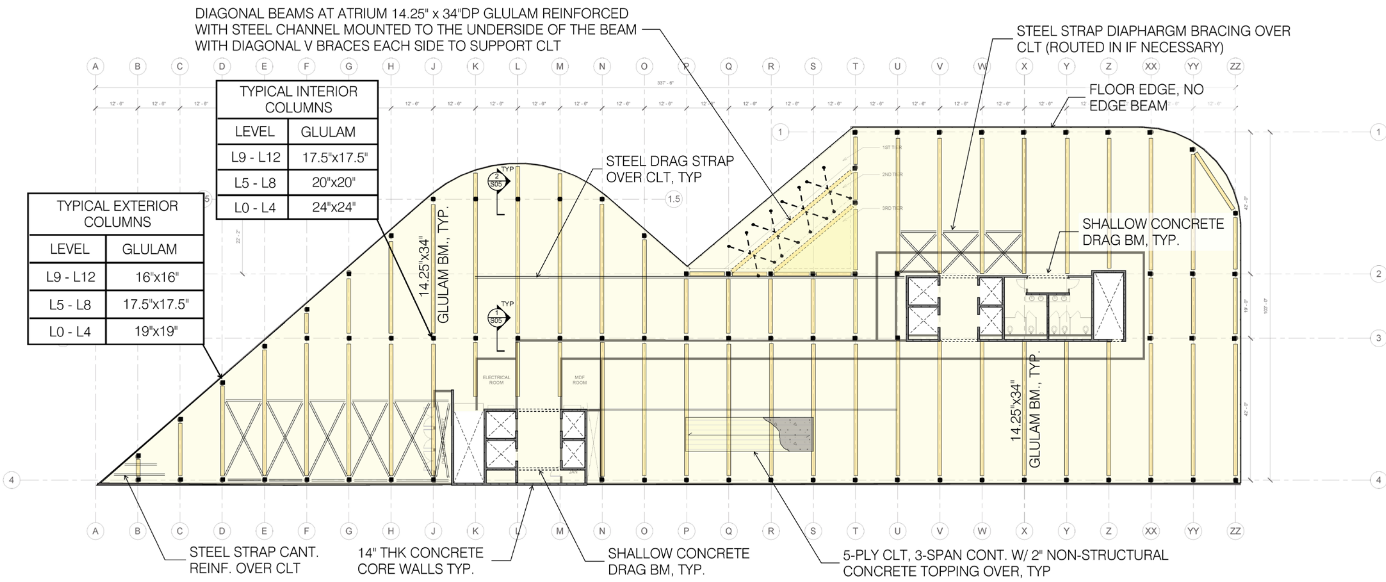


Fig. 42.1 | SMTT | Typical Framing Plan | ◄ N

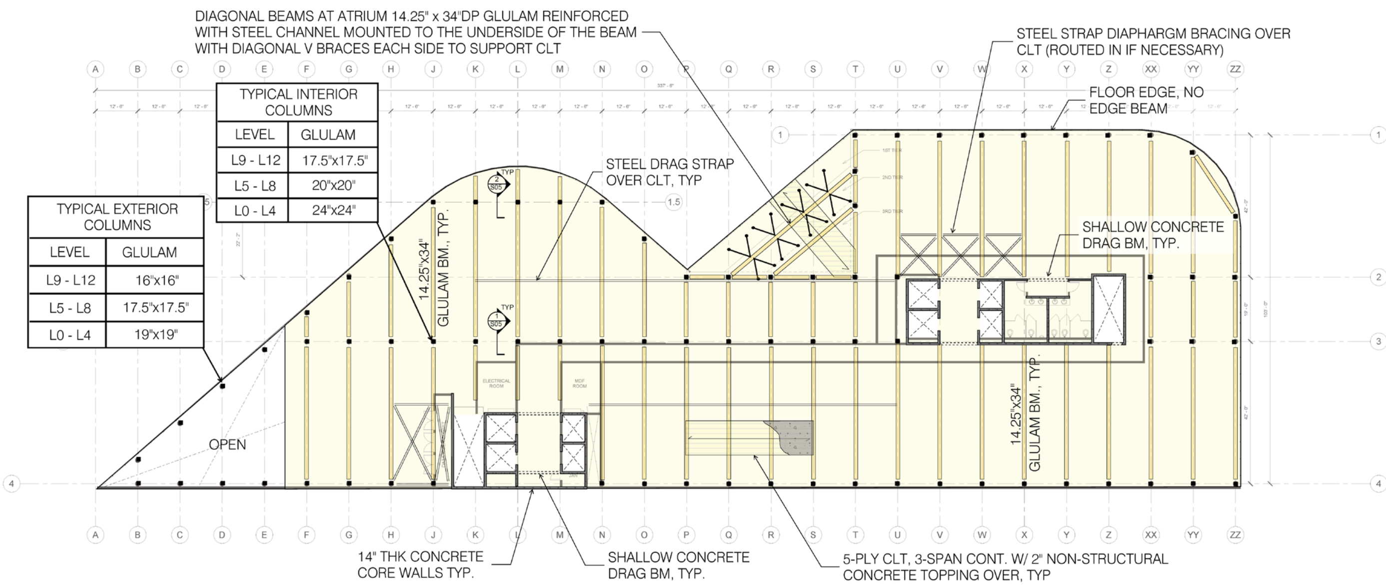


Fig. 42.2 | SMTT | Second Floor Framing Plan | ◄ N

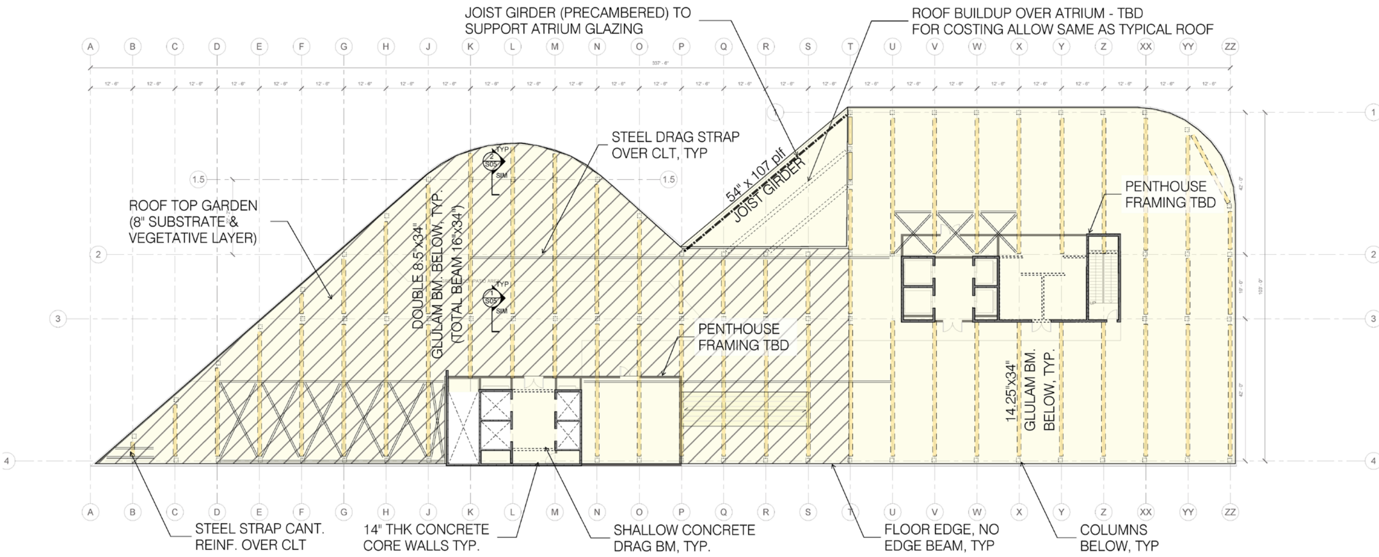


Fig. 43.1 | SMTT | Roof Framing Plan | ◄ N

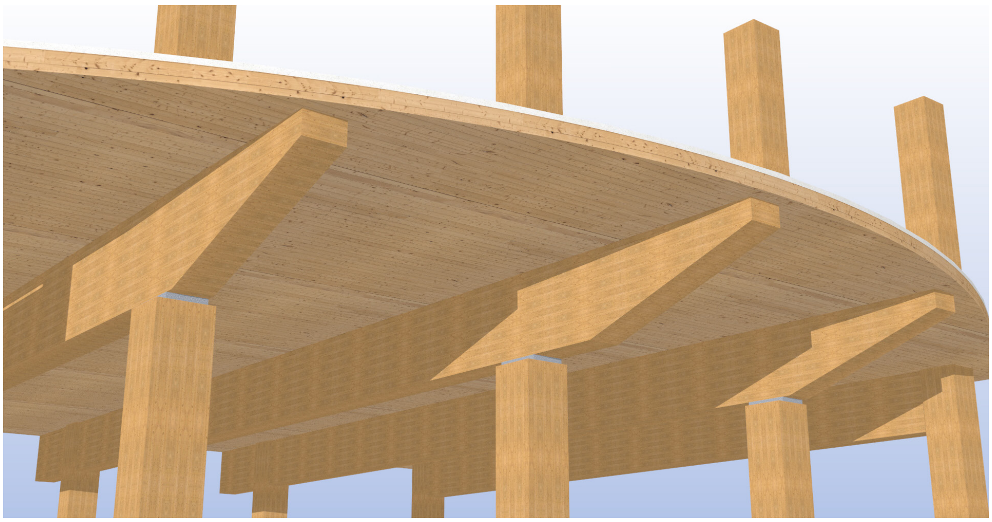


Fig. 43.2 | SMTT | Cantilevered Glue-Laminated Beams

See Appendix A for Baseline Concrete Drawings

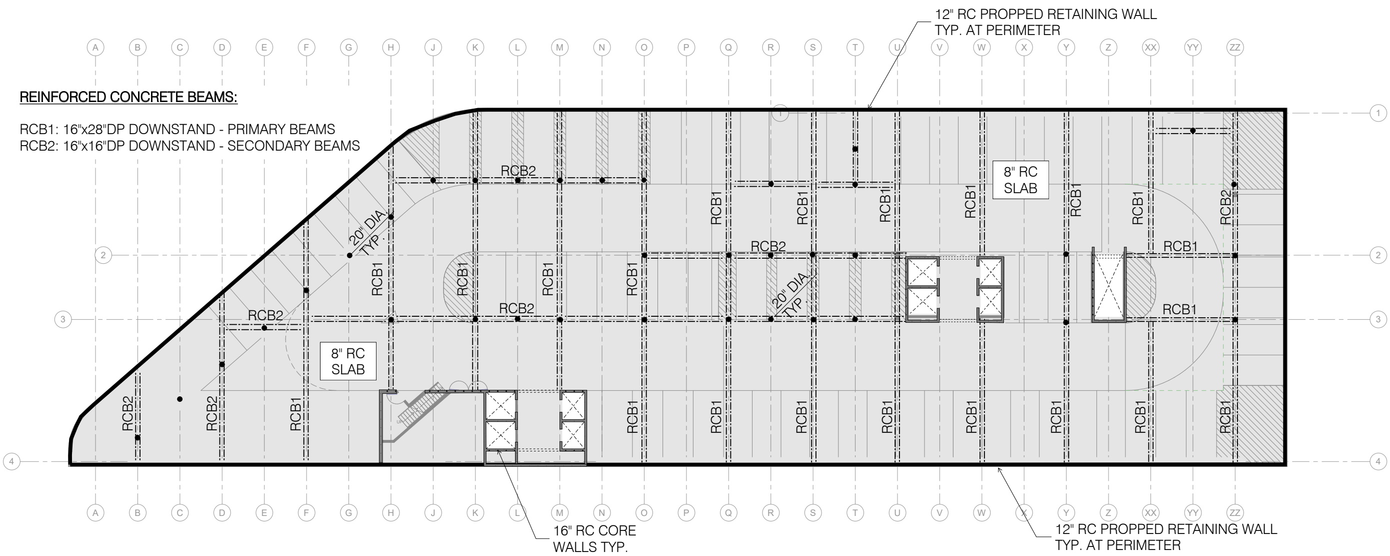


Fig. 44.1 | SMTT | P-2 & P-3 Framing Plan | ◄ N

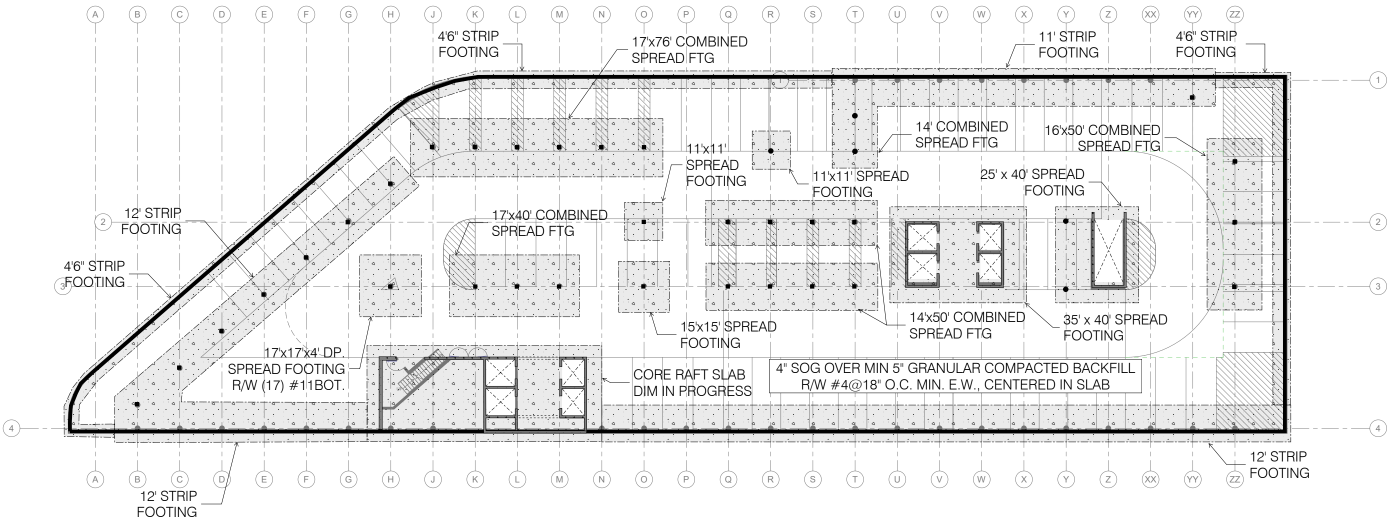


Fig. 44.2 | SMTT | Foundation Plan | ◄ N

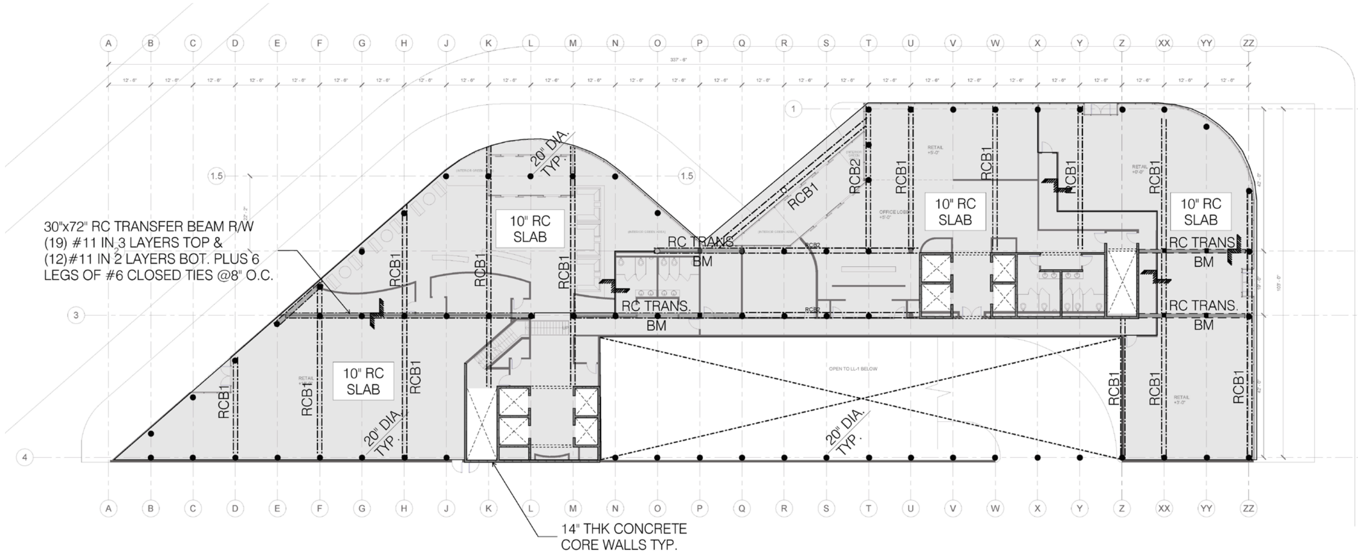


Fig. 45.1 | SMTT | First Level Structure Plan | ◄ N

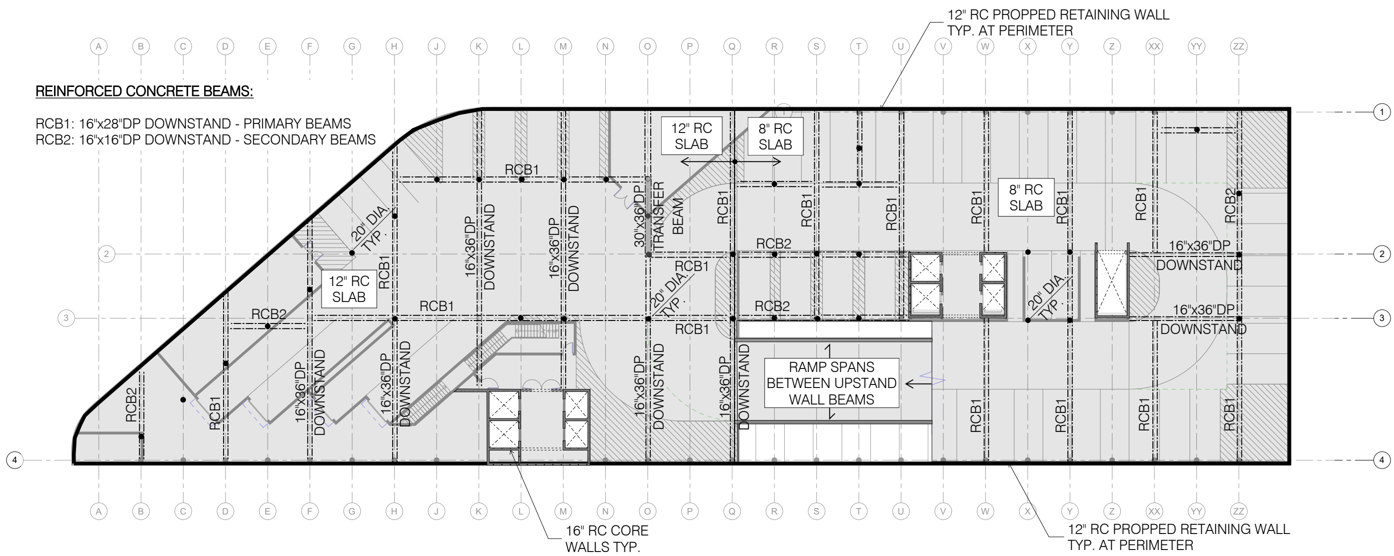


Fig. 45.2 | SMTT | P-1 Structure Plan | ◄ N

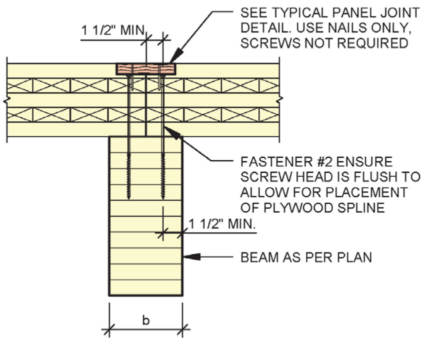


Fig. 46.1 | Panel Joint at Beam Support (Beam Perpendicular to CLT)

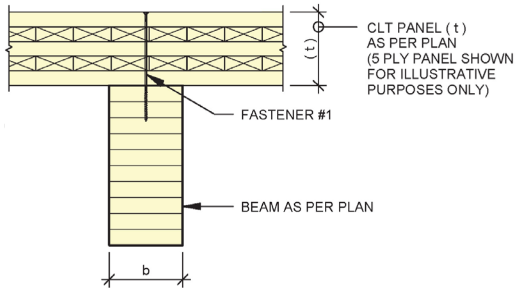


Fig. 46.2 | Panel Continuous at Beam Support (Beam Perpendicular to CLT)

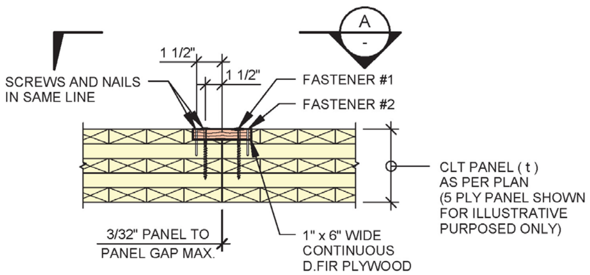


Fig. 46.3 | Typical CLT Spline Detail

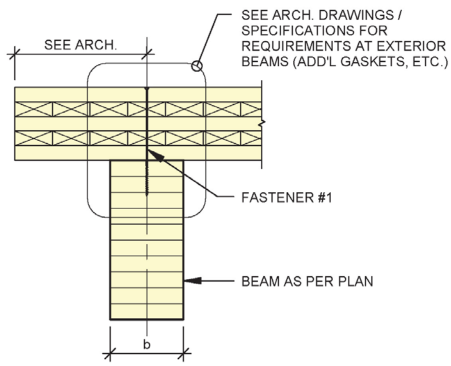


Fig. 46.4 | Panel End at Beam Support (Beam Perpendicular to CLT)

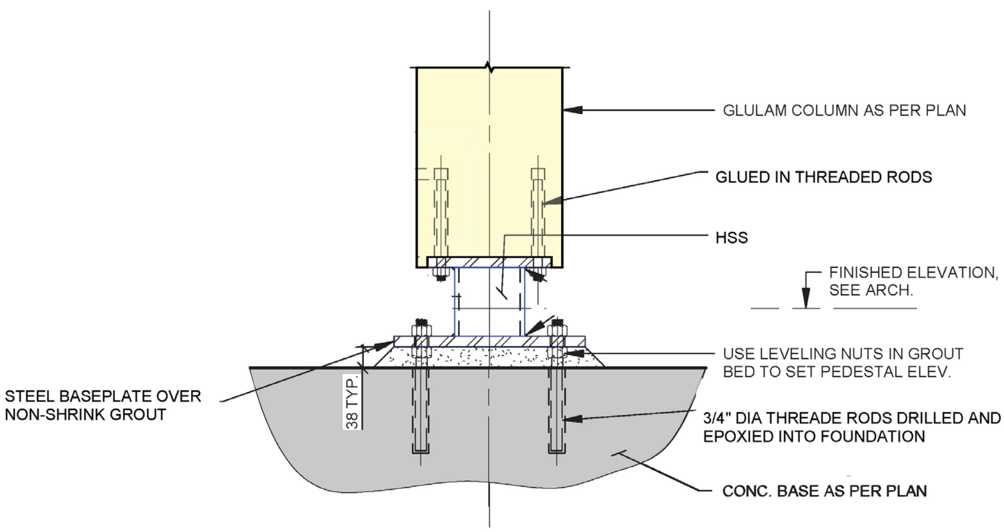


Fig. 46.5 | Typical Column Base Detail

Fig. 47.1 | Typical Beam-to-Column Connection Under Construction | First Tech Federal Credit Union

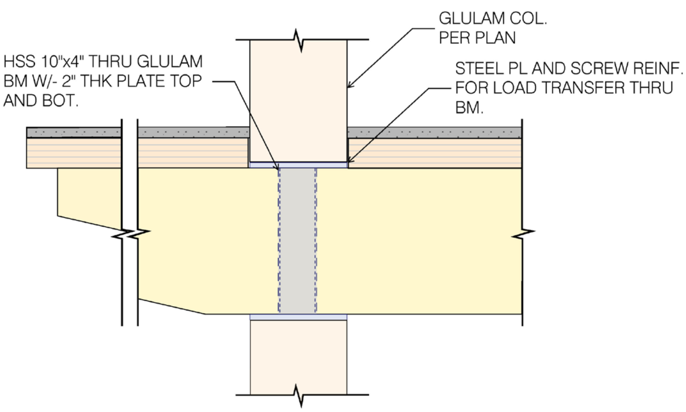


Fig. 47.2 | Typical Beam to Column Connection at Gridlines K, L, & M on Each Level

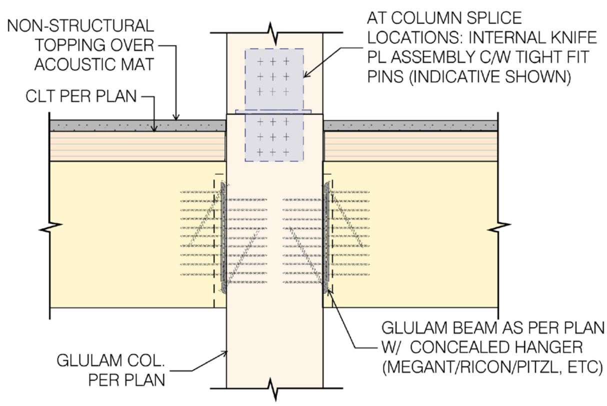


Fig. 47.3 | Typical Beam to Column Connection

LANDSCAPE ARCHITECTURE

Seattle was built on a foundation of timber. Fortunes were built from the logs and milled timber culled from the vast forests that surrounded the city, eventually funding the construction of a park system designed by the father of landscape architecture, Frederick Law Olmsted. Wielding his acclaimed picturesque vision as a brush, Olmsted painted the city's urban canvas with water features, wooded slopes, lawns, and breath-taking views of the Puget Sound. These forest-covered hills defined and framed the Seattle's growth and shaped its status of having year-round greenery.

This urban-rural juxtaposition is echoed in the landscape of the mass timber project, which embraces the rich materiality associated with and afforded by the city's historic legacy.

Embracing the credo that the landscape should feel like it's part of a place, Seattle Mass Timber Tower has created an immersive space that seamlessly transitions from street, to building interior, to skyward exterior. Marrying the materiality of the building with the natural elements of the urban spaces adjacent to the site, the design intention for the project is to create a unique environment within each area of the site, each allowing for various functions to occur. Each area is designed to reflect the timber at the heart of the project, projected through patterning and with three dimensional installations that create a unique address within the neighborhood.

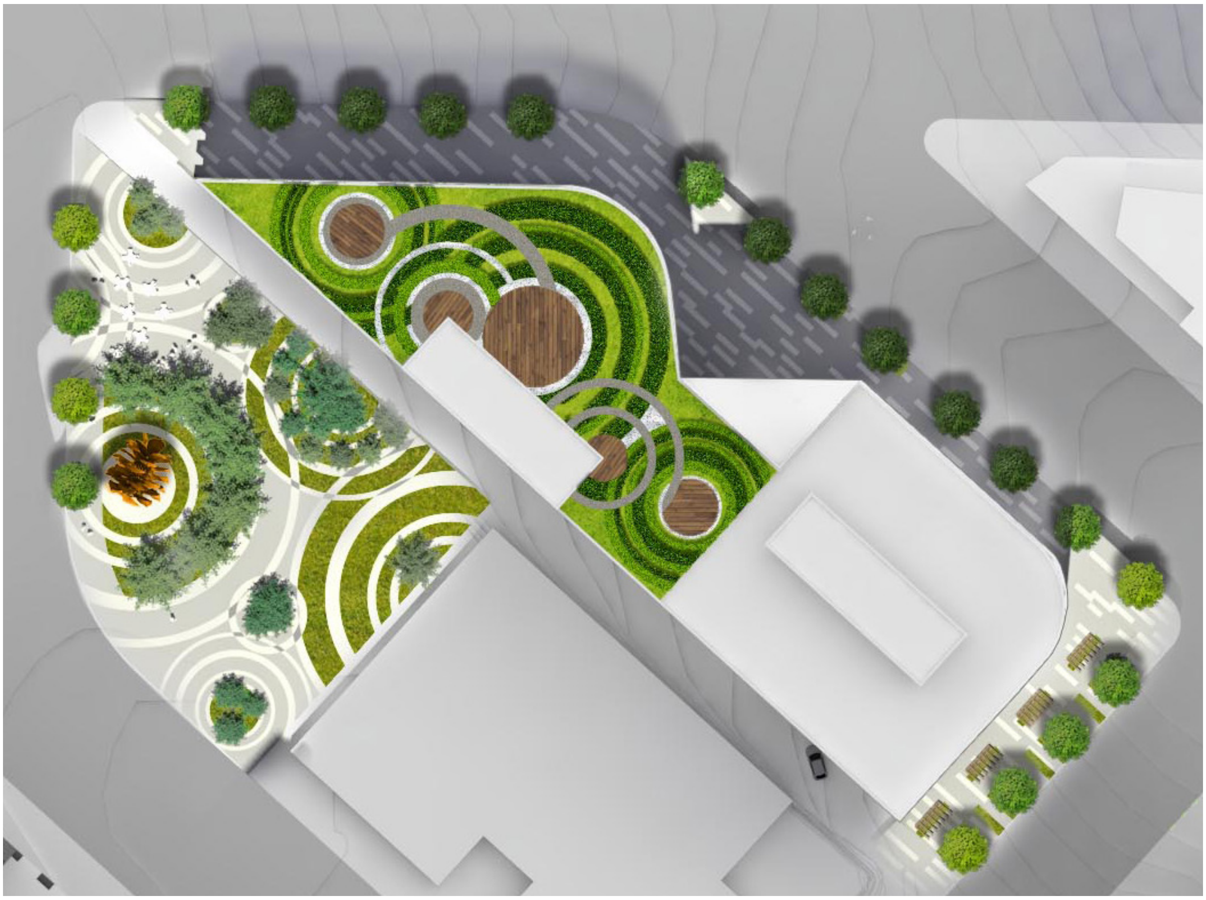


Fig. 48 | SMTT | Landscape Site Plan

The Green Street Streetscape

Seattle's green spaces and urban forests are enforced through a vibrant Green Street program and areas that surround the building. With visual interest in mind, trees will be selected for their growing habit, visual characteristics, and status on the city's approved street tree list. These areas will address the run-off created by seasonal rains and offer shade and wind screening to pedestrians.

As an alternative to the traditional city tree pit that serves as hallmark of a typical urban streetscape, the tower can evolve this feature to better reflect the critical need to provide connection at the root level for these street trees. Tree trenches ensure a healthier microclimate and soil-level environment for plants, which in turn will allow them to be more effective in their effort to reduce heat island effect and water absorption.

Hemlock Plaza

Situated near Denny Park, the building's dual entrances will be framed by a sculptural plaza, punctuated by a large sculptural form reminiscent of the region's native hemlock. Crafted as a large cone for conversation, this sculpture is intended to become a landmark within the neighborhood and serve as a permanent navigational tool for visitors and residents alike.

Raised planters and beds laid out in circular patterns reminiscent of tree rings will ripple outward from the center of the plaza, framing the open spaces for seating, passive activities, and offering an appealing view of the parkland nearby.

Fig. 49 | SMTT | Hemlock Plaza

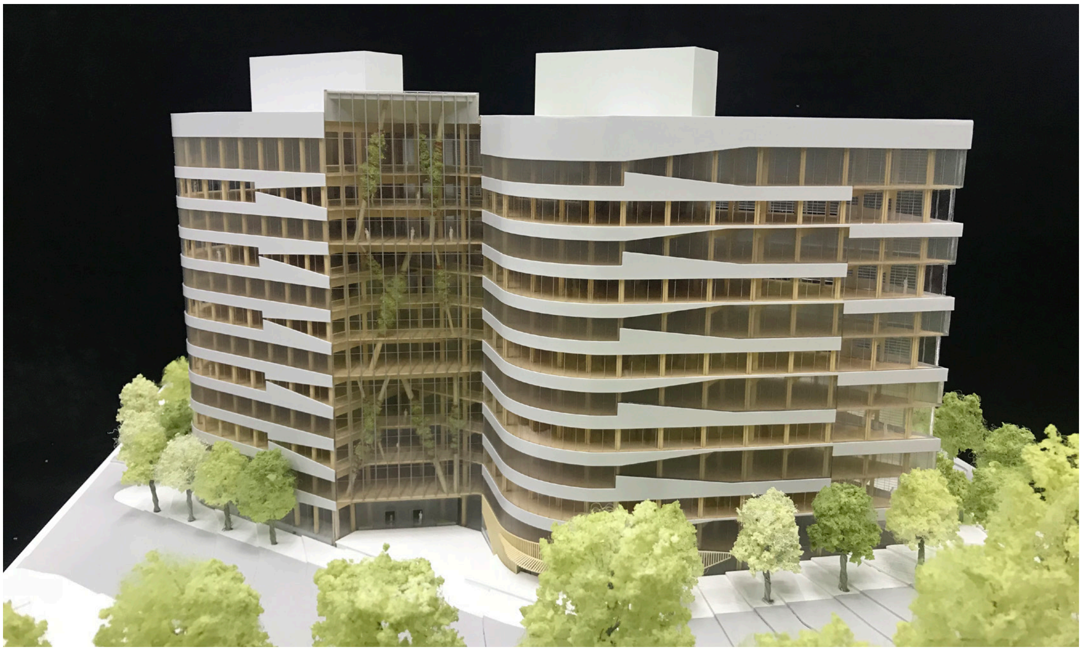


Fig. 50.1 | SMTT | Atrium Oriented Toward Denny Park

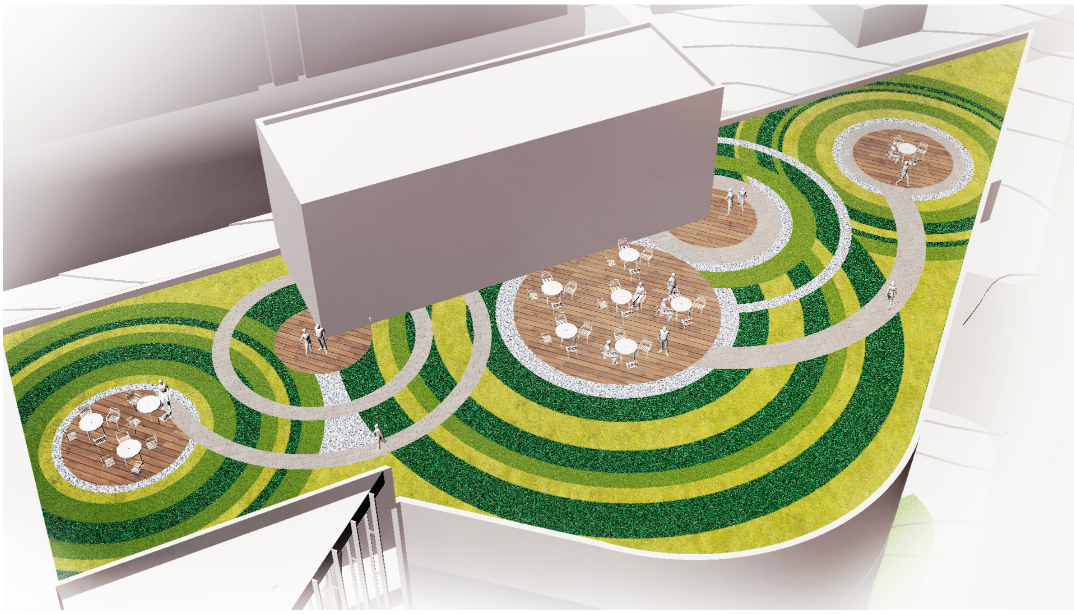


Fig. 50.2 | SMTT | Rooftop Deck

Fig. 51 | SMTT | Atrium View of the Model

The Atrium

The treeline of Denny Park will be reflected upon the 12-story glass facade of the tower, viewed as a leafy layer over the glimpse of the verdant building atrium interior. Passing through the sculpted wood entrance, visitors will be greeted by a striking array of massive, wooden spindles suspended from the ceiling, creating a tropical, jungle-like canopy, mirrored by seating areas demarcated on the floor with planted beds of bamboo and other tree-like plants.

While some of these structures will house a variety of lush vines and woody perennial plantings, others will serve as vessels for live saplings displayed to hang at varying angles. The raw materiality of this abstracted, aerial forest serves as a visceral reminder of the source of the building's structure, and allows for vibrant views from above, below and through the planted structures.

The Canopy Roof Top

Hotel residents and members of the public will have access to the hotel's rooftop bar and lounge and unprecedented views of Denny Park. Undulating, concentric circles of evergreen shrub hedges and groundcover will create structure to dedicated spaces for seating, events, and leisure activities. Dedicated seating areas will be buffered by the circular shrub parterre that alternatively tips upwards to form sheltered pockets. In contrast, varying heights of perennial grasses will contrast with the solid shapes of the hedge, accentuating the building form and panoramic views. This strategy of incorporating hardy native and alpine perennials and greenery will reduce maintenance needs and offer additional economic benefits by absorbing runoff.

The Park

Seattle's commitment to sustainability and integration of the natural environment into the urban environment is also showcased in the parklet adjacent to the mass timber building. Building upon the immersive quality of the design and informed by the incredibly rich natural sensuality of wood, park features will reflect the same design sensibility as the other areas surrounding the building to create a visual connection between them and historic Denny Park.

MECHANICAL SYSTEM DESIGN

The key objective of the high-performance HVAC design is to highlight a minimally intrusive, energy concise HVAC design, preserving both the aesthetics and structural integrity of a mass timber design.

Codes and Standards

- 2015 Seattle Commercial Energy Code
- 2016 Seattle Mechanical Code
- 2015 Seattle Plumbing Code
- ASHRAE – American Society of Heating, Refrigerating, and Air Conditioning Engineers.
- NFPA 13 – Installation of Sprinkler Systems

Benefits and Advantages

Not only are radiant floor systems on the lower end of energy consumption, the systems also lend themselves well to the challenges of MEP system installation and coordination of CLT and mass timber construction. The reduction in duct distribution systems throughout the building greatly minimizes the number and size of floor, wall and beam penetrations and internal chase requirements. Additionally, the ability to embed the space conditioning systems in concrete topping slabs, maintaining the architectural aesthetics make radiant floor systems a particularly attractive option.

Proposed High Performance HVAC, DOAS + Radiant Heating/Cooling

Ventilation – Floors 1 - 12:
Dedicated outside air handling unit systems (DOAS) will be provided with 100 percent OA economizer as a first stage of cooling, by an air-source heat pump with electric supplemental heat for supplying tempered ventilation air, maintaining 55º F - 70º F supply air temperature. Each area will be zoned with a dedicated DOAS unit providing code-required ventilation air to all occupied spaces. All DOAS units will have energy recovery wheels for heat recovery and dehumidification for indoor humidity control. VAV boxes will be provided for each occupied space, modulating ventilation air as required to maintain code required airflow rates and to satisfy locations with demand control ventilation (CO2).

Space Conditioning – Floors 1-12:
Each floor of the building will be zoned independently and served by a radiant floor system satisfying both heating and cooling requirements, decoupling ventilation from space conditioning per the 2015 Seattle Energy Code. The spaces throughout each floor will be zoned with multiple water temperature zones according to occupancy, exterior orientation and other space conditions. Consistent radiant slab temperatures will be maintained at a heating maximum of 84º F and cooling minimum of 66º F. Internal space/zone temperatures will be controlled through a wall mounted thermostat like traditional airside HVAC systems.

Central Plant Chilled Water/Heating Water Loops, Central Chillers + Boilers:
The building automation system (BAS) determines the delivery water temperature generated by the central plant equipment based on outside air temperature, median slab temperatures, and relative humidity requirements. Building hydronic pumps distribute heating and chilled water throughout the building hydronic loops, serving zonal two pipe radiant manifolds. The building pumps will be sized for the full flow of each loop and operate in a lead/standby fashion. The chilled water (55º F - 58º F) and heating water (95º F - 110º F) loops will be maintained by central modular air-to-water heat pumps with both heating and cooling capabilities. The heating water loop will also be served by high efficiency gas fired boilers for backup heating requirements.

Thermal Slab Zonal Heating/Cooling Controls:
When heating or cooling is required within a zone as determined by the zone thermostat, zone control valves modulate to maintain the target water temperature satisfying space temperatures based on operative and slab temperatures.

Baseline (Code/Typical) HVAC, DOAS + Variable Refrigerant Flow (VRF)

Ventilation – Floors 1 - 12:
Dedicated outside air handling unit systems (DOAS) will be provided with 100 percent OA economizer as a first stage of cooling, by an air-source heat pump with electric supplemental heat for supplying tempered ventilation air, maintaining 65º F - 70º F. Each area will be zoned with a dedicated DOAS unit providing code-required ventilation air to all occupied spaces. All DOAS units will have energy recovery wheels for heat recovery and dehumidification for indoor humidity control. VAV boxes will be provided for each occupied space, modulating ventilation air as required to maintain code required airflow rates and to satisfy locations with demand control ventilation (CO2).

Space Conditioning – Floors 1-12:
Ventilation and space conditioning will be decoupled per the current Washington State Energy Code. Each space will be zoned independently and served by dedicated ducted VRF fan coil units. The dedicated cassette is designed to circulate airflow within the space mixing with the ventilation air provided by a DOAS VAV box, providing the airflow required to maintain comfort conditions throughout the year. Spaces throughout each floor will be zoned according to occupancy and exterior orientation. The VRF system will transfer energy from zone to zone, handling simultaneous heating and cooling needs. Air will be delivered near the ceiling level like a traditional overhead system, satisfying zone temperature requirements.

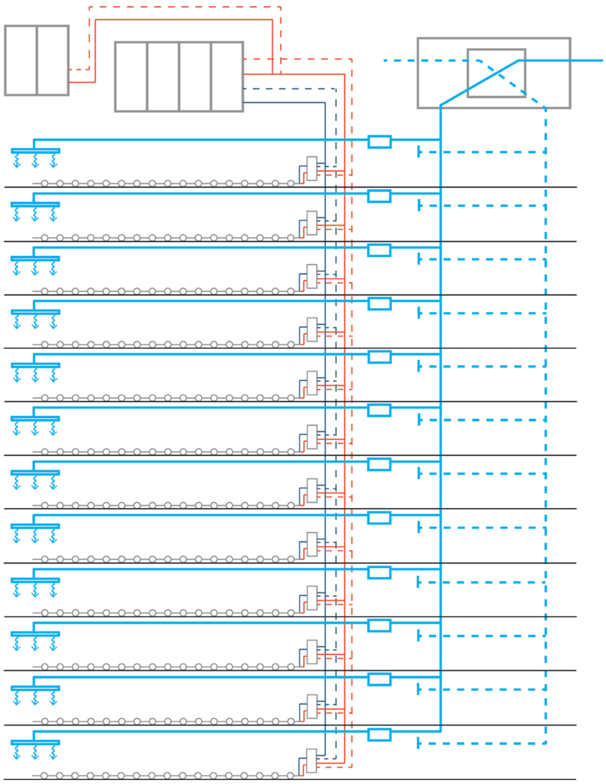


Fig. 53.1 | SMTT | High Performance HVAC, DOAS + Radiant Heating/Cooling Line Diagram

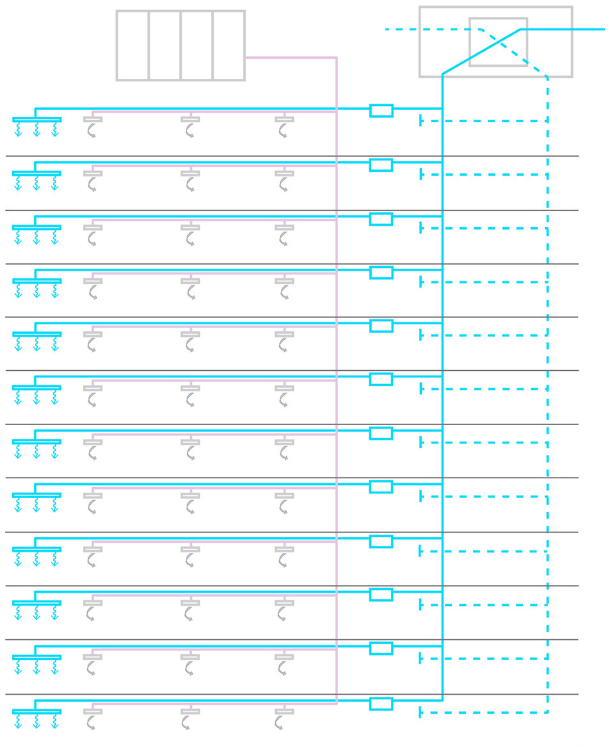


Fig. 53.2 | SMTT | Baseline (Code/Typical) HVAC, DOAS + Variable Refrigerant Flor (VRF) Line Diagram

VAV box | Supply air, 100% OA | Return air | Supply air diffuser | Return air grille

Radiant slab piping | Hot water supply for slab heating | Cold water supply for slab cooling

VRF refrigerant piping | VRF indoor unit | VRF recirculated air supply for heating/cooling

ELECTRICAL SYSTEM DESIGN

The key objective of the electrical design is to allow for adequate power and flexibility of future tenant improvements while maintaining the design aesthetic of the building. The lighting design shall complement the design aesthetic as well as provide adequate illumination, energy efficient performance, and customizable controllability.

Codes and Standards

- National Electrical Code (NEC) – 2017
- International Building Code (IBC) - 2015
- International Fire Code (IFC) – 2015
- Washington State Energy Code (WSEC)
- Commercial Provisions – 2015
- Washington Administrative Code (WAC)

Latest edition publications from the following standards organizations will be used as design guidelines for the project:

- National Fire Protection Association (NFPA)
- Illuminating Engineering Society of North America (IES)
- Building Industry Consulting Service International (BICSI)
- Americans with Disabilities Act (ADA)
- National Electrical Manufacturer's Association (NEMA)
- Electrical Industries Alliance (EIA)
- Telecommunications Industry Association (TIA)

The project will be designed to conform to the Oregon Energy Trust requirements and Americans with Disabilities Act and Architectural Guidelines (ADAAG).

Power Distribution

The new tower will be fed from (2) 3000A, 480Y/277V services for the office floors and 600A service for the retail floor. The retail level will be prewired with multiple utility meters. The service will be designed to accommodate the electrical loads for lighting, general purpose receptacles, mechanical loads, and special equipment for the tower. A main electrical room will contain all of the primary distribution equipment. (2) 1200A vertical bus ducts, one from each service, will each feed five or six floors of the tower. 208Y/120V transformers and branch circuit panelboards will be located in the main electrical room and in electrical closets on each floor. A rooftop distribution board(s) will feed roof mounted mechanical equipment.

Submetering of mechanical and electrical core and shell loads will be per the Washington State Energy Code.

A diesel generator will be provided to power emergency and legally required standby loads (high rise required loads like stair pressurization fans, elevators, etc.) and fire pump. The preliminary size of the generator shall be 500kW/625kVA.

The main distribution switchgear will have a surge protective device (SPD) installed to protect all loads within the building. Surge strips in individual offices will not be necessary for protecting electronic equipment from power spikes. This will be mitigated at the main distribution switchgear in the main electrical room. The main switchgear will have a power quality meter as well.

All interior electrical conductors will be stranded copper, #12 minimum, (#14 for control) Type THHN/THWN-600V. Exterior conductors where the ambient temperature will be below 32 degrees F will be type XHHW. Ground conductor shall be provided in all feeders, branch and lighting circuits' raceways.

Power

Power feeds will be installed by future tenants. The basis of design for feeding circuits through the floor will be Free Axez floor system. For the core and shell, the basic unpowered floor units will be provided. Power feeds are to be by tenant. The design shall also include vent modules as required per mechanical to allow for heat transfer from the radiant floor to occur more efficiently. The alternate system for feeding power and low voltage will be an in-slab walkerduct with raceways between sections of radiant flooring.

This system does not allow the flexibility of the Free Axez flooring.

Receptacles will be placed throughout the finished core and shell spaces for utility use like cleaning, etc.

Per the state code, rough in and electrical capacity for future EV chargers will be provided on the parking garage levels.

Lighting

Interior lighting in TI spaces will only be trip lighting. Prudential Lighting LED snap designed to 2 FC average.

Corridors, stairs, and transition areas will be designed to 10 fc, the public lobby will also be designed to 10 fc but will have additional decorative and accent lighting.

Fig. 55 | Integrated Lighting in Atrium Precedent | The Library at the Dock | Docklands, Australia

Parking garage lighting will be 3000k LED and will utilize uniform optic fixtures as opposed to discrete LED fixtures. (Example, Eaton Top Tier). Echelon Microwave controls will be used to control portions of ramps to provide better light level control and fewer occupancy sensors.

Exterior lighting and site lighting will be 3000K LED and will be controlled by a central relay panel. Light poles with cameras will have 120V circuits as well.

Spaces with daylight access, will utilize continuous dimming drivers and photocells to automatically dim fixtures. This will ensure that distraction is not caused by lights turning on and off. All spaces will be controlled by occupancy sensors, however sensors in open office areas and public spaces will be disabled during working hours to prevent false switching and to maintain an appearance of “open for business.” After hours, all sensors will function. In spaces with variable occupancy, the occupancy sensor will also control mechanical units.

Basis of design for lighting controls in the building will be Encelium or Lutron.

Fire Alarm

All fire alarm devices will be of the intelligent, addressable type. This means every fire alarm pull station, strobe, horn, detector, etc., has a unique identity within the fire alarm system. When a device is activated (manually or automatically), the fire alarm control panel knows specifically which device(s) is/are in alarm condition and where they are located. The annunciator panel located at the building’s main entrance will then indicate to the fire department precisely where the event is happening.

Communications and Data Systems

A communication demarcation room will be provided on the main level or first parking garage level. Pathways up through the electrical riser will be provided for future tie in to TI MDF/IDF rooms. Basic communication systems, such as POTS lines, etc. will be provided for core and shell systems such as fire alarm panels and elevators.

BUILDING PERFORMANCE

The key to good design is the balancing act of varying and sometimes conflicting priorities to enhance building performance. Using iterations to finding overlapping techniques and using metrics to define success can help balance project goals and approach project budgets holistically. The three lenses used to define and meet the desired metrics or goals were:

- Total Cost of Ownership
- Health and Wellness (Indoor Environmental Quality)
- Carbon Footprint

The proposed Seattle Mass Timber Tower design was compared to a business as usual Project Baseline using the three lenses highlighted above, to quantify performance and estimate magnitude of improvement over Project Baseline.

The primary differences between the Project Baseline and Proposed SMTT used for the building performance analysis include the structural system, mechanical system, and external shading on the southwest facade. All other aspects between the two cases remain consistent and business as usual. Both the Project Baseline and the Proposed SMTT are designed to perform better than the current stringent 2015 Seattle Energy code. This new building uses passive techniques and other strategies to enhance performance and the potential to meet the future 2018 Seattle energy code through the performance-based path.

The Baseline systems were selected based on business as usual, using most economical solutions while still meeting the stringent 2015 Seattle Energy code. The proposed design utilizes more robust solutions that dovetail into and build on each other. Additional, more robust solutions or systems can be integrated with the Seattle Mass Timber Tower option, and have been mentioned here as 'enhancements', but these would come with an added first cost. For a list of assumptions used for analysis see Appendices C and D.

TOTAL COST OF OWNERSHIP

First costs are often the driver for decision making, however the future costs including, maintenance, replacement, and utility costs can have large impacts on the owner's total cost of ownership. These are recurring costs that can add up over the years.

This section includes a qualitative analysis, with only utility cost numbers identified below and first costs included in an earlier chapter. The maintenance, replacement costs, and total cost of ownership calculation would be next steps for this study.

First Costs

The following systems are the primary differences between the Project Baseline and the Proposed SMTT.

- Concrete / timber,
- Variable refrigerant flow / radiant slab,
- No external shading / with external shading

Utility Costs

Both the Project Baseline and the Proposed SMTT design were modeled using IES virtual environment. Both options use an estimated 7.5 cents/kWh. The new tower will save roughly $27,500 per year in utility costs or 1.4 million dollars in 50 years life of the building, without capturing any escalation in electricity costs.

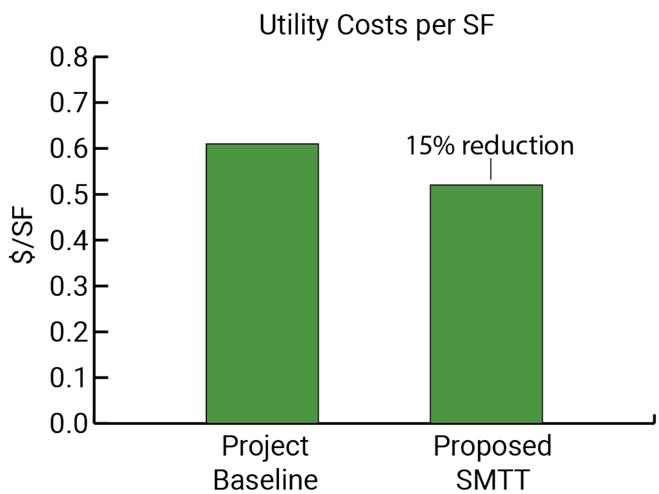


Fig. 56 | Annual Utility Cost Comparison | City of Seattle 2018

Maintenance and Replacement Costs

Project Baseline: VRF zone air system will require internal air filters to be changed, and systems will be replaced every 15 years based on the typical life of the equipment. Additionally, the refrigerant in the system will need to be recharged periodically. How often the building would need recharge can vary based on numerous unknown factors.

Proposed SMTT: The Radiant Slab with hydronic piping does not have moving parts and will need minimal or no maintenance in the zones or tenant spaces. The central heat pump will need maintenance and will need to be replaced every 20 years based on typical life of the equipment.

Though the maintenance and replacement costs can vary based on numerous factors, it is evident due to the moving parts and life of the VRF equipment compared to the Radiant slab that the costs for the VRF will be higher by 3-4 times, ranging from $3-7 million for the life of the building. Some of these maintenance and replacement costs may fall under tenant improvement, especially the VRF systems, depending on the lease.

Future Proofing

It is important to tie current building designs and concepts to what we anticipate in the future. The Project Baseline uses a mechanical system type that is dependent on refrigerants to be routed throughout the building interiors. This core and shell concept requires the tenant to install equipment as part of tenant improvement. The limitations from a future proofing standpoint include: 1) the building is dependent on refrigerants; the future of refrigerants is changing rapidly in the industry and 2) the refrigerant based system cannot integrate into and take advantage of district systems, which typically tie into hydronic loops.

The system design for this new tower uses a hydronic system tied to a central plant. The central plant can be 'Enhanced' in the future to use more robust equipment, utilizing future compliant refrigerants, district loops, geothermal wells etc to meet more stringent codes and requirements in the future, like Net Zero. Additional cooling or heating systems like 'radiant ceilings' can be added to tenant spaces if needed, at a higher cost, not included in this analysis.

Fig. 57 | Hydronic Piping Installation

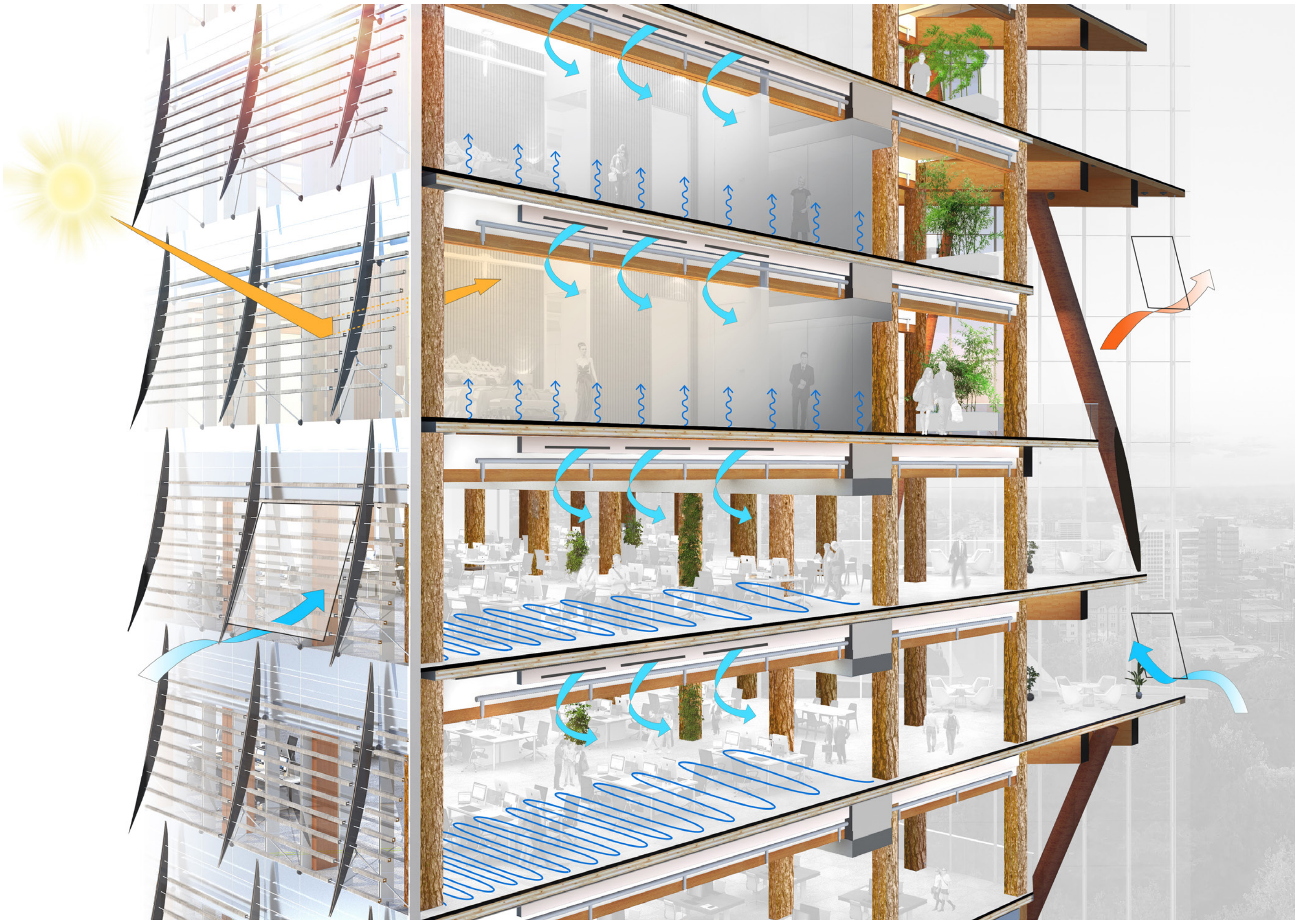


Fig. 58 | SMTT | Passive strategies incorporated into the design to optimize the indoor environmental quality. All of these systems are part of the core and shell building and are considered an amenity to enhance tenant improvement.

External shading reduces solar load and cooling load for thermal slabs to work effectively during cooling season, and provides glare-free daylighting throughout the day.

Minimum outside air ventilation is provided through overhead diffusers, using a dedicated outside air system with heat recovery, this system also helps meet required latent loads.

Radiant slab with hydronic piping provides heating or cooling with improved thermal comfort; higher perimeter loads are met through denser piping for higher heat gain/loss; the concrete slab also provides thermal storage.

Operable windows are an amenity that allow additional fresh air and free cooling during shoulder seasons.

Atrium provides stack effect for enhanced cross ventilation.

HEALTH & WELLNESS

Our indoor environment has a large impact on how effectively we can work and be at our optimum performance. Views, daylighting, indoor air quality, thermal comfort, and acoustics have all been shown to have significant positive impacts on our health and wellness, and in extension our productivity. The indoor environmental quality in this building design has been enhanced through use of good design practices discussed here.

Visual Comfort

Research shows that daylight helps set our circadian rhythm and that sunlight is important for mood. Daylighting in buildings has been shown to reduce absenteeism and improve mood, productivity and sleep patterns.

A 2011 study by Ihab Elzeyedi examined an open-plan office building at the University of Oregon. The study linked a 10 percent reduction in occupant sick days to both view of nature and exposure to daylight.[7]

Daylighting and views have been optimized in the design through:

- Maximizing use of building perimeter for occupied spaces
- Higher ceiling heights with use of thermal slab
- Optimizing building glazing and external shading to eliminate glare and need for interior shades

Thermal Comfort

Thermal comfort is a topic of discussion in offices everywhere you go. From the Washington Post to the BBC to the Wall Street Journal, potentially contributing factors such as age, gender, and clothing choices have been explored, especially with regards to over-cooling and offices being too cold for a portion of the population.

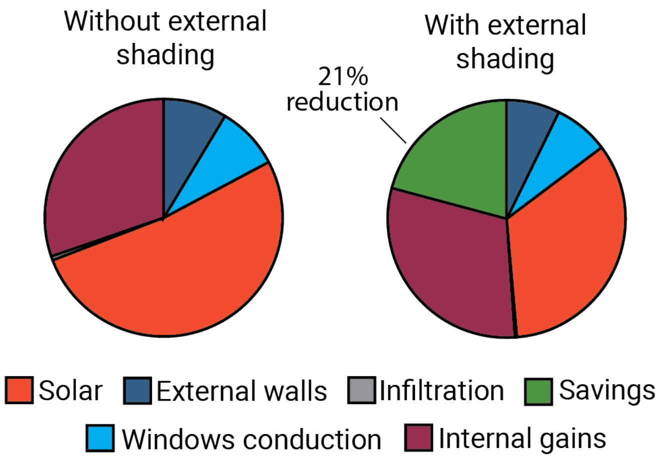


Fig. 59.1 | SMTT | Solar Load on SE & NE Facades Without External Shading

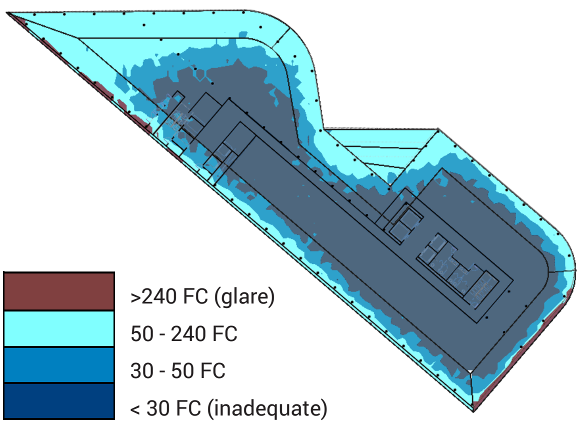


Fig. 59.2 | Proposed SMTT Useful Daylight Illuminanace and Footcandle (FC) Levels on Floor Plan

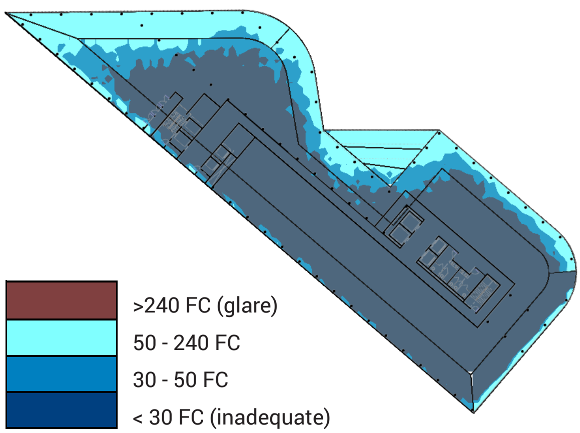


Fig. 59.3 | Project Baseline Useful Daylight Illuminanace and Footcandle (FC) Levels Without External Shading.

In 2011, Lan et al used an office simulation to study twelve participants completing both performance tasks and neurobehavioral tests at varying temperatures. The study found a 4 percent reduction in productivity at cooler temperatures, and a 6 percent reduction at warmer temperatures.[7]

Thermal comfort has been optimized in the design through:

Use of external shading on southwest facade. External shading is required to reduce cooling load in the space and to meet cooling load using a thermal slab, which has a limited cooling capacity. External shading reduces the cooling load by roughly 21 percent. This strategy is used to reduce solar load and it also impacts the operative temperature in the space. Operative temperature can be estimated as the average between air temperature and the mean radiant temperature. The external shading helps reduce the temperature of the vertical glazing surface, which in turn reduces the mean radiant temperature and the operative temperature in the space.

Use of thermal slab for heating and cooling. Radiant systems focus on operative temperature rather than solely air temperature. A user's temperature perception is based on heat exchange with their immediate environment, through convective and radiant heat loss or gain relative to the surroundings. Operative temperature is how one experiences thermal comfort, even though a space is typically controlled or monitored solely using air temperature. Experiencing heating and cooling through radiant exchange can allow users to feel more comfortable at lower air temperatures during heating and higher air temperatures during cooling.

Thermal slab temperature of 84°F for heating and 66°F for cooling is provided to meet ASHRAE 55 standard's thermal comfort requirements by keeping the temperature variation from a person's feet to the head to a minimum of 7°F.

Additionally, tenants can utilize personal control strategies like desk fans to further enhance thermal comfort. Research shows that access to personal control makes users feel more comfortable.

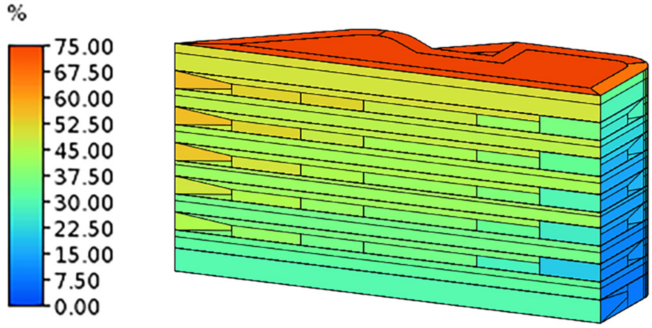


Fig. 60.1 | Solar Load on the SW Facade Without External Shading

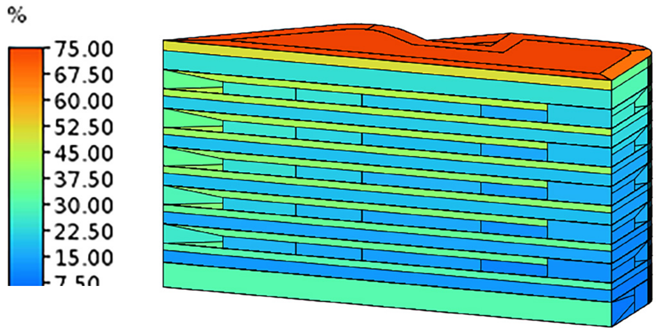


Fig. 60.2 | Solar Load on the SW Facade with External Shading

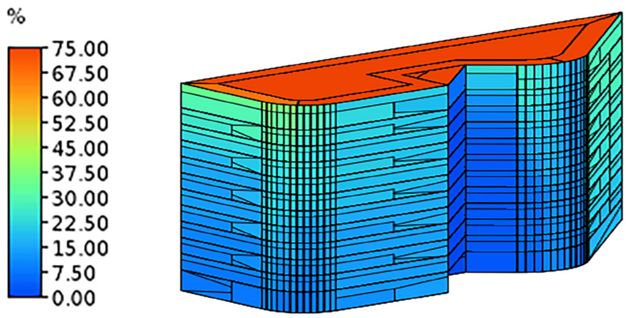


Fig. 60.3 | Solar Load on the SE & NE Facade Without External Shading

Indoor Air Quality

The quality and quantity of air in the spaces we inhabit has a direct impact on our health, wellbeing, and cognitive function. The impacts can vary widely, depending on multiple factors including the quality of indoor air and the concentration of contaminants; the rate of intake, or quantity of outside air supplied; and the length of exposure to the air, or the amount of time spent indoors. The lengthy amount of time we spend indoors heightens the importance for the indoor environment and its potential to reduce contaminants and improve the quality and quantity of outside air.

Studies like that of Allen et al in 2012 have shown that "green" workspaces with higher outdoor ventilation rates can improve cognition and task performance by removing harmful compounds from the air. Participants completed office-type tasks during exposure to varying concentrations of airborne VOCs and carbon dioxide. The study tested three environments: high concentration of VOCs, or conventional; low concentration of VOCs, or green; and low concentration of both VOCs and CO2, green+, which are typical characteristics of a system with a high outdoor air ventilation rate. The study found that the green environment improved cognition by 61 percent, and the green+ environment by 101 percent.[8]

A Dedicated Outside Air System (DOAS) will provide 100 percent fresh filtered outside air, with no mixing of return air. The Proposed SMTT utilizes the thermal slab for heating and cooling and the DOAS to meet outside air requirements and meet latent loads to keep space humidity less than 50 percent, to allow for radiant cooling without any risk of condensation.

The mild climate in the Pacific Northwest allows for numerous days that can leverage natural cooling by using operable windows. In addition to natural cooling, operable windows are considered an amenity in today and can also enhance air quality through the increase in the quantity of outside air and reduction in CO2 (ppm), when outside air conditions permit.

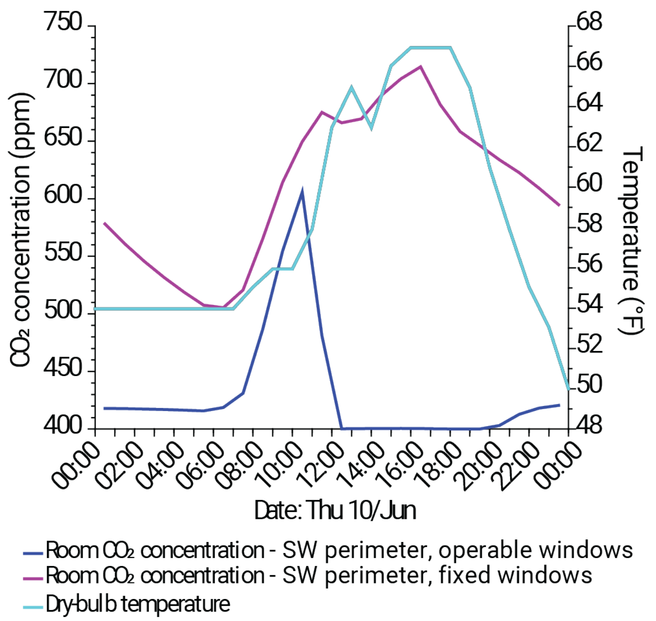


Fig. 61 | Simulated CO2 (ppm) with and Without Operable Windows in June When Outside Air Conditions Allow

The energy model for this building was simulated with and without operable windows and the CO2 concentration in a perimeter space with use of operable windows is reduced to outside air levels, almost 300 PPM less than Project Baseline. This may be more applicable on high floor levels where noise and pollution are less compared to lower levels.

Acoustics

Acoustics is one of the largest contributors to productivity and can have an impact of up to 66 percent.[9] A large contributor to this statistic is the distraction caused by an open office and conversations around people working on tasks. Though open offices can also enhance collaboration, it is important to provide the right ratio of focused rooms and open office; large and small conference rooms, dependent on the tenants requirements. These would be tenant improvement criteria, but can impact the visual comfort, if partition design limits daylight access and resulting productivity as well.

Other acoustics factors include sounds of mechanical systems, including air flow; and switching on/off of air flow and fans in a space. Radiant slabs provide heating and cooling through radiant effects from hydronic piping & thermal mass, rather than air flow. This reduces the air flow supplied through the space, making for a quieter space and reduced ambient noise levels from HVAC, compared to the Project Baseline air system.

Bare laminated timber isn't suitable for the acoustic demands of most structures on its own. For the Seattle Mass Timber Tower, the 2 1/2" of non-structural concrete topping and an acoustic rubber mat over the CLT floor panels will enhance acoustic performance while also meeting fire protection requirements for Type IV-B.

Testing has shown that a 5-ply CLT panel achieves an STC rating of approximately 40 and an IIC rating of 25. This is much lower than the code minimums for both of these parameters. In contrast, once a 3/4" acoustic mat and 1.5" of concrete topping are applied to the top of a 5-ply CLT panel, testing has shown these numbers jump to 59 and 42, a significant improvement.

ENERGY & CARBON

Benchmarking

The energy performance for buildings is typically measured using EUI (Energy Use Intensity) kBtu/SF/yr. EUI highlights the energy consumed by a building over a period of one year. Energy use for office buildings can vary based on several factors which are discussed in the Sensitivity Analysis section, however benchmarking is key to setting targets and realistic goals based on actual performance. Benchmarking was done using existing data-sets as well as building energy simulation of the code building, Project Baseline (Business as usual) and Proposed SMTT. National data-set (CBECS) and Seattle data-set.[10]

The primary differences between the Project Baseline and Proposed SMMT buildings are:

- The mechanical system, with VRF as the source for heating and cooling for the Project Baseline and the Radiant slab with a central plant used for heating and cooling in the Proposed SMTT.
- External shading on the southwest facade for the Proposed SMTT design.

Assumptions for the energy model are included in the Appendix.

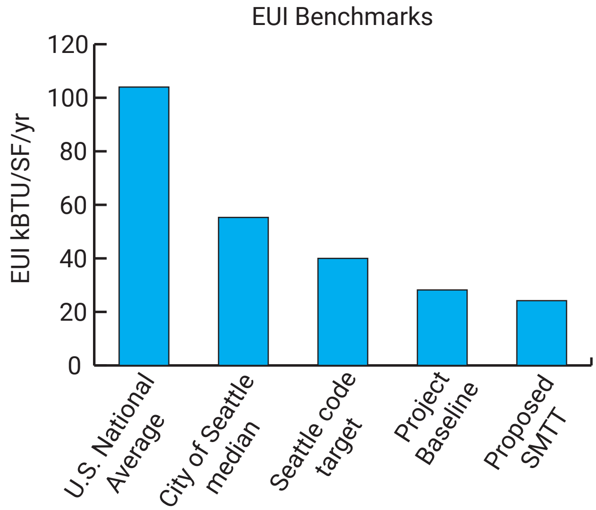


Fig. 62 | Energy Use Intensity (EUI) for large office buildings for actual datasets, nationally and locally as well as modeled performance for Code Baseline, Project Baseline (business as usual) and Proposed SMTT.

Seattle Energy Code

Both the Project Baseline and our new mass timber building meet the prescriptive Seattle Energy Code requirements by use of DOAS with heat recovery and zone heating and cooling, heat pump technology for heating, and through similar additional energy efficiency package measures. Through use of more efficient lighting and controls and potentially other measures including higher performing envelope, which is not part of the scope for this study because these would be similar between the Project Baseline and the SMTT. The focus of this study is to highlight potential differences between the two solutions.

As future codes often target additional efficiency features, including performance-based codes, this project targets achieving higher efficiency through:

- Use of radiant slabs for heating and cooling,
- Use of external shading on the southwest facade where it can improve daylighting performance and reduce cooling loads,
- Operable windows for natural cooling
- Selection of a central plant that can connect to any future district systems or more efficient systems that become available as future technology improves

Enhancements

Other opportunities to further enhance performance may be pursued for projects with additional budgets, for example: radiant ceiling panels for heating and cooling, geothermal wells for enhanced central heat pump performance during heating, and reduced energy use for heat rejection, external shading or automated interior shades on other orientations for even better reduction in glare and solar loads.

Energy Savings

The largest chunk of savings for the Seattle Mass Timber Tower is attributed to reduced fan energy, cooling energy, and lighting energy. The largest chunk of energy consumption in the building is due to plug loads or receptacles, which have been kept constant in both cases.

Fans: The Seattle Mass Timber Tower uses less fan energy since the spaces use the radiant slab for heating and cooling rather than fans to heat and cool using air. In the Project Baseline the VRF system/fans cycle on/off to meet the heating and cooling load. The DOAS with air side heat recovery provides minimum ventilation using tempered air in both the Project Baseline and the mass timber building. Both options use similar fan energy at the DOAS/system side.

Cooling: The Seattle Mass Timber Tower design has reduced cooling energy consumption due to:

- Use of external shading on the southwest facade that reduces cooling load and need for cooling.
- Higher water temperatures used for cooling through the radiant slab, allow central heat pump to run at high efficiencies.
- Cooling is reduced during shoulder season, through use of operable windows. Natural ventilation allows occupants to feel comfortable at higher setpoints, using the adaptive thermal comfort model, where higher setpoints are acceptable during higher outdoor air temperatures.
- Reduced internal loads in perimeter spaces due to useful daylight and reduced lighting loads.

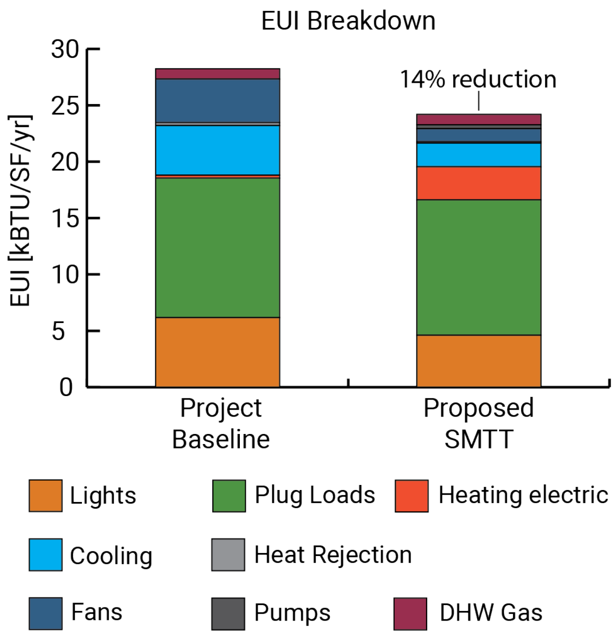


Fig. 63 | Energy Use Intensity and Energy Use Breakdown for the Project Baseline (Business as usual) and the Proposed SMTT.

Lighting: The Seattle Mass Timber Tower has reduced lighting energy due to use of daylight sensors. This is because internal shades are not needed as much as a result of reduced glare from external shading devices, making the daylight useful. In the Project Baseline, where the external shading may not be included, the glare leads to use of internal shades for a large chunk of the day, increasing the use of lighting in the perimeter spaces.

Heating: The Seattle Mass Timber Tower uses more heating because of reduced lighting energy and external shading that reduces some free heating from internal loads and solar gain. There is also less heat recovered during shoulder months due to reduced cooling. The central heat pump equipment efficiencies have also been modeled conservatively to capture inefficiencies during lower outside air temperatures below 40^{o}F, when this equipment may need to rely on electric resistance back up. Typically these temperatures are now below 32^{o}F or even lower, as the technology is improving with more sophisticated equipment in the market.

Plug loads: The receptacles or plug loads have been kept consistent between the Project Baseline and the SMTT, though there may be some opportunity to reduce these further in collaboration with the tenants.

Results

The EUI is estimated to be roughly 24 kBtu/SF/yr and the Seattle Mass Timber Tower performs roughly 15 percent better than the Project Baseline.

Operational Carbon

The carbon emissions from operating energy were calculated per the Seattle City Light emission factor presented in the 2018 Greenhouse Gas Emissions Inventory report compiled by the Puget Sound Clean Air Agency. The emissions can vary from one grid to another. In the Pacific Northwest, due to a cleaner grid, switching to more efficient electric systems like the Central Plant Heat Pump in the Seattle Mass Timber Tower can reduce carbon emissions significantly.

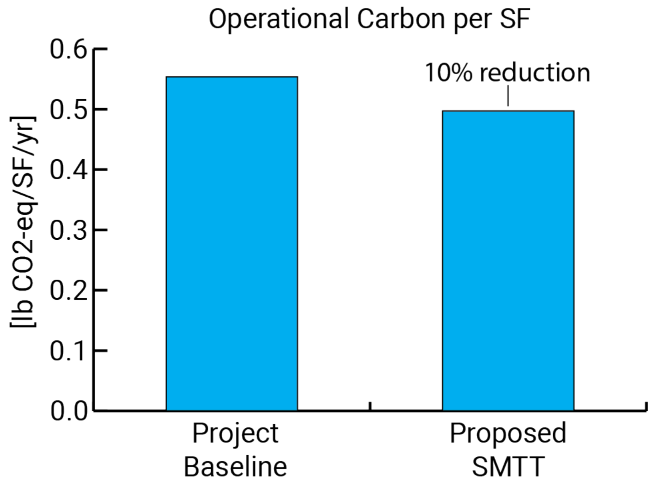


Fig. 64.1 | The Proposed SMTT is projected to emit nearly 10 percent less GHGs per year than the Project Baseline in operational energy.

Sensitivity Study

We performed a sensitivity analysis of the energy model for the new mass timber tower. This sensitivity analysis assesses the sensitivity of the energy model to a range of design, operational and modeling uncertainties that affect energy performance. The results inform estimates of the amount of uncertainty associated with building design and operational parameters, while also providing insight into which areas of uncertainty have the largest impact on energy use. Ultimately, the results help inform the target range of energy performance for the project.

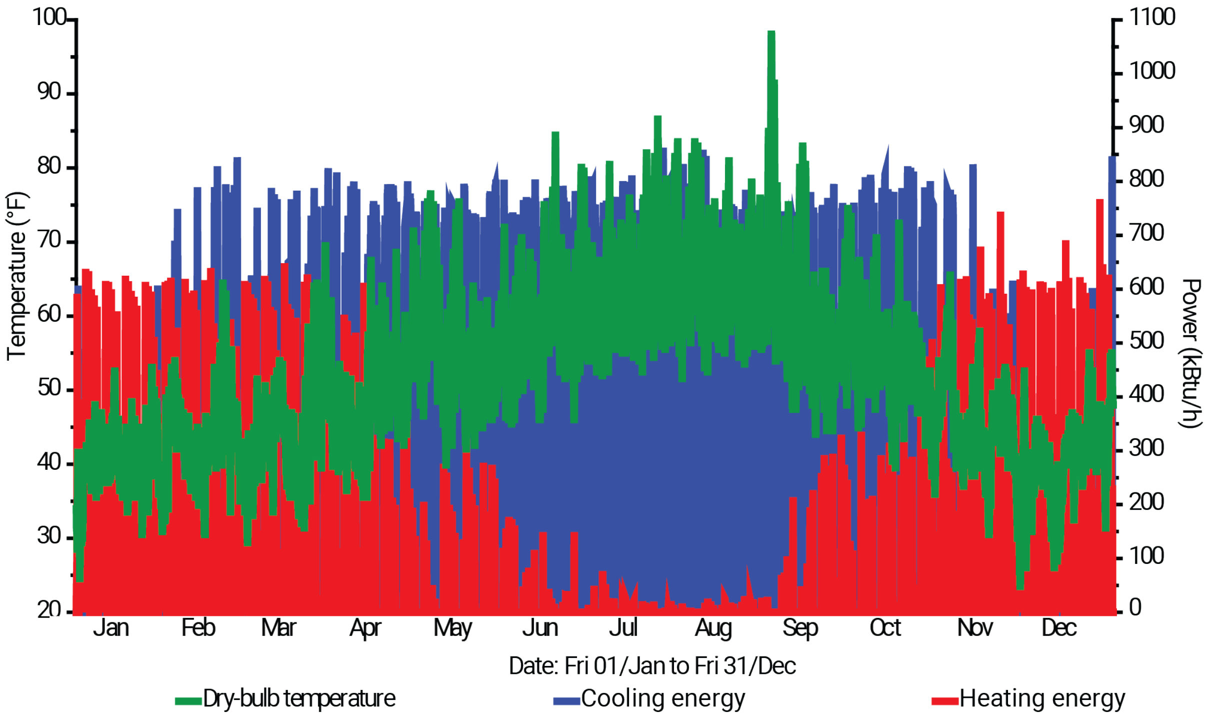


Fig. 64.2 | Heat recovery potential during the spring and fall season, through heat recovery module in central heat pump. This feature allows the cooling energy for the core zones to be used to heat the perimeter spaces that may be in heating mode.

Summary of Analysis

For each of the design and operational parameters included in the sensitivity analysis, a set of assumptions were developed to represent a lower and higher range energy use. The model run that includes only the lower energy use assumptions is the "Lower Range." Each successive bundle of measures was applied cumulatively, such that the final bundle on each end represents all of the higher range or lower range assumptions in the analysis

Lower Range: Includes the lower energy use assumptions in receptacles, lighting, and set points. This case would reflect a very aggressive "best case scenario" where all of the uncertainties studied would be resolved in favor of lower building energy use. The simulations were run incrementally starting with the Seattle Mass Timber Tower. The order for the incremental changes was: Proposed SMTT > reduced receptacle loads of 0.5 W/SF > lower lighting of 0.5 W/SF > higher cooling set point of 78^{O}F and lower heating setpoint of 78^{O}F.

Higher Range: Includes the higher energy use assumptions in receptacles, occupancy, lighting, and set points. This case would reflect a very aggressive "worst case scenario" where all of the uncertainties studied would be resolved in favor of higher building energy use. The simulations were run incrementally starting with the Seattle Mass Timber Tower. The order for the incremental changes was: Proposed SMTT < increased receptacle loads of 2.0 W/SF < increased occupancy hours < higher lighting of 1W/SF < lower cooling set point of 72^{O}F and a higher heating setpoint of 72^{O}F.

Results

The EUI is estimated to be roughly 24 kBtu/SF/yr. However, if design or operational parameters are modified the EUI can range from 20 kBtu/SF/yr to 55 kBtu/SF/yr. The plug loads (and occupancy) have the largest impact on the energy performance and can change the projected EUI by over 50 percent.

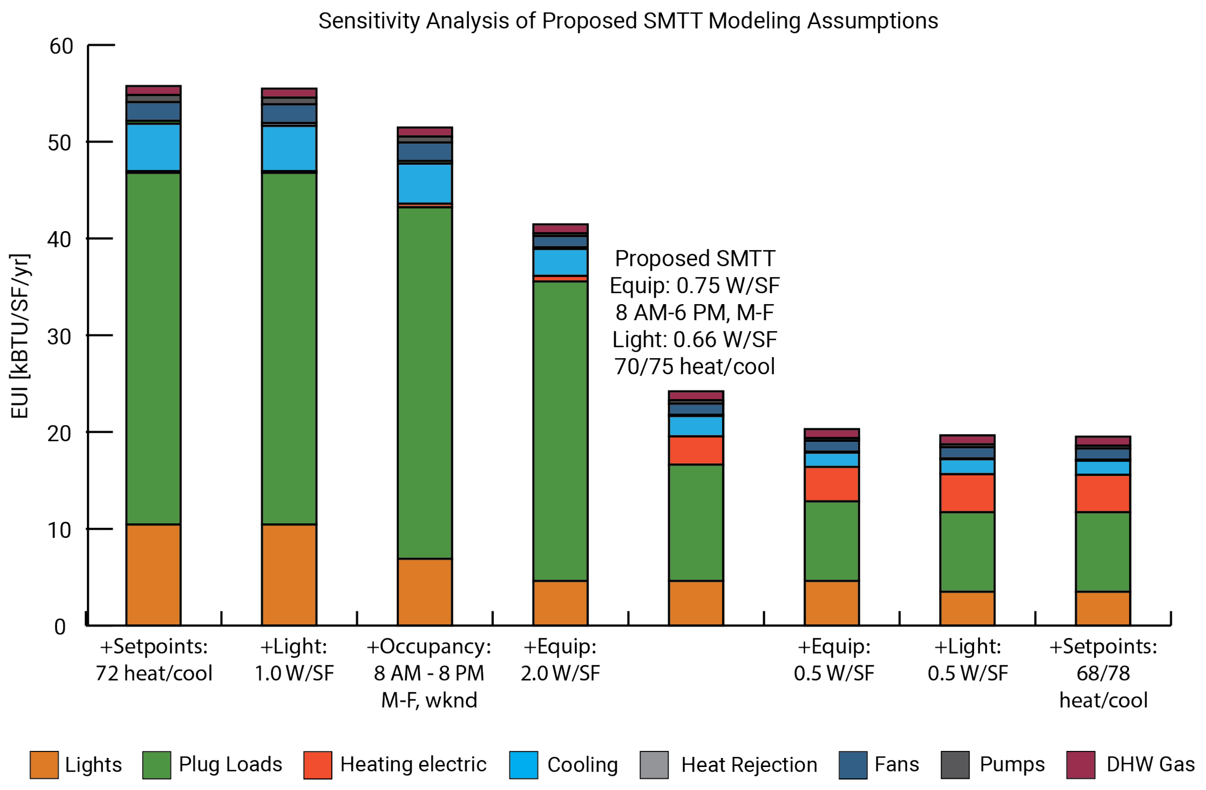


Fig. 65 | Energy Use Intensity (EUI) for the Proposed SMTT and the lower and upper EUI range for modified parameters. Plug loads have a potential to increase or reduce energy use significantly.

The plug loads will also impact the cooling loads and potential of the radiant slab to 100 percent of the loads. Additional tenant systems may be required for spaces with very high plug loads. External and/or internal shades can impact the use of daylighting and reduced use of lighting energy, and occupant density can impact receptacles, outside air and internal loads.

Embodied Carbon

Embodied carbon reflects the amount of CO2 emitted in the production of materials, including energy used for raw material extraction and processing, transportation, and construction. Global Warming Potential (GWP) is the typical metric used to analyze embodied carbon and indicates the emissions of all greenhouse gases (GHGs) including CO2 over the course of material production.

The complete 'carbon' (or GHG) footprint of a building also includes the GWP of operational energy in addition to the GWP embodied in the materials. As buildings are designed to be more energy efficient, the relative percentage of carbon and other GHGs embodied in the materials increases.

The embodied carbon in materials over a building's lifespan is significantly larger than the total carbon emitted through operational energy use over the same lifespan, especially as codes become more stringent and the grid gets cleaner.

The conventional carbon emissions broken down by sector typically separates buildings by industry sector; yet a substantial amount of industrial activity targets building construction. Thus, buildings have a much more significant role in global carbon reduction when including both operational and embodied carbon.

Benchmarking

Analyzing embodied carbon as compared to operational carbon is a relatively new exercise for the building industry, and therefore benchmarking data is not readily available. The Embodied Carbon Network affiliated with the University of Washington is working on setting benchmarking data currently. More studies are needed to be able to reliably compare data and estimate embodied carbon of materials accurately.

Analysis

The impact of the differences in material choice, most importantly the concrete superstructure in the Project Baseline versus the mass timber superstructure in the Proposed SMTT proves far more significant in terms of carbon and GHG emissions than operational energy.

The embodied carbon for materials differing between Project Baseline and the Seattle Mass Timber Tower foundations and superstructure were calculated with Athena Impact Estimator for Buildings, using quantities estimated from the structural drawings. Assumptions for this analysis can be found in the Appendix.

Results

SMTT is projected to emit nearly 45 percent less greenhouse gases in its extraction, processing, transportation and construction of materials than our project baseline of a PT Concrete structure.

Estimating the embodied carbon for all identified material differences between the Project Baseline and the Seattle Mass Timber Tower results in emissions on the order of 10^3 greater than annual emissions from operational energy.

As future building codes and Green Building guidelines consider embodied carbon, material choices particularly for a building's superstructure will become increasingly important. This analysis highlights the potential for mass timber to significantly reduce embodied carbon compared to traditional concrete and steel structures.

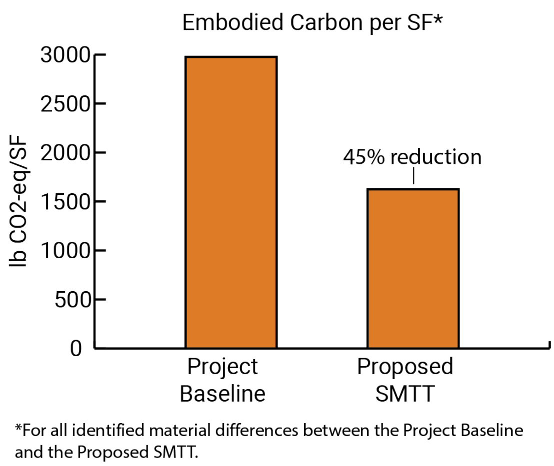


Fig. 66 | Comparison of Embodied Carbon

RISK MANAGEMENT & INSURANCE

Type IV Heavy Timber Construction was born out of the New England mills in the 1820's. The textile industry was prone to fire due to the dust accumulation in the air and the mill owners recognized that their facilities designed with post, beam, and plank construction, instead of post, beam, joist, and decking, suffered localized damage under fire but not catastrophic loss. Eventually "Slow Burning Construction" was adopted by the mill owners, and became the basis of their self-insurance program which is today known as The Factory Mutual Insurance Company or FM GLOBAL.

Today, the general liability insurance risks of a mass timber building versus and concrete or steel building are no different. There is an impact, however, to the Builder's Risk Insurance (BRI) pricing associated with the project. As insurance companies are slow to adapt to new technology, the current industry view is that mass timber, from a BRI point of view, has a similar risk profile to that of a light wood-framed building. BRI, on projects over 12 months in duration, is priced on a time basis.

While there is a cost premium for a mass timber project for the BRI, the time savings for using BRI on a project helps to offset the premium as time savings can shave off 15 percent to 25 percent of the project duration.

With respect to safety a mass timber solution has many benefits, including a lower number of workers on-site, more work being performed in controlled environments off-site, minimal cutting and coring on site, and less temporary structures (formwork) being put in place on-site.

Fig. 67.1 | Charred CLT Panel

Fig. 67.2 | First Tech Federal Credit Union Headquarters under construction | Hillsboro, OR

CONSTRUCTION TECHNOLOGY, PROCUREMENT & LABOR POOL

Construction Technology

As discussed in a previous section, procurement of construction projects is becoming more of a technological process involving the use of computer aided software to develop a virtual model to a high degree of accuracy. Combining the use of Building Information Modeling (BIM) with CNC machining with robots, the procurement of sophisticated building systems that are extremely accurate on dimensions and quality, are becoming more prevalent in all building systems.

The movement back to mass timber buildings is therefore a movement forward into a sophisticated delivery model where the most challenging aspects of the process are virtually designing the building and constructing it over and over in a virtual world. Are the days gone where six construction workers are staring up at their problem and writing an RFI for a perfectly foreseeable issue while the job stalls? The mass timber movement is a step in this direction.

Everyone is enamored with the installation of a mass timber building, but the real work is in the months leading up to a construction project. The shop drawing and design periods are where the work is done and where time can be saved and wasted effort can be engineered out of the project.

On-Site Logistics & Procurement

Site logistics and procurement of mass timber is a time sensitive and intensive process. It is essential when procuring this type of building to have an engineer managing the delivery schedule and plant fabrication schedule. Because of the volume of wood being produced, and the time involved in handling the product, the manufacturers want to produce the project, set it on a truck, and ship it out to the construction site. Manufacturers do not want to sit on inventory or product because it would require a large amount of climate-controlled space. This means that a mass timber building is going to be fabricated within days or weeks of installation and the coordination of the construction schedule to plant fabrication schedule is paramount.

Labor Pool

Mass timber buildings help create a sustained labor utilization in the workforce by reinvigorating our rural communities and leveling the resources required to complete a construction project. Normally, a repetitive project will have a spike of on-site labor required for each trade and the project. Mass timber projects help to level of the resource demand on a project and force the trade partners involved to think proactively and prefabricate pieces of the project off-site. Additionally, the distribution of work to off-site fabrication facilities, trucking companies, the logging industry, and wood detailing industry is rising with the increasing demand for mass timber buildings.

As example, an electrician on a mass timber project, where the conduit runs, and light fixture holes are pre-coordinated and drilled into the mass timber panels, will require less on-site labor during construction. Prior to construction, however, the electrician will prefabricate components in their facility with the same workforce. Instead of hiring 15 electricians to meet the temporary demand of the project peak, the trade partner can use a crew of long-term employees to prefabricate components offsite and then perform the on-site work as well.

Fig. 69 | CLT Panel Lifted Into Place | Vancouver, BC

COST ANALYSIS & SCHEDULE

Schedule Analysis

There are four main drivers to completing a construction project after the site and ground work is complete:

1. Time to build the structure
2. Lag time to start the exterior skin
3. Lag time to start interior rough-in trade work
4. The finish of the elevator system

Our mass timber design case affects all four of these drivers favorably contributing to a 5-month savings in the total duration of the project from the post tensioned design case. There is a savings on the overall time to build the structure. The mass timber frame installs 13 weeks quicker than a traditional post-tensioned frame. This is primarily due to utilizing offsite prefabricated mass timber panels, glulam columns, and glulam beams. The prefabricated elements replace the intense falsework required in the post tensioned design case. Additionally, there is a savings in the lag time between when both the exterior skin can begin and the interior rough-in can begin because of the lack of re-shore required for the mass timber frame compared to a post tensioned frame. When the mass timber frame is locked into the lateral system, follow on trades can immediately start working on the floor below.

This savings in lag is significant and accounts for a minimum of 6 weeks of total duration savings. Finally, because the mass timber frame installation is a quicker process than the post tensioned process, the elevator shafts are advanced on the critical path and are ready earlier in the construction project for the elevator buildout.

Reducing the time to build a structure translates into a reduced cost for the building. The easiest way to reduce time is remove unnecessary steps from the construction sequence. The mass timber design solution provides the simplicity of quickly constructing a structure with prefabricated pieces while enhancing the interior finish with the warm aesthetic of the exposed wood.

By using a mass timber frame instead of a post-tensioned frame for the building, there is a 5-month savings on the total duration of the project, which means the mass timber building can be completed and turned over in ¾ of the time as a traditionally framed concrete structure.

In both cases, two tower cranes are being used due to the layout of the building and size of the deck. In the mass timber case, the concrete cores are being advanced ahead of the structure so that they do not

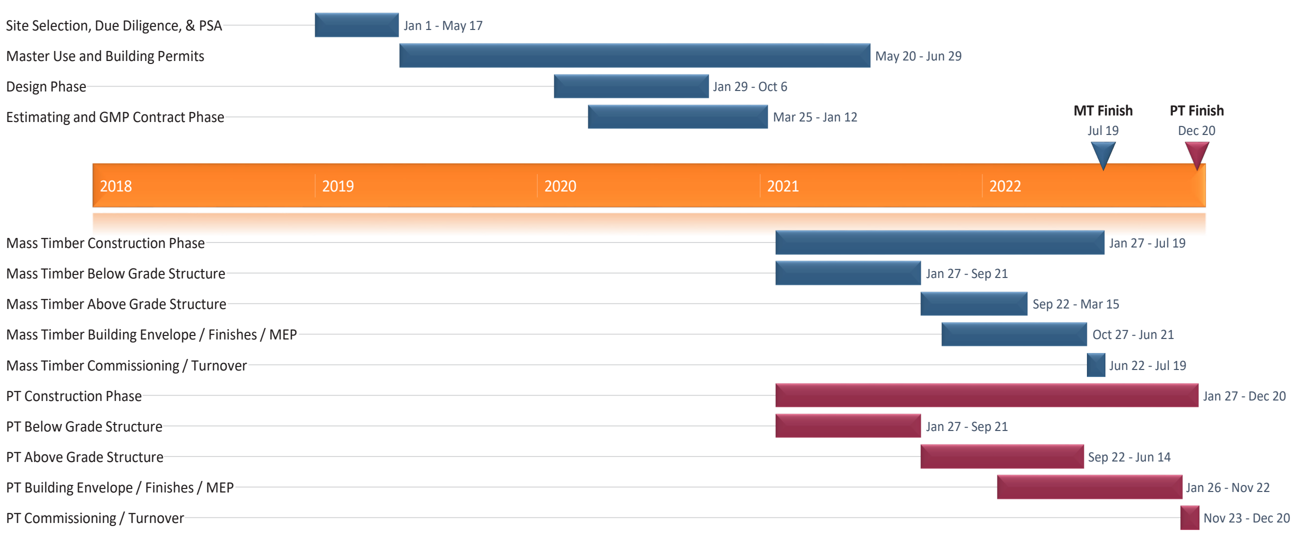


Fig. 70 | Seattle Mass Timber Tower Development Schedule become a critical path constraint to erecting the mass timber frame. Employing two tower cranes allows the exterior system to progress along with the mass timber structure without stopping either work activities.

Cost Analysis

We analyzed two design cases for this project site: a mass timber frame, and a post tensioned concrete frame. Both design cases are meant to meet the finish aesthetic of the building except that the mass timber building provides a more complete fit-out as many of the ceilings are finished with drywall, and the glulam columns should be left exposed as a finished product.

Previous studies related to cost and feasibility of mass timber buildings have been limited to analysis of the costs of the structural systems but have not compared total project costs. The goal of this analysis was to evaluate the complete project construction costs with respect to time. This means the cost analysis within this text is not limited to a comparison of the structural frames, rather, it is a comparison of a project optimized with mass timber versus a project optimized with post tensioned concrete. Additionally, the analysis incorporates the benefits of mass timber frame building with regards to the following: lighter structural frame, schedule benefit, and aesthetic finish.

Our analysis found that the direct cost of work is higher with a mass timber frame, while the project indirect costs are much lower because of schedule savings achieved with the mass timber frame, with the result of a 0.5 percent savings for the mass timber design in the overall price of the project. The higher direct cost can be viewed as an investment in reduced tenant buildout costs because there will be fewer finishes to put in place in the completed structure. Previous studies of mass timber frames versus post tensioned structures have not accounted for the benefit to the schedule, which is a significant driver to the cost competitiveness.

Our analysis accounted for realistic pricing for a post tensioned frame based upon the scale, size, and complexity of the site and design requirements. With respect to the mass timber frame, six different structural solutions were analyzed for the project. A big reason the mass timber solution offers significant cost and schedule advantages is because the design and construction team went through the rigor of determining the most cost effective structural frame for the project. (See Appendix B for considered structural schemes.) To make mass timber a viable and reasonable solution for a construction project, early engagement with the design and construction team is critical. Designing the building to a cost-effective mass timber frame is essential to overall project cost control. The cost data is based on 2018-numbers and to simplify the process of our estimation, i.e. for establishing a cost-competitive evaluation of two structural systems, we based the calculations on an all office-use with street level retail.

Future Considerations

In the future, more mass timber suppliers will be in the market place which should, in turn, result in lower costs for the manufactured components. Over time, labor costs will continue to rise on construction sites resulting in a benefit to use offsite premanufactured components to build large commercial projects. Prefabricated mass timber components will help stabilize construction prices and become more and more feasible as the supply chain and code adoption develops.

System	**Mass Timber Design**	**PT Concrete Design**	**Mass Timber Savings**
Direct Cost of Work	$86,997,136	$85,105,091	2.2%
Project Overhead	$ 9,393,750	$11,768,750	-20.2%
Add-Ons	$ 8,387,345	$ 8,429,368	-0.5%
Total	**$104,778,231**	**$105,303,209**	**-0.5%**

Fig. 71.1 | Cost Comparison Chart | Detailed Cost Comparison in Appendix E

Cost Per Square Foot	
Mass Timber Tower:	PT Concrete Tower:
$ 104,778,231	$ 105,303,209
424,175 GSF (incl. parking)	424,175 GSF (incl. parking)
$247.02/sf	**$248.25/sf**

Fig. 71.2 | Cost Per Square Foot Chart

CONCLUSION

The time is now, the place is here.

This report is the result of a collaboration by a team of architects, engineers, landscape designers, contractors, and industry experts who came together to imagine the best possible path and solution for the design of a 12-story mass timber mixed-use building in Seattle, Washington. The goal was to conceive a compelling and elegant design that would reflect innovative spirit, cost-effectiveness, resource-efficiency, and technological rigor. The team based the design parameters and constraints on real-life assumptions relative to the assumed jurisdiction and site, environmental, economic and socio-cultural criteria. The expectations on design performance are ambitious as they should be, and the results of the cost estimate are promising in that the mass timber solution produces a .5 percent savings as compared to the baseline post-tension concrete system.

The legislative framework is in place in Seattle for “tall timber” to follow. For our team, the best takeaway is the realization that quality, cost and time are no longer necessarily exclusive tangibles but an inclusive part of a new value proposition and business model. Mass timber assembles on site with factory-applied precision and finishes, has the potential to be the less expensive structural system choice, and reduces the construction schedule by several months. Imagine a new crop of design and construction that will change us as it will change the face of our cities. Now, go and do it!

Fig. 72 | New National Gallery | Berlin, Germany

TELL YOUR FRIENDS

Key Takeaways

- Mass timber high-rise developments are now price competitive with conventional construction in concrete or steel. The construction cost of SMTT is 0.5 percent below the cost of the concrete baseline.
- Mass timber construction has significant potential to yield higher rentable leases and appeal to higher end tenants. Reputable Seattle industry experts suggest that a premium of 5 percent might be possible.
- Our design achieves a 15 percent reduction of operational cost as compared to our baseline and results in a significant reduction of carbon emissions during operations.
- SMTT is projected to emit nearly 45 percent less greenhouse gases in its extraction, processing, transportation and construction of materials than our project baseline of a PT Concrete structure.
- More up front collaboration between developers, architects, engineers, contractors, and manufacturers yields a higher quality product.

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Construction and Cost

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Gary Chubb
Erica Spiritos

Heartland LLC
Real Estate Development and Underwriting

Carson Bowlin

APPENDIX

Appendix A | Concrete (Baseline) Structural System

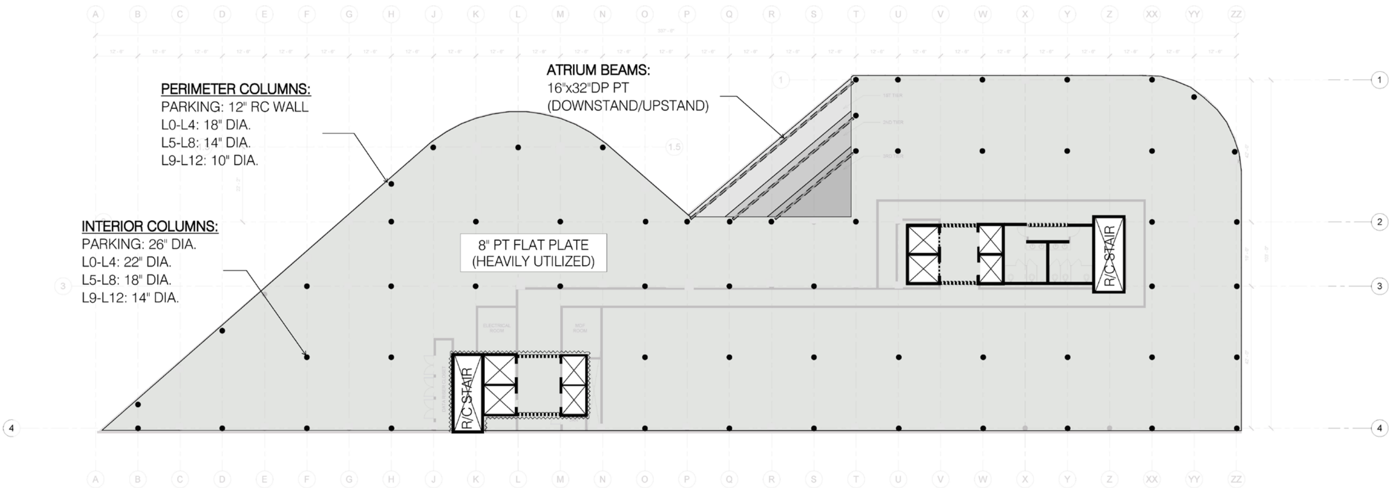


Fig. 76.1 | Typical Floor Structure Plan | ◄ N

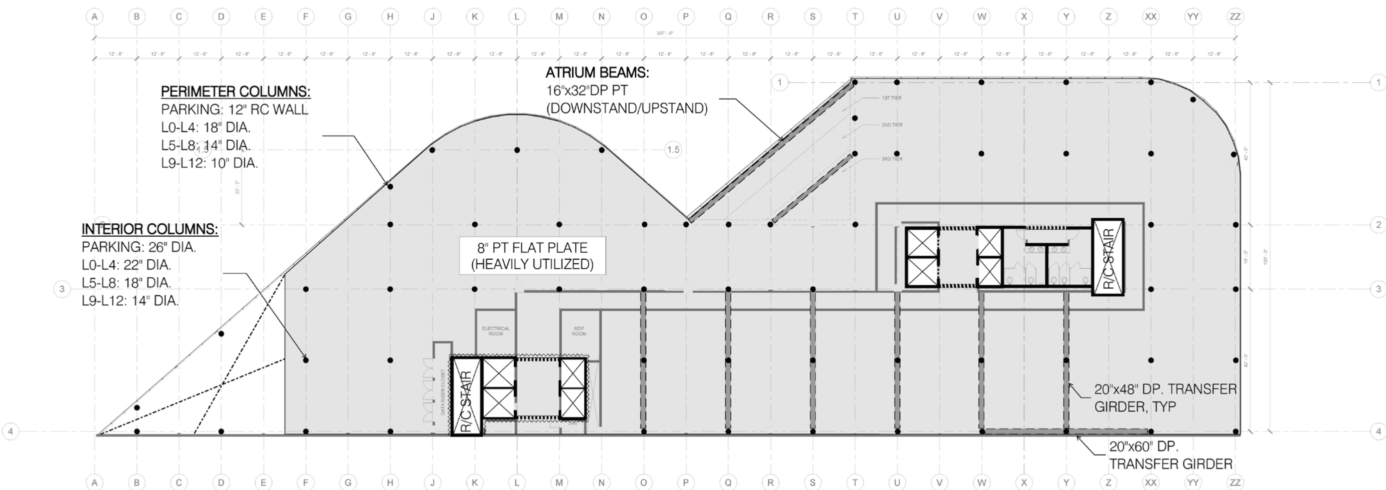


Fig. 76.2 | Second Floor Structure Plan | ◄ N

Fig. 77 | Roof Structure Plan | ◄ N

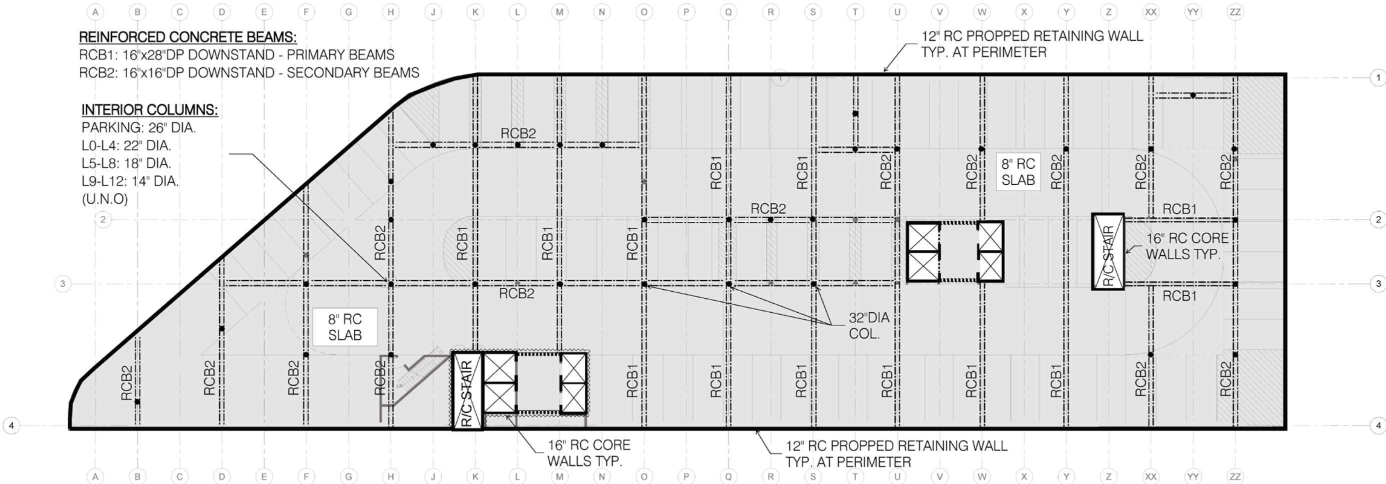


Fig. 78.1 | P-2 & P-3 Structure Plan | ◄ N

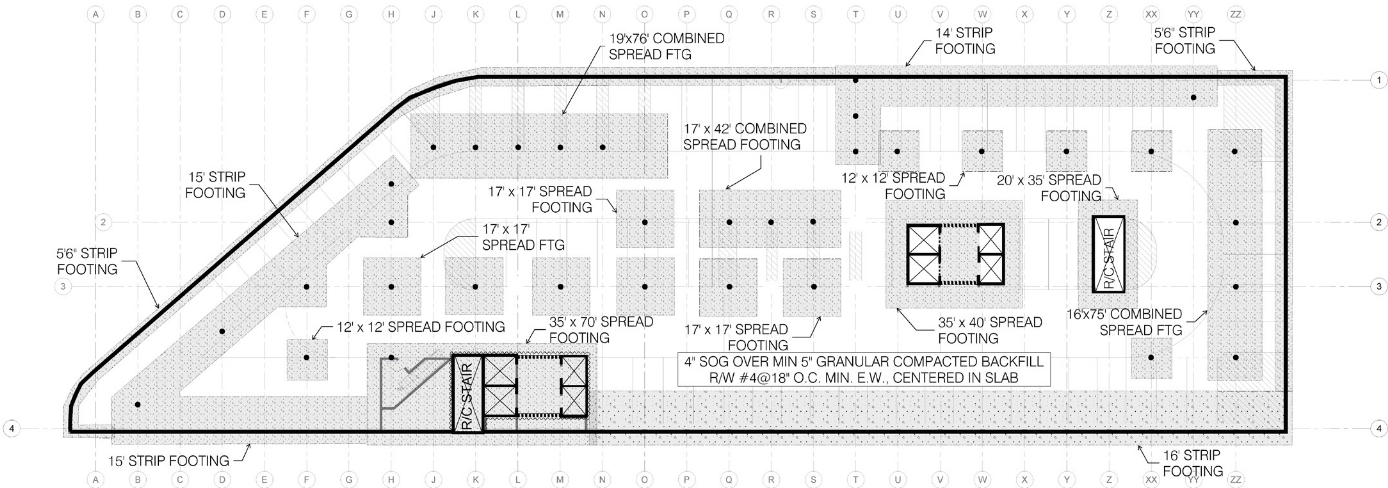


Fig. 78.2 | Foundation Plan | ◄ N

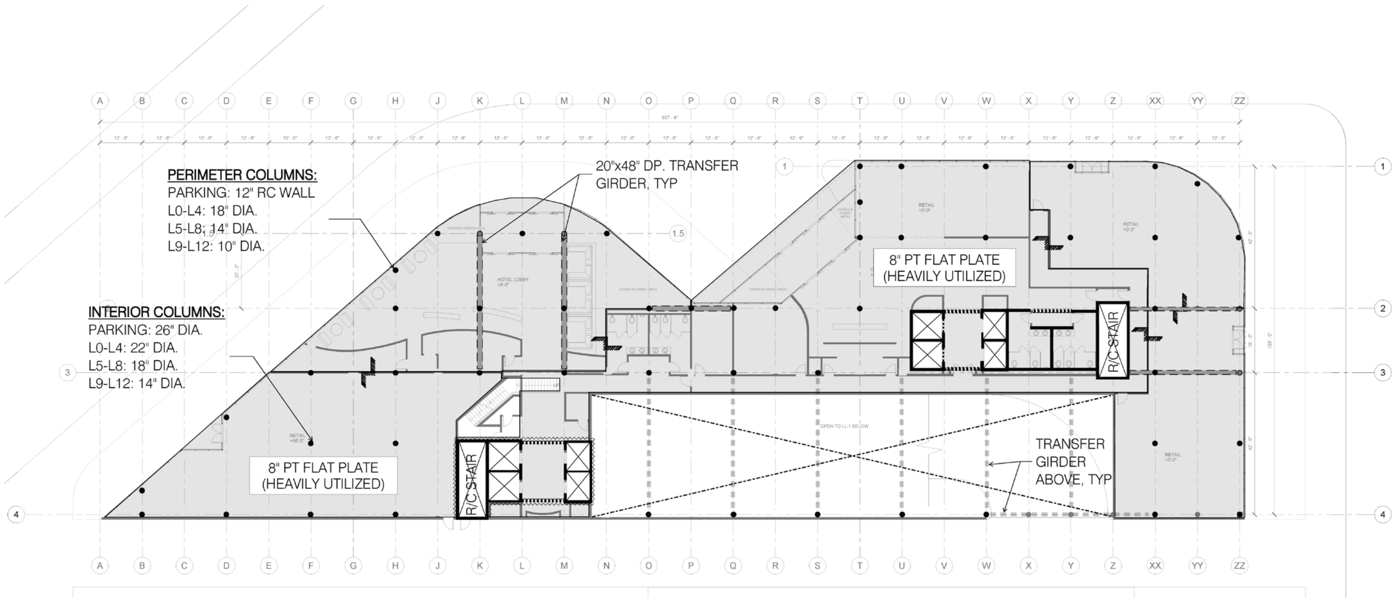


Fig. 79.1 | First Level Structure Plan | ◄ N

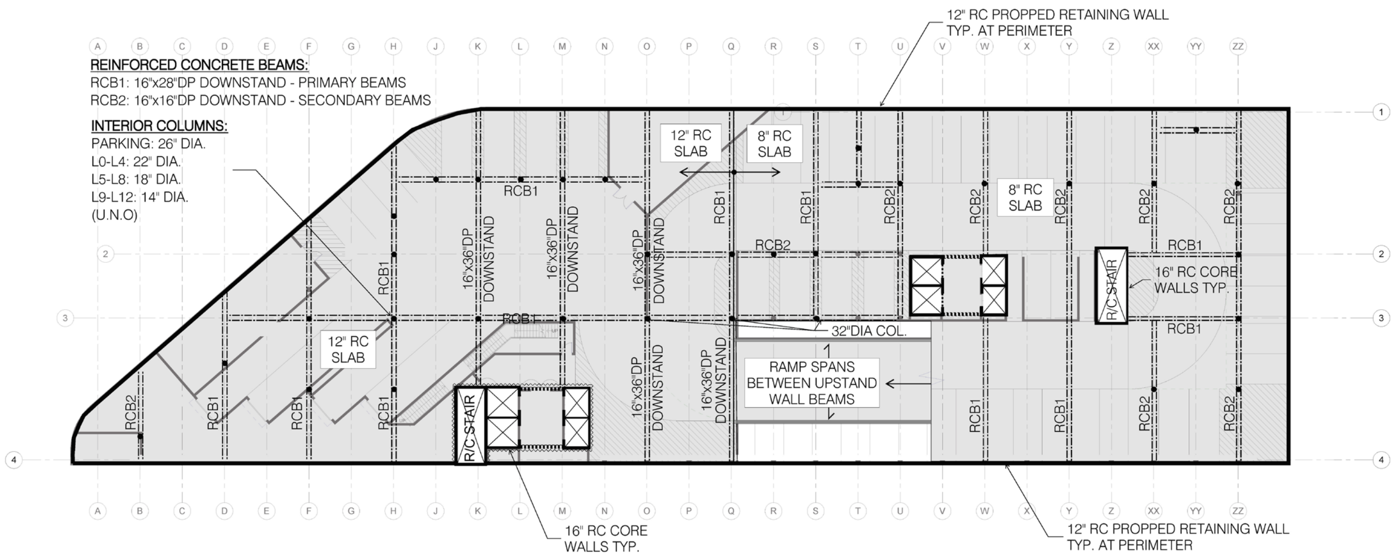


Fig. 79.2 | P-1 Structure Plan | ◄ N

Appendix B | Mass Timber Structural Schemes

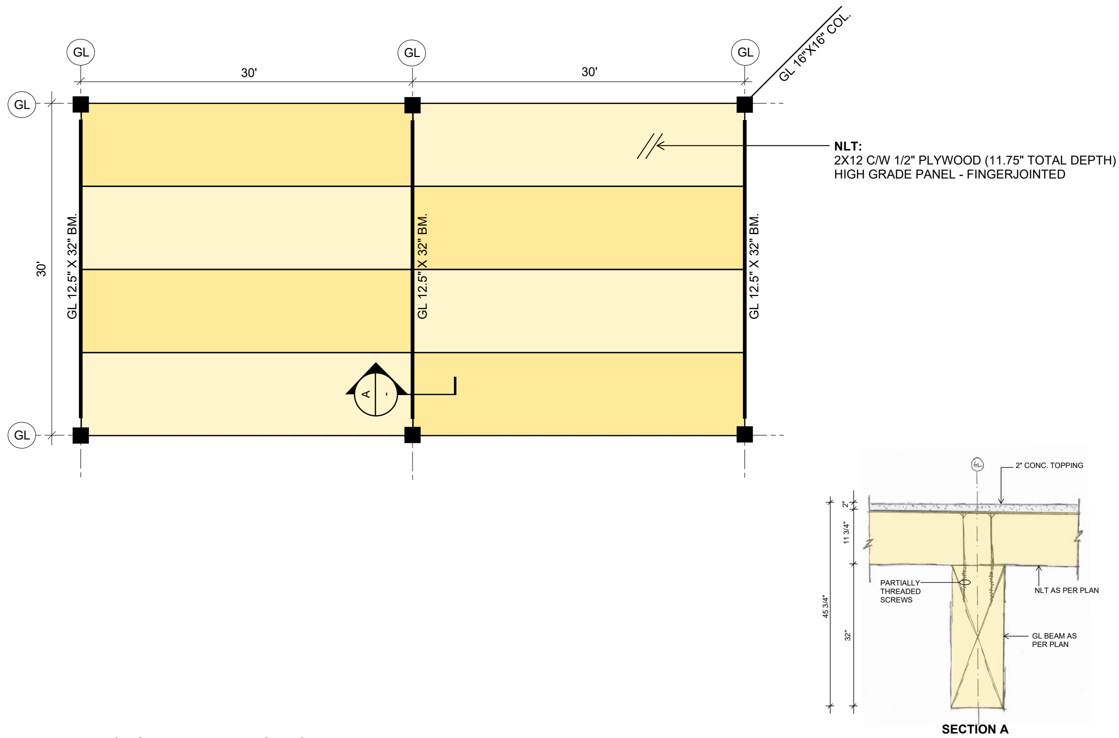


Fig. 80.1 | Mass Timber Structural Scheme 1

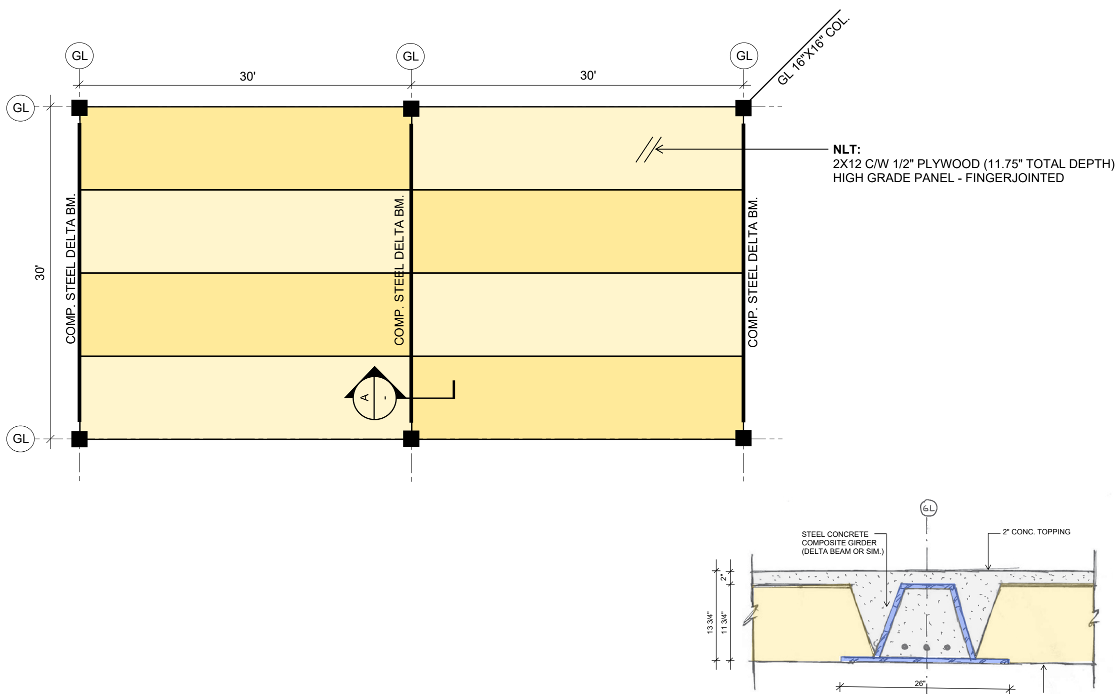


Fig. 80.2 | Mass Timber Structural Scheme 2

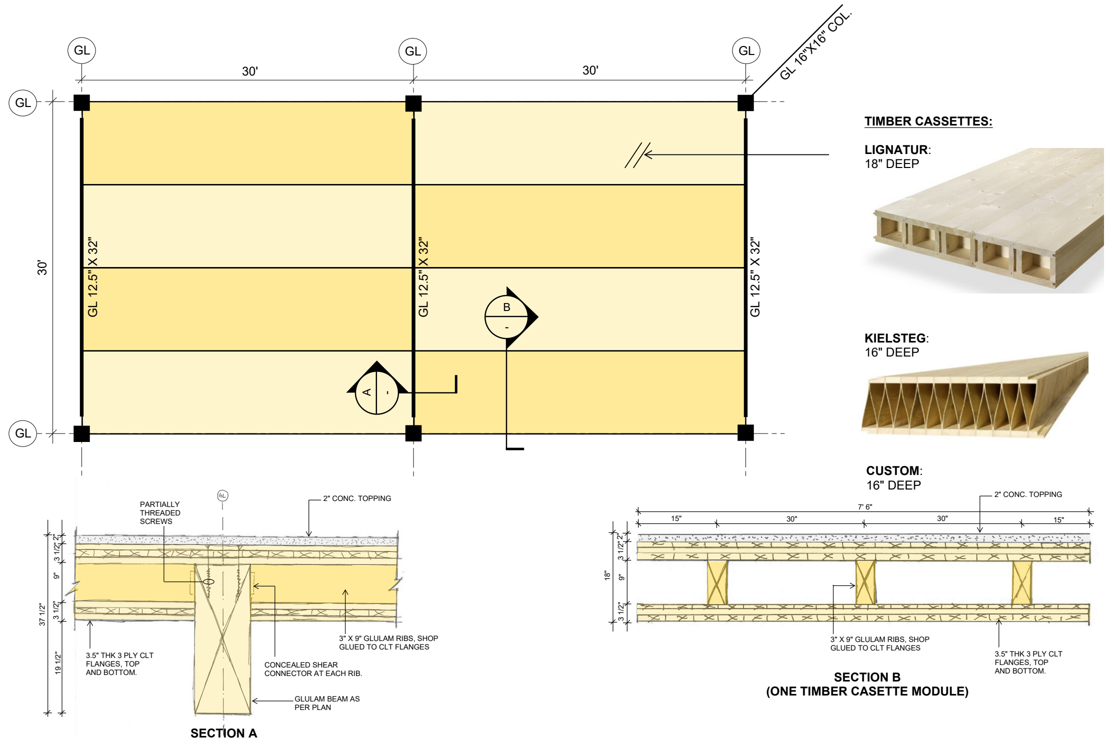
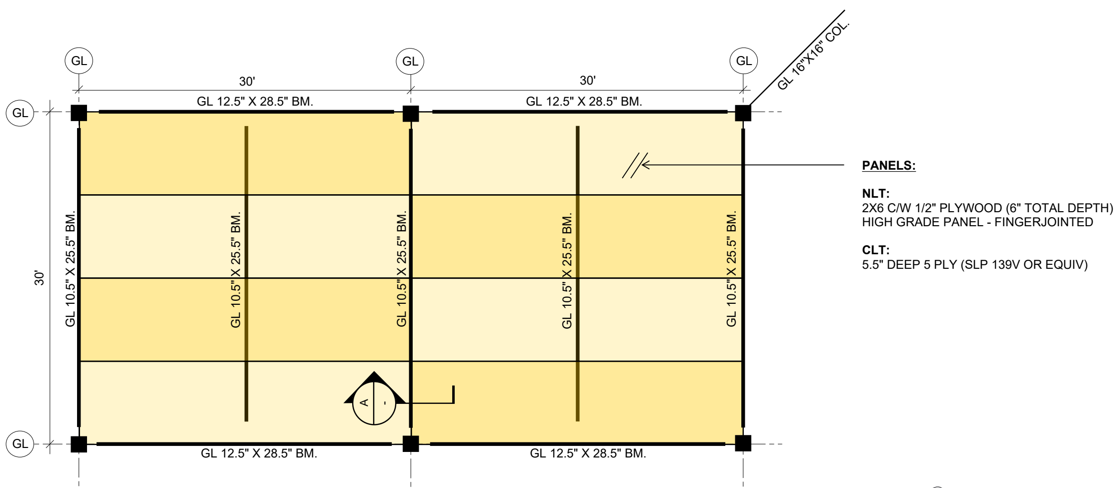


Fig. 81.1 | Mass Timber Structural Scheme 3



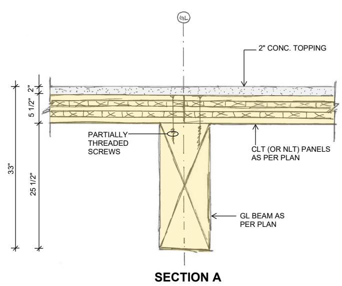


Fig. 81.2 | Mass Timber Structural Scheme 4

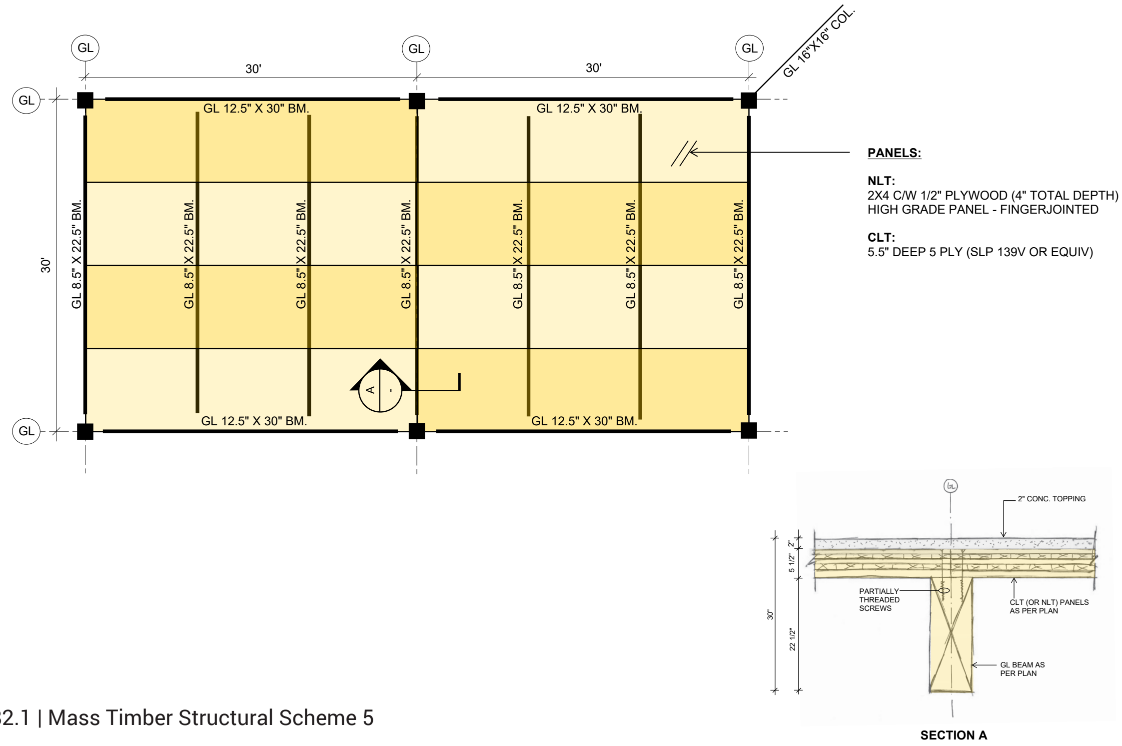


Fig. 82.1 | Mass Timber Structural Scheme 5

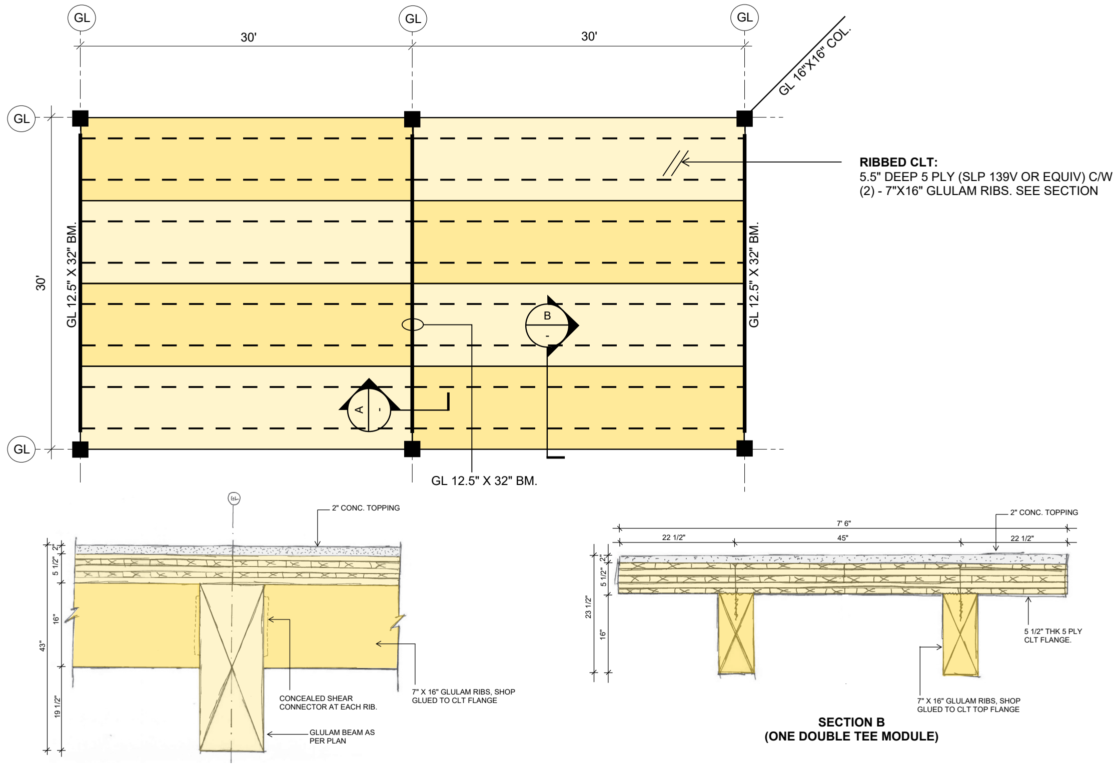


Fig. 82.2 | Mass Timber Structural Scheme 6

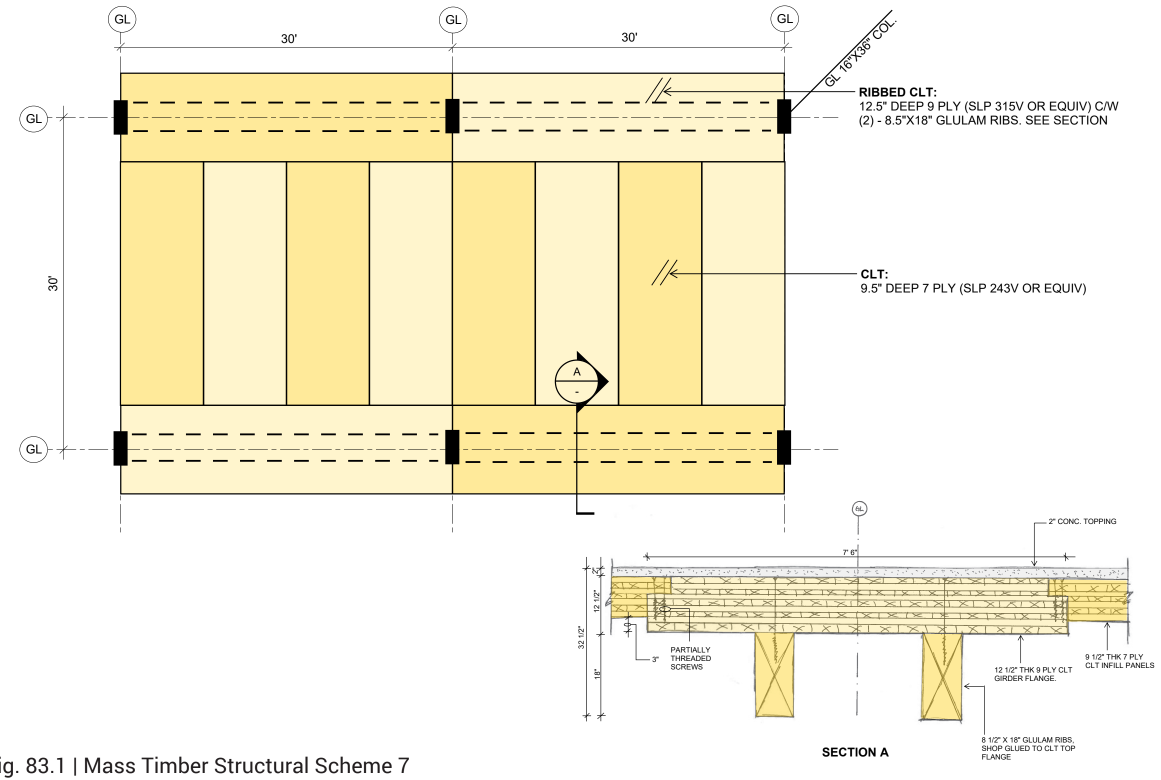


Fig. 83.1 | Mass Timber Structural Scheme 7

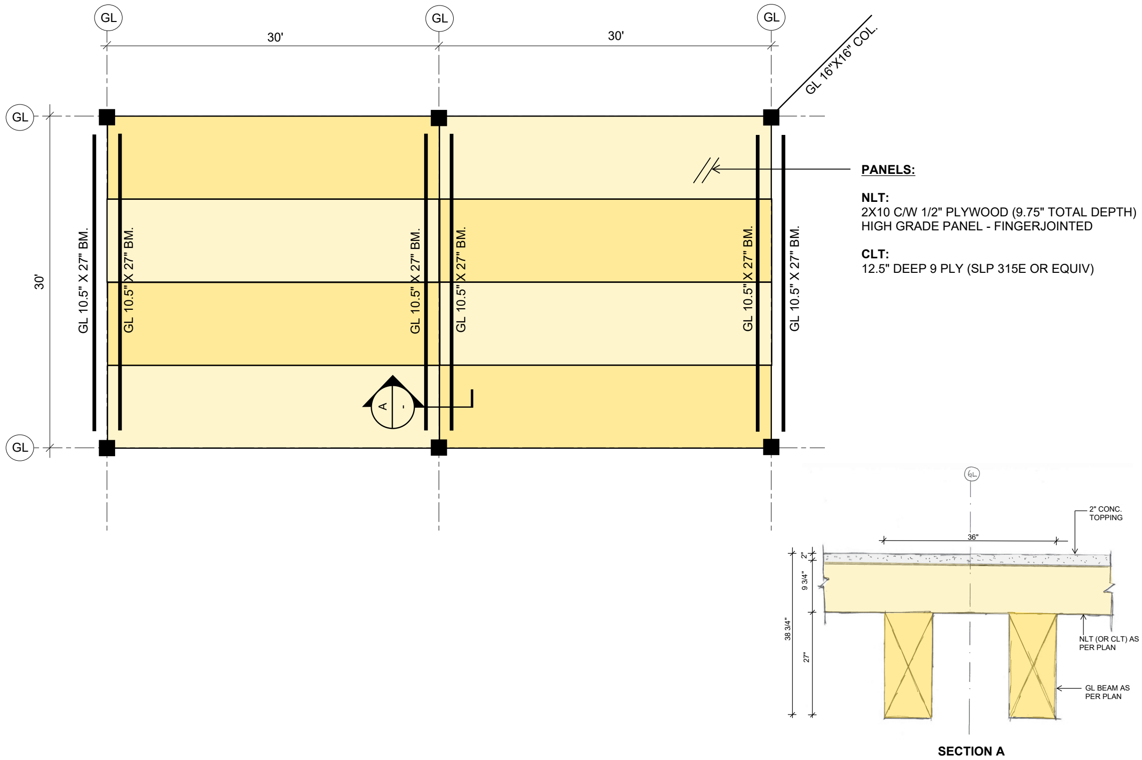
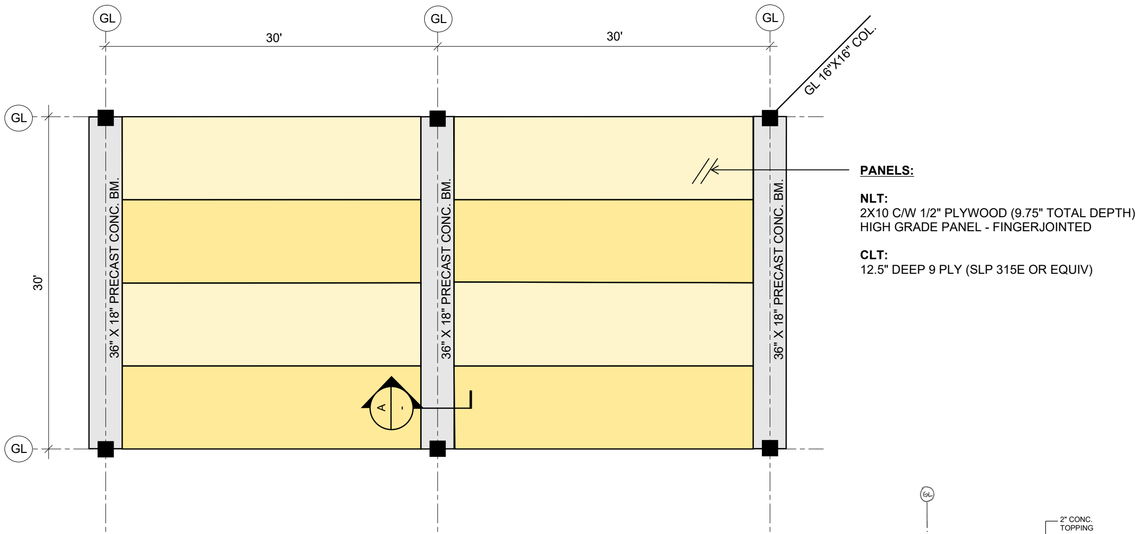


Fig. 83.2 | Mass Timber Structural Scheme 8



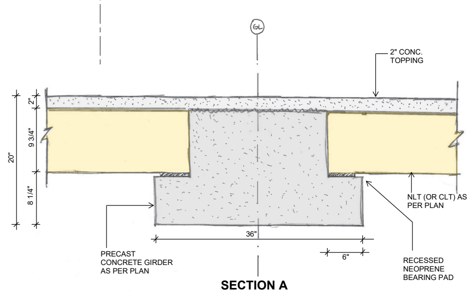
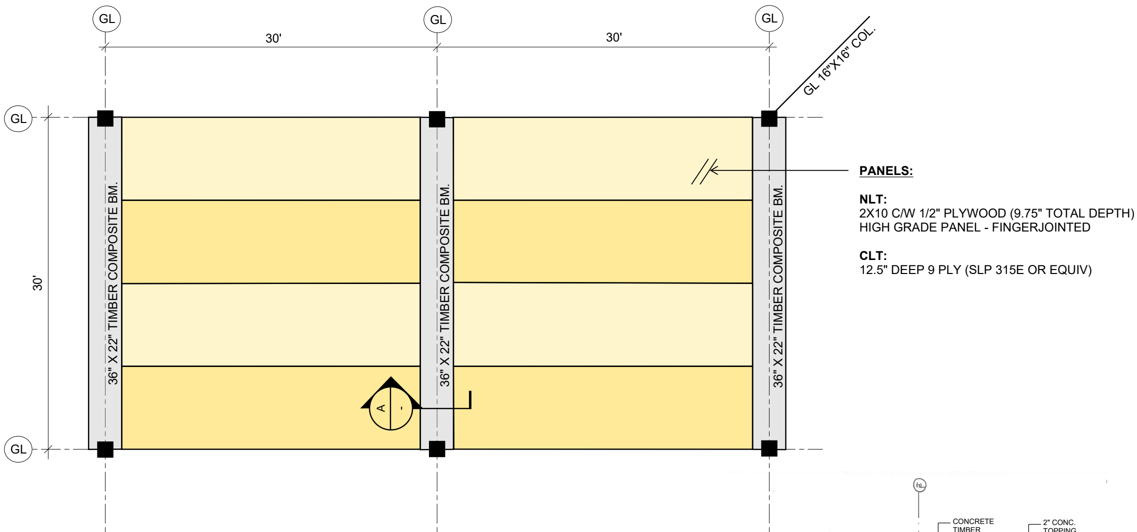


Fig. 84.1 | Mass Timber Structural Scheme 9



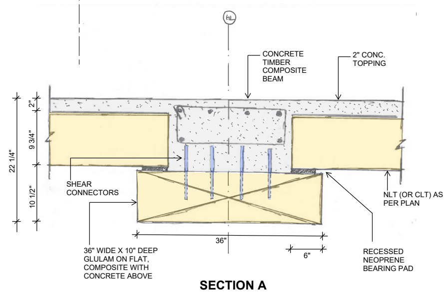


Fig. 84.2 | Mass Timber Structural Scheme 10

Appendix C | IES Virtual Environment Modeling Assumptions

	Project Baseline	Proposed SMTT
General		
Location	Seattle, WA	
Floor Area	~27,000 ft² (design GSF=25,400)	
Building Area	~317,000 ft² (design GSF=304,800)	
Floor to Floor height	18'-0" first floor 21'-0" twelfth floor 14'-0" all other floors	
ASHRAE method + template	Building Area Method, Office – all floors	
Occupied hours	8AM – 6PM (sensitivity analysis: Office LR none – HR 8-8 + weekends *)	
Simulation Weather File	SeattleTMY2.fwt	
Climate Zone	Climate Zone 4C	
Envelope Performance		
Roof characteristics	Type: Insulation entirely above deck U-factor: 0.027 Btu/hr·SF·°F Solar absorptance: 0.70 Emittance: 0.90	Type: Insulation entirely above deck U-factor: 0.027 Btu/hr·SF·°F Solar absorptance: 0.70 Emittance: 0.9
Wall characteristics	Type: Steel-framed U-factor: 0.055 Btu/hr·SF·°F Solar absorptance: 0.70 Emittance: 0.90	Type: Insulated metal panel U-factor: 0.052 Btu/hr·SF·°F Solar absorptance: 0.70 Emittance: 0.90
Floor characteristics	Type: Steel joist/framed floor U-factor: 0.029 Btu/hr·SF·°F	Type: Mass 2 ½" concrete slab with hydronic piping U-factor: 0.029 Btu/hr·SF·°F
Percentage Glazing	Per design	Per design
Overall Glazing U-value including frame	Type: Double pane, metal frame Col B SEA code U-factor: 0.38 Btu/hr·SF·°F	Type: Double pane, wood + glass fiber composite frame Col B SEA code U-factor: 0.30 Btu/hr·SF·°F Type: Double pane, metal frame (curtain wall in atrium) Col B SEA code U-factor: 0.38 Btu/hr·SF·°F
Solar Heat Gain Coefficient (SHGC)	0.27	0.27
Visible Transmittance	0.6 (vision) 0.3 (tinted)	0.6 (vision) 0.3 (tinted)
Shading	N/A	Per design
Infiltration	0.25 cfm/SF	0.25 cfm/SF

	Project Baseline	Proposed SMTT
Internal Loads		
Average Lighting Power [W/SF]– Building Area Method, Office	0.66 W/SF (sensitivity analysis: Office LR 0.5 W/SF – HR 1.0 W/SF *)	
Lighting Controls	Sidelighting daylight controls, Automatic Full OFF	
Plug-Loads [W/SF]	Office: 0.750 W/SF, Unoccupied hours: 0.4 W/SF (sensitivity analysis: Office LR 0.5 W/SF – HR 2.0 W/SF *)	
Elevators	8 Elevators	
Domestic Hot Water	DHW Consumption: 1.0 gal/day Occupancy: 1100 (based on 275 SF/person)	
Mechanical Systems		
Indoor Design Temperatures	Cooling - 75°F/85°F Heating - 70°F/60°F	Cooling - 75°F/80°F Heating - 70°F/65°F (sensitivity analysis*): Cooling LR 78 - HR 72°F Heating, LR 68 - HR 72°F
Outdoor Design Conditions	Cooling DB/WB: 86°F / 67°F Heating DB: 24°F	
Central Plant		
Heating Type	VRF Hor. equiv. piping length: 300’	Back up Boiler only [Electric HW boiler (100% eff.)]
Cooling Type	VRF IPLV ≥13.700 EER Hor. equiv. piping length: 300’	Central Heat Pump w/HR Chilled water (air-cooled chiller) (Full load ≥10.100 EER IPLV ≥13.700 EER)
Pumps	Included in VRF system	Dedicated heating equipment pumps 19 W/gpm
Domestic Hot Water	Electric HW boiler (100% eff.)	Electric HW boiler (100% eff.)
Air Side		
Air Handling Units/ System Description	DOAS w/ HR	DOAS w/ HR and heat pump for tempering supply air for dehumidification and pre-warm up operation only
Supply Air Temp	Tempered air (heat recovery) 60°F – cooling 60°F – heating	Tempered air (heat recovery) + 50°F Supply for dehumidification 60°F – cooling 60°F – heating
Utility Rates		
Electricity	7.5¢/kWh	
Carbon Rates		
Electricity	0.048 lb CO_2-eq/kWh	

*LR=Lower range for sensitivity analysis
HR=Higher range for sensitivity analysis

Appendix D | Impact Estimator for Building Assumptions

	Project Baseline		Proposed SMTT	
Foundations				
Footings – concrete	2,444	CY	2,668	CY
Footings – rebar	N/A		0.54	Ton
Parking Levels				
Concrete beams and columns (Assuming 5,000 psi)			The proposed design is likely to use less material overall than the concrete baseline (due to reduced weight of the superstructure), resulting in a **lower GWP compared to the concrete baseline**	
Superstructure				
Concrete beams and columns (Assuming 5,000 psi)	474	CY	N/A	
PT floor slabs (Assuming 5,000 psi)	90,252	CY	N/A	
Glulam beams and columns (Assuming non-biogenic carbon)	N/A		351,757	CF
5-ply CLT ceiling (Assuming non-biogenic carbon)	N/A		2,094,125	CF
Concrete topping slab (Assuming 5000 psi)	N/A		22,563	CY
2 layers sheetrock at ceiling, glulam beams	N/A		806,930	SF
Metal connections			Steel straps, reinforcing, and metal fasteners needed for mass timber superstructure will **increase the overall GWP of the proposed design**	
Envelope				
Glazing frames (excl. atrium)			The proposed design will use wood and glass fiber composite frames for the majority of the glazing, compared to aluminum framing in the baseline, which will likely result in a **lower GWP compared to the concrete baseline**	
GWP for all identified differences between Baseline and SMTT	2,976 lb CO_2/SF		1,625 lb CO_2/SF	
Δ GWP	> 1351 lb CO_2/SF reduction in Proposed SMTT			

Appendix E | Detailed Cost Comparison

SYSTEM	MASS TIMBER	PT CONCRETE	MASS TIMBER SAVINGS VS. PT CONCRETE (%)
SUBSTRUCTURE	8,662,161	8,759,502	-1.1%
SHELL	44,976,388	43,858,598	2.5%
INTERIORS	7,034,462	6,235,296	12.8%
SERVICES	19,919,344	19,869,896	0.2%
EQUIPMENT & FURNISHINGS	312,000	312,000	0.0%
OTHER BUILDING CONSTRUCTION	412,125	411,375	0.2%
BUILDING SITEWORK	4,560,000	4,560,000	0.0%
ADMINISTRATIVE REQUIREMENTS	131,563	130,843	0.6%
SUBGUARD INSURANCE	989,093	967,581	2.2%
DIRECT COST OF WORK	**86,997,136**	**85,105,091**	**2.2%**
GENERAL CONDITIONS	4,928,125	6,115,625	-19.4%
GENERAL REQUIREMENTS	4,215,625	5,403,125	-22.0%
PRECON SERVICES	250,000	250,000	0.0%
PROJECT OVERHEAD	**9,393,750**	**11,768,750**	**-20.2%**
GENERAL CONTRACTOR CONTINGENCY	2,891,727	2,906,215	-0.5%
ESCALATION	-	-	
CONTRACTOR FEE	3,667,238	3,685,612	-0.5%
GL Insurance - CCIP w/o BR	1,068,738	1,074,093	-0.5%
B & O Tax	759,642	763,448	-0.5%
ADD-ONS	**8,387,345**	**8,429,368**	**-0.5%**
Total	***104,778,231***	***105,303,209***	***-0.5%***

Appendix F | Concrete (Baseline) Development Schedule

ID	Task Name	Duration	Start	Finish
1	**Development Schedule**	**1037 days**	**Tue 1/1/19**	**Wed 12/21/22**
2				
3	**Site Selection, Land Offer/Acceptance, Due Diligence, & PSA**	**99 days**	**Tue 1/1/19**	**Fri 5/17/19**
4	**Entitlements and Permitting**	**938 days**	**Mon 5/20/19**	**Wed 12/21/22**
5	**Master Use Permit**	**552 days**	**Mon 5/20/19**	**Tue 6/29/21**
6	Conceptual Design for SDCI Pre-App Meeting	6 wks	Mon 5/20/19	Fri 6/28/19
7	Schedule Pre-Application Meeting	1 day	Mon 5/20/19	Mon 5/20/19
8	Pre-Application Meeting	1 day	Tue 7/16/19	Tue 7/16/19
9	Community Outreach	12 wks	Wed 7/17/19	Tue 10/8/19
10	Early Design Guidance	16 wks	Wed 10/9/19	Tue 1/28/20
11	Design Review	12 wks	Wed 3/25/20	Tue 6/16/20
12	Land Use Review	35 wks	Wed 3/25/20	Tue 11/24/20
13	SEPA checklist review	12 wks	Wed 1/29/20	Tue 4/21/20
14	**Street Improvement Permit**	**130 days**	**Wed 6/17/20**	**Tue 12/15/20**
15	Street Improvement Plan Check and Permit	26 wks	Wed 6/17/20	Tue 12/15/20
16	**Building Permits**	**190 days**	**Wed 10/7/20**	**Tue 6/29/21**
17	Phase 1 Permit (demo/shoring/below grade parking)	16 wks	Wed 10/7/20	Tue 1/26/21
18	Phase 2 Permit (above grade construction)	30 wks	Wed 12/2/20	Tue 6/29/21
19	**Design Phase**	**180 days**	**Wed 1/29/20**	**Tue 10/6/20**
20	Schematic Design	8 wks	Wed 1/29/20	Tue 3/24/20
21	Design Development	12 wks	Wed 3/25/20	Tue 6/16/20
22	Contract Documents	16 wks	Wed 6/17/20	Tue 10/6/20
23	**Estimating & GMP Contract Phase**	**210 days**	**Wed 3/25/20**	**Tue 1/12/21**
24	Schematic Design Estimate	4 wks	Wed 3/25/20	Tue 4/21/20
25	Design Development Estimate	5 wks	Wed 6/17/20	Tue 7/21/20
26	GMP Estimate & Contracts	14 wks	Wed 10/7/20	Tue 1/12/21
27	**Construction Phase**	**495 days**	**Wed 1/27/21**	**Tue 12/20/22**
28	Demolition and Utilities	4 wks	Wed 1/27/21	Tue 2/23/21
29	Shoring, Excavation, & Mass Grading	12 wks	Wed 2/24/21	Tue 5/18/21
30	Below Grade Parking	18 wks	Wed 5/19/21	Tue 9/21/21
31	Superstructure - Cast-In-Place Concrete and Post Tension	38 wks	Wed 9/22/21	Tue 6/14/22
32	Exterior Skin and Roofing	24 wks	Wed 1/26/22	Tue 7/12/22
33	Elevators	23 wks	Wed 6/15/22	Tue 11/22/22
34	Core and Shell Rough-In, M/E/P, Common Areas Finishes	34 wks	Wed 2/23/22	Tue 10/18/22
35	Sitework & Landscaping	8 wks	Wed 9/14/22	Tue 11/8/22
36	Life Safety Testing and Commissioning	3 wks	Wed 11/23/22	Tue 12/13/22
37	Temporary Certificate of Occupancy	1 wk	Wed 12/14/22	Tue 12/20/22
38	**Project Substantial Completion**	1 day	Wed 12/21/22	Wed 12/21/22

Project: Master Development S
Date: Mon 10/15/18

Task
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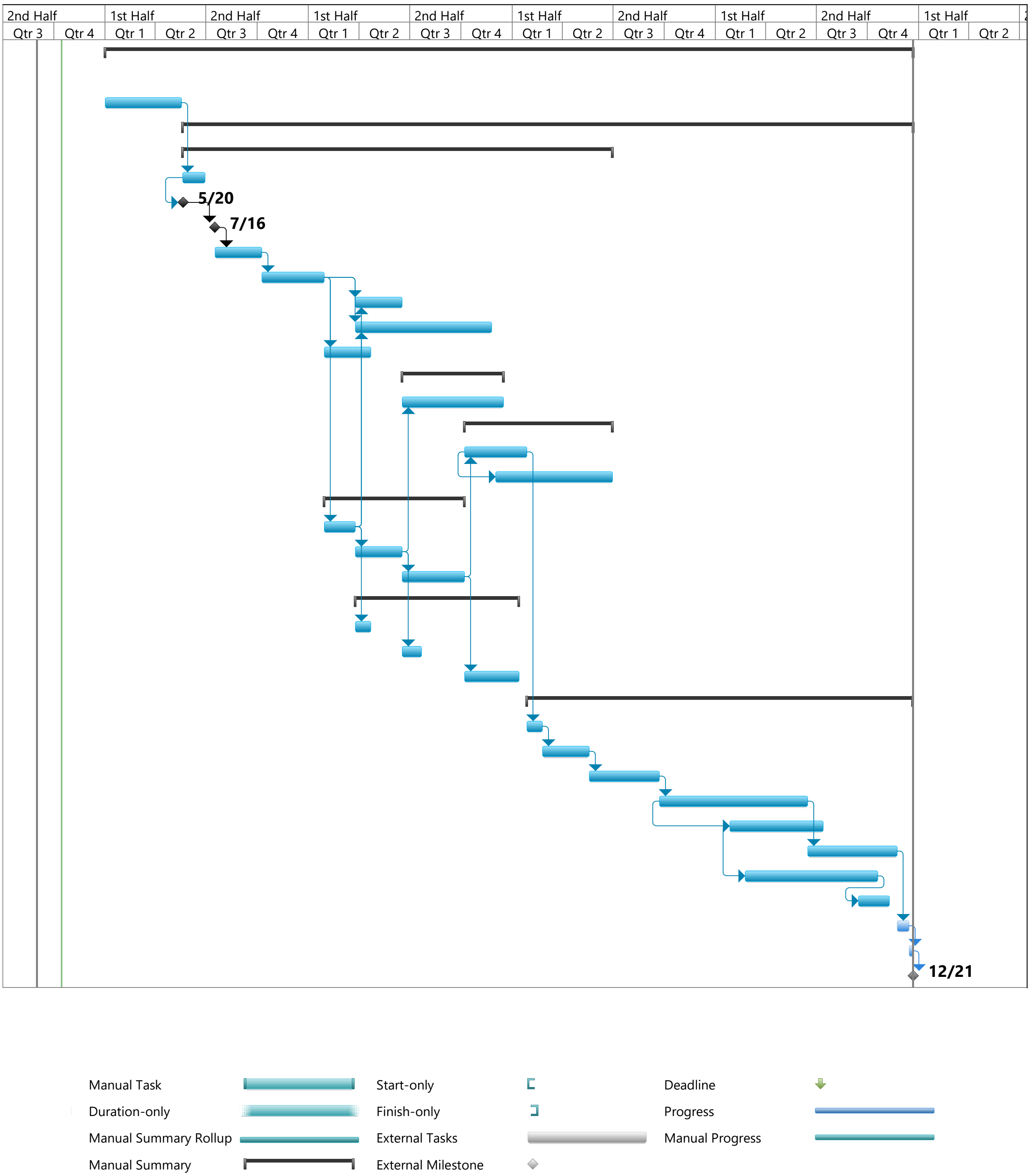
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary



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Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

Appendix G | Seattle Mass Timber Tower Development Schedule

ID	Task Name	Duration	Start	Finish
1	**Development Schedule**	**927 days**	**Tue 1/1/19**	**Wed 7/20/22**
2				
3	**Site Selection, Land Offer/Acceptance, Due Diligence, & PSA**	**99 days**	**Tue 1/1/19**	**Fri 5/17/19**
4	**Entitlements and Permitting**	**828 days**	**Mon 5/20/19**	**Wed 7/20/22**
5	**Master Use Permit**	**552 days**	**Mon 5/20/19**	**Tue 6/29/21**
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21	Design Development	12 wks	Wed 3/25/20	Tue 6/16/20
22	Contract Documents	16 wks	Wed 6/17/20	Tue 10/6/20
23	**Estimating & GMP Contract Phase**	**210 days**	**Wed 3/25/20**	**Tue 1/12/21**
24	Schematic Design Estimate	4 wks	Wed 3/25/20	Tue 4/21/20
25	Design Development Estimate	5 wks	Wed 6/17/20	Tue 7/21/20
26	GMP Estimate & Contracts	14 wks	Wed 10/7/20	Tue 1/12/21
27	**Construction Phase**	**385 days**	**Wed 1/27/21**	**Tue 7/19/22**
28	Demolition and Utilities	4 wks	Wed 1/27/21	Tue 2/23/21
29	Shoring, Excavation, & Mass Grading	12 wks	Wed 2/24/21	Tue 5/18/21
30	Below Grade Parking	18 wks	Wed 5/19/21	Tue 9/21/21
31	Ground Floor PT/Concrete	5 wks	Wed 9/22/21	Tue 10/26/21
32	CIP Concrete Cores Above Grade	17 wks	Wed 7/21/21	Tue 11/16/21
33	Superstructure - Mass Timber	20 wks	Wed 10/27/21	Tue 3/15/22
34	Exterior Skin and Roofing	21 wks	Wed 11/17/21	Tue 4/12/22
35	Elevators	24 wks	Wed 11/17/21	Tue 5/3/22
36	Core and Shell Rough-In, M/E/P, Common Areas Finishes	29 wks	Wed 12/1/21	Tue 6/21/22
37	Sitework & Landscaping	8 wks	Wed 5/25/22	Tue 7/19/22
38	Life Safety Testing and Commissioning	3 wks	Wed 6/22/22	Tue 7/12/22
39	Temporary Certificate of Occupancy	1 wk	Wed 7/13/22	Tue 7/19/22
40	**Project Substantial Completion**	1 day	Wed 7/20/22	Wed 7/20/22

Project: Master Development S
Date: Mon 10/15/18

Task
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Summary
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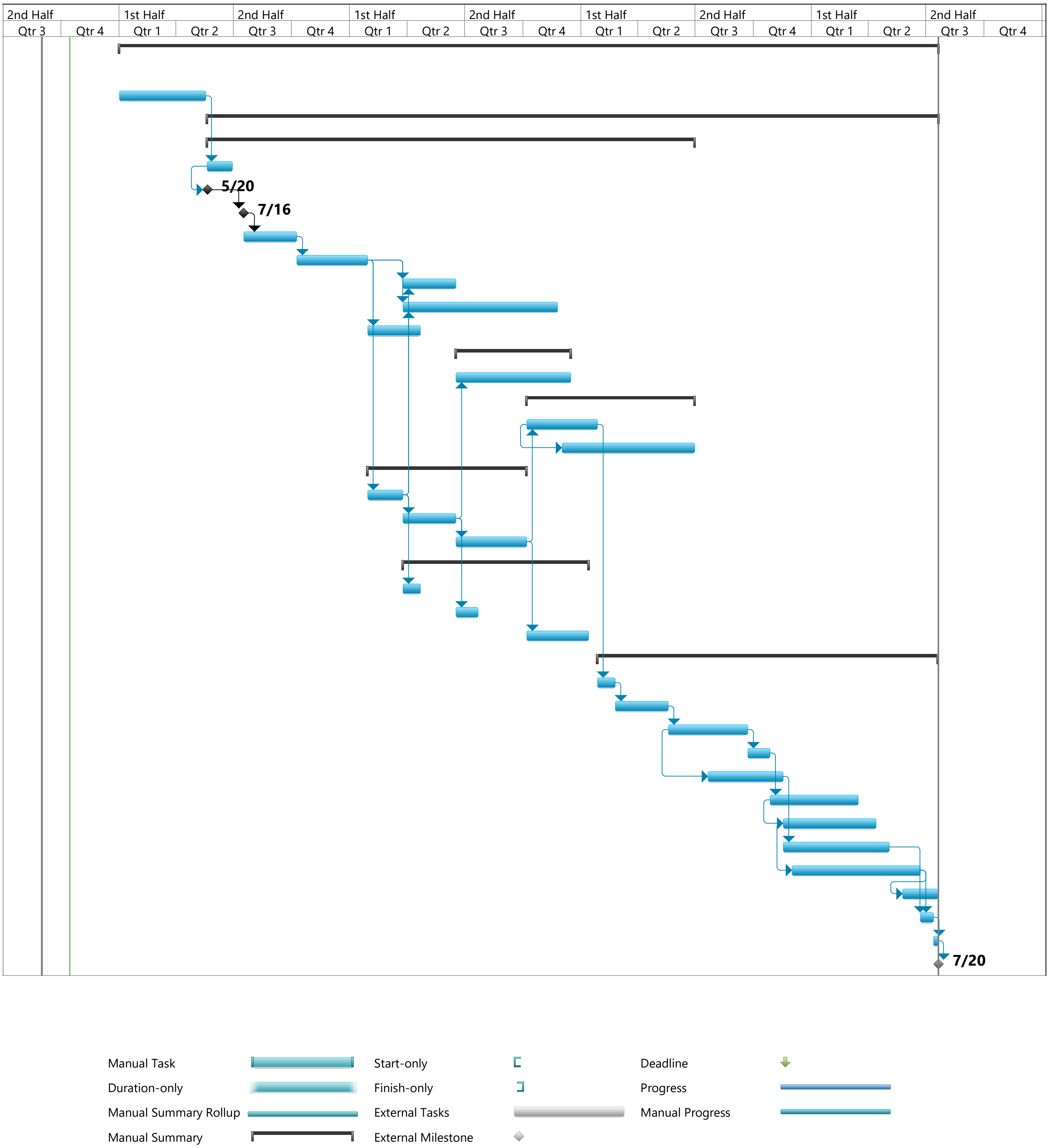

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Qtr 4
5/20
7/16
7/20
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

Appendix H | Material Takeoff Comparison

Item	Description	Takeoff Qty		Takeoff Qty	
		Mass Timber		PT	
A	***SUBSTRUCTURE***				
A1010	**Foundation Bearing Elements**				
A10_017123.000	*Foundations - Field Engineering*				
1000	Layout Foundation	16,540.00	SF	18,360.00	SF
	Foundations - Field Engineering		*SF*		*SF*
A10_032100.000	*Foundations - Reinforcing Steel*				
1010	Reinforcing - Walls - Misc. Pits, etc.	1.00	LS	1.00	LS
1010	Reinforcing - Walls - Misc. Pits, etc.	1.00	LS	1.00	LS
1030	Reinforcing - Rebar End Protection	1.00	LS	1.00	LS
1060	Reinforcing - Mat Foundation	393,131.00	LB	393,131.00	LB
	Foundations - Reinforcing Steel		*SF*		*SF*
A10_033100.000	*Foundations - Structural Concrete*				
1060	Concrete - Mud Slab	17,463.00	SF	15,640.00	SF
1060	Concrete - SOG w/ Reinforcing			34,000.00	SF
1060	Concrete - Slab on Grade	34,000.00	SF		
1070	Concrete - Mat Foundation	2,450.00	CY	2,720.00	CY
	Foundations - Structural Concrete		*SF*		*SF*
A10_055000.000	*Foundations - Metal Fabrications*				
1010	Elevator Sill Support Angles	8.00	EA	8.00	EA
	Foundations - Metal Fabrications		*SF*		*SF*
A10_071000.000	*Foundations - Dampproofing And Waterproofing*				
1000	Horizontal Waterproofing	2,400.00	SF		
1000	Horizontal Waterproofing - Elevator Pits			2,400.00	SF
	Foundations - Dampproofing And Waterproofing		*SF*		*SF*
A10_310010.000	*Foundations - Earthwork*				
1000	Export Foundation Spoils	2,450.00	CY	2,720.00	CY
1010	Excavate Foundation Spoils	2,450.00	CY	2,720.00	CY
	Foundations - Earthwork		*SF*		*SF*
	A1010 Foundation Bearing Elements		**SF**		**SF**

Amount	Amount
Mass Timber	PT
4,135	4,590
4,135	*4,590*
1,000	1,000
1,000	1,000
2,000	2,000
471,757	471,757
475,757	*475,757*
87,315	78,200
	272,000
272,000	
857,500	952,000
1,216,815	*1,302,200*
2,000	2,000
2,000	*2,000*
16,800	
	16,800
16,800	*16,800*
61,250	68,000
9,800	10,880
71,050	*78,880*
1,786,557	**1,880,227**

IMAGE REFERENCES

Fig. 13 | 16 | 69
Seagate Structures. (n.d.). UBC Brock Commons by Acton Ostry Architects under Construction [Photographs]. Vancouver, BC.

Fig. 7
Skog i tåke svart hvit veggbilde . (2018, October). Source: https://www.happywall.no/veggbilder/skog-i-take-svart-hvit-bilde

Fig. 11 | 23 | 24 | 28 | 29.1 | 29.2 | 31.1 | 32.1
DLR Group. (2018, October). Renderings. Seattle, WA

Fig. 12
Pg. 74
Forest. (2013, January). Source: https://favim.com/image/614865/

Fig. 14
Denny Park. (n.d.). Source: DLR Group

Fig. 15 | 27 | 36.1 | 36.2 | 37 | 50.1 | 51
DLR Group. (2018, October). Model [Photographs]. Seattle, WA.

Fig. 17 | 18.1 | 70 | 71.1 | 71.2
Appendix C | D | E | F | G | H
Swinerton. (2018, October). Charts. Seattle, WA & Portland, OR

Fig 18.2
WoodWorks. (2018). Mass Timber Projects in Design and Construction in the U.S. [Map].

Fig. 19
Structurlam. (n.d.). Source: CNC Machine Framing Glulam Beam for Steel Connector [Photograph].

Fig. 20
Fast + Epp. (n.d.). Wilson School of Design by KPMB Architects [Photograph]. Richmond, BC.

Fig. 39.1 | 39.2 | 39.3 | 41.1 | 41.2 | 41.3 | 42.1 | 42.2 | 43.1 | 43.2 | 44.1 | 44.2 | 45.1 | 45.2 | 46.1 | 46.2 | 46.3 | 46.4 | 46.5 | 47.2 | 47.3 | 76.1 | 76.2 | 77 | 78.1 | 78.2 | 79.1 | 79.2
Appendix A | B
Fast + Epp. (2018, October). Plans & Diagrams. Seattle, WA

Fig. 26.1
Y. (n.d.). Japanese Woodworking Corner Joints. Source: http://www.yourstreetgiftcards.com/japanese-woodworking-corner-joints/

Fig. 26.2 | 30.2 | 31.2 | 32.2 | 33.1 | 33.2 | 33.3 | 35.1 | 35.2 | 35.3 | 53.1 | 53.2 | 56 | 58 | 59.1 | 59.2 | 59.3 | 60.1 | 60.2 | 60.3 | 61 | 62 | 63 | 64.1 | 64.2 | 65 | 66
DLR Group. (2018, October). Plans & Diagrams. Seattle, WA

Fig. 30.1
Do a little window shopping. (n.d.). Source: https://www.sierrapacificwindows.com/Galleries/Detail/121

Fig. 40 | 55
Cross, E. (n.d.). The Library at the Dock [Photograph]. Melbourne, Australia.
Copywright: Stora Enso. Client: The City of Melbourne. Architect: Clare Design. Architect of Record: Hayball

Fig. 47.1
MyTiCon, courtesy WoodWorks, First Tech Federal Credit Union, Structurlam, & Swinerton. (n.d.). Typical Beam to Column Connection under Construction [Photograph]. Hillsboro, OR.
Architect: Hacker. Engineer: Kramer Gehlen and Associates.

Fig. 48 | 49 | 50.2
Martha Schwartz Partners (2018, October). Plan & Renderings. New York, NY

Fig. 57
DLR Group. (n.d.). Fairmount Kindergarten Center Hydronic Piping Installation [Photograph]. Mukilteo, WA.

Fig. 67.1
Structurlam. (n.d.). Charred CLT Panel [Photograph].

Fig. 67.2
MyTiCon, courtesy WoodWorks, First Tech Federal Credit Union, Structurlam, & Swinerton. (n.d.). First Tech Federal Credit Union Headquarters under Construction [Photograph]. Hillsboro, OR.
Architect: Hacker. Engineer: Kramer Gehlen and Associates.

Fig. 72
Gallery of David Chipperfield's "Sticks and Stones" Toys with Van Der Rohe's Bones in Berlin - 11. (n.d.). Source: https://www.archdaily.com/552553/david-chipperfield-s-sticks-and-stones-toys-with-van-der-rohe-s-bones-in-berlin/542b0fb1c07a80548f000304-david-chipperfield-s-sticks-and-stones-toys-with-van-der-rohe-s-bones-in-berlin-photo

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