Tall Timber

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Master of Architecture

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Abstract

From the inception of high rise construction concrete and steel have been the foundation both literally and figuratively of the construction process. As we, a society, become more aware and conscious of the environmental impacts of our built environment we must ask ourselves, are our current construction practices the best or are there ways that we can not only become more environmentally cognizant, but also more efficient in our construction of buildings. This project is an investigation of how a joint can help to improve the construction process and manifest itself into creating the tectonic nature of a project by using timber in high rise construction.
To my mom and dad, who have always been there for me. Thank you for your support and guidance over the years. None of this would have been possible without you. Thank you!
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“The joint is the beginning of ornament and that must be distinguished from decoration which is simply applied. ornament is the adoration of the joint.”

-Louis Kahn
“The 17th century was the age of stone, the 18th century was the peak of brick. The 19th century was the era of iron. The 20th century was the century of concrete. The 21st century will be the time for timber.”

-Alex de Rijke
Abstract:

As we, a society, become more aware and conscious of the environmental impacts of our built environment we must ask ourselves, are our current construction practices the best or are there ways that we can not only become more environmentally cognizant, but also more efficient in our construction of buildings.

“The joint, that is the fertile detail, it is the place where both the construction and the construing of architecture take place.”
-Carlo Scarpa

This project is an investigation of how a joint can manifest itself into creating the tectonic nature of a project by using timber in high rise construction.
Introduction:

For myself, I have always found there to be a need for architects to not only understand architecture, but also construction. It’s the idea of returning to the “master builder” and while today’s’ complicated building systems and components make it nearly impossible, I feel architects still have the responsibility to understand as much about the building industry as possible.

Therefore, when I began my thesis I began with the question of how to incorporate both my interest in architecture, as well as construction. The idea of constructability is something often mentioned in the construction classes and construction industry but is not often spoken of in architecture school.

The success of a project is not only determined by its aesthetic beauty, but also by the ability to deliver the project on time. Today, while owners continually ask for tighter project schedules and often times the incorporation of sustainable design, we must ask ourselves if our current design practices are the best, or if we are in a new era which calls for new building technologies. To this I say we must forgo our current practices and pursue new means in construction such as CLT (cross laminated timber) to keep up with the demand for new buildings, as well as to help maintain our environment.

Wood, when harvested responsibly, is one of the best tools architects have in reducing the effect buildings have on the environment. While the use of mass timber in high-rise construction is often dismissed due to preconceived notions, this report challenges those ideas and argues that the use of mass timber will not only be beneficial to the environment but will also have positive cost savings associated with it.
Details are more than minor elements of a project. They can be considered the elements which produce genius loci or the “spirit of place”. While the plan is often given the role as the organizer of space in architecture, one could argue that details could be used as generators of this organization. For within the detail is both the construction of architecture, but also the construing of architecture (Frascari 1983).

Detailing is not just a means of production. Rather, it is the art of joining materials, elements, components, and building parts in a functional and aesthetic manner. To understand the concept of detailing requires an inquiry of how details function at different architectural scales. The result of these inquiries is the identification of details with the making of a joint, as well as the recognition that details can impose order.

According to Merriam-Webster a detail is “a part of whole”. This statement however is challenged in the realm of architecture for once scale and dimension are introduced the definition loses it meaning. In architecture the method by which columns and beams join is a detail, but so are the spaces that comprise a piece of architecture. However, we can gather that any architectural element defined as a method of joining is always a detail (Frascari 1983). This means details can be “material joints” such as a column and beam coming together, or they can be “formal joints” such as a space linking to other areas. No matter the scale, architectural details can be viewed as words in a sentence. And it is the selection of the words and how they are arranged that give a style. It is this “style” which is tectonics (Frascari 1983).

If all details are joints, then the joint is the place where the construing and construction meet. For architects then the joint can not merely be thought of from a practical means. One must consider the joint as the most important aspect of a building. For a joint does not only serve as a practical means, it also serves to create an order, a structure, an aesthetic, a language. All words that are so often used by architects, but so often fail to associate them to a joint. Joints are the minimal unit of signification but are the pretexts for generating the texts. So, while they appear minimal they play a very significant role.

A piece of architecture that focuses on the details is regarded as more refined than one that does not. This focus shows a beauty that might not have been seen and can reveal much about how the project was thought about, designed and constructed. It also reveals the art of design, and the craft of construction. While a single piece of architecture can reveal thoughts and intentions of the architect, a society’s architecture reveals a great deal about their customs, ideals, and way of life. One can look at time periods within architecture and define what was important to the culture at that time. For some of the early religious groups of the Americas such as the Puritans, Shakers, and Mormons, their architecture is nothing more than a continuation of their principles they followed in their everyday lives.

For the Shakers, the ideas of simplicity, functionality, practicality, and humbleness were seen throughout their lifestyle. A lifestyle that also included celibacy, community, pacifism, and equality of the sexes, traits that were at the core of their beliefs (Hancock). Though they appear more liberal than the Quakers with the idea of equality of the sexes, the Shakers were more conservative, and wanted to live a stricter lifestyle. Besides these attribute, the Shakers were also known for their simple living, architecture, and furniture. Through their trades the Shakers beliefs of being representatives to God can be seen from their craftsmanship and attention to detail. It was
from these details that Shaker furniture gained its popularity but also its beauty.

The Shaker joinery was as Louis Kahn would say “the beginning of ornament”. It was from these joints that the Shaker furniture obtained its aesthetic quality. One of these pieces of furniture which has withstood time is the Shaker trestle table.

The origins of the trestle table can be traced back to medieval times. During this time the trestle table was narrower, since people often only sat on one side of the table with their backs facing the wall. As times changed the trestle table began to become wider, and at the same time shorter. The shakers did not invent the trestle table, although you could argue they improved it.

The trestle table is simple yet elegant. From the ends the table appears like a tree, with its “roots”, a straight post or “trunk”, and lastly the support at the top, which could be viewed as “branches”. Although the trestle table appears elegant it goes without saying it is also very sturdy. Trestle tables often are extremely lightweight for their size, which ranged in length from 8 to 12 feet.

For the shakers who often had communal gatherings, the trestle table was the perfect fit. However, the trestle did have one drawback for the shakers, its center member. The member interfered with the shakers being able to properly and efficiently clean under the table, due to this the shakers raised the center member up several inches allowing for more room and no obstructions under the table.

Though the trestle table is simple it expresses what is at the heart of the shaker lifestyle, and that is to be efficient, clean, and practical.
Zoomed In Exploded Axon of Joint
Exploded Axon of Joint With Forces
From examining the shaker joint, it became apparent that it resisted both forces that would pull as well as twist, the joint. These two forces however were dealt with in different ways. The pulling force was dealt with by introducing wedges to cause friction, while the rotational force was dealt with by the introduction of pegs. To resist these two forces however, pegs can be introduced as the main joinery rather than two different joint conditions. By running pegs perpendicular to each other the rotational force is not only controlled, but also any pushing and pulling force as well.
By having three pegs connecting three members you produce a resistance to forces in all directions. However, once one peg is removed the structure is compromised. The removal of one peg however, allows for the joint or structure to condense. This enables the joint to be transported easily. This idea enables the design to have flexibility and be used on both large as well as small scales. The joint can be used for something as small as a child’s puzzle, to a member for a large structure.

Below, are diagrams and images from the study of reimagining the shaker trestle table joint.
Rule and Principles:
1. The use of pegs in the x, y, and z axis resist lateral forces as well as rotational forces in all directions.
2. The three pegs come together to hold three members together. The removal of one peg compromises the structural integrity of the joint.
3. All members have openings in the same location.
4. Specific faces match up and will never be in contact with another face. Similarly, certain faces do not have a match and therefore have the ability to grow.
5. The removal of both a vertical pin and horizontal pin allows the joint to collapse. (set 3)
6. The removal of only vertical pins enables the joint to condense but still have a sense of verticality. (set 4)
7. By combining joints a system begins to form. If four joints are connected together, both pins and members must be removed in order for the system to collapse.
Reimagined Joint

Node of Joint

Shared Faces
Manifestation of Joint
Background:
CLT
The study of the joint dictated the type of material to be used, and that was wood. From listening to a TED talk given by Michael Green the means to apply the tectonic nature of this joint became clear. Through implementation of the joint in the construction process you are creating the tectonic nature for a high rise building. When proposing the idea for the use of wood in highrise construction people tend to typically have preconceived notions about it. A few of these notions are:

- It is not sustainable
- Fire resistance of tall wood structures cannot replicate the performance of steel of concrete
- Wood shrinks, wood rots, wood burns, glued wood off-gases
- Tall wood buildings will not withstand earthquakes
- Tall wood structures will have thicker walls

The following aims to combat these preconceptions and show that for a better future we must consider a shift in the tectonic nature of our highrise buildings.

To start, we must state what mass timber is. Mass timber are products such as cross-laminated timber (CLT), nailed-laminated timber (NLT), glued-laminated timber (GLT), laminated strand lumber (LSL), laminated veneer lumber (LVL) and other large-dimensioned structural composite lumber (SCL) products are part of a bigger classification known as ‘mass timber’ (Green 2017).

Although mass timber is an emerging term, traditional post-and-beam (timber frame) construction has been around for centuries. Today, mass timber products can be formed by mechanically fastening and/or bonding with adhesive smaller wood components such as dimension lumber or wood veneers, strands or fibers to form large pre-fabricated wood elements used as beams, columns, arches, walls, floors and roofs (Green 2017). Mass timber products have sufficient volume and cross-sectional dimensions to offer significant benefits in terms of fire, acoustics and structural performance, in addition to providing construction efficiency.

Cross Laminated Timber (CLT):

CLT consists of several layers of boards stacked crosswise (at 90 degrees) and glued together on their wide faces and, sometimes, on the narrow faces as well. A cross-section of a CLT element has at least three glued layers of boards placed in orthogonally alternating orientation to the neighboring layers. In special configurations, consecutive layers may be placed in the same direction, giving a double layer to obtain specific structural capacities. CLT products are usually fabricated with three to seven layers (Green 2017).

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

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

Laminated Strand Lumber (LSL):

LSL is a structural composite lumber manufactured from strands of wood species or species combinations blended with an adhesive. The strands are oriented parallel to the length of the member and then pressed into mats using a steam injection press (Green 2017).

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

Adhesives: Phenol formaldehyde (PF), Phenol-resorcinol formaldehyde (PRF).
Laminated Veneer Lumber (LVL):

Laminated veneer lumber is made up of layers of wood veneers laminated together using a waterproof structural adhesive. The manufacturing process consists of rotary peeling a log into veneers that are then dried and graded for strength and stiffness. After the graded veneers are coated with adhesive they are laid-up into a billet that is then fed into a hot press that cures the adhesive under heat and pressure. The cured and compressed billet then leaves the hot press and is ripped into boards (Green 2017).

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

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

Currently there are several different types of adhesives used in engineered wood. They are as followed.

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

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

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

Polymeric Methylene Diphenyl Diisocyanate (pMDI) is an isocyanate based adhesive. As is the case with PF and PRF, cured pMDI forms a strong bond that is not susceptible to the hydrolysis reaction that would cause the adhesive to release VOCs (Green 2017). Properly hardened pMDI is inert and is proven to be well below any emissions standard. pMDI is limited in use due to higher costs and its unique handling procedures.

While there is some concern over the gases offed from the adhesives, LVL and LSL testing has shown that formaldehyde emissions from these products range from 0.02 ppm to 0.04 ppm. A CLT panel emits
between 0.015 ppm to 0.05 ppm (Green 2017). The Environmental Protection Agency considers 0.10 parts per million as elevated. The Housing and Urban Development (HUD) has also set limits on the amount of allowable formaldehyde which may be emitted for building materials and contents at 0.3 parts per million.

So why use CLT? As the world population continues to migrate to urban areas and carbon dioxide emissions present a concern to our atmosphere, architects must explore alternative building materials that can contribute to a healthier environment. Some estimates reflect the shift to urban areas to be significant with increases as high as 20% (over current numbers) bringing the population of urban areas to 70% of the world’s population (UN Habitat estimate).

Urbanization:

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage of Urban Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>2 out of 10 people lived in urban area</td>
</tr>
<tr>
<td>1990</td>
<td>4 out of 10 people lived in urban area</td>
</tr>
<tr>
<td>2010</td>
<td>5 out of 10 people lived in urban area</td>
</tr>
<tr>
<td>2030</td>
<td>6 out of 10 people lived in urban area</td>
</tr>
<tr>
<td>2050</td>
<td>7 out of 10 people lived in urban area</td>
</tr>
</tbody>
</table>

Besides the growing urban population, UN Habitat estimated that 3 billion people will need a new affordable home in the next 20 years.

While climate change is certainly not a new topic and scientists have been studying ice and its advances and retreats from the earth’s heating and cooling for many years, as architects and dwellers of this planet we have a responsibility to be mindful of the structures we create and their effect on the environment. Some people will offer that climate change has existed long before humans have inhabited this earth, but that does not eliminate the necessity to make improvements in building materials. While concrete and steel have proven to be very dependable building materials, exploration and advancement in materials must continue.

Wood buildings have existed for hundreds of years, the shift now is to explore “tall” wood buildings, or skyscrapers. Tall wood buildings would not be constructed of lumber that can be purchased at your neighborhood lumber yard, but from large scale solid panels of wood that are engineered using a layering method that promotes strength and density. The options include: Cross Laminated Timber (CLT) that is made from layers of solid wood set at 90 degree orientations, Laminated Strand Lumber (LSL) made from a matrix of thin chips, and Laminated Veneer Lumber (LVL) made from thin layers of wood similar to that of jumbo sheet plywood. Building with this large scale timber would contribute to a healthier environment by both reducing and storing carbon and other greenhouse gas emissions.

The building industry represents approximately 1/3 of greenhouse gas emissions worldwide. The concrete and steel structures constructed during the last century create emissions starting with the manufacturing of the materials and continuing through the life of the building because of the energy that is used to climatize these structures. Concrete and steel production represents roughly 8% of world carbon dioxide emissions. According to one source steel and concrete designs embody 26% and 57% more energy relative to the wood design, emit 34% and 81% more greenhouse gases, release 24% and 47% more pollutants into the air, discharge 400% and 350% more water pollution, produce 8% and 23% more solid waste, and use 11% and 81% more resources (from a weighted resource use perspective) (Embodied).
Solid Waste

Resources Required

Released Pollutants Into Air

Water Pollution
Wood, on the other hand, is created by nature and is able to store carbon for its complete lifecycle, similar to the way forests work. Wood stores somewhere between 1 to 1.6 metric tons of carbon dioxide per cubic meter of wood depending on species. A typical North American timber-frame home captures about 28 metric tons of carbon dioxide (over its lifetime), the equivalent of seven years of driving a mid-size car or about 12,500 liters of gasoline (Green 2017). There is no need to think that wood would become a replacement for concrete and steel, but instead can be used alongside these other materials to combat climate change. At a minimum, it needs to be explored in greater detail especially in the urban environments. One must be cognizant of the fact that while wood will store carbon, we are only delaying climate change instead of reversing it. In order to reverse climate change, an alternative life for the wood would be necessary after the life cycle of the building has come to an end.

The notion of using wood for large buildings has been slow to take hold, especially in the United States. While large scale timber was being used in Europe at least 20 years ago, the U.S. has watched from the sidelines. The tallest modern mass timber building in the U.S. opened in 2016; it is located in Minneapolis, MN. The building in Minneapolis is a mixed use building of retail and office space at seven stories high with 220,000 square feet of space. In 2017 a design building opened at the University of Massachusetts in Amherst, MA. In New York City a 10 story luxury residential building, designed by SHoP Architects, is in the approval process to be constructed at 475 West 18th Street. As building codes change and more manufacturers of these products enter the marketplace, we will see an increase in the use of this material. In addition to building codes, perceptions must change. Critics view wood as a combustible material that is not suitable for large scale construction. Critics would also point out that timber is not fire proof, but steel is not fire proof either unless it is coated with a fire proof material. Advocates argue that tests have shown that these large scale panels can achieve a fire rating of three hours and that wood has a natural tendency to char which slows the burning process while maintaining the structural integrity. Test have shown that when mass timber burns, the char layer actually helps to insulate the remaining wood from heat penetration. Due to the ability of wood to form a protective char layer during combustion, the fire-resistance rating of large-sized members can be calculated based on minimum structural thicknesses and the remaining sacrificial thickness available for charring. Another means of improving fire performance is to encapsulate the mass timber in two layers of gypsum board similar to standard construction techniques.

In addition to timber being a renewable source, capable of capturing and holding carbon dioxide emissions, it also provides a more cost effective and time competitive approach to building. The cost preconception of tall wood buildings has been eliminated. The square foot cost in a dollar to dollar comparison shows timber to be more cost effective for low rise construction and equal in the mid/high rise category when compared to reinforced concrete (Green 2017). However, there is a cost benefit to consider because there is no curing time, no time limit for installation, it can be easily shipped, it does not require large crews for installation, and it is lighter to transport. It is the time factor of building with timber where the cost savings is realized. Timber also has better performance in the areas of acoustics due to its ability to absorb sound and in seismic shifts because it is ductile (with a high strength-to-weight ratio) as opposed to steel which
is brittle. The drawback to mass timber construction is the high capacity to store moisture, with low vapor permeability. Accommodations would need to be made to avoid excessive wetting during transport, construction, and storage to avoid excessive drying times.

What are the unknowns? While barriers to mass timber construction are slowly eroding, much skepticism still exists from insurers, regulators, and code officials. Full scale fire tests, resulting in consistent data, will move wood construction to the next level and begin to satisfy municipalities. In 2016 The Framework Project LLC (which owns Framework) announced that two fire tests of CLT and glulam had achieved two hour fire ratings, which showed that mass timber could meet stringent fire code requirements (Green 2017). That same year, D.R. Johnson’s CLT panels met fire safety requirements under tests that gauge flame spread and fire resistance. However, it is the prospect of carbon taxes (or penalties) that will catapult mass wood construction mainstream. Currently New York City has begun a program to “benchmark” buildings in order to arrive at the building’s fossil fuel consumption. Their motive is to eliminate the need for more power plants by persuading building owners to adopt more energy efficient mechanical and electrical equipment. This can translate into more efficient building materials.

In addition to providing structural support for a building, the building enclosure plays a vital role in the comfort of the occupants as well as air quality, energy consumption, and structure durability. A building constructed of wood, concrete, or steel will encounter the same challenges with regard to moisture penetration. Mass timber is not immune from shrinkage from moisture, so even though mass timber panels have some level of airtightness, an additional barrier membrane is recommended to alleviate water penetration issues.

System integration pertains to the mechanical and plumbing systems integration into the main components of a building. You can customize mass wood timber panels and have them arrive on site, pre-cut to accommodate the services as originally designed by architects and engineers using computer aided design software. Because the designs are computer generated, the panel fabrication are computer generated to exact specification.

In a concrete and steel construction, much labor is required to prepare the steel frame, then to prepare the decking rebar and opening frames prior to pour of the concrete, then the pouring takes place, and then the curing time must be allowed (about seven days for curing). The prefabricated nature of the wood panels makes the construction process streamlined because once the prefabricated panels arrive onsite, with the required mechanical openings, they can be secured with minimal labor. The mass timber panels can be fabricated in very large sizes enabling more of the structure to be completed with a single piece. Steel and concrete require multiple crews with different skill sets to enable the steel and concrete to bond. In the construction of a steel and concrete building multiple labor rates are involved due to the different trades that must be employed to construct the building. With a timber structure there may be one single trade responsible for the wood members.
CASE STUDY - OPTION 1

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

In this option, which allows up to 12 stories in building height, the wooden core and exterior perimeter glulam columns are the primary structure. Since none of the interior walls are required to be load bearing there is a great amount of flexibility for floor plan layout. Also, in the absence of exterior load bearing walls, this option allows for freedom when it comes to facade design. Additionally, like many buildings with such open spaces, interior modifications are easily made to allow for future changes in occupancy or use. Its open floor plan and ability to easily accommodate future changes positions this option quite competitively in terms of use and planning to its concrete benchmark, particularly in the office market.

Image From: Green 2017
CASE STUDY - OPTION 2

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

In addition to the structural wooden core and exterior perimeter glulam columns, interior structural walls are introduced in order to increase the possible building height up to 20 stories. Similarly to Option 1, in the absence of exterior structural walls, this option also allows for great flexibility in facade design. The interior load bearing walls diminish some flexibility in floor plan layout and future changes as optimized in Option 1. However, the interior structural walls can be located and designed accordingly to be demising walls between units.

This structure lends itself best for a residential application, because it does not offer the open plans desired in an office layout. However, because of its structure, it offers a competitive building height, pushing it from a mid-rise to a high-rise structure.

Image From: Green 2017
CASE STUDY - OPTION 3

Up to 20 stories in height
Structural core and exterior walls

This option is similar to Option 2, with a maximum achievable building height of 20 stories. However, this option uses a wooden core as well as wooden exterior structural walls. In this example, the exterior structural walls have replaced the interior structural walls and perimeter glulam columns that were present in Option 2. The impact of this is that the plan is now structure free, again allowing flexibility for floor plan layout and use. However, the presence of the exterior structural walls now limits the flexibility of the facade. As a result of the exterior structural walls, punched or bay windows would be most suitable. Additionally, from a thermal performance point, these exterior walls provide opportunities for greater insulating assemblies.

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

Image From: Green 2017
CASE STUDY - OPTION 4

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

This option pushes the maximum building height to 30 stories. To achieve this, this option combines the ideas from the previous options into one design. To do this it utilizes structural core walls, structural interior walls and structural exterior walls. As a result, it offers the least flexibility of the four options. Its interior structural walls would limit it to residential use, similarly to Option 2, and its exterior structural walls would limit the envelope options as discussed in Option 3.

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

Image From: Green 2017
Project Overview:

This project, what could also be called 127 + 10 for its location in New York City uses the idea found both within the study of the joint, as well as the case studies to produce a project that is a hybrid for highrise construction out of mass timber. By using a CLT core, Glulam exterior columns, and large CLT shear walls, as well as limited interior CLT structural demising walls, the project aims to push the limits of highrise construction out of wood, while also striving to maintain the flexibility associated with steel and concrete towers.

The project is comprised of three levels of parking for a total of 279 parking spaces. The podium has retail shops and services with a daycare, conference center, two gyms, three public lobbies, one residential lobby, a rooftop garden, and a courtyard. The east tower has a maximum of 17 stories of corporate office space and the west tower has a maximum of 23 stories of 192 residential units. The residential tower has a residential lounge and business center.
The location for this thesis is in New York City between 17th and 18th Street and 10th and 11th Avenue. Also known as Block 689 on the island of Manhattan. Located in the West Chelsea district, the site is located within a diverse neighborhood both socially as well as architecturally. The site was chosen due to a couple factors. The primary reason when looking for a site was to find a site where materials could easily be delivered. Due to the nature of the manufacturing of CLT there really is no limit as to the length of the product. Shipping is the determining factor for the length and currently the longest length that can be shipped via highway is approximately 90 feet. This meant for a project that was to be located in a city, the logistics of shipping had to be considered if any member longer than a standard flatbed truck was to be used. With this in mind, a site that allowed for materials to be brought in by barge was desired. The secondary role the site had to fulfill was an interaction with a public space. These two parameters led me to discover the site I used due its proximity to the Hudson River, as well as its relationship to the Highline. There were no zoning variances required for this structure.

The following information was taken from the Zoning Resolution of the City of New York, Chapter 8, 8/24/2017.

98-122
Location within buildings

In any C6 District in the Special West Chelsea District, the provisions of Section 32-422 (Location of floors occupied by commercial uses) are modified to permit commercial uses on the same story as a residential use or on a story higher than that occupied by residential uses, provided that the commercial uses:

(a) are located in a portion of the building that has separate direct access to the street with no access to the residential portion of the building at any story; and

(b) are not located directly over any portion of a building containing dwelling units, except this limitation shall not preclude the location of:

(1) residential lobby space below or on the same story as commercial uses, or

(2) a commercial use that fronts on the High Line and is located within five feet of the level of the High Line bed.

98-423
Street wall location, minimum and maximum base heights and maximum building heights

The provisions set forth in paragraph (a) of this Section shall apply to all buildings or other structures. Such provisions are modified for certain subareas as set forth in paragraphs (b) through (g) of this Section.

(a) For all buildings

(1) Street wall location provisions

On wide streets, and on narrow streets within 50 feet of their intersection with a wide street, the street wall shall be located on the street line and extend along such entire street frontage of the zoning lot up to at least the minimum base height specified in the table in this Section. On narrow street frontages, beyond 50 feet of their intersection with a wide street, the street wall shall be located on the street line and extend along at least 70 percent of the narrow street frontage of the zoning lot up to at least the minimum base height specified in the table in this Section.

Where street walls are required to be located on the street line, recesses, not to exceed three feet in depth from the street line, shall be permitted on the ground floor where required to provide access to the building. Above a height of 12 feet, up to 30 percent of the aggregate width of street walls may be recessed beyond the street line, provided any such recesses deeper than 10 feet along a wide street, or 15 feet along a narrow street, are
located within an #outer court#. Furthermore, no recesses shall be permitted within 30 feet of the intersection of two #street lines# except that, to allow articulation of #street walls# at the intersection of two #street lines#, the #street wall# may be located anywhere within an area bounded by the two #street lines# and a line connecting such #street lines# at points 15 feet from their intersection.

For #developments# that occupy the entire #block# frontage of a #street# and provide a continuous sidewalk widening along such #street line#, the boundary of the sidewalk widening shall be considered to be the #street line# for the purposes of this Section.

The #street wall# location provisions of this Section shall not apply along that portion of any #street# frontage:

(i) over which the #High Line# passes;
(ii) occupied by existing #buildings# to remain, unless such #buildings# are vertically #enlarged#;
(iii) between the #High Line# and a #side lot line#, where such frontage measures less than 20 feet.

(e) Subarea H

No #building or other structure# shall be located east of the #High Line#, unless otherwise specified in agreements and other instruments that provide for City construction of some or all of the At-Grade Plaza Work and some or all of the Stairway and Elevator Work, executed in accordance with Appendix D.

No portion of a #building or other structure# shall exceed a height of 85 feet except for two #buildings#, or portions of #buildings#, hereinafter referred to as “Tower East” and “Tower West.” At or above the base height, both such towers shall be set back at least 10 feet from any #street wall# facing a #wide street# and at least 15 feet from any #street wall# facing a #narrow street#. Such setbacks shall be provided at a height not lower than 60 feet, except that such setbacks may be provided at a height not lower than 40 feet, provided at least 65 percent of the #aggregate width of street walls# facing #narrow streets# and at least 60 percent of the #aggregate width of street walls# facing #wide streets# have a minimum base height of 60 feet.

Tower East shall be located in its entirety within 240 feet of the Tenth Avenue #street line#, and Tower West shall be located in its entirety within 200 feet of the Eleventh Avenue #street line#. Tower East shall not exceed a height of 290 feet and Tower West shall not exceed a height of 390 feet. No portion of Tower East shall be located closer than 25 feet to any portion of Tower West.

A maximum of 50 percent of the #street wall# of Tower West may rise without setback from a #narrow street line#. Such portion of the #street wall# shall be located a minimum of 15 feet and a maximum of 20 feet from the #narrow street line#.
Buildable Area:
The area in which a building can be placed is to the west of the Highline, as highlighted by the red. To the east of the Highline will be a public plaza with access to the Highline.
Setbacks:
The setbacks are 10 feet along wide street (highlighted in blue) and 15 feet along narrow streets (highlighted in red)
Podium:
The podium is allowed to be between 45’-60’ tall. The 15’ area along the Highline is not allowed to exceed the height of the Highline. Hence a shift in height in the podium.
Tower East:
Tower East must be located in its entirety within 240’ of the street line of 10th Avenue, and is allowed a maximum height of 290’.
Tower West:
Tower West must be located in its entirety within 200’ of the street line of 11th Avenue, and is allowed a maximum height of 390’.
Tower Relationship:
No portion of Tower East shall be located closer than 25’ to any portion of Tower West.
West Chelsea District Subareas

- **Site**

High Line Transfer Corridor

- **10' curb level**
- **15' min.**
- **10' min.**

- **15' max.**
- **25' min.**

- **350 sq ft. min.**
- **18'-6" min.**

- **15' frontage; west side of high line**
- **25' frontage; east side of high line**

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43
West Chelsea District Zoning + Far

**FAR**
- 5.0 max.
- High Line Transfer Sites:
  - 5.0 base / 6.0 max.
  - 5.0 base / 7.5 max.
  - 6.0 base / 7.5 max.
- High Line Transfer Sites:
  - 5.0 base / 7.5-6.0 max.
  - 5.0 base / 7.5 max.
  - 7.5 base / 10.0 max.

**LAND USE**
- RESIDENTIAL
- COMMERCIAL
- INDUSTRIAL
- INSTITUTIONAL
- TRANSPORTATION AND UTILITY
- PARKING
- OPEN SPACE
- VACANT
- SITE

HIGH LINE TRANSFER CORRIDOR
- HIGH LINE
Site Logistics:

Construction of the buildings will commence with below grade activities. These activities will include excavation, pile driving to support the main structure of the building, and the completion of the three level of parking below grade. The majority of the material will be brought in on barges and off loaded, by a tower crane across the street from the site, in the Chelsea Pier district. Trucks will transport the above grade materials across the street to the site where it will be off loaded from the trucks via tower cranes and installed into its final place. The use of two cranes will ensure that both tower east and tower west can be erected simultaneously. The towers will get erected following the sub levels to enable maximum site usage. The podium will be constructed once the towers have been completed.

Overall view:

The above image shows the direction of traffic flow on the streets around the site, as well as the path barges will take to the pier. The yellow areas are laydown areas for materials. The area located to the east of the Highline will be used for jobsite offices which will be located in trailers. Lastly, the blue areas show the areas which the cranes will be able to reach.
Form Design:

To maximize buildable area to achieve maximum financial return, the towers were placed in the northwest and southeast sections of the buildable area. The east side of the podium was designed to mimic the contour of the Highline to achieve the best aesthetic appeal and avoid conflict of forms. Tower east follows the standard north-south grid pattern of New York City while tower west is based on a perpendicular axis to 11th Avenue. I allowed for sunlight to pass between the towers by offsetting the buildings 20 feet to maximize the natural sunlight exposure to the site and the building beyond. The original floor areas were extruded to their maximum heights, divided into quadrants based on the rules established from the joint described earlier, and then the heights of each quadrant were changed to minimize the shadow impact of the buildings on the surrounding areas.
GAP FOR SUNLIGHT

SHIFTING FOR SUNLIGHT

RESULT
The assembly of the project occurs in stages and is designed to be as efficient as possible. The following series shows the typical construction of 2 floors. For this we will begin on floor 11 located in the southwest corner of the residential tower. In the above image we can see a section of open floor, with the larger shear walls remaining from the previous construction of floor groups.

Step 1: The large shear walls are placed. These walls are the main walls the beams tie back into when they are not tied into the core walls. The shear walls are comprised of CLT panels that are staggered to allow for a more rigid connection. While not shown in the diagram, some panels would be removed in certain sections to allow for services to be run vertically. The standard dimension for the panels are one foot thick by 8 feet wide, by 70 feet high.
Step 2: Secondary walls will be put in place. These walls will be demising walls between units, and will allow the beams to span shorter distances. By having the beams span shorter distances the depths of the beams could be reduced. This not only reduces materials, but also allows for more space to run MEP.

Step 3: Primary columns with attached beams are placed.
Step 4: The first group of beams that are attached to the columns are rotated into place and secured.

Step 5: Tertiary walls are put into place and secured. The panels arrive on site pre cut with the openings for the beams to slot into. These panels are used to divide rooms within units. They are not load bearing, but add rigidity to the overall structure.
Step 6: A layer of 3-ply CLT is placed. This layer acts as the ceiling for the apartments on the 11th floor.

Step 7: The second group of beams that are attached to the columns are rotated into place and secured.
Step 8: Secondary columns are put into place. These columns have beams attached for the next floor. They also secure to the beams that are already in place to provide more support.

Step 9: A 5-ply layer of CLT is placed and secured. This layer encloses the interstitial space between floors and allows for a finished floor to be placed.
Step 10: Beams for the next floor are unfolded into place and secured.

Step 11: Tertiary walls are put into place and secured. The panels arrive on site pre cut with the openings for the beams to slot into. These panels are used to divided rooms within units. They are not load bearing, but add rigidity to the overall structure.
Step 12: A 5-ply layer of CLT is put into place and secured.

Result: This image shows the result of the typical construction of two floors. It is important to note that every other floor has an interstitial space for MEP. This means that for some apartments the services are run up through the floor, and for others they are run down through the ceiling. It also means that every other floor has a floor to ceiling height of nine feet, while every other floor has a floor to ceiling height of 13’6”.
Residential Lobby
Public Lobby


Lebow, Patricia; Young, Timothy. “Statistical analyses of the retention testing protocol for treated lumber.” USDA Forest Products Laboratory. United States Department of Agriculture. 2016. Web. 15 Oct. 2017


