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THE DEVELOPMENT OF A TALL WOOD BUILDING

ABSTRACT

Climate change and demographical increase in developing countries are inducing us to reconsider the way we build the buildings. Concrete and steel have already reshaped our cities for 2 centuries but problems related to the non-sustainable aspects of steel and concrete are now appearing in their productive system, characteristics, creation process and energy demands.
It is necessary to find new solutions, especially regarding high-rise buildings which will be one of the main typologies of construction in a more and more urban future scenario.
The only structural material that can tackle the future demand of building is wood as Mass Timber Products. There are already several successful examples of how this material could answer architectural challenges.
As architects, we have the power to choose how the building is built and realized. On our profession stands a great chance to increase the realization of sustainable buildings. Since the beginning of mankind, wood structure was one of the most common types and this trend was decreased only in the last 2 centuries thanks to the rise of steel and concrete structures.
The 21st century can be instead the century of the renaissance of wood an the motifs are really a lot. Sustainable, renewable, zero impact and other qualities certified that it must be considered as possible solution.
The context of the competition *Wien Heiligendstadt Wohnen und Arbeiten* is a pretext to show how an international competition can adopt Mass Timber as technological solution compared with a concrete solution. Showing the plus points and demerits of wood as a structural material is the main aim of this Master Thesis.
Additionally, this Master Thesis aims to demonstrate the feasibility of an on field context rather than a theoretical solution, while also displaying the current status of wood technology.

ABSTRACT (ITALIANO)

Il cambiamento climatico e la crescita demografica nei principali paesi in via di sviluppo sono elementi che ci devono far ripensare al modo in cui costruiamo gli edifici. Cemento e acciaio hanno già trasformato le nostre città per 2 secoli ma solo adesso emergono i problemi ambientali relativi al loro processo produttivo, le loro caratteristiche e il loro negativo impatto sull'ambiente.
E' necessario trovare soluzioni alternative, in particolare riguardo edifici multi-piano, una delle principali tipologie in un futuro molto più urbano.
L'unico materiale strutturale che può contrastare la futura richiesta di edifici è il legno, inteso come prodotto di legno massiccio e di cui ci sono già significativi esempi di come questo materiale possa risolvere diverse sfide che l'architettura pone.
Come architetti, abbiamo il potere di scegliere come concepire gli edifici e di come realizzarli. Nella nostra professione è riposta la grande possibilità di aumentare la realizzazione di edifici sostenibili.
Sin dall'alba dell'umanità, le strutture di legno furono le più comuni e il loro trend diminuì solo negli ultimi 2 secoli a causa della nascita delle strutture in acciaio e in cemento.
Il 21esimo secolo può essere il secolo della rinascita del legno e sono diversi i motivi. Sostenibile, rinnovabile, a zero impatto ambientale sono alcune delle sue qualità che la devono far considerare come la soluzione possibile.
La competizione internazionale *Wien Heiligendstadt Wohnen und Arbeiten* è il pretesto per mostrare come una competizione internazionale possa adottare il legno massiccio come soluzione tecnologica.
Il confronto con il progetto di concorso concepito in cemento ambisce a mostrare i vantaggi e gli svantaggi di questa soluzione strutturale.
Inoltre, si cercherà di concepire il progetto di tesi come soluzione professionale, non teorica, adattando le attuali tecnologie per il legno massiccio.

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TABLE OF CONTENTS

PART 1 CONTEXT FOR TALL WOOD

1.1 Climate and urban changes 10

1.2 Wood as sustainable solution 12

1.3 Wood as building material 16

1.3.1 Wood based examples
1.3.2 Hybrid examples

1.4 Challenges for Tall wood 22

1.5 Tall wood projects 30

1.5.1 Mid-Rise projects
1.5.2 High-Rise projects

1.6 General considerations 60

PART 2 THE REFERENTIAL CONCRETE BUILDING

2.1 Overview of the Competition 68

2.2 Phase 1 results and Phase 2 data 72

PART 3 THE ALTERNATIVE TALL WOOD BUILDING

3.1 Project goals 76

3.2 The Plot 3 Project structure 78

3.3 Lessons from the Tall Wood examples 82

3.4 Structural design 86

3.4.1 Structural plans
3.4.2 Gravity resisting system
3.4.3 Gravity resisting system - Tests

3.4.4 Lateral load resisting system
3.4.5 Structural materials
3.4.6 The application of the structural systems
3.4.7 Structural considerations related to fire
3.4.8 Building process considerations

3.5 Architectural Design 125

3.5.1 Plans
3.5.2 Typical details

3.6 Building services Design 151

3.6.1 Systems comparison

3.7 Structures comparison 157

3.7.1 Pros and cons of the Mass Timber structure

PART 4 NEXT STEPS AND CONCLUSIONS

4.1 Recommendations 163

4.2 Conclusions 165

List of reference 167

Bibliography 168

Vittorio Salvadori

The Development of a Tall Wood building

PART 1

THE CONTEXT FOR TALL WOOD

The climate change, the material and examples

Master Thesis

1.1 CLIMATE AND URBAN CHANGES

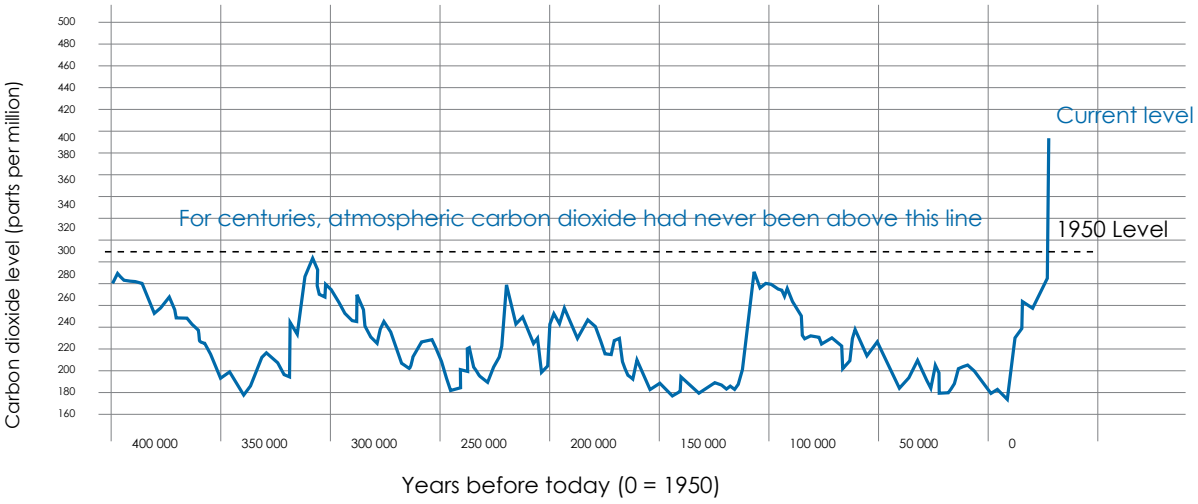


Figure 1: This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO2 has increased since the Industrial Revolution. (Credit: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO2 record, Source: NASA)

There are two main challenges regarding the worldwide environment which mankind will to face this century: climate change and demographical urban growth in developing countries.

Climate change situation

The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat. The abrupt end of the last ice age about 7,000 years ago marked the beginning of the modern climate era and of human civilization. The main thing responsible for these climate changes are very small variations in Earth's orbit that change the amount of solar energy our planet receives.

Scientific evidence for warming of the climate system is unequivocal. The current warming trend is of particular significance because most of it is extremely likely (greater than 95 percent probability) to be the result of human activity since the mid-20th century.

The trend is proceeding at a rate that is unprecedented over decades to millennia.[1]

Earth-orbiting satellites and other technological advances have enabled scientists to see the big picture by collecting many different types of information about our planet and its climate on a global scale. This body of data, collected over many years, reveals the signals of a changing climate.

The heat-trapping nature of carbon dioxide and other gases was demonstrated in the mid-19th century.[2]

Many of the tools own by NASA have the ability to affect the transfer of energy through the atmosphere. There is no question that increased levels of greenhouse gases are causing the Earth to warm in response.

Ice cores drawn from Greenland, Antarctica, and tropical mountain glaciers show that the Earth's climate responds to changes in greenhouse gas levels. Ancient evidence can also be found in tree rings, ocean sediments, coral reefs, and layers of sedimentary rocks.

This ancient, or paleoclimate, evidence reveals that current warming is occurring roughly ten times faster than the average rate of ice-age-recovery warming.[3]
CO^2 emissions are most responsible for the climate change effects on our planet.
The rising economy strongly demands fuel and emits pollutions; the most polluted cities are in India and China, presently both countries have rising economies and hold the majority of mankind. The Paris Climate Agreement signed in 2016 by most of the countries in the world follows the Tokyo Agreement and is another step towards real action to reduce CO^2 emissions by the richest countries in the world.
The effect of the slight rise of the temperature is already clear in all its damage and devastation. These effects prove the need for strong action and intervention on the lifestyle of people along with the production of their necessities.

Urban situation and previsions

Today half of the people of the earth live in a city and by the 2040 this number will rise to 75%. City means density and density means tall buildings. 3 Billion people in 30 years will need a home, which will equal 40% of the world. The challenge for architects and for the society will be to find a suitable solution to house these people.[4]

Figure 2: This schematic map shows where there will be the greatest human concentration in 2050. India, China and Africa will be the most populated areas in the world.

The city materials

Cities are made of two materials: concrete and steel and the 20th Century was definitely the century for these two building materials. From the research of Perret passing by Le Corbusier's "*Vers un'architecture*" followed by the Modern Movement, concrete replaced brick, wood and stone and started its golden age. In America, it became common practice to build with steel especially when it came to high rise buildings. Today, these two materials are held most responsible for shaping our cities. They are great materials but they also embody a great amount of energy and greenhouse gas emissions in their process. In fact steel represents 3% of human greenhouse emissions on earth and concrete over 5%. So, 8% of the entire human gas emissions come from only these 2 materials. Moreover, statistics say that almost half of the CO^2 emissions are related to the building industry. This is in comparison to the highly criticized transportation industry which produces "only" 33%.[5]
If we understand that 3 billion people will need a new home in the next 30 years, and we think about the fact that the usual materials we build the city with are so heavy in resource emissions, we need to consider an alternative material to build with, and that alternative is wood.

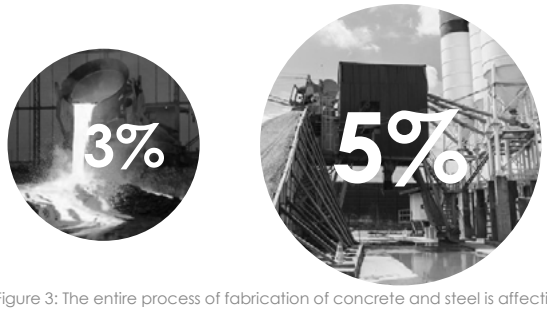


Figure 3: The entire process of fabrication of concrete and steel is affecting the CO2 emissions for 8% together.

1.2 WOOD AS SUSTAINABLE SOLUTION

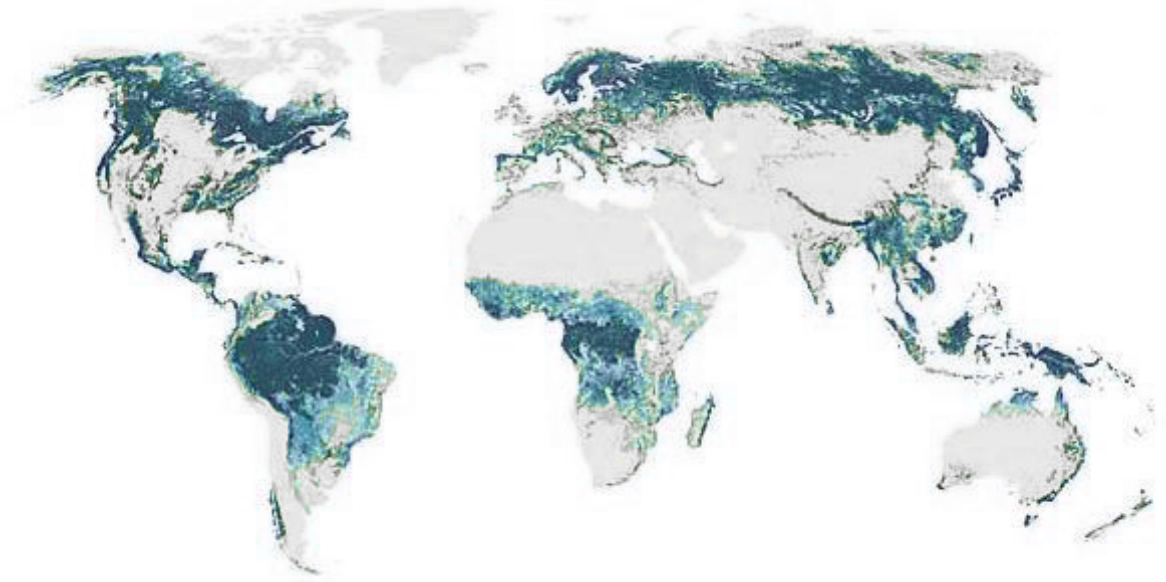
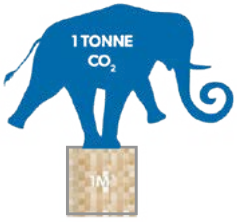


Figure 4: The Forest in the world.

As architects, when facing the climate change and pollution process, the only material that grows in a sustainable way, grows by the natural power of the sun, is wood. When a tree grows in a forest, it gives off oxygen soaks up dioxide. When that tree dies and decomposes in the forest, the CO^2 stored inside will be released into the atmosphere and will burn away. But if you take that piece of wood and use it as part of building, a furniture or a toy, it has the great capability to store that amount of CO^2. 1 m^3 of wood can store 1 ton of carbon dioxide. For the future of humanity we need to reduce and store the CO^2 emissions. As architects we can use a material that can do both.[6]



Forest status in the Europe and in the world

When we think about wood as building material we could think about the risk of deforestation.

We must know that in the world, forests represent the 29,6% of the earth surface. The European forests represent only the 5% but are the most used for the wood production: in fact the European forest sector covers around 25% of the actual worldwide production of forest products and around 30% of wood panels, paper and cardboard.[7]

Forest area in Europe currently amounts to 215 million hectares and accounts for 33% of the total land area.[8]

Every year 776 million cubic meters of wood is grown in Europe and only around two-third of them are harvested: the remaining 286 million cubic meters are in forests and are thereby increasing the total European forest area every single year.[9]

Despite the fact that the internal demand for forest products is growing and the European

Union is becoming one of the largest exporters of wood products, its forests are growing. To better understand how vast the forests in Europe are, take this example: if we divided the overall forest surface for every European citizen, each would receive a portion equal to the size of two and a half football fields.[10]

Furthermore data shows that over the last 25 years, the total growing stock in forests increased by an average of 403 million m^3 each year. This corresponds approximately to a daily increase in the total stem volume of living trees in European forests equivalent to twice the volume of the Eiffel Tower.

Currently in Europe's forests there are 20 billion cubic meters of wood. Annually only 64% of the increment is cut.
The European forest industry recognizes that its future is inextricably linked to forest protection and expansion. There is an intention to plant more trees than they are cut. All European countries have policies and measures related to reforestation. Although the number of trees planted per hectare vary depending on the species and the nature of the ground, these will always be greater in number than those cut, which allows the forest to regenerate. But if Europe's forests are gaining ground, globally the situation is more complex. According to the FAO, Latin America and Africa are the continents with

Figure 5: The increase (or decrease) as a percentage of forest areas from 1990 to 2015 in European countries.

the highest rate of deforestation in the world, respectively 4 and 3.4 million hectares lost each year from 2000 to 2010. As for Asia, the large tree planting programs in China are able to offset the heavy losses of Southeast Asia, a region that appears among those at high risk of deforestation.[11]

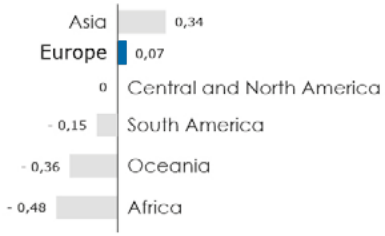


Figure 6: The increase and the annual decline in forest areas in the world. Data period 2000-2010.

Carbon Footprint

No other material has as small of a carbon footprint as wood. A carbon footprint is a measure of the volume of carbon dioxide emitted into the atmosphere as a result of particular activities, products or behaviours. Using the footprint, you can measure the impact a material has on the environment. A lot of materials leave a very large footprint. In comparison to other materials, wood has a very small carbon footprint. This is due to sunlight and the photosynthesis process helping the trees absorb CO^2. Trees store the "C" and they release the "O^2" back to the atmosphere. Forest management allows trees to be taken out before they rot and release their stored CO^2 back into the atmosphere. This creates space for new trees to quickly grow and actively absorb CO^2. Additionally, forest management is important because the use of timber vastly prolongs CO^2 storage, allowing it to remain in secure place for decades. Using timber instead concrete or steel reduces the CO^2 building's emission by 50%. Moreover, wooden buildings store tons of CO^2 similar to forests and an entire district made out of Timber products could be considered just like a second forest

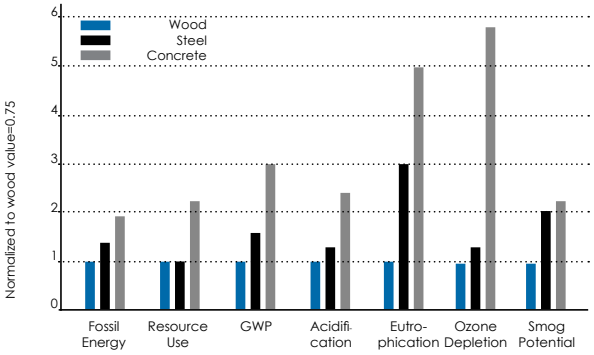


Figure 7: Embodied effects relative to the wood design across all measures

Protected forests

In Europe, about 12% of the forest area is specifically protected in order to preserve the biological and landscape diversity. Of these, more than 1.6 million hectares are forest reserves. There are large tracts of protected forests in Northern and Eastern Europe, which are managed by keeping human intervention to a minimum. 85-90% of European forests perform multiple functions at the same time and helps to protect the soil, water and natural ecosystem.

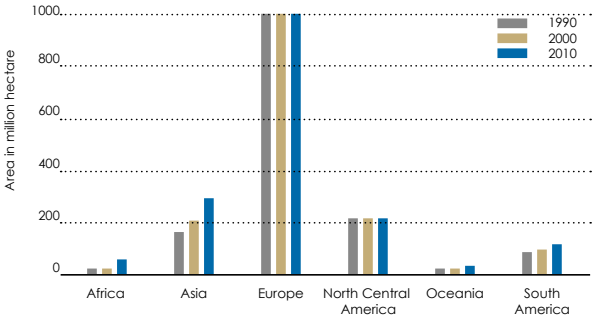


Figure 8: Million hectare proteced in each continent.

Sustainable forest Management

Despite the great variety of natural and plantation forest types, there are third party administered, internationally recognized sustainable forest management (SFM) protocols applicable to each.

These protocols provide assurance to governments, industries, architects and the public alike that the quantity of wood fibre harvested does not exceed the quantity of wood fibre produced by tree growth on an annual basis, nor compromises the ecological services the forest provides.

The main regional and national system is endorsed by the Programme for the Endorsement of Forest Certification (PEFC) which is a non-profit organization based in

Geneva, Switzerland. Alone PEFC certifies around 65% of the world's certified forests.
The other main organization is the Forest Stewardship Council (FSC) which is also a non-profit organization formed by multi-stakeholders.
The main difference between these 2 methods is that PEFC is a "bottom up" organization, in order to be easily recognizable between countries while FSC is "top down" which means that it develops its own standards and applies them to the different bio-scenarios.

Forest and Carbon Cycle

The main aim of the forest management is to guarantee the continued growth of trees that sequester and store carbon dioxide from the atmosphere. Adopting smart ways to use wood, guarantees a long-term mitigation of climate change.
For most of its life a growing tree uses the sunlight it receives to sequester CO^2 and converts the carbon it contains into cellulose, the main component of wood fibre.
This carbon remains in the wood until the tree begins to decay or is destroyed by fire, at which point it is released again as CO2. This process is part of a complex system of global carbon exchange known as the carbon cycle. Deforestation is the main problem the carbon cycle is faced with, along with the increase in human activity dependant on fossil fuel per capita and the resulting impact it causes. These new factors have created now a climate instability that is shown daily.

Life cycle Assessment (LCA)

The preferred method of comparison is the Life Cycle Assessment. LCA is accepted across the world as an impartial way to evaluate and compare the environmental impacts of different buildings materials, products and complete structures over their lifetime. It therefore combines the impacts of embodied energy (the amount of energy required to extract, process, fabricate, transport and install a particular material or product) with those of building operations, maintenance and end-of-life dismantling and disposal. In almost every case, LCA demonstrates that wood is the most environmentally responsible structural material when used in functionally appropriate applications.

Conclusion

Forests are complex systems that especially in the present moment are showing us their weak points. Despite the huge problem of deforestation, it is important to state that cutting trees in a managed process can be not only an economical advantage but also a sustainable way to guarantee the carbon cycle, especially when that wood is transformed in building material.

1.3 WOOD AS BUILDING MATERIAL

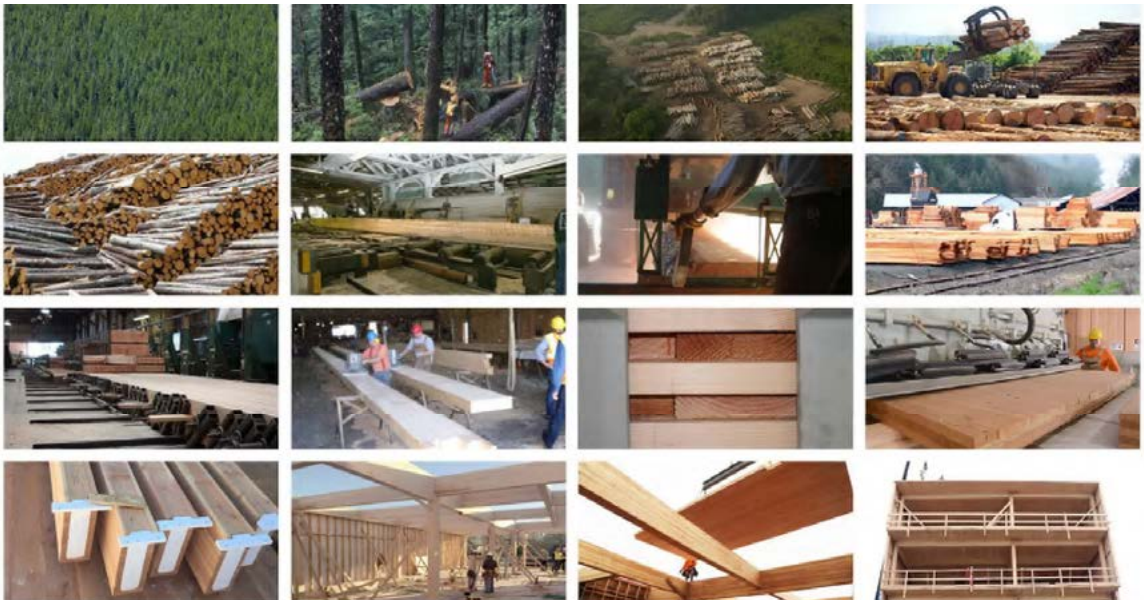


Figure 9: The different phases of the production of engineered wood elements.

Wood is like the snow, no two pieces are the same, it has a natural effect on people that is not comparable with steel or concrete. It is a renewable building material that can be dismantled and re-used really quickly. It is locally produced and certified. In Austria but also in Italy, Germany, Slovenia and in the Scandinavian countries. Wood is a great economical resource and it could be even more so if the wood building technology becomes predominant. As we said wood ia a high-tech industrial product with a low CO^2 footprint. Compared with concrete and steel it has less weight, less transportation and lifts, less foundation and piling, less people and effective mounting. It has also a fire resistant capability. From a technical point of view, timber can compete with all other construction materials.

Wood characteristics

Because of its natural origin, the strength and stability of wood varies with the orientation of grain and moisture content. Controlling these two variables is the key to creating components and structures that are precise, dimensionally stable, strong and ultimately more durable.

Wood only becomes biodegradable in a moist milieu. As long as it is the right wood, treated with care, utilized with know-how ,and therefore shielded from moisture, wood's endurance is almost unlimited. Wood is highly resistant to acids, bases, salts and other chemicals. Ventilation is important; it avoids the penetration of humidity, allows surface water to drain off and assures quick drying due to air circulation. Right angled to the grain, wood has 100 times less tensile strength than along the grain, it swells and shrinks - depending on humidity.

These problems can be solved with derived timber products. Plywood panels for example neither swell nor shrink and show a constant strength. In general, the used wood should never exceed 20% moisture content.

The lifetime of a timber building is remarkable, timber frame houses often have to be renovated after they are more than 300 years old, but they still do not need more care and effort than other buildings.

Fire behaviour

Metal construction deform rapidly under the influence of heat. A wooden beam however, keeps its stability for a longer period of time. This is because even dry wood contains water that has to vaporize. Until then, the temperature of wood ranges around 100 °C. At around 270°C, combustion starts with a burning velocity of around 1mm/min (pine wood *0,76mm/min; hardwood *0.5mm/min). Even at 1000°C temperature wood stays unharmed 1 cm under the charred surface, while the residual cross of the compression strength of concrete is reduced by two-thirds.

Figure 10: the section of a trunk with the charred layer

Comparison with other building materials

Wood grows again, fossilized raw materials of unlasting resources are being preserved. Due to the emergence of construction material wood, the environment is supported. Trees only need water, earth and air and from the air they even extract harmful CO^2.

If we analyse the CO^2 emission for the production of different construction materials (kg/m3) we can see:

Wood	16
Concrete	120
Steel	5 300
Aluminium	23 000

Since the transport route of regionally grown material is short, it saves energy, avoids complicated further processing, 100% of the material can be used (no wastage) and it has a low use of energy for manufacturing. Furthermore Timber construction is flexible.

The modern processing methods

The common perception people have about wood, is soft wood, susceptible both to physical damage by fire and to decay if allowed to remain wet for a prolonged period of time.

In reality, the engineered processed wood we now use as building material is engineered massive wood products which are stronger, more consistent and more dimensionally stable than traditional solid sawn material.

Engineered wood products

The engineered wood products are realized by bonding together wood strands, veneers, small sections of solid lumber or other forms of wood fibre to produce a larger and integral composite unit that is stronger and stiffer than the sum of its parts.

The wood that makes the engineered products is generally made up from smaller trees using a greater percentage of the tree.

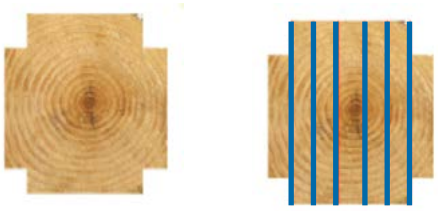


Figure 11: The way a tree is cut to obtain CLT panels

1.3.1 WOOD BASED EXAMPLES

The wood industry is rapidly developing, and always advancing new techniques. Especially in Europe there are deep-rooted and powerful companies contending in the world market. Most of the wood supplier companies can produce a wide range of products but most of them are specialized in a particular product such as CLT or glulam products. The following materials are the main ones used in current day practice and in the next Mass Timber chart building.

Glue-Laminated Timber

Definition: Glulam is manufactured by gluing together individual pieces of dimension lumber under controlled conditions to form larger linear elements.

Used for: Columns, beams, headers and horizontal trusses

Wood source: North America: Douglas Fir, SPF (spruce, pine, fir), larch (*Larix Decidua*)/ Europe: red pine (*Pinus resinosa*) and white spruce.

Dimensions: Thickness of 25, 34 mm, widths of 80 to 170 mm. Lengths 3 m or longer.

Laminated Veneer Lumber

Definition: LVL is produced by bonding thin wood veneers together in a large billet so that the grain of all veneers is parallel to the long direction.

Used for: Floors, walls and roofs mainly but also beams and headers.

Wood source: Different wood spices (Douglas Fir and lodge pole pines)

Span:1 direction spanning capabilities

Dimensions: Because is made with scarfed jointed veneer, is available in lengths far beyond conventional lumber lengths.

Laminated Strand Lumber

Definition: LSL is made from flaked wood strands that have a length-to-thickness ratio approximately around 150.
Used for: Floor, walls, roof panelling or vertical members
Wood source: Strands of fast growing aspen (*Populus remuloides*) or tulip poplar (*Liriodendron tuipitera*)
Span:1 direction spanning capabilities
Dimensions: Panels came with a range of standard thickness and a maximum width of 2,4 meters.

Cross-Laminated Timber

Definition: CLT is comprised of multiple layers of alternating boards stacked together, with the alternating layers at right angles to one another. Layers are bonded to form a composite panel with exterior layer following the direction of the applied loads.
Used for: Floor, walls, roof panelling
Wood source: Variety of species (often beech)
Span: 2 way direction spanning capability
Dimensions: 3 to 7 layers (16 to 51 mm each layer); width 1,2; 2,4 or 3,0 meters.

Nail-Laminated Timber

Definition: NLT is made up of regular solid sawn framing members arranged side by side on edge and fastened together with nails or lag screws.
Used for: Floor
Wood source: Variety of species (Douglas fir and SPF)
Span: 1 way direction spanning capability
Dimensions: Non applicable standards
Other: It doesn't need capital investment to be produced because it could be produced in a conventional wood shop.

Adhesives

Except for Nailed Laminated Timber products and CLT, all the other previous mentioned panels are glued using formaldehyde-based glues. The type of glue depends on the temperature of the process, interior or exterior use, or finishing requirements.

1.3.2 HYBRID EXAMPLES

Massive Timber + Concrete Composite Floor

Definition: This type of hybrid solution is composed generally of a layer of CLT or Mass timber panel with another layer of concrete (mostly pre fabricated) divided by a protecting thin layer between the 2 materials in order to avoid moisture effect.

Used for: Floor

Wood source: Depends on Mass Timber source panels

Span: 2 way direction spanning capability

Dimensions: Depending on truck capability because of the prefabrication process took place not in the building site.

Glue-Laminated Steel Beams

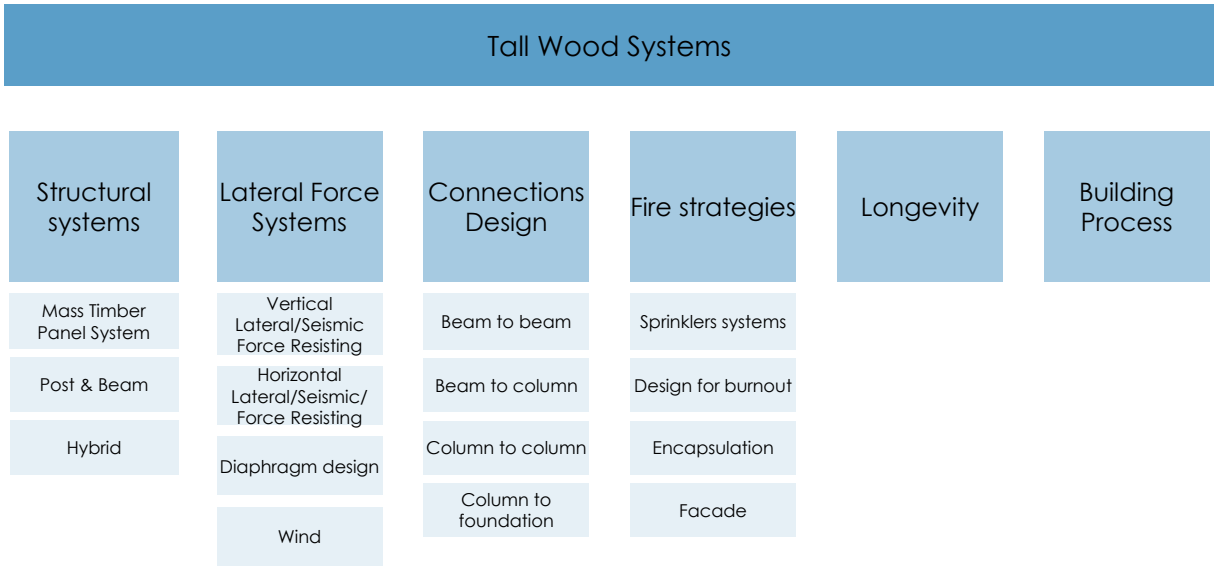
Definition: A beam formed by a core of steel folded by 2 glulam beams which both protect and work mechanically together with the steel beams. It is a solution developed and tested by the TU University of Vienna, by the ITI department.

Used for: Beams, headers and horizontal trusses

Wood source: North America: Douglas Fir, SPF (spruce, pine, fir), larch (*Larix Decidua*)/ Europe: red pine (*Pinus resinosa*) and white spruce.

Dimensions: It follows the typical steel sizes adopting the Glulam beams to the length and thickness of the steel beams.

1.4 CHALLENGES FOR TALL WOOD



Tall wood buildings are a cutting edge topic. In the last decades depending on the continent, wood companies and engineers already faced several challenges which are reported in the following chapter.

Structural systems

Structural Form

Stiffness is the key-word for a tall wood building. Stiffness then will dictate the structural form of tall timber buildings. Designing for stiffness rather than strength creates a situation where it is necessary to use walls to limit deflections.

Moment-resisting structural frames become too flexible even for 3 or 4 storey buildings, and are unable to provide economical section sizes that are sufficiently stiff for taller buildings. In order to increase the feasibility of structural frames for tall timber buildings, diagonal bracing elements must be added to increase the stiffness of the whole structure, following the example of many structural steel frame designs.

Stiffness can be significantly increased using box, C or I section walls around the stairwell and lift cores. Converting a single wall into an I-shaped core group will increase the area of timber required by 2 while increasing flexural stiffness by 3.9 times. In the design of these walls, however, the tube stiffness could be significantly reduced by connections between panels which should be considered as part of the system design and not be left for last-minute verification during detailing. Post-tensioning can be used to connect solid wood panels to each other and to the foundations.[12]

In structures without sufficient walls to carry all of the gravity loading, floors are supported on timber beams and columns. Prefabricated timber floors and timber-concrete composite floors represent some of the timber based flooring systems available. These can be post-tensioned if long spans and low floor-to-floor heights are necessary.

There are 3 different possible categories to

recollect the number of buildings realized presently.

Mass Timber Panel systems

The particularity of the wood buildings is that they are made, if chosen, in massive wood. This could be developed in a structural system that is becoming normal to design houses and mid-rise buildings in Europe.

Figure 12: Schematic image which shows the elements of a panel system.

Post & Beams systems

As for concrete or steel buildings, post & beams structure is also used particularly in wood buildings. The principles is the same as the other construction system: size of the beams, depth of the ceiling and span all must be considered.

Figure 13: The interior view of the structure of the Wood Innovation Centre.

Hybrid systems

There were some cases where the designers decided to mix the characteristics of various materials in order to achieve goals of high prefabrication, cost reduction or higher stiffness. This is why there are some hybrid solutions realized where concrete, Mass Timber and steel are working together to guarantee the structure performance. One of the most famous example is the case of LCT Tower which is a combination of prefabricated floors of concrete and glulam columns integrated to prefabricated glulam with special steel connections columns which makes the building an interesting example of high prefabrication.

Figure 14: The hybrid concrete+glulam floor in the Life Cycle Tower

Lateral Force Systems

The structural form of a tall timber building will most likely be governed by the desire to limit lateral movement. The need to limit lateral displacements may also govern connection design.[13] The physical size of possible timber element production, transportation limits, or limits on what can be placed on-site, all lead to many connections being required for a tall timber structure. Each of these connections acts as a 'soft' area reducing stiffness in the wall system. Early in the design process, the impact of connections on total building stiffness must be accounted for, even if this is simply by applying an estimated reduction to the total stiffness of solid walls. If this stiffness reduction is not considered early on, more walls and expensive fasteners may be needed during the detailed design, leading to unforeseen structural costs. Because the lateral load design of tall timber structures is often governed by the displacement of the lateral load resisting system, is it necessary to know the stiffness of all the timber members and their connections. Unfortunately the stiffness of fasteners is often neglected in design, with only limited guidance given in design codes, and values often affected by large scatter. Manufacturers of proprietary products like brackets or hold-downs normally provide strength values, but little information about stiffness. This represents one significant area of improvement needed to enable tall timber structural design.

Vertical Lateral/Seismic Force Resisting Systems

To resist against the Lateral Force effects the Mass Timber can introduce in their structural system shear walls or a rigid core. The core for several reasons could be preferred in concrete but there are several examples with the mass timber core. If the designers chose the second one there is always shear walls that are inside and on the facade, depending on the height and the plan. The constructive difference that exists between concrete and wood core is that the concrete one has to be complete until the last level in order to start the wood construction. This means the building must be cantilevered twice, which requires more time. The wood core instead could be designed every 4-5-6 floors (depending on floor-to-floor height and transportation of the trucks) and assembled on site. This shaft could be used to help the erection of the rest of the building.

Figure 15: The different CLT core walls mounted in the building site.

Horizontal Lateral/Seismic Force Resisting Systems

When we consider the Vertical Resisting systems it is usually referred to as the Diaphragm: roof, floor transferring lateral forces to the vertical resisting elements

- Diaphragm loads are generally uniform loads, resisted by the diaphragm in bending, similar to a horizontal deep beam
- Diaphragm bending results in tension/ compression in chords perpendicular to load

Diaphragm Design

Timber diaphragms tend to be more flexible than their concrete counterparts, with increasing floor spans further reducing stiffness. In seismic design, although the presence of flexible diaphragms causes closely spaced modes (i.e. a number of modes with almost the same period of vibration, corresponding to the diaphragm frequency) and elongates the fundamental period of the structures, this can normally be neglected in the design of the vertical lateral load resisting system. Because of the higher modes of the lateral load resisting system and the diaphragms, the force demand on the diaphragms cannot be estimated with a simple equivalent static analysis.

When designing for wind loads, the role of the diaphragm in tying lateral load resisting elements together is crucial to good performance. The load path from the façade elements to the vertical load resisting elements needs to be guaranteed. Wind loads normally create line loads along the diaphragm boundary, so it is necessary to transfer these forces into the remaining part of the diaphragm to fully activate it.

Wind suction on the leeward face of the building is a special case requiring tension connections to the adjacent diaphragm panels and between all components of the diaphragm, whether they be massive timber panels or light timber framing.

Considerations about wind

A wood structure is highly flexible and this means that design base shear from wind loading is usually higher than that from possible earthquake loading, even in high seismic areas. In this way the goal of tall wood building is assessing the strength of the lateral load resisting system at the ultimate limit state (ULS), and checking the lateral deflections at the serviceability limit state (SLS).

Beside this there are also the wind-induced vibrations to take in account. They are a general problem for all the tall buildings, but because of the low mass of the building and the low stiffness of the wood materials in wood building they need to be carefully considered. Possible solutions include vibration control such as tuned mass dampers or increased understanding and modification of the building profile through wind tunnel testing.

Connections Design

Tall timber buildings will have very large structural members which must be designed to resist very large structural forces. Because wood is a brittle material, ductility in timber structures generally comes from ductility in the steel connections, which have to be carefully designed to ensure appropriate behaviour.[13] This is why the connections in Mass Timber Buildings are one of the main aspects to consider from the beginning of the design of the building.

The considerations that must be made are regarding:

- Structural capacity
- Shrinkage
- Fire
- Constructibility
- Aesthetics
- Cost

What is always common in wood buildings in general it is the large use during the construction of Long self tapping screws: sizes, role and position can change.

Beam to beam connection

It consists of two steel parts nailed both in the 2 beams that has to be connected in a perpendicular way.

Figure 16: An example of hidden Beam to beam connection.

Beam to column connections

The wood companies developed different ways to connect the beam to a column but the main principle is that there is a predisposition in the section of the column that allows the beam to be fixed in the required place.

Column to column connections

This is a particular topic in the "2 way deck" systems but it could be found also in other systems. Usually the floors are shaped to fit in the connection that it is in steel and is nailed to the top and in the bottom of the 2 columns.

Column to foundation connection

One important topic in mass timber building is the ground floor connection. All the buildings require concrete foundations and the connection between these 2 different systems has to be carefully planned in order to avoid moisture problems that can affect the wood part and compromise the entire building life. Similar to the column to column connection, the column to foundation connection is usually comprised of a steel plate with a moisture barrier.

Figure 17: An example of Beam-Foundation connection.

A large number of connectors can add significantly to the cost of tall timber buildings. The use of proper products is one way to limit this cost, however early consideration is necessary to assess how they will interact with other aspects of design and consenting.

Fire systems strategies

The main cultural problem related with wood is fire resistance and its behaviour in case of fire for the safety of the occupants of the building. Heavy timber has excellent fire resistance, which is well documented in the literature. This excellent behaviour is a result of the slow and predictable rate of surface charring in severe fires, leading to simple calculation of fire resistance by subtracting the charred area and a thin layer of heat-affected wood from the original cross-section. As a result of this charring behaviour, unprotected heavy timber structural elements have excellent fire resistance, much better than unprotected structural steel, for example.

Fire safety goals

Fire safety is a major concern in all tall buildings, regardless of materials. The taller the building, the more attention must be given to:

1. Prevention of vertical fire spread
2. Fire resistance to avoid structural collapse.
3. Encapsulation of structural timber.
4. Design for burnout.

Sprinkler systems

Generally every high-rise building need to be sprinkled. This is not mandatory in the case of mid-rise buildings except for some cases (hospitals, laboratory, particular program.

Automatic fire sprinkler systems provide by far the best fire safety for tall buildings (active fire protection). However they are not 100% reliable. Possible failure can occur as a result of maintenance problems, too many sprinkler heads being activated due to an explosion, or no water supply due to a major earthquake or terrorist event. If the sprinklers work as intended, zero structural fire resistance is required, but everything changes if the sprinklers do not work for any reason, and a small fire grows through flash-over to a fully developed fire.

Sprinkler reliability is essential for fire safety in tall timber buildings. Strategies to reduce the risk of sprinkler failure include on-site water supplies, reliable pumps, enhanced maintenance systems, and frequent security checks.

Design for a burnout

Design for burnout requires prevention of vertical fire spread from floor to floor, regardless of structural materials.

The only certain way to design for burnout in a timber building is to apply full encapsulation, so that none of the structural timber ever begins to char, throughout the full process of fire growth, development and decay. The required encapsulation will depend on several factors:

- The fire severity, and duration of the burning period
- The rate of temperature drop due to ventilation in the decay phase of the fire
- The effectiveness of partial encapsulation
- Intervention after the fire is out

Encapsulation

One of the main issues between architects and fire engineers is not the use of wood as building material but rather the encapsulation of the wood in gypsum boards in order to drastically reduce the risk of fire. But from a structural engineering viewpoint, critical structural elements such as isolated columns must be well protected to prevent any chance of disproportionate collapse. This can be done by adding extra sacrificial

wood or full encapsulation.
For burnout control, in the unlikely event of sprinkler failure, full encapsulation of all wood surfaces solves the possible residual charring problem, but it is expensive, and may be unacceptable to the architect and the building owner who want to see the exposed wood linings and structure.

Facade

Besides the requirement of fire resistance of the floor-ceiling system and all walls enclosing vertical stairs, shafts or services, it is also essential to design the exterior façade. Spandrels and windows can contribute to the propagation of the fire to other levels of the buildings and a detailed design will reduce the risks.

Design for longevity

Long term performance and durability of tall timber buildings is similar to regular timber buildings, however, the cost of failure is significantly greater due to the increased cost of the structure.
Long term deflections can be controlled and designed for using widely accepted creep coefficients. Care must be taken where a combination of materials is used, for example the attachment of non-flexible facade or around steel lift shafts, to ensure that movement can be accommodated.
Internal and external moisture control always requires careful attention in a timber building. Moisture and temperature change will cause timber to shrink and swell, however under normal, climate controlled, conditions this is not a significant factor even in a tall timber building. Nevertheless, this should be checked throughout the design phase to make sure there are no real issues.

Figure 18: Wood walls and ceiling exposed.

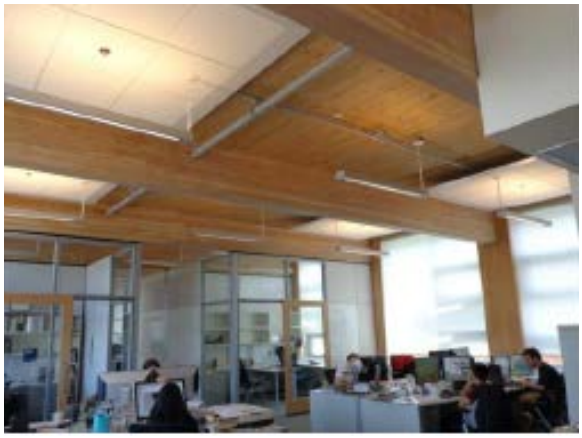


Figure 19: Columns, beams and part of the ceiling exposed.

Figure 20: Wood ceiling and furniture exposed.

Figure 21: Wood columns exposed.

Figure 22: Wood columns and beams exposed, also post-tensioning anchorages and dissipation devices.

Figure 23: Wood ceiling, beams and columns during the process of encapsulation.

Design for construction

A big challenge for designers of tall timber buildings is to design and detail structural elements that can be economically produced under factory conditions, then be erected rapidly and be connected together with suitable connections which will serve the life of the structure.

Big cost advantages of timber structures are the cost savings in preliminaries, i.e. the on-site costs. Accurate dimensioning through CNC machining leads to rapid construction. Reduced erection time, lighter members, therefore requiring less cranes, improved handling, and accurate tolerances of the pre-fabricated timber members can provide large savings, in addition to those from early occupation of the building. Cost savings can be further increased by partial or full pre-fabrication of sub-assemblies like wall or floor panels and by pre-installing all steel hardware on the timber elements.

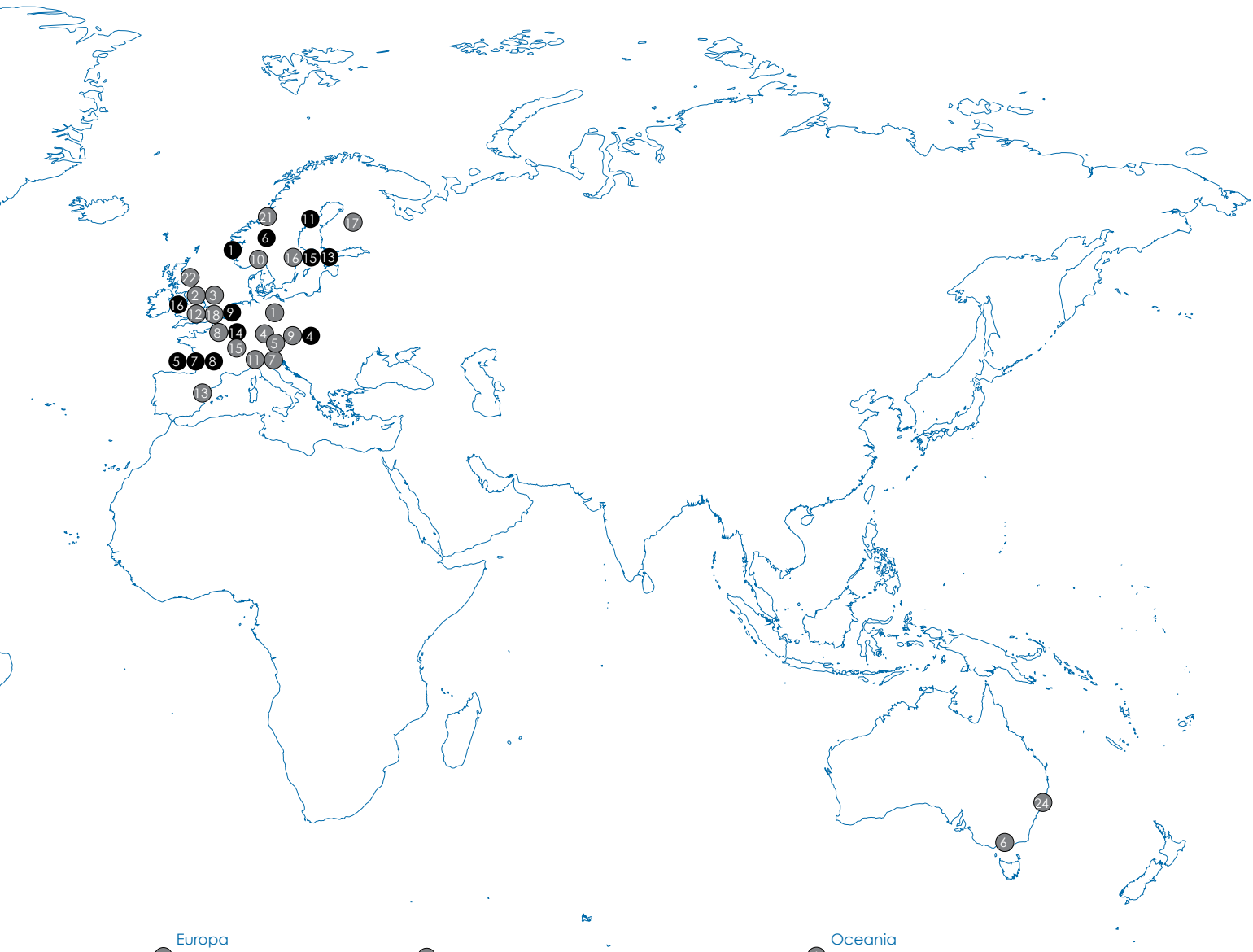
Bed weather conditions during construction can impair the constructibility and aesthetics of timber structures due to swelling and staining of the timber. To prevent this, proper erection planning is necessary and timber members should be protected temporarily by wrapping them individually, or by the use of temporary cover of the whole structure. Contrary to common belief, timber will not deteriorate if exposed to the weather for a short period of time, but care should be taken to keep this time to a minimum.

1.5 TALL WOOD PROJECTS

Because of these, along with many other research project performed mainly by universities and companies, the number of mid-rise and high-rise buildings has grown significantly.
The architects, the engineers and the companies started since the beginning to apply new technology as CLT or Glue laminated columns and beams at some projects.
Some offices specialized themselves from the beginning regarding some particular wood technology such as Wough & Thilsdome from London who focused international attention on their project of 7-storeys CLT building in London.
As it is possible to see from the map, the most of the projects are made or proposed in Europe, where the CLT technology is born. Besides that, only Canada, USA and Australia are developing their own way to solve high-rise challenges.

America
14 Wood Innovation Design Centre, Canada
19 T3, USA
20 Arbora, Canada
23 Portland 12, USA

2 UBC Brock Commons, Canada
3 Origine Condos, Canada
10 Framework, USA
12 Port Living, Canada



Europa

1. E3, Germany
2. StadtHaus, UK
3. Bridport House, UK
4. Holz8 Germany
5. Life Cycle Tower, Austria
7. Panorama Giustinelli, Italy
8. Maison de l'Inde, France
9. Wagramerstrasse, Austria
10. Pentagon II, Norway
11. Cenni di cambiamento, Italy
12. Dalston Lane, UK
13. Contralaminada, Spain
15. St. Diè des Vosges, France
16. Strandparken, Sweden
17. Puukuokka; Finland
18. Banyan Wharf, UK
21. Moholt 50/50, Norway
22. Santuary, UK

1. TREET, Norway
4. HoHo Tower, Austria
5. Silva, France
6. Mjøstårnet, Norway
7. Hyperion, France
8. Canopia, France
9. Haut, Netherlands
11. Frihamnen towers, Sweden
13. Sida Vid Sida, Sweden
14. HSB landmark, Sweden
15. Baobab, France
16. Life cycle tower, Austria

Oceania

6. Forté, Australia
24. 5 King, Australia

1.5.1 MID-RISE BUILDINGS

Mid rise structure are not new in the history of human buildings but the following chart displays the most representative examples of mid-rise buildings made with the modern technology of Mass Timber products.
Respect to high-rise buildings, nowadays more than 100 projects are realized with a number in storeys between 4 and 10. The race began immediately in Berlin in 2007 and the continuous perfection of techniques brought for new solutions. It is also important that not only a specific building typology was developed in these years, but nearly all of the buildings typologies have examples in mid-rise mass timber building.

Figure 24: E3, Berlin.

The distinction

While there are no universally accepted definitions for low-, mid- and high-rise buildings, the following division is commonly accepted:
Low-rise = 1-4 stories
Mid-rise = 4 -10 stories
High-rise = 10 stories and above
The actual division which exists between mid rise and high rise buildings is given mainly by the Buildings Code. In fact normally a building of maximum 10 storeys needs less fire regulation strategies compared with a much higher building. In addition usually the Buildings Code requires more building's characteristics because higher a building is, the higher the number of people live in it.

The direction

This first generation of buildings is continuously developing and every year wood providers, companies and building companies are proposing new systems respective the junction, products and prefabrication improvements.

Figure 25: Stadthaus, London.

Figure 26: Wood Innovation Centre, Vancouver.

Figure 27: Life Cycle Tower, Dorbirn, Austria.

Figure 28: Via Cenni, Milan.

Building data							Main professionals		
ICON NAME	YEAR	NUMBER WOOD STOREYS	CLEAR HEIGHT	TOTAL SURFACE	CITY COUNTRY	PROGRAM	ARCHITECT COUNTRY	ENGINEER COUNTRY	MAIN WOOD SUPPLIER COUNTRY
 E3	2007	7	25 m	2 700 m²	Berlin GER	Residential	Kaden-Klingbeil Architekten GER	Dl. Ing. Professor J.Netterer GER	-
 StadtHaus	2008	7	23 m	3 100 m²	London UK	Residential	Waugh Thistleton Architects UK	Techniker UK	KLH AT
 Bridport House	2010	8	26 m	5 500 m²	London UK	Residential	Karakusevic Carson Architects UK	Peter Bret Associates UK	Stora Enso AT
 Holz8	2011	8	25 m	6 000 m²	Bad Aibling GER	Office	Schankula Architekten GER	Bauart Konstruktion GER	Binderholz AT
 Life Cycle Tower One	2012	8	27 m	18 400 m²	Dornbirn AT	Office	Hermann Kaufmann Architekten AT	Merz Kley Partners + 2F GmbH AT	Wiehagat AT
 Forté	2012	10	32 m	2 500 m²	Melbourne AUS	Residential	Lend Lease UK	Lend Lease UK	KLH AT
 Panorama Giustinelli	2013	7	22 m	4 500 m²	Trieste ITA	Residential	Luciano Lazzari Architetto ITA	BDL Progetti ITA	Rubner ITA
 Maison de l'Inde	2013	7	23 m	14 500 m²	Paris FRA	Student Residence	Libsky Rollet Architects FRA	Rubner ITA	Rubner ITA

	Structural System			Beams		Column		Ceiling		Core		Lateral Force Systems			Fire systems			Facade				Sustainability		
	Panel System	Post & Beam	Hybrid	Glulam	Glulam + Steel	Glulam	Glulam + Steel	Mass Timber	Mass Timber + Concrete	Concrete	Mass Timber	Rigid Facade	Shear Walls	Concrete Podium	Exposed wood	Enveloped gypsum	Sprinkled	Wood facade	Non combustible material	Double Glass Layer	Balconies / Loggias	Energy	Tons CO2 Saved	Cycle and Prizes
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		●		●		●		●		●			●	●		●			●		●			

Source: Project Websites, Wood suppliers websites, bibliography, ProHolz Austria, specialized articles.

Building data							Main professionals		
ICON	YEAR	NUMBER WOOD STOREYS	CLEAR HEIGHT	TOTAL SURFACE	CITY	PROGRAM	ARCHITECT	ENGINEER	MAIN WOOD SUPPLIER
Wagramerstrasse	2013	7	22 m	8.440 m²	Vienna AT	Social Housing	Schluder Architektur, Hagmüller Architekten AT	Woschitz Group AT	Binderholz AT
Pentagon II	2013	8	24 m	4 000 m²	Oslo NO	Residential	BAS Arkitekter NO	Høyer Finseth NO	Moelven NOR
Cenni di Cambiamento	2013	9	27 m	30 000 m²	Milan ITA	Social Housing	Rossiprodi Associati ITA	Borlini& Zanini CH	Stora Enso FIN
Dalston Lane	2013	9	32 m	16 000 m²	London UK	Residential	Waugh Thistleton Architects UK	ARUP UK	Binderholz AT
Contralaminada	2014	6	20 m	900 m²	SPA	Residential	Ramon Llobera Arquitecte SPA	Ramon Llobera Arquitecte SPA	KLH AT
Wood Innovation Centre	2014	8	29 m	4820 m²	Vancouver CAN	Office	Micheal Green Architects CAN	Equilibrium CAN	Structurlam CAN
St. Dié-des-Vosges	2014	8	27 m	2 100 m²	St.Diè des Vosges FRA	Residential	ASP architecture FRA	Ingénierie Bois FRA	KLH AT
Strandparken	2014	7	22 m	4 060 m²	Stockholm SWE	Residential	Wingårdhs Arkitekter SWE	Martinsons SWE	Martinsons SWE

	Structural System			Beams		Column		Ceiling		Core		Lateral Force Systems			Fire systems			Facade				Sustainability		
	Panel System	Post & Beam	Hybrid	Glulam	Glulam + Steel	Glulam	Glulam + Steel	Mass Timber	Mass Timber + Concrete	Concrete	Mass Timber	Rigid Facade	Shear Walls	Concrete Podium	Exposed wood	Enveloped gypsum	Sprinkled	Wood facade	Non combustible material	Double Glass Layer	Balconies / Loggias	Energy	Tons CO2 Saved	Cycle and Prizes
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Source: Project Websites, Wood suppliers websites, bibliography, ProHolz Austria, specialized articles.

Building data							Main professionals		
ICON NAME	YEAR	NUMBER WOOD STOREYS	CLEAR HEIGHT	TOTAL SURFACE	CITY COUNTRY	PROGRAM	ARCHITECT COUNTRY	ENGINEER COUNTRY	MAIN WOOD SUPPLIER COUNTRY
 Puukuokka	2015	8	28 m	10 000 m²	Jyväskylä FIN	Residential	OOPEAA Office FIN	Stora Enso FIN	Stora Enso FIN
 Banyan Wharf	2015	10	33 m	6 750 m²	London UK	Residential	Hawkins\ Brown Architects UK	Pringuer James Consulting Engineers UK	B & K Structures UK
 T3	2016	7	31 m	21 000 m²	Minnesota USA	Office	Micheal Green Architects CAN	Magnusson Klemencic Associates USA	Structure Craft CAN
 Arbora	2016	8	27 m	55 000 m²	Montréal CAN	Office Residential	Lemay + CHA CAN	Nordic Structure CAN	Nordic Structure CAN
 Moholt 50/50	2016	9	31 m	21 800 m²	Trondheim NO	Student Housing	MDH Arkitekter NOR	Moelven NOR	Moelven NOR
 Sanctuary	Under Construction (2018)	7	30 m	4 200 m²	Glasgow UK	Residential	Mast Architects UK	CCG UK	CCG UK
 Carbon 12	Design Phase (2018)	8	25 m	3 200 m²	Portland USA	Residential	PATH Architecture USA	-	-
 5 King	Under Construction (2018)	10	52 m	14 900 m²	Brisbane AUS	Office	Bates Smart Architects AUS	Aurecon AUS	-

Structural System			Beams		Column		Ceiling		Core		Lateral Force Systems			Fire systems			Facade				Sustainability		
Panel System	Post & Beam	Hybrid	Glulam	Glulam + Steel	Glulam	Glulam + Steel	Mass Timber	Mass Timber + Concrete	Concrete	Mass Timber	Rigid Facade	Shear Walls	Concrete Podium	Exposed wood	Enveloped gypsum	Sprinkled	Wood facade	Non combustible material	Double Glass Layer	Balconies / Loggias	Energy	Tons CO2 Saved	Cycle and Prizes
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	●		●		●		●		●	●		●		●	●		●		●			2.800	6 Star Green Star Design

Source: Project Websites, Wood suppliers websites, bibliography, ProHolz Austria, specialized articles.

1.5.2 HIGH-RISE BUILDINGS

High-rise buildings in building construction is recent and at its initial stages. As we saw, there were several mid-rise buildings already realized in 2007 like the E3 building. But to find the tallest structure in Mass Timber up to 10 storeys we had to wait until 2014 when TREET in Norway reached, for the first time in modern wood construction, 53 meters.

The race

Since 2014 we can see how regularly towers rise and break previously held records. The chart reveals that post & beams structural systems is presently the main strategy for building high with wood structures. What is also emerging is the unclear and uncommon strategies used to solve the different problems that arise. It is clear we are still in a first generation of buildings which are rapidly rising in the Western part of the world, creating the necessary experience for the coming generations.

The role of local government

Most of the buildings in the chart are partially founded by government funding in order to help mainly architects and engineers to develop and face challenges that otherwise could be too risky in terms of economical investment or for testing. These countries active funds must be another incentive for those who do not recognize the importance of these necessary first buildings. We have also to remind people that all the realized buildings are an active source of information and knowledge for the community. This is because they are still tested and analysed by local universities in particular or by the same wood provider companies with the aim to understand fully the goal achieved and the possible future challenges.

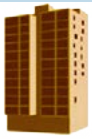
Figure 29: TREET, Bergen.

Figure 30: Framework, Portland.

Figure 31: Mjøstårnet in Norway.

Figure 32: Canopia, Bordeaux.

Figure 33: UBC Brock Commons under construction.

Building data							Main professionals		
ICON NAME	YEAR	NUMBER WOOD STOREYS	CLEAR HEIGHT	TOTAL SURFACE	CITY COUNTRY	PROGRAM	ARCHITECT COUNTRY	ENGINEER COUNTRY	MAIN WOOD SUPPLIER COUNTRY
 TREET	2014	14	52 m	7 000 m² 480 m²	Bergen NOR	Residential	Artec Architecture NOR	Sweco Norge NOR	Merk GER
 UBC Brock Commons	2017	18	53 m	15 000 m² 825 m²	Vancouver CAN	Students Housing	Acton Ostry Architects CAN + Hermann Kaufmann Architekten AT	FAST + EPP CAN	StructurLam CAN
 Origine Condos	2017	12	41 m	10 000 m² 880 m²	Quebec City CAN	Residential	Yvan Blouin Architecture CAN	WSP Canada + Génécor CAN	Nordic Structure CAN
 Hoho Vienna Tower	Under Construction (2018)	24	84 m	25 000 m² 1210 m² Tot / 480 m² main tower	Vienna AT	Mixed Use	Rudiger Leiner Architekten AT	Woschitz Group AT	-
 Mjøstårnet	Under Construction (2018)	18	81 m	15 000 m² 840 m²	Brumunddal NOR	Mixed Use	Voll Architects NOR	Moelven NOR	Moelven NOR
 Framework	Under Construction (2018)	12	44 m	8 400 m² 700 m²	Portland USA	Mixed Use	LEVER Architecture USA	Kpff + Arup (Fire) USA	Structure Craft CAN
 Silva	Design Phase (2019)	18	54 m	14 200 m² 800 m²	Bordeaux FRA	Residential	Studio Bellacour + Art & Build FRA	Elioth FRA	Lamecol FRA
 Haut	Design Phase (2019)	21	73 m	14 500 m² 600 m²	Amsterdam NL	Residential	Team V Architects NL	Arup NL	-

	Structural System			Beams		Column		Ceiling		Core		Lateral Force Systems			Fire systems			Facade				Sustainability		
	Panel System	Post & Beam	Hybrid	Glulam	Glulam + Steel	Glulam	Glulam + Steel	Mass Timber	Mass Timber + Concrete	Concrete	Mass Timber	Rigid Facade	Shear Walls	Concrete Podium	Exposed wood	Enveloped gypsum	Sprinkled	Wood facade	Non combustible material	Double Glass Layer	Balconies / Loggias	Energy	Tons CO2 Saved	Cycle and Prizes
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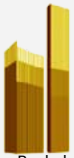
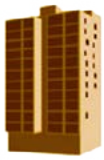
			●			●			●	●				●	●		●		●			Fan coil air system and radiant floors	-	-
		●		●		●		●			●	●			●	●	●		●		●	-	-	Norway class B
															columns, beams									
	●			●		●					●		●	●	●		●		●			-	-	LEED
															columns, beams									
		●		●		●		●		●		●		●		●			●			-	1 000	NF Habitat HQE
		●		●		●		●		●		●	●		●				●		●	Energy generating facade and waste water purification system	3 000	BREEM
															columns, beams									

Source: Project Websites, Wood suppliers websites, bibliography, ProHolz Austria, specialized articles.

Building data							Main professionals		
ICON NAME	YEAR	NUMBER WOOD STOREYS	CLEAR HEIGHT	TOTAL SURFACE	CITY COUNTRY	PROGRAM	ARCHITECT COUNTRY	ENGINEER COUNTRY	MAIN WOOD SUPPLIER COUNTRY
 Sida Vid Sida	Design Phase (2019)	19	76 m	12 000 m² 600 m²	Skelleftea SWE	Cultural Centre / Hotel (Tower)	White Architects SWE	Florian Kosche SWE	-
 Port Living	Design Phase (2019)	18	71 m	8 000 m² 290 m²	Vancouver CAN	Residential	Shigeru Ban JAP	Equilibrium + RJC CAN	-
 Frihamnen Towers	Design Phase (2019)	20	41 m	10 000 m² 470 m² x4 towers	Stockholm SWE	Mixed Use	Tham & Videgård Arkitekter SWE	Folkhem SWE	-
 Hypérion	Design Phase (2020)	18	57 m	7 000 m² 400 m²	Bordeaux FRA	Residential	Jean-Paul Viguier FRA	?	Woodeum FRA
 Canopia	Design Phase (2023)	19	54 m (64 m top)	5 700 m² 300 m²	Bordeaux FRA	Residential	Sou Fujimoto JAP + Laisné Rousell Architects FRA	Mathis FRA	Mathis FRA
 Life Cycle Tower One	Proposed (2011)	20	63 m	18 300 m² 900 m²	Prototype Dorbirn AT	Mixed Use	Hermann Kaufmann Architekten AT	Arup GER	Wiehagat AT
 HSB 2023	Proposed (2014)	34	100 m	15 000 m² 450 m²	Stockholm SWE	Residential	C.F. Moller Architects SWE	Tyrens SWE	-
 Baobab	Proposed (2015)	35	(120 m)	-	Paris FRA	Residential, Hotel	Micheal Green Architects CAN	DVVD FRA	REI Habitat FRA

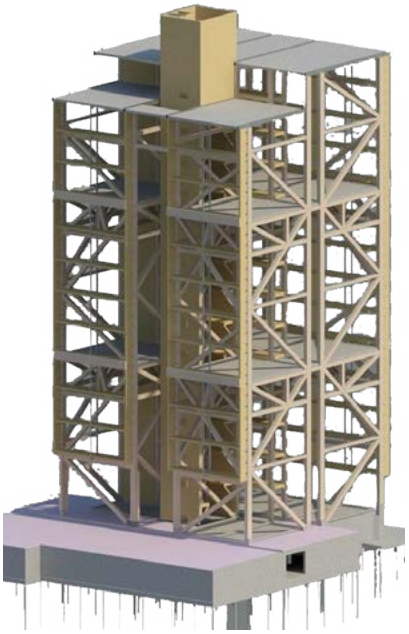
	Structural System			Beams		Column		Ceiling		Core		Lateral Force Systems			Fire systems			Facade				Sustainability		
	Panel System	Post & Beam	Hybrid	Glulam	Glulam + Steel	Glulam	Glulam + Steel	Mass Timber	Mass Timber + Concrete	Concrete	Mass Timber	Rigid Facade	Shear Walls	Concrete Podium	Exposed wood	Enveloped gypsum	Sprinkled	Wood facade	Non combustible material	Double Glass Layer	Balconies / Loggias	Energy	Tons CO2 Saved	Cycle and Prizes
		●		●		●		●		●			●	●	●		●			●		-	-	-
			●		●		●	●	●	●	●	●		●	●		●				●		-	-	LEED
		●		●		●		●		●			●	●		●	●	●					-	-	-
		●		●		●		●		●			●	●		●			●		●		-	1 000	-
		●		●		●		●			●	●		●	●					●		●		-	-	Biosource Certification
			●	●		●			●	●				●	●		●			●			Energy generating facade and floor system with tubes and cables	-	-
		●		●			●	●		●			●	●	●		●			●	●	Passive hause standard achieved	-	-
		●		●		●		●		●				●		●	●	●		●	●	-	3 700	REI habitat

Source: Project Websites, Wood suppliers websites, bibliography, ProHolz Austria, specialized articles.



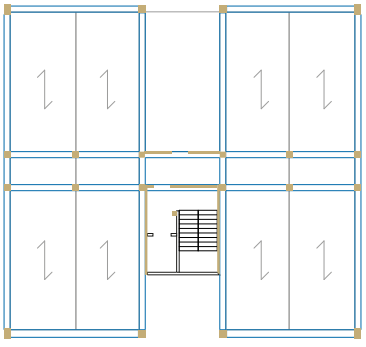
TREET

The building is formed by a net of diagonal, vertical and horizontal beams and columns structure standing above a concrete podium with a Mass Timber core.
The residential units are fully prefabricated and were mounted on site already finished.
The gravity loads system is composed of CLT floors which support the residential modules.
In two levels there are concrete floors that are necessary for the construction phase and help for the general stiffness of the building.
The lateral forces are taken mainly by the big diagonal beams which also the building visually. There is a Mass Timber Core the main stairs, elevator shaft and walls in corridors are made in CLT.
The main fire strategy is to provide encapsulation for the structural elements, but keep the vertical and diagonal columns exposed, which are inside the building. Regardless, all the constructive parts have a R90 Fire resistance, meanwhile the modules compose the flats are dimensioned to withstand fire for 74min.
All exposed timber elements are fire treated and there are no cavities with combustible materials left uninsulated The building is fully sprinkled, including the balconies.



STRUCTURAL DATA

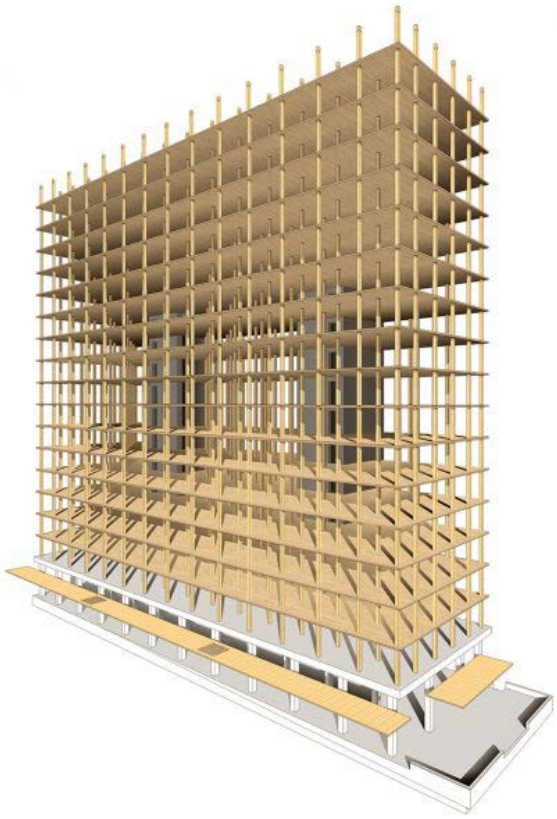
Year: 2014 (1st /13)
Height: 52,8 m (13th /15)
Floor surface: 480 m² (11th /15)



Storeys: 14
Floor to floor height: 2,9 m
Position of the core: Lateral/central
Floor Plans measure: ~ 25 x 25 m
Columns - Distance: ~ 8 x 8 m
Floor - Span: ~ 8 x 4 m
Structural System: Post & Beams
Beams: Glulam (40x40 cm)
Columns: Glulam (40x60 cm / 50x50 cm)
Floor: Mass Timber (only 3 storeys concrete)
Core: Mass Timber
Lateral Force Systems: Concrete podium and diagonal beams

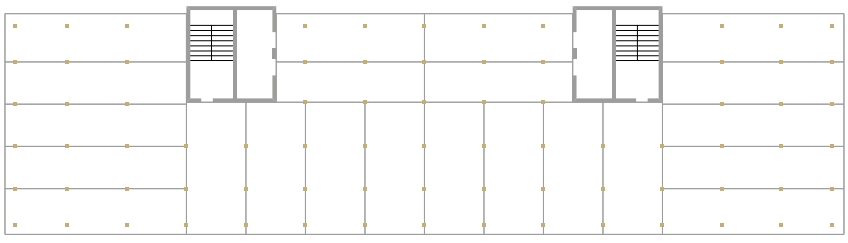
BROCK COMMONS

This tower is a hybrid structure consisting of 17 storeys of mass timber construction erected on a concrete podium.
The vertical loads are carried by the timber structure, and the two concrete cores provide lateral stability.
The gravity load system of levels 2 to 18 consists of glulam columns with steel connectors supported by 5-ply CLT panels on a regular grid, which acts as a two-way slab diaphragm: the CLT panels will be oriented on the long axis of the building and installed in a staggered configuration.
All structural elements are encapsulated with multiple layers of gypsum board, which encapsulates the mass wood structure for fire-rating purposes, but the wood is left exposed in an amenity space on the top floor. It has an automatic sprinkler system with back-up water supply, and the compartmentalized units have a 2-hour fire rating between suites, as opposed to the typical 1-hour rating.
The facade of the building is highly prefabricated; the size of the panel is 8 m long x the height of one floor, 2,8 m. The facade is composed by high-pressure laminate panels containing 70% wood based fibres, and pre-installed windows.



STRUCTURAL DATA

Year: 2017 (2nd /13)
Height: 53 m (12th /15)
Floor surface: 840 m² (5th /15)



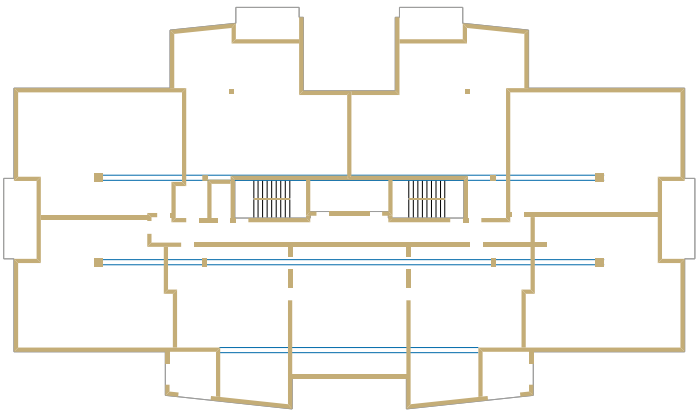
Storeys: 18
Floor to floor height: 2,8 m
Position of the core: Lateral/Double
Floor Plans measure: ~ 15 x 55 m
Columns - Distance: ~ 2,85 x 4 m
Floor - Span: ~ 2,6 x 9,6 m
Structural System: Post & Beams
Beams: Floors act like beams
Columns: Glulam (26x26 cm / 26x21 cm)
Floor: Mass Timber
Core: Concrete
Lateral Force Systems: Concrete podium and concrete cores

ORIGINE CONDOS

Origine Condos is a residential building with a combined structural system that behaves like a Panel system, up to 13 storeys.
The gravity load system is composed by CLT floors which are supported by some beams along the building. The building stands on the top the concrete podium where the forces are transmitted.
The lateral forces are taken mainly by Mass Timber core, the several shear walls and by the rigid facade. Also in this case the wood is fully encapsulated with several layers of gypsum boards.
A long time in the making, the project has drawn on input from federal and provincial officials as well as research institutes, and will help pave the way for the development of a North American market for solid wood building products made in Quebec.
The building was chosen in Mass Timber because of the lightness of the wood, the ground where the project was made is not so resistant and therefore concrete building could permit only half of the storeys.

STRUCTURAL DATA

Year: 2017 (3rd/ 13)
Height: 40,9 m (15th /15)
Floor surface: 880 m² (3rd /15)



Storeys: 13
Floor to floor height: 2,9m
Position of the core: Central
Floor Plans measure: ~ 25 x 45 m
Columns - Distance: -
Floor - Span: ~ 10 x 5 m
Structural System: Panel system
Beams: Glulam (40x40 cm / 28x28 cm)
Columns: Glulam (40x40 cm / 28x28 cm)
Floor: Mass Timber
Core: Mass Timber
Lateral Force Systems: Concrete podium, Mass Timber core, shear walls and rigid facade

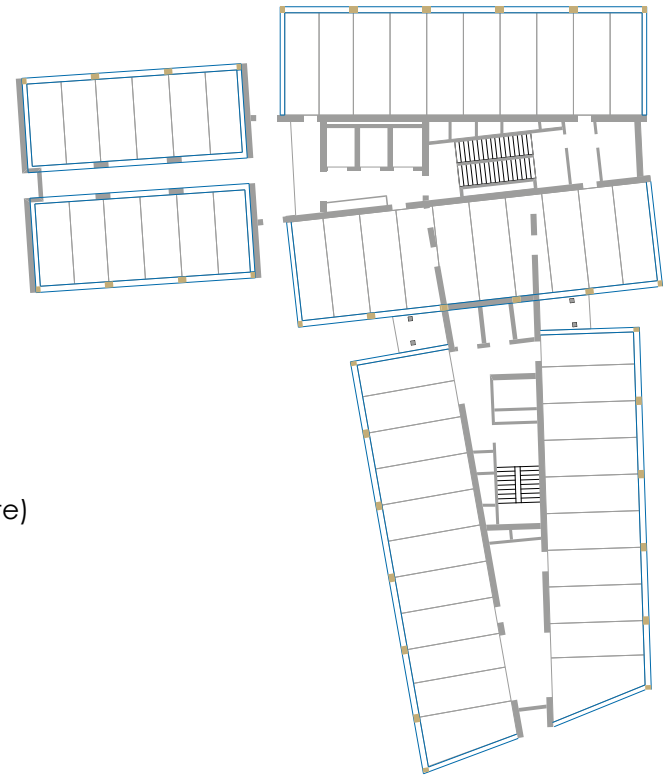
HOHO TOWER VIENNA

This building is composed of 3 parts with different heights and 2 reinforced concrete cores, each with integrated stairs, elevators and shafts.
The gravity loads system is composed by Precast Concrete Beams standing on Glulam columns and supporting a hybrid concrete floor with the necessary tubes and pipes already installed (12 cm) and CLT (16 cm floor) for a total of 28 cm of structural prefabricated floor.
All the lateral forces are taken by the 2 concrete cores.
All the wooden surfaces inside are visible: ceiling, supports and exterior walls.
The fire strategy is innovative for Austria, the hybrid concrete and CLT floors are approved for a charring method, therefore all the floor ceilings are exposed, but with a calculated 8 cm charring fire protection which ensure 90 min fire resistance.
To minimize the fire effects, the building has small fire compartments, with extremely short escape routes and fire brigade attack routes.
The exterior walls are solid pre-fabricated components with non combustible (A2) external cladding.

STRUCTURAL DATA

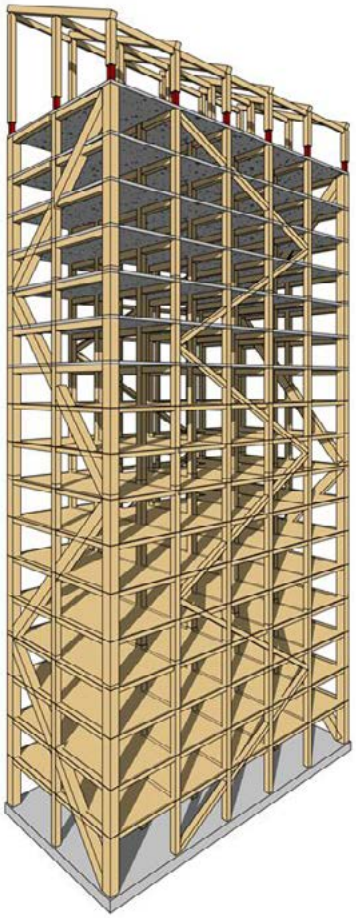
Year: 2014 (4th/ 13)
Height: 84 m (2nd /15)
Floor surface: 1270 m² (1st /15)

Storeys: 24
Floor to floor height: 3,5 m
Position of the core: Central
Floor Plans measure: ~ 55 x 40/20 m
Columns - Distance: ~ 2,3 x 6,5 m
Floor - Span: ~ 2,3 x 6,5 m
Structural System: Hybrid System
Beams: no beams
Columns: Glulam (40x30 cm / 40x55 cm)
Floor: Mass Timber (only 3 storeys concrete)
Core: Concrete
Lateral Force Systems: 3 Concrete cores



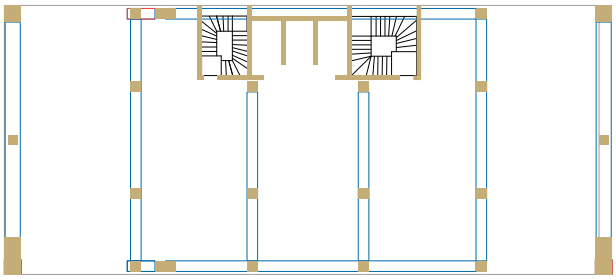
MJØSTÅRNET

The main structure will consist of glulam columns, beams, diagonal beams, and cross laminated timber in elevator shafts and stairwells.
The gravity load system is composed mainly of CLT floors, except for the last 7 floors, in order to increase the stiffness of the tower.
The Mass Timber structure starts already from the ground floor of the building and has only concrete foundations without an underground level.
The lateral loads system is a combination of a Mass Timber core on one side and several diagonal beams located on other 3 sides of the rectangular plan. These diagonal beams are behaving like TREET in Bergen (also in Norway) and are not exposed to the outside but are included inside the building, keeping them visible.
The fire strategy consist of full encapsulation of the building but not of the vertical elements such as columns and diagonal beams.
There will be an automatic sprinkler system.
The elevation of Mjøstårnet will be dressed in wood panels in a stylized and repeating pattern, inspired by the movement of water and the way light dances on the ripples of its surface.



STRUCTURAL DATA

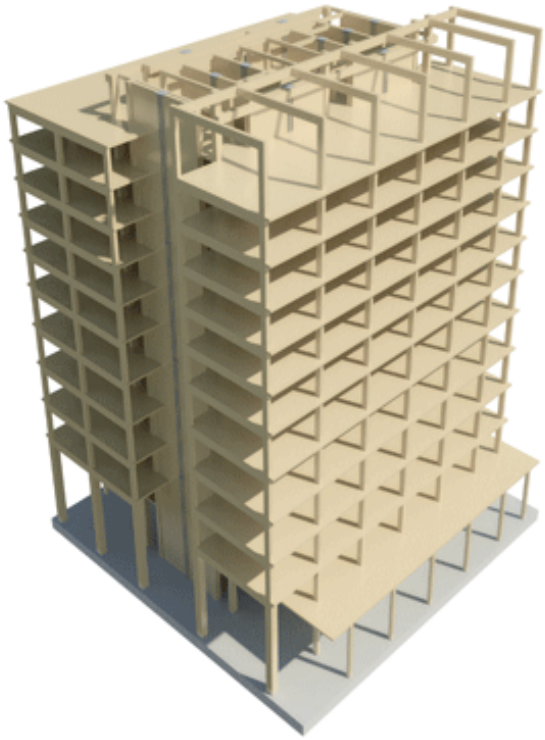
Year: Design Phase - 2018 (5th/13)
Height: 81 m (3rd /15)
Floor surface: 840 m² (4th /15)



Storeys: 18
Floor to floor height: 3,20 m
Position of the core: Lateral/central
Floor Plans measure: ~ 42 x 20 m
Columns - Distance: ~ 8 x 8 m (main ones)
Floor - Span: ~ 9 x 7 m
Structural System: Post & Beams
Beams: Glulam (70x50 cm)
Columns: Glulam (110x110 cm / 70x70 cm)
Floor: Mass Timber (last 7 storeys concrete)
Core: Mass Timber
Lateral Force Systems: Diagonal beams and Mass Timber Core

FRAMEWORK

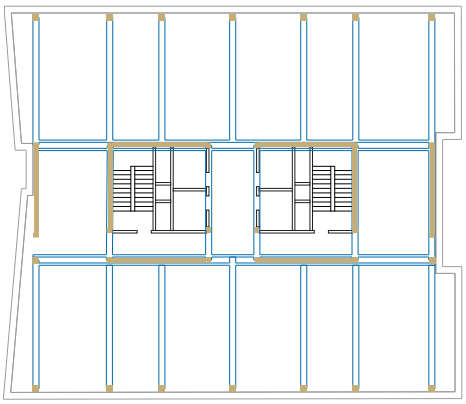
Framework will be the first Mass Timber high-rise building in the USA and will be completed in 2018. The structural system consists of a post and beams structure anchored to a Mass Timber core. The shape of the plan is nearly a square, and the maximal beam span is 7 meters.
The gravity load system is composed of CLT floors nailed to the beam which connect a column to the beam's core.
The lateral load system is mainly based on the big CLT core, which is composed by CLT panels, glulam columns, and 2 rows of beams (inside and outside the core) which are supporting the horizontal beams. Because of the seismic zone the building introduces a particular anti-seismic system invented in New Zeeland, a post tensioning CLT rocking walls system which will provide a fixed and set movement in case of an earthquake.
Most of the Mass Timber structure is exposed because of the charring strategy. The highest grade of exposition in the building is in the office storeys and the residential section where only the ceiling is exposed. The building will be fully sprinkled.



STRUCTURAL DATA

Year: Design Phase - 2018 (6th/13)
Height: 44 m (14th /15)
Floor surface: 700 m² (7th /15)

Storeys: 12
Floor to floor height: 2,9 m
Position of the core: Central
Floor Plans measure: ~ 30 x 26 m
Columns - Distance: ~ 8 x 3 m
Floor - Span: ~ 8 x 3 m
Structural System: Post & Beams
Beams: Glulam (40x30 cm)
Columns: Glulam (40x40)
Floor: Mass Timber
Core: Mass Timber (CLT+ Glulam Colums)
Lateral Force Systems: Mass Timber core

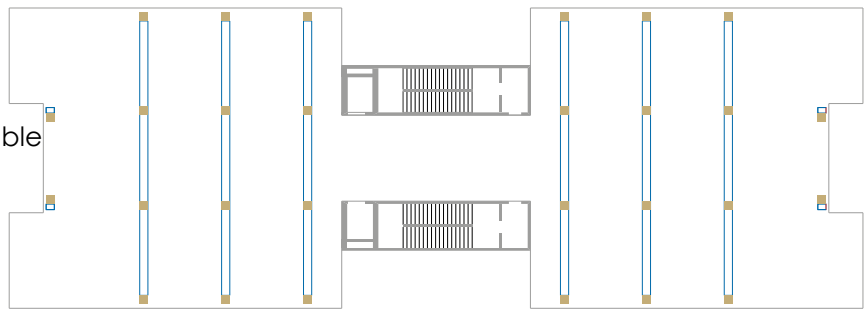


SILVA

Silva is a Mass Timber building based on a rectangular form with 2 concrete cores in the middle. The post and beams structure is developed in the East-West direction and has big 3-story high double diagonal beams on the end of the North-South side of the building.
The gravity load system is composed by CLT floors supported by horizontal beams which connect 4 in line columns.
The lateral loads are taken by the two concrete cores which are located in the centre of the building, and by the big diagonal beams at the both ends of the North and South sides.
The fire strategy consist of a full encapsulation of the building. The big diagonal beams which characterize the building are protected by a glass layer which forms the facade.

STRUCTURAL DATA

Year: Design Phase - 2019 (7th/13)
Height: 54 m (12th /15)
Floor surface: 800 m² (6th /15)



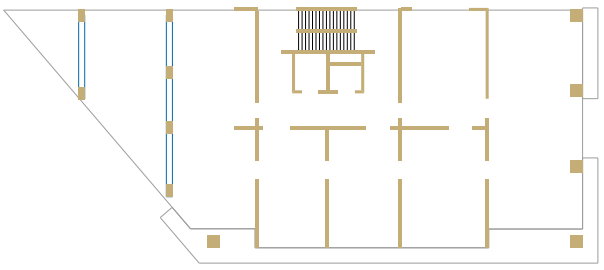
Storeys: 18
Floor to floor height: 2,7 m
Position of the core: Central / Double
Floor Plans measure: ~ 62 x 22 m
Columns - Distance: ~ 6 x 5 m
Floor - Span: *(no data found)*
Structural System: Post & Beams
Beams: Glulam (60x40 cm)
Columns: Glulam (60x60 cm)
Floor: Mass Timber
Core: Concrete
Lateral Force Systems: Concrete Cores and V shapes Facade beams

HAUT

The building is developed by ARUP Netherlands, which is a company already involved in the development of Tall wood buildings.
The structure in this case is based on the post & beams system, with long shear walls and a concrete core contrasting the lateral loads.
CLT is used especially for the floors system. Meanwhile, beams and columns are made in Glulam.
From the official website it is possible to understand that the fire strategy is based on partial encapsulation of the structural elements, it's columns and ceiling are also left exposed also because they are inside the building and protected by glass or walls.

STRUCTURAL DATA

Year: Design Phase - 2019 (8th/13)
Height: 73 m (5th /15)
Floor surface: 600 m^2 (9 /15)



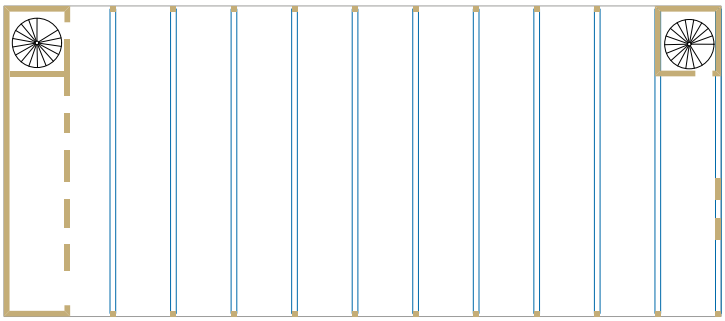
Storeys: 21
Floor to floor height: 3 m
Position of the core: Lateral/central
Floor Plans measure: ~ 40 x 26 m
Columns - Distance: ~ 5 x 4 m
Floor - Span: *(no data found)*
Structural System: Post & Beams
Beams: Glulam (40x40 cm)
Columns: Glulam (40x40 cm)
Floor: Mass Timber
Core: Concrete
Lateral Force Systems: Concrete core and Diagonal Beams

SIDA VID SIDA

The Mass Timber tower is part of a complex urban development in Sweden.
The tower will contain the hotel rooms for the cultural centre in Skellefteå which will include a museum and conference centre.
The project is now in its design phase after that White Architects won the international competition.
From the competition boards emerges a double core tower with the rooms disposed on the longer side of a rectangular shape.
From the official render is possible to see a glass envelop.

STRUCTURAL DATA

Year: Design Phase - 2019 (9th/13)
Height: 76 m (4yh /15)
Floor surface: 600 m² (8th /15)



Storeys: 19
Floor to floor height: 2,9 m
Position of the core: Lateral/central
Floor Plans measure: ~ 50 x 21 m
Columns - Distance: ~ 4,2 m
Floor - Span: *(no data found)*
Structural System: Post & Beams
Beams: *(no data found)*
Columns: Glulam (30x30 cm)
Floor: Mass Timber
Core: Mass Timber
Lateral Force Systems: Mass Timber Core

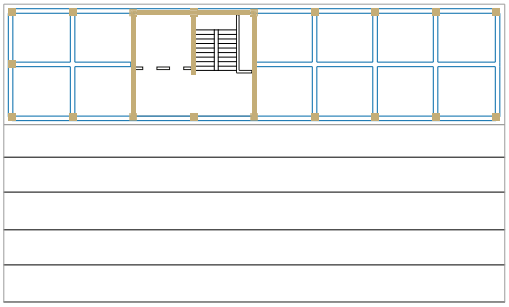
PORT LIVING

A slender 19-storey mixed-use building in downtown Vancouver's is the hybrid solution designed by Japanese architect Shigeru Ban and local firm Francl Architecture.
Totalling 54,503 square feet of floor area, the 223-foot-tall (68 metres) building will have 20 residential units, retail space on the ground floor, and three levels of underground parking accessible from the street. The first 12 floors of the building will be constructed using traditional concrete and steel methods with balconies and the concrete facade aligned with the levels of the adjacent Evergreen Building designed by the late Arthur Erickson. As for the top portion of the building, the remaining seven floors, a Mass Timber Structure design with a triangular shape has been proposed. While the exterior and floor plates will be constructed out of wood, these levels will still be supported by a concrete and steel core to meet local seismic building codes. There will be a clear distinction between the concrete base and the upper wooden floors. All wood used for the project will be exclusively sourced locally from the province.

STRUCTURAL DATA

Year: Design Phase - 2019 (10th/13)
Height: 71 m (6th /15)
Floor surface: 290 m² (15th /15)

Storeys: 18
Floor to floor height: 3,1 m
Position of the core: Central
Floor Plans measure: ~ 33 x 8 m (Wood tower)
Columns - Distance: ~ 8 x 4 m
Floor - Span: *(no data found)*
Structural System: Hybrid Post & Beams
Beams: Glulam (50x40 cm)
Columns: Glulam (50x50 cm)
Floor: Mass Timber (last 13 floors)
Core: Concrete / Mass Timber (last 13 floors)
Lateral Force Systems: Concrete/Mass Timber core



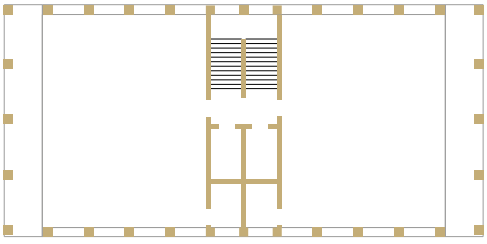
FRIHAMNEN TOWERS

The project proposes four Mass Timber towers above a continuous urban block structure.
The towers are based on the same structure but have different orientations in order to maximize the sunlight on the mainly residential rooms of each tower.
A particular condition of the project is the proximity to the sea.
The towers are planned entirely in one material, Swedish solid wood, from the load bearing structure to the facade, finishes and windows. Through consistent use of a renewable material like wood, the result is a sustainable, well insulated and robust house structure with good potential to perform well over time, and minimize the total energy consumption.
The roof of the lower base will be covered with plants that take care of storm water, while the roof of the four towers will be fitted with solar cells. At the top of each tower, there is a common winter garden for recreation and social activities.

STRUCTURAL DATA

Year: Design Phase - 2019 (11th/13)
Height: 63 m (8th /15)
Floor surface: 470 m² (10/15)

Storeys: 20
Floor to floor height: 2,9 m
Position of the core: Central
Floor Plans measure: ~ 31 x 15 m
Columns - Distance: ~ 2,2 m
Floor - Span: *(no data found)*
Structural System: Post & Beams
Beams: Glulam (60x60 cm)
Columns: Glulam (60x60 cm)
Floor: Mass Timber
Core: Mass Timber
Lateral Force Systems: Mass Timber core



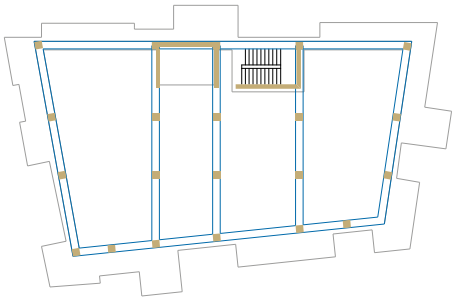
CANOPIA

Canopia is a project proposed for the great sustainable development of Bordeaux.
The building won an international competition and is designed by the Japanese architect Sou Fujimoto and another local office.
The proper tower is relatively small but it is a part of the project which ic composed by several parts.
For the competition was studied a mass timber frame supported by the wood company Mathis. The frame aims to solve the different technical construction problems.
The project uses silver fir and spruce beams and posts. Floors are made from cross-laminated timber, of either silver fir or spruce, using the Mathis ATEX technique for high-rise buildings. Glulam timber beams are used in the post-and-beam frame to stabilize the tower. Each building on the site aims for a "Biosourcé" certification.
In addition, an H&E A-rating is being sought for the homes, and the offices will have double HQE BREEAM certification to guarantee their environmental performance.

STRUCTURAL DATA

Year: Design Phase - 2023 (13th/13)
Height: 64 m (7th /15)
Floor surface: 300 m² (14th /15)

Storeys: 19
Floor to floor height: 2,9 m
Position of the core: Lateral/Central
Floor Plans measure: ~ 25 x 15 m
Columns - Distance: ~ 4 x 4 m
Floor - Span: *(no data found)*
Structural System: Post & Beams
Beams: Glulam (40x40 cm)
Columns: Glulam (40x40 cm)
Floor: Mass Timber
Core: Mass Timber
Lateral Force Systems: Mass Timber core and diagonal beams

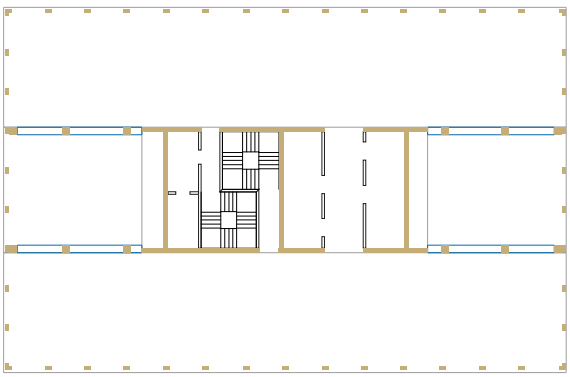


LIFE CYCLE TOWER

This is a pilot project aimed at the realization of an innovative construction system characterized by a high degree of industrial prefabrication capable of meeting the needs of the contemporary real estate market.
18 floors are made of wood and stand on 2-story basements of reinforced concrete. The massive central core contributes to the stabilization of the building and collects the horizontal stresses of the soles made of composite material, wood and concrete. They stand on uncoated laminated wood pillars, integrated in the facade elements to form a grid with a 2.70m module.
The columns are dimensioned for fire resistance. The vertical forces are directly transferred through the glulam columns to the reinforced concrete architrave of the soles and from there to the next pair of glulam columns. This prevents unwanted cross-over compression due to heavy duty loads. The elements of the plants and technical services (lighting, cooling, heating, automatic sprinkler fire extinguishers) were integrated between the visible ribs of the slab conceived in laminated wood beams.

STRUCTURAL DATA

Year: Proposed 2011
Height: 63 m (9th /15)
Floor surface: 760 m^2 (2nd /15)



Storeys: 20
Floor to floor height: 3 m
Position of the core: Central
Floor Plans measure: 38 x 20 m
Columns - Distance: 2,6 x 8 m
Floor - Span: 2,6 x 8 m
Structural System: Hybrid
Beams: Glulam (20x20 cm)
Columns: Double Glulam (20x20 cm)
Floor: Mass Timber + Concrete
Core: Concrete
Lateral Force Systems: Concrete Core

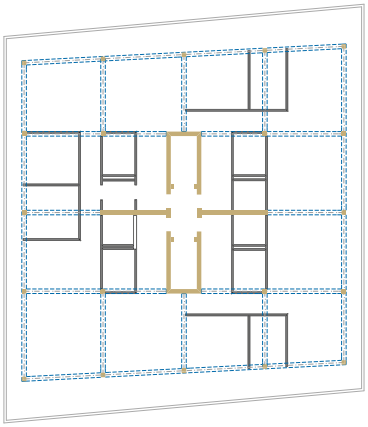
HSB 2023 - VÄSTERBROPLAN

The building is designed around a Mass Timber structure with stabilizing concrete core and was thought to act as a new characteristic landmark and meeting place in the city.
Columns and beams were designed as glulam and the walls as CLT.
Inside the apartments walls, ceilings and window frames will be made from wood, visible from the outside thanks the double-glass facade.
Both social and environmental sustainability have been considered, including the construction process and choice of materials, but also in terms of residents' lifestyle. Continuous surrounding double-shell in the form of a winter-garden zone surrounds the building, and adds extra living space to the homes. The winter gardens' exterior glazing shelters the exposed timber structure, and acts as an energy-efficient thermal climate buffer zone. At street level there was a café and a nursery and, in a new neighbourhood building, all residents in the area will be able to enjoy a marketplace, gym and bicycle storage location. A shared winter garden will make allotments possible.

STRUCTURAL DATA

Year: Proposed 2014
Height: 100 m (1st /15)
Floor surface: 450 m² (12th /15)

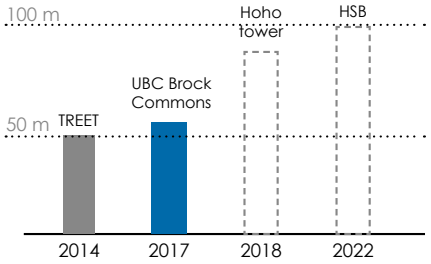
Storeys: 34
Floor to floor height: 2,75 m
Position of the core: Central
Floor Plans measure: ~ 21 x 21 m
Columns - Distance: ~ 5 x 5 m
Floor - Span: *(no data found)*
Structural System: Post & Beams
Beams: Glulam (50x30 cm)
Columns: Glulam + Steel (30x30 cm)
Floor: Mass Timber
Core: Concrete
Lateral Force Systems: Concrete Core



1.6 GENERAL CONSIDERATIONS

Building high-rise buildings is possible and there are several techniques to do it. We are only at the beginning of a particular structural and environmental approach in architecture but by 2023 at least 13 projects will be realized and they will help for next generations of projects.
Following, there are some considerations based mainly on the high-rise data. The goal is to understand in sections what are today's trend in Tall wood design.

Year



The chart reveals that the buildings continue to grow and reach new heights. Since 2015, when TREET building broke the limit of 10-story, there has been continuous production of high-rise buildings that annually break the previous years record for the tallest wooden building in the world. In 2017 UBC Brock Commons is the highest wood building but when Hoho tower in Vienna will be finished, it will be in Vienna the highest in the world and what seems possible is that situation will not last so long.

The plans

Another interesting characteristic that emerges from the chart is the clear division between two approaches: central and on one side core.
The core plays one of the most important roles in the lateral load dynamic and it's behaviour is one of the most detailed characteristic engineers need to consider. Besides UBC Brock Commons and Hoho tower, all the other buildings have a Mass Timber core. This is also an interesting characteristic because it shows that Mass Timber core could be used also as lateral load system (even if concrete is now preferable for Buildings Code and

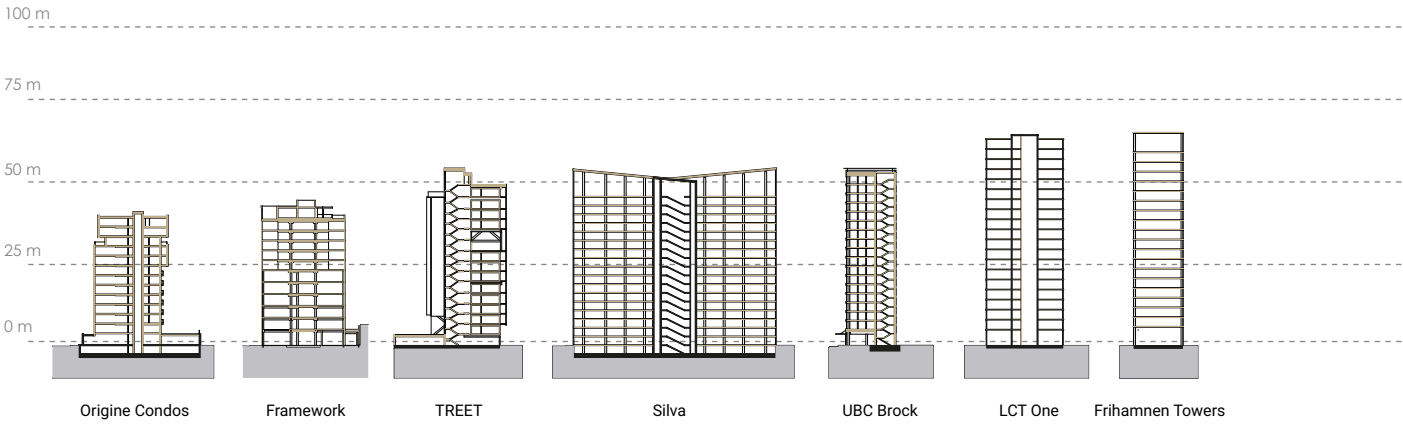
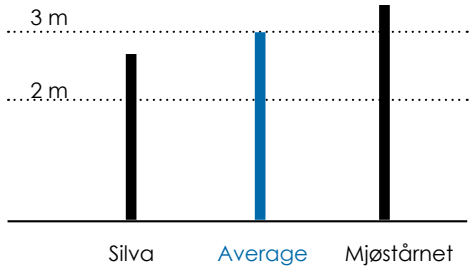


Figure 34: The main high-rise projects aligned from the smaller to the biggest.

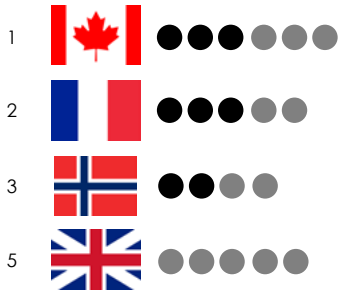
safety).
The size of the building is usually inside the 20x20/30m square. Only UBC Brock Commons and Silva are longer buildings with the special exception of the Hoho tower that is in reality composed of 3 buildings together with 2 concrete cores. The longest span is in the Framework building in Portland, with 8,5 meters.

Floor to floor height



High rise buildings are tall and particular but they can compete with concrete buildings also in terms of serviceability. For example the average floor to floor height is nearly 3 meters high. This means that depth of the ceiling, that has an average of 28 cm (structural), is like the normal concrete ones.

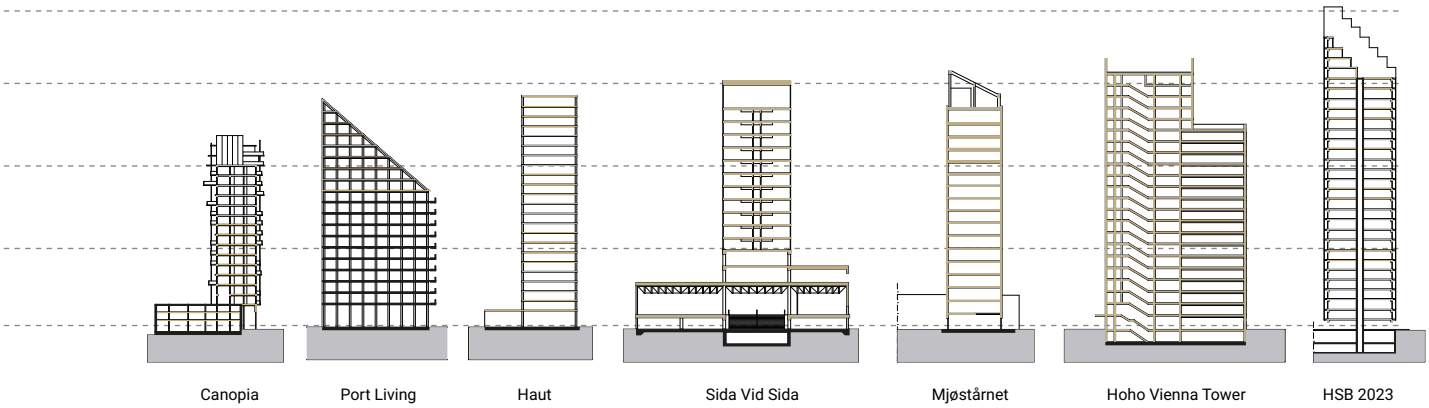
High rise location



Until now it seems that 4 countries will have a great number of high rise wood buildings. They are Canada, Norway, France and United Kingdom: if the first 2 are great wood producers, it can be interesting for France, because there they have launched a program to push the boundaries of sustainability, which naturally involves and affects the building sector.

Sustainability

Sustainability, decreased CO^2 emissions, and life cycle are the main reasons why high rise wood buildings should be designed. Therefore there is no sense to make this market operation without a guarantee that

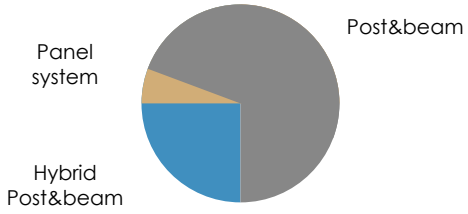


the building will be sustainable also after its realization. This is why all of these buildings are always certified with high scores.

Professionals

Michael Green architects, Hermann Kaufmann and Waugh&Thielston are the professionals with more Tall wood building realized. But from this chart, a clear leader does not emerge from among the professional groups involved in the creation of high-rise buildings. Interesting is that Austrian wood suppliers are the main ones.

Structural System



If the Panel system was the most common in the mid-rise buildings, in the high -rise the preferred system is Post&Beams (Hybrid or not). The limit for the Panel system seems reached by Origine Condos with its 10 Mass Timber floor. After this height it is normal consider the high-rise building with a Mass Timber or Hybrid Post&beam structure.

Beams

If there are Beams in the project most of the time they are made out of Mass Timber Products, especially glulam. Discovered in the first half of the 20th century, the glulam technology is now a great solution that performs really well in structural behaviour.

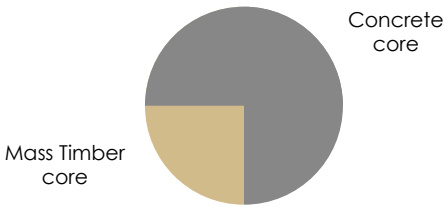
Columns

Also in this case the most common column used by these high-rise projects, is glulam column. Exist different types, one with a steel component inside the column, or composed of 2 glulam columns together, but the main material is always the same.

Floor

Also in this case the floors are mainly composed of Mass Timber products, but there are differentiations. Some projects use CLT floors, others use concrete, others use Hybrid solutions (concrete + CLT) others use concrete + glulam beams and still others has in the same projects different types of floors (concrete and CLT).

Foundations and Core



All the projects have a concrete foundations and most of them have a concrete podium (usually as part of the underground and ground floor) in order to avoid moisture problems in that specific part of the project.

Also the concrete core is preferred to the Mass Timber one.
Usually the core is liked with fire regulations or strong laws which forced the buildings to be created with concrete cores, but there are several (6 projects) which are realized with Mass Timber core, showing that they are able to guarantee safety and fire resistance standards.

Other Lateral Force resisting systems

Wind is the main problem high-rise buildings face and therefore the designer must consider a way to contrast these forces.
A simple and effective way is a rigid core which can take all the forces and transfer them down to the foundations. For small footprint towers and smaller towers, this technique is usually enough but if the building is big, than tall shear walls, a rigid facade, or diagonal beams must be added to create the right stiffness.
This the case of most of the Tall buildings analysed where besides the core there are shear walls perpendicular the core, a rigid facade or some diagonal beams (Or V beams like in the case of Silva), which add stiffness.

Fire strategies

As we saw before, the fire strategy of a high-rise building will consist of total protection, partial protection or structural exposure of the wood in the project .
Most of the buildings analysed protect totally the structure but there are some exceptions. Some buildings leave exposed the columns and beams which are usually inside the building. We are talking about structural elements of 50 or 70 cm thickness so their presence in the flat are therefore significant.
In Hoho, the ceiling is also exposed thanks to the approval of the charring strategy for the floor part by the Austrian government. If it is not so unusual to use the charring strategy with small wooden houses, than HoHo could provide an interesting reference point for future projects upon its completion. All of the building has a fire alarm system and most of them have a sprinkler system.

Facade

The external cladding of a building is important, especially for fire protections. Nearly all of the high-rise buildings have a non-combustible cladding facade. Many of them have also balconies and loggias.

Conclusions

This overview of the actual Tall wood situation can shows us different characteristics and different approaches that differing years and differing countries had regarding the realization and the conception of a Tall wood building.
What it is clear is that the more time passes, the higher the buildings become.
In the last 10 years (completion of E3 in Berlin, 2007), the tallest Mass Timber structure in the world passed from 25m to 53m (UBC Brocke Commons in Vancouver)which is until now (2017) the tallest structure.
Moreover, other wood Mass Timber buildings are just now under construction and promise to reach even higher heights in less than 3 years. The Mjøstårnet tower of Voll Architects will be 84 meters high.
Another interesting data point that emerges from this chart is the fact that most of the CLT of the Tall timber buildings in the world in made from wood of the Austrian forests. In fact if we see in the “wood origin” column

we can see that also in case of Forté in Melbourne and UBC Brocke Commons in Vancouver, the CLT panels where made out of Austrian wood. Even though the CLT was technologically born in Austria, it is interesting how Austrian companies (first of all KLH, BinderHolz) are keeping the level of their products in the top choices of designers from all over the world.

Considerations about the gravity and lateral loads strategies

What seems clear from the chart is the fact that it is possible reach at least 10 storeys with CLT panels and CLT core. Projects like Via Cenni and Origine Condos have shown not only the feasibility of this approach but also the economical aspect (Via Cenni is a Social Housing project).

A different approach is made for structures of more that 10-13 storeys. Here the characteristics of the taller buildings are always changing and there is not a similar structural approach. What it is generally chosen is the inner core made out of concrete. As we read in some interviews made by investors or designers, this seems to be the most diplomatic choice regarding fire safety, despite knowing that wood is able to resist fire well. What seems to happened is that this first generation of tall wood building will be more like hybrid buildings, with some parts in wood but with trusses in steel, wood-concrete hybrid slabs and concrete cores.

Considerations about constructibility

Another aspect which emerges from this first part is the synonymous: "wood = prefabrication". Several realized examples pushed the boundaries of prefabrication systems like Life Cycle Tower and show to architects and engineers how quick, sustainable, and renewable designing could be with wood. What is also emerging is the importance of details and pre-designing. Concrete structures allow some different measures in some building parts but wood buildings do not permit even a centimetres

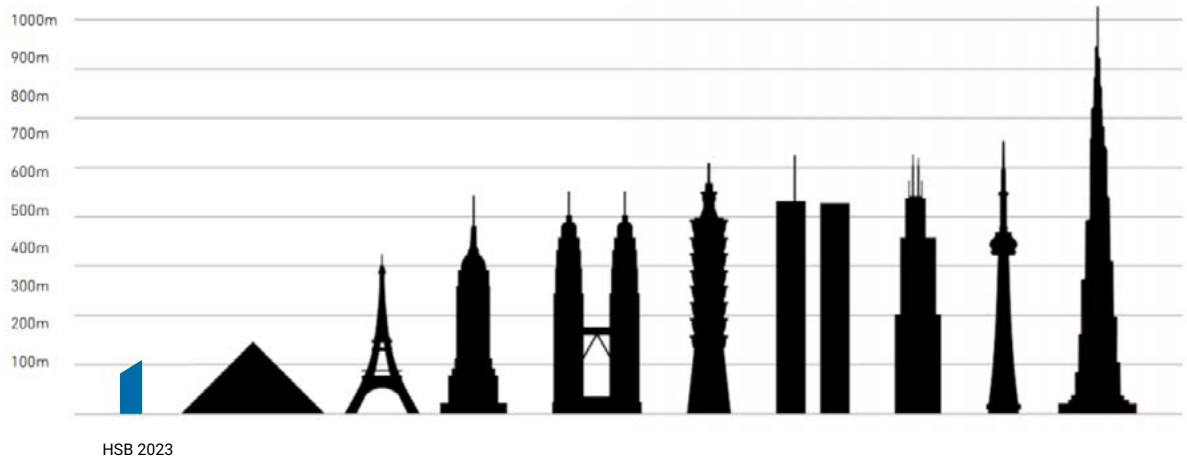


Figure 35: The highest Tall wood tower analysed compared with the other high building of the world.

mistake. In order to fully take advantage of one of timber's construction advantages, every single prefabricated pieces has to came in the building site perfectly arranged and correct. This grade of precision and detailing could be a problem for unprepared offices but could be also a great advantage for experienced ones, allowing them to achieve the best grade of prefabrication and speed in construction and safety.

Considerations about the future of the tall wood buildings

The possibilities offered in today environment still favour concrete and steel in terms of building height and economic value. We are talking about two different situations, concrete and steel as building materials were "born" during the end of the 19th century. Wood as Mass Timber Technology is instead relatively new but as we saw form the chart there are signals that this technology could reach not only higher heights but also achieve more standard applications and solutions.

Anyway, because of the variety and versatility of hybrid wood and steel or wood and concrete systems, it is more likely that these will constitute the majority of the structures to being built in the future.

This must not seem a defeat of wood as a building material, but must be seen as an opportunity to develop more and more sustainable solutions while merging the best characteristics of every single building material. Starting with the cost competitive component and structural easiness.

Vittorio Salvadori

The Development of a Tall Wood building

PART 2

THE COMPETITION REFERENCE

Wien-Heiligendstadt Competition

Master Thesis ITI

2.1 OVERVIEW OF THE COMPETITION

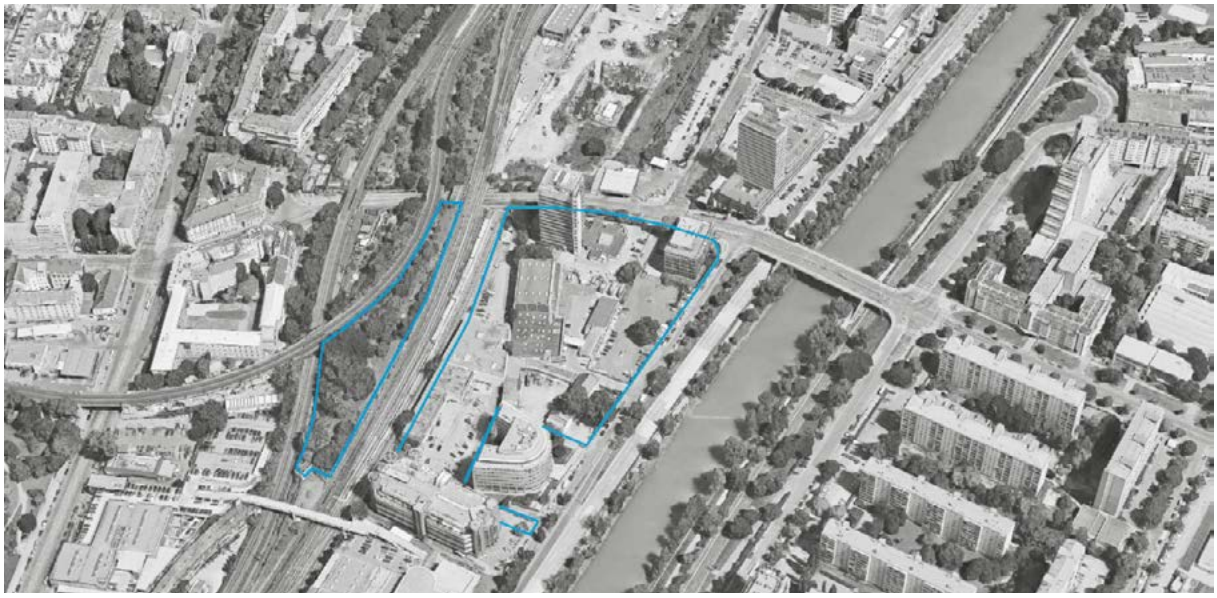


Figure 36: The competition area.

The competition "*Wohnen und Arbeiten in Wien Heiligenstadt*" is an international competition that took place in the quarters Wien-Heiligendstadt from August 2016 and June 2017.

Location

The exact location of the Competition area is Muthgasse Süd, Heiligendstadt, 1190 Wien. The site is located in the North part of Vienna, near the metro station Heiligendstadt and the residential complex Karl-Marks Hof, one of the most famous building of Vienna.

Urban Context

The Competition area is characterized by the presence of the Danube-channel, a small channel which has cycle paths and sidewalks along its channel banks.
Other relevant landmarks are the high-rise head-quarter building of one of the newspapers of Vienna and the Otto Wagner viaduct, a 20th elevated metro path.

The competition plot is divided by the metro railways that leads to the metro stop Heiligendstadt and also by an office building with a particular "C" shape. The area will be part of a future strategic urban development.

The Investors

The projects are funded by a group of private investors each owning a different part of the complete plot.

The investors list:

Liegeschaften-Eigentümergemeinschaft (BWS-Goup)
Fritz Quester Liegenschaftsverwaltung GmbH
Ing. Wolfgang Kaim
Song+Kong Immoblien GmbH
Sparkassen Versicherung AG.

The Jury

The Judges evaluated both the first and second phase projects. The board is composed by a group of international professors and architects along with a group of representative people of the city.

Figure 37: The competition area. Is located in the north of the city centre of Vienna.

Main jury members:

Fritz Schumacher, Architekt, Basel
Ute Schneider, Architektin, Zürich (KCAP)
Marina Stankovic, Architektin, Berlin
Robert Kniefacz, MA19, Wien
Gregor Puscher, MA21, Wien
Isolde Rajek, Landschaftsarchitektin, Wien
Peter Lorenz, Architekt, Wien
Irene Ludstöm, MA19, Wien
Eckart Herrmann, MA21, Wien
Carla Lo, Landschaftsarchitektin, Wien

Architectural Offices of the first and the second phase:

Regarding the offices admitted on the competition there was a remarkable international presence

The competing offices 1st and 2nd phase:

Eller + Eller Architekten, Düsseldort
HNP Architects, Wien
Kleboth Lindinger Dollnig ZT GmbH, Linz
Sauerbruch Hutton, Berlin
Zechner Zechner ZT GmbH, Wien
AllesWirdGut with Erich Raith, Atelier an der Wien
Behnisch Architekten, Stuttgart
COBE, Berlin
Hohensinn Architektur, Graz
Mecanoo, Delft
Morger Partner, Basel
Schneider Schuhmacher, Frankfurt with Dierich+Untertrifaller, Bregenz

The Program (First phase)

The program consists of the realization of a urban masterplan, landscape program, floor plans of high rise buildings and division of the programme of a 111.000 m^2 mixed use typology with a great number of residential and office square meters.

Several programs are mandatory to be placed on the ground floor or underground, meanwhile the placement of the different type of flats (time shared, for students, big flats and small ones), the hotel facilities, the offices spaces and others like gastronomies, will be placed where there is free space in the upper floor.

Material requested for the 1 Phase project

1)Masterplan 1:1000 about the general idea regarding the urban development and the landscape project
2) Supervision of buildings with storey numbers and building heights
3) Plans with trees, traffic, access
4) Interior layout of the buildings
5) Entrances and exits underground car park
6) Usage concept Schematic representation of the distribution of use
7)Axonometric representations and explanations
8) Renderings
9) Statements about materials and colours
10) Proof of 2 hour shadow
11) Schematic floor 1: 500 pedestal floor with access, free spaces, uses
12) Underground floor plan
13) Views + Sections 1: 500 Design and layout of the new building complex
14) Flexibility of the typology of apartments
15) Model 1: 1000 on insert plate
16) Text explanatory report
17) Statements on planning urban development, architecture, wind comfort,
18) Noise protection, internal traffic

Figure 38: The 70 meters tower near the competition area.

Figure 39: The underpass near the competition area.

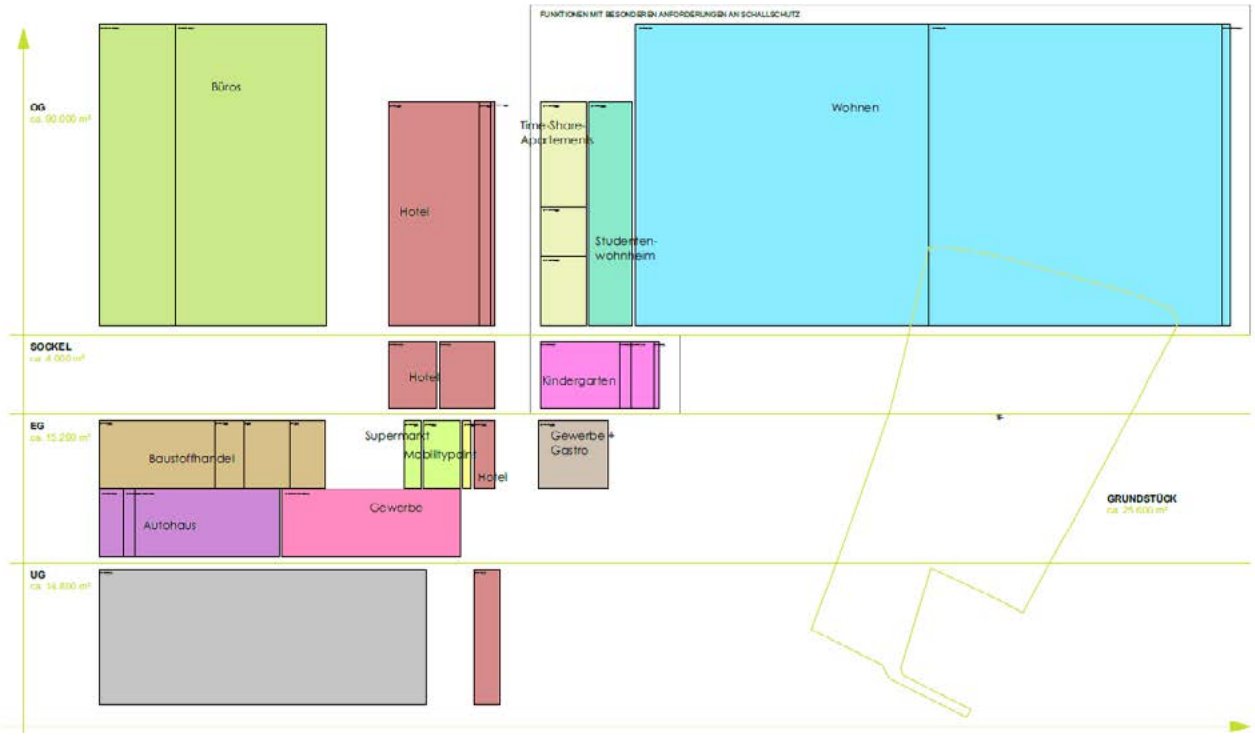


Figure 40: Scheme of the program requested per floor.

2.2 PHASE 1 RESULTS AND PHASE 2 DATA

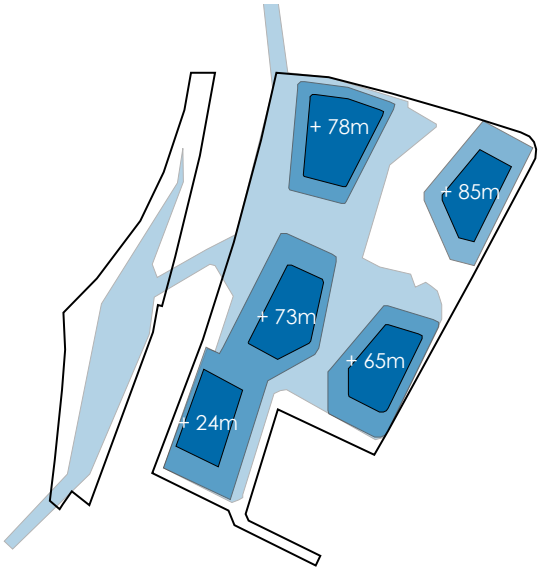


Figure 45: The winning masterpla with the height limits for each tower.

The competition was divided in 2 phases. The Phase 1 required a Masterplan which would have been the starting point for the Phase 2, which consisted in the design of the specific towers.
For the winning Masterplan it is important the topic of the Ground-floor which is a complete built floor with 2 main stairs.
The towers are punctual, without any inner courtyard.
Regarding the programmatic organizationin the masterplan, there functions are strongly divided and therefore there is a complete tower only for offices.

Program Issues

The new urban development has the public program in the ground floor and in the first floor, the offices are requested to design them only in the first floor meanwhile the ones in the ground-floor will be designed by the winning first phase team.

Division of the Plot to the winning teams

The plot is divided in 4 parts each submitted to 3 different offices: Plot 1 (Office tower/s), Plot 2 (Mainly Hotel tower), Plot 3, divided in north and south (Residential tower) and Plot 4 (Residential tower).
The thesis project is based on a project for the Plot 3.

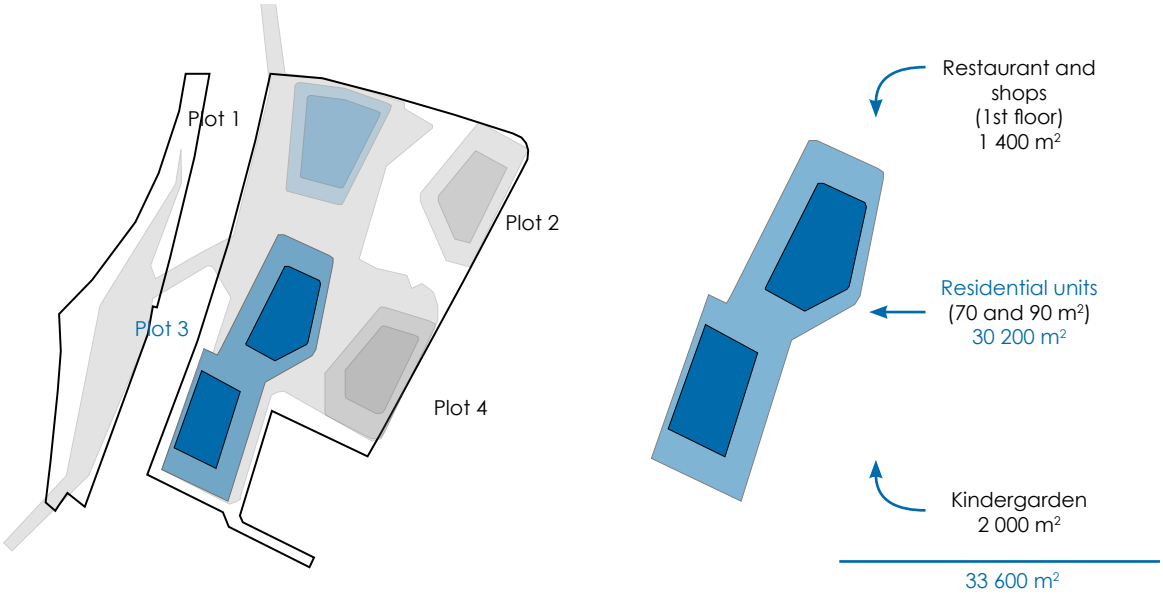


Figure 46: General tasks given by the Phase 2 Masterplan.

Plot 3 characteristics

Heights

Both the Plots have a maximal height to relate with: Plot 1: 78 meters, Plot 3: 73 meters.

Noise Considerations

Because of the Metro railway nearby, constructional noise protection will be managed by location, shielding, loggias and location of uses.

Wind comfort

Each studio received a detailed previous study regarding the wind behaviour in the competition area. The result shows the strongest wind is coming from North-East in direction South. These will induce to find particular strategies to protect the entrances to the towers and to the Restaurant/Bar level.

Constructable limits

The winning Masterplan given some building limit to respect and the ideal position where the core of the future towers will be.
Regarding in particular the Plot 3, there were no obligations to have a separated building in the division north and south of the plot, but it was mandatory in respect to the height of 22 meters in the southern part.

Vittorio Salvadori

The Development of a Tall Wood building

PART 3

THE ALTERNATIVE TALL WOOD BUILDING

Re-thinking the concrete structure in Mass timber

Master Thesis

3.1 PROJECT GOALS

The aim of the Design part is to design with a Mass Timber structure the Plot 3 competition tower made by Alles Wird Gut Architekten.
For a practical motif, the studio of the structure will be made only on the north part of the Plot 3 project, where the 73 meter concrete tower is located.
There are 2 types of goals: the general and specific. The general goals are the goals which every high-rise project has; specific goals refer to the main design ideas of the Plot 3 Project which we want to keep.

General Goals

The following characteristics makes the design of a high-rise building successful:

Marketable

The project must be flexible in the plan and must be open for other layouts of the plan configurations.
The depth of the flats, the ratio of the corridor surface in respect to the total surface per floor and the number of flats per floor are important elements which must be considered.

Serviceable

Facilities, spaces and common spaces, paths and quality of detail (acoustic, fire resistance, etc.) create the serviceability of the building.
Also in this point of view the project must be addressed.

Economical

Every investor wants an economical building. Thinking about an economical Tall Wood Building is already difficult. There are several elements of the structure which could be

PROJECT GOALS

Marketable	The volumetric division
	The position of the core
Serviceable	The heights of the building
	The general architectural layout
Economical	The same Total Surface
	The Podium in concrete
Sustainable	The terraces
	The green areas
	Develop the installation system

helpful to push down the overall cost of the building, if fully developed,
The floor system (which usually is 70% of the structural material) and the core are possible examples of cheap solutions.

Sustainable

Building with wood must be sustainable and if it could be possible to save CO^2 emissions with in the structure, the rest of the architectural choices could also lead to sustainable solutions.

Specific Goals

In direct reference to the Plot 3 project, there were some issues and building characteristic which were considered important to keep:

The volumetric division

The project is divided in 3 parts: the bottom part has a bigger volume and has a symmetrical plan, the middle part has one floor with offset and straight walls in respect to the other part of the building and the third part, the tallest, is composed by the tower;

The position of the core

The position of the core could be a problem for the lateral load system of a tall wood tower. Keeping the core as it is will ensure the similarity of the design project;

The heights of the building

The Competition project reaches 73 meters. The floor to floor height is 2,88 meters with a first floor of 4, meters and 20 other storeys.

The general architectural layout

The building is formed by middle sized flats (from 70 to 95 m^2). Obviously some layout changes (switching form a concrete walls structure to a post and beams ones) will be necessary.
The overall goal will be keeping the possibility of having a flexible plan for the middle sized flats.

The same Total Surface

The Total Surface is around 33 700 m^2. The aim is to keep the same amount of m^2 without any big offset or movement of the plans.

The Podium in concrete

Because it was also in the 2nd phase task to not touch the Podium (Underground+Ground floor), the aim is to consider it as a concrete platform as it will be. This part will be not consider in the specific design and it will not appear in the main drawings.

The terraces

What characterize the elevation of the Competition building are the continuous terraces.
There are two types of them:
- Loggias: 1,80 m depth
- Balconies: 0,80 m depth.

The terraces are thought as prefabricated elements which are in a second moment attached to the concrete structure of the building.

The green areas

There are 3 different green areas which characterize the Competition project: above the first floor platform, at the 8th floor and on the top floor of the tower.

Develop the installation system

The competition didn't required a detailed studio regarding the installations (cooling, heating and water systems) but only a short description in the competition official text.

3.2 THE PLOT 3 PROJECT STRUCTURE

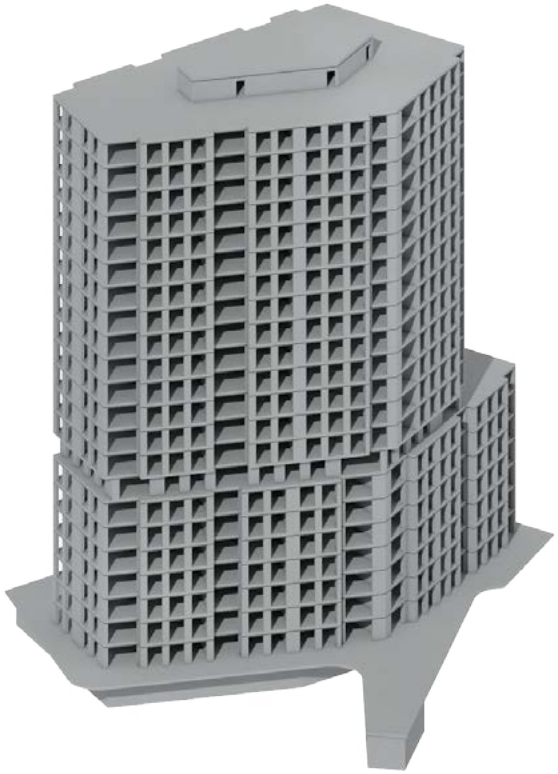


Figure 56: Perspective view of Plot 3 Project concrete structure

Foundations

The foundation is made by means of a floor slab adapted to the ground conditions, below the high-rise building.

The energy design provides for the formation of the piles as energy piles, which is similar to a concrete core activation where concrete is stored or withdrawn via liquid pipes according to the season and demand. The surrounding soil with ground water is a storage volume which is excellent and very useful for energy purposes. The thickness of the floor slab is around 1.6 meters in the high-rise area and can be used as a storage-buffer mass for geothermal entries.

Structure

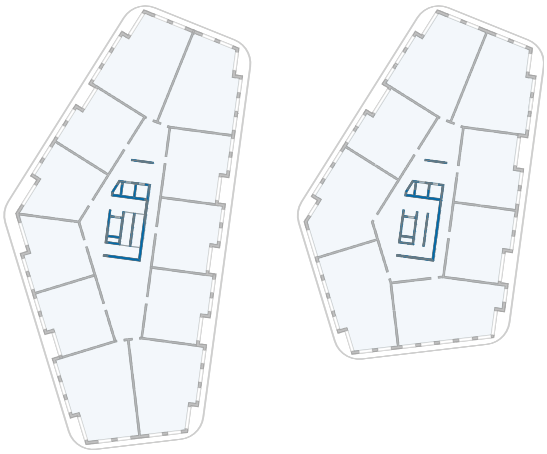
The structure consists of a reinforced concrete structure with a bracing core, walls, flat ceilings without linings and support. The loads run perpendicular to the foundation without any displacement. The only supporting elements are the outer walls, the partition walls and the reinforcing walls of around the core.

Residential walls are planned as lightweight construction walls, which means that the residential building in the planning phase and in the long term is very flexible.

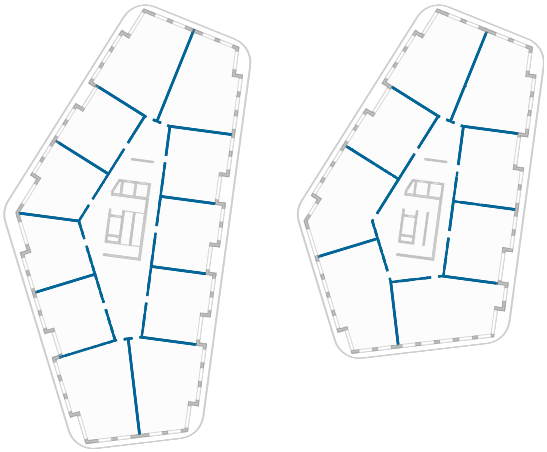
Reinforcement and cores

The core of the tower is formed by an inner part in the area of stairs and lifts along with an outer shell. The outer shell is comprised of a circulating wall in the development. In the upper half of the project, the outer core shell

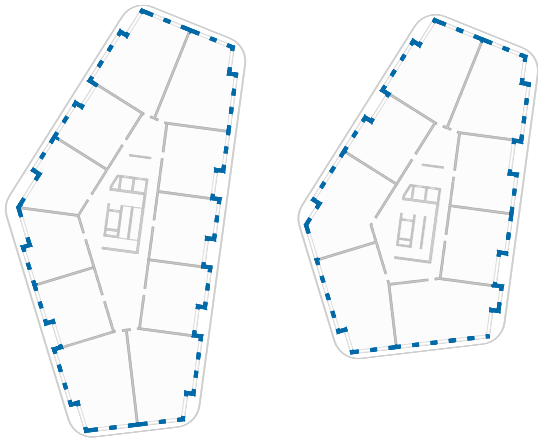
CORE AND FLOORS



SHEAR WALLS



FACADE



is no longer required for stiffening.

Floors

The floor construction is planned as a steel concrete flat roof. The ceilings are characterized by low support widths and throughout with an economically feasible strength of 20 cm. Due to the high number of repetitions of ceilings and walls, the use of large area form-work paving is possible in order to optimize the work-flow, meanwhile making the most of the available abilities. In the floors below the rising tower, the use of semi-finished parts is a possible alternative.

Facade

The facade is composed of reinforced concrete walls with ETICS dark grey plastered, and a mineral wool system.
The appearance is characterized by balcony bands (white cement concrete parts and broken white powder coated perforated sheet metal) with differentiated railings and greening as an ecological and climatic effect design element.
Up to the height of the accustomed urban eaves the buildings are strongly horizontally structured, the parapets are more massive and dense with white cement concrete parts and broken white powder-coated perforated plate inserts in the lower region.
The apartment divisions on the balcony are designed as high-rise planting trays, evergreen climbing plants ensure the separation and cover the undersides of the balcony bands.
In the upper part of the high-rise building, the design of the anti-fall device is flat and light. The material is white powder coated perforated plate and glass inserts in the lower area).

Structure of roof / Roof

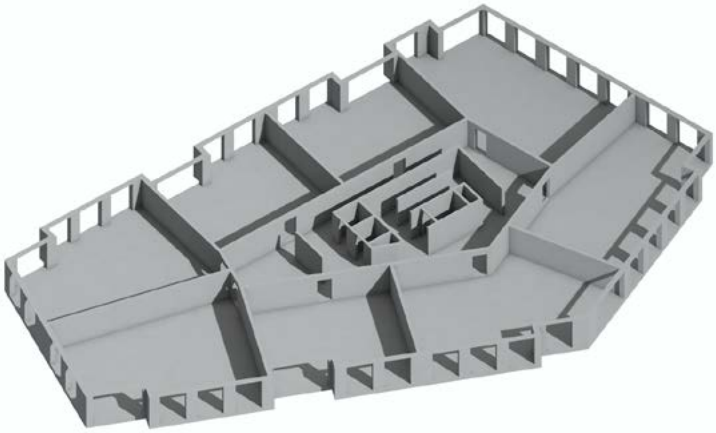
The final floor is planned as a steel concrete flat roof. The roof construction is suitable for use and greening. The warm roof will be comprised of EPS plus bituminous where necessary. It will be roughness-proof, waterproof and have internal drainage in the area of individual housing shafts.

Windows

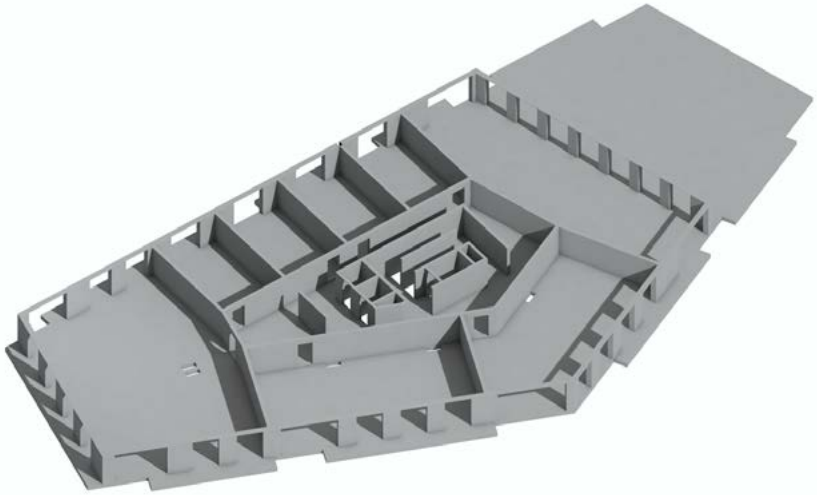
Windows will be made of wood-aluminum with triple-glazed heat-proof glazing, cover plates and powder-coated anthracite. Ground floor facades, portals mullion and transom construction, massive panes of ventilated construction pre-bearing STB-panels or insulated metal panels integrated in PR construction.
Sun protection will be solved by projecting balconies and loggias (reinforced concrete parts, thermally separated). Where necessary, inside are provided high-reflective screen roller. Is also considered the possibility to have a preparation for installation of external screens (in the high-rise wind-proof Zip-System) in upper floor extensions of the windows.

Surface finishes

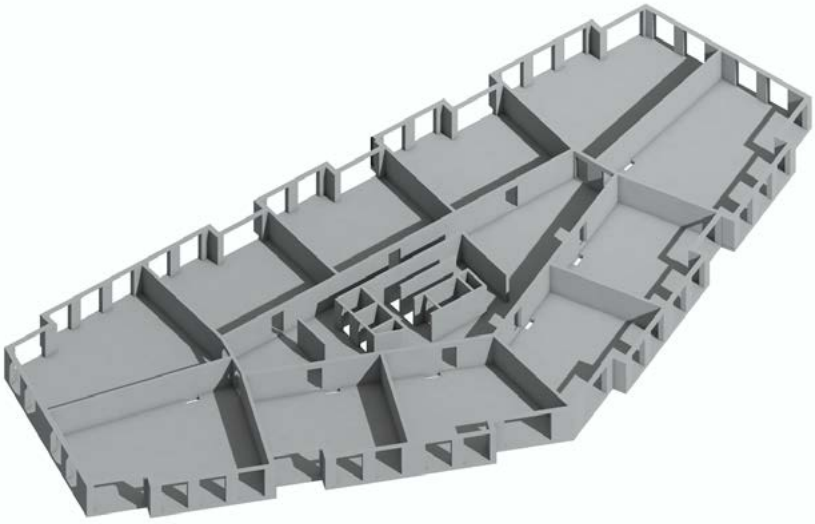
The finish will be large format light grey in-place concrete slabs with perforated light grey in-place concrete slabs and wooden decks of Robinia.



9th TO 21st FLOOR
STRUCTURAL PLAN



8th FLOOR
STRUCTURAL PLAN



1st TO 7th FLOOR
STRUCTURAL PLAN

3.3 LESSONS FROM THE TALL WOOD EXAMPLES

The first part of the research aimed to understand the structural scheme of most of the realized and on going Tall Wood buildings.
The main goal of this section is define the best wood structural system for the Alles Wird Gut tower considering the existing Tall wood examples.

Plan surface

The project tower is 73 meters tall, the larger part (from 1 to 7th story) will be around 1200 m^2, while the main part will be around 1000 m^2.
If we compare these dimensions with the other Tall wood projects analysed, it will appear that only Hoho Tower has a bigger footprint. But Hoho Tower is composed by 3 parts, each with different heights and only a small one, with an area of 450 m^2, is reaching 84 meters, which are less than half of the Alles Wird Gut tower part.
The other buildings that are following are around 800 m^2, all of them with a rectangular shape (except for Origine Condos, that is not exactly the shape of the design project).
There are then no clearly similar examples to related the structure of Alles Wird Gut project with. The project we want to transform in timber structure has the greatest surface respect the Tall wood examples researched which is already a challenging problem to solve.

Spans

The maximum span that the competition project has, is 10 meters.
A Panel structural systems does not seem a reasonable structural solution because first of all a panel system solution above 10 storeys does not exist and secondly the distance between some walls in the Competition project are more than the economical limit of 3,20 meters that wood producer companies gave for a economical slab.
Therefore the Thesis project will need a Post&beams structural scheme (Mass Timber or Hybrid) in order to make the distance between the floor system supports as small as possible.
The following aim is understand what is it the best Post&beam solution between Mass Timber solution or Hybrid solution.
Ones again, the Hoho tower seems similar in the design tower characteristics.
The Hoho tower has 2 concrete cores located in the centre of the 3 divided building with an average span of 6,5 meters.
Framework project and the Life Cycle Tower have even better spans, both around 8 meters.
The other projects solve the span problem in other ways. UBC Brock Commons has a fixed grid of 2,60 x 2,60 meters, while TREET and Mjøstårnet uses a different Post&Beams approach, which is difficult to imagine in the plan of the Competition Project.
The multi-angular plan of the Competition project also does compare with other plans: they are, too small in comparison.

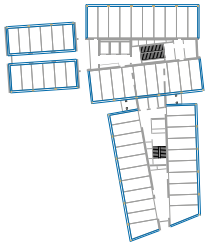
Hoho Tower, Framework and Life Cycle Tower

The 3 possible projects which are then comparable in terms of surface and span are Hoho Tower, Framework and the Life Cycle Tower. The Post&beams scheme of these project is similar: all of them have a punctual system in behind a prefabricated facade, which is connected directly to the main core.

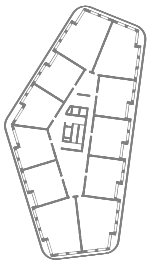
Hoho Technical solutions

The technical solution of Hoho tower is based on a concrete core that support a concrete bending beam with hybrid Mass Timber and pre-fabricated core slabs.
The use of the concrete beam in the perimeter of the facade will be not a correct solution for the irregular facade and the loggias of

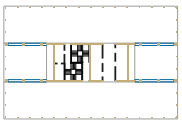
SINGLE FLOOR SURFACE



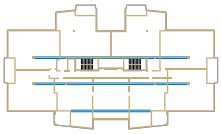
1 270 m²



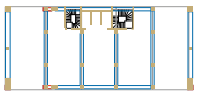
1200 m²



900 m²

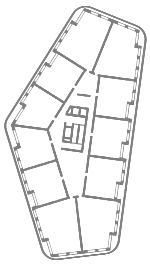


880 m²

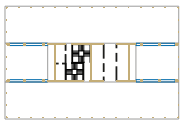


840 m²

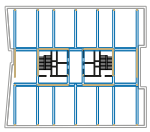
FLOOR SPAN



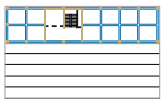
10 m



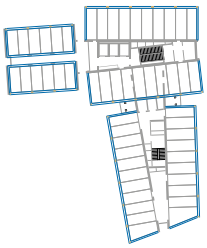
8 m



8 m

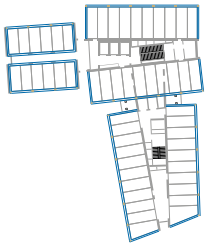


8 m

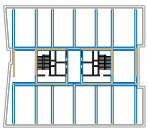


6,5 m

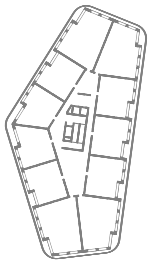
CENTRAL CORE - AREA



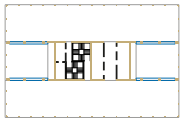
230 m²



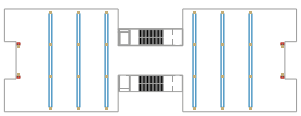
210 m²



200 m²



180 m²



160 m²

the Competition project. The concrete beam will also need to support the terraces and the prefabricated facade and therefore has to be designed in a different way.
Regarding the slabs system of HoHo, the solution of a prefabricated floor is optimal if it is possible to regularize the plan scheme.
The core of the competition project has to be re-designed in order to have a maximum of 8 meters distance between the core and the columns in the facade. It seems therefore necessary to consider the core not only comprehending the stairs and elevator shafts, but also in regards to the entire corridor.

Framework Technical solutions

Framework's system is based on a combination between glulam column + glulam beam that work together to contrast the forces. The span is 8 meters and the beams are only in one direction reaching the wood core.
The column-beam-floor system could be a difficult problem where are the Loggias. The Framework system is also made for a regular plan and the offsets of the Competition plans need to modify the general concept of the Framework system while maintaining the column-beam connection.
The core of the project is also interesting. It is the only project on the short list that propose a CLT core Even if the original core is made for a rectangular shape, the overall approach could be applied also to the irregular core of the competition project.

Life Cycle Tower Technical solutions

The structure is a Hybrid glulam beams under reinforced concrete slab. The building is highly prefabricated.
The double columns systems which are connected to a prefabricated concrete-glulam beam floor, permit a flexible approach for the loggias' offset of the competition project.
This solution could be the most appropriate option, provided the core can be modified in order to have fixed distances and the double column scheme can also make use of fixed distances.

Hoho Tower, Framework or Life Cycle Tower ?

From the previous technical analysis we saw that there is no a singular right solution. Every project has it own pros and cons.
Anyway, the Life Cycle Tower seems the most adequate one in terms of structural concept. The highly prefabrication approach could be used also in the Mass Timber structure we are developing, only if there will be fixed and overall regular distances.

Figure 57: Framework Gravity Load system

Figure 58: Life Cycle Tower One Gravity Load system

Figure 59: Framework Lateral Load system - Model view

Figure 60: Hoho Vienna tower model

3.4 STRUCTURAL DESIGN

On the basis of all the previous discussions Life Cycle Tower system was chosen as main developable design, keeping Hoho tower and Framework for other characteristics.
The primary plus point of Life Cycle tower solution is the possibility to have an adaptable system which allows to have some backward movement along the facade.
It is also possible to have a smaller floor to floor height, along with an empty space created by the beams for mechanical installations, sprinkler systems and an air layer to improve the acoustic.
Before develop the entire structure of the Thesis project, was created a structural concept where all the feedbacks, considerations and ideas were put in a common solution.

Post&Beam structure

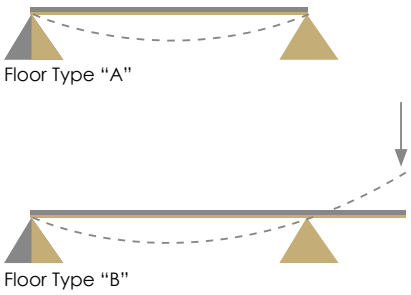
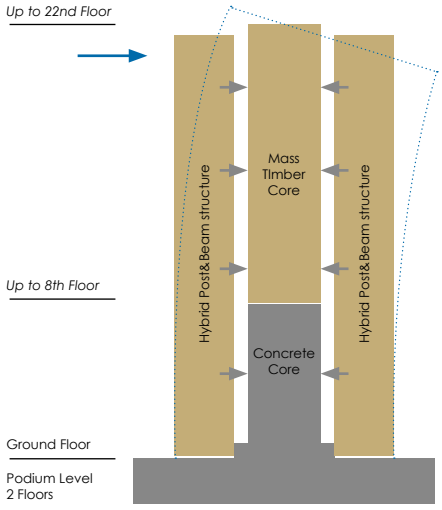


Figure 61: Structural Scheme of the 2 Floor Types

A post&beams structure uses columns and beams to support the gravity loads (both structural and non-structural loads such as people, furniture etc.).
Therefore it is necessary to understand where, how many, with what distance between the elements and with what span the structural elements (columns and beams) need to relate with.

The Plot 3 Project has a 8,5 meters span meanwhile the biggest floor span from the examples analysed is not bigger than 8 meters. For this reason there was the need to reduce the span. This brought to redefine the core along the perimeter walls of the apartment (and not of the corridor as it was for the concrete one).
In this way was also possible consider only one raw of columns directly connected to the main core. Another necessity was to have an adaptable system which allows 2 types of floors: one until the column in order to form a loggia, another with 1 meter span more.

The core



Today does not exist a Mass Timber core of 21 storeys. It will exist in 2018 a 18 storeys Mass Timber core thanks to the realization of Mjøstårnet tower but the structural system approach is not the same of the one we considered (we do not want diagonal beams to stiff the entire structure).
The comparable one it is the Framework core which is 13 storeys high.
The Thesis project aims to design a feasible structural approach so it was preferable not

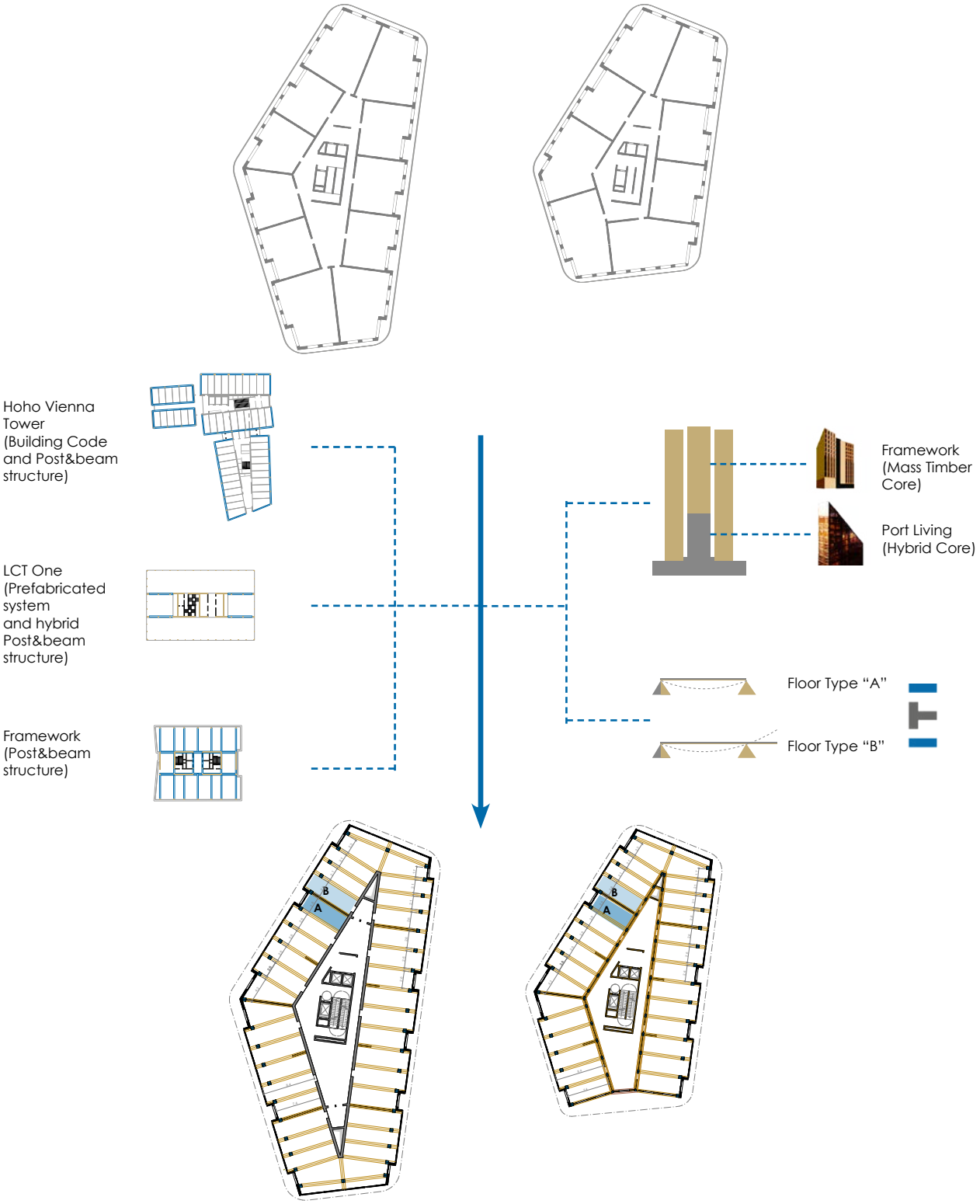


Figure 62: Structural plan generation scheme

consider too much difficult solutions.
What is possible is the Port Living solution.
Port Living core has a 19 storeys hybrid core, half concrete and half hybrid Mass Timber and steel. Considering the core of the Thesis building formed by a concrete podium and a Mass Timber part seemed then the best feasible approach possible.
The Mass Timber core proposed by the structural concept is based on Framework core, a combined core formed by glulam columns supporting the beams and CLT panels in-between the glulam columns.
The concept core instead do not have the earthquake elastic elements which are necessary in a earthquake area as the Framework one. There are instead steel beams which help both to stiff the core also for the construction phases and to guide the CLT panels in the space in-between the columns. The steel beams are placed only when also the gravity system (floors and columns) is placed.

Overview

The structure consists of a Hybrid Post&beam structure composed by a single line of double columns (25x50 cm each) connected to the building core through double glulam beams.
Hybrid glulam+steel beams are used in the Mass Timber core to keep the Mass Timber walls unified.
The mixed concrete and wood concrete composite floors are located between the beams, and will be a maximum size of 2,8 m x 8,5 meters.
The structural facade is wood composed and consists of prefabricated modules.
The parts are thought as highly prefabricated elements mounted in a specific order to achieve stiffness to the overall structure.

Structural Grid

The main core of the Project building has became bigger than the competition project core and now is the entire perimeter walls of the corridor.
The 1,5 meter distance between columns of LCT Tower is too small. In Framework the average is exactly 2,9 meters and considering a normal depth of the floor at 30 cm plus the 40 cm of the beams the comparison seems possible. The aspect to consider is the choice of the beams: if it will be a hybrid solution glulam+steel, it could be possible have an even smaller beam.
In order to have a small section of the floor, the building has a grid of columns which have a distance between 2,5 and 2,9 meters with some particular point where the floor is not regular.
The facade is not always structural. When the facade is attached to the columns line it is structural and helps stiffening the tower. When the facade is not attached, does not have any structural role and it could be completely glass.

Gravity Load System

The floor system consists on an hybrid solution of glulam beams with a in-between double layer composed by concrete and wood concrete composed material.
The solution is mixed in order to the keep the solution relatively cheap, one of the main goal of the Mass Timber structure.
Because of the distance between the columns is small, the first concrete part will be 8 cm thick and the second will be 5 cm thick.
The prefabricated floors will be attached to the main beams in order to save space and create a continuous system. The way they are attached is clarified with the drawings: the beams will be CNC cut in order to have a indentation where the concrete part is linked.

Figure 63: Axonometric view of the structural concept

This particular solution was thought because of space savings: in the floor solution of Life Cycle Tower the concrete is above the glulam beams, not at the same level of the Thesis project. The problematic behaviour will be explained later in the specific gravity load part.
The solutions is not only theoretical and the ITI department is now developing already a second row of tests on a similar type of floor.
Columns, beams and shear walls deliver the gravity loads to the storeys below and ultimately to the foundations.
The 8th floor and the roof of the building is also made with mixed concrete and wood based material assembled in prefabricated floors, with a special finishing treatment in order to avoid moisture and permit a enough depth layer of ground to grow plans and small trees.

Lateral Load System

Even though a Mass Timber core for high rise building has not yet been created in Austria, as Hoho tower has shown (but also other projects already realized like LCT tower or Wagramerstrasse), the aim of the project is to have a Mass Timber core, at least for most of the storeys.
Beside the hybrid concrete and Mass Timber core, the lateral load system consists also on Mass Timber shear walls.
The shear walls are located symmetrically in perpendicular positions respect the core and they are of two types
- A full 7,5 meters length
- A 2 meters length

These 2 measures depends on the necessity to have a lateral system in certain points of the plan but at the same time the necessity for relative flexibility of the plan.
These walls are critical to resist net building uplift due to wind forces on the broad face of the building.
The core is located in the centre of the first part of the building and in the south/central part of the tower part. Until the 8th floor it consist of prefabricated concrete 20 cm thick panels with steel bars reaching the top.
Up to the 8th floor the core switch its material in Mass Timber CLT panels, glulam columns (supported by steel bars coming from the concrete core) and hybrid steel/glulam beams.

First Floor and Substructure system

The tower stays in a podium formed by an Underground floor, a Ground floor and a First floor. All these floors are designed in reinforced concrete due to competition requests and to be able to resist high construction loads as well as enhance the durability of the building that will be in contact with the outside weather.

Foundation system

The foundation will be based on the same proposed for the Alles Wird Gut competition project. The Mass Timber tower will be significantly lighter compared to the concrete one thus only 60 to 80 percent of the original foundation elements will be required to support the lighter Mass Timber tower.

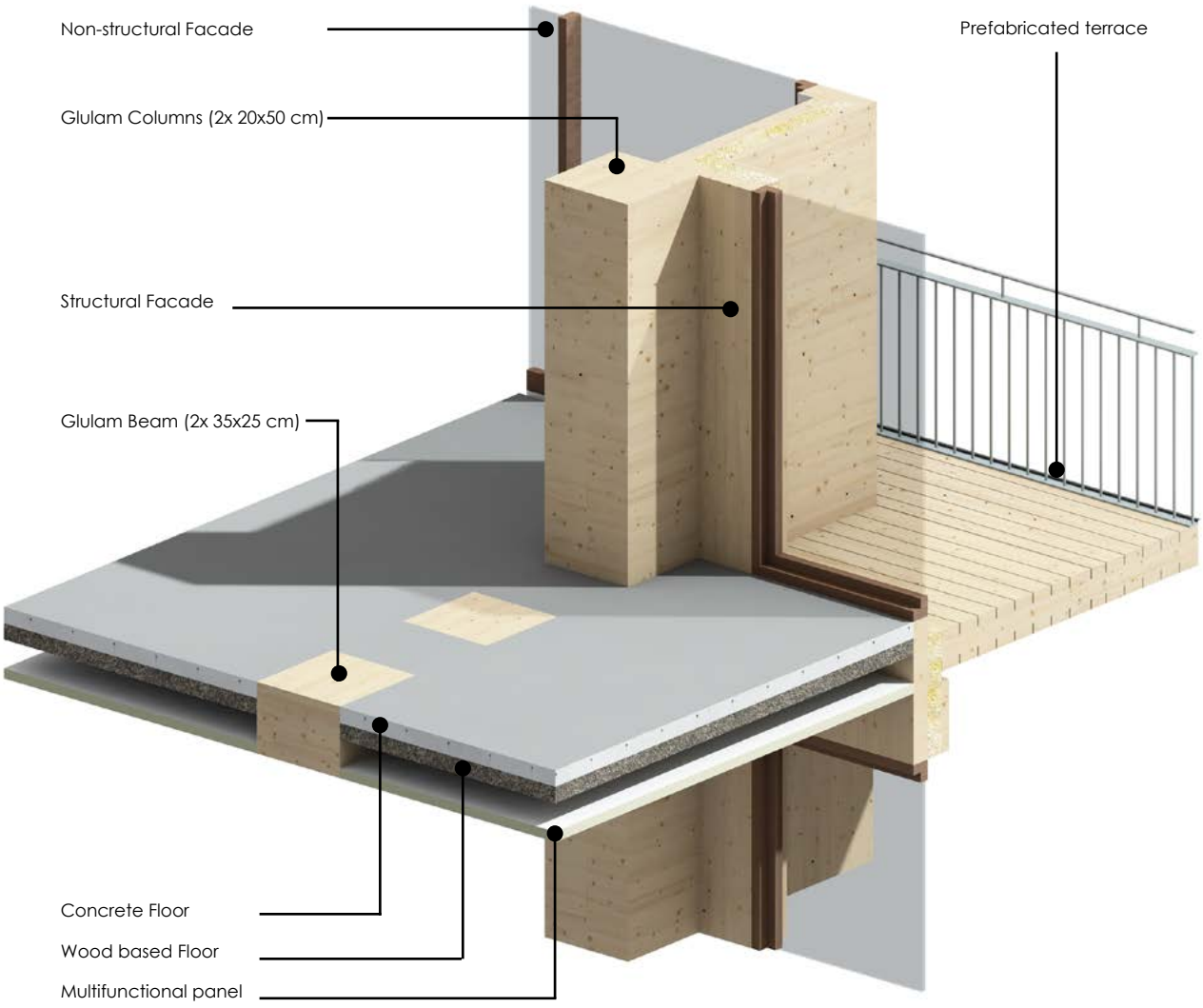
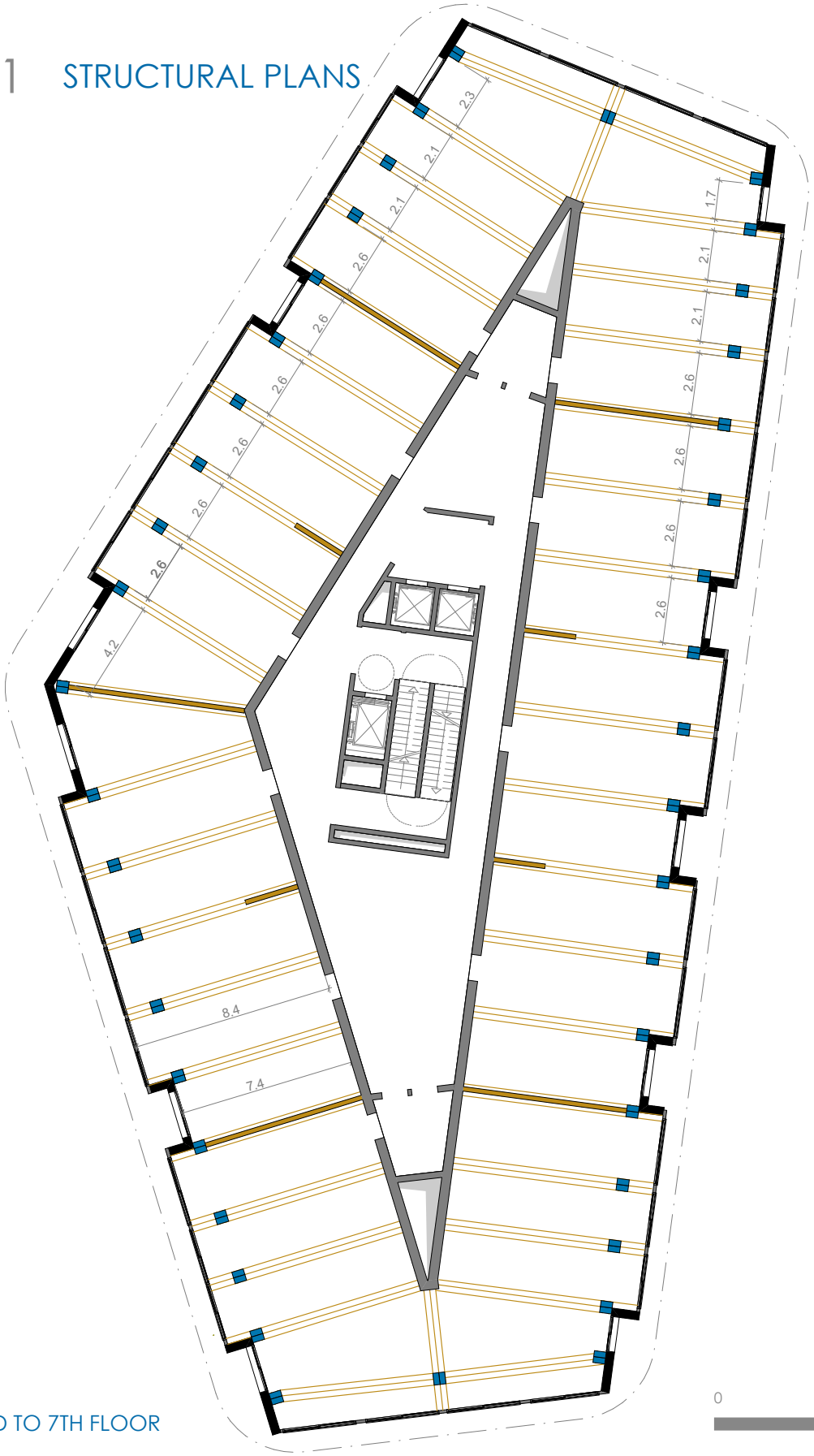
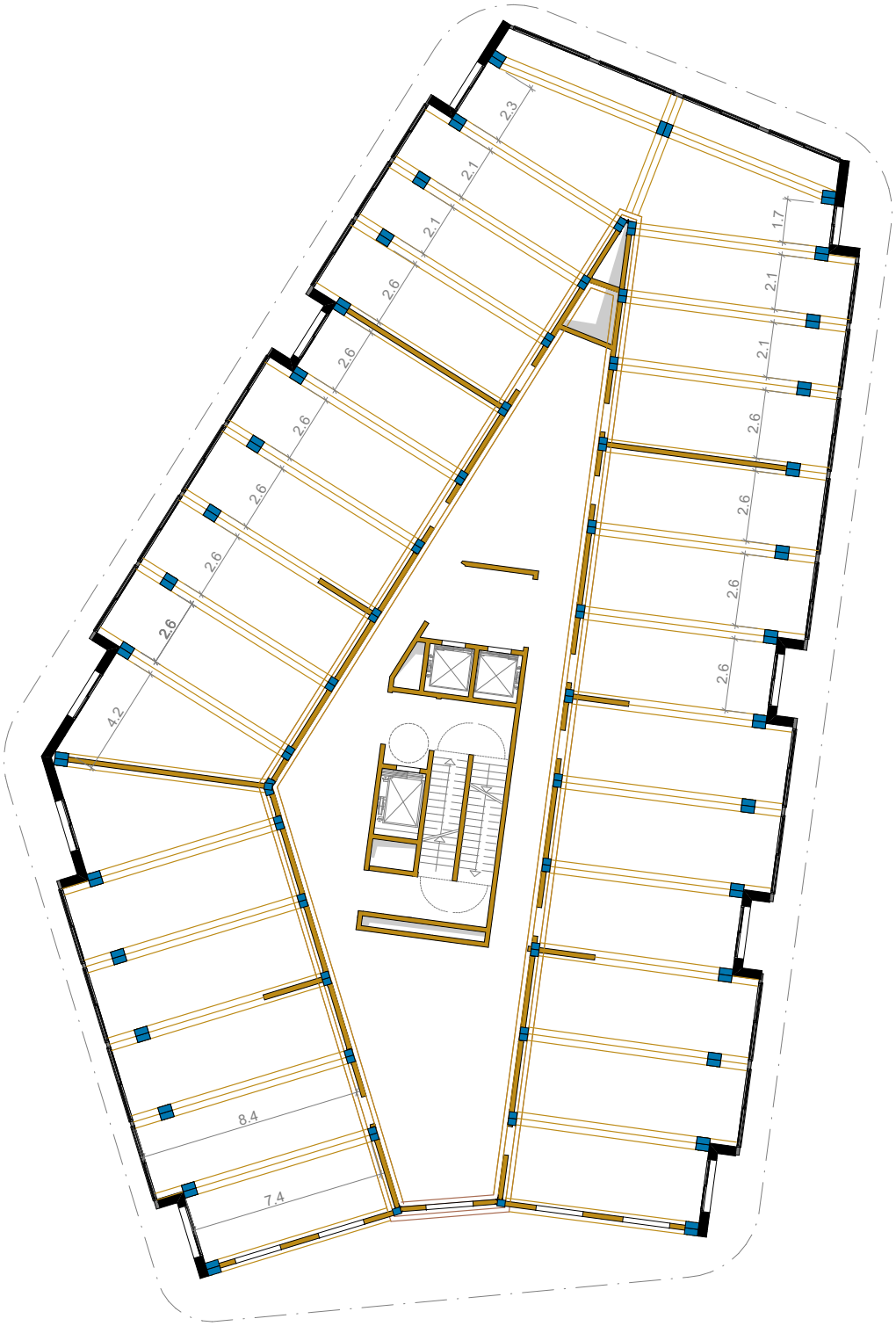


Figure 64: Axonometric section of the structure concept

3.4.1 STRUCTURAL PLANS



2ND TO 7TH FLOOR



9TH TO 21ST FLOOR PLAN

0 5 10

3.4.2 GRAVITY RESISTING SYSTEM

Consideration about Floor system

The floor system is one of the main aspect in the definition of a structural system. Regarding percentage of material in a high rise building, 70% of it is the total floor material required. It seems clear that an economical floor system will strongly influence the overall cost of the structure. The Competition project consists of a 20 cm thick reinforced concrete flat plate: a successful design will use the same or less amount of material.

Span length and Columns

The Competition project has a floor span of 10 meter from the small inner core, to the loading facade.
This span was considered too much even for a hybrid solution and therefore 2 solutions were introduced to the Thesis project:
- A interior row of columns;
- Offset the main core moved in the perimeter walls between the interior corridor and the flats.
This solutions will guarantee 8,5 maximum span.

Interior row of columns

The columns break the span and bring the length of the beams to 8,5 meters.
The main problem with introducing a system of columns to a tall wood structure is the following: interior columns take gravity loads away from the primary shear wall core at the centre of the building. This increases the net uplift due to wind which is the controlling design condition for the lateral resisting system.
For this reason it is possible to believe that core, columns and shear walls will be not enough to stiff the building and for this reason an additional strategy was added: the structural facade.
The role of the structural facade will be to stiff part of the vertical facade in order to work together with the floor and columns elements.

Offset Core

The core of the Competition project was not compatible anymore with a column system and a small span strategy for floors. This is why the best option seemed to be switching the main core with an offset operation to the perimeter walls of the flats. This operation needed a modification in the conjunction between the 3 main walls creating 2 cavities useful for installations (or for possible additional storage rooms). Because of the 2 types of floor, the longest span will be 8.5 but the smaller one will be 7,5.

Floor panels and column spacing

As we said before, small span for wooden floor is necessary to limit the cost of the structure.
The hybrid solution chosen will guarantee a certain level of cost competitiveness but the floor has to also consider the distance between columns.
The plans of the competition project are based on the fixed modules 2,4, 2,9 and 3,6 meter regarding small and big bedrooms and living room minimum depth, requirements according to the Austrian building Code regulations. It was chosen a not fixed grid of column, but 2

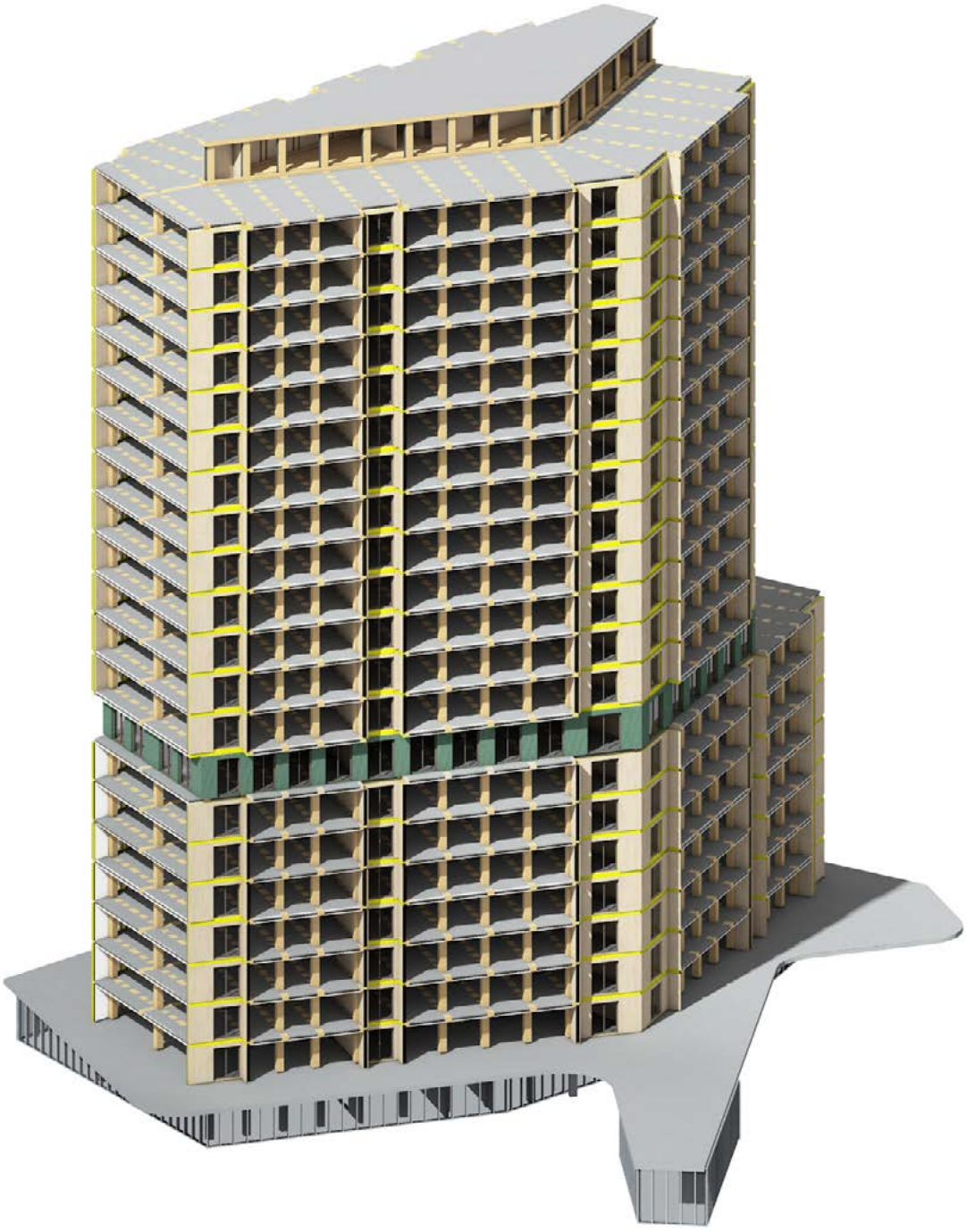


Figure 65: Axonometric view of the Gravity Resisting system (included the core)

main distances from column-to-column which are 3,1meter and 2.6 meter.
In reality, these are not the same distances also for the floor, because the column are linked with the beams at the same level of the floors, therefore the maximal length span is around 2,6 meter, which will guarantee an even smaller depth of the structural floor and cheaper solution.

Floor-to-floor height modification

If the proposed system will create a competitive floor, it will be necessary to modify the floor-to-floor height of all of the floors from 2,8 meter to 3 meters.
Both the main researches regarding a comparison concrete benchmark building and tall wood building underlined the necessity for the Mass Timber structures to have higher floor-to-floor height.
Beside this it is obvious most of the time that the adoption of a different structural system, from a flat plate of the concrete Competition project to the post&beam one of the Thesis project will introduce beams that will carry the main load.
The beams will have a 8,5 meter span with a section of 35x35 cm. Considering 10 cm of finishing floor level and a lower layer for acoustic and gypsum suspended ceiling, the overall section of the building will pass from 36 cm to 48 cm. In order to guarantee the same floor to floor height, was then necessary to bring the overall height up to 3 meters per floor.
A special case is given by the intermediate 8th floor. In these case, going deep in the detailing of the section, it was necessary bring the floor-to-floor height from 2,8 meters to 3,5 meters. This necessity came from the insulation thickness that will be for sure thicker in comparison with the normal one.

Connection of the beams with concrete

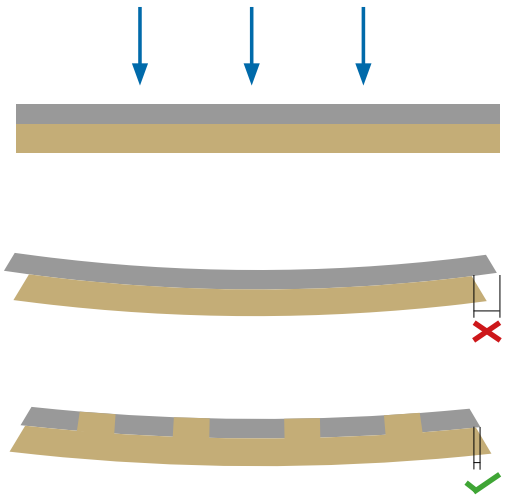


Figure 66: The connection glulam-concrete explained.

The connection of the concrete and the beams had to be designed in a different way respect Life Cycle Tower. LCT floor system uses glulam beams and a concrete layer which is above (not in-between the Thesis one).
In the Thesis project the concrete layer is in the same line of the beams and a simple nailed solution like LCT could not be possible.
It was therefore necessary make some considerations in terms of material behaviour under the action of the gravity forces.
The problem is explained with the scheme above. We can see that under the gravity forces, the 2 different materials will behave too different regarding their physical characteristic and they will tend to slip one on each other, moving too much in an horizontal side.
For this reason it was chosen a combing junction where part of the concrete goes above the beam in order to perform together in a better connected way to the forces influence.
The connection type will therefore guarantee a better level of structural behaviour.

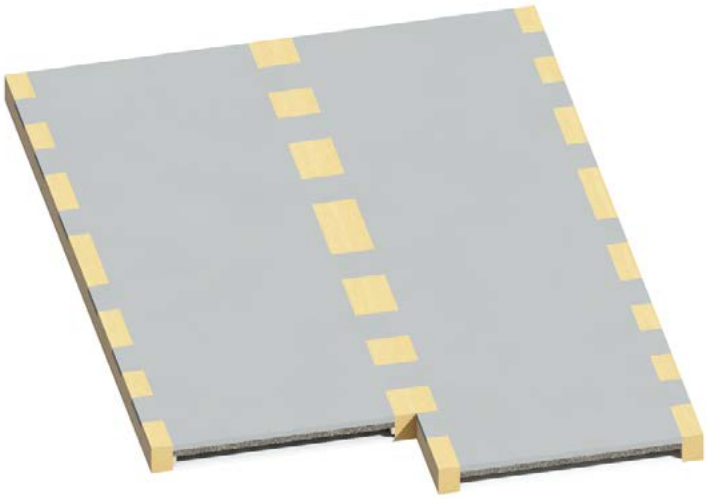


Figure 67: Axonometric view of the 2 floor system

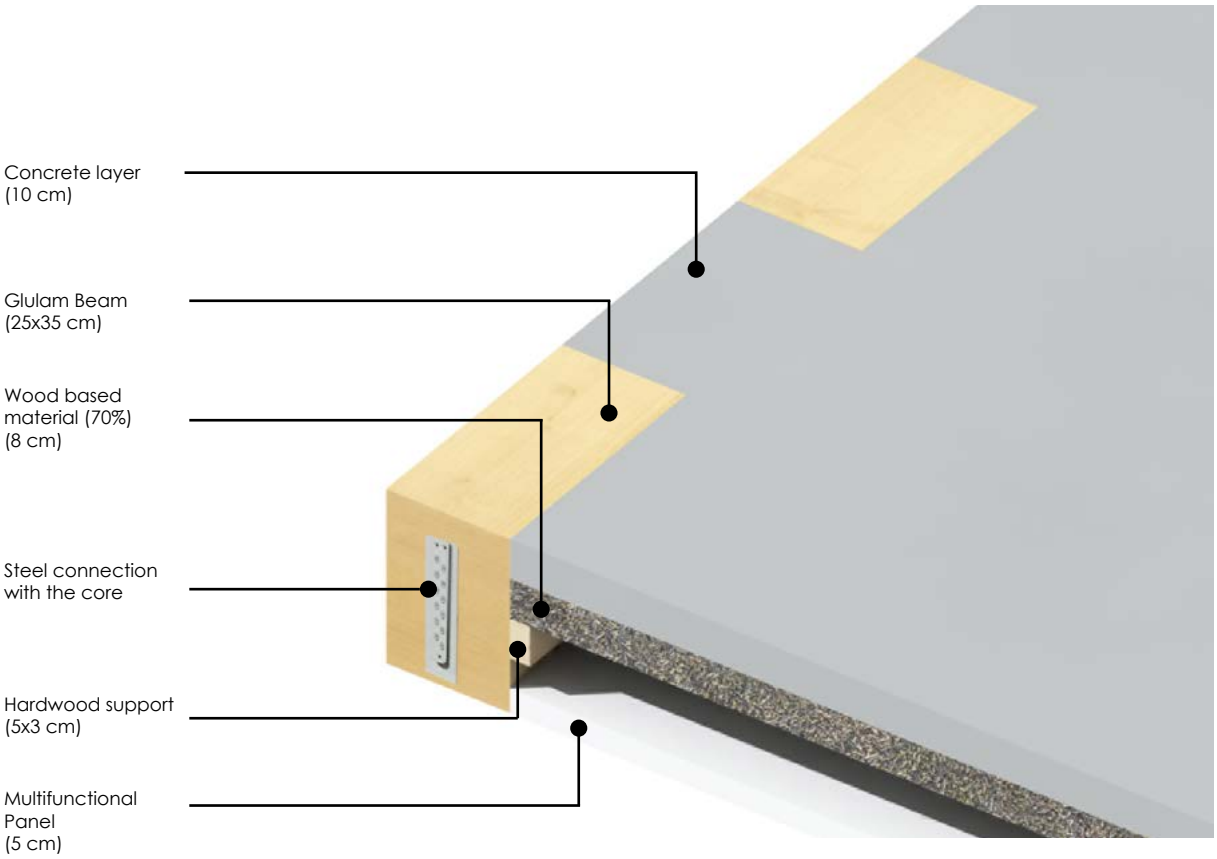


Figure 68: Axonometric view of floor system - Detailed view

Gravity system combination process

Prefabrication is one of the key aspect of a Mass Timber building. Also in Thesis elements are thought to be prefabricated but prefabrication concept brings to combination of the elements concept.

Prefabrication in fact is not enough. A successful design consider also how the elements are combined together in order to realized quicker and simpler the building.

The combination process of the gravity system is here explained.

Starting from the position of the columns, the building process follows the combination of the columns with the floors and than again with the connection column-to-column.

Connection elements are also a key aspect in Mass Timber building. The type and behaviour of the connection can influence the entire building. The proposed steel connection is consisting in a combination of steel plates (vertical and horizontal) which will be nailed to both the columns and the prefabricated floor and will connect also column and column as showed in the step 5.

The steel plate of the under column will remain outside the floor system and will allow to nail that part to the upcoming upper columns in order to have a system which is working all together.

1. GLULAM COLUMN

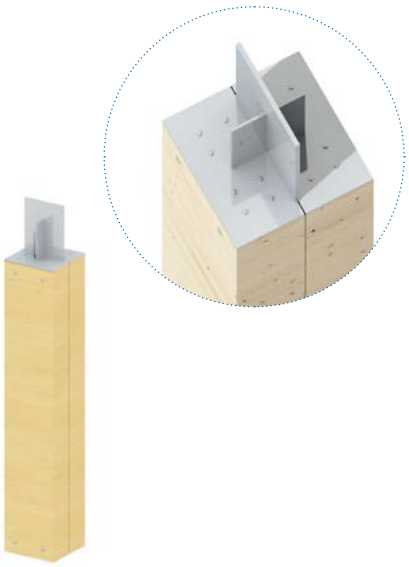
The first element of the gravity load system is composed by a column 25 x 50 cm with already the steel connection attached.

4. 1ST TYPE FLOOR CONNECTION

The first type of floor is connected to the column through the glulam beam and the steel plate of the columns.

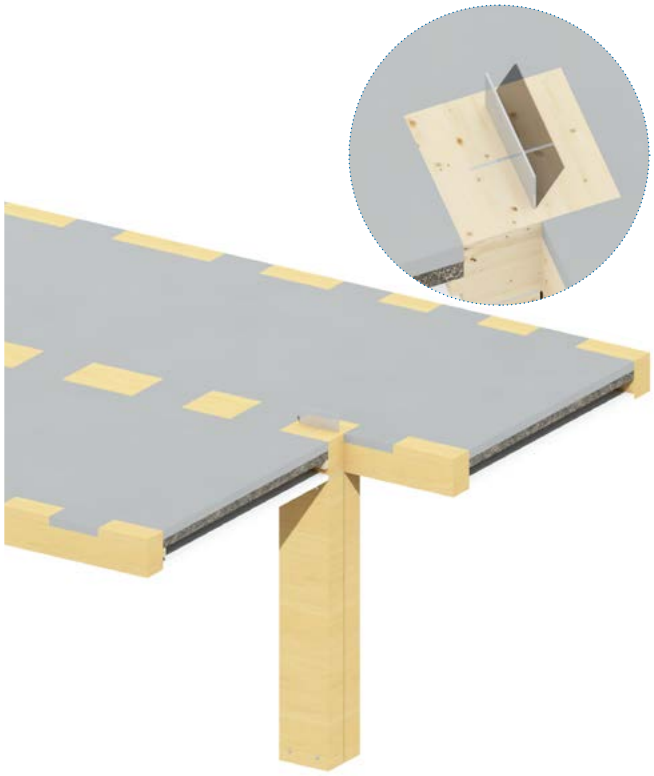
2. 2ND GLULAM COLUMN

The real punctual system is composed by 2 glulam connected which form a 50 x 50 cm column.



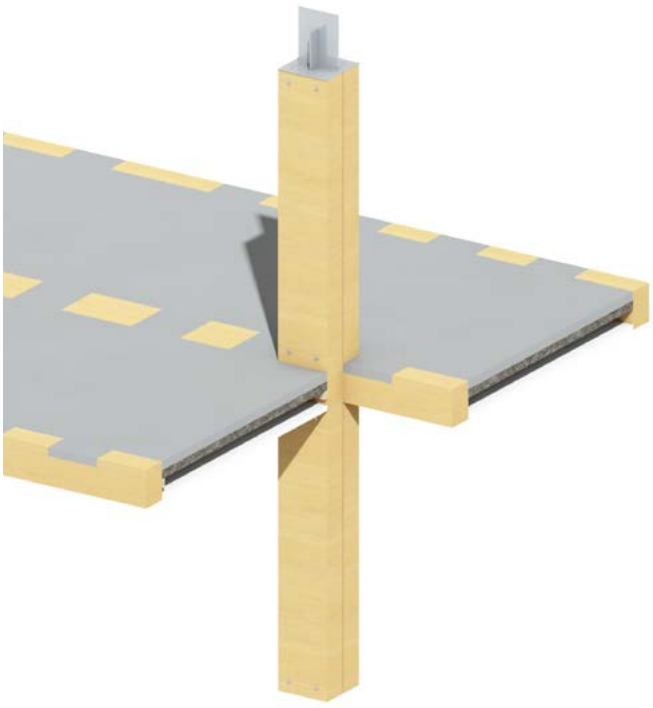
3. FINAL GLULAM COLUMN - CONNECTION

The combination of the 2 glulam columns form also the connection system for the floor and the other column above.



5. 2ND TYPE FLOOR CONNECTION

The second type of floor is connected in its final part always through the glulam beam and the steel plate which remains out in order to connect the upcoming column.



6. UPPER COLUMN CONNECTION

The upper column will be connected to the entire below system through the steel plate. The same process is applied to the entire gravity system.

3.4.3 GRAVITY RESISTING SYSTEM - TESTS

While the Thesis was been developed the ITI (Institut für Architekturwissenschaften Tragwerksplanung und Ingenieurholzbau) department of TU Wien with prof. W. Winter as head of department, was testing some floor systems of a similar composition to the one in the Thesis project.
The main difference between the floor system tested and the floor system of the Thesis project is the type of beam used. Instead of glulam beams, the tested floor adopt LVL beams, with a smaller section.

Type of testing

The first type of testing was made on 2 types of different floors: one floor system composed was composed of concrete, 70% wood based material and LVL beams (Type 1) while the other was composed of concrete, 70% wood material and CLT floor panels (Type 2).
The CLT floor (different sections were tested), has a thicker section (both concrete and CLT layers are thicker than the ones in the LVL floor). The reason for this testing is that the TU University is involved in the development of Hoho Tower. Type 2 performs well from a structural point of view, but is too thick in comparison with a beam floor type. This is why it was not considered a possible solution for the Thesis project.

Type 1 floor solution

The LVL floor solution has 8 cm concrete floor, 5 cm, 70% wood based material and 2 LVL beams (32cm high an 4cm thick).
The tests were made in the laboratories of TU Wien and they were overall satisfactory. There was only one point in the final part of the beam which performed poorly. The solution of reinforcing that part with two nails resulted in a much better performance when tested.

Figure 69: The type 2 floor tested with the CLT layer

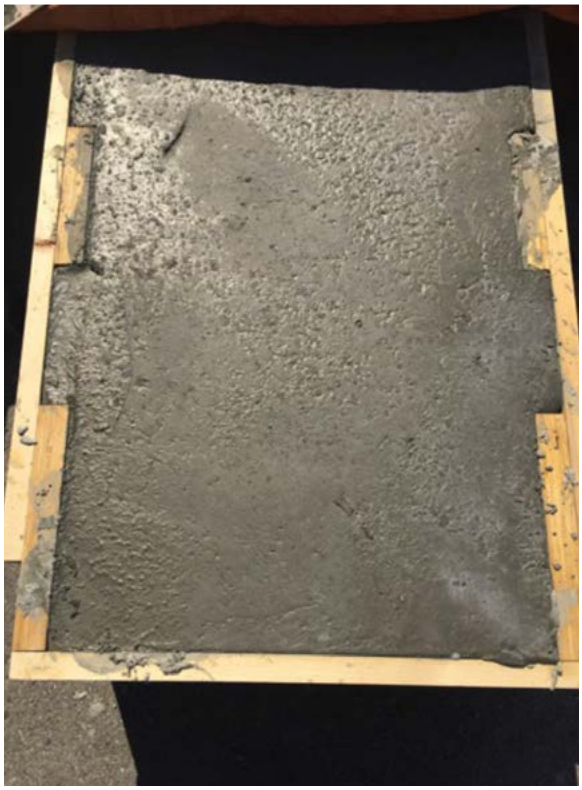


Figure 70: The wet concrete layer with the formworks still on

Figure 71: The type 1 floor tested

Figure 72: The type 1 floor prepared to be tested

Figure 73: The type 1 floor after the test phase

Figure 74: Several type 1 floor system tested

Considerations regarding the tests

The first series of tests proved that the floor system with the LVL is feasible. The beams of the Thesis project are 35 cm high and 25 cm thick meanwhile the LVL section is 32x4 cm.
With this data, we can confidently conclude that the structural behaviour of the floor system in the thesis (which has ticker concrete layers and thicker glulam beams) will perform well.
However specific tests still need to be done to prove it definitely.

LVL vs Glulam

For testing, LVL beams were preferred because their shear stiffness outperformed the glulam beams.
With LVL it is possible to pay per cubic meter for sizes between 20 to 75 mm because it is composed of 3mm ply-wood layers. Glulam has the board in the opposite way and normally it is impossible go slender as the LVL beam. Glulam places the boards in the opposite direction and it is normally not possible to be as slander as the LVL beams.
LVL is a relatively new technology and is just now starting to be interesting to the European market. Indeed there are not many projects especially which adopt this particular solution. Some years ago LVL in Europe was produced only by Kerto, a Finnish company. Now there are 3 producers and they compete with each other to decrease the cost of LVL beams from 750 € to 550 € /cubic meter, against an average prize of 400 € /cubic meter of glulam. If you look at LVL's resistance it takes 50 N (Newton)/ square mm and glulam 35 N. The problem of LVL is fire. With glulam the sacrifice layer is made also of glulam, meaning the cost is the same. However LVL is too expensive to use as sacrifice layer so it will be necessary to consider all of the ways it can be protected.

Figure 75: The additional nails inserted in the second round of tests

Figure 76: The effects of the second round of tests

Figure 77: The crack of the beam

Figure 78: The crack of the beam

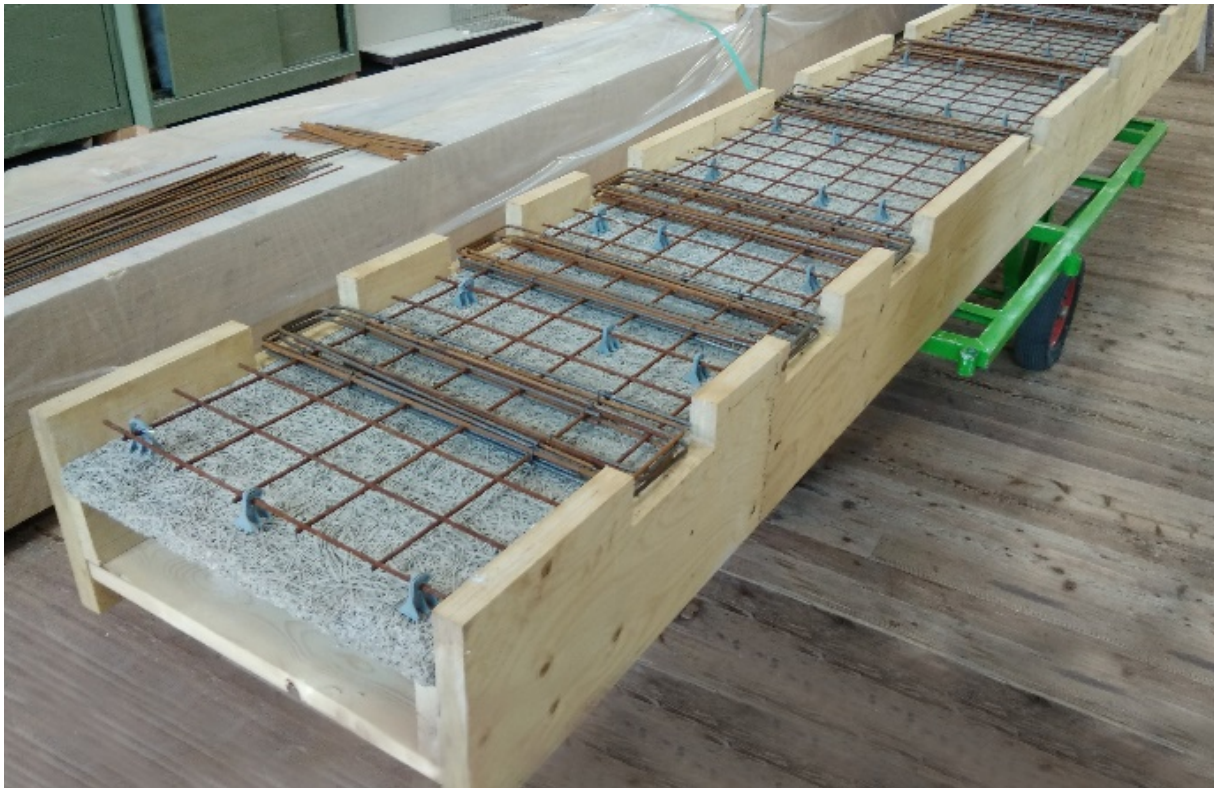


Figure 79: Type 3 floor with glulam beams prepared for the concrete layer

3.4.4 LATERAL LOAD RESISTING SYSTEM

Lateral Loads forces are wind and earthquakes waves.
The area of Vienna does not need earthquake requirements because is not an earthquake area. This means that wind is the main lateral force to resist for the project.
The main aspects to consider a lateral load system are system strength, system stiffness and the net uplift. Together with these aspects follow also the projects and building regulations aspects.

System strength

The system as a whole and each individual component must be strong enough to resist the necessary loads. In tall buildings using a core wall lateral system, the most difficult part is to design a link beams which couple the movements of individual wall panels.

System stiffness

The system has to be stiff enough so that cladding and elevator are serviceable.
As we saw in the Part 1 of this work (page 20 - Challenges for Tall Wood), stiffness is the main structural goal a Mass Timber structure has to aim. Due to the lightness of Mass Timber in fact, several right choices have to be made.

Net uplift

Net uplift occurs when the lateral load overturning forces overcome the gravity dead load forces of the building. This causes the building to lift up and places the vertical elements in tension. Net uplift is more avoidable in a concrete building due to additional material weight. A critical point is the bottom of the core if it is not rigid enough. The choice to make the bottom of the core (or the entire core) will help to avoid the uplift risk.

System choice

What emerged from the research analysis of the main Tall Wood buildings is that the core (concrete or wood) is never enough and must always be supported by another lateral system (diagonal beams, shear walls).
The Total surface area (per floor) with a central core of the Competition project is the greatest of the chart and made it clear that even a big core could be not enough to resist properly for the wind loads.

The Core

The core is where all the lateral forces are driven and thought it they are transmitted to the foundation system.
For several structural considerations explained before, it is right to consider the core of the Thesis building as an hybrid solution between a first part (Underground to 8th floor) made out of prefabricated concrete panels, and a second part made out of a combination of glulam columns, CLT panels, glulam+steel beams and vertical steel elements.

Concrete Core (Underground to 8th floor)

The first part of the core will be in prefabricated concrete. Prefabricated concrete as written previously has several advantages.
This part of the core is composed by 3 elements: two 5 cm thick panels linked with a steel grid will be positioned in the building site and then liquid concrete will be than versed. The section will be than 5 cm + 20 cm + 5 cm for a total of 30 cm structural core.
For the floor of the concrete core is considered again a prefabricated floor panel, composed only with a layer of 5 cm concrete panel with a steel grid but without the last layer of 5 cm. There will be inserted an addition steel grid which links the floor

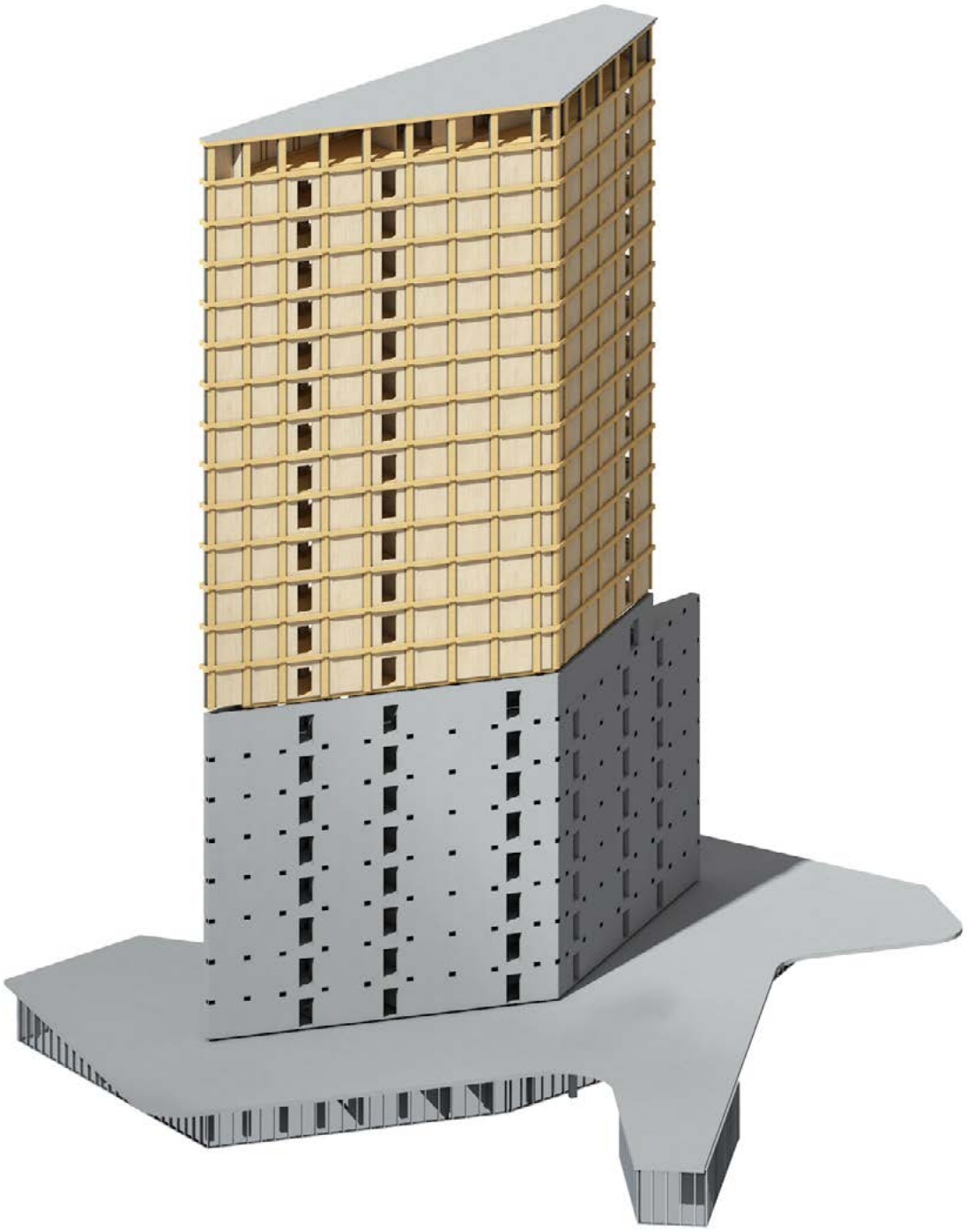


Figure 80: Axonometric view of the core of the building

to the vertical walls and than a final liquid concrete layer will be put and finished.

The Mass Timber Core

The Mass Timber core of the upper part of the project is based on the Framework one with some adjustments.
The main idea is to have a glulam column which is connected to the beam of the floor system. The glulam column of the core is thought as 15m high: this is because of the will to have a 5 storeys core height for construction phase. The columns will be supported by 2 steel vertical columns in that are connected to CLT panels with size of 16 m x 3,5 m (maximum) x 20 cm thick.
The construction of the Mass Timber core will be composed by a first positioning of the CLT panels along the vertical steel beams, than the glulam columns will complete the 5 storeys high part and than for every floor concluded by 2 row of hybrid glulam+steel beams which will run along the perimeter of the Mass timber core, both inside and outside the walls.
The floor in the Mass Timber core will be a 14cm CLT floor panel with a variable length and an average depth of 1,5 m with a concrete layer above which add weight to the core.
The original core of the Competition project (the part of the building with stairs and elevator shafts) will help to the overall stabilization of the building but it can not be considerate a core.
It will be composed of 12 cm CLT panels with 2 gypsum boards layer (on both sides) which will rise the REI resistance of this part, where all the safe exits are located.

Vienna Building code considerations

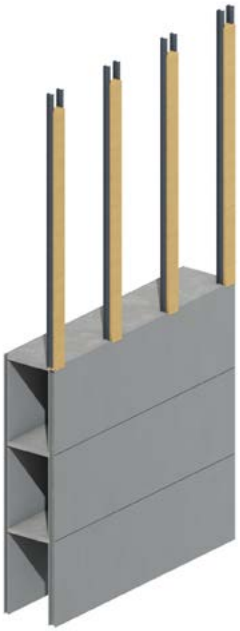
It is important to state that a simple and effective choice based on what is already realized could be simply consider the core as fully concrete. The case of Hoho tower in Vienna prove that Vienna building code will not allow a Mass Timber core. For this reasons it is possible to say that if this building will be realized in Vienna today, it will have a complete concrete core. But this does not mean that the building does not have a safe Mass Timber Core. The Mass Timber part are thought to be fully encapsulated in order to have not Mass Timber part exposed. In general 1 layer of gypsum board will be enough but several projects adopts 2 layer of gypsum-boards.

Building construction considerations

The concrete part is thought as built at once. The prefabricated walls will arrive in the building site after the completion of the underground and ground floor which are part in common of the rest of the urban development. The concrete core once concluded, will be used already to mount and transport materials.
Good examples of this are the building process of UBC Brock Commons and Life Cycle Tower.
Both the projects realized at first the entire core and than builders used it to complete the rest of the prefabricated parts.
A general disadvantage of a concrete core is the necessity of two stages of scaffoldings: one for the concrete core, one for the Mass Timber parts.
The advantage showed by the Mass Timber building, instead is usually a partial realization of the building of a floor-per-floor realization of it which reduces significantly the cost and

PHASE 1 - CONCRETE CORE

The prefabricated concrete core will be realized until the 9th floor



PHASE 2 - MASS TIMBER COLUMNS

The first part of the Mass Timber core is composed by the glulam columns (15 m height) and the steel bars which helps for the structural resistance. The steel bars will be inserted also into the concrtete core.

PHASE 3 - MASS TIMBER CLT WALLS

The role of the steel bars is also be a guideline for the CLT walls which will be inserted in a second moment to stiff more the Mass Timber Core. The CLT walls will have already the hole for the door cut.

PHASE 4 - HYBRID STEEL-GLULAM BEAMS

To finally stiff the entire system will be necessary an hybrid solution of steel-glulam double row of beams along every floor. The glulam will provide mechanical support and fire protection for the steel beam.

makes more quickly the realization of the building.

Shear Walls

What help instead is the strong symmetry of the plan in the basement part (1st to 7th floor).
For structural necessities and flexibility choices, 2 type of shear walls were introduced:

Shear wall 1

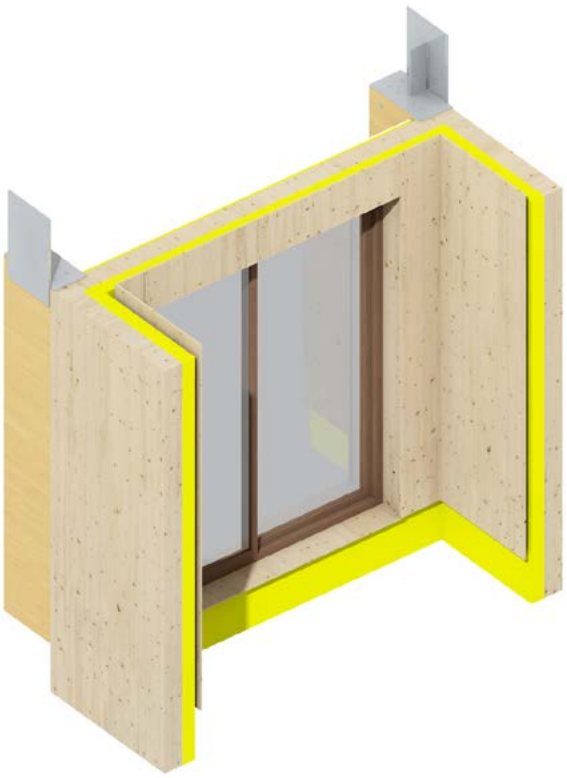
7m x 2,5m x 25cm(total with insulation and gypsum boards included) thick.
In the bottom part of the building there are 3 shear walls on the west side and 2 on the east side positioned in a symmetrical way.
From the 8th floor, the number remain the same but the south shear wall became the facade of the upper south part.
This is the greatest change there is with the competition project and is due the necessary stiffness required for the 13-storeys tower part.
These shear walls then, connected directly to the Mass Timber core can provide complete rigidity of one facade.
The role played by these walls is not only structural nut also they create an effective fire compartments as required.

Shear wall 2

2,3m x2,5m x 20cm thick.
Beside the 5 big shear walls 1, there are other 4 smaller shear walls 2 which provide continuity up to the last floor.
The necessity is to guarantee a constant continuity along the 3 different parts of the building and also to reinforce the Mass Timber core.

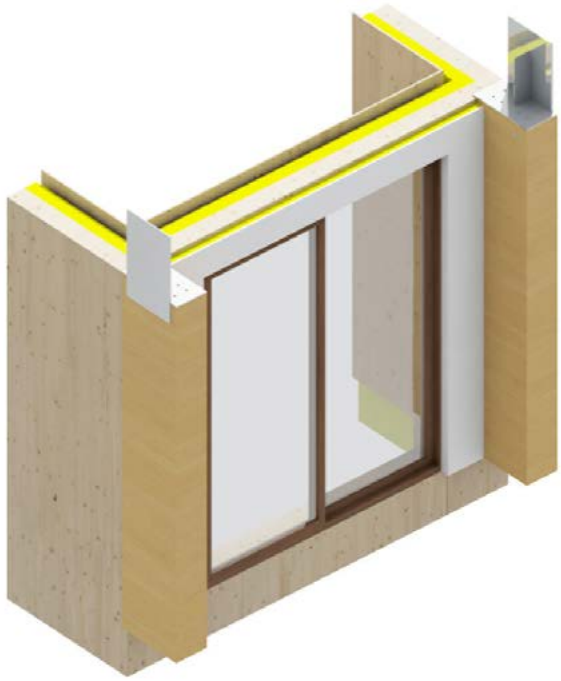
Structural Facade

The last elements which help with the stiffness of the building are the facade in the loggia parts of the project.
In order to have a continuous vertical system, less wide than the shear wall in the facade but anyway necessary, it was thought to consider the part of the facade in direct contact with the structural columns as also structural part.
The result is a prefabricated facade which can arrive already mounted in the building site, saving time and guaranteeing a high level of precision.
The prefabricated facade is composed by a 14 cm thick CLT panel with a already mounted window (2,1 m height - 2 m lenght) with a 10 cm insulation layer and other 6 cm additional layer for ventilaed facade cavity and wood cladding.



STRUCTURAL FACADE - EXTERNAL VIEW

The structural facade is prefabricated in a factory, therefore will arrive with all the possible elements already mounted. In particular the CLT walls will be connected to the 2 columns in front of them in order to form already a continuous system for the force transmission.



STRUCTURAL FACADE - INTERNAL VIEW

In the internal part could be possible already locate the gypsum board of the internal finishes. The columns instead will remain exposed. The connection to the floor system is not only through the columns, but also through the bottom part of the wall with the window, which will be connected to the concrete part of the floor.

3.4.5 STRUCTURAL MATERIALS

Floor panels

The floor panels are prefabricated floors composed by two glulam beams attached to a layer of prefabricated concrete and a second layer of wood based material.
This combination is the result of several thoughts regarding cost competitiveness, thermal and acoustical performances and because is a known solution in ITI department.

Columns

The columns are designed as structurally glulam elements. They are 2 glulam columns which are connected together. The primary requirements for the columns are high axial strength and stiffness which is good provided by these type of Mass Timber Product. Particular attention has to be given to the steel connection which links the 2 glulam columns, the floors and the upper glulam columns connection.

Shear walls

The shear walls are designed in CLT. The walls need dimensional stability along their length which is provided by the CLT build up of alternating ply orientations.
The primary demands of the walls are axial compression, in-plane bending and in-plane shear. The axial stiffness is the key-necessity because the axial stiffness of the individual shear walls contributes, to most of the overall building movements due to wind loads.
For this reason the walls have been built up using 3 ply CLT panels with the grains primarily oriented vertically.

Concrete core panels

The concrete used in the core of the first 8 floors of project is composed of prefabricated walls. The choice of prefabricated panels is due the several advantages of this solution, it needs less time for realization, it is cheaper and it has a better precision of the elements, which are fundamental characteristics in a prefabricate building. It consists on two 5 cm thick panels with a steel grid which keeps the 2 panel with a distance of 20 cm. In the space in-between will be poured liquid concrete.

Mass Timber wood core panels

From the 9th to the 22th floor the core is formed by a combination of vertical 5 storeys glulam columns, horizontal hybrid glulam+ steel beams and CLT panels. Like for the shear walls, the use of CLT is mainly for its stiffness properties and also for the possibility to have a maximum of 16 meters long panel that will allow a rapidly 5 storeys erection.

Steel Glulam beams

To keep the core unified it has been chosen the TU Wien ITI Department research hybrid glulam+steel beam. The section chosen is 36 cm height and 17 cm depth. It consists on a steel beam, protected and performance helped by 2 glulam beams cut.

Prefabricated facade

The facade is composed by 2 type of prefabricated facade. The first type is located where there is a loggia and has incorporated 2 glulam columns, it has structural behaviour and provide vertical stiffness. This facade is prefabricated and it is composed by a CLT 14 cm thick panel, a insulation layer and a cladding system easily mountable. There are 2 different type of facade due the necessity to provide stiffness to the glulam columns grid.
The other type of facade is not in direct contact with the columns and does not have structural role. For this reason is highly glass composed and has the characteristic of a curtain wall.

Figure 81: Velux- wood based material: 70% wood and 30% concrete.

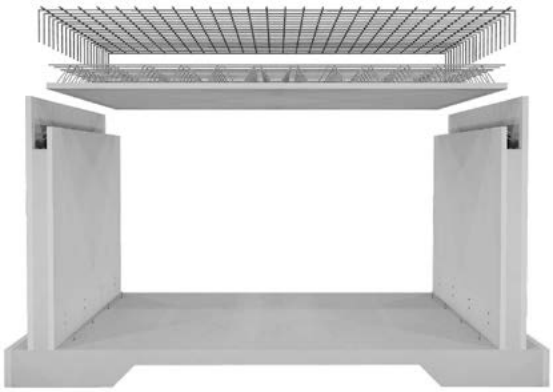


Figure 82: Schematic realization of the prefabricated concrete core.

Figure 83: Example of ERNE prefabricated concrete + glulam beams floors.

3.4.6 THE APPLICATION OF THE STRUCTURAL SYSTEMS

Apply the Structural concept was not immediate and there were several step back in order to arrange all the building elements. These 2 images shows the possible horizontal section in the building construction process of the building where the bottom part is completed and the tower part is on going.
The general structural plan will be with all the gravity and lateral system elements exposed with the columns waiting the next floor system to be placed.

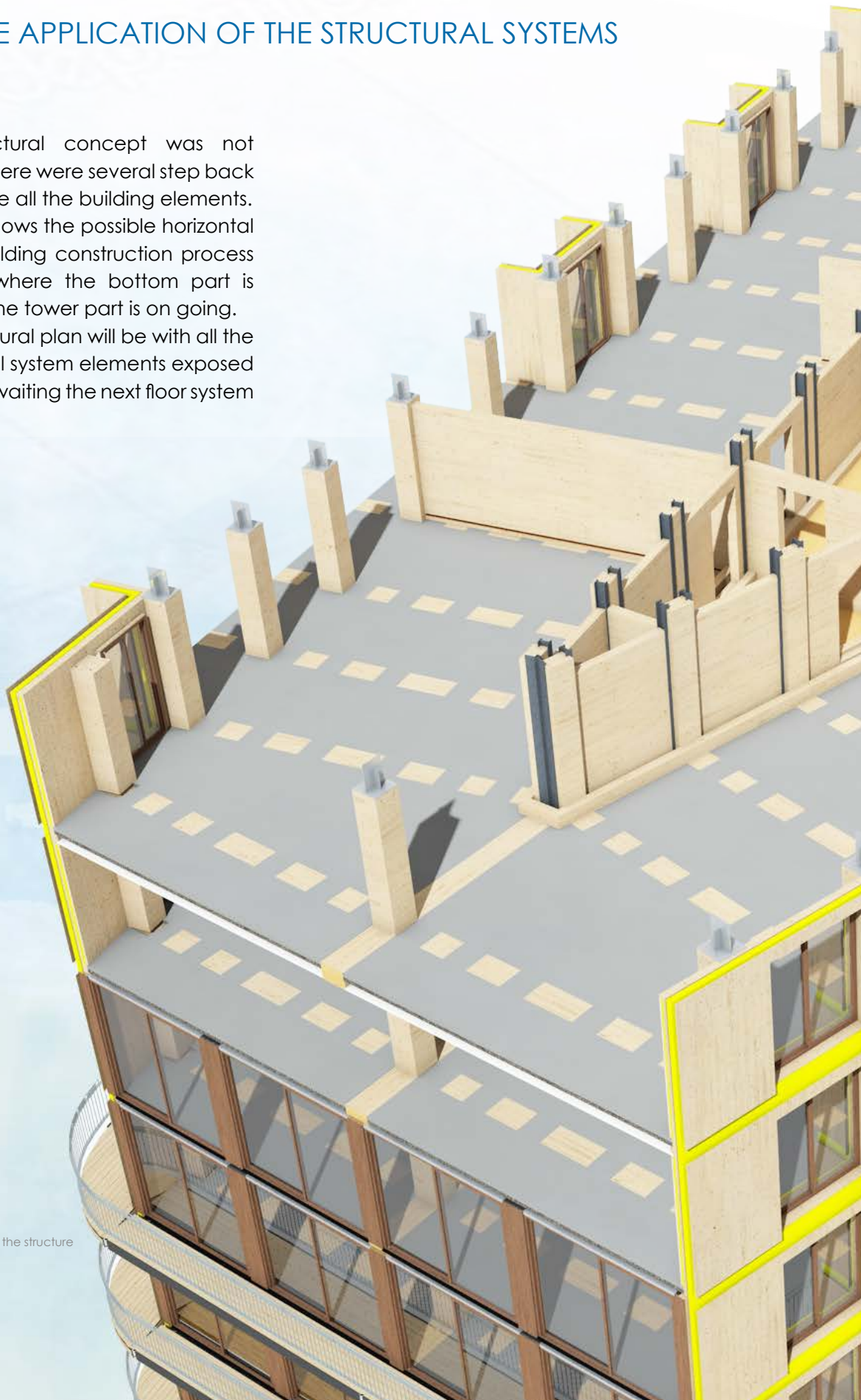


Figure 84: Perspective view of the structure

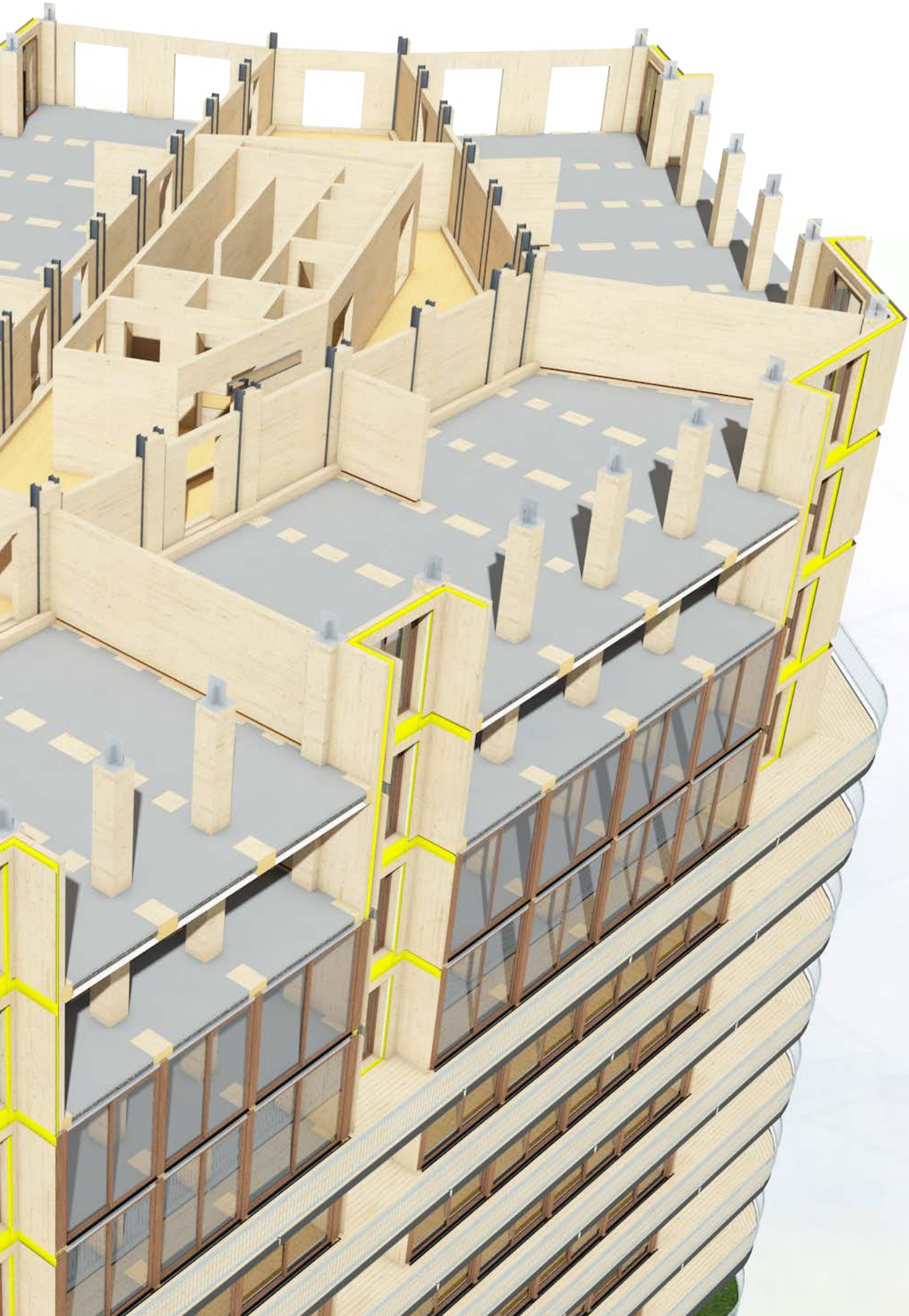
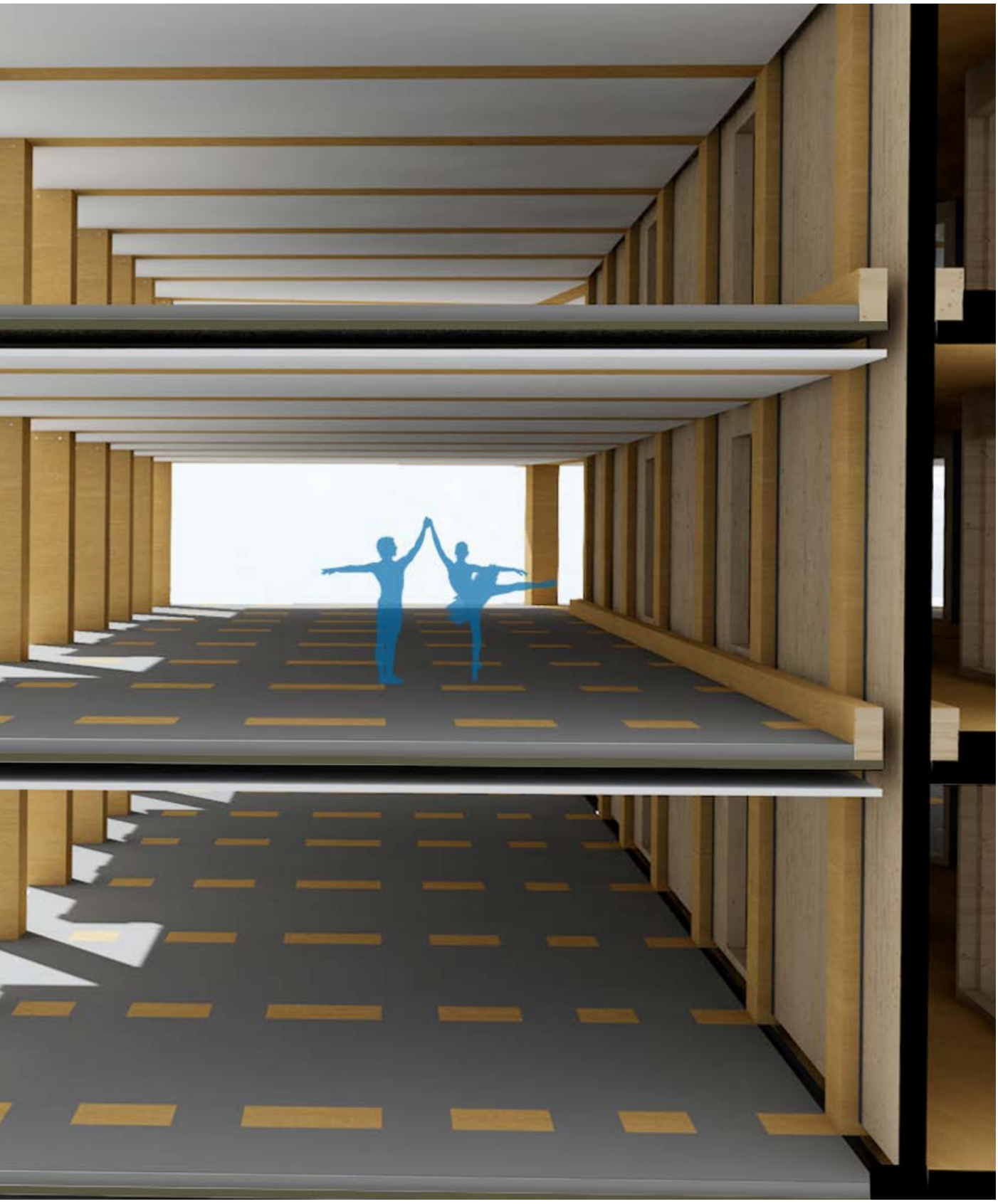


Figure 85: Perspective view of the structure - The shear /facade part

Figure 86, 87: Perspective section of the structure, general and detailed



3.4.7 STRUCTURAL CONSIDERATIONS RELATED TO FIRE

The main questions regarding fire were: what is allowed by current buildings codes? What is required to satisfy those codes? How is performance based design and fire engineering currently used, and what are the opportunities for these approaches in tall wood structure?

Austrian Building Code

Building a Tall wood is possible in Austria. The case of Hoho Tower (that at the time of this Thesis is under construction) simplifies the topic. The main difference between Hoho tower and the Thesis project is the core: Hoho Tower has a 24 storeys core totally in concrete, the Thesis project core is around one-third concrete and two-third Mass Timber.
Another difference is the fire strategy. Hoho Tower will use a charring approach meanwhile the Thesis project will opt for a partial encapsulation of the ceiling, leaving the columns and the beams exposed.

Encapsulation

To achieve a full grade of safety in Mass Timber structures the best option is consider a full encapsulation of the structure.
As we saw in the chapter *1.4 Challenges for Tall Wood*, there are several possible grade of encapsulation which will guarantee a certain level of fire safety.
Beside the glulam beams, the floor system adopted is provided with a wood-concrete material which it will be not visible form the interior flat because covered by a layer of air space and a 5 cm panel for heating and acoustic. The floor therefore will be encapsulated.
Also the shear walls of the flats are designed to be encapsulated. Beside the architectural choice, there is also the necessity to create fire compartment in the building. For this reason the shear walls, which are disposed in a regular distance between each other, will have the role not only of flat separation, but also as fire compartment walls.

Charring approach

The element that will be exposed are the glulam columns and the glulam beams.
The double columns are 50cm x 25cm each, so they will form a unique column of 50x50cm. The span, the distances between column and the characteristics of the glulam material can maybe guarantee good performance also with a different section (40cm x 20 cm each).
In this order was consider to design the columns with an extra 10 cm layer in order to guarantee a REI90 fire resistance level.
The same consideration was made for the glulam beams of the floor system.
Oversize the beams section will guarantee again REI90 fire resistance and will allow beams and columns to be exposed inside the flat.
Fundamental care has to be taken in the design of the steel connection. Steel connections have to be protected by the glulam in order to be not attached by the fire before the time requested by law.
There are already several realized examples which hide the steel connection element in the column-to-column and column-to-beam junctions.

Sprinkler system

In order to guarantee the highest defence against fire, an automatic sprinkler system was designed.

Figure 88: Fire emergency plan scheme

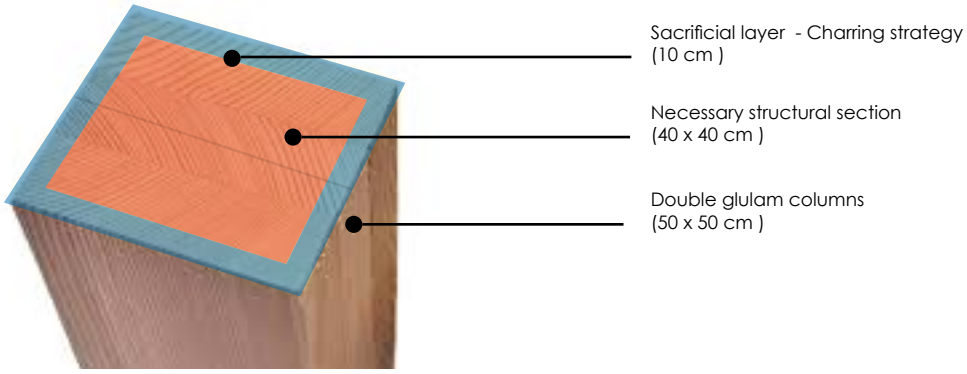


Figure 89: Charring approach of the structural element

3.4.8 BUILDING PROCESS CONSIDERATIONS

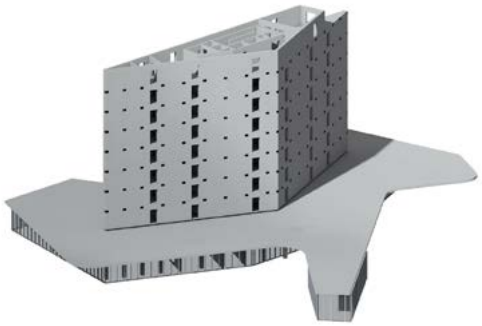
The erection system is an effective aspect architects have to challenge the typical structural erection systems for concrete and steel.
Construction considerations, cost competitiveness and technology will play a large part in determining the success of Mass Timber as a structural material for use in high-rise buildings
The construction industry already obtained great results in prefabricated Mass Timber house assembly but the challenges to face high-rise Mass Timber building must still be faced properly.
Regarding the cases studied in the research part of the thesis, it is clear how logistics including procuring, shipping, handling, scheduling and managing the construction process must precisely thought through and carefully programmed.
Total construction cost relates to schedule, material, labour, tolerances and required equipment. Each of these element needs to be developed and refined to result in a cost competitive project.
The big challenge for architects today is understand all these construction principles and apply them in the detailing of the building. Prefabrication is in fact the main advantage of the Mass Timber Building but only if the process and the detailing of each of the pieces of the building are carefully done.

The chosen construction sequence

For the thesis project was considered a construction sequence following the characteristics designed for gravity and lateral loads
The main goal was to not erect entire central core of the building. The negative aspect of this choice made for example for LCT tower or for UBC Brock Commons is not optimization of time because a cantilever system has to be made twice, ones for the erection of the core, secondly for the erection of the rest of the building.
A 21 storeys core could be even more problematic for the context of the project.
Seeing the example of Port Living in Vancouver, a 2 part core, concrete and Mass timber seemed the most adequate.
In this way the primary structure formed by the core will be built and it will control the overall pace of construction. The secondary trades follow behind to avoid space conflict between operations and unions.

The construction phases

The imagined sequence to erect the building is described graphically on the right side of this page.
Starting from the concrete podium given by the competition phase, the entire prefabricated concrete core will be erected entirely and than the shafts will be used to complete the first part of the building.
From the 8th floor will start the erection of the 5 -storeys Mass Timber core which again will allows to build the first part of the tower.
This process will take place 3 times more and than the structure of the building will be completed, waiting for the finishing and for the prefabricated terraces.



PHASE 1 - CONCRETE CORE

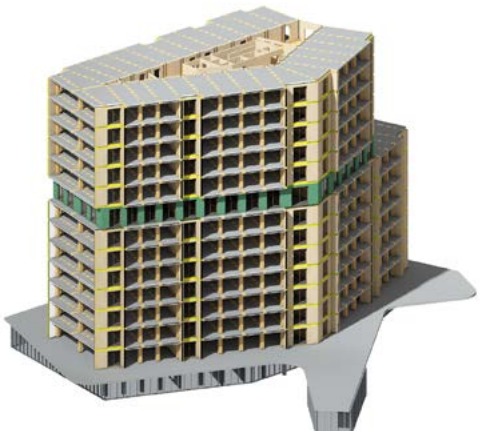
The prefabricated concrete core will be realized after the common underground core and ground floor.

PHASE 2 - STRUCTURE FIRST PART

The concrete shaft is used to easily carry up columns and provide logistic help.

PHASE 3 - MASS TIMBER CORE PART 1

Only the Mass Timber walls, glulam 5-story with the steel connectors are lifted up.



PHASE 4 - STRUCTURE SECOND PART

The rest of the second part of the structure is completed floor-by-floor until the end of the 5 storey first part of the Mass Timber core.

PHASE 5 - MASS TIMBER CORE PART 2

Only the Mass Timber walls, glulam 5-story with the steel connectors are lifted up.

PHASE 6 - STRUCTURE THIRD PART

The rest of the third part of the structure is completed floor-by-floor until the end of the 5 storey second part of the Mass Timber core.

PHASE 7 - MASS TIMBER CORE PART 3

The last part of the Mass Timber core is completed also with the ceiling part to cover the core.

PHASE 8 - STRUCTURE FORTH PART

Meanwhile the last part of the structure is completed, the architectural elements are placed in the first part of the building.

PHASE 9 - STRUCTURE AND ARCHITECTURE PART COMPLETED

In order to protect the structure from the weather the architectural elements will be immediately placed. Terraces, handrail, finished floor and walls, and green roofs will be realized.

3.5 ARCHITECTURAL CONSIDERATIONS

The architectural design overview

The architectural design consists mainly in the design of middle sizes flats.
The aim of the architectural part is to match the existing program unit types, layouts and quantities. The design has been modified to adequate the flats to the new structural system and dimensions.

The core

The core of the Competition project was designed for a floor-to-floor height of 2,8 meters and for a different structural behaviour in comparison to the wood one.
The main goal was to maximize the rental area and make the corridor as efficient as possible.
The Thesis Project is composed of a two-part core which has different building characteristics. What they have in common is the number of elevator shafts, the two emergency stairs and some technical cavity.
The change in floor-to-floor height needed to enlarge the length of the stairs with 2 additional steps.
The Mass Timber part of the core is thought as CLT panels already provided with a double layer gypsum covering to protect the structure from fire and moisture.
Every CLT panel has a steel frame to connect them to the steel bars in the core.

Encapsulation approach

Columns and beams of the structural part are left exposed with charring method.
The other walls are designed as covered by a layer of gypsum board.
The shear walls A, the longer, which have the role of perimeter of fire compartment, will have instead 2 layer of gypsum board in order to increase the fire resistance.
The floor system is designed to have space inside to locate cables and tubes for the building system. The choice to not expose the wood part is due 3 motifs:
1) Structural CLT panels are not made to be exposed, therefore they are not aesthetically treated. Some companies could provide the last layer with better quality wood but it will cost more, and the aim of the Thesis is to provide feasible economical solutions
2) Structural CLT cracks. It happens for a structural motif and is normal and well-known but it could be possible that over time cracks will appear in the ceiling. This could be a problem for some people and it could cause complaints.
3) The possible solution will be a sort of lie. As made already in *Cube Haus* in Hamburg, the ceiling could be composed of a suspended ceiling with a wood panels in the exposed layer. This solution creates undoubtedly an aesthetic solution for the flat but it will increase the floor-to-floor height, that has been increased.
For this reason the floor was intended as a combination of beams and suspended ceiling which guarantee the technical space and save space in the floor in order to achieve 3m floor-to-floor height.

Additional architectural choices

One of the main topic of the external facade treatment in the Competition Project was the underlining of the Loggia cavity thanks to another cladding material (in that case a green mosaic cladding) that was also used intensively in the 8th floor. The rest of the external walls are thought as black plaster.
What could be interesting instead is the use of wood cladding while keeping the same differentiation between loggia cavity-

Figure 90: Perspective view of the Tall Wood project in the competition context

external walls.
For the loggia cavity could be possible to use an untreated Cedar panel, with a light appearance. The choice to use a incombustible material in the cladding could be possible because a sprinkler system is already consider in the interior building services design and then it will be possible have also have he exterior of the building sprinkled. In fact, it is possible to have a Class B combustible material in Austria if there is a sprinkler system for the facade (ONORM 15061-1).

Exterior wall design

Figure 91: Green mosaic of the 8th external wall.

If the exterior walls in the loggia are designed as prefabricated structural walls, the other type of exterior are free to be designed with the maximum glass surface possible.
The motif is due their not structural task and due the fact they could be hanged to the structural floor continuing after the columns row.
The exterior walls have therefore big openable sliding windows, they are thinner in comparison with the Competition project, and they have a layer of insulation where the terraces will be attached.

Terraces

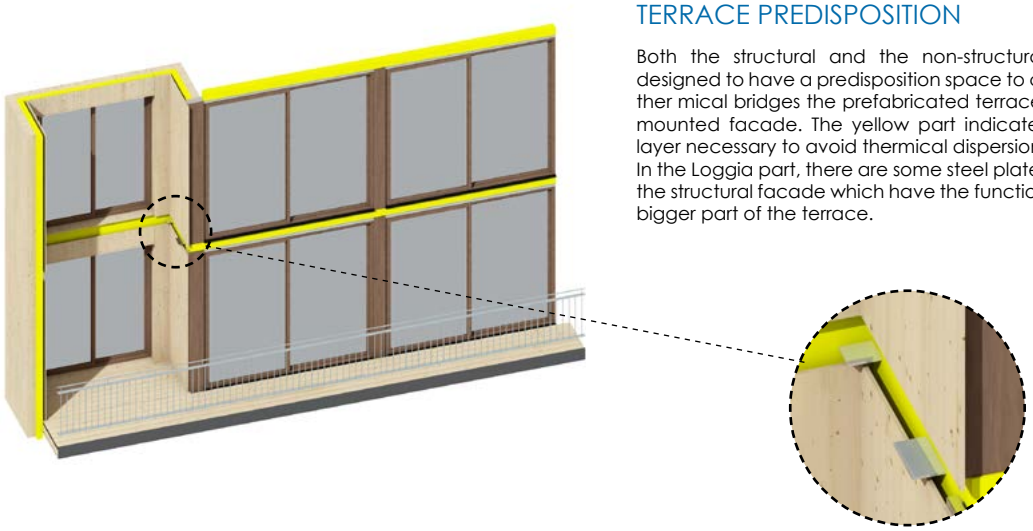
Terraces characterize visually the Competition project. They run all over the external walls and they became bigger in where they meet the loggia offset.
In the Competition project, terraces were thought as prefabricated concrete which will be attached to the structural facade in a second moment.
Also in the Thesis project, they are considered as prefabricated but made out of Mass Timber.
The project *Strandparken Hus* B in Sweden have hanging prefabricated wood terraces which are similar to the designed ones.
Wood Cube in Hamburg has instead attached prefabricated terraces, but they are bigger in comparison with the Thesis project.
These project show that prefabricated wood terraces are possible and if the connection and the detailing are designed well they are not vulnerable against moisture and water.

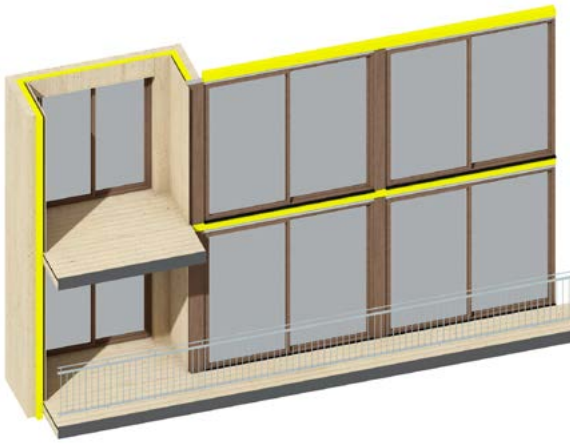
Acoustical Considerations

Wood is not a good sound-proof material.
The floor system proposed is thought with a layer of 8 cm of wood-concrete material which has, beside a good acoustic resistance, an irregular surface which increase the acoustical behaviour.
In addition to this there is an air cavity between the Velux material and the heating panel where cables and wires pass but where the sound coming from the rooms could be mitigate.
The finishing consist in 13 cm thick additional total layer composed by
- 3 cm acoustical insulation;
- 6,5 cm of air space created by a layer of double pavement which guarantee space for wires and cables
- 3,5 cm of pavement with parquet covering.
It will be necessary verify instead the sound transmission thought the exposed beams and in the through the beam-column connection.

TERRACE PREDISPOSITION

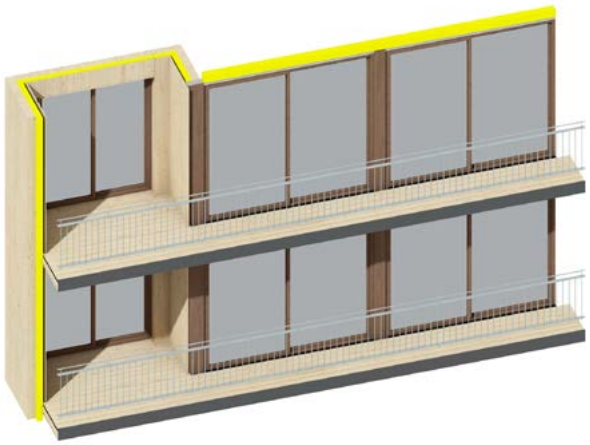
Both the structural and the non-structural façades are designed to have a predisposition space to connect without ther mical bridges the prefabricated terrace to the already mounted facade. The yellow part indicates the insulation layer necessary to avoid thermical dispersions.
In the Loggia part, there are some steel plates connected to the structural facade which have the function to support the bigger part of the terrace.





TERRACE COLLOCATION 1

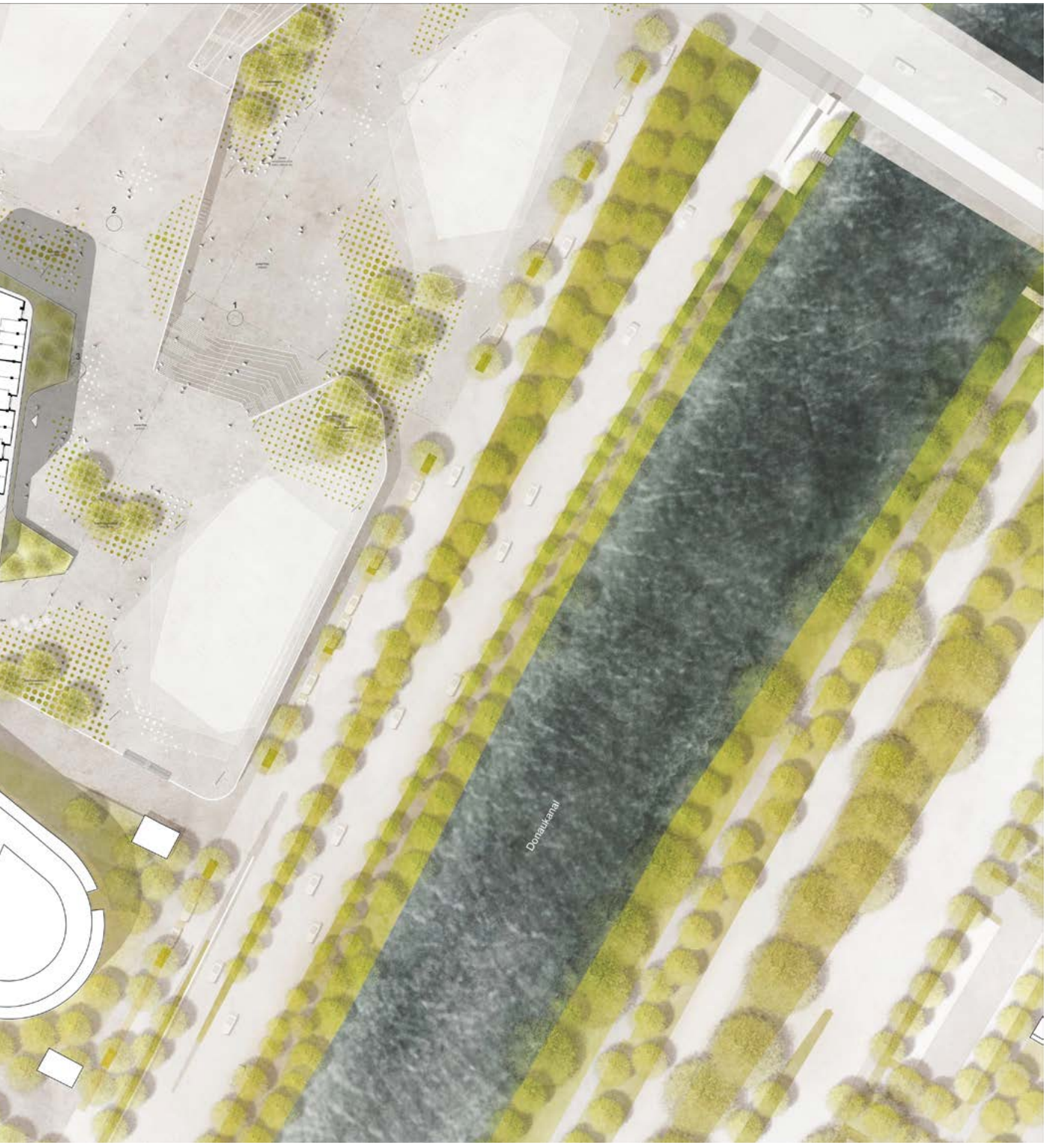
The prefabricated terrace is thought in 2 type: a big one located in every loggia, and another of 80 cm large.
The hypothesis is to located the big prefabricated terrace at first in the relative steel connector in the structural facade.



TERRACE COLLOCATION 2

The second type of the terrace could be located after the big one, connected to the floor system passing though the insulation layer of the non-structural facade.
The handrail will then be mounted and will be possible mount another terrace.

3.5.1 PLANS


Donaukanal

2ND TO 7TH FLOOR

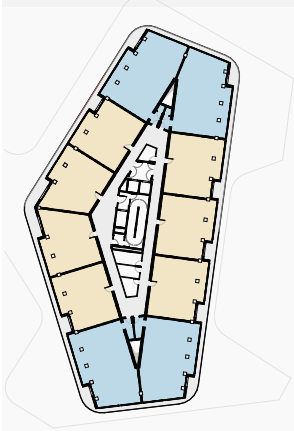
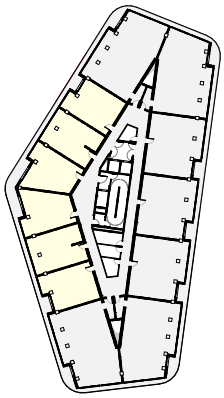
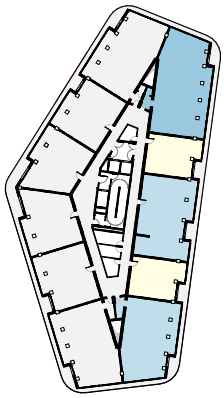
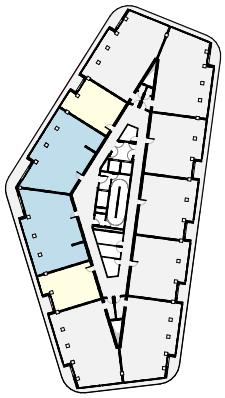
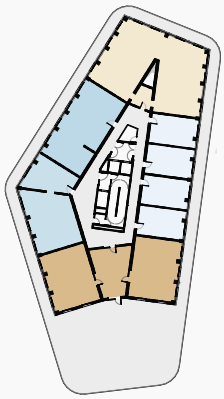
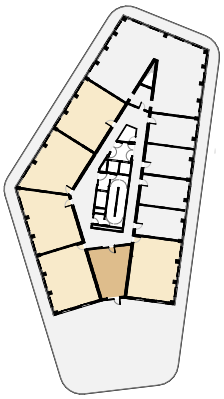
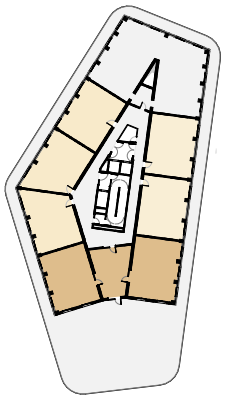
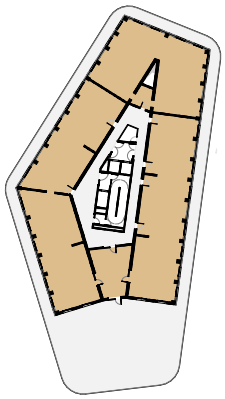
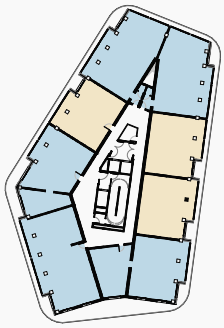
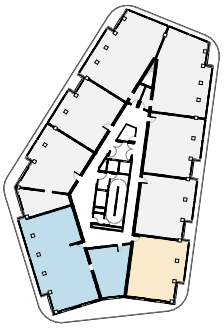
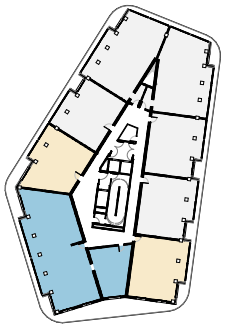
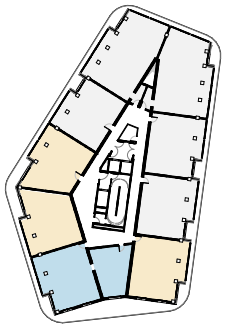
180 m² - Student shared flat
95 m² - Student shared flat
35 m² - Rentable guests flat
Sharing spaces
0
5
10

8TH FLOOR

9TH TO 21ST FLOOR PLAN

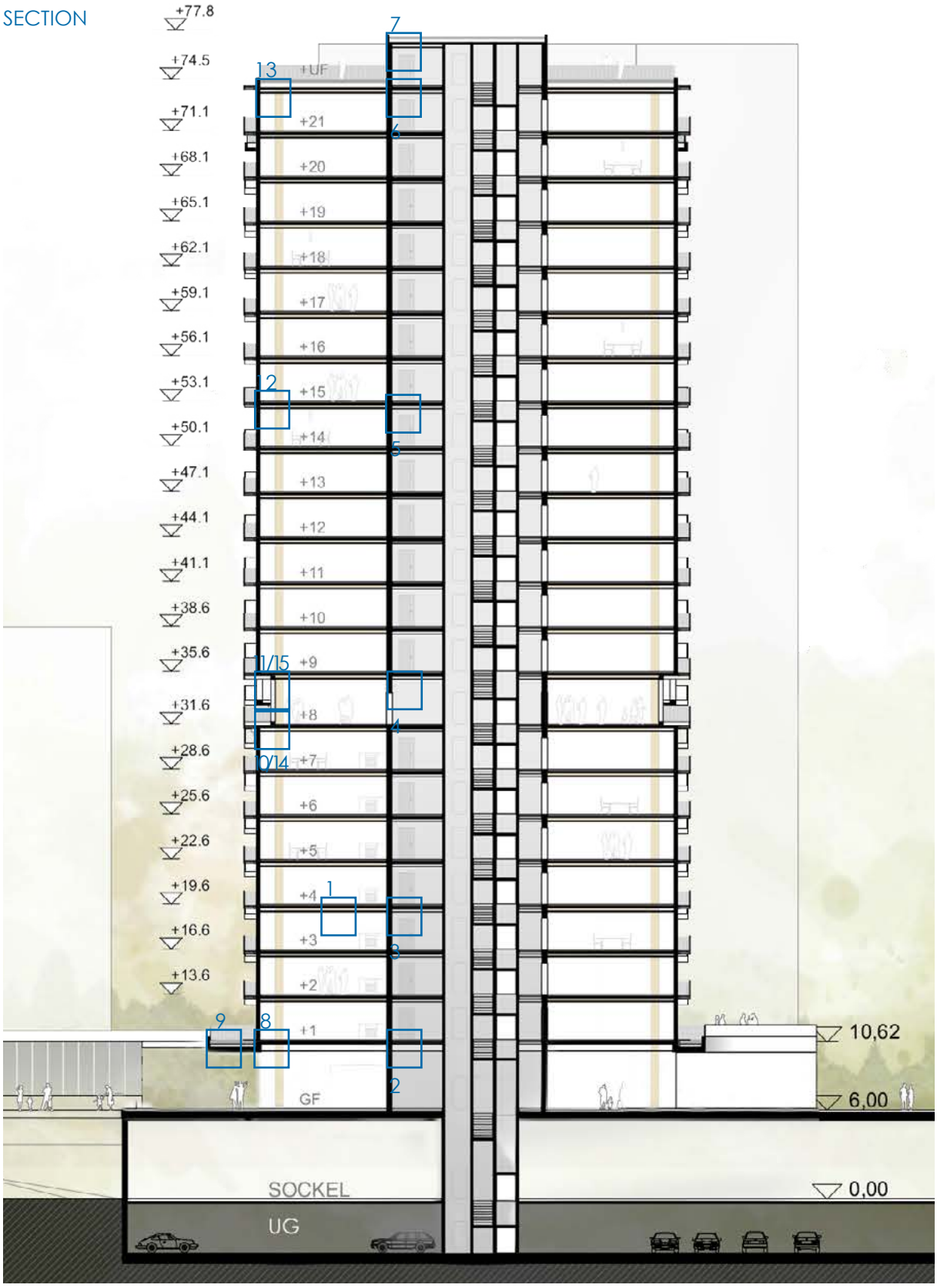
FLEXIBILITY OF THE PLANS

The structure can guarantee a good level of flexibility. The shear walls could be considered with holes that in a second moment could be open for other plan layout.

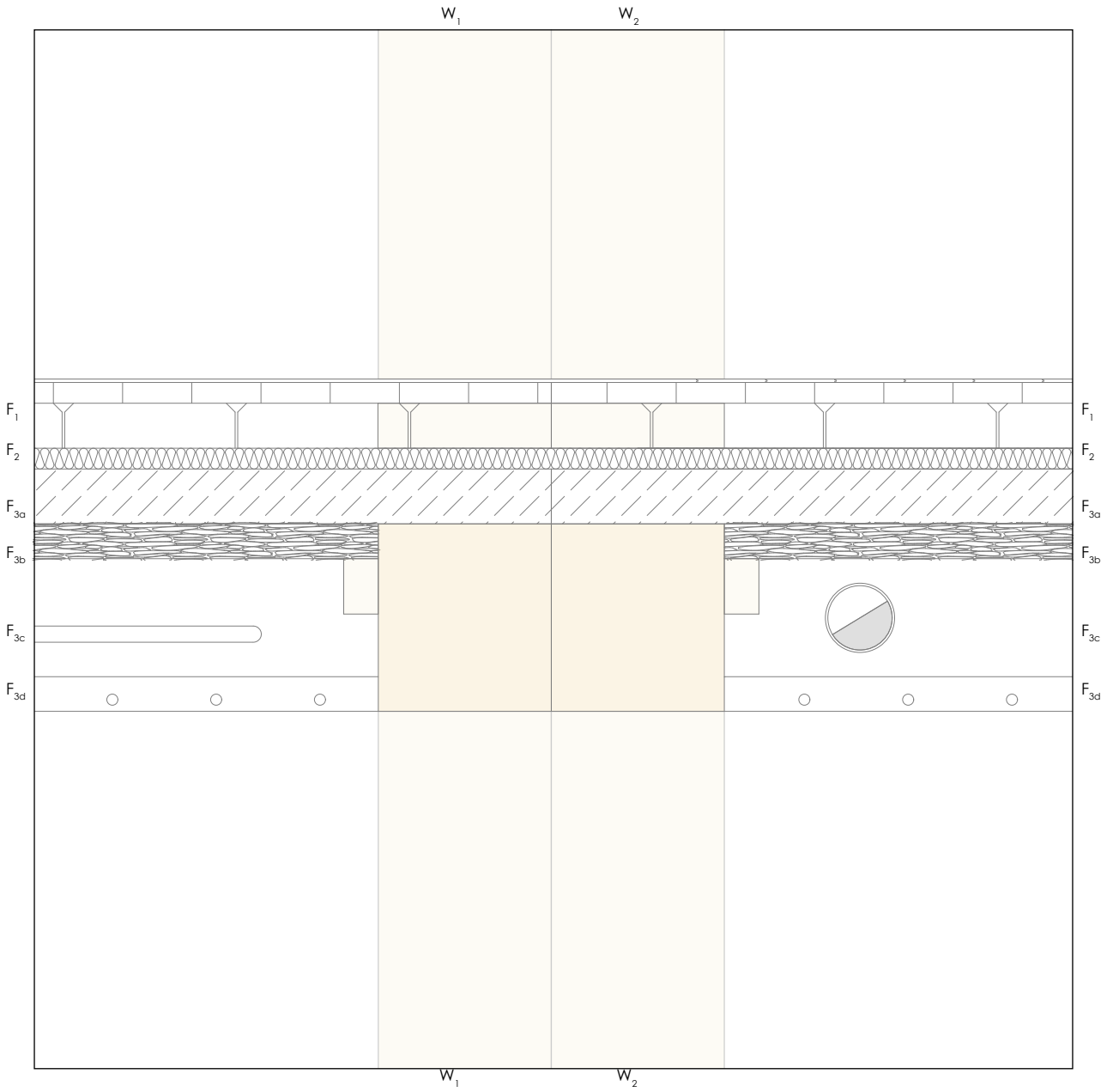
Original plan	Possible combinations		
 1st to 7th Floor			
 8th Floor			
 9th to 21st Floor			

3.5.2 TYPICAL DETAILS

SECTION



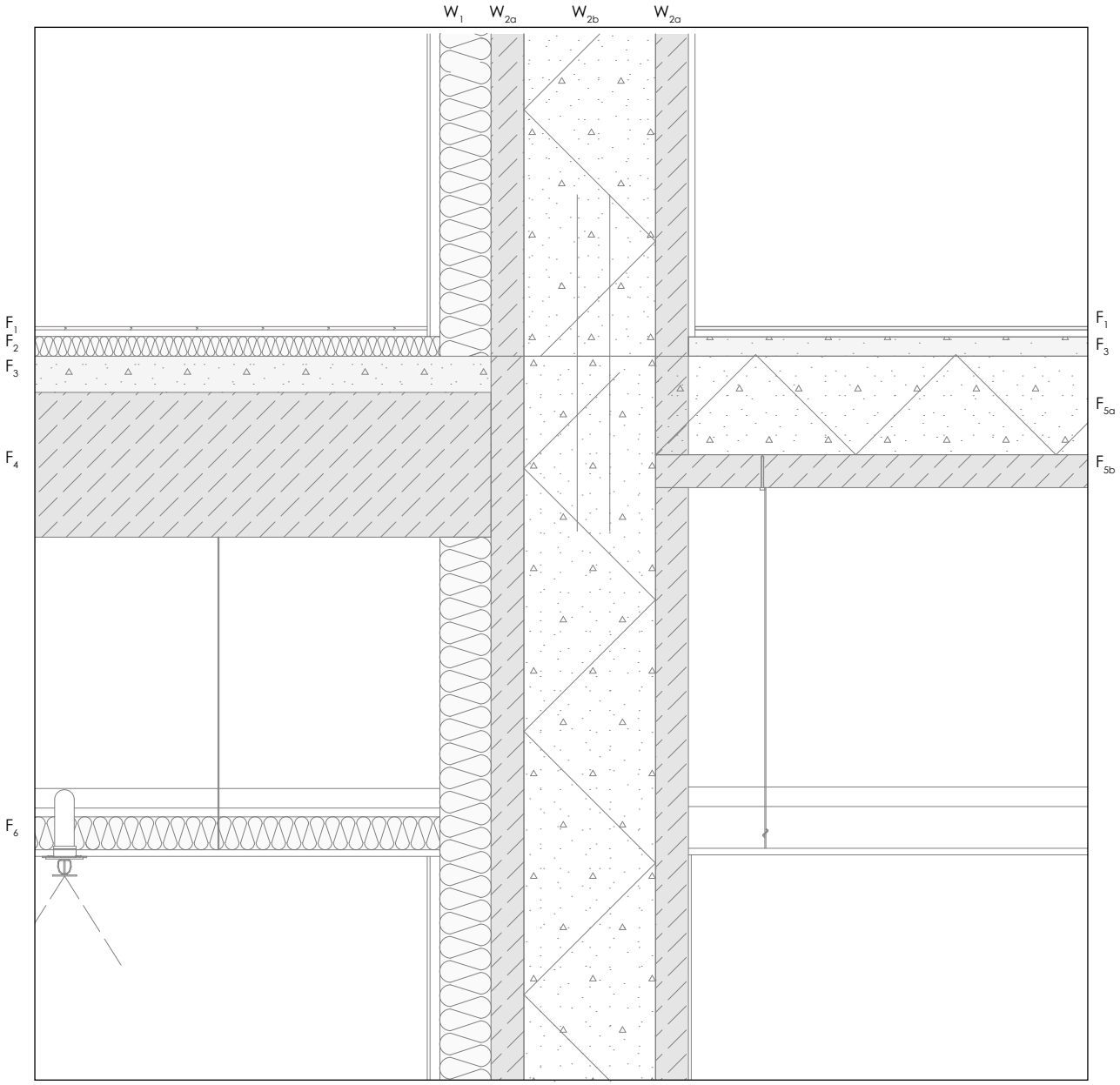
1. HYBRID TIMBER FLOOR



FLOOR
F_1: Finish floor - Parquet (1,5 cm)
F_2: Finish floor - Double floor with stabilizer and acoustical insulation
F_{3a}: Pre-fabricated floor: concrete layer (8 cm)
F_{3b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{3c}: Pre-fabricated floor: air space layer (17 cm)
F_{3d}: Pre-fabricated floor: multifunctional panel (5 cm)

COLUMNS
W_1: Glulam column1 (25 cm x 50 cm)
W_2: Glulam column1 (25 cm x 50 cm

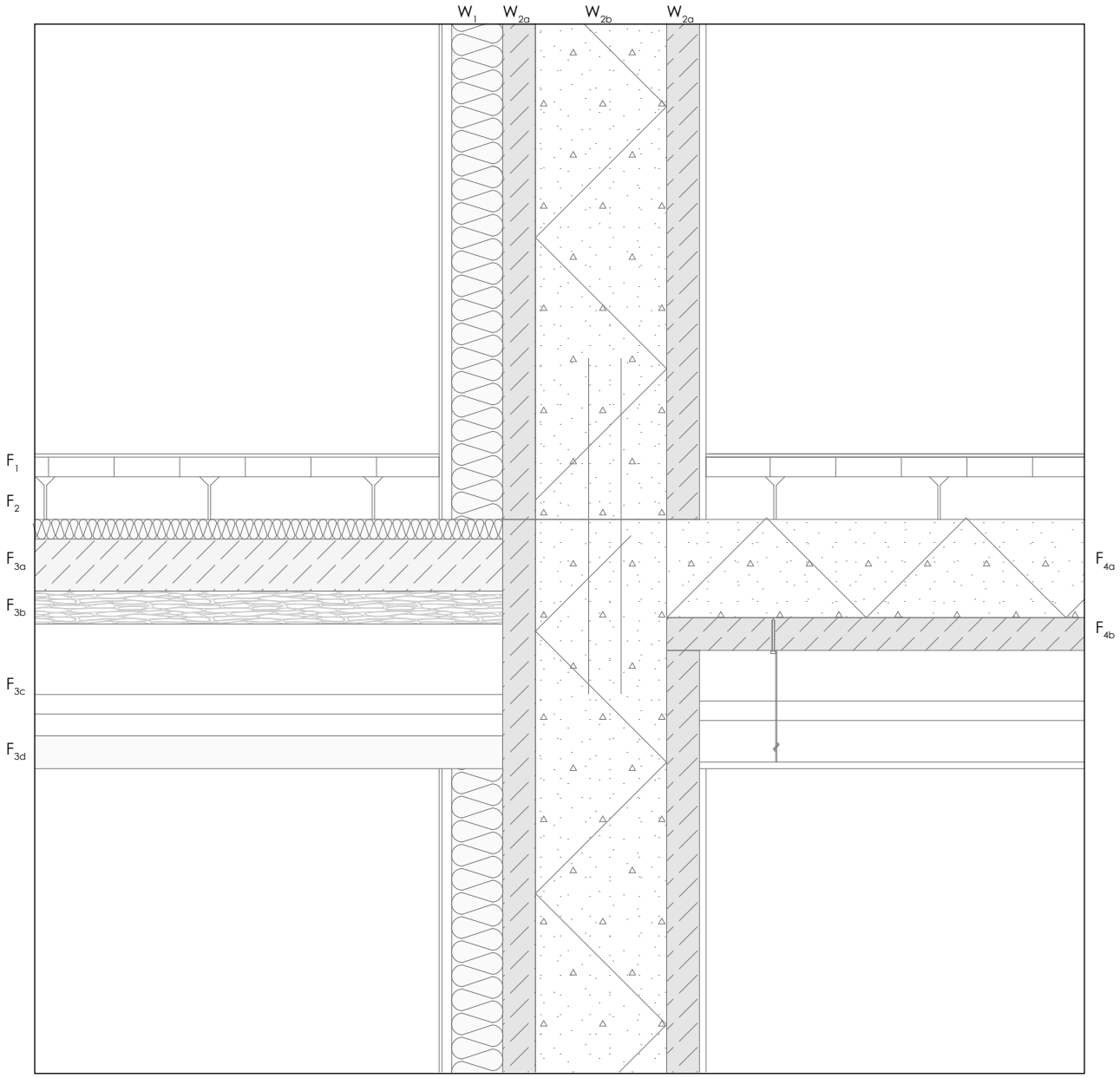
2. CONCRETE CORE - CONCRETE FLOOR



FLOOR
F_1: Finish floor
F_2: Insulation layer
F_3: Screed
F_4: Cast in place reinforced concrete floor
F_{5a}: Cast in place concrete floor
F_{5b}: Pre-cast concrete panel (5cm)
F_6: Finish ceiling - gypsum board and mineral wool insulation for sound absorption

WALL
W_1: Finish wall - gypsum board and insulation
W_{2a}: Pre-cast concrete panel (5cm)
W_{2b}: Cast in place concrete floor

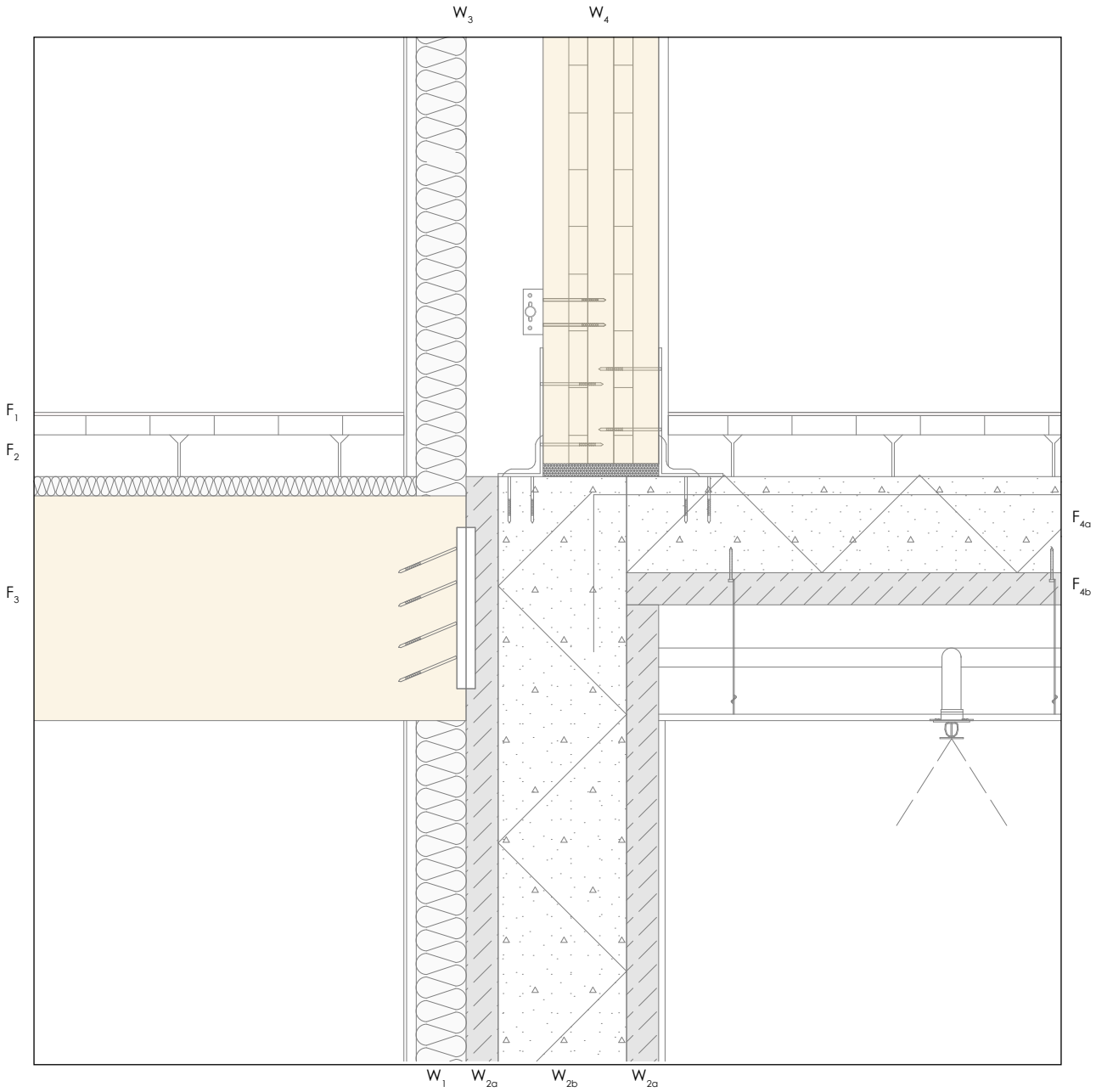
3. CONCRETE CORE - HYBRID TIMBER FLOOR



FLOOR
F_1: Finish floor - Parquet (1,5 cm)
F_2: Finish floor - Double floor with stabilizer and acoustical insulation
F_{3a}: Pre-fabricated floor: concrete layer (8 cm)
F_{3b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{3c}: Pre-fabricated floor: air space layer (17 cm)
F_{3d}: Pre-fabricated floor: multifunctional panel (5 cm)
F_{4a}: Cast in place concrete floor
F_{4a}: Pre-cast concrete panel (5cm)

WALL
W_1: Finish wall - gypsum board and insulation
W_{2a}: Pre-cast concrete panel (5cm)
W_{2b}: Cast in place concrete floor

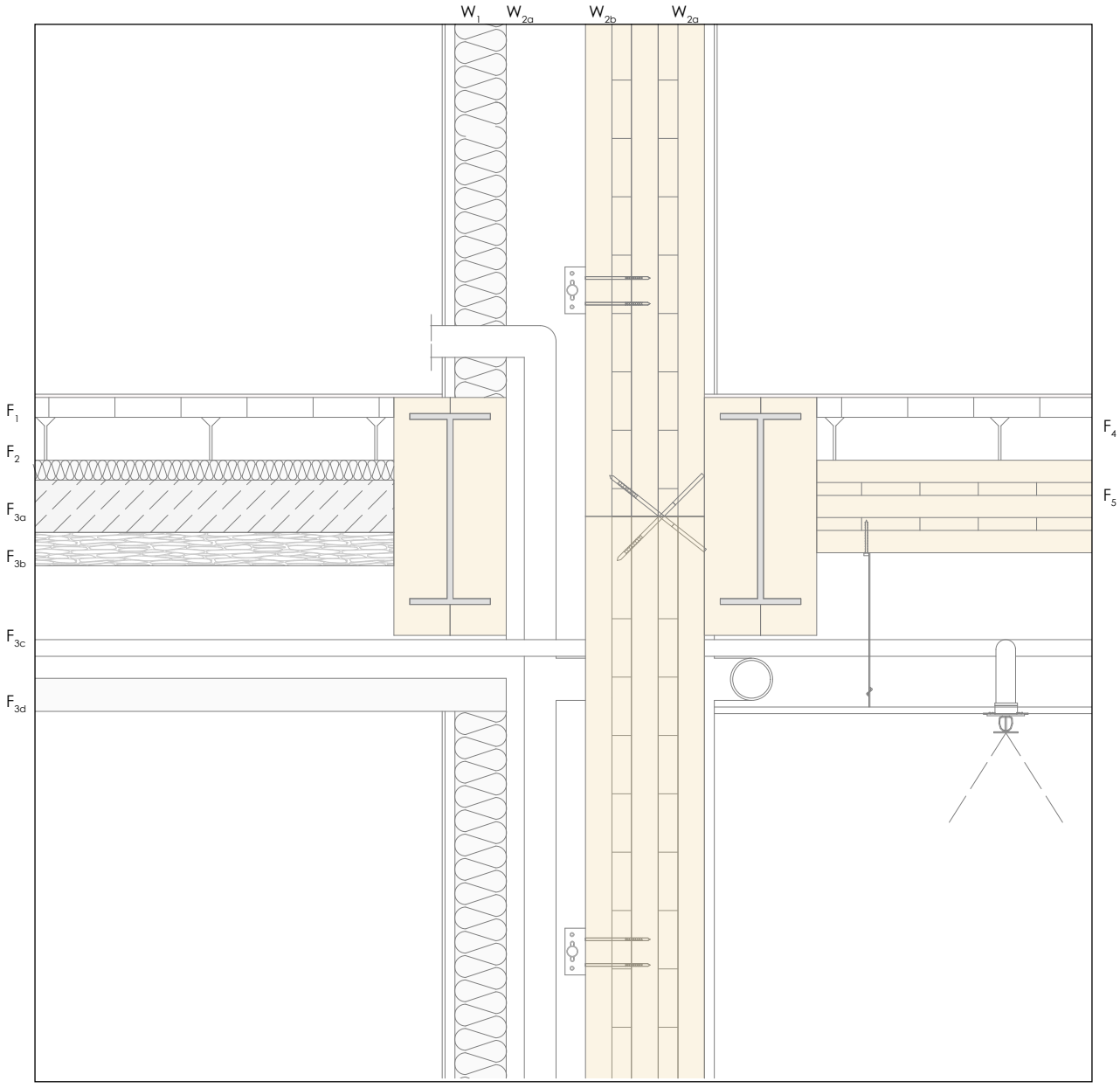
4. CONCRETE CORE - GLULAM BEAM



FLOOR
F_1: Finish floor - Parquet (1,5 cm)
F_2: Finish floor - Double floor with stabilizer and acoustical insulation
F_{3a}: Pre-fabricated floor: concrete layer (8 cm)
F_{3b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{3c}: Pre-fabricated floor: air space layer (17 cm)
F_{3d}: Pre-fabricated floor: multifunctional panel (5 cm)
F_{4a}: Cast in place concrete floor
F_{4a}: Pre-cast concrete panel (5cm)

WALL
W_1: Finish wall - gypsum board and insulation
W_{2a}: Pre-cast concrete panel (5cm)
W_{2b}: Cast in place concrete floor

5. MASS TIMBER CORE - HYBRID TIMBER FLOOR



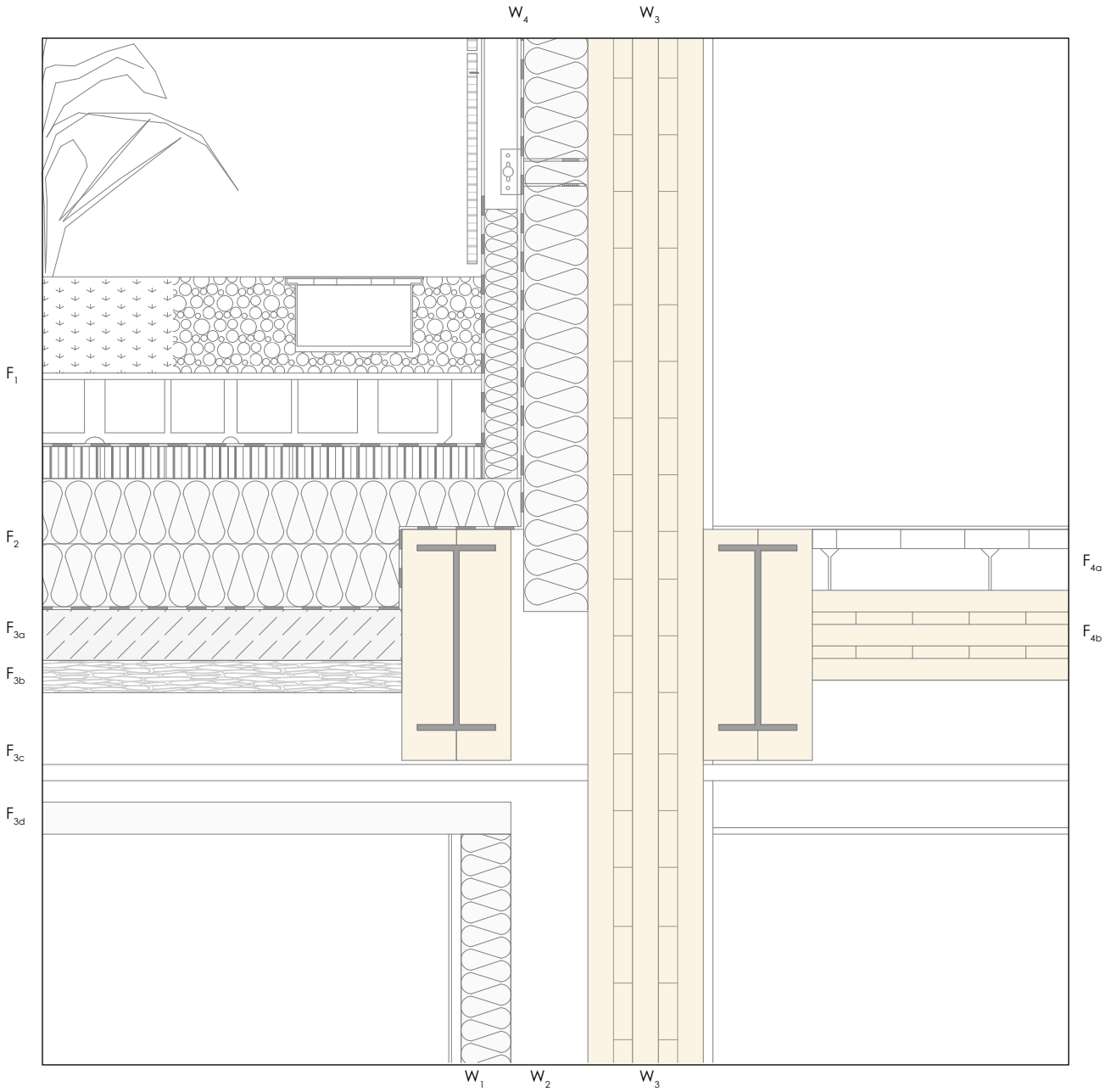
FLOOR

F_1: Finish floor - Parquet (1,5 cm)
F_2: Finish floor - Double floor with stabilizer and acoustical insulation
F_{3a}: Pre-fabricated floor: concrete layer (8 cm)
F_{3b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{3c}: Pre-fabricated floor: air space layer (17 cm)
F_{3d}: Pre-fabricated floor: multifunctional panel (5 cm)
F_{4a}: Cast in place concrete floor
F_{4a}: Pre-cast concrete panel (5cm)

WALL

W_1: Finish wall - gypsum board and insulation
W_{2a}: Pre-cast concrete panel (5cm)
W_{2b}: Cast in place concrete floor

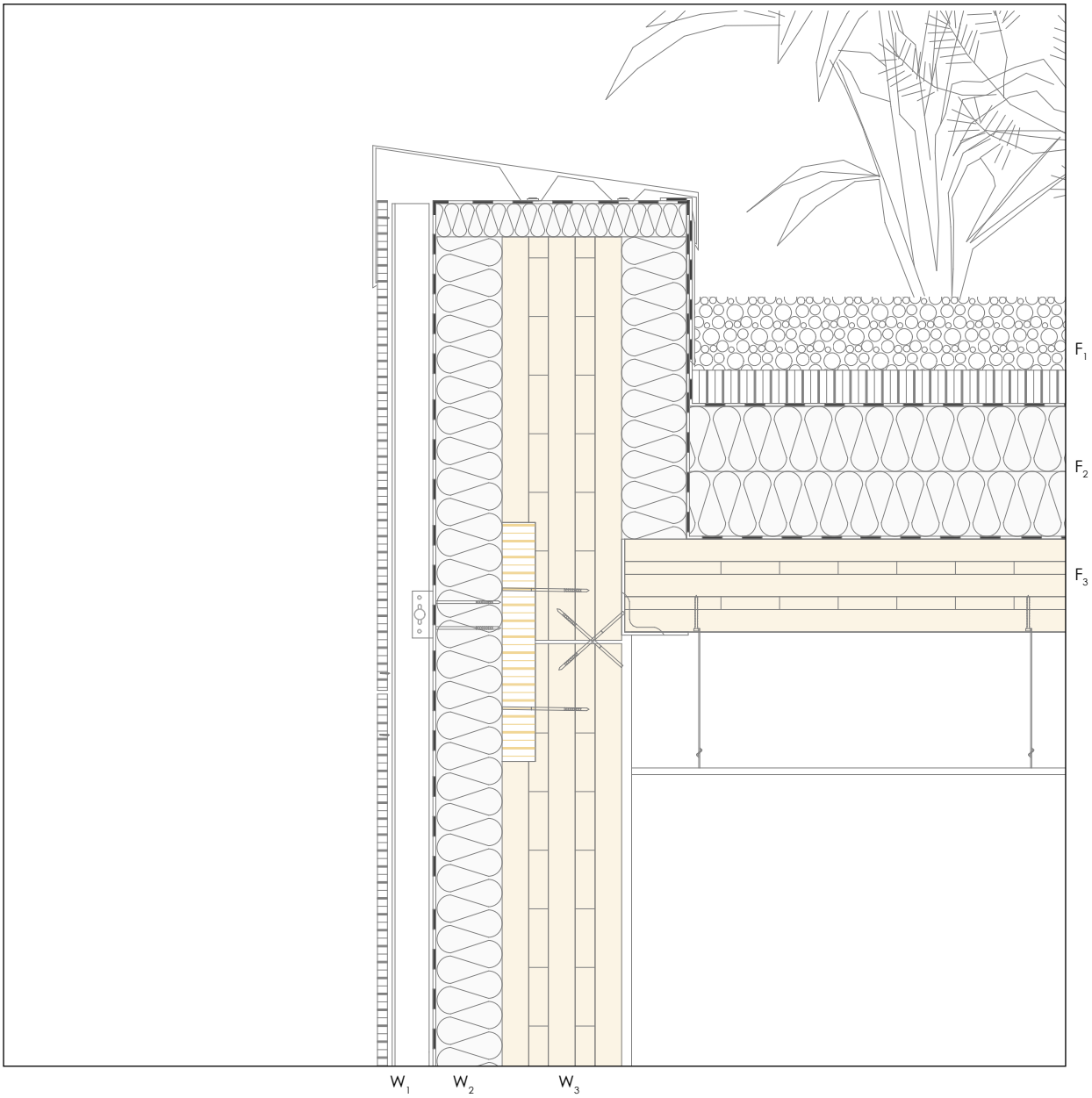
6. MASS TIMBER CORE - TOP FLOOR



FLOOR
F_1: External finish floor for green roof
F_2: Finish floor - Double insulation layer for green roof
F_{3a}: Pre-fabricated floor: concrete layer (8 cm)
F_{3b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{3c}: Pre-fabricated floor: air space layer (17 cm)
F_{3d}: Pre-fabricated floor: multifunctional panel (5 cm)
F_{4a}: Finish floor internal core
F_{4a}: CLT floor panel (14 cm)

WALL
W_1: Finish wall - gypsum board and insulation
W_2: Air space for building systems
W_3: CLT Mass Timber Core wall (18 cm)
W_4: External finish wall - external cladding and insulation

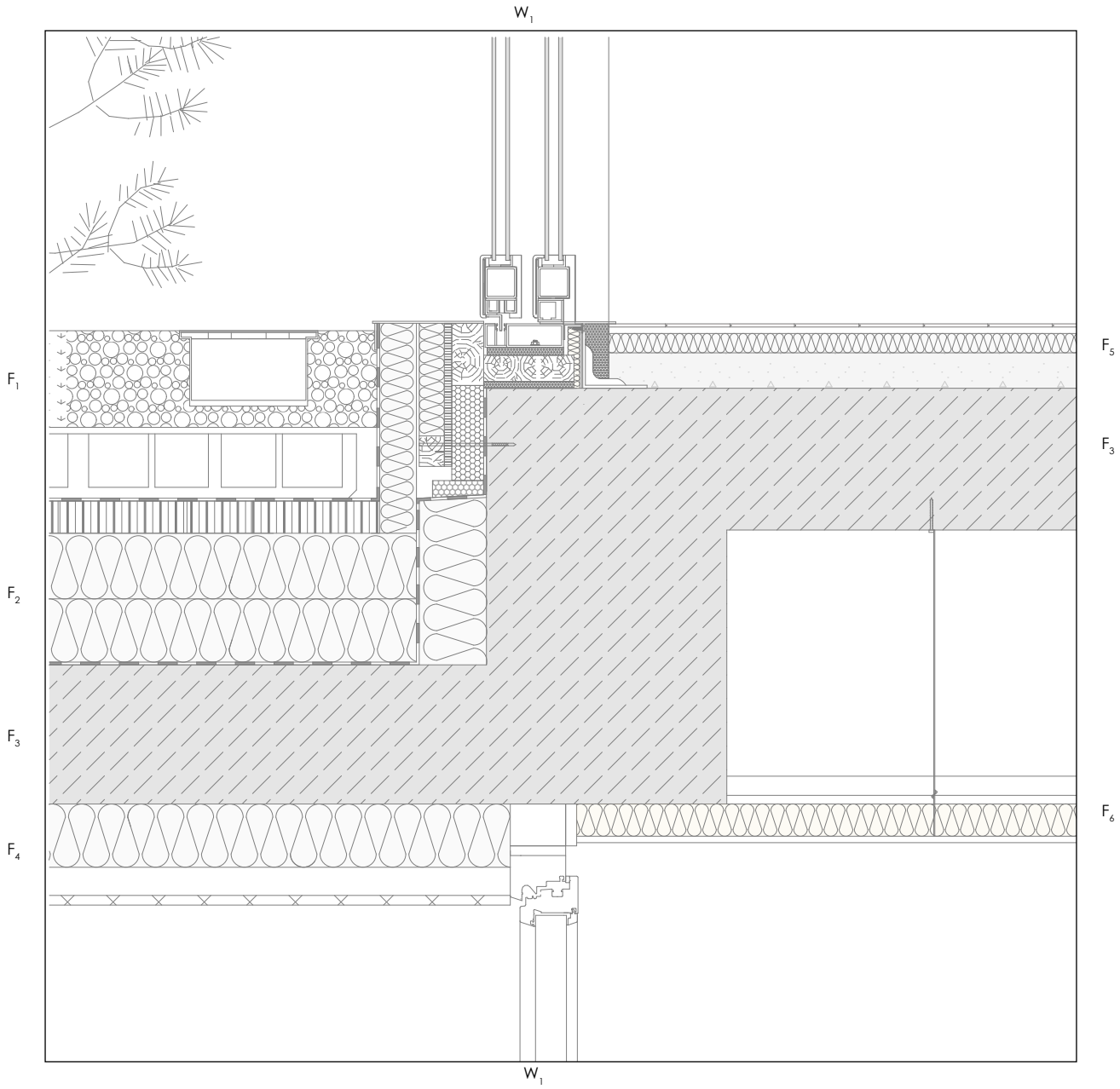
7. MASS TIMBER CORE ROOF



FLOOR
F_1: External finish floor for green roof
F_2: Finish floor - Double insulation layer for green roof
F_3: CLT floor panel (14 cm)

WALL
W_1: Finish wall - External finish wall - external cladding
W_2: Finish wall - Insulation
W_3: CLT Mass Timber Core wall (18 cm)

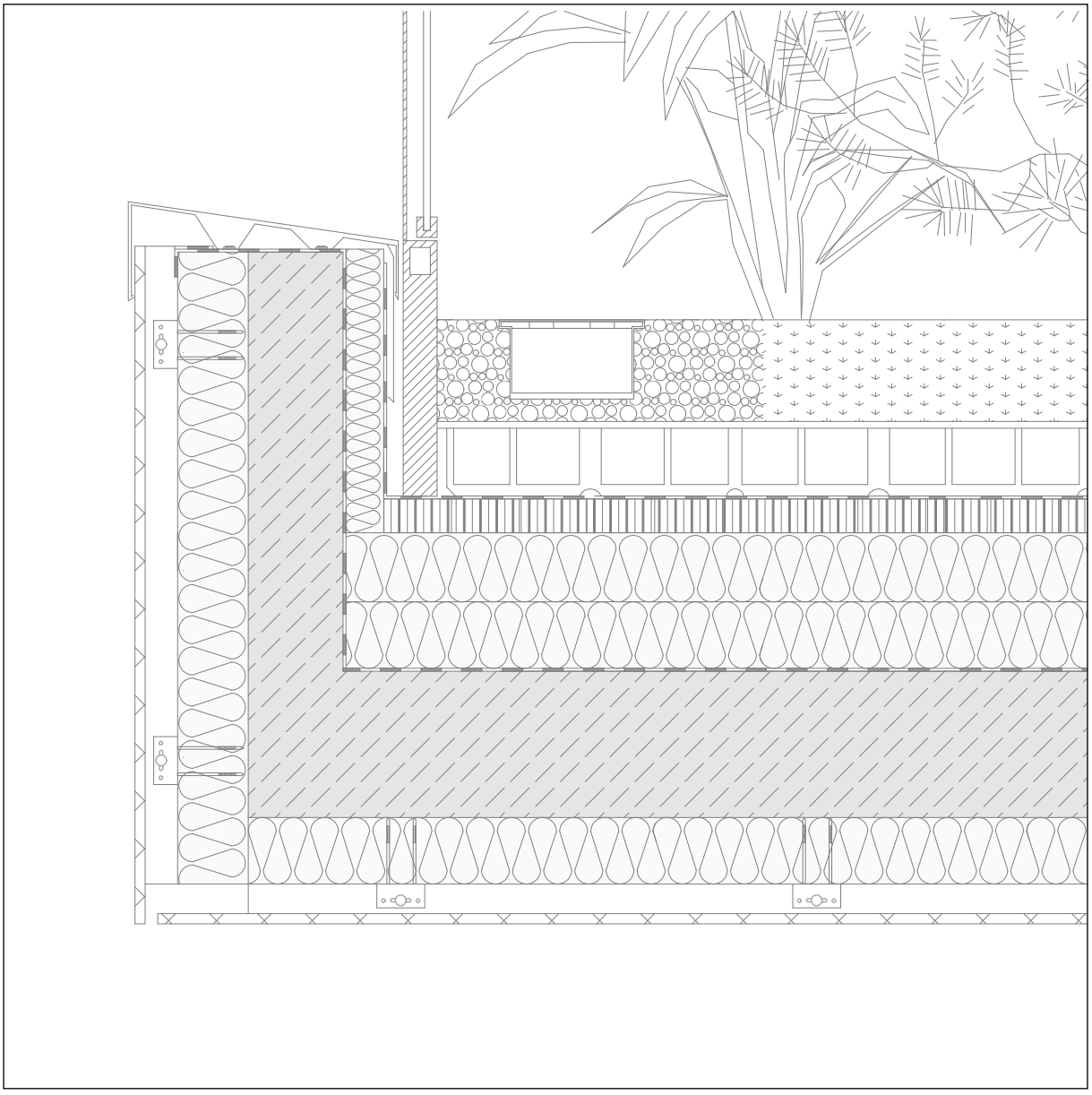
8. CONCRETE 1ST FLOOR



FLOOR
F_1: External finish floor for green roof
F_2: Finish floor - Double insulation layer for green roof
F_3: Concrete floor, ceiling of the ground floor
F_4: Finish cladding
F_5: Finish floor first floor
F_6: Finish claddind with acoustical insulation of the ground floor

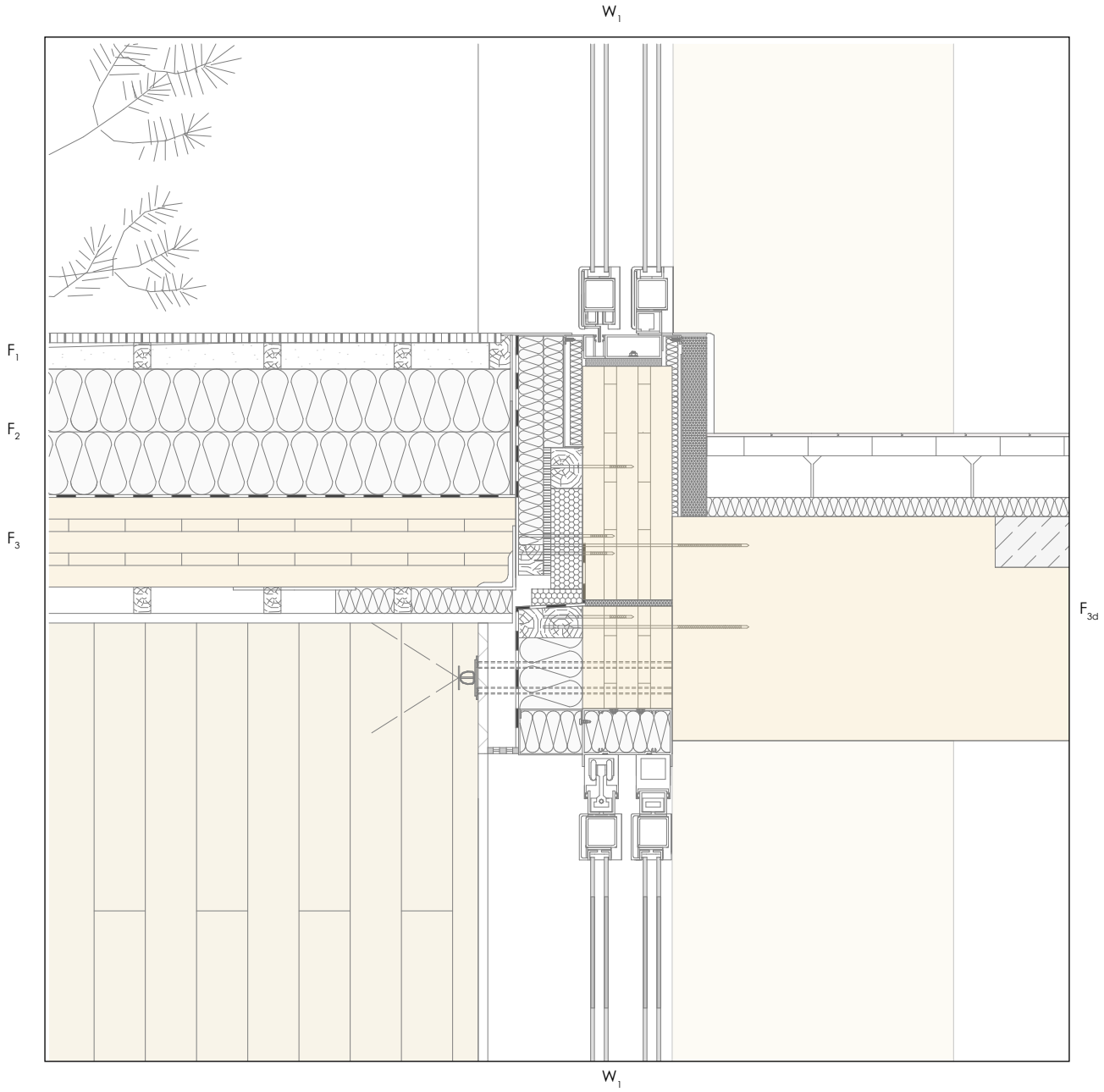
WALL
W_1: External windows of the ground floor
W_2: External sliding windows of the first floor

9. MASS TIMBER CORE ROOF



FLOOR
F_1: External finish floor for green roof
F_2: Finish floor - Double insulation layer for green roof
F_3: Concrete floor, ceiling of the ground floor
F_4: Finish cladding

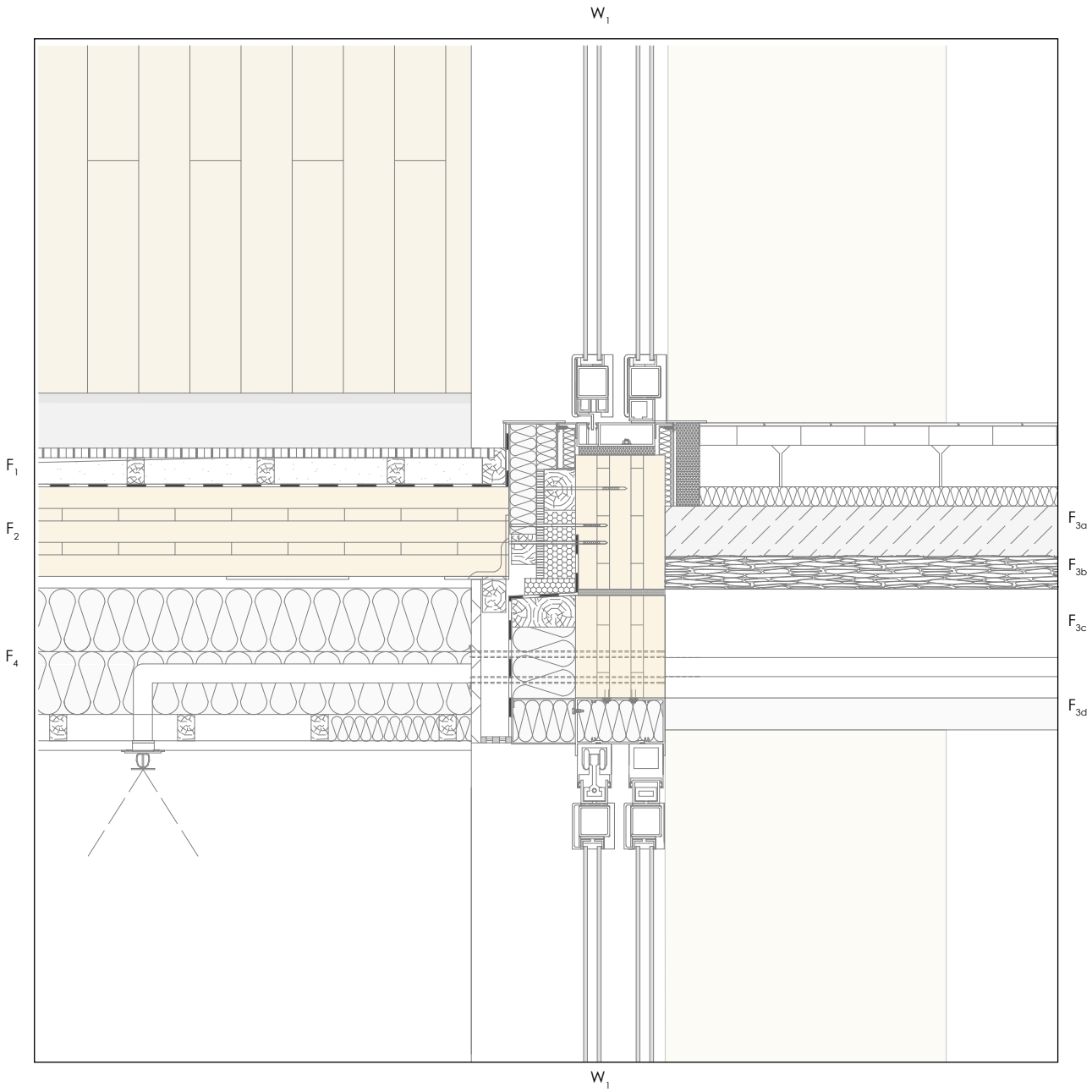
10. 8TH FLOOR - LOGGIA DETAIL



FLOOR
F_1: Finish floor Terrace
F_2: Thermal insulation of the external floor
F_3: Prefabricated CLT Terrace (14 cm)
F_5: Pre-fabricated floor: glulam beam (35cm)

WALL
W_1: External sliding window

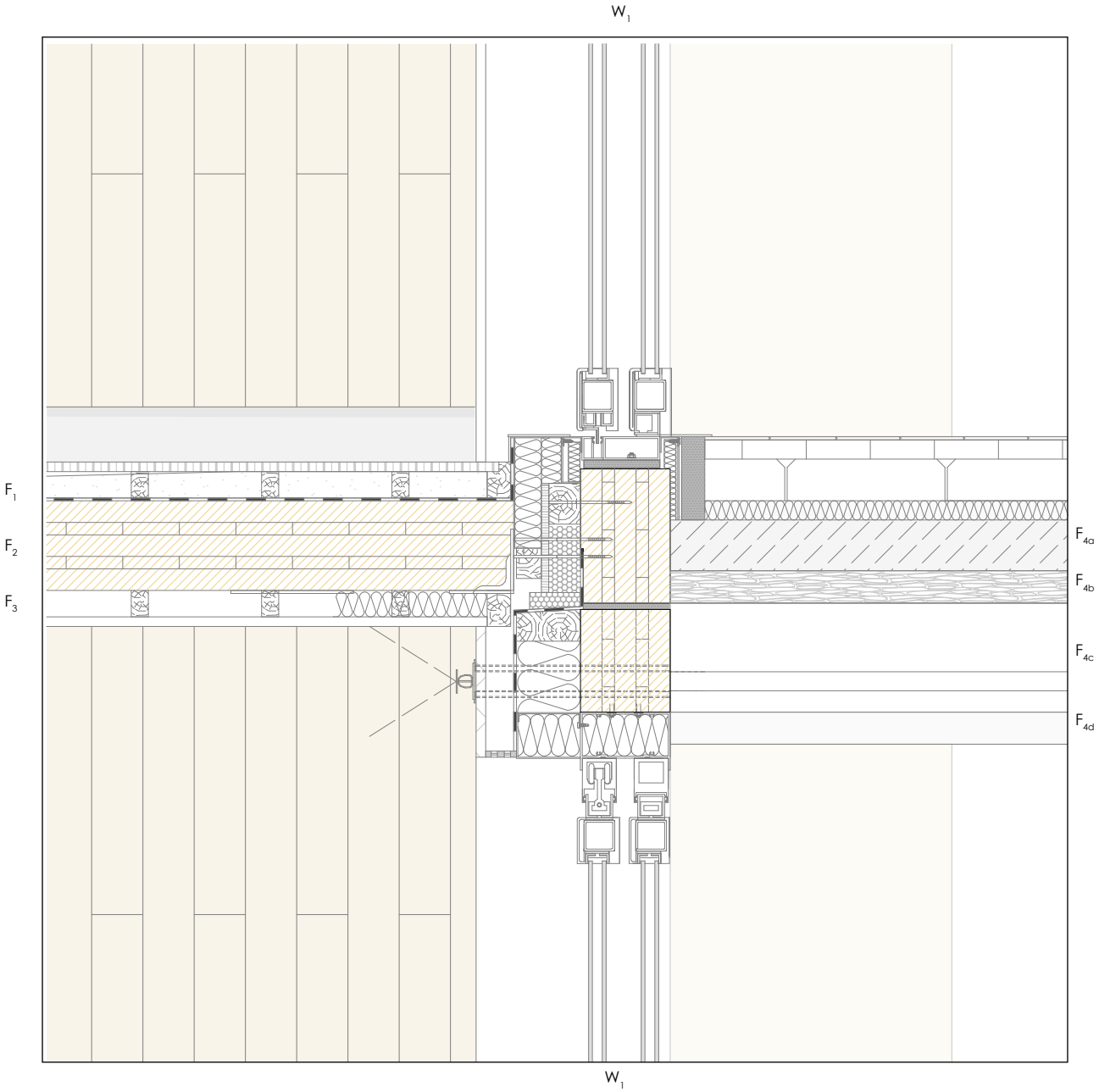
11. 9TH FLOOR - DETAIL



FLOOR
F_1: Finish floor Terrace
F_2: Prefabricated CLT Terrace (14 cm)
F_{3a}: Pre-fabricated floor: concrete layer (8 cm)
F_{3b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{3c}: Pre-fabricated floor: air space layer (17 cm)
F_{3d}: Pre-fabricated floor: multifunctional panel (5 cm)
F_4: Thermal insulation of the external ceiling

WALL
W_1: External sliding window

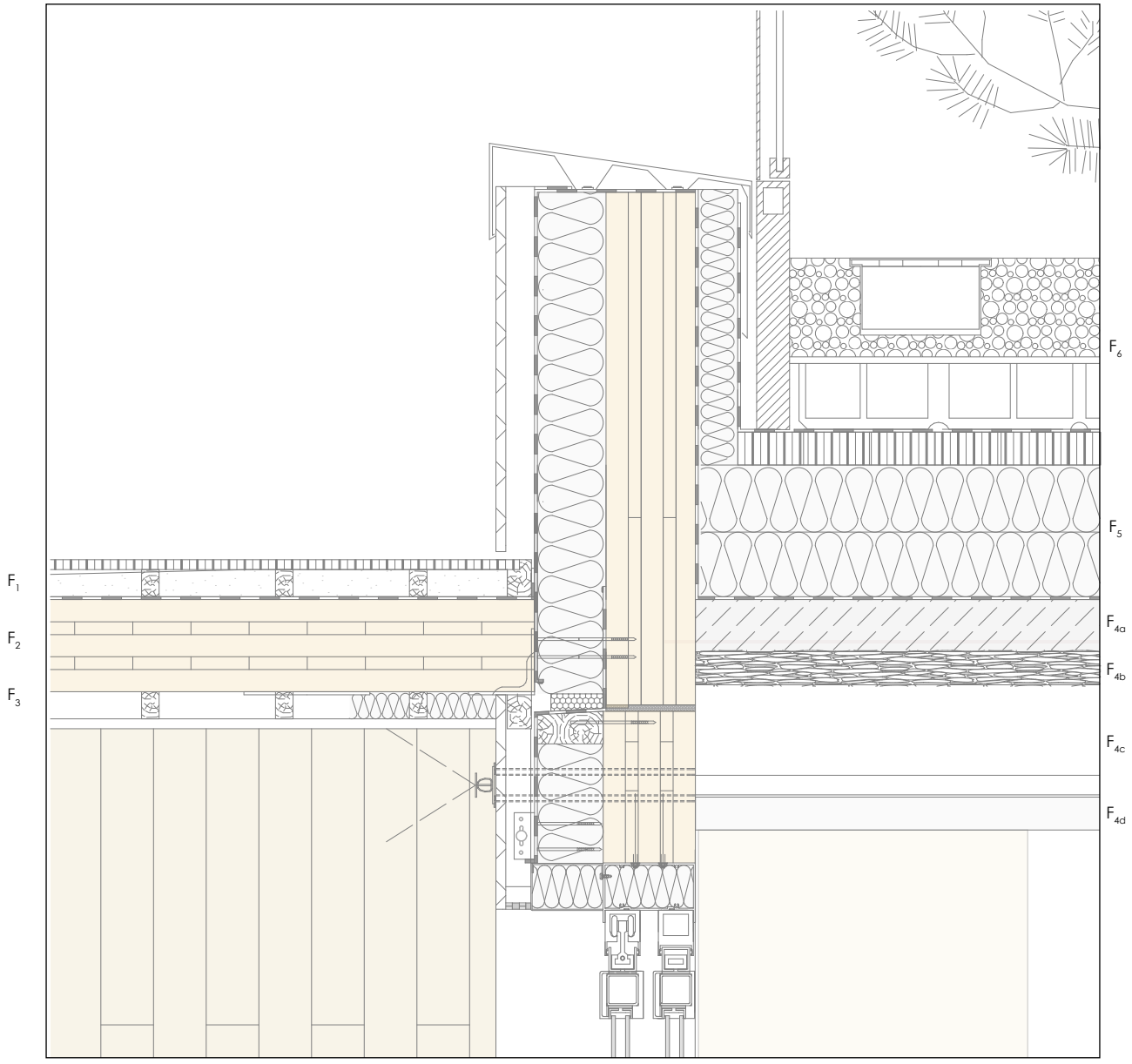
12. 8TH FLOOR - DETAIL GREEN TERRACE



FLOOR
F_1: Finish floor Terrace
F_2: Prefabricated CLT Terrace (14 cm)
F_3: Finish ceiling terrace
F_{4a}: Pre-fabricated floor: concrete layer (8 cm)
F_{4b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{4c}: Pre-fabricated floor: air space layer (17 cm)
F_{4d}: Pre-fabricated floor: multifunctional panel (5 cm)

WALL
W_1: External sliding window

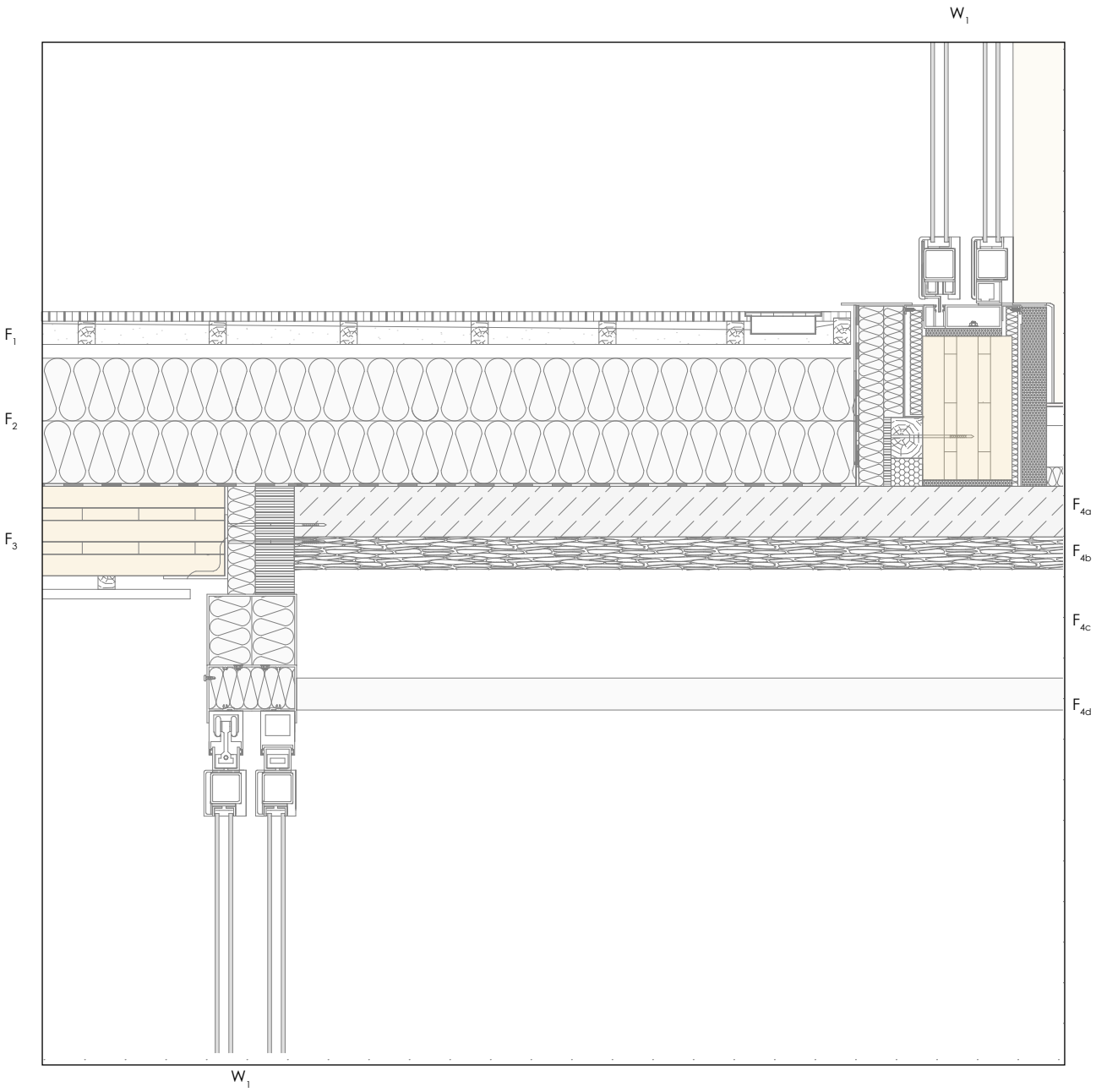
13. 8TH FLOOR - TOP FLOOR DETAIL



FLOOR
F_1: Finish floor Terrace
F_2: Prefabricated CLT Terrace (14 cm)
F_3: Finish ceiling terrace
F_{4a}: Pre-fabricated floor: concrete layer (8 cm)
F_{4b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{4c}: Pre-fabricated floor: air space layer (17 cm)
F_{4d}: Pre-fabricated floor: multifunctional panel (5 cm)
F_5: External finish floor for green roof
F_6: Finish floor - Double insulation layer for green roof

WALL
W_1: External sliding window

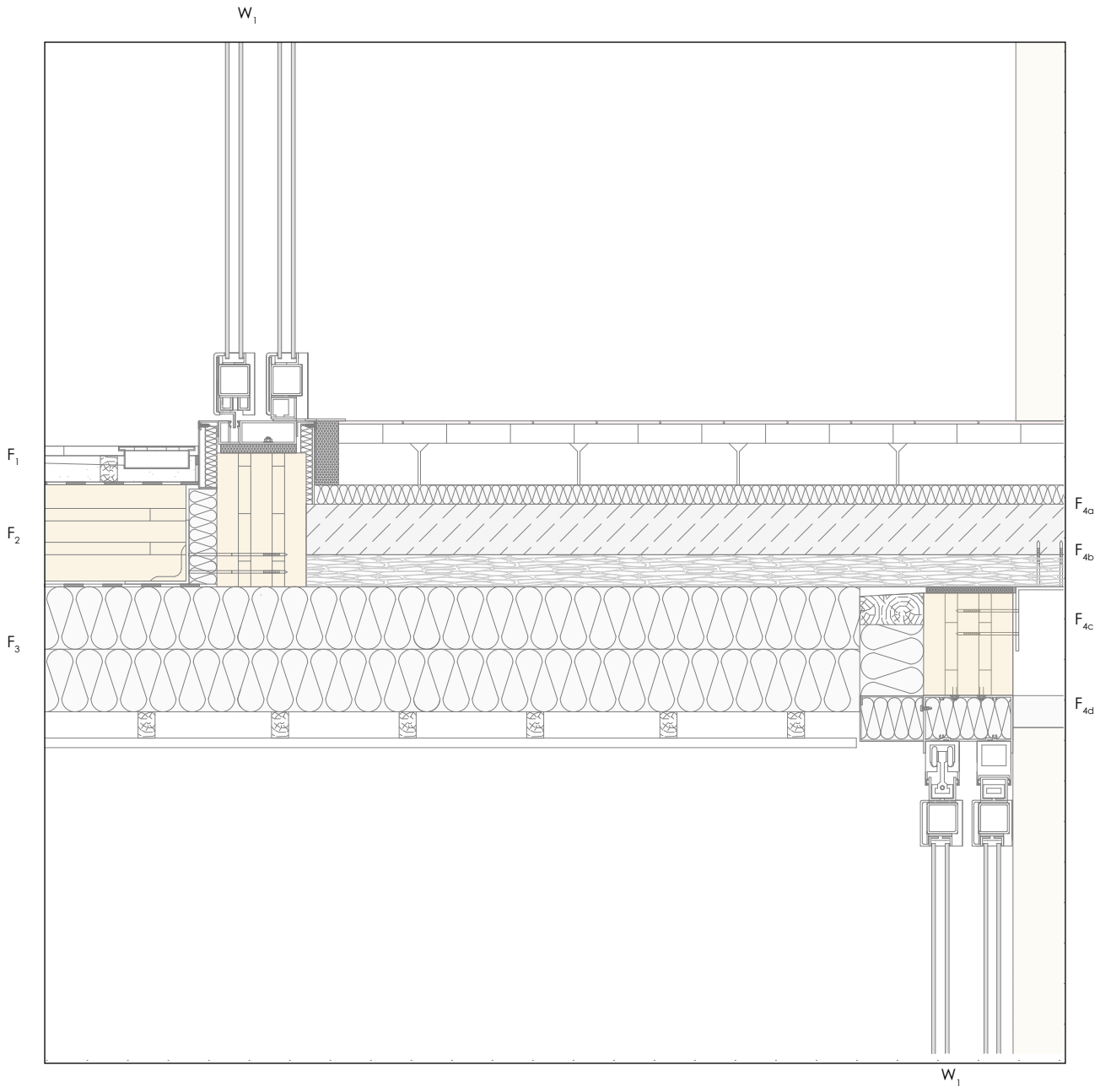
14. 8TH FLOOR - FACADE DETAIL



FLOOR
F_1: Finish floor Terrace
F_2: Thermal insulation of the external floor
F_3: Prefabricated CLT Terrace (14 cm)
F_{4a}: Pre-fabricated floor: concrete layer (8 cm)
F_{4b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{4c}: Pre-fabricated floor: air space layer (17 cm)
F_{4d}: Pre-fabricated floor: multifunctional panel (5 cm)

WALL
W_1: External sliding window

15. 9TH FLOOR - FACADE DETAIL



FLOOR
F_1: Finish floor Terrace
F_2: Prefabricated CLT Terrace (14 cm)
F_3: Thermal insulation of the external ceiling
F_{4a}: Pre-fabricated floor: concrete layer (8 cm)
F_{4b}: Pre-fabricated floor: wood+concrete layer (5 cm)
F_{4c}: Pre-fabricated floor: air space layer (17 cm)
F_{4d}: Pre-fabricated floor: multifunctional panel (5 cm)

WALL
W_1: External sliding window

3.6 BUILDING SERVICES DESIGN

The Thesis building is a tower of 77 meters with 1 underground level, an extended ground floor and 22 floors above the ground.
The last floor consist in a terrace.
In the underground there are parking lots and in the ground floor there are several activities such as supermarket, shops, restaurants.
The underground and the ground floor design were not required by the 2nd phase of the competition because it was a task of the 1st place office winner to coordinate the design of these 2 main floor which are extended to all the 4 towers.
From floor 2 to 21 then, the only programmatic program is residential.
The size of the flats is between 70 m^2 and 90 m^2 with a special condition regarding the floor 8th, which have 2 shared apartments of around 120 m^2 each and 4 flats with 35 m^2 each.
The building service system was based on the basis of these data. Every flat needs a mechanical, electrical, plumbing and fire system, and each floor needs a vertical transportation system.

Cooling / Heating System

It is becoming increasingly important plan a cooling or heating system in order to be environmentally friendly and save money on energy supplies.
The system proposed to heat and cool each residential units is due radiant panels. They are based on radiant principle which involves positioning radiant panels on the ceiling with cold or hot water flowing through them.
In this way the panels can adsorb the heat radiation from people, electronic devices, objects and surfaces thanks to the cold water, or creates a comfortable indoor climate which works in the similar way of the sun because the warm water realise the energy in the room in form of infrared radiation, converted into heat when comes into contact with people or surfaces.
The surface temperature drop and the place becomes cool all without mechanical noise or drafts. Moreover, the sound absorbing of the cooling ceiling increases comfort level further to create a healthy indoor climate.
This system is also really responsive, meaning that the room temperature can be quickly adapted as needed and it is maintenance free.

Ventilation System

To guarantee a good level of comfort in each flat the building will have also a ventilation system which control the air quality in each room of each flat.
In order to do so, every flat will have a mechanical ventilation unit which will manage fresh and exhaust air.
Pipes and tubes for the ventilation system will be located in the air space between the heating/cooling system and the structural wood panels.

Electrical system

Electrical, data and telephone conduits are run vertically through the core and are distributed to each unit within the ceiling. Each must also be coordinated.
The floor system will need a electrical connection due the presence of lights, located in the multifunctional panel.

Plumbing system

The domestic water system will be supply by the city's water main with a combined domestic water / fire protection dual metered water service into the building.

Figure 92: The Floor system with the cables and pipes integrated in the cavity space.

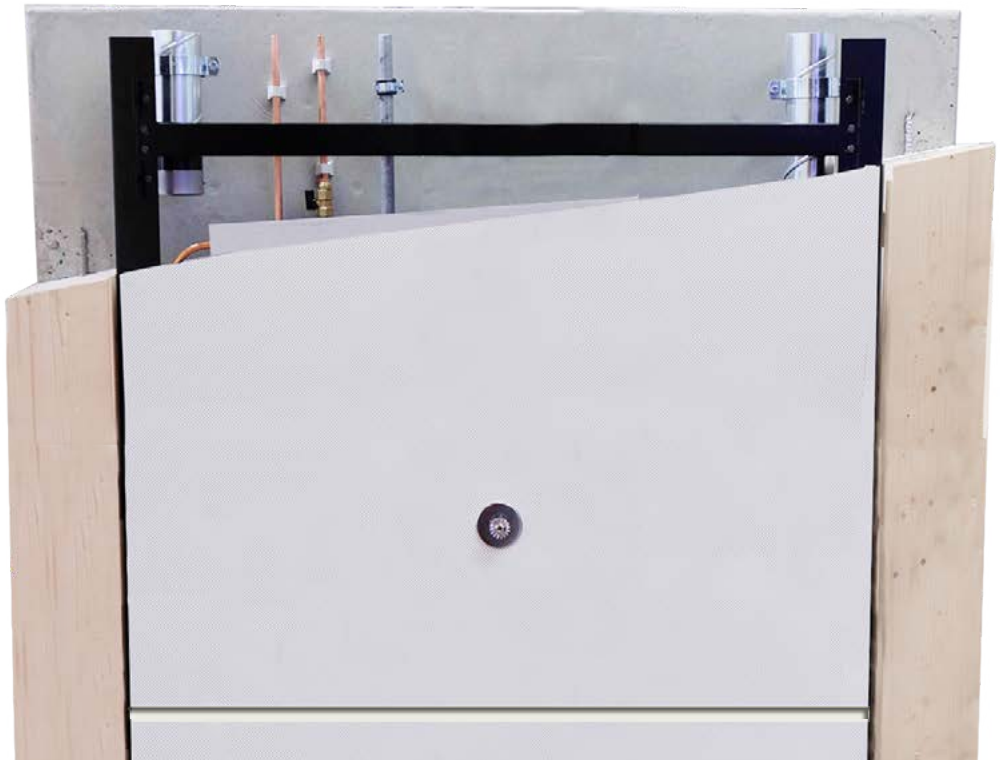


Figure 93: The floor system is based on the ERNE suprafloor ecoboost2. The image above is a modification of the ENRE system in order to make it similar tot the floor system.

Water will be provided to the residential units by high and low zone booster pump assemblies.

Fire protection System

Fire protection water supply will be provided with double detector check valves from the combined domestic and fire protection water service.
The building is provided with an automatic sprinkler system which is installed in the ceiling. Sprinklers are also located outside the building, to provide fire safety also for the terraces,

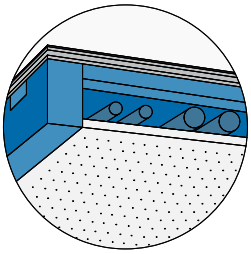
Vertical transportation

The vertical system is composed by 2 elevators and 1 elevator big enough for disable people in the safe core.
2 emergency stairs are also located in the core according to the ONORM, the Building Code of Austria.

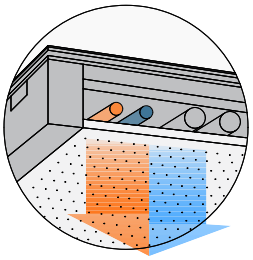
Discipline coordination

Building system coordination of a Tall Wood building is handled in much the same way that a conventional steel or concrete building is designed.
The Thesis project has 3 cavities: 2 on the end of the long side and one near the centre. The 2 bigger cavities have a triangular shape and they have 4 m^2 area so they can guarantee the necessary space for cables and installations along the building.
In the centre of the core there are rooms that are originally thought to be rent as additional storage space for the inhabitants of the tower, or as technical spaces for additional space if necessary.
Underground and ground floor level have space to store technical rooms and also the top floor of the building could provide space for some technical machines.
Primary mechanical and plumbing systems are routed vertically within the units and distributed on a floor by floor basis.
Also electrical wires, telephone cords and data wires are routed through the core on a floor by floor bases.

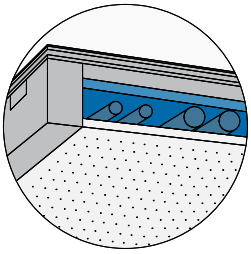
THE MULTIFUNCTIONAL PANEL



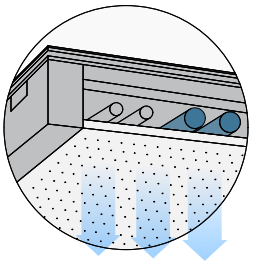
Structural



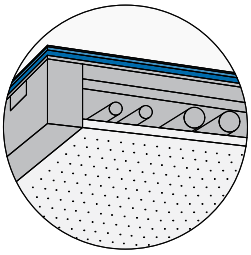
Heating / Cooling



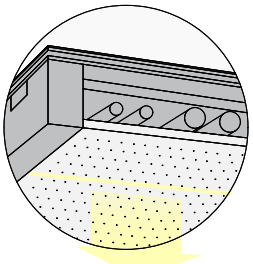
Mass



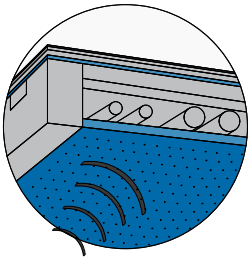
Ventilation



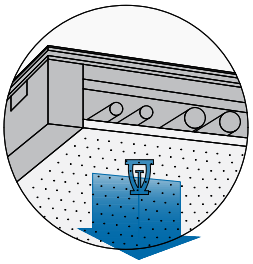
Finished ceiling



Light



Acoustic



Sprinkler

3.6.1 SYSTEM COMPARISONS

The floor system was also thought for help the collocation of building systems like heating/ cooling or air controlling.
The multifunctional panel is particularly conformed for a radiant ceiling system.

The following scheme wants to enlist some advantages of this system particularly used in Tall Wood examples previously analysed.

CEILING RADIANT vs HEATER

Energy saving
Radiant system works with low water temperature to obtain better comfort and consequently maximum efficiency in the management of the energy resource.

Simple installation
As radiant panel, the system will not require heavy builder works.

Climate comfort uniformity
Radiant systems guarantee the same temperature at each point of the room respect a punctual source. Furthermore the floor space is clear of any kind of machine or obstruction.

CEILING RADIANT vs AIR

Climate comfort uniformity
Radiant system use the water to cool or heat the space. The air system instead use the air and in some cases it could help to distribute allergens and bacteria in the house.
Radiant systems do not need filters as the air system and then they require less maintenance.

No physical discomfort
Radiant systems do not suffer the physical discomfort typical of the traditional air systems that could have strong cold or hot air flows.

Architectural versatility
Usually the ventilation system occupy a part of the wall or of the ceiling like the heaters system. Radiant system will leave instead the layout of the room free.

CEILING RADIANT vs FLOOR RADIANT

Versatility
The ceiling system will be not in direct contact with the pavement of the rooms.
This will let free to put furniture and carpets allowing cooling without condensation problems together with a simple installation.

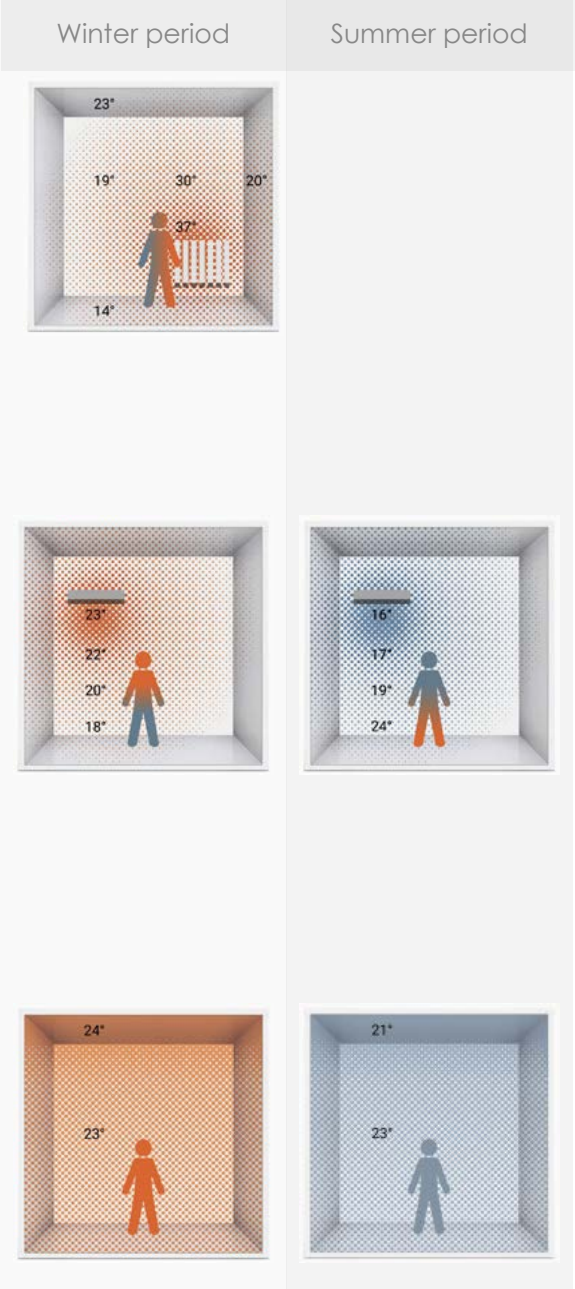


Figure 94: A typical flat unit will consist in a 3 floor system configuration. Pipes, tubes, cables are connected thought the cavity of the ceiling to the main technical rooms or cavity.

3.7 STRUCTURES COMPARISON

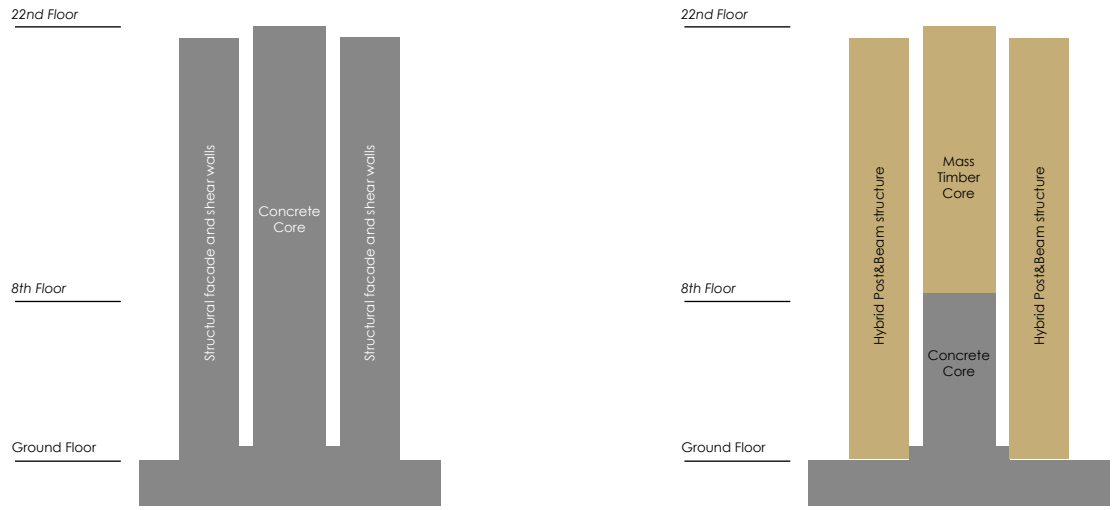


Figure 95: Schematic representation of the 2 structures

Overview

The result of this section is a preliminary result of the environmental impact of using wood (notably Mass Timber products and glulam) as the primary structural material for a tall building.

Based on the results, it could be possible to understand the plus point and the weak points of Mass Timber structure compared with a concrete one.

In this section the reinforced concrete structure of the Plot 3 Project is compared with the hybrid Mass Timber structure of the Thesis project.

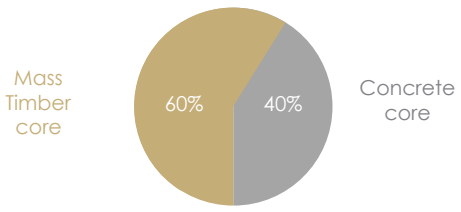
The focus of this section is on percentage of sustainable material used in every part.

Material used

In the competition project 100% of the material used in the structure in reinforced concrete.

The thesis project instead has different percentage of concrete and Mass Timber products:

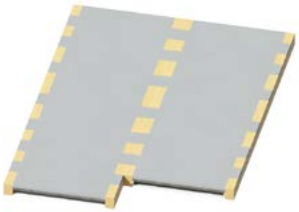
Core

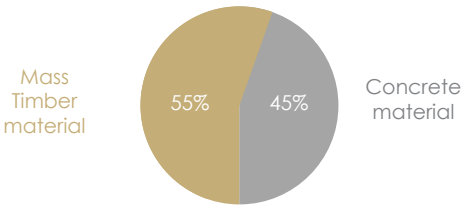


In the Thesis project the core is around 250

m^2, slightly bigger than the Competition core. From the ground floor to the 8th floor the Thesis project has a concrete core which switched to a Mass Timber one from the 9th to the 22th. Because the volume of the walls and of the area could be considered the same, it is possible to say that the 60% of the entire core will be in Mass Timber material.

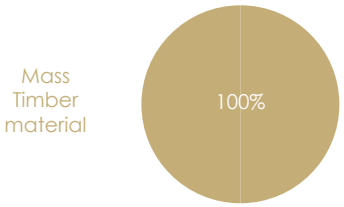
Floor system





The material used for the floor system in a building is usually 70% of all the material used in that building.[15]
So it is possible to affirm that the percentage of material which composes the floor system is strongly influencing the overall system.
If we analyse then the floor system, the Mass Timber part is formed by the 2 glulam beams and the 70% based wood product positioned under the concrete layer.
The average quantity are 55% of Mass Timber material and the 45% for the concrete one which is a result similar to the core.

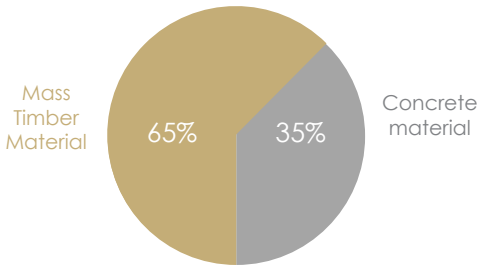
Rest of the structure



The rest of the structural part of the building is composed by:
- Gluam columns
- CLT structural facade
- CLT Shear walls

They are 100% Mass Timber materials therefore the rest of the structure is composed by Mass Timber.

Quantity assumptions



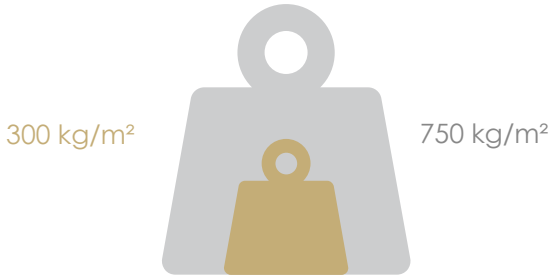
In order to make a probable calculation assumption it could be possible to consider that the overall percentage of the building is around 65% Mass Timber material and 35% concrete.
The correct amount of these quantities should be analysed in terms of Life Cycle Assessment to fully understand the value of these percentages.

3.7.1 PROS AND CONS OF THE MASS TIMBER STRUCTURE

The previous percentage analysis helped to understand quantities comparison between the 2 building's structure. In this section pros and cons of the quantity assumptions will be compared with the data given by CREE Rhomberg. CREE is the company that realized the Life Cycle Tower in Dorbirn and made some calculation to evaluate LCT.

WEIGHT

- 40%



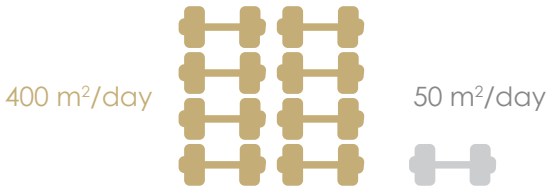
As we saw in the Part 1, Mass Timber is a really light structural material but with great structural performances.
The most common plus point of Mass Timber structures is indeed that they are the lightest structure possible.
If we apply these data we could obtain that the entire weight of the structure can decrease around 40% starting from the weight of the concrete structure.
The foundation system in this way will be reduced, saving some money.

CO^2 EMISSION

- 50%

In the process of creation of the building material the CO^2 is one of the most important one because of all the considerations regarding the climate change.
Mass Timber products, because of their sustainable process, perform better than any other building materials because they are based on wood which is simply growing by the power of the sun and it can even store the CO^2. If we compare the 2 structure in these terms, we will see a decrease of CO^2 emissions around 50% less.

SPEED OF OPERATION (5 WORKERS + CRANE)

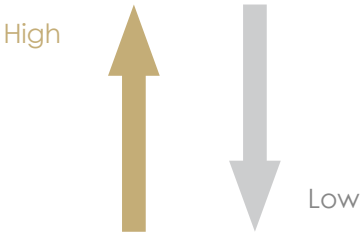


The structural system of the Thesis project is based on Life Cycle tower. The grade of prefabrication in fact which the 2 buildings have in comparison is nearly the same. CREE, which realized LCT demonstrates that the speed of realization was incredibly higher in comparison with a concrete similar building.

HEALTH ENHANCING INDOOR SPACE QUALITY

Wood is a living material even as glulam or CLT. The quality of the space it can create are not comparable with the grey concrete. The columns and beams left exposed will increase the overall aesthetic values.

ASSURANCE OF COST



If the Mass Timber structure is thought as highly prefabricated one, it will be possible be sure of the exact amount of elements and therefore the exact amount of the cost of the structure, unlike the concrete structure, always uncertain for several possible problems in the building site during the construction.(weather, time, details).

SYSTEM COST

Mass Timber products cost more in comparison with a concrete structure especially in Vienna. Generally a Mass Timber structure cost 10% more. In the building market which always try to find the cheapest solutions, this is a important aspect.

Vittorio Salvadori

The Design of a Tall Wood building

PART 4

NEXT STEPS AND CONCLUSIONS

Project considerations and address for research

4.1 NEXT STEPS

The proposed structural system was developed after a detailed study of the already realized and on going projects.
From the data and the structural approaches a defined system was designed. The system will need specific engineered calculations to be proved definitively.
The structural behaviour must therefore be verified with additional research and physical testing.
This section outlines recommended additional work.

Structural Design

Connections

A key aspect for the successful design of a Mass Timber buildings are the connections. One of the main aspects needed to fully understand the structure is to study in detail what will be the stresses and the energies the connections will face.

Structural testing

As for every structural concept and preliminary design, the Thesis structure needs to be tested with the common engineer software / calculations. It will be analysed the combination of the gravity and lateral systems and a feedback in terms of size of the elements and other characteristics will be given.

Fire resistance

A fire engineer should review the proposed structural system and connections and help develop necessary performance based design criteria and details.
It will be important to establish performance based- design criteria specific for Tall wood building, to develop fire design criteria specific to composite timber-concrete system and to create fire models to establish required exposure times.

Building Process Considerations

A construction engineer or contractor should review and comment on the systems and possible erection sequence. The building process is based on already realized concrete-core building and normally Mass Timber building are erected with phases.
A general feedback on the possibility to build easily the Mass Timber above the concrete one is one of the main aspects to take care and especially the connections between the 2 different cores.

Architectural Considerations

Durability detailing

Additional studies should be done to determine the necessary details of all concrete/timber joints for long-term durability. The study should include cost-benefit analysis of cost and total design life.
The impact due to moisture or water exposure should be studied for areas that may be exposed for long periods of time or to a large amount of water.

Acoustical aspects

Wood in general performs badly from an acoustical point of view. The proposed floor system can imagine a good quality of the sound insulation also because is guaranteed by the similar ERNE system, but to be sure of the real grade of insulation the entire system has to be tested.
The building code of the city of Vienna regarding the Sound impact performance (LnTw) is 48 LnTw. This value is already difficult to obtain for entire concrete floors so this is an aspect to consider carefully.

Manufacturing

Mass timber industry representatives should review and comment on the products/ materials and system so that the design can be optimized. It will be important to determine the manufacturing and installations process and limitations of reinforcement epoxy connected to timber. Also the CLT core panels should be considered determining the thickness and possible other solutions in order to obtain a maybe cheaper solution.

Cost estimating

A cost estimator should review the proposed system in conjunction with construction engineering and manufacturer comments in order to estimate the total cost of the system. Specific attention should be given to new details and new uses of products and materials. Comparison of alternate materials, manufacturing, processes and erection sequences and schedules should be included.

Code consultant

Hoho tower showed that in Austria several cutting-edge fire strategy could be used.
Anyway a code consultant should evaluate the results of this report and develop appropriate performance based design requirements for high-rise Mass Timber building.
These design requirements should consider the level of service currently provided by the perspective design of reinforced concrete and structural steel buildings.

4.2 CONCLUSIONS

The main goal of the Thesis project was to design an alternative Mass Timber structure which could be enough detailed to both understand what it means to design a Tall wood building and see how its structure could be compared with a similar concrete one.
The case of the Competition project made by the architectural office Alles Wird Gut was a particular pretext because it was a well known project by the student and it is detailed at the level of a competition project, in order to keep feasible the general comparison of the 2 different approaches.

Comparison with Project Goals

The proposed system meets the initial goals given by the first chapter "3.1 *Project Goals*".
The overall goals are achieved except for some cases.

The building is not economical

What is clear is that a Mass Timber building can not be cheaper than a concrete building. The concurrent market of the concrete builders is too strong and developed to easily convince a building owner to chose in Mass Timber structure.
What seems possible instead is to propose hybrid solutions, mixed solution between Mass Timber Products and concrete.
The core of the building is for sure an element to study more in detail and it is an element of additional cost.
By 2023 there will be 13 projects in Mass Timber that will help to understand the

PROJECT GOALS

Marketable	✓
Serviceable	✓
Economical	⊘
Sustainable	✓

The volumetric division	✓
The position of the core	✓
The heights of the building	⊘
The general architectural layout	✓
The same Total Surface	⊘
The Podium in concrete	✓
The terraces	✓
The green areas	✓
Develop the installation system	✓

possible solutions to the economical aspects.

The Thesis project is taller

The Thesis project needed an higher floor-to-floor height.
From 2,88 meters of the concrete project, the Thesis project proposes a 3 meter floor-to-floor height and a 3,5 meter one in the 8th floor, in order to guarantee enough space for insulation and green parts.
This will rise the tower up to 77 meters against the 72 of the concrete one and will collide with the Competition limit height of 73 meters.
A possible solution could be to delete 2 floors but for a market point of view it will be unlikely.

The Thesis project is overall similar to the concrete one

From a preliminary aspect, the projects are overall similar. Some architectural considerations were deliberately chosen in different ways to aesthetically emphasize the Tall Wood characteristics (such as non-structural facade, not-panellized handrail).
But regarding ideas and concepts behind (such as clear differentiations between 2 part of the building, tower-bigger part at the bottom) the buildings are the same.
Green areas which characterize the 8th and the Top floor could be created also in the Tall wood Thesis project because Mass Timber does not create moisture problems if perfectly water-proof.

Final considerations

Tall wood building need to be designed properly and are a particular field of structural/architectural field still in progress.
We are at the beginning of a possible revolution which needs to be realized because of the several environmental problems our century has to face.
The bigger obstacle does not seem to be the technology necessary to realize Tall Wood buildings because engineers, architect, wood suppliers companies, universities and builder all around the world are every year achieving new successes and accomplishments.
What is important is to convince people, the public opinion, investors that wood as Mass Timber product is the only possibility we have in order to build sustainably.
It is important to make them to understand that is not enough have building which emits low or zero CO^2 after they are realized, but also since the beginning of their realization, from the building material origin.
Only if we do this, we will fully contribute as architects to the health of out planet.

LIST OF REFERENCE

1. IPCC Fifth Assessment Report
https://www.ipcc.ch/report/ar5/

2. In the 1860s, physicist John Tyndall recognized the Earth's natural greenhouse effect and suggested that slight changes in the atmospheric composition could bring about climatic variations. In 1896, a seminal paper by Swedish scientist Svante Arrhenius first predicted that changes in the levels of carbon dioxide in the atmosphere could substantially alter the surface temperature through the greenhouse effect.

3. National Research Council (NRC), 2006. Surface Temperature Reconstructions For the Last 2,000 Years. National Academy Press, Washington, D.C.
http://earthobservatory.nasa.gov/Features/GlobalWarming/page3.php

4. Micheal Green, Why we should build wooden skyscrapers, TED Talking 2013
https://www.ted.com/talks/michael_green_why_we_should_build_wooden_skyscrapers?language=it

5. Micheal Green, Why we should build wooden skyscrapers, TED Talking 2013
https://www.ted.com/talks/michael_green_why_we_should_build_wooden_skyscrapers?language=it

6. Wooddays.eu - Wood and climate
http://www.wooddays.eu/it/wood-and-climate/

7. State of Europe's Forests 2011, Oslo,Norway: Ministerial Conference on the Protection of For-

ests in Europe - FOREST EUROPE Liaison Unit Oslo, 2011
http://www.foresteurope.org/documentos/State_of_Europes_Forests_2011_Report_Revised_November_2011.pdf

8. State of Europe´s Forests 2015, 2015.
http://www.foresteurope.org/docs/fullsoef2015.pdf

9. Wooddays.eu - Wood and climate
http://www.wooddays.eu/it/wood-and-climate/

10. Promo_Legno, Foreste
http://www.promolegno.com/foreste/

11. E. Mosca, La protezione delle foreste in Europa: gli obiettivi della gestione forestale,
http://www.legnotrentino.it/documenti/pubblicazioni/2008/asfor_op_dnatura01_2008_09_17.pdf

12. A.H. Buchanan, A. Palermo, D. Carradine, S. Pampanin. Post-Tensioned Timber Frame Buildings. Journal of Structural Engineering, UK. Sept 2011. Vol 89, No. 17. pp 24-30.

13. A.H. Buchanan and T. Smith, 2015. The Displacement Paradox for Seismic Design of Tall Timber Buildings. New Zealand Society of Earthquake Engineering Conference, Rotorua, New Zealand.

14. Timber Tower research Project, Final report, Skidome, Owings & Merrill, 2013.

BIBLIOGRAPHY

Benedetti Cristina, *Costruire in legno* - Bolzano university 2010

Bernasconi Andrea, *Atti del convegno: XLAM, Proprietà e caratteristiche di un materiale innovativo* - Turin 2010

Bernasconi Andrea, *L'altro massiccio: Caratteristiche e possibilità d'impiego del materiale* - Promolegno 2008.

Cheret Pierre, *Handbuch und Planungshilfe Urbaner Holzbau* - DOM Publishers 2014

Council Canadian Wood, *Wood Reference Handbook* - Canadian Wood Council 2007

Forest Europe, *State of Europe´s Forests 2015,* United Nations 2015

Green Micheal, *The case for Tall Wood Buildings*, Vancouver 2012

Green Micheal, Taggart Jim, *Tall Wood Buildings* - Birkhauser 2017

Herzog Thomas, Netterer Julius, Schweizer Roland, Volz Micheal, Winter Wolfgang, Holzbau Atlas, Birkauser Edition Detail 2003

Hausladen Gerhard, *Climate Design* - Birkhauser 2004

Kapfinger Otto, *Hermann Kaufann Wood works* - SpringerWienNewYor 2016

Kaufamnn Hermann, Krotsch Stefan, Winter Stefan, *Atlas Mehrgeschossiger Holzbau* - Edition Detail 2017

Jodidio Philip, *Wood buildings* - Taschen 2016

Lantschner Norbert, *Smile Energy: Il coraggio di cambiare per un futuro con futuro* - Raetia 2014

Laner Franco, *Vecchi morfemi per nuovi tecnemi* - Materia 2010

Skidome, Owings & Merrill, Timber Tower research Project - Final report, 2013

Climate change and demographical increase in developing countries are inducing us to reconsider the way we build the buildings. Concrete and steel have already reshaped our cities for 2 centuries but problems related to the non-sustainable aspects of steel and concrete are now appearing in their productive system, characteristics, creation process and energy demands.

It is necessary to find new solutions, especially regarding high-rise buildings which will be one of the main typologies of construction in a more and more urban future scenario.

The only structural material that can tackle the future demand of building is wood as Mass Timber Products. There are already several successful examples of how this material could answer architectural challenges.

As architects, we have the power to choose how the building is built and realized. On our profession stands a great chance to increase the realization of sustainable buildings. Since the beginning of mankind, wood structure was one of the most common types and this trend was decreased only in the last 2 centuries thanks to the rise of steel and concrete structures.

The 21st century can be instead the century of the renaissance of wood an the motifs are really a lot. Sustainable, renewable, zero impact and other qualities certified that it must be considered as possible solution.

The context of the competition *Wien Heiligendstadt Wohnen und Arbeiten* is a pretext to show how an international competition can adopt Mass Timber as technological solution compared with a concrete solution. Showing the plus points and demerits of wood as a structural material is the main aim of this Master Thesis.

Additionally, this Master Thesis aims to demonstrate the feasibility of an on field context rather than a theoretical solution, while also displaying the current status of wood technology.