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SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING AND ARCHITECTURE

CROSS LAMINATED TIMBER HIGH-RISE OFFICE BUILDING IN ÜLEMISTE CITY.

INFLUENCE OF FIRE SAFETY ENGINEERING TO ARCHITECTURAL DESIGN

RISTKIHTPUIT KONSTRUKTSIOONIST 13 - KORRUSELINE BÜROOHOONE ÜLEMISTE CITY LINNAKUS.

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PREFACE

I would like to thank the thesis supervisor Kimmo Sakari Lylykangas for the guidance and support. In addition, I would like to thank other institutions and experts who invested their time and knowledge: Mainor Ülemiste AS (Rauno Mätas, Katrin Sulg, Neeme Nõmme), Markku Kauriala Oy (Markku Kauriala, Päivi Myllylä, Risto Ranua), TalTech (Alar Just), Arcwood (Peeter Peedomaa, Indrek Mäe).

ABSTRACT

This Master's Thesis has been prepared within the framework of the Ülemiste City thesis competition. The dissertation consists of a research part and thirteen-storey CLT structure office building, which is designed on the findings of the first part.

The European Union aims to achieve a climate-neutral economy by 2050. More than a third of Europe's greenhouse gas emissions are also related to the construction sector. In order to achieve this goal we need to start using more sustainable technologies and building materials. The solution may include increasing use of wood, which is a common building material but not in high-rise buildings. There are several challenges in the construction of timber high-rise buildings, such as load-bearing capacity, acoustics and maintenance of exterior timber facades - but the main obstacle in Estonia is fire safety. Timber is a combustible material and the strict fire safety regulation makes the construction of timber high-rise buildings too expensive to be an economical option.

In the first research part I focus on the limitations for tall timber buildings, especially fire safety regulations that prevent the construction of wooden high-rise buildings. It is necessary to use non-standard solutions and prove the safety of the building by an alternative method - Fire Safety Engineering (FSE). I will introduce this approach and how it can be used to prove that a building is safe. This is a method where every design decision is based on fire safety and therefore FSE should be integrated in the designing process from the very beginning. First CLT structure high-rise buildings are rising around the world, which are stable, acoustically functional and fire safe. In the research part I examine what kind of design solutions are needed to achieve this, and how architectural design can support fire safety.

Based on the findings of the research part, I introduce a design of a 13-storey office building with a CLT frame in Ülemiste City. Finnish fire safety engineering experts from Markku Kauriala office participated in the design process. In addition, they conducted a fire spread test on one of the standard floors, which helps to analyse how much visible wood surfaces and where we can have in the interior and still keep the building safe.

As a conclusion, I present design principles for timber high-rise office buildings, including fire safety engineering and its possibilities in proving fire safety so that it would become more common and a reasonable option in Ülemiste City and Estonia.

ABSTRAKT

Käesolev magistritöö on valminud Ülemiste City lõputööde konkursi raames. Lõputöö koosneb teoreetilisest osast ja kolmeteist korruselisest CLT struktuuril kontorihoonest, mis on kavandatud esimese osa järeldustel.

Euroopa Liidu eesmärk on saavutada aastaks 2050 kliimaneutraalne majandus. Üle kolmandiku Euroopa kasvuhoonegaasidest on seotud ehitussektoriga. Selle eesmärgi saavutamiseks peame kasutama loodust säästvaid tehnoloogiaid ning ehitusmaterjale. Lahendus võib hõlmata puidu kasutamise suurendamist, mis on levinud ehitusmaterjal, kuid mitte kõrghoonete puhul. Puidust kõrghoonete ehitamisel on mitmeid väljakutseid: kandevõime, akustika ja puitfassaadide hooldamine - kuid peamine takistus Eestis on tuleohutus. Puit on põlev materjal ja ranged tuleohutuse regulatsioonid muudavad puidust kõrghoonete ehitamise majanduslikult põhjendamatuks.

Esimeses uurimuslikus osas keskendun väljakutsetele ja piirangutele, mis takistavad puidust kõrghoonete ehitamist, eriti tuleohutuseeskirjadele. Vajalik on kasutada ebastandardseid lahendusi ning tõestada hoone ohutust alternatiivsete meetoditega - tuleohutusinseneeria (Fire safety engineering). Teoreetilises osas tutvustan antud meetodit ja kuidas see võimaldab tõestada hoone tuleohutust. Tegemist on meetodiga, kus iga projekteerimise otsus põhineb tuleohutusel, mistõttu peaks FSE olema integreeritud projekteerimisprotsessi varajases staadiumis. Üle maailma kerkivad esimesed CLT konstruktsioonil põhinevad kõrghooned, mis on stabiilsed, akustiliselt toimivad ja tuleohutud. Uurimuslikus osas selgitan välja, milliste konstruktiivsete lahendustega on seda võimalik saavutada ja kuidas võib hoone arhitektuur toetada tuleohutust.

Uurimistulemuste tulemuste põhjal projekteerin Ülemiste Citysse CLT konstruktsioonil põhineva 13-korruselise büroohoone. Projekteerimises osalesid Soome tuleohutustehnika eksperdid Markku Kauriala büroost. Lisaks viisid nad ühel standard korrusel läbi tule leviku testi, mis aitas analüüsida, kui palju ning kus võib interjööris puit pindasid kasutada, nii et säiliks hoone tuleohutus.

Kokkuvõtteks koostan nimekirja printsiipidest, millest lähtuda puidust kõrghoonete projekteerimisel. Sealhulgas tutvustan FSE tulemusi ja protsessi tuleohutuse tõendamisel, et see muutuks Ülemiste Citys ja Eestis rohkem kasutatavaks võimaluseks.

LIST OF ABBREVIATIONS

CLT	cross-laminated timber
CO_2	carbon dioxide sympathetic
SNS	nervous system fire safety
FSE	engineering

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1.1 THE OBJECTIVES OF THE THESIS

The aim of this Master`s thesis is to compile an architectural theoretical study to find solutions for the main challenges in the construction of timber high-rise buildings: fire safety, load-bearing capacity, acoustics, maintenance of wood facades and cost. Based on these answers, design a 13-storey modern office building with a CLT frame in Ülemiste City that is safe, comfortable and functional for visitors. From practiced knowledge, compile a small set of principles for architects to use in the design of a wooden high-rise building.

1.2 PROBLEM STATEMENT

The construction of timber-structured high-rise buildings is very justified from an environmental point of view, but nevertheless the challenges seem insurmountable. The biggest obstacle is considered to be fire safety requirements that make it impossible to build such buildings in Estonia. Nevertheless, the first wooden high-rise buildings are emerging around the world, proving the opposite. These are safe buildings, but their fire safety has been proven by alternative methods. Estonia is also taking the first steps in this direction, but despite this, this area is quite unknown to us.

1.3 METHODS AND SOURCES

In the first research part are used the general methods of scientific methodology: documentation analysis - standards, regulations, guidelines and statistics. Analysis of manuals compiled outside Estonia, which provide instructions for the design of a CLT frame high-rise building. Text and literature analysis - a summary of the problem statements as well as suggestions for this top

2.1 LOW EMBODIED GHG EMISSIONS

Climate change is caused by several factors that are classified as natural or anthropogenic. Since the middle of the 20th century, the average atmospheric temperature has started to rise sharply. The reason lies in the Industrial Revolution, when manufacturers started using fossil fuels such as coal, oil, natural gas etc. The use of fossil fuels definitely accelerated the economic and technological development, but it also involved large quantities of greenhouse gases, which they emit during combustion. Carbon dioxide (CO_2) is the most common greenhouse gas, which is also anthropogenic. It has the greatest impact on climate change. Although carbon dioxide absorbs less heat than other greenhouse gases, it's amount is the largest and it stays the longest in the atmosphere. (Climate Change: Atmospheric Carbon Dioxide). Throughout the history of the world, the temperature of the atmosphere has fluctuated up and down before, but such a rapid rise is the first time. It can be clearly seen from the Stable Climate graph that the concentration of CO_2 emissions and the average atmospheric temperature are clearly related. (Climate change and its causes)

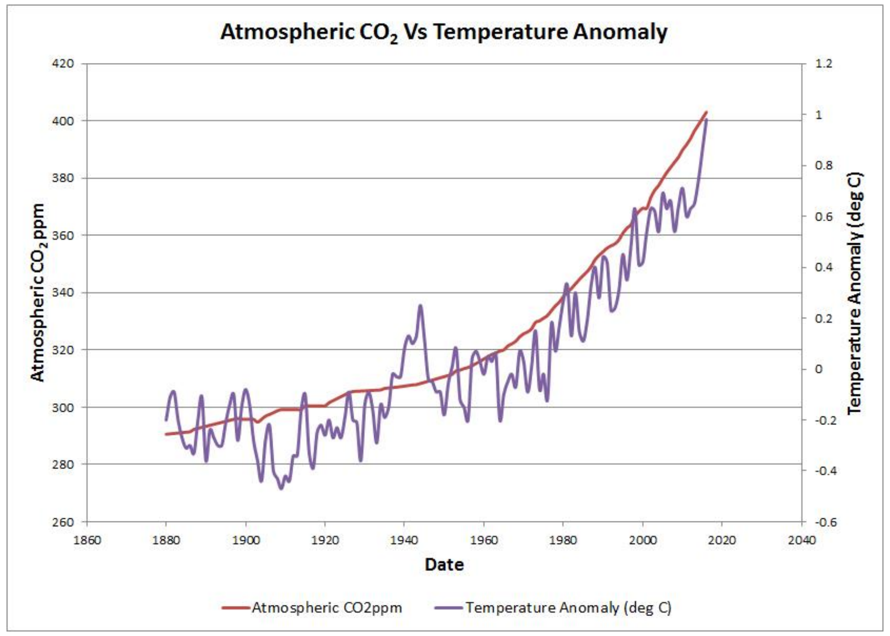


Image 1. Atmospheric CO_2 Vs Temperature Anomaly. (Stable climate)

On 28 November 2018, the European Commission set out a strategy for achieving a climate-neutral economy by 2050. Commissioner for Climate Action and Energy, Miguel Arias Cañete said: "The EU has already started the modernisation and transformation towards a climate neutral economy. And today, we are stepping up our efforts as we propose a strategy for Europe to become the world's first major economy to go climate neutral by 2050. Going climate neutral is necessary, possible and in Europe's interest. It is necessary to meet the long-term temperature goals of the Paris Agreement." The Paris Agreement set the goal of keeping the global average temperature rise below 2°C and even tightening it up to 1,5°C. (The Commission calls for a climate neutral Europe by 2050) In a study commissioned by the Estonian Ministry of the Environment in 2013 "Estonia's opportunities to move to a competitive low-carbon economy trend in 2050" brought out that the main sectors where CO_2 emissions should be reduced are energy, transportation, industry, waste management, agriculture and land use, land use change, forestry - LULUCF. (Ministry of the environment, 2013, lk 18) More than a third of Europe's greenhouse gas emissions are also related to the construction sector. It is generally acknowledged that forests act as air purifiers and offsets greenhouse gas emissions, but the similar effects of using wood in construction have been underestimated. (Riistop, M., Välja, H. 2016. lk. 4-5)

According to the Food and Agriculture Organization (FAO), 3.966 million m3 of roundwood were harvested worldwide in 2019, of which 1.945 million m3 were used for wood fuel and 2.021 million m3 industrially. (Global production and trade in forest products in 2019) Timber products contain about 424 million tonnes of carbon, a portion for the short-term but a large part for several decades. The whole world's carbon stocks in wood products are estimated to grow by 150 million tonnes per year, equivalent to scavenging 540 million tonnes of CO_2 in the atmosphere per year (FAO Forestry Paper, 2010. lk 159).

In addition to the positive impact to the environment by storing CO_2 in timber products it is possible to replace steel and concrete with timber in construction - substitution effect. The production of components for timber structures does not pollute the environment and is less carbon intensive, which allows to avoid the huge amount of CO_2 emissions that would otherwise be emitted into the air during the production and processing of steel and concrete. Replacing concrete with wood in construction could reduce carbon emissions by 2.5 tonnes per tonne of wood used (CORRIM, 2009). This is confirmed by the experiment carried out in Helsinki, where two identical multi-storey buildings were built, one of them with a timber frame and the other with a concrete structure. The test proved that the carbon emissions from building materials were 20 percent lower in a wooden building than in a concrete building (A-Kruunu Oy, Yrjö Hanna -Säätiö, Rakennusliike Reponen Oy,

2.2 POSITIVE EFFECTS ON HEALTH

Chronic stress is often caused by small tensive situations that occur on a daily basis. They can cause serious long-term consequences for health and are a growing concern in today's society. (Protective and Damaging Effects of Stress Mediators, Bruce S. McEwen, 1998.) More and more people have started to prioritize the environment and examine its impact on health and well-being. It is believed that the integration of greenery and nature into the urban environment helps to reduce people's stress levels. From the beginning of human existence, man has depended on the natural environment. It has affected human biological development - only those survived who were able to hide, found food, knew the plants and animals. Man has not evolved to stay indoors behind computer screens day to day. (Beyond toxicity: Human health and the natural environment, Howard Frumkin, 2001). Biologist E.O Wilson has said: “It would...be quite extraordinary to find that all learning rules related to that world have been erased in a few thousand years, even in the tiny minority of peoples who have existed for more than one or two generations in wholly urban environments.” (Wilson E.O. Biophilia and the conservation ethic. In: Kellert SR, Wilson EO, eds. The biophilia hypothesis. Washington, DC: Island Press, 1993:31–41.).

The field experiment: “The influence of urban green environments on stress relief measures” was carried out in Helsinki, the Capital of Finland. The study was conducted among 95 participants and its purpose was to find out how short-term visits in different urban environments affect people's stress levels. The study compared three regions: Alppipuisto - Helsinki 's oldest city park, Keskuspuisto - Helsinki' s largest greenery and a main street with a few trees. The study found that green environments increased the feelings of restoration, vitality and positive mood. The study concluded that the stay in a natural environment should last at least 15 minutes to have an impact (Tyrväinen, L, Ojala A, Korpela K, Lanki T, Tsunetsugu, Y, Kagawa T, 2013).

Most people spend 90% of their day indoors. (Euroopa Keskkonnaagentuur, 2013). Staying in nature is beneficial to our mental and physical health and is recognized by the public. It is difficult to influence people's lifestyles, we are often forced to spend our days indoors because of work or school. An easier way is to make people's work and home environments healthier, and to incorporate more nature into it. The results of studies, that the use of plants indoors works in a similar way as a person's presence in nature - reduces stress, improves attention and mood, motivated the University of British Columbia and FPInnovations to conduct a study: “Wood and Human Health”. The experiment focused on the use of wood surfaces in the interior and its effects on the human sympathetic nervous system (SNS). SNS is responsible for a person's response to physiological stress. In the experiment was created four different office environments with identical designs. The first office space was without wood finish and plants, the second was without wood finish but with plants, third with wood finish and without plants and the last one with wood finish and plants. Students were placed in one of four rooms and were not informed of the objectives of the experiment. During the experiment, students' heart rate (EKG) and galvanic skin response (GSR) were measured. The study consisted of three time periods: the baseline period - where students spent ten minutes alone in a room. Test period in which students had to complete mathematical tasks and recovery period in which students were given time to recover from effort. The results of the study show that during all test periods, the SNS activation was lower in office rooms with wooden finishing. The level of SNS activation shows how the body prepares itself to cope with stress. Research proves that using visible wood in interiors is a way to create healthier environments - where we spend most of our lives. (The University of British Columbia and FPInnovations, 2011

3.1 THE CHALLENGE OF TALL TIMBER BUILDINGS

Today, about 4.3 billion people live in cities, that is more than half of the world's population. This number is predicted to be 6,7 billion by 2050. (United Nations, Department of Economic and Social Affairs, Population Division, World Urbanization Prospects: The 2018 Revision). This means we need to build new homes for more than three billion people over the next thirty years. Michael Green performed at TEDX talks in 2013 “Why we should build wooden skyscrapers?”. He pointed out the problem that people are not aware that using concrete and steel in construction emits so many CO_2 emissions. 5% of the world's anthropogenic greenhouse gases are caused by the use of concrete and 3% by the use of steel. But transport and industry are mainly blamed for greenhouse gas emissions. In reality 47% of greenhouse gases come from the construction sector, 33% from the transport sector and only 19% from industry in the USA. By continuing in the same way, we will increase global warming further. The solution is in a wood element panel. If we don't use the forest and at one point it just rots or is destroyed by fire, it returns the stored CO_2 to the atmosphere. However, if we use wood in construction or produce something else from it, we can store it for decades to come.

Micheal Green pointed out that we are facing a revolution, but due to fire safety regulations, it is still possible to build wooden buildings of up to only four storeys in many countries.

Micheal Green commented on fire safety in high-rise buildings: *“If I asked you to take a match and light it and hold up a log and try to get that log to go on fire, it doesn't happen, right? We all know that. But to build a fire, you kind of start with small pieces of wood and you work your way up, and eventually you can add the log to the fire, and when you do add the log to the fire, of course, it burns, but it burns slowly. Well, mass timber panels, these new products that we're using, are much like the log. It's hard to start them on fire, and when they do, they actually burn extraordinarily predictably, and we can use fire science in order to predict and make these buildings as safe as concrete and as safe as steel” (*Green, M, 2013).

3.2 HISTORY OF HIGH-RISE BUILDINGS

The construction of high-rise buildings and their widespread use were based on two important inventions: elevator and introduction of steel and concrete structures. The first safe elevator was invented in 1852 by Elisha Otis. The elevator system included a safety mechanism, which would prevent the elevator from falling if the cable breaks. The invention made the upper floors of buildings more popular because people no longer had to walk up the stairs. Five years later, in 1972, the E.V. Haughwout Building was opened in New York, with a height of five floors and the first elevator for people. (150 years of reaching for the sky: the evolution of tall buildings, 2016)

The Home Insurance Building, built in 1885 in Chicago, is considered to be the first modern skyscraper. The height of the 10-storey building was 42 meters and it was designed by engineer William LeBaron Jenney. During the construction of the building, the city authorities were so worried that the building could fall over that they decided to stop the construction and check that the building is still safe. The construction of the building consisted of an innovative and revolutionary steel frame, which made it possible to build taller and more stable buildings without adding much weight. The load-bearing structure of the building consisted of steel vertical posts and horizontal beams. The steel structure was not only lighter, but was able to withstand heavier loads than traditional brick. Masonry walls bear on steel structure which made them able to be much thinner. The whole building became lighter and there was no need to worry about building collapsing under its own weight. The exterior façade acted as a skin, which laid the foundation for the curtain wall used in tall buildings to this day (Home Insurance Building, 2010).

Since then, skyscrapers have become higher and higher. As early as the end of the 20th century, only buildings with a height of more than 40 or 50 floors were mentioned as skyscrapers. One of the reasons is definitely urbanization and cities becoming denser. Land in cities is expensive and it is more profitable to build as many floors as possible on the property. Throughout history, the appearance of skyscrapers has been influenced by various architectural movements from neoclassical to modernism. The function has also changed a bit, if initially high-rise buildings were only commercial buildings then more and more it is a residential or mixed use. The idea of the load-bearing structure of the building has remained the same. Today, the world's tallest building is the Burj Khalifa in Dubai, with a height of 828 meters, but a project has already been drawn up for a building with a height of more than one kilometer (The Editors of Encyclopaedia Britannica, 2020).

In parallel with the construction of higher and higher buildings, alternative structure methods for high-rise buildings are developed. Although concrete and steel allow us to build very tall buildings, the use of these materials emits a huge amount of C02 emissions. Alternative sustainable material is wood and CLT panels, which have been feared for fire safety and load bearing capacity reasons. Increasingly, engineers and architects around the world have proven the opposite by building safe high-rise from wood. Today, the tallest wooden building is Mjosa Tower in Norway that is 85.4 m high. Micheal Green has said in TED talk "Why we should build wooden skyscrapers": " *The first skyscraper, technically - and the definition of a skyscraper is 10 stories tall, believe it or not - but the first skyscraper was this one in Chicago, and people were terrified to walk underneath this building. But only four years after it was built, Gustave Eiffel was building the Eiffel Tower, and as he built the Eiffel Tower, he changed the skylines of the cities of the world, changed and created a competition between places like New York City and Chicago, where developers started building bigger and bigger buildings and pushing the envelope up higher and higher with better and better engineering….. I'm looking for this opportunity to create an Eiffel Tower moment, we call it. Buildings are starting to go up around the world. There's a building in London that's nine stories, a new building that just finished in Australia that I believe is 10 or 11. We're starting to push the height up of these wood buildings, and we're hoping, and I'm hoping, that my hometown of Vancouver actually potentially announces the world's tallest at around 20 stories in the not-so-distant future. That Eiffel Tower moment will break the ceiling, these arbitrary ceilings of height, and allow wood buildings to join the competition. And I believe the race is ultimately on."* (Green, M, 2013)

3.3 THE BOTTLENECKS OF TALL TIMBER BUILDINGS

The main challenges in the construction of high-rise buildings made of CLT panels are:

- Fire safety
- Acoustics
- Load-bearing capacity
- Maintenance of exterior wood surfaces
- Cost

4.1 ENGINEERED WOOD PRODUCTS - CLT

The idea of clt:

- The dimensions of components can be larger than with solid timber (without gluing)
- Layers with varying grain direction provide more dimensional stability
- Wood material for visible surfaces can be selected and the impact of knots can be minimized.

The use of cross-laminated timber (CLT) in the construction of high-rise buildings is limited by current standards and regulations, which make the use of CLT panels impractical or impossible. CLT panels can be used to build acoustically functional, fire safe and stable high-rise buildings. Appropriate design solutions have been developed and the fire performance of the building must be proven by alternative methods.

Cross-laminated timber (CLT) consists of at least three layers, but usually more layers of lumber boards. Lumber boards are stacked on top of each other, usually at an angle of 90 degrees, and glued together. Nails, screws or wooden dowels are often used to achieve extra strength. The width of one lumber board may be between 16 mm to 51 mm and the full width of CLT panels is usually 60 mm up to 240 mm. The dimensions of the panel may vary depending on the manufacturer, in special cases, the maximum width of the panel can be up to 508 mm and the length 18 m. The dimensions of the panel are limited by their transport. The main efficiency factor of CLT is that they are easy and quick to install on construction sites. Manufacturing the panels in their complete form in the factory saves both time and money during construction. CLT is lighter than concrete and masonry which means that structural elements can be thinner and smaller cranes are capable of lifting the panels. As a result of massive wood structure other benefits are good thermal insulation, sound insulation and performance in fire (Karacabeyli, E., Gagnon, S, 2019, Ch. 1, p. 5).

HISTORY

CLT is an innovative wood product that was first introduced in Austria and Germany in the early 1990s. Since then, the panels have gained a lot of popularity and are increasingly used in residential as well as other building types. The popularity of the panels has been fueled by the environmentally friendly movement. The fastest growth has taken place in the 21st century, where more and more complex and tall buildings are being built from CLT panels. (Karacabeyli, E, Gagnon, S, 2019, Ch. 1, p. 2.). Today, the world's tallest CLT panel building is the Mjøstårnet Tower, which is 84.4 m high. The building is located in Brumunddal, Norway and was completed in 2019. Wooden boarding is also used on the external facade of the building (Äripäev, 2021).

MANUFACTURING

CLT production consists of lumber selection and grouping, glueing, adding and pressing the next layer, shape cutting, surface treatment and packaging. Finished products are also subjected to Stringent in-plant quality control tests to ensure that the product meets the requirements. The necessary openings (windows, doors etc.) are cut at the end. CNC (Computer Numerical Controlled) routers are used for cutting to achieve high precision. (Karacabeyli, E, Gagnon, S, 2019 Ch. 1, p. 10)

4.2 SOLUTIONS FOR FIRE SAFETY

In Estonia, it is possible to prove the fire safety of a building in two ways:

1. Simplified design - the building is designed in accordance with pre-approved requirements (legislation, standards, guidelines).
2. Fire Safety Engineering- alternative methods of demonstrating compliance with pre-approved requirements based on essential fire safety requirements. (Päästeamet, 2018).

4.2.1 SIMPLIFIED DESIGN

In general the purpose of compliance with essential fire safety requirements in the course of design, construction and use of a structure, maintenance and other activities related to a structure is to reduce the risk to human life or health, property or the environment. A building shall be designed and constructed so that in the event of a fire:

1) the load-bearing capacity is maintained for the prescribed time;
2) the generation and spread of fire and smoke in the building is limited;
3) the spread of fire to neighboring buildings is limited;
4) safe evacuation is ensured;
5) the safety and operational possibilities of the rescue team are considered

(Riigi teataja, 2017)

Estonian act of fire safety says that the structure of a building shall be designed so that sufficient load-bearing capacity of the structure in the event of a fire is ensured within the prescribed time. The load-bearing capacity of a building structure shall be verified in the design in the course of its preparation in at least one of the following ways:

1) experimentally;
2) by calculation;
3) combining test and calculation results;
4) using a recognized spreadsheet

(Riigi teataja, 2017)

When designing high-rise buildings must be taken into account that:

Children's and educational establishments (except for higher education institutions), medical, welfare and penitentiary establishments, or production and storage premises with flammable and explosive activities may not be provided in a high-rise building. (Fire safety of constructions, 2019)

The maximum number of seats in a conference hall, restaurant or other meeting room shall not exceed 100 if it is located higher than the 8th floor or if the floor of this room is more than 24 meters above the ground. (Fire safety of constructions, 2019)
Fire compartment boundary area:

- One floor up to 2400 m2
- The two-storey fire compartment section is up to1600 m2
- The three-storey fire compartment section is 800 m2
- The fire compartment section in the basement is 800 m2

(Fire safety of constructions, 2019)

REGULATIONS THAT PREVENT TIMBER HIGH-RISE BUILDINGS:

High-rise buildings must be designed as TP1 class buildings. The required fire resistance class (tulepüsivusklass) of the load-bearing structures of a building is ensured according to the fire load (eripõlemiskoormus) of the rooms (Fire safety of constructions, 2018).

Fire resistance is the ability of a building structure or part thereof to maintain the required load-bearing capacity, integrity and thermal insulation capacity in the event of a fire, which is generally determined by a standard fire test (Riigi teataja, 2017).

TP1 - the load bearing structure of a building shall not collapse in a fire within the prescribed time (Riigi teataja, 2017).

A load bearing structure of a building made of combustible material is deemed to be a non-combustible material if it is sufficiently encapsulated with covering materials made of non-combustible materials. For fire resistance R 30 or R 60, the fire-retardant capacity of the coating material shall be at least K 2 30 and for fire resistance R 90 the fire-retardant capacity of the coating material shall be at least K 2 60 (Riigi teataja, 2017).

Table 1. Fire resistance of building load-bearing structures (Riigi teataja, 2017).

KINNITATUD
Siseministri 30.03.2017 määrusega nr 1-1/17
„Ehitisele esitatavad tuleohutusnõuded ja
nõuded tuletõrje veevarustusele“
LISA 3
(siseministri 21.11.2018 määruse nr 1-1/29
sõnastuses)

HOONE JÄIGASTAVATE JA KANDEKONSTRUKTSIOONIDE TULEPÜSIVUS

	Ehitise tuleohutusklass						
	TP1			**TP2**			**TP3**
	Eripõlemiskoormus MJ/m^2			**Eripõlemiskoormus MJ/m^2**			
	üle 1200	600–1200	alla 600	üle 1200	600–1200	alla 600	
Kuni kahekorruseline hoone üldiselt	R 120*	R 90*	R 60*	R 30	R 30	R 30	–
– II ja III kasutusviis ning keldrid	R 120**	R 90**	R 60**	R 30	R 30	R 30	–
3–8-korruseline hoone üldiselt	R 180**	R 120**	R 60**	X	X	X	X
3–8-korruseline I ja V kasutusviisiga ehitise							
– pealmaakorrused	R 180**	R 120**	R 60**	R 180*	R 120*	R 60*	X
– keldrikorrused	R 180**	R 120**	R 60**	R 180**	R 120**	R 60**	X
Üle 8-korruseline hoone	R 240**	R 180**	R 120**	X	X	X	X
Esimese maa-aluse keldrikorruse all asuvad keldrikorrused	R 240**	R 180**	R 120**	R 240**	R 180**	R 120**	R 60**

Märkused
* Kui kandetarindid ei ole vähemalt A2-s1,d0 tuletundlikkusega, peab hoone soojustusmaterjal olema vähemalt A2 tuletundlikkusega.
** Kandetarindid peavad olema vähemalt A2 tuletundlikkusega.
– Nõudeid ei esitata.
X Sellist hoonet pole lubatud ehitada.

Table 2. Fire resistance of fire protected structures. (Riigi teataja, 2017)

KINNITATUD
Siseministri 30.03.2017 määrusega nr 1-1/17
„Ehitisele esitatavad tuleohutusnõuded ja
nõuded tuletõrje veevarustusele“
LISA 4

HOONE TULETÕKKEKONSTRUKTSIOONIDE TULEPÜSIVUS

	Hoone tuleohutusklass				
	TP1 ja TP2 3–8-korruseline			**TP2**	**TP3**
	Eripõlemiskoormus MJ/m^2			Korruste arv	
	üle 1200	600–1200	alla 600	kuni 2	kuni 2
Tuletõkkekonstruktsioonid pealmaakorrustel	EI 120	EI 90	EI 60	EI 30	EI 30
Tuletõkkekonstruktsioonid pööningul	EI 30	EI 30	EI 30	EI 30	EI 30
Tuletõkkekonstruktsioonid keldris	EI 120	EI 90	EI 60	EI 60	EI 30
II kasutusviisi hoone majutusruumide seinad ja uksed	EI 15	EI 15	EI 15	EI 15	EI 15

The fire resistance of the load-bearing structure of a building and the structures forming the fire barrier section shall be indicated on the basis of the load-bearing capacity of the structure (symbol R) (Riigi teataja, 2017)

Depending on the fire load, fire resistance of the loadbearing and fire compartment (tuletõkkesektsioon) structures must comply with the parameters given in the table. (Fire safety of constructions, 2018)

Table 3. Requirements for fire resistance of structures (Fire safety of constructions, 2018).

Tabel 1 — Nõuded tarindite tulepüsivusele

Tarindi otstarve	Eripõlemiskoormus MJ/m²		
	kuni 600	600 kuni 1200	üle 1200
Kandetarindid	R 120	R 180	R 240
Trepimademed ja käigud	R 60	R 90	R 120
Mitmekorruselised keldrid	R 180	R 240	R 300
Tuletõkketarindid			
Üldjuhul	EI 120	EI 180	EI 240
Suitsuvaba (Tk2) ning suitsu- ja tulekindel (Tk3a ja Tk3b) trepikoda	EI 120	EI 180	EI 240
Tk2, Tk3a ja Tk3b trepikodade ja tuletõrjujate lifti juures olevad lüüstamburid	EI 60	EI 90	EI 120
Tuletõrjujate liftišaht	EI 120	EI 180	EI 240
Kommunikatsiooni- ja liftišahtid	EI 120	EI 180	EI 240

Table 3 continuation. Requirements for fire resistance of structures. (Fire safety of constructions, 2018)

Tabel 1 (*järg*)

Tarindi otstarve	Eripõlemiskoormus MJ/m²		
	kuni 600	600 kuni 1200	üle 1200
Diiselgeneraatori ruum	EI 120	EI 180	EI 240
Tuletõrje- ja päästevahendite, juhtimiskeskus, kustutussüsteemide keskused, tugipunkt	EI 120	EI 180	EI 240
Korterid ja majutusruumid	EI 60	–	–
Tehnilised ruumid	EI 60	EI 120	EI 180
Mitmekorruselised keldrid	EI 120	EI 180	EI 240
Laoruumid	EI 120	EI 180	EI 240

A fire load less than 600 MJ / m2 is characteristic of accommodation establishments, residential buildings, universities, entertainment and cultural institutions and other gathering buildings, as well as canteens, cafes, office buildings and garages (Fire safety of constructions, 2018).

The load bearing structures must meet the requirements of class A1 (Fire safety of constructions, 2018).

Fire sensitivity (tuletundlikkus) is the ability of a material to ignite, spread fire, emit heat, smoke, toxic gases or flammable or hot drops upon contact with fire (Riigi teataja, 2017)

Table 4. Fires sensitivity classes (Riigi teataja, 2017).

§ 8. Tuletundlikkus

(1) Materjalid ja tooted jaotatakse standardtulekatsete alusel järgmiselt:
1) A1 – ei ole tuletundlik;
2) A2 – ei ole tuletundlik, suitsu eraldub eriti vähesel määral;
3) B – on tuletundlik, materjal on süttiv, suitsu eraldub eriti vähesel määral ning põlevaid tilku ega tükke ei esine;
4) C – on tuletundlik, suitsu eraldub vähesel määral ja põlevad tilgad või tükid kustuvad kiiresti;
5) D – on tuletundlik, materjal võib tulekahjus osaleda;
6) E – osavõtt tulekahjust on tavapärane;
7) F – kergesti süttiv või määramata;
8) s1 – suitsu eraldub eriti vähesel määral;
9) s2 – suitsu moodustub vähesel määral;
10) s3 – suitsu moodustub määral, mis ei täida s1 ega s2 nõudeid;
11) d0 – põlevaid tilku või tükke ei esine;
12) d1 – põlevad tilgad või tükid kustuvad kiiresti;
13) d2 – põlevate tilkade või tükkide esinemine ei täida d0 ega d1 nõudeid.

(2) Ehitamisel kasutatavate ehitusmaterjalide tuletundlikkus on sätestatud käesoleva määruse lisades 6 ja 7.

Depending on the function of the room, the fire sensitivity of the surface layer must comply with the parameters given in the table.

Tabel 5. Fire sensitivity of the surface (Fire safety of constructions, 2018).

Tabel 2 — Tarindite pinnakihi tuletundlikkus

Tarindi otstarve	Seinad ja lagi	Põrand
Trepikäigud ja -mademed	A2-s1,d0	$A2_{FL}$s1
Suitsuvaba (Tk2) trepikoda ning tule- ja suitsukindlad (Tk3a ja Tk3b) trepikojad	A2-s1,d0	$A2_{FL}$s1
Tk2 ja Tk3a trepikodade juures olevad lüüstamburid	A2-s1,d0	$A2_{FL}$s1
Diiselgeneraatori ruum	A2-s1,d0	$A2_{FL}$s1
Tuletõrje- ja päästevahendite juhtimiskeskus, kustutussüsteemide keskused, tugipunkt	A2-s1,d0	$A2_{FL}$s1
Evakuatsioonikoridor	A2-s1,d0	$A2_{FL}$s1
Sisekoridor	B-s1,d0	D_{FL}s1
I kasutusviisiga ruumid	C-s2,d1	–
II kasutusviisiga ruumid	B-s1,d0	D_{FL}s1
IV kasutusviisiga ruumid	B-s1,d0	D_{FL}s1
V kasutusviisiga ruumid	C-s2,d1	D_{FL}s1
VI ja VII kasutusviisiga ruumid	A2-s1,d0	$A2_{FL}$s1
Sauna leiliruumid	D-s2,d0	D_{FL}s1
Keldrikorrused	A2-s1,d0	$A2_{FL}$s1

FACADES AND EXTERNAL WALLS

The surface layer of external walls in buildings up to 16 storeys must meet the requirements of class B-s1, d0. - Technically it is possible to use a timber boarding facade (Fire safety of constructions, 2018).

A load-bearing structure belonging to the TP1 class:

2) the non-load-bearing structure of the external wall of a three- to eight-storey building may be made of D-s2, d2 fire-sensitive material, whereas the insulation material must meet at least A2 fire-sensitivity requirements;

3) the fire sensitivity of the outer surface of the outer wall of an up to eight-storey building and the outer surface of the ventilation gap may be D if the structure surrounding this part prevents the spread of fire on the wall surface and the insulation material meets at least A2 fire sensitivity requirements;

4) the external wall of a building higher than eight storeys must meet the requirements set out in the relevant standard
(Riigi teataja, 2017).

EVACUATION AND THE CONSTRUCTIONS

The required level of measures shall be implemented in the building to enable people to evacuate quickly, independently and safely, or to wait for outside assistance in a safe place (Fire safety of constructions, 2018).

7.4.1 Evakuatsioonipääsuna kasutatavad trepikojad peavad olema kas

— suitsuvabad (Tk2) või

— tule- ja suitsukindlad (Tk3a) trepikojad,

— tule- ja suitsukindlad (Tk3b) trepikojad.

7.4.2 Kõrghoones peab olema ette nähtud

— ühe trepikojaga hoones: suitsuvaba (Tk2) või tule- ja suitsukindel (Tk3a) trepikoda;

— kahe trepikojaga hoones: üks suitsuvaba (Tk2) ning üks tule- ja suitsukindel (Tk3a) trepikoda;

— üks suitsuvaba (Tk2) ning üks tule- ja suitsukindel trepikoda (Tk3b);

— mõlemad tule- ja suitsukindlad (Tk3a) trepikojad;

— üks tule- ja suitsukindel (Tk3a) trepikoda ning üks tule- ja suitsukindel trepikoda (Tk3b);

— tule- ja suitsukindlad trepikojad (Tk3a või Tk3b), mis on ette nähtud mitmekorruselisest keldrist evakuatsiooniks.

Image 2. Requirements for evacuation routes. (Fire safety of constructions, 2018)

As a conclusion it can be stated that the main reason that prevents building timber element high-rise buildings is that according to current regulations, high-rise buildings must be constructed as TP1 class buildings (EVS 812, paragraph 5; 5.1). Its technical output is the encapsulation of all wooden structures, in other words the covering with gypsum or concrete. Otherwise you would not meet the requirements of the fire sensitivity, which for the load bearing structures must be A2-s1,d0. Depending on the function of the room, the fire sensitivity requirement loosens to D-s2, d2. In some cases (but not for all structural elements) the required fire resistance is obtained.

Encapsulating all load-bearing constructions is irrational in both environmental and cost point of view. The whole idea of building from wooden structure disappears if the wood is not even visible.

Sisekaitseakadeemia and Eesti puitmajaklaster have created guidelines for building up to eight storey office or residential buildings from timber structure. The instructions are in accordance with the requirement no. 17 from Home Secretary from 30.03.2017. The guidelines concern the fire safety of buildings belonging to the class of TP1 or TP2. For TP1 class buildings it has been taken into account that the fire load is in the range of 600-1200 MJ/m2 and the fire resistance up to 120 minutes in the case of standard fire. The guide illustrates the structure of encapsulated structures. (Urmer, M., Mäger, K. N., Just, A., Kliimask, J., Friedenthal, T., Piik, M., Jalas, R., Nu Arhitektuur OÜ, 2017)

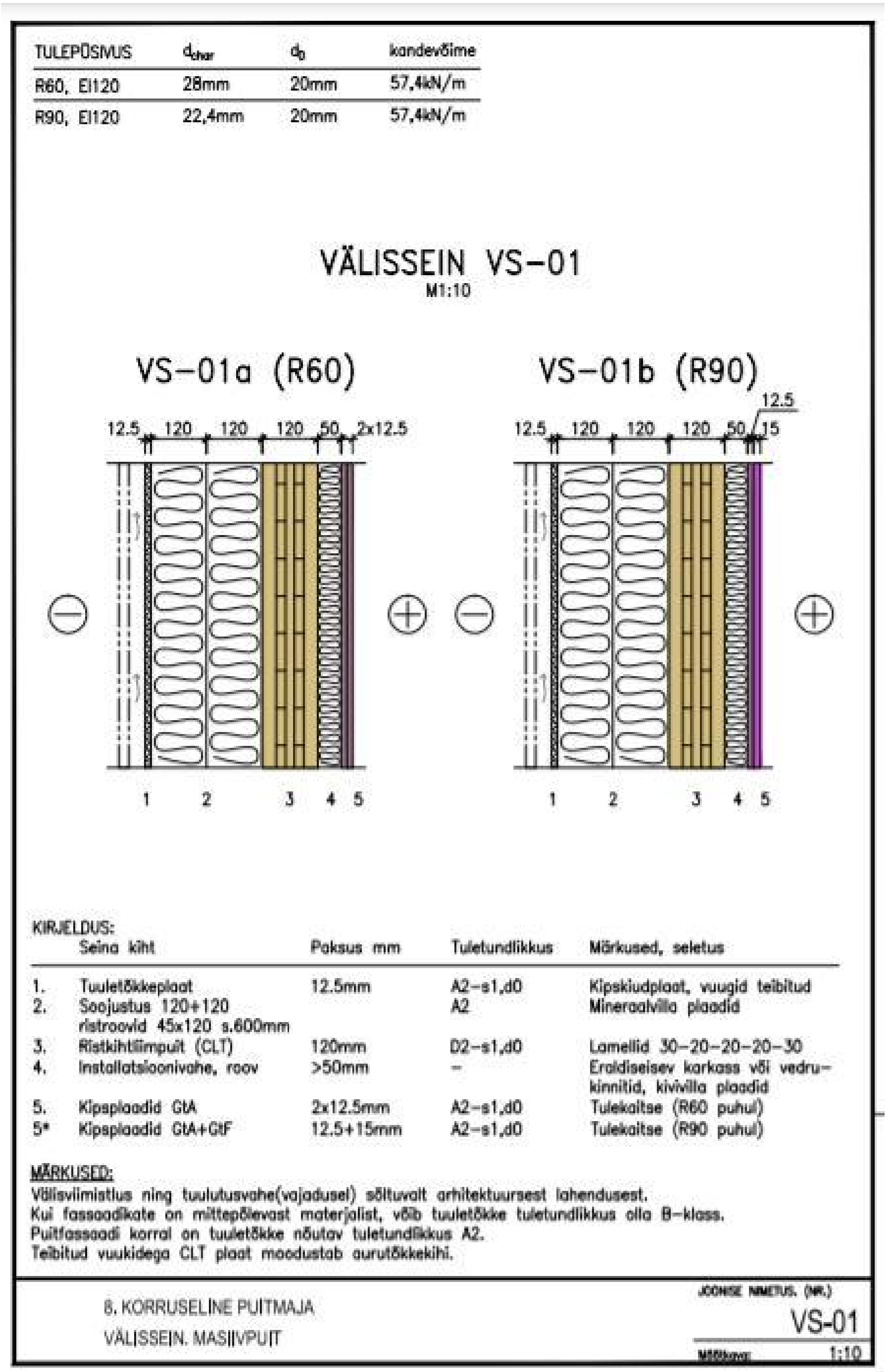


Image 3. External wall (Urmer, M., Mäger, K. N., Just, A., Kliimask, J., Friedenthal, T., Piik, M., Jalas, R., Nu Arhitektuur OÜ, 2017).

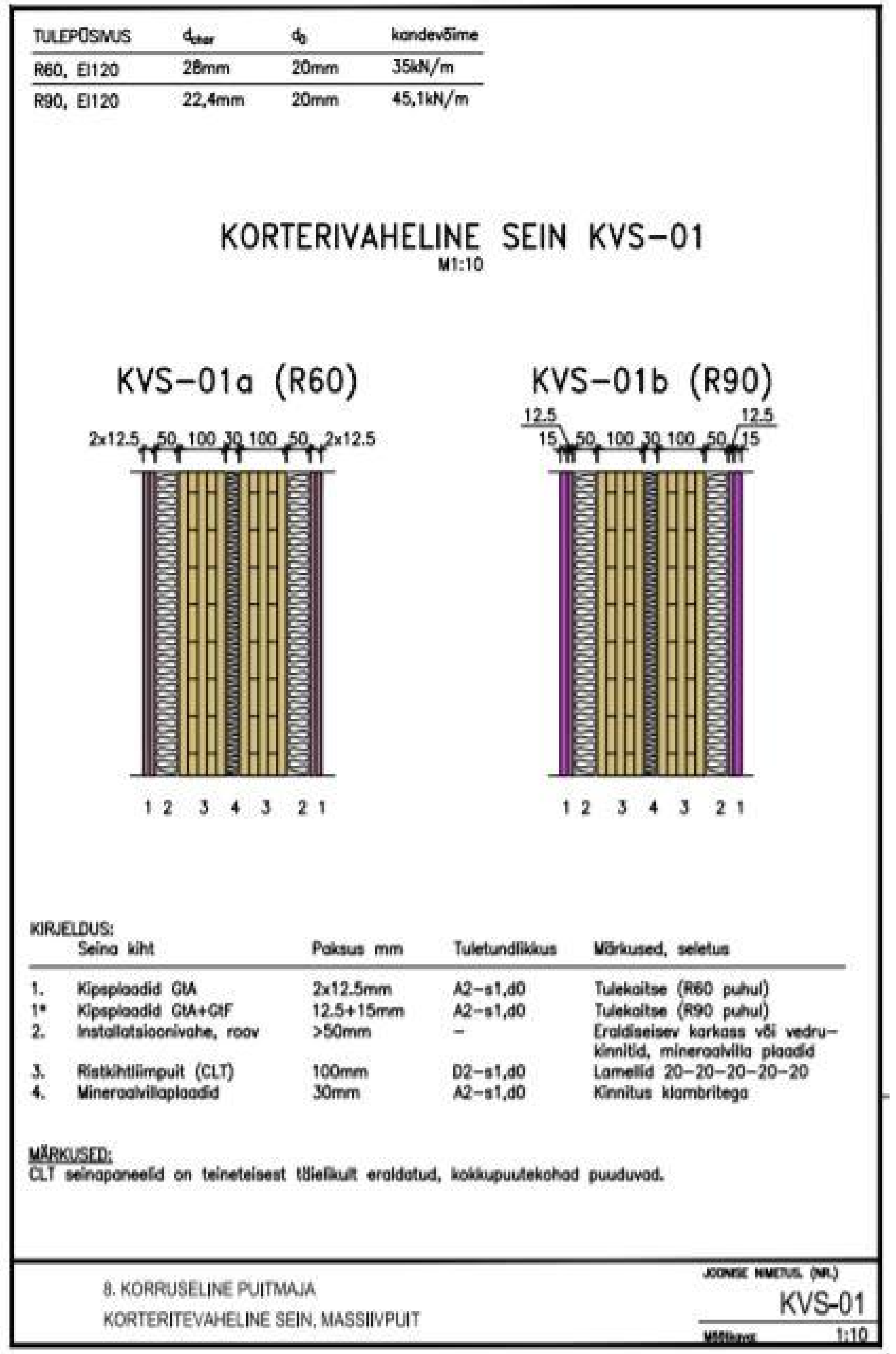


Image 4. Inner wall (Urmer, M., Mäger, K. N., Just, A., Kliimask, J., Friedenthal, T., Piik, M., Jalas, R., Nu Arhitektuur OÜ, 2017).

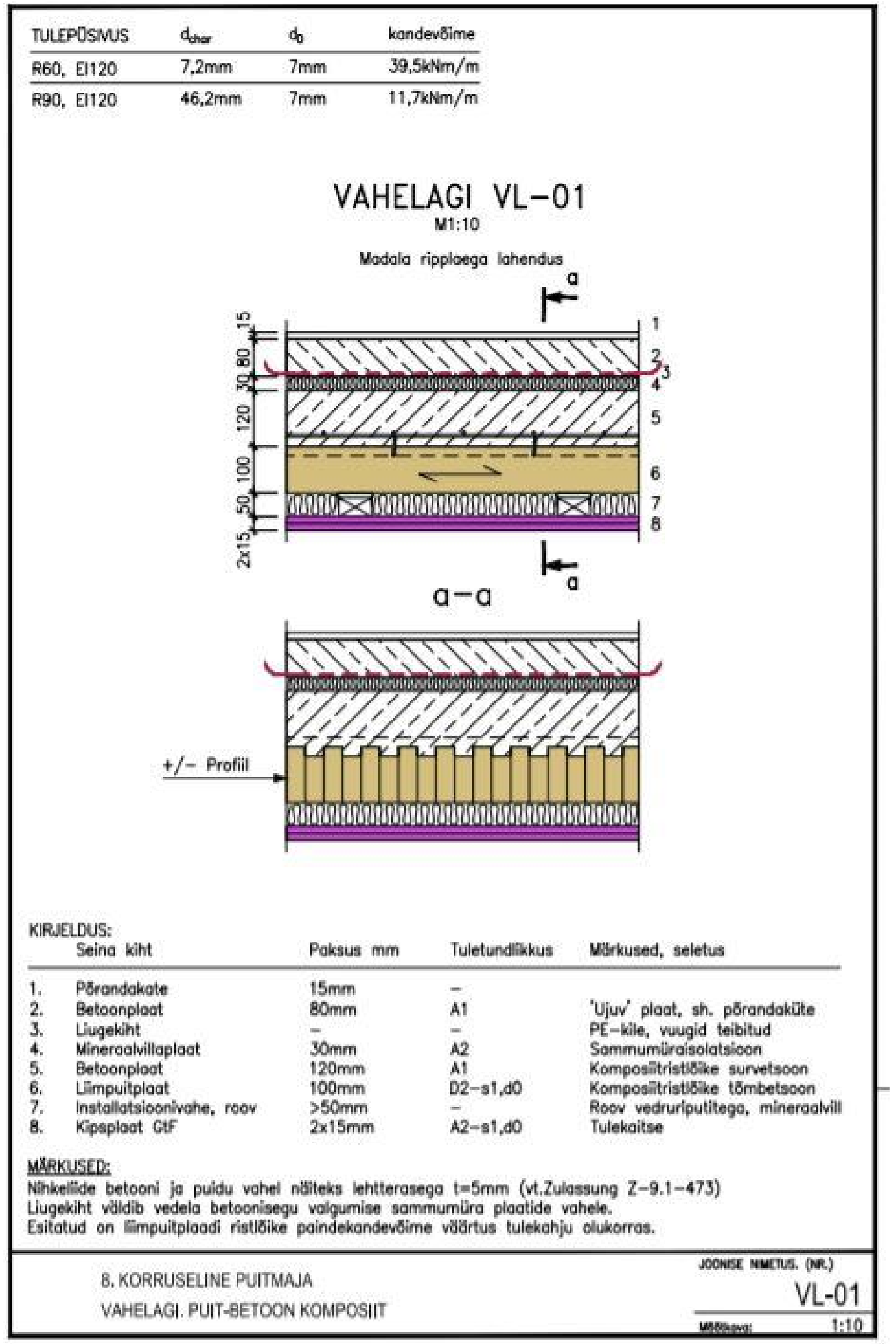


Image 5. Ceiling (Urmer, M., Mäger, K. N., Just, A., Kliimask, J., Friedenthal, T., Piik, M., Jalas, R., Nu Arhitektuur OÜ, 2017).

4.2.2 ANALYTICAL DESIGN

If the design of the building deviates from the relevant fire safety regulations, standards or norms, the alternative method of proving fire safety is analytical verification. Analytical verification is very uncommon in Estonia, although it is increasingly used in other European countries, because the existing norms do not allow the introduction of new technologies and materials. Another reason is that European countries are taking over more and more European (EN) and international (ISO) standards which support alternative methods for proving safety.

For more than ten years, proving fire safety analytically has been allowed in Estonia, but what it is and how it should be done was not described. Regulation no. 315 "Fire safety requirements for the building and its parts" adopted by the Estonian Government in 2004 mentioned analytical verification just in one sentence: "The compliance of a building and its parts to the essential fire safety requirements deemed to have proven, if the possible evacuation, minimization of property damage and potential damage to the public, including the environment in the event of fire is taken into account. The compliance of the building with the essential fire safety requirements must be proved by calculation, analytical or other reliable means, taking into account the possible outbreak and extinguishing of the fire" (Riigi teataja, 2004).

In 2010, the Estonian Ministry of the Interior and the Academy of Internal Affairs prepared a report: "Analysis of the adequacy of fire safety requirements" As a result of the report the research team decided to propose a regulation to establish fire safety criteria that would allow to assess the effectiveness of the solution provided by other methods. As long as they are not fixed, it is difficult to ensure fire safety requirements by other methods. However, the issue is very important to start using new architectural and technical solutions. (Käerdi, H., Angelstok, F., Luht, K., Valge, A., Ambel, A., 2010, p 71.)

During the preparation of the same report, Kadi Luht interviewed Micheal Strümgren, who is Fire Safety Regulator at The National Board of Housing, Building and Planning (Boverket). The interview focused on the fire safety of Swedish buildings and its certification. The interview took place on 19.12.20.

Micheal Strümgren commented (2020) that today, the legal space is largely based on European Union standards and directives. Due to the performance-based verification, which is widely discussed in the Eurocodes, it is planned to make changes in fire safety requirements regarding construction in Sweden next year. Although Sweden is well ahead of Estonia in the development of alternative fire safety methods, they also have problems. Technological developments have not left untouched the construction sector, where more and more new materials and constructive solutions are being introduced. At the same time, the construction of tunnels, high-rise buildings, very large open areas, etc. has become more common. In such cases, it is neither economically nor constructively appropriate to follow exactly the prescribed norms. It is very difficult to design according to the prescribed requirements and standards. It is more sensible to use performance-based verification methods to prove the suitability of selected construction and technical solutions for building safety in fire conditions. There is a need to prove the safety of a building in alternative ways. A building is also considered to be fire safe if it is designed in accordance with the presumed fire development, which describes the situations that are likely to occur in the building. (Käerdi, H., Angelstok, F., Luht, K., Valge, A., Ambel, A., 2010, p 38 - 39.)

Artur Eisenbeiss (2007) argues that as long as there are no clear criteria and performance-based standards, decisions are based to a large extent on expert knowledge and experience and even on the feelings that the designed solution is at the same level of safety as required by the prescribed standards. (Käerdi, H., Angelstok, F., Luht, K., Valge, A., Ambel, A., 2010, p 58.)

Mari Tikan, Adviser of the Rescue and Crisis Management Department of the Ministry of the Interior, told the Annual Fire Safety Conference in 2015 that the regulation needs to be changed because the situation in the construction market has changed and new technologies, construction materials are used and safety can be ensured by different methods. (Matson, 2015)

In 2017, a new regulation was introduced in Estonia: “Fire safety requirements for building and requirements for fire water supply”. This regulation clarifies analytical verification in more detail and proposes different ways of doing it. However, the descriptions of the methods are rather brief and there are still no clear criteria for an accurate assessment.

“Fire safety requirements for building and requirements for fire water supply”

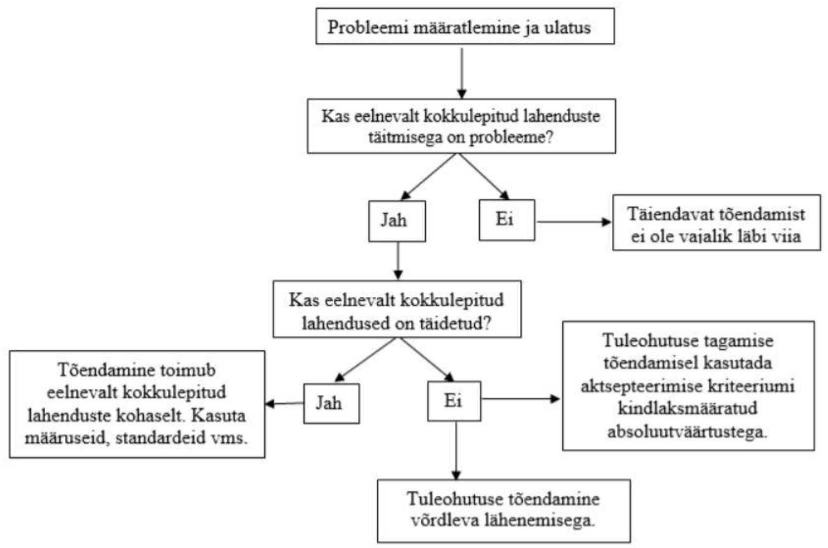
If the fire safety requirements of a regulation, relevant technical norm or standard are deviated from, the conformity of the construction work with the essential fire safety requirements shall be proved analytically. The impact of the deviation on the different areas of the requirements is assessed using the following reliable methodologies:

1. Qualitative assessment is based on statistics, experience, tests, research and development reports or other similar documents.
2. In the case of quantitative analysis, the probability and impact of risks are analyzed numerically and the overall risk of the project is calculated. Quantitative analysis is a forecasting method that generally uses modeling and expert judgment
3. Analytical verification shall be performed by a person holding a level 6 professional certificate of a fire safety expert who involves a person who knows or is competent in a special field.
4. The instructions of an international organization, professional association or the Rescue Board or other relevant documents shall be used for analytical verification. If documents other than those referred to in this paragraph are used, the reliability of the means of proof used must be demonstrated.

(Riigi teataja, 2017)

In 2018, the Estonian Rescue Board issued instructions for Analytical verification. The purpose of the guidelines were creating a basis for analytical verification focusing on comparative approach. The guide will help identify and make sure that the data obtained by analytical verification are equivalent to fire safety requirements from other regulations and standards. As well as guidance on how to verify alternative methods using qualitative and quantitative estimation methods (Päästeamet, 2018, p. 3).

The first step is to choose the method of proof. It can be an absolute or comparative approach. Absolute approach can be only used when there are quantifiable acceptance criteria. In other cases, the only option is comparative approach. The comparative approach is a comparison with a fire safety plan and an equivalent reference building. (Päästeamet, 2018, p. 10-11).



Joonis 1 – Meetodi valik

Image 6. Method selection. (Päästeamet, 2018, p. 7).

In the case of comparative approach, fire safety can be demonstrated by qualitative assessment, deterministic analyse (scenario analysis), probabilistic analysis (quantitative risk analysis) or a combination of them. it is very important to verify the results obtained and it must be possible to verify them again. (Päästeamet, 2018,)

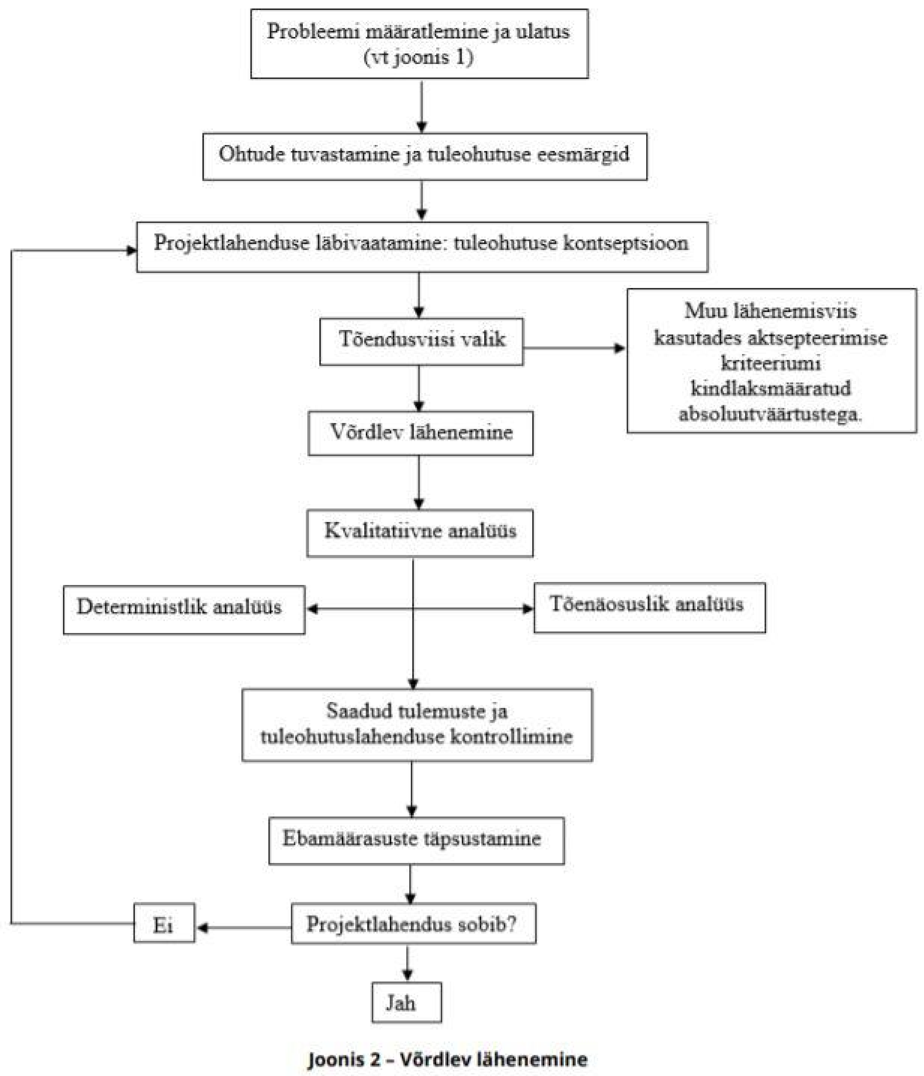


Image 7. Comparative approach. (Päästeamet, 2018, p. 8).

Qualitative assessment is a control method where the project is simply controlled by logical reasoning or other evidence (statistics, tests or documents showing the constriction have worked well over time in the relevant fire scenarios). The analysis is based on the identification of hazards and the assessment is based on several worst plausible cases.

Deterministic analysis is a control method that is based on consequences and the test demonstrates the adequate safety in different fire scenarios. Deterministic analysis uses models based on physical, chemical, thermodynamic, and human behavioral patterns derived from scientific theories and empirical calculations. The analysis involves an assessment of a set of circumstances that yields a single result. The comparative approach compares this individual result of the pilot project with an equivalent reference building. Evaluation criteria can be defined for each fire safety objective, which is analyzed with deterministic models. Evaluation criteria can be defined for each fire safety objective, which is analyzed with deterministic models that include at least one of the most reliable cases.

Probabilistic analysis focuses on the probability of a specific unwanted event. This can be achieved by using fire and the reliability of fire protection systems statistics, together with the consequences of possible fire scenarios, using deterministic assessment. Probability analysis is based on the distribution of input variables.

The breakdown of variables must reflect the conditions expected during the life of the building. The desired level of security is determined when making comparative decisions, compared with the building with an equivalent level of risk. (Päästeamet, 2018, p. 12-13).

Even with analytical verification the fire sensitivity of construction products and materials have to be at least D-s2,d0. Products with lower fire sensitivity contribute to the development of fire to an unacceptable extent and may endanger people's safety. (Päästeamet, 2018, p. 5).

For controlling, fire scenarios must be identified systematically. Each scenario is complex and realistic and must present fire scenarios that could realistically occur in the building (Päästeamet, 2018, p.13).

When creating a fire model, one or more fires must be identified for impact assessment. The location of the designed fire must be assumed where the consequences of such a fire are most severe in order to assess a reliable worst-case fire scenario. The fire model can be characterized in different ways, depending on the objective of the fire safety and the corresponding phase of the fire.

In the early phase (growth phase), designed fires can be described:

- Heat release rate (soojuse vabastamise kiirus)
- Fire growth (tulekahju kasvamine)
- Smoke production rate (suitsu tootmise määr)
- Fire heat (põlengu kuumus)

In the phase of full fire, designed fires can be described:

- Burning load (põlemiskoormus)
- Ventilation conditions (ventilatsiooni tingimused)
- Temperature (temperatuur)

Example: When analyzing fire safety objectives for evacuation, a fire is usually designed with rapid fire growth rate, heat release rate and smoke production rate. But when you are analyzing fire safety objectives related to fire resistance and load-bearing capacity, a fire is usually designed with burning load, evolution of temperature and maximum temperature. (Päästeamet, 2018, p. 13).

Softwares for fire design :

- Fire simulations
- Evacuation simulations
- Resistance of structural elements

An alternative option is to apply the index method (FRIM-MAB: Fire Risk Index Method for Multi-storey Apartment Buildings). (Käerdi, H., Angelstok, F., Luht, K., Valge, A., Ambel, A., 2010, p 59.)

Simulation programs:

- Fire dynamics simulator FDS
- Fluid dynamics calculation program ANSYS CFX
- Evacuation simulator Pathfinder

(Käerdi, H., Angelstok, F., Luht, K., Valge, A., Ambel, A., 2010, p 65.)

4.2.3 FIRE SAFETY OF CLT STRUCTURES

Massive CLT panels work similarly to reinforced concrete elements, they keep the fire within the boundaries of the room so that it does not spread further to other rooms. CLT panels are mainly used as load-bearing structural elements, which also allows inherent fire-rated compartmentalization. Although massive CLT panels are combustible material they perform well under fire conditions. CLT panels have a slow rate of charring. The char layer has a low density and acts as an insulating layer, protecting the following layers from heat. Charring is a property of wood that can be used by engineers and architects to assess the behavior of a structure in a fire. (Karacabeyli, E, Gagnon, S. 2019 Ch. 1, p. 17).

The first step of fire design is determining the fire rate of the structure and sizing of structural elements. Once we know how thick the CLT panel must be to keep the building and how fast the panel charts, we can over dimension our load-bearing structures. In this way it is possible to ensure the stability of the building in the event of a fire. The burning rate of CLT panels with the gap between the lamellae of no more than 2 mm is 0,65m/min. (CLT ristkihtpuit) Depending on the structure and type of wood the burning rate may vary. In the simplified example, assume that the CLT wall panel must be at least 120 mm thick to achieve the load-bearing capacity. Assume that a building must remain stable for at least 60 minutes in the event of a fire. This means that the panel should actually be at least 159 mm thick to ensure stability in the event of a fire for 60 minutes. Other benefits can be achieved by oversizing the panels: wider panels improve thermal performance of the structure and reduce sound transmission between rooms. Also improve the robustness of the building, which reduces the cost of expensive detailing between the building. (Cross Laminated Timber)

Although solid CLT panels can maintain long-term stability in the event of fire, they are a flammable material. There are three main principles for achieving adequate fire resistance of CLT elements:

- Exposed massive wood. No additional layers, the full fire resistance is achieved by massive wood.
- Limited capsulation. Additional fire proof layers, but the wood is allowed to char.
- Complete encapsulation. Additional fire proof layers, the wood is not allowed to char. (Stora Enso, 2016, p. 19)

USDA Forest Service's Forest Product Laboratory (USDA FPL) in cooperation with the American Wood Council, the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF), and the Forest Service's State and Private Forestry in Beltsville, Maryland conducted a series of five tests. A two-storey building was constructed in a test. The dimensions of the building were approximately 9,2m x 9,2 m and the load-bearing structure consisted of 175 mm thick 5-ply CLT panels.

1. Test - full encapsulation - entire CLT structures covered with 2 layers of 15,9 mm gypsum board.
2. Test - Partial encapsulation - 30 % of the CLT panel was exposed on the center portion of the ceiling in the living room and bedroom.
3. Test - Exposed CLT on walls in bedroom and living room.

4. Test Exposed CLT throughout - automatic sprinkler activation
5. Exposed CLT throughout - automated sprinkler activation delayed 20 minutes.

The result of the experiment was that tests 1-3, which ranged from complete encapsulation to some encapsulation, showed similar heat release rate profiles and all three attenuated the fire naturally. Tests 4 and 5 where sprinklers were used proved that the sprinklers were effective in lowering the temperature for a few minutes and preventing flashover from occurring. (Karacabeyli, E, Gagnon, S. 2019 Ch. 8, p. 9).

Automatic sprinkler systems are important tools for ensuring the fire safety of any building. With fire simulation engineering, it is possible to prove that approved and capable fire sprinkler systems can make concessions to other fire safety requirements. For example, to allow the construction of larger and higher rooms, use elements with lower fire resistance requirements, as well as to allow higher surface flammability for interior surfaces. (Karacabeyli, E, Gagnon, S. 2019 Ch. 8, p. 69).

From a fire safety point of view, it is important to draw attention to the CLT panel assemblies. Metallic fasteners are mainly used for joining CLT panels: bolts, dowels, steel plates or brackets. Steel has high thermal conductivity, metal connections that come in contact with fire can heat up and transfer heat to the wood layers. Therefore, the CLT may also ignite around the fasteners on the inside of the panel. Another reason is that as the heat increases, the steel loses strength, which can lead to the structure collapsing. Therefore, metal connections or fasteners should either be covered with insulating layers or should be covered by the panel itself. (Karacabeyli, E, Gagnon, S. 2019 Ch. 8, p. 62).

4.3 ACOUSTICS

Sound is an audible oscillation of air characterized by the frequency and amplitude of the oscillations. The oscillation frequency describes the pitch of a sound in Hz (number of oscillations per second). The human ear is able to hear sound at a frequency of approximately 16-16000 Hz. The amplitude of the oscillations characterizes the volume of sound, which is expressed in a logarithmic unit of bell. In practice, a tenth of a bell, a decibel, is used. (Masso, 2012, p. 89)

Disturbing sound is called noise. In the case of noise, a distinction is made between airborne noise, which is made by oscillation of air (speech and music) and impact noise resulting from walking or mechanical effects. Impact noise can also be accompanied by vibration. (Masso, 2012, p. 91). In order to control the transmission of sound between structures, we need to understand what sound is and where it comes from. (Karacabeyli, E, Gagnon, S. 2019 Ch. 9, p. 2)

In Estonia, the assessment of air and impact noise is based on the requirements of the standards EN ISO 717-1 (airborne sound) and EN ISO 717-2 (impact sound). These international standards are used in many other countries besides Estonia. Sound insulation is evaluated with the singular parameter R`w (airborne noise insulation index) and L`nw (impact noise level index) both in dB. In the case of lightweight structures, such as wooden structures, it is recommended to assess the sound insulation at lower sound frequencies. At lower sound frequencies, the sound insulation of wooden structures can deteriorate significantly. Therefore, sound insulation parameters for structures are often given in the form of R`w (C, Ctr). (Madalik, L. 2004)

Standard EVS 842: 2003 "Sound insulation requirements for buildings, Protection against noise" sets out the minimum sound insulation requirements for the internal boundaries of a building depending on the function of the room. The numerical values of the index R`w in the table require insulation of airborne noise in the horizontal and vertical directions. The index L`nw is the required impact sound insulation in all directions (vertical, horizontal and diagonal). (Sound insulation requirements in buildings Protection against noise, 2003)

Table 5. Sound insulation requirements for internal borders considering the residential and office building. (Sound insulation requirements in buildings Protection against noise, 2003)

Residential building. Airborne noise insulation index R`w (dB)	
Building and room type	**Sound insulation requirements**
Between apartment living space rooms	55
Between apartment living, public and office space rooms.	55
Between apartments and noise-producing rooms (maintenance, service, work and rest rooms, garages)	60
Between the rooms of one apartment	43
Between apartments and common areas if there is a door in the wall of the apartment	39

Residential building. Reduced impact noise index L`nw (dB)	
Building and room type	**Sound insulation requirements**
From one apartment to another	53
From the balcony, stairs, corridor, bathroom, toilet etc. to another apartment	55
Between apartments and noise-producing rooms (maintenance, service, work and rest rooms, garages)	58
Between the living space rooms of a two storey apartment	63

Office and administrative building. Airborne noise insulation index R`w (dB)	
Building and room type	**Sound insulation requirements**
Between work rooms, between work rooms and common areas (staircase, corridor, hall, lobby)	48
Between the cabinet, the workroom and the common areas if there is a door in the wall.	34

Office and administrative building. Reduced impact noise index L`nw (dB)	
Building and room type	**Sound insulation requirements**
From work space to work space; from the public space to the work space.	63

Similar to the internal boundaries of a building, there are also requirements for the external boundaries of the building, which depend on the amount of external noise in the immediate vicinity of the building and the permissible noise level in the room.

Table 6. Standard levels of traffic noise in residential and public buildings. (Sound insulation requirements in buildings Protection against noise, 2003)

Building and room type	**Allowed noise level**	
Residential building		
Living and sleeping rooms	LpAeqT (day)	35
	LpAeqT (night)	30
	LpAmax (night)	45
Office and administrative building		
Meeting rooms, offices, reading rooms, classrooms and equivalent rooms	LpAeqT (day)	35
In open-plan office spaces, exhibition spaces	LpAeqT (day)	40
Trade and service premises		
Sales areas	LpAeqT (day)	50 (45)
Canteens, bars, restaurants	LpAeqT (day)	45

Table 7. Sound insulation requirements for external boundaries (airborne noise insulation index R`tr8w) depending on the external noise level, unit dB. (Sound insulation requirements in buildings Protection against noise, 2003)

Building and room type	Range of external noise level, LpAeq, T						
	-55	56-60	61-65	66-70	71-75	76-80	80-
Living and bedroom in an apartment, higher category hotel, bedroom in a kindergarten, holiday home, care institution, and dormitory	30	35	40	45	50	55	Special measures
Office space and equivalent work space	-	30	30	35	40	45	50

Noise control design of CLT buildings

The most common way to achieve room acoustic standards is to limit the sound in one room and prevent noise from being transmitted to other structures. High mass materials should be used, that absorb the sound and prevent sound from moving between the rooms.

Additional techniques to help achieve acoustic standards in CLT buildings:

- Porosity of the material, especially finishing materials. The lower the porosity, the lower the propagation of airborne noise.
- Material density. The higher the density, the better the sound insulation, especially for low frequency sound.
- Use multi-layer constructions with air gaps. The larger the air gap, the better the sound insulation. Air gaps smaller than 12.7mm should be avoided.
- Sound-absorbing materials in the air gaps between the layers improve sound insulation for assemblies with non-rigidly connected faces. for assemblies with rigidly connected faces, using absorbing materials in the cavity does not improve sound insulation noticeably.
- Soft materials should be used between the layers of the structure. For example, between gypsum board and CLT or between finishing material and CLT. The more elastic the materials between the layers, the better the sound insulation.
- When connecting structures, direct contact of the CLT panels in the assemblies should be avoided as they transmit impact noise.

(Karacabeyli, E, Gagnon, S. 2019 Ch. 9, p. 17)

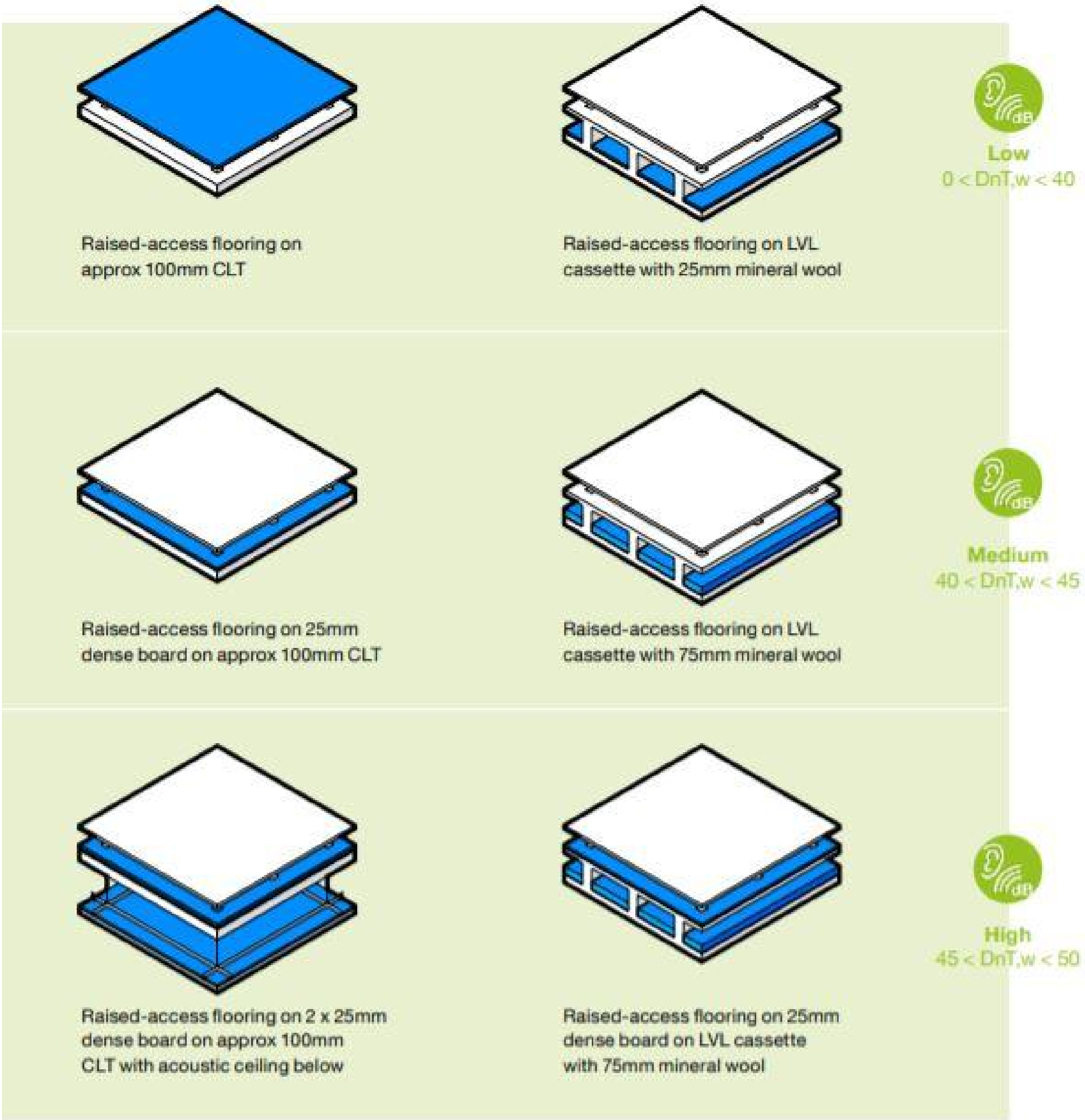


Image 8: Sound Insulation of a floor (Stora Enso, 2019, p. 29)

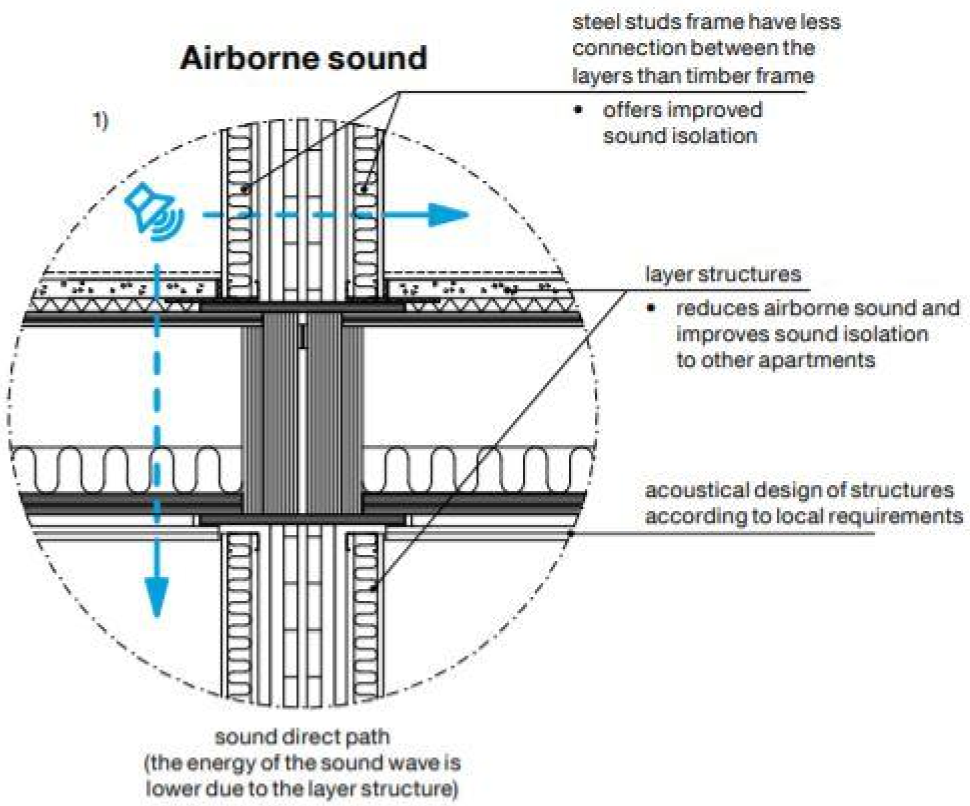


Image 9: Airborne sound, (Stora Enso, 2016, p. 18)

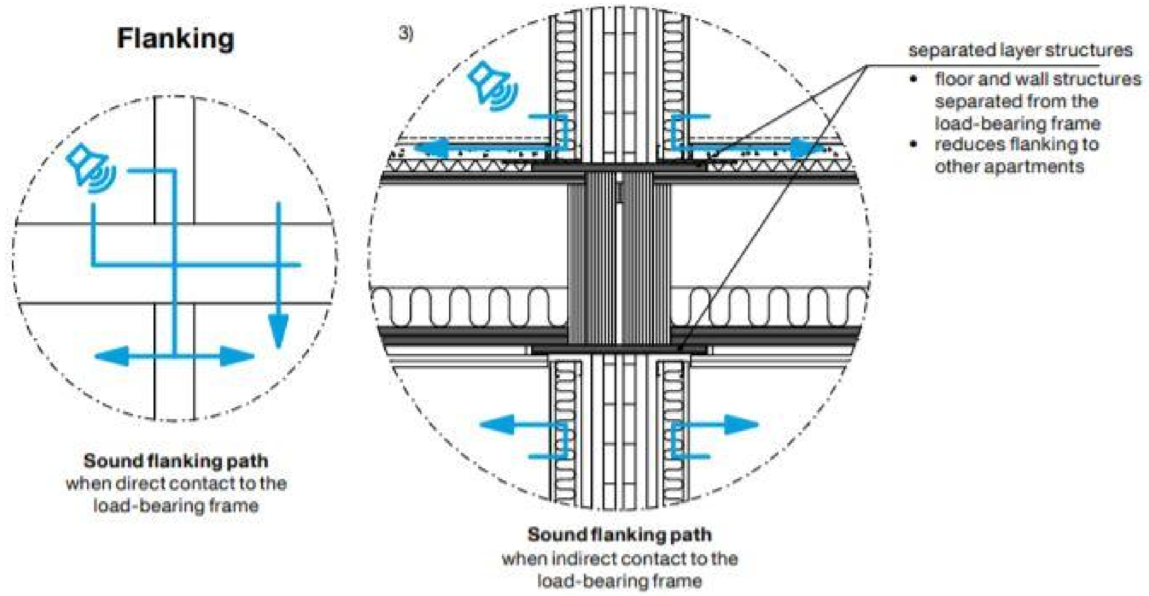


Image 10: Flanking, (Stora Enso, 2016, p. 18)

4.4 LOAD-BEARING CAPACITY AND COMPRESSION

A comparison of pine wood CLT panels with structural steel and unreinforced concrete shows that the CLT panels strength to weight ratio is 20% higher. (Australian Government Forest and Wood Products Research and development Corporation). CLT panels have created unlimited opportunities for architects and engineers to build long and wide floor panels, wall elements, posts and beams from a wooden structure. The strength of the panels lies in their structure cross laminating process provides improved dimensional stability. Cross layering provides an extra in-plane and out-of-plane strength and stiffness. The CLT panel works similarly to reinforcement concrete slabs, which has two-way action capabilities. The "concrete effect" achieved by cross-lamination significantly reduces the splitting resistance and connector strength of wood, which is common with conventional balks. (Karacabeyli, E, Gagnon, S. 2019 Ch. 1, p. 8). CLT panels used as wall elements have normally oriented lumber in the outer layers up and down and parallel to gravity loads to maximize the walls vertical load capacity. In the floor and roof elements the outer layers are parallel to the major span direction. (Karacabeyli, E, Gagnon, S. 2019 Ch. 1 , p. 5) Since the CLT panels are mainly used as load-bearing structural elements such as floor and ceiling panels, walls, beams and posts, therefore architects and engineers must definitely consider load duration and creep behavior when designing. Considering the structure of CLT, orthogonal arrangement of layers that are bonded with structural adhesive, CLT is rather dependent on time-dependent deformations under load. (Karacabeyli, E, Gagnon, S. 2019 Ch. 1, p. 16)

4.5 LOW-MAINTENANCE WOOD FACADE

Wood is weather-sensitive material, which can change it`s properties if it is incorrectly designed or not maintained. Material properties change may be reflected in the appearance or even disintegration. The most critical for wood is light, which together with oxygen and water can cause photodegradation phenomenon. The main reason why it is preferable not to use wooden facades in non-residential buildings is that the maintenance of wooden facades is time and cost consuming and in the end it is still customary to replace them. Several studies have shown that wood can be very durable if it is protected from the weather and properly maintained. The main strategy to protect the wood is to use finishing systems. Manufacturers offer products with a warranty of up to 25 years. (Guy-Plourde, S., de Blois, M. Blanchet, P., Barbuta, C., Robichaud, F., 2018)

The longevity of wooden facades is determined by architectural solutions and construction practices of facade details. Eaves help to protect the facade from direct water and plinth is required to allow the water to drain. The thickness of the facade board should be wider than 25 mm and ventilation is needed to allow the moisture to dry out. The installation must be kept in mind that the connections must be made with joints or table tops to prevent water from seeping in and not drying out at the ends. The board should be fastened with nails and the safe distance is 7 cm from the end of the board. If it is necessary to fasten more closely, screws should be used and holes drilled in advance. (Nagel, P., Tammert, M., 2003, p. 30-38)

Material selection must take into account the residence characteristics of different types of wood. Spruce is suitable for the external environment, the cell structure of which closes when it dries and thus creates a layer of protection. (Rakennustietosäätiö, 2004, p. 2)

Titan Wood has been producing acetylated wood since 2003 in Arnhem, the Netherlands. They have developed an acetylation process for radiata pine lumber up to 100 mm thickness. Product is called Accoya wood. (Bongers, F., Roberts, M., Stebbins, H., Rowell, R. 2009) The natural wood material contains a little acetyl and a lot of free hydroxyl, with which water binds itself causing damage to the wood. Titan wood has developed a method that uses acetic anhydride, which is very strong vinegar and allows to boost the acetyl content of the wood. (What makes Accoya so special?) The result is highly durable wood, which does not swell, shrink or deform under the influence of the weather. Wood is suitable for any climate and the manufacturer provides a warranty for above the ground use - years and below the ground use - 25 years. (Benefits of Accoya)

Living tree moisture content of the timber is more than 30%, at the time of installation it should not exceed 20% because wood shrinks when it dries. Horizontal cladding is recommended to place with the heart side facing outwards. Vertical cladding is recommended to install mainly as a cardiac side out. This helps to avoid deformations such as convexity and concavity caused by moisture fluctuations. (Rakennustietosäätiö, 2004, p. 3)

The wood surface should be treated to protect from weather conditions and fungi. The options are: painting, Lacquering or treatment with other wood preservatives. It is recommended to apply a double layer to increase the protection. Another way to increase the protection o is to process the wood material itself by impregnation or heat treatment. (Nagel, P., Tammert, M., 2003, p. 30-38)

4.6 Price compared to concrete

Previous studies have met that the construction cost of mass timber is 2-6% higher than concrete structure construction. A study conducted by researchers at the State University of Oregon "Analysis of cost comparison and effects of change orders during construction: Study of a mass timber and a concrete building project" acknowledged that construction cost of mass timber building is 6.43% higher than for concrete building. (Shafayet, A., Arocho, I., 2021) The higher cost of a wooden structure is often due to the fact that the structures are more complex and require more engineering resources, as well as the fact that some structures have to be encapsulated to achieve fire safety, which makes the structure more expensive.

Researchers at Aalto University conducted a study comparing apartments sold in Helsinki in 1999-2018. The results of the survey showed that the transaction price of wooden houses was 8.85% higher compared to buildings made of other materials. The study used a regression analysis that compared only prices and standardized all other variables. This means that if customers are willing to prefer timber-framed buildings and are willing to pay more for them, we can charge 10% more for timber-framed buildings. This will offset the higher cost of construction and design and may even make timber-framed buildings profitable compared to concrete buildings. (Aalto University 2021)

Another advantage of massive timber construction is the speed of installation of structures on the construction site, which can save almost 50% of the time. Installation savings help us save on labor, equipment rental and project management costs. (Sorathiya. R., 2019, p. 19)

Design principles are a conclusion of the theoretical part of the Master`s Thesis. In addition, it contains recommendations I received in consultation with various experts on my project. These principles were the basis for the CLT frame high-rise office building design.

PROTECT THE STRUCTURES DURING THE CONSTRUCTION WITH A TENT

During the construction of timber frame buildings it is necessary to protect the CLT panels from rain on site in cold humid climates. When CLT panels get wet during construction, moisture traps in the structure and may not escape afterwards. Moisture has the greatest effect on the durability of wood and can lead to mold and fungi. (Liisma, E., Kuus, B., Kukk, V., Kalamees, T., 2019)

STRUCTURE

Elevator shafts and stairwells of high-rise office buildings should be built from concrete. One reason is the fire safety of the evacuation routes. Another reason is that the concrete core provides stiffness and stability to the building and allows to use CLT panels more optimally. Horizontal forces such as wind are transmitted to the core through diaphragm forces in the connections. (Stora Enso, 2016, p. 19)

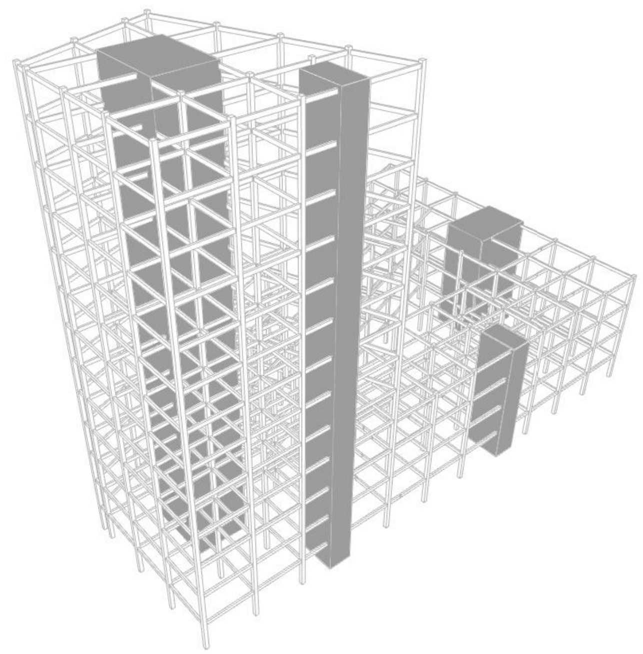


Image 11: Concrete core

LOAD-BEARING GRID

The effective load-bearing grid of the high-rise office building built of massive timber is 4.5-7.5m, which creates a greater efficiency level, which also allows panels to be installed faster during construction. (Stora Enso, 2019, p. 23)

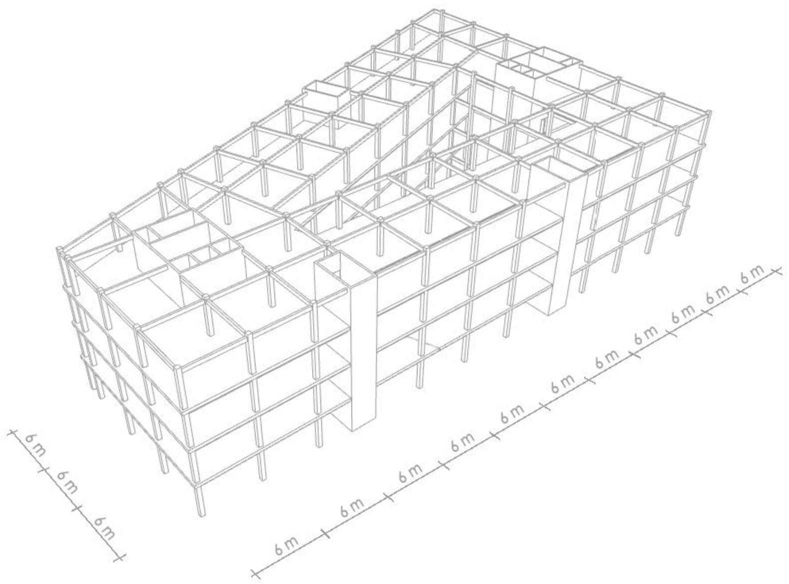


Image 11: Grid

THICKNESS OF THE BEAMS

The thickness of the CLT beam depends on the span. Floors can bear directly on the beams, allowing for quick installation. (Stora Enso, 2019, p. 24)

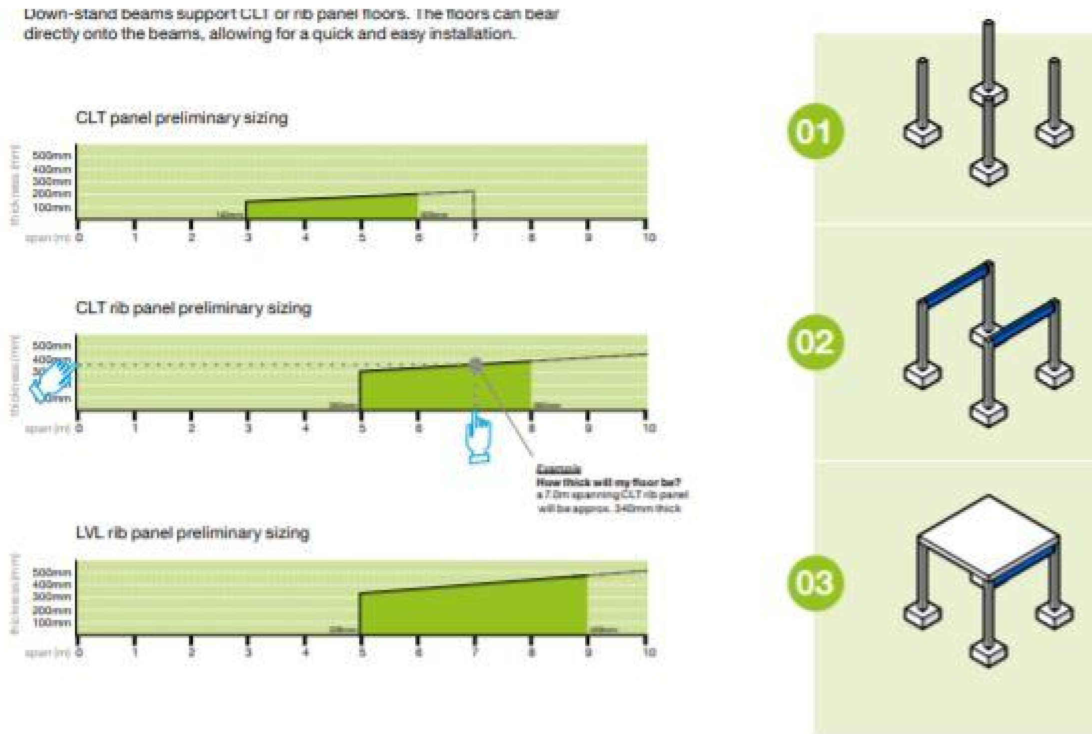


Image 12: Floors and beams (Stora Enso, 2019)

SERVICE ZONE

If the main grid of the building is in the range of 5-7.5m then it is wise to create a 3m service zone without down-stand structural beams around the core. This allows to coordinate and distribute mechanical and electrical services from the vertical risers. without compromising the clear heights by using a CLT slab in this zone. (Stora Enso, 2019, p. 63)

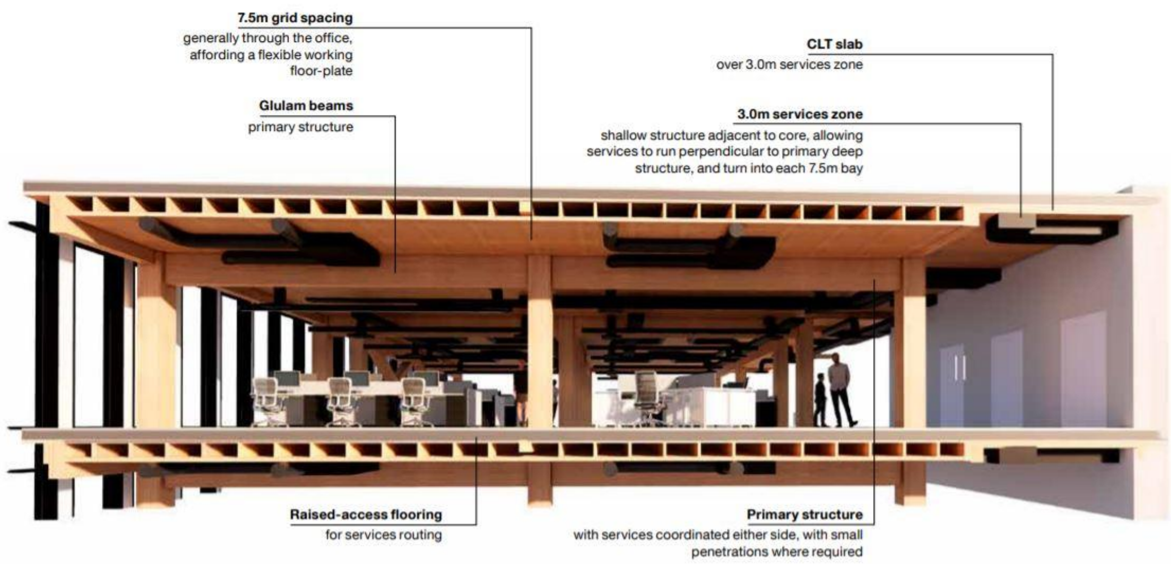


Image 14: Section (Stora Enso, 2019)

OVER DIMENSIONED LOAD-BEARING STRUCTURES.

In the case of fire, it is possible to ensure the stability of the building by over-dimensioning the load-bearing structures. Firstly catches fire the outer layer and forms a protective layer of coal around itself. It takes time for the fire to reach the inner layers and we can ensure the stability of the building in the required time. Problems are caused by adhesives that are used to connect the layers, which are not fireproof. When the fire reaches the glue layer, the protective coal layer falls off. Following layers burn faster because the fire has reached high heat by that time. Therefore, the outer layers should be made as thick as possible and the inside layer may be thinner. In Estonia, manufacturers are able to produce panels with a single layer thickness of up to 45 mm.

Image 15: Over dimensioned load-bearing structures

NATURAL VENTILATION

It is possible to remove smoke naturally from a depth of up to 10 meters. The maximum width of the building can be up to 20 meters. For natural ventilation, corridors should be connected to external walls and have windows that can be opened for ventilation in the event of a fire.

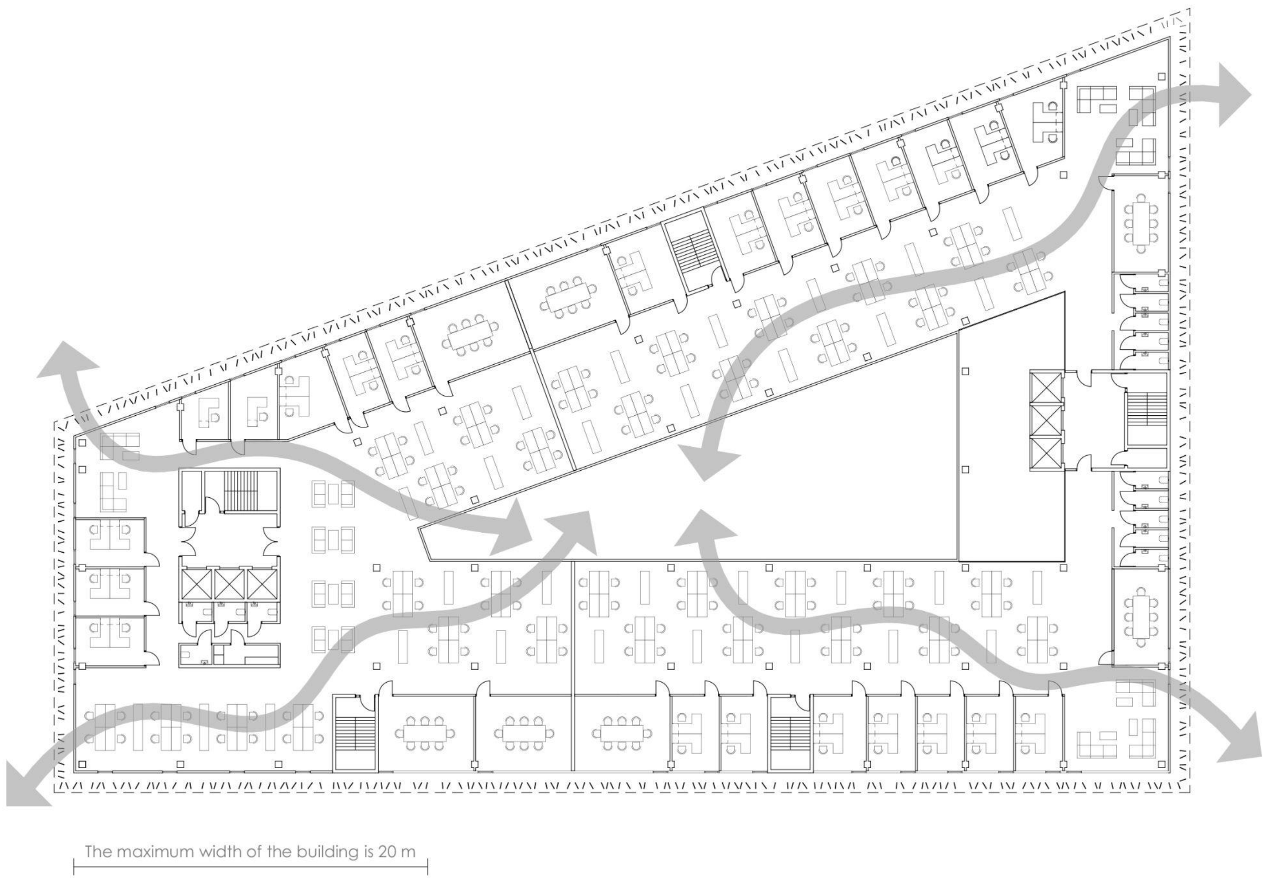


Image 16: Natural ventilation

EVACUATION ROUTES

The evacuation must be available for at least two escape routes. The maximum length of the escape route must not exceed 45 m. Escape stairwells must be constructed from concrete and it is recommended to place them on the outer wall. The fire brigade can directly enter the evacuation entrance and quickly find the right floor.

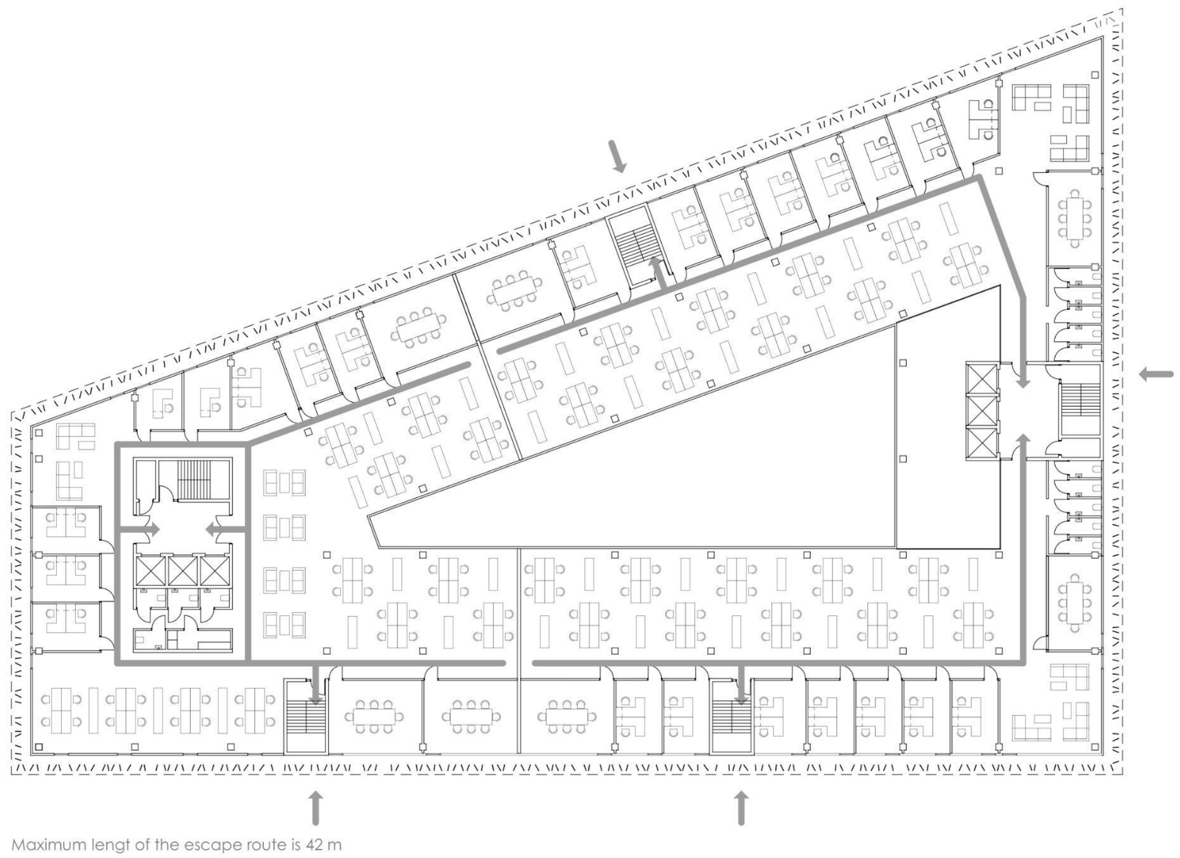


Image 17: Evacuation

BALCONIES

The balconies protect the building from overheating by providing shading for the glass facades. The protruding massive CLT panels prevent the spread of fire from the bottom to the top of the facade. In addition, it is possible to use the balconies to maintain the wooden exterior facade.

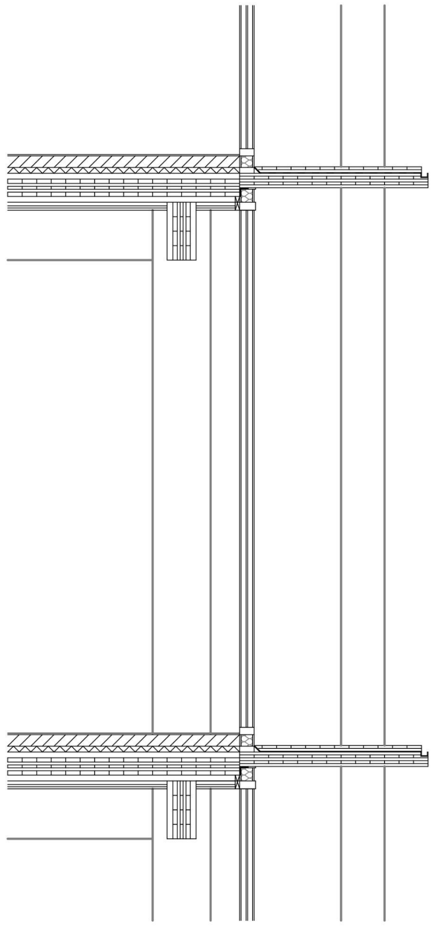


Image 18: Balconies

INVOLVE FIRE SAFETY ENGINEERING (FSE)

Fire safety engineering is a method that does not exactly follow the standards for the design of safe buildings, but uses alternative methods. It is a method where every design decision is based on fire safety and dictates the final architectural appearance, therefore the FSE should be included at an early stage. Fire safety simulation helps to prove our decisions and make corrections if necessary. I was consulted by fire safety experts from the office of Markku Kauriala in the design stage. They conducted a fire spread test on one standard floor.

As we know from the fire safety standard, we are able to build secure buildings by encapsulating all wooden structures. But how much visible wood surfaces and where we can have in the interior and still keep the building safe if we will use FSE? To find the answer to this question, the experts conducted a Fire spread test using PyroSim software. We created two different models for the test:

1. Design - Walls, beams, columns, ceiling - visible wood (combustible)
2. Design Walls, beams, columns - visible wood (combustible)
   Ceiling - encapsulated (non-combustible)

Both designs were tested with two scenarios: with and without sprinklers. It took 3-6 days to calculate one simulation. As a conclusion it can be stated that an encapsulated ceiling is necessary to ensure the safety of people in the building, but we can leave the wood visible on other surfaces such as walls, beams and columns. Another knowledge is that sprinklers play a very important role in quickly extinguishing a fire.

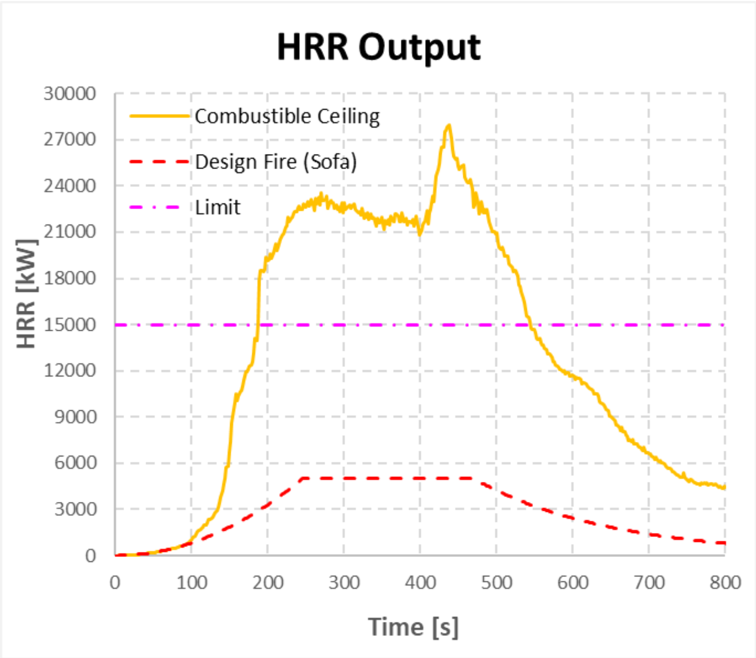


Image 19: HHR combustible ceiling

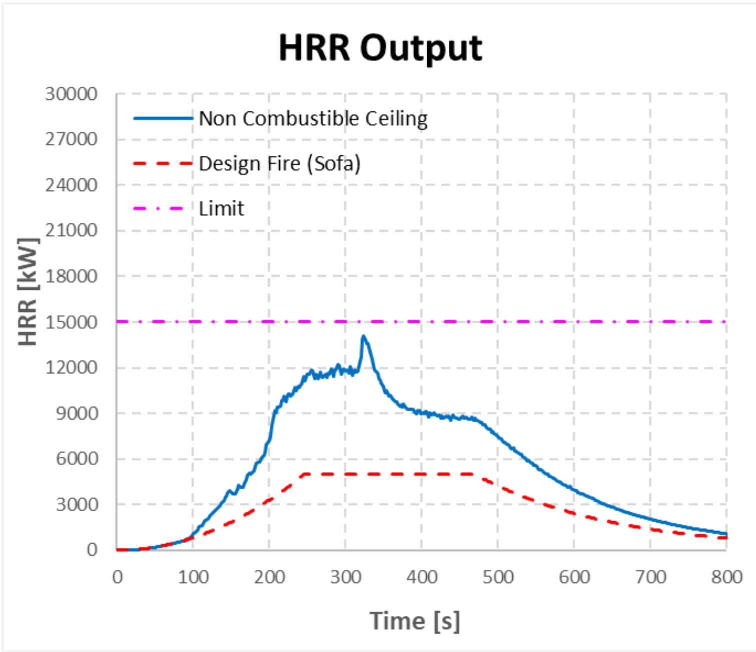


Image 20: HHR non-combustible ceiling

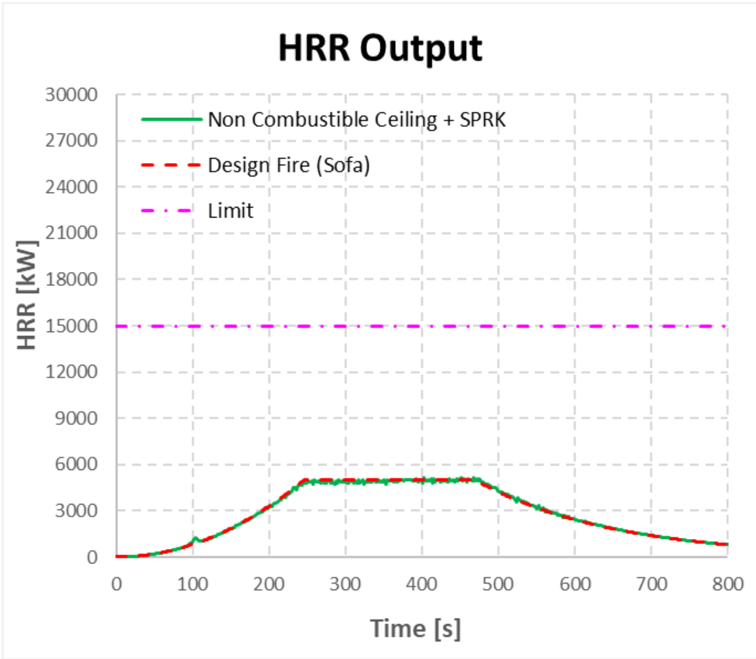


Image 21: Noncombustible ceiling + sprinklers

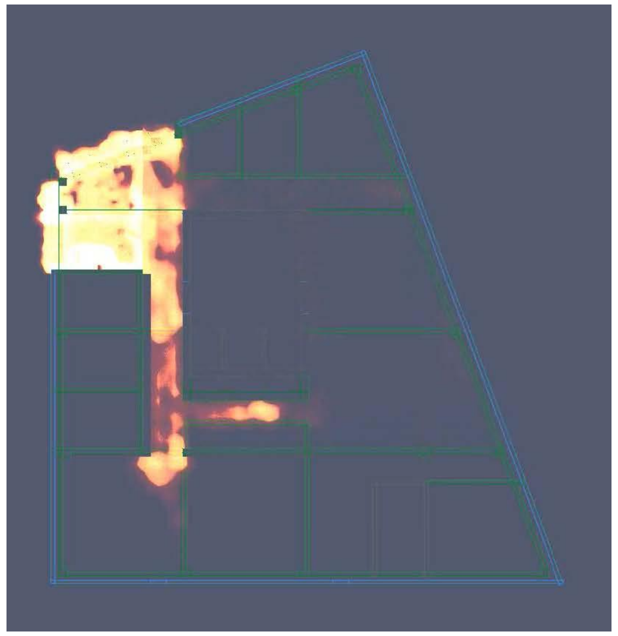


Image 22: Fire spread test combustible ceiling

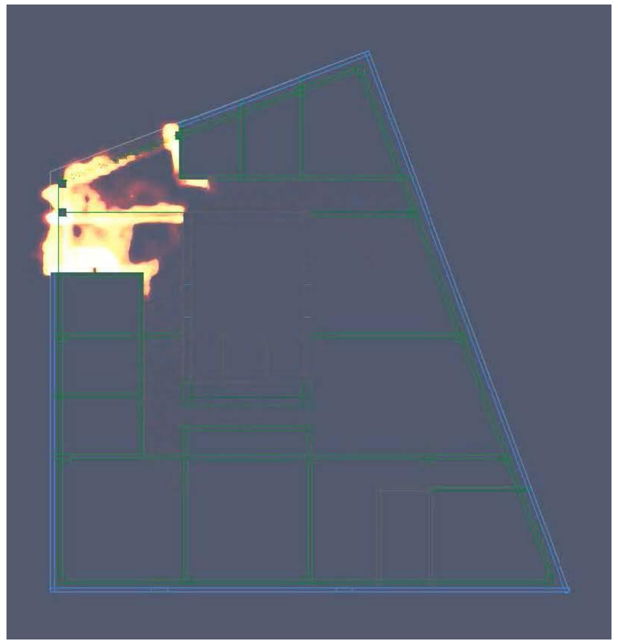


Image 23: Fire spread test non-combustible ceiling

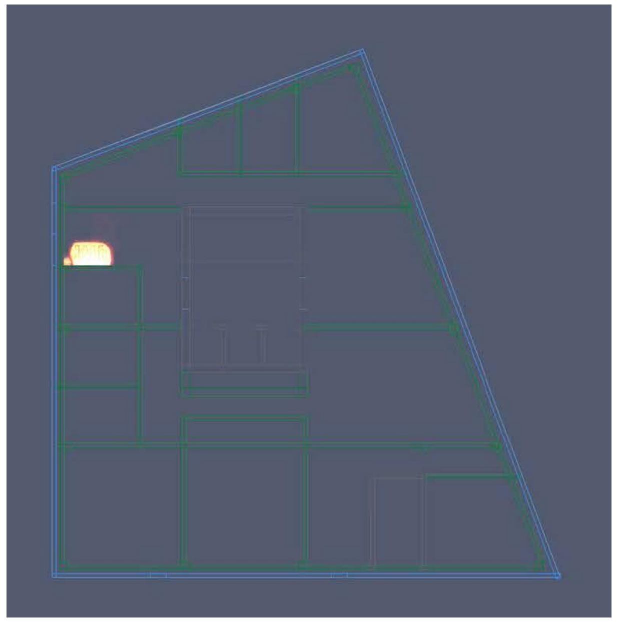


Image 24: Fire spread test
non-combustible ceiling +sprinklers

Types of standard constructions

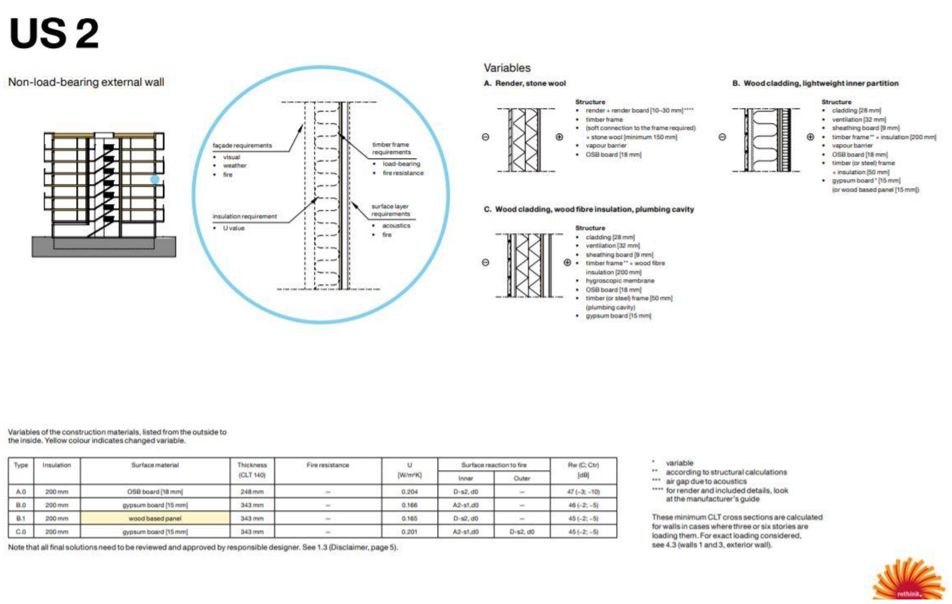


Image 25: Non-load bearing external wall (Stora Enso, 2016)

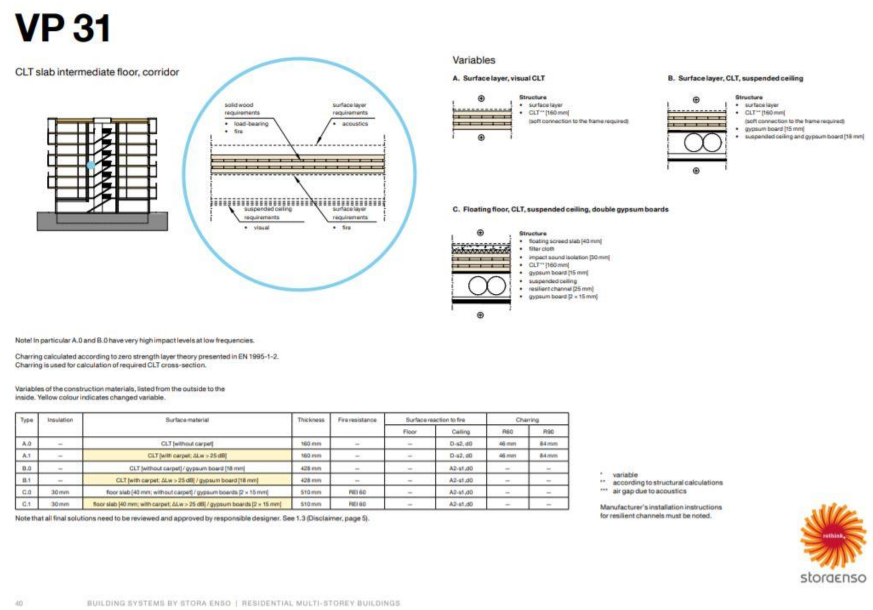


Image 27: CLT slab intermediate floor, service zone (Stora Enso, 2016)

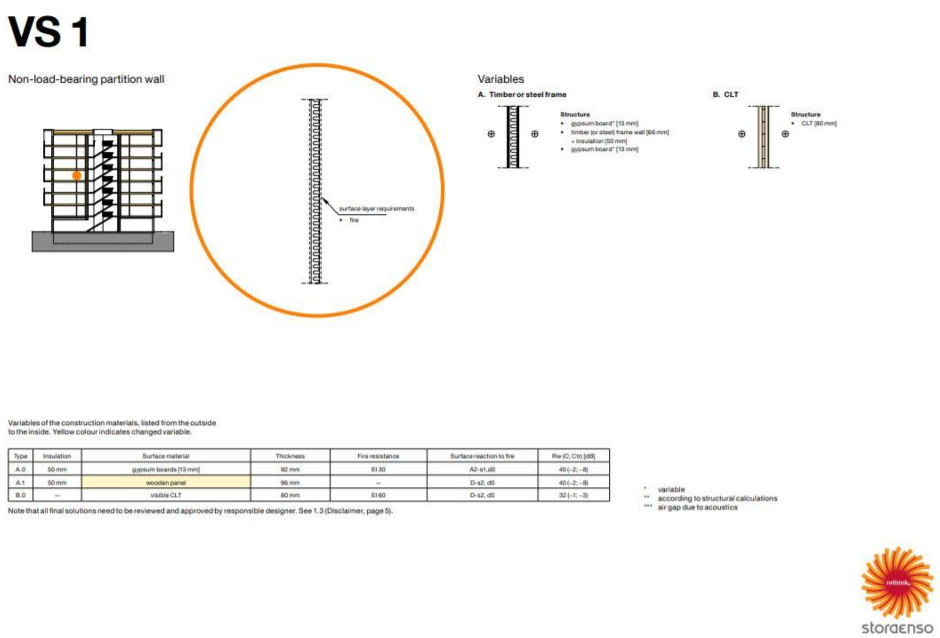


Image 26: Non-load-bearing partition wall (Stora Enso, 2016)

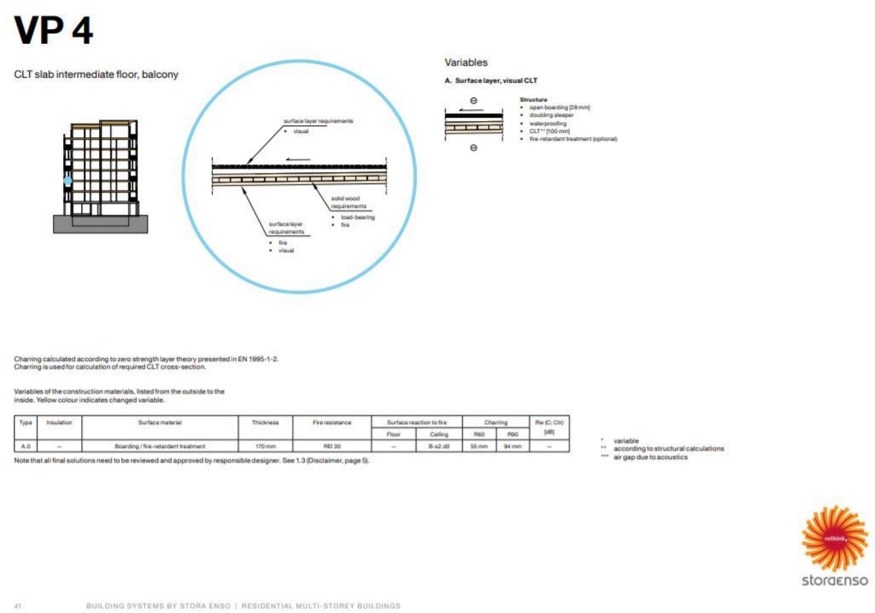


Image 28: CLT slab intermediate floor, balcony, evacuation road on the facade (Stora Enso, 2016)

6.1 REFERENCES OF HIGH-RISE TIMBER BUILDINGS

Building: WoHo

Location: Berlin, Germany

Architectural design: MAD Architects

Construction year: design stage

Height: 98m

Function: Residential

Load-bearing system: Core - reinforced concrete. Other - timber (WoHo)

Image 29: (UTB Projektmanagement GmbH)

Building: HoHo

Location: Vienna, Austria

Architectural design: RLP Rüdiger Lainer + PartnerArch.

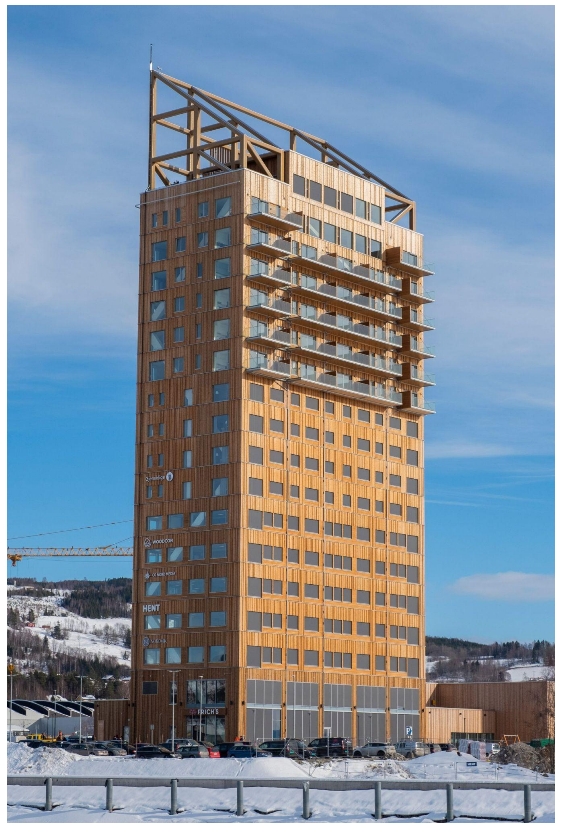
Construction year: 2019

Height: 84m

Function: Commercial

Load-bearing system: 75% wood (Erstes Büro aus Fichtenholz fertig)

Image 30: HoHo (Housing Evolutions)



Building: Mjøstårnet

Location: Brumunddal, Norway

Architectural design: Voll Architects

Construction year: 2019

Height: 85,4 m

Function: Mixed

Load-bearing system: CLT

(Mjøstårnet in Norway becomes world's tallest timber tower)

Image 31: Mjøstårnet (Dezeen)

Building: Brock Commons Tallwood House

Location: Vancouver, Canada

Architectural design: Acton Ostry Architects

Construction year: 2017

Height: 53 m

Function: Residential

Load-bearing system: Core - reinforced concrete. Other - CLT

(Brock Commons Tallwood House

Image 32: Brock Commons Tallwood House (Actonostry)

Building: Treet

Location: Bergen, Norway

Architectural design: Artec Architects

Construction year: 2015

Height: 52,8 m

Function: Residential

Load-bearing system: CLT

("Treet" Residential High-Rise, Bergen)

Image: 33. Treet (zueblin-timber)

6.2 ÜLEMISTE CITY

The location of the timber structure high-rise office building that is designed in the course of this Master`s Thesis is Ülemiste City. The development of the Ülemiste City region began in 1987, when the Russian Emperor Nikolai 2. decided to build a railway industry near Tallinn on the shores of Lake Ülemiste, which became known as "Dvigatel". (Ülemise City)

Image 34: Ülemiste City 1987 (Ülemiste City)

The factory was well on track by 1899. The factory produced thousands of wagons destined for Russia. Estonia became independent after the First World War. The factory faded since there was no longer demand for Russia. The company went bankrupt and became state-owned. In 1931, the factory began to produce aircrafts, which was next to the largest airport in Eastern Europe at that time and next to it formed the largest airport in Eastern Europe at that time.

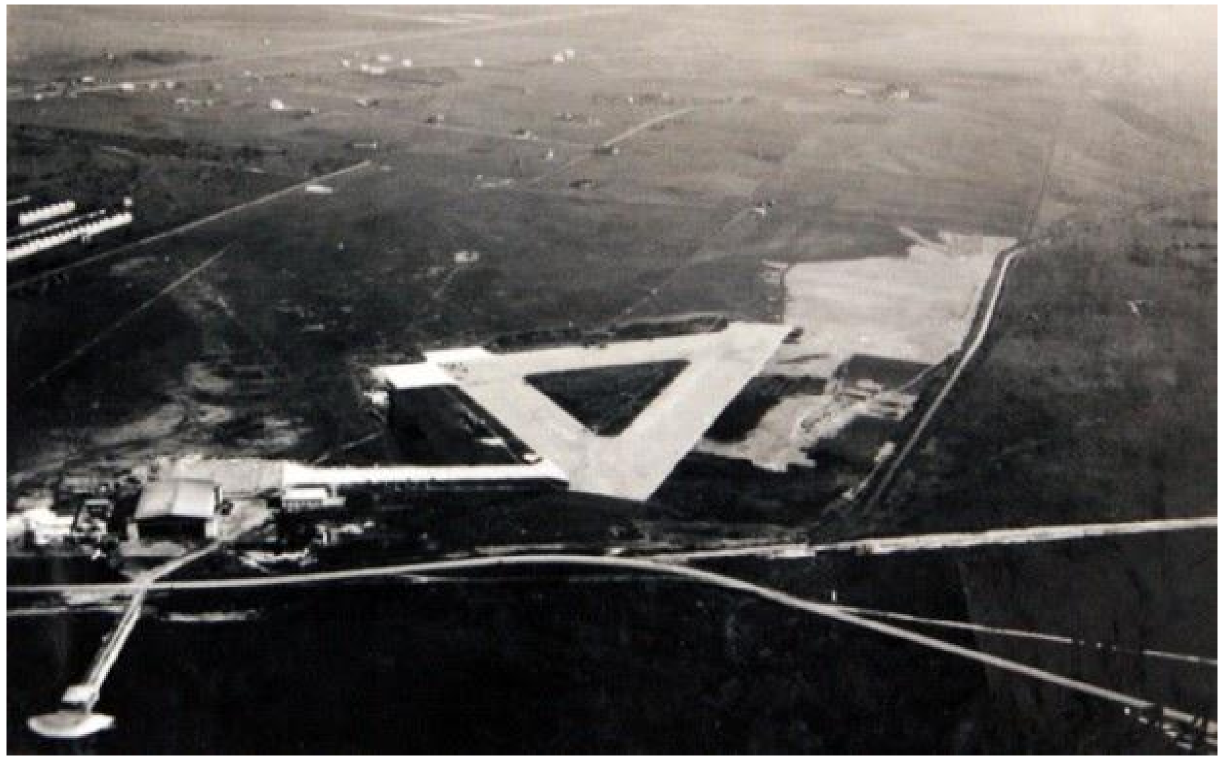


Image 35: Ülemiste City 1931. (Ülemiste City)

Estonia became a part of the USSR again in 1939 with the Molotov-Ribbentrop Pact. The factory was used to build a new communist society. That period is important for the development of the region, as thousands of workers were brought there from the Soviet Union, for whom new residential areas were built. This was followed by the Cold War, and the factory started producing equipment for the Soviet army and the space industry. But local residents remained a mystery, what was actually happening behind the high walls of the factory. In 1991, with the collapse of the Soviet Union, the factory lost its market potential and the state-owned company Dvigatel was privatized a few years later by AS Mainor.

Image 36: Ülemiste City 1991 (Ülemiste City)

The year 2005 can be considered the most important year for the development of today's Ülemiste City. Ülo Pärnits, the head of AS Mainor at that time, had an idea to create a smart business city on the ruins of Dvigatel. Ülemiste City was born.

Image 37: Ülemiste City 2005 (Ülemiste City)

In 2010, the privately owned company Technopolis joined the development of Ülemiste City. Today Ülemiste City is part of the largest network of business cities in the Nordic and Baltic countries. It is one of the fastest growing districts in Tallinn. Former Dvigatel factory complex has become an innovative city in 15 years. Ülemiste City employs more than 10,000 people every day with the highest average salary in Estonia, more than 2,000 euros per month. The first residential areas have been completed and Ülemiste City is a separate independent city with home, work and entertainment together.

Image 38: Ülemiste City today (Ülemiste City)

Ülemiste City`s ambition is to grow further. Their vision is to be known and recognized as the best business, life and learning environment for talents as specialists, leaders and entrepreneurs who, through their activities, have an impact on the global economy. Their mission is to develop a work, development and living environment with an international reach. Their expected results are to be a smart business town that operates 24/7. Supports rapid growth, Ülemiste City environment is green and diverse and part of the international traffic junction.

Image 39: Future of the Ülemiste City (Ülemiste City)

Ülemiste City is a suitable location for timber structure high-rise building that is designed within the framework of this Master`s Thesis, because Ülemiste City is an innovative business center, whose aim is to offer the best working and development environment. The innovative city also stands for environmental sustainability and Ülemiste City is a pioneer in the use of new technologies and materials in construction.

6.3 SITE ANALYSIS

Currently the site Valukoja 21 is surrounded by wasteland and old industrial buildings that will be demolished in the future. Next to the plot goes through the main street Valukoja. It is planned to build a modern business quarter instead of the old factory buildings. The wasteland next to the property belongs to the airport. The airport had plans to build office space and logistics buildings on empty land, but due to the Covid-19 crisis, these plans were frozen for some time. Today, Ülemiste City is mainly a business center, but the developer's wish is to turn it into a multifunctional city with residential, entertainment and shopping facilities. The first living quarters have been built, but nevertheless the town is quite empty in the evening. Construction of a kindergarten and school will start soon, which will definitely make the area a more attractive place to live.

The location of the Ülemiste City is excellent because it is next to the largest traffic junction in Estonia. The city has a direct connection to the airport, and in the future a Rail Baltica station will be built, which, in addition to train traffic, will also include a bus station and tram connection. If one day Talsinki tunnel will be built, Rail Baltica terminal has been considered as a final stop.

Looking at the development of Ülemiste City over the last ten years, it can be said that the city is developing from east to west. but the Valukoja 21 property has not yet been reached, so its contact zone is empty. In general, I would be a little critical in the Ülemiste City planning. It seems to be a combination of different concepts and masterplans that have been developed. Therefore, it lacks integrity and seems a bit confusing. It gives the impression that the city is developing site by site developing real estate.

Image 40: Site (Google Maps)

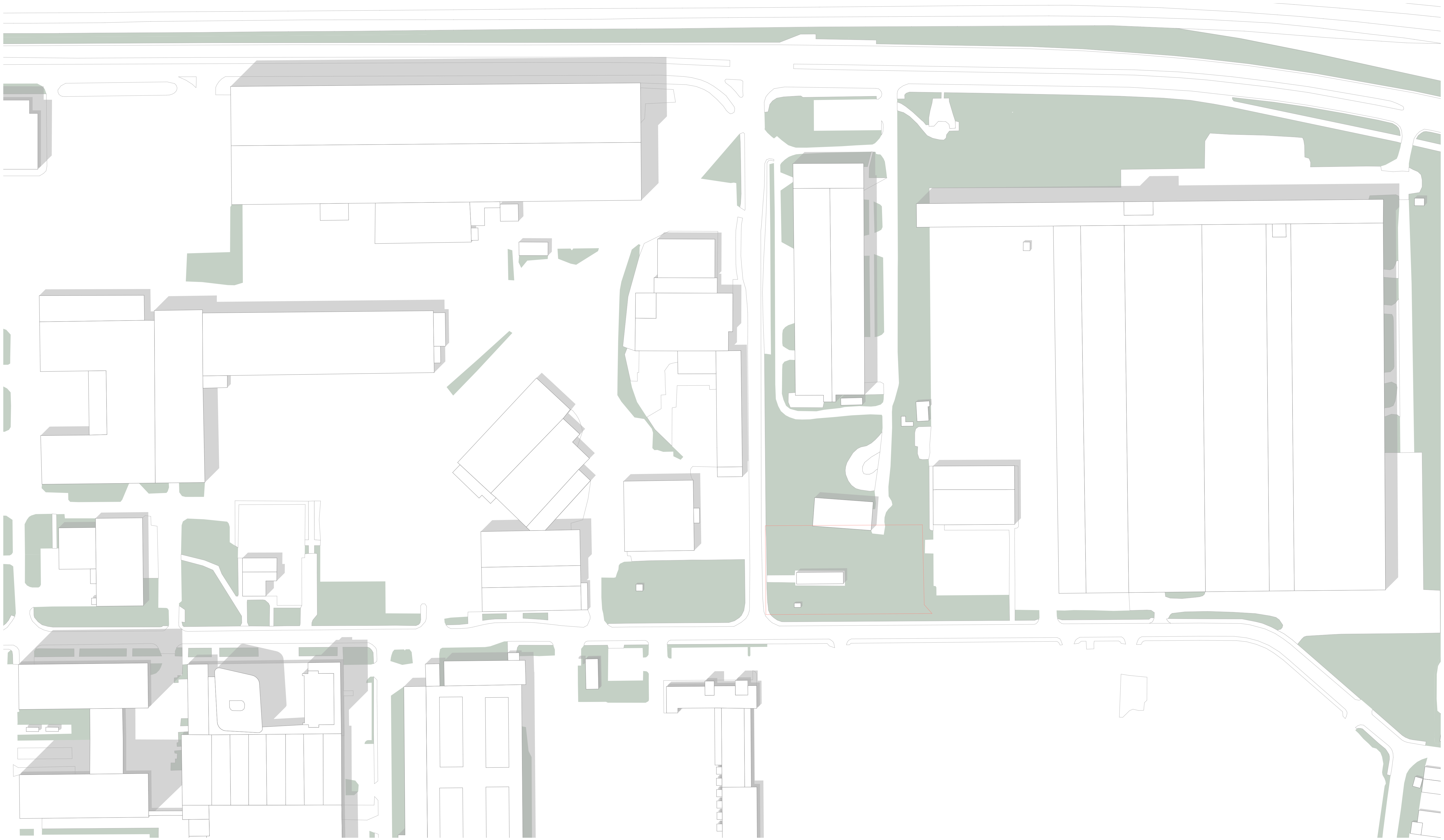


Image 41: Site, Valukoja 21

1 :2000

6.4 PROJECT

MASTERPLAN

As the northeastern part of Ülemiste City does not have a clear vision, I started a design stage from the preparation of the planning proposal. Ülemiste City is a varied environment: a combination of old industrial low-rise buildings and modern high-rise buildings. It has a bowl cityscape: center - low, edges - high. These keywords were the basis for creating a new volumetrical concept. To connect the exciting Ülemiste City and new business centre I created a green corridor in the core, which adds character to the town. The cars are aimed at the edges to create a cozy environment for pedestrians in the heart of the city.

The projected CLT frame office building will not have underground parking. The main reason to build a wooden high-rise building is to reduce the building's carbon footprint, however a concrete underground parking will go against that concept. In the future, as the demand for parking spaces decreases, it will be possible to change the function of the building using the existing structure.

13-STOREY OFFICE BUILDING WITH A CLT FRAME

The design of the building and the constructive solutions are based on the principles I have compiled. Every design decision of this building has been made considering the fire safety. The core of the building and the escape staircases are made of concrete, which ensures fire safety and stiffness. There is an extra protection zone in the core, where you can take shelter before evacuation. The load-bearing structure of the rest of the building is based on the CLT frame. Visible constructions are over-dimensioned, posts are 400 x 400 mm and beam dimensions are 200 x 400 mm.

The building consists of two volumes, the lower part has 4 floors and the higher part has 13 floors. The volume of the building results from the proposed masterplan. The building is located on an active site, surrounded by the main street, a park and a green corridor. It is possible to enter the building from three different directions. In the middle is a square, which is opened to the street through two floors. The ground floor of the building offers commercial spaces and catering. On the following floors there are offices, which are a combination of open office and private workplaces. Office space has been planned so that it can be divided into smaller rental spaces according to demand in the future. Rest areas are in the corners of the building, which allows natural ventilation to remove smoke from the corridors in the event of a fire.

As much visible wood as possible has been used in the interior - walls, posts and beams, which present the load-bearing structure. The outer wall of the building is a glass facade, the windows can be opened to remove smoke in the event of a fire. The building is surrounded by protruding CLT panel balconies. Balconies are not used on a daily basis, their task is to provide shading and prevent fire spread on the facade. In addition, they maintain the external wooden facade, which consists of a white wooden boarding.

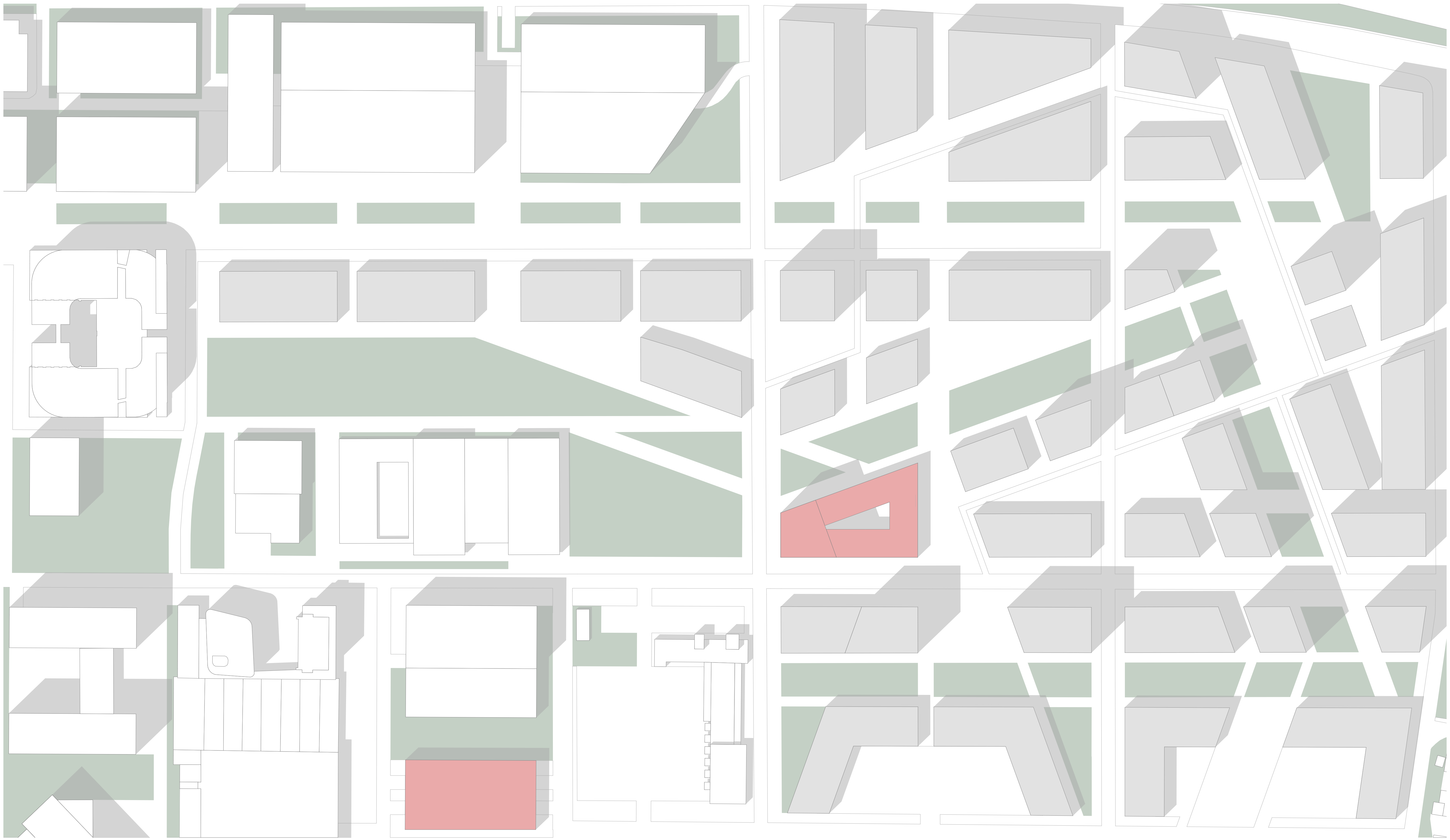
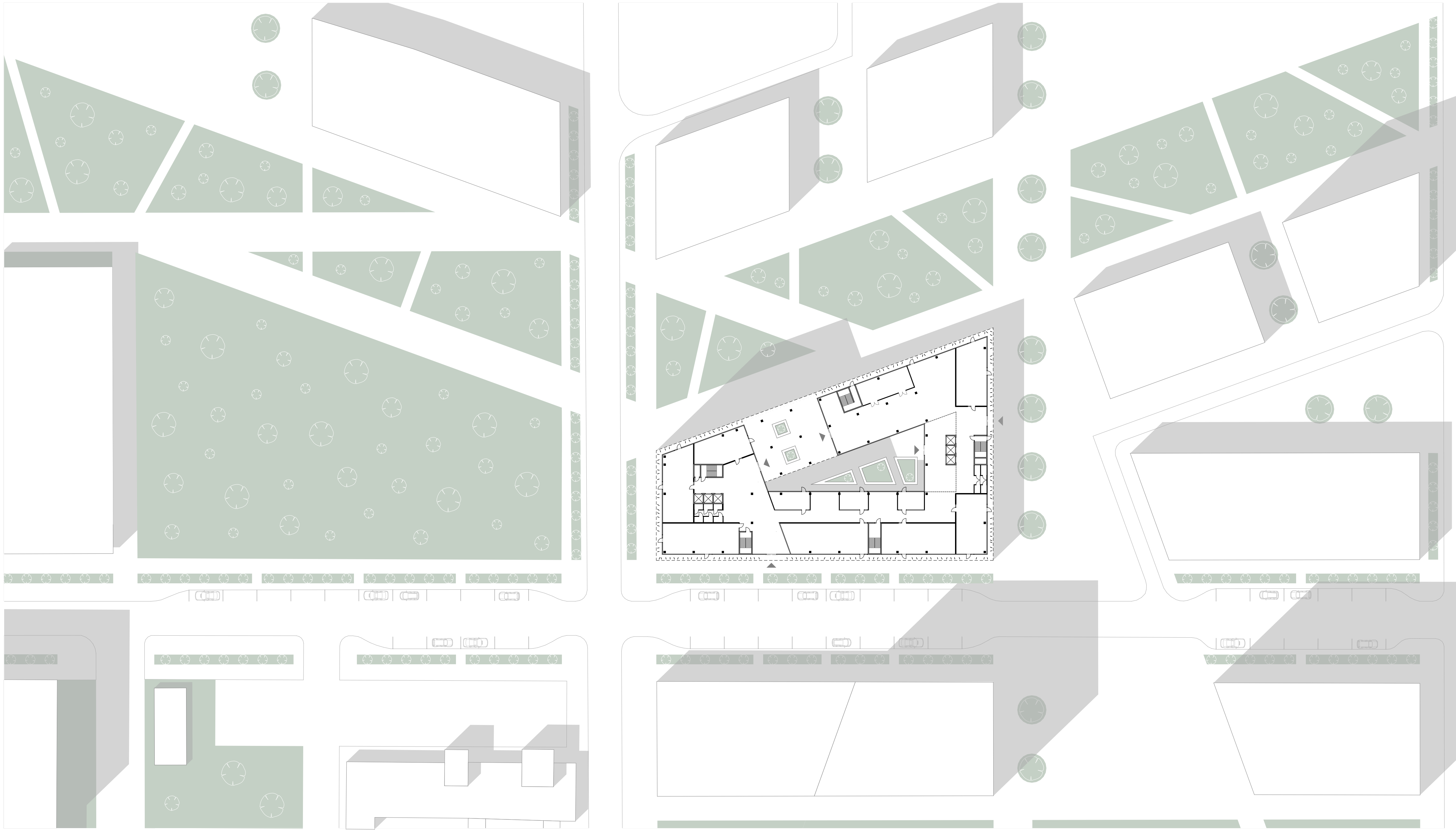


Image 42: Masterplan

1:2000



Siteplan

Image 43: Site plan

1:500

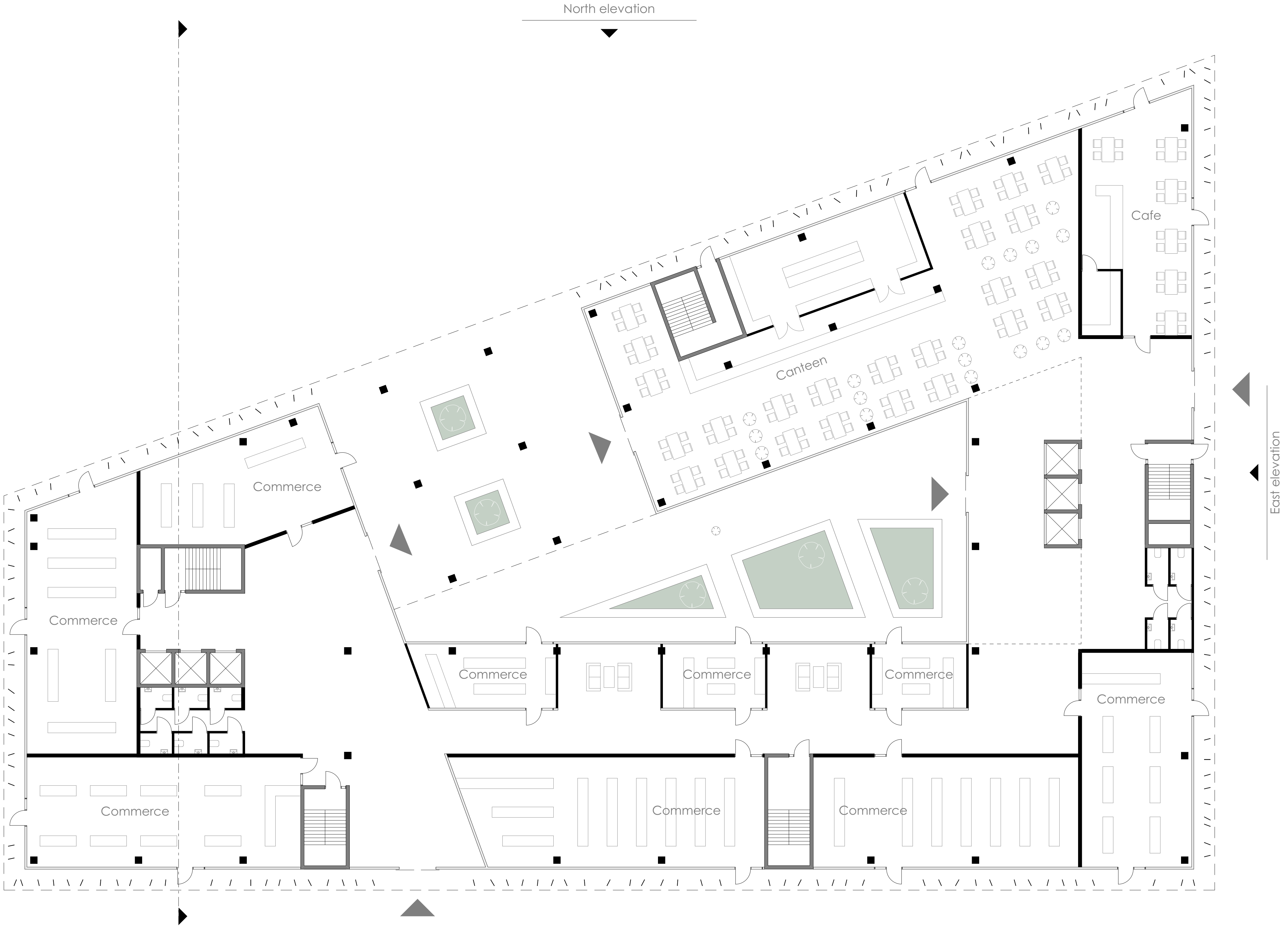


Image 44: Ground floor

1 :250

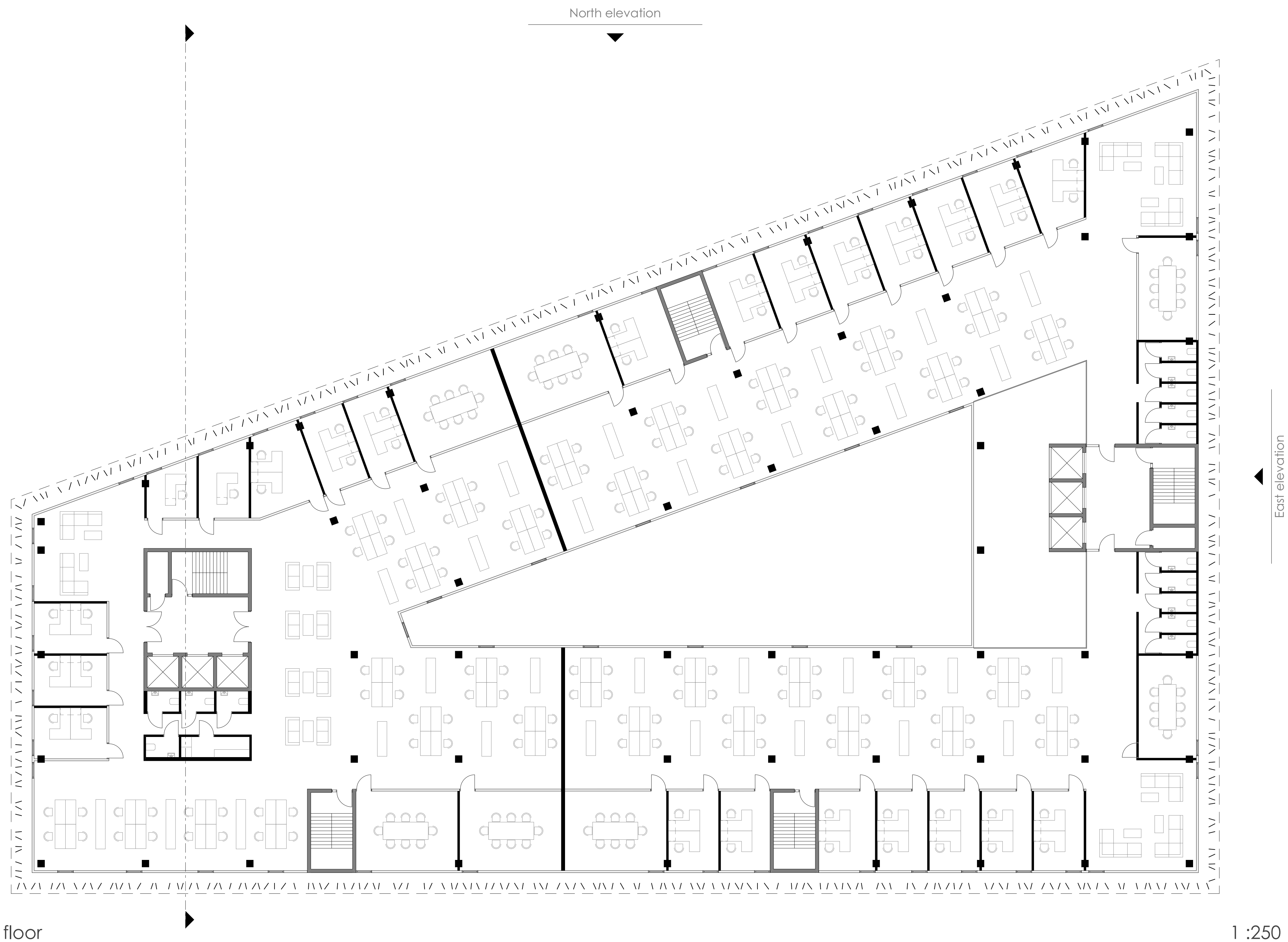


Image 45: 3. - 4. floor

1 :250

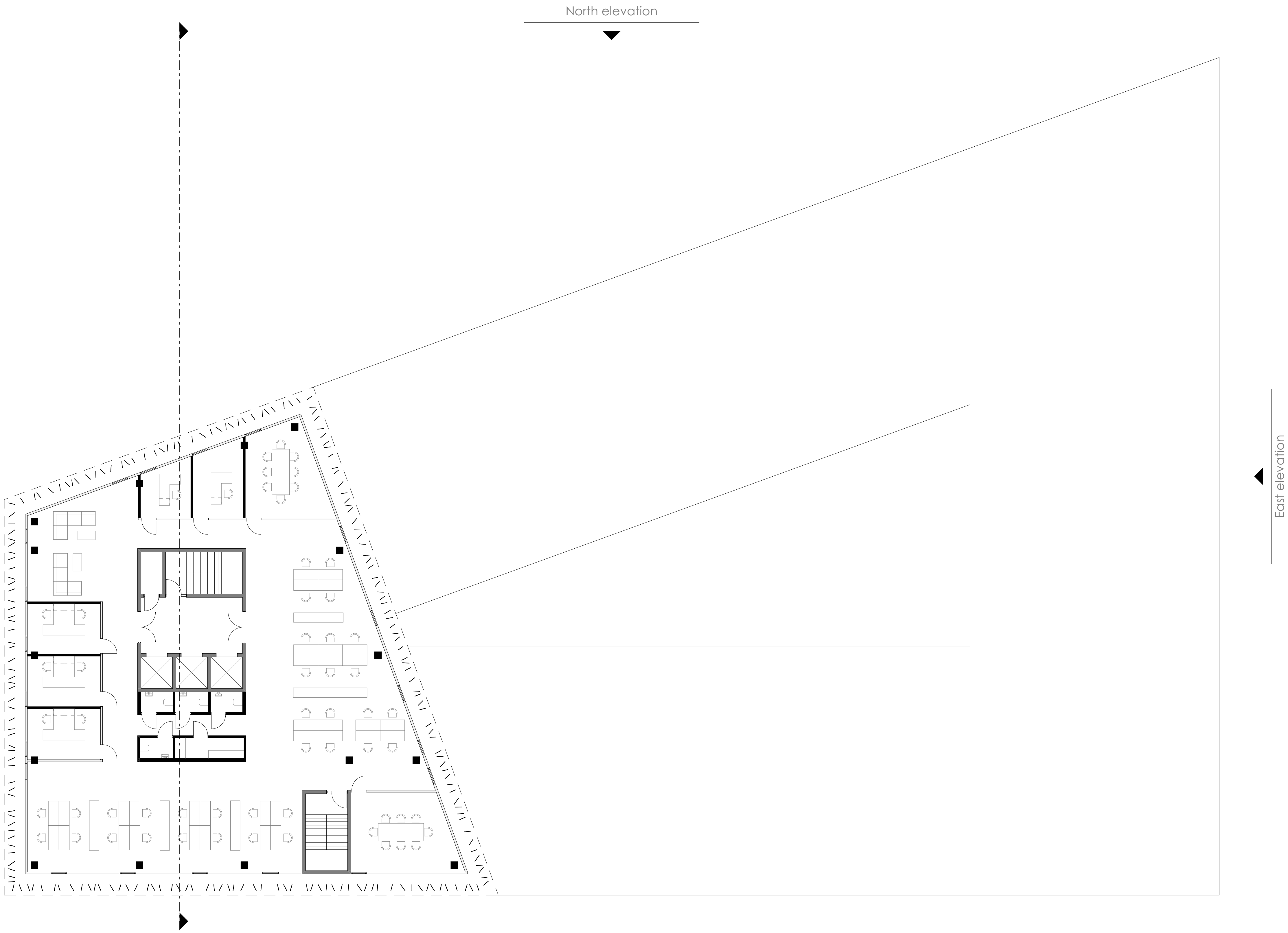


Image 46: 5. - 13. floor

1 :250

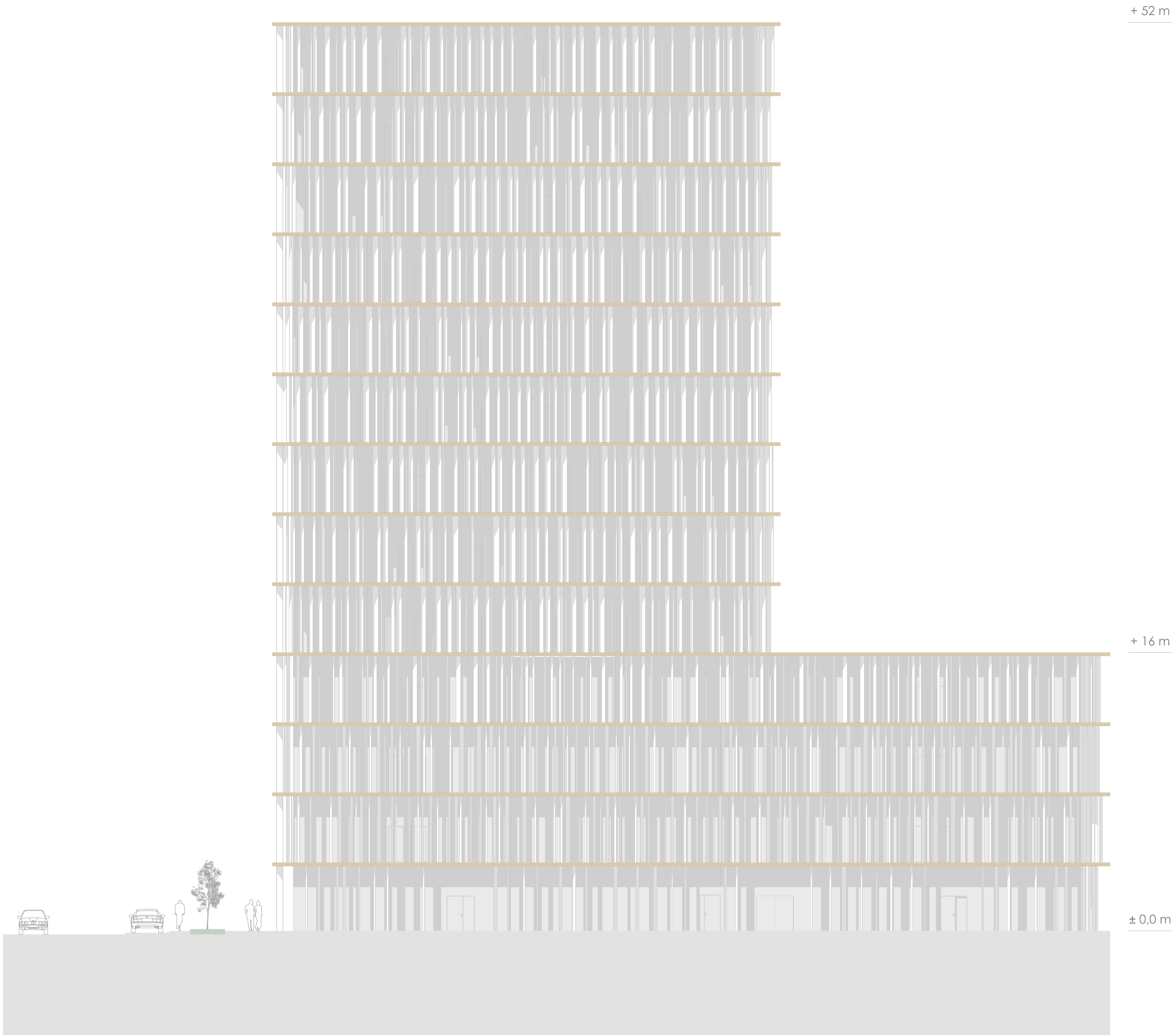


Image 47: East elevation

1 : 250

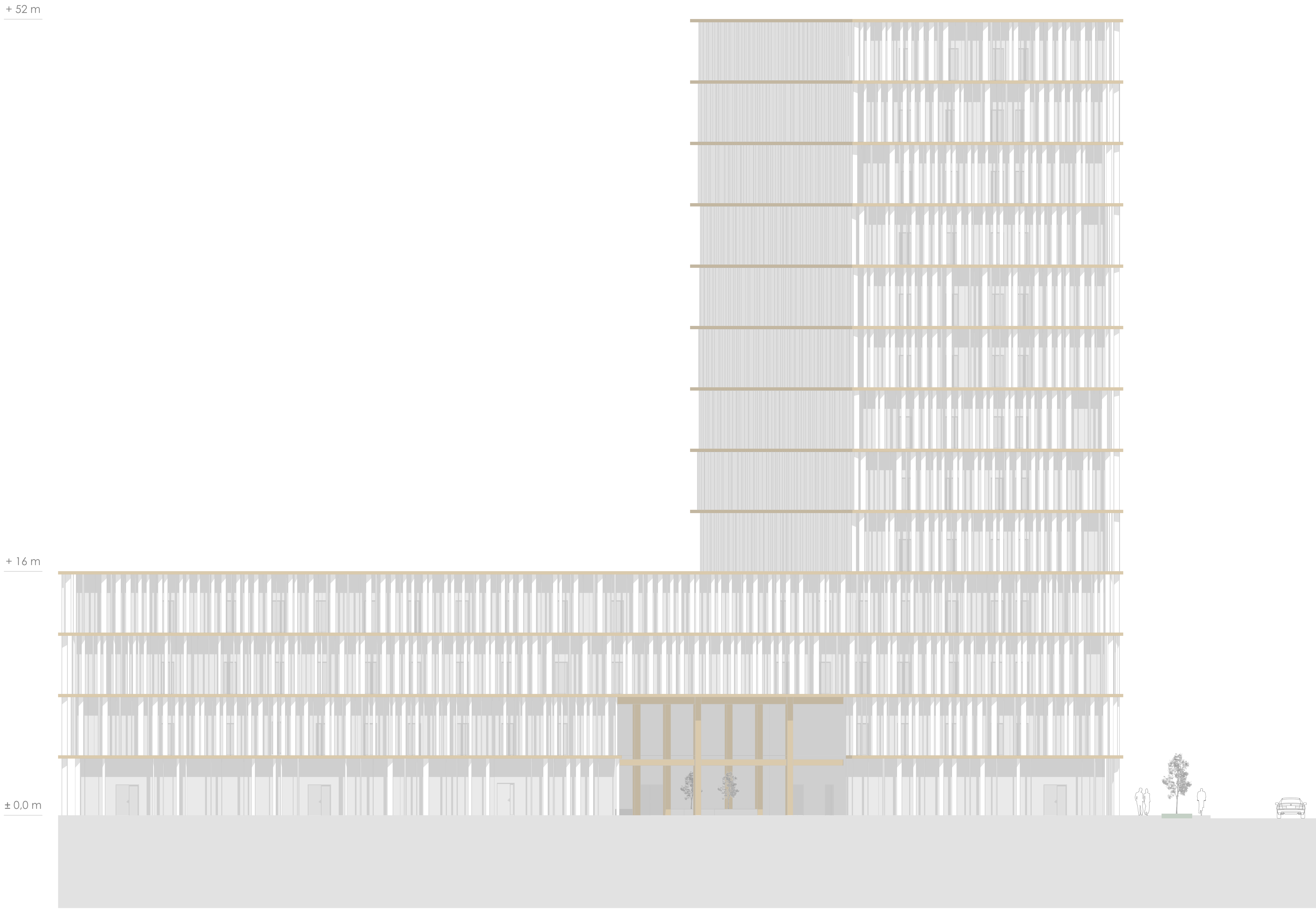


Image 47: North elevation

1 : 250

Image 48: Section

1 :250

Image 49: Exterior visualization

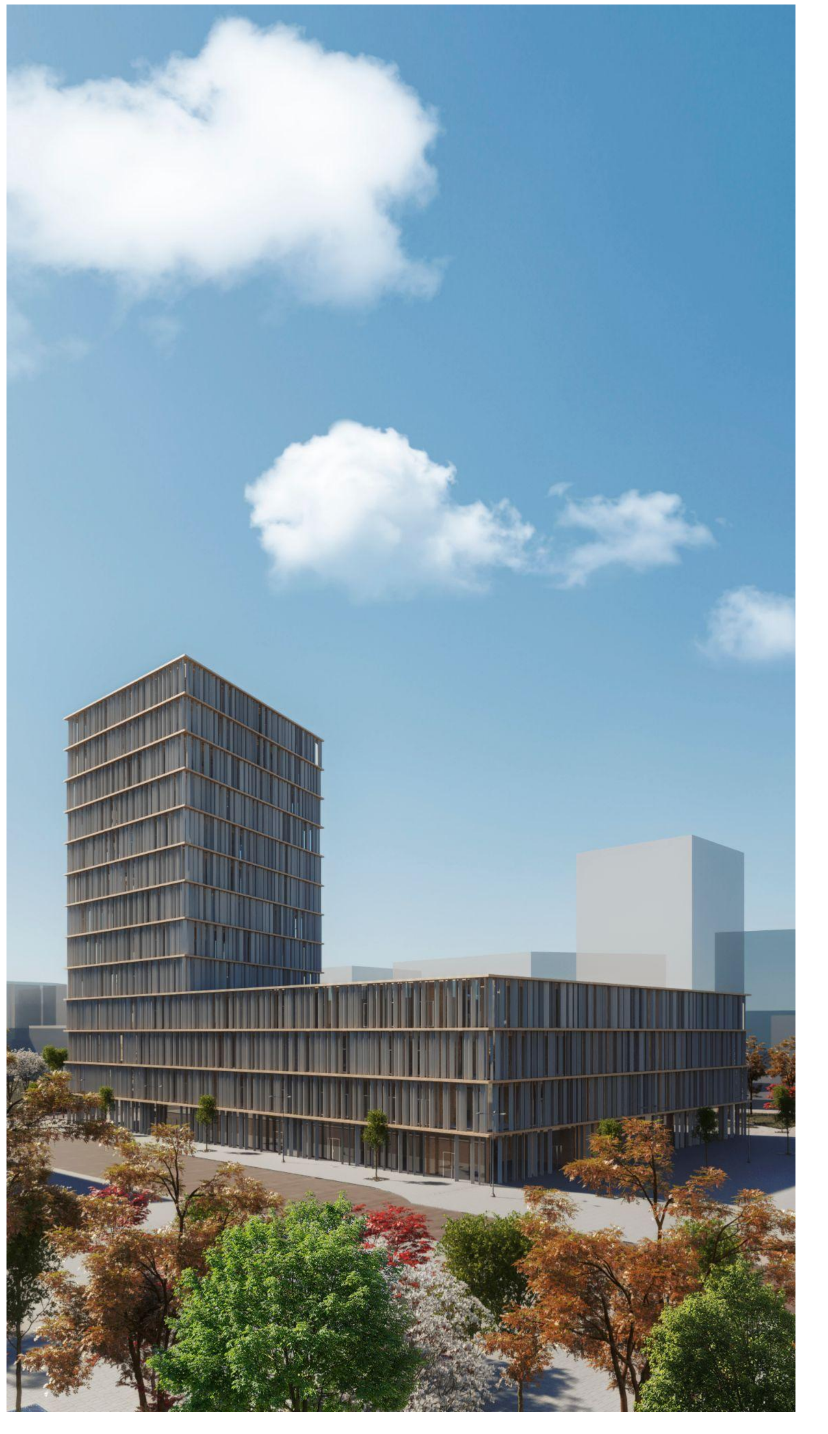


Image 50: Exterior visualization

Image 51: Interior visualization

Image 5: Interior visualization

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