THE IMPLICATIONS OF MASS TIMBER IN HIGH-RISE BUILDINGS WITH A FOCUS ON INNOVATIVE HOTEL DESIGN

A Thesis

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by

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Miami University Master of Architecture Thesis Document

The Implications of Mass Timber in High-rise Buildings

With a focus on innovative hotel design

[1] Abstract

In the 21st century, the focus of architecture has moved toward sustainability. Sustainability has become a fundamental aspect of each architecture design and there are several certificates including LEED or Passive House certificate for each building to encourage people and architects to design their projects in a sustainable way. Wood, of course, is one of the most sustainable materials for construction and it can also be recycled after the end of the building's life cycle. Designing a sustainable passive residential complex made out of timber can be a great solution for energy matters.

In the past two decades, architects and engineers have started to increase the use of timber in building constructions, especially for structural systems. Timber has so many advantages as a sustainable, light weighted material to other traditional steel and concrete materials. Also, there is a great history behind using timber as a fundamental material for buildings. For example, the Japanese temple Horyu-ji is a 5 story building that is constructed out of timber and has survived since 603 for so many years. In this project, I aimed to encourage the public to use sustainable materials especially mass timber in construction and trust it.

In addition, there is an ongoing demand in Seattle for long-stay units for people who are visiting the city or plan to stay there for a couple of months. They do not technically move to Seattle but they need a place to stay. By designing a sustainable hotel with two types of units: hotel guest rooms and 1-2 bedroom apartments. The hotel also has a gallery and library with exposed mass-timber interiors.

[2] Thesis Questions

How to design a sustainable highrise building?

How to encourage the public in using and trusting more in mass timber as a sustainable material?

How to design a mass timber building with more interesting exterior and interior spaces?

How do we solve the challenges of using mass timber construction in designing curve buildings?

[3] Project Description and Key Terms

In recent years climate change has been one of the most critical issues on a global scale. The building and construction sector is one of the significant causes of climate change. According to the 2019 Global Status Report for Buildings and Construction coordinated by the United Nations Environment Program, the architecture sector accounted for 36 percent of final energy use and 39 percent of energy and process-related CO2 emissions in 2018. To meet the basic standard of the Paris Agreement and the United Nations Sustainable Development Goals, the building and construction sector should reduce its carbon footprint by 3% each year. (Elizabeth Stamp,2020) Nowadays the main focus of architecture has been mostly on sustainable design approaches. There are three areas of focus in sustainable architecture: ecology, economy, and society (Das, 2021).

The key idea of this project comes from the integration of architecture, and sustainability. In this regard, I have tried to implement mass timber as a product of wood with a very low carbon footprint as the main material in the building. This material has been used not only in the structure but also as an exposed finishing for interior spaces. As a result of this, not only do we reduce the cost and carbon footprint of the building by using mass timber, but also we reduce the need for other finishing materials which can be costly and not sustainable. Although some work has been done regarding the impact of using mass timber in the field of architecture, still a lot has remained undone. For example, most of the mass timber buildings are designed in a very modular and boxy form, which means the challenges of having this structural system in a more curve design have remained unsolved. The question can be can mass timber replace concrete or steel? Can we trust Wood in Highrises to bear the load? Can we design highrises with acceptable fire resistance?

What is mass timber construction?

Mass timber construction is the use of engineered wood products such as Cross Laminate Timber, Glue Laminated Timber to construct building elements including beams, walls, floors, and columns. Mass timber is capable to bear loads as much as concrete and steel can, while it is considerably lighter than them. To reduce the limitation of mass timber structure it can be combined with steel and/or concrete to take advantage of all of these materials.

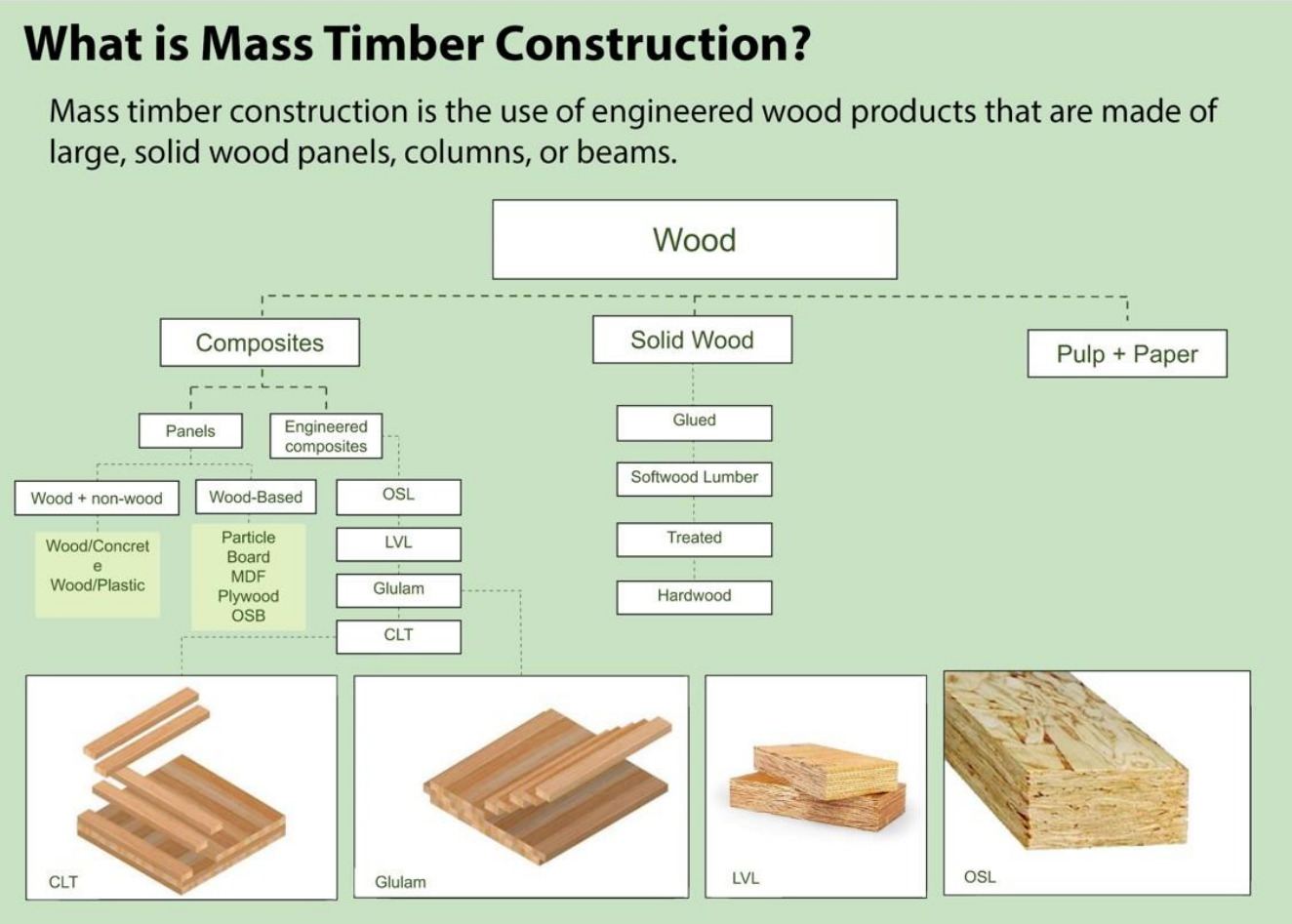


Fig 01 Mass timber diagram

Keywords: MASS TIMBER, MASS TIMBER CONSTRUCTION, SUSTAINABILITY, HOTEL DESIGN, HYBRID CONCERETE MASS TIMBER STRUCTURE.

[4] Literature Review

[4, 1] Sustainable Architecture

It has been over a decade that the importance of architectural work on the issue of climate change has been widely discussed. According to the Paris Agreement and the United Nations Sustainable Development Goals, we need to decrease the carbon footprint in the construction industry by 3% every year, which demands the essential act of all architects. The immediate action of architects can make a difference in slowing down global warming as well as improving it. AIA is one of the leaders in taking action regarding this. There are more than 500 firms that have signed the AIA 2023 commitment to reduce the carbon footprint of the construction sector. (Paula Melton, 2018)

An architect who has an applicable approach to architectural design is Moshe Safdie. He argues that the new buildings should be more responsive to the changes in the climate. For example, new buildings should be able to manage the predictable climate crisis such as temperature fluctuations over the next decades. He argues that the spaces that are not functional without air conditioning, should be revised and more thought should be put into them. One way purposed by him in this regard is retractable shading canvases which reduce the impact of the changes in temperature in the interior spaces.

The importance of his notion is undebatable. In the northeast US, the climate will be more harsh in both summer and winter and it demands more reactive architecture. One approach to this can be providing outdoor spaces with functional living spaces instead of being dependent on having conditioned spaces. As an illustration, considering Boston's environment where the winters are getting colder and the summer more scorching, having a balcony that can be used half of the year is the first step, but thinking about developing the design in a way that we use this balcony other times of the year is what a designer should be considering. Having a greenhouse section in terraces can be a solution to make more use of the outdoor spaces. He has done something similar in his own house in Cambridge, Massachusetts. He designed a greenhouse roof that provides shading in summer to make more use of the space. (Bridget Cogley, 2019)

He has done several projects focusing on mitigating climate change. One of his famous projects is Sky Habitat towers in Singapore, where he practiced the balconies with adaptable shadings.

Fig 02 The sky habitat view.

[4, 2] Mass Timber Construction

As I have mentioned before mass timber construction is the use of engineered wood products that are made of large, solid wood panels, columns, or beams. Most of the time they are built off-site and can be used for load-bearing walls, floors, roofs, and columns.

The advantages of using mass timber as a sustainable construction material are as follows:

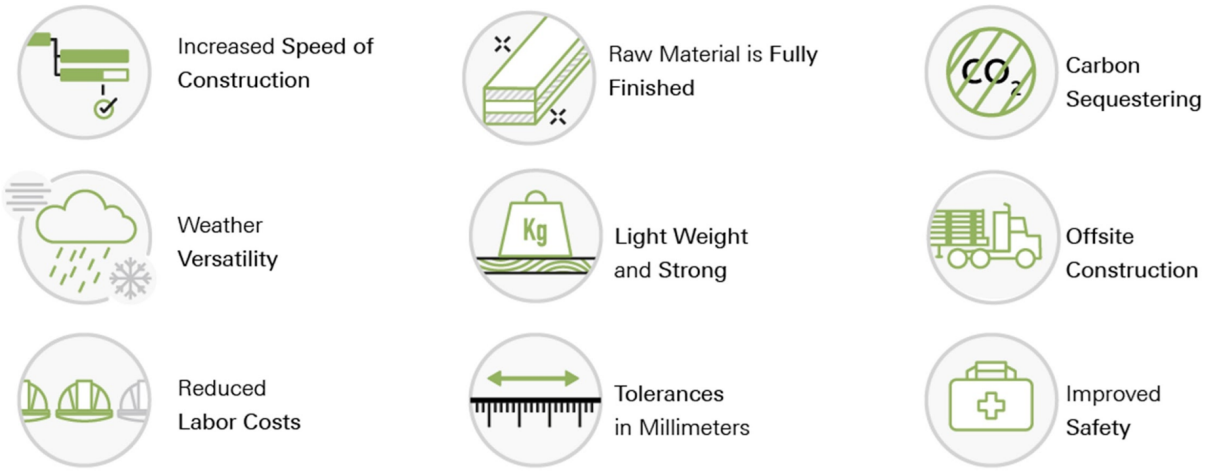


Fig 03 Mass timber construction advantages.

There are several projects designed with mass timber all over the world in the last 20 years. The history of using wood and timber as construction material goes back to 603 when the Horyu-Ji Temple was built as a 5 story wooden building. The number of stories and construction techniques has developed till today that now we can design up to 18-story highrise buildings using mass timber in the United States.

In International Building Code it has mentioned that there are three types of construction with mass timber: IV-A, IV-B, and IV-C. In type A construction the whole building structure can be with mass timber products and everything can be exposed. In type B construction you can have some exposed mass timber materials, while in type C construction you should not have any mass timber structure exposed. The raising interest in using this material in highrise buildings leads to increasing development in design techniques. You can see that in the 2021 IBC 20% exposure if mass timber is allowed in construction type IV-B, while in the 2024 IBC, this allowance has increased to 100% exposure. This shows the potential of using mass timber as a future sustainable construction material in high-rise buildings. (*Status of building code allowances for tall mass timber in the IBC - woodworks: Wood products council,* 2023)

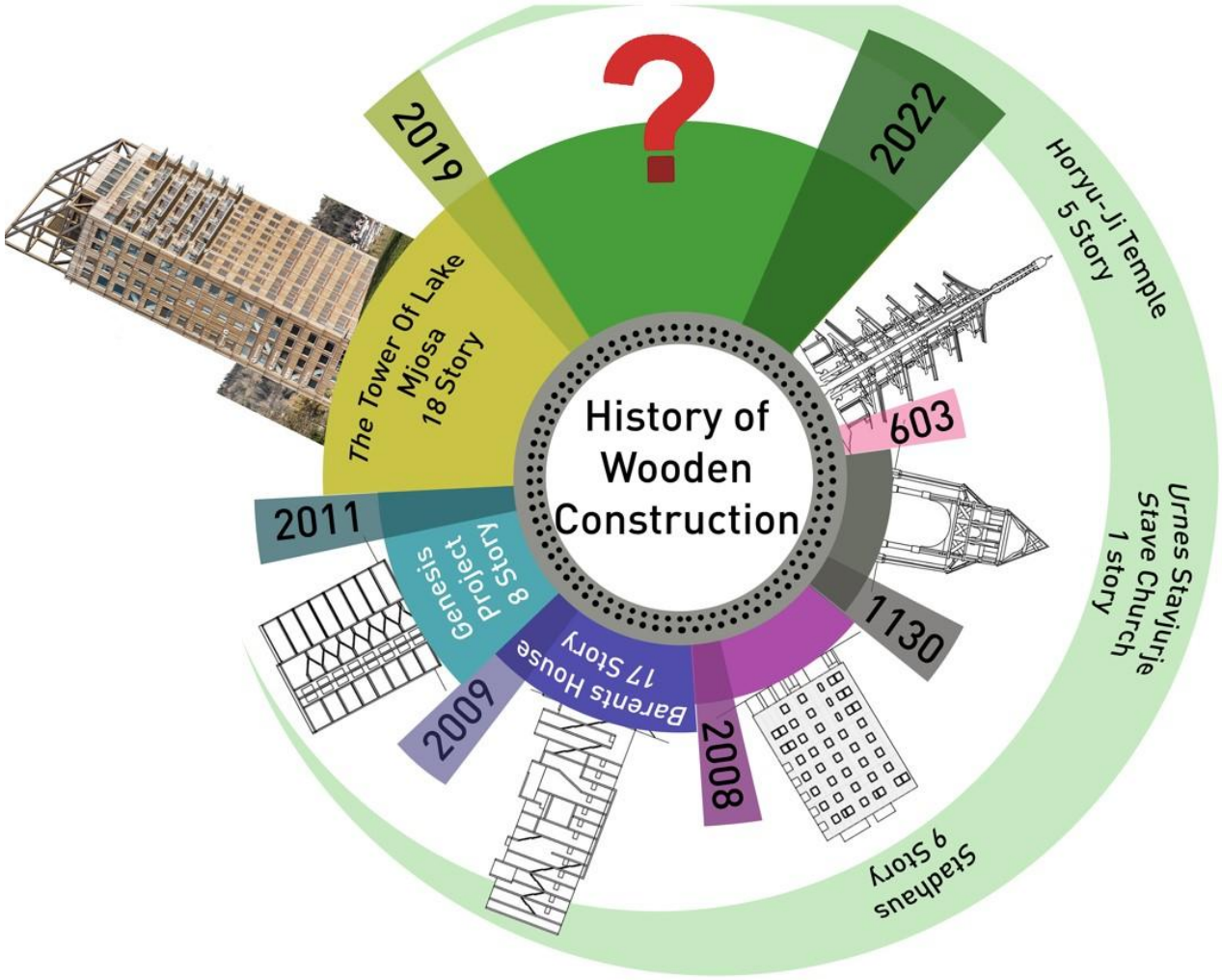


Fig 04 History of mass timber construction.

There are several mass timber products, the most common types are Cross Laminated Timber (CLT), and Glue Laminated Timber (Glulam). Cross-laminated timber consists of layered lumber boards from 3 to 7 layers, stacked crosswise at 90-degree angles. In glulam, the laminations are joined end to end and bonded with a durable moisture-resistant adhesive.

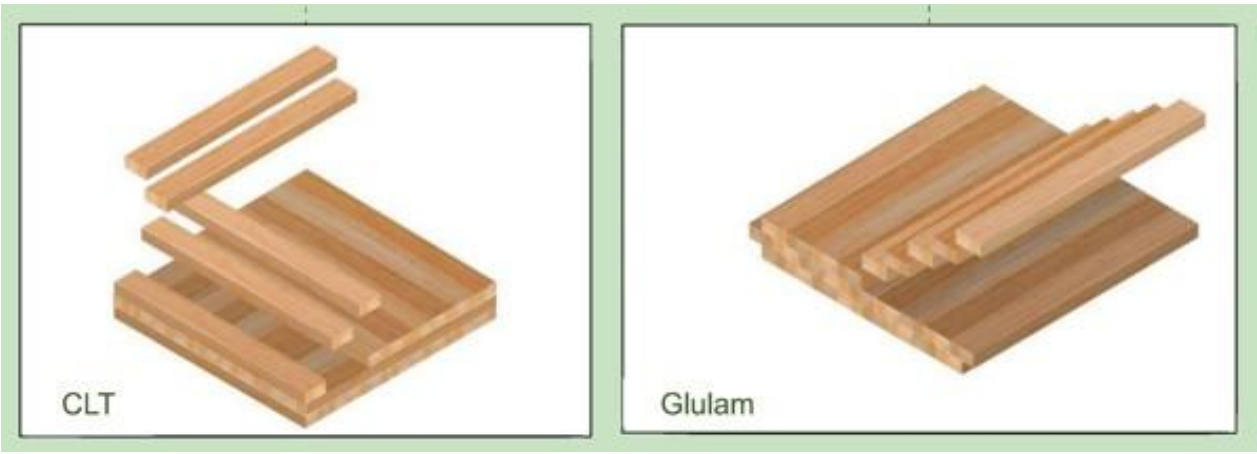


Fig 05 CLT and Glulam.

There are four main tree species used for timber production. Douglas fir, Spruce fir, Southern yellow pine, and Scot pine.

Fig 06 Common Tree Species as Sources of mass timber.

Douglas fir the main source for CLT is most commonly found in Canada and the west coast. Spruce fir is mostly in the northeast of the USA and eastern Canada, and southern yellow pine can be found in the southeast USA.

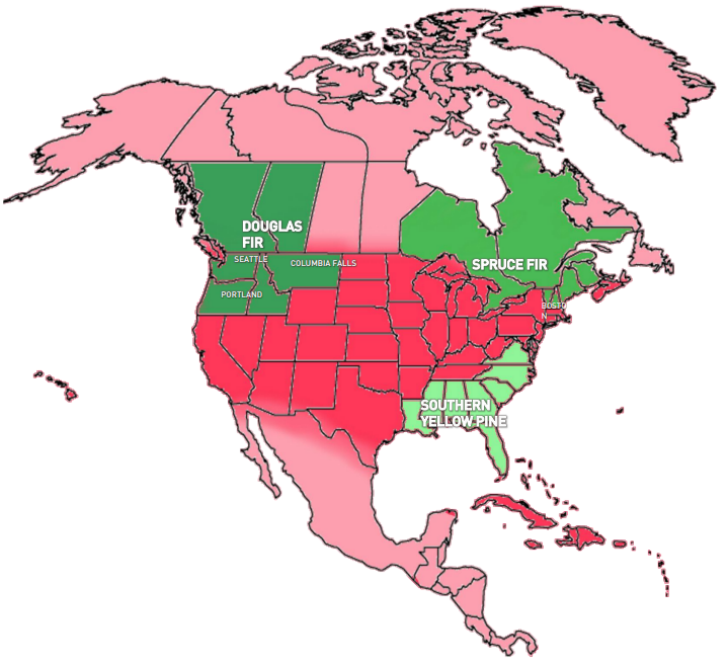


Fig 07 North American softwood timber resources.

In the USA the active timber production sites are as follows. CLT is mostly produced in Oregon and Montana. While Glulam is mostly produced in the eastern parts of the USA.

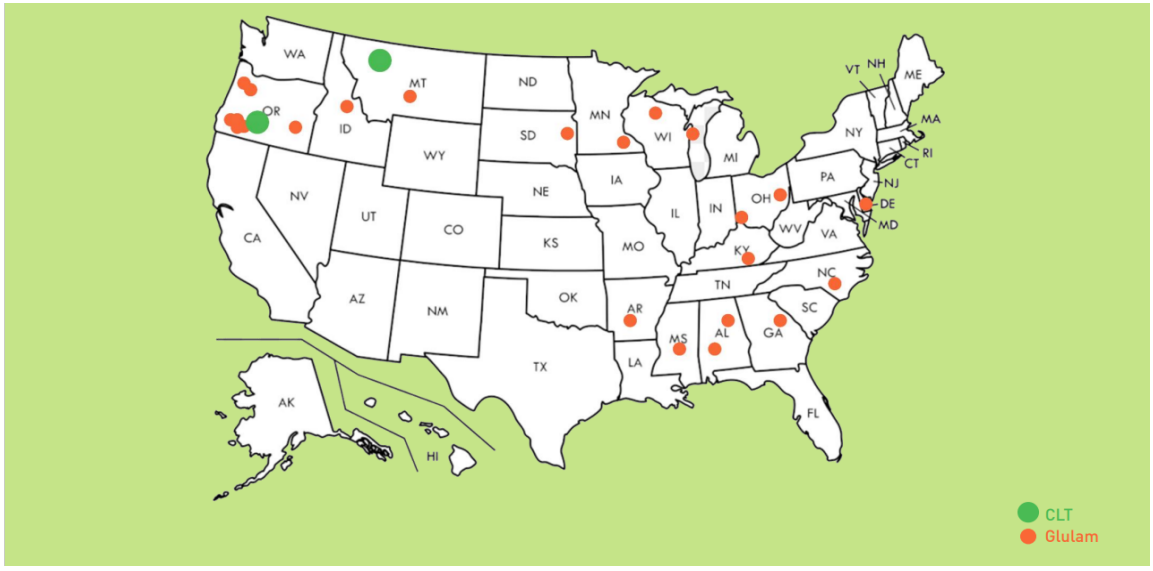


Fig 08 United States active timber production.

[5] Precedents

The use of precedents to develop ideas in the design process is inevitable. Many architects or designers are inspired by exploring precedents related to their project, picking ideas from them, and paying attention to their weak points and strength to get an overall understanding of the success of the project. Once the mentioned steps have been taken, the architect starts producing the concept of the project and developing it more. To achieve this I have studied recently designed projects as follows.

[5, 1] McEvoy and Dupont Apartments

The McEvoy and Dupont Apartments project. Located in San Jose. It is in its initial stage of construction. Consists of two 13-story towers and overall 365 units. It is 100% affordable. The significant sustainable benefit of LEED platinum. Also, they considered the future public transportation plan of the area, The speed of the construction for each floor is almost 2 days. It is mostly off-site panels even for the facades. So the speed of the construction and the much less weight of the building reduce the costs of the project significantly. 29% percent of the construction costs are provided by the state density bonus, and Landlease and first community housing as well as Google Endeavor LLC are partners in this project.

Fig 09 McEvoy and Dupont apartments

Some features of the project include exposed timber, a green roof, having an urban farm, play areas, and using healthy materials and etc. So considering that 43% of families have children designing a safe complex with different activities including play areas is important. (McEvoy and DuPont apartments,2021)

Fig 10 McEvoy and DuPont apartments,2021.

[5, 2] Brock Commons Tallwood House

This project is designed as an addition to the Tall Wood Building Demonstration Initiative launched in 2013 by National Resources Canada and Canadian Wood Council.

Fig 11 Brock Commons Tallwood House, 2022.

This project is a showcase of highrise buildings designed with wood to show the potential of wood-based solutions in the building industry in Canada. (Brock Commons Tallwood House,2022)

It is a home for more than 400 students as well as study and amenity spaces.

This project shares the same hybrid structure as the designed thesis project in this document. It has a hybrid structure with cross-laminated timber floor panels, glue-laminated timber for supports, cast-in-place concrete foundations, ground floor, and elevator/stair cores.

This project has been designed in 18 stories, with a gross area of 15,120 m2. The design started in Jan 2015 and reached the occupancy level in April 2018.

The unique factors in this project:

1. This is a case study for researchers and designers to learn more about mass timber applications in high-rise building design.
2. There are sensors embedded within the structure of this project, that can analyze the long-term performance of this structure.
3. It is a showcase of collaboration between Forestry and Civil Engineering as well as Architects.

Fig 12 Brock Commons Tallwood House structure, 2022.

[5, 3]Tallwood 1 at District 56

This project is a multi-family+ residential building designed by D'Ambrosio Architecture and Urbanism. This project is completed in 2021, in Langford, British Columbia, Canada. The total area of this project is 15,977 m2. It is a 12-story building with a two-way spanning CLT.

The structure of this project has similarities useful for the design of the upcoming thesis project. It is a hybrid mass timber structure. Consisting of CLT panels and Glulam elements. The two-way spanning CLT allows the design to eliminate the additional support beams to have wide-span spaces.

Fig 13 Tallwood 1 at District 56, 2022

The unique characteristics of this project are it is a landmark building in the downtown area, is pedestrian-friendly and is a climate-smart design. (Tallwood 1 at District 56, 2022)

Up to level 11, the mass timber structure is encapsulated, while on the top floor, there is exposed mass timber to add to the biophilic design of the project.

Fig 14 Tallwood 1 at District 56, 2022

[5, 4] PMX- A Prototype Mass Timber High-Rise Design by Sidewalk Labs

According to ArchDaily, Sidewalk Labs introduced a prototype for mass timber tall buildings. This prototype is an all-timber high-rise initially designed for Toronto's eastern waterfront area. PMX, a 35-story design, will be 2.5X lighter compared to the concrete version. US-based architecture companies including Michael Green Architecture and Gensler have worked on this project to achieve the best collaboration between architects and engineers as well as environmental designers. (Baldwin,2020)

Fig 15 PMX, ArchDaily, 2020

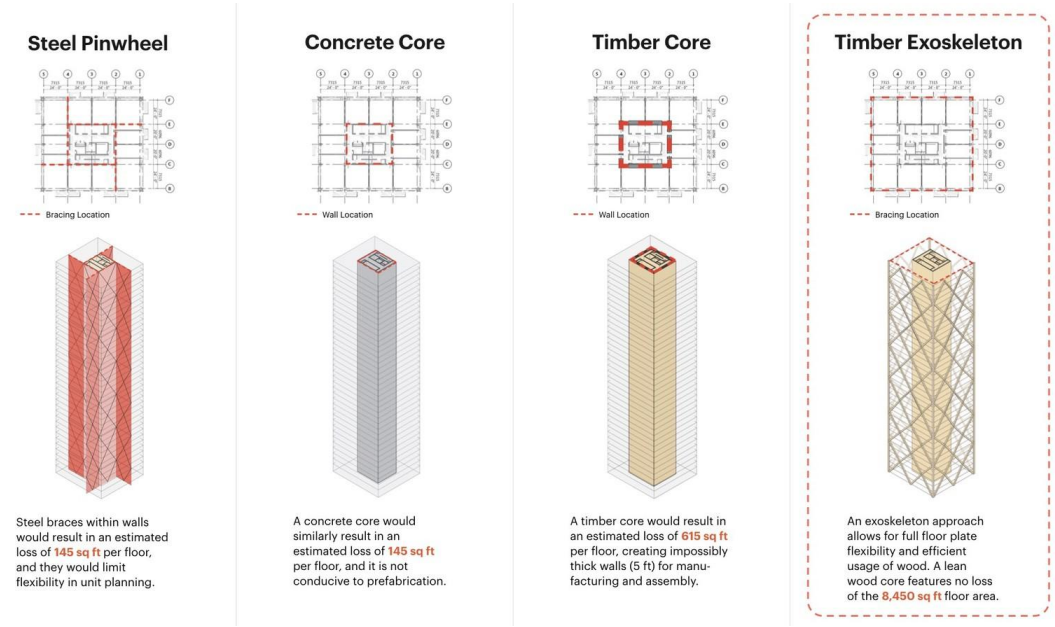


Fig 16 PMX, ArchDaily, 2020

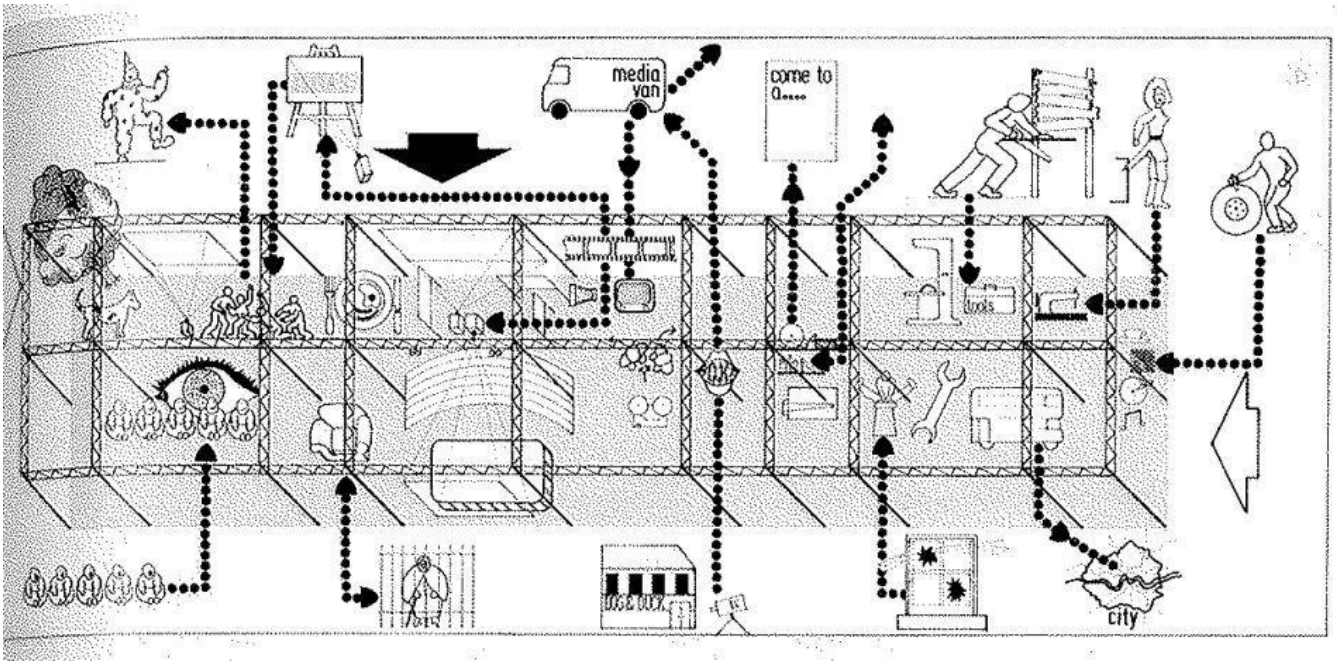
[6] Methodology

[6, 1] Diagrams

Diagrams are amongst the best tools to represent an idea in an abstract visual format. According to Mark Garcia, a diagram is the architecture of an idea or entity (Garcia, Mark. The Diagrams of Architecture. AD Reader. Hoboken, NJ: Wiley, 2010). The potential of using diagrams is very high and it is even more in fields like architecture due to the need for visualization and design representation in this field.

In this thesis computer programming is going to be used as a tool in architecture. In order to design the railing components designed in this project, a computer code has been made in the Dynamo plug-in in Revit. To use computer programming codes as a tool to design previously architects and designers had to have deep knowledge of programming, while nowadays there are new plugins that have a sort of visual programming capability such as Dynamo in Revit or Grasshopper in Rhino. These plugins usually use diagrams to visualize programming instead of traditional languages like C++. It made it easier for designers to use the computer and computational design for their work.

The advantages of using diagrams in this thesis are, help to visualize codes and computer tools regarding design and assist to show the connection between ideas and outcomes of the thesis. Also, using diagrams an issue, the potential solutions, and the approximate result can be present.
Moreover, since this thesis is an interdisciplinary topic diagrams are practical to show the connection between architecture and computer science.



Cedric Price, diagram mapping programme and community for Inter-Action Centre, London, England, c 1977. Fonds Cedric Price. Collection Centre Canadien d'Architecture/Canadian Centre for Architecture, Montreal. © CCA.

Figure 17. Sample of a diagram

[6, 2] Dynamo

Dynamo is an add-in feature for Autodesk Revit software. It is a type of visual programming that can assist to produce graphical codes to do computational design and automation processes in BIM.

After finishing the theoretical part of the study, an algorithm should be introduced as the final result. Once the algorithm is produced, it should be programmed using Dynamo. Dynamo is actually a visual and designerly method to be used. It is designed for architects and people who work with Revit which is BIM-based and can be used widely for architectural purposes.

There is a picture of the Dynamo used interface to show how it can be used as a visual graphical tool to assist in this thesis. In this project, Dynamo has been used in designing and placing features such as railing elements and curve floors in exterior and interior spaces.

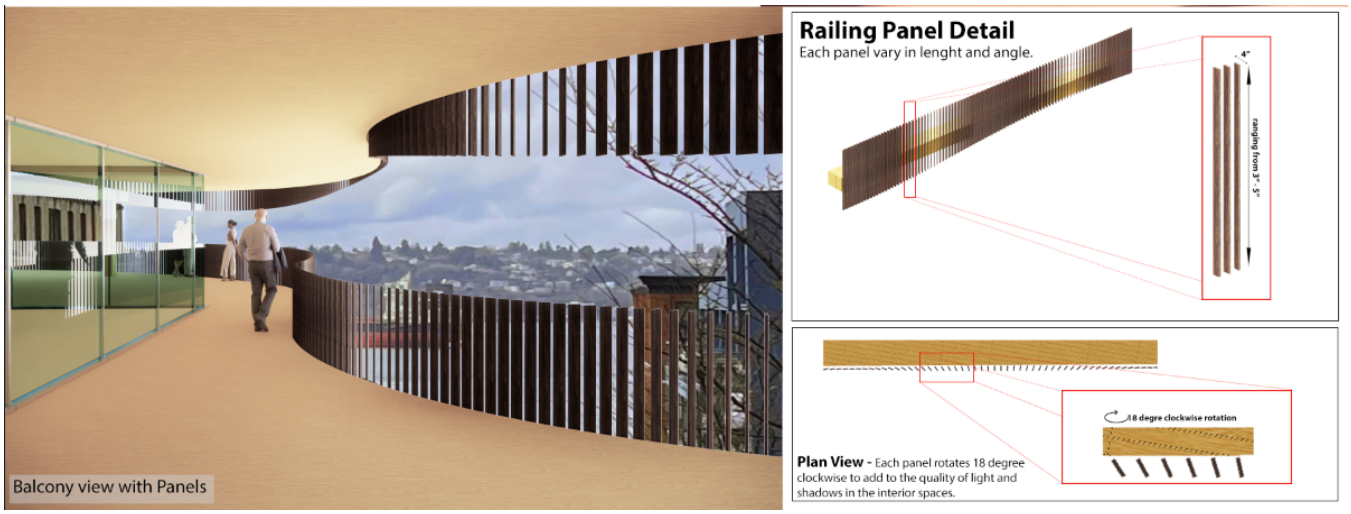


Figure 18. Introduced design of Railing and curved floor panels using Dynamo

[6, 3] GIS and Mapping

Mapping has been one of the most useful tools in architectural design and urban planning. One of the most practical software helping with mapping is GIS. In this project, the initial process of design, mapping, and GIS has been used in order to identify proper locations for the design.

In the first phase of design, the initial location of the project was Cincinnati. Several maps have been exported and created using GIS tools. Although the final location has been chosen to be in Seattle, some examples of the initial maps from the Cincinnati area are as follows.

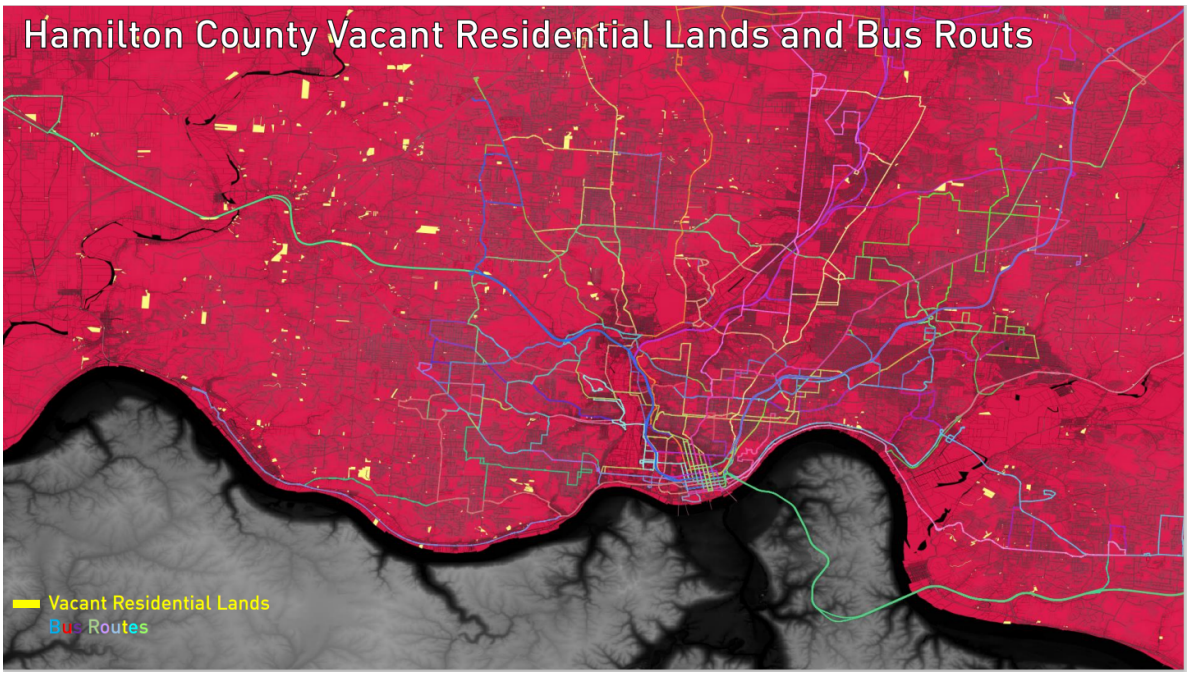


Figure 19. Initial mapping was exercised to identify potential locations

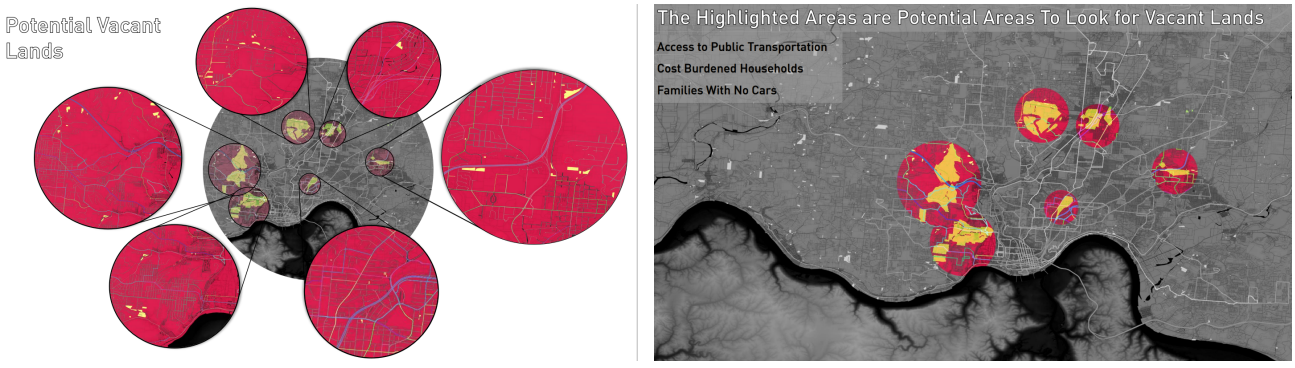


Figure 20. Initial mapping was exercised to identify potential locations

[7] Context and location

The sources of mass timber in the united states are varied and due to the large number of factories producing mass timber in the pacific west, I have chosen to design my project in the Seattle waterfront area. This approach not only reduces the cost of construction with mass timber but also relates to Seattle's history of using wood as a construction material.

My site is located in the Seattle waterfront area where the largest construction event in the city is happening.

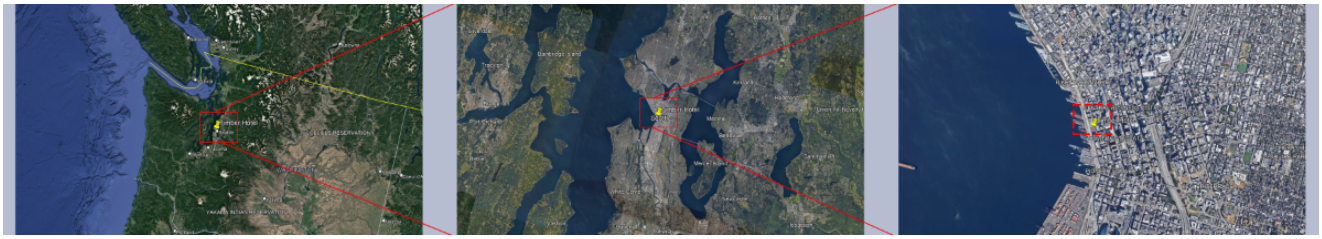


Figure 21. Map and location of the site

The initial idea of this design was based on the fact that Seattle historically has been built with wood, and then there was a great fire in 1889 when the whole city was burnt. Due to the strategic location of the city and the large number of available trees they have rebuilt the city with wooden buildings again.

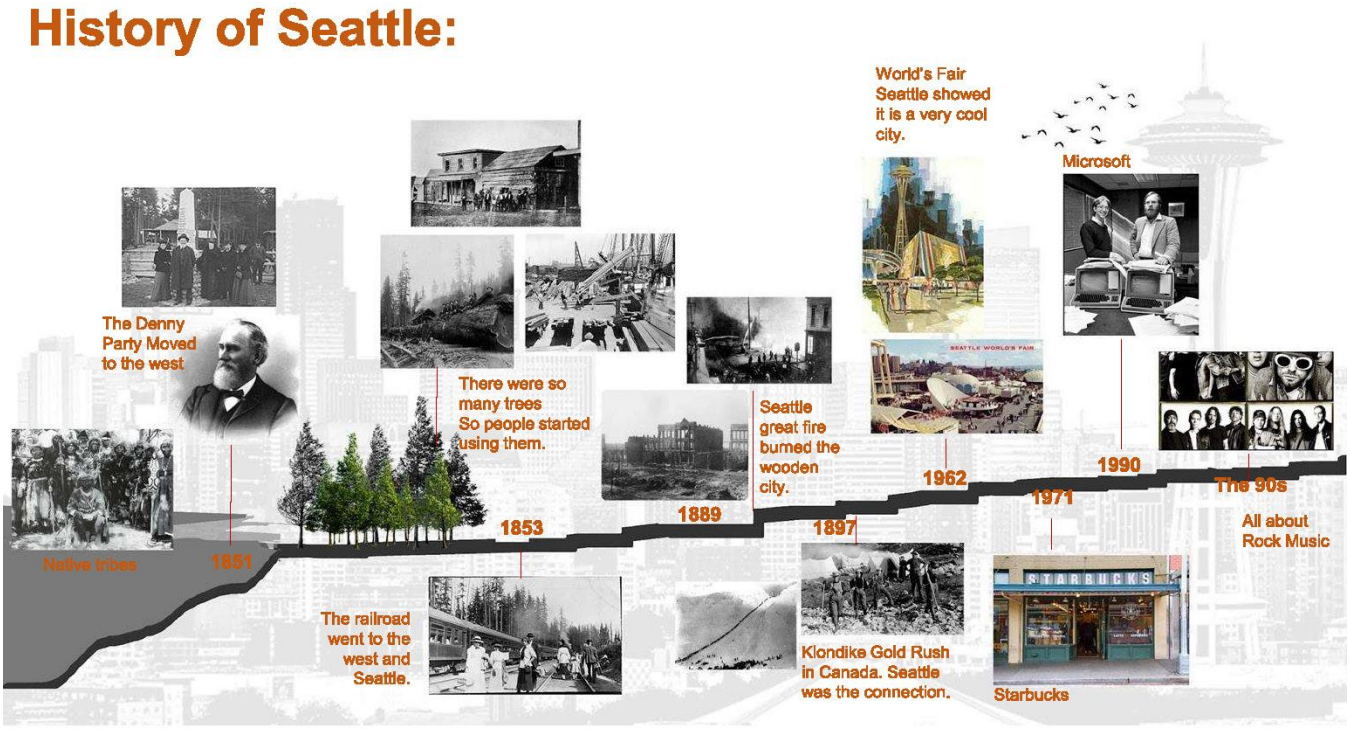


Figure 22. History of Seattle-Context study

[8] Design Process

[8, 1] Site analysis

Based on the analysis that has been done the number of visitors to Seattle and the number of people sicking for a long-term place to stay is increasing. The mentioned factors as well as the analysis of the relationship between the downtown area and the site, led me to design a 17-story hotel with long-stay apartment units.

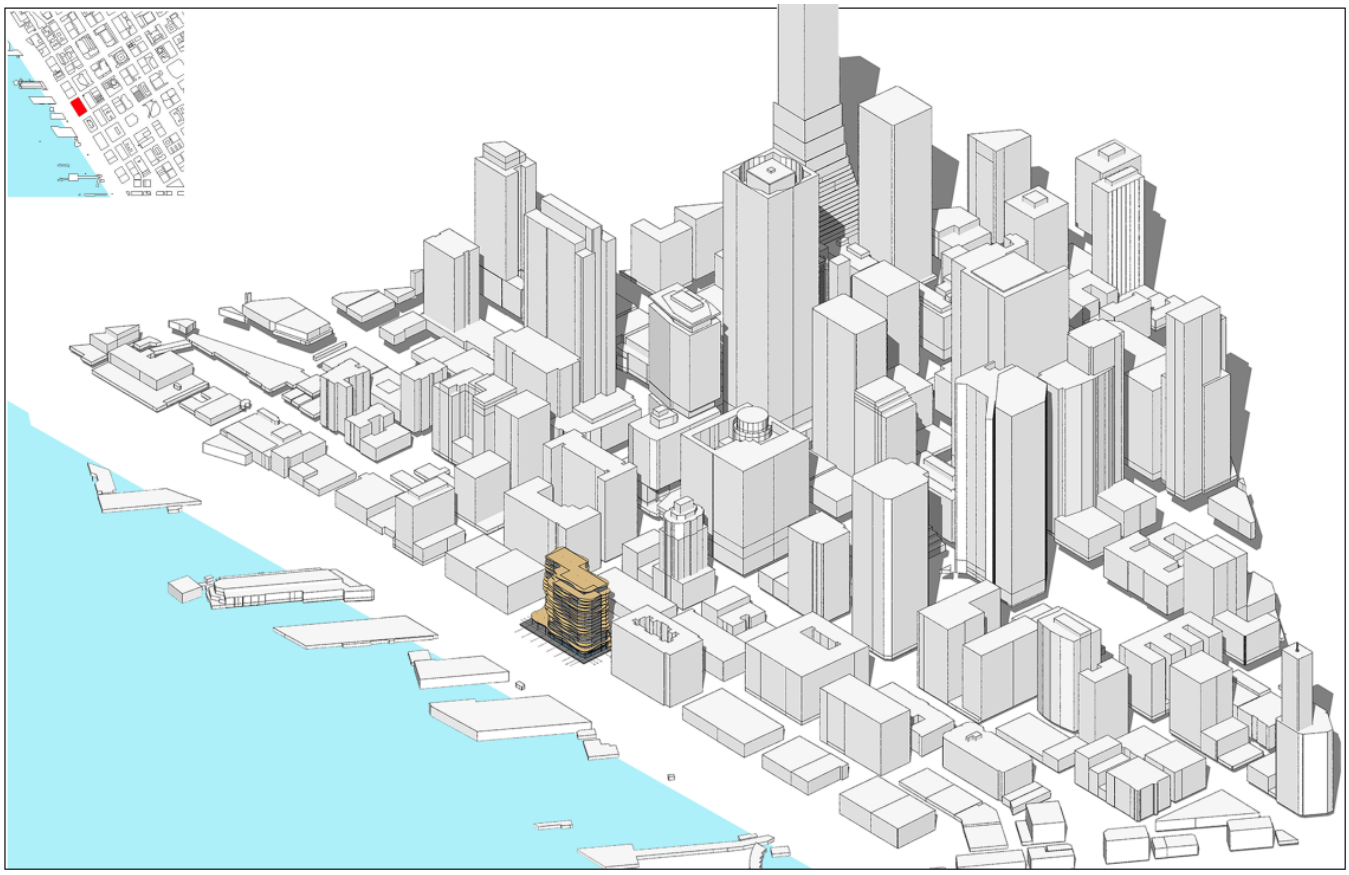


Figure 23 Seattle Waterfront area

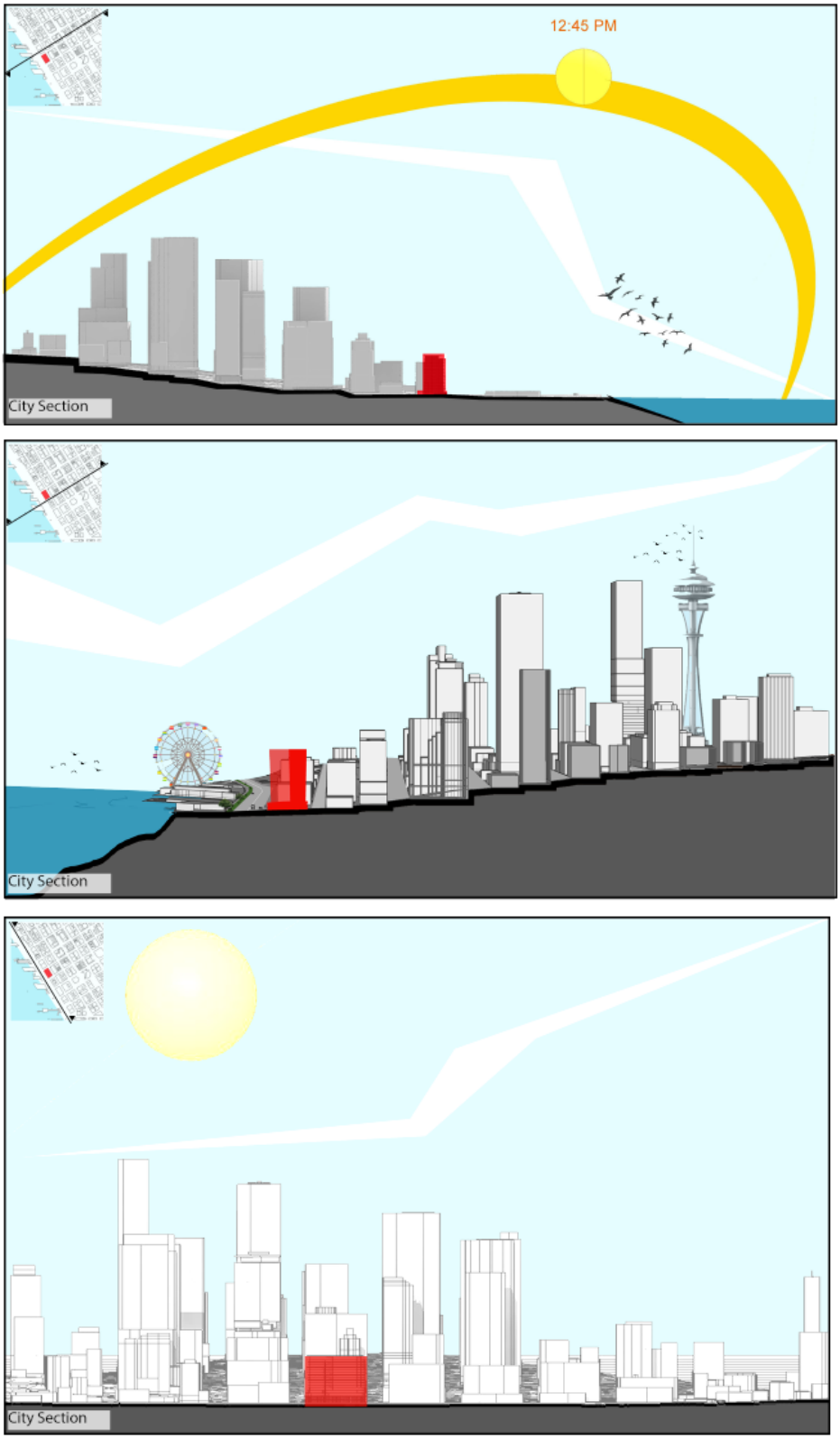


Figure 24 City Sections

Figure 25,26,27 Site photos taken by Sam Toland

[8,2] Initial Sketches and Design

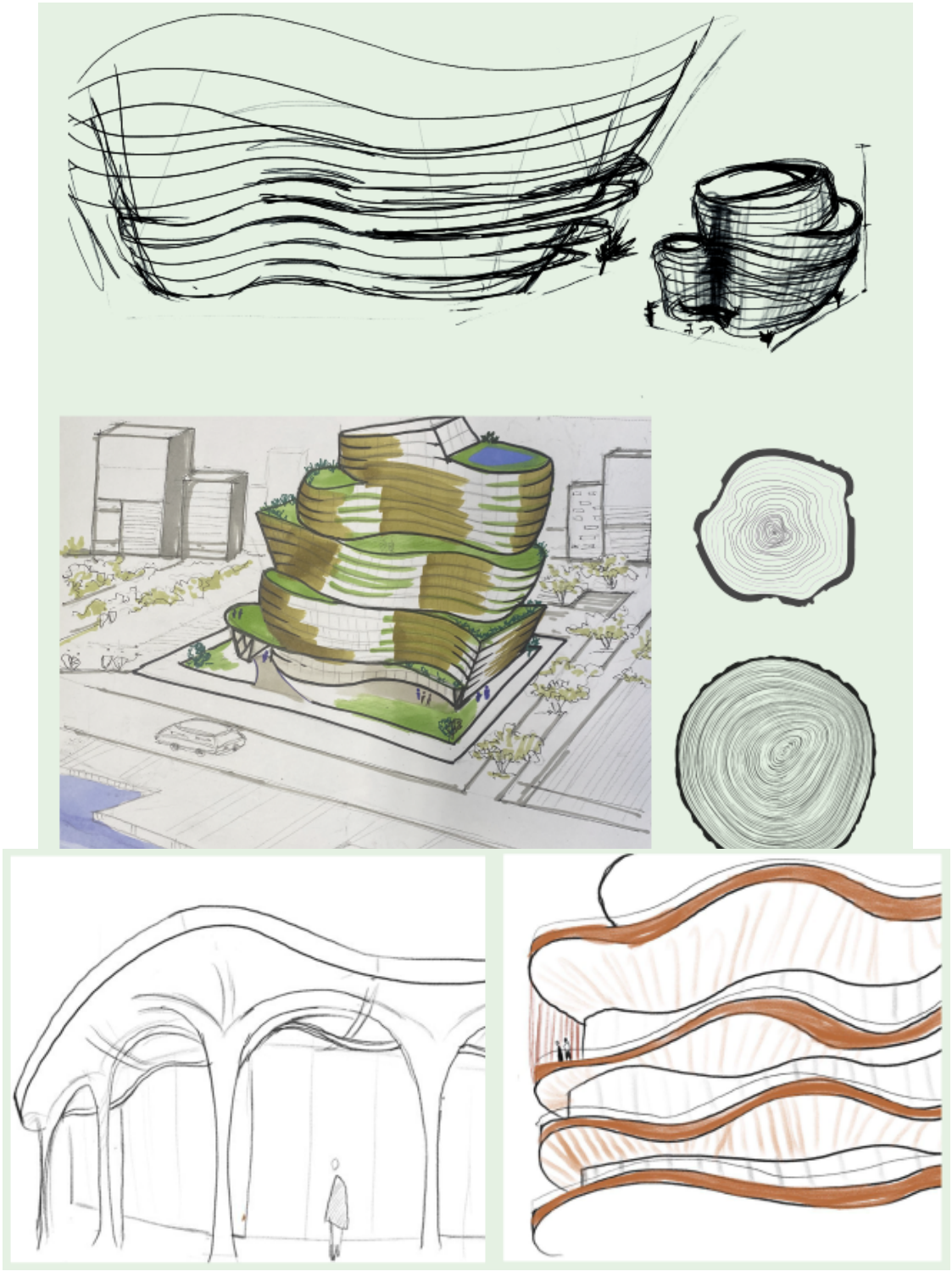


Figure 28 Sketches and Inspiration

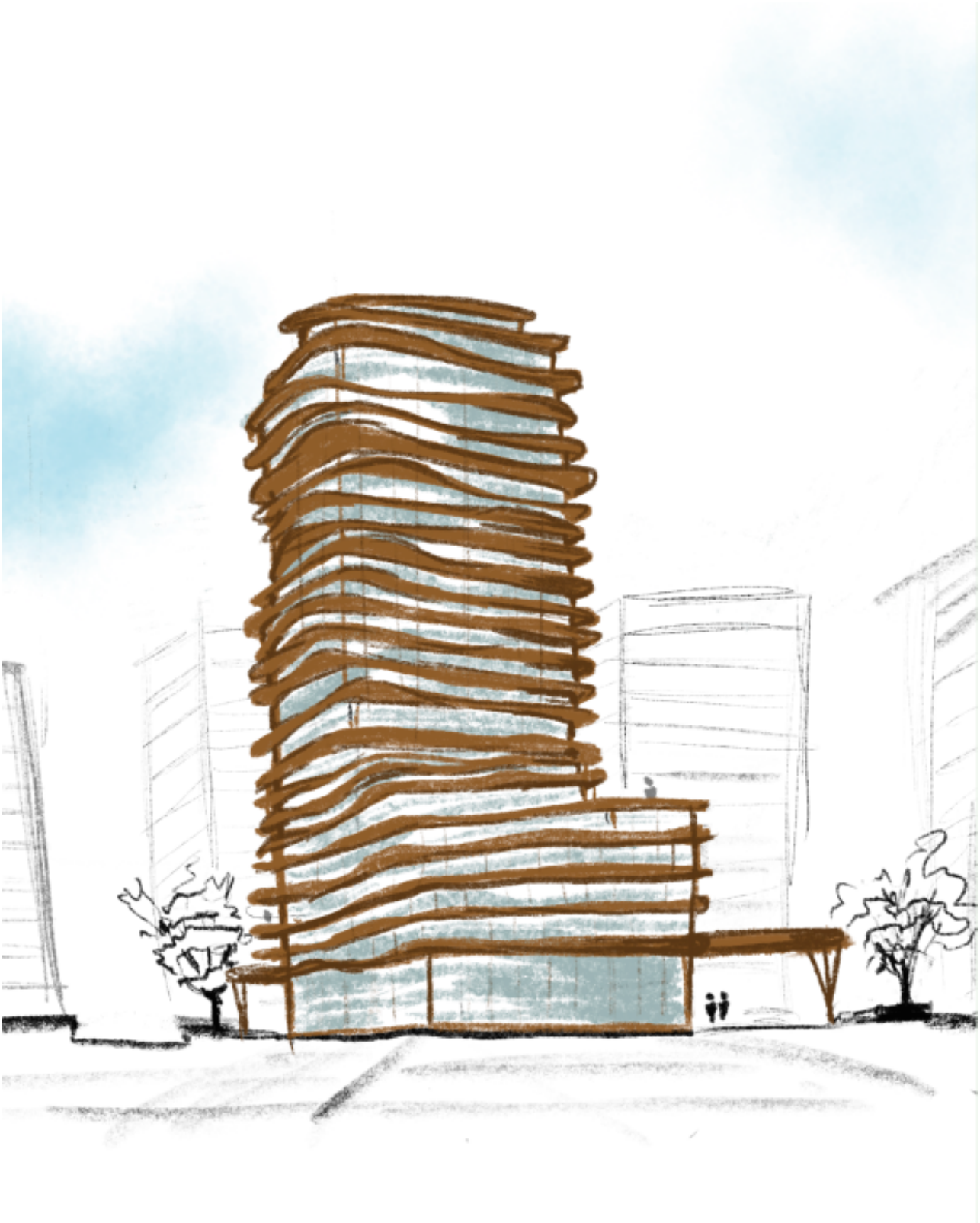


Figure 29 Sketches and Inspiration

[8,3] Design

Studying the wood and tree grow rings inspired me to push the limits of a typical mass timber building from a boxy building design to a curve design.

Figure 30 Exterior view

Figure 31 Sections

Figure 32 Elevations

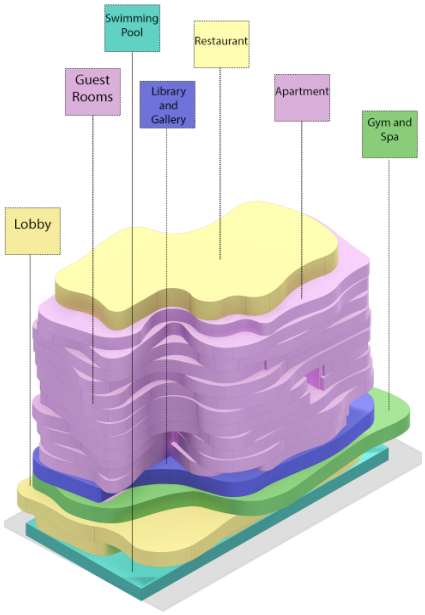


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Figure 33 Program and FAR diagram

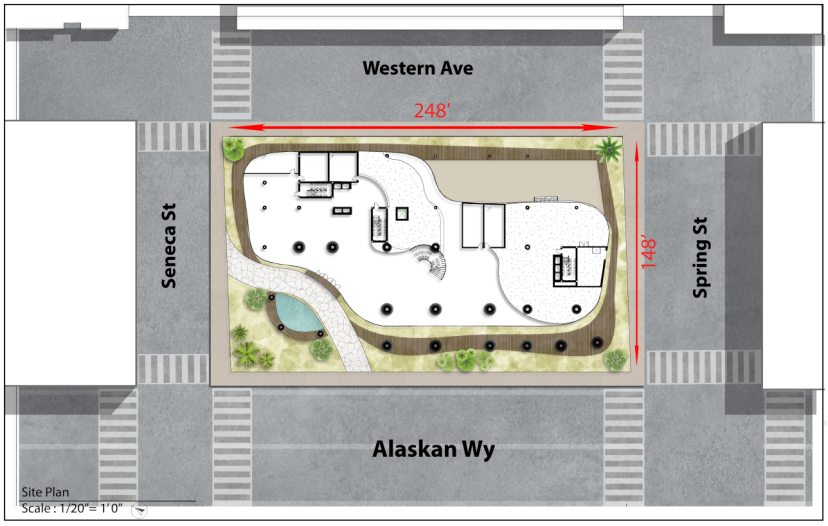


Figure 34 Site plan

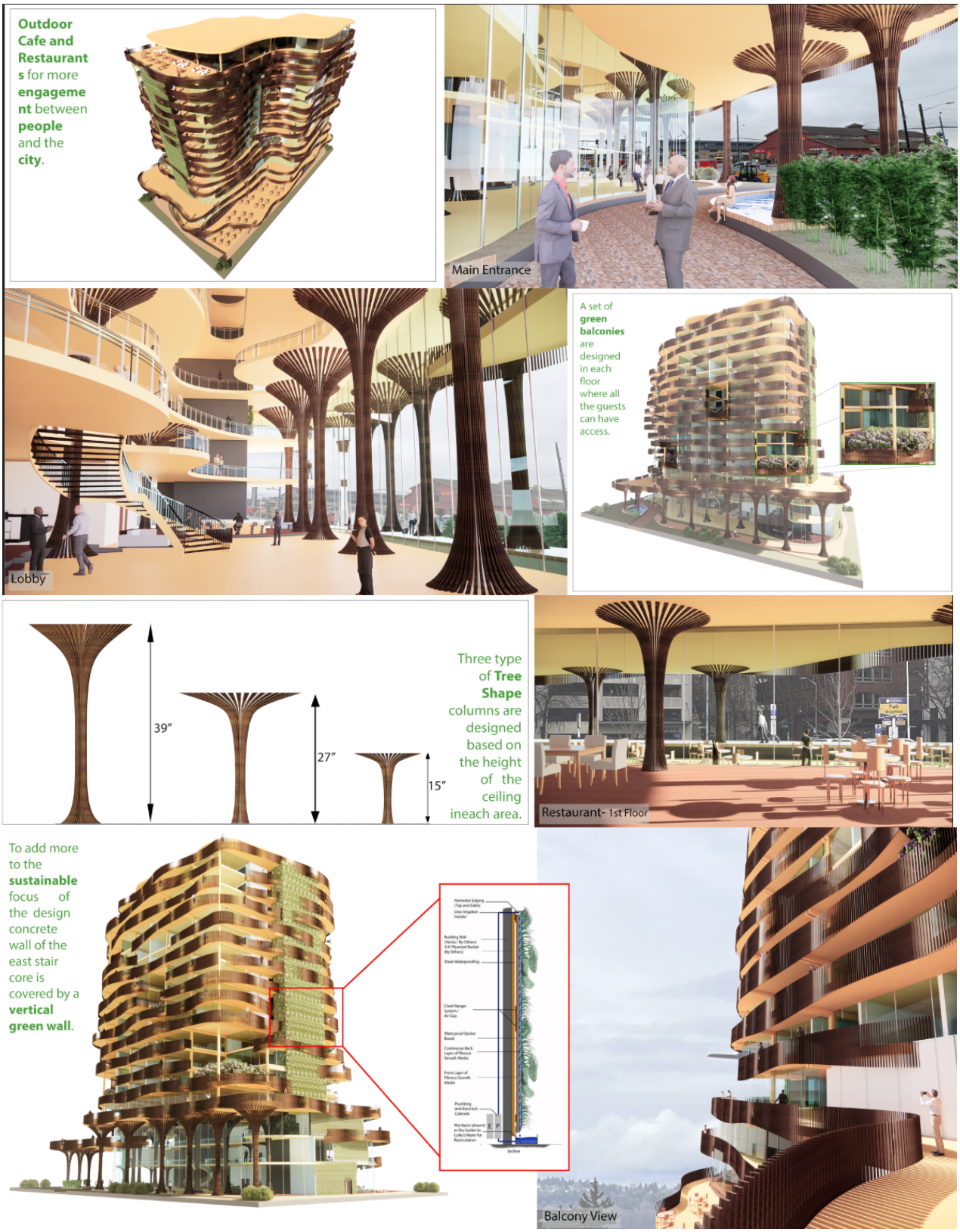
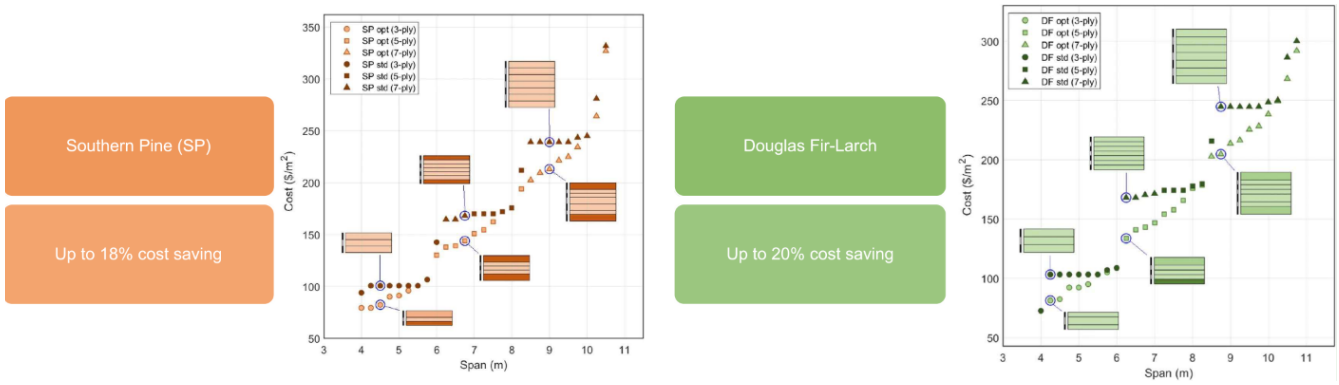


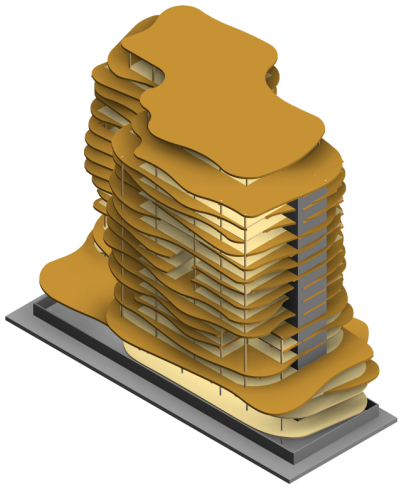
Figure 35 Detail Diagrams

[8, 4] Structural Design

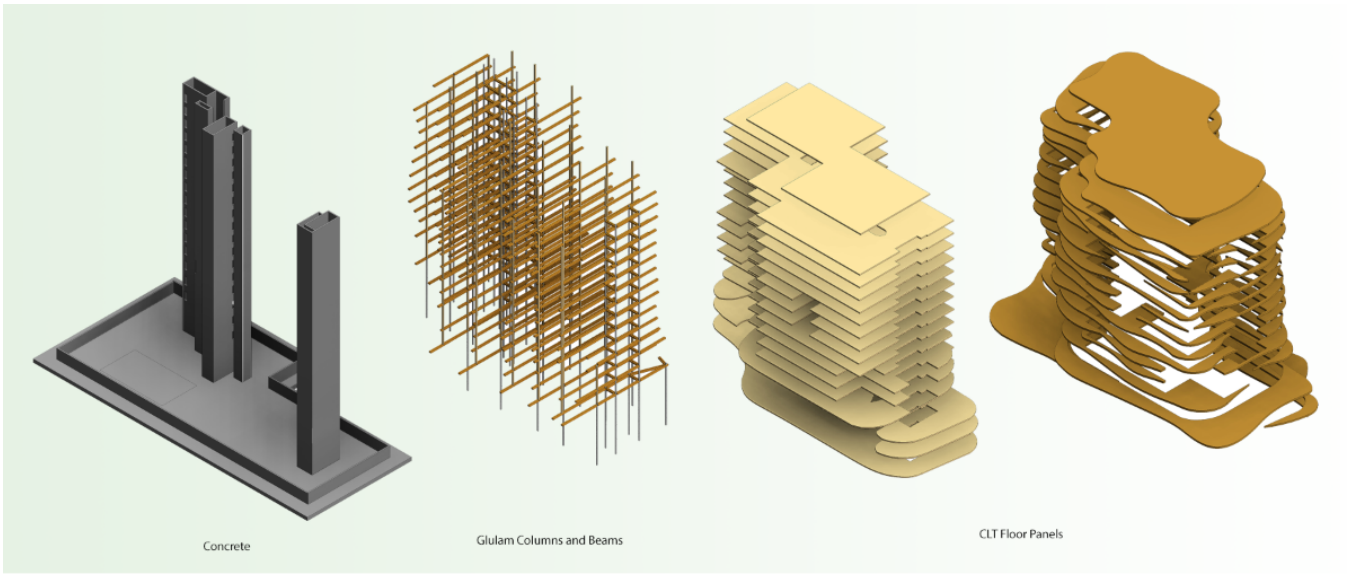
Based on the studies I have done I realized that The most challenging part for the developers to decide to move forward with mass timber building is convincing people that this building has an appropriate tolerance and is fire resistant for up to 90 minutes.
In this project, I tried to design the public areas with wood and have the whole building showcase using wood and mass timber. The aim is to encourage people to use and trust more in this material even in highrise buildings. To achieve this the design has a library and gallery with the focus of mass timber applications. Moreover, the site is located in a crowded part of the city where people interaction is very important, thus there are several outdoor spaces such as cafes, restaurants, and balconies to facilitate that.

The structure of this project has consisted of two structural systems integrated to shape a hybrid structural system. The foundation and first three floors of the building are concrete base structures with concrete columns and the rest of the upper floors are made out of mass timber. There are three concrete cores in the building. The floors are 5-layer CLT panels, the columns are glulams and the beams are double-beam glulam beams. In order to reduce the associated cost of the mass timber design, an innovative optimized CLT panel design for floors has been introduced. In this design, the thickness of each layer is different as well as the grade of the timber used in each layer. So The results show that significant cost savings of up to 20% are achieved.

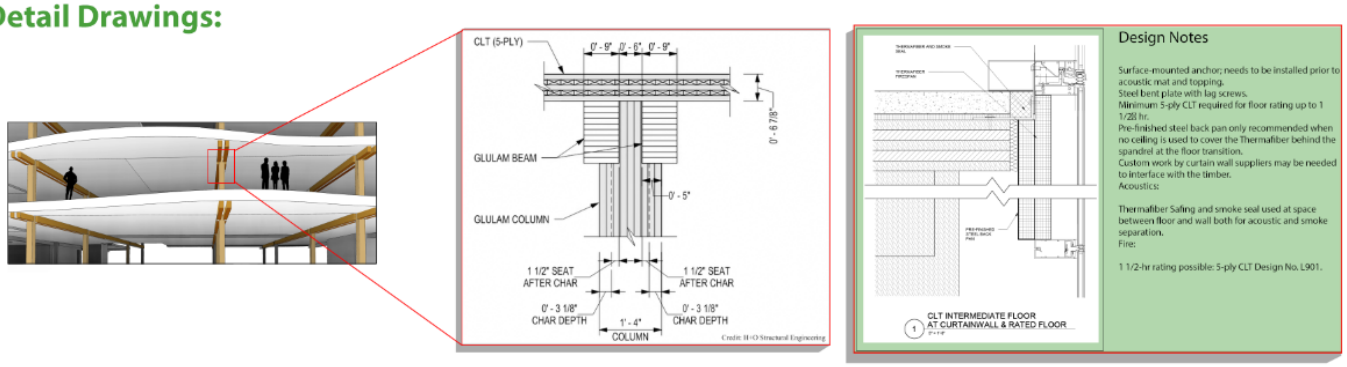




The structure of the building is consisted of two structural systems, concrete in the cores and foundation, where the columns rise up to the 3rd level, and then the rest is mass timber glulam columns, and double beams, as well as CLT panels for the floors. Instead of typical glulam beams, double glulam beams are used to increase the span up to 45fts and also increase the fire resistance to 2 hours. This hybrid structural system provides the opportunity to add to the number of stories of this design for future development. The mass timber tower can be duplicated and used as an addition for future needs.

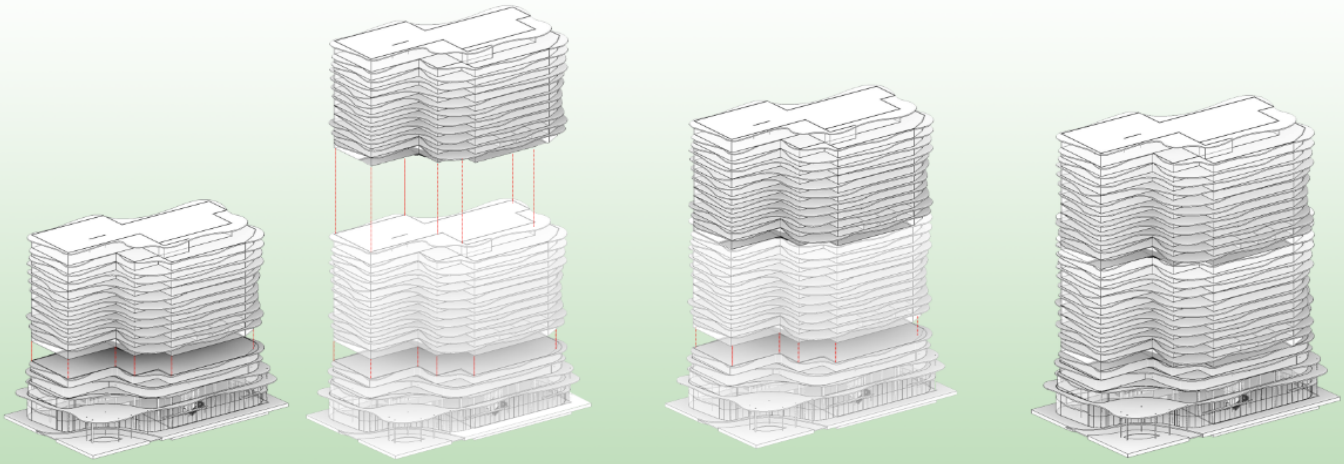


Detail Drawings:



Future Phase:

Since the city is growing and the number of people seeking a place to stay, whether long-term or short-term, is increasing, a second phase has been introduced for the design. The Hybrid mass timber- conceret structural system of the building, allows us to add more mass timber stories to the mass timber section of the building.



Phase one: Foundation, the first three stories, and the cores are concrete. The walls, floors, columns, and beams are mass timber.

The mass timber tower can be duplicated.

Phase two: the mass timber tower can be used as a section of the building that can be duplicated and add to the number of apartments and guest rooms.

Figure 36 Structural drawings

[8, 5] Plans

As I have mentioned the concept is to encourage people to trust in mass timber material. Thus the main impression of the building is the innovative use of wood in almost all areas. To do that I have designed the columns in the public spaces in a way to convey the feeling that trees are holding the hold building and bearing the load. Moreover, to increase the use of balconies during the year, a set of wooden panels are designed that work as railings for the balconies and also act as shading devices for lower floors. The railings rotate 18 degrees in relation to each other to make the shadows more interesting, there is a slight curve in the lower part of the railings as a symbol of the waves of the sea in such a city.

Two other important aspects of my design are trying to design curve balconies as opposed to the traditional boxy mass timber buildings, to show the qualities of this material. The second aspect is that the eastern staircase wall here is covered fully as a vertical green wall to add more to the sustainable aspect of this project.

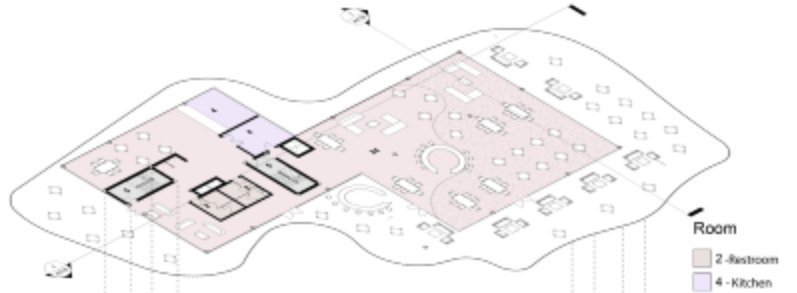
The basement consists of a swimming pool and other hotel facilities such as storage and laundry rooms. On the first floor, the main entrance is from here where the cars can also enter and drop off the guests. In this part, there are columns with the height of two stories, and then in the lobby entrance the ceiling height is up to 39 ft and the view to the voids in the rest of the building is full of curves and interesting views.

There are two outdoor cafes and restaurant areas on the first and second floors. The third floor is the gym and spa area, and the fourth floor is the library and gallery that I have mentioned.

In a typical residential floor plan there are one to three-bedroom units for long stays in the east section and guest rooms in the west section. There are a total of 55 apartments and 88 guest rooms in the whole building.

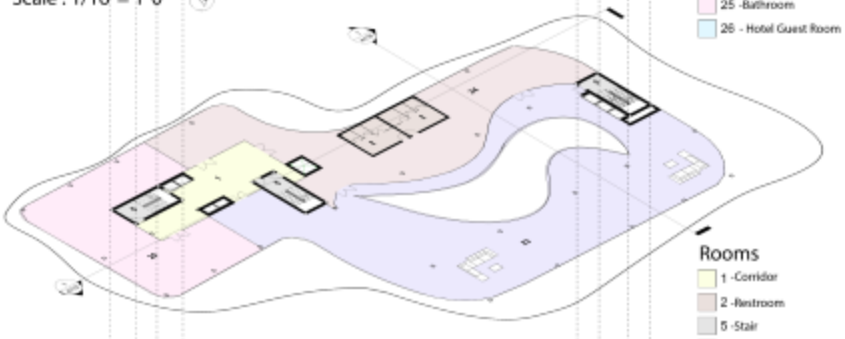
One interesting approach to this design is having gardens on almost every floor of the residential tower. These gardens as you can see are located here where people can gather around in their lounge and enjoy the greenery while spending time with each other.

Last but not least there is a restaurant on the top of the building with an outstanding view of the sea on one side and the downtown city life on the other side, with outdoor seating areas and a bar.

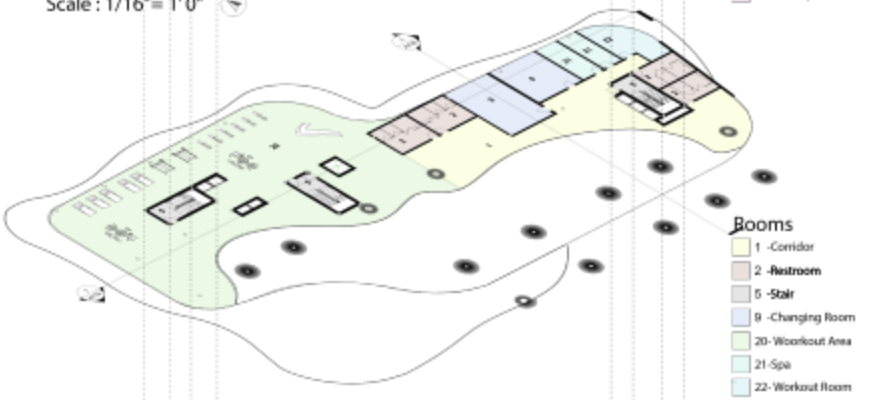


17th Floor Plan
Scale : 1/16"= 1'0"

5th Floor Plan
Scale : 1/16"= 1'0"



4th Floor Plan
Scale : 1/16"= 1'0"



3rd Floor Plan
Scale : 1/16"= 1'0"

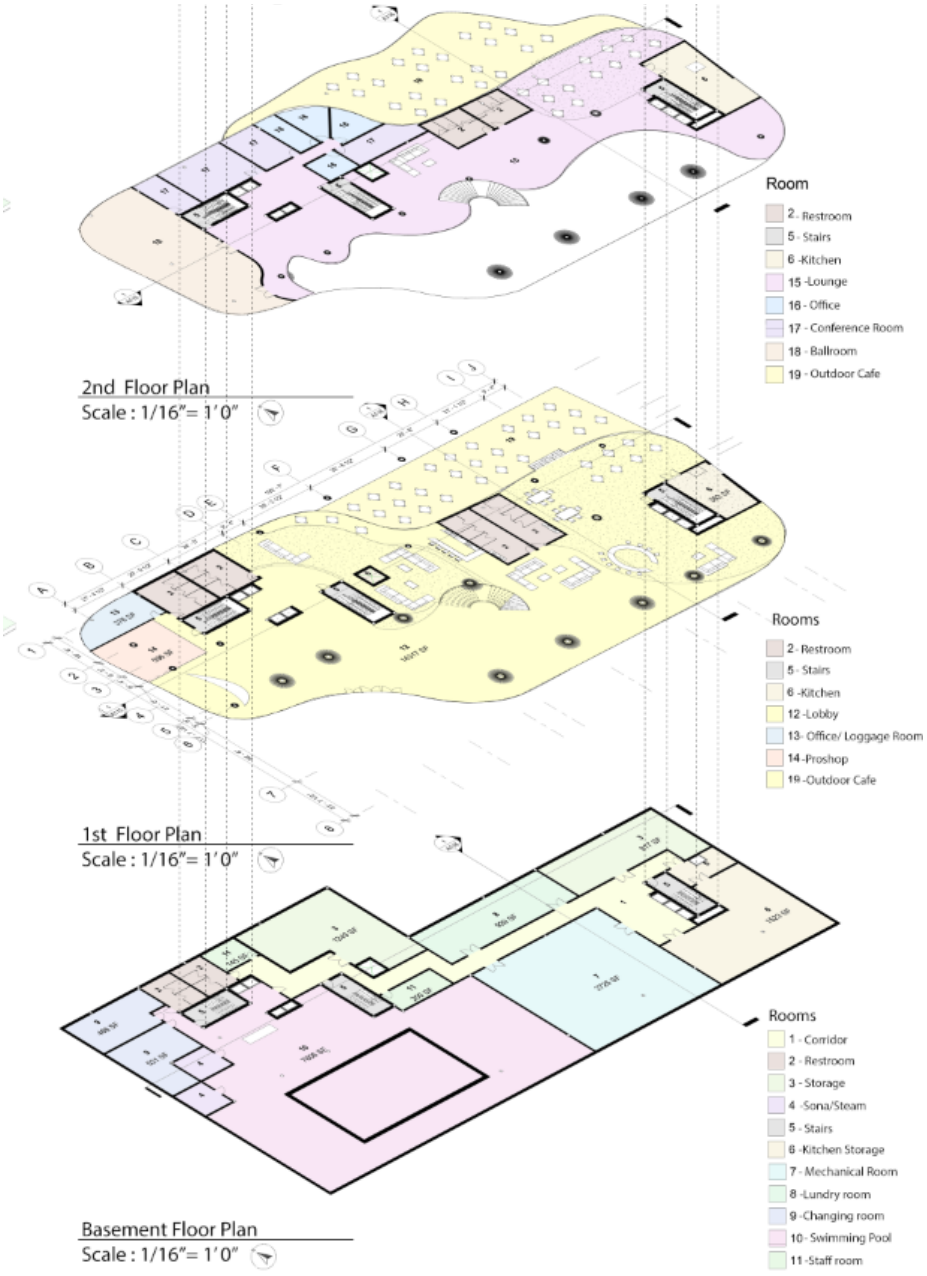


Figure 37 Floor plans

Isometric view of the interior curve voids:

Isometric view of the 5th-floor interior spaces:

Rooftop restaurant with outdoor seating:

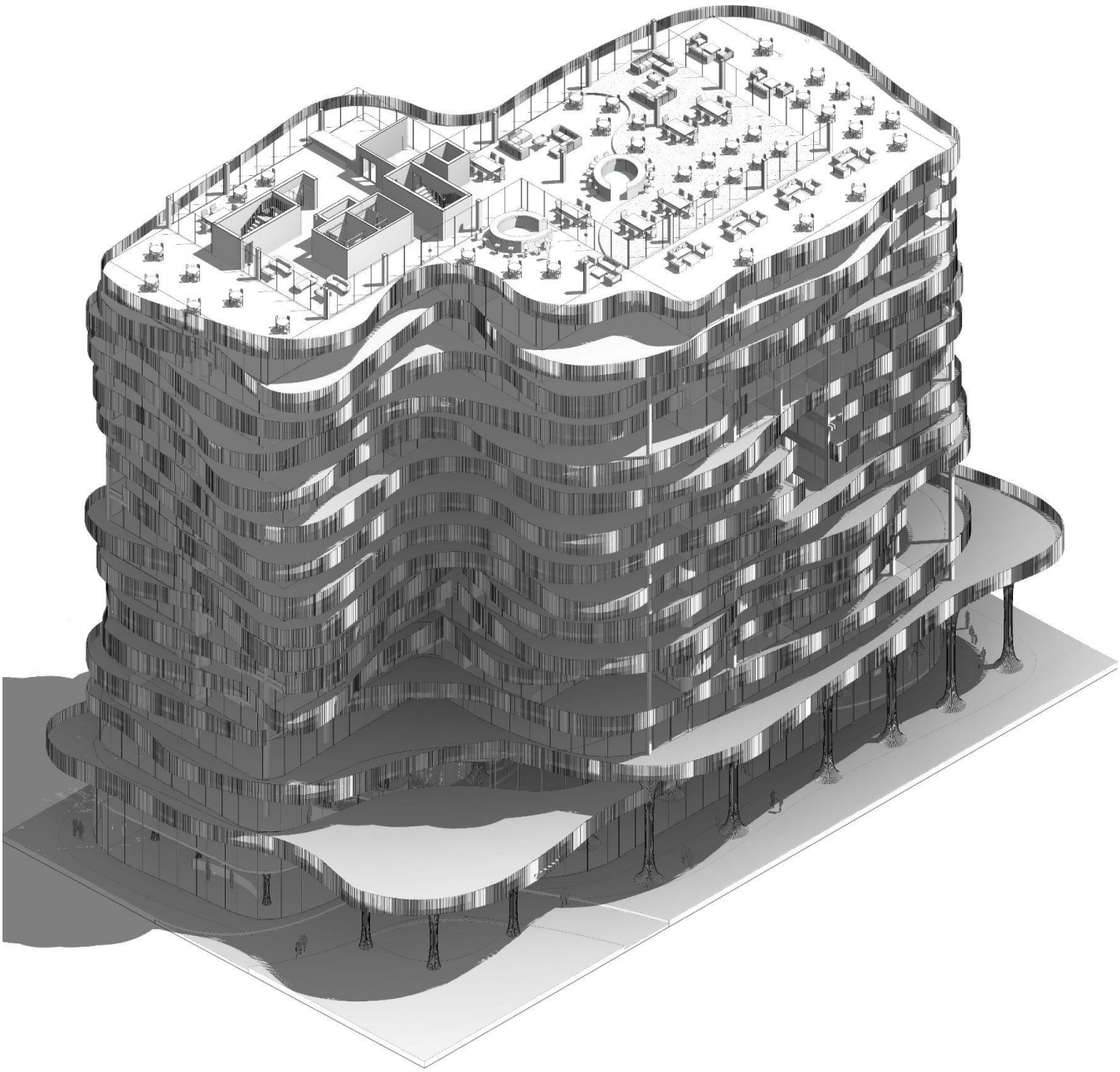


Figure 38 Isometric Drawings

[9] Further Research

1. How to design more organic forms for the columns and concept?
2. How to come up with a more mass timber structure rather than the hybrid system?
3. Increase the level of modularity in the design.

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[11] Figures: