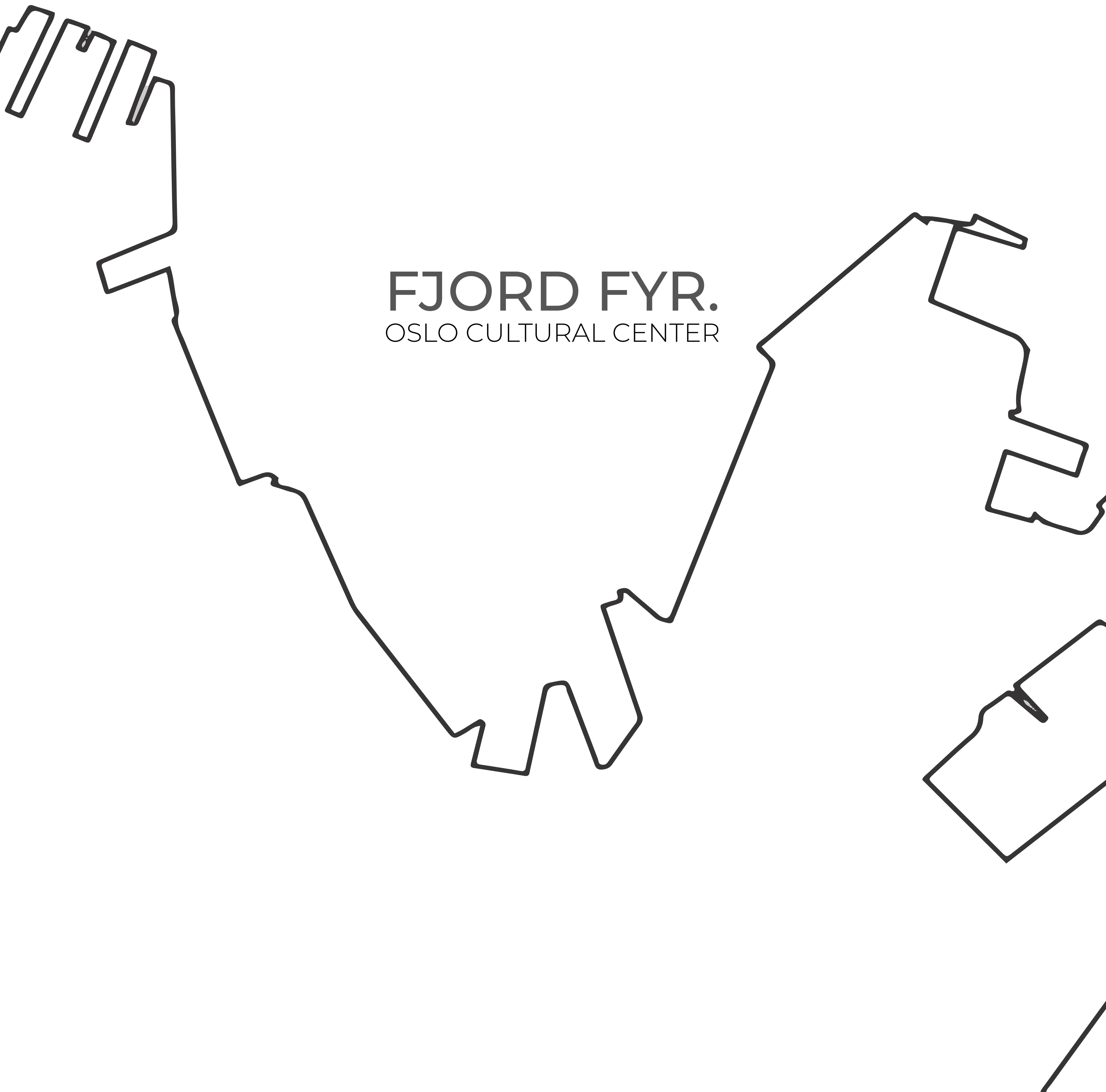
FJORD FYR.

OSLO CULTURAL CENTER



POLITECNICO
MILANO 1863

FJORD FYR.

OSLO CULTURAL CENTER

Master thesis for Building and Architectural Engineering

Politecnico di Milano

Polo territoriale di Lecco

Authors:
Norman Ayyad
Keti Taushanova

Supervisor:
Prof. Massimo Tadi

Lecco
June 2020

Acknowledgment

We would like to express our gratitude and appreciation to our supervisor, Professor Massimo Tadi, for his guidance and support during this project.

Additionally, we want to thank all the professors, assistants, tutors, and members who contributed to our knowledge during our study at Politecnico Di Milano.

Also we would also like to thank:

Mr. Maurizio Moscati, K-SOL SRL

Mr. Rolf Thore Bekkhus, Oslo municipality

Mr. Jakob Rønn Hedegaard, Oslo municipality

Mr. Luigi Carboni, Politecnico Di Milano

We want to thank in particular:

Keti:

First, I would like to dedicate this book to my family - my mother Margarita, my father Lyubomir, and my grandmother Maria. Their support has been the reason I was able to experience this journey.

Next, I am grateful to everyone who I met during this Masters's degree.

Special thanks to Norman for his patience and his hard work in the project.

Finally, I would like to thank all my family and friends who have been supporting me from a distance.

Norman:

I would like to express my gratitude to my parents Emad and Hanan, my sister Jacqueline and my brother Youssef for providing me with support and encouragement throughout my years of study. This accomplishment would not have been possible without them. Thank you.

Thanks to Keti, for all the efforts she put in the project.

Thank you to all whom were part of this journey, Dina M. Ebeid, Matthieu Veldekens, Cecilia Burtica, Mirette Bakir, Carmel Delshad and Andrew Gerges.

Absract

The revitalization of post-industrial spaces in Oslo is significantly changing the shape of the city and emphasizing the green infrastructure of the urban area. In the Vippetangen, Oslo Fjord-Fyr. The project is introducing a new transformation phase, where it links the Bjørvika neighborhood with the Oslo city center through the waterfront passing by prominent cultural landmarks Oslo Opera House, Akershus Castle, and in between them Fjord-Fyr., the new cultural center.

The project's objective is to provide a green cultural axis that integrates the original identity of the neighborhood, maintains the role of public space, and cope with the new urban transformation of the fjords on a medium scale, alongside introducing the architectural and engineering solutions on the micro-scale. Extensive investigations were conducted on different levels, analyzing numerous sub-systems including its accessibility, connectivity, and proximity as main complexes and performing additional optimizations that helped to improve the quality of surrounding, and to align the project goals with the Oslo development plan.

The urban and architectural design evolution process was supported by further augmented analysis concerning the building energy and daylight performance, structural verifications, and materials suitability with the environment, following the Norwegian building technical regulations.

La revitalizzazione degli spazi post-industriali di Oslo sta mutando in maniera significativa la forma della città, mettendo in risalto le infrastrutture “green” dell’area urbana. Nell’area di Vippetangen, il Progetto Oslo Fjord-Fyr. sta introducendo una nuova fase di trasformazione, collegando i dintorni di Bjørvika con il centro città di Oslo passando per il lungo mare e toccando i punti d’interesse culturali più significativi: la Opera House di Oslo, il Castello Akershus e, in mezzo a questi due, il Fjord-Fyr., il nuovo centro culturale.

L’obiettivo del progetto consiste nel mettere a disposizione un asse culturale in grado di integrare l’identità originale di quartiere, mantenendone il ruolo di spazio pubblico, e nel far fronte alla nuova trasformazione dei fiordi su scala media, al tempo stesso introducendo soluzioni architettoniche ed ingegneristiche su scala micro. Indagini approfondite sono state effettuate su diversi livelli, analizzando numerosi sottosistemi inclusi quelli dell’accessibilità, della connettività e della prossimità ai complessi urbani principali, e effettuando ulteriori ottimizzazioni in grado di migliorare la qualità degli ambienti circostanti, per allineare gli obiettivi del progetto con il programma di sviluppo di Oslo.

Il processo di evoluzione del design urbano e architettonico è stato supportato da ulteriori, più approfondite analisi riguardanti l’energia del’edificio e la performance diurna, verifiche strutturali e adeguatezza dei materiali nei confronti dell’ambiente, seguendo i regolamenti tecnici norvegesi in material di costruzioni.

Contents

1

Figure.1. Photo of Vippetangen, Oslo (source: Oslo municipality)

INTODUCTION

1. Architectural competition

The thesis project based on the architectural competition #OSLOCALL created by the internet portal start for talents, and it is a platform for anyone who wants to take part in an international architectural design competition.

| Location

The location is the city of Oslo in Norway and, in particular, along Oslo's waterfront. The city of Oslo is a home to many artistic personalities such as Munch and Viegeland that have characterized the history and culture of Norway. History and tradition are mixed in the city with many examples of contemporary design: the Astrup Feornley Museum, the Opera house, the Barcode district. Those are just some of the architecture that has given a new image to the urban waterfront.

| Theme

The theme of the contest was to design the Oslo Cultural Center, a place for culture that gives continuity to the already started Fjord city development program.

| Project area

The project is located in the Vippetangen area, one of the ten areas part of the Fjord city project.

| Project goal

On a large urban scale, the main goal of the project is to link the city together from east to west, turning different parts of it into a string of modern architecture and attractive common areas close to the sea. On a smaller urban scale, the main goal is to revitalize Vippetangen area. On the micro scale, the objective of the project is to imagine a modern cultural landmark that allows the local community to share experiences of historical-cultural value.

Figure.2. Area of the competition

| Architectural project requirements

Area surface for the Cultural Center: 2900 m^2

Minimum functional specifications:

Hall: 100 m^2

Auditorium: 200 people

Dressing room for staff: 50 m^2

Two Exhibition halls for temporary photographic exhibitions: 100 m^2 for each one

Two Laboratory (picture and sculpture): 100 m^2 for each one

Library: 300 m^2

Coffee space: 200 m^2

Technical room (for water and electric machines): 100 m^2

One public WC for plan: 3 for man, 3 for woman, 1 for disabled

Four Offices: 20 m^2

Green public area: free dimension.

2. The Fjord city project

In January 2000, Oslo faced the choice of either port city or fjord city. Oslo City Council chose the fjord city strategy and adopted the so-called "Fjord City Decision" on 19 January 2000. It was a decision that meant that former port areas would be released for urban development. The strategy was to relocate, concentrate and modernize the new logistics areas for more rational and efficient port operation. Development of the new port would be funded by the sale of the former port and logistics areas for urban development purposes. The new container port was moved Sydhavna, while ferries and cruise ships still doc at quays in city central areas at Vippetangen, Revierkaia, Hjortnes and Akershusstranda.

In 2008 the Fjord City Plan was adopted by the City council. This plan follows up the Fjord City decision and provides detailed guidelines for the further development of the whole of the Fjord City and of important subsections such as Filipstad, Vippetangen and the Alna river outlet at Kongshavn.

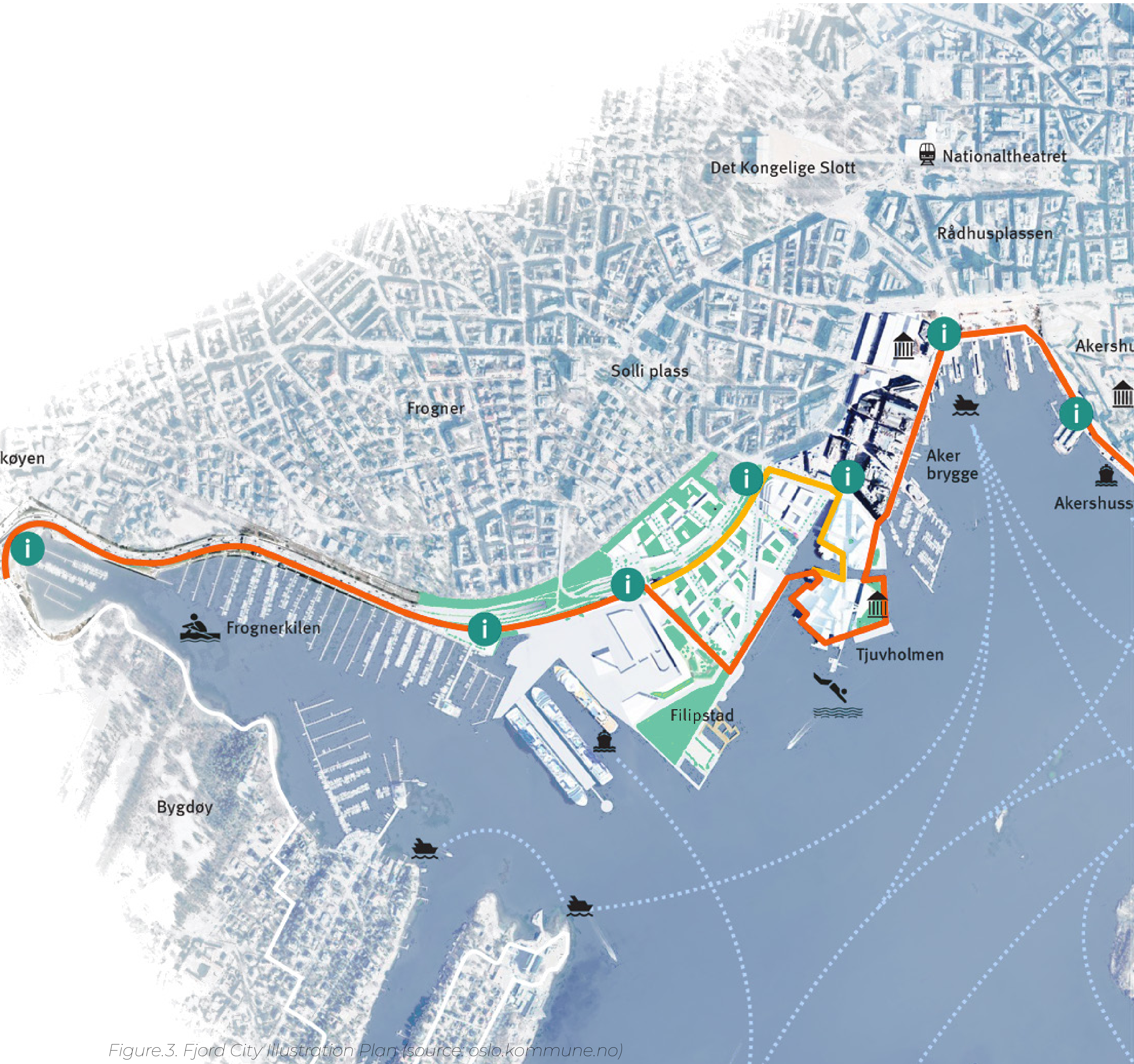
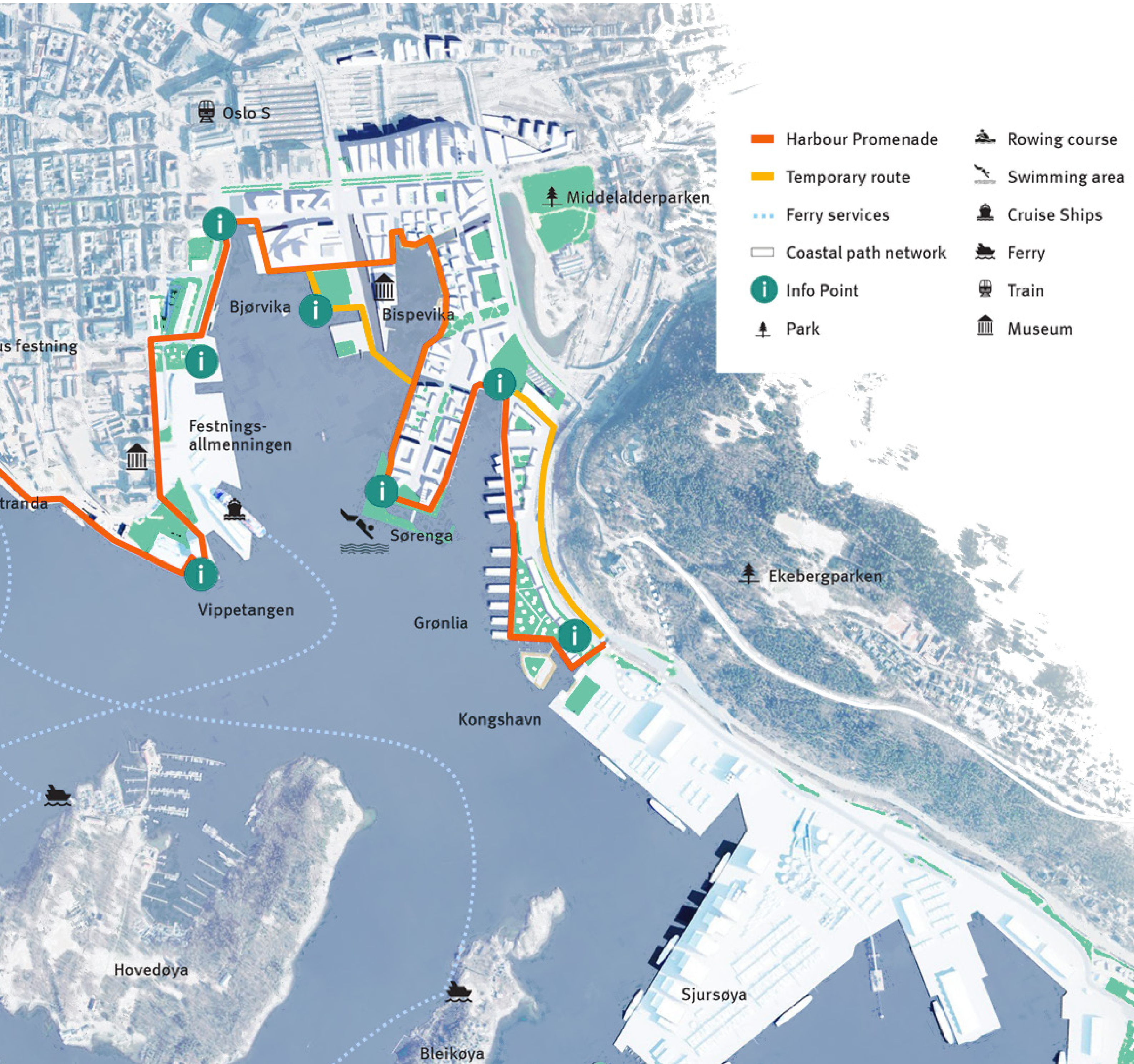


Figure.3. Fjord City Illustration Plan (source: oslo.kommune.no)

| The Fjord City Project Goals

The development of the Fjord City was driven by a strong desire to create attractive common areas and good, vibrant urban spaces that are inclusive and accessible to the general public. Promoting pedestrian areas, the harbor promenade, bicycle paths and public transport has been a priority. A new tram line alongside the fjord will be established to increase the capacity of the city central transport system and ensure areas free of cars.

An implementation model has been developed for the fjord city development based on binding-cooperation between landowners, developersvand the City. Among other things, developers pay a fee for every new square metre of floor area built. This provides income to fund the necessary public infrastructure such as streets and squares, transport solutions, quays, canals, public areas and parks. In addition there are requirements to the proportion of public spaces, the environment and universal design.



| The Harbour Promenade

The harbor promenade is a 9 km long walk through attractions in the Fjord City. It stretches from Kongshavn in the east to Frognerkilen in the west. The harbor promenade is open all year, and accessible to everyone.

The harbor promenade is divided into nine sections. Each of the sections has its own characteristics and own history. In each part, the project created unique architectural opportunities, and the area has become a place where residents and visitors can experience modern architecture and attractive common areas.

The Opera house, home of the Norwegian National Opera and Ballet, was the first element in the planned transformation of the Bjørvika harbor. Designed by Norwegian architects Snøhetta and opened in early 2008, the building has become an essential cultural landmark in the city.

The next large project in Bjørvika is the Barcode development that consists of twelve narrow high-rise buildings of different heights and widths. The facilities are built with some space in between them, thus jointly resembling a barcode.

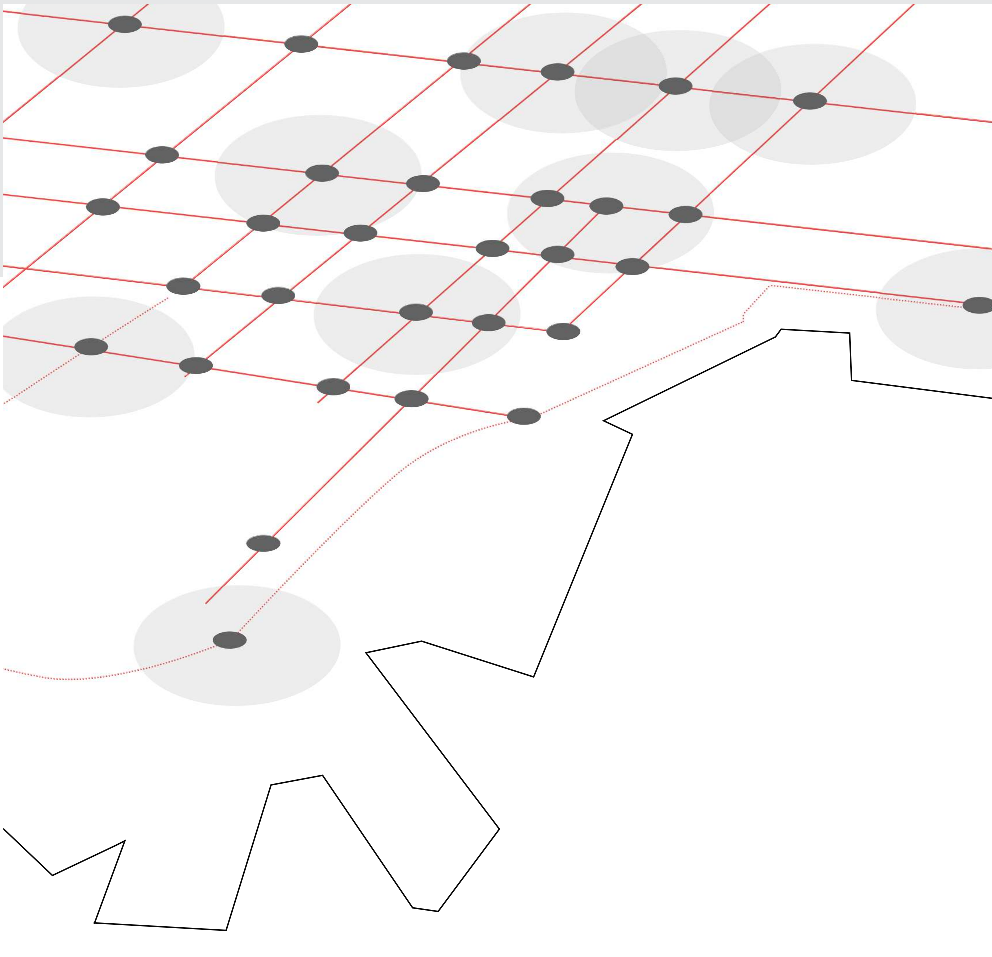
Another important part of the Fjord City urban renewal program is the Tjuvholmen area, located on a peninsula sticking out from Aker Brygge into the Oslofjord. In this place, there has been an opening of several art galleries, among them the Astrup Fearnley Museum of Modern Art, created by Renzo Piano.

Figure.4. Opera house (source: .oslo-fjord.com)

Figure.6. Bjørvika Barcode (source: oslo.kommune.no)

Figure.5. Astrup Fearnley Museet (source: afmuseet.no)

2



ANALYSIS OF THE URBAN CONTEXT

1. Historical Analysis

| A Brief History of Oslo

The history of Oslo stretches back to the start of the first millennium. The first mentions in Norse sagas date to 1049, but there is evidence proving a settlement existed earlier.

The former name of Oslo

During the Viking Age the area was part of Viken, the northernmost Danish province. Oslo was founded as a city at the end of the Viking Age in the year 1040 under the name Ánslo,and established as a kaupstad or trading place in 1048 by Harald Hardrada. The city was elevated to a bishopric in 1070 and a capital under Haakon V of Norway around 1300. Personal unions with Denmark from 1397 to 1523 and again from 1536 to 1814 reduced its influence. After being destroyed by a fire in 1624, during the reign of King Christian IV, a new city was built closer to Akershus Fortress and named Christiania in the king's honor. It was established as a municipality (formannskapsdistrikt) on 1 January 1838. The city functioned as the capital of Norway during the 1814–1905 union between Sweden and Norway. From 1877, the city's name was spelled Kristiania in government usage, a spelling that was adopted by the municipal authorities only in 1897. In 1925 the city, after incorporating the village retaining its former name, was renamed Oslo.

Medieval Oslo

The medieval town of Oslo was located below the Ekeberg hills, on the east side of the Bjørvika inlet. Around the year 1300 AD Oslo had about 3000 inhabitants. The town was the residence of King Haakon V (1299-1319) who commenced the building of what is today known as the Akershus Fortress.

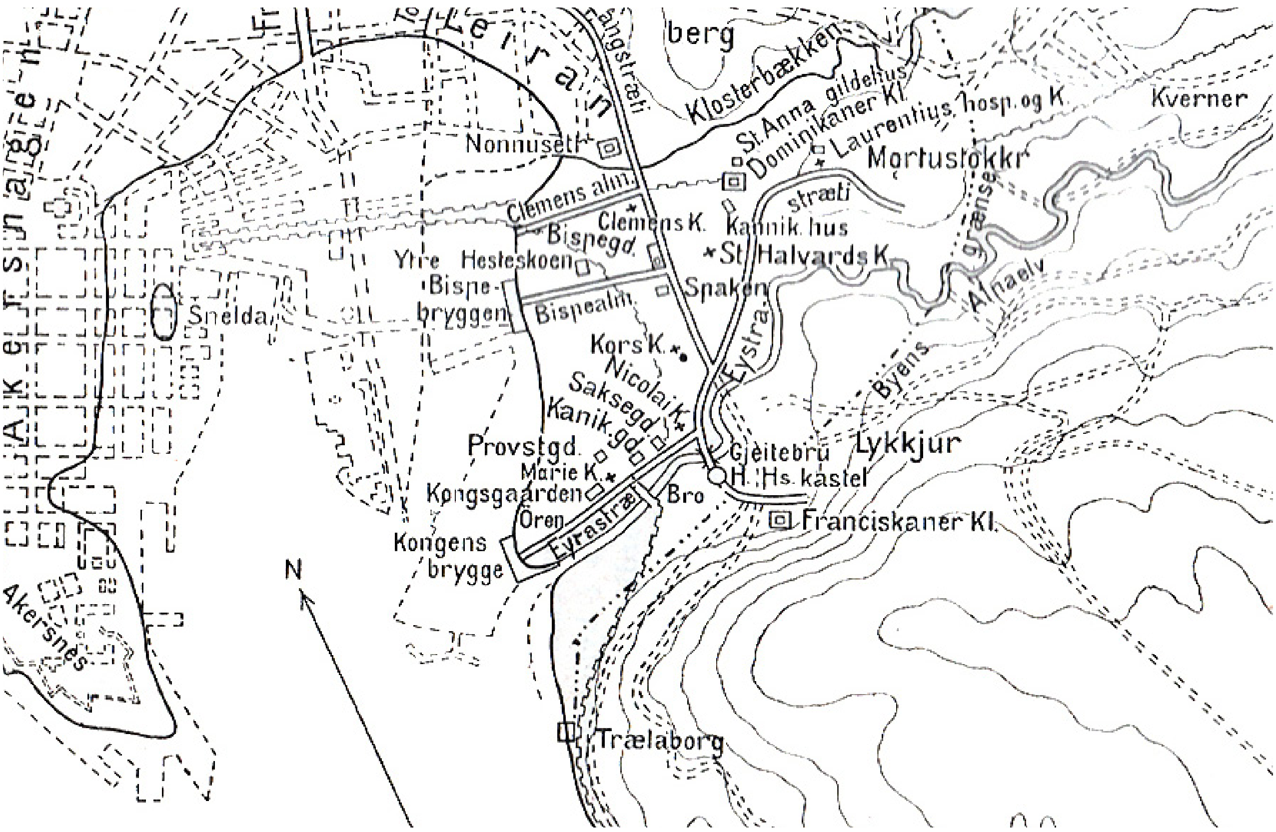


Figure.7. Medieval Oslo (source: snl.no)

The renaissance town

From 1536 Norway was in a union with Denmark. After a dramatic fire in 1624, the Danish King Christian IV decided that the town be rebuilt below Akersus, so the fortress could function as a defense for the town. That was the time when the town was named Christiania, after the king himself.

As most older cities Oslo has gone through big character changes as a result of fires and redevelopment. This part of Oslo's center between the Akershus Fortress and Oslo Cathedral, Øvre Vollgate and Skippergata is today known as Kvadraturen ("the quadrature") because of the rectangular street pattern of Christian IV's renaissance town. Several well-preserved buildings from the 17th century can be seen here. In Kvadraturen the building that housed Oslo's first town hall, and the city's oldest restaurant Café Engebret can be still seen nowadays.

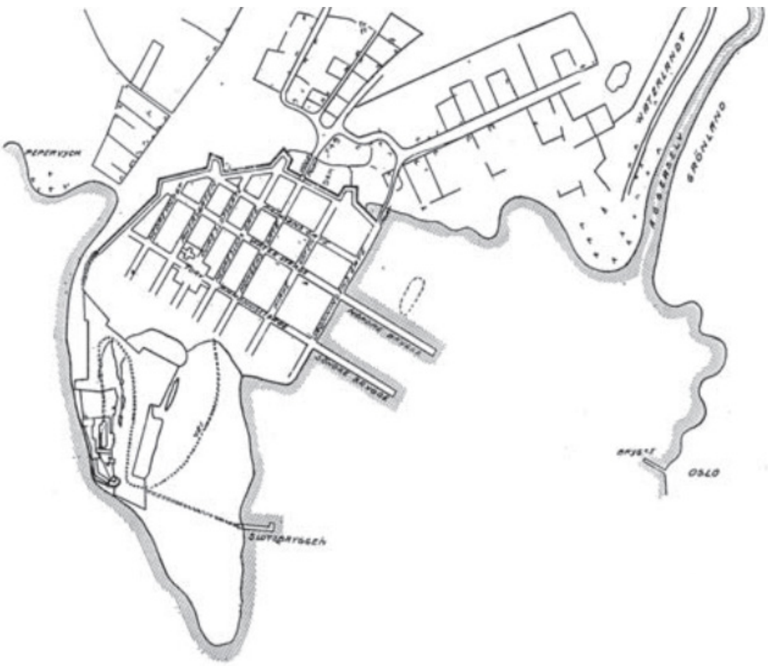


Figure.8. Map of Christiania in 1648(source: drawing from Kjelstrup, 1962 Oslo Havn KF)

Figure.9. Café Engebret (source: slobilder.no)

Figure.10. Øvre Vollgate (source: slobilder.no)

A capital is built

In 1814, the city regained its status as capital of the independent Kingdom of Norway. In 1877, the city underwent another name change according to an official spelling reform in Norway changed 'ch' to 'k' and so Christiania officially became Kristiania.

Throughout the 19th century, celebrating its return to capital status, the city built many of the institutions of government that are still in place today. The Bank of Norway (1828), the Royal Palace (1848), and the Storting (1866) were all constructed.

The industrial era started along the river Akerselva around 1850. In the years between 1850 and 1900 the population of Kristiania increased from about 30,000 to 230,000 mainly due to an influx of workers from rural areas.

The 20th Century was an important time for Norway. In 1905, the personal union with Sweden was dissolved amicably and Norway finally became the independent state that we know today, and the name of the city was finally changed to Oslo.

Figure.12. Map of Oslo in 1879 (source:kart.finn.no)

Figure.11. Map of Oslo in 1938 (source:kart.finn.no)

Figure.13. Kristiania (source: slobilder.no)

Figure.14. Karl Johans gate (source: oslobilder.no)

Figure.15. Kongens gate 14 (source: taptoslo.no)

Figure.16. National Bank of Norway (source: oslobilder.no)

Figure.17. Royal Palace (source: oslobilder.no)

Harbor Area Development

Glimpses of the port area through the ages

Oslo has always been a seaport. A port is a meeting point between the sea and land transport and provides intermodal transportation of goods between ships, car, and train. This meeting has laid the foundation for urban growth in many places, such as in Oslo, which has been a key port city in a thousand years.

Bjørvika is the city's oldest known harbor. The first settlement was located on the east side of the bay, under the Ekebergåsen. After a fire in 1624, the city decided to rebuild the headland, protected by the fortress. This led to the new port facility was established on the western side of Bjørvika.

From being a single port facility under Ekebergåsen, the port has evolved to cover much of the city's central seafront.

Seafaring life established the main contact with the outside world, both nationally and internationally. During the 1800s developed Oslo to become a city of industry and activities related to maritime transport. Moreover, during the 1800s Oslo evolved to become the country's main port city.

Figure.18. Oslo port view from Grønnlia 1875 (source: oslobilder.no)

It was not until the 19th century that Pipervika gained importance as a port area. The construction of the West Railway and the construction of the station building in 1872 made the area more central.

The strong urban growth in the latter half of the 1800s, combined with fast the introduction of a new technology in a number of areas, resulting in a complexity in port construction. In 1897, called the City of Oslo, therefore, an international port plan competition. This was largely the basis for the further port development. Roads, railways and quayside came where there had previously been steep natural terrain, bastions and public sea baths

In the 1900s the city continued to expand, and the commercial and economic aspects of the shipping industry left its mark on the city until the present day.

Within a few years, from 1898 to 1911, the area around Akershus Fortress completely transformed. Vippetangen was developed also during the period 1899 to 1914. The port facilities west towards Pipervika was built about the same time, in the period 1909-1919.

In 1907 fishing boats and the new industrial facilities were relocated to Vippetangen.

In total, Oslo's total harbor length, that is, facilities used by merchant and passenger ships, has been reduced from eleven kilometers at most in the 1990s to about six kilometers by 2020.

Figure.19. Oslo port view 1938 (source: oslobilder.no)

| Vippetangen history and heritage

Vippetangen area is located on the headland between Pipervika and Akershus Castle and Fortress. The name derives from vippe (a shortening of vippefyr, or bascule light: a simple form of lighthouse that once stood there); the second element, tangen, means "the headland".

The place has been the location of a military facility and of a stone quarry, as well as military and civilian baths. In the 1880s and 1890s there was ice skating on the fjord, including the first national championships. The construction of modern dock facilities started in 1899, and on 25 November 1905 Vippetangen was the landing place for King Haakon VII and his family when they arrived from Denmark on the Norwegian warship Heimdal to assume the Norwegian throne.

The port facilities included fishing facilities, docks for international passenger ships, and a grain silo. For more than 60 years grain was transported by tram via the Vippetangen Line to Nedre Foss Mill at Grünerløkka. The tram line had been built to Vippetangen by Kristiania Kommunale Sporveie in 1900 and remained in service until 1961. The Oslo Port Line railway also ran through the area.

The area's cultural heritage is linked to its central role through Oslo's history - from medieval fortifications, through emigration via the Atlantic traffic of the emigration era until the 20th century industrial port. Through these time phases, the area has been an important part of the capital's development and a place for important events. The area has maintained a wide range of historical buildings through a long and continuous use until today. The Fish Market, the Grain silo, Sheds 38 and 39 are all listed as property of Oslo heritage registration.

| Historical buildings

Grain silo

The first grain silo was erected in 1913 and demolished after a dust explosion in 1976 and it was the first concrete building and the first silo in the harbor. It stood on the north side of the current one.

The second Grain silo was built in 1958 and completed in 1959 by the Norwegian Government's grain business. It is maid by reinforced concrete and used for import and storage facilities for bread grains. It then had a storage capacity of 28,000 tons of grain. In 1972 extended with a capacity for additional 15,000 tons.

Fish market

Oslo has never been regarded as a fishing port but buying and selling fresh fish from local boats is a tradition. In 1935 was built a new, for its time, modern fish hall in Vippetangen. The building still stands today and host the largest fish market in Norway.

Akershus Fortress

Akershus Fortress is a cultural monument of national importance, and even though it is located outside of Vippetangen the building is a significant landmark in the cityscape.

Akershus Fortress was built during the medieval time to protect and provide a royal residence for the city. Since the middle ages, the fortress was the namesake and center of the main fief and later main county of Akershus, which was originally one of Norway's four main regions and which included most of Eastern Norway. The fortress itself was located within Akershus main county until 1919, and also within the smaller Akershus sub county until 1842.

The castle has also been used as a military base, a prison and is currently the temporary office of the Prime minister of Norway.

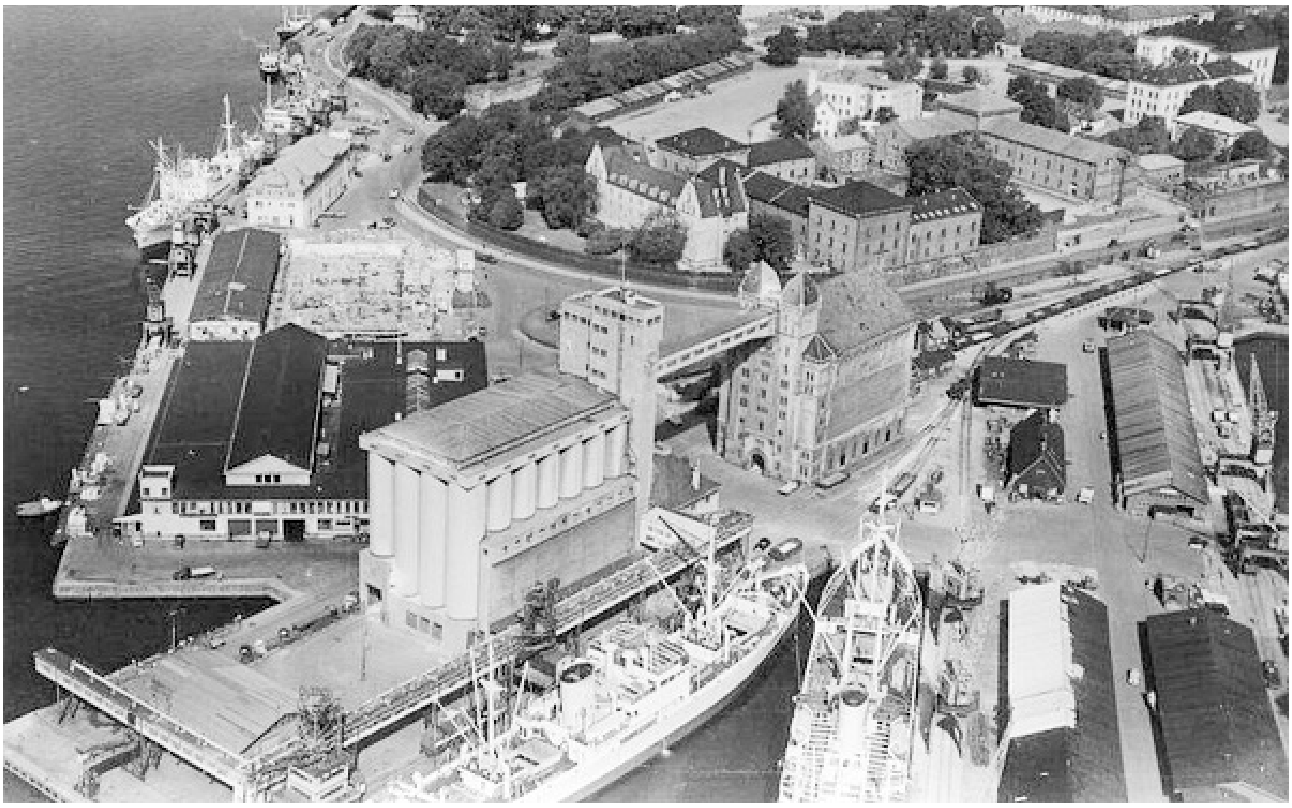


Figure.20. Vippetangen view 1938 (source: oslobilder.no)

Figure.21. First silo (source: oslobilder.no)

Figure.22. Second silo (source: oslobilder.no)

Figure.23. Fish market (source: oslobilder.no)

Figure.24. Akershus Fortress (source: oslobilder.no)

2. Environmental Analysis

2.1. Climate

Location: Oslo, Norway

Geographical Coordinates:

59°56'58" N , 10°45'23" E

As part of the semi-continental Scandinavia, Oslo city has a similar climate to that of the cities located along the coasts of the Baltic Sea, so it is very cold in winter, with average temperatures below freezing (0°C), and mild or pleasantly warm in summer.

According to the Köppen Climate Classification subtype for the climate of Oslo is defined “Dfb”. (Warm Summer Continental Climate).

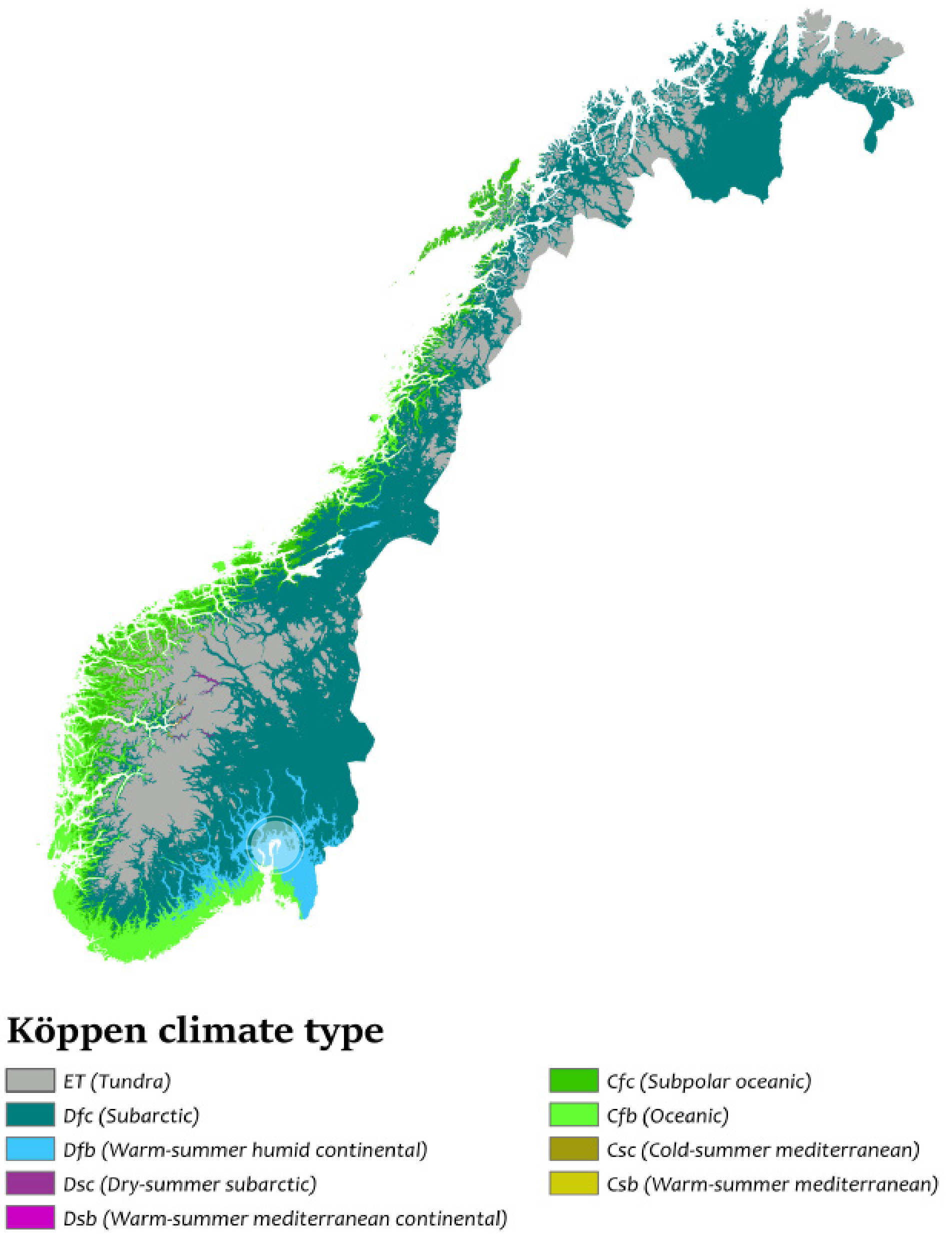


Figure.25. Köppen Climate Classification zones in Norway

| Temperature:

From November to March, the temperature says around freezing or below with about 80 days of snowfall, which usually occur from late October to mid-April. However, the city can experience a great variation of in temperature in several cases: when Atlantic currents prevail, the temperature can exceed freezing even in winter and snow can melt, while when currents Siberia or a polar anticyclone moves over Scandinavia, it can drop below -20 °C.

The summer months last from May to August when Oslo experience mild climate with a temperature that can get as high as 30°C, while the average stays around 20 °C.

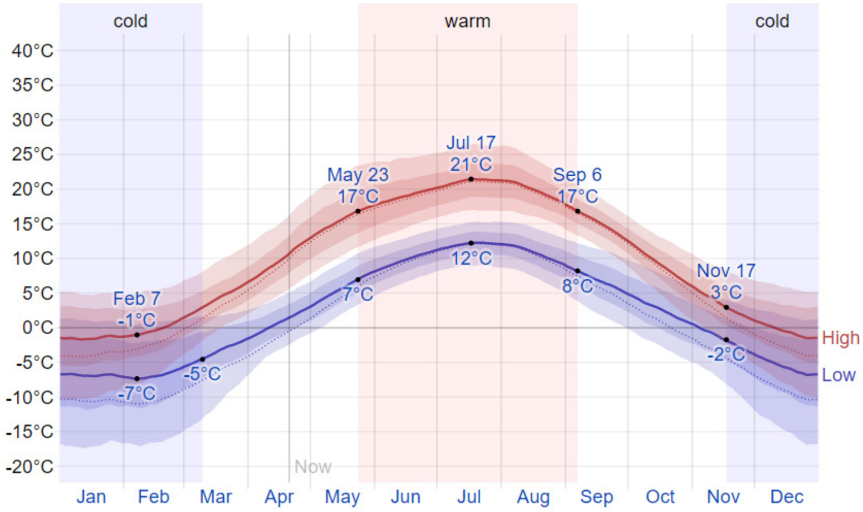


Figure.26. The daily average high (red line) and low (blue line) temperature(source: weatherspark)

| Water Temperature:

Oslo is located near a large body of water. This section reports on the wide-area average surface temperature of that water.

The average water temperature experiences extreme seasonal variation over the course of the year. The time of year with warmer water lasts for 2.7 months, from June 27 to September 17, with an average temperature above 14°C. The day of the year with the warmest water is August 6, with an average temperature of 17°C. The time of year with cooler water lasts for 4.3 months, from December 13 to April 22, with an average temperature below 5°C.

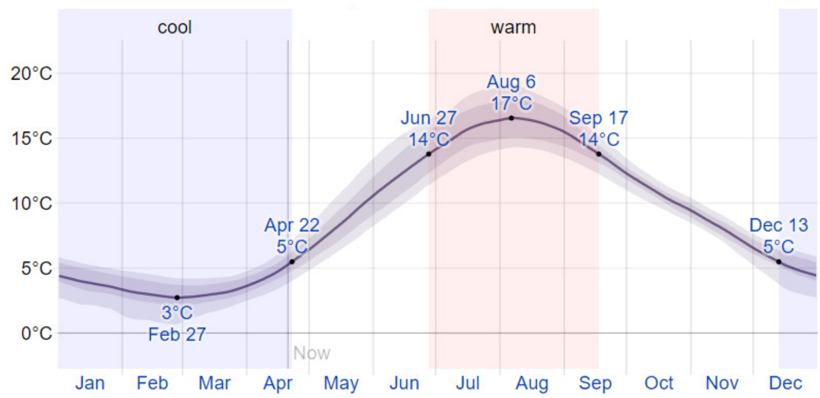


Figure.27. Average high and low water temperature(source: weatherspark)

| Precipitation:

The average amount of precipitation for the year in Oslo is 759.5 mm. The month with the most precipitation on average is August with 88.9 mm) of precipitation. The month with the least precipitation on average is February with an average of 40.6 mm There are an average of 232 days of precipitation, with the most precipitation occurring in January with 21days and the least precipitation occurring in April with 17.0 days.

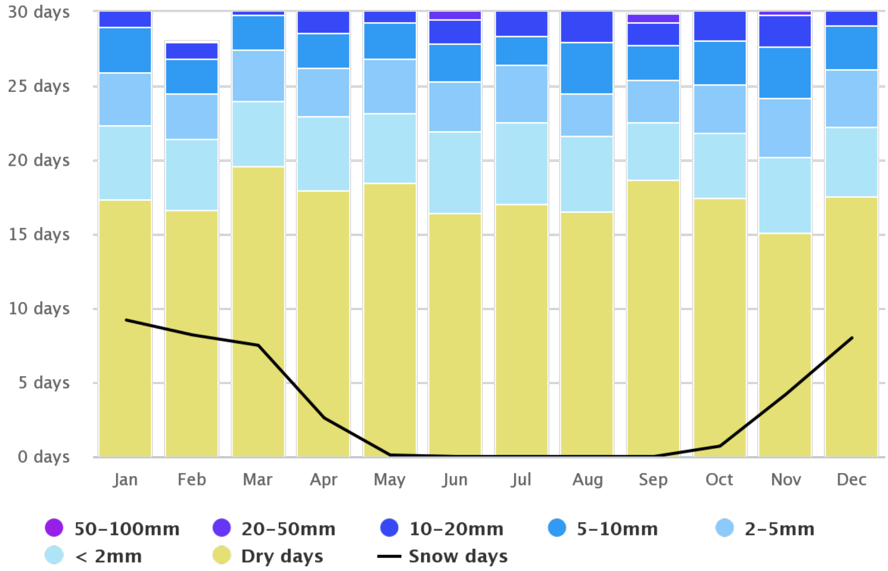


Figure.29. The maximum temperature diagram for Oslo (source: meteoblue)

| Clouds:

The city of Oslo has a significant seasonal variation of the average percentage of clouds in the sky over the year. The clearest time of the year begins around the last week of April and lasts for almost 5.2 months to end late in September. During that period, the city has the sky clear, mostly clear or partly cloudy for 53% of the year and on the other hand, overcast or mostly cloudy for 47% of the time.

The cloudier period of the year begins in late September and it lasts for almost 6.8 months, to end in the third week of April. During that period, Oslo experiences the overcast or mostly cloudy sky for 70% of the time, and clear, mostly clear, or partly cloudy 30% of the time.

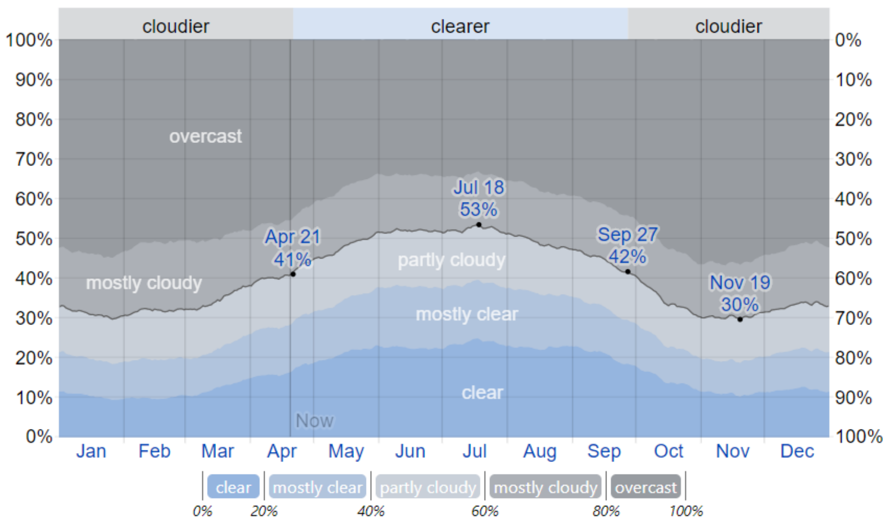


Figure.28. The percentage of of the sky covered by clouds (source: weatherspark).

| Wind:

The wind is most often from the south for 1.3 months, from February 23 to April 1 and for 7.1 months, from April 11 to November 13, with a peak percentage of 48% on July 22. The wind is most often from the north for 1.4 weeks, from April 1 to April 11 and for 3.4 months, from November 13 to February 23, with a peak percentage of 31% on April 6. The average hourly wind speed in Oslo does not vary significantly over the course of the year, remaining within 0.8 km per hour to 7.2 km per hour throughout.

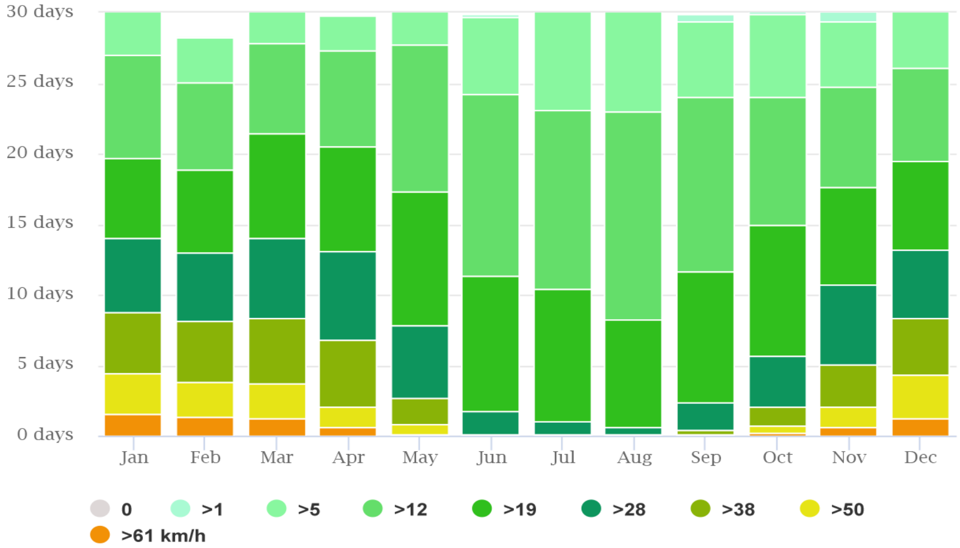


Figure.32. Wind speed per month (source: meteoblue)

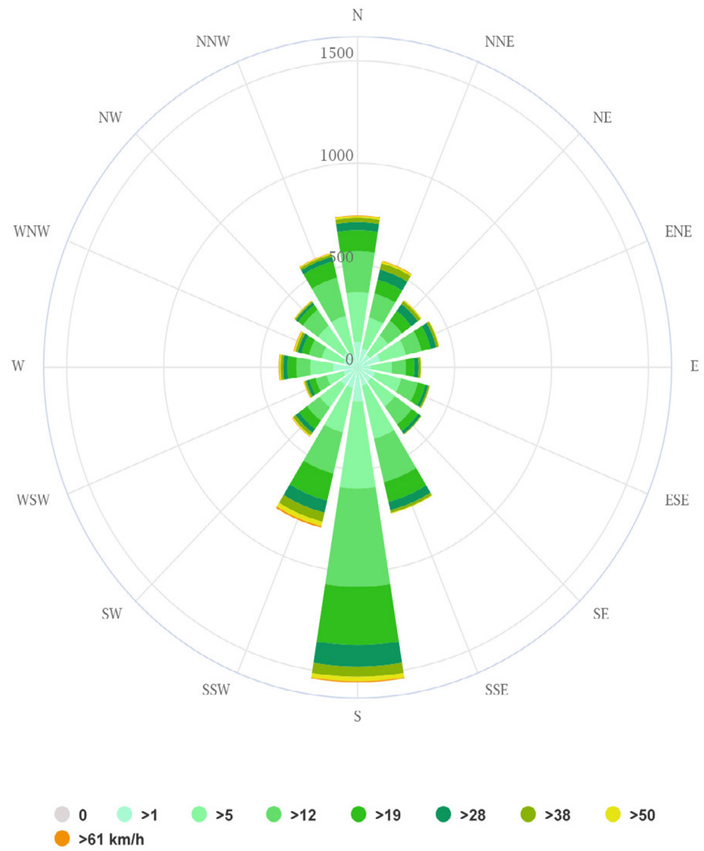


Figure.30. Wind rose diagram (source: meteoblue)

| Solar Energy:

The total daily incident shortwave solar energy reaching the surface of the ground over a wide area, taking full account of seasonal variations in the length of the day, the elevation of the Sun above the horizon, and absorption by clouds and other atmospheric constituents. Shortwave radiation includes visible light and ultraviolet radiation.

The average daily incident shortwave solar energy experiences extreme seasonal variation over the course of the year.

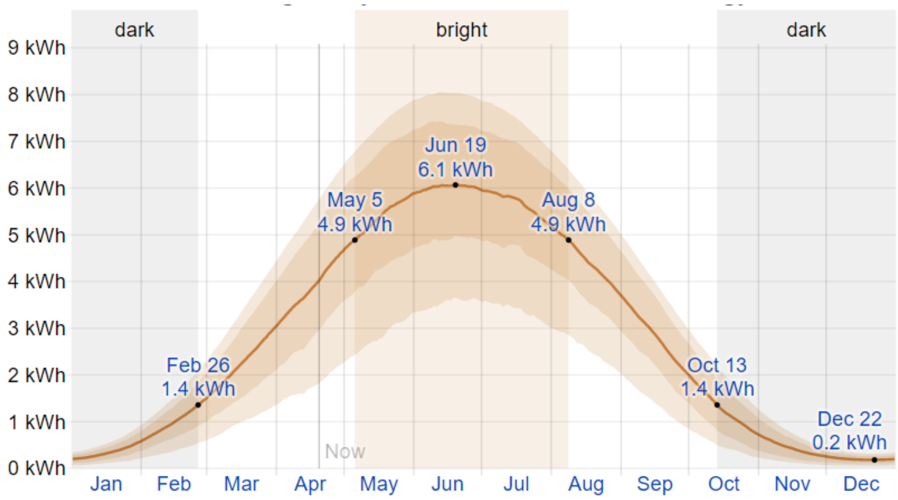


Figure.33. The average daily shortwave solar energy reaching the ground per square meter - orange line (source: weatherspark).

The brighter period of the year lasts for 3.1 months, from May 5 to August 8. The brightest day of the year is June 19.

The darker period of the year lasts for 4.4 months, from October 13 to February 26. The darkest day of the year is December 22.

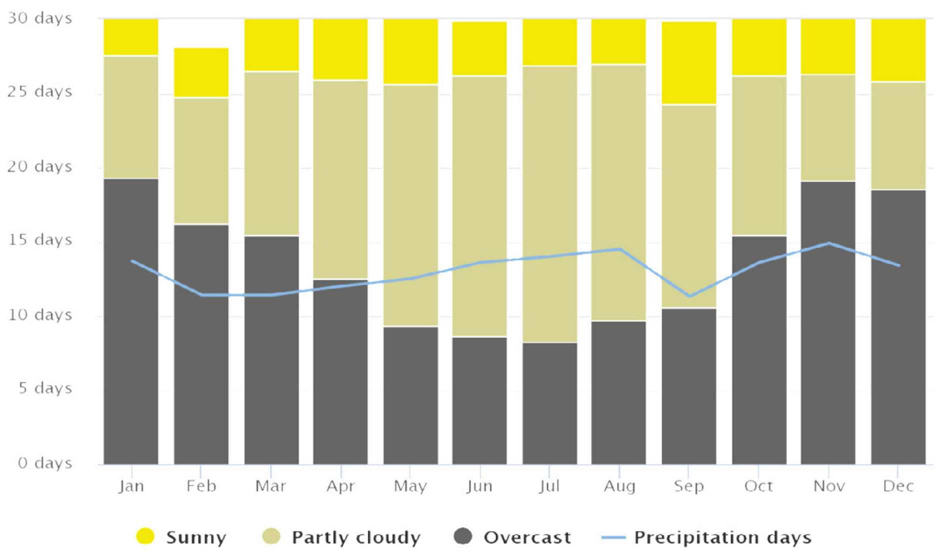


Figure.34. The amount of sunny, partly cloudy, overcast and precipitation days (source: meteoblue).

Solar Radiation:

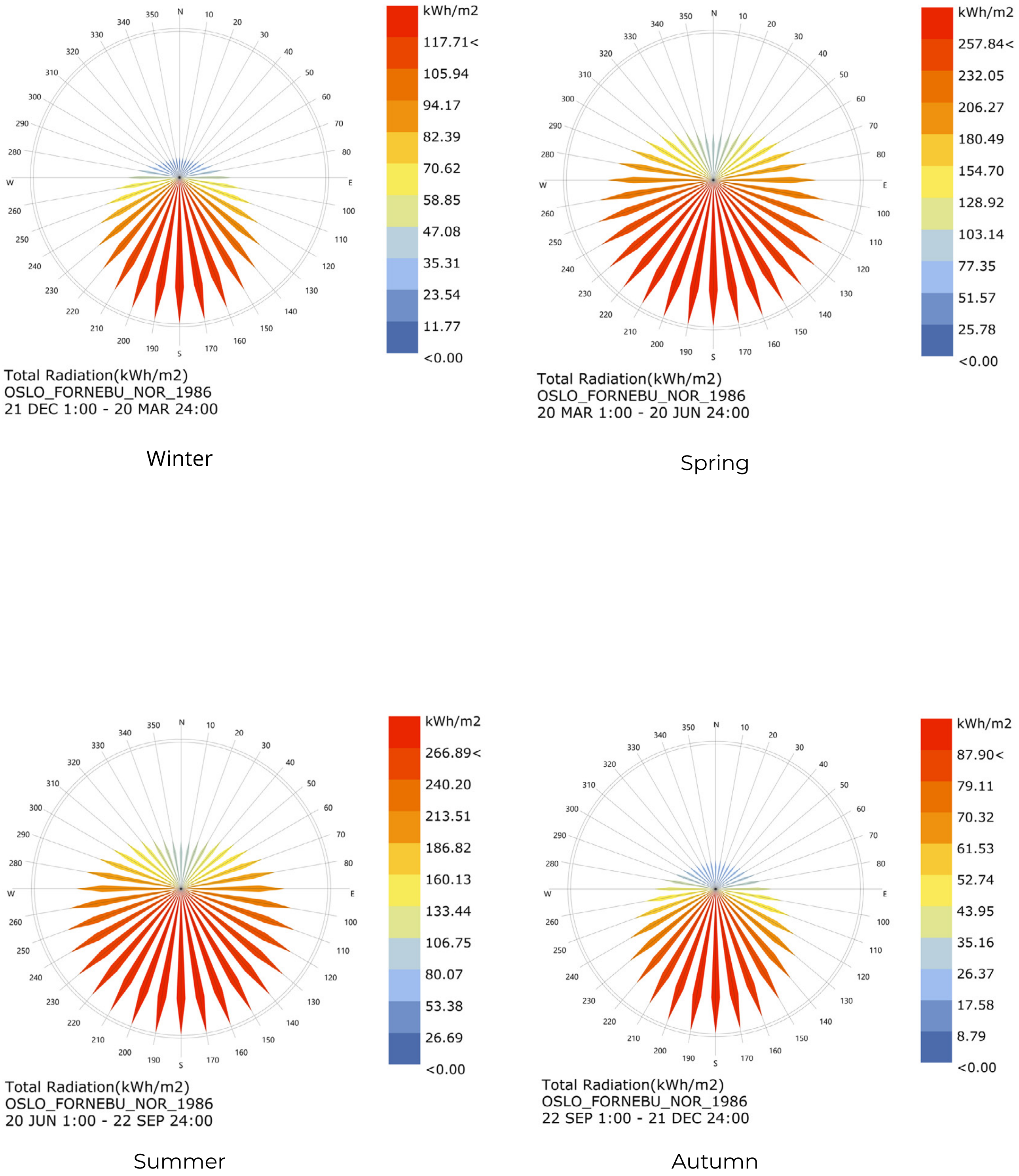


Figure.35. Radiation rose diagram

| Pollution:

Air quality

The transport sector makes the greatest contribution to high levels of coarse particles. Road wear, partly caused by use of studded tires, and dust from roads make a significant contribution. Levels of fine particles are also associated with impact on health in major Norwegian towns. Levels of fine particles peak in winter when a lot of people burn wood.

Oslo city Laws and restrictions set minimum requirements for local air quality and specify limit values for nitrogen dioxide and dust particles.Thanks to the daily and annual observation through 13 measuring station around the city which help the authorities to measure the main components of Oslo’s ambient air.

.

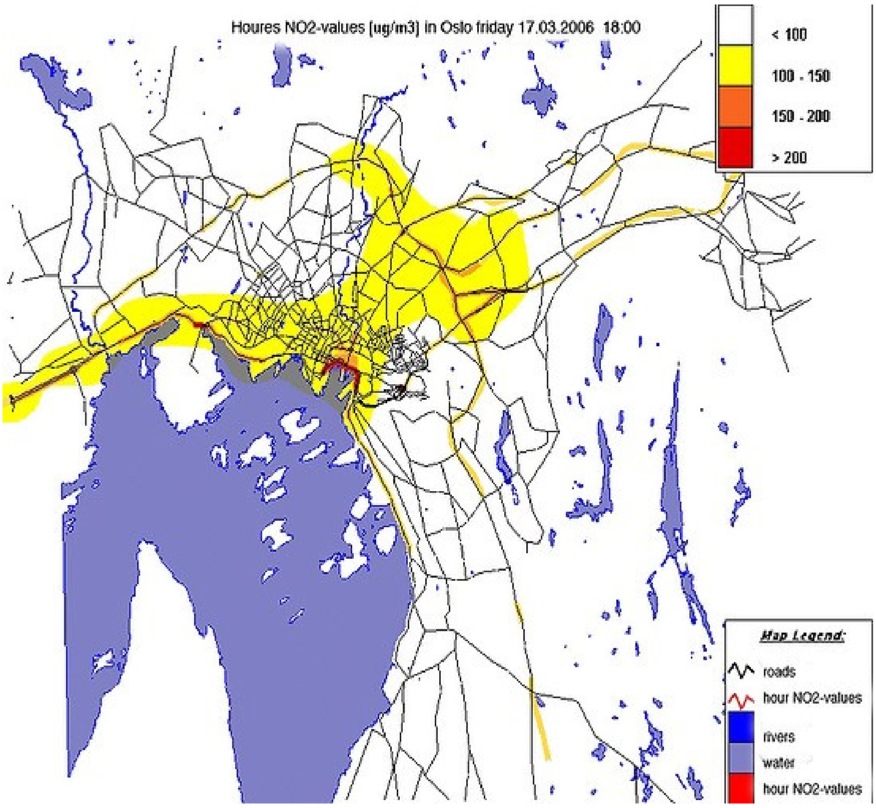


Table for the forecasting classes (national standard)

Level	NO2 hourly (µg/m^3)	PM10 daily (µg/m^3)	PM2.5 daily (µg/m^3)	Health effects
Good	< 100	< 35	< 20	No health effect
Moderate	100 - 150	35 - 50	35 - 60	Asthmatics may experience health effects in these areas, especially during physical activities.
Poor	150 - 200	50 - 100	20 - 35	Asthmatics and people with serious heart and bronchial diseases should avoid longer outdoor stays in areas with high air pollution.
Very Poor	> 200	> 100	> 35	Asthmatics and people with serious heart and bronchial diseases should avoid areas with very high air pollution. Healthy people may experience incidentally irritations in the mucous membrane and unpleasantness.

Figure.36. Typical pollution distribution in the centre of Oslo.(source airqualitynow.eu)

Greenhouse gas emissions

Locally, construction and shipbuilding or ship and port activities can also contribute significantly to pollution. In addition, pollution is brought to Oslo as a result of wind currents from other regions and countries.

The Port of Oslo is responsible for around 55 thousand tons of CO_2 equivalents per year (4 per cent) of total emissions of 1,280 thousand tons of CO_2e per year in the City of Oslo.

The authority's general measures to reduce the pollution include, among other things, environmental differentiation of vehicles, emission reduction from Oslo port, measures for the transition to electric vans, and measures to reduce emissions from wood burning.

Implemented measures, such as changed tariffs on toll roads, fees for the usage of snow tires with metal studs, cleaning and dust reduction, and environmental speed limits have resulted in reduced levels of nitrogen dioxide and dust particles.

The city has implemented some of the most effective climate and environmental measures in Europe. In 2016, Oslo set itself important goals, including an emission reduction of 95% by 2030. This is being done not by offsetting, but by implementing actual emissions cuts. In just one year, from 2016 to 2017, emissions were reduced by 9%.

Oslo municipality solution for minimizing the pollution from Oslo Port is taking a lead in developing emission free solutions, aiming to reduce its emissions by 85% by 2030 and become emission free by 2050. Traditionally, ships use their own fossil powered generators for lighting, ventilation, heating and technological equipment, but the Port provides shore-based electrical power from the onshore, hydro-powered grid. By 2020, all ferries going from Oslo to Denmark and Germany will use shore-based power, reducing the port's annual CO_2 emissions by 5000 tonnes.

Another solution is the public transport which is steadily going green and already, most public transport journeys are powered by renewable energy. The target is for all public transport to run on renewable energy by 2020 (such as biogas produced from household food waste) and to be totally emission free by 2028.

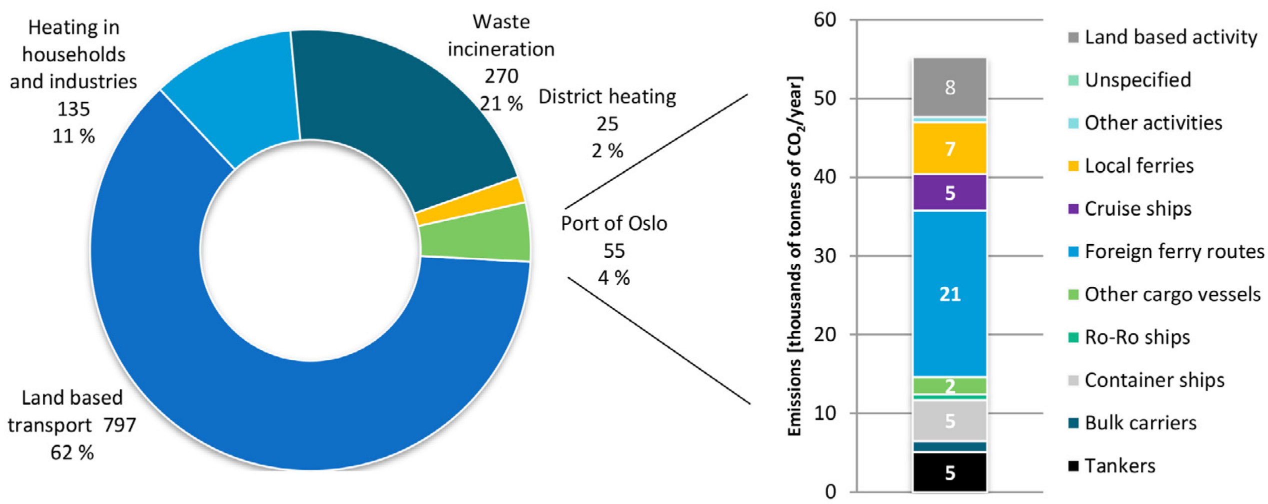


Figure.37. Distribution of greenhouse gas emissions in Oslo, per sector [thousands of tons of CO2e/year] and [%], and distribution of greenhouse gas emissions per shipping segment [thousands of tons of CO2e/year] within the Port of Oslo. (source: oslo kommune).

3. Urban Analysis

| IMM methodology

IMM is the acronym of Integrated Modification Methodology, an innovative design methodology, based on a specific process with the main goal of improving the CAS' (complex adaptive systems) energy performance, through the modification of its constituents and the optimization of the architecture of their ligands. Its approach is fundamentally Holistic, Multi-Layer, Multi-scale.

The main object of this design process is to address a more sustainable and better performing urban arrangement. Moreover, IMM approach to sustainability is aligned to the 17 UN Sustainable Development Goals 2030.

IMM investigates the urban context as a Complex Adaptive System analyzes patterns of problems and malfunctioning conditions to infer the source of the problem. IMM methodology is based on a multi-stage process composed of four different but fully integrated phases. It shows, through an interconnected Phasing Design Process, how incorporating a wide range of issues makes it possible to improve the metabolism of the city as well as its energy performance.

Just like any other system, built environment is characterized by including parts and subsystem between which there are complex relationships. Accordingly, in Investigation phase, the system is being broken into its parts. Morphologically speaking, these parts for the cities would be Urban Volume, Urban Void, Links, and Types of Uses which represent the horizontal layers of the urban texture.

After analyzing the mention subsystems individually, the synergy between them is being investigated. The result of the relationships between the ovelapping levels creates the second stage of the ivenstigation that is the Key Categories: Porosity, Permeability, Proximity, Diversity, Interface, Accessibility, and Effectiveness.

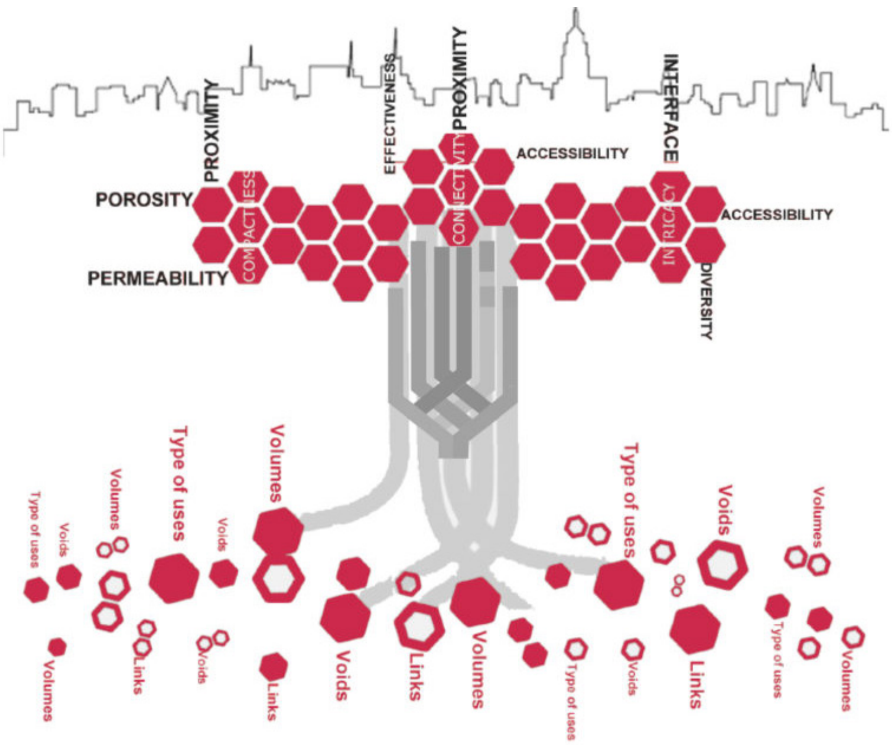


Figure.38. IMM (source: immdesignlab.com)

| IMM Investigation for Oslo's harbour promenade

The IMM methodology was applied for the analysis of the urban environment of Oslo's waterfront. The investigation's main goal was to identify the relationships between the systems of the city and analyze in debt how the systems are performing. Since a large part of Oslo's waterfront is still under development, IMM offers an essential insight for future transformations.

The first part of the investigation was carried out by defining the horizontal layers of the city morphology and networks, also known as the Horizontal Investigation phase. In this phase, open and free geospatial data, found on the internet.

Next, for the Vertical Investigation to reach accurate results GIS (Geographic Information System) was used. With the software QGIS we can analyze in a precise way the catchment area by using isochrones. In this phase of the investigation, we focused our attention mainly on the Key Categories connected to Links and Transportation. The result showed patterns of pedestrian mobility and highlighted the areas of the city, which can be improved in the future.

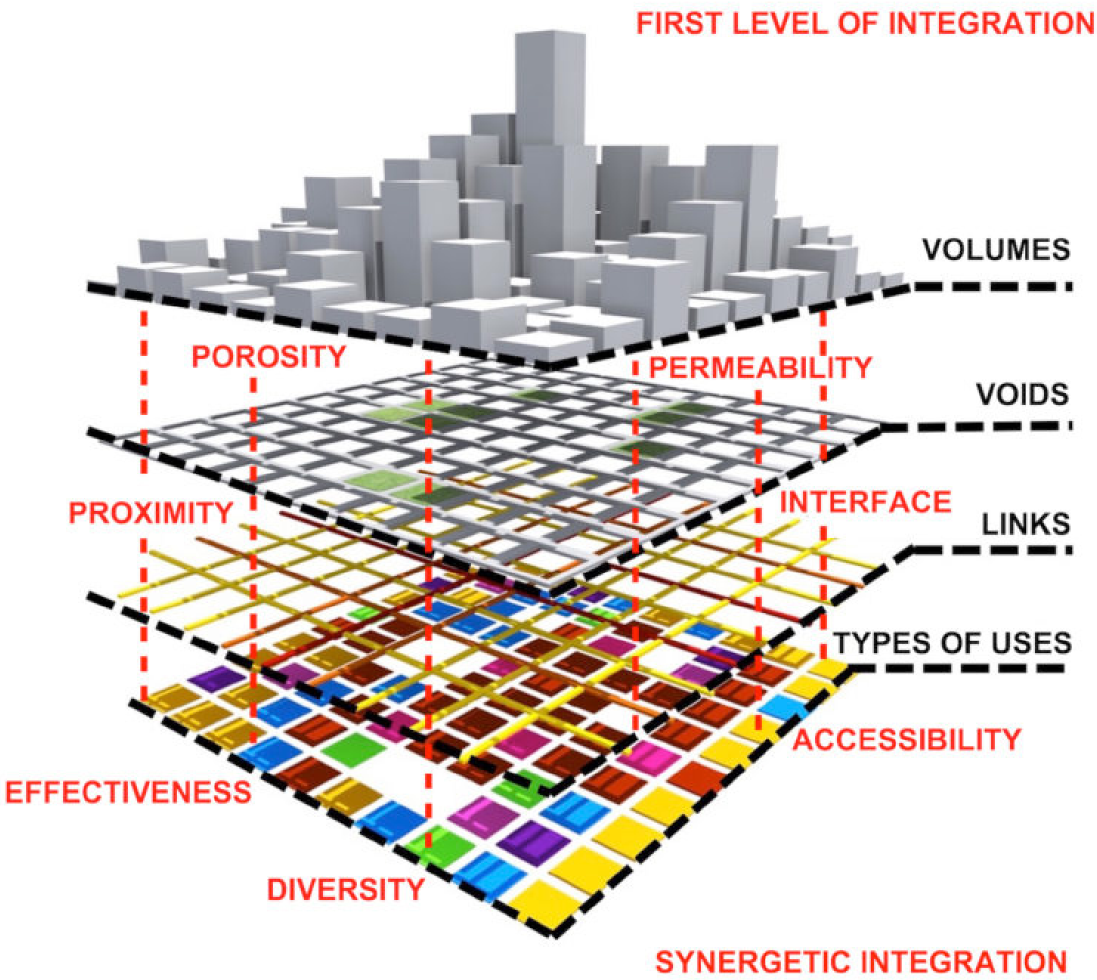


Figure.39. Key categories (source: immdesignlab.com)

| VOLUME

From the Volume analysis of the Oslo harbor area, it is visible that the building pattern towards the north is following a linear grid with a higher density than the south, east, and west parts. The area located near the sea is characterized mostly by lower density, mostly with height less than 30 meters and scattered geometry.

The port area is mainly used as part of the industrial functions of the former port, and nowadays, some of those harbor activities still exist. A large footprint characterizes the volumes in those areas with respect to their heights. There are some exceptions like one, in particular, the Silo, has a large footprint, and significant height reaching 50m

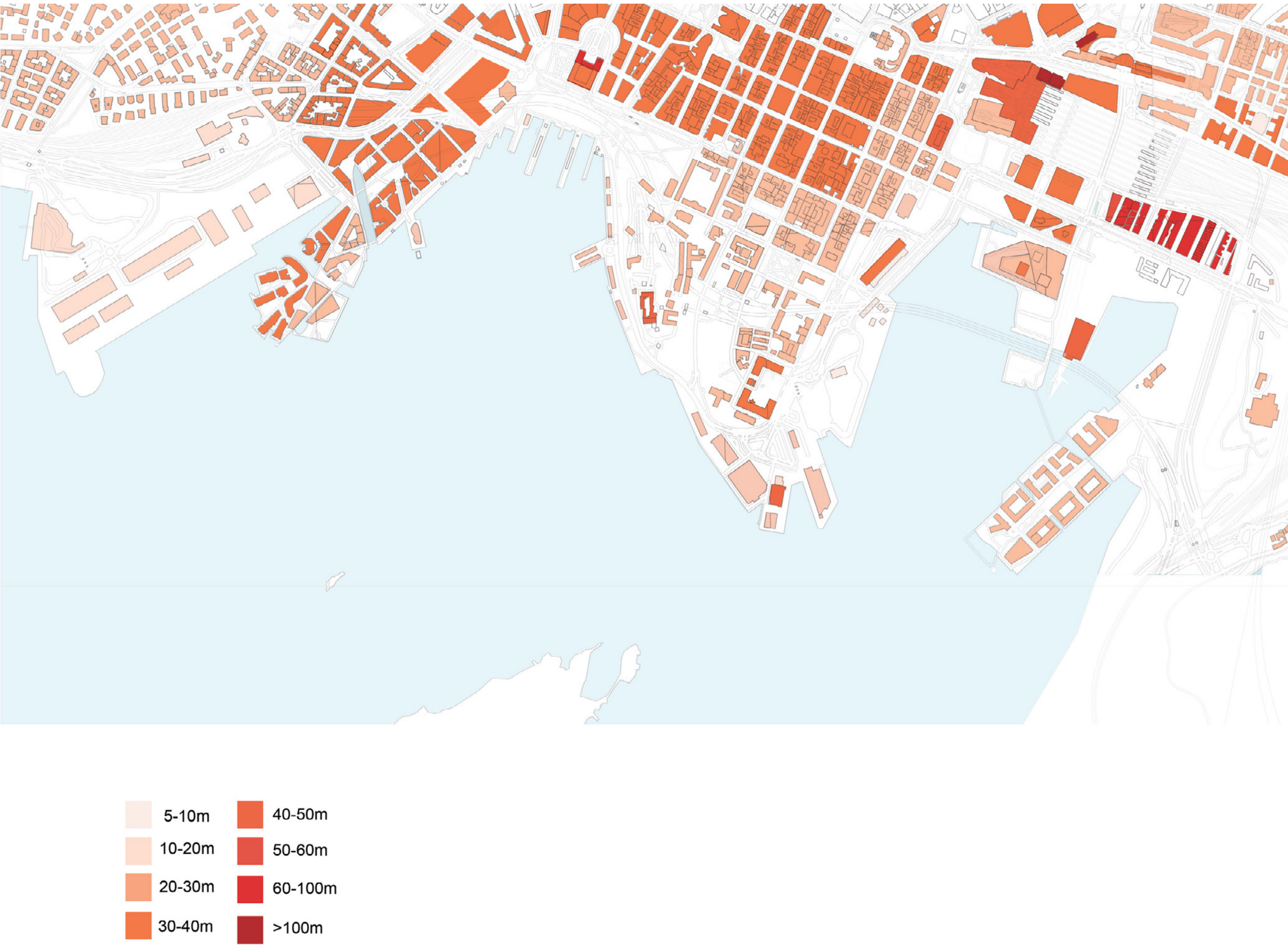


Figure.40. Volume Analysis

| VOID

From the Void analysis of the harbor area of Oslo, it is visible how the voids are distributed in the morphology of the shoreline and the city center. It can be seen that the voids are smaller in the city center compared to the area around the seashore.

Another important aspect is the steet network. Along the sea there are highways and underground tunnels. Major part of the waterfront is still under construction and another large part of it is still used for port activities.

Oslo is ahead with having green, open spaces, and these are an integral part of the city landscape. There are various parks and open spaces that are interconnected by paths. Thus the city's inhabitants can walk between them and experience multiple activities related to the areas.

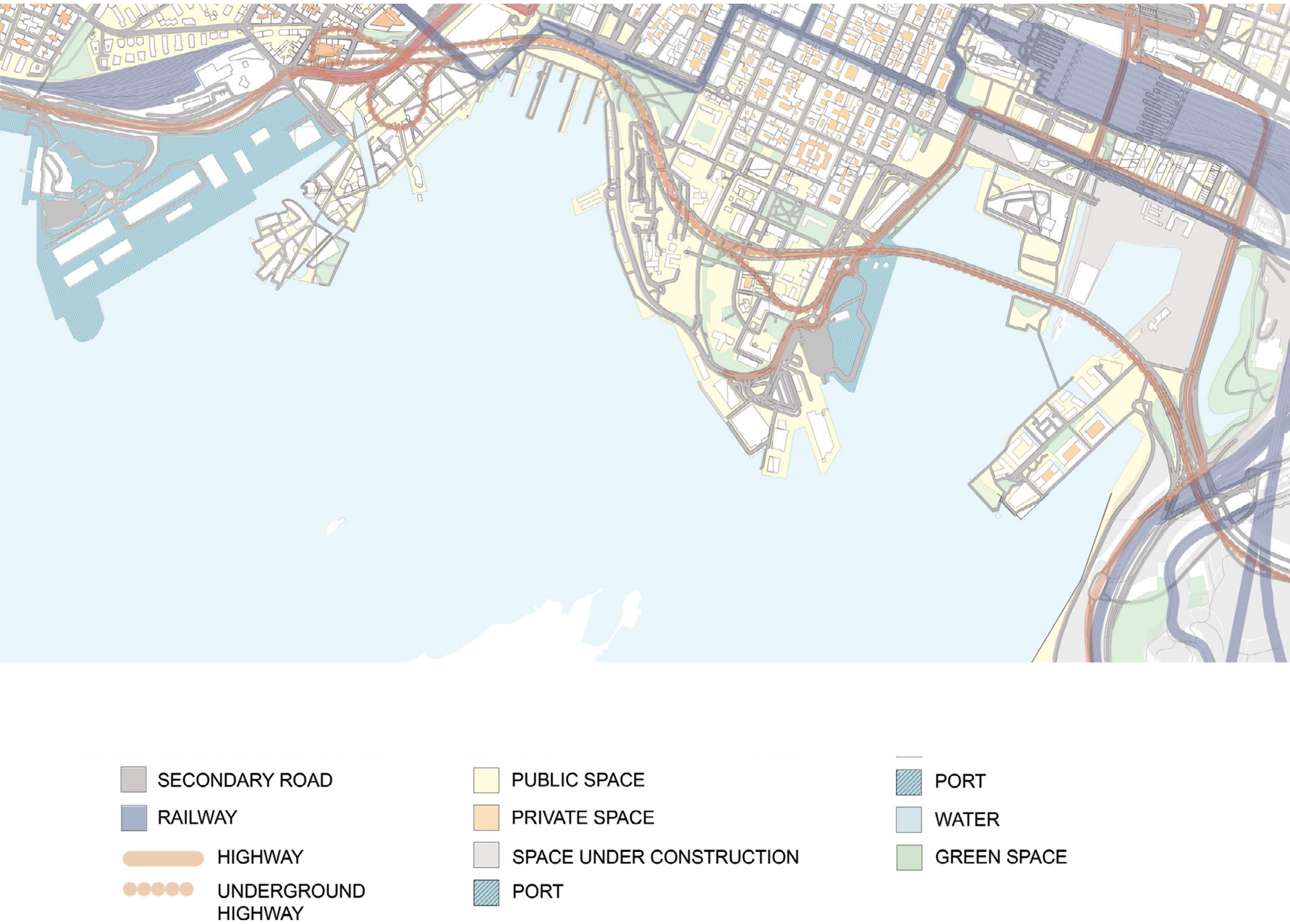


Figure.41. Void Analysis

TYPES OF USES

In the following map analysis of the types of facilities along Oslo's waterfront is performed. As it can be seen on the map, Oslo's waterfront has a variety of functions.

The city center is occupied mostly by administrative buildings like offices, courthouses, and governmental facilities. There are many of the public buildings as museums, galleries, libraries, and historical buildings. In the city center are some large shopping centers located. Also, some residential buildings are located , but their presence is more significant in the periphery of the studied area.

One of the area's part of the new harbor development in Sørenga district has mostly new residential buildings. The developments around the harbor promenade include new Cultural zones in Bjørvika as the Opera house and the new Munch Museum and the new Deichman main library. In this zone next to Oslo Central Station, there are mostly new multi-purpose high-rise buildings present.

Another important section of the promenade is Aker Brygge and Tjuvholmen zones. The area is characterized by an intriguing architectural diversity and unique outdoor areas. It plays host to several galleries and art installations, including the Astrup Fearnley Museum. Aker Brygge is known for its many restaurants and shops, and also some residential blocks are located there.

Vippetangen is situated at the end of the peninsular that sits between the city's two major waterfront redevelopments: Aker Brygge, Tjuvholmen and the City Hall, and the Bjørvika. Most importantly, Vippetangen is located directly south of the iconic Akershus fortress. In Vippetangen, the buildings of the Port Authority and the Ferry and Cruise Terminal are located. In this area, there some of the former industrial facilities of the Port – the Silo and the Fishmarket.

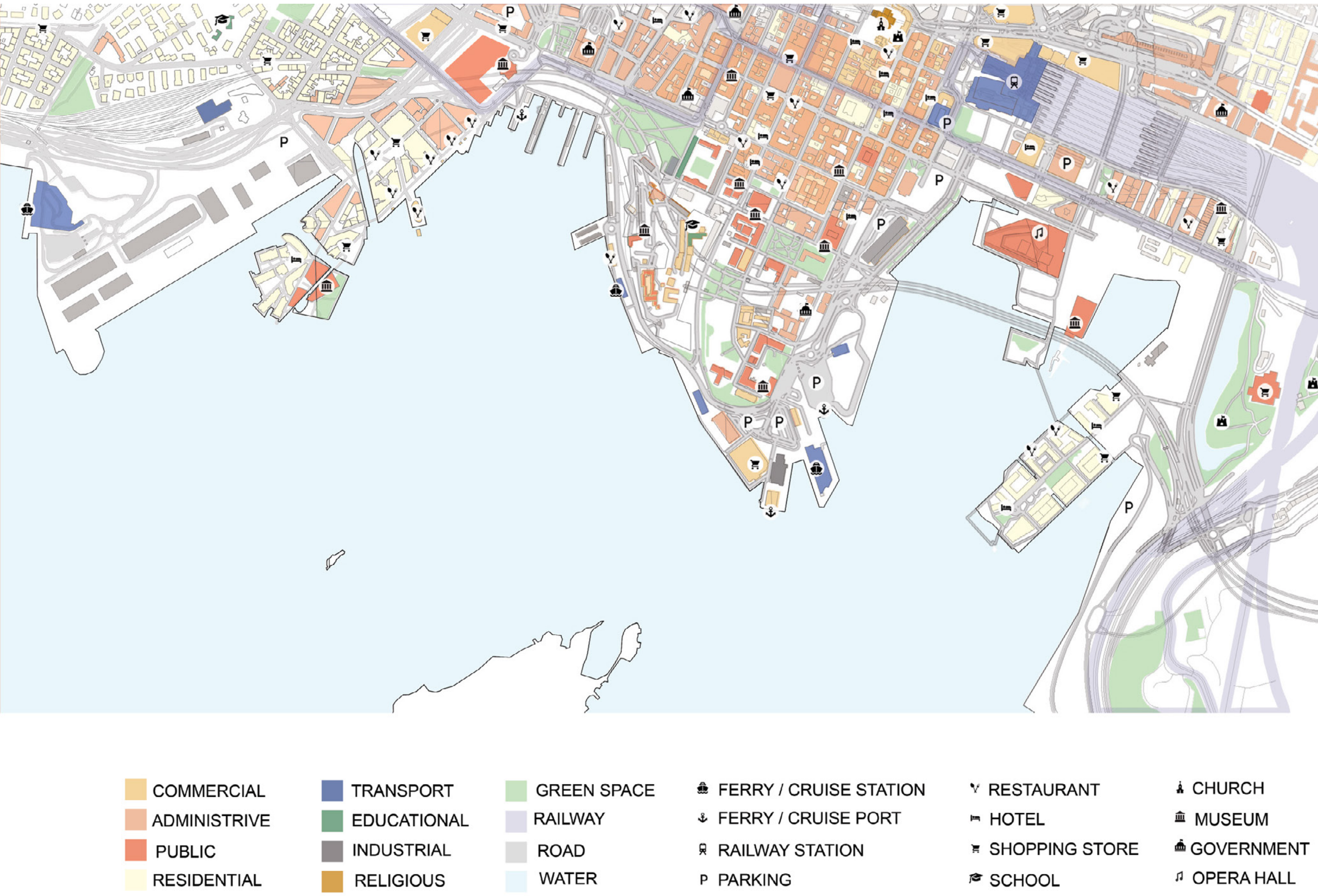


Figure.42. Types of uses

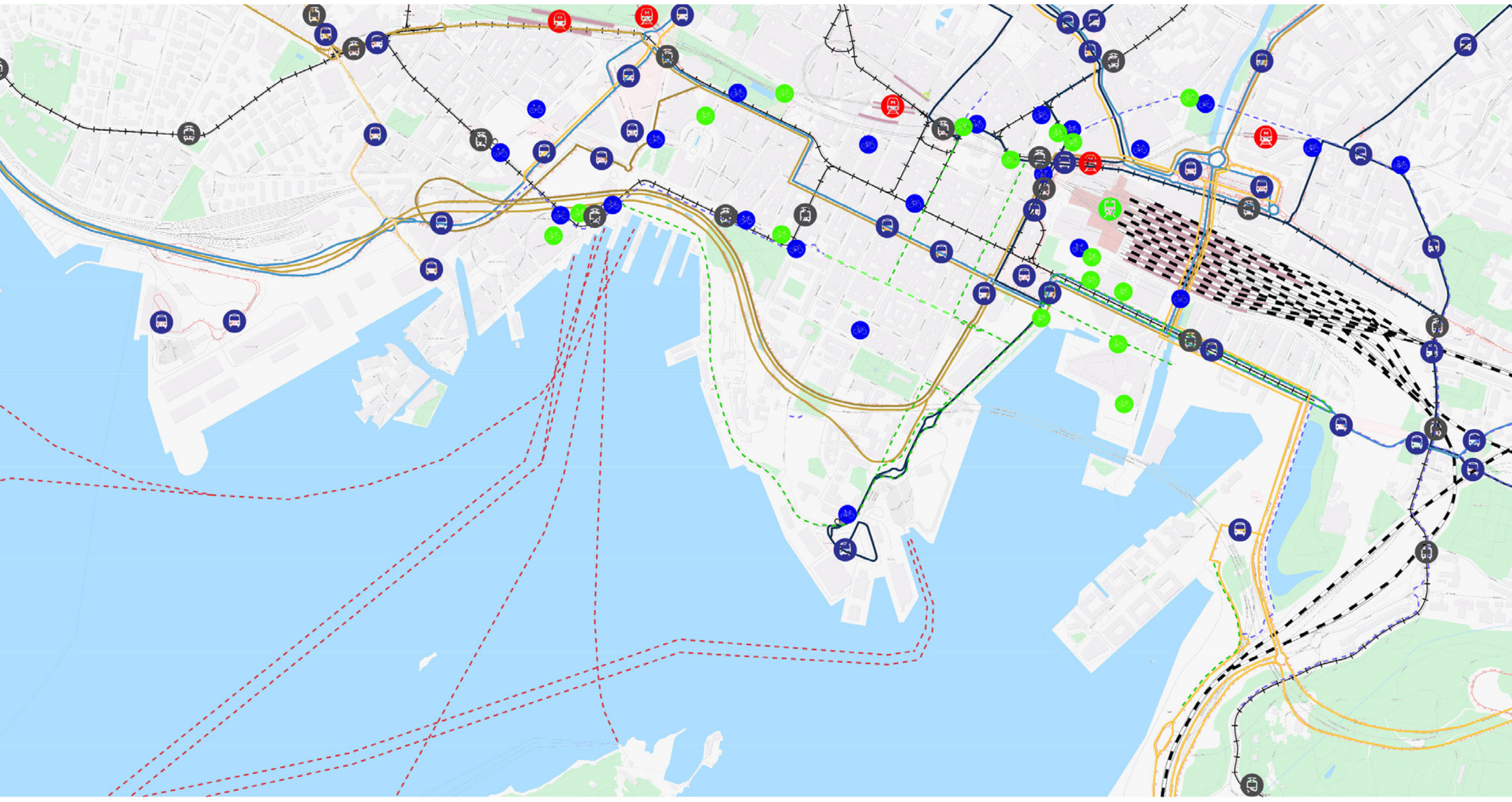
| LINKS

The public transportation in Oslo offers many modes of transportation such as metro, light rail, trams, buses, and ferries. The types of transportation are well connected and integrated into the city. The main transportation hub is the Oslo Central Train Station, where most of the transport modes can be interchanged. Moreover, the main junction of the public transport system is connected to a network of pedestrian paths.

There are 5 lines of the metro and 19 lines for the tram. The bus lines within the city are 88, and there are nighttime buses as well. On the map on the figure are shown cycling paths and bike-sharing stops because they are an essential part of the sustainable urban mobility.

Oslo has in total 1,208 cycle routes, which accounts for 362,798 km. They go through all parts of the city and make it possible to reach all the attractions. There are many city bike-sharing stops.

The city and its fjords are connected by a system of ferry routes all around the waterfront.



TRAIN STATION
METRO STATION
TRAM STOP
BUS STOP
BICYCLE PARKING
BICYCLE SHARING

TRAIN RAIL
METRO RAIL
TRAM RAIL
BUS LINE
CYCLING DIRECT PATH
CYCLING INDIRECT PATH

60, 54, 37, 36E, 18N, 12N, 11N
32, 32N, 33, 70, 71A, 160
80E, 81, 81N, 83
30, 30N, 31, 31E
85, 100, 110N, 300, 500, 500N, 505
21

Figure.43. Links

| PROXIMITY

In the following map, the walking behavior of pedestrians is studied. In the analysis, both 5 and 10-minute walk thresholds are applied.

The analysis considers the morphological specifics of the studied area. As mentioned before, the GIS (Geographic Information System)was used, and the catchment areas are determined using isochrones. From the analysis, it is visible that the proximity in the areas around the city center is in the zone of 5 minutes, and this means that the site is well planned and easy to access. In contrast, the situation around the waterfront is different. There is a clear miss connection in particular between Akershus fortress and the Cruise Port in the Vippetangen area. Although relationships exist, there are too far apart, and that disconnection makes it harder to have easy access.

BUILDINGS

400m- 5 min

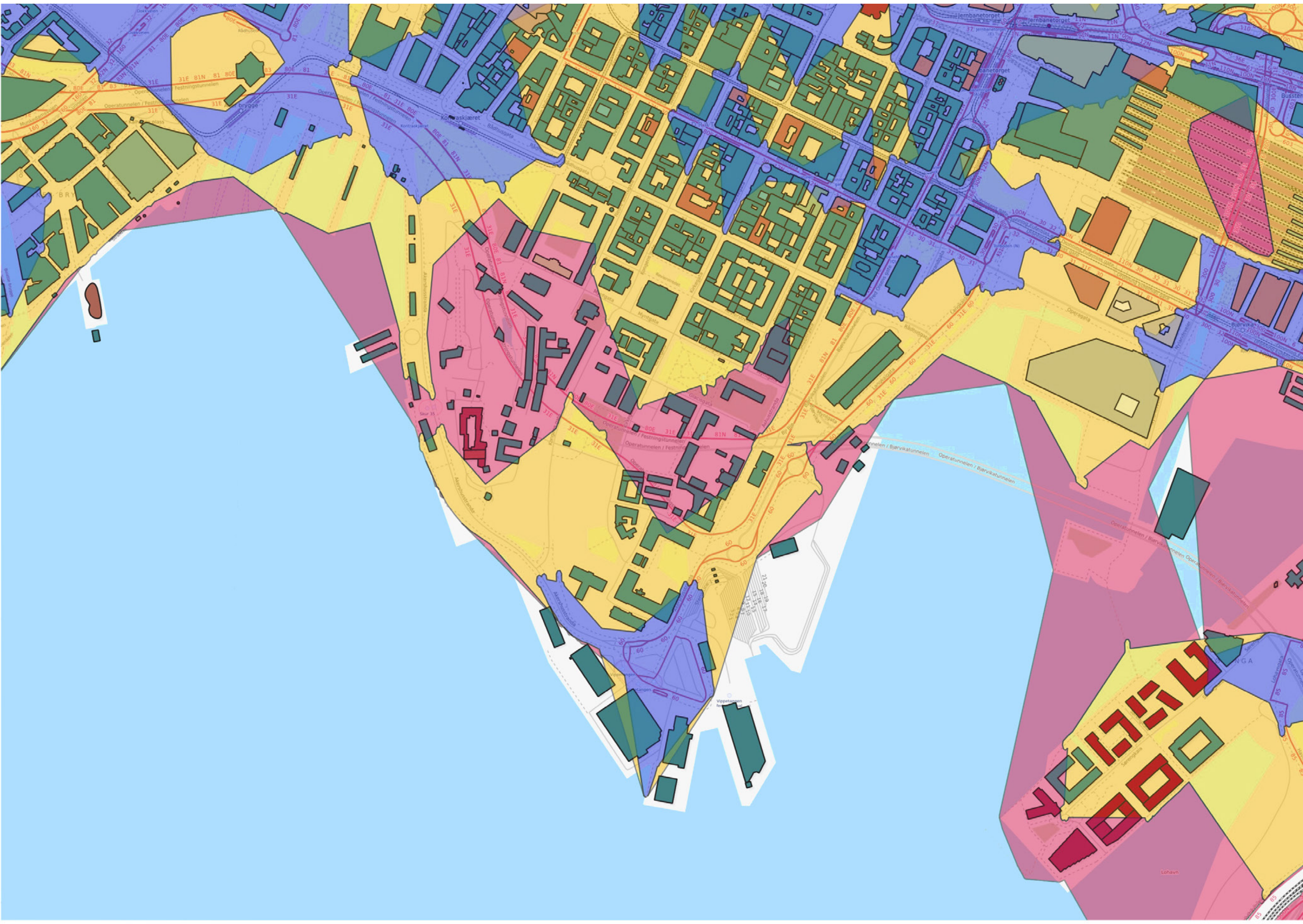
800m - 10 min

Figure.44. Proximity

| ACCESSIBILITY

In the current map, the Accessibility Analysis is shown. Again, we considered the analysis for both 5, 10 and 20-minute walk thresholds.

The accessibility analysis makes more evident the observations made for the horizontal layers of transportation and functions. The result shows that the city center is well connected by public transportation. The stops stay in a comfortable range between 5 and 10 minutes. For the lower part of the city center extending to the waterfront, the situation is different. There are only a few bus stops, and they are further apart. In particular, the stop next to the ferry terminal which is operated by one line. The results show that the existing network is not sufficient enough to create a continuous connection between the east and west side of the waterfront.



400 m - 5min

800 m - 10min

1600 m - 20 min

Figure.45. Accessibility

| EFFECTIVENESS

For the effectiveness analysis, we considered how the transportation network is integrated and how well it serves the different parts of the city. The quality of this service is expressed by the scale of the map – from high to low integration. One the one hand, it can be noticed that most of the city has high integration of public transport mobility, incredibly close to prominent locations in the city center. On the other hand, some parts of the waterfront lack enough integration. This issue is visible around the historical site Akershus Fortress. It is a result of the need for the road network to go underground, and the distance between stops is more considerable.

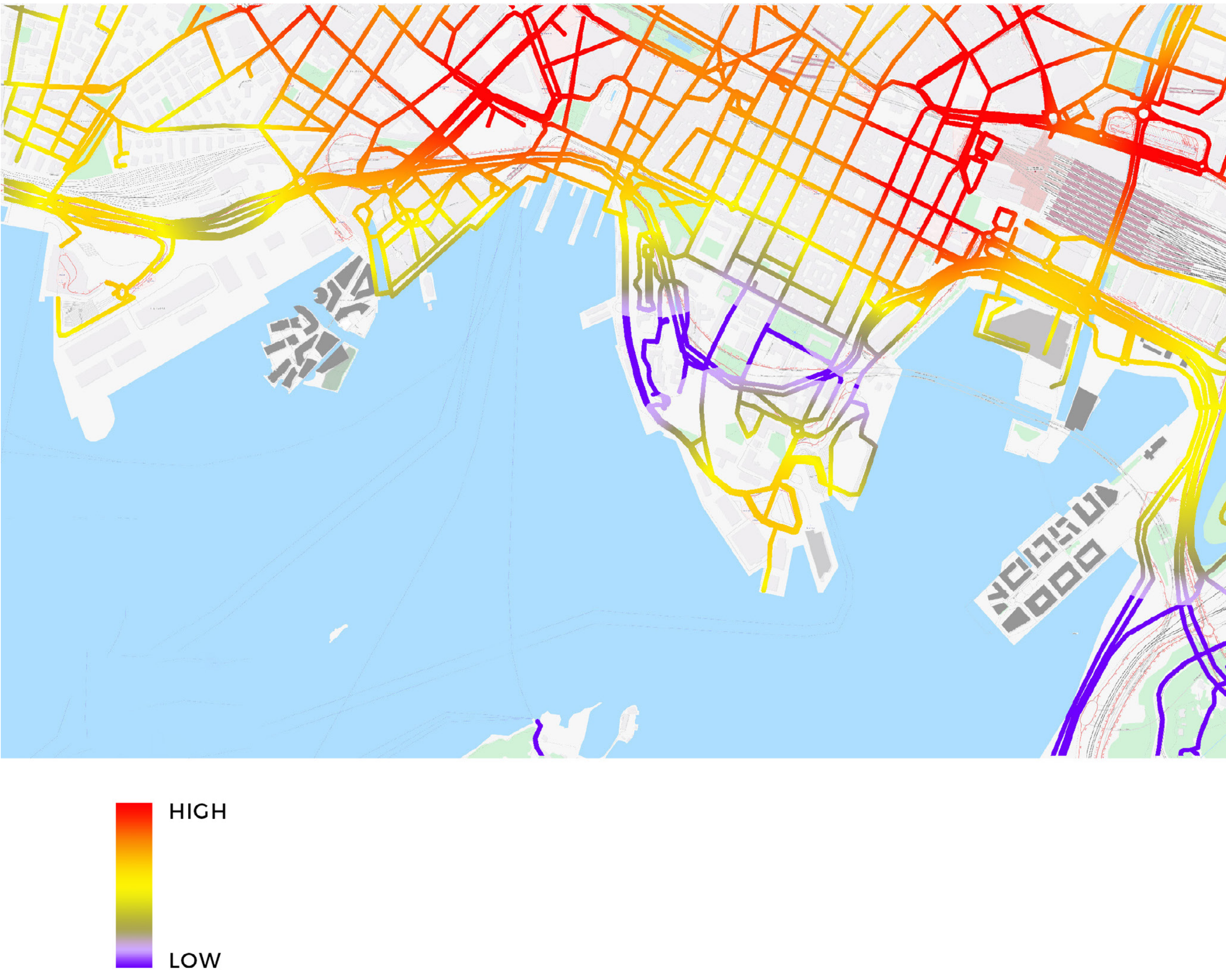


Figure.46. Effectiveness

STRENGHTS

– Closeness to historical and newly built landmarks.
- Close to the city center and the railway station.
– Strong identity and cultural transition gate due to the harbor.
– waterfront access.
– Existence of bicycle path.

S

O

OPPORTUNITIES

– proximity to main city landmarks.
– Strategic position between the harbor and the city.
– Existence of the historical silo.
– Existence of potential transformation spaces.

Figure.47. SWOT Analysis

WEAKNESSES

- Lack of public transportation modes.
- Lack of green and public spaces.
- Poor public urban furniture along the waterfront.
- Lack of pedestrian mobility inferastructure.

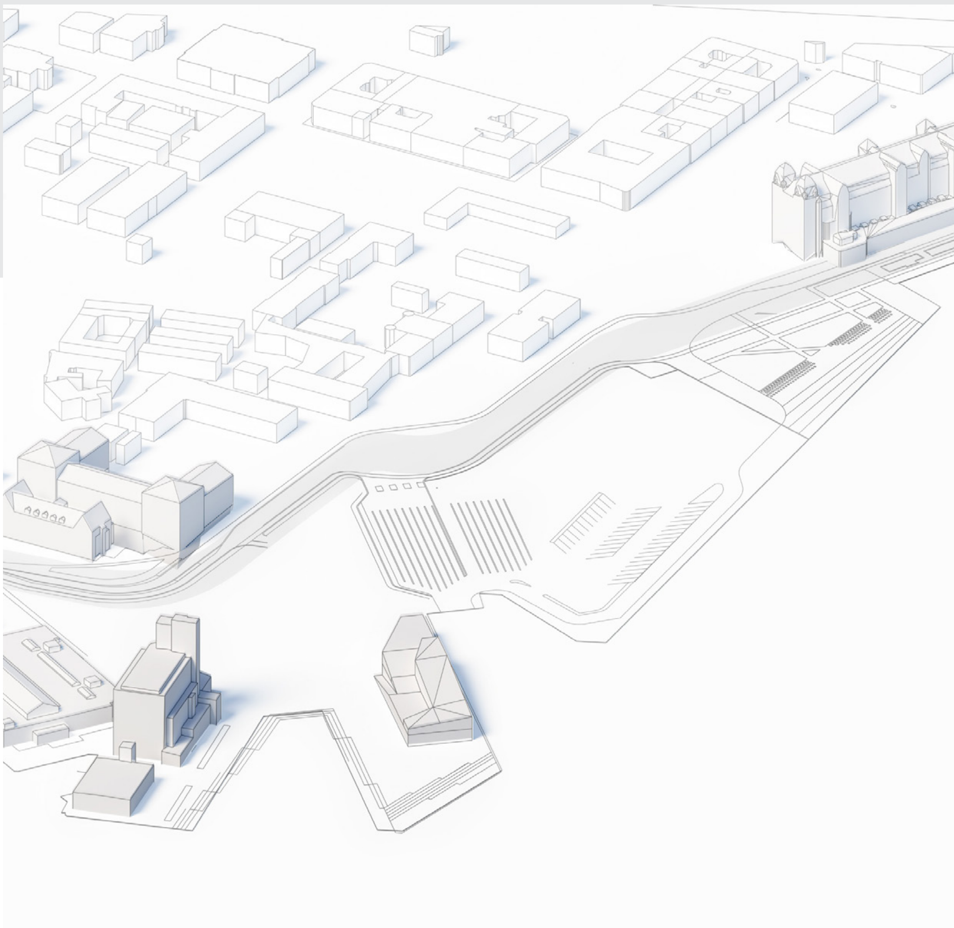
W

T

THREATS

- Noise pollution from marine and road traffic
- Air pollutant emissions from cruise ships

3



URBAN DESIGN

1. Introduction

The urban planning of the Oslo harbor promenade has been ongoing for many years. In 2000 Oslo City Council chose to adopt the so-called “Fjord City Decision.” It was a decision that meant that former port areas would be released for urban revitalization.

The city of Oslo defined strategic plans for 2030 to redevelop the harbor promenade. The points of departure for the development have been laid out by the municipality and knowledge was generated to build the next-generation sustainable urban districts. There are cities like Oslo which have already achieved a high level of sustainability. In 2009 the city received the prestigious title of European Green Capital and declared its reputation as an excellent location for sustainable living.

Oslo has been working towards the ambitious goals of its 2020-2030 strategies. New initiatives were launched to achieve even greener tomorrow. One of the significant subjects of the sustainable design is eliminating the emissions from the public mobility systems.

Public transport is steadily going green, and already, most public transport journeys are powered by renewable energy. The target is for all public transport to run on renewable energy by 2020 (such as biogas produced from household food waste) and to be emission-free by 2028.

Oslo established its first Metro line in 1966, and today, its Metro is one of the largest in Europe. New investment and expansion are planned, including a new line to the Fornebu peninsula in Bærum. A new fleet of modern trams is planned for 2020-21 too. They will be more spacious and accessible than much of Oslo’s older stock, with step-on at street level.

Oslo Port is taking the lead in developing emission-free solutions, aiming to reduce its emissions by 85% by 2030 and become emission-free by 2050.

Today, Oslo is a modern, busy capital, yet more than two-thirds of the municipality’s acreage is protected forest, waterways, and agricultural land. This means 95% of inhabitants have a park or open green space within 300 meters of their homes, many of them linked by convenient paths.

1.1. Fjord city plan guidelines

Adopted by the Oslo City Council 27.02.2008, provides policy and planning guidelines for further planning work both for the Fjord City in general and for Vippetangen in particular.

Objectives

- City and fjord should interact with each other.

- There should be provided public access to the area.

- The land used for port activities to be reduced.

- The unique character and the historical buildings should be preserved.

- Balance between port functions and new functions.

New types of uses and facilities

- Vippetangen to be a cultural-based destination that strengthens the contribution of Akerhus castle and the historical heritage.

- New area for parking access for the ferry terminal.

- New cycling paths, pedestrian connections and mobility systems.

1.2. The urban design of Vippetangen

A walk through Oslo's waterfront and its variety of experiences and historical sites, and the unique character of the fjords were the drive that motivated the new urban transformation in Vippetangen. The purpose of the urban design was through thoughtful, comprehensive solutions to lay the foundations of inclusive urban lifestyle, the participation of the community, and the tourist in large cultural events, leisure, and recreational activities near the sea.

In Oslo city's waterfront, nature is part of the urban environment. The visual contact with the fjord landscape is an essential element of the urban setting of Vippetangen. Another vital element is the historical and cultural character of the area. By integrating those aspects, the name of the Vison for the transformation was defined as Cultural Lighthouse. The name has a symbolic meaning because the name of the area Vippetangen derives from two Norwegian words - vippe that means a simple form of a lighthouse, and the second word, tangen, means "the headland".

For the design of the future Vippetangen district, it was essential to understand all the sustainability targets and the urban design principles inside the city council documents. That guided the decisions about the goals that were defined. The goals and strategies served as guidelines and as a catalyst for change. The application of the strategies was made by considering two central core values - the people and the city.

The first goal considered that the revitalization could invite the local community and the visitors of the city to experience a variety of activities and public spaces and explore the natural landscape of the fjords. This goal underlined the main strategies of utilizing the waterfront by activating it and introducing attractive indoor and outdoor activities and public spaces open to everyone. Existing buildings and environments would be given a new life by acquiring new functions while their historical value will be preserved. They will become part of a new context, including new additional members.

The access to water and redesigning the waterline would provide people with opportunities to experience the sea and the landscape.

The role of the port will be taken as a gate to the city, and the urban environment will be enhanced by bringing it as close as possible to the port. The flow of people generated by the terminal will be used to promote tourism around the site.

The second goal considered the spatial experience and the physical connections of the waterfront. It meant implementing efficient and accessible networks, short cycling, and pedestrian routes. Some of the industrial character barriers would be minimized, and in result, natural connections to the surrounding districts will be improved.

In conclusion, all of these actions will provide robust and interconnected urban system that utilize the flow of people and give access to the waterfront and create a vibrant urban environment.

VISION: CULTURAL LIGHTHOUSE

GOALS	STRATEGIES
1 BOOST COMMUNITY INTERACTION	1.1. Preserve the identity of the port area 1.2. Introduce new attractive activities and public spaces 1.3. Activate the waterfront 1.4. Utilize the flow of people generated by the port
2 ENHANCE THE SPATIAL EXPERIENCE	2.1. Promote public transportation 2.2. Prioritize bicyclists and pedestrians 2.3. Introduce a robust and interconnected urban structure

Figure.48. Vision, goals, strategies and actions

ACTIONS

– Use the Port operations and industial heritage in the design of the area.
– Preserve and reuse the historical buildings and host new exiting activities inside.
– Create new activities that attract variety of visitors.

– Create new green and recreational spaces.

– Redesign the waterline and create highquality water space.

– Improve proximity to the water.
– Invite tourism and provide services adjacent to the ferry terminal.

– Extend the tram line along Vippetangen waterfront area.

– Create easy connestions and short routes for cyclist and pedestrian.
– Develop a wide bicycle lanes and pedestrian friendly street spaces.

– Develop natural connections to surrounding urban districts.
– Create conditions for versitile use of public spaces.
– Plan for good access to parks and recreational activities.

1.3. Concept map

In the vision, study about the existing urban environment, and the current systems of the city was made. For this reason, a concept map was created to illustrate the conceptual strategies of the transformation process. Analyzing the current urban planning guidelines gave a critical knowledge. First, were considered the urban planning strategies for the revitalization process of the port areas along the harbor promenade. The essential part of the urban planning instructions gave us the restricted zones and sites which will continue to function as a cruise terminal and harbor port.

Additionally, the urban planning instructions from the municipality guided the decision of the mobility system for the public transportation to be a new tram line along the waterfront. Following this, the decision to improve the existing system for cycling and create a separate space for bicycles was taken. All of that meant promoting pedestrian mobility close to the sea.

Next, in the concept map, the cultural path was drawn, and it was considered as an essential pedestrian link in the city. It creates access to various cultural landmarks by promoting pedestrian paths and limiting car access. This connection gave continuity to the existing facilities into an integrated experience of cultural and historical value.

1.4. Masterplan concept

Integration of the public mobility system and green links

By introducing the tram line extension to pass by the new cultural center project, a well-connected waterfront with other parts of the city is guaranteed. In Vippetangen, the slow mobility is strongly encouraged through the creation of a new cycle-pedestrian path. Also, the implementation of green links, along the waterfront, along with the cycling and pedestrian path, creates an integrated network of green and public spaces. Bike-sharing will be included in the area of Vippetangen and connected to the existing system of the city.

According to the urban plan, car mobility will be limited through the area, and the harbor `gate will be relocated for ease of accessibility.

Utilizing the view angles and the orientation

As part of the project strategies, direct visual connections with the waterfront, Oslo opera house, and Akershus Castle are provided through different spots in the urban design and in the building taken by supporting architectural decisions. This would allow people to experience different views of the city from a multitude of locations throughout the project.

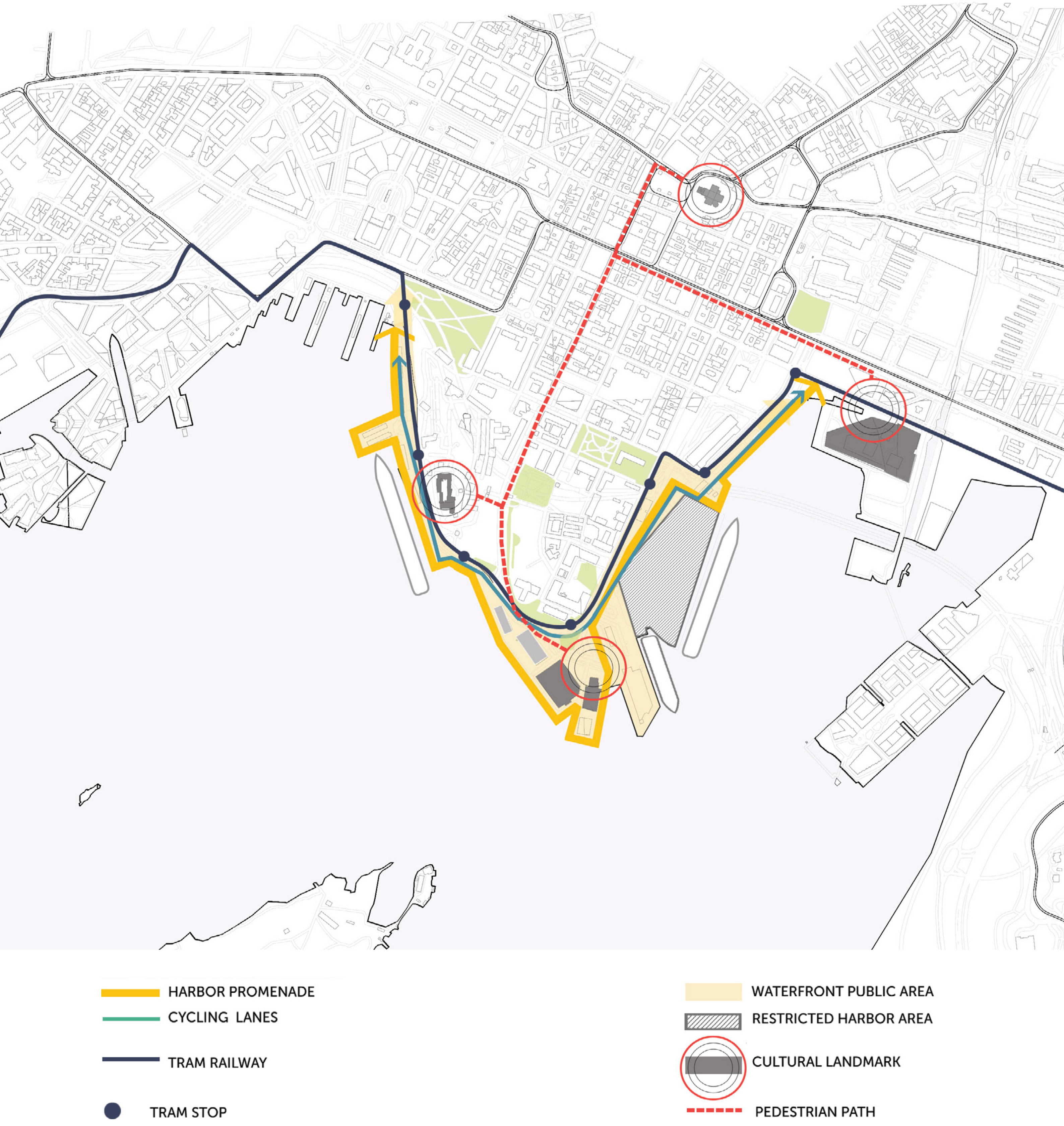


Figure.49. Concept map

1.5. Masterplan concept map

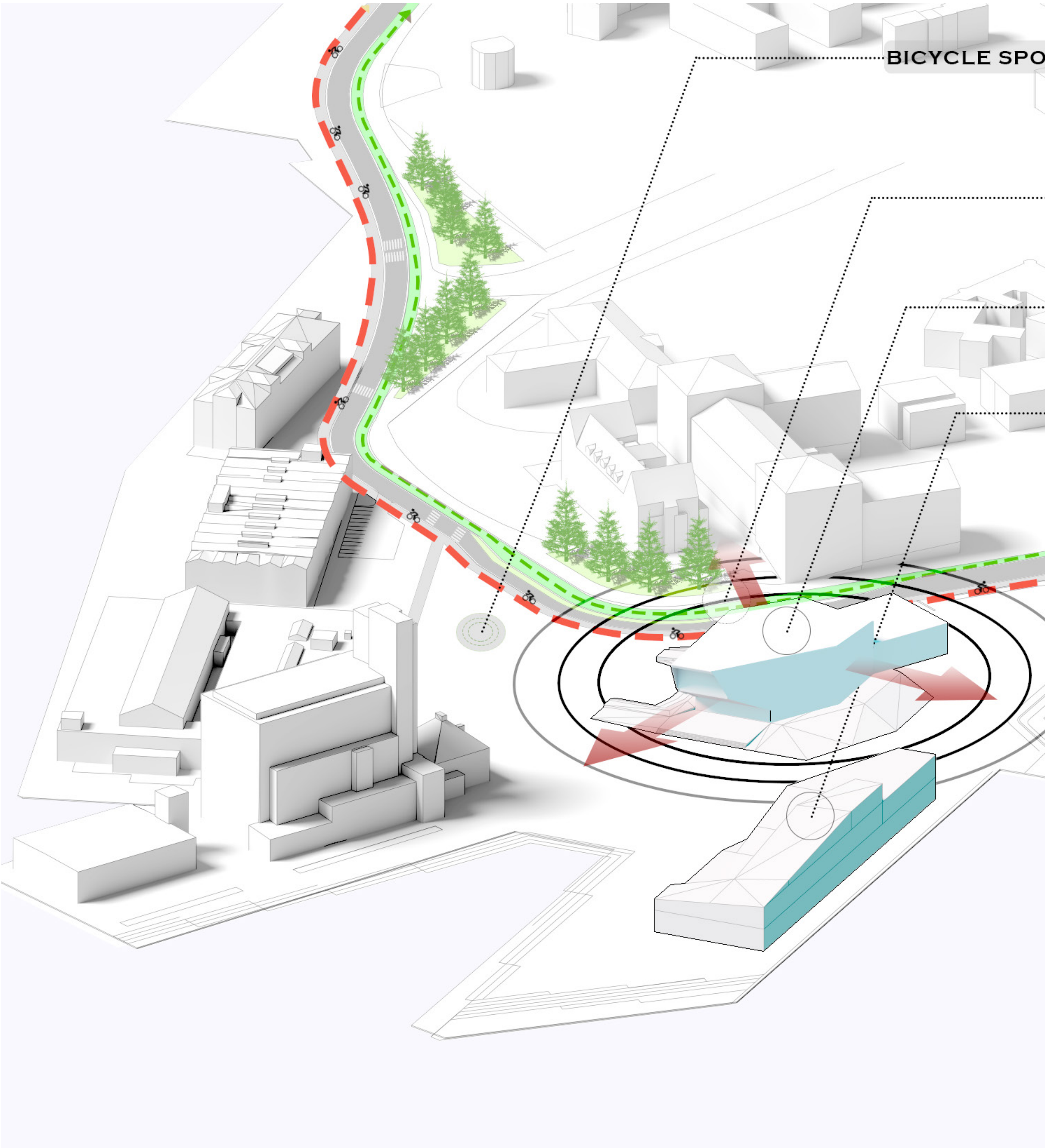


Figure.50. Masterplan concept


T
TRAM STOP
CULTURAL CENTER
NEW FERRY TERMINAL

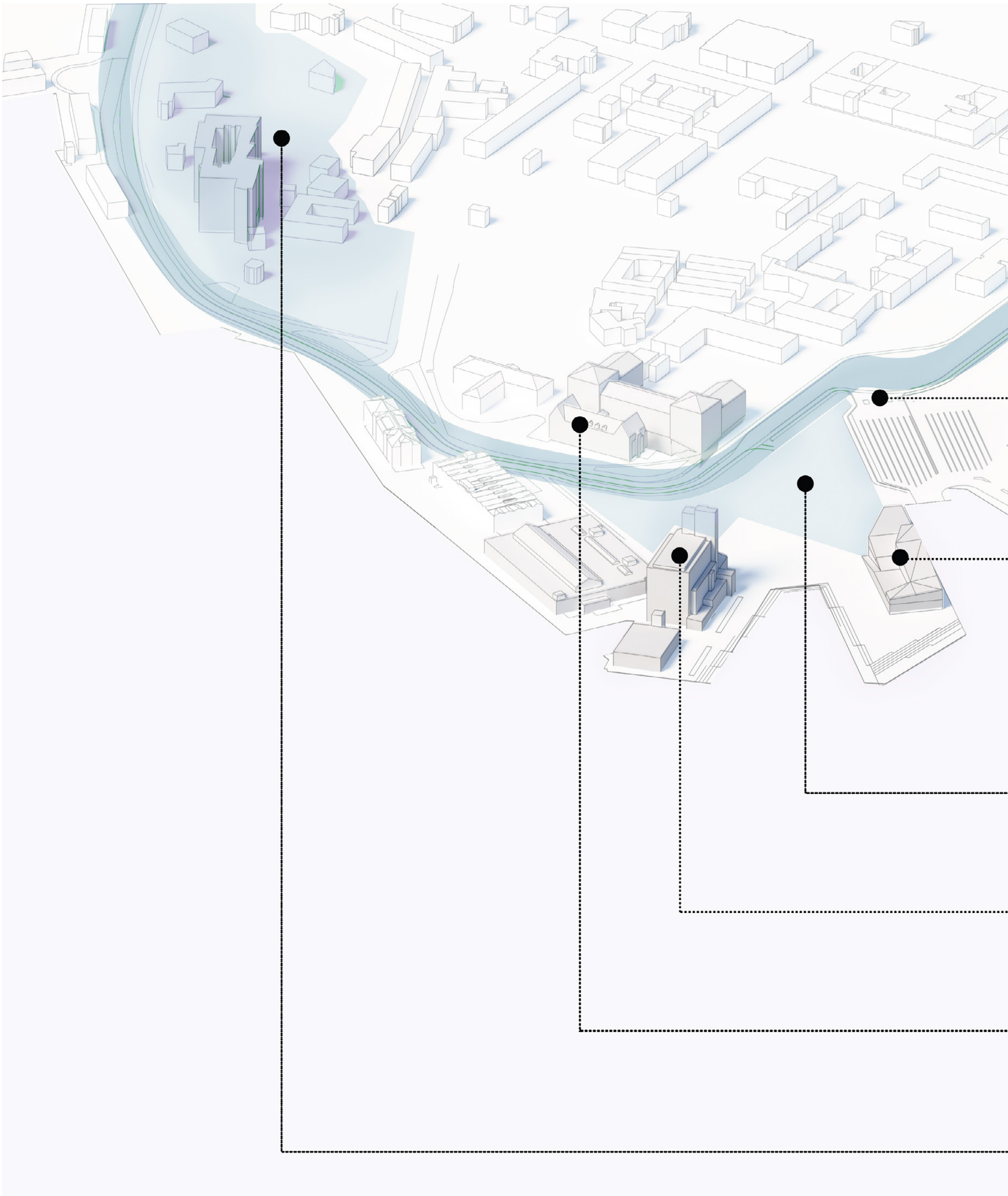
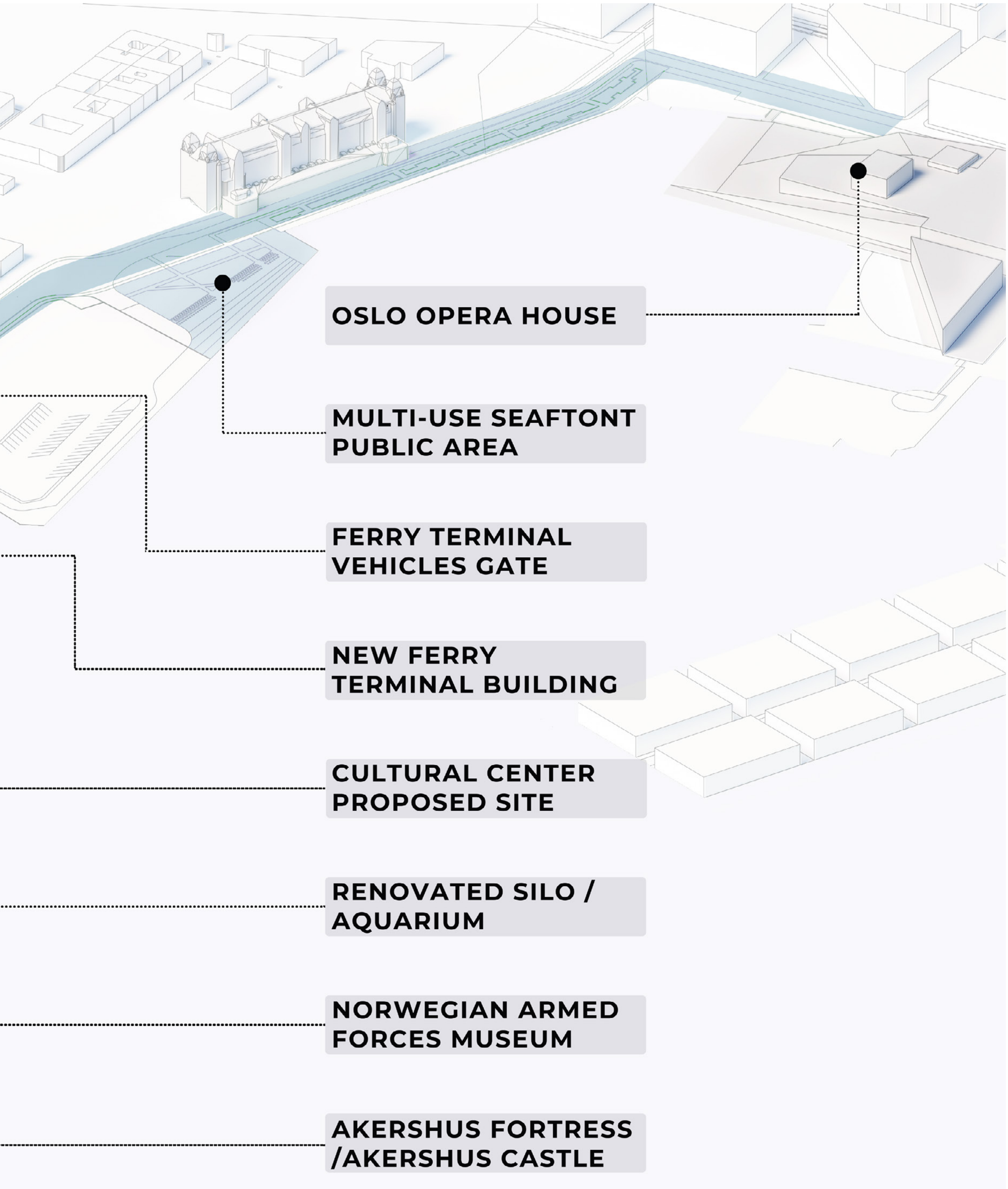


Figure.51. Functional distribution of the buildings in the masterplan


OSLO OPERA HOUSE
MULTI-USE SEAFTONT PUBLIC AREA
FERRY TERMINAL VEHICLES GATE
NEW FERRY TERMINAL BUILDING
CULTURAL CENTER PROPOSED SITE
RENOVATED SILO / AQUARIUM
NORWEGIAN ARMED FORCES MUSEUM
AKERSHUS FORTRESS /AKERSHUS CASTLE

1.6. The masterplan

The city of Oslo is transforming. The post-industrialized zones of the waterfront are given a new look and given back to the people. It is a vital opportunity for those areas to preserve their identity while becoming more green, vibrant, and sustainable.

The masterplan of the Vippetangen area is considered essential to link in the harbor promenade. It pays special attention to public spaces, streets, green spaces, and public buildings, making them inclusive to all ages and genders. By honoring historic buildings such as the Grain silo and Akershus castle while also introducing new urban elements into the development, the plan becomes the point of transition between the past and the future, defining its identity as a balance between new and old.

There were a variety of key elements to the masterplan. First, the new tramline and it was integrated into the existing road system by taking space away from the vehicle lanes. In that way, the limitation of the traffic around Vippetangen was encouraged. Next, cycling-pedestrian paths were developed to create a link to the harbor promenade.

Another critical decsion was to relocate the gate of the ferry terminal to create good access to the port without having the vehicle come inside the area. Also, next to the entrance for the ferry, a parking zone was designed on two levels on the ground and underground level, with a total of 100 parking spots. This parking would serve the public buildings in Vippetangen.

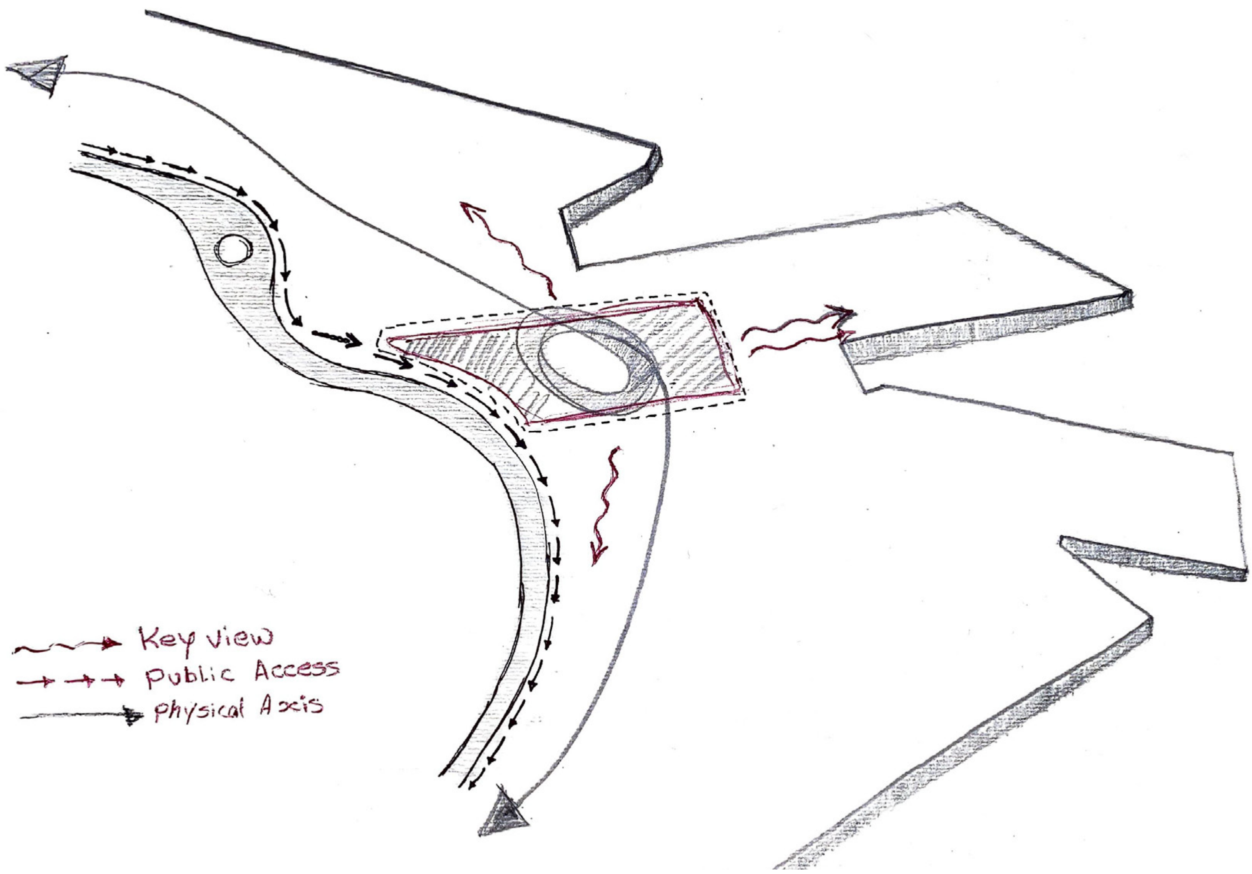


Figure.52. Masterplan development sketch

Next, there are two new buildings proposed—the building of the Cultural Center and the one for the terminal building. There is an additional building added as an information center for tourists or people who would like to receive information and about the district. The new function of the silo was chosen to be an aquarium. As a public space, the tower of the silo on the last floor was considered to be an observation platform for the city. For the other facilities in the district, like the fish market and the remaining buildings, will keep their current roles.

After this, the public spaces and green links were considered. The design involved substituting the large part of the existing asphalt pavement with new and introducing greenery to the environment. Open public spaces were created that can be adaptable to temporary shows and art. The waterline was redesigned in some areas to bring the opportunity to enjoy the sea and experience the landscape of the fjords.

A main aspect of the design of the waterfront were the recreational spaces. Therefore, a variety of new urban furniture was added and distributed in the site around the green spaces and around the shoreline. In that way, more attractive seating areas were provided. Another new additions were playgrounds, areas equipped for swimming, and sunbathing.

Another important element was the streets and implementing an energy-efficient LED-Solar powered street and sidewalk lighting and solar charging stations for mobile devices and electric bicycles. Space for bicycle and bicycle sharing was designed next to the tram stop and the cycling path.

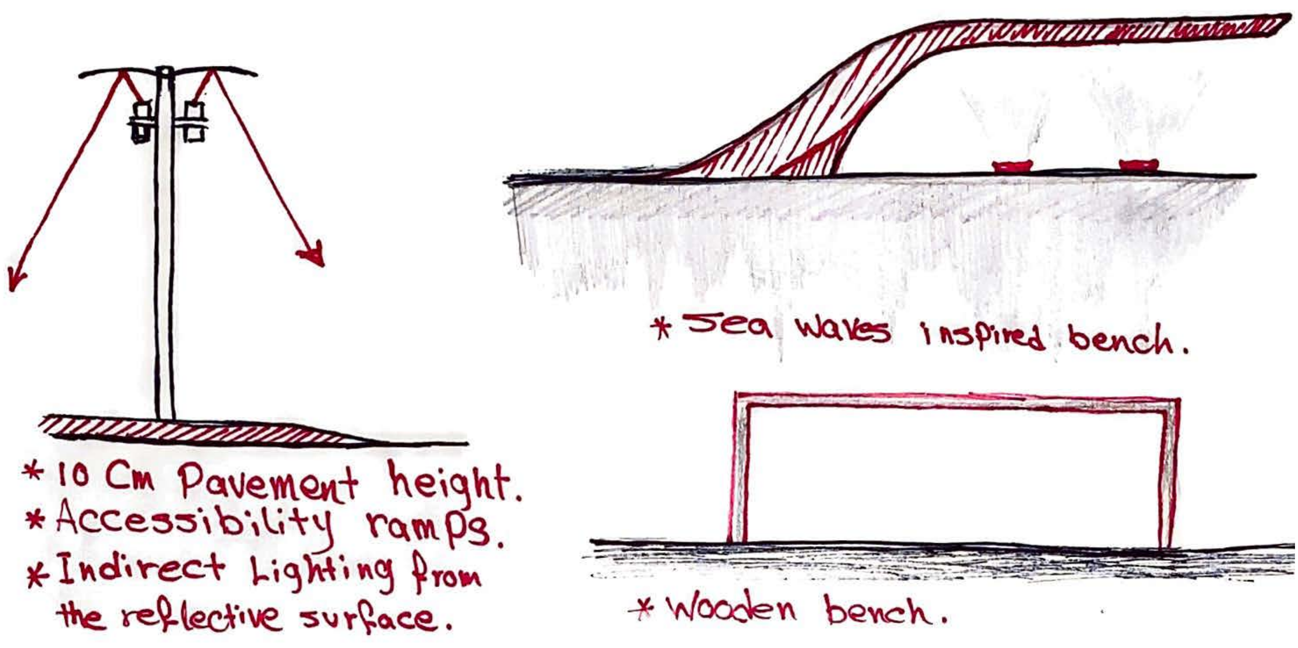


Figure.53. Sketch of the urban furniture and the street lights

In the following view, it can be seen the proposal for the new tram line with the stop location. Also, the new pavement is shown with the ramps designed to provide accessibility to the pedestrian sidewalks.

View of the street mobility system

Likewise, the pedestrian-cycling path with the solar-powered street lighting is presented. This solution of the street network serves in favor of the public and soft mobility system and gives limitations of the access of vehicles through the site.

Masterplan
1:5000

In this visualization, other essential urban design solutions are presented. The view is situated before the ferry terminal parking site in the direction of the Cultural Center. Here direct access to the sea was possible, and the space was designed with additional green areas.

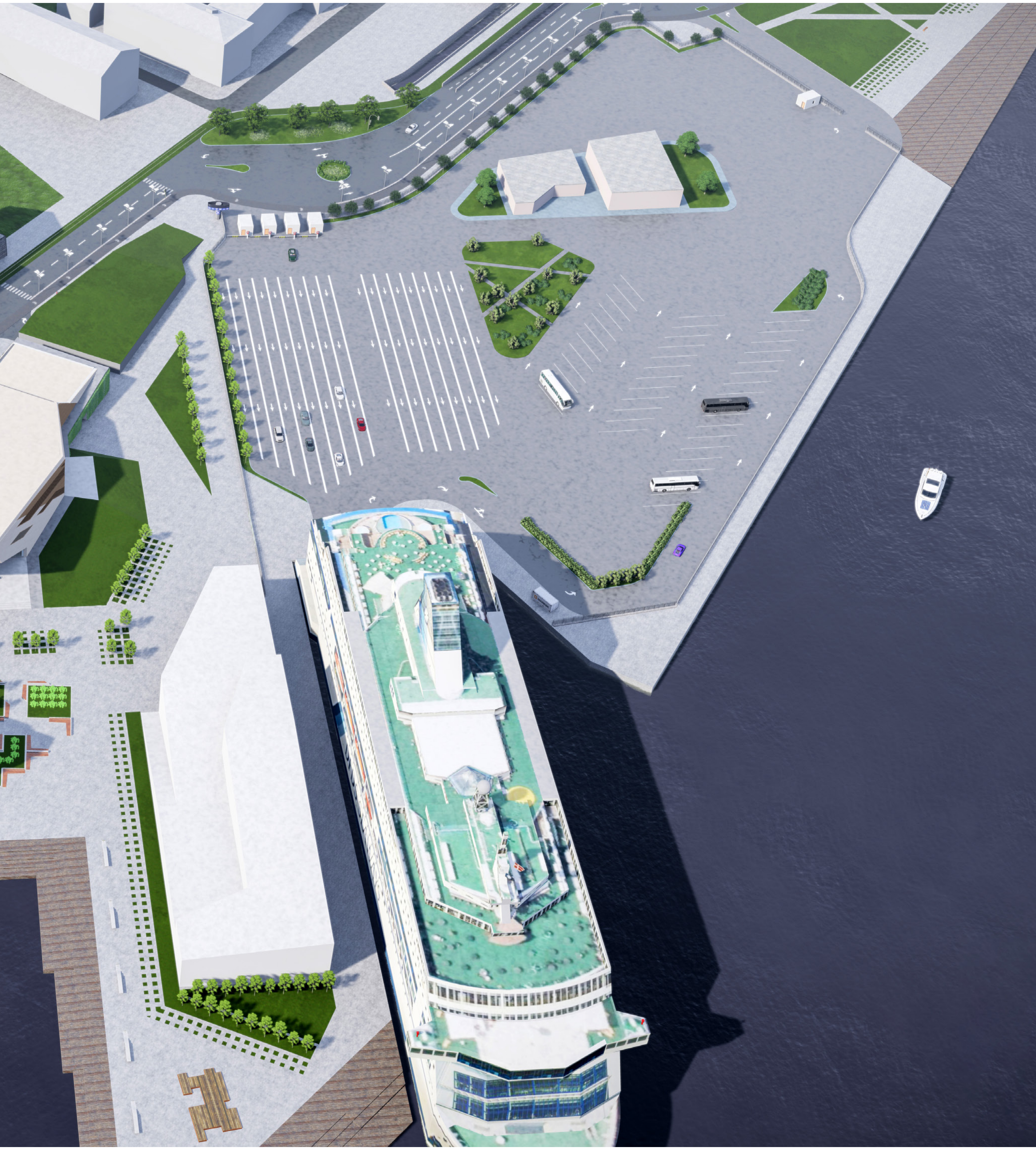
View of the direct access location to the waterfront

Also, the implementation of the public mobility connections to the train station and the Opera house is visible. Around the green spaces, urban furniture was added. The place provides playgrounds and spaces for swimming, sunbathing, and relaxation.

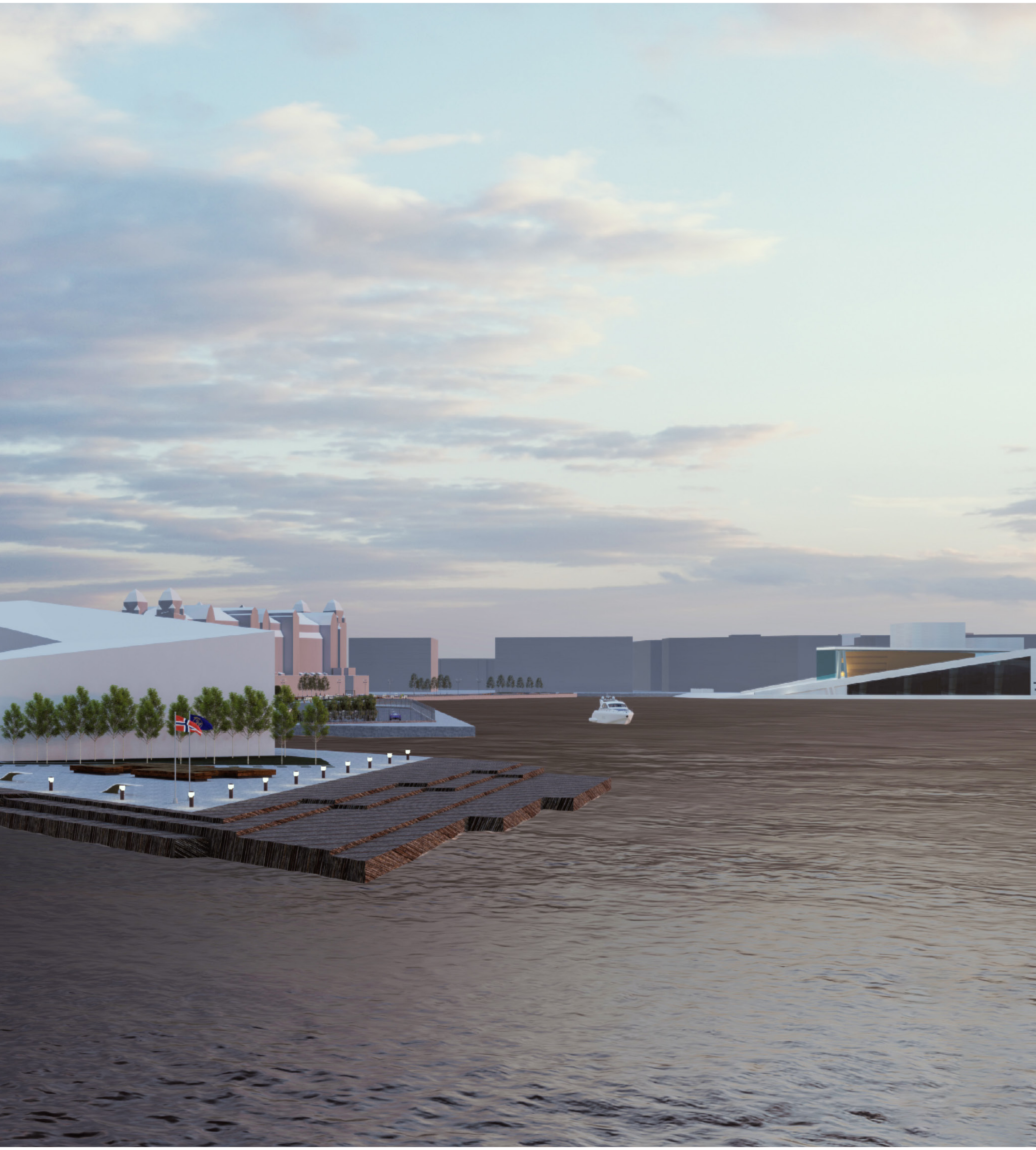
Masterplan
1:2000

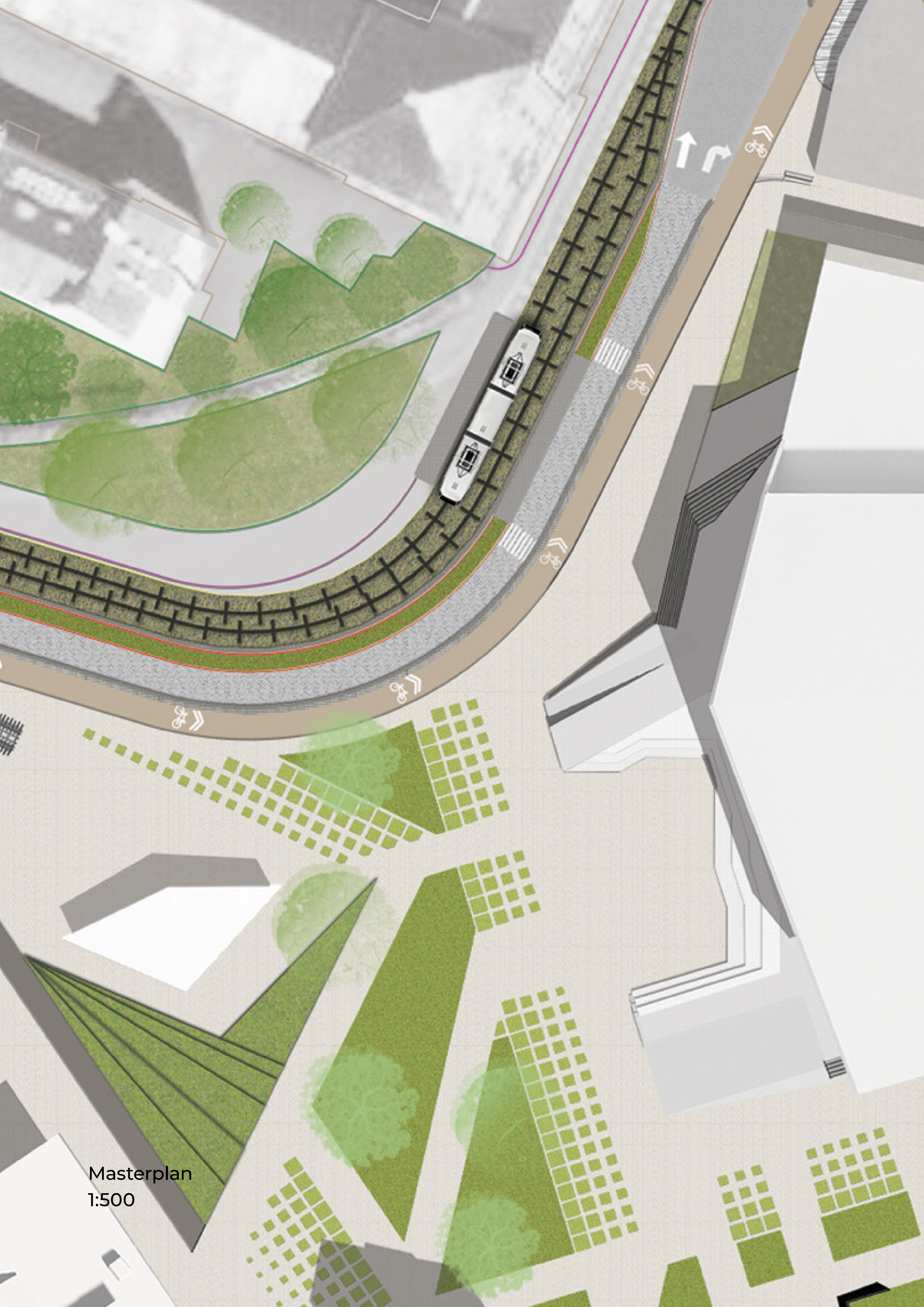
Masterplan
1:1000

Areal view of the masterplan

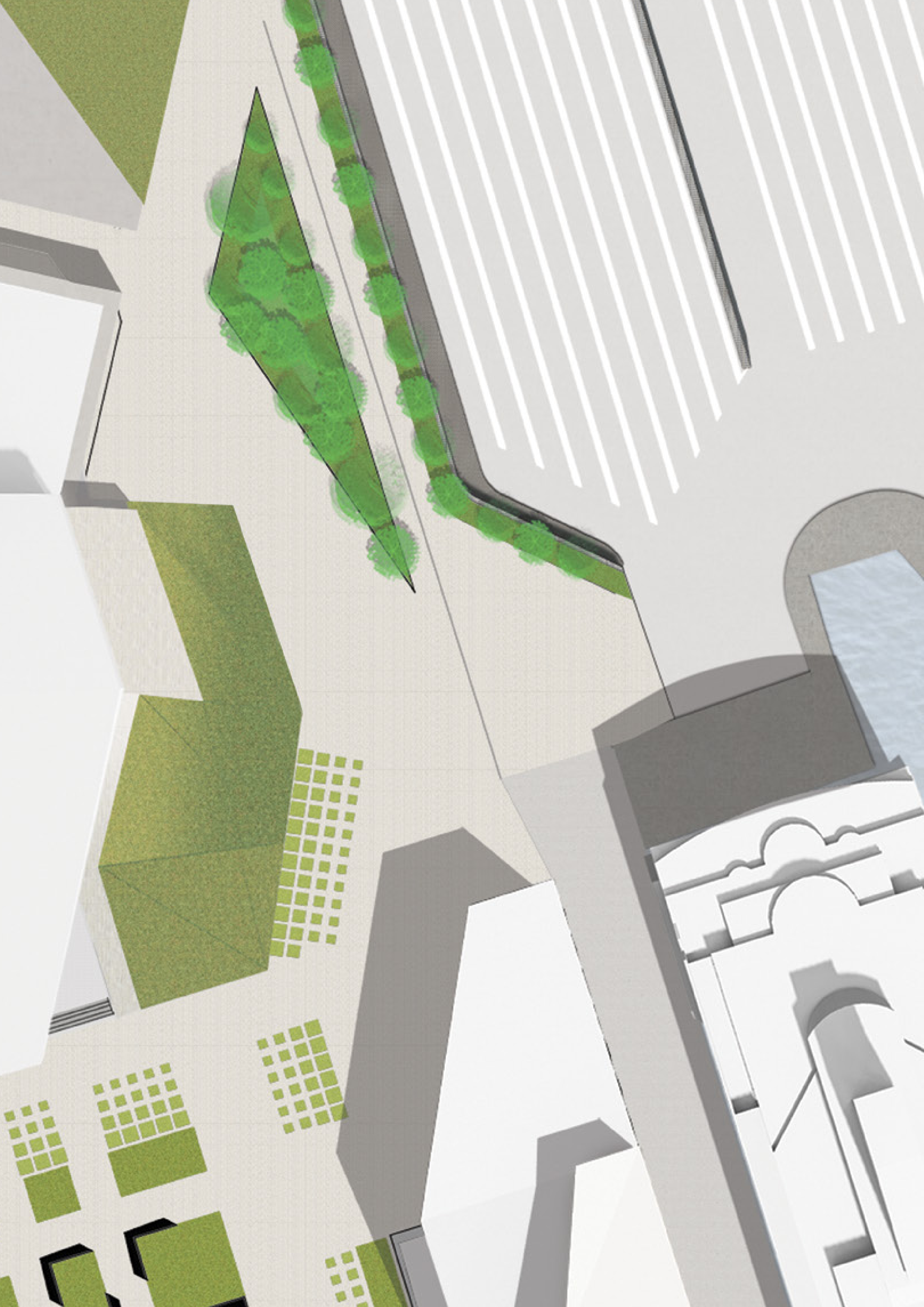


View of the waterfront and the surroundings





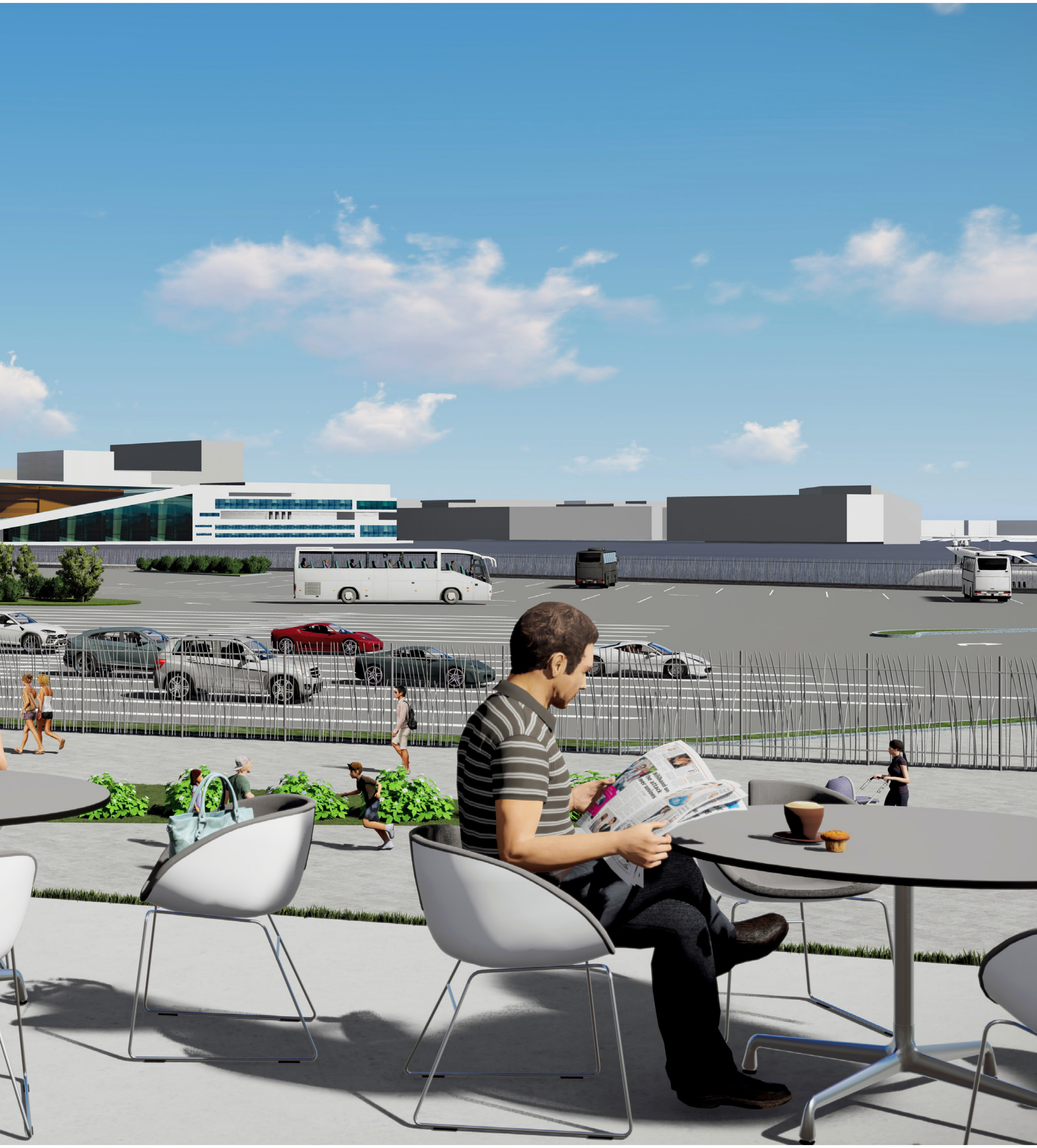
Masterplan
1:500



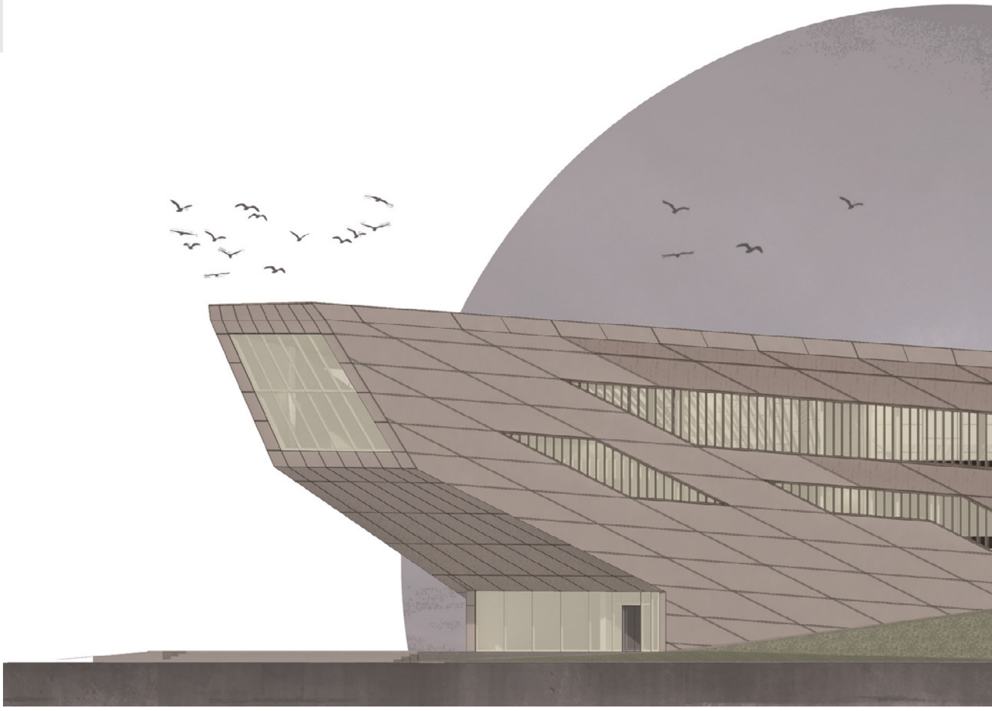
In this visualization, the view angles between the open seating area of the café and the Opera house are shown. This is another important design consideration of the project because of the transition of the city and the port.

Visualization of the view towars north-east

Since the port had to be integrated into the design, the solution to mitigatev the effects of the vehicals was to use a green filter between the parking the public spaces.



4



ARCHITECTURAL DESIGN

1. Introduction

In the architectural design, the concept was derived for the idea of the lighthouse. Based on the characteristics of the site with the idea of light and transition between the spatial experience of the fjord, the site, and the surroundings.

The lighthouse is adapted into the urban environment as a meeting point between the fjord, the historical site, and the city center. The building of the Cultural Center was oriented from the city to the fjord and overlooking the sea. This created changing views of the surroundings from inside of the building itself. The progression of the geometrical lines of the building followed the orientation towards the fjord and the views of the harbor.

The Cultural Center serves as a landmark in the harbor promenade and links the historical sites with the newly built additions of the waterfront. This is achieved by the connections to the site from different directions by a ferry, bicycle path, and vehicular route. The flexible outdoor spaces around the building, designed as steps, serve as an open-air seating area. And the sloped green spaces link the indoor spaces with the outdoor environment.

In this condition, the area of Vippetangen will become more attractive, lively, accessible, and will host important cultural events that will bring people together.

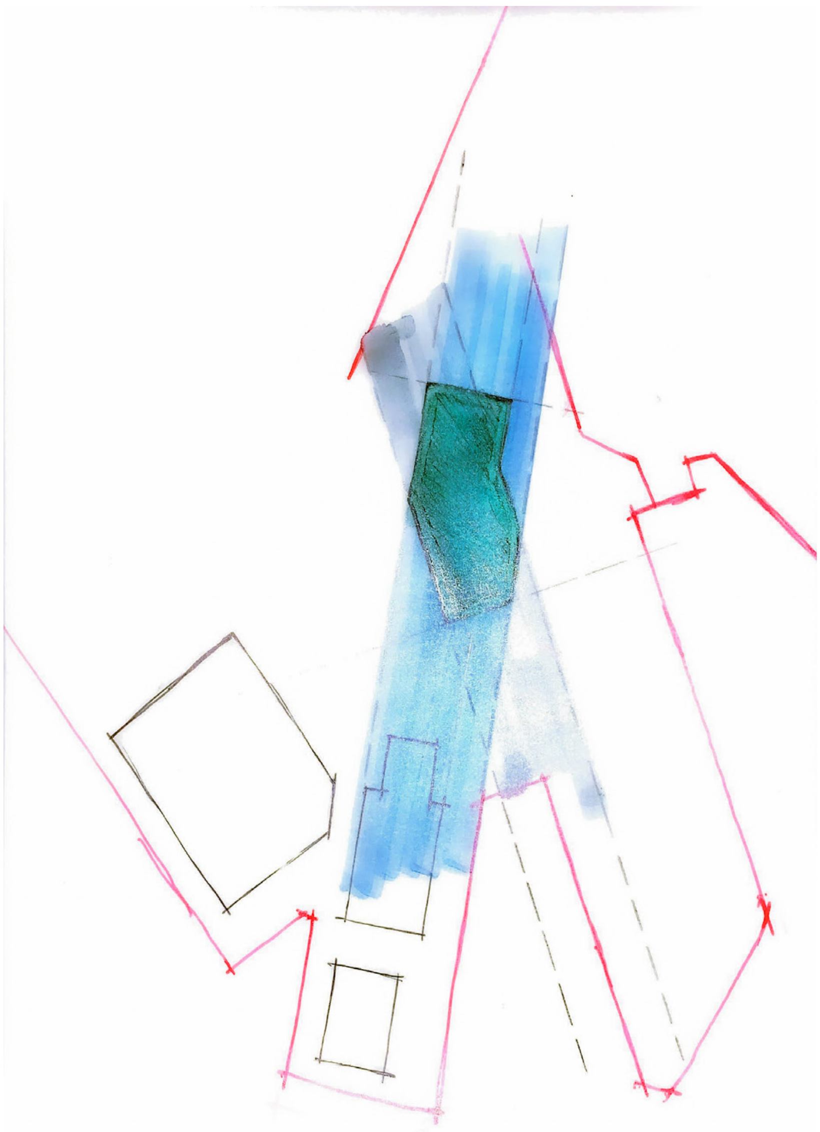


Figure.54. Sketch of the form study

2. Architectural design process

Three main themes drove the early stage of the design process, where the ideas were translated from an intangible realm into an architectural form:

Contextual approach

Looking at the context of the site and analyzing the collected data allowed us to develop the architectural design of the building better, respecting the existing constraints and taking advantage of the opportunities that the Vippetangen area has. Although the project provides a noticeable contrast to the current industrial context, however, it harmoniously plays a great role in the transformation process of the city towards cultural and touristic promenade fjords.

Conceptual approach

Setting conceptual parameters helped to maintain clarity of the design intent; thus, a coherent project that provides harmony on different levels from the visual, thermal comfort to the user experience both outside and inside the building. The approach was to ensure the continuity of the greenery through the waterfront area while maintaining a harmonious threshold relationship between the Vippetangen area and the city of Oslo.

Functional approach

The distribution of the functions inside the building and providing smooth movement modes between the different activities, but also designing facilitated and well-oriented spaces, was one of the main drivers of the design process.

The emergence of the themes together evolves the final mass of the building, where the project represents a strong relationship with the city and mainly with the users, alongside providing visual connectivity to the nearby landmarks of Oslo, which are; Oslo opera house and Akershus Castle.

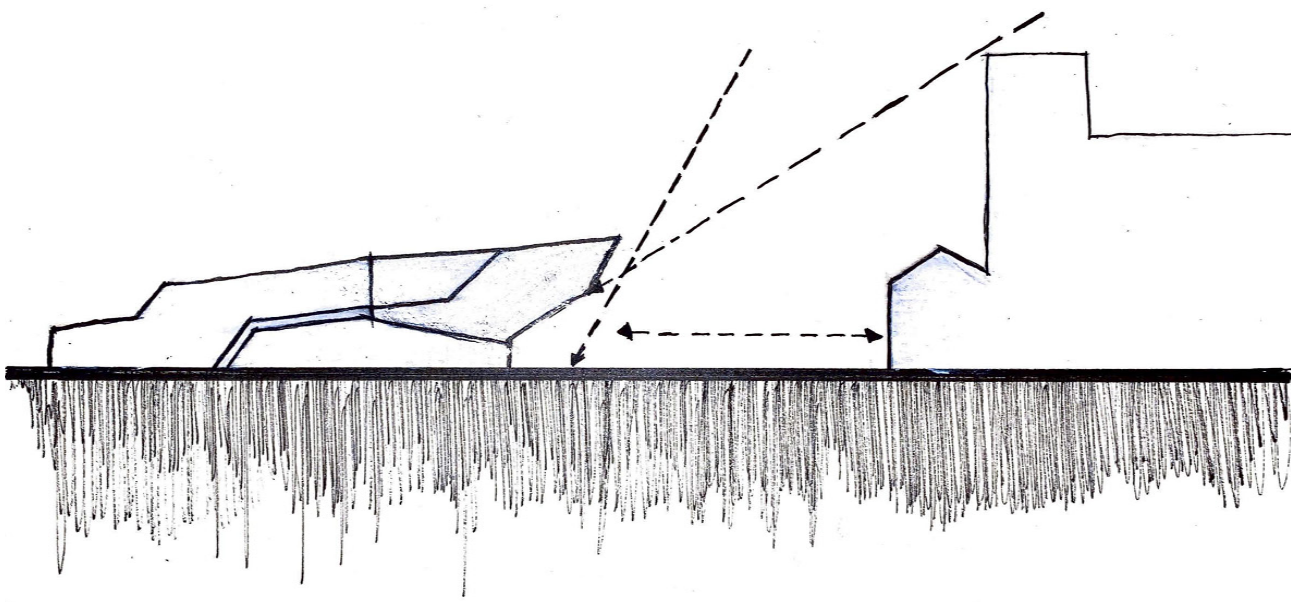
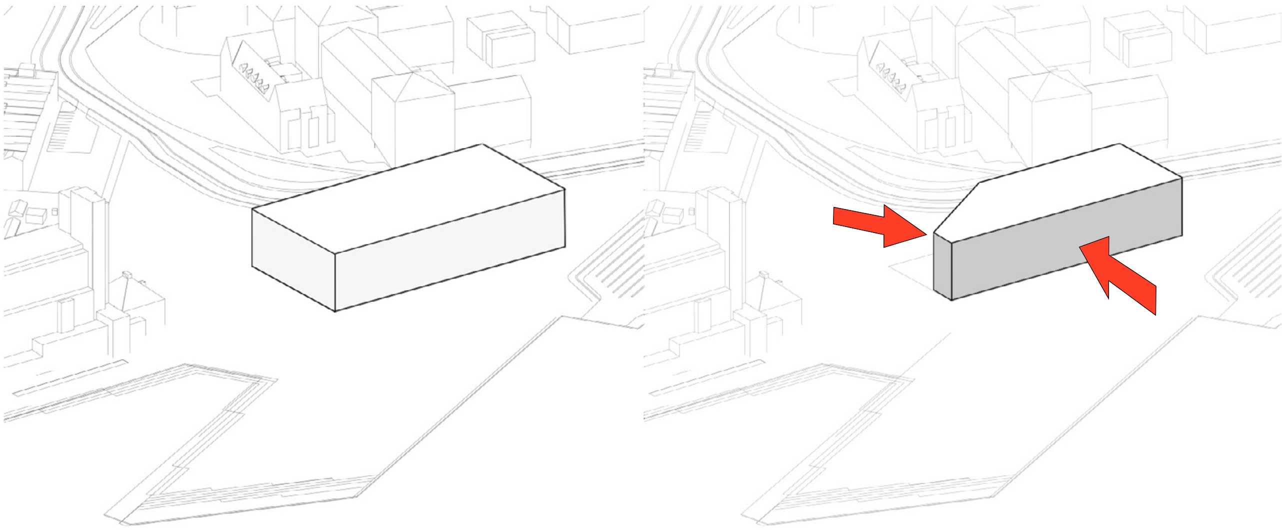


Figure.55. Sketch of the relationship with the surroundings

| Mass evolution

First, the extrusion of the area of the site is created without taking into consideration the surroundings. Next, the mass is being transformed in stages, and the geometrical lines of the surroundings are taken as a reference. After this, the functional orientation, the dimensions of the spaces defined some volume constraints and guidelines.



Next, the view angles with the cultural landmarks were studied, and the mass was molded to utilize the multitude of view angles between the surroundings and the fjords.

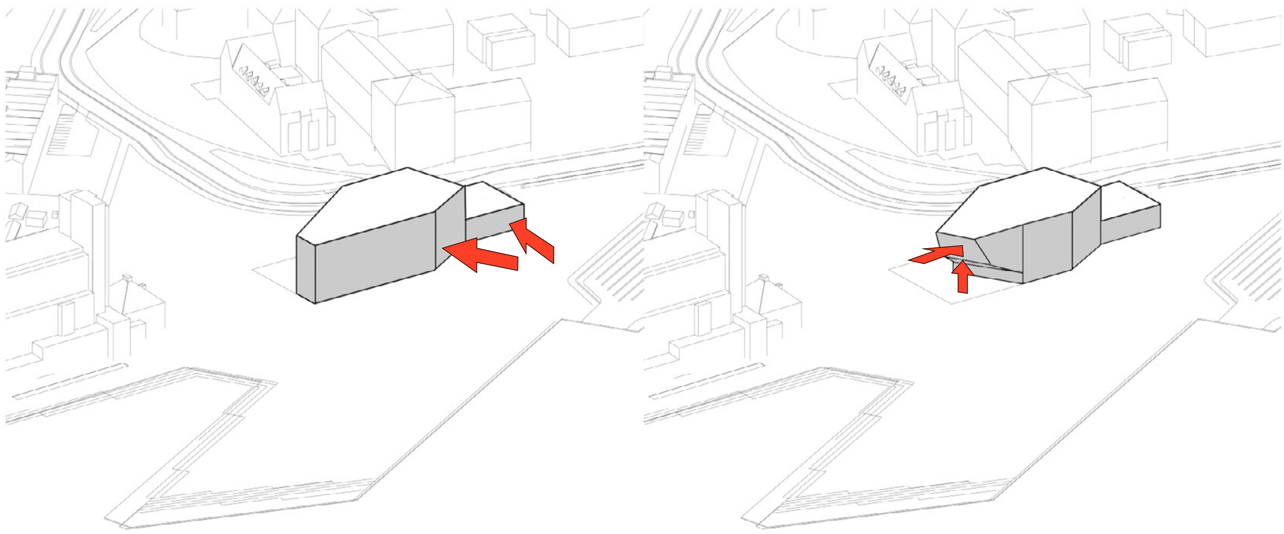
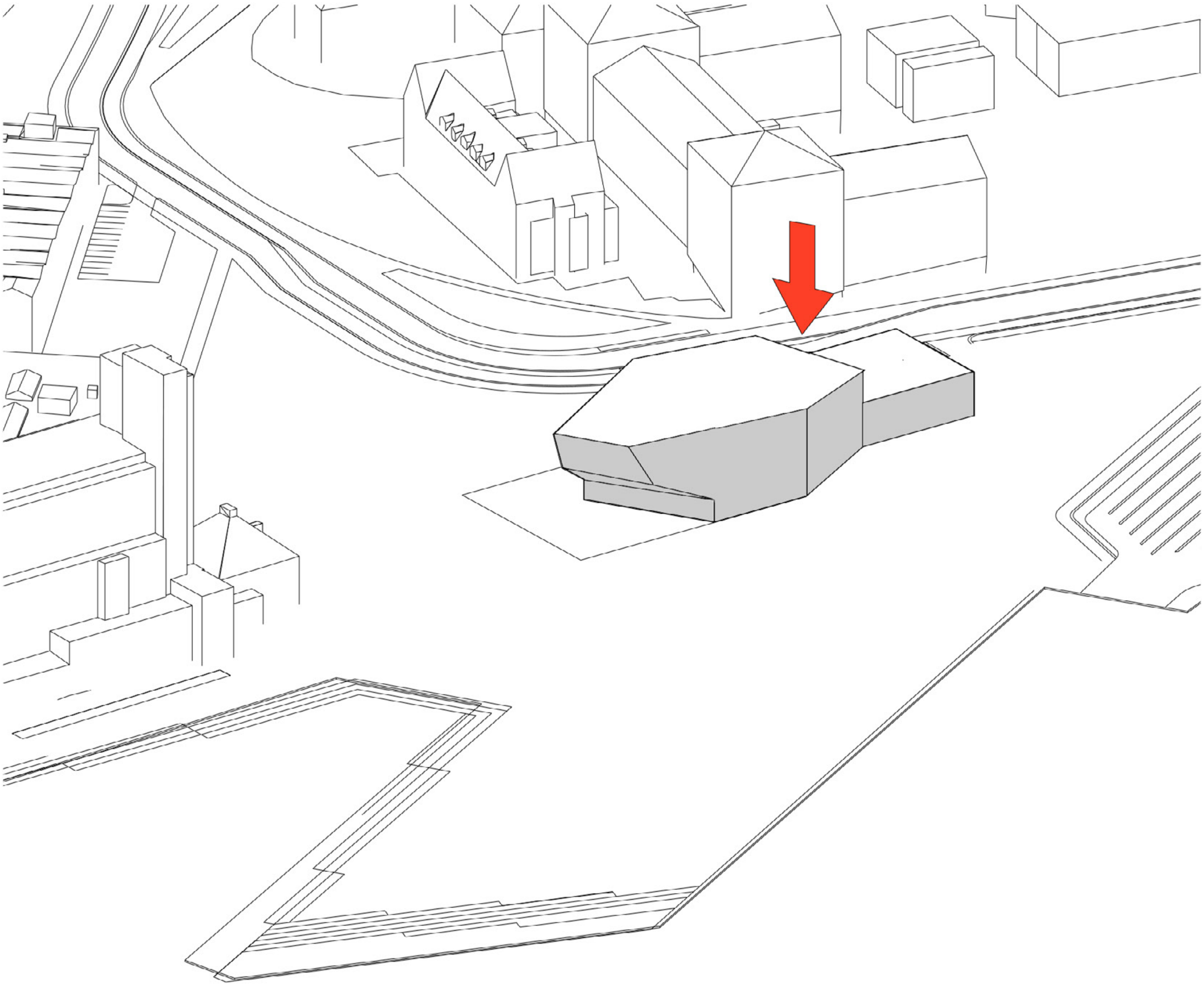


Figure.56. Mass development phases

The final stage involved shaping the inclination of the roof that was made based on the idea of a progression of the mass from the city to the fjords.



| Functional distribution

In the following diagram of the functional distribution of the Cultural Center is presented. On the ground floor first is the main entrance and information space, then the auditorium, the exhibition, the café, and the gift shop. On the first floor, the library and exhibition space is located. In addition, the level includes two laboratories and four office spaces. On the second floor, the space dedicated to the library continues, and there is a multifunctional space that can be adapted to different types of activities and workshops. All the floors are equipped with services like restrooms and vertical communications – stairs and elevator.

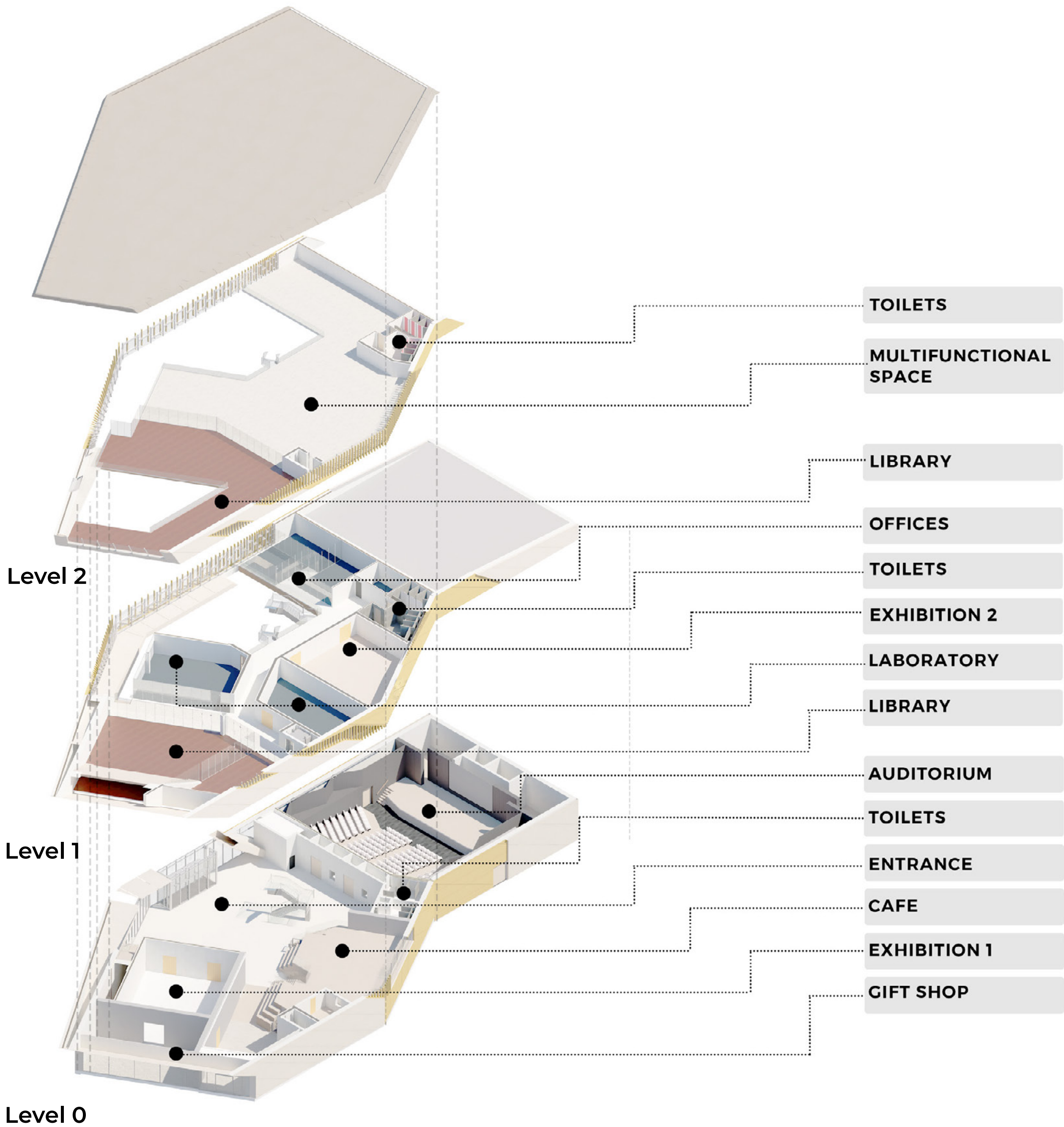


Figure.57. Diagram of the funtions distribution

| Accessibility of the building

This diagram shows the accessibility of the Cultural Center building. The building has two main entrances from the west and south-east. The same can also be used as exits and evacuation points. The access to the auditorium is from the inside of the building on the ground floor level. The main exits of the auditorium are shown. They lead to the outside in east and west directions.

The vertical connections are achieved by staircases. There two main staircases that reach all of the floors, one of them is designed to serve in case of emergency. In addition, there are also interior stairs for the levels of the cafeteria, between the ground and the first floor, between first and the second floor. The vertical communication provides an elevator to all floors and special elevators to the cafeteria level for the disabled.

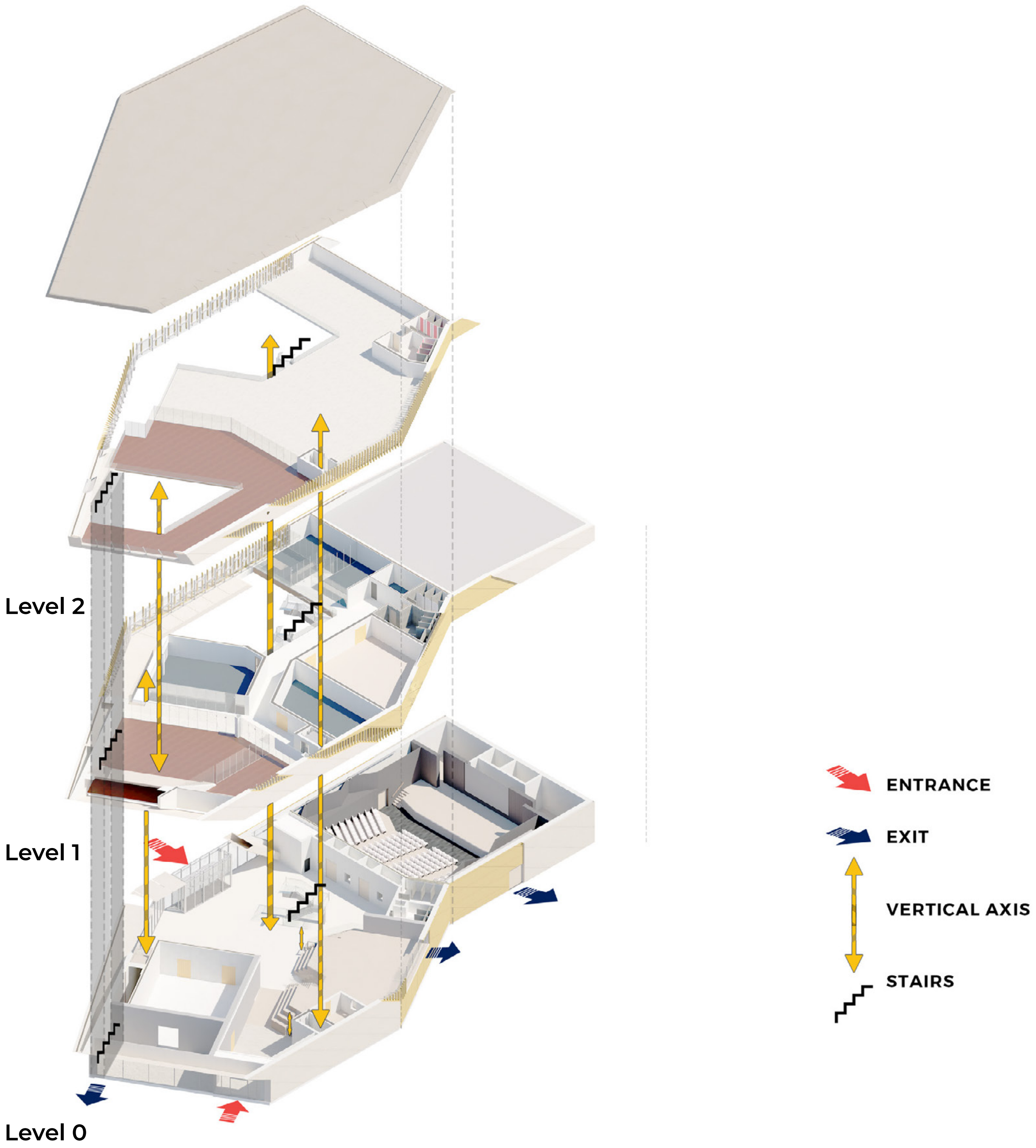
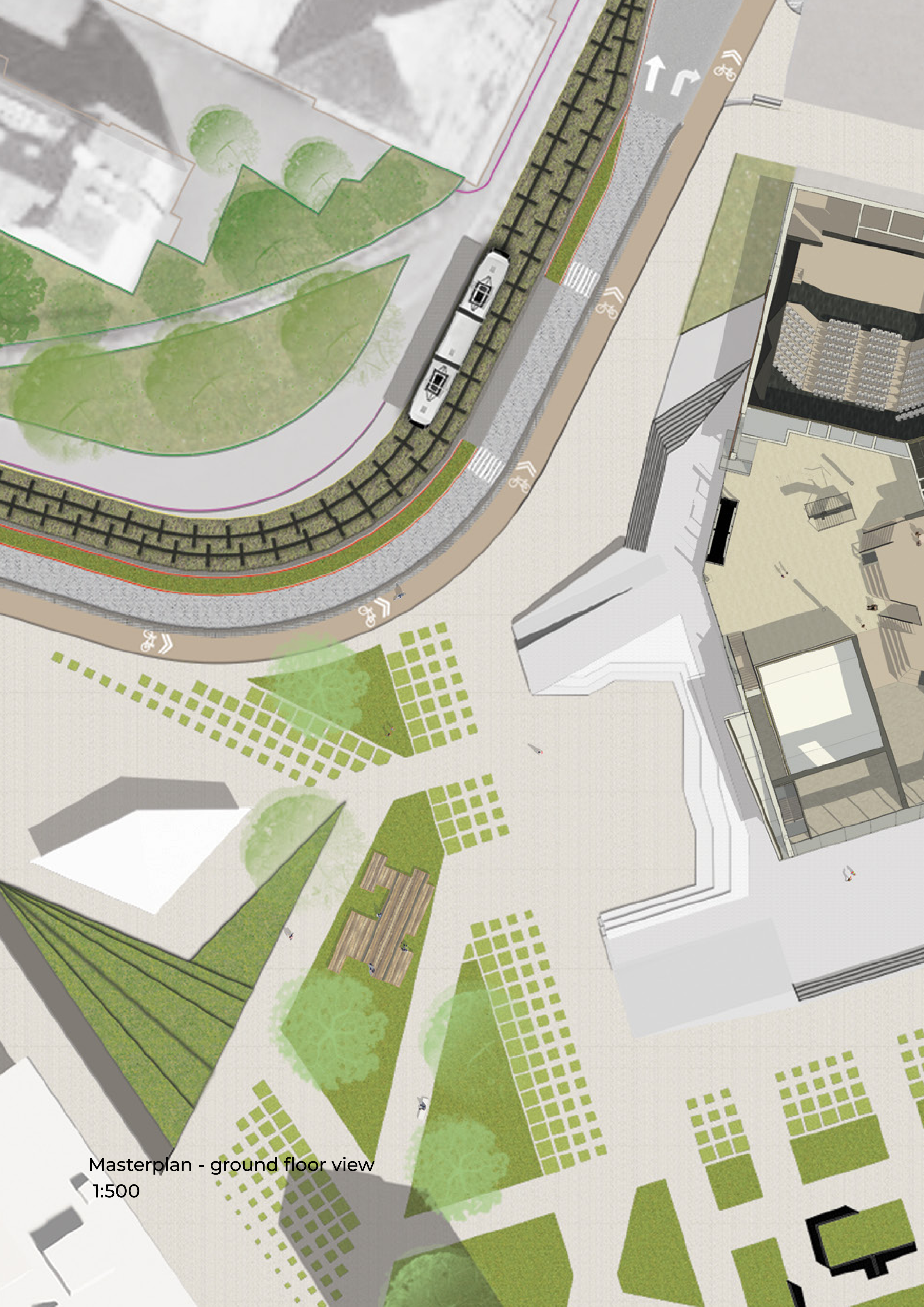
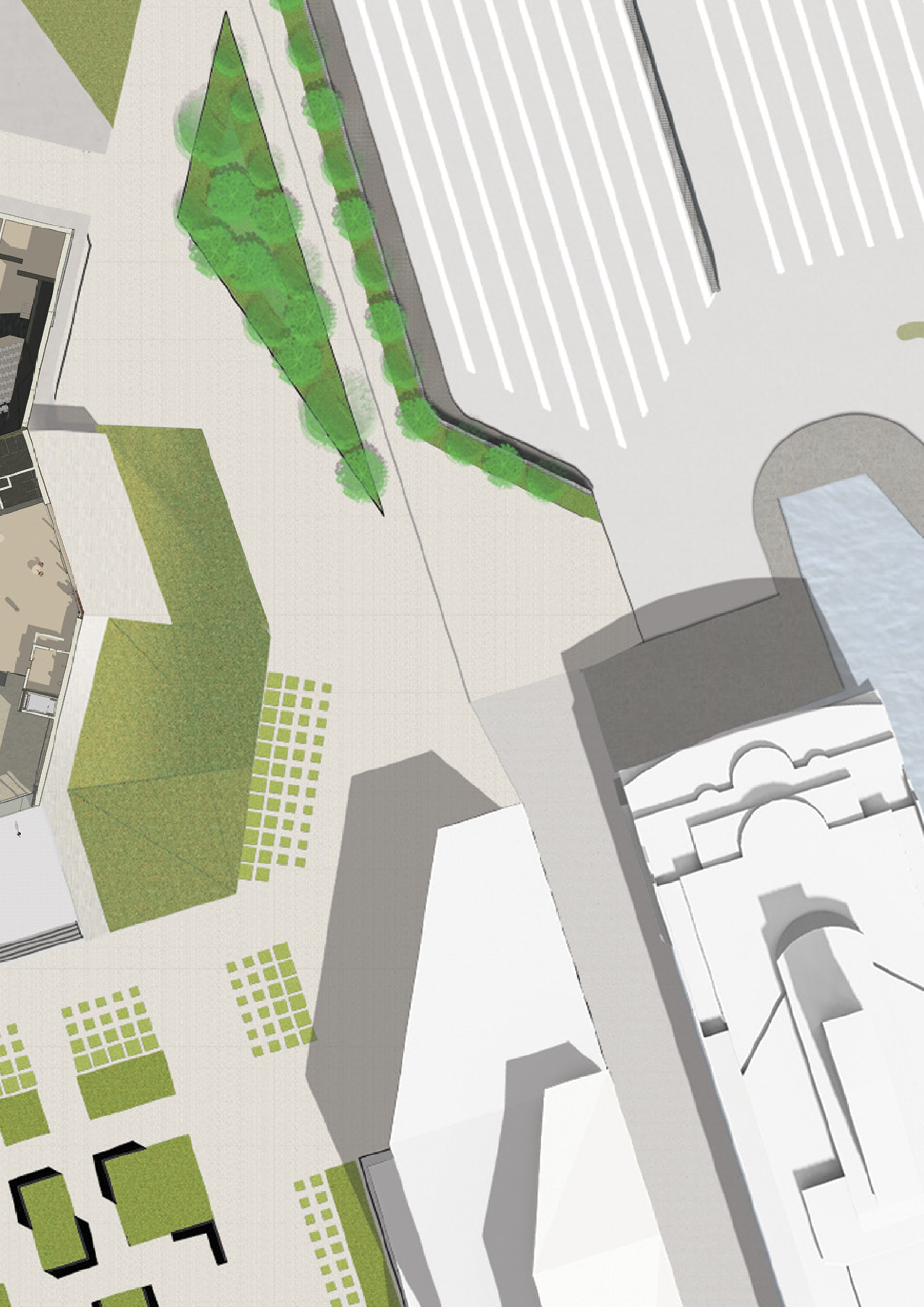
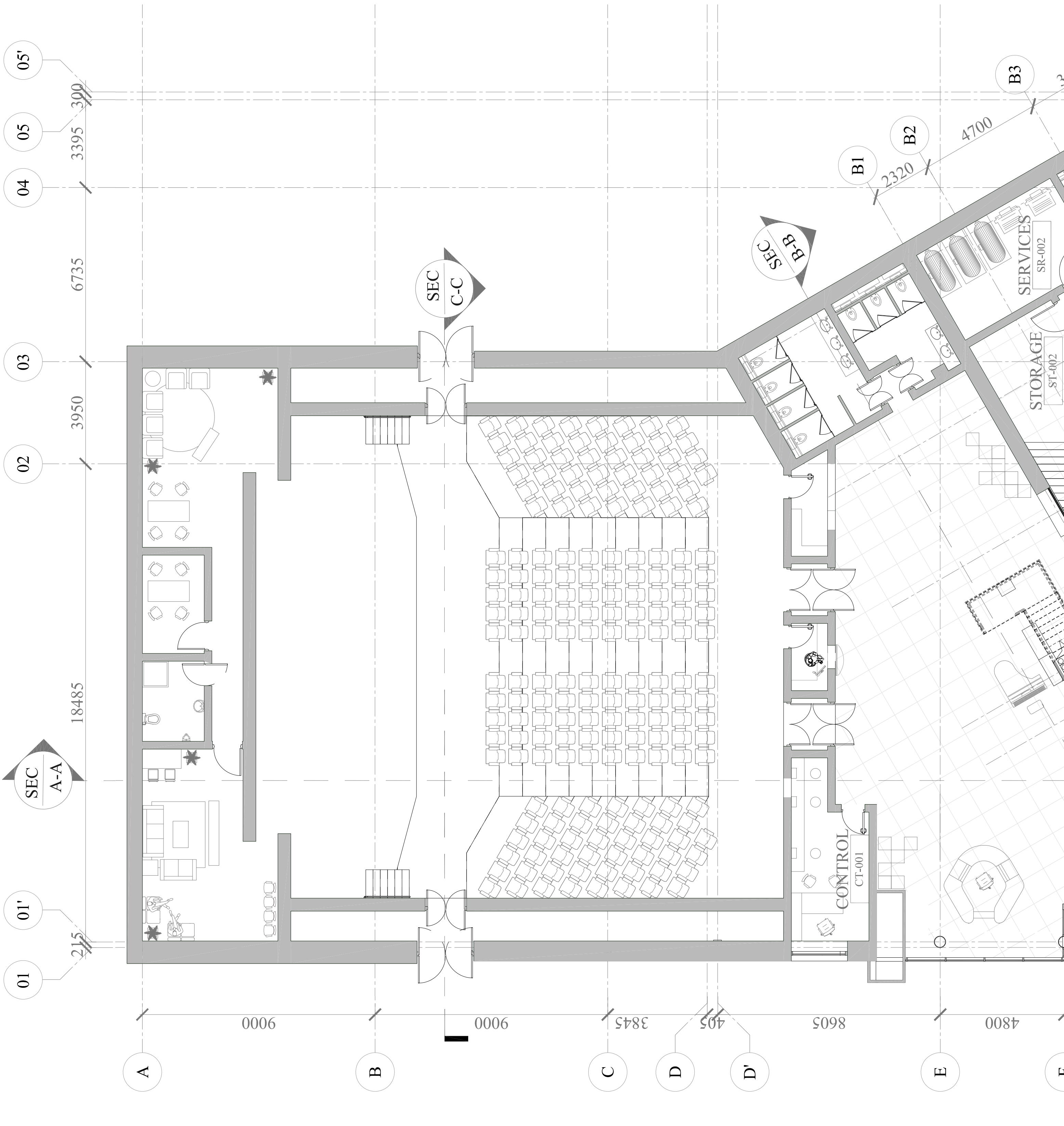


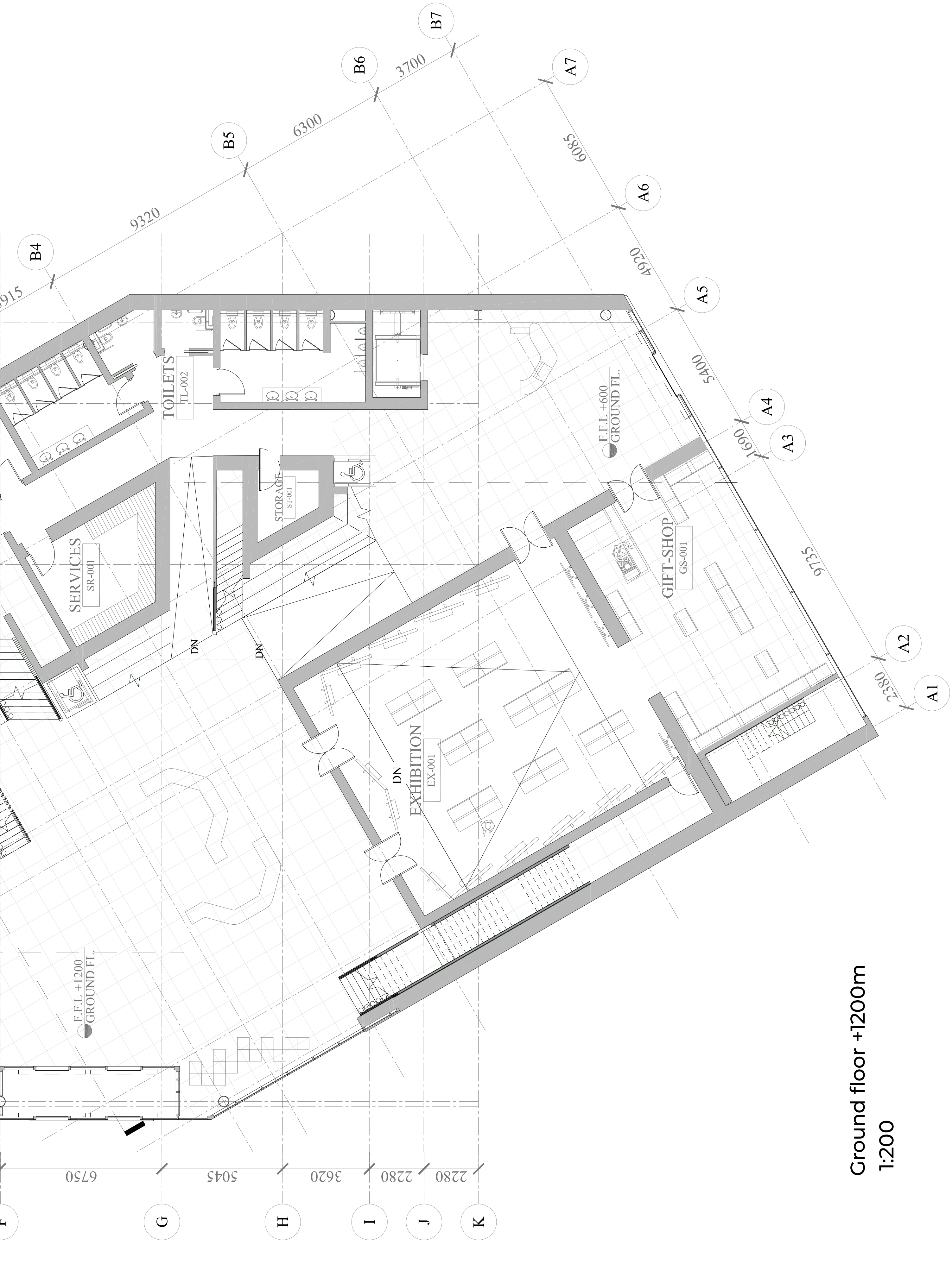
Figure.58. Diagram of the accessibility of the building



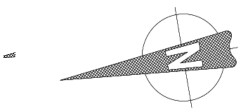
Masterplan - ground floor view
1:500

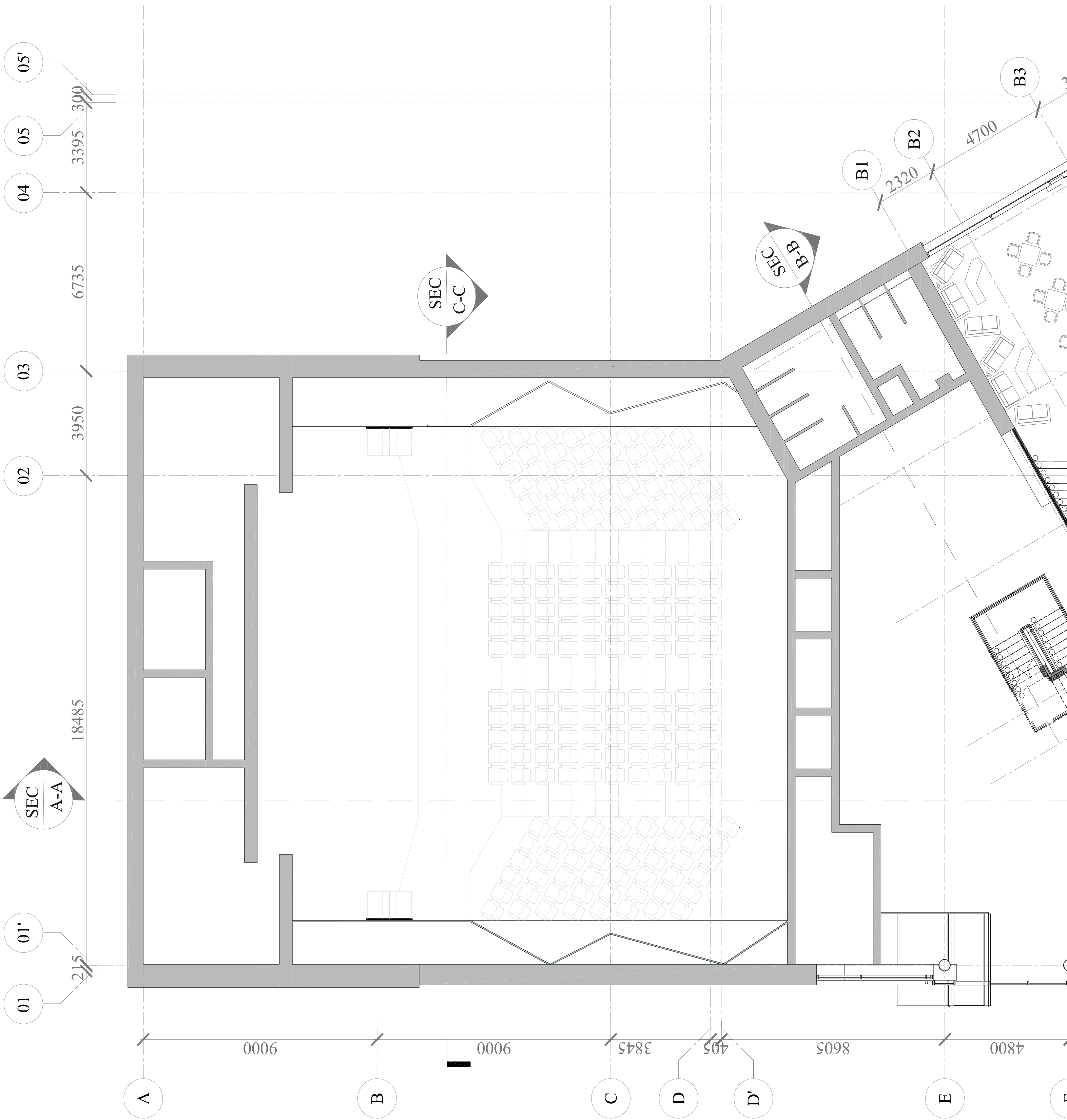


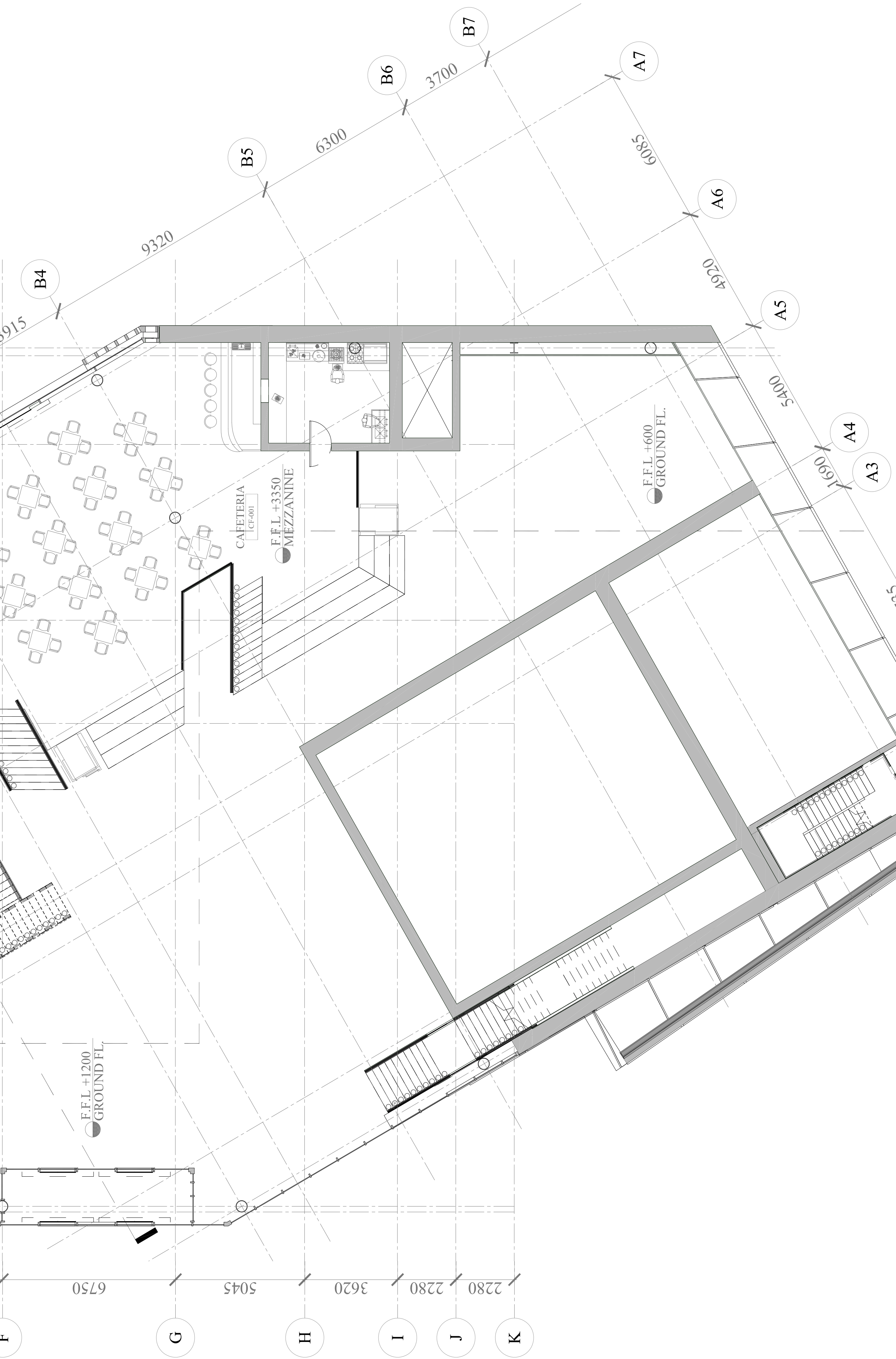

05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
B1
B2
B3
2320
4700
SEC
B-B
SEC
C-C
SEC
A-A
SERVICES
SR-002
STORAGE
ST-002
CONTROL
CT-001
9000
9000
3845
405
8605
4800
A
B
C
D
D'
E



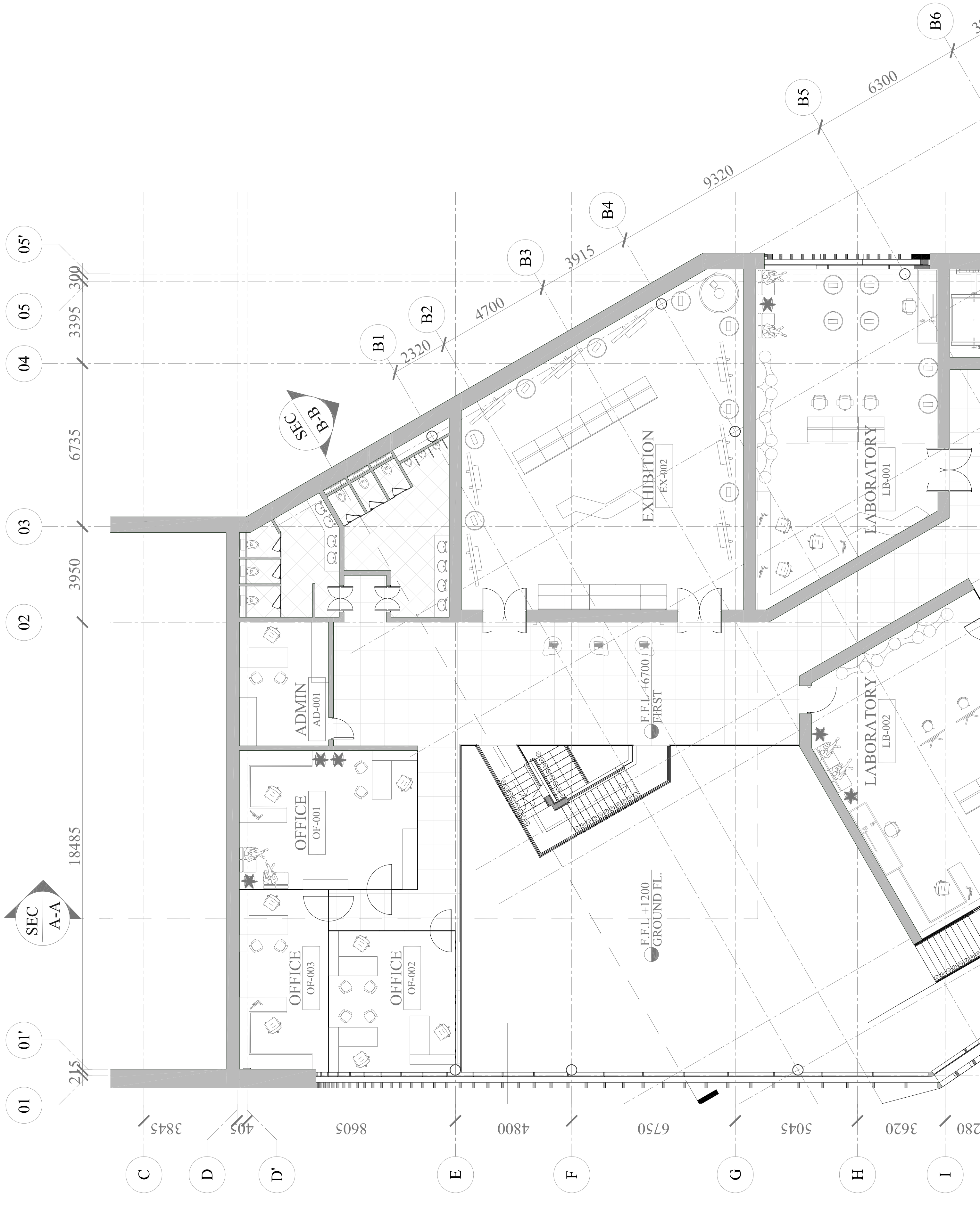
Ground floor +1200m
1:200



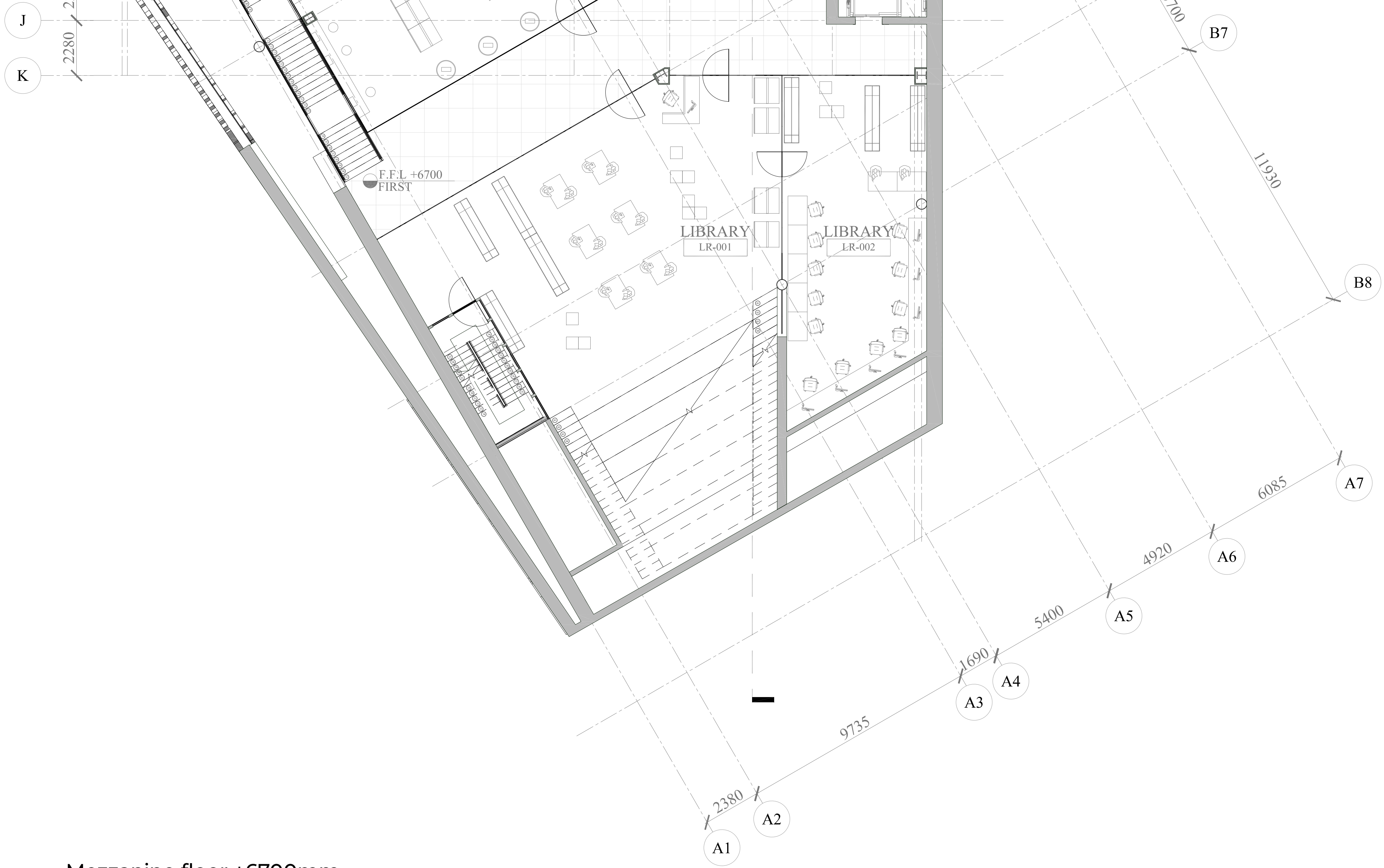

05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
SEC C-C
SEC B-B
SEC A-A
B1
B2
B3
2320
4700
9000
9000
3845
405
8605
4800
A
B
C
D
D'
E



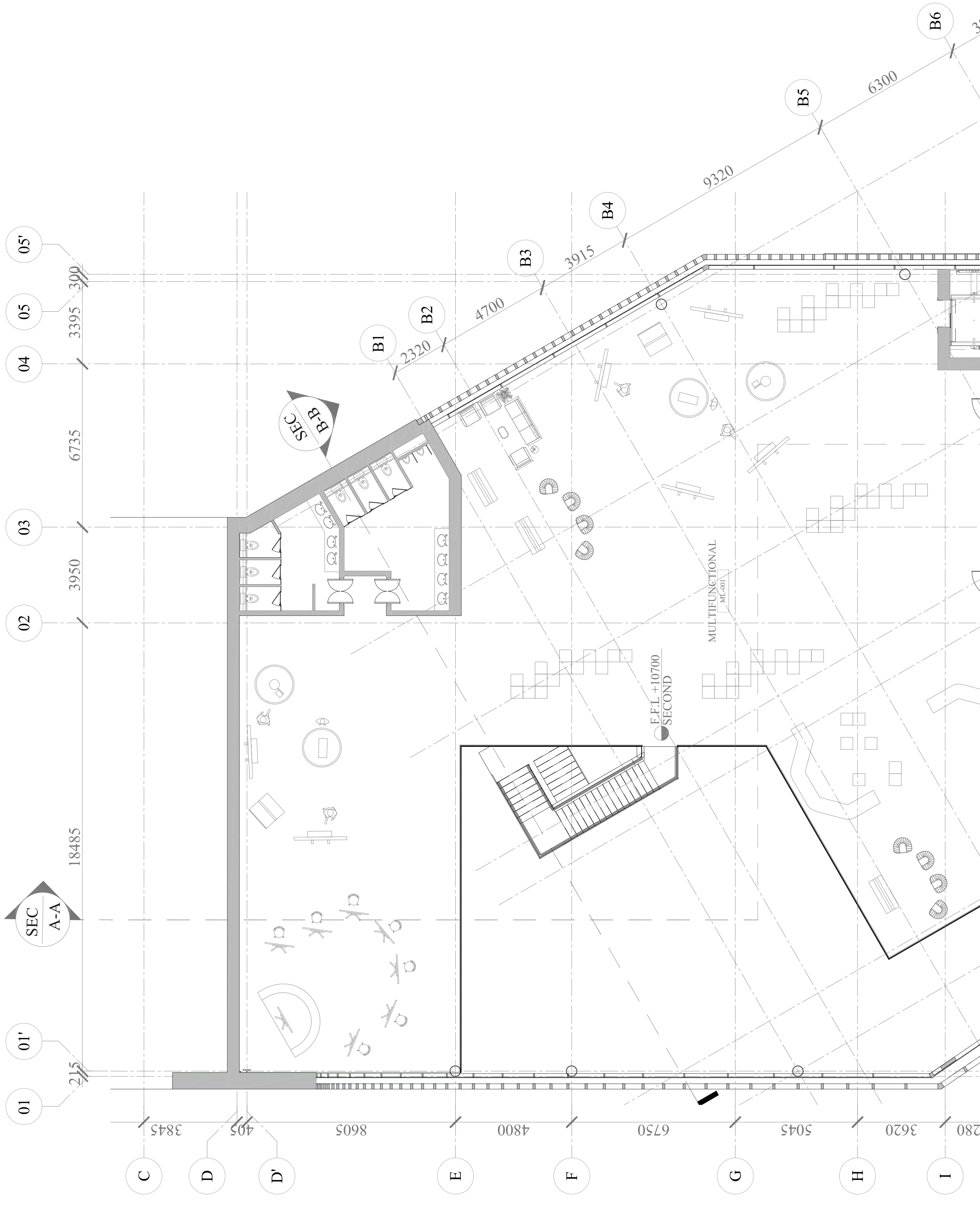
Mezzanine floor +3350mm
1:200

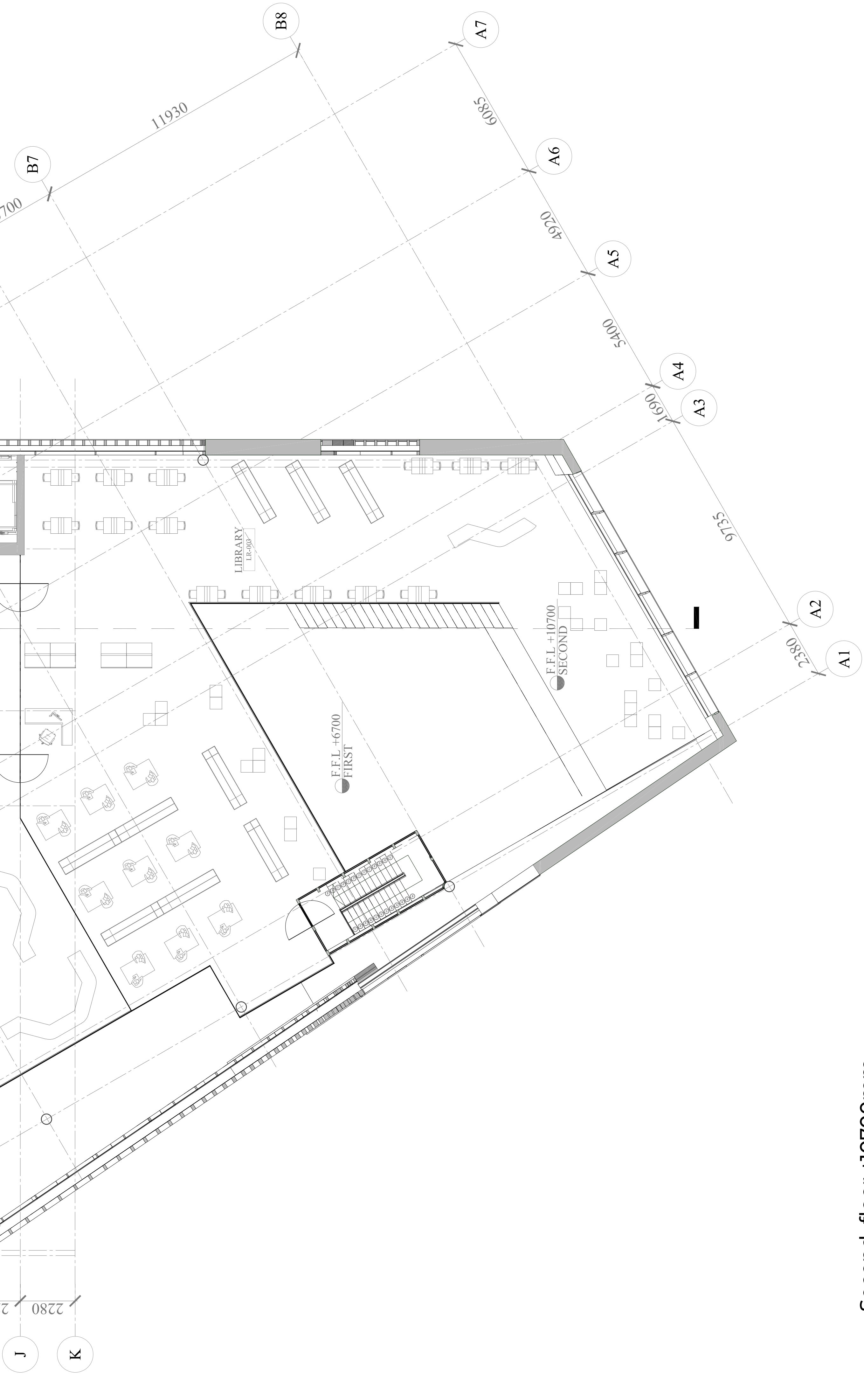


EXHIBITION
EX-002
LABORATORY
LB-001
LABORATORY
LB-002
ADMIN
AD-001
OFFICE
OF-001
OFFICE
OF-002
OFFICE
OF-003
F.F.L +6700
FIRST
F.F.L +1200
GROUND FL.
SEC
A-A
SEC
B-B
B1
B2
B3
B4
B5
B6
2320
4700
3915
9320
6300
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
C
D
D'
E
F
G
H
I
3845
405
8605
4800
6750
5045
3620
280



Mezzanine floor +6700mm
1:200


B1
B2
B3
B4
B5
B6
2320
4700
3915
9320
6300
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
SEC B-B
SEC A-A
MULTIFUNCTIONAL
ML-001
F.F.L +10700
SECOND
3845
405
8605
4800
6750
5045
3620
280
C
D
D'
E
F
G
H
I

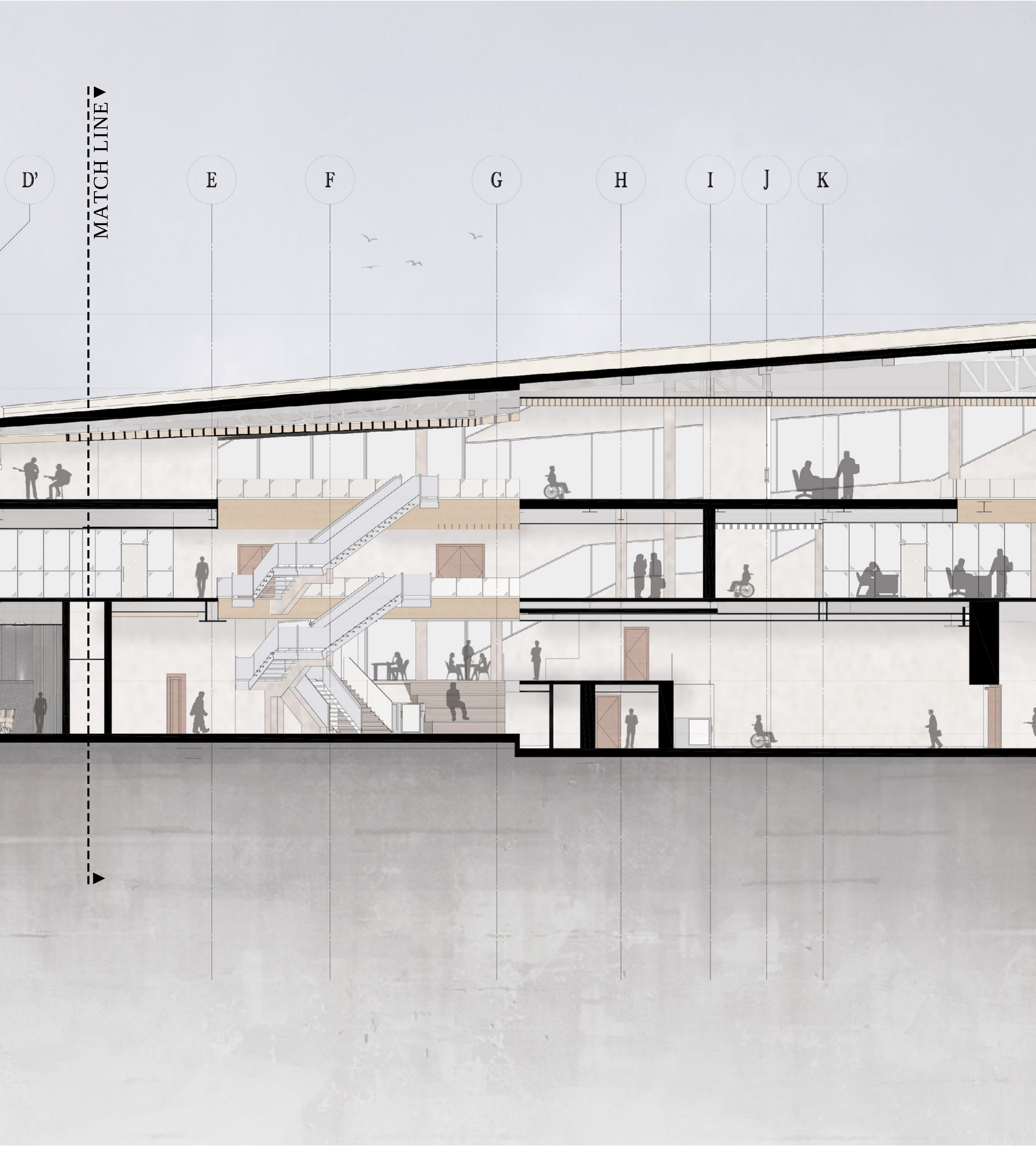


Second floor +10700mm
1:200

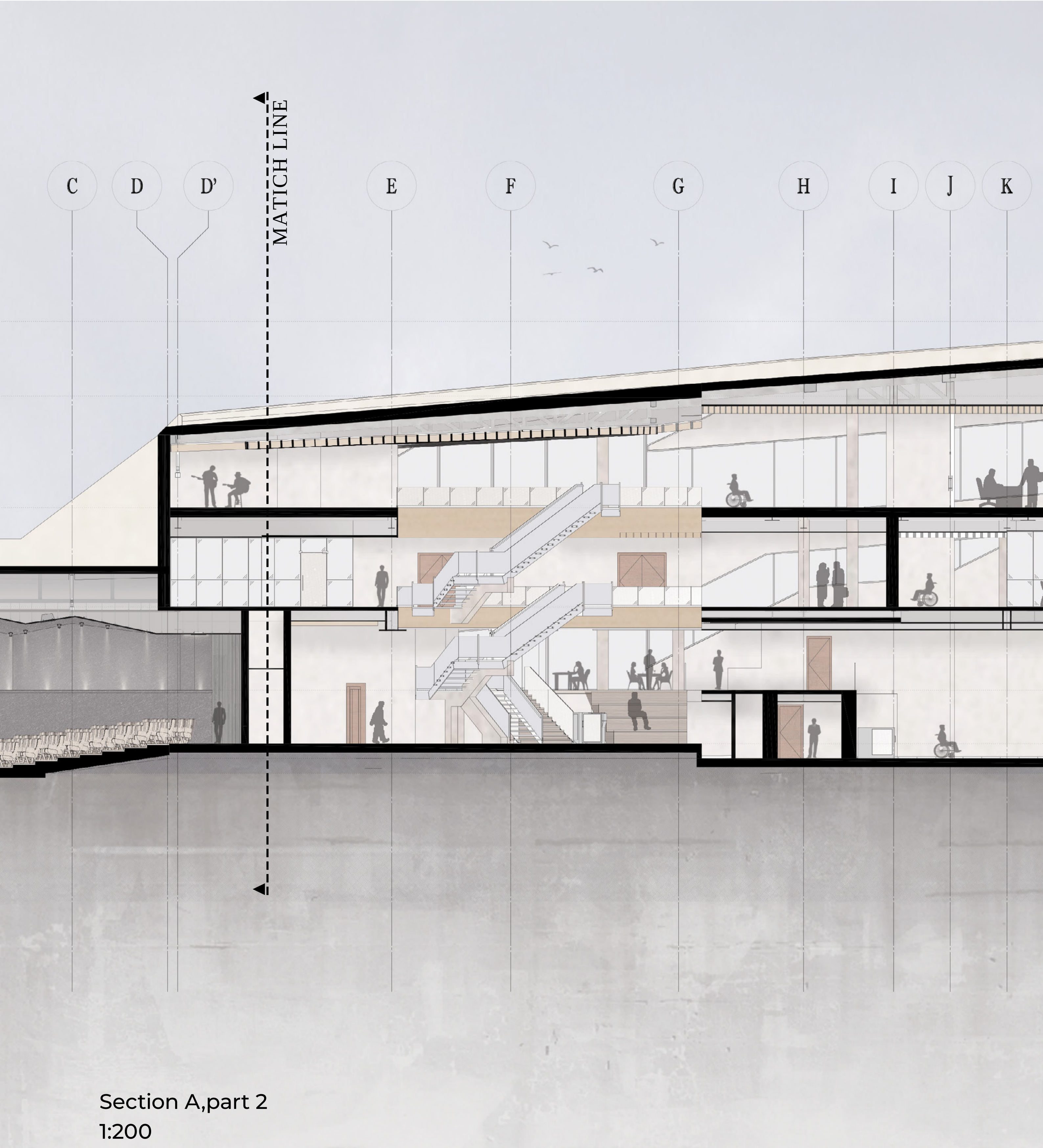
Section A
1:200


G
H
I
J
K
F.F.L+18200
F.F.L+15200
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

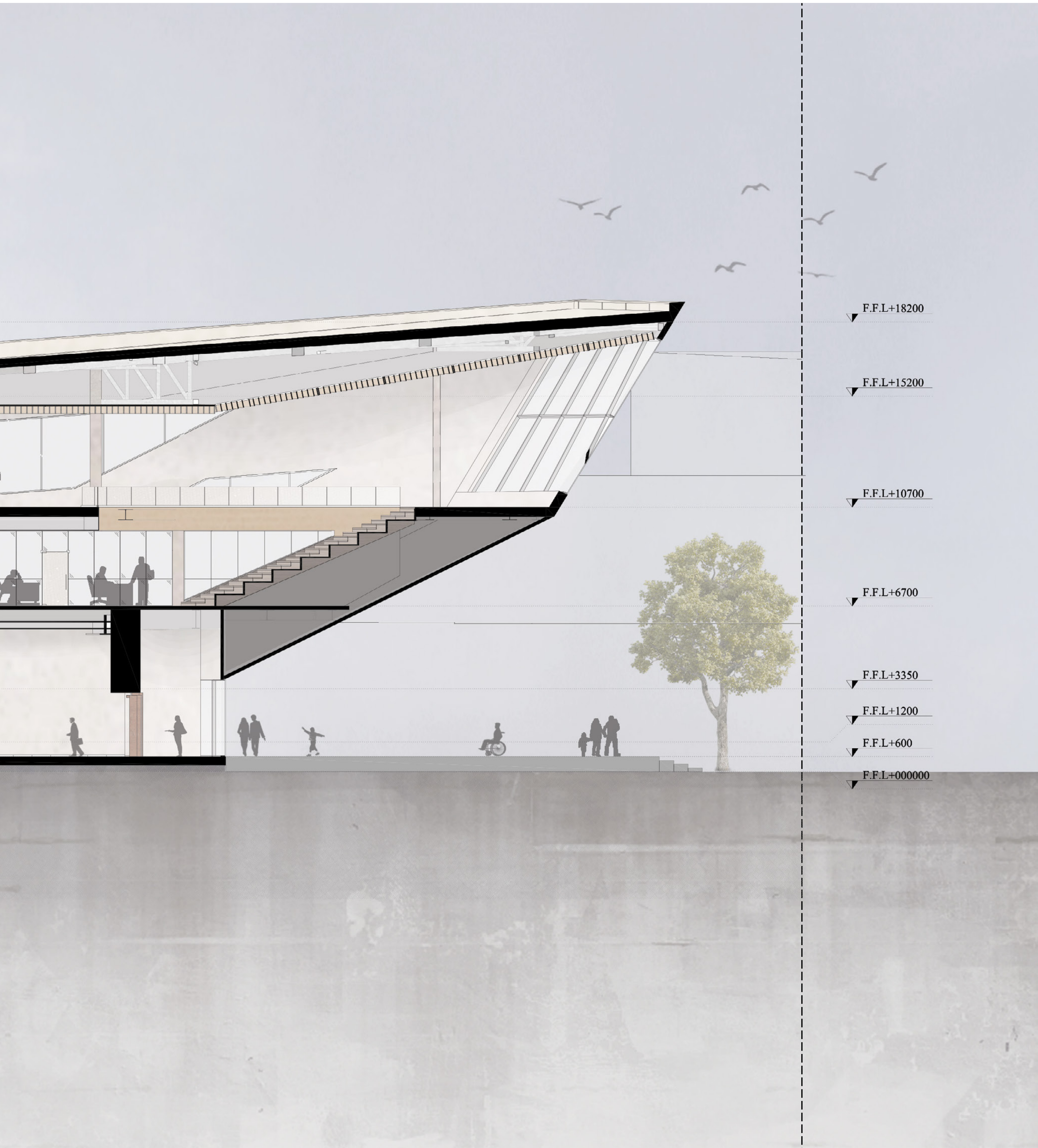
Section A, part 1
1:200



MATCH LINE
D'
E
F
G
H
I
J
K



Section A,part 2
1:200


F.F.L+18200
F.F.L+15200
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

Section B
1:200


A2
A1
F.F.L+18200
F.F.L+15200
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

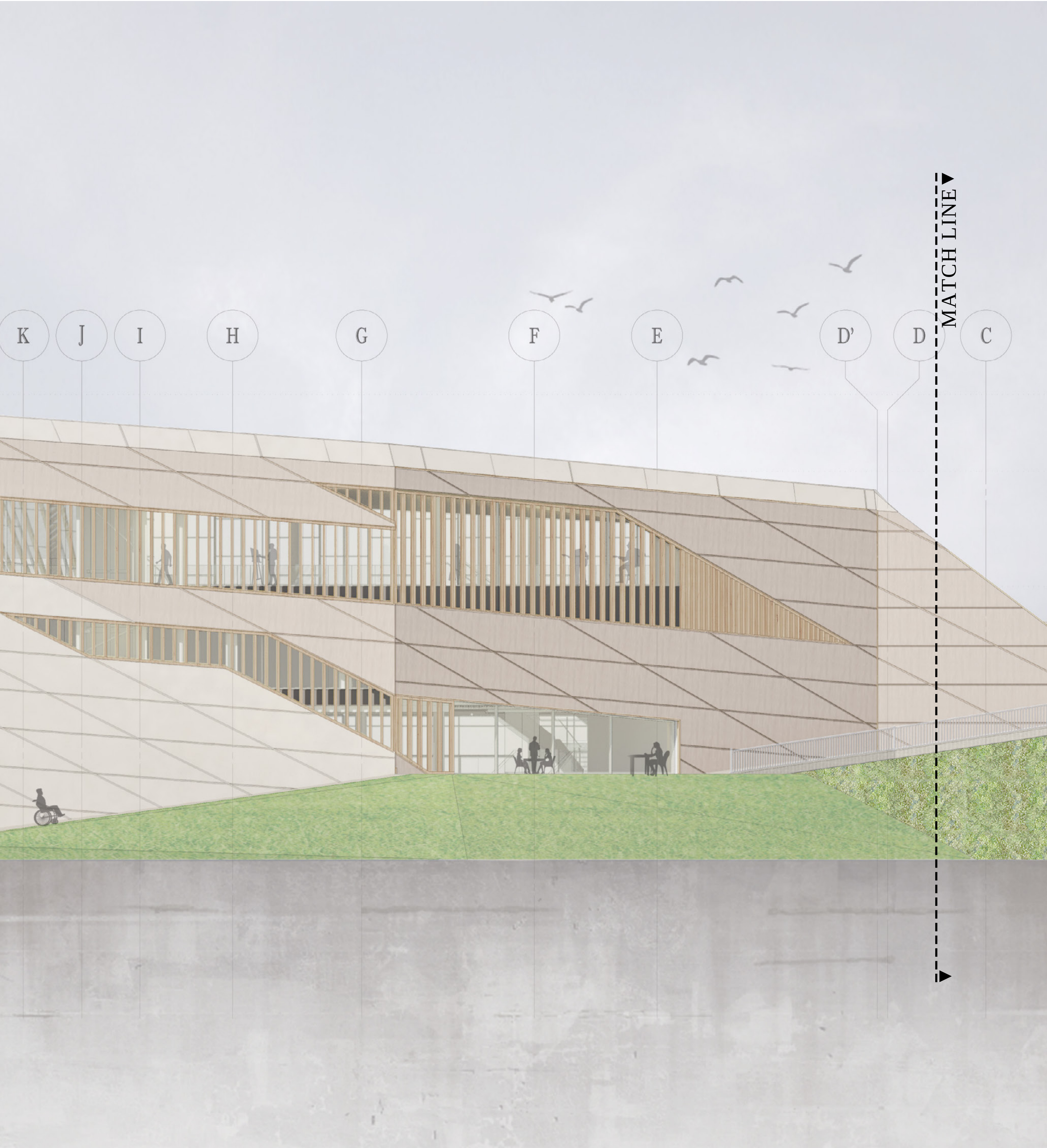
Section C
1:200

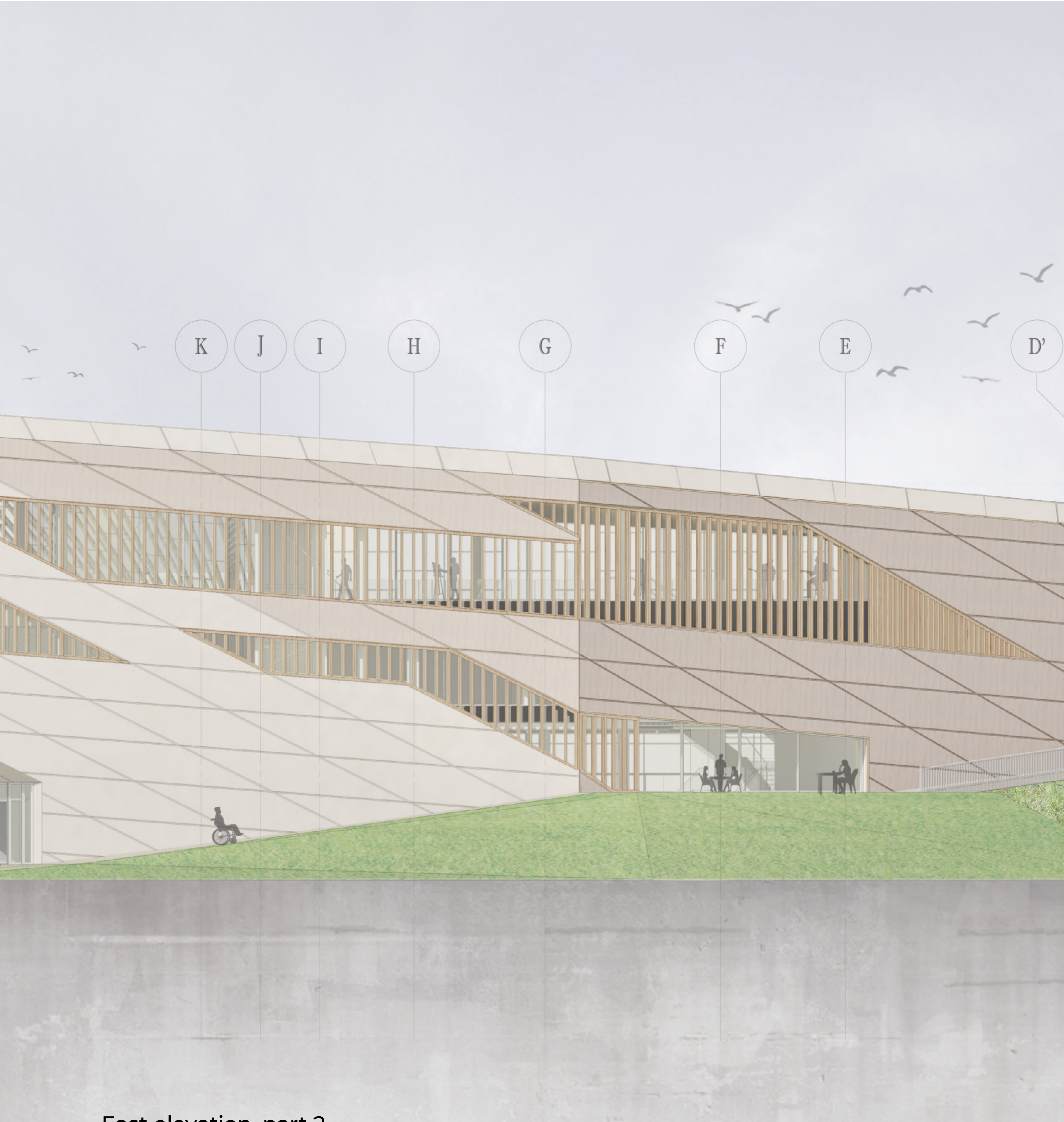

01'
01
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

East elevation
1:200

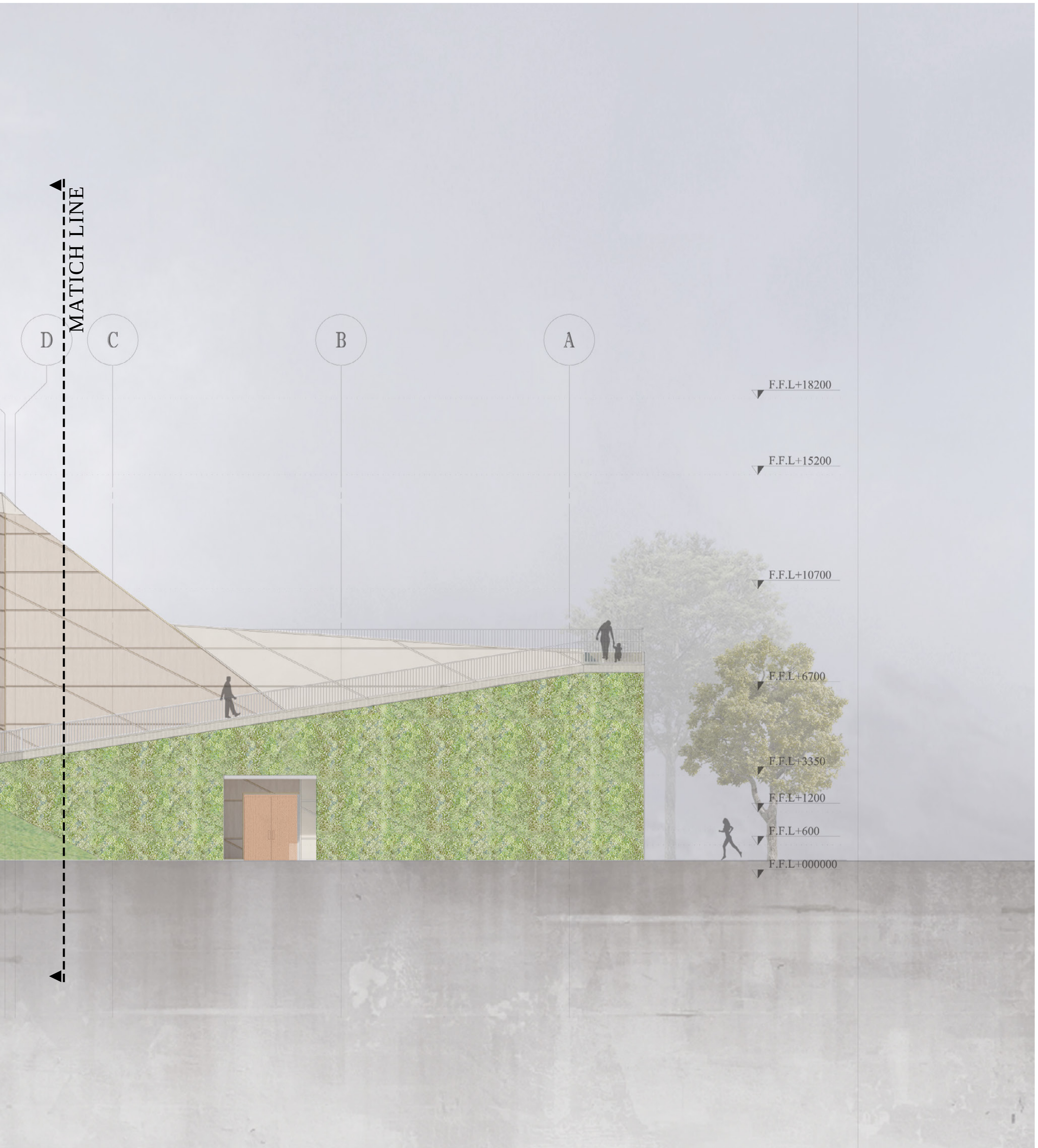

F
E
D'
D
C
B
A
F.F.L+18200
F.F.L+15200
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

East elevation, part 1
1:200

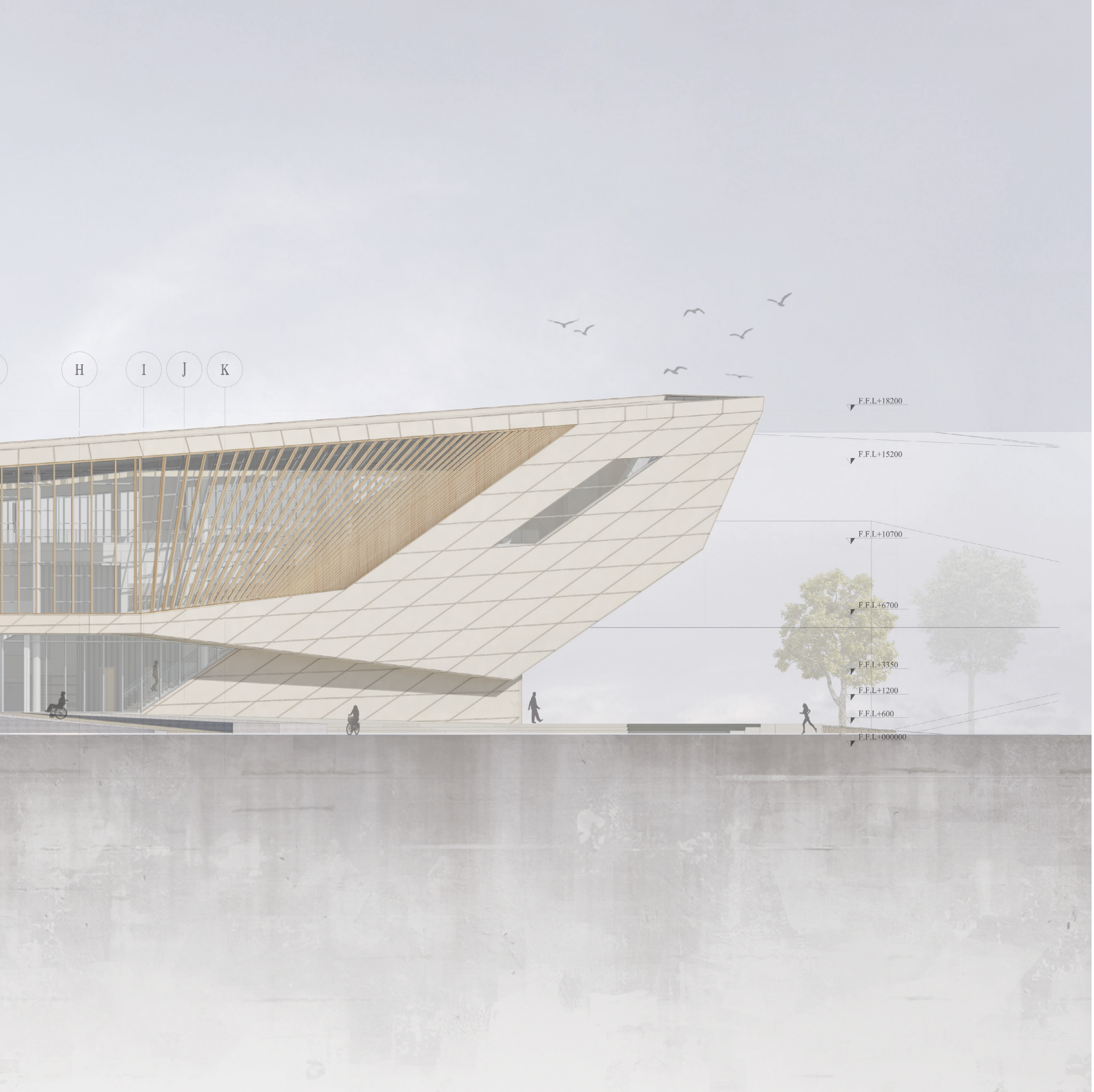

K
J
I
H
G
F
E
D'
D
C
MATCH LINE

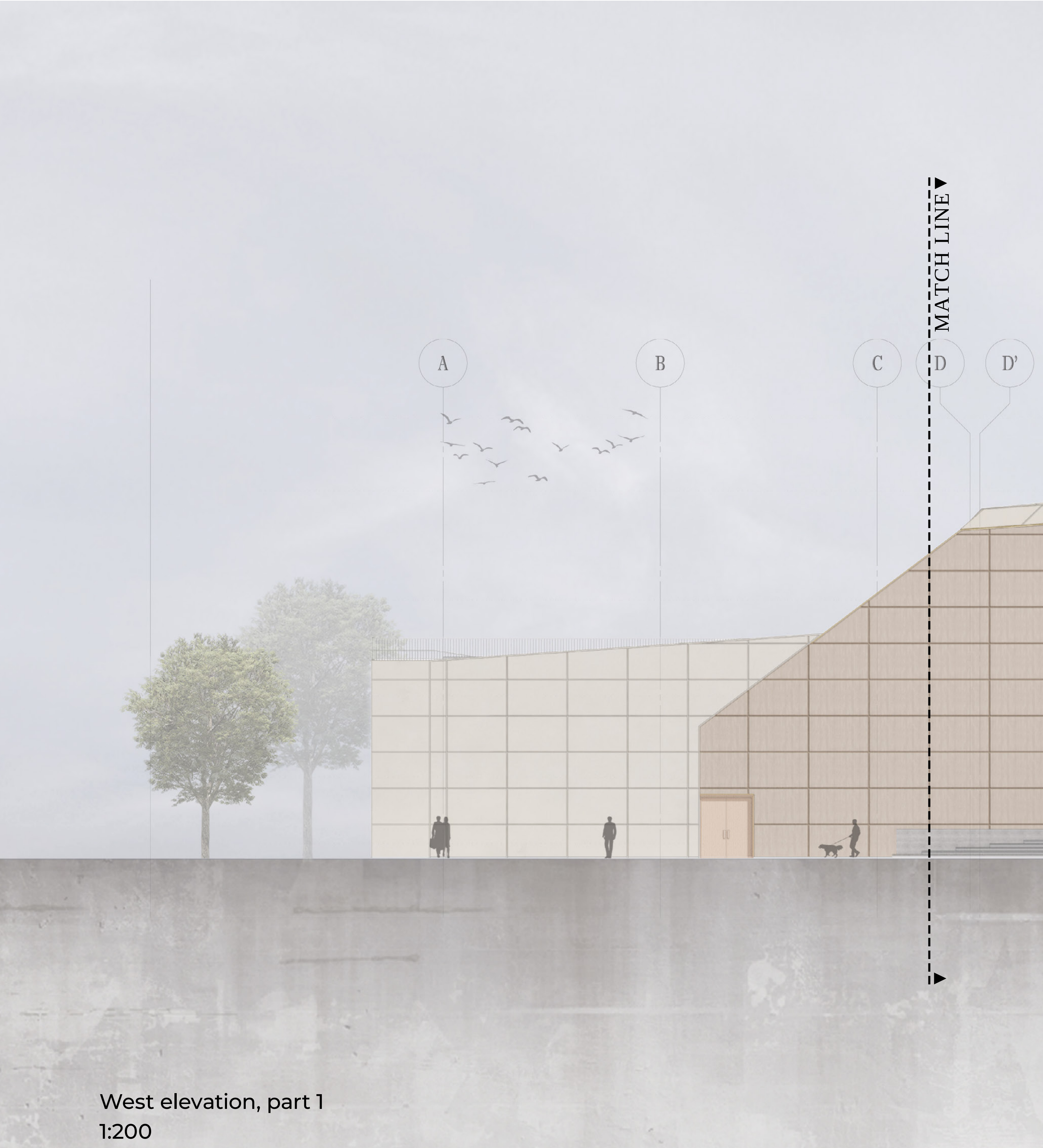


East elevation, part 2
1:200


MATICH LINE
D
C
B
A
F.F.L+18200
F.F.L+15200
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

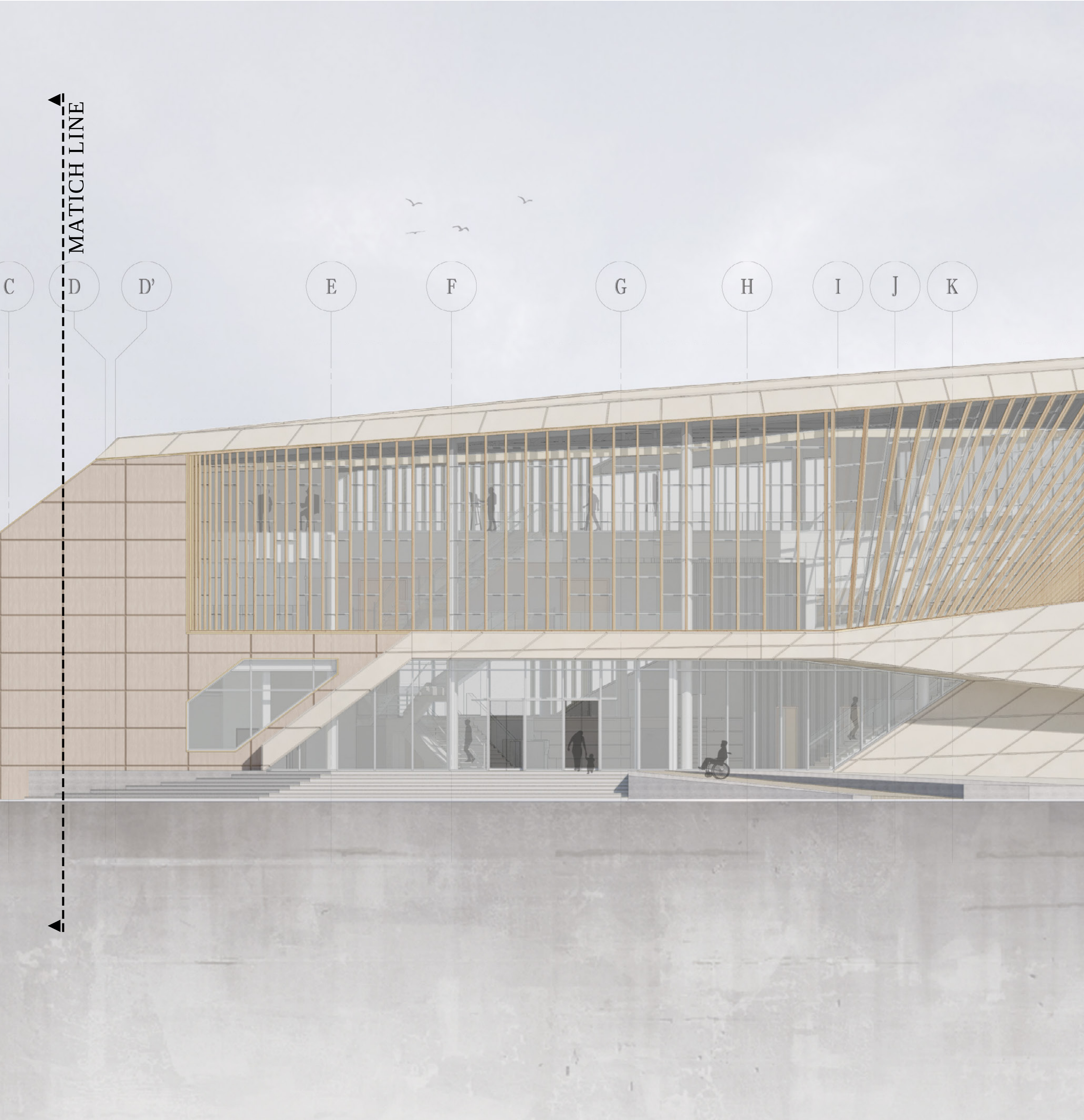

A
B
C
D
D'
E
F
G


H
I
J
K
F.F.L+18200
F.F.L+15200
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

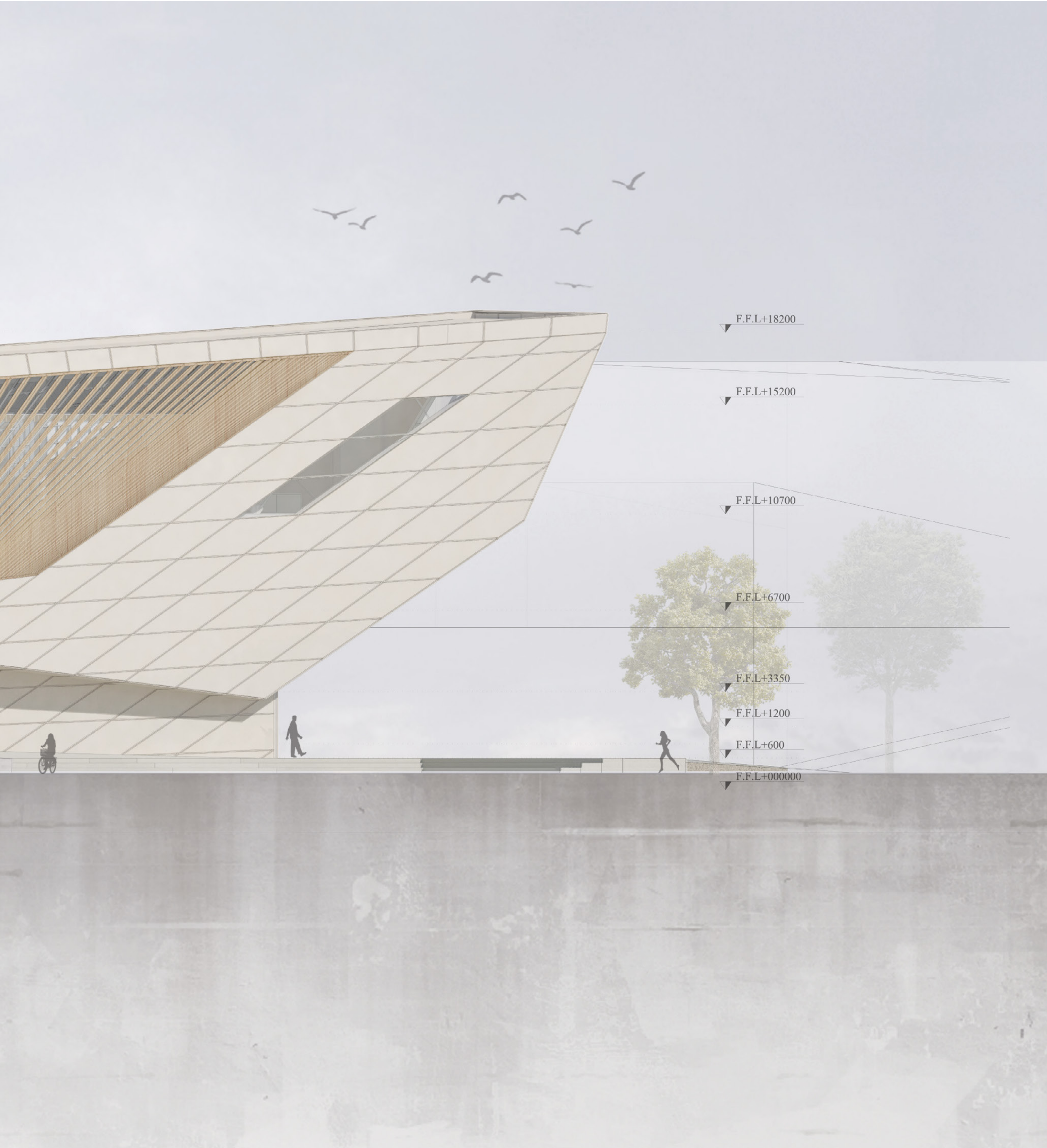


West elevation, part 1
1:200

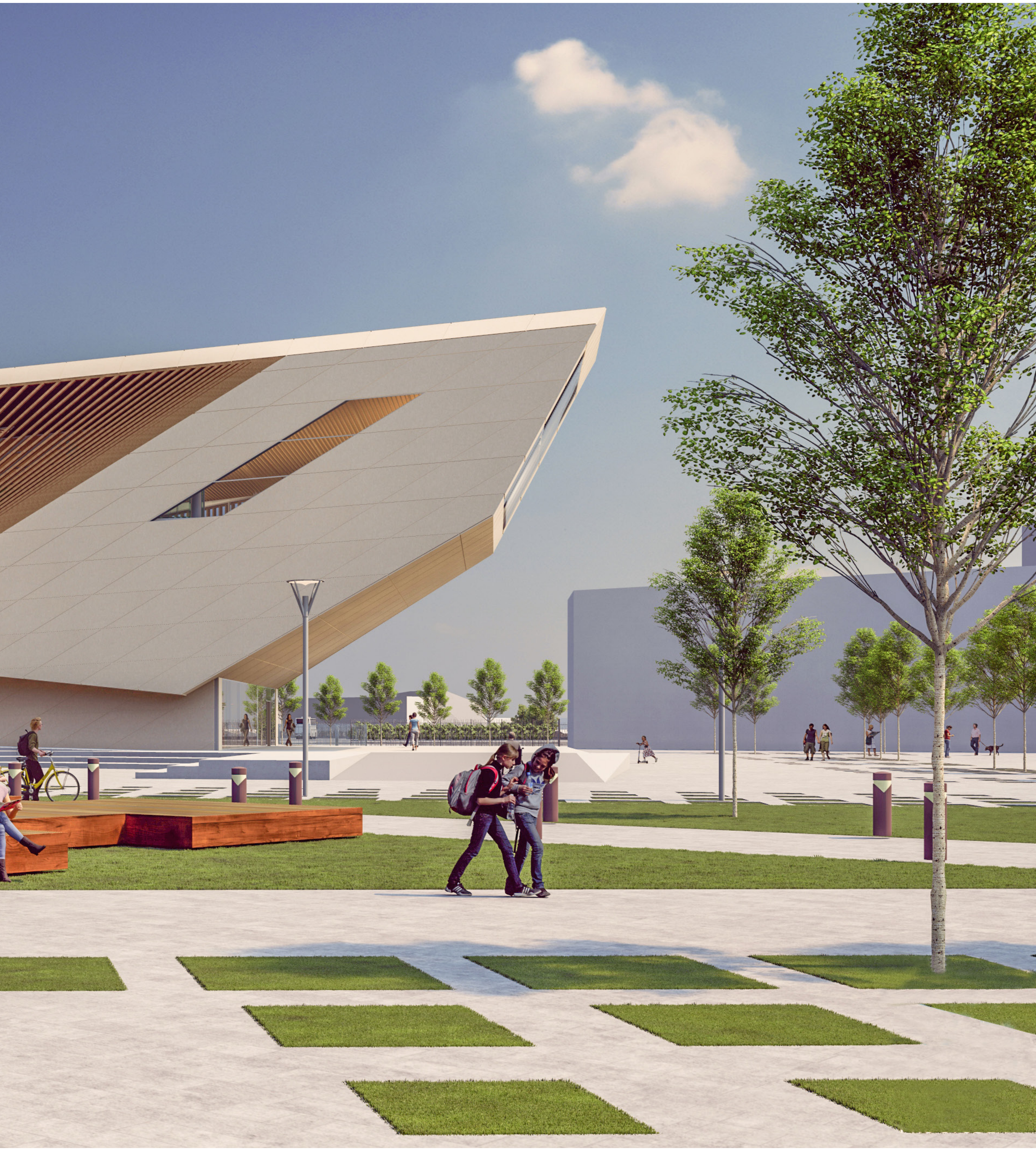

E
F
G
H
I
J
K



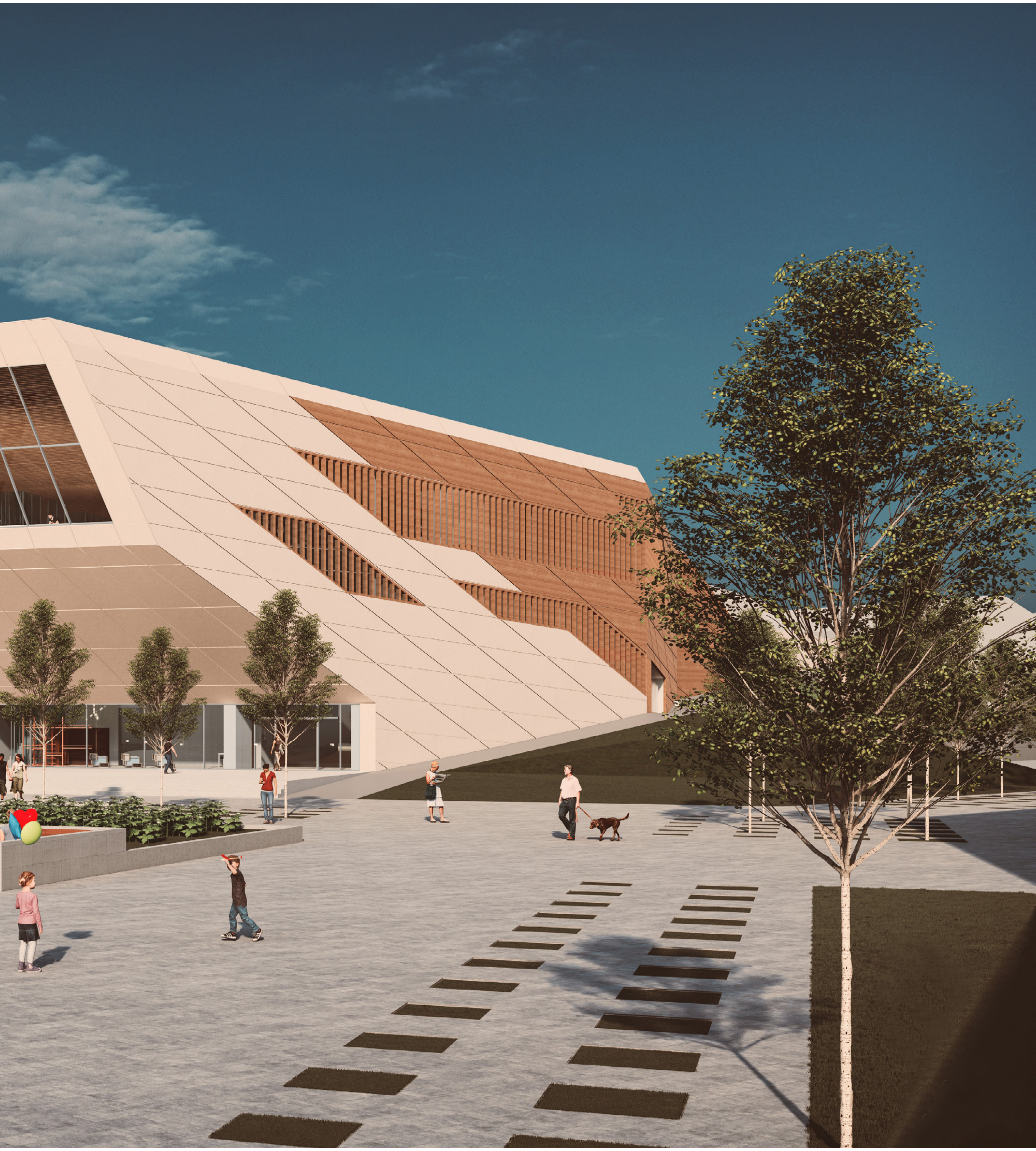
West elevation, part 2
1:200


F.F.L+18200
F.F.L+15200
F.F.L+10700
F.F.L+6700
F.F.L+3350
F.F.L+1200
F.F.L+600
F.F.L+000000

Exterior view of the west facade



Exterior view of the south-east facade



View of the lobby of the building

View of the lobby of the building


Interior view of the auditorium

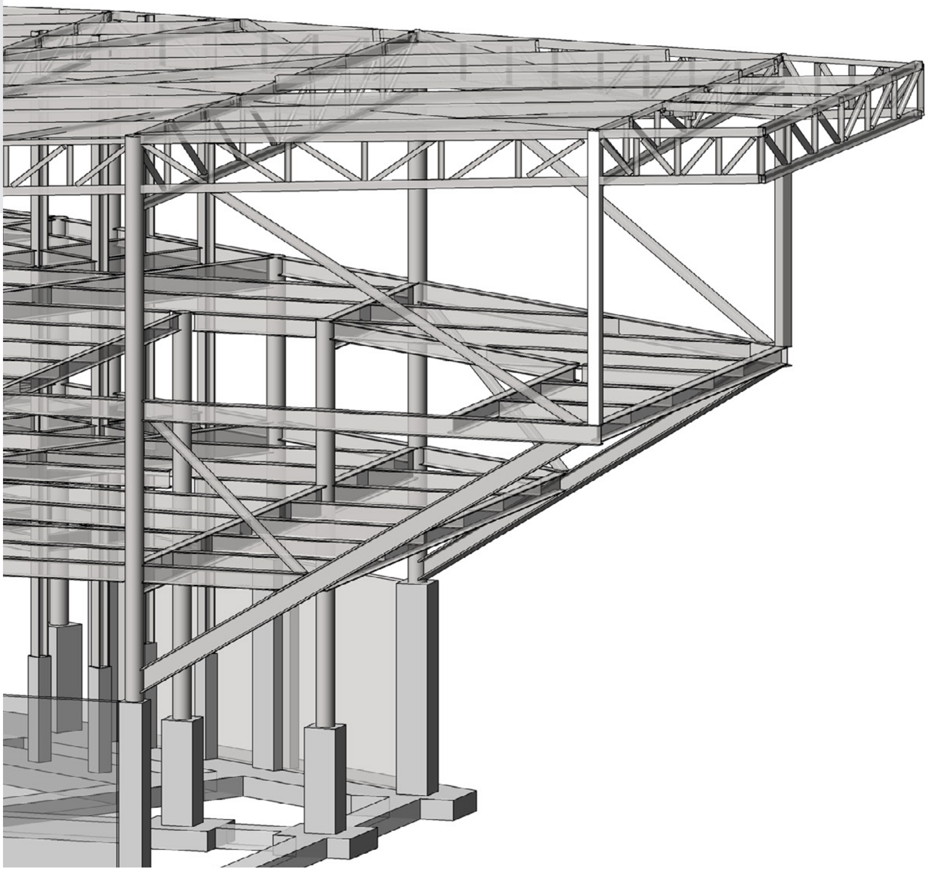
Interior view of the auditorium

Interior view of the second floor of the libarary


1000 chairs
THE JOY OF
CASE STUDY HOUSES
Cool Hotels

Interior view of the exhibition

5



STRUCTURAL DESIGN

1. Introduction

1.1. Building description

The need and the desire to create large open spaces and a large cantilever led to selecting a structural system that provides a large span, and Its superior strength-to-weight ratio means it results in economical use of the material.

In addition, the steel construction is made as a choice regarding a sustainable approach of construction with the desire to reduce greenhouse gas emissions and the carbon footprint of buildings. The next advantage of steel construction is the flexibility to customize, dismantle, recycle, and reuse.

In the end, the important advantage of our project is that it allows achieving our concept of large public spaces and aesthetic appearance.

1.2. Structural system

The system for the main loadbearing structure was chosen to be a steel structure with frames in two directions that consist of beams, trusses and columns and bracing elements which provide lateral stability to the frames.

The main structure of the Cultural Center is divided into two independent parts with an expansion joint. The structure has three accessible floors and two roof structures – one accessible and one not.

The ground floor slab and the foundations structure are made of reinforced concrete. The first and the second-floor slab are composite made by cast-in-place concrete on steel profiled decking. The system of steel structure of the floor consists of secondary and main beams. The roof structure is considered to have a linear steel profiled deck system. The supporting system of the steel deck system is purlins and trusses. The trusses are designed in the direction of the largest span

A particular structural solution was adapted for the cantilever portion of the building. First, we have vertical and inclined pillar members that support the first and second floors. Those elements distribute their load on reinforced concrete shear walls, which improve the stability and the rigidity of their base. Next, the cantilever of the roof is realized by truss systems in parallel and longitudinal directions to ensure that the internal actions and deflection criteria are met.

The sub-structure of stairs was not developed in dept in this stage of design. They are referred to as a separate element and considered as loads on the load-bearing structure.

2. Structural Analysis

2.1. Method

For the calculations of the structural elements first, the static schemes of each element was analyzed. Then the structural analysis was performed by the software SAP2000, which uses a finite-element analysis procedure. After obtaining the results of the internal actions in the elements, the Eurocode is used for performing their verification.

2.2. Reference Design Codes

EN 1991.1-1: Eurocode 1. Actions on structures. Part 1-1: General actions: densities, self-weight and imposed loads for buildings

EN 1991.1-3: Eurocode 1. Actions on structures. Part 1-3: General actions: snow loads

EN 1991.1-3: Eurocode 1. Actions on structures. Part 1-4: General actions: wind actions

EN 1992-1.1: Eurocode 2. Design of concrete structures. Part 1-1. General rules and rules for buildings.

EN 1993-1.1: Eurocode 3. Design of steel structures – Part 1-1. General rules and rules for building

EN 1994: Eurocode 4: Design of composite steel and concrete structures

For Nationally Determined Parameters (NDP), the recommended values will be adopted.

However, different assumptions, according to National Annexes, will be applied if needed.

2.3. Materials

2.3.1. Concrete

Concrete strength class C30/37 [Eurocode 2 Table 3.1] with the following properties:

Concrete characteristic cubic compressive strength: $f_{ck,cube} = 37\,MPa$

Characteristic cylinder compressive strength: $f_{ck} = 30\,MPa$

Design compressive strength:

$$f_{cd} = \alpha_{cc} \frac{f_{ck}}{\gamma_c} = 0,85.\frac{30}{1,5} = 17N/mm^2$$

$\alpha_{cc} = 0,85$ is according to the National Annex

Medium tensile strength:

$$f_{ctm} = 2,9N/mm^2$$

Characteristic tensile strength:

$$f_{ctk,0.05} = 2,0N/mm^2$$

Design tensile strength:

$$f_{ctd} = \alpha_{ct} \frac{f_{ctk,0.05}}{\gamma_c} = 1,0\frac{2,0}{1,5} = 1,33N/mm^2$$

Secant modules:

$$E_{cm} = 33GPa = 33000N/mm^2$$

2.3.2. Steel for reinforcement

Reinforcing steel class B450C [Eurocode 2 Table 3.4] with the following properties:

Characteristic yield strength: $f_{yk} = 450\,\text{MPa}$

Design yield strength:

$$f_{sd} = \frac{f_{yk}}{\gamma_s} = \frac{450}{1,15} = 391\text{N}/\text{mm}^2$$

Modules of elasticity:

$$E_s = 200000\text{N}/\text{mm}^2$$

2.3.3. Steel load-bearing structure

Structural Steel S355 [Eurocode 3 Table 3.1]

Characteristic yield strength $f_{yk} = 355\,\text{N}/\text{mm}^2 (t \leq 40\text{mm})$

Design yield strength:

$$f_{yd} = \frac{f_{yk}}{\gamma_M} = \frac{355}{1,05} = 391\text{N}/\text{mm}^2$$

Ultimate tensile strength:

$$f_u = 510\,\text{N}/\text{mm}^2 (t \leq 40\text{mm})$$

Modules of elasticity:

$$E_s = 210000\text{N}/\text{mm}^2$$

Shear Modules:

$$G = \frac{E}{2(1+\nu)} \approx 81000\text{N}/\text{mm}^2$$

2.4. Classification of actions

2.4.1. Permanent loads

2.4.1.1. Self-weight of structural elements

| Reinforced concrete:

According to Table A.1 - Construction materials-concrete and mortar taken from Annex A in EN 1991-1-1:2002 (E):

$$\rho = 25\text{kN}/\text{m}^3$$

| Steel:

According to Table A.4 - Construction materials-concrete and mortar taken from Annex A in EN 1991-1-1:2002 (E)

$$\rho = 78,5\text{kN}/\text{m}^3$$

2.4.1.2. Self-weight of non-structural elements

Vertical closures

EXTERNAL WALL				
Layer	Material	Thickness [m]	Specific weight [kN/m^3]	Weight [kN/m^2]
1	Timber interior cladding panels	0.01	5.5	0.06
2	Double gypsum board	0.025	-	0.21
3	Vapour barrier	0.0022	-	-
4	Gypsum board	0.025	-	0.21
5	Dry wall structure	0.1	-	0.50
6	Thermal insulation layer (rockwool)	0.12	1.75	0.21
8	Dry wall structure	0.1	-	0.50
9	Thermal insulation layer (rockwool)	0.12	1.75	0.21
10	Fiber reinforced cement board	0.025	-	0.21
11	Vapour barrier	0.0022	-	-
12	Thermal insulation layer- EPS	0.14	-	0.20
13	Ventilated air gap	0.04	-	-
14	Double fiber cement cladding panels	0.024	-	0.60
			Total	**2.90**

Table.1. Self-weight of vertical closures - external wall

INTERNAL WALL				
Layer	Material	Thickness [m]	Specific weight [kN/m3]	Weight [kN/m2]
1	Timber interior cladding	-	5.5	0.30
2	Double gypsum board	0.025	8	0.20
3	Vapour barrier	0.0022	-	-
4	Plasterboard with finishing	0.025	-	0.10
5	Dry wall structure	0.05	-	0.40
6	Thermal insulation layer (rockwool)	0.04	1.75	0.07
7	Acoustic cavity still air	0.18	-	-
8	Dry wall structure	0.05	-	0.40
9	Thermal insulation layer (rockwool)	0.04	1.75	0.07
10	Double gypsum board	0.025	8	0.20
			Total	**1.74**

Table.2. Self-weight of vertical closures - internal wall

Since the internal walls are different heights and the maximum is 4.5m, so 1.74x4.5 = 7.92 kN/m

EN 1991-1-1 [§ 6.3.1.2(8)] permits to consider an equivalent uniformly distributed load all over the floor, instead of the free action of movable partitions if the slab can well redistribute the load transversally. The nominal value of this uniform load is given in function of the linear self-weight of the wall considered:

- for movable partitions with a self-weight $\leq$1.0 kN/m wall length: q_k = 0.5 kN/m^2

- for movable partitions with a self-weight $\leq$ 2.0 kN/m wall length: qk = 0.8 kN/m2

- for movable partitions with a self-weight $\leq$ 3.0 kN/m wall length: qk = 1.2 kN/m2

In case of partitions with linear self-weight exceeding 3,0 kN/m EN 1991-1-1 [§6.3.1.2(9)] recommends considering the effective position of the load on the slab.

However, the load of inside walls is hereby considered to be uniformly distributed in order to avoid further Calculations in case of a possible change of disposition of partitions during the design working life of the building. Assuming a 3 m span between inside walls, following the assumptions of EN 1991-1-1, the correspondent equivalent uniformly distributed load is

$$7.9 / 5 = 1.58 kN / m^2 \approx 1.60 kN / m^2$$

It has to be specified that this equivalent uniform load has to be considered as a live load with partial safety factor $\gamma_Q = 1,5$ (=0 where favorable) for Ultimate Limit State (ULS) combinations and coefficients $\psi_0 = \psi_1 = \psi_2 = 1,0$ for Serviceability Limit State (SLS) combinations.

| Horizontal closures

INTERNAL SLAB				
Layer	Material	Thickness [m]	Specific weight [kN/m3]	Weight [kN/m2]
1	Stone tiles and base	0.05	27	1.35
2	Service hosting perlite	0.1	2	0.20
3	Concrete slab	0.112	25	2.80
4	Soundproof carpet	0.012	-	-
5	Profiled steel sheet	-	-	0.12
6	Acoustic insulation layer in rockwool	0.1	1.75	0.18
7	Ceiling system	-	-	0.40
8	Building services	-	-	0.30
10	Internal wood finishing	-	5	0.30
			Total	**5.65**

ACCESSIBLE ROOF				
Layer	Material	Thickness [m]	Specific weight [kN/m3]	Weight [kN/m2]
1	Stone tiles and base	0.05	27	1.35
2	Drainage layer	0.05	15	0.75
3	Waterproof bituminous membrane	0.004	10.5	0.04
4	Double thermal insulation in XPS	0.18	-	0.20
5	Anti vapor layer -polyethylene	0.02	-	-
6	Concrete slab	0.12	25	3.00
7	Profiled steel sheet	-	-	0.12
8	Acoustic insulation layer in rockwool	0.1	1.75	0.18
9	False ceiling system	-	-	0.40
10	Building services	-	-	0.50
11	Internal wood cladding	0.02	5.5	0.11
			Total	**6.65**

Table.3. Self-weight of horizontal closures -internal slab and accessible roof

NON-ACCESSIBLE ROOF				
Layer	Material	Thickness [m]	Specific weight [kN/m3]	Weight [kN/m2]
1	Double fiber cement cladding panels	0.024	-	0.60
2	Ventilated air gap	0.04	-	-
3	Waterproof bituminous membrane	0.004	10	0.04
4	Double thermal insulation in XPS	0.18	-	0.20
5	Anti vapor layer -polyethylene	0.02	-	-
6	Acoustic air gap with metal deck	0.083	-	0.10
7	Acoustic insulation layer in rockwool panels	0.1	1.75	0.18
8	Ceiling system	-	-	0.40
9	Building services	-	-	0.50
10	Internal cladding with double gypsum boards	0.025	8	0.20
11	Wood interior ceiling finishing	-	5.5	0.30
			Total	**2.52**

Table.4. Self-weight of horizontal closures non-accessible roof

2.4.2. Imposed loads on internal floors and accessible roof

According to EN 1991-1-1:2002 Table 6.1 we have category of use type C and more specifically:

Category	Specific Use	Example
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilets.
B	Office areas	
C	Areas where people may congregate (with the exception of areas defined under category A, B, and D[1)])	**C1**: Areas with tables, etc. e.g. areas in schools, cafés, restaurants, dining halls, reading rooms, receptions.
		C2: Areas with fixed seats, e.g. areas in churches, theatres or cinemas, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms.
		C3: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts.
		C4: Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages.
		C5: Areas susceptible to large crowds, e.g. in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platforms.
D	Shopping areas	**D1**: Areas in general retail shops **D2**: Areas in department stores
[1)] Attention is drawn to 6.3.1.1(2), in particular for C4 and C5. See EN 1990 when dynamic effects need to be considered. For Category E, see Table 6.3		
NOTE 1 Depending on their anticipated uses, areas likely to be categorised as C2, C3, C4 may be categorised as C5 by decision of the client and/or National annex. NOTE 2 The National annex may provide sub categories to A, B, C1 to C5, D1 and D2 NOTE 3 See 6.3.2 for storage or industrial activity		

Table.5. Categories of intespecific use (Eurocode 1 Table 6.1)

According to EN 1991-1-1:2002 Table 6.2 we have Imposed loads on floors, balconies and stairs in buildings:

Categories of loaded areas	q_k [kN/m^2]	Q_k [kN]
Category A		
- **Floors**	1,5 to2,0	2,0 to 3,0
- **Stairs**	2,0 to4,0	2,0 to 4,0
- **Balconies**	2,5 to 4,0	2,0 to 3,0
Category B	2,0 to 3,0	1,5 to 4,5
Category C		
- C1	2,0 to 3,0	3,0 to 4,0
- C2	3,0 to 4,0	2,5 to 7,0 (4,0)
- C3	3,0 to 5,0	4,0 to 7,0
- C4	4,5 to 5,0	3,5 to 7,0
- C5	5,0 to 7,5	3,5 to 4,5
category D		
- D1	4,0 to 5,0	3,5 to 7,0 (4,0)
- D2	4,0 to 5,0	3,5 to 7,0

Table.6. Imposed loads on internal floors (Eurocode 1 Table 6.2)

Finally, we have imposed load of:

$$q_k = 2.65 + 5.00 = 7.65 kN / m^2$$

2.4.3. Imposed loads on the non-accessible roof

According to EN 1991-1-1:2002 Table 6.9 we have Imposed loads on roof as following:

Roof	q_k [kN/m^2]	Q_k [kN]
Category H	q_k	Q_k
NOTE 1 For category H q_k may be selected within the range 0,00 kN/m^2 to 1,0 kN/m^2 and Q_k may be selected within the range 0,9 kN to 1,5 kN. Where a range is given the values may be set by the National Annex. The recommended values are: q_k = 0,4 kN/m^2, Q_k = 1,0kN NOTE 2 q_k may be varied by the National Annex dependent upon the roof slope. NOTE 3 q_k may be assumed to act on an area A which may be set by the National Annex. The recommended value for A is 10 m^2, within the range of zero to the whole area of the roof. NOTE 4 See also 3.3.2 (1)		

Table.7. Imposed loads on roofs (Eurocode 1 Table 6.9

We take the imposed load on the roof according to the recommended value of:

$$q_k = 0.4 kN / m^2$$

2.4.4. Snow load

EN 1991-1-3 with specifications according to the National Annex dated 24-11-2004 apply. For the persistent design situation, the snow load on the roof is expressed by the formula [Expression 5.1-EC1-1-3]:

$$s = \mu . C_e . C_t . s_k$$

μ is the snow load shape coefficient equal to 0,8 for an angle of the pitch of the roofless than 30° [EN1991-1-3 §5.3.2 and 5.3.3 - Figure 5.2]

C_e is the exposure coefficient function of the topography of the site. C_e = 1,0 for normal topography, that is: “areas where there is no significant removal of snow by wind on construction work, because of terrain, other construction works or trees.” [EN1991-1-3 § 5.2.(7) – Table 5.1 following the National Annex].

C_t is the thermal coefficient that should be used to account for the reduction of snow loads on roofs with high thermal transmittance (> 1 W/m²K); C_t = 1,0 unless otherwise specified [EN1991-1-3 § 5.2.(8) and National Annex].

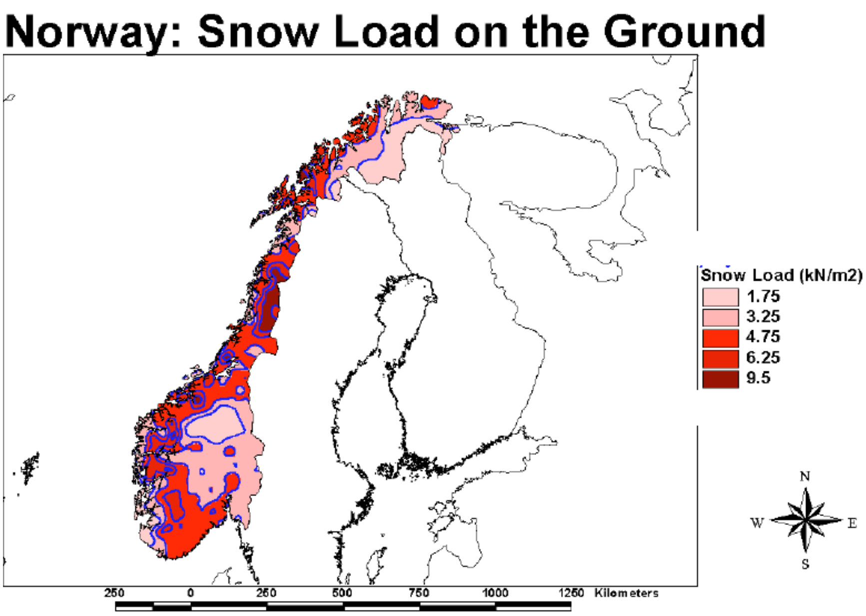


Figure.59. Snow load on the ground

$\boxed{s_k = 4.75 \mathrm{kN/m^2}}$ is the characteristic value of snow load on the ground for Oslo [Figure C.10 EN 1991-1-3:2003] for a design working life of the structure of 50 years following the initial design assumptions.

In the end, the value of the snow load is:

$s = 0.8x1.00x1.00x4.75 = \boxed{3.8 \mathrm{kN/m^2}}$

2.4.5. Wind load

According to EN 1991-1-4, the following procedure applies.

From the National Annex of Norway -Table NA.4(90.1) from NS-EN 1991-1-4:2005/ NA:2009 The fundamental value of the basic wind velocity, $v_{b,0}$, is taken.

For the city of Oslo: $\boxed{\mathrm{v_{b,0}} = 22\,\mathrm{m/s}}$

2.4.5.1. The basic wind velocity

The basic wind velocity shall be calculated from Expression (4.1):

$\mathrm{v_b = c_{dir}.\,c_{season}.\,v_{b,o}}$

where:

$\mathrm{v_b}$is the basic wind velocity, defined as a function of wind direction and time of year at 10 m above ground of terrain category II.

$\mathrm{v_{b,o}}$ is the fundamental value of the basic wind velocity;

$\mathrm{c_{dir}}$ is the directional factor, the recommended value is 1,0;

$\mathrm{c_{season}}$ is the season factor, the recommended value is 1,0;

$\mathrm{v_b = v_{b,0}} = 22\,\mathrm{m/s}$

2.4.5.2. Mean wind velocity

The mean wind velocity $v_{m,z}(z)$ at a height *z* above the terrain depends on the terrain roughness and orography and on the basic wind velocity v_b, and should be determined using Expression (4.3):

$\mathrm{v_m(z) = C_r(z).\,C_0(z)v_{b,o}}$

$\mathrm{C_r(z)}$ is the roughness factor;

$\mathrm{C_0(z)}$ is the orography factor, taken as 1,0 unless otherwise specified;

The roughness factor $\mathrm{C_r(z)}$, accounts for the variability of the mean wind velocity at the site of the structure due to the height above ground level and the ground roughness of the terrain upwind of the structure in the wind direction considered.

The recommended procedure for the determination of the roughness factor at height z is based on a logarithmic velocity profile and is given by the following Expression [Expression 4.4-EC1-1-4]:

$\mathrm{C_r(z) = k_r.\,ln\left(\frac{z}{z_0}\right)}$ for $\mathrm{z_{min} \leq z \quad \leq z_{max}} = 200\mathrm{m}$

where:

$k_r = 0{,}19\left(\frac{z_0}{z_{0,II}}\right)^{0.07}$ with $z_{0,II} = 0.05$

Recommended values for z_{min} and z_{max} are given in Tab. 3.1 [Table 4.1 – EC1-1-4] depending on the five representative terrain categories.

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10

Table.8. Terrain categories (Eurocode 1, Table 3.1)

The building is located in Oslo. The building is located near to the sea with surfaces covered by buildings, as described in category IV from the table Tab. 3.1 [Table 4.1 – EC1-1-4]:

IV category:

$z_0 = 1.0$ m, $z_{min} = 10$ m

The maximum height of the building is: $z = 20\text{m}$

$$k_r = 0.19\left(\frac{1.0}{0.05}\right)^{0.07} = 0.234$$

$$C_r(z) = k_r . \ln\left(\frac{z}{z_0}\right) = 0{,}234 . \ln\left(\frac{20}{1.0}\right) = 0{,}7$$

$$v_m(z) = 0.7 \times 0.1 \times 22 = 15.4\text{m/s}$$

2.4.5.3. Wind turbulence

The turbulence intensity $I_v(z)$ at height z can be evaluated with the following formula

[Expression 4.7-EC1-1-4]:

$$I_v(z) = \frac{k_I}{C_0(z)\ln(z/z_0)}; \text{ for } z_{min} \leq z \quad \leq z_{max} = 200\text{m}$$

k_I is the turbulence factor. The value of k_I may be given in the National Annex. The recommended value for k_I is 1,0;

$C_0(z)$ is the orography factor;

z_0 is the roughness length;

$$I_v(z) = \frac{1}{1.\ln(20/1)} = 0{,}34;$$

2.4.5.4. Peak velocity pressure

$q_p(z) = [1 + 7I_v(z)]\frac{1}{2}\rho V_m^2(z) = \left[1 + \frac{7k_I}{C_0(z)\ln(z/z_o)}\right].\frac{1}{2}\rho V_b^2[C_o(z)k_r\ln(z/z_0)]^2$

$\rho = 1{,}25\text{kg/m}^3$ is the air density (recommended value)

$q_p(z) = [1 + 7 \times 0.34].\frac{1}{2} \times 1{,}25 \times 15.4^2 = 400.8\text{N/mm}^2 = 0.4\text{kN/m}^2$

Wind pressure on surfaces

A positive wind load stands for pressure whereas a negative wind load indicates suction on the surface. This definition applies for the external wind action as well as for the internal wind action.

External pressure coefficients

The wind pressure acting on the external surfaces, w_e, can be obtained by the following Expression [Expression 5.1-EC1-1-4]:

$$w_e = c_{pe}.q_p(z_e);$$

Where z_e is the reference height for the external pressure and c_{pe} is the pressure coefficient for the external pressure that will be specified later on.

Internal pressure coefficient

The internal pressure coefficient depends on the size and distribution of the openings in the building envelope.

Within the building in this project it is not possible to estimate the permeability and opening ratio of the building. So c_{pi} should be taken as the more onerous of + 0,2 and – 0,3. In this case c_{pi} is unfavorable when c_{pi} is taken to + 0,2.

The wind force, acting on a structure or a structural element may be determined by vector summation of the forces acting on their reference surfaces [Expression 5.5-EC1-1-4]:

$$F_w = c_s c_d \sum_i w_{ei}.A_i$$

where the structural factor $c_s c_d$ (separated into a size factor c_s and a c_d dynamic factor)

The structural factor $c_s c_d$ is taken as 1,0 as recommended for low-rise buildings(h ≤ 15m). Also, to graph for determining the structural factor $c_s c_d$ Figure D.1 from [Annex D EN 1991-1-4:2005 (E)] is studied. Even though the building is not with constant dimensions in plan and elevation, we can evaluate from Figure D.1 that for all wight/ height ratios, the value of the factor $c_s c_d$ is $[0{,}90 \div 0{,}95]$ which means that taking $c_s c_d = 1$ is on the safe side in our case.

2.4.5.5. Wind pressure coefficients for horizontal walls

For the project, we are going to use an approximation of the geometry. The goal of the approximation is to simplify the calculation and to make possible the use of coefficients and reference cases for rectangular in plan buildings.

The roof is defined flat according to [EN 1991-1-4:2005 §7.2.3] with a slope (α) of 5°< α=4° < 5°

| Wind in the X direction θ = 0° (in the longitudinal direction)

$b = 100m$- where b is the parallel dimension of the building to the wind direction:

$e \;\; = \min(b; 2h) = \min(100; 2.20) = 40 \text{ m}$

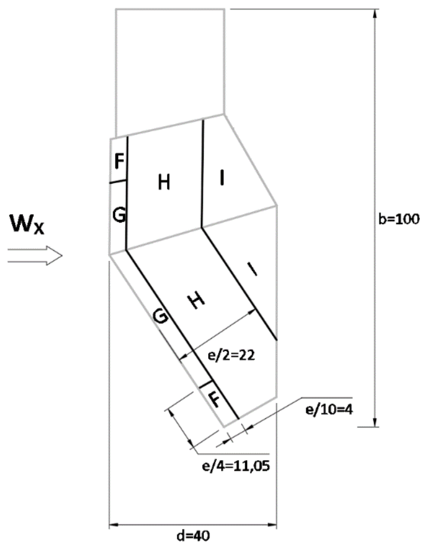


Figure.60. Wind pressure zones for horizontal walls in X direction

Wind pressure coefficients for the external surfaces of the roof for wind in the longitudinal direction taken as x direction:

Wind in X direction		
zone	$C_{pe,10}$	w_e [kN/m^2]
F	-1.8	-0.72
G	-1.2	-0.48
H	-0.7	-0.28
I	-0.2	-0.08

Table.9. Wind pressure coefficinets on horizontal walls in X direction

| Wind in the Y direction θ = 90° (in parallel direction)

$b = 40\text{m}$ - where b is the parallel dimension of the building to the wind direction:

$e \quad = \min(b; 2h) = \min(40; 2.20) = 40 \text{ m}$

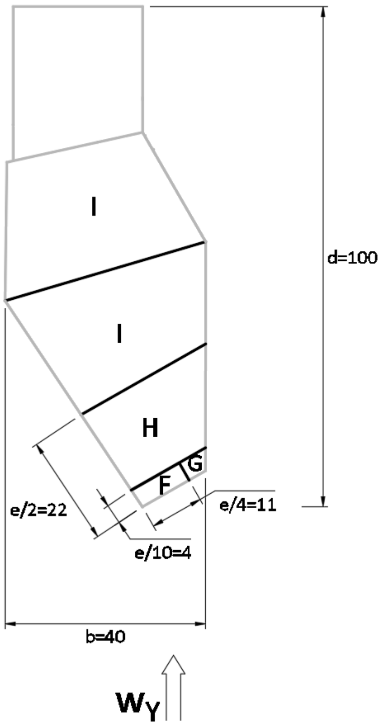


Figure.61. Wind pressure zones for horizontal walls in Y direction

Wind pressure coefficients for the external surfaces of the roof for wind in the parallel direction taken as y-direction:

Wind in Y direction		
zone	$C_{pe,10}$	w_e [kN/m²]
F	-1.8	-0.72
G	-1.2	-0.48
H	-0.7	-0.28
I	-0.2	-0.08

Table.10. Wind pressure coefficinets on horizontal walls in Y direction

2.4.5.6. Wind pressure coefficients for vertical walls

| Wind in the X direction $\theta = 0°$

$h_{max} = \max(h_1; h_2) = \max(23{,}1; 25{,}2) = 25{,}2m$

$b = 100m$

$e = \min(b; 2h) = \min(100; 2 \times 25.2) = 50.4m$

$e / 5 = 50.4 / 5 = 10{,}1m$

$e > d_1 = 25{,}85$ - zone A, B

$e > d_2 = 15$ - zone A, B

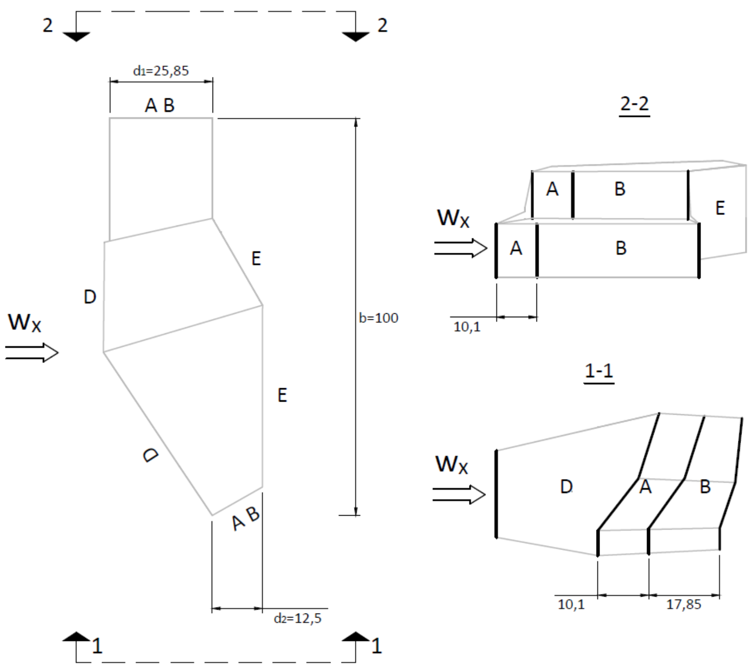


Figure.62. Wind pressure zones for vertical walls in X direction

Wind in X direction		
zone	$C_{pe,10}$	w_e [kN/m^2]
A	-1.2	-0.48
B	-0.8	-0.32
C	-0.5	-0.2
D	0.8	0.32
E	-0.7	-0.28

Table.11. Wind pressure coefficinets on vertical walls in X direction

| Wind in Y direction $\theta = 90°$

$h_{max} = \max(h_1; h_2) = \max(23{,}1; 25{,}2) = 25{,}2m$

$b = 40m$

$e = \min(b; 2h) = \min(40; 2 \times 25.2) = 40m$

$e / 5 = 40 / 5 = 8m$

$e < d = 100$ - zone A, B, C

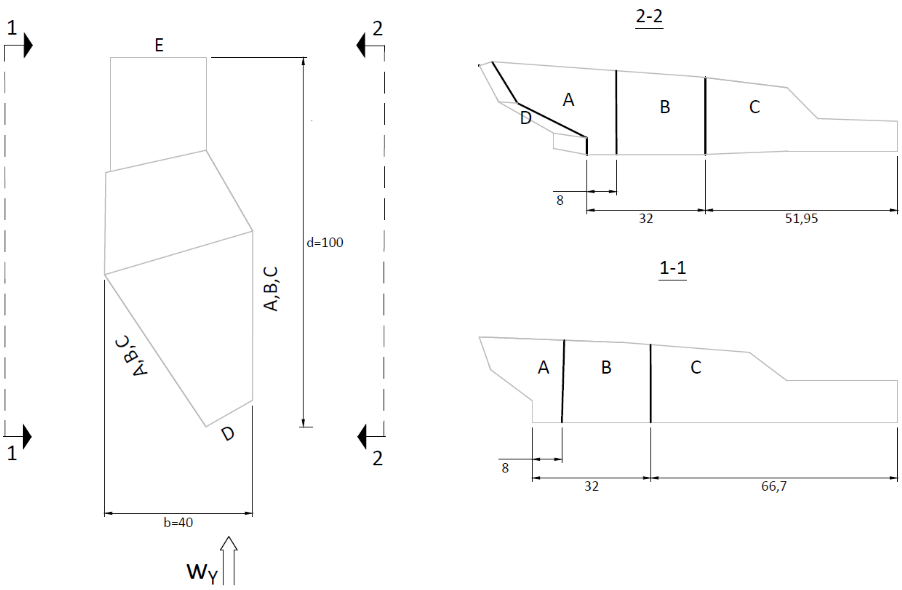


Figure.63. Wind pressure zones for vertical walls in Y direction

Wind in Y direction		
zone	$C_{pe,10}$	w_e [kN/m^2]
A	-1.2	-0.48
B	-0.8	-0.32
C	-0.5	-0.2
D	0.8	0.32
E	-0.7	-0.28

Table.12. Wind pressure coefficinets on vertical walls in Y direction

2.5. Composite concrete-steel slab design

2.5.1. Steel composite deck choice

This trapezoidal sheet is produced using special prints that make it perfectly linked with the concrete, preventing horizontal sliding and vertical detachment. Along with the properties of formwork, which are exerted during the casting stage, trapezoidal sheets also offer a much more important function of positive stressed reinforcement after the concrete has set. The system has been consolidated for years, so this system is the fastest system available for the construction of a floor, as the sheets simply have to be laid and filled with inert materials.

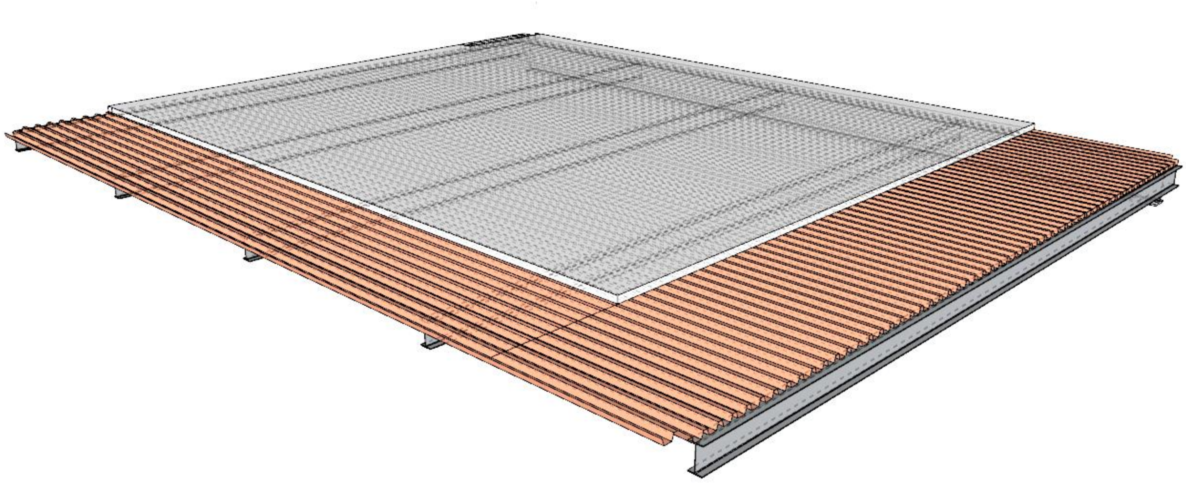


Figure.64. Composite floor system

The profile of the steel sheet is selected is ComFlor® 46, made of steel type S280GD(EN10346) defined by the UNI EN 10147 standard and equivalent for mechanical performance, to Fe 360 steel as laid down in the UNICNR 10022 standard.

The total stress of the steel should be not greater than 165 N/mm^2 $f_{yb} = 280MPa; f_y = 250MPa; E = 210000MPa$ with the following section:

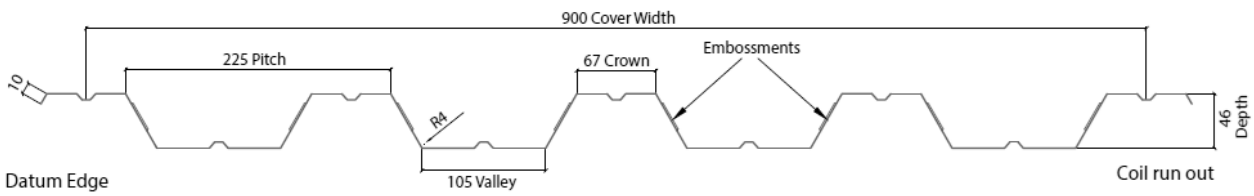


Figure.65. ComFlor steel sheet section (source: tatasteelconstruction.com)

The ComFlor® 46 collaborating slab consists of a trapezoidal sheet on which a slab of concrete is cast. During the casting stage and up to the point when the concrete has reached a suitable level of maturity (phase 1), the weight of the concrete, personal, and machinery are supported only by the sheet. Upon reaching maturity (phase 2), the sheet and concrete form a homogeneous section with all the characteristics of traditional reinforced concrete sections, in which the sheet acts as the reinforcement bars to withstand the positive bending moments. To absorb the negative moments, bars have to be used, as in typical slabs.

2.5.2. Design Load Phase 1

The sheet is regarded as continuous and that means that the sheeting is a continuous beam and also a statically indeterminate structure. The continuous beam, in this case, has four roller support and one hinge. For the calculation of the reactions in the supports, each section is considered as an independent beam.

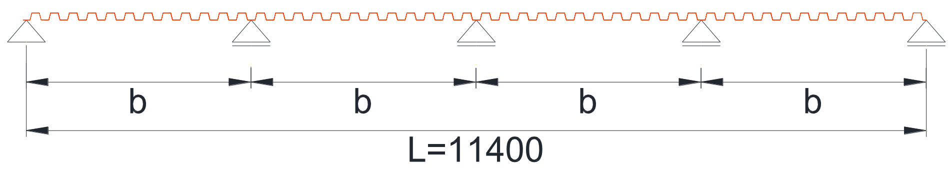


Figure.66. Static scheme of the steel sheet and the composite slab

2.5.3. Load definition

2.5.3.1. Construction loads

As mentioned before during casting the sheet is subjected to construction loads.

The loads that the sheeting is subjected to are the load of the concrete during casting as well as other construction load as follows by 4.11.2 (1) EN 1991-1-6;

Actions to be taken into account simultaneously during the casting of concrete may include working personnel with small site equipment (Q_{ca}), formwork and load-bearing members (Q_{cc}) and the weight of fresh concrete (which is one example of Q_{cf}), as appropriate.

The recommended characteristic values of actions due to construction loads during casting of concrete are given by Table 4.2 of EN 1991-1-6:

Action	Loaded area	Load in kN/m^2
(1)	Outside the working area	0,75 covering Q_{ca}
(2)	Inside the working area 3 m x 3 m (or the span length if less)	10 % of the self-weight of the concrete but not less than 0,75 and not more than 1,5 Includes Q_{ca} and Q_{cf}
(3)	Actual area	Self-weight of the formwork, load-bearing element (Q_{cc}) and the weight of the fresh concrete for the design thickness (Q_{cf})

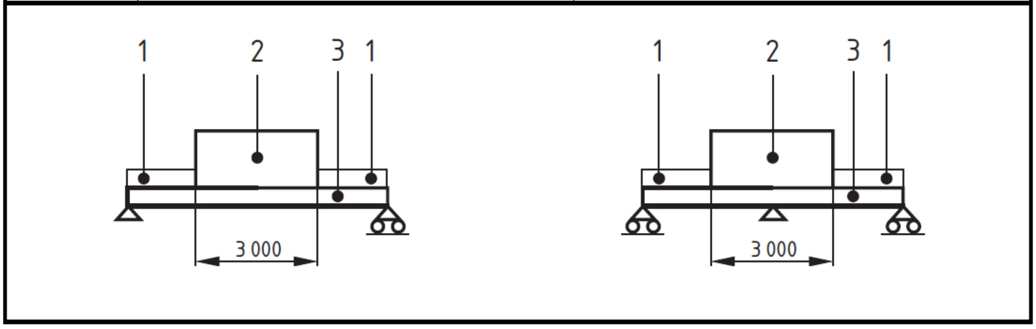


Figure.67. Load distribution in the construction phase (source: Eurocode 1)

2.5.3.2. The load is for 1m' of the profiled sheet

The typical analysis for the sheeting considers a strip with size of 1 m' and all the loads and calculations are made for 1 m'.

$Q_{cf} = 1{,}50\ \ kN/m^2 . 1m = 1{,}50kN/m$ load inside the working area with size 3mx3m;

$Q_{ca} = 0{,}75\ \ kN/m^2 . 1m = 0{,}75kN/m$ load outside of the working area;

$Q_{cc} = 0{,}12kN/m^2 . 1m = 0{,}12kN/m$ is the self-weight of the loadbearing element – the steel sheet;

$Q_{cf} = h_{eq} . \gamma_c$ is the weight of the fresh concrete and where h_{eq} is the equivalent height of the composite slab;

| Section Properties:

To calculate the properties of the composite slab, we need to calculate the actual section properties of it.

The first step is to calculate the area of the profiled section of the slab and the equalized height of the slab section:

$A = 22{,}5.9{,}4 + 0{,}5(6{,}7 + 10{,}5).4{,}6 = 251{,}1\text{cm}^2$

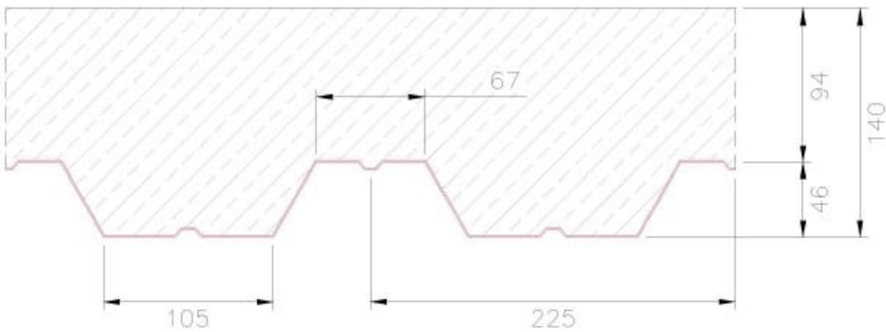


Figure.68. Composite slab section properties for 1m'

$h_{eq}=\frac{251{,}1}{22{,}5}=11{,}16\approx 11{,}2\text{cm}$

$Q_{cf}=h_{eq}.\gamma_c=0{,}112.25=2{,}80\text{kN/m}^2.1\text{m}=2{,}80\text{kN/m}$

Next, we calculate the number of ribs of the sheet in 1m'

$n=\frac{1000}{105}=9{,}5$

Following this, we calculate the area of the ribs of the sheet in 1m'

$A_p=(33{,}5.2+53{,}09.2+105).1{,}2.9{,}5=3171{,}3\text{mm}^2/\text{m}=31{,}7\text{cm}^2/\text{m}$

After this, we calculate the section modulus S_{1-1}, the location of the barycenter z_1, and the moment of inertia of the sheet:

$S_{1\text{-}1}=A_i.z_i=(33{,}5.46.2+53{,}09.46.0{,}5.2)1{,}2.9{,}5=62975{,}2\text{mm}^2/\text{m}=62{,}9\text{cm}^2/\text{m}$

$z_1=S_{1\text{-}1}/A_p=62{,}9/31{,}7=1{,}99\text{cm}$

$I_{1\text{-}1}=\left[\Sigma l_i.h_i^2/12+l_i.z_i^2\right]1{,}2.9{,}5.2=(33{,}5.46^2+\frac{53{,}09.46^2}{12}+53{,}09.1{,}2.2.9{,}5=2469972\text{mm}^4/\text{m}=247\text{cm}^4/\text{m}$

Finally, we calculate the moment of inertia I_p and the section modulus W_p of the composite slab:

$I_p=I_{1\text{-}1}\text{-}A_p z_1^2=247\text{-}31{,}7.1{,}99^2=121{,}5\text{cm}^4/\text{m}$

$W_p=I_p/z_1=121{,}5/1{,}99=61{,}04\text{cm}^3/\text{m}$

2.5.3.3. Design Load Combinations

| Ultimate Limit State

$\sum \gamma_G G_k + \gamma_{Q,1} . Q_{k,1} + \sum \gamma Qi . \varphi_{0,i} . Q_{k,i}$

$G_k = 1,50 + 0,12 + 2,80 = 4,42 kN/m$
$1,35G_k + 1,5 . Q_k = 1,35.4,4 = 6,0 kN/m$

| Serviceability Limit State

$G_{k,j} + Q_{k,1} + \sum_{i>1} \psi_{0,i} . Q_{k,i}$

$G_k = 0,12 + 2,80 = 2,92 kN/m$
$G_k + Q_k = 2,92 kN/m$

2.5.3.4. Sizing the steel sheet by producer load tables

The structural design of the floor deck is performed by using datasheets from the manufacturer of the steel sheet profiles. These data sheets will specify the maximum spans or loads that the deck is designed to carry, as well as other parameters fire-resisting time, crippling capacity, and deflection limit states.

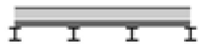
| Ultimate Limit State

Total load applied:

$$1{,}35G_k + 1{,}5.Q_k = 1{,}35.4{,}4 = 6{,}0\mathrm{kN/m^2}$$

From the following table from the manufacturer of the steel sheet profiles by selecting the slab thickness $140\mathrm{mm}$ and total load $7{,}5\ \mathrm{kN/m^2}$ (on a safety side), the fire-resisting period of 90 minutes and the thickness of the sheet $1{,}20\mathrm{mm}$ we obtain the maximum span possible for the sheet.

After this we selected span $\boxed{b = 2{,}85\mathrm{m}}$.



Props	Fire period	Slab depth (mm)	Mesh 0.1% min.reqd.	Total applied load (kN/m²)					
				5.00	7.50	10.00	5.00	7.50	10.00
				0.90mm			1.20mm		
None	60 minutes	120	A142	2.90 (A142)	2.90 (A142)	2.90 (A193)	3.27 (A142)	3.27 (A142)	3.26 (A252)
		130	A142	2.87 (A142)	2.87 (A142)	2.88 (A193)	3.19 (A142)	3.19 (A142)	3.19 (A193)
		140	A142	2.82 (A142)	2.82 (A142)	2.82 (A142)	3.12 (A142)	3.12 (A142)	3.11 (A193)
		150	A142	2.74 (A142)	2.74 (A142)	2.74 (A142)	3.05 (A142)	3.05 (A142)	3.05 (A142)
		160	A142	2.67 (A142)	2.67 (A142)	2.67 (A142)	3.02 (A142)	3.02 (A142)	3.02 (A142)
		170	A193	2.60 (A193)	2.60 (A193)	2.60 (A193)	2.97 (A193)	2.97 (A193)	2.97 (A193)
		180	A193	2.53 (A193)	2.53 (A193)	2.53 (A193)	2.91 (A193)	2.91 (A193)	2.91 (A193)
		190	A193	2.45 (A193)	2.45 (A193)	2.45 (A193)	2.86 (A193)	2.86 (A193)	2.86 (A193)
		200	A193	2.38 (A193)	2.38 (A193)	2.38 (A193)	2.80 (A193)	2.80 (A193)	2.80 (A193)
None	90 minutes	130	A142	2.87 (A142)	2.87 (A193)	2.87 (A252)	3.19 (A142)	3.19 (A193)	3.17 (A393)
		140	A142	2.82 (A142)	2.82 (A142)	2.81 (A193)	3.12 (A142)	3.11 (A193)	3.11 (A252)
		150	A142	2.74 (A142)	2.74 (A142)	2.74 (A193)	3.05 (A142)	3.05 (A142)	3.05 (A193)
		160	A142	2.67 (A142)	2.67 (A142)	2.67 (A142)	3.02 (A142)	3.02 (A142)	3.02 (A193)
		170	A193	2.60 (A193)	2.60 (A193)	2.60 (A193)	2.97 (A193)	2.97 (A193)	2.97 (A193)
		180	A193	2.53 (A193)	2.53 (A193)	2.53 (A193)	2.91 (A193)	2.91 (A193)	2.91 (A193)
		190	A193	2.45 (A193)	2.45 (A193)	2.45 (A193)	2.86 (A193)	2.86 (A193)	2.86 (A193)
		200	A193	2.38 (A193)	2.38 (A193)	2.38 (A193)	2.80 (A193)	2.80 (A193)	2.80 (A193)
None	120 minutes	140	A142	2.82 (A142)	2.81 (A193)	2.81 (A252)	3.11 (A193)	3.11 (A252)	3.10 (A393)
		150	A142	2.74 (A142)	2.74 (A193)	2.73 (A252)	3.05 (A142)	3.05 (A193)	3.04 (A252)
		160	A142	2.67 (A142)	2.67 (A142)	2.66 (A193)	3.02 (A142)	3.02 (A193)	3.02 (A252)
		170	A193	2.60 (A193)	2.60 (A193)	2.60 (A193)	2.97 (A193)	2.97 (A193)	2.96 (A252)
		180	A193	2.53 (A193)	2.53 (A193)	2.53 (A193)	2.91 (A193)	2.91 (A193)	2.91 (A193)
		190	A193	2.45 (A193)	2.45 (A193)	2.45 (A193)	2.86 (A193)	2.86 (A193)	2.86 (A193)
		200	A193	2.38 (A193)	2.38 (A193)	2.38 (A193)	2.80 (A193)	2.80 (A193)	2.80 (A193)

Figure.69. Table from Comflor 46 manufacturer (source: tatasteelconstruction.com)

2.5.4. Design Phase 2

2.5.4.1. Characteristic loads

| Permanent loads

Floor self-weight:

$G_k = 5,65 kN/m^2$

| Variable loads

Live load:

$Q_{k,1} = 5,00 kN/m^2$

Inside partitions self-weight:

$Q_{k,2} = 1,60 kN/m^2$

2.5.4.2. Ultimate Limit State (ULS)

| Load combinations

The stress analysis will be carried out referring to the following static schemes shown and for the appropriate ULS load combinations.

The continuous beam is loaded in combinations in order to obtain the most unfavorable position of the variable load. The permanent load is always constantly distributed.

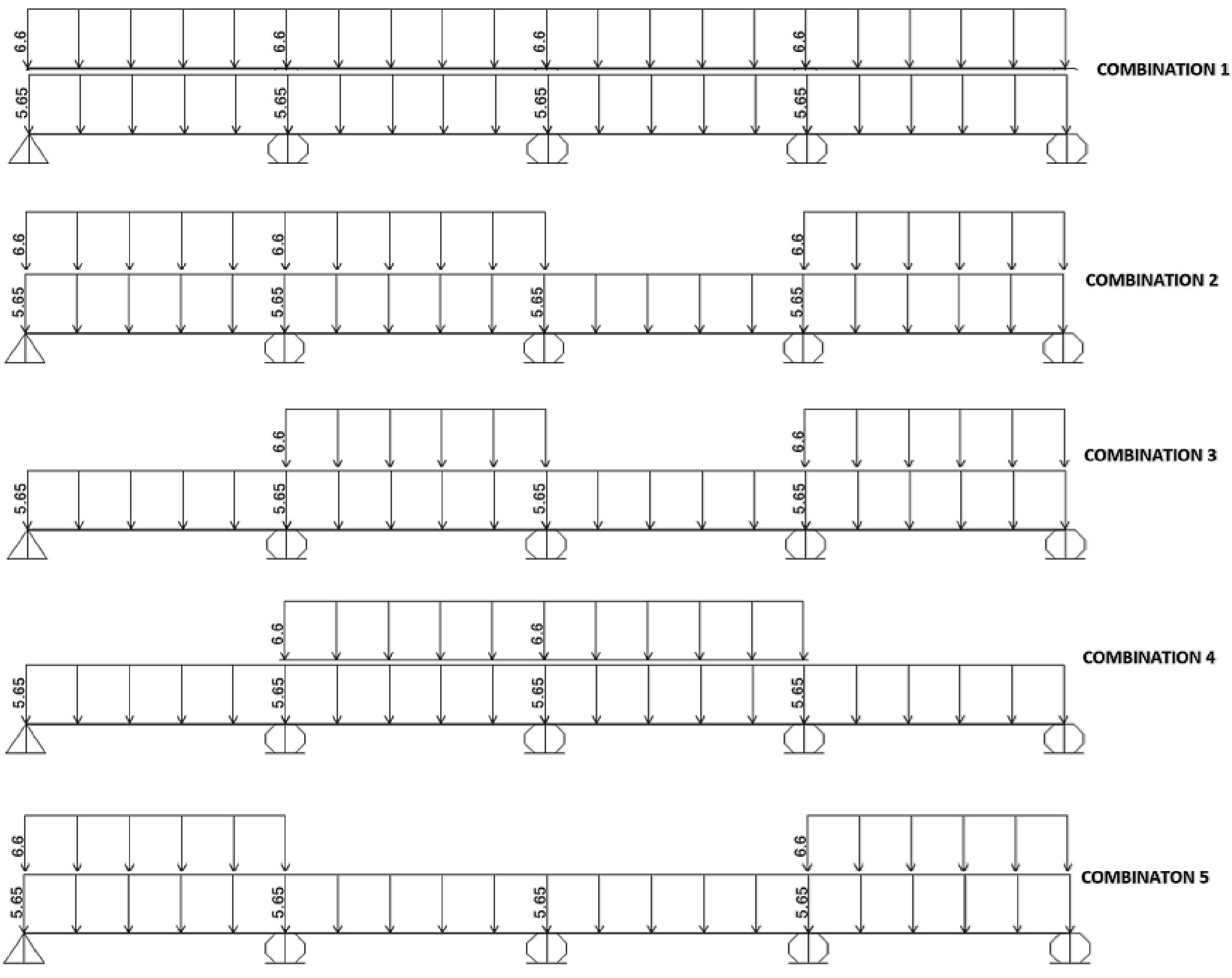
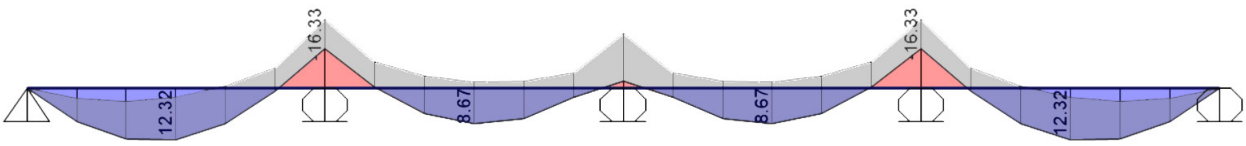


Figure.70. Load combinations for ULS verification of the composite slab

| Envelope Moment Diagram [kN.m/m]



| Envelope Shear Diagram[kN/m]

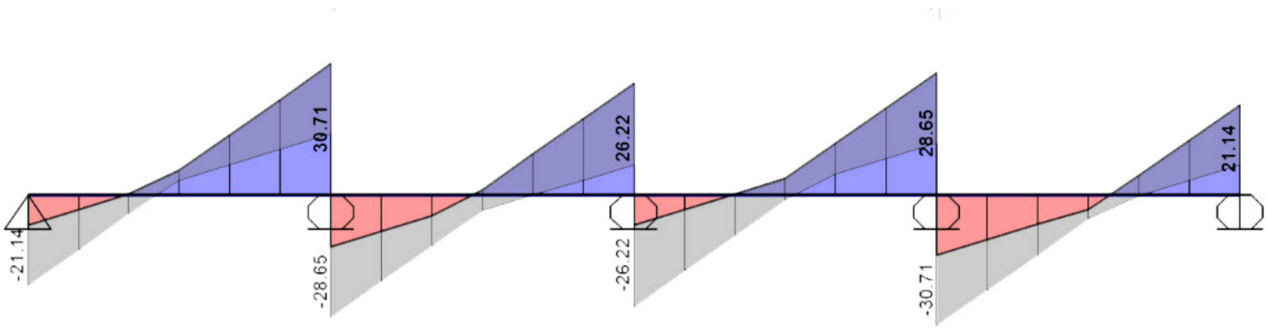


Figure.71. Envelope diagrams for the composite slabs

2.5.4.2.1. Reinforcement pre-dimensioning

The longitudinal reinforcing bars will be pre-dimensioned using the same formulas that will be used for further verifications.

The following assumptions are then made:

- only tension reinforcement is considered
- plane sections remain plane
- the strain in bonded reinforcement is the same as the surrounding concrete
- the tensile strength of the concrete is ignored
- a rectangular stress distribution is assumed for the concrete in compression [EC2 – 3.1.7(3)] where the factor η is equal to 0,8 [EC2 – Expression 3.19] and the factor λ is equal to 1,0 [EC2 – Expression 3.21] for a concrete strength class C25/30.

An elastic-perfectly plastic stress/strain relationship is assumed for reinforcing bars without the need to check the strain limit [EC2 – 3.2.7(2)b];

The rotational equilibrium about the barycentre of the tension reinforcement is:

$$0,8bxf_{cd}(d-0,4x)=M_{Ed}$$

The translational equilibrium, under the hypothesis of yielded tension reinforcement, is:

$$0,8bxf_{cd}-A_s.f_{yd}=0$$

and the required reinforcement area is:

$$A_s=\frac{0,8bxf_{cd}}{f_{yd}}$$

The hypothesis of yielded steel is verified if

$$\xi=\frac{x}{d}\leq\frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}}\leq\frac{0,0035}{0,0035+0,00196}=0,641$$

The so determined reinforcement needs to be not less than the minimum recommended [EC2 – 9.2.1.1, Expression 9.1N]:

$$A_{s,min}=0,26\frac{f_{ctm}}{f_{yk}}b_t d$$

In order to determine the cover, the prescriptions in EN 1992-1-1 §4.4.1 apply.

The nominal cover is defined as a minimum cover, c_{min}, plus an allowance in design for deviation, Δc_{dev} [Expression 4.1-EC2]:

$$c_{nom}=c_{min,dur}+\Delta c_{dev}$$

$c_{min,dur}$ = 15 mm [§ 4.4.1.2(5)-EC2 and Table 4.4 N-EC2 for exposure class X1 and structural class S4, being used concrete of strength class C25/30]

Assuming Δc_{dev} = 10 mm, as recommended by EC2 [§4.4.1.3], the nominal concrete cover is:

$$c_{nom}=c_{min,dur}+\Delta c_{dev}=25mm$$

| Maximum Positive Bending Moment

For simplification of the calculations, the contribution of the trapezoidal sheet as reinforcement is ignored, and additional reinforcement is designed.

The design of the slab is made considering a 1 m wide strip.

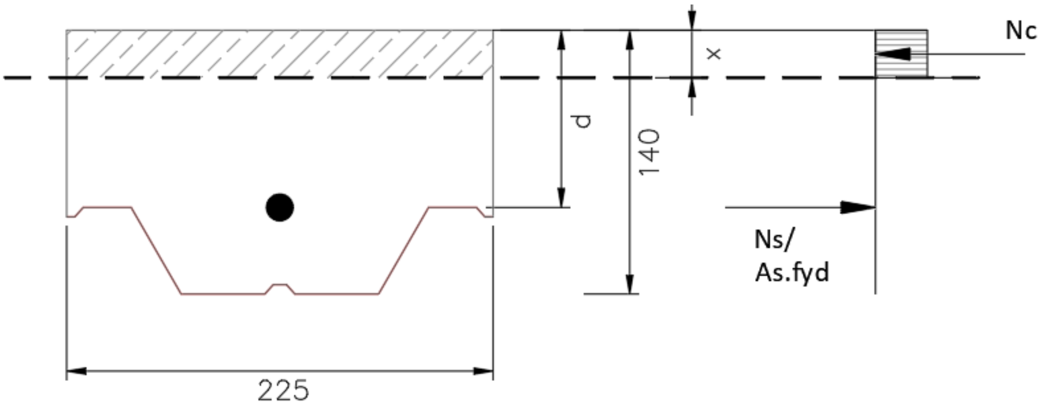


Figure.72. Maximum positive bending moment verification

The width b of the cross-section in the tension zone is 1000 mm

The effective depth of the slab is:

$$d = h - c - \phi / 2 = 94 + (46 - 25 - 6) = 109mm = 10,9cm$$

The minimum recommended reinforcement is:

$$A_{s,min} = 0,26.\frac{fctm}{fyk}.b.d = 0,26.\frac{2,9}{450}.100.10,9 = 1,84cm^2 / m$$

$\longrightarrow$ Assuming $\boxed{4\phi 12 / m}$ $A_S = 4,52cm^2 / m$

The position of the neutral axis is obtained by translational equilibrium:

$$x = (A_s.f_{yk} / \gamma_s) / (0,85.f_{ck}.b / \gamma_c) = (4,52.45 / 1,15) / (0,85.3,0.100 / 1,5) = 1,04cm$$

The following limit for the depth of the neutral axis applies:

$$\xi = \frac{x}{d} = \frac{10,4}{109} = 0,096 < \frac{\varepsilon_{cu2}}{\varepsilon_{cu2} + \varepsilon_{syd}} = \frac{0,0035}{0,0035 + 0,00196} = 0,641$$

The forces in the concrete and in the rebar are obtained by translational equilibrium:

$$N_{cf} = N_s = \frac{A_s f_{sk}}{\gamma_s} = \frac{4,52.45}{1,15} = 176,9kN / m$$

Through the rotational equilibrium about the barycentre either of the compressions or tensions, the resisting moment can be determined as follows:

$$M_{pl,Rd} = N_{cf}(d - 0,5x) = 176,9(11 - 0,5.1,04) = 1854kNcm / m = 18,5kNm / m$$

We compare the resisting moment to the maximum positive moment from the envelope diagram:

$$\boxed{M_{Ed} = 12,32kN.m / m < M_{pl,Rd} = 18,5kN.m / m}$$

| Maximum Negative Bending Moment

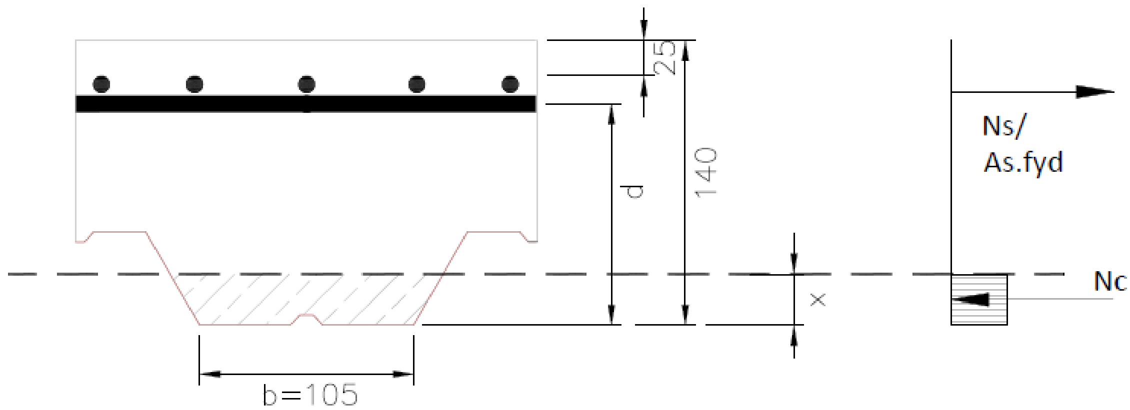


Figure.73. Maximum negative bending moment verification

The width of the cross-section in the tension zone for all ribs located in 1m strip is :

b=9,5.105=997,5mm=9,98cm

The effective depth of the slab is:

$$d = h - c - \varphi / 2 = 140 - 25 - 6 = 109mm = 10,9cm$$

The minimum recommended reinforcement is:

$$A_{s,min} = 0,26.\frac{fctm}{fyk}.b.d = 0,26.\frac{2,9}{450}.99,8.10,9 = 1,82cm^2 / m$$

$\rightarrow$ Assuming $\boxed{5\phi 12 / m}$ $A_s = 5,66cm^2 / m$

The position of the neutral axis is obtained by translational equilibrium:

$$x = (A_s.f_{yk} / \gamma_s) / (0,8.f_{ck}.b / \gamma_c) = (5,66.45 / 1,15) / (0,8.3,0.99,8 / 1,5) = 1,39cm$$

The following limit for the depth of the neutral axis applies:

$$\xi = \frac{x}{d} = \frac{13,9}{109} = 0,128 < \frac{\varepsilon_{cu2}}{\varepsilon_{cu2} + \varepsilon_{syd}} = \frac{0,0035}{0,0035 + 0,00196} = 0,641$$

The forces in the concrete and in the rebar are obtained by translational equilibrium:

$$N_{cf} = N_s = \frac{A_s f_{sk}}{\gamma_s} = \frac{5,66.45}{1,15} = 221,5kN / m$$

Through the rotational equilibrium about the barycentre either of the compressions or tensions, the resisting moment can be determined as follows:

$$M_{pl,Rd} = N_{cf}(d - 0,5x) = 221,5(10,9 - 0,5.1,39) = 1952kNcm / m = 19,52kNm /$$

We compare the resisting moment to the maximum negative moment from the envelope diagram:

$$\boxed{M_{Ed} = 16,33kN.m / m < M_{pl,Rd} = 19,52kN.m / m}$$

| Detail of the reinforcement in the slab

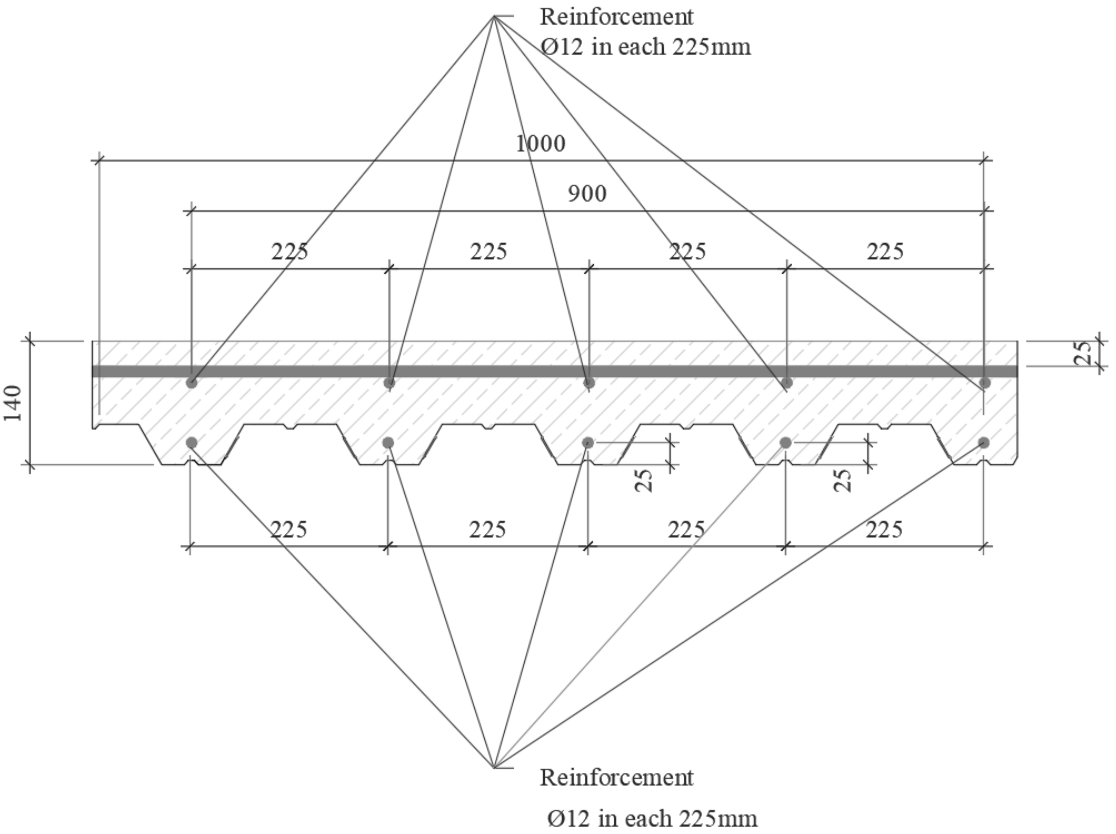


Figure.74. Detail of the reinforcement in the slab

2.5.4.2.2. Shear Ultimate Limit State verification (ULS)

$$V_{Rd,c} = \frac{C_{Rd,c}}{\gamma_c}\left[\left(1+\sqrt{\frac{200}{d}}\right)(100.\rho_l.f_{ck})^{1/3}\right]b_w.d$$

For cross-sections in the zones of the positive moment and negative moment near the continuity support, the shear resistance is assumed to be:

$$b_w = 9,5.105 = 997,5mm$$

$$d = h - x = 140 - 13,9 = 126,1mm$$

$$\rho_l = \frac{A_{sl}}{bd} = \frac{566}{997,5.126} = 0,0045 < 0,02$$

$$A_{sl} = 5\phi 12 = 566mm^2$$

The shear resistance of the slab without any additional shear reinforcement is:

$$V_{Rd,c} = \frac{0,18}{1,5}\left[\left(1+\sqrt{\frac{200}{126,1}}\right)(100.0,0045.25)^{1/3}\right]105.126,1 = 8,04kN$$

$$V_{Rd} = 19.8,04 = 152,7kN$$

We compare the resisting shear resistance to the maximum sher force from the envelope diagram:

$$\boxed{V_{Ed} = 30,71kN < 152,7kN}$$

2.5.4.3. Serviceability Limit State (SLS)

The load combination for the SLS is as follows:

$$G_{k,j} + Q_{k,1} + \sum_{i>1} \psi_{0,i}.Q_{k,i} = 5,65 + 5,00 + 1,6 = 12,25kN/m$$

We calculate the maximum deflection of the composite slab using the homogenization factor:

$$n = \frac{E_s}{E_c} = \frac{210000}{33000} = 6,4$$

$$w_{max} = \frac{3}{384}\frac{(G_k + Q_k).L^4}{E.I_c / n} \leq \frac{L}{250}$$

Then the maximum deflection is calculated as follows:

$$w_{max} = \frac{3}{384}.\frac{12,25.10^{-2}.285^4}{21000.11091,7 / 6,4} = 0,17cm < \frac{285}{250} = 1,14$$

2.6. Secondary beam design

2.6.1. Structural scheme

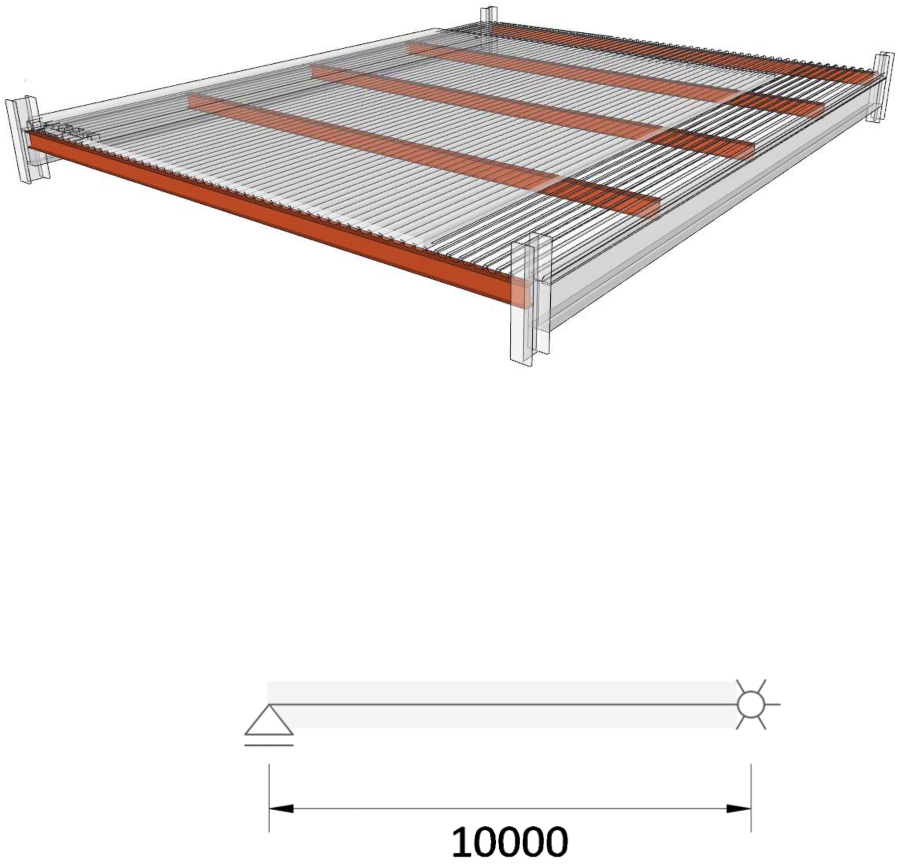


Figure.75. Secondary beam direction and static scheme

2.6.2. Design loads

2.6.2.1. Design load phase 1 - Construction Phase:

| Self Weight:

Trapezoidal sheet	$G_t = 0,2kN/m^2$	$0,2.2,85 = 0,6kN/m$
Concrete	$G_c = 2,8kN/m^2$	$2,8.2,85 = 8,02kN/m$
	Total:	$\Sigma G = 8,62kN/m^2$
working area 3m x3m	$Q_{cf} = 1,5kN/m^2$	$1,5.2,85 = 4,3kN/m$
outside of the working area	$Q_{ca} = 0,75kN/m^2$	$0,75.2,85 = 2,14kN/m$

2.6.2.2. Design load phase 2

| Permanent Loads:

- Internal slab	$G_1 = 5,65kN/m^2$	$5,65.2,85 = 16,1kN/m$
Variable Loads:		$\Sigma G = 16,1kN/m^2$
- Live load	$Q_1 = 5,00kN/m^2$	$5.2,85 = 14,25kN/m$
- Internal walls	$Q_2 = 1,6kN/m^2$	$1,6.2,85 = 4,56kN/m$
	Total:	$\Sigma Q = 18,81kN/m^2$

2.6.3. Design load combinations

| Ultimate Limit State

$$\sum_{j\geq 1} \gamma_{G,j}.G_{k,j} + \gamma_{Q,1}.Q_{k,1} + \sum_{i>1} \gamma_{Qi}.\psi_{0,i}.Q_{k,i}$$

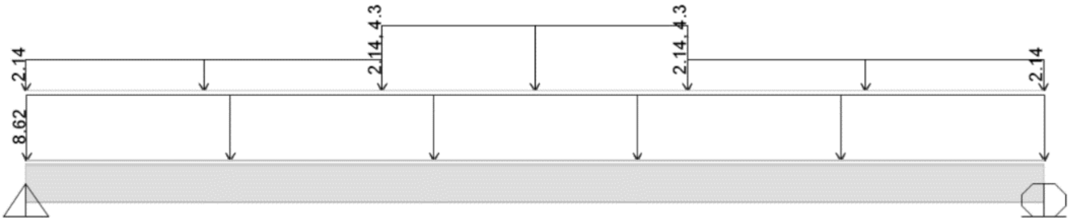
| Serviceability Limit State

$$G_{k,j} + Q_{k,1} + \sum_{i>1} \psi_{0,i}.Q_{k,i}$$

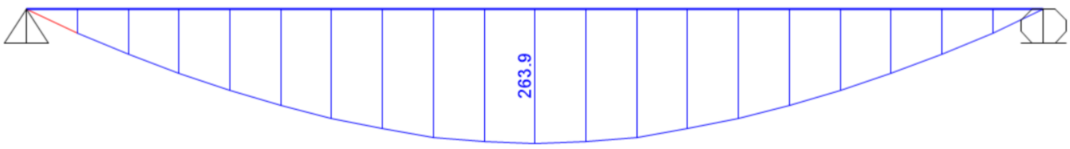
2.6.4. Envelope diagrams

2.6.4.1. Construction Phase 1

| Loads [kN/m²]



| Moment Diagram [kN.m]



| Shear Force Diagram [kN]

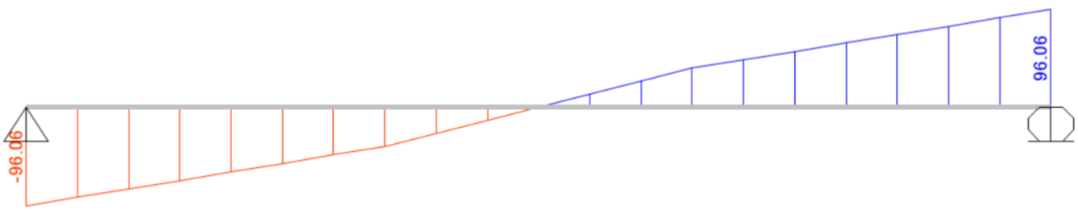
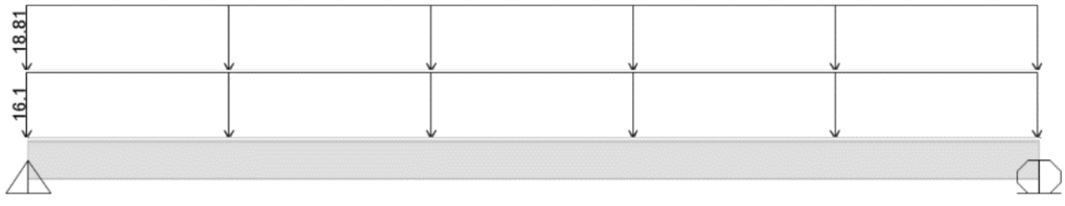


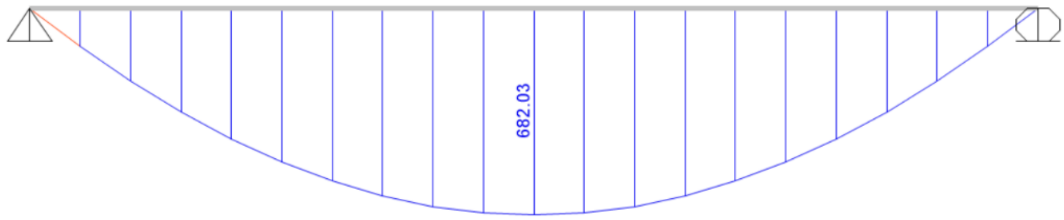
Figure.76. Load distribution, moment and shear diagrams for Phase 1

2.6.4.2. Phase 2

| Loads [kN/m²]



| Moment Diagram [kN.m]



| Shear Force Diagram [kN]

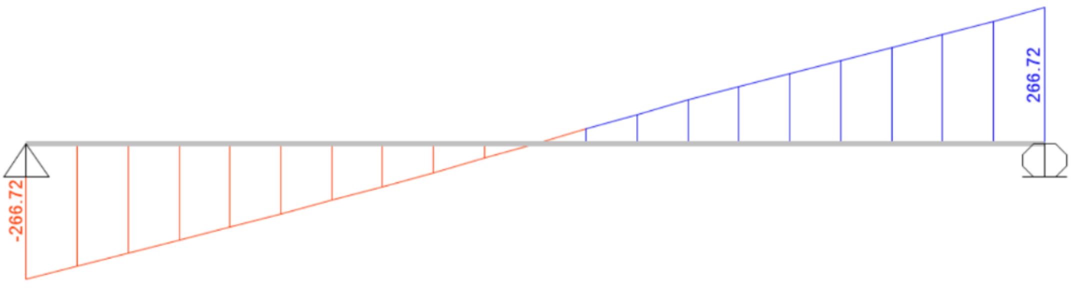


Figure.77. Load distribution, moment and shear diagrams for Phase 2

2.6.5. Design verifications

| Phase 2

The following design verifications was performed.

- Bending about the major axis y-y
- Shear force about the major axis y-y

| Phase 1

In phase 1 also specified as the construction phase, the concrete has not been cast yet, and the top flange of the beam is supported in lateral direction only by the sheet. Nevertheless, buckling can still occur. In the design verification of the beam, the sheet is not taken into consideration, and the design buckling resistance moment is calculated only for the steel beam considered as a laterally unrestrained beam.

- Buckling about major axis y-y

2.6.5.1. Phase 2

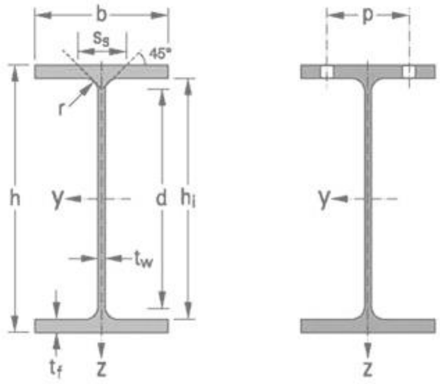
First, we used the ULS and SLS verifications to select a cross-section that satisfies the bending moment and the deflection about the strong axis y-y The selection of the cross-section with minimum characteristics was done as follows:

$$M_{Ed,max} \leq M_{pl,Rd} = \frac{W_{pl,y}.f_y}{\gamma_{M0}}$$

$$(1)\, W_{pl,y} \geq \frac{\gamma_{M0}.M_{Ed,max}}{f_y} = \frac{1,05.682.100}{35,5} = 2017,2cm^3 = 2017,2.10^3mm^3$$

$$w_{max} = \frac{5}{384}\frac{(G_k + Q_k).L^4}{E.I_y} = \frac{5}{384}.\frac{0,35.1000^4}{21000.I_y} \leq \frac{L}{250} = \frac{1000}{250} = 4cm$$

$$(2)\, I_y \geq \frac{5}{384}.\frac{0,35.1000^4}{21000.4} = 54254\,cm^4 = 54254.10^4\,mm^4$$



Denominazione		Dimensioni						Dimensioni di costruzione					Superficie	
	G kg/m	h mm	b mm	t_w mm	t_f mm	r mm	A mm^2	h_i mm	d mm	Ø	Pmin mm	Pmax mm	A_L m^2/m	A_G m^2/t
							x 10^2							
HE 400 AA*	92,4	378	300	9,5	13	27	117,7	352	298	M27	118	198	1,891	20,46
HE 400 A	125	390	300	11	19	27	159,0	352	298	M27	120	198	1,912	15,32
HE 400 B	155	400	300	13,5	24	27	197,8	352	298	M27	124	198	1,927	12,41
HE 400 M	256	432	307	21	40	27	325,8	352	298	M27	132	202	2,004	7,835
HE 450 AA*	99,7	425	300	10	13,5	27	127,1	398	344	M27	120	198	1,984	19,89
HE 450 A	140	440	300	11,5	21	27	178,0	398	344	M27	122	198	2,011	14,39
HE 450 B	171	450	300	14	26	27	218,0	398	344	M27	124	198	2,026	11,84
HE 450 M	263	478	307	21	40	27	335,4	398	344	M27	132	202	2,096	7,959

DENOMINAZIONE		PROPRIETÀ DEL PROFILATO												CLASSIFICAZIONE ENV 1993-1-1						EN 10025:1993	EN 10113-3:1993	EN 10225:2001
		eje fuerte y-y / strong axis y-y / asse forte y-y					eje débil z-z / weak axis z-z / asse debole z-z							pure bending y-y			pure compression					
	G kg/m	I_y mm^4	$W_{el.y}$ mm^3	$W_{pl.y}$◆ mm^3	i_y mm	A_{vz} mm^2	I_z mm^4	$W_{el.z}$ mm^3	$W_{pl.z}$◆ mm^3	i_z mm	s_s mm	I_t mm^4	I_w mm^6	S 235	S 355	S 460	S 235	S 355	S 460			
		x 10^4	x 10^3	x 10^3	x 10	x 10^2	x 10^4	x 10^3	x 10^3	x 10		x 10^4	x 10^9									
HE 400 AA	92,4	31250	1654	1824	16,30	47,95	5861	390,8	599,7	7,06	67,13	84,69	1948	3	3	4	3	3	4	✓	✓	✓
HE 400 A	125	45070	2311	2562	16,84	57,33	8564	570,9	872,9	7,34	80,63	189,0	2942	1	1	3	1	2	3	✓	HI	HI
HE 400 B	155	57680	2884	3232	17,08	69,98	10820	721,3	1104	7,40	93,13	355,7	3817	1	1	1	1	1	1	✓	HI	HI
HE 400 M	256	104100	4820	5571	17,88	110,2	19340	1260	1934	7,70	132,6	1515	7410	1	1	1	1	1	1	✓	HI	HI
HE 450 AA	99,7	41890	1971	2183	18,16	54,70	6088	405,8	624,4	6,92	68,63	95,61	2572	3	3	4	3	4	4	✓	✓	✓
HE 450 A	140	63720	2896	3216	18,92	65,78	9465	631,0	965,5	7,29	85,13	243,8	4148	1	1	1	1	2	3	✓	HI	HI
HE 450 B	171	79890	3551	3982	19,14	79,66	11720	781,4	1198	7,33	97,63	440,5	5258	1	1	1	1	1	2	✓	HI	HI
HE 450 M	263	131500	5501	6331	19,80	119,8	19340	1260	1939	7,59	132,6	1529	9251	1	1	1	1	1	1	✓	HI	HI

Figure.78. Section properties (source perlitayvermiculita.com)

2.6.5.2. Class of the section:

The section HE 450A was selected.

The class of the cross section is determined from Table 5.2 of BS EN 1993-1-1, where a cross section is classified according to the highest (least favorable) class of its compression parts:

Class of the web: $\frac{c}{t_f} = \frac{d}{t_w} = \frac{344}{11,5} = 29,8 < 72\varepsilon = 72\sqrt{\frac{235}{355}} = 58,6 \rightarrow$ class 1

Class of the flange: $\frac{c}{t} = \frac{b_f - t_w - 2r}{2t_f} = \frac{300 - 11,5 - 2.27}{2.21} = 5,58 < 9\sqrt{\frac{235}{355}} = 7,3 \rightarrow$ class 1

The section is class 1

2.6.5.3. Bending Moment Verification

The section is subjected to bending about the major axis y-y.

The design value of the bending moment M_{Ed} at each cross-section should satisfy:

$$\frac{M_{Ed}}{M_{Rd}} \leq 1$$

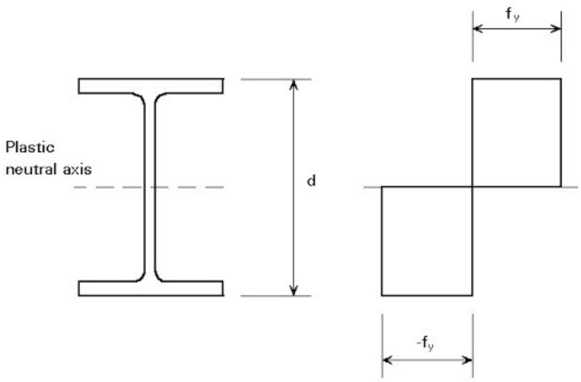


Figure.79. Plastic stress distribution for symmetrical profile (source ESDEP)

The cross-section is a class 1. This allows the section to reach a plastic distribution of the stress fy. So, we can use the plastic properties of the section $W_{pl,y}$ and calculate the design plastic bending moment resistance $M_{pl,Rd,y}$.

$$M_{Ed} \leq M_{pl,Rd} = \frac{W_{pl,y}.f_y}{\gamma_m};$$

$$M_{pl,Rd,y} = \frac{3216.35,5}{1,05.100} = 1087,3kN.m;$$

$$\frac{M_{Ed}}{M_{pl,Rd,y}} = \frac{682,03}{1087,3} = 0,63 < 1$$

2.6.5.4. Shear Force Verification

For the shear verification, the same applies, and we can use the plastic properties of the section to calculate the design plastic shear resistance $V_{pl,Rd,y}$.

$$\frac{V_{Ed}}{V_{Rd}} \leq 1$$

$$A_v = A - 2.b.t_f + (t_w + 2r)t_f$$

$$A_v = 178 - 2.30.2,3 + (1.2 + 2.2,7).2,3 = 74,68\,cm^2$$

$$V_{pl,Rd,y} = \frac{A_v.f_y}{\gamma_{M0}.\sqrt{3}} = \frac{74,68.27,5}{1,05.\sqrt{3}} = 1129,3\,kN$$

$$V_{pl,Rd,y} = 1129,3\,kN > 266,08\,kN = V_{Ed}$$

2.6.6. Serviceability Limit State (SLS)

This verification considered the maximum deflection of the beam.

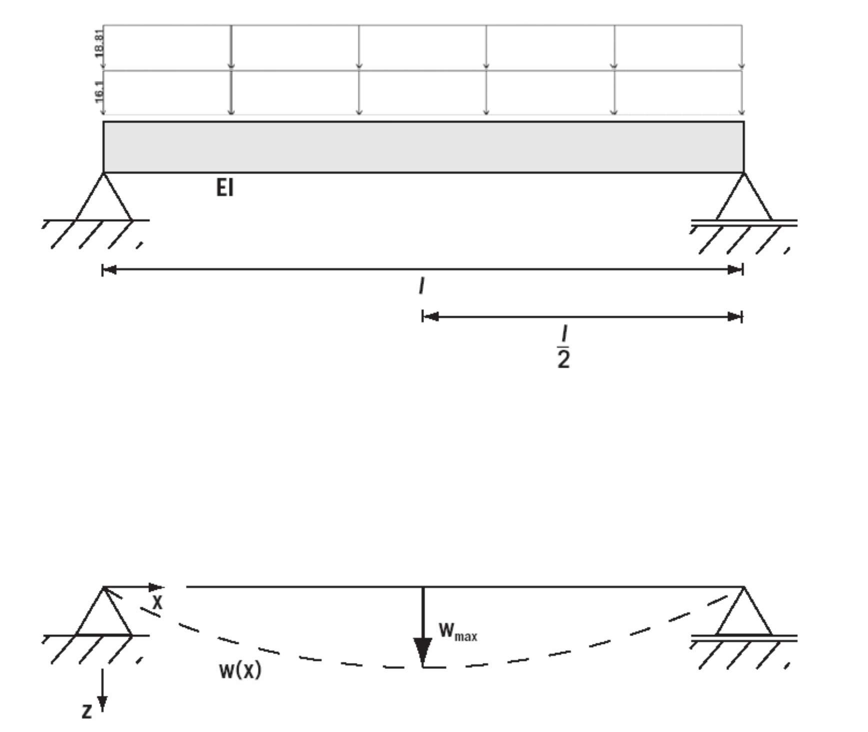


Figure.80. Verification of the maximum deflection in the middle of the span

$$w_{max} = \frac{5}{384}\frac{(G_k + Q_k).L^4}{E.I} = \frac{5}{384}.\frac{0,35.1000^4}{21000.63700} = 3,41cm < \frac{L}{250} = \frac{1000}{250} = 4,00cm$$

2.6.6.1. Phase 1

The verification examines a hot-rolled steel HEA 450 -beam subjected to lateral-torsional buckling (LTB) due to bending moment in the construction phase where the concrete slab does not support the beam laterally.

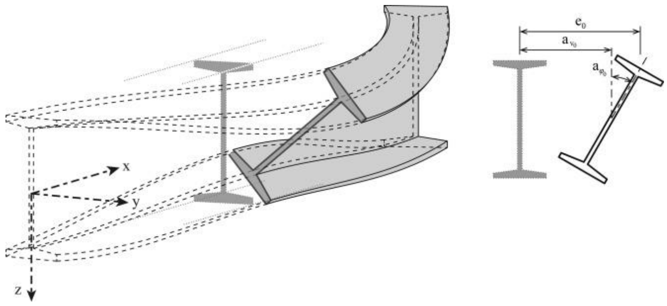


Figure.81. Analysis of lateral-torsional buckling resistance (source: sciencedirect.com)

The verification is based on calculating the buckling resistance.

A laterally unrestrained member subject to major axis bending should be verified against lateral-torsional buckling as follows:

$$\frac{M_{Ed}}{M_{b,Rd}} \leq 1;$$

The design buckling resistance moment of a laterally unrestrained beam should be taken as:

$$M_{b,Rd} = \frac{\chi_{LT}.W_{y,pl}.f_y}{\gamma_{M1}};$$

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \beta\lambda_{LT}^2}} \text{ but } \begin{cases} \chi_{LT} \leq 1,0 \\ \chi_{LT} \leq \dfrac{1}{\lambda_{LT}^2} \end{cases}$$

$$\Phi_{LT} = 0,5\left[1 + \alpha_{LT}(\overline{\lambda_{LT}} - \overline{\lambda_{LT,0}}) + \beta\overline{\lambda_{LT}^2}\right]$$

$$\overline{\lambda_{LT}} = \sqrt{\frac{W_y f_y}{M_{cr}}} \text{ - slenderness}$$

For doubly symmetric sections the critical moment for lateral-torsional buckling is:

$$M_{cr} = C_1.\frac{\pi^2.EI_z}{(K.L)^2}.\left(\sqrt{\left(\frac{K}{K_w}\right)^2.\frac{I_w}{I_z} + \frac{(K.L)^2.G.I_t}{\pi^2.EI_z} + (C_2.z_g)^2} - C_2.z_g\right)$$

M_{cr} is based on gross cross-sectional properties and considers the loading conditions, the real moment distribution, and the lateral restraints.

z_g = +225mm - is the distance between the point of load application and the shear center

$K = 1$ and $K_w = 1$ are effective length factors;

C_1 and C_2 - are coefficients depending on the loading and the restraint;

$\rightarrow$ $C_1 = 1,132$ and $C_2 = 0,459$

$$M_{cr} = 1,132\frac{\pi^2.21000}{(1.1000)^2}.\left(\sqrt{\left(\frac{1}{1}\right)^2.\frac{4,15.10^6}{9465}+\frac{(1.1000)^2.8100.243,8}{\pi^2.21000.9465}+0,459.22,5^2}-0,459.22,5\right)=$$

$= 71863,1 kN.cm$

$$\overline{\lambda_{LT}} = \sqrt{\frac{3216.35,5}{71863,1}} = 1,26 > \overline{\lambda_{LT,0}} = 0,4$$

The imperfection factor α_{LT} corresponding to the appropriate buckling curve may be obtained from the National Annex. The recommended values α_{LT} are given in Table 6.3.

Buckling curve	a	b	c	d
Imperfection factor α_{LT}	0,21	0,34	0,49	0,76

The recommendations for buckling curves are given in Table 6.5.

Cross-section	Limits	Buckling curve
Rolled I-sections	$h/b \leq 2$ $h/b > 2$	b c
Welded I-sections	$h/b \leq 2$ $h/b > 2$	c d

Lateral torsional buckling curves - b and $\alpha_{LT} = 0,34$;

$\overline{\lambda_{LT,0}} = 0,4; \beta = 0,75$

$$\Phi_{LT} = 0,5\left[1+\alpha_{LT}(\overline{\lambda_{LT}}-\overline{\lambda_{LT,0}})+\beta\overline{\lambda_{LT}^2}\right] = 0,5\left[1+0,34(1,26-0,4)+0,75.1,26^2\right] = 1,24$$

$$\chi_{LT} = \frac{1}{\Phi_{LT}+\sqrt{\Phi_{LT}^2-\beta\lambda_{LT}^2}} \text{ but } \begin{cases}\chi_{LT} \leq 1,0 \\ \chi_{LT} \leq \dfrac{1}{\lambda_{LT}^2}\end{cases}$$

$$\chi_{LT} = \frac{1}{1,24^2+\sqrt{1,24^2-0,75.1,26^2}} = 0,47$$

$$M_{b,Rd} = \frac{\chi_{LT}W_{pl,y}.f_y}{\gamma_{M1}} = \frac{0,47.3216.35,5}{1,05} = 51129 kN.cm = 511,3 kN.m$$

$$\frac{M_{Ed}}{M_{b,Rd}} = \frac{283,9}{511,3} = 0,56 < 1,0$$

2.7. Main beam design

2.7.1. Static scheme

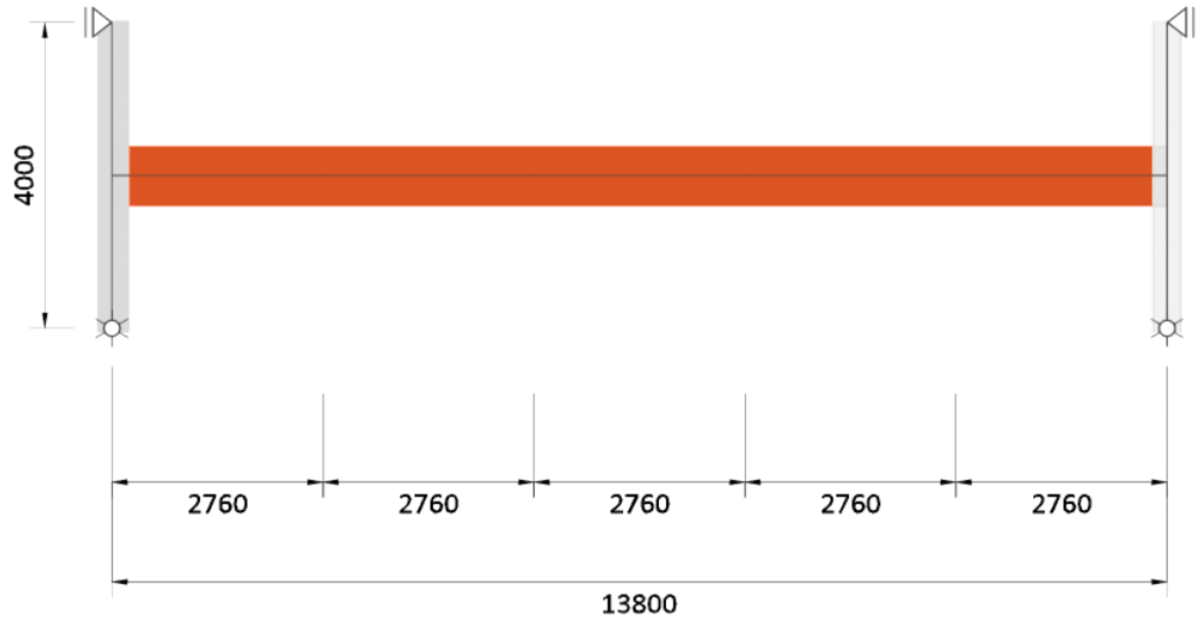


Figure.82. Static scheme of the main beam

2.7.2. Design Loads

Permanent:

$A = 10.2,85 = 28,5m^2$ - area of one secondary beam.

Action on the main beam from one secondary beam:

$F_{G,k} = 5,65.28,5 + 14 = 175kN$

Variable Loads:

$F_{Q,k} = 6,6.28,5 = 188,1kN$

2.7.3. Design load combinations

| Ultimate Limit State

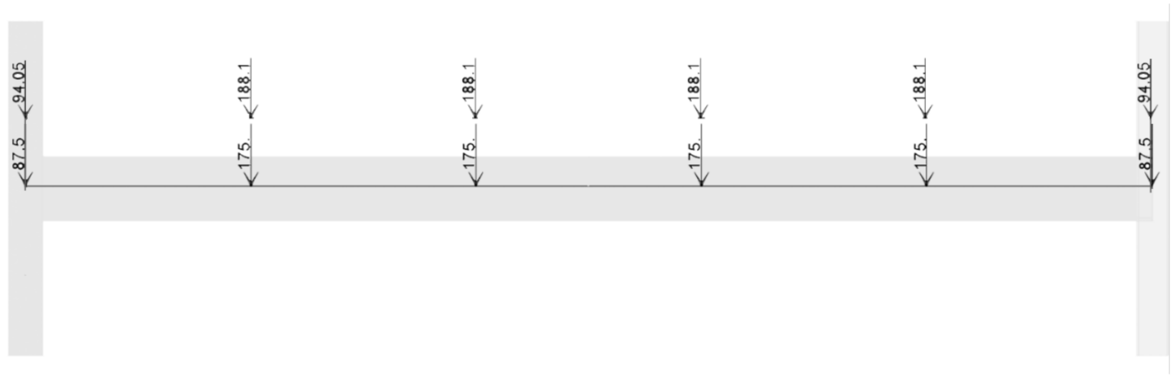
$$\sum_{j\geq1} \gamma_{G,j}.G_{k,j} + \gamma_{Q,1}.Q_{k,1} + \sum_{i>1} \gamma_{Qi}.\psi_{0,i}.Q_{k,i}$$

| Serviceability Limit State

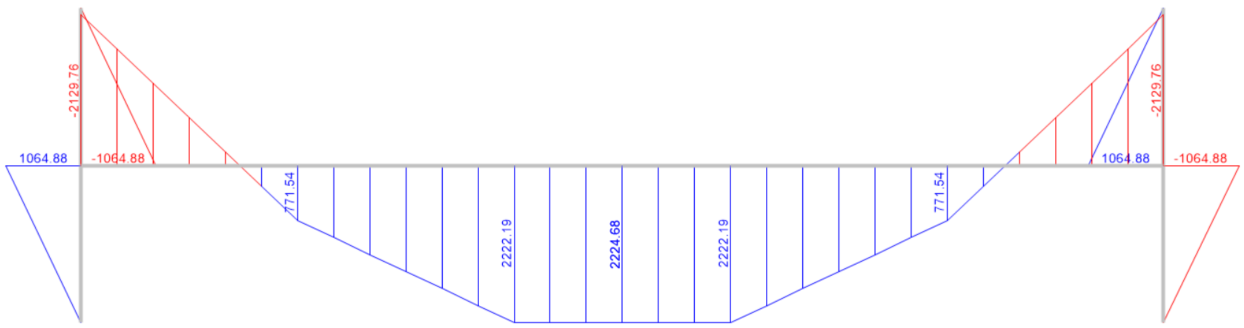
$$G_{k,j} + Q_{k,1} + \sum_{i>1} \psi_{0,i}.Q_{k,i}$$

2.7.4. Envelope diagrams

| Loads [kN]



| Moment Diagram [kN.m]



| Shear force diagram [kN]

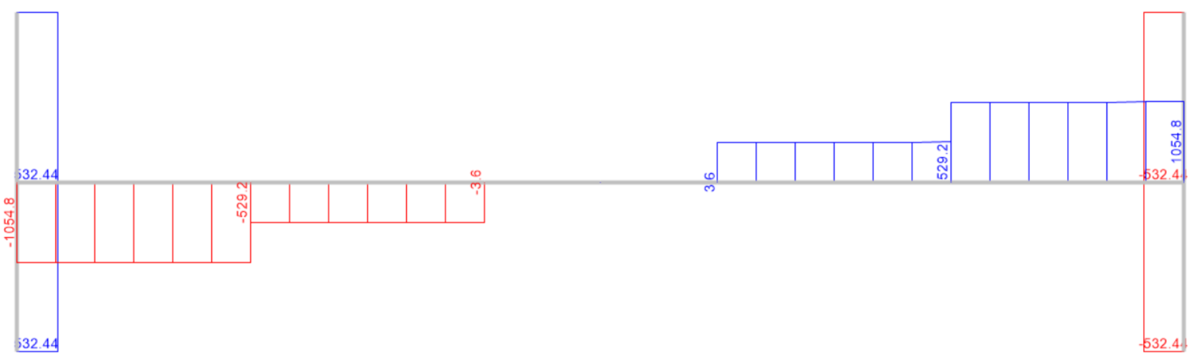


Figure.83. Load distribution, envelope moment and shear diagrams for the main beam

2.7.5. Design verification

Selection of the cross-section with minimum characteristics:

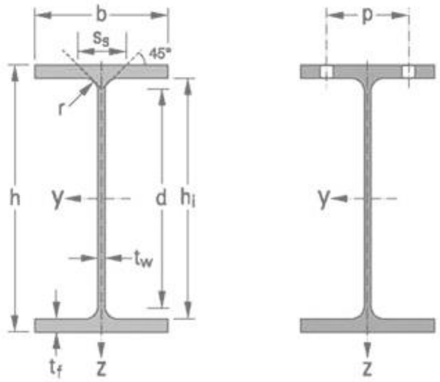
$$M_{Ed,max} \leq M_{pl,Rd} = \frac{W_{pl,y}.f_y}{\gamma_{M0}}$$

$$(1)\, W_{pl,y} \geq \frac{\gamma_{M0}.M_{Ed,max}}{f_y} = \frac{1,05.2129,8.1000}{0,355} = 6299,4.10^3 mm^3$$

$$w_{max} = \frac{3}{384} \frac{(F_{G,k}\ / b + F_{Q,k}\ / b + 2,00).L^4}{E.I_y} \leq \frac{L}{250}$$

$$w_{max} = \frac{3}{384} . \frac{135,5.10^{-3}.1380^4}{21000.I_y} \leq \frac{1380}{250} = 5,52cm$$

$$(2)\, I_y \geq \frac{3}{384} . \frac{135,5.10^{-2}.1380^4}{21000.5,52} = 331198.10^4 mm^4$$



NAME		MEASUREMENTS						MEASUREMETS FOR DETAILING					SURFACE	
	G kg/m	h mm	b mm	t_w mm	t_f mm	r mm	A mm²	h_i mm	d mm	ø	Pmin mm	Pmax mm	A_L m²/m	A_G m²/t
							x 10²							
IPE A 500*	79,4	497	200	8,4	14,5	21	101	468	426	M24	100	112	1,741	21,94
IPE 500	90,7	500	200	10,2	16	21	116	468	426	M24	102	112	1,744	19,23
IPE O 500+	107	506	202	12	19	21	137	468	426	M24	104	114	1,760	16,40
IPE A 550*	92,1	547	210	9	15,7	24	117	515,6	467,6	M24	106	122	1,875	20,36
IPE 550	106	550	210	11,1	17,2	24	134	515,6	467,6	M24	110	122	1,877	17,78
IPE O 550+	123	556	212	12,7	20,2	24	156	515,6	467,6	M24	110	122	1,893	15,45
IPE A 600*	108	597	220	9,8	17,5	24	137	562	514	M27	114	118	2,013	18,72
IPE 600	122	600	220	12	19	24	156	562	514	M27	116	118	2,015	16,45
IPE O 600+	154	610	224	15	24	24	197	562	514	M27	118	122	2,045	13,24
IPE 750 x 137*	137	753	263	11,5	17	17	175	719	685	M27	102	162	2,506	18,28
IPE 750 x 147	147	753	265	13,2	17	17	188	719	685	M27	104	164	2,510	17,06
IPE 750 x 173+	173	762	267	14,4	21,6	17	221	718,8	684,8	M27	104	166	2,534	14,58
IPE 750 x 196+	196	770	268	15,6	25,4	17	251	719,2	685,2	M27	106	166	2,552	12,96

NAME		BEAM PROPERTIES													RATING ENV 1993-1-1								
		eje fuerte y-y strong axis y-y asse forte y-y					eje débil z-z weak axis z-z asse debole z-z							pure bending y-y			pure compression					
	G kg/m	I_y mm⁴	$W_{el.y}$ mm³	$W_{pl.y}$ mm³	i_y mm	A_{vz} mm²	I_z mm⁴	$W_{el.z}$ mm³	$W_{pl.z}$ mm³	i_z mm	s_s mm	I_t mm⁴	I_w mm⁶	S 235	S 355	S 460	S 235	S 355	S 460	EN 10025:1993	EN 10113-3:1993	EN 10225:2001
		x 10⁴	x 10³	x 10³	x 10	x 10²	x 10⁴	x 10³	x 10³	x 10		x 10⁴	x 10⁹									
IPE A 500	79,4	42930	1728	1946	20,61	50,41	1939	193,9	301,6	4,38	62,00	62,78	1125	1	1	1	4	4	4	✓	✓	✓
IPE 500	90,7	48200	1928	2194	20,43	59,87	2142	214,2	335,9	4,31	66,80	89,29	1249	1	1	1	3	4	4	✓	HI	HI
IPE O 500	107	57780	2284	2613	20,56	70,21	2622	259,6	408,5	4,38	74,60	143,5	1548	1	1	1	2	4	4	✓	HI	HI
IPE A 550	92,1	59980	2193	2475	22,61	60,30	2432	231,6	361,5	4,55	68,52	86,53	1710	1	1	2	4	4	4	✓	✓	✓
IPE 550	106	67120	2441	2787	22,35	72,34	2668	254,1	400,5	4,45	73,62	123,2	1884	1	1	1	4	4	4	✓	HI	HI
IPE O 550	123	79160	2847	3263	22,52	82,69	3224	304,2	480,5	4,55	81,22	187,5	2302	1	1	1	2	4	4	✓	HI	HI
IPE A 600	108	82920	2778	3141	24,60	70,14	3116	283,3	442,1	4,77	72,92	118,8	2607	1	1	2	4	4	4	✓	✓	✓
IPE 600	122	92080	3069	3512	24,30	83,78	3387	307,9	485,6	4,66	78,12	165,4	2846	1	1	1	4	4	4	✓	HI	HI
IPE O 600	154	118300	3879	4471	24,52	104,4	4521	403,6	640,1	4,79	91,12	318,1	3860	1	1	1	2	4	4	✓	HI	HI
IPE 750 x 137	137	159900	4246	4865	30,26	92,90	5166	392,8	614,1	5,44	65,42	137,1	6980	1	2	-	4	4	-	✓	✓	✓
IPE 750 x 147	147	166100	4411	5110	29,76	105,4	5289	399,2	630,8	5,31	67,12	161,5	7141	1	1	2	4	4	4	✓	✓	✓
IPE 750 x 173	173	205800	5402	6218	30,49	116,4	6873	514,9	809,9	5,57	77,52	273,6	9391	1	1	1	4	4	4	✓	HI	HI
IPE 750 x 196	196	240300	6241	7174	30,95	127,3	8175	610,1	958,8	5,71	86,32	408,9	11290	1	1	1	4	4	4	✓	HI	HI

Figure.84. Section properties (source perlita.com)

2.7.5.1. Class of the section:

A section IPE 750x196 made from steel S355JR is selected.

The class of the cross-section is determined from Table 5.2 of BS EN 1993-1-1, where a cross-section is classified according to the highest (least favorable) class of its compression parts:

Class of the web: $\frac{c}{t_f} = \frac{d}{t_w} = \frac{685,2}{15,6} = 42,19 < 72\varepsilon = 72\sqrt{\frac{235}{355}} = 58,6 \rightarrow$ class 1

Class of the flange: $\frac{c}{t} = \frac{b_f - t_w - 2r}{2t_f} = \frac{268 - 15,6 - 2.17}{2.25,4} = 4,3 < 9\sqrt{\frac{235}{355}} = 7,3 \rightarrow$ class 1

The section is class 1

2.7.5.2. Bending moment verification

Bending about major axis y-y

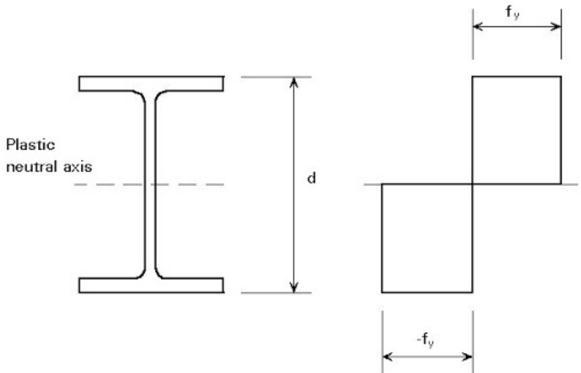


Figure.85. Plastic stress distribution for symmetrical profile (source ESDEP)

The cross-section is a class 1. This allows the section to reach a plastic distribution of the stress fy. So, we can use the plastic properties of the section $W_{pl,y}$ and calculate the design plastic bending moment resistance $M_{pl,Rd,y}$.

The design value of the bending moment M_{Ed} at each cross-section should satisfy:

$$\frac{M_{Ed}}{M_{Rd}} \leq 1$$

$$M_{Ed} \leq M_{pl,Rd} = \frac{W_{pl}.f_y}{\gamma_m};$$

$$M_{pl,Rd} = \frac{7174.35,5}{1,05.100} = 2425,5kN.m;$$

$$\frac{M_{Ed}}{M_{pl,Rd}} = \frac{2129,8}{2425,5} = 0,88 < 1$$

2.7.5.3. Shear Force Verification

For the shear verification, the same applies, and we can use the plastic properties of the section to calculate the design plastic shear resistance $V_{pl,Rd,y}$.

The design value of the shear force V_{Ed} at each cross-section should satisfy:

$$\frac{V_{Ed}}{V_{Rd}} \leq 1$$

$$A_v = A - 2.b.t_f + (t_w + 2r)t_f$$

$$A_v = 127,3\,cm^2$$

$$V_{pl,Rd} = \frac{A_v.f_y}{\gamma_{M0}.\sqrt{3}} = \frac{127,3.35,5}{1,05.\sqrt{3}} = 2484,9\,kN$$

$$\frac{V_{Ed}}{V_{pl,Rd}} = \frac{1054,8}{2484,9} = 0,43 < 1$$

2.7.6. Serviceability Limit State (SLS)

| Deformed shape [m]

The static beam scheme is statically undetermined, so the maximum displacement is obtained by a software (SAP 2000) using the characteristics of the section already selected before IPE 750x196.

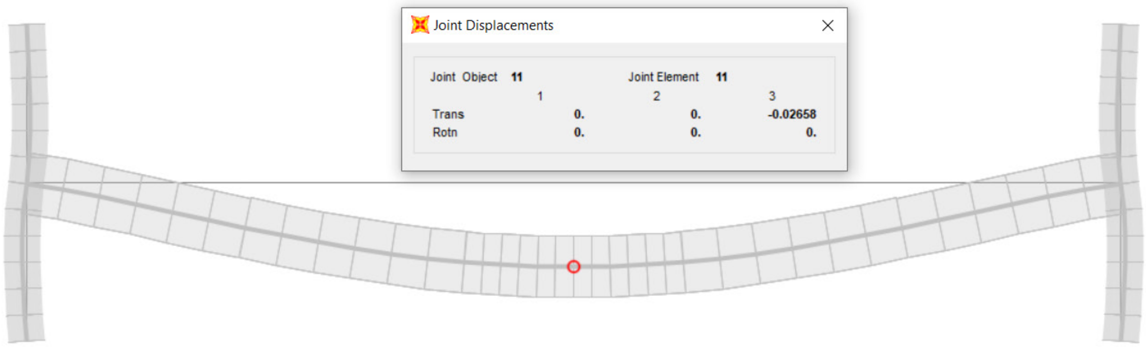
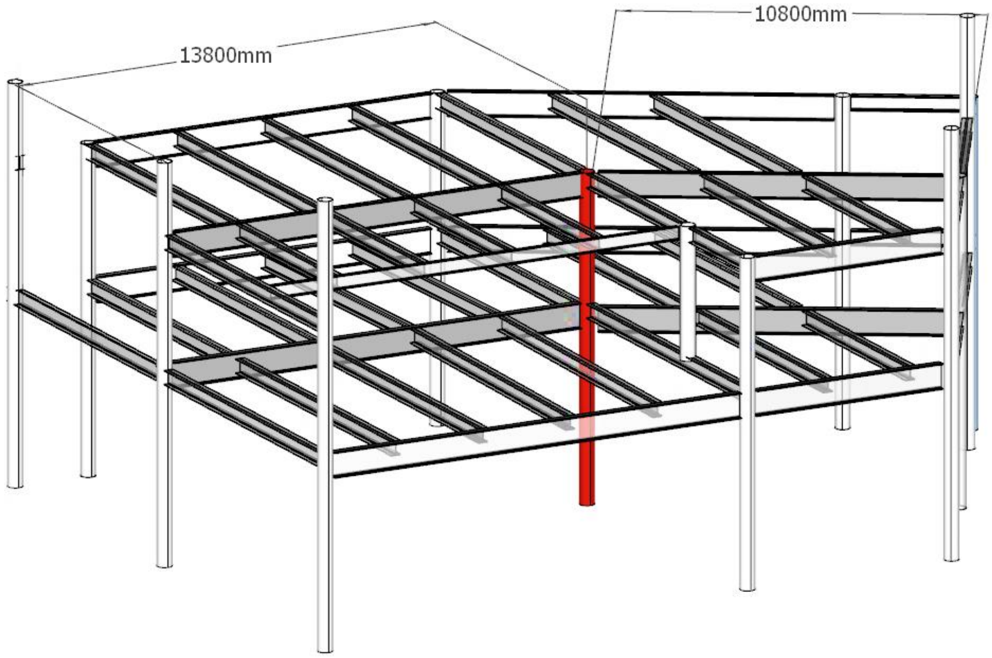


Figure.86. SLS verification of the maximum deflection in the middle of the span of the main beam

$$w_{max} = 2,66cm < \frac{L}{250} = \frac{1380}{250} = 5,52cm$$

2.8. Column design

2.8.1. Structural scheme



Static scheme of the support. At the base, the column is clamped, and on the first and second floors, it is laterally supported by the beams of the floor.

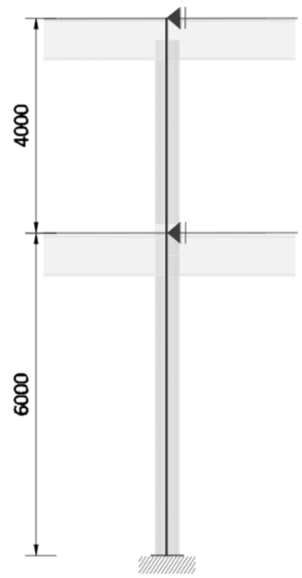


Figure.87. Sheme of the column location and static sheme

2.8.2. Design loads

Level	Axis	Effective area [m2]	Dead Load G_k [kN]	Live Load Q_k [kN]	Σ Gk +Qk [kN]
1	axis A1-A3	28.5	175.025	188.1	363.125
1	axis A3-5	27	166.55	178.2	344.75
2	axis A1-A3	17.1	110.615	112.86	223.475
2	axis A3-5	17.1	110.615	112.86	223.475

2.8.3. Design load combinations

| Ultimate Limit State

$$\sum_{j\geq 1} \gamma_{G,j}.G_{k,j} + \gamma_{Q,1}.Q_{k,1} + \sum_{i>1} \gamma_{Qi}\cdot\psi_{0,i}\cdot Q_{k,i}$$

| Serviceability Limit State

$$G_{k,j} + Q_{k,1} + \sum_{i>1} \psi_{0,i}.Q_{k,i}$$

2.8.4. Design verification

A section HE400B made from steel S355 JR is selected.

HE400B

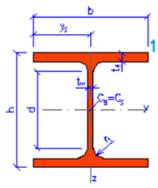
Geometry		Section properties	
h = 40 cm		Axis y	Axis z
b = 30 cm		I_y = 5.77E+4 cm^4	I_z = 1.08E+4 cm^4
t_f = 2.4 cm		W_{y1} = 2880 cm^3	W_{z1} = 721.0 cm^3
t_w = 1.35 cm		$W_{y,pl}$ = 3240 cm^3	$W_{z,pl}$ = 1100 cm^3
r_1 = 2.7 cm		i_y = 17.10 cm	i_z = 7.400 cm
y_s = 15 cm		S_y = 1620 cm^3	S_z = 550.0 cm^3
d = 29.8 cm		**Warping and buckling**	
A = 198 cm^2		I_w = 3.82E+6 cm^6	I_t = 360.0 cm^4
A_L = 1.93 $m^2.m^{-1}$	G = 155 $kg.m^{-1}$	i_w = 7.470 cm	i_{pc} = 18.60 cm

Figure.88. Section properties of the column (source: staticstools.eu)

2.8.4.1. Classification of the cross-section

The class of the cross-section was determined from Table 5.2 of BS EN 1993-1-1, where a cross-section is classified according to the highest (least favorable) class of its compression parts:

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{355}} = 0,81$$

Web class: $\frac{c}{t_f} = \frac{d}{t_w} = \frac{298}{21} = 23,05 < 33\varepsilon = 26,73 \rightarrow$ class 1

Flange class: $\frac{c}{t} = \frac{b_f - t_w - 2r}{2t_f} = \frac{305 - 21 - 2.27}{2.40} = 2,88 < 9\varepsilon = 7,29 \rightarrow$ class 1

The section is class 1

The section is subjected to axial force N_{Ed} and bending moment $M_{y,Ed}$ about the major axis.

The verifications were made for first for cross-section and its bending force and axial compression capacity then the check of the member is calculated. These checks concern the cases in which the element is subjected to the combined action of compression and bending. To calculate the resistance of the member in uniform bending and axial compression, we use the buckling resistance.

The following design verifications were performed.

| Resistance of the cross-section

- Compression verification
- Bending and axial force

| Buckling resistance of the member

- Uniform members in bending and axial compression

2.8.4.2. Resistance of the cross-section

As a conservative approximation for all cross-section classes, a linear summation of the utilization ratios for each stress resultant may be used. For class 1, class 2 or class 3 cross-sections subjected to the combination of N_{Ed} , $M_{y,Ed}$ and $M_{z,Ed}$ this method may be applied by using the following criteria:

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1$$

2.8.4.3. Compression verification

$$\frac{N_{Ed}}{N_{c,Rd}} \leq 1$$

$$N_{c,Rd} = N_{pl,Rd} = \frac{A.f_y}{\gamma_{M0}} = \frac{198.35,5}{1,05} = 6694,3kN$$

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{4025,64}{6694,3} = 0,6 < 1$$

2.8.4.4. Bending and axial force

$$M_{pl,y,Rd} = \frac{W_{pl,y}.f_y}{\gamma_{M0}} = \frac{3240.35,5}{1,05} = 109542,9kN.cm = 1095,4kN.m$$

$$M_{pl,z,Rd} = \frac{W_{pl,z}.f_y}{\gamma_{M0}} = \frac{1100.35,5}{1,05} = 37190kN.cm = 371,9kN.m$$

For doubly symmetrical I- and H-sections or other flanges sections, allowance need not be made for the effect of the axial force on the plastic resistance moment about the y-y axis when both the following criteria are satisfied:

$$N_{Ed} \leq 0,25N_{pl,Rd}$$

$$N_{Ed} = 4025,64kN > 0,25.6694,3 = 1673,6kN$$

and

$$N_{Ed} \leq 0,5\frac{h_w.t_w.f_y}{\gamma_{M0}}$$

$$N_{Ed} = 4025,64 > 0,5\frac{35,2.1,35.35,5}{1,05} = 803,3kN$$

For cross-sections where fastener holes are not to be accounted for, the following approximations may be used for standard rolled I or H sections and for welded I or H sections with equal flanges:

$$M_{N,y,Rd} = \frac{M_{pl,y}(1-n\ )}{1-0,5a} = \frac{1095,4(1-0,6)}{1-0,5.0,27} = 506,6kN.m \leq M_{pl,y,Rd}$$

$$n = \frac{N_{Ed}}{N_{pl,Rd}} = \frac{4025,64}{6694,3} = 0,6$$

$$a = \frac{A-2b.t_f}{A} = \frac{198-2.30.2,4}{198} = 0,27$$

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} = \frac{4025,64}{6694,3} + \frac{131,36}{506,6} + 0 = 0,86 < 1$$

2.8.4.5. Buckling resistance of members

$$N_{Ed} \leq N_{b,Rd} = \frac{\chi.A.f_y}{\gamma_{M1}}$$

for Class 1, 2 and 3 cross-sections: $N_{b,Rd} = \frac{\chi.A.f_y}{\gamma_{M1}}$

Buckling curves:

$$\frac{h}{b} = \frac{400}{300} = 1,3 > 1,2$$

and $t_f < 40mm$

Buckling about axis y-y: $\rightarrow$curve „a“ ; $\alpha = 0,21$

Buckling about axis z-z: $\rightarrow$curve „b“ ; $\alpha = 0,34$

2.8.4.5.1. Members in compression

$$\frac{N_{Ed}}{N_{b,y,Rd}} \leq 1$$

$$\bar{\lambda}_{y,1} = \frac{l_{cr,y}}{i_y}.\frac{1}{\lambda_1} = \frac{600}{17,1}.\frac{1}{75,12} = 0,45$$

$$\lambda_1 = \pi\sqrt{\frac{E}{f_y}} = 93,9\varepsilon = 93,9.0,8 = 75,12$$

$$t_f = 24 > 16mm \rightarrow f_y = 34,5kN/cm^2$$

$$\Phi_y = 0,5.[1+\alpha(\bar{\lambda}_y - 0,2)+\bar{\lambda}_y^{\,2}] = 0,5.[1+0,21(0,45-0,2)+0,37^2] = 0,63$$

$$\chi_y = \frac{1}{\Phi_y + \sqrt{\Phi_y^{\,2} - \bar{\lambda}_y^{\,2}}} = \frac{1}{0,63+\sqrt{0,63^2 - 0,45^2}} = 0,934$$

$$N_{B,y,Rd} = \frac{\chi_y.A.f_y}{\gamma_{M,1}} = \frac{0,934.198.34,5}{1,05} = 6076,3kN$$

$$\frac{N_{Ed}}{N_{B,y,Rd}} = \frac{4025,64}{6076,3} = 0,66 < 1$$

2.8.4.5.2. Members in bending and axial compression

| Case with maximum axial force:

$$N_{Ed} = 4025,64\,kN$$
$$M_{Ed} = 131,36 kN$$

$$\frac{N_{Ed}}{N_{b,y,Rd}} + k_{yy}\frac{M_{Ed}}{M_{b,Rd}} \le 1$$

$$M_{b,Rd} = \frac{\chi_{LT}.W_{y,pl}.f_y}{\gamma_{Mo}}$$

$$\psi = \frac{-131,36}{17,73} = -0,21 \approx -1/4 \rightarrow C_1 = 2,538$$

$$M_{cr} = C_1\frac{\pi^2 EI_z}{(k.l_{LT})^2}\sqrt{\left(\frac{k}{k_w}\right)^2\frac{I_w}{I_z} + \frac{(k.l_{LT})^2 G.I_t}{\pi^2.EI_z}} =$$

$$= 2,538\frac{\pi^2.21000.1,08.10^4}{(0,7.600)^2}\sqrt{\left(\frac{0,7}{0,7}\right)^2\frac{3,82.10^6}{1,08.10^4} + \frac{(0,7.600)^2.8100.360}{\pi^2.21000.1,08.10^4}}$$

$$M_{cr} = 845606\,kNcm$$

$$\overline{\lambda_{LT}} = \sqrt{\frac{W_{y,pl}.f_y}{M_{cr}}} = \sqrt{\frac{3240.34,5}{845606}} = 0,36 < \overline{\lambda_{LT,0}} = 0,4$$

$$\rightarrow \chi_{LT} = 1$$

$$M_{b,y,Rd} = M_{pl,y,Rd} = \frac{3240.34,5}{1,05} = 106457 kNcm = 1064,6 kN.m$$

$$C_{my} = 0,6 + 0,4\psi = 0,6 + 0,4.(-0,135) = 0,55 > 0,4$$

$$\psi = \frac{17,73}{-131,36} = -0,135$$

$$\overline{\lambda_y} = \frac{\lambda}{\lambda_1} = \frac{L_{cr,y}}{i_y}.\frac{1}{\lambda_1} = \frac{600}{17,1}.\frac{1}{75} = 0,47$$

$$k_{yy} = C_{my}\left[1 + \left(\overline{\lambda_y} - 0,2\right).\frac{N_{Ed}}{N_{b,Rd}}\right] = 0,55\left[1 + (0,47 - 0,2).\frac{4025,64}{6076,3}\right] = 0,65$$

$$k_{yy} = 1,06 < C_{my}.\left(1 + 0,8.\frac{N_{Ed}}{N_{b,y,Rd}}\right) = 0,55.\left(1 + 0,8.\frac{4025,64}{6076,3}\right) = 1,84$$

$$k_{zy} = 0,6.k_{yy} = 0,6.0,65 = 0,39$$

$$\frac{4025,64}{6076,64} + 0,65\frac{131,36}{1064,6} = 0,74 < 1$$

| Case with maximum bending moment:

$$\boxed{\begin{array}{l} N_{Ed} = 1657kN \\ M_{Ed} = 385,88kN \end{array}}$$

$$\frac{N_{Ed}}{N_{b,y,Rd}} + k_{yy}\frac{M_{Ed}}{M_{b,Rd}} \leq 1$$

$$\psi = \frac{-241,46}{385,88} = -0,63 \text{ » } -3/4 \text{ ® } C_1 = 3,009$$

$$M_{cr} = C_1\frac{\pi^2 EI_z}{(k.l_{LT})^2}\sqrt{\left(\frac{k}{k_w}\right)^2\frac{I_w}{I_z} + \frac{(k.l_{LT})^2 G.I_t}{\pi^2.EI_z}} =$$

$$= 3,009\frac{\pi^2.21000.1,08.10^4}{(1.400)^2}\sqrt{\left(\frac{1}{1}\right)^2\frac{3,82.10^6}{1,08.10^4} + \frac{(1.400)^2.8100.360}{\pi^2.21000.1,08.10^4}}$$

$$M_{cr} = 998080,7kNcm$$

$$\overline{\lambda_{LT}} = \sqrt{\frac{W_{y,pl}.f_y}{M_{cr}}} = \sqrt{\frac{3240.34,5}{998080,7}} = 0,34 < \overline{\lambda_{LT,0}} = 0,4$$

$$\rightarrow \chi_{LT} = 1$$

$$M_{b,y,Rd} = M_{pl,y,Rd} = \frac{3240.34,5}{1,05} = 106457kNcm = 1064,6kN.m$$

$$C_{my} = 0,6 + 0,4\psi = 0,6 + 0,4.(-0,63) = 0,35 < 0,4$$

$$\psi = \frac{-241,46}{385,88} = -0,63$$

$$\overline{\lambda_y} = \frac{\lambda}{\lambda_1} = \frac{L_{cr,y}}{i_y}.\frac{1}{\lambda_1} = \frac{400}{17,1}.\frac{1}{75} = 0,47$$

$$k_{yy} = C_{my}\left[1 + \left(\overline{\lambda_y} - 0,2\right).\frac{N_{Ed}}{N_{b,Rd}}\right] = 0,4\left[1 + (0,47 - 0,2).\frac{4025,64}{6076,3}\right] = 0,5$$

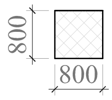
$$k_{yy} = 1,06 < C_{my}.\left(1 + 0,8.\frac{N_{Ed}}{N_{b,y,Rd}}\right) = 0,4.\left(1 + 0,8.\frac{4025,64}{6076,3}\right) = 1,84$$

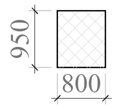
$$k_{zy} = 0,6.k_{yy} = 0,6.0,5 = 0,3$$

$$\frac{4025,64}{6076,64} + 0,5\frac{385,88}{1064,6} = 0,84 < 1$$

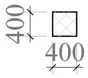
Structural drawings

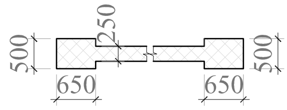
FC1	Footing base 800x800mm	FC2	Footing base950x800mm



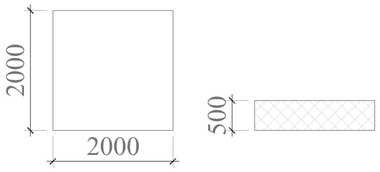


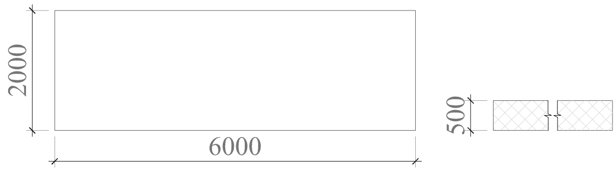
FC3	Footing base 400x400mm	W1	Shear wall



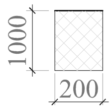


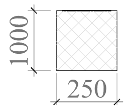
F1	Footing 2000x2000mm	F2	Footing 2000x6000mm



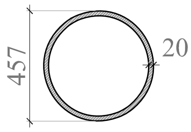


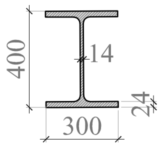
FB1	Footing beam 800x1000mm	FB1	Footing beam 1000x1000mm



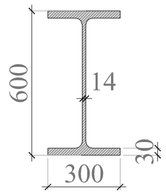


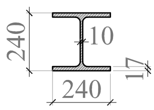
C1	Column CHS 457x20mm	C2	Column HEB 400mm



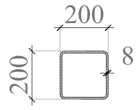


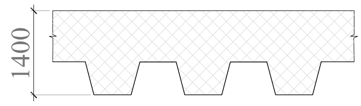
C3	Column HEB 600mm	C4	Column HEB 240mm

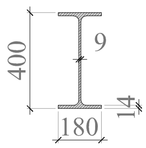
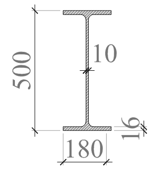
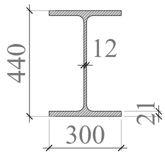
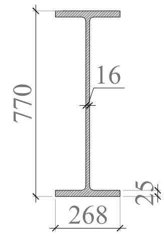
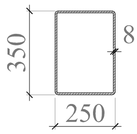
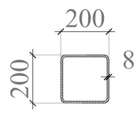




C5	Column SHS 200x8mm	S1	Slab 1



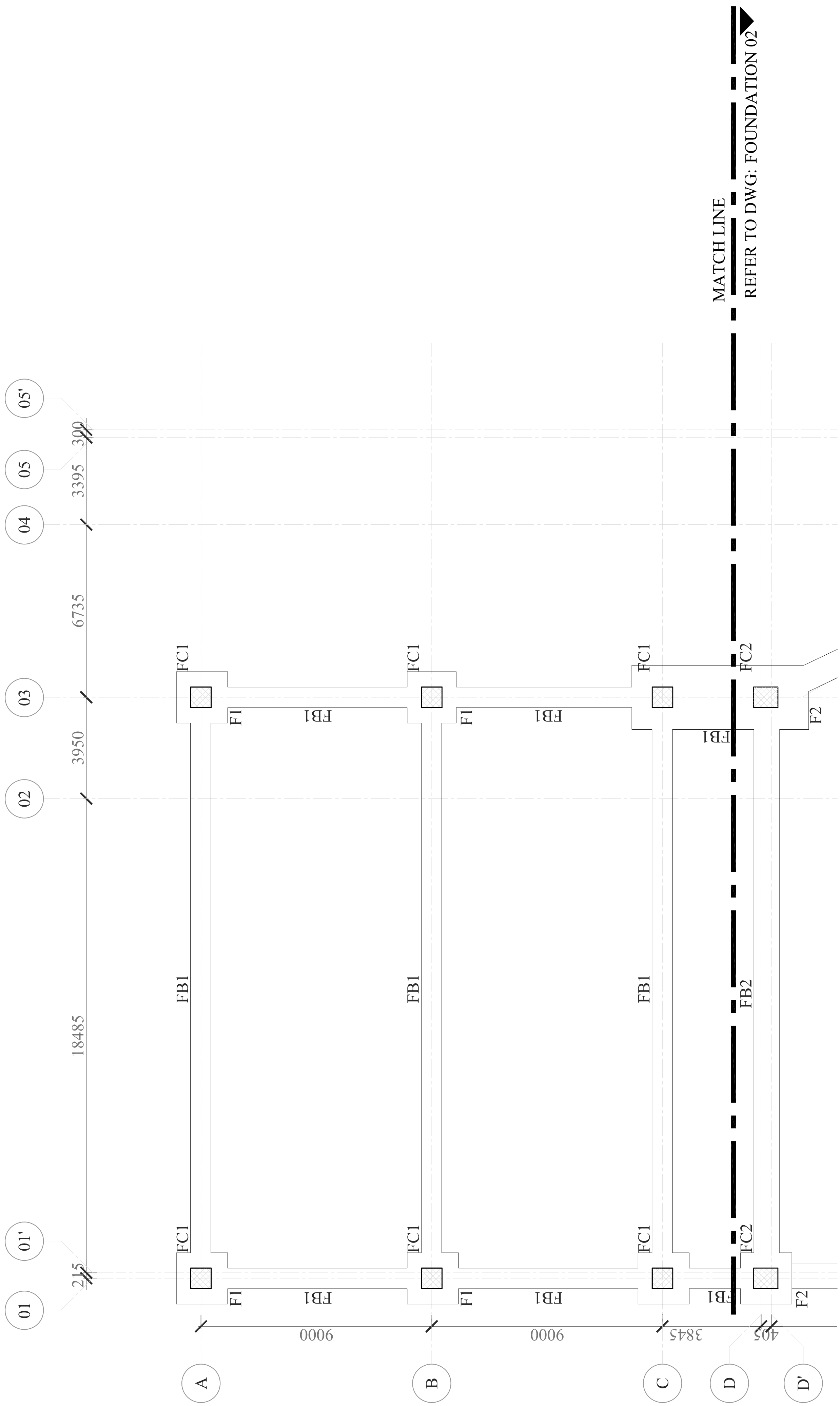


B1	Beam IPE 400mm	B2	Beam IPE 500mm
			
B3	**Beam HEA 450mm**	**B4**	**Beam IPE 750 x196mm**
			
P1	**Purlin RHS 350x250x8mm**	**BT1**	**Bracing SHS 200x8mm**
			

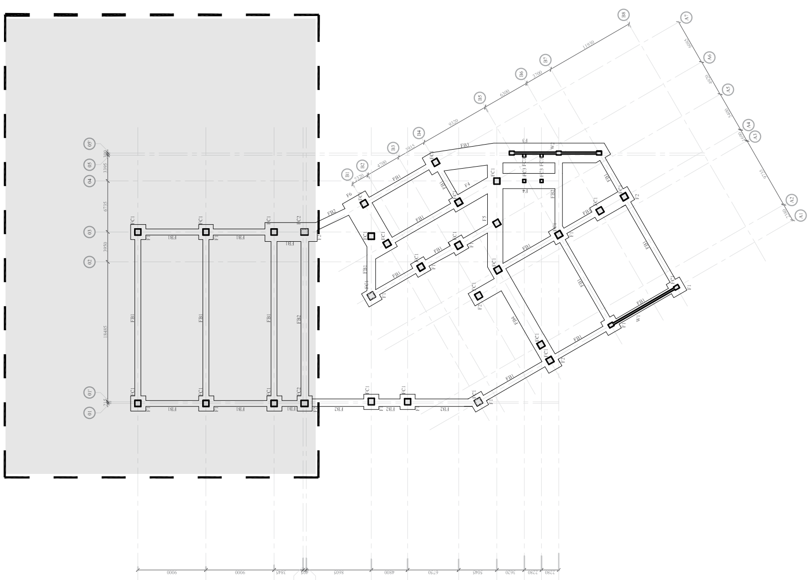
NOTE:

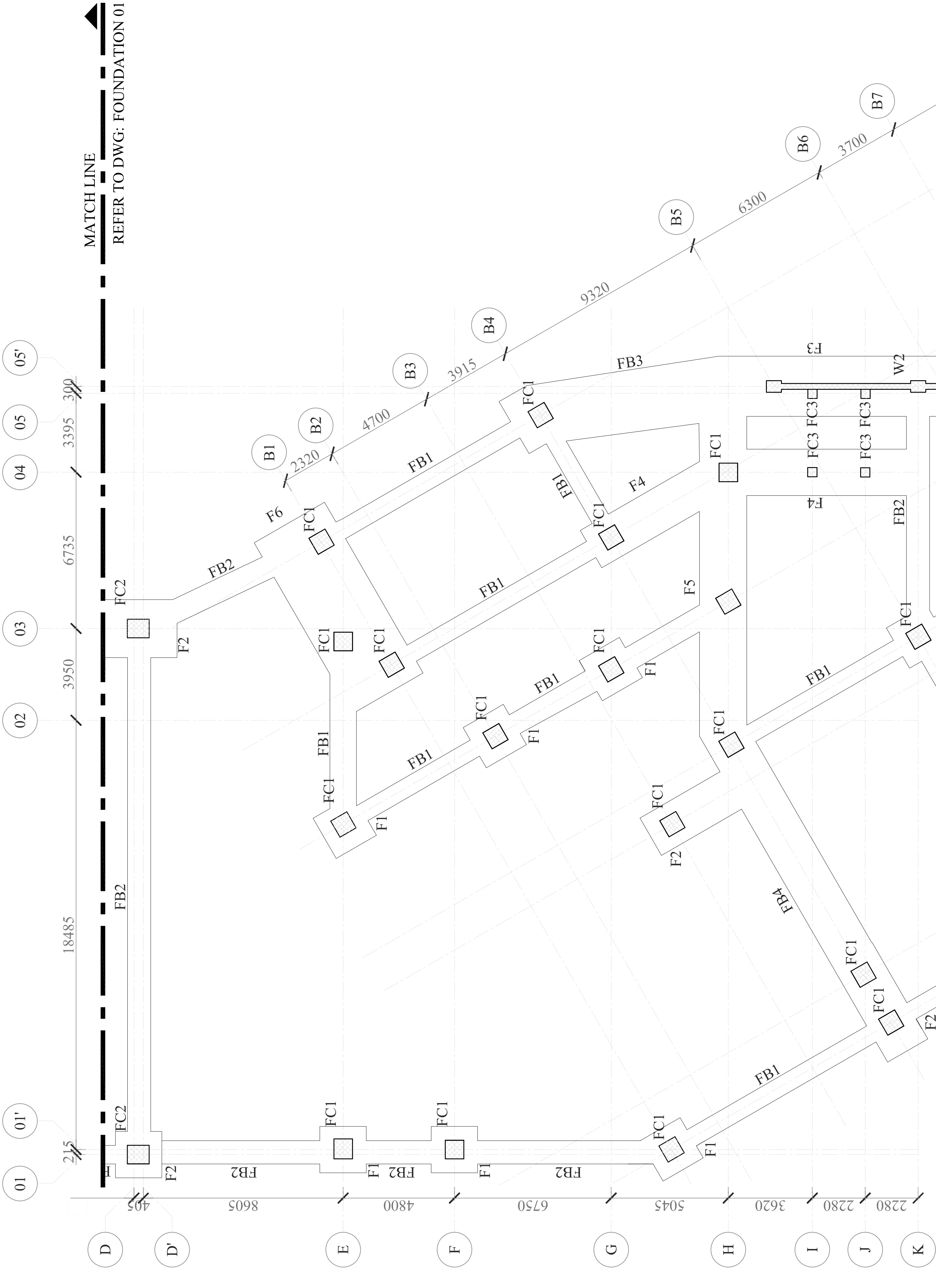
REINFORCEMENT STEEL		B 450 C	
STRUCTURAL STEEL		S 3555 JR	
CONCRETE	blinding layer	C12/15	
	footing	C25/30	
		Exposure class:	XC2
		Consistency:	S3
		Concrete cover:	45mm
	slabs, shear walls	C30/37	
		Exposure class:	XC1
		Consistency:	S3
		Concrete cover:	25mm
WELDING		Class I	
BOLT		Class min. 8.8	

All the dimensions are in mm

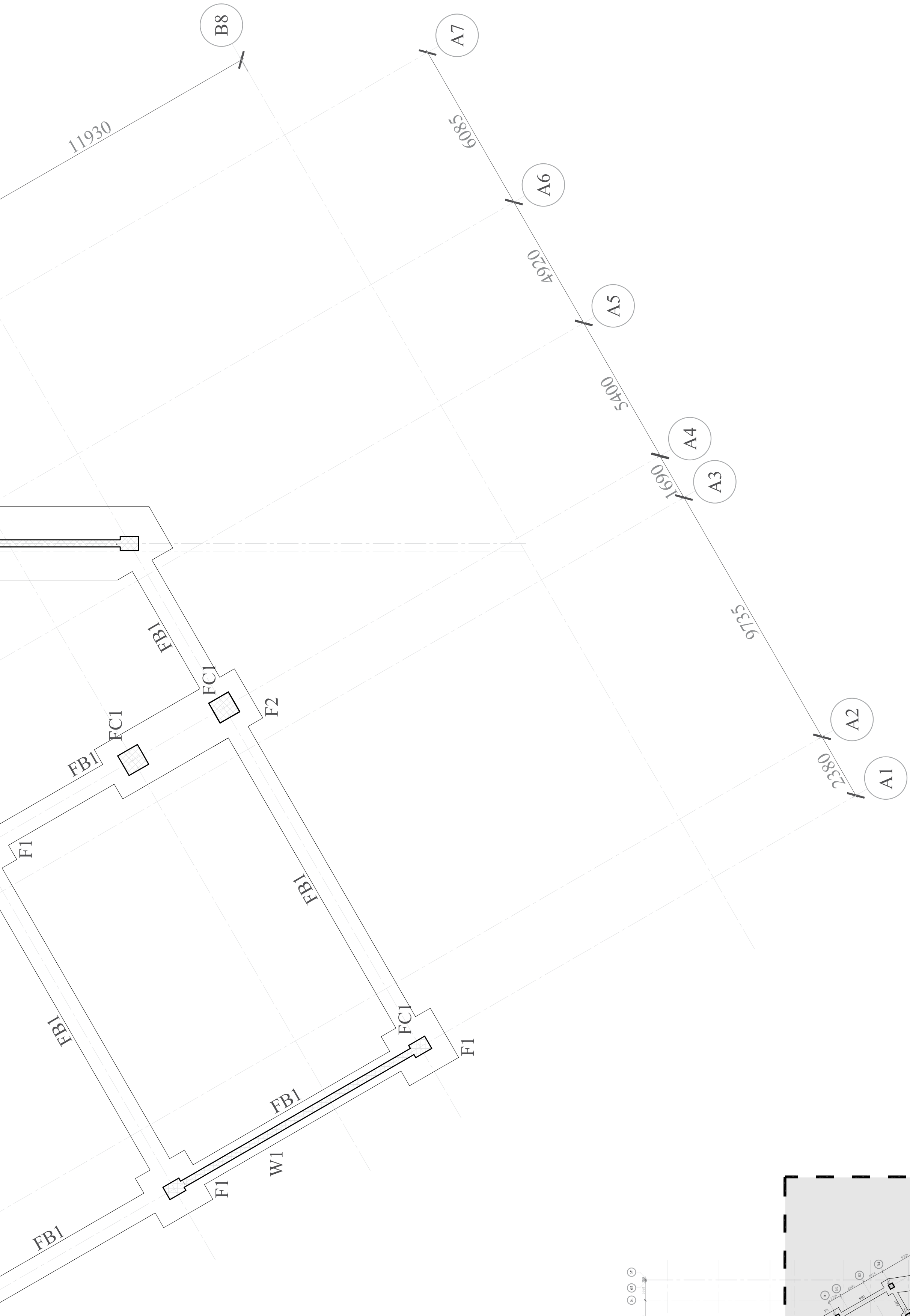

MATCH LINE
REFER TO DWG: FOUNDATION 02
FC1
FC2
F1
F2
FB1
FB2
01
01'
02
03
04
05
05'
A
B
C
D
D'
215
3950
6735
3395
300
18485
9000
3845
405

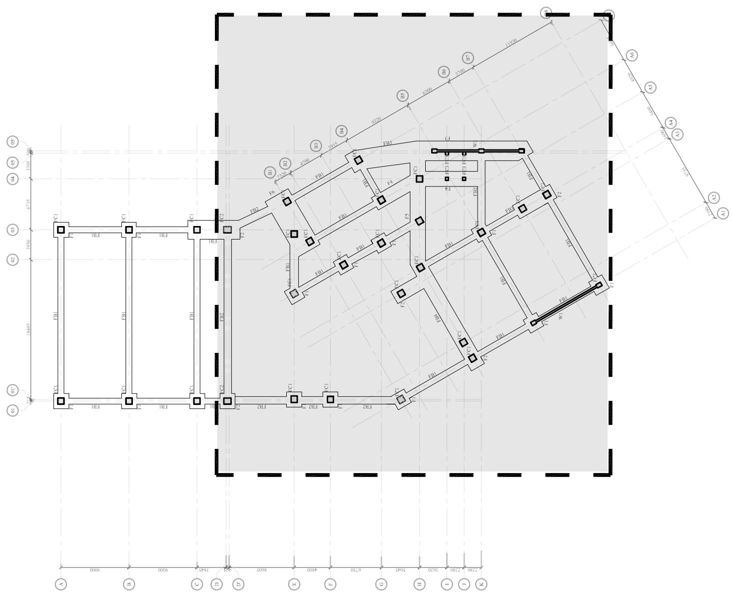
Foundation -2000m
1:200

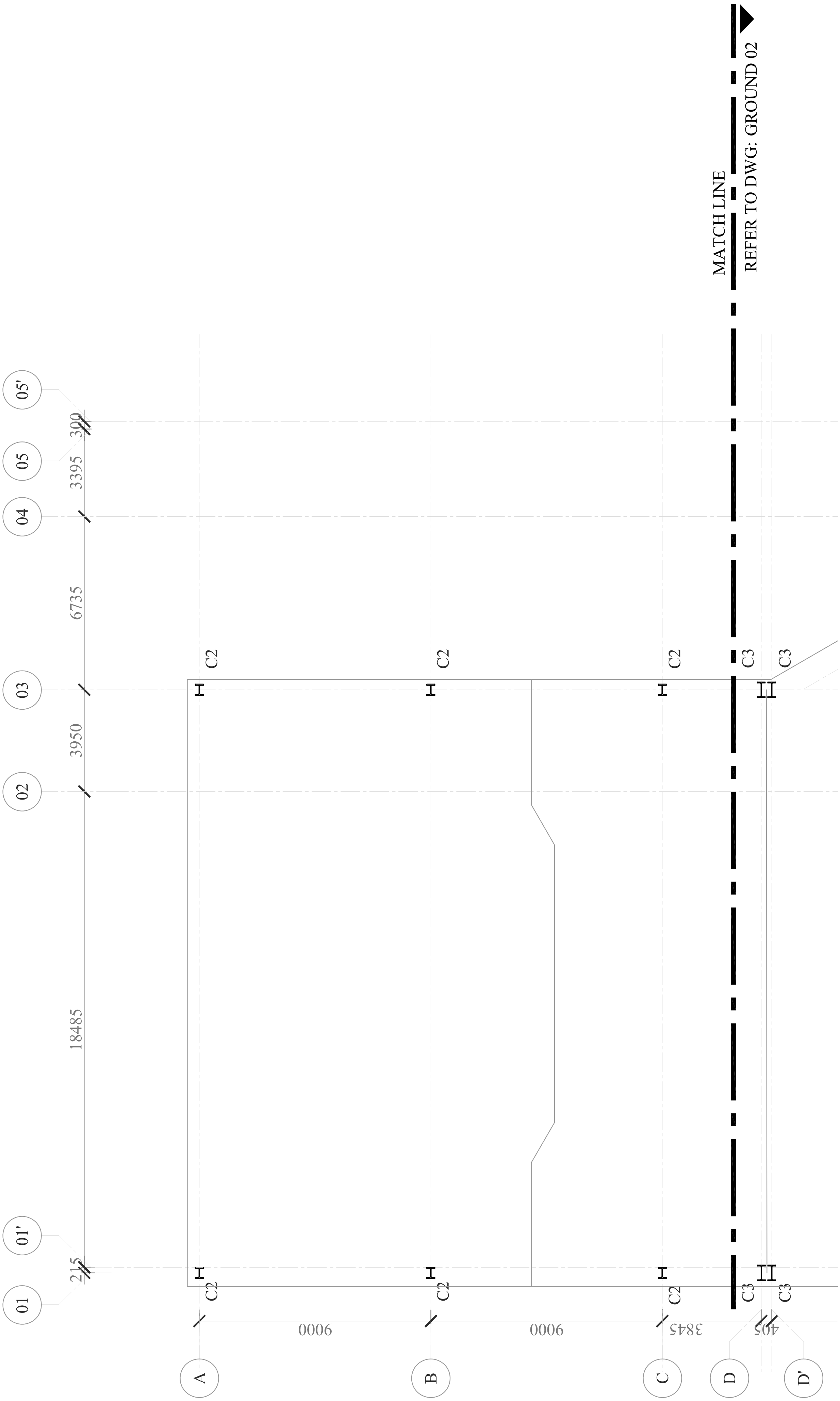



MATCH LINE
REFER TO DWG: FOUNDATION 01
D
D'
E
F
G
H
I
J
K
01
01'
02
03
04
05
05'
B1
B2
B3
B4
B5
B6
B7

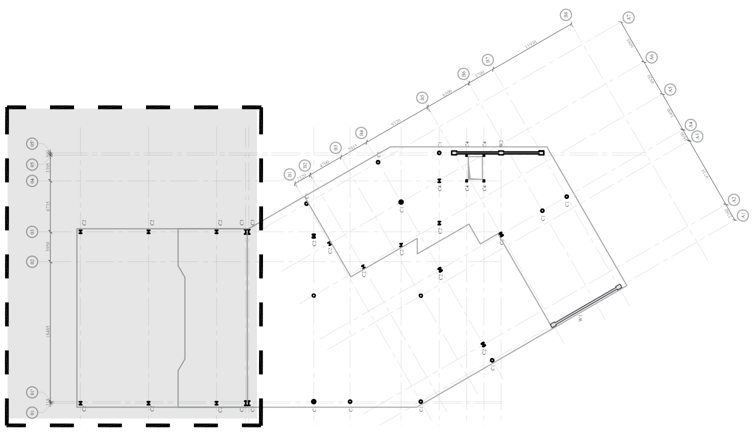
Foundation -2000mm
1:200

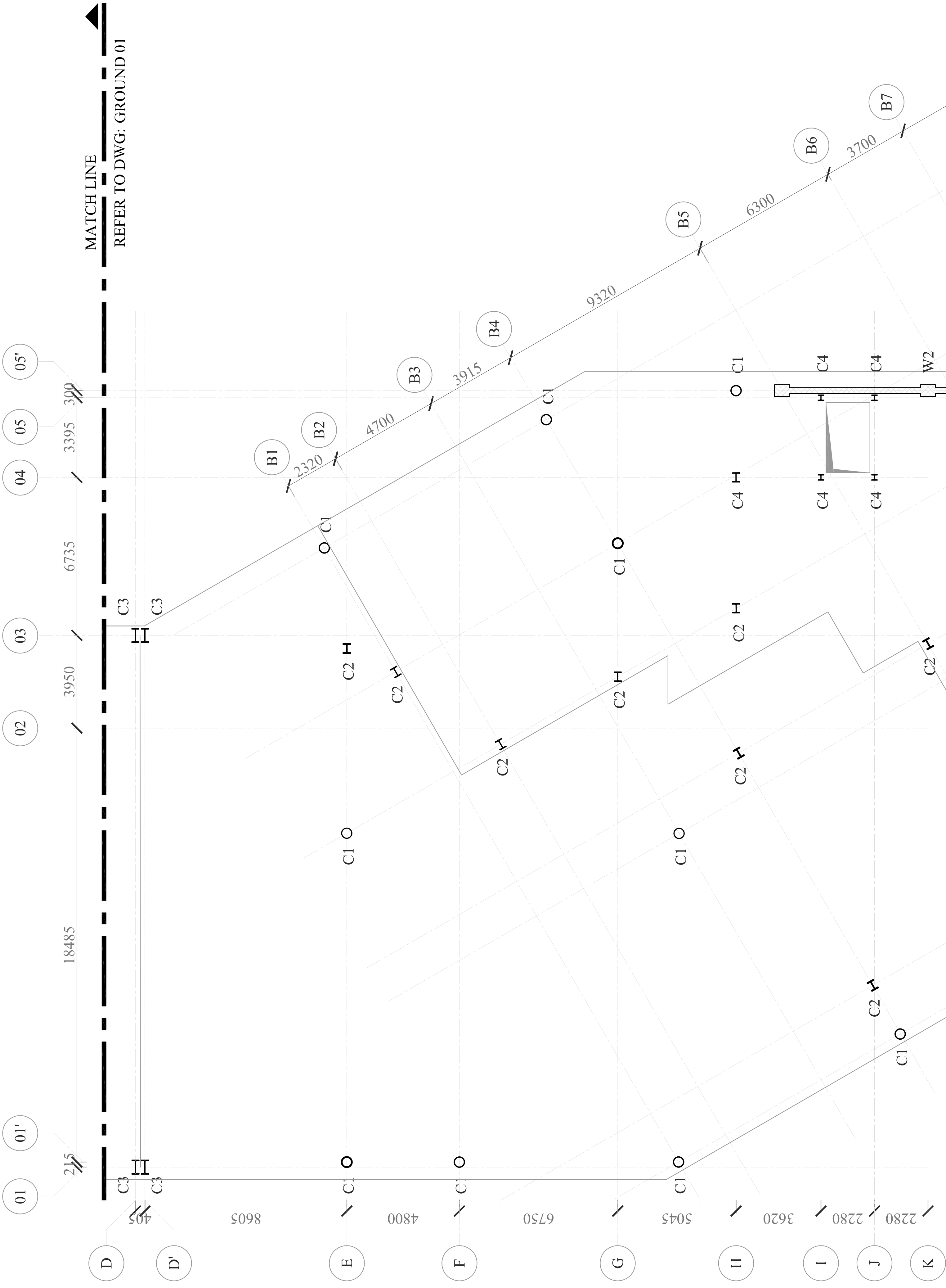


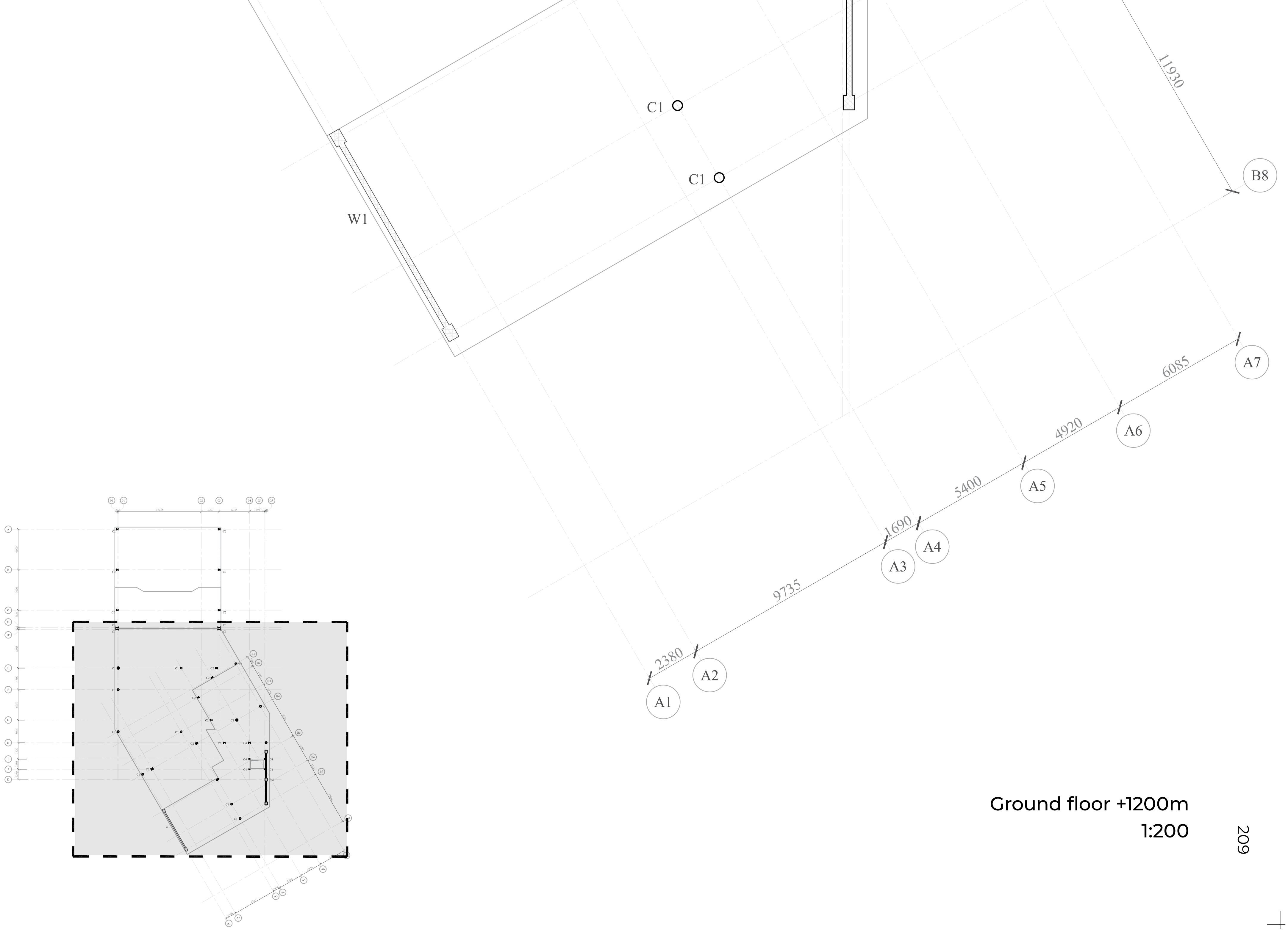



MATCH LINE
REFER TO DWG: GROUND 02
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
C2
C3
9000
9000
3845
405
A
B
C
D
D'

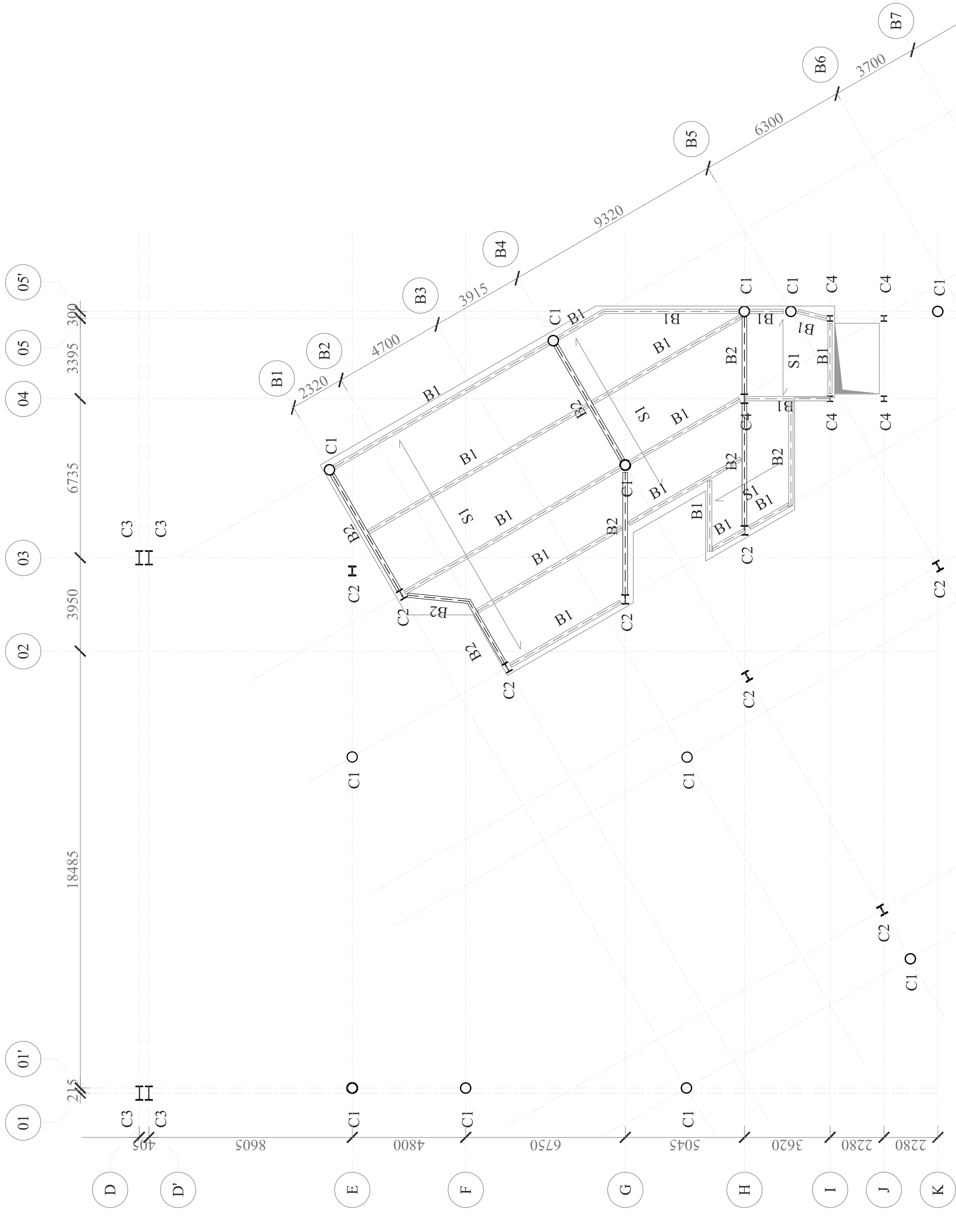
Ground floor +1200m
1:200

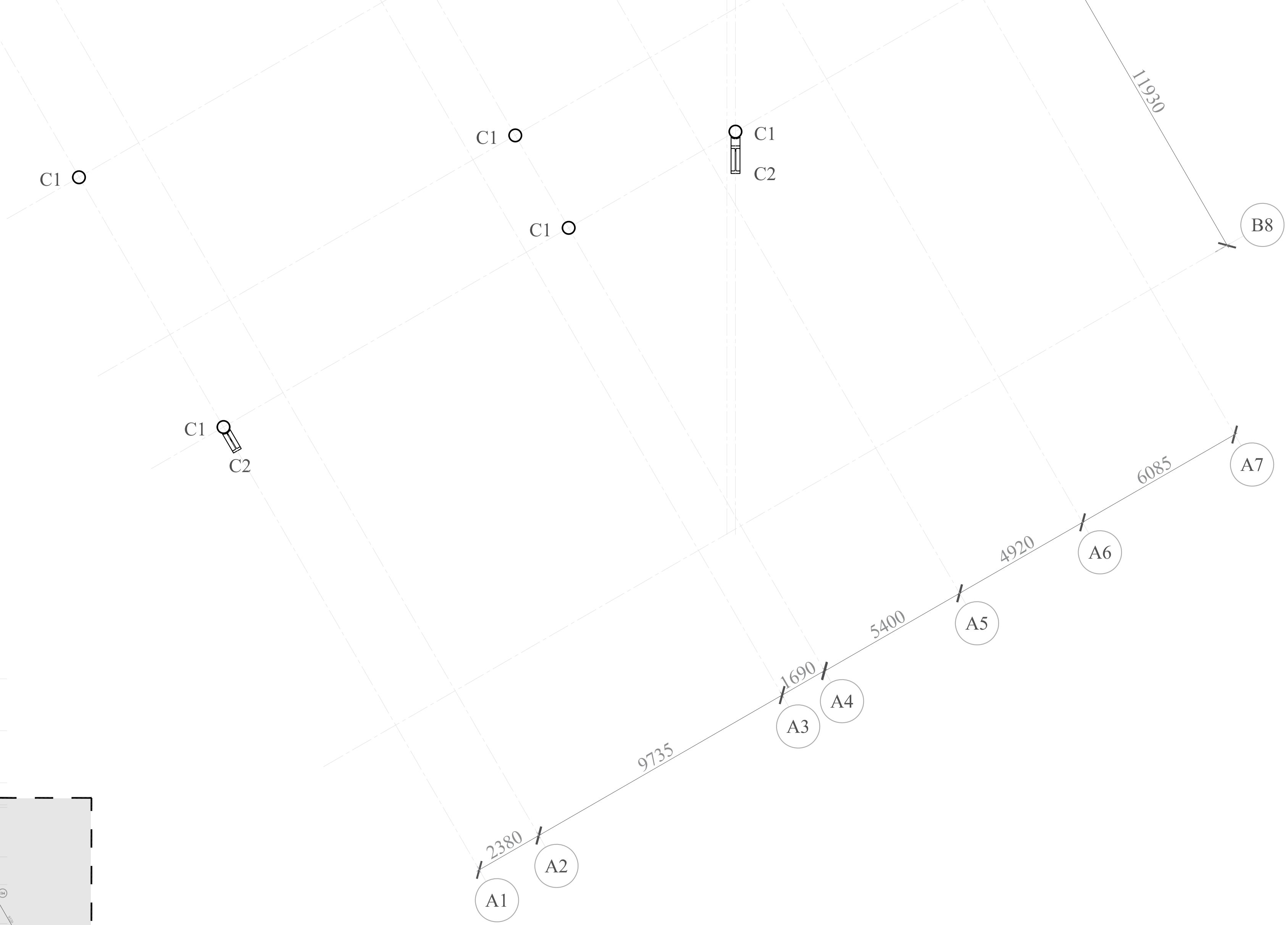


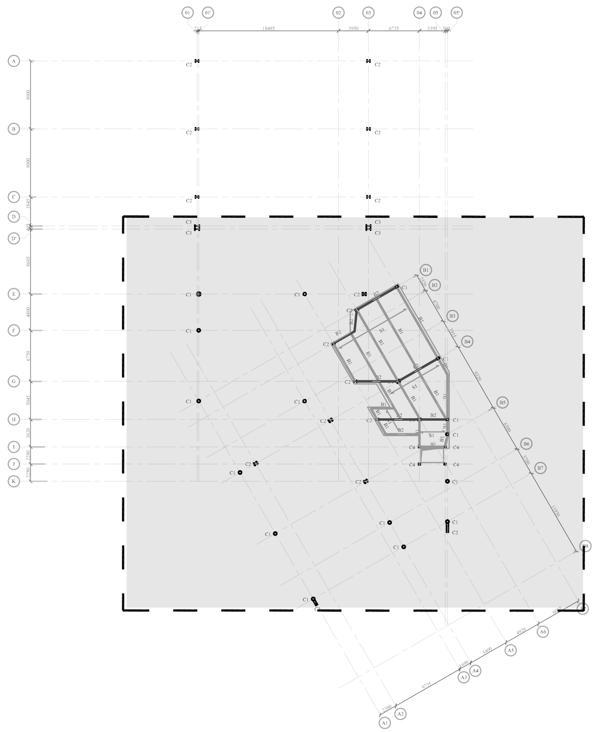

MATCH LINE
REFER TO DWG: GROUND 01
B1
B2
B3
B4
B5
B6
B7
2320
4700
3915
9320
6300
3700
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
D
D'
E
F
G
H
I
J
K
405
8605
4800
6750
5045
3620
2280
2280
C1
C2
C3
C4
W2



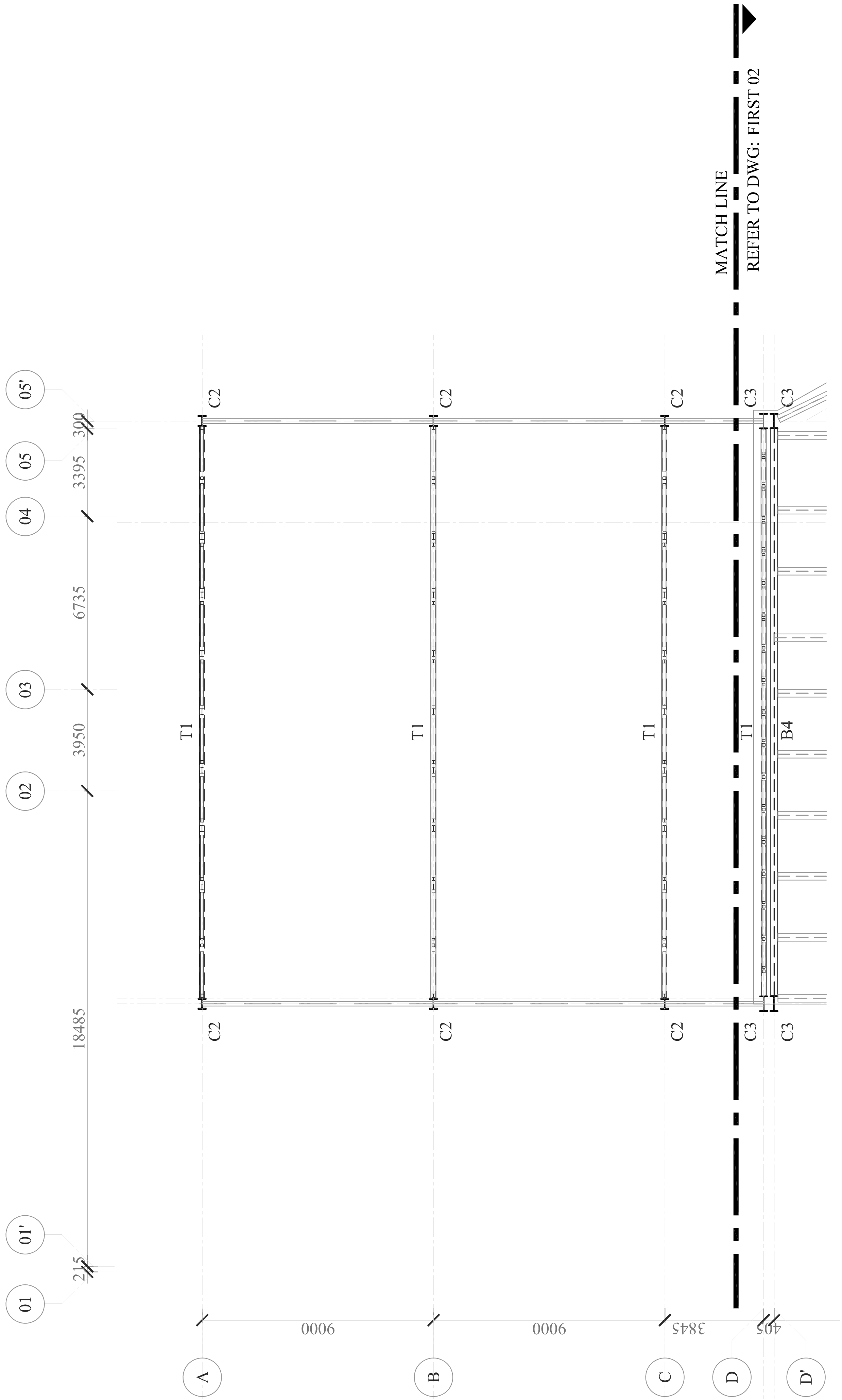
Ground floor +1200m
1:200

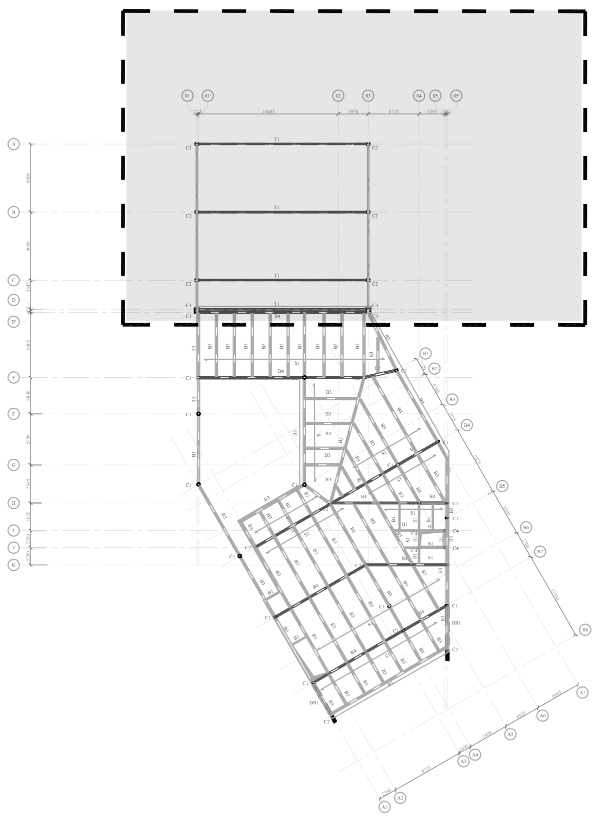

B1
B2
B3
B4
B5
B6
B7
2320
4700
3915
9320
6300
3700
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
D
D'
E
F
G
H
I
J
K
405
8605
4800
6750
5045
3620
2280
2280
C1
C2
C3
C4
S1



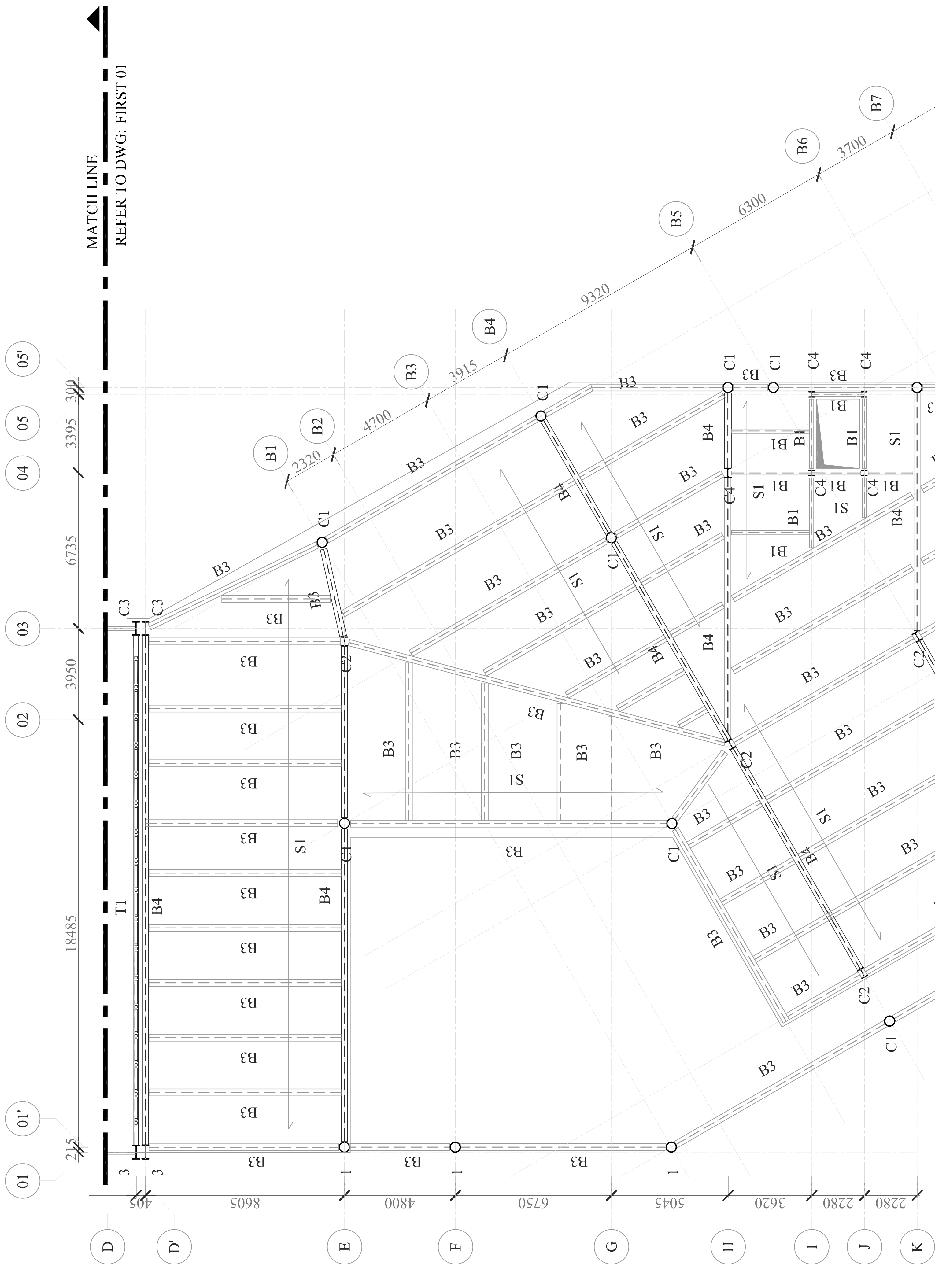


Mezzanine floor +3600mm
1:200

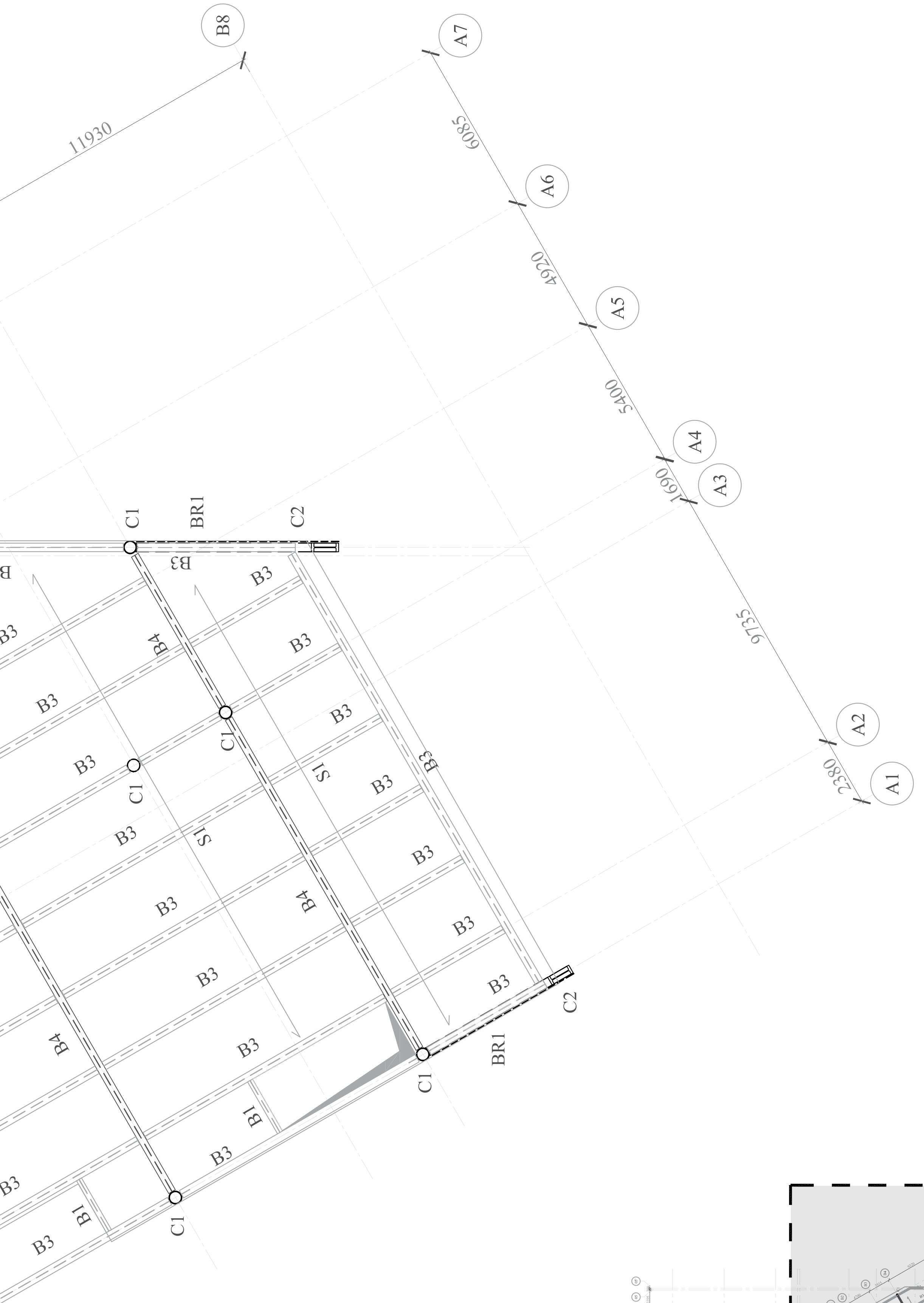

MATCH LINE
REFER TO DWG: FIRST 02
C2
C3
T1
B4
01
01'
02
03
04
05
05'
A
B
C
D
D'
215
18485
3950
6735
3395
300
9000
9000
3845
405

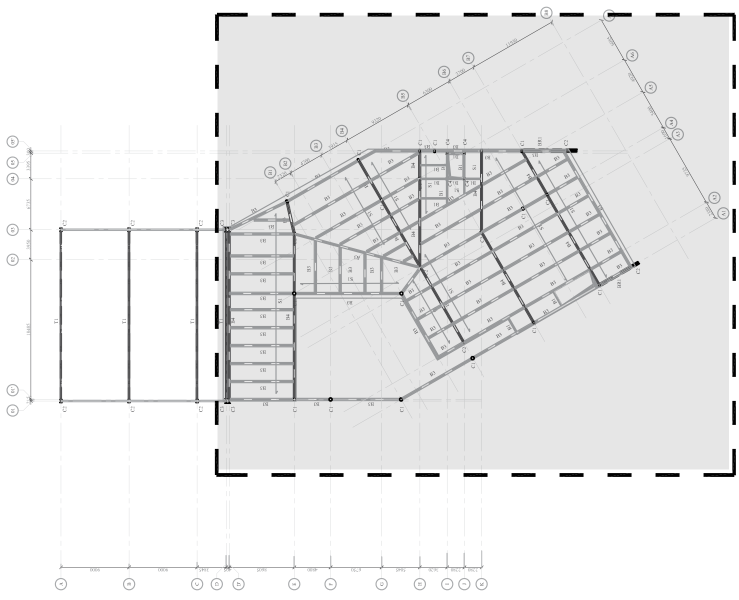


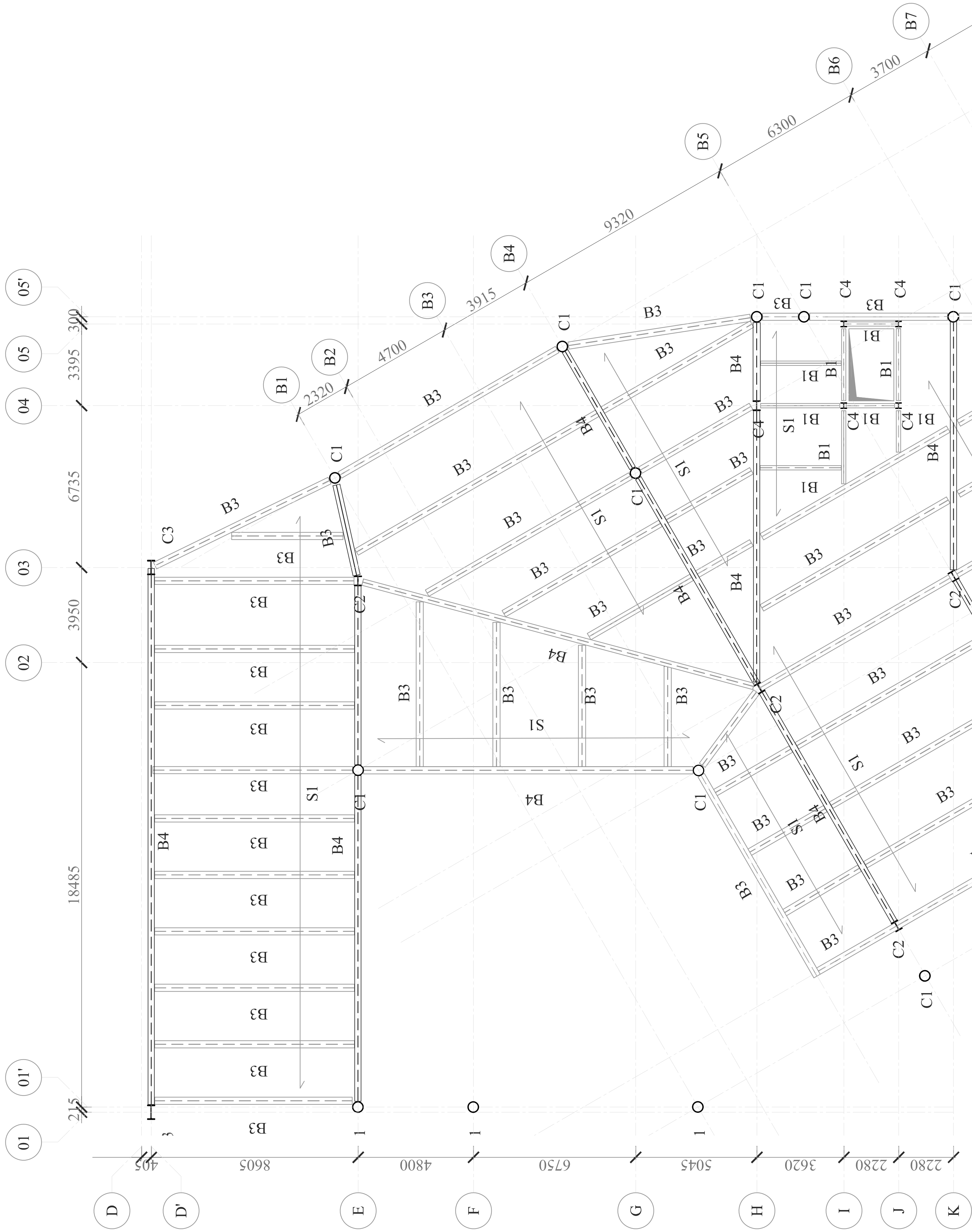
First floor +6700mm
1:200


MATCH LINE
REFER TO DWG: FIRST 01
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
D
D'
E
F
G
H
I
J
K
405
8605
4800
6750
5045
3620
2280
2280
B1
B2
B3
B4
B5
B6
B7
2320
4700
3915
9320
6300
3700

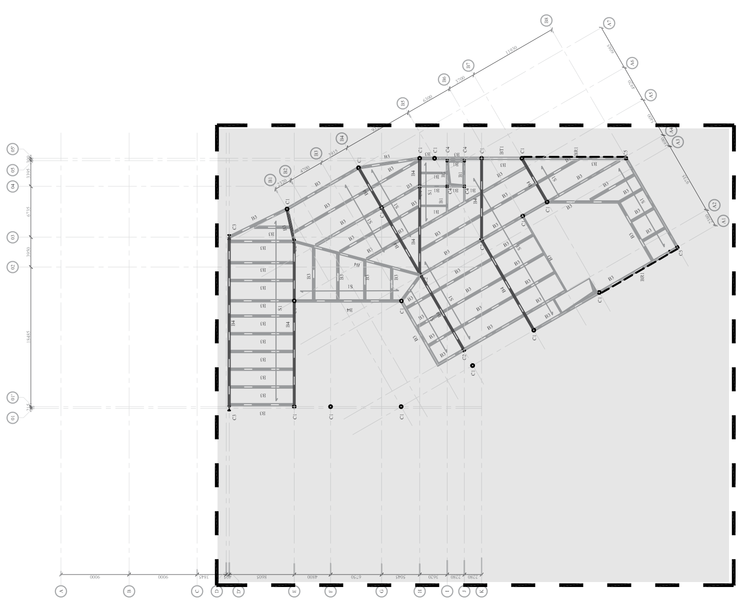
First floor +6700m
1:200

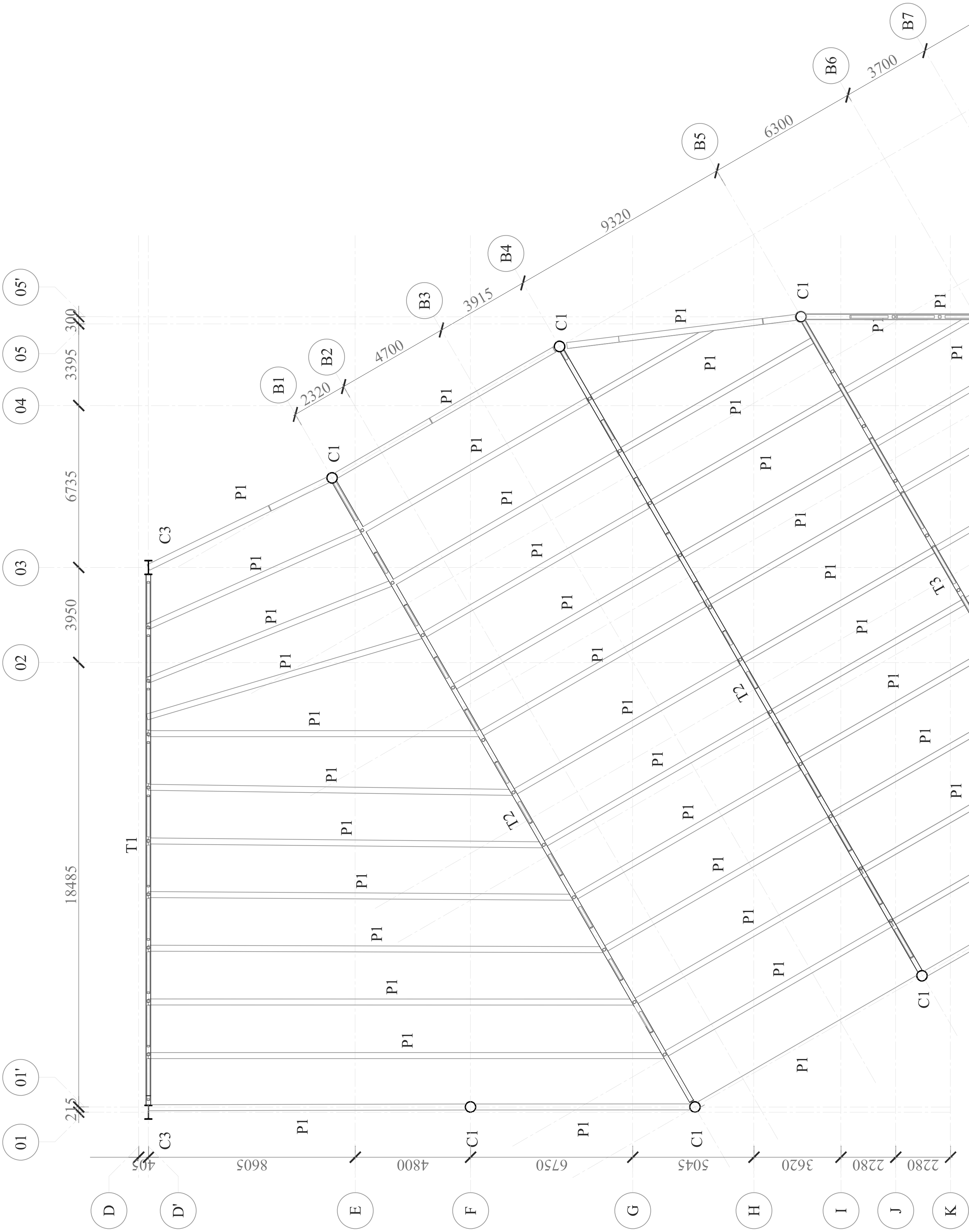




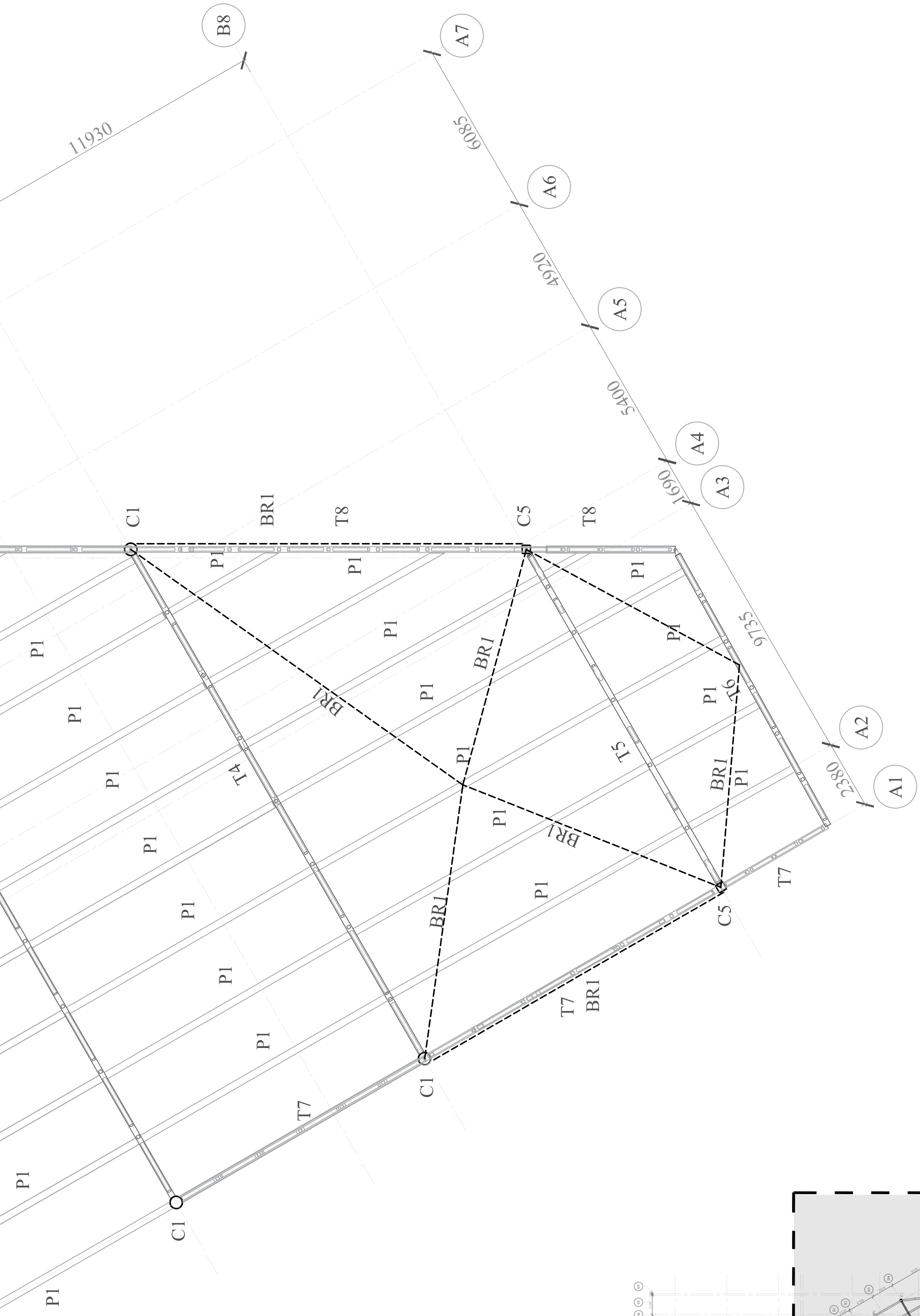

B1
B2
B3
B4
B5
B6
B7
2320
4700
3915
9320
6300
3700
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
D
D'
E
F
G
H
I
J
K
405
8605
4800
6750
5045
3620
2280
2280
C1
C2
C3
C4
B1
B3
B4
S1

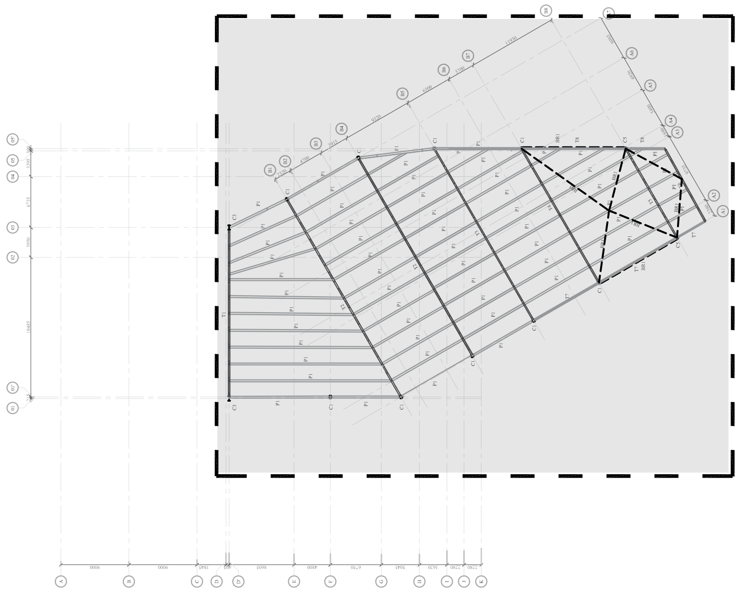
Second floor 10600+m
1:200




B1
B2
B3
B4
B5
B6
B7
2320
4700
3915
9320
6300
3700
05'
05
04
03
02
01'
01
300
3395
6735
3950
18485
215
D
D'
E
F
G
H
I
J
K
405
8605
4800
6750
5045
3620
2280
2280
C1
C3
T1
T2
T3
P1

Roof +14400m
1:200





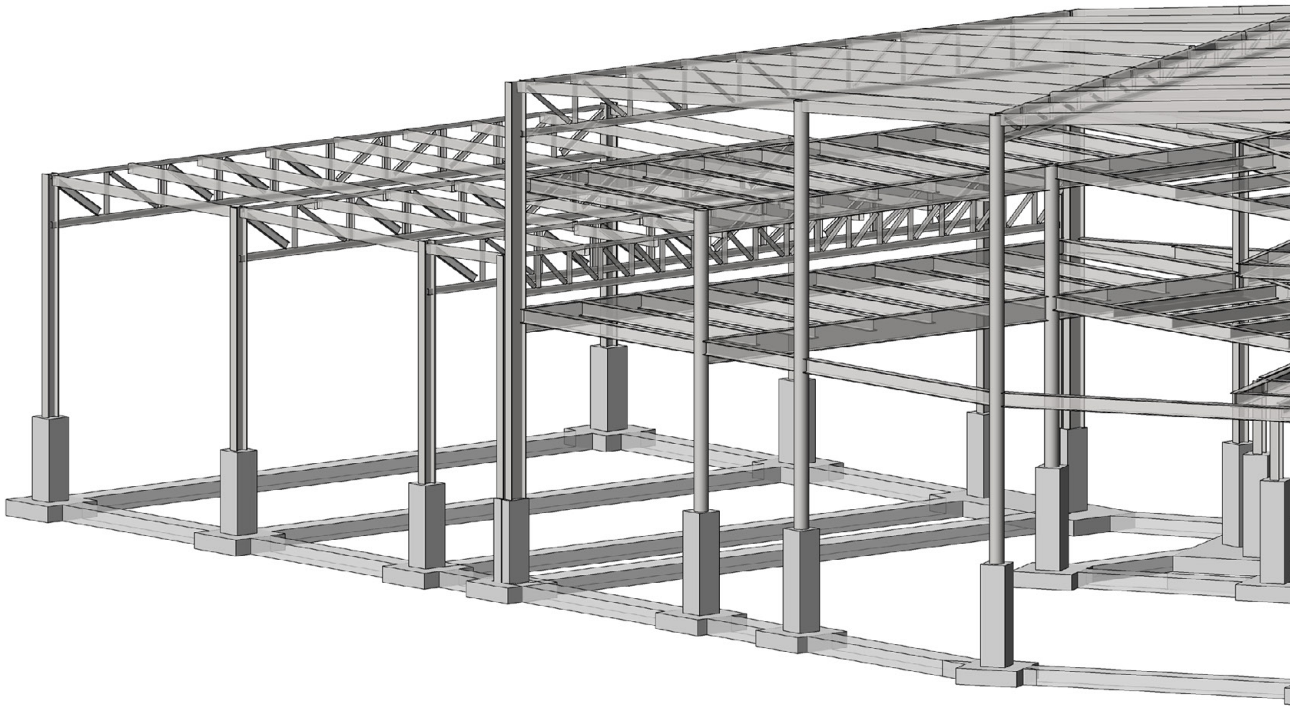
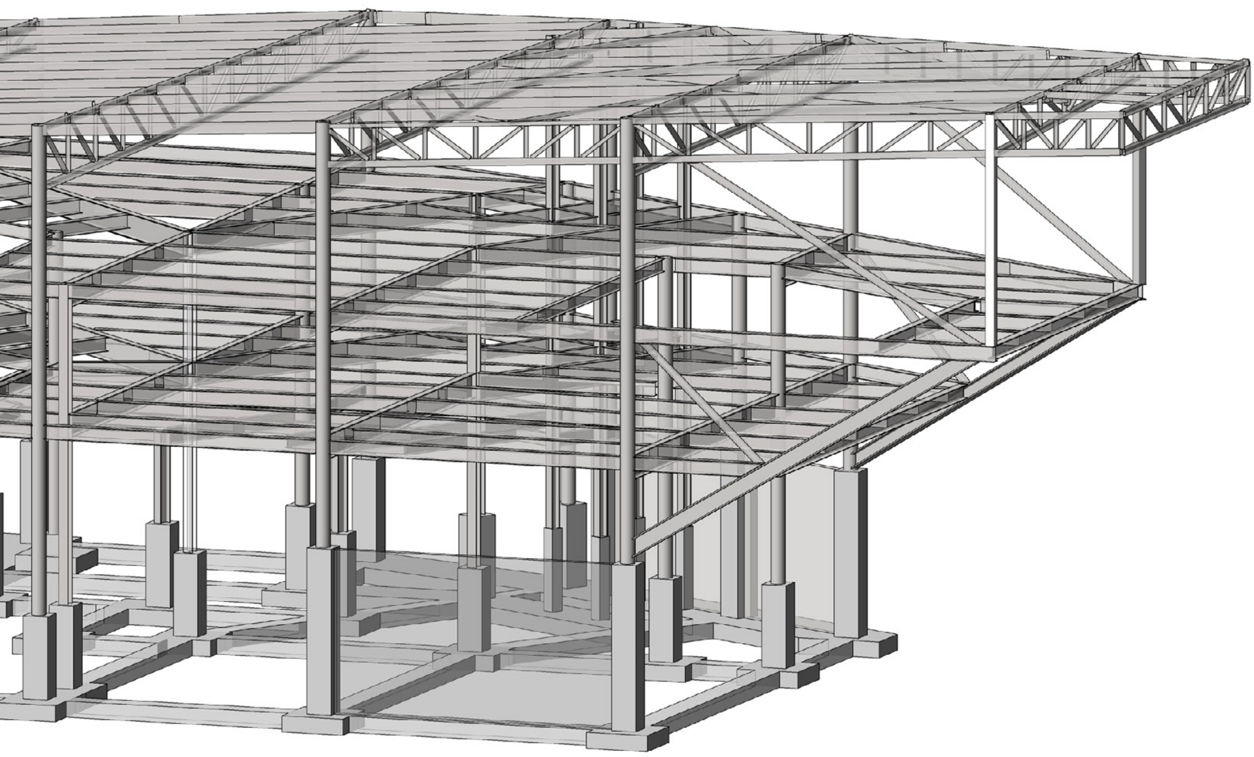
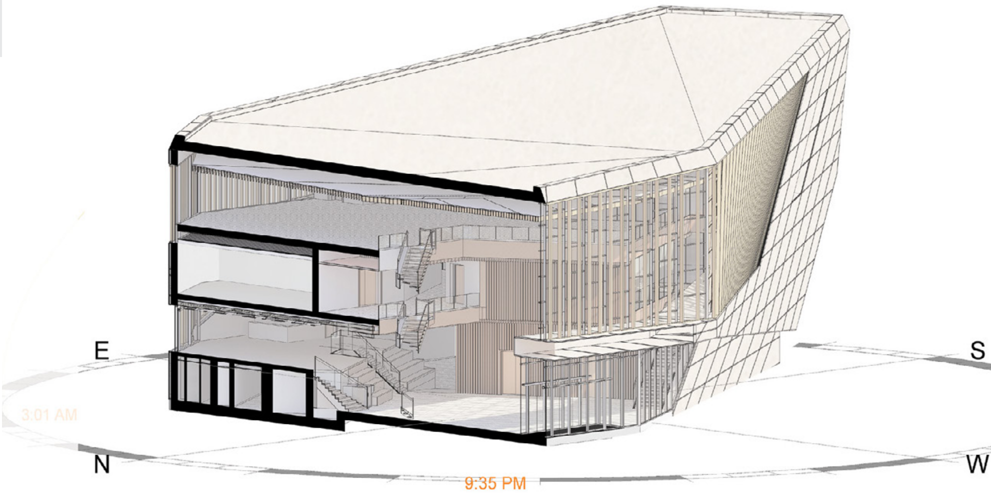


Figure.89. 3D visualization of the steel structure



6



SUSTAINABLE DESIGN AND TECHNOLOGIES

1. Introduction

Like any other major city, Oslo has an important role in demonstrating sustainable urban approaches and building development that enables urban areas to grow while reducing resource requirements. The built environment should meet these demands with low resource use and be robust over time. Reducing the buildings' environmental effect means making responsible decisions while designing a new addition to the built environment and implementing high standard construction technologies. The facilities are to offer a comfortable and healthy indoor environment concerning natural light, noise levels, and air quality.

In the early stages of the design of the Cultural Center was considered that the buildings volume, placement, and orientation are significant for energy use. This is why the decision of the location of the spaces inside the building is taken from the beginning of the design. The other important aspect is the properties of the building envelope, which were also studied closely in the following pages of this chapter.

Another important aspect of the evaluation of the building's performance was to understand the climatic conditions and the specific requirements of the location.

With the help of the available tools to analyze the energy and daylight performance, the assessment of the building performance was achieved, and that made possible the choice of appropriate technologies and materials to be taken. While performing the analysis, all the reference design codes were used as guidelines, and the values adapted in those regulations were taken.

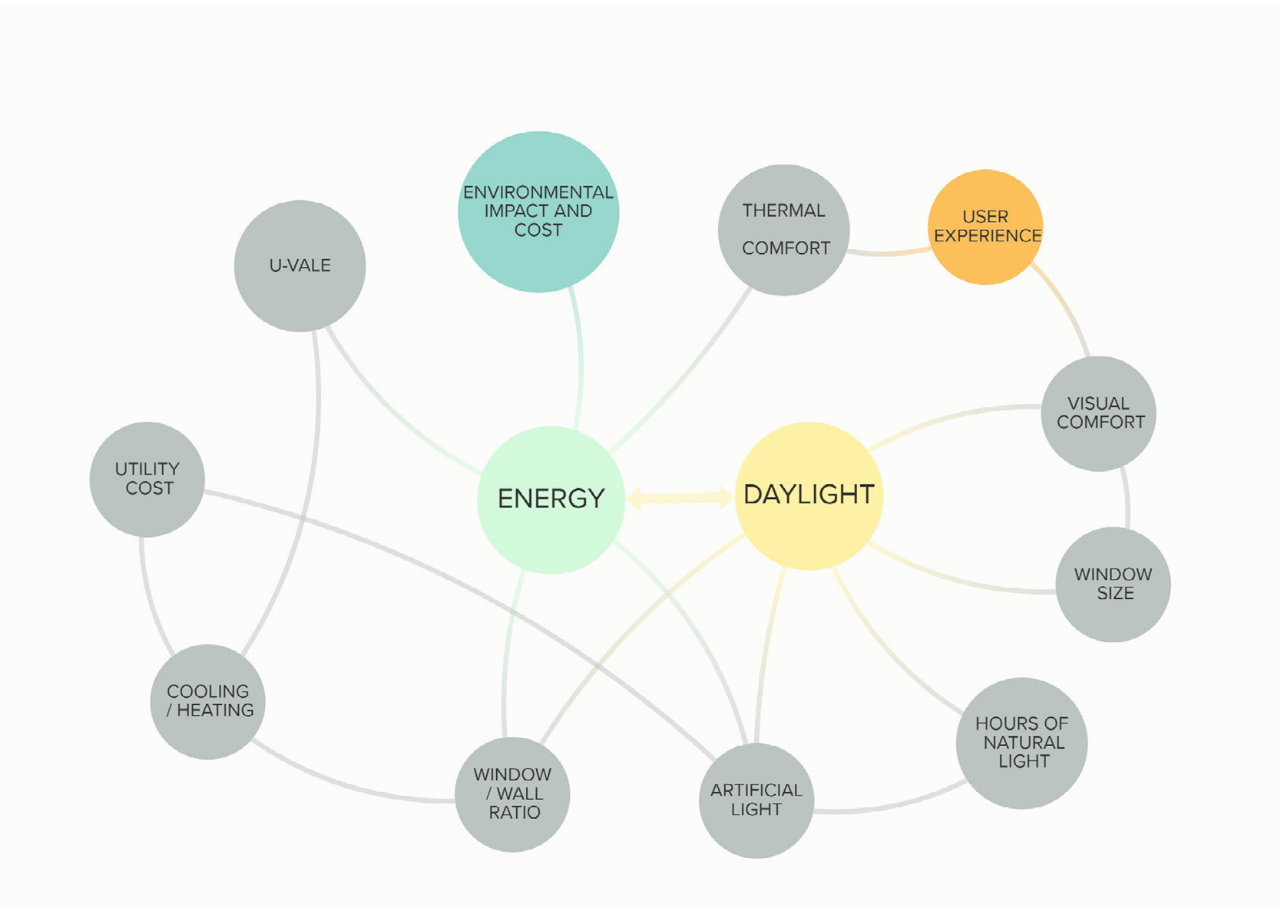


Figure.90. Sustainable design approach diagram for the project

2. Schematic design

In the schematic design, the strategies adopted for the building of the Cultural Center are described. The first and one of the most significant parameters for the building was the orientation. The decision of the location of the building both in the urban environment and the cardinal directions was made in the preliminary architectural design phase and had a significant impact performance of the building.

The next step was to develop the skin of the building – walls, windows, and the roof – which had to be adapted to the effect of the climate. The selection of building envelope with appropriate thermal insulation, materials, and technologies based on climate was a vital part of the process. This is why a sufficient thermal insulation was designed, and the number of possible thermal bridges was minimized. For this reason, the rain-screen cladding system was selected because it provides thermal and acoustic insulation qualities and provides durability over time.

Another important feature of the design of the envelope was the airtightness, and with the technologies used, there is as little infiltration as possible.

The glazing was designed with respect to the need for natural light inside the building and the desire to achieve visual comfort. Therefore, to optimize the energy demand, a high energy efficient glazing was chosen to reach sufficient light distribution and comfort.

The next important aspect of the project was to use artificial lighting, which is energy-efficient, flexible to use, and provides a long lifespan of use.

SUPER INSULATED ENVELOPE

Building envelope designed with the minimum thermal bridgs.

U-Value :	Roof	0.12 W/m²K
	Walls	0.12 W/m²K
	Glazing	0.5 W/m²K

RAINSCREEN FACADES

An outer skin attached to an airtight insulated backing wall separated by a ventilated cavity.

ENVELOPE AIRTIGHTNESS

High resistance to inward or outward air leakage with very low infiltration in winter,

ENERGY EFFICIENT GLAZING WITH LIGHT CONTROL

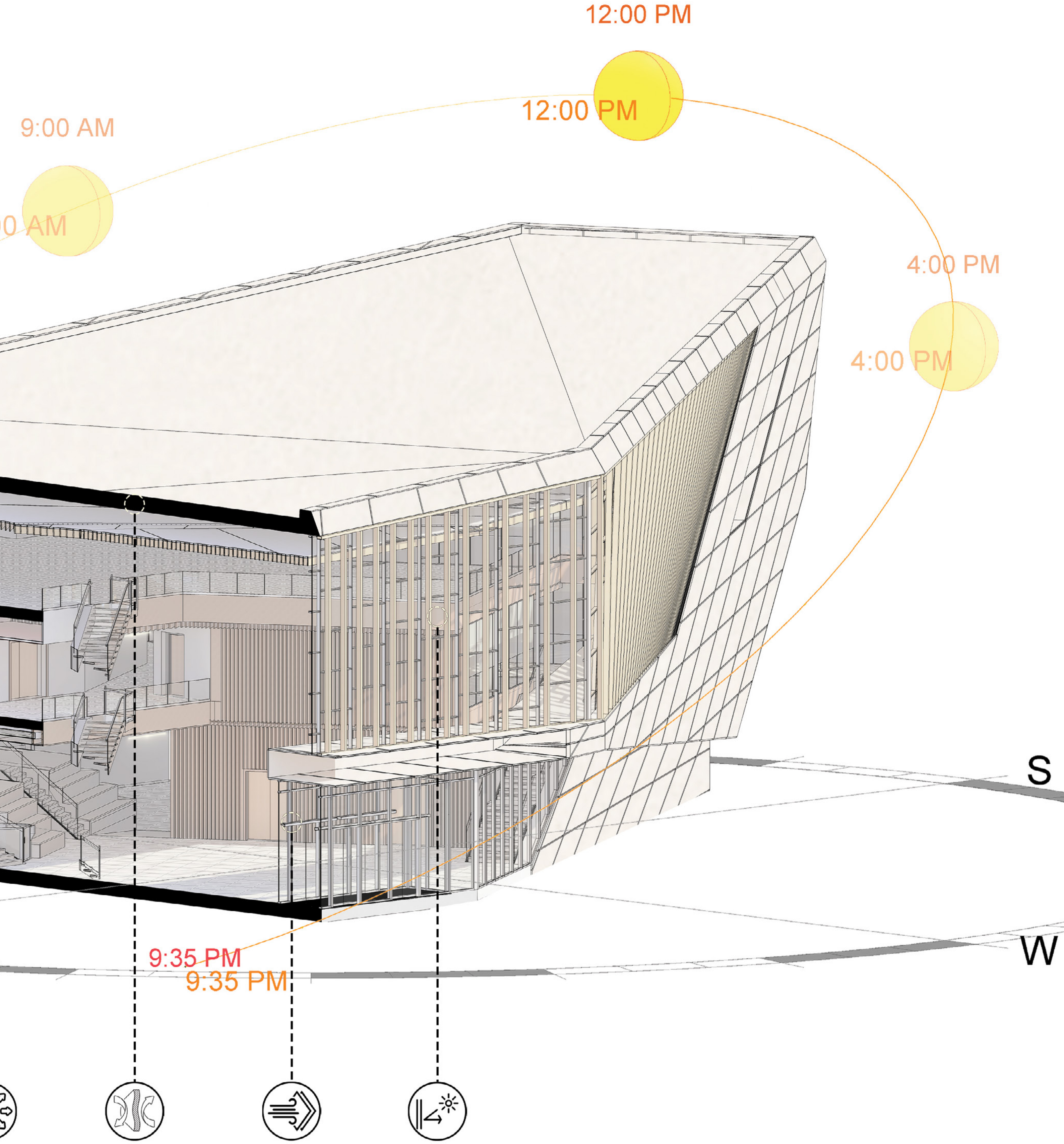
low-emissivity coated glass allows 60% visible light, reflects UV-rays and cuts glare, Integrated with shading for good light distribution and comfort.

ENERGY-EFFICIENT LIGHT

High energy performance LED lighting fixtures.

BUILDING ORIENTATION

Enhancment of the energy and environmental performance of the building thanks to the orientation respecting the site microclimate.


12:00 PM
12:00 PM
9:00 AM
0 AM
4:00 PM
4:00 PM
S
W
9:35 PM
9:35 PM

3. Energy Analysis

3.1. Introduction

In this chapter, the building of the Cultural Center was analyzed for the energy consumption following the established design regulations of Norway's Building Technical Regulations (TEK17). To satisfy thermal, air quality, acoustic and visual comfort, the European Standard EN 15251 was used.

The energy consumption of the building is calculated by energy simulations done by the software Sefaira. The application demonstrates the energy demands of the building for heating, cooling, and lighting.

In the energy simulations, the conditions of the climate of Norway were considered by observing the energy demands of the Scandinavian climate area, and this meant taking into account the prevalence of heating energy demand. Further, considerations of the space uses in the building were maid as well as lighting needs following the standarts ASHRAE 55, ASHRAE 62, UNI 10339, EN 12464 and 12193.

3.2. Guidelines

The following data was used as input for the energy requirements of the site in Oslo. According to the Regulations on technical requirements for construction works (TEK 17) Section 14-2 Energy efficiency requirements:

Total net energy requirement

The building's total net energy requirement shall not exceed the energy requirement levels in the following table and shall at the same time satisfy the requirements stipulated in section 14-3.

According to TEK 17 Section 14-3: Minimum requirements for energy efficiency the following minimum requirements for the bulding envelope should be met:

Building category	**Total net energy requirement [kWh/m^2] heated gross internal area per year]**
Small houses and leisure homes with more than 150 m2 of heated gross internal area	100 + 1,600/m2 heated gross internal area
Block of flats	95
Kindergarten	135
Office building	115
School buidling	110
University/university college	125
Hospital	225(265)
Nursing home	195(230)
Hotel building	170
Sports building	145
Commercial building	180
Cultural building	**130**
Light industry/ workshop	140(160)

Table.13. Total net energy requirement

| Minimum envelope requirements

Section 14-3 Minimum requirements for energy efficiency. The following requirements should be met:

U-value outer walls [W/m^{2}K]	U-value roof [W/m^{2}K]	U-value floors on ground and facing open air [W/m^{2}K]	U-value windows and doors including frames [W/m^{2}K]	Leakage figures at 50 Pa pressure differential [air change per hour]:
≤0.22	≤0.18	≤0.18	≤1.2	≤1.5

Table.14. Minimum requirements for energy efficiency

3.3. Space use requirements

Since the analyzed building has mixed-use function and as every function requires different space use parameters, the design temperatures and ventilation rate requirements depend on the type of use. Therefore,following the standard ASHRAE 55 (Thermal environmental conditions for human occupancy) and ASHRAE 62 (Ventilation for acceptable indoor air quality), we determine the comfort category and ventilation rate requirements for each functional zone.

Defining the space use types

In the following diagram, the different space uses are defined for the mechanical systems in the building. In this way, the different thermal zones inside the building were defined. These requirements have been set according to the codes ASHRAE 55 (Thermal environmental conditions for human occupancy), ASHRAE 62 (Ventilation for acceptable indoor air quality), the normative UNI 10339 (Performance requirements for ventilation and room-conditioning systems) and EN 12464 and 12193 (Light and lighting). The parameters are defined as follows:

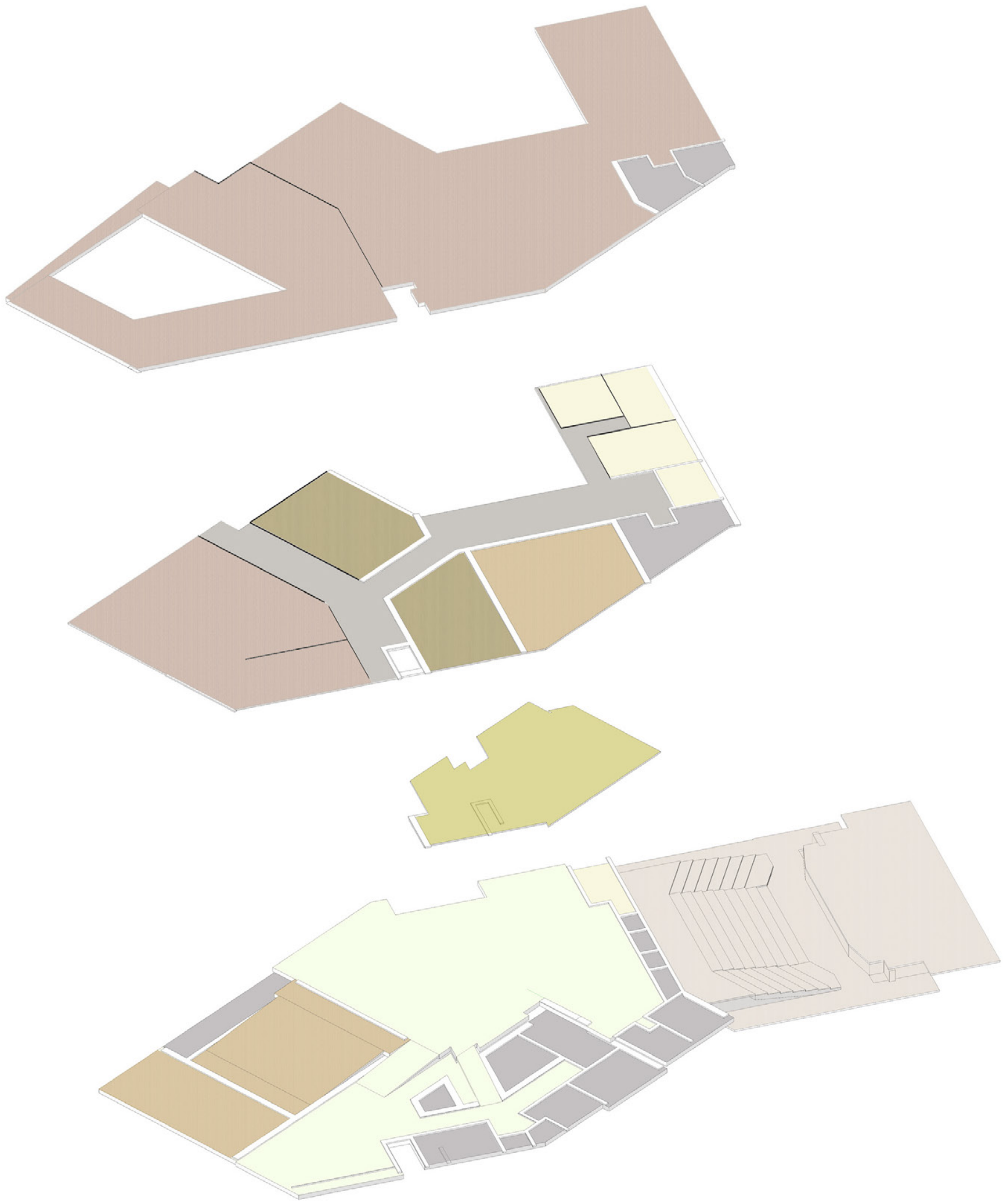


Figure.92. Types of space uses diagram

Lobby/Atrium			
Design Loads			
Occupant density	m2/person	1.5	
Equipment power density	W/m2	4	
Lighting power density	W/m2	10	
Ventilation and outside air			
Outside air rate/person	L/s.person	2.5	
Outside air rate/unit area	L/m2.s	0.6	
Design Temperatures			
Setpoint temperature	°C	20	25
Setback temperature	°C	15	28
HVAC Schedule			
Operating hours		9am	11pm

Corridor/Services			
Design Loads			
Occupant density	m2/person	30	
Equipment power density	W/m2	4	
Lighting power density	W/m2	10	
Ventilation and outside air			
Outside air rate/person	L/s.person	1	
Outside air rate/unit area	L/m2.s	0.3	
Design Temperatures			
Setpoint temperature	°C	19	26
Setback temperature	°C	15	28
HVAC Schedule			
Operating hours		9am	11pm

Auditorium			
Design Loads			
Occupant density	m2/person	1.5	
Equipment power density	W/m2	6	
Lighting power density	W/m2	15	
Ventilation and outside air			
Outside air rate/person	L/s.person	2.5	
Outside air rate/unit area	L/m2.s	0.3	
Design Temperatures			
Setpoint temperature	°C	20	25
Setback temperature	°C	15	28
HVAC Schedule			
Operating hours		1pm	11pm

Exhibition			
Design Loads			
Occupant density	m2/person	2	
Equipment power density	W/m2	4	
Lighting power density	W/m2	20	
Ventilation and outside air			
Outside air rate/person	L/s.person	3.8	
Outside air rate/unit area	L/m2.s	0.3	
Design Temperatures			
Setpoint temperature	°C	20	25
Setback temperature	°C	15	28
HVAC Schedule			
Operating hours		9am	11pm

Caffe			
Design Loads			
Occupant density	m2/person	1.5	
Equipment power density	W/m2	10	
Lighting power density	W/m2	15	
Ventilation and outside air			
Outside air rate/person	L/s.person	3.8	
Outside air rate/unit area	L/m2.s	0.9	
Design Temperatures			
Setpoint temperature	°C	20	25
Setback temperature	°C	15	28
HVAC Schedule			
Operating hours		9am	9pm

Office/Lab			
Design Loads			
Occupant density	m2/person	10	
Equipment power density	W/m2	10	
Lighting power density	W/m2	15	
Ventilation and outside air			
Outside air rate/person	L/s.person	3.8	
Outside air rate/unit area	L/m2.s	0.9	
Design Temperatures			
Setpoint temperature	°C	20	25
Setback temperature	°C	15	28
HVAC Schedule			
Operating hours		9am	9pm

Library			
Design Loads			
Occupant density	m2/person	3	
Equipment power density	W/m2	12	
Lighting power density	W/m2	15	
Ventilation and outside air			
Outside air rate/person	L/s.person	2.5	
Outside air rate/unit area	L/m2.s	0.6	
Design Temperatures			
Setpoint temperature	°C	20	25
Setback temperature	°C	15	28
HVAC Schedule			
Operating hours		9am	9pm

Table.15. Space use zones

3.4. Energy simulations

| Case 0 - opaque envelope

The building envelope parameters are defines as:

Element	U [W/m2K]
Exterior wall	0.22
Floor	0.24
Roof	0.18
Glazing	-
Solar heat gain coefficient	-

Table.16. Building envelope parameters case 0

First, in the energy simulation is considered a reference case in which the envelope of the building is opaque. This case study is a model of the mass of the building, and it is simplified. Therefore, it is used for preliminary simulation of the model and obtaining the baseline of the energy results.

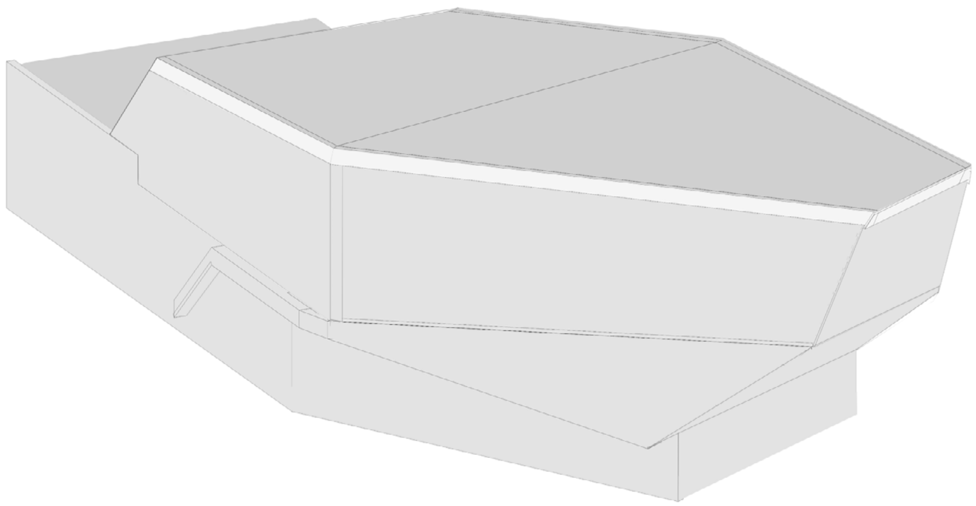
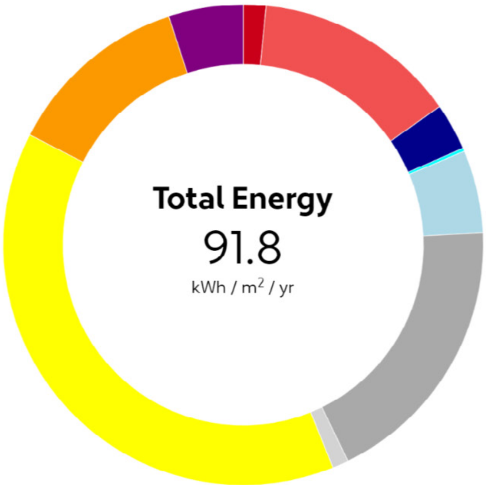


Figure.93. Energy model in Case 0

Annual Energy Use



Segment	kWh / m² / yr	% of total use
Heating	**14.0**	**15 %**
AHU	1.4	2 %
Zones	12.6	14 %
Humidification	0.0	0 %
Cooling	**8.2**	**9 %**
AHU	2.9	3 %
Heat Rejection	0.2	0 %
Zones	5.1	6 %
Fans	**18.1**	**20 %**
AHU	17.1	19 %
Zones	1.0	1 %
Interior	**46.9**	**51 %**
Lighting	35.5	39 %
Equipment	11.4	12 %
Pumps	**4.6**	**5 %**

Figure.94. Annual Energy Use Case 0 (Sefaira)

Monthly Energy Use

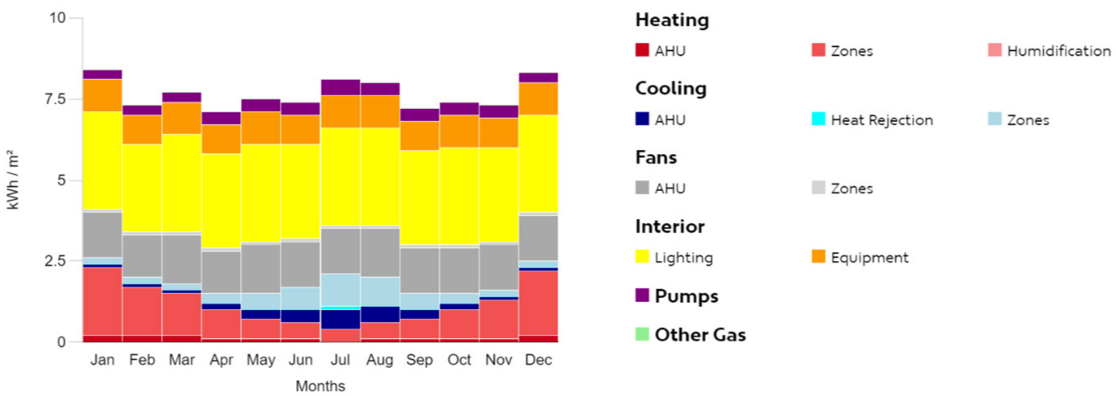


Figure.95. Montly Energy Use Case 0 (Sefaira)

Case 1 - opaque and transparent envelope

The building envelope parameters are defined as:

Element	U [W/m2K]
Exterior wall	0.22
Floor	0.24
Roof	0.18
Glazing	1.2
Solar heat gain coefficient	0.6

Table.17. Building envelope parameters case 1

First, in the energy simulation is considered a reference case in which the envelope of the building is opaque. This case is a model of the mass of the building, and it is simplified. Therefore, it is used for preliminary simulation of the model and obtaining the baseline of the energy results. In the first case, the model studies both the glazing and the opaque envelope of the building. The minimum required thermal transmittance values, taken from TEK17, are used to evaluate the building's performance. The analysis results show that the annual energy amount of 96,4 kW/h/m2 is within the minimum requirement for energy efficiency in TEK17 — 130kW/h/m2, and this means that even with the minimum values for the thermal transmittance, the building envelope has adequate energy performance.

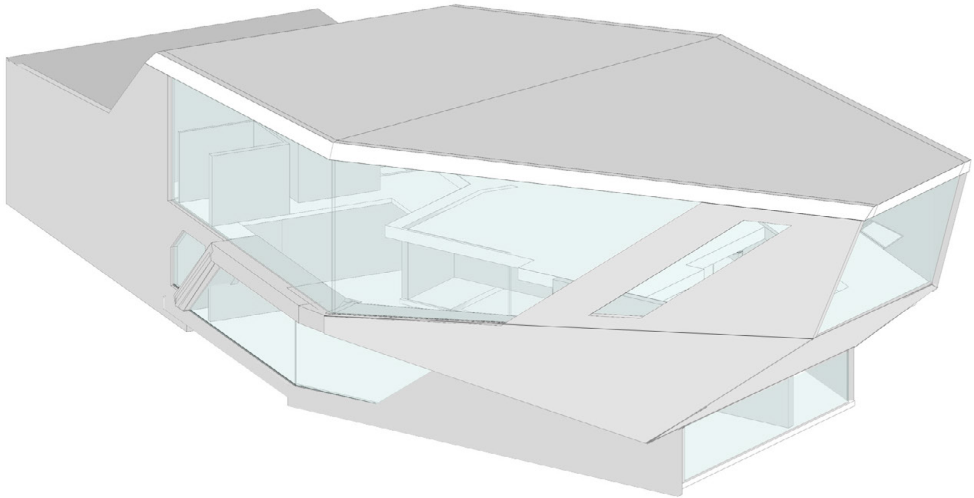
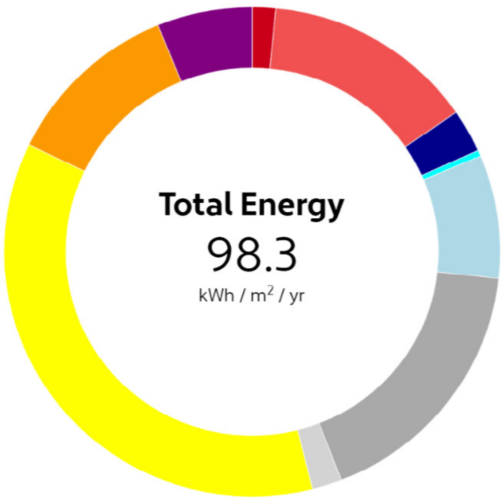


Figure.96. Energy model in Case 1

Annual Energy Use



Segment	kWh / m^2 / yr	% of total use
Heating	**15.1**	**15 %**
AHU	1.5	2 %
Zones	13.6	14 %
Humidification	0.0	0 %
Cooling	**11.2**	**11 %**
AHU	2.8	3 %
Heat Rejection	0.4	0 %
Zones	8.0	8 %
Fans	**19.0**	**19 %**
AHU	17.1	17 %
Zones	1.9	2 %
Interior	**46.9**	**48 %**
Lighting	35.5	36 %
Equipment	11.4	12 %
Pumps	**6.1**	**6 %**

Figure.97. Annual Energy Use Case 1 (Sefaira)

Monthly Energy Use

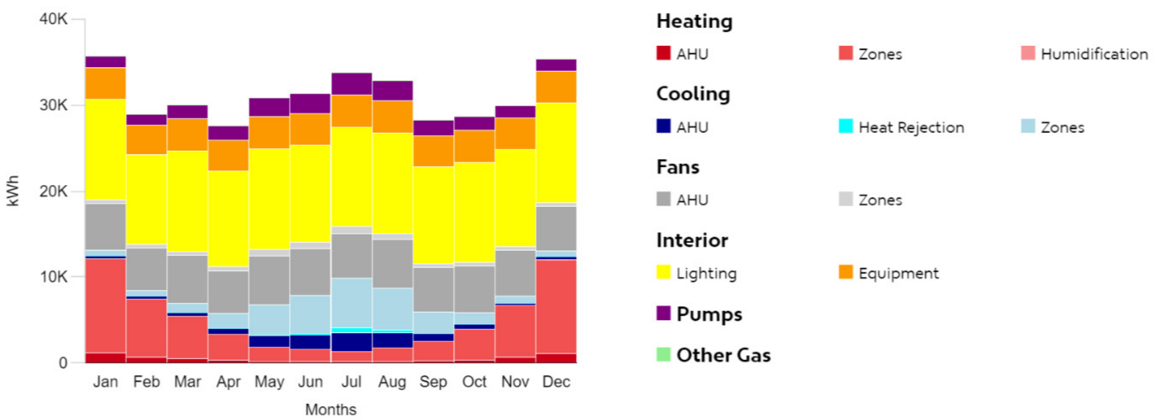


Figure.98. Montly Energy Use Case 1 (Sefaira)

Case 2 - shading impact

The building envelope parameters are defined as:

Element	U [W/m2K]
Exterior wall	0.22
Floor	0.24
Roof	0.18
Glazing	1.2
Solar heat gain coefficient	0.6

Table.18. Building envelope parameters case 2

Three types of shading were analyzed to understand their impact on energy consumption. First, vertical shading was considered. For the energy consumption analysis, multiple interpolations of the depth of the shadings were performed in a response curve diagram. The diagram shows results for 0.8m maximum dept of the louvers. First, the analysis is done for vertical shading. The improvement of energy is not significant about 0,1 kWh/m2 /yr. Next, the analysis for the horizontal shading was done. It showed that the horizontal shading would be slightly more efficient with a large size. Finally, the option of operable shading was also examined. It considers mainly external types of blinds, and the result showed lower optimization of the energy than the other categories. Also, this type of shading was not regarded as appropriate for aesthetic reasons as well.

In conclusion, it can be said that with small depts of 0.2 m, the shading did not have a significant impact on minimizing the energy. The decision to use shading was shown on another type of analysis about the daylight and shading was used mostly for achieving visual comfort and aesthetic appearance.

Vertical shading

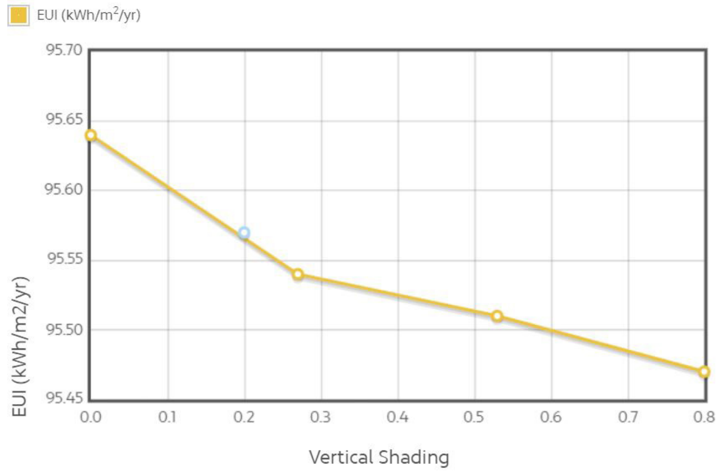


Figure.99. Vertical shading response diagram (source:Sefaira)

Horizontal shading

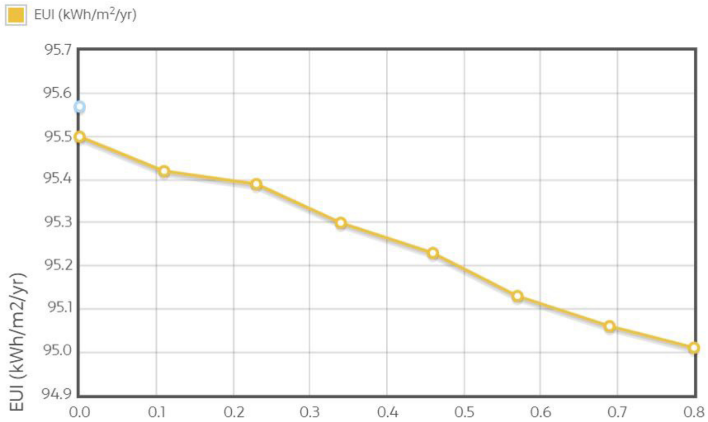


Figure.100. Horizontal shading response diagram (source: Sefaira)

Operable external shading

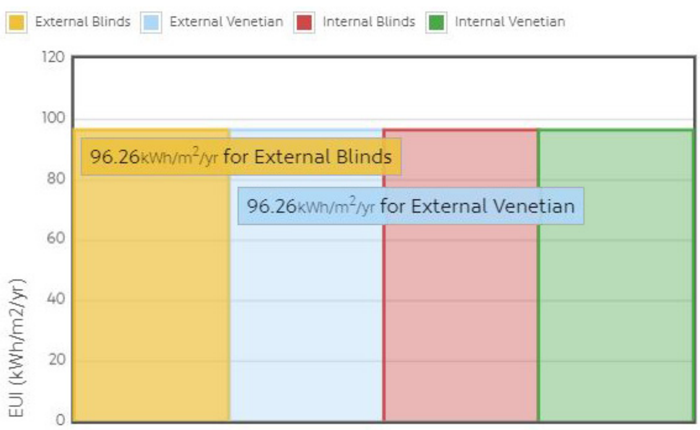


Figure.101. Operable shading response diagram (source: Sefaira)

Optimization of the envelope

The next step was to analyze strategies to improve the energy performance of the envelope. For these four, passive strategies were considered. The first of the strategy was to optimize the opaque envelope thermal transmittance value. The strategy reduces the heating load by 17% and the cooling load by 4%. The second strategy was to optimize the performance of the glazing by using triple glazing with thermal transmittance value of 0,5 W/m2K, and this has the most significant effect on the cooling load reducing it by 27%. The third strategy was to reduce the solar heat gain coefficient using low emissivity coatings. This strategy concerns the solar heat gains and the cooling load. Since the building has large glazed facades towards east, west, and south lowering the SHGC would decrease the cooling load demand. As the simulation shows, the cooling is reduced by 21%. Finally, the fourth strategy was to implement shading devices. This strategy again was oriented mostly towards cooling optimization but also allowed us to understand how using a shading can be applied in the design process. The analysis shows that this strategy, in fact, reduces the cooling demand by 14% with an increase of the heating load by 12% and, overall, a 2% decrease in total annual energy consumption.

Next, the combinations of each strategy were studied. The reduction of heating load is the most significant improvement in all of the cases. In the first combination, it is reduced by 47%, and the cooling is reduced by 4%. The effect of the second combination is more critical on the reduction of the cooling load because it minimizes the solar heat gains, and it results in a reduction of cooling load by 10%. The total energy is reduced by 7%.

Further, we have the combination of the first, second, and fourth strategy. This strategy results in a reduction of 7% in the total energy consumption. Finally, we have the full combination of all strategies. The total energy in that situation is 90.2 kWh/m2/yr, which shows an overall 9% reduction in annual energy consumption.

In conclusion, we choose the final combination that gives a significant improvement in energy performance for cooling and heating. In the initial situation, we had bigger heating loads that, by optimizing the thermal properties of the envelope, we improved significantly. Then we considered that we should address the considerable amounts of solar heat gains in the east, west, and south directions by using triple glazing with low emissivity coating. Following this, we considered the daylight optimization by integrating shading elements. They have an impact on energy consumption, increasing the heating load, but overall, they allow the integration of daylight and energy into a system that creates a positive environment.

Strategy		Description	Annual Energy Consumption [kWh/m2/yr]	Saving [%]	Heating Load [kWh/m2/yr]	Saving [%]	Cooling Load [kWh/m2/yr]	Saving [%]
0	Base case	U [W/m2K] wall - 0.22 floor -0.24 roof -0.18 U [W/m2K] glazing -1.2 SHGC - 0.6	98.30	-	15.10	-	11.20	-
1	Opaque envelope	U [W/m2K] wall - 0.12 floor -0.24 roof -0.12 U [W/m2K] glazing -1.2 SHGC - 0.6	94.30	-4	12.50	-17	10.70	-4
2	Glazing	U [W/m2K] wall - 0.22 floor -0.24 roof -0.18 U [W/m2K] glazing -0.5 SHGC - 0.6	91.80	-7	14.00	-7	8.20	-27
3	Glazing SHGC	U [W/m2K] wall - 0.22 floor -0.24 roof -0.18 U [W/m2K] glazing -1.2 SHGC - 0.35	95.70	-3	16.50	9	8.90	-21
4	Shading	U [W/m2K] wall - 0.22 floor -0.24 roof -0.18 U [W/m2K] glazing -1.2 SHGC - 0.6	96.50	-2	17.20	12	9.80	-14
1+2	Combination		**93.50**	**-5**	**10.30**	**-47**	**10.80**	**-4**
1+2+3			**91.20**	**-7**	**10.60**	**-42**	**10.20**	**-10**
1+2+4			**94.20**	**-4**	**11.50**	**-31**	**9.80**	**-14**
1+2+3+4			**90.20**	**-9**	**11.90**	**-27**	**8.80**	**-27**

Table.19. Envelope optimization

| Case 3 Optimized envelope

The final building envelope parameters are defined as:

Element	U [W/m2K]
Exterior wall	0.12
Floor	0.25
Roof	0.12
Glazing	0.5
Solar heat gain coefficient	0.35

Table.20. Building envelope parameters case 3

The final case represents the optimization of the envelope and the final results of the energy simulations. The shading is studied again more closely because it is a combination of vertical and inclined louvers. The vertical system protects in the east and west facades whereas the inclined system is located in the south-west and acts as a combination of vertical and horizontal shading.

In the investigation, the inlined shading is considered simplified because of the requirements of the software. After the study, the size of the louvers were set to 0,22m depth and 0,1 m width. This size was considered an optimum size for both daylight and energy analysis.

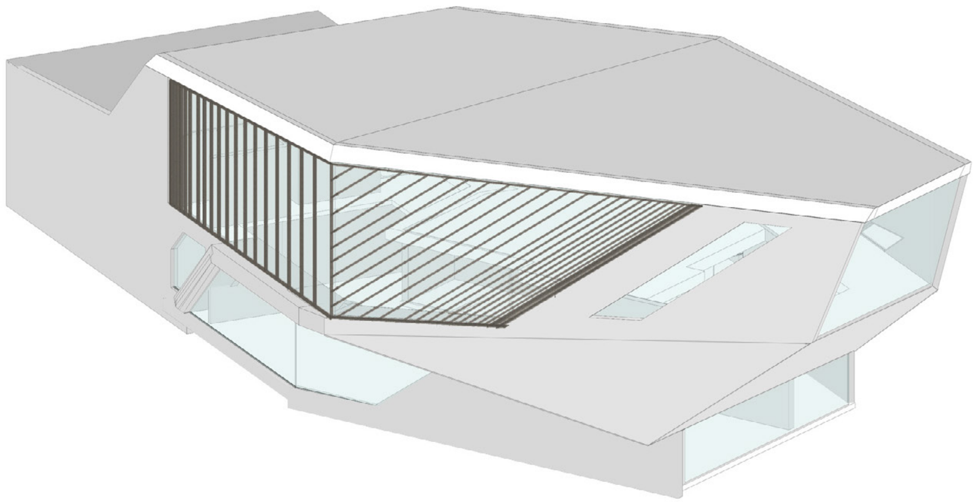
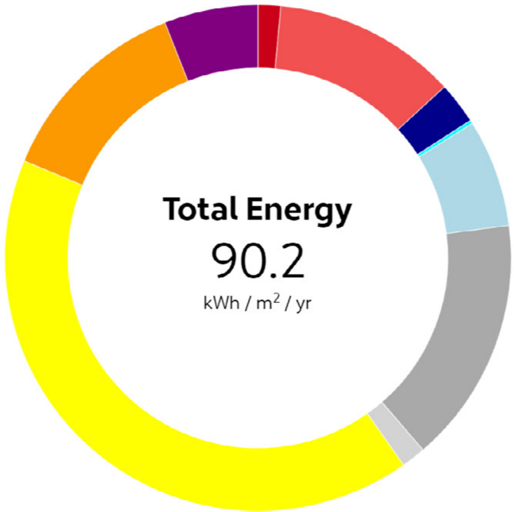


Figure.102. Energy model in Case 4

Annual Energy Use



Segment	kWh / m^2 / yr	% of total use
Heating	**11.9**	**13 %**
AHU	1.3	1 %
Zones	10.6	12 %
Humidification	0.0	0 %
Cooling	**8.8**	**10 %**
AHU	2.4	3 %
Heat Rejection	0.2	0 %
Zones	6.2	7 %
Fans	**15.6**	**17 %**
AHU	14.2	16 %
Zones	1.4	2 %
Interior	**48.5**	**54 %**
Lighting	37.0	41 %
Equipment	11.5	13 %
Pumps	**5.4**	**6 %**

Figure.103. Annual Energy Use Case 1 (Sefaira)

Monthly Energy Use

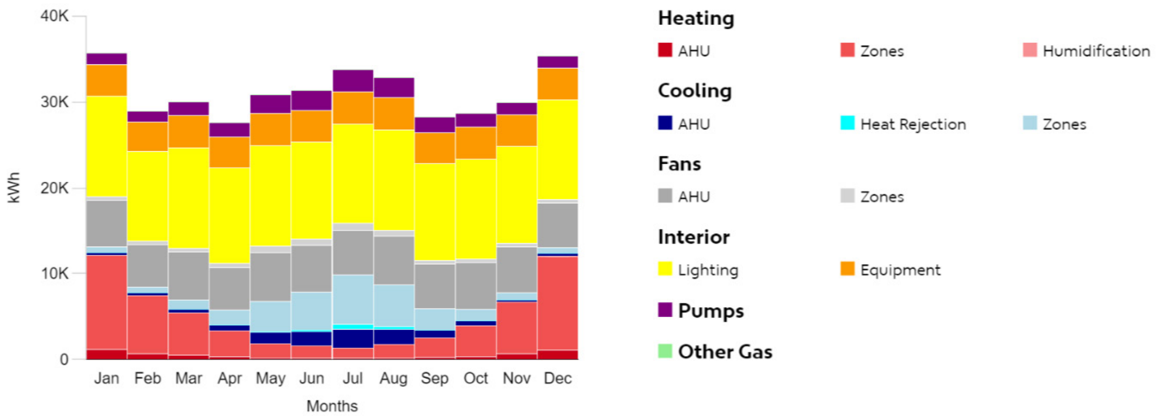


Figure.104. Montly Energy Use Case 1 (Sefaira)

4. Daylight Analysis

4.1. Introduction

In this section, the daylight analysis was done. To perform it simulations of the building were maid by the software Sefaira.

The daylight analysis considered the climatic conditions of the location of the project – the city of Oslo, Norway closely. The requirements were essential because of the low solar altitude, frequent overcast conditions, and the considerable seasonal variation in day-length. These conditions meant that the daylight optimization has more constraints of application and has to be studied in depth.

The studies has been made to understand the effects of the overcast sky conditions on the daylight. Using daylight successfully was a crucial part of the design of the spaces in the building because we wanted to provide comfortable, enjoyable spaces while minimizing the needs of artificial lighting.

In the studies were analyzed the impact of the large glazing facades. Even though the sky conditions in Oslo are mostly overcast, there is still the possibility of visual discomfort. After obtaining the results of the initial daylight analysis, strategies to improve the conditions were studied. That meant examining methods to improve comfort whiteout compromising the daylight amount in seasons with low solar altitude. In the case of the Cultural Center, there were types of functions where utilizing daylight was reccomended, like the library, the cafe, the office, and laboratory spaces.

Daylighting alone, even if distributed with the help of daylighting systems, can not secure adequate lighting conditions for all working hours during a year and all visual tasks. It is due partly to the limited availability of daylight during the year. Artificial lighting is an irreplaceable part of the daylight needs. It should supplement daylight in the periods when daylight level is too low or in places where a specific distribution of light is desired. This was the case for some functions in the Cultural Center, like the exhibitions and the auditorium, where artificial lighting will be used as the main light source.

| Daylight parameters

In the project we used the parameters which are used to evaluate visual comfort. They are defined as:

Spatial Daylight Autonomy (sDA)

Spatial Daylight Autonomy (sDA) describes how much of a space receives sufficient daylight. Specifically, it describes the percentage of floor area that receives a minimum illumination level for a minimum percentage of annual occupied hours — for instance, the area that receives at least 300 lux for at least 50% of occupied hours (which would be notated as sDA300/50%). It is a climate-based daylighting metric, meaning that it is simulated using a location-specific weather file (similar to an energy model).

Annual Sunlight Exposure (ASE)

Annual Sun Exposure (ASE) describes how much of space receives too much direct sunlight, which can cause visual discomfort (glare) or thermal discomfort. Specifically, ASE measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year (ASE1000,250).

Useful daylight illuminance (UDI)

Useful daylight illuminance (UDI) is a daylight availability metric that corresponds to the percentage of the occupied time when a target range of illuminances at a point in a space is met by daylight.

Daylight illuminances in the range 100 to 300 lux are considered effective either as the sole source of illumination or in conjunction with artificial lighting. Daylight illuminances in the range 300 to around 3 000 lux are often perceived as desirable (Mardaljevic et al, 2012).

Daylight factor (DF)

Daylight factor (DF) is a daylight availability metric that expresses as a percentage the amount of daylight available inside a room (on a work plane) compared to the amount of unobstructed daylight available outside under overcast sky conditions (Hopkins,1963).

The higher the DF, the more daylight is available in the room. Rooms with an average DF of 2% or more can be considered daylit, but electric lighting may still be needed to perform visual tasks. A room will appear strongly daylit when the average DF is 5% or more, in which case electric lighting will most likely not be used during daytime (CIBSE, 2002).

Spatial Daylight Autonomy (sDA)	
0 to 55 %	Not acceptable
55 to 75%	Acceptable level
> 75%	Optimum level

Useful Daylight Autonomy (UDI)	
0 to100 lux	Not effective
100-300 lux	Effective
300 to 3000lux	Desirable

Annual Sunlight Exposure (ASE)	
0 to 10%	Comfortable
>10%	May result in visual discomfort

Daylight Factor(DF)	
<2%	Not adequately lit
2 to 5%	Adequately lit
> 5%	Well lit

Table.21. Daylight parameters

4.2. Daylight Simiulations

As mentioned before, the software Sefaira was used for the Daylight visualizations. The application produces graphical heatmaps associated with a given floor. There are two types of analysis. The first is called Overlit and Underlit analysis that uses annual weather data and it gives information about the direct sunlight by reporting the sDA and ASE parameters. This analysis defines the areas which have adequate lighting called well lit, the spaces with not enough direct light - underlit, and the spaces with too much direct sunlight. The second type of analysis is named Daylight factor and reports daylighting ratios under uniform cloudy sky.

| Case 1

The parameters for the analysis have been set to:

Visible Light Transmittance : 65%

Window/Wall ratios:

Window/Wall ratio							
South	0.7	East	0.2	West	0.5	North	0

Table.22. Window to Wall ratios Case 1

In the following case, the first daylight simulation was performed. The model and the window/ wall ratios were defined in the architectural design phase. The purpose of this study was to find the amount and the distribution of the natural daylight in the building. On the ground floor, the auditorium is not analyzed in the daylight model because it does not need natural light.

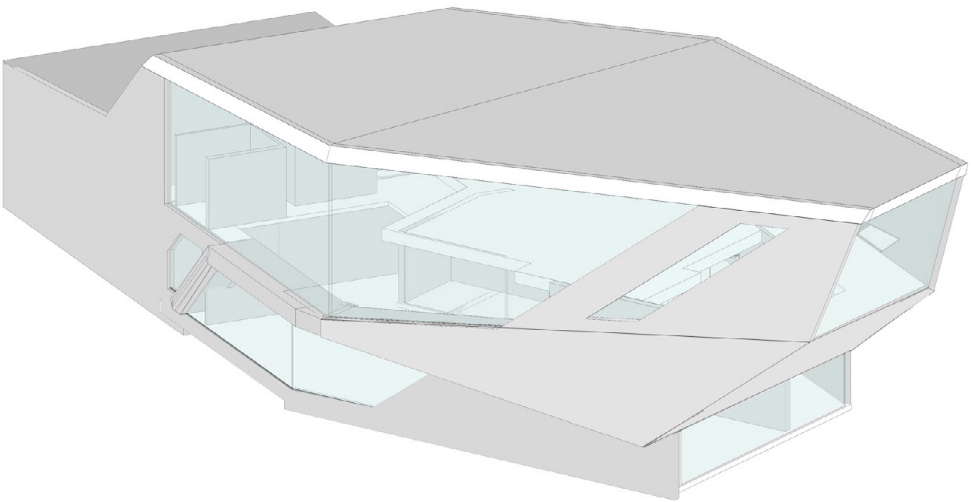


Figure.105. Daylight model in Case 1

| Overlit and underlit analysis

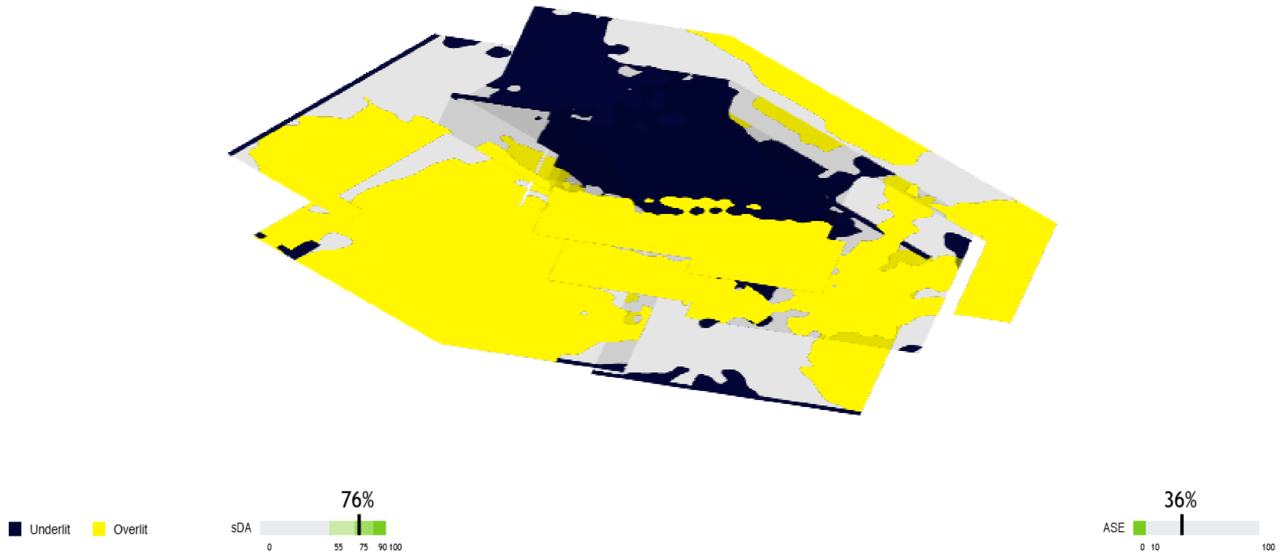


Figure.107. Overlit and Underlit in Case 1

| Daylight factor analysis

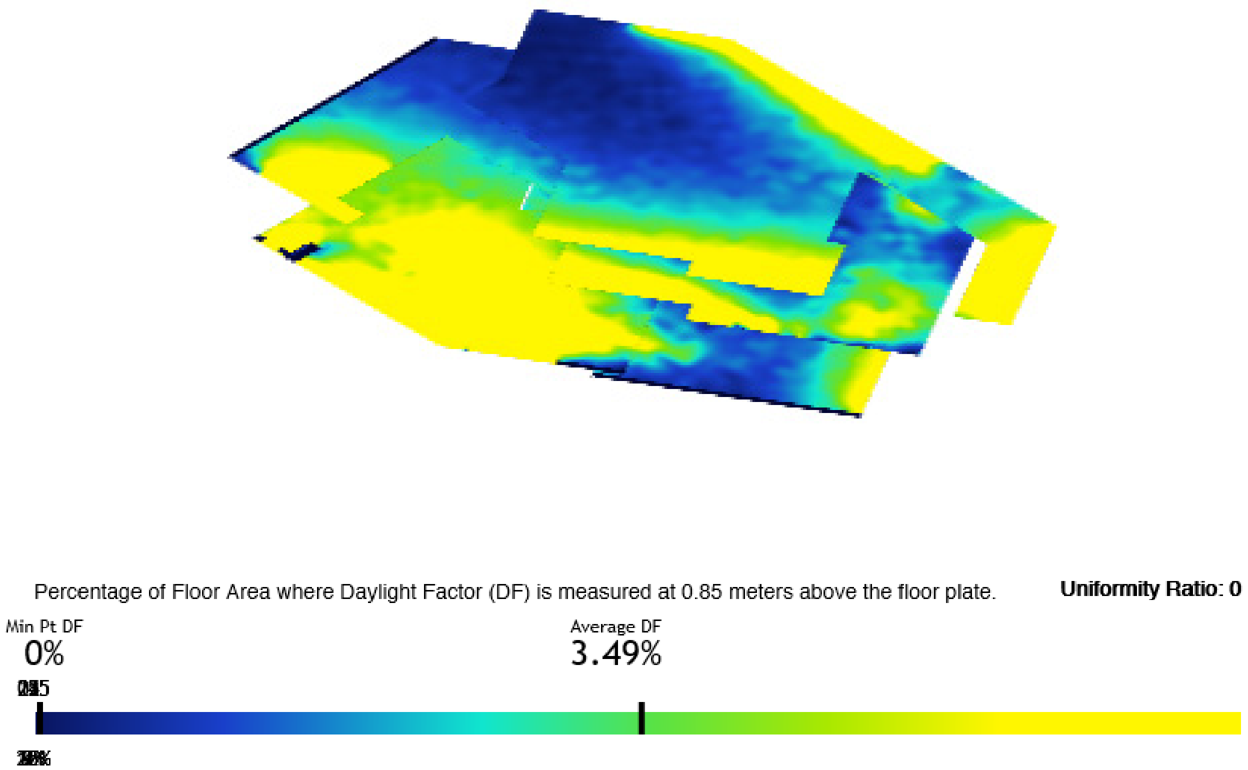


Figure.106. Daylight factor in Case 1

| Case 1

Ground floor

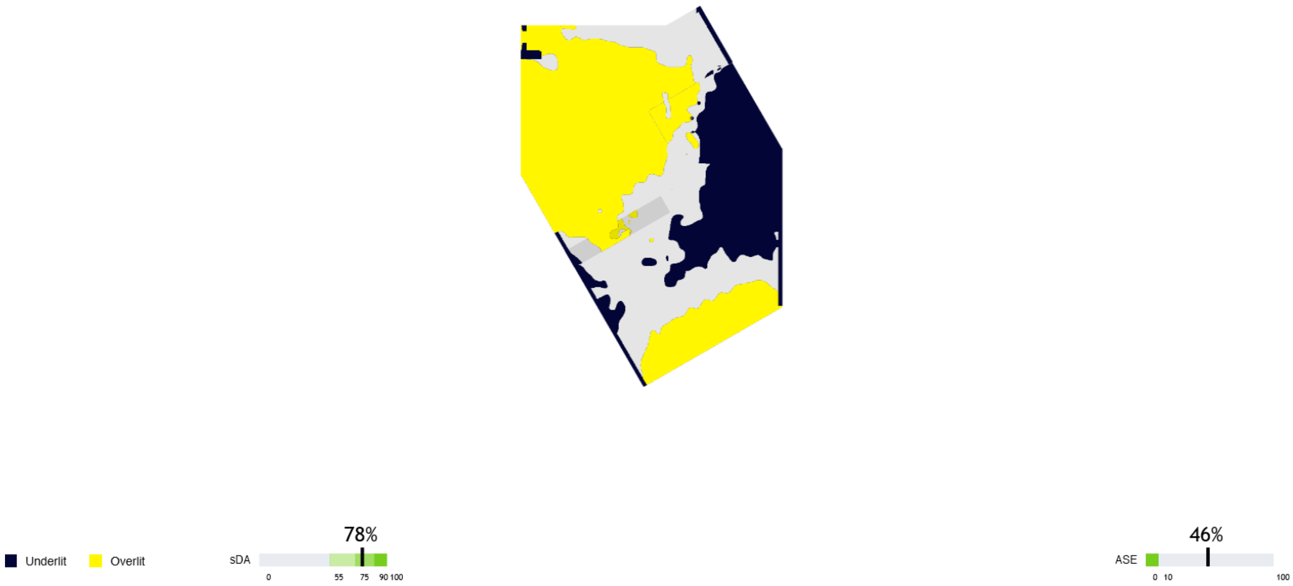


Figure.108. Underlit and Overlit on the ground floor Case 1

On the ground floor, a large amount of the space is overlit, which means that there is a probability for discomfort caused by glare. The sDA value is more than 75%, which means that the space is more than adequately lit, and it receives illumination of 300lux 78% of the time.

The situation on the middle floor is different. The parameter ASE is less than 10%, which means there is no discomfort caused by glare. The sDa is 38%, and the area is well lit, but this floor does not achieve the requirement.

Middle floor

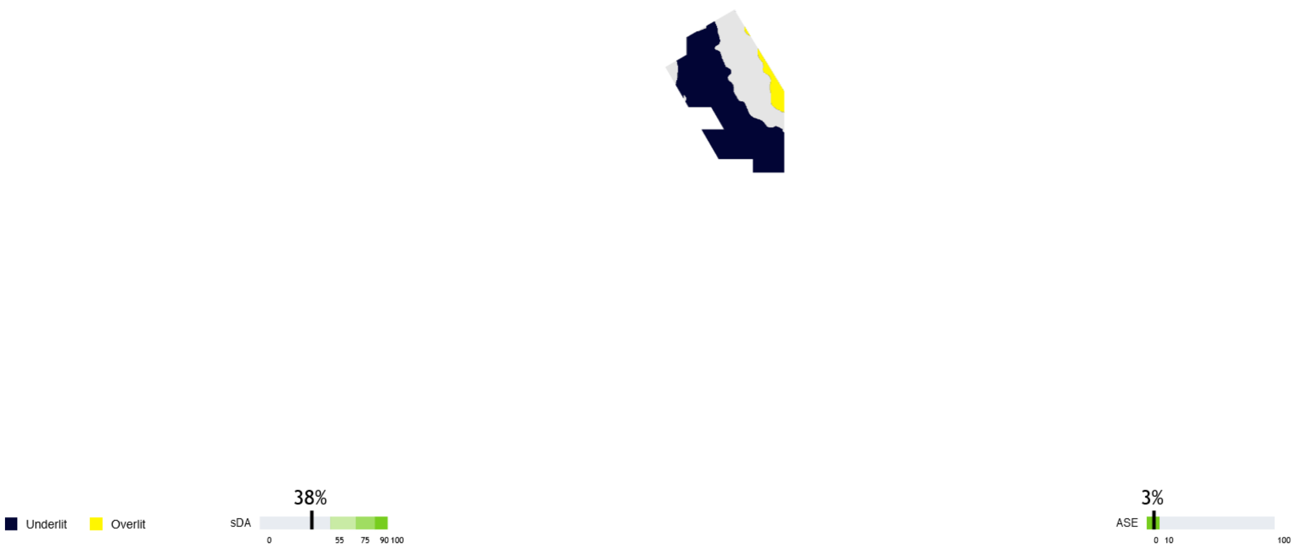


Figure.109. Underlit and Overlit middle floor Case 1 on the

First floor

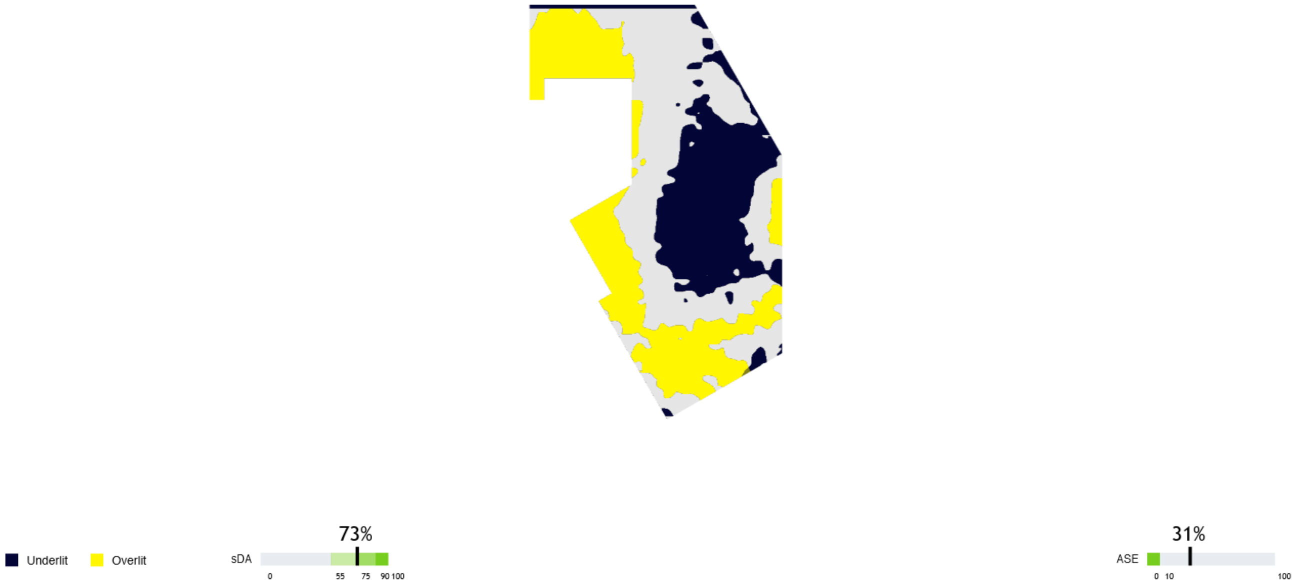


Figure.110. Underlit and Overlit on the first floor Case 1

On the first floor, a large amount of space is overlit. This means that there is a probability for the discomfort caused by glare. The sDA value is more than 55%, and this shows that the space is more than adequately lit.

The situation on the second floor is similar. The parameter for the glare is 34%, which is higher than the desired value of 10%. The sDA value is 67%, and the area is very well lit, which achieves satisfying levels of daylight illumination.

Second floor

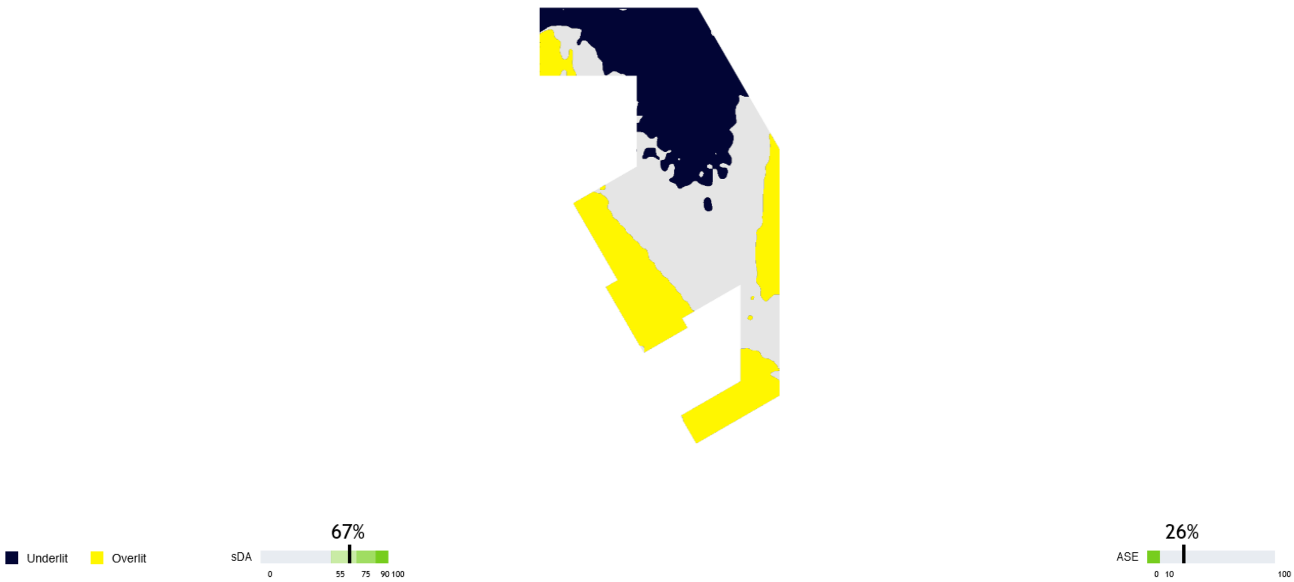


Figure.111. Underlit and Overlit on the second floor Case 1

| Case 1

Ground floor

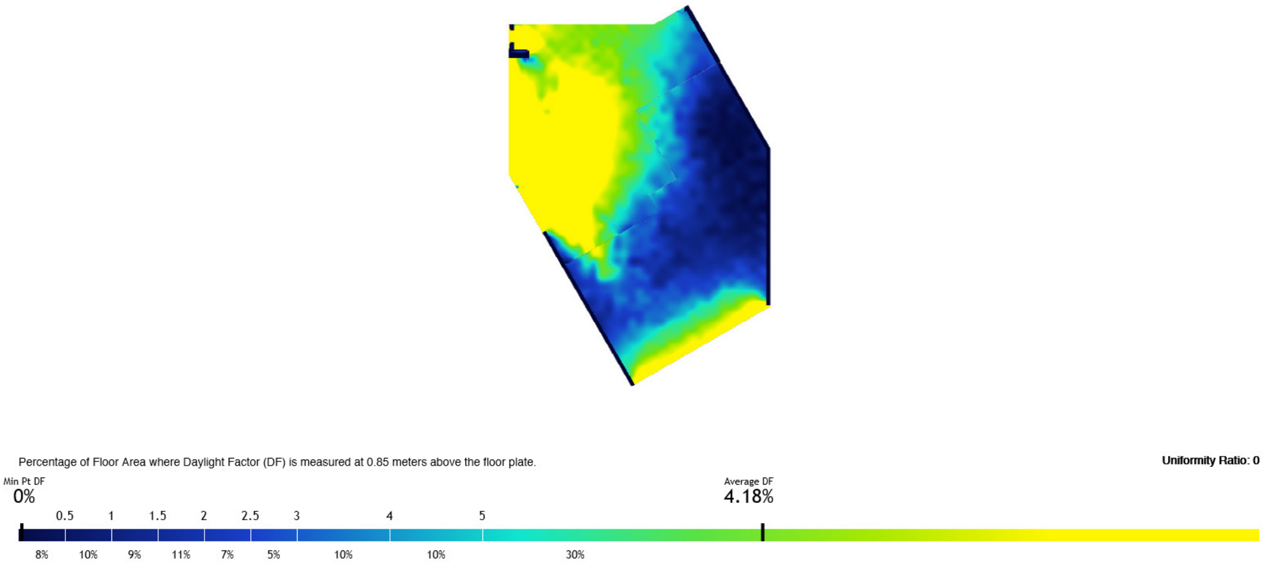


Figure.112. Daylight factor on the ground floor Case 1

On the ground floor, the average value of the daylight factor DF is 4,18 %, which means that the spaces receive excellent daylight provision. It is crucial to specify that in the zones of low values, the functions do not require natural daylight. These are the exhibition room, the restrooms and service rooms.

On the middle floor, the seating area of the cafe is located. That said, the area receives an average of 2,27 % of daylight, so it meets the required comfort.

Middle floor

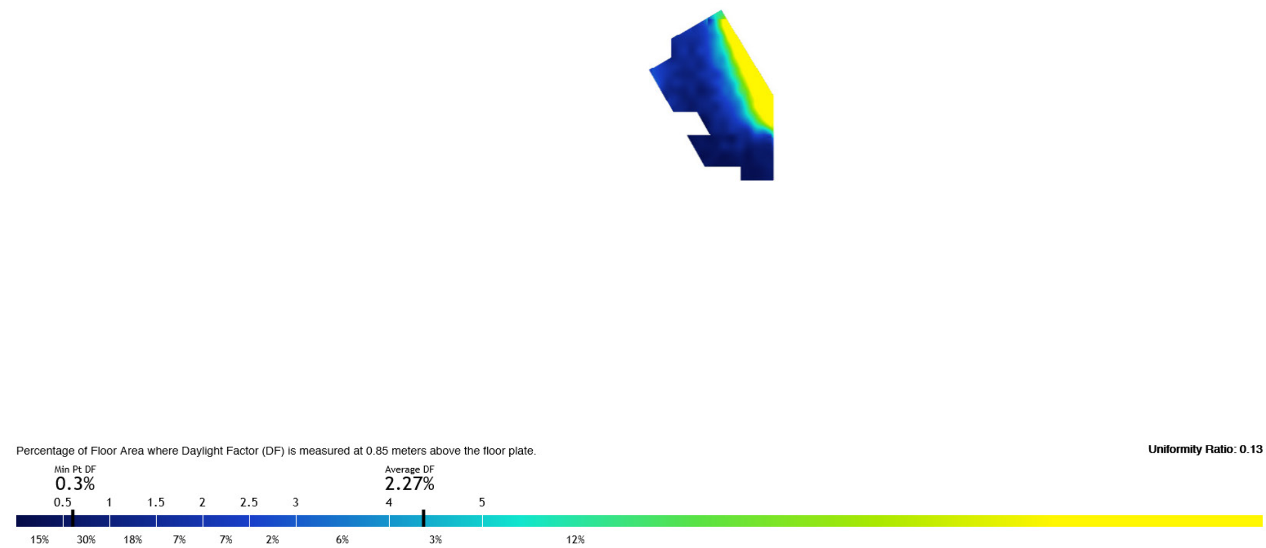


Figure.113. Daylight factor on the middle floor Case 1

First floor

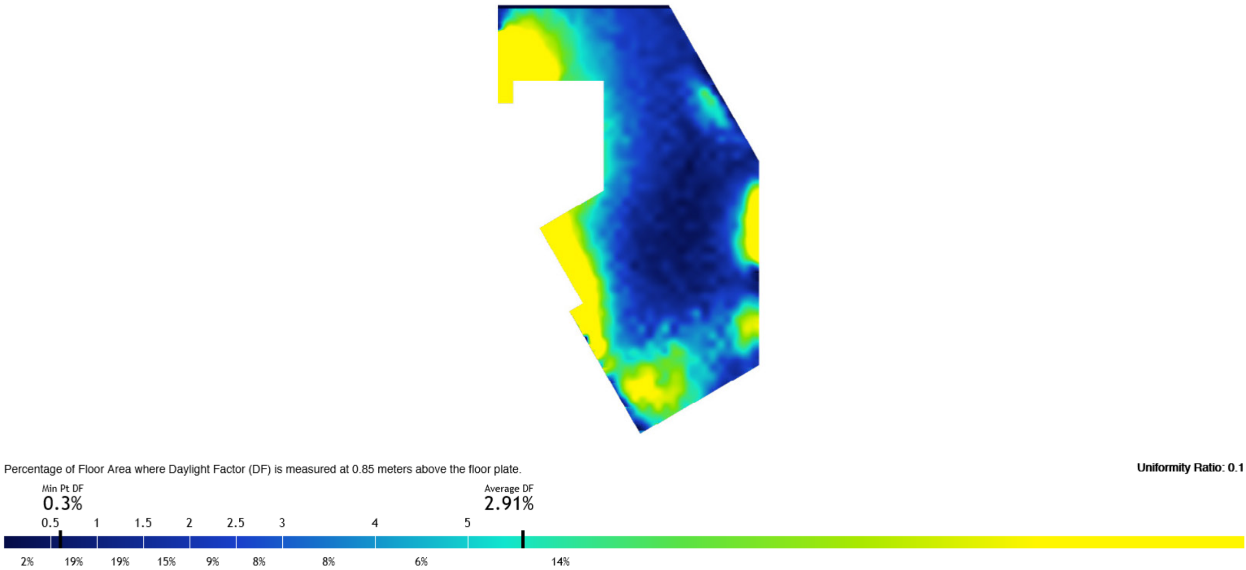


Figure.114. Daylight factor on the first floor Case 1

On the first floor, the average value of the daylight factor DF is 2,91 %, which means that the spaces required daylight are provided with an excellent daylight amount. Also, the areas which do not require natural light are strategically located in the dark zones. These are the exhibition room, the restrooms and service rooms.

On the second floor, the library and mixed-used rooms are located. These rooms need natural daylight. This floor meets the requirement with a uniform value of DF 3,07%.

Second floor

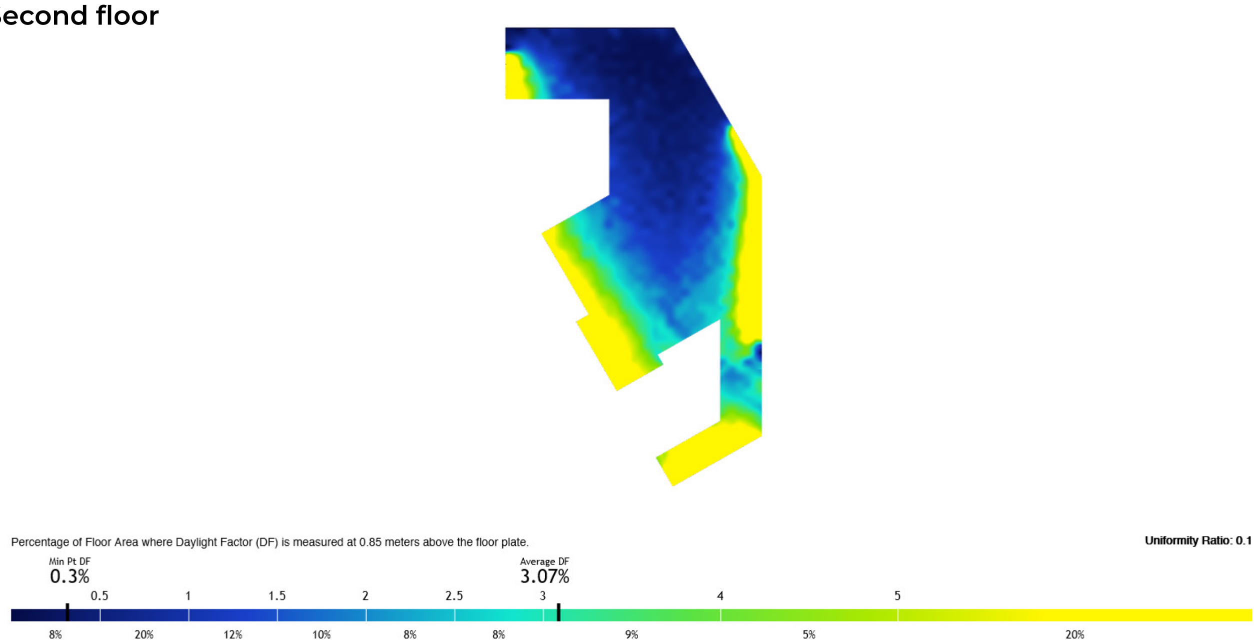


Figure.115. Daylight factor on the second floor Case 1

| Case 2

The parameters for the analysis have been set to:

Visible Light Transmittance : New value of 60%

Window/Wall ratios:

Window/Wall ratio							
South	0.7	East	0.2	West	0.5	North	0

Table.23. Window to Wall ratios Case 2

As can be seen from the previous results of case 1, the daylight conditions in the building are satisfying. Still, glare can cause unwanted visual discomfort, and that means not fully utilizing the nice views from inside to the outside of the project.

For this reason, daylight simulation with the shading elements was performed. This investigation was about how much glare (Annual Sunlight Exposure) can be reduced by introducing shading devices while still harnessing as much daylight as possible.

The study case analyzes the spacing between the shading elements and their dimensions. The investigations concern the first and second floor for east and west facades. The glazing on the ground floor was not considered in the studies because the spaces of the entrance and the open atrium does not require daylight optimization. On the ground floor, special protective coating was applied.

The areas in which glare was considered problematic are the offices, the lab, and the ibrary spaces. These are the locations in which a further optimization was applied.

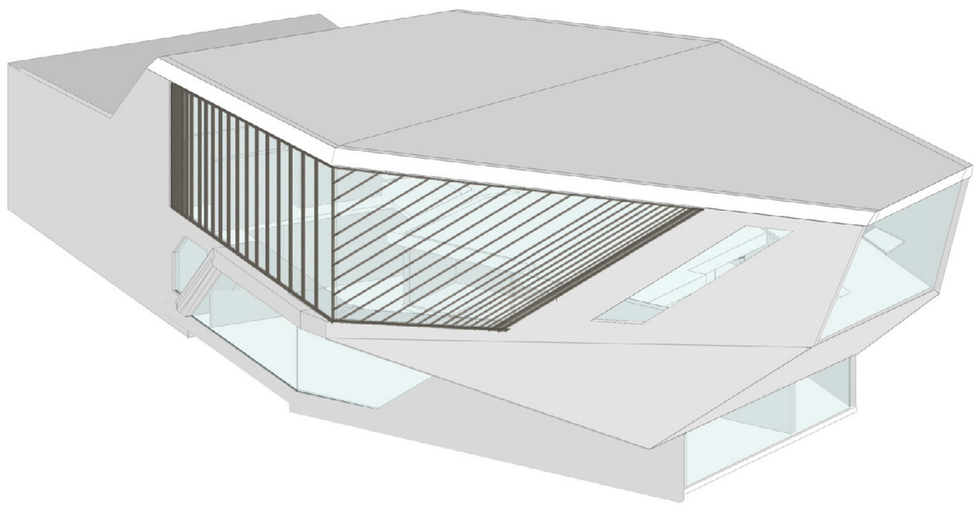


Figure.116. Daylight model in Case 1

| Annual Sunlight Exposure analysis

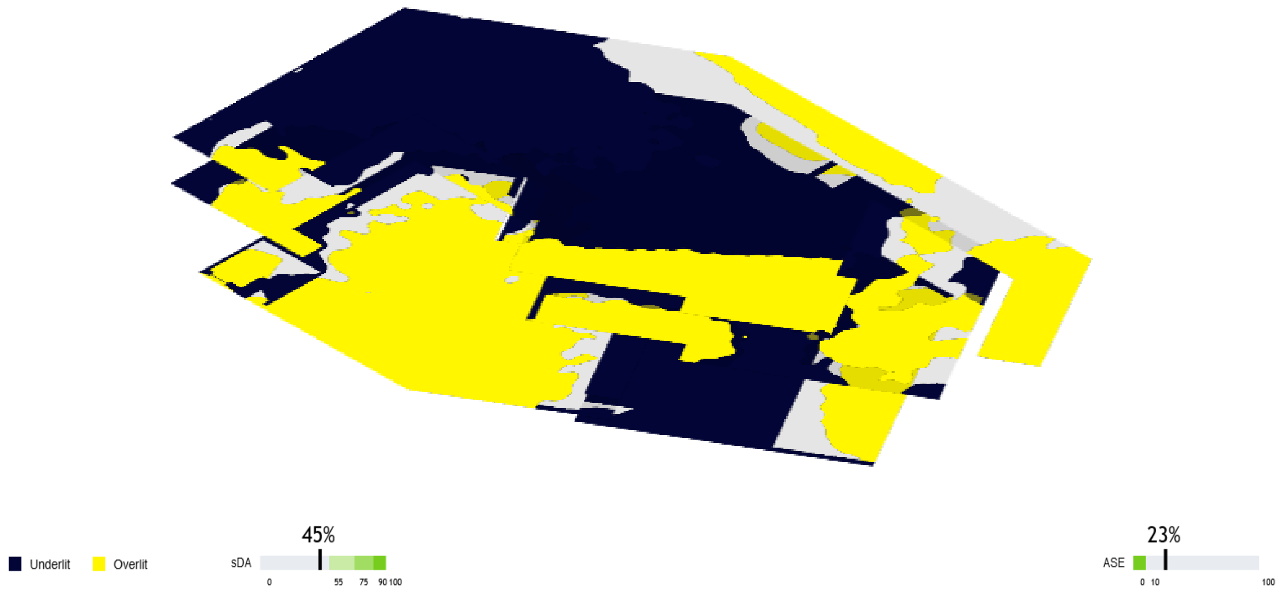


Figure.118. Overlit and Underlit in Case 2

| Daylight factor analysis

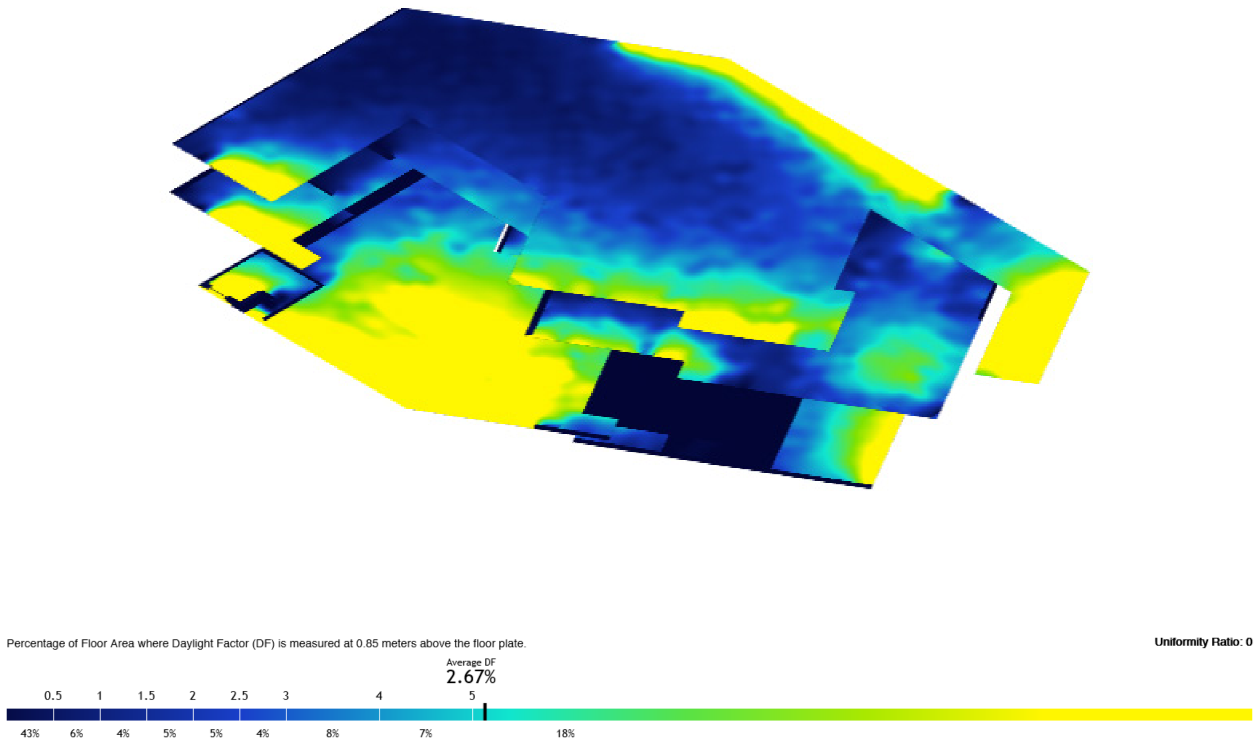


Figure.117. Daylight factor in Case 2

| Case 2

Ground floor

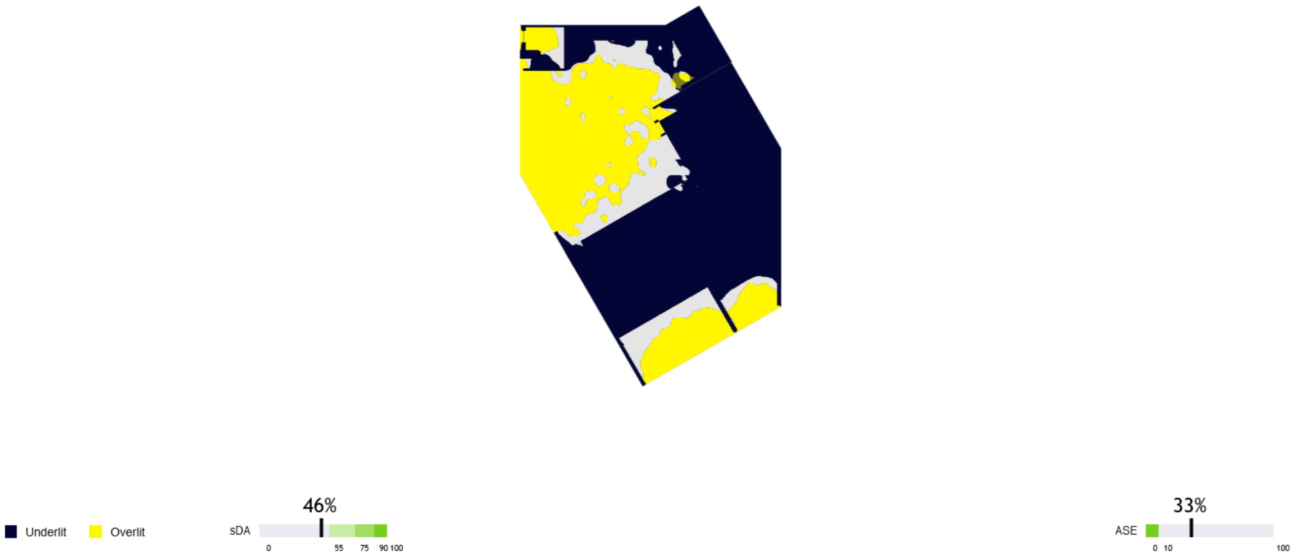


Figure.119. Underlit and Overlit on the ground floor Case 2

On the ground floor, the zones exceeding the direct sunlight is less because the light transmittance was decreased to 60%. The probability of glare was still present, so the final solution was to use a special selective coating. Also, the sDA value became lower, and it is under 55%. Still, the result meant the requirement for the spaces that required daylight.

For the middle floor, the parameter ASE is very low 1%, which means there is no discomfort caused by glare. The sDA dropped down to 28%, and the area is mostly well lit. In situations when daylight is not enough, artificial light will be used.

Middle floor

Figure.120. Underlit and Overlit on the middle floor Case 2

First floor

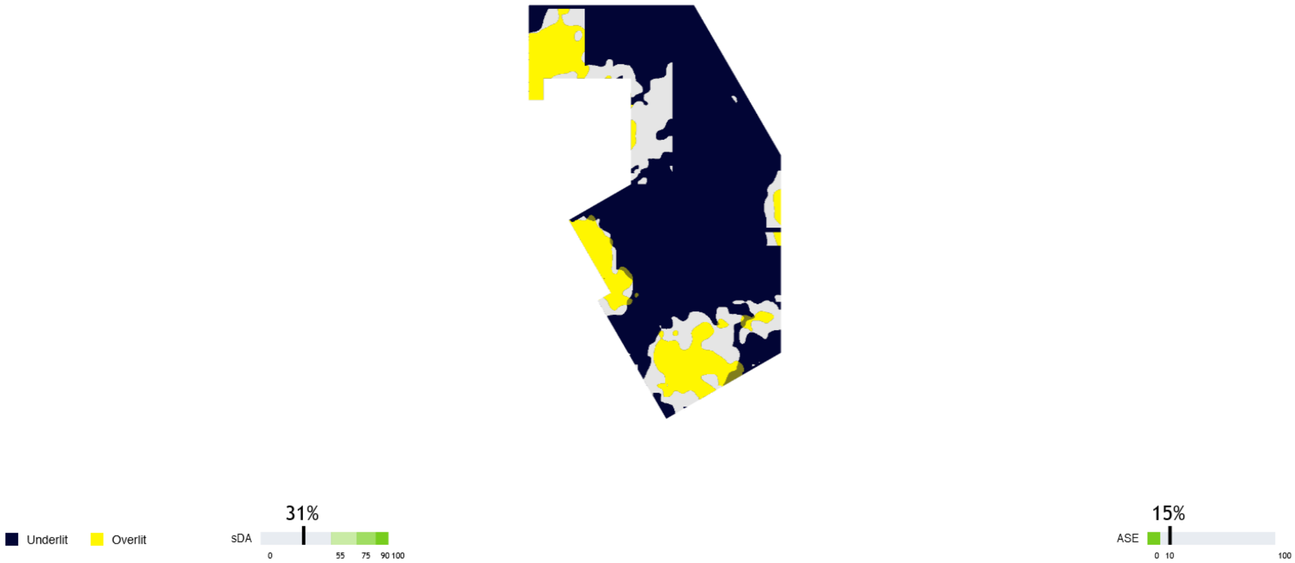


Figure.121. Underlit and Overlit on the the first floor Case 2

On the first floor, the overlit zones in the target areas decreased. The ASE glare component dropped down to 15%, but so did the sDA value to an average of 31%. The comfortable levels of sDA are reached for the functions requiring daylight. For the corridor, restrooms, exhibitions, artificial light will be used.

The analysis of the second floor shows the parameter for the glare decreased to 21%, which is still higher than the desired value of 10%. That is why the glazing on this floor was optimized with a special coating. The sDA value is 60%, and the area is very well lit, which achieves the desired levels of daylight illumination for the library space.

Second floor

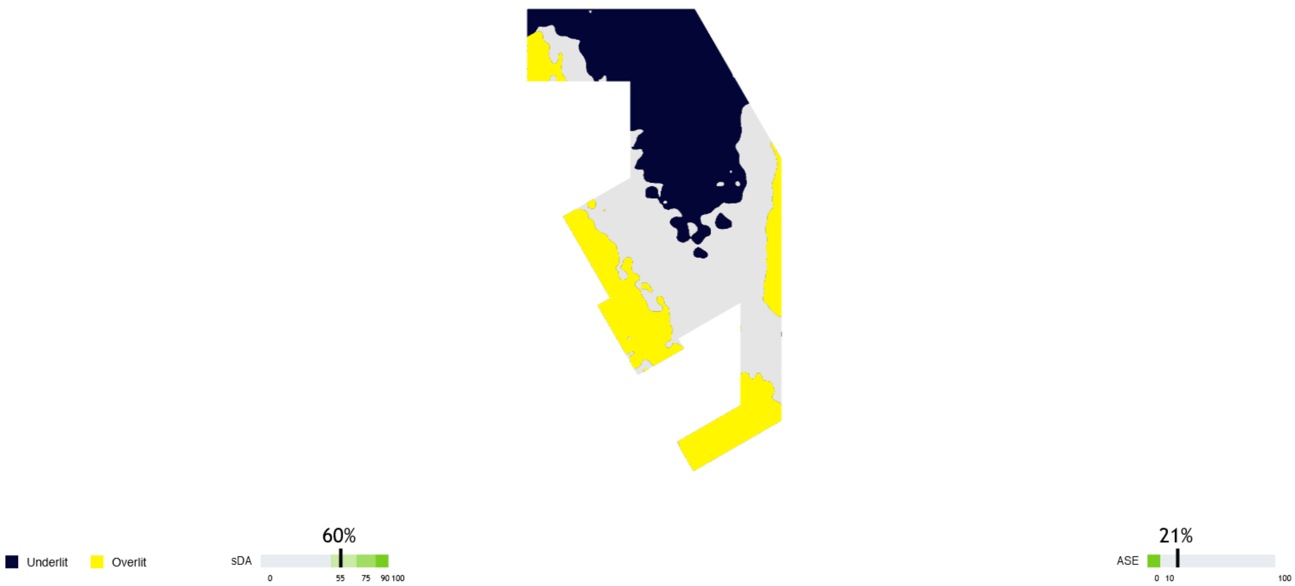


Figure.122. Underlit and Overlit one the second floor Case 2

| Case 1

Ground floor

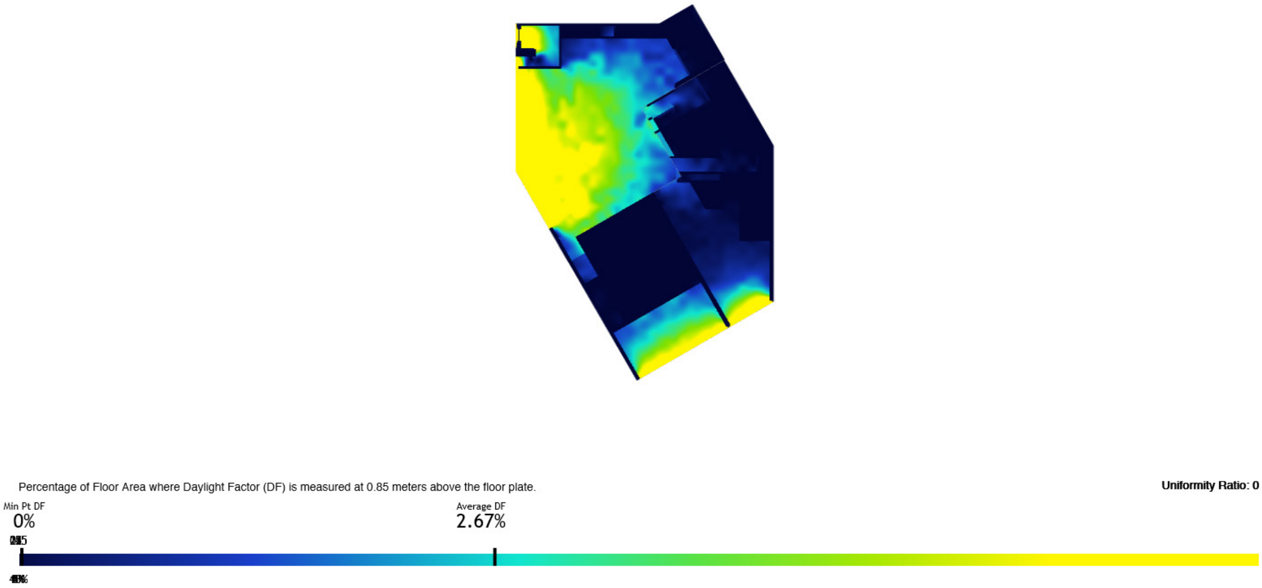


Figure.123. Daylight factor on the ground floor Case 2

On the ground floor, the average value of the daylight factor DF is 4,18 %, which means that the spaces receive excellent daylight provision. It is crucial to specify that in the zones of low values, the functions do not require natural daylight. These are the exhibition room, the restrooms and service rooms.

On the middle floor, the seating area of the cafe is located. That said, the area receives an average of 2,27 % of daylight, so it meets the required comfort.

Middle floor

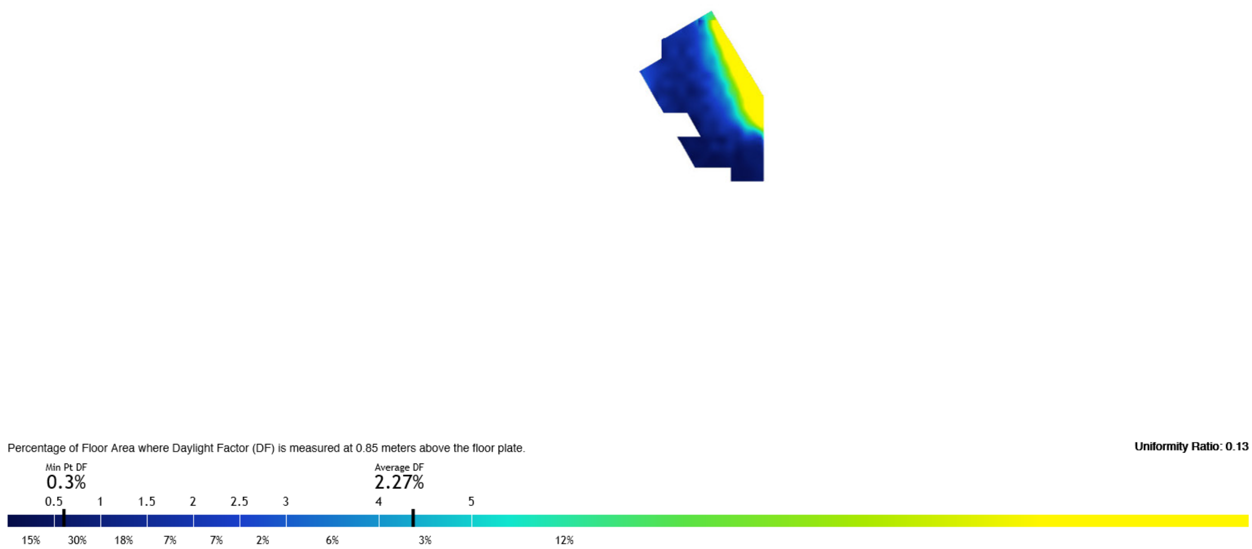


Figure.124. Daylight factor on the middle floor Case 2

First floor

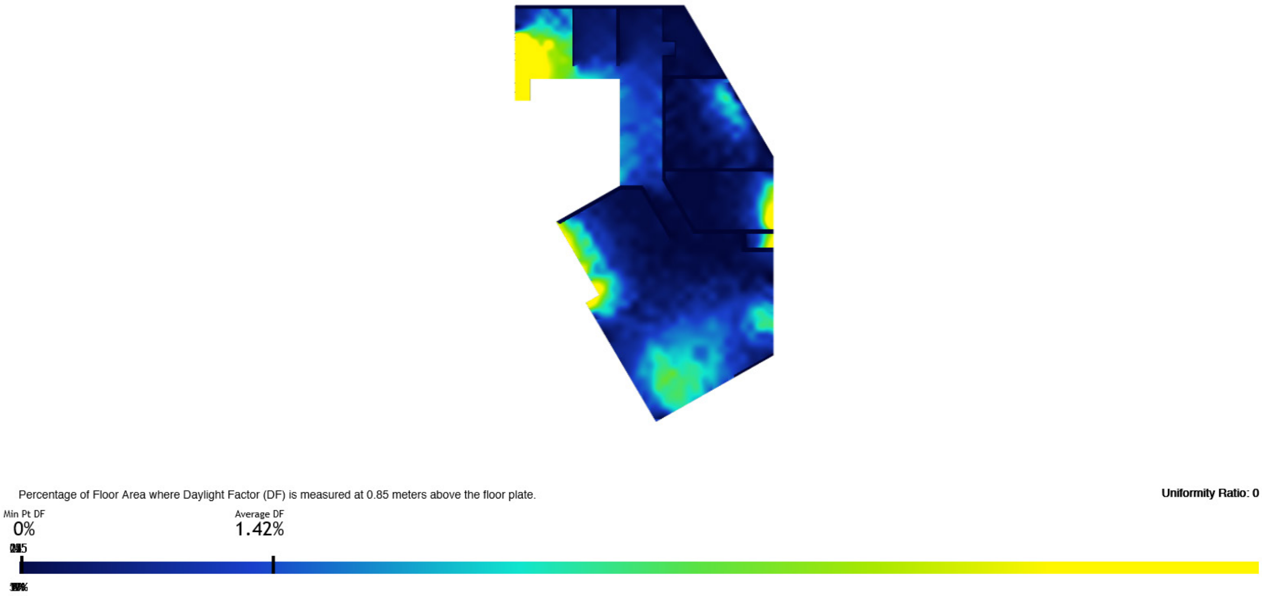


Figure.125. Daylight factor on the first floor Case 2

On the first floor, the average value of the average daylight factor DF dropped to 1,42 %, which means that some of the spaces do not receive enough daylight. This is not the case only for the offices where the daylight factor exceeds the minimum. In the laboratories and the library, there will be a need to use artificial lighting when there is not enough daylight.

On the second floor, where the library is located, the conditions are still excellent, with a daylight factor of 3,07%. That means the area receives the required comfort.

Second floor

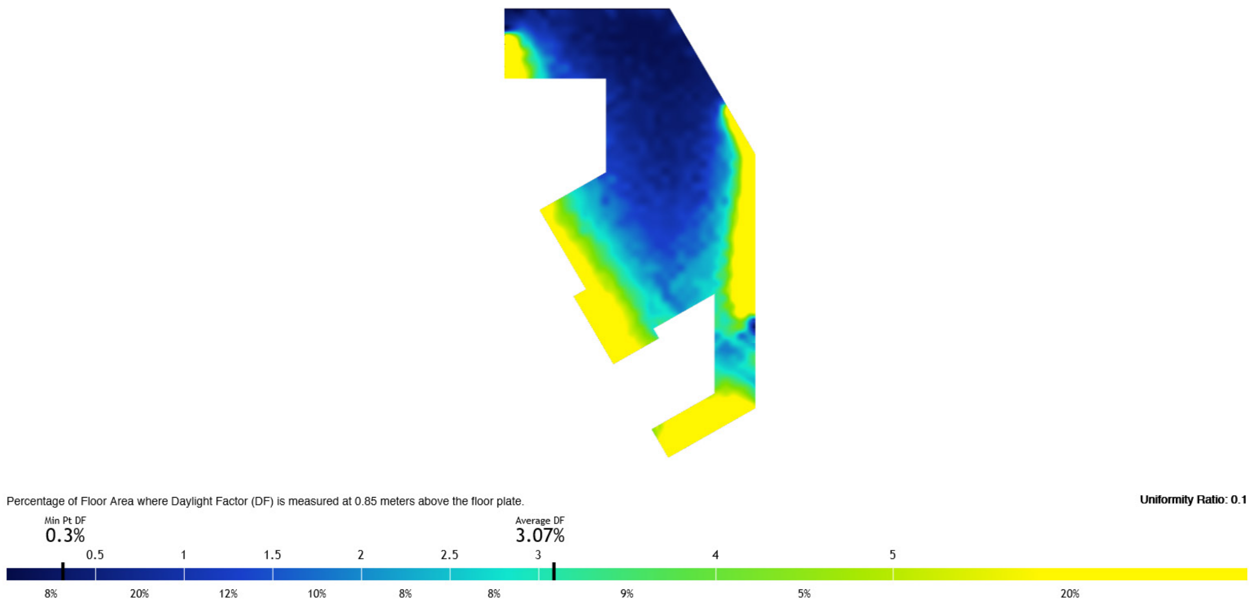


Figure.126. Daylight factor on the second floor

5. Technical detailing

5.1. Introduction

The technical detailing has been created to illustrate the design of the Cultural Center in the technological stage. The final results have been achieved by firstly looking for materials and systems and how they were manufactured. The next step was to select the durability of those systems and materials that were appropriate for the environmental conditions of the site. Next, the stratigraphy of the elements of the building was studied, and then their thermal properties were defined. After this, the connections between these elements are developed by using different sections in which all connection types are apparent. Consequently, details, sections, and blowups were designed to represent technologically how the materials and the systems are connected and how they work together.

The goal of achieving sustainability was set. Therefore most of the building envelope is made up out of a dry technology system, excluding floors and foundations. An essential characteristic of the drywall is easy to recycle and is made from 90 to 95 percent recycled materials. Both composite and drywall structures eliminate the need for formwork and minimize the use of water on-site significantly. The slabs were constructed by composite steel deck construction supported by the main load-bearing structure from steel. The elements of the structure can be dismantled, melted and reused again without loss of quality.

Another vital aspect of the project was using materials that respect the Norwegian tradition and their inherent character. The qualities of natural materials like timber and stone were implemented into the detailing design of the building. The materials selected contributed to very high durability standards. Therefore, rains-creen façade made by fiber cement was used to achieve both sustainability and resistance to the weather conditions.

5.2. Durability requirements

| Corrosion durability specification:

The city of Oslo experiences an average annual percentage of humidity at 74.0%.

Equitone Rainscreen façade system:

The framing system used for the facade fixations was stainless steel because it is very durable in aggressive environments and more corrosion resistant than the standard galvanized steel.

Durability of the steel load-bearing structure:

According to BS EN ISO 12944-2 the category for corrosion inside the building itself is C1 - very low. Even though the class does not require particular actions for corrosion resistance, barrier coatings such as paint can isolate the structure from water and oxygen and secure its long-time durability.

Durability of the reinforced conctete structure:

According to EN 206-1 the exposure class for the reinforced concrete structures is XC1 and exposure category C0 which define the minimum water/cement ratio, the cement content and the concrete cover.

5.3. Technical details stratigraphy

| Thermal performance of the building walls

EXTERNAL WALL						
Layer	Material	Thickness [m]	Thermal Conductivity [W/mK]		Thermal Resistance [m2K/W]	
1	Gypsum board with finishing	0.0125	0.2		0.06	
2	Vapour barrier	0.0022	0.4		0.01	
3	Gypsum board	0.0125	0.2		0.06	
4	Acoustical and thermal insulation layer (rockwool) with dry wall structure	0.225	0.038		5.92	
5	Fiber reinforced cementboard	0.0125	0.35		0.04	
6	Still air cavity	-	-		-	
7	Thermal insulation layer- EPS	0.1	0.04		2.50	
8	Ventilated air gap	0.06	-		-	
9	Fiber cement cladding panels / timber veneer	0.012	0.6	0.27	0.02	0.04
				U [W/m2K]	**0.12**	

Table.24. Thermal properties of the external wall

INTERNAL WALL				
Layer	Material	Thickness [m]	Thermal Conductivity [W/mK]	Thermal Resistance [m2K/W]
1	Gypsum board with finishing	0.0125	0.2	0.06
2	Vapour barrier	0.0022	0.4	0.01
3	Gypsum board	0.0125	0.2	0.13
4	Acoustical and thermal insulation layer (rockwool) with dry wall structure	0.06	0.04	1.50
5	Acoustic cavity still air	0.18	-	-
6	Acoustical and thermal insulation layer (rockwool) with dry wall structure	0.06	0.04	1.50
7	Double gypsum board with finishing	0.025	0.2	0.13
			U [W/m2K]	**0.30**

Table.25. Thermal properties of the internal wall

Thermal performance of the building floors and roofs

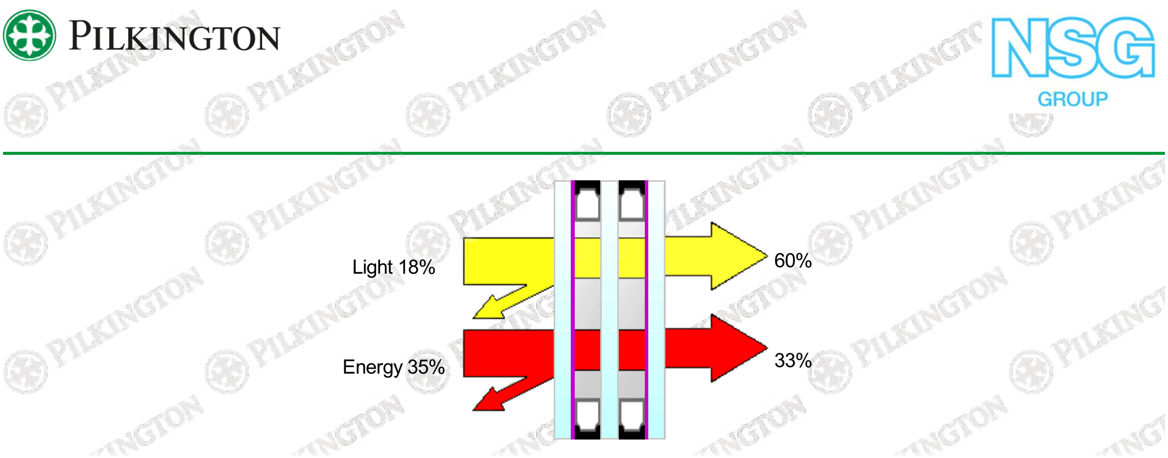
INTEMIDIATE FLOOR				
Layer	Material	Thickness [m]	Thermal Conductivity [W/mK]	Thermal Resistance [m2K/W]
1	Stone tiles	0.02	1.3	0.02
2	Screed	0.02	0.2	0.10
3	Service hosting layer in perlite	0.1	0.23	0.43
4	Acoustic insulation carpet in rubber	0.01	0.035	0.29
5	Composite slab with profiled steel sheeting	0.14	1.8	0.08
6	Acoustic insulation layer in rockwool panels	0.1	0.032	3.13
7	Light weight gypsum ceiling tiles	0.024	0.2	0.12
			U [W/m2K]	**0.24**

Table.26. Thermal properties of the intermidiate floor

ROOF				
Layer	Material	Thickness [m]	Thermal Conductivity [W/mK]	Thermal Resistance [m2K/W]
1	Fiber cement cladding panel	0.012	0.6	0.02
2	Ventilated air gap	0.04	-	-
3	Waterproof bituminous membrane	0.004	0.17	0.02
4	Double thermal insulation in XPS	0.2	0.035	5.14
5	Anti vapor layer -polyethylene	0.02	0.06	0.33
6	Acoustic air gap with metal deck	0.083	-	-
7	Acoustic insulation layer in rockwool panels	0.1	0.032	2.94
8	Light weight gypsum ceiling tiles	0.024	0.2	0.12
			U [W/m2K]	**0.12**

Table.27. Thermal properties of the roof

| Thermal performance of the glazing



DESCRIPTION				
Position	**Product**	**Process**	**Tickness (nominal) mm**	**Weight kg/m2**
Glass 1	Pilkington Suncool™ 66/33 Pro T	Toughened	6	
Cavity 1	Krypton (90%)		10	
Glass 2	Pilkington Optifloat™ Clear	Annealed	6	
Cavity 2	Krypton (90%)		10	
Glass 2	Pilkington Optitherm™ S3 Pro T	Toughened	6	
Product Code	6C(66)T-10Kr-6-10Kr-S(3)6T		38	45.00

PERFORMANCE					
Light			**Energy**	**Weight kg/m2**	
Transmittance	LT	60%	Direct Transmittance	ET	28%
	UV%	6%	Reflectance	ER	35%
Reflectance Out	LR out	18%	Absorptance	EA	37%
Reflectance In	LR in	19%	Total Transmittance	g	33%
			Shading Coefficient Total		0.38
			Shading Coefficinet Shortwave		0.32
			Thermal Transmittance	**U [W/m2K]**	**0.5**

Table.28. Thermal properties of the glazing

5.4. Schedule of the finishing materials

	MATERIALS REFERENCE			
	MATERIAL	DESCRIPTION	MANUFACTURER	THICKNESS/ LENGTH
VERTICAL FINISHES	OUTDOOR CLADDING	EQUITONE NATURE EXTERNAL CLADDING PANELS N861	EQUITONE	2*12 MM
	TIMBER CLADDING	HIGH-DENSITY STRATIFIED PANEL WITH NATURAL TIMBER VENEER FOR OUTDOOR USE	PARKLEX	12 MM
	TIMBER BATTEN	TIMBER LOCKING WITH DIAGONAL CUT TOP SUPPORT PATTENS	BERRYALLOC	12 MM
	DIVIDING FIBERCAMENT	CEMENT BASED OUTDOOR BOARD WITH COATED GLASS FIBRE MESH	KNAUF	12.5 MM
	INDOOR CLADDING	GYPSUM BOARD FOR INTERNAL CLADDING	KNAUF	2*12 MM
	INTERNAL INSULATION	RIGID PANEL IN MINERAL WOOL WITHOUT COATING	KNAUF	VARIABLE
	EXTERNAL INSULATION	RIGID ROCK MINERAL WOOL PANEL COVERED ON ONE SIDE WITH BLACK GLASS FILM	KNAUF	100 MM
	LOUVERS	EXTRUDED ALUMINIUM PROFILE COVERED WITH NATURAL VENEER FINISHING	REDAELLI	100*220 MM
	CURTAIN WALL	TRIPLE PILKINGTON GLAZING MULLION AND TRANSOM CURTAIN WALL SYSTEM WITH BACK-PAINTED GLASS TRANSITION PANELS WITH 0.5 W/M²K THERMAL TRANSMITTANCE	SCHÜCO / PILKINGTON	VARIABLE
FLOORING	STONE	POLISHED STONE FINISHING LAYER - COLOR TO BE ACCORDING TO SPACE	NORBLOCK	15 MM
	HPL	HIGH-PRESSURE DECORATIVE LAMINATE IMPREGNATED WITH MELAMINE AND PHENOLIC RESINS	BERRYALLOC	12 MM
	SERVICE LAYER	PERLITE	KNAUF	VARIABLE
	SILENT PAD	KNAUF SILENT PAD E - EXPANDED POLYETHYLENE, CROSS-LINKED, WITH CLOSED CELLS TO BE USED UNDER THE ARCHITECTURAL FINISHES	KNAUF	5 MM
CEILING	SUSPENTION SYSTEM	D112 - FREE-SPANING CEILING SUSPENTION GRID SYSTEM MADE OF CARRYING AND FURRING CHANNELS	KNAUF	VARIABLE
	ACOUSTIC LAYER	ACOUSTIC MINERAL WOOL ROLL WITHOUT COATING	KNAUF	50 MM
	CEILIING TILES	LIGHT WEIGHT GYPSUM CEILING TILES TO BE POST RENDERED	KNAUF	2*12 MM
	LOUVERS	EXTRUDED ALUMINIUM PROFILE COVERED WITH NATURAL VENEER FINISHING	REDAELLI	50*150 MM
ROOF	TILING	AVERA FIBER CEMENT PANELS	SWISSPEARL	
	INSULATION	RIGID MINERAL WOOL INSULATION PANEL WITHOUT COATING	KNAUF	VARIABLE

Table.29. Schedule of the finishing materials

5.5. Technical detailing

| Key plan

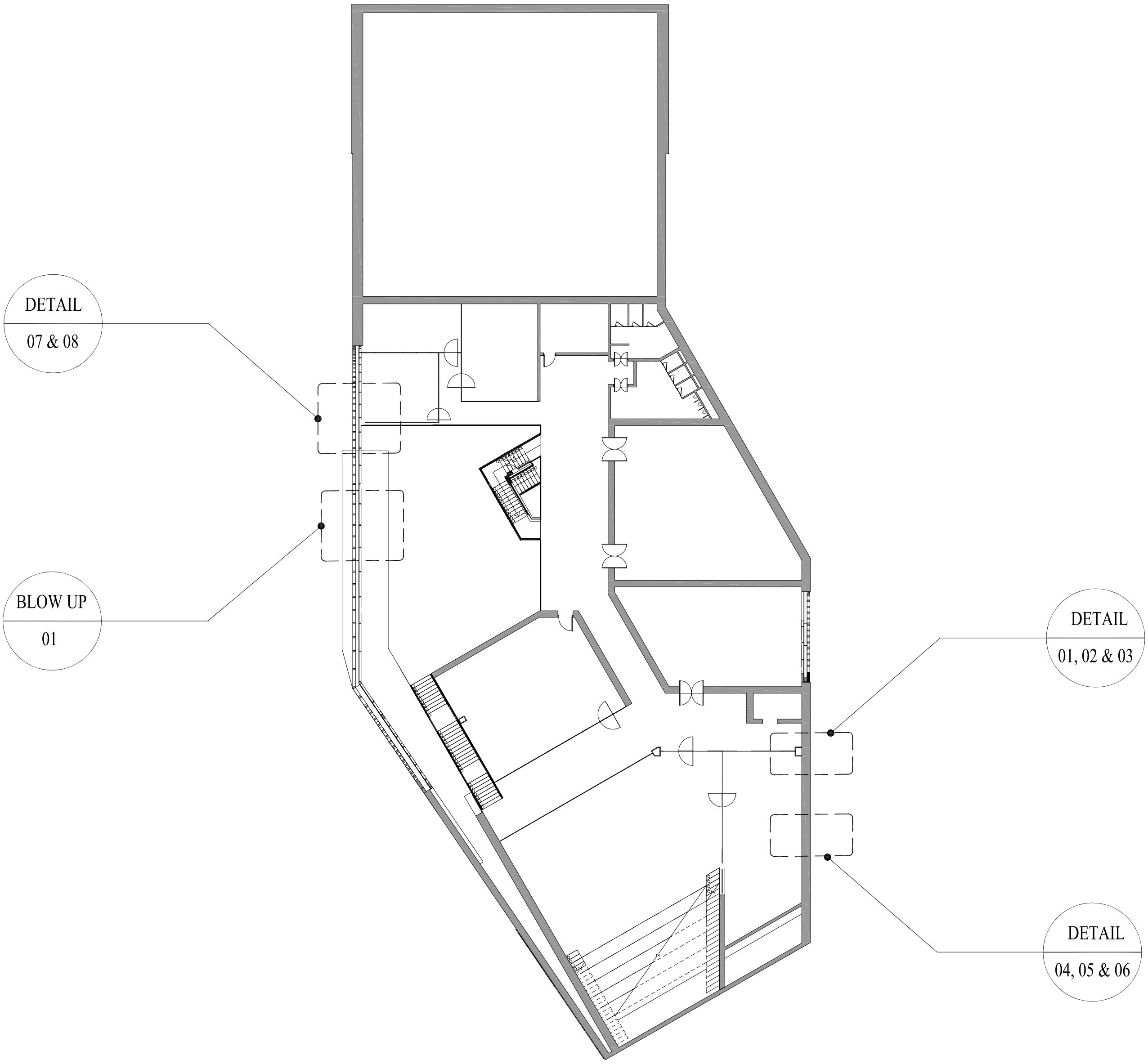
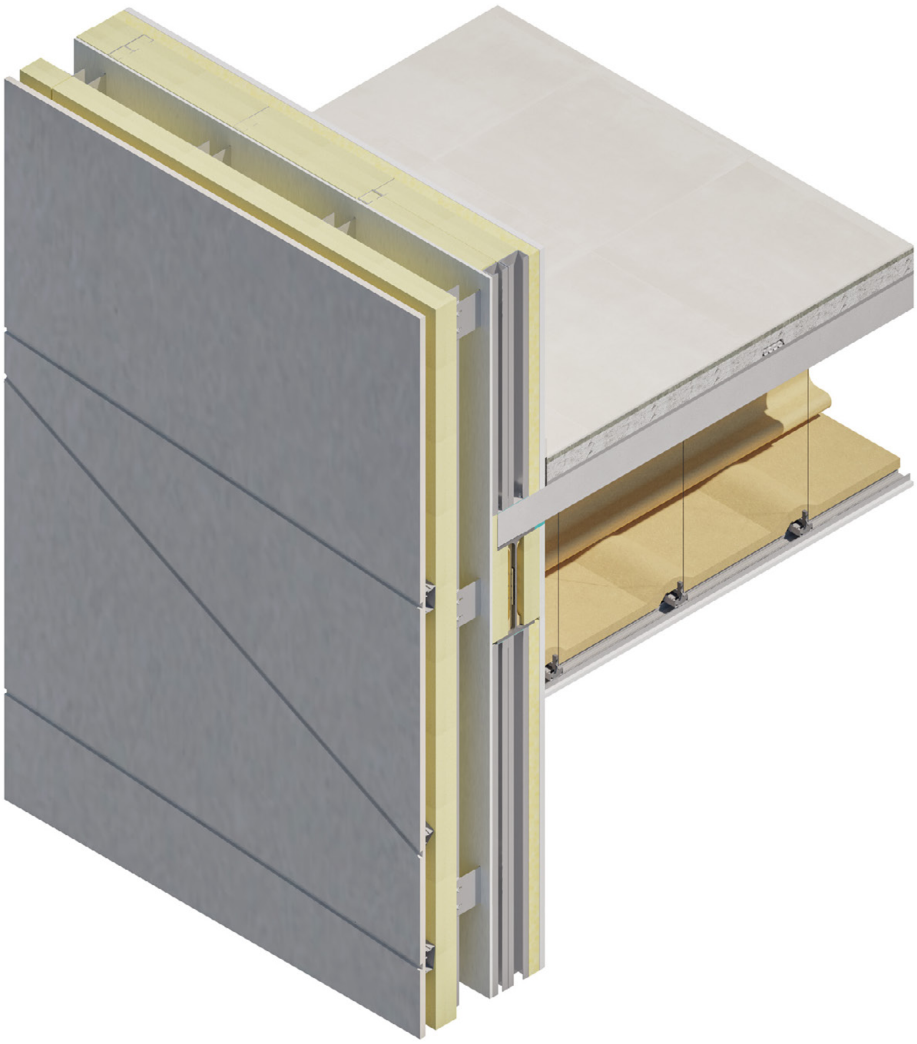
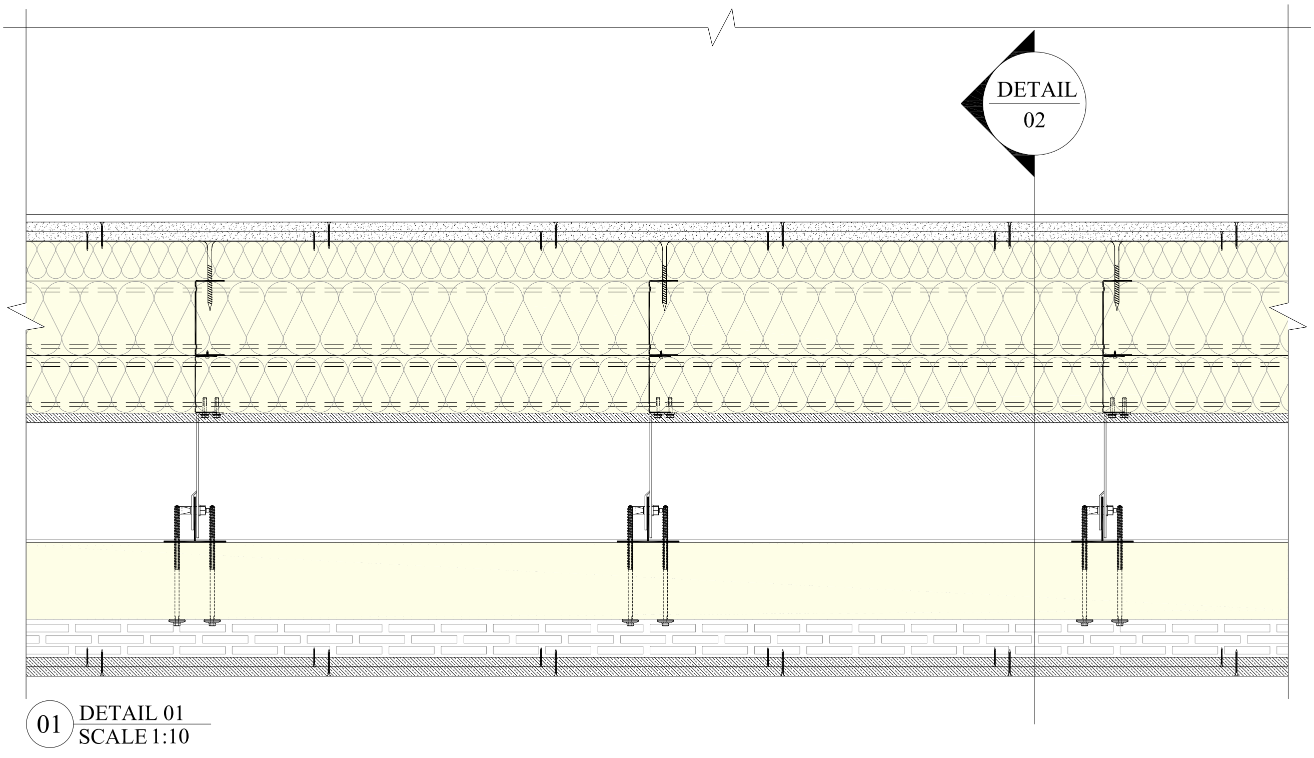
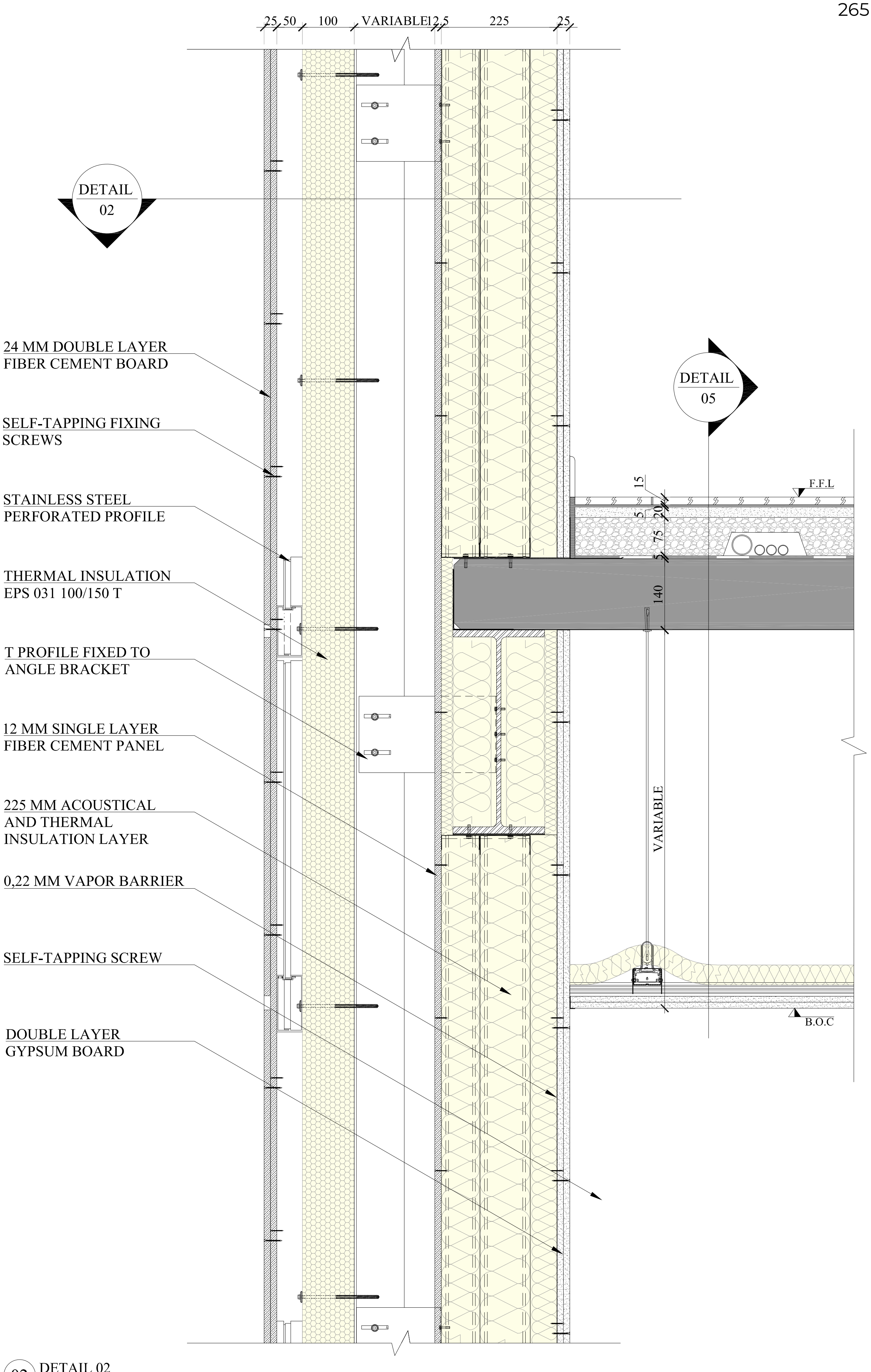


Figure.127. Key plan

| Detail 1 and 2

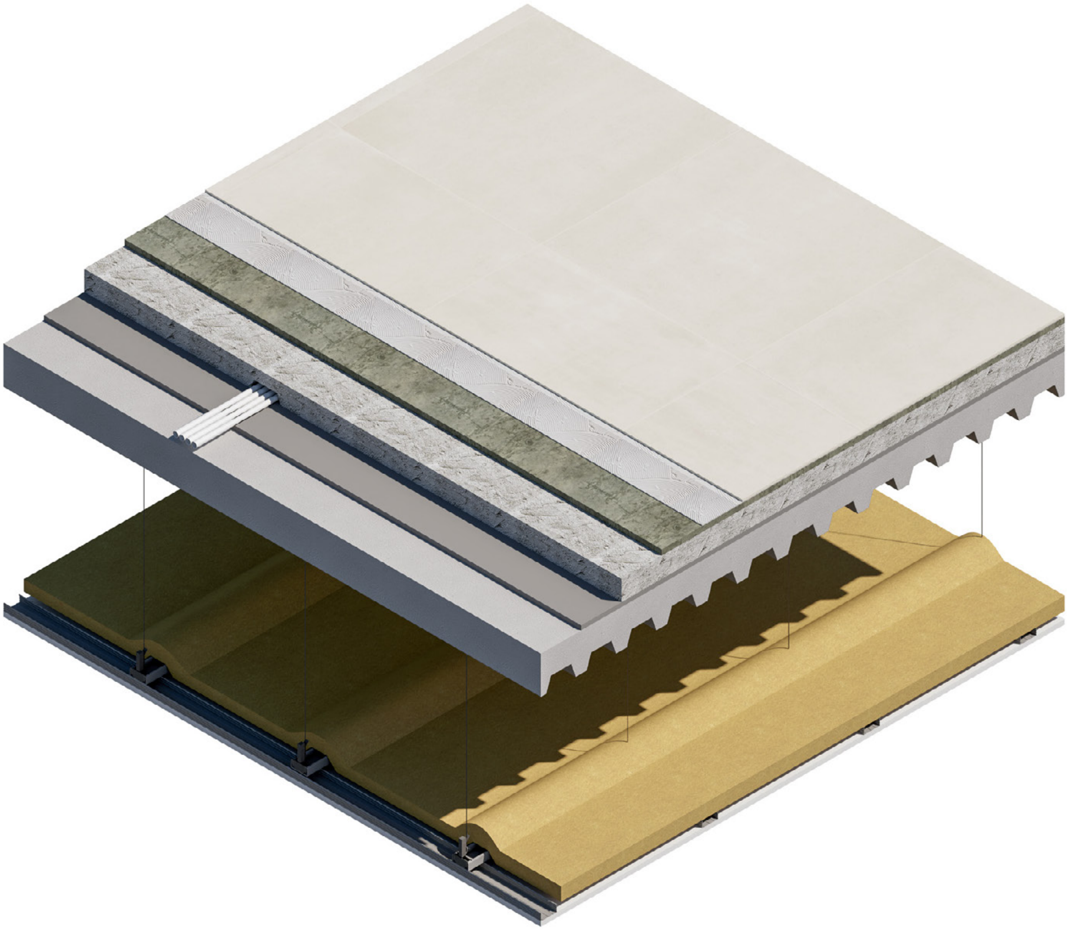


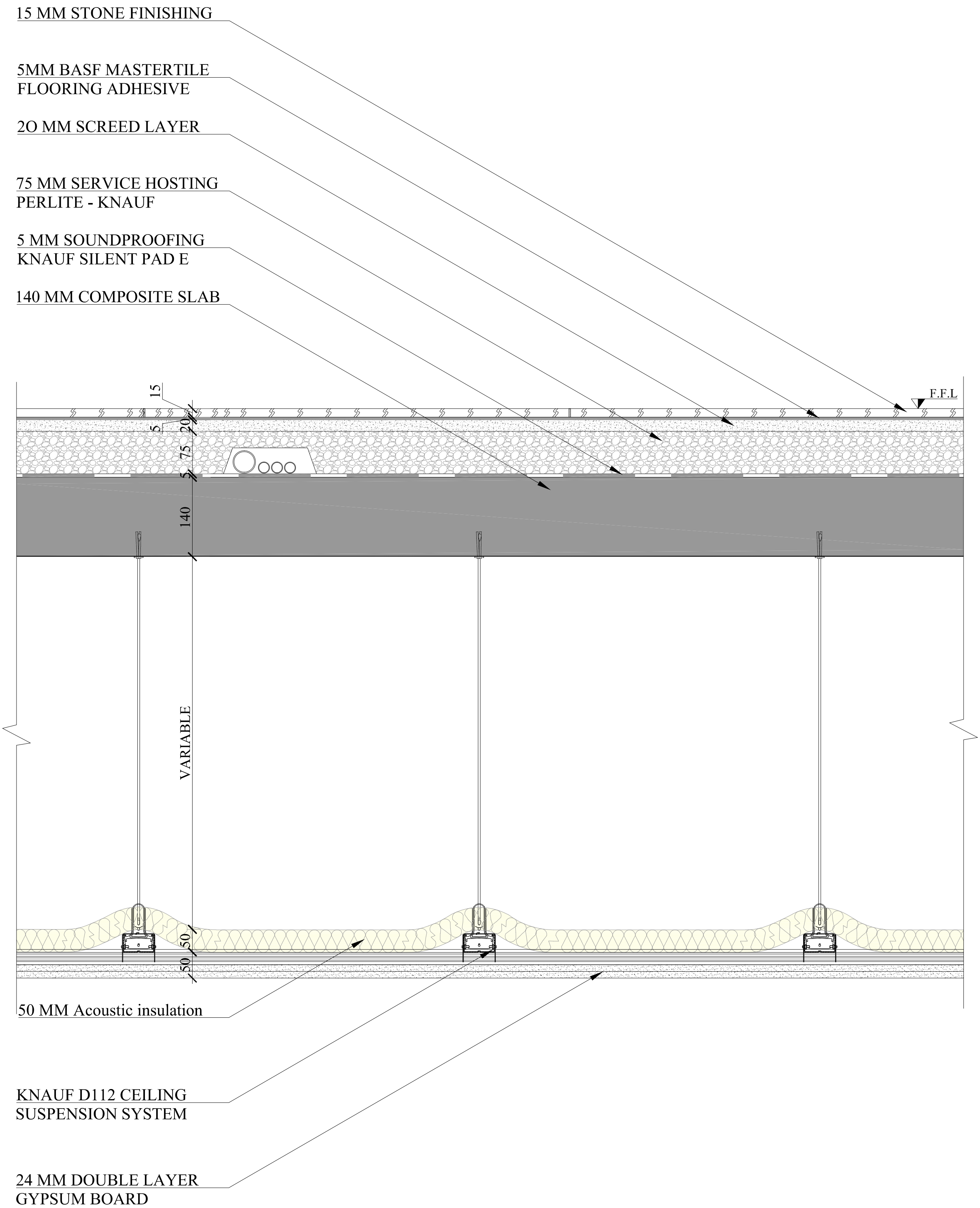




02 DETAIL 02
SCALE 1:10

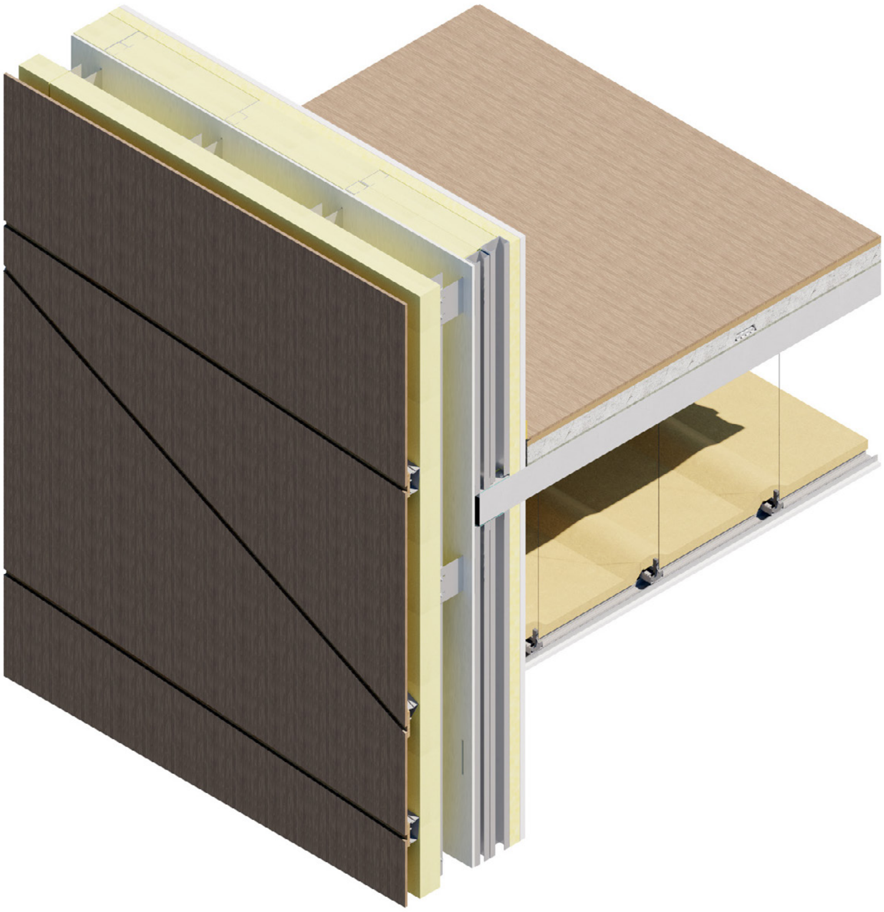
Detail 3

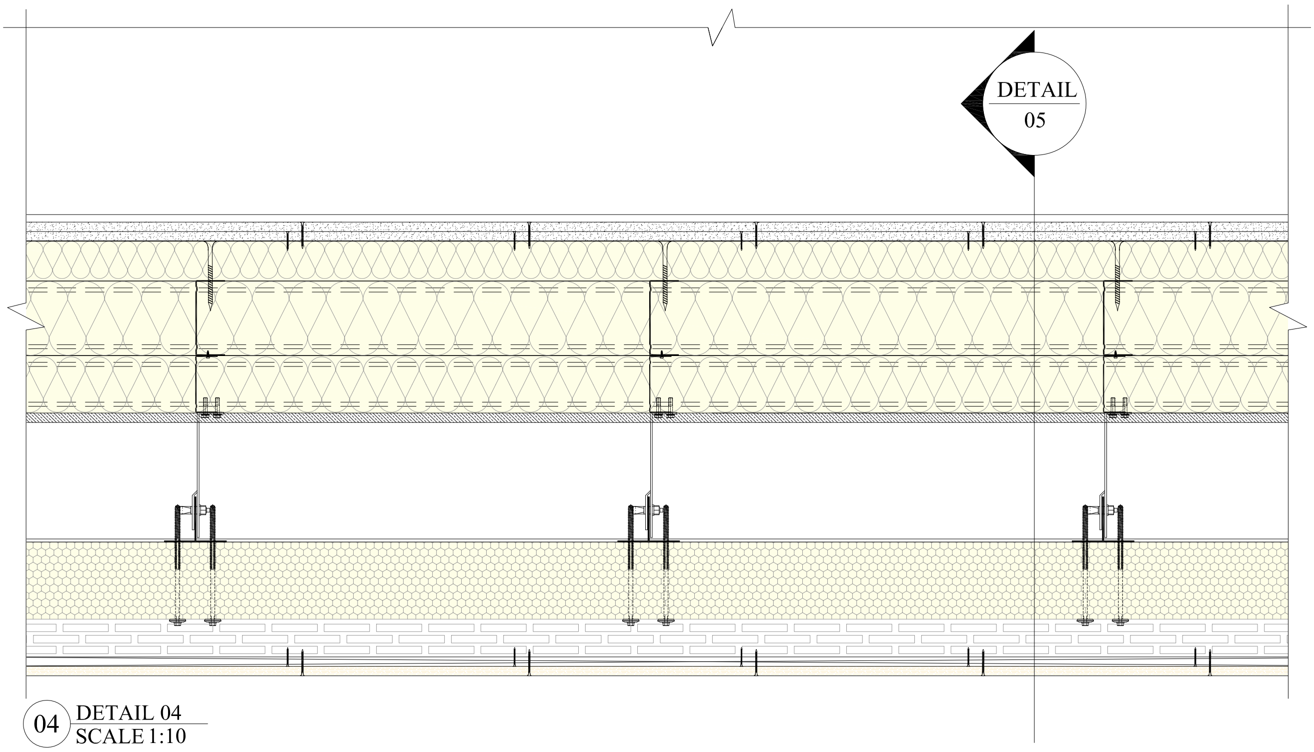


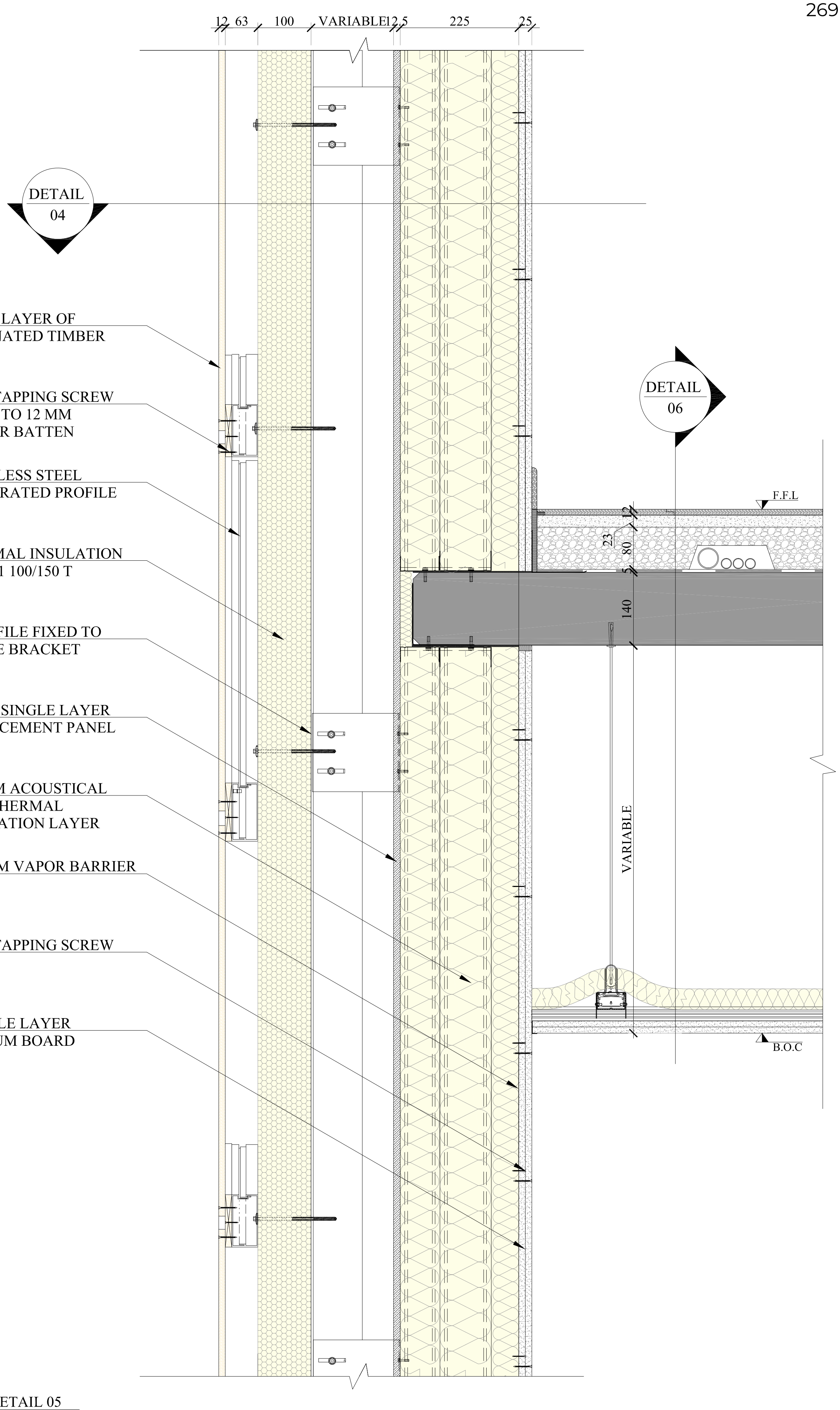


03 DETAIL 03
SCALE 1:10

Detail 4 and 5

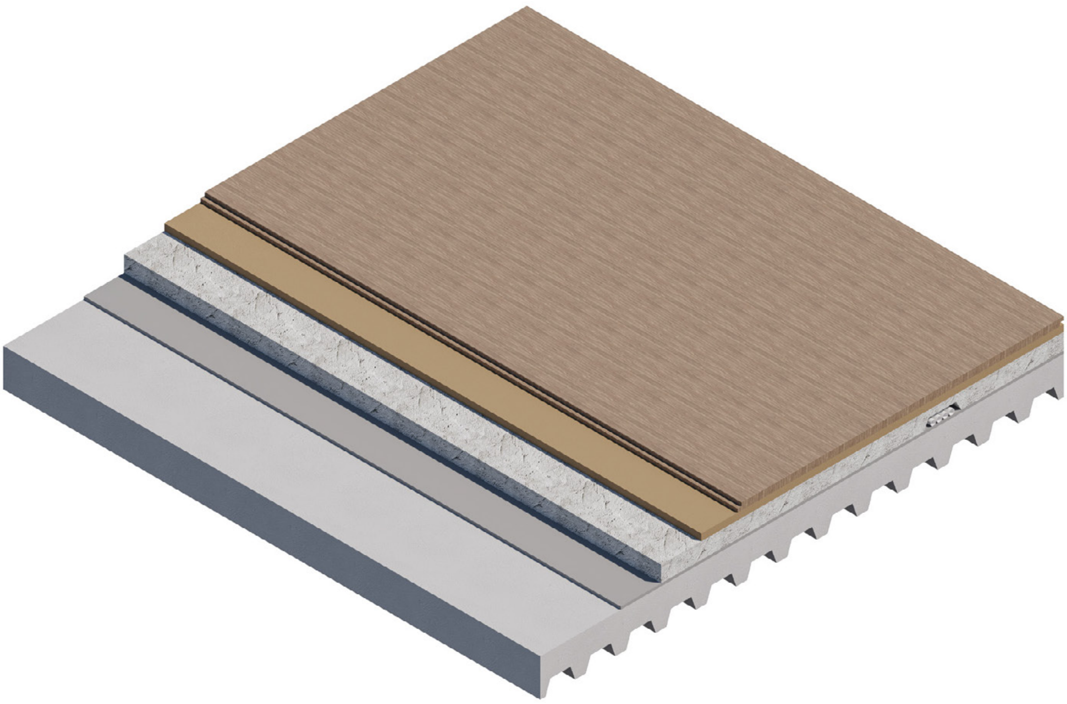


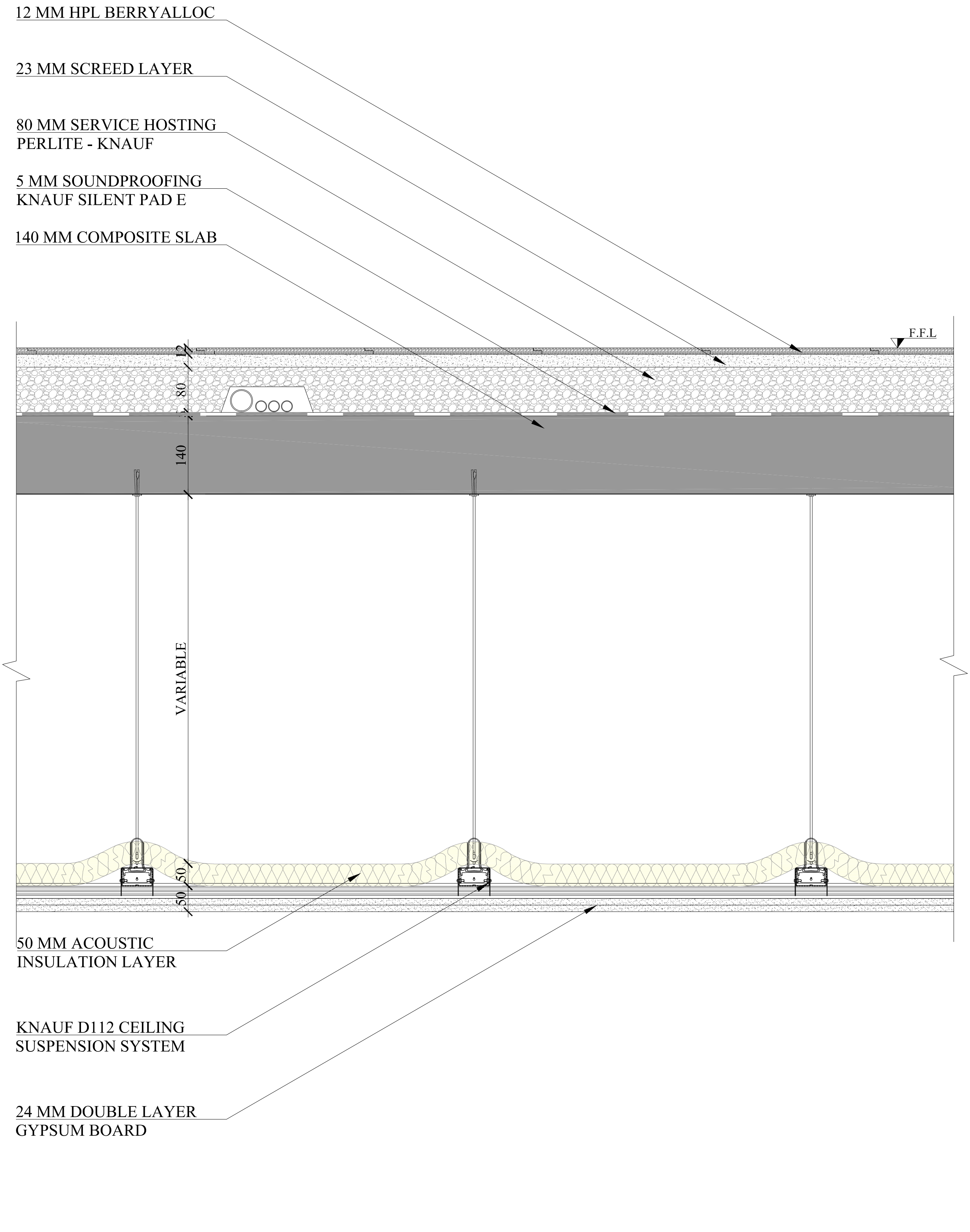




05 DETAIL 05
SCALE 1:10

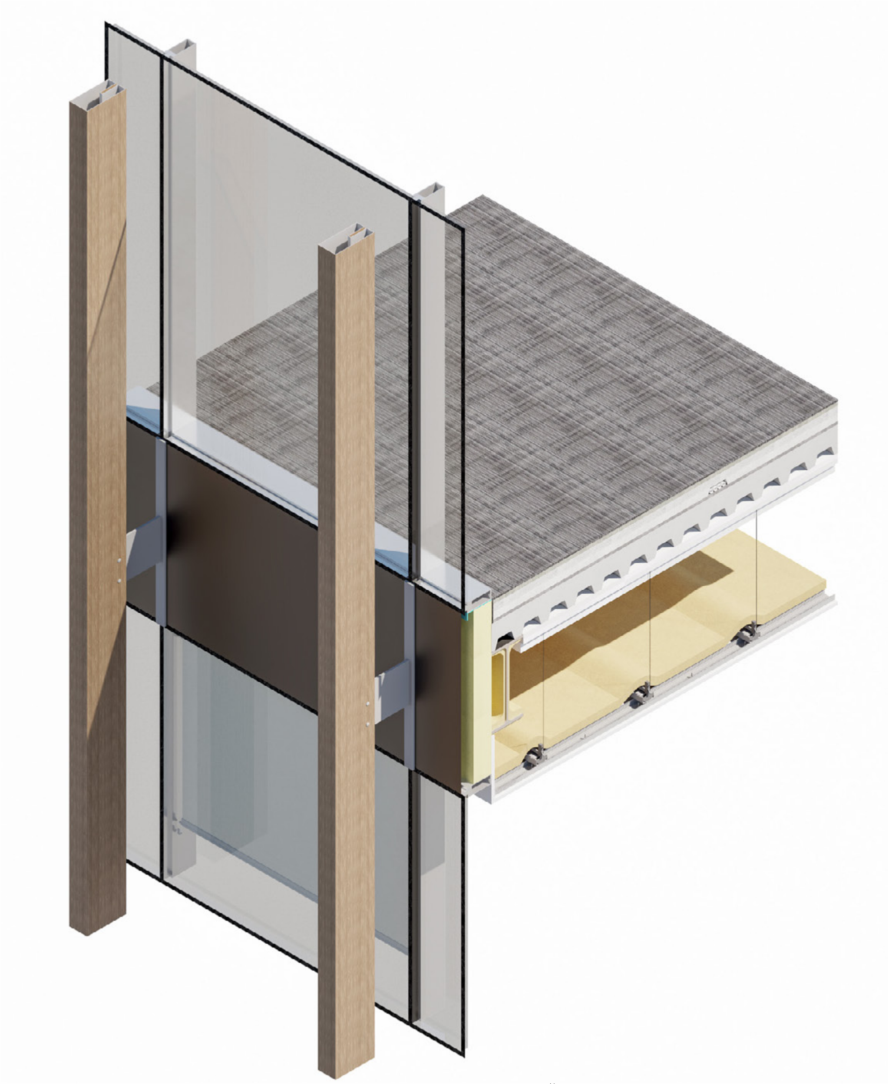
Detail 6

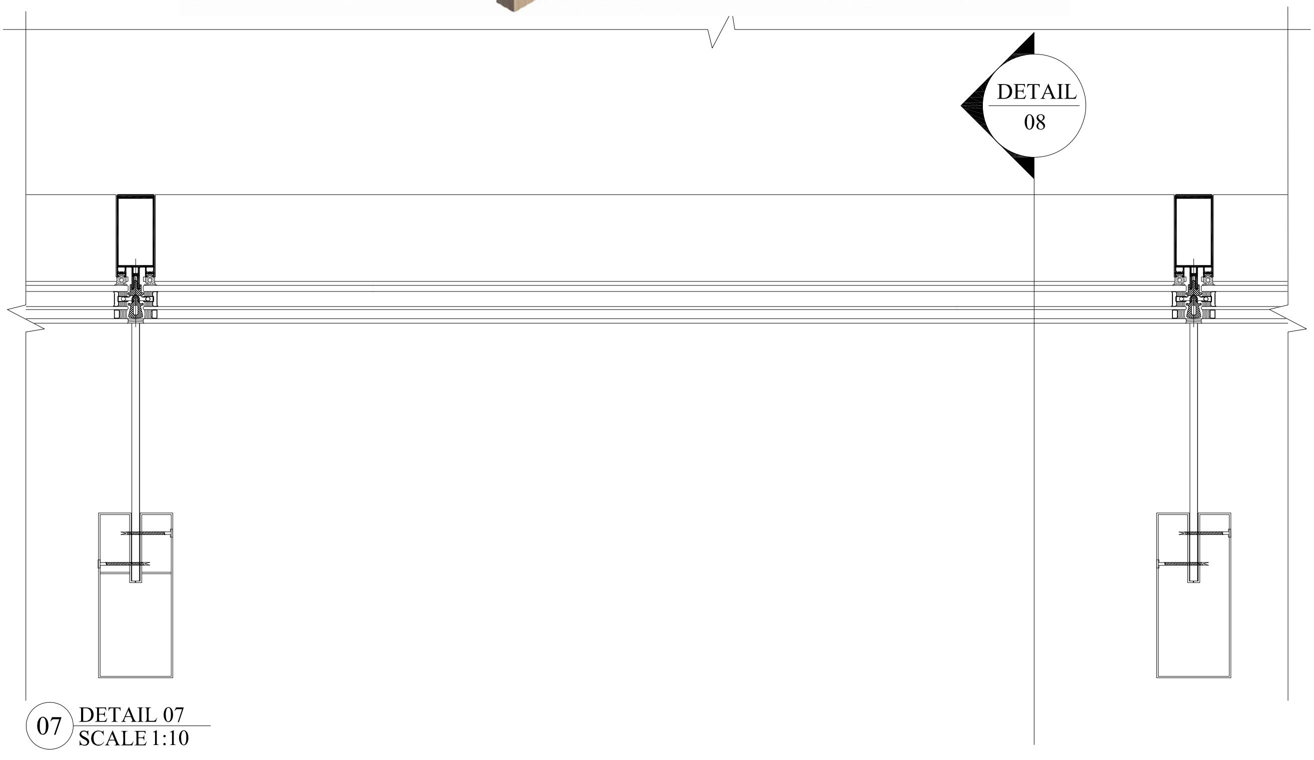


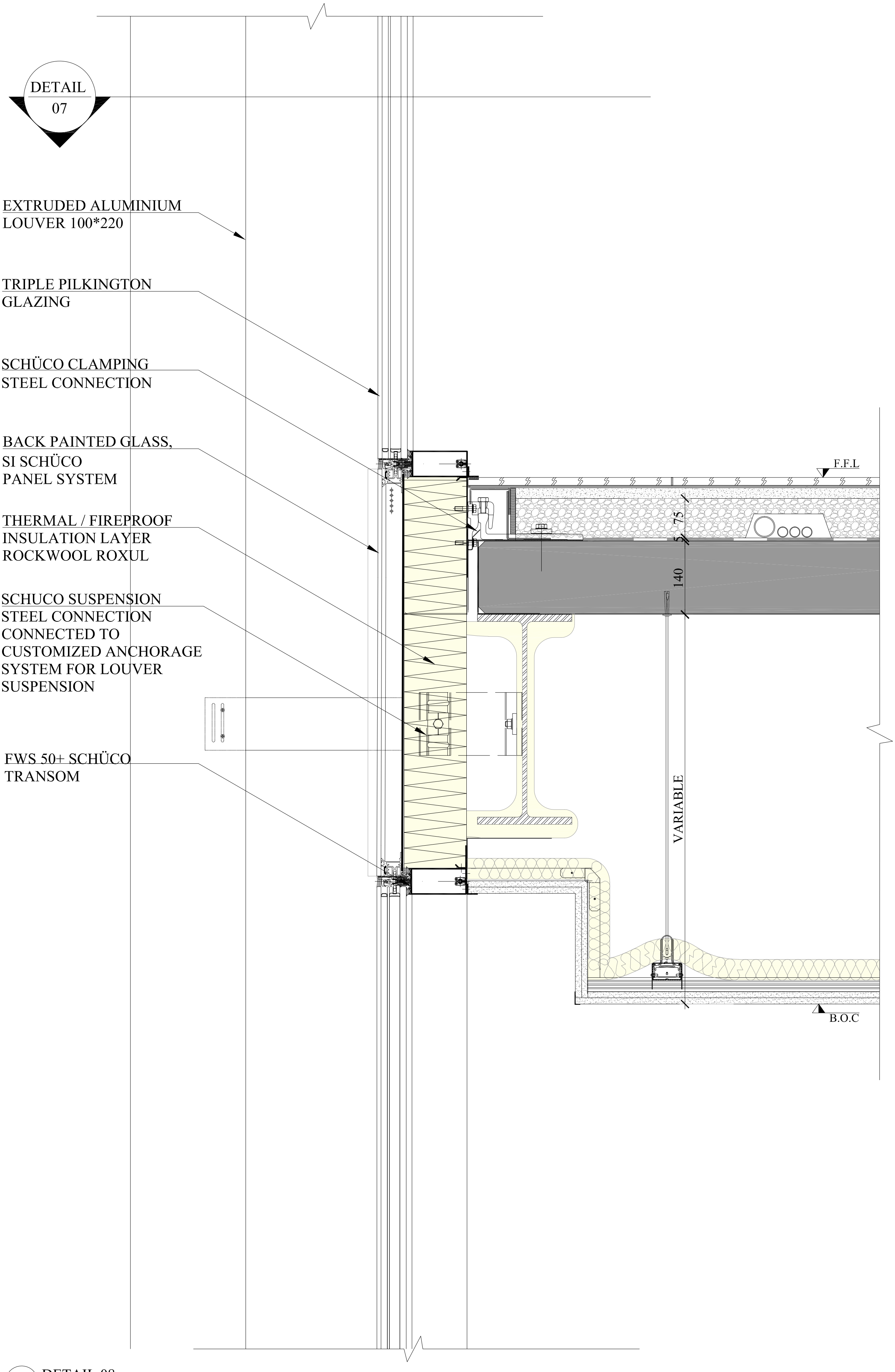


06 DETAIL 06
SCALE 1:10

| Detail 7 and 8

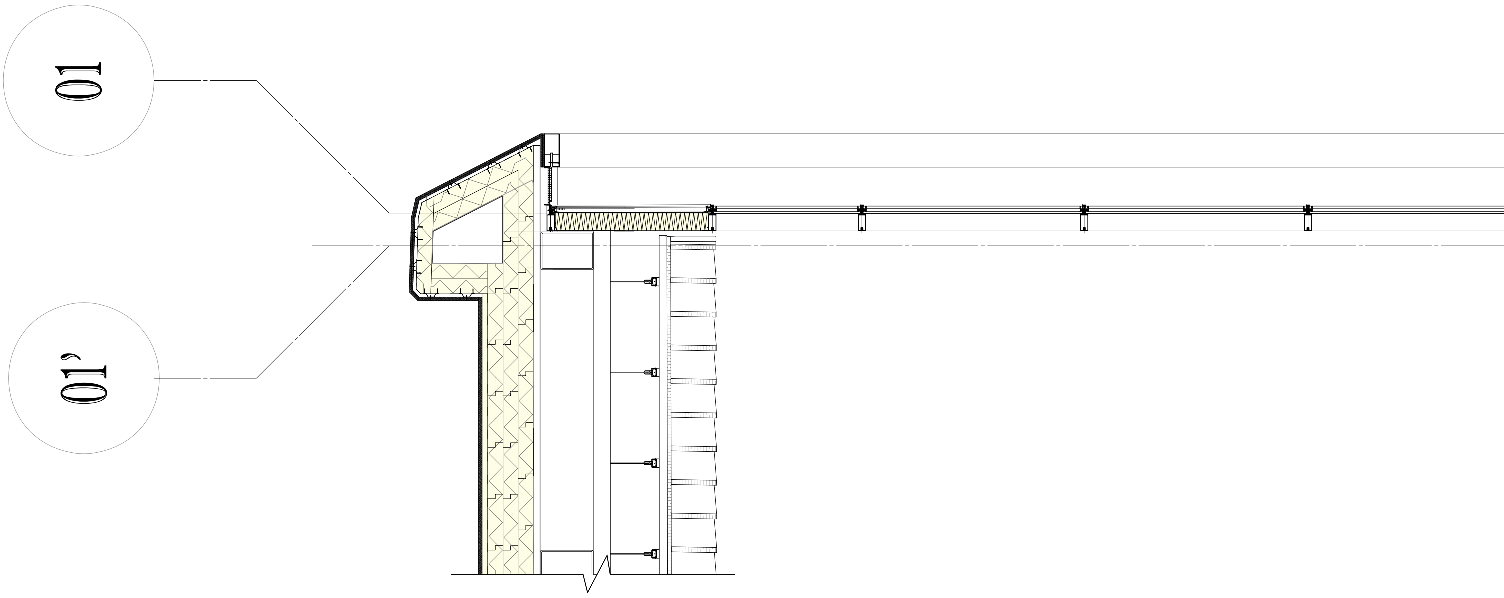


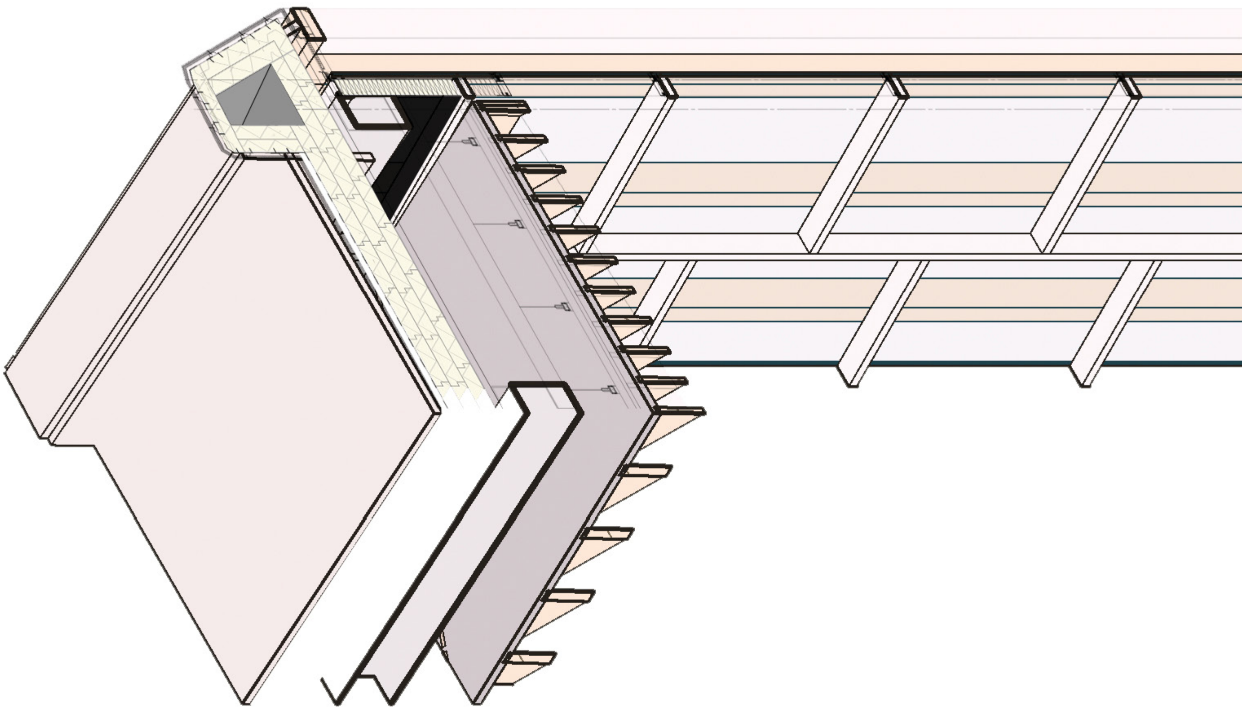


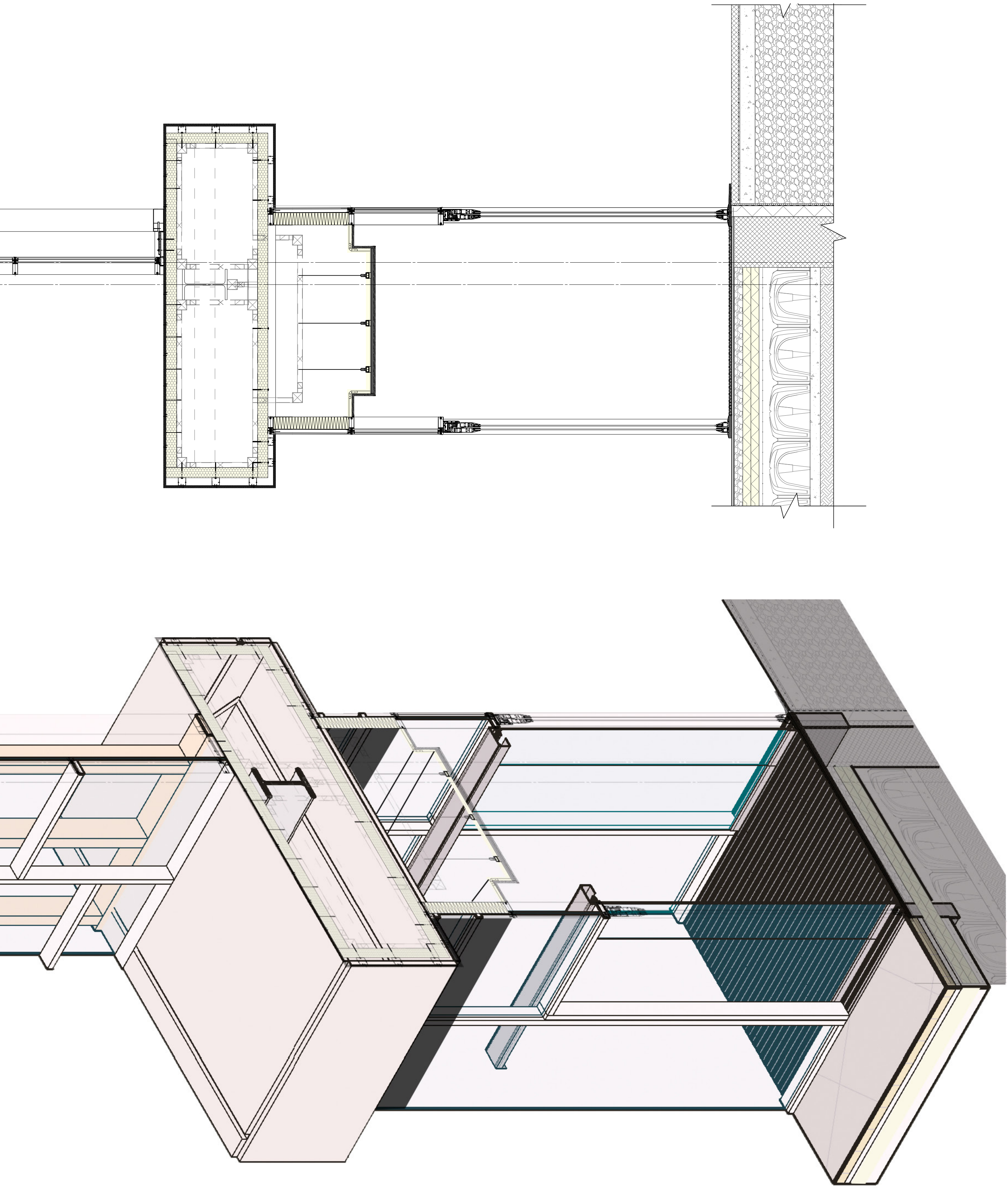


08 DETAIL 08
SCALE 1:10

Blowup Section

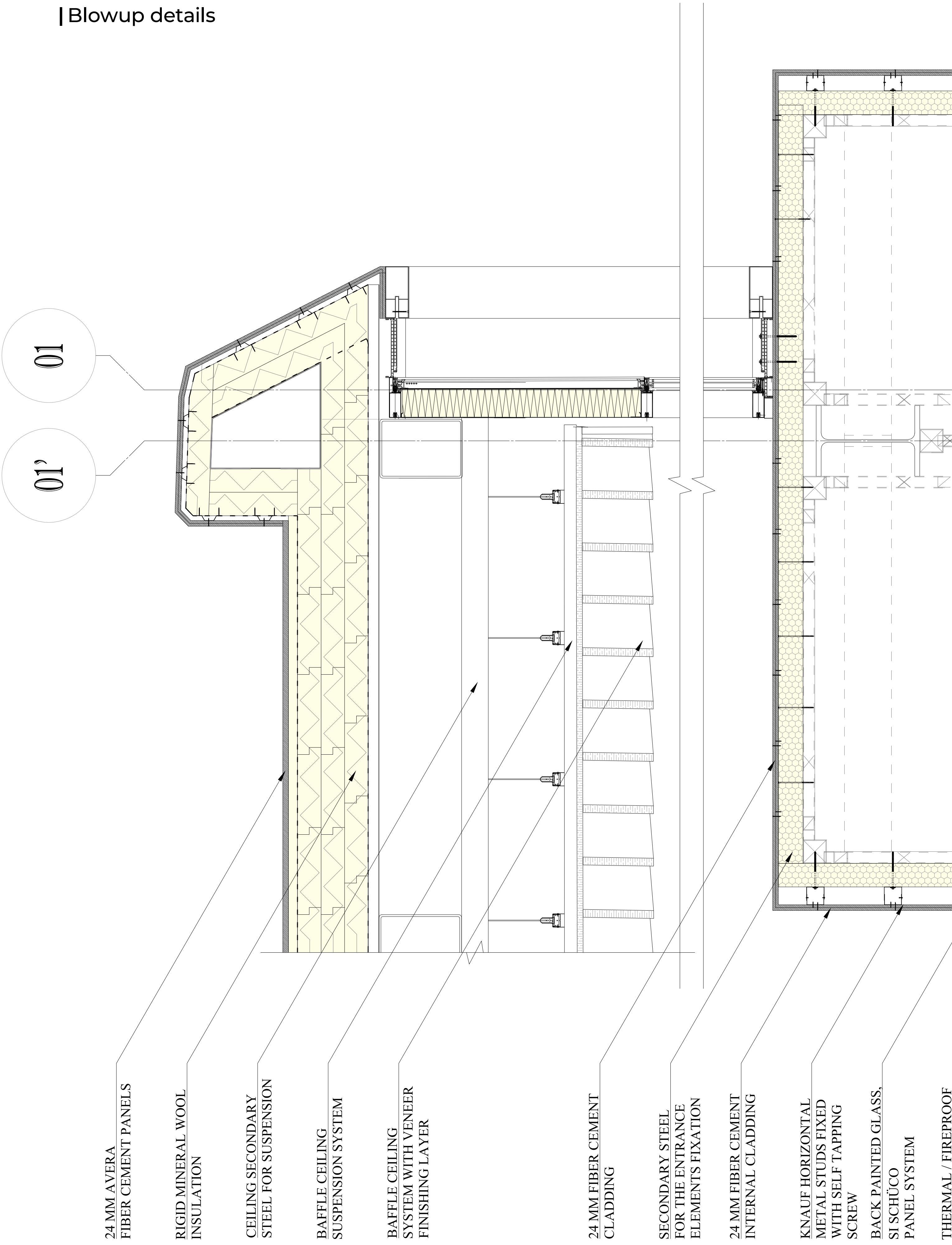


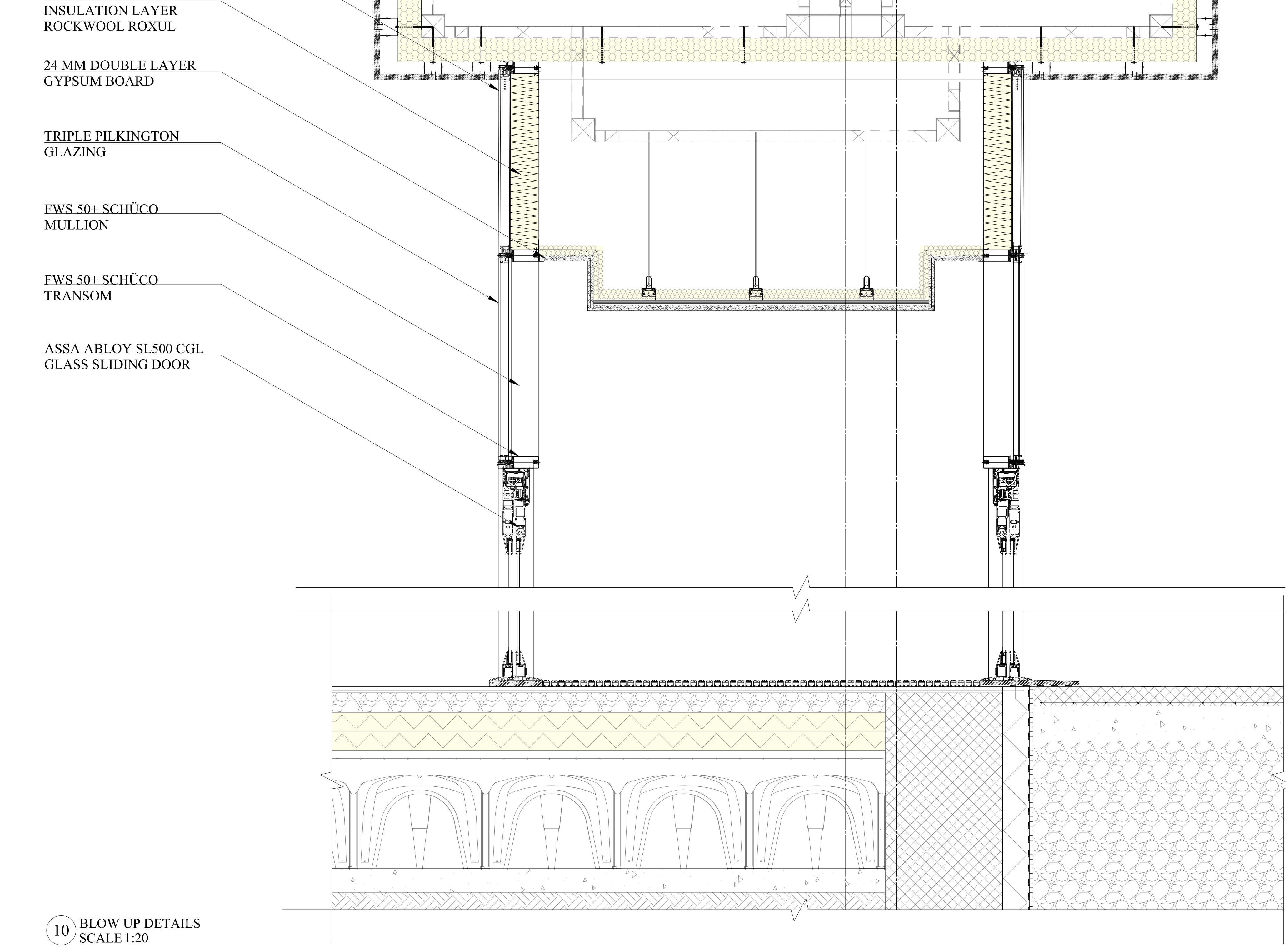




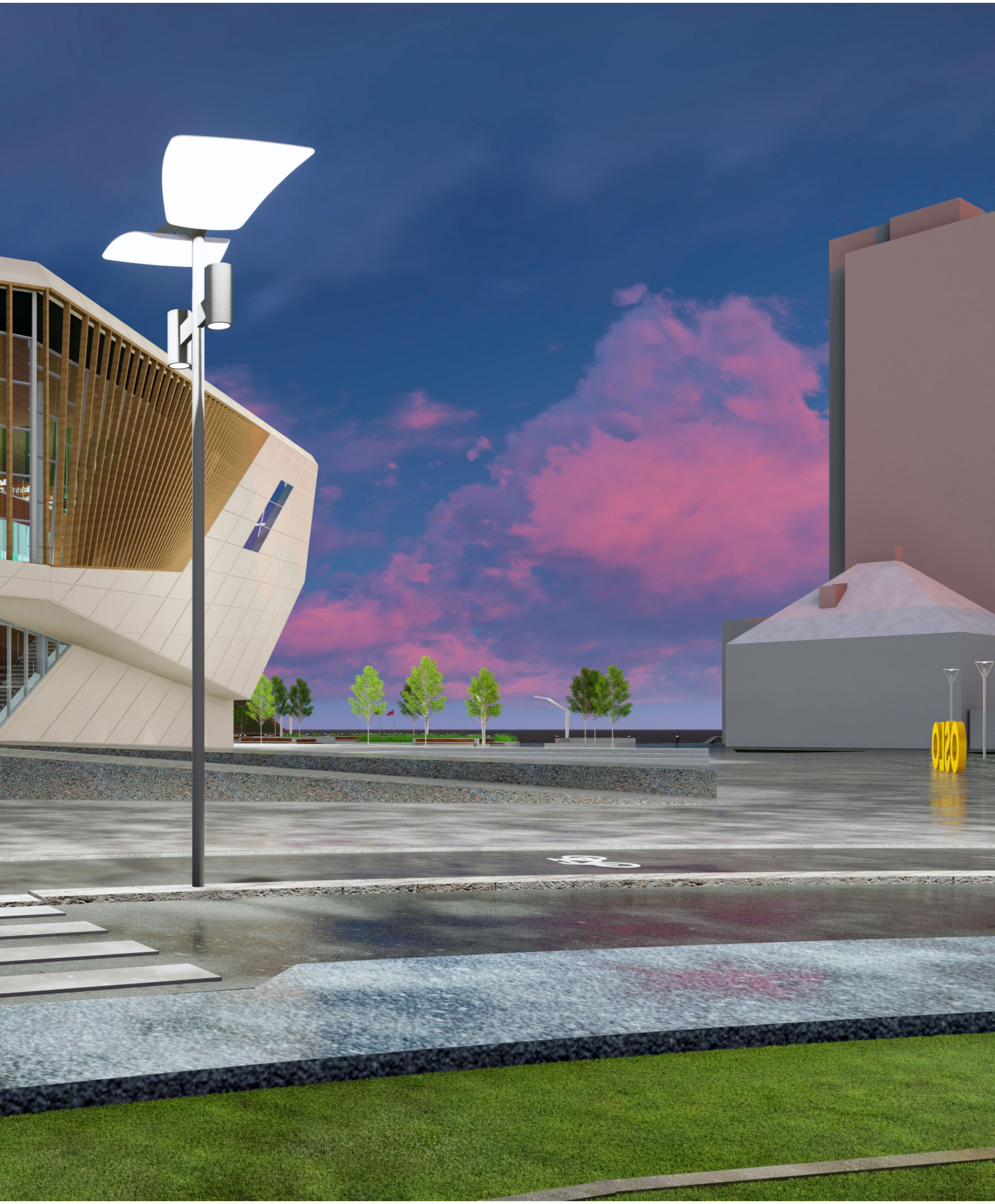
09 BLOW UP
SCALE 1:50

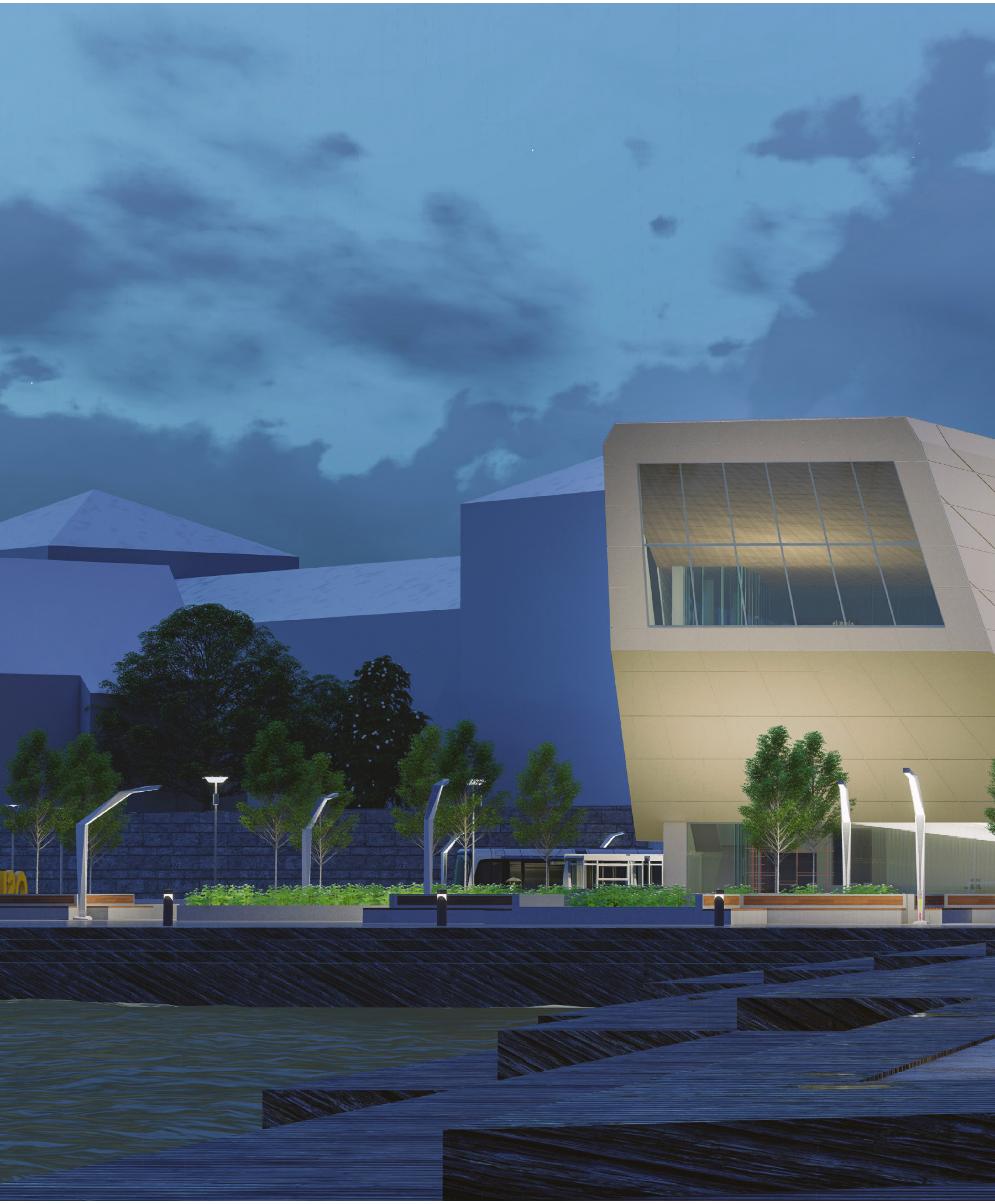
Blowup details





10 BLOW UP DETAILS
SCALE 1:20





BIBLIOGRAPHY

CHAPTER 1

#OSLOCALL, https://startfortalents.net/resultas-oslocall-startfortalents/ (Accessed March 2019

Oslo's Fjord City, Agency for Planning and Building Services. https://www.oslo.kommune.no/english/

(Accessed April 2019)

Opera house https://www.oslo-fjord.com/

(Accessed February 2020)

Astrup Fearnley Museet https://www.afmuseet.no/

(Accessed February 2020)

CHAPTER 2

Maritim kulturminneplan for Oslo havn, 2011. https://www.oslohavn.no/no/arkiv/arkiv-2011/vil-ta-vare-pa-havnehistorien/

(Accessed May 2019)

Oslo https://en.wikipedia.org/wiki/Oslo

(Accessed February 2020)

History of Oslo https://www.lifeinnorway.net/history-of-oslo/

(Accessed February 2020)

History of Vippetangen https://en.wikipedia.org/wiki/Vippetangen

(Accessed February 2020

History of Oslo https://www.oslohavn.no/no/meny/om-oslo-havn/om-oslo-havns-historie/

(Accessed February 2020)

Medieval Oslo https://snl.no/Oslo_Havn

(Accessed February 2020)

Historical images http://oslobilder.no/

Accessed February 2020

Historical images http://taptoslo.no/sentrum/kongens-gate-14/

Accessed February 2020

Historical maps https://kart.finn.no/

Accessed February 2020

Historical buildings https://kulturminnesok.no

Accessed February 2020

Climatehttps://en.wikipedia.org/wiki/Geography_of_Norway

Accessed February 2020

Climate https://weatherspark.com/y/68697/Average-Weather-in-Oslo-Norway-Year-Round

Accessed February 2020

Climate

https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/59.904N10.742E4_Europe%2FOslo

Accessed February 2020

Pollution http://www.airqualitynow.eu/city_info/oslo/page2.php

Accessed February 2020

Oslo commune, Port of Oslo as a zero-emission port Action plan, June 2018 Department of Business Development and Public Ownership

Pollution https://www.sustaineurope.com/oslo-european-green-capital-2019-20191023.html

Accessed February 2020

IMM http://www.immdesignlab.com/informazioni/

Accessed March 2019

Public transportation https://www.oslo.kommune.no/politics-and-administration/green-oslo/best-practices/public-transport-in-oslo/#gref

Accessed March 2019

Public transportation https://www.lifeinnorway.net/public-transport-in-oslo/

Accessed April 2019

Public transportation https://ruter.no/en/journey/route-maps/

Accessed April 2019

Cycling https://www.visitoslo.com/en/activities-and-attractions/activities/biking/

Accessed April 2019

CHAPTER 3

https://www.sustaineurope.com/oslo-european-green-capital-2019-20191023.html

Accessed February 2020

Brosjyren Visjoner for Vippetangen, https://www.oslo.kommune.no/slik-bygger-vi-oslo/fjordbyen/vippetangkaia-og-vippetangen/#gref

Accessed April 2019

Fjordbyplanen, https://www.oslo.kommune.no/slik-bygger-vi-oslo/fjordbyen/vippetang-kaia-og-vippetangen/#gref

Accessed April 2019

Områdeprogram Vippetangen, https://www.oslo.kommune.no/slik-bygger-vi-oslo/fjordbyen/vip-petangkaia-og-vippetangen/#gref

Accessed April 2019

CHAPTER 5

EN 1991.1-1: Eurocode 1. Actions on structures. Part 1-1: General actions: densities, self-weight and imposed loads for buildings

EN 1991.1-3: Eurocode 1. Actions on structures. Part 1-3: General actions: snow loads

EN 1991.1-3: Eurocode 1. Actions on structures. Part 1-4: General actions: wind actions

EN 1992-1.1: Eurocode 2. Design of concrete structures. Part 1-1. General rules and rules for buildings.

EN 1993-1.1: Eurocode 3. Design of steel structures – Part 1-1. General rules and rules for building

EN 1994: Eurocode 4: Design of composite steel and concrete structures

National Annex of Norway NS-EN 1991-1-4:2005/ NA:2009

Steel sheet section properties and load tables https://www.tatasteelconstruction.com/en_GB/Products/structural-buildings-and-bridges/Composite-floor-deck/ComFlor%C2%AE-46

Accessed December 2019

Steel section properties table http://www.perlitayvermiculita.com/

ESDEP WG 7, Figure 4 http://fgg-web.fgg.uni-lj.si/~/pmoze/ESDEP/master/wg07/l0810.htm

Accessed December 2019

Lateral-torsional buckling resistance

https://www.sciencedirect.com/science/article/abs/pii/S0141029616316315

Accessed December 2019

Steel section properties table http://www.staticstools.eu/

Accessed December 2019

CHAPTER 6

Regulations on technical requirements for construction works, Norwegian Building Authority, 2017

Heidi Arnesen, Tore Kolås and Barbara Matusiak (NTNU), A guide to daylighting and solar shading systems at high latitude, 2011

Daylight https://www.velux.com/deic/daylight/daylight-calculations-and-measurements

Accessed February 2020

Daylight https://blog.sketchup.com/article/six-metrics-every-architect-should-know-and-how-use-them

Accessed February 2020

https://spectrum.pilkington.com/

Accessed February 2020