DESIGN OF THE NEW 2022 BAUHAUS CAMPUS

POLITECNICO MILANO 1863

POLO TERRITORIALE DI LECCO

School of Architecture Urban planning Construction Engineering

Master of Science in Building and Architectural Engineering

Academic year 2021-2022

Thesis title :

Design of the new 2022 Bauhaus Campus

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ABSTRACT

The definition of Teaching and learning environments has changed during the past decades. The requirements of learning institutions today are developing and changing at a fast pace. Connectivity, collaboration, co-creation, innovation and sociality are at the core of new design approaches and bring together people, ideas and innovation.

New generation need a space to share their ideas and visions, to communicate and discuss. A campus can meet their needs and bring all these activities together.Also, A campus has a potential to work as a strategic center for the citizen and students and this can lead to innovation, creativity and increase the quality of the urban environment.

This thesis is a competition about Design of the new 2021 Bauhaus Campus. The aim of is to combining the city with the campus. Create not only an educational space, but a large fluid space that offers both students and citizen an environment in which they can learn, develop, live and interact. We try to design a highly accessible urban complex, a going through public space which connect the original Bauhaus to the Bauhaus museum with designing a bridge. Also work as a mediator which allows people to use this complex for passing from the street by using a bridge.

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CHAPTER 01
Introduction

1.1 Germany

1.1.1 Geography

Germany is the seventh-largest country in Europe. German territory covers 357,022 km2 (137,847 sq mi), consisting of 348,672 km2 (of land and 8,350 km2 of water. The forested uplands of central Germany and the lowlands of northern Germany (lowest point: in the municipality Neuendorf-Sachsenbande, Wilstermarsch at 3.54 metres or 11.6 feet below sea level) are traversed by such major rivers as the Rhine, Danube and Elbe. Significant natural resources include iron ore, coal, potash, timber, lignite, uranium, copper, natural gas, salt, and nickel.

1.1.2 Economy

Germany is a great power with a strong economy; it has the largest economy in Europe, the world's fourth-largest economy by nominal GDP and the fifth-largest by PPP. As a global leader in several industrial, scientific and technological sectors, it is both the world's third-largest exporter and importer of goods. As a developed country, which ranks very high on the Human Development Index, it offers social security and a universal health care system, environmental protections, a tuition-free university education, and it is ranked as 16th most peaceful country in the world. Germany is a member of the United Nations, NATO, the G7, the G20 and the OECD.

It has the third-greatest number of UNESCO World Heritage Sites. Research and development efforts form an integral part of the German economy. In 2018 Germany ranked fourth globally in terms of number of science and engineering research papers published. Germany was ranked 9th in the Global Innovation Index in 2019 and 2020 and 10th in 2021. Research institutions in Germany include the Max Planck Society, the Helmholtz Association, and the Fraunhofer Society and the Leibniz Association. Germany is the largest contributor to the European Space Agency.

1.1.3 Population

The current population of Germany is 84,339,825 And is is equivalent to 1.07% of the total world population 76.3 % of the population is urban and the median age in Germany is 45.7 years. Germany has one of the world's highest levels of education, technological development, and economic productivity. Since the end of World War II, the number of students entering university has more than tripled, and the trade and technical schools are among the world's best.

German is a West Germanic language of the Indo-European language family, mainly spoken in Central Europe. It is the most widely spoken and official or co-official language in Germany, Austria, Switzerland, Liechtenstein, and the Italian province of South Tyrol. It is also a co-official language of Luxembourg and Belgium, as well as a national language in Namibia. German is a pluricentric language; the three standardized variants are German, Austrian, and Swiss Standard High German. It is also notable for its broad spectrum of dialects, with many varieties existing in Europe and other parts of the world.

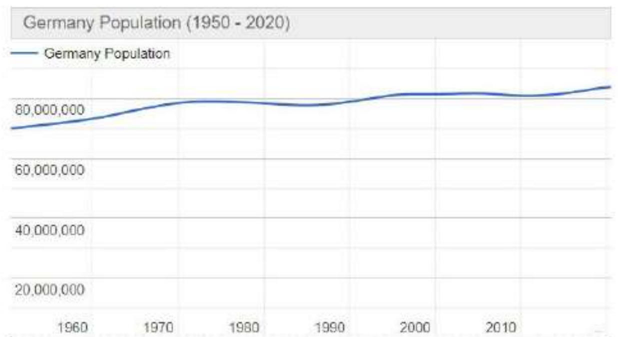


Figure 1.1 Germany population

1.1.4 Environment

1.1.4.1 Climate

Germany's climate can be described as a temperate seasonal climate and it is dominated by humid westerly winds. The Northern extension of the Gulf Stream, the North Atlantic Drift, moderates Germany's climate and as a result the north and northwest coastal regions have an oceanic climate.

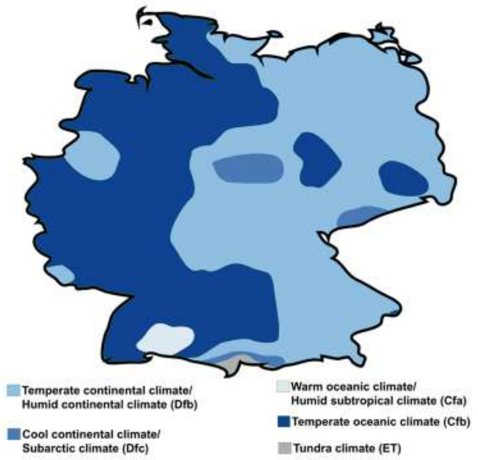


Figure 1.2 Climate classification

1.1.4.2 Ecosystem

Germany has a diverse range of ecosystems: coastlines along the Baltic and North seas, fertile plains, highlands, forests, and the mountainous Alps in the southern part of the country. Despite being surrounded by an array of breathtaking ecosystems and scenery, Germans tend to live in urban areas, with around 86 percent of the population living in cities and have a population density of approximately 583/per square, ranking 58th globally. Germany also has one of the lowest birthrates in the world.

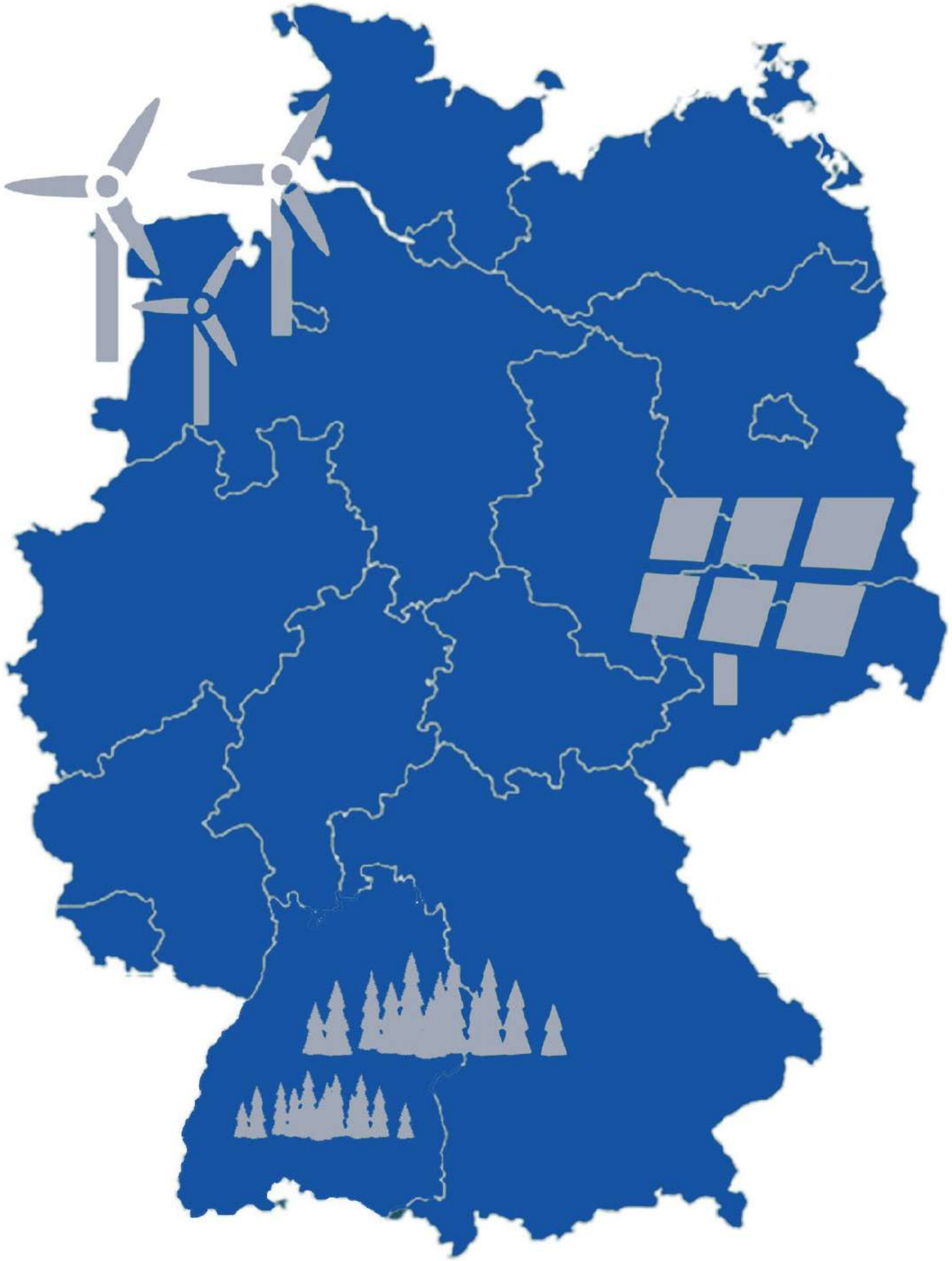


Figure 1.3 Map of renewable energy in Germany

1.1.4.3 Renewable energy

Renewable energy in Germany is mainly based on wind and biomass, plus solar and hydro. Germany had the world's largest photovoltaic installed capacity until 2014, and as of 2021 it has over 58 GW. It is also the world's third country by installed total wind power capacity, 64 GW in 2021 (59 GW in 2018) and second for offshore wind, with over 7 GW. Germany has been called "the world's first major renewable energy economy". Heavy winds on the North Sea and Baltic Coast increase power production from North Germany wind farms. More than 21,607 wind turbines are located in the German federal area and the country has plans to build more. The key provider of biomass supply in Germany is supposed to be agriculture. Moreover, 40% of German wood production is also used as a biomass feed stock.

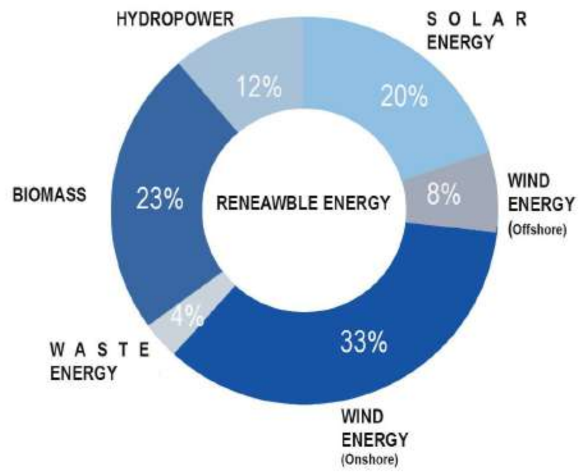


Figure 1.4 Renewable energy in Germany

1.1.4.4 Environmental Issues

Like many industrialized nations, Germany has a significant air pollution problem, but unlike other Western countries it has worsened in recent years. After the Fukushima nuclear disaster of 2011, Chancellor Angela Merkel and the German government adopted a policy of phasing out the country's nuclear power plants. To do so, the government allowed for utilities to burn more coal and as a result, the air pollution levels in 2012 and 2013 were two of the highest since the 1980s. In addition to air pollution, decades of open-cast mining in East Germany has resulted in significant water pollution in some rivers. During mining days, the areas around the mine were drain of water, but now that the mines are no longer in operation water levels have risen and caused a brown sludge to start filling up the Spree River, killing wildlife in the popular tourist attraction and UNESCO biosphere reserve. According to a 2018 pole by Statista, 36% of respondents believed that global warming was the most important environmental issue facing Germany today. Future energy sources and air pollution came a close second and third with 30% and 27% respectively.

Figure 1.5 Germany aims to achieve for environment and climate action

Figure 1.6 Nuclear power plant in Grohnde near Hameln in Lower Saxony,Germany

1.1.4.5 Environmental Policies

Germany, like the rest of the world, faces the consequences of global warming and the country has been one of the global leaders in battling carbon emissions. One effort involves the increasing the efficiency of the use of resources. The German government has set a goal of trying to use fewer resources while maintaining the same amount of prosperity and according to a 2014 report, efficient use of raw materials in 2020 is expected to be double that of 1994. The Germany government has also aggressively pursued the implementation of renewable energy production. In 2013, 12 percent of final energy consumption came from renewable energy sources, according to the European Environmental Agency. Renewables also accounted for 9.1 percent of heat and 5.5 percent of fuel consumption. The country is currently embracing its Energiewende, or "energy turn," policy as it tries to position itself as a future provider of renewable energy technology to the rest of the world. Solar energy makes up a large part of Germanys renewable push. German innovators are pursuing two types of solar energy: conventional photovoltaics and concentrated solar power (CSP). As the name implies, CSP involves using mirrors atop a tower to bundle together the sun's rays on a single, central receiver. The technology generates heat, which can either be stored or used to create electricity through a standard turbine. Germany has been known to be able to provide 100% of the country's daily need through clean energy alone.

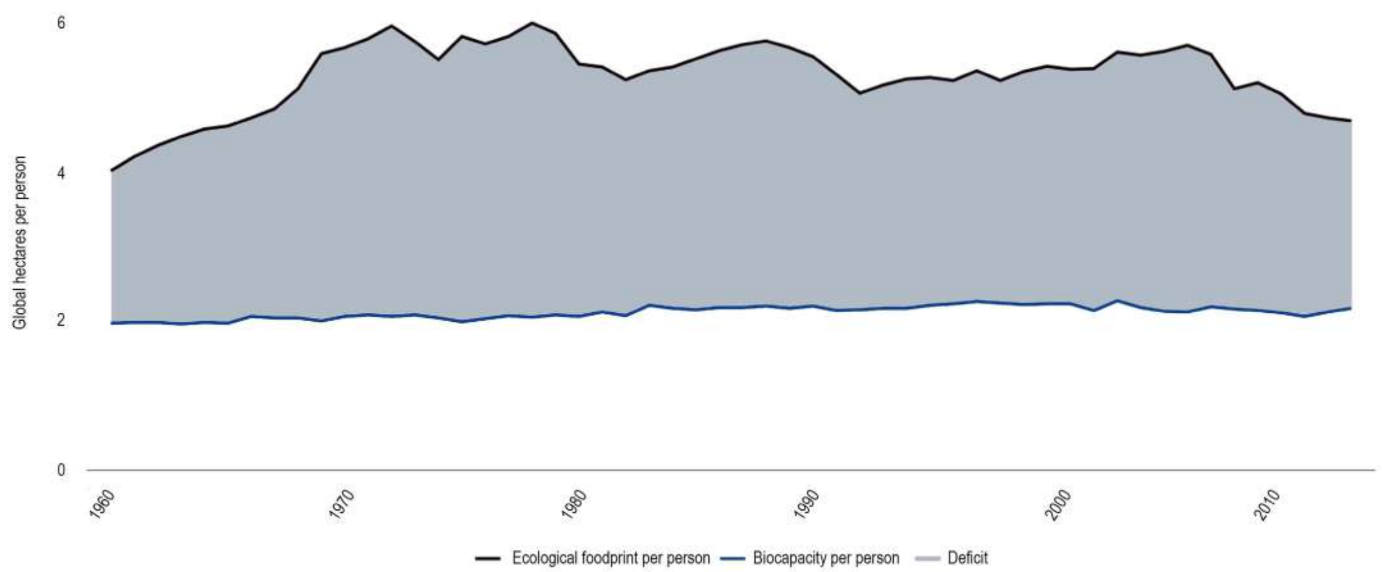


Figure 1.7 Ecological footprint, biocapacity and biocapacity deficit per person

1.1.5 Architecture

Throughout its history, German architecture combined influences from elsewhere in Europe with its own national character. During the medieval period, the Romanesque style dominated. In the 13th century, as the Gothic style took hold, some of Germany's most notable structures were built, including the cathedrals at Cologne (begun 1248) and Strasbourg (planned 1277). Variations on the Gothic and Renaissance styles predominated through the 15th and 16th centuries, but, after the Protestant Reformation, commissions for elaborate religious structures decreased for a time. A revival of the Gothic began in the 17th century, when an increasing amount of ornamentation became the chief characteristic of churches and palaces; this decorative bent in German design reached a crescendo in the first half of the 18th century with the influence of the French and Italian Rococo style. Such lightness evaporated by the 19th century, when a forbidding sort of Neoclassicism came to represent the Prussian military spirit of the time. The Romantically tinged Neoclassicism of Karl Friedrich Schinkel, who became state architect of Prussia in 1815, embodied this era. Although radical architecture was generally suppressed during this period, some architects, inspired in part by the Jugendstil movement and figures such as Henry van de Velde and Peter Behrens, questioned by the turn of the century the validity of architecture that appeared so disengaged from modernity; such questioning opened the door for the radical experiments that characterized German architecture in the 20th century.

Figure 1.8 The Römer the old town hall Frankfurt am Main

Figure 1.9 Cologne Cathedral on the Rhine River

Contemporary German architecture indeed world architecture is very much the creature of the Bauhaus school that originated in Weimar in the 1920s and is associated with the names of Walter Gropius and Ludwig Mies van der Rohe. In the postwar years the dogmas of the Bauhaus school the insistence on strict harmony of style with function and on the intrinsic beauty of materials, as well as a puritan disdain of decorativeness were dutifully applied in building after building in city after city. Yet in West Germany, as elsewhere in the 1960s and '70s, the stark Bauhaus style began to yield to the more free-ranging postmodernism, which took as its precept "not just function but fiction as well." The unremitting rectangularity of the International style was to be softened by elements of regionalism. Leading exponents of this school include Josef Paul Kleihues, Oswald Mathias Ungers, and the brothers Rob and Leon Krier.

Figure 1.10 Bauhaus Archiv Museum für Gestaltung

Figure 1.11 Masters' Houses by Walter Gropius

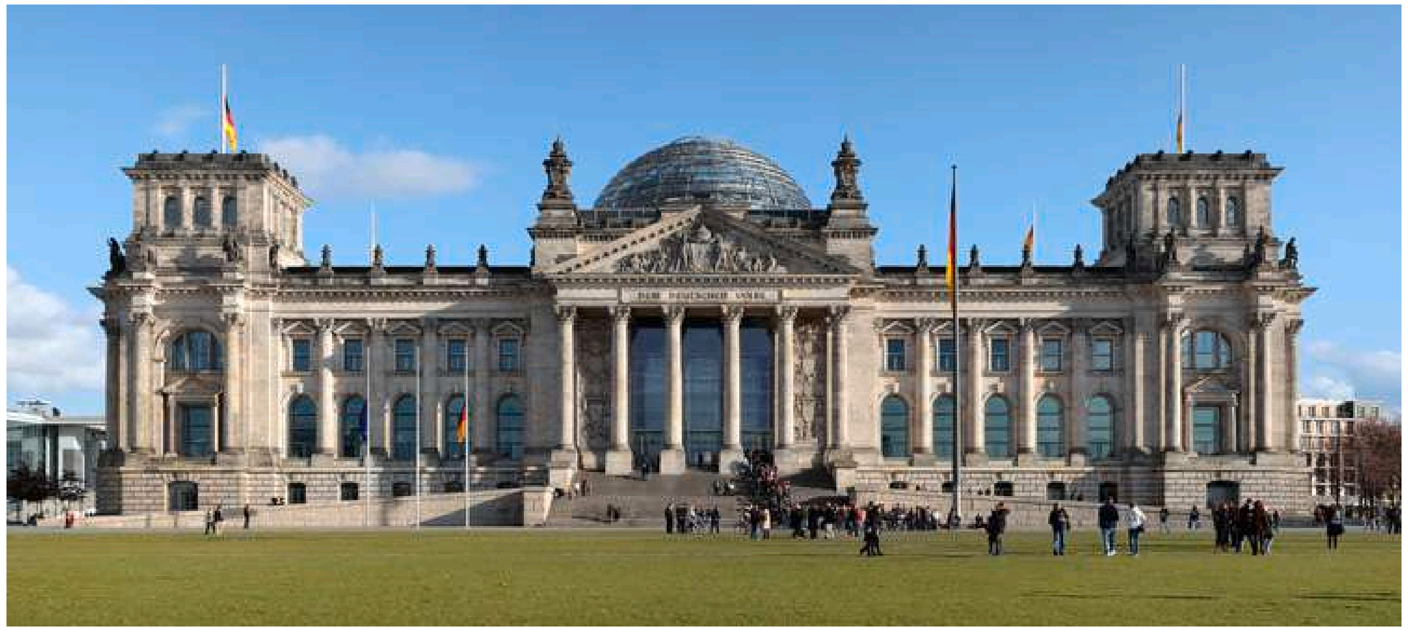


Figure 1.12 Reichstag Building Berlin

1.2 DESSAU
1.2.1 GEOGRAPHY

Dessau, city, Saxony-Anhalt Land (state), east-central Germany, is located at 51°50'19"N 12°14'44"E with the area of 182.81 km2. The German town, which developed from a Sorbian settlement, was first mentioned in 1213. It lies on the Mulde River at its confluence with the Elbe River, northeast of Halle. It is an industrial city, river port, and rail and road transport center. Before World War II it was the site of a large aircraft factory. Present industries include a shipyard, armaments, and vehicle, machinery, and chemical works. In the 18th century the Anhalt line had a castle built in the Mosigkau district of the town in the southwest; it contains a museum of the Rococo period and a notable collection of paintings. Dessau was the seat of the Bauhaus architectural school under Walter Gropius from 1925 to 1933; the Bauhaus structures in the city were designated a UNESCO World Heritage site in 1996. Nearby is the Garden Kingdom of Dessau-Wörlitz, which applies Enlightenment philosophical principles to landscape design; it was named a World Heritage site in 2000.


Figure 1.15 Town Hall

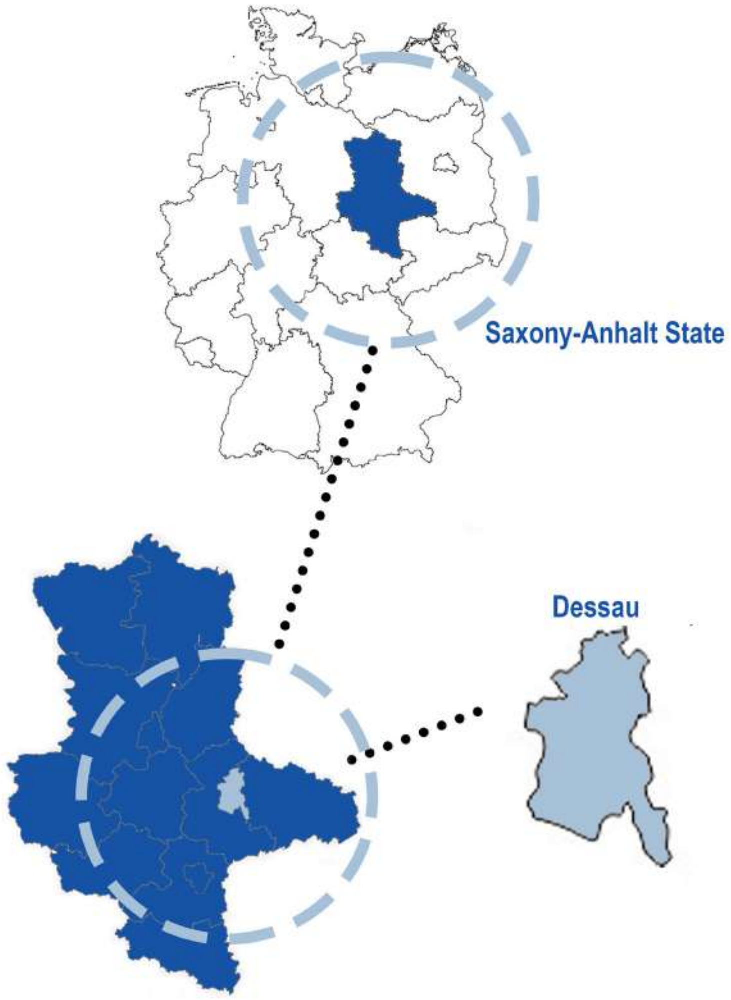


Figure 1.13 Project site location

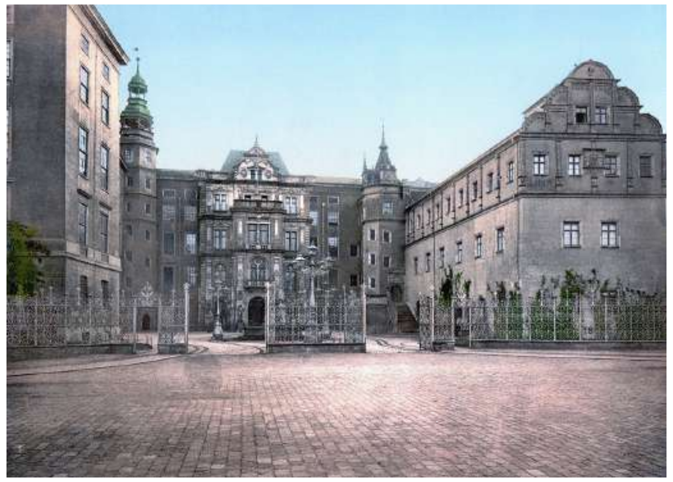


Figure 1.14 Dessau Palace


Figure 1.16 The river Mulde near Dessau

1.2.2 History

Dessau was not always known as a dying city. Throughout the history of Dessau, the city has experienced a fluctuating sense of stability influenced by the political and ideological movements of the Medieval Era, the Enlightenment Era, Industrialization, the Nazi Regime, and the GDR. Ultimately, it was the events of the 20th century that led to Dessau's gradual decline and have brought the city to a standstill in attempting to revitalize.


Figure 1.17 Church of St. Peter and Paul

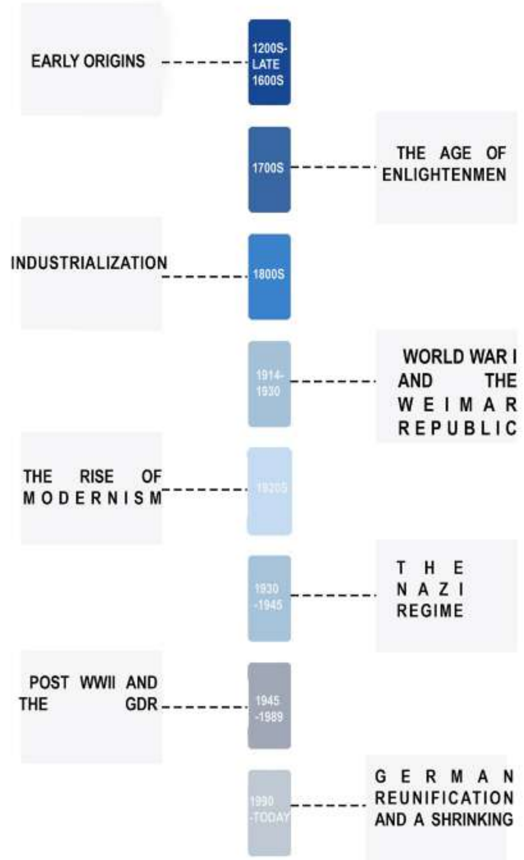


Figure 1.18 Chronology of Dessau's history

The towns of Dessau and Roßlau were united as one in 2007though divided by the River Elbe. Dessau also has an industrial history that incorporates the building of gas motors and full metal airplanes. This is also the land of the famous Bauhaus style of architecture. Many buildings here belong on the World Cultural Heritage list, such as the Bauhaus Dessau and the Meisterhäuser, or Master's House. The south of Dessau touches a well-wooded area called Mosigkauer Heide. The highest elevation is a 110 m high former rubbish dump called Scherbelberg in the southwest of Dessau. Dessau is surrounded by numerous parks and palaces that make it one of the greenest towns in Germany.


Figure 1.19 Dessau marktplat

1.2.3 Transport

1.2.3.1 Railway stations

Dessau Hauptbahnhof (main station) has connections to Magdeburg, Berlin, Leipzig, Halle, Bitterfeld and Lutherstadt Wittenberg. The line from Berlin was opened on 1 September 1840. The Dessau-Bitterfeld line (opened on 17 August 1857) was electrified in 1911, the first fully electrified long-distance railway in Germany. Dessau was part of the InterCity long-distance network until the year 2002. Regional trains also stop at the stations Dessau-Süd, Dessau-Alten, Dessau-Mosigkau and Rodleben. The Dessau-Wörlitzer-Eisenbahn (railway) connects Dessau to Wörlitz, a town situated 15 km to the east, and the Wörlitzer Park. The starting point of this railway is the main station. This train also stops at the stations Dessau-Waldersee and Dessau-Adria.

1.2.3.2 Airfield

The airfield of Dessau is situated northwest of the town between the districts Kleinkühnau, Alten and Siedlung. A destination with a charter airplane is possible. The runway has a length of 1000 m. The Hugo Junkers Technical Museum is situated in the neighbourhood (directly east) of the airfield, which has the eastern end of the modern runway almost directly abutting the historical World War II Junkers factory airstrip's western end.

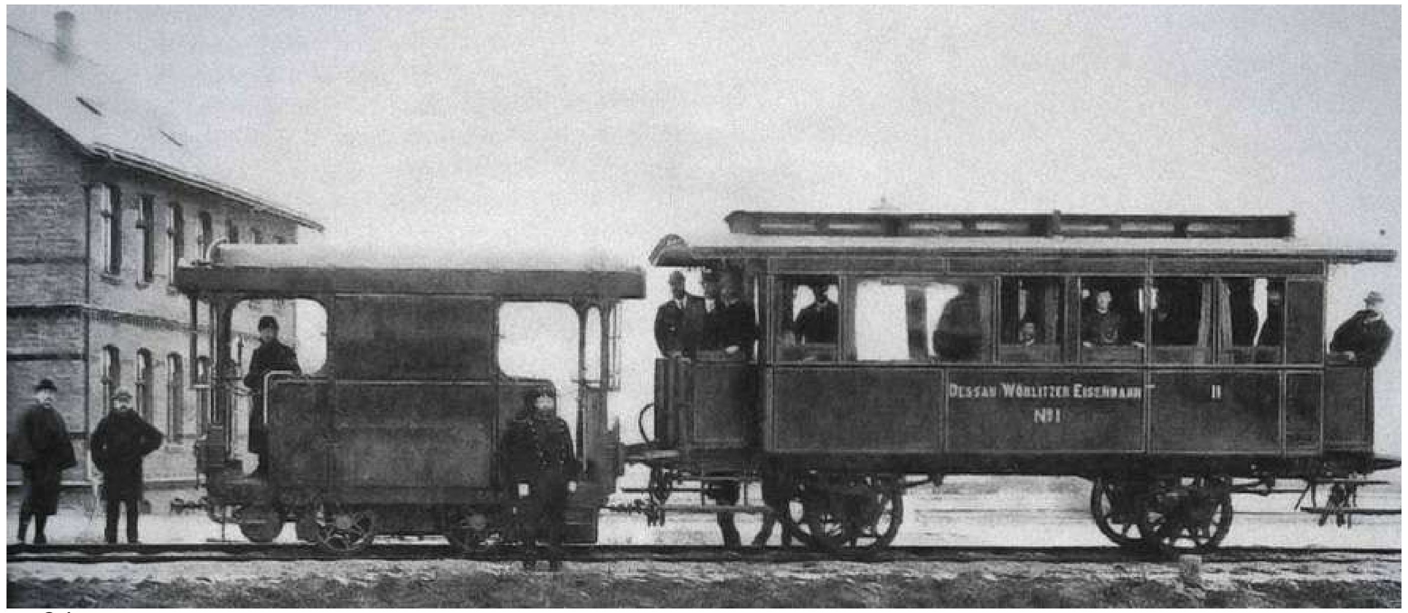
1.2.3.3 Roads

In 1938 the autobahn A9 (Munich-Berlin) was built southeast of the town area. The two exits to Dessau on the A9 are called "Dessau-Ost" and "Dessau-Süd". Dessau is also crossed by the "Bundesstrassen" (federal roads) B 184 and B 185.

1.2.3.4 Bikes

Dessau is located in the flat landscape of the Saxon Lowland. The bike roads have a length of about 146 km and connect all the parks and sights.

Figure 1.20 Dessau marktplat



1.2.3.5 Public transport

The Dessau tramway network has three lines and is supplemented by numerous bus lines. Dessau's public transport is operated by Dessauer Verkehrsgesellschaft [de] (DVG), which transports around 6 million people each year.

1.2.3.6 Water

Today the "Leopoldshafen" (harbour) is used for the annual international motorboat racing events. The "Wallwitzhafen" is used as a private sportboat harbour and the "Elbehafen" near the Grain House is used for cruisers. The next harbour for goods is situated in Rosslau.

Figure 1.21 Bridge of the A9 near Dessau crossing the river Elbe

Figure 1.22 The Dessau-Wörlitzer-Eisenbahn

1.2.4 Population

The City of Dessau-Roßlau, in German Dessau-Roßlau, with a population size of about 83'000 people is one of the medium cities of Germany, covering an area of 244 km2, The population density of the city is 335 people per 1 km2.

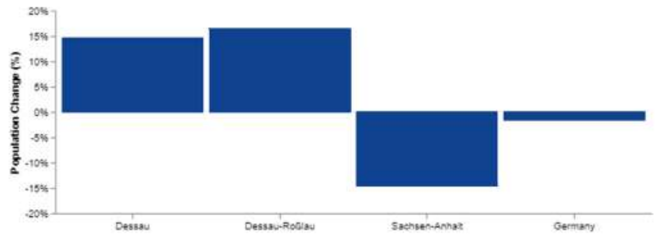


Figure 1.23 Population change

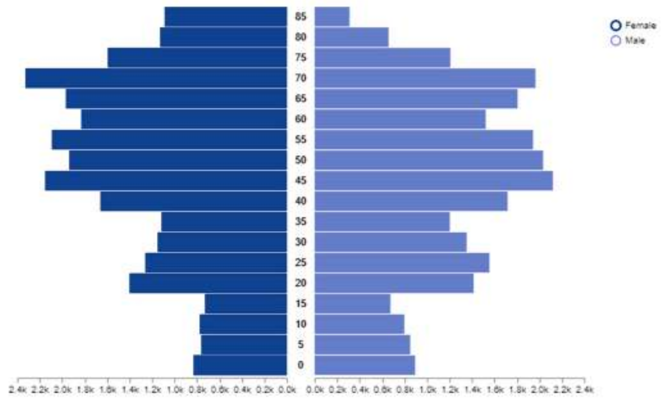


Figure 1.24 Dessau-Roßlau Population By Age and Gender

1.2.5 History of the Bauhaus

After putting his career as an architect on hold to fight the first world war between 1914 and 1918, Walter Gropius sensed the world needed a radical change, a change in which arts and architecture would play a fundamental role. His previous ideas of what architectures would be, did not quite make sense anymore. His new vision of architecture was one where all arts came together to re-imagine the material world, where craftmanship would reclaim its leading position in the production process and where artists would find a way to imprint their soul and essence in to rational, useful and beautiful objects that could be mass produced followin the ide- als of Fordism and Taylorism

It was 1919 in post-war Weimar, Germany. Walter Gropius had just founded the Bauhaus. One of the most radical evolutions architecture has ever experienced was about to begin. During the next 14 years the Bauhaus explored these ideals to its full extent. Never free from criticisms and political pressure, the school had to move from Weimar to Dessau in1925, and later to Berlin in 1930. Directors did not have it easy either, with Gropius being forced to resign in1928 and his successor Hannes Meyer being replaced by Ludwig Mies der Rohe after only two short years in office in 1930. Finally, in1933, the Bauhaus leadership, with Mies at the helm, decided to close the school under Nazi pressure.

At that time, with the Bauhaus dismantled and most of its staff spread all over the world to avoid the Nazi regime, one could easily think the whole project was a failure.

It might not have been that obvious to them back then, but looking back from where we stand today, we can clearly see how those years at the Bauhaus had an enormous impact in the architects that were to come, for decades. Even today, most of their ideas are still valid.If the Bauhaus was still active today, we believe it would welcome all these new variables with excitement,challengetheirownideasand adapt their solutions to this new reality.

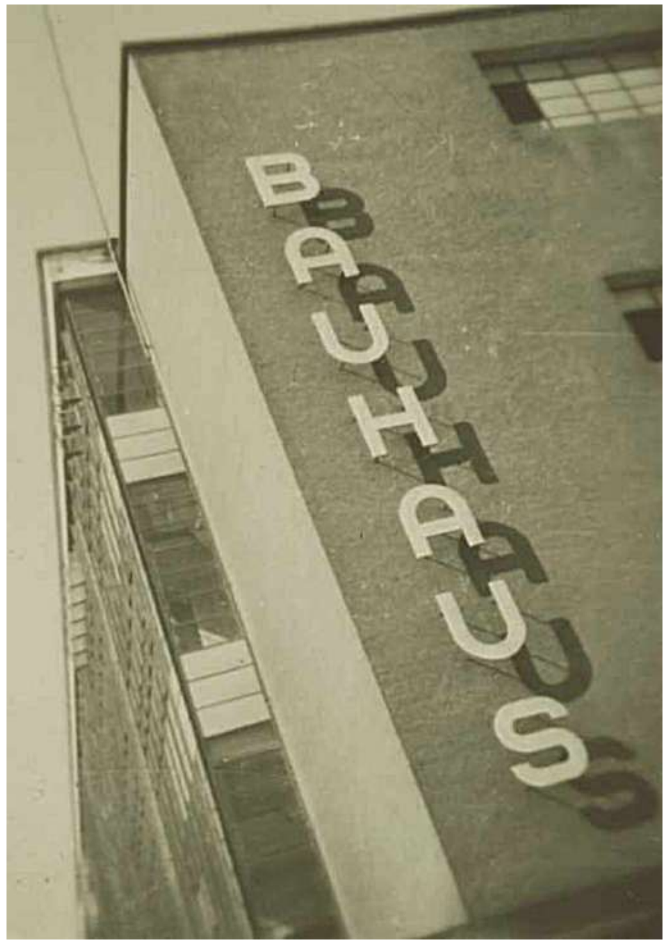


Figure 1.25 The bauhaus building

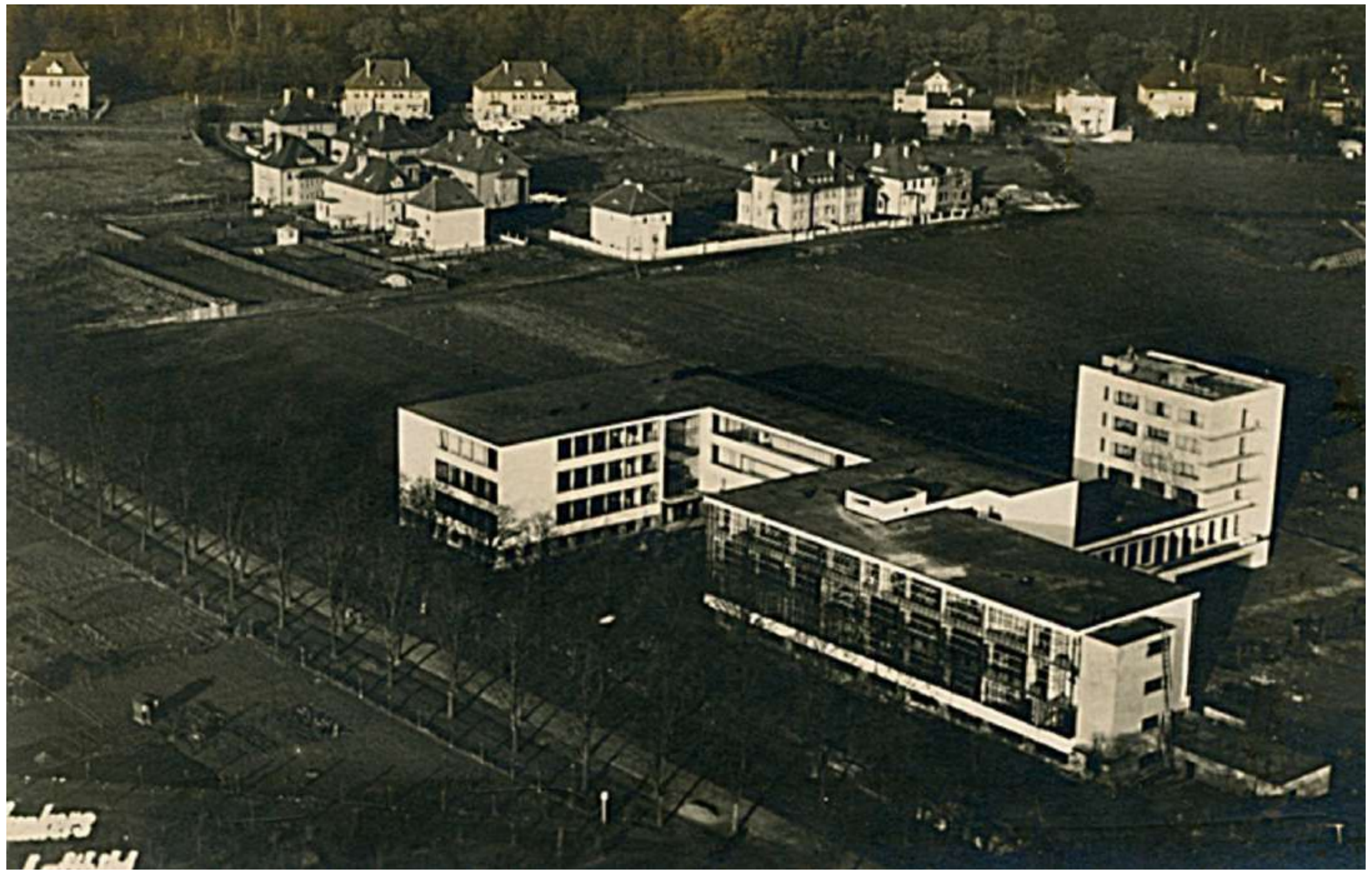
1.2.5.1 The Bauhaus

The early intention was for the Bauhaus to be a combined architecture school, crafts school, and academy of the arts. The school became famous for its approach to design, which attempted to unify the principles of mass production with individual artistic vision and strove to combine aesthetics with everyday function. The Bauhaus style later became one of the most influential currents in modern design, modernist architecture and art, design, and architectural education. The Bauhaus movement had a profound influence upon subsequent developments in art, architecture, graphic design, interior design, industrial design, and typography.

The Bauhaus Building is regarded as a seminal work of European modernism. In the building the principles of functionalism are combined with a remarkable architectonic quality for which then pioneering materials like glass and reinforced concrete were used. Built as an institute of higher education, the building is a manifestation of the Bauhaus' ideas. Beyond the architectonic significance with its radical new approaches, the site has a historically unique impact. Here, essential contributions were made to the revolutionary renewal of art, design and architecture in the twentieth century. The building is currently the seat of the Bauhaus Dessau Foundation.

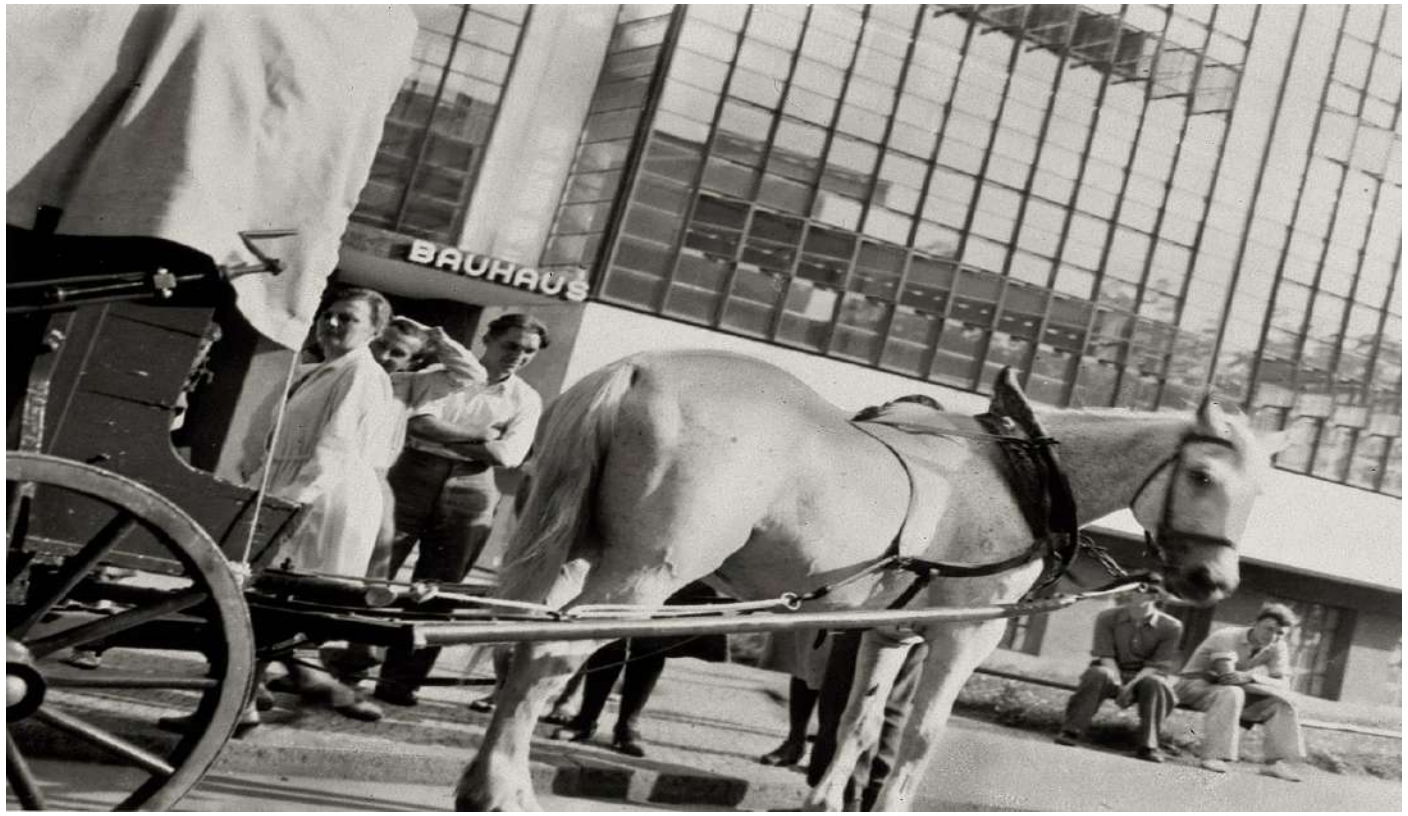
1.2.5.2 The Bauhaus and the city

In Dessau the Bauhaus was able to directly realise its desire to play a part in shaping modern society. Dessau in the 1920s is an up and coming industrial location, with Lord Mayor Fritz Hesse, engineer Hugo Junkers and state-appointed conservator Ludwig Grote as its driving forces. In 1924, when the Bauhaus was compelled to leave Weimar for political reasons, other cities such as Frankfurt am Main, Darmstadt and Magdeburg competed to host the Bauhaus school. Dessau then emerged victorious. The school of design, designed by Walter Gropius and financed by the city, opened in 1926. Some 1,500 guests from all over the world arrived in Dessau for the inauguration.



1.2.5.3 Shaping the modern age

The catastrophic experiences of WWI motivated the Bauhauslers to r adically rethink life, society and the everyday world. Rejecting traditional knowledge, with the Bauhaus they forged a school of design in which young people were to develop their artistic creativity by learning with and from materials so that they could give shape to the modern age and meet its many demands. In doing so, the focus was less on the individual work of art than on everyday objects which were to be manufactured in collaboration with industry.Out of this emerged the lion's share of the best-known products and buildings that continue to influence the image of the Bauhaus today, from Marcel Breuer's tubular steel furniture to Marianne Brandt's ashtray, from the Stahlhaus (Steel House) to the school's best-selling product, the Bauhaus wallpaper. The Bauhaus and its Sites in Weimar and Dessau have been included on the UNESCO World Heritage list since 1996.



1.2.5.4 The Bauhaus Movement

The school itself ignited an entire movement that would change design history. Modern furniture designers, graphic designers, architects, and painters still often work with principles developed at The Bauhaus. The Bauhaus movement affected so many disciplines due to Gropius' grand vision of bringing all arts and crafts together under one roof. It was founded upon the intention to unite art forms and create a Gesamtkunstwerk, meaning a "comprehensive artwork.

Figure 1.26 Poster for the Bauhausaustellung (1923)

Under the leadership of Gropius, the Bauhaus movement made no special distinction between the applied and fine arts. Painting, typography, architecture, textile design, furniture-making, theater design, stained glass, woodworking, metalworking, these all found a place there. The Bauhaus style of architecture featured rigid angles of glass, masonry and steel, together creating patterns and resulting in buildings that some historians characterize as looking as if no human had a hand in their creation. This austere aesthetics favored function and mass production, and were influential in the worldwide redesign of everyday buildings that did not hint at any class structure or hierarchy.

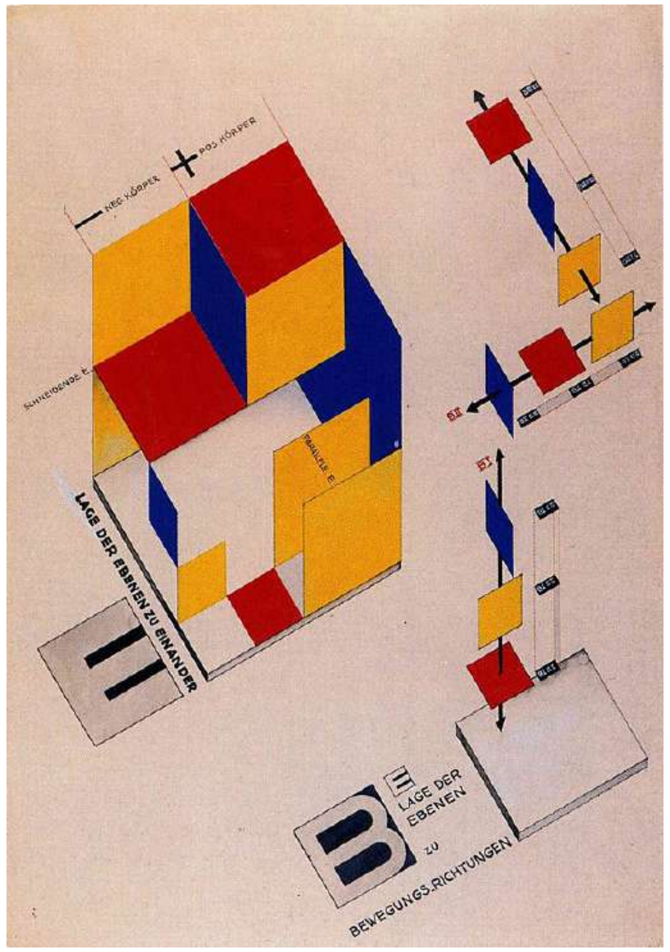


Figure 1.27 Mechanical stage design by Joost Schmidt

1.2.5.5 The Bauhaus Museum Dessau

In 2015, Barcelona based Addenda Architects won the international competition for the Bauhaus Museum Dessau, which received 830 entries. The most significant aspect of the pragmatic and austere design is the subtle reincarnation of the Bauhaus spirit, notably identified with Mies' famous oxymoron "less is more". Referring to some specific features of the Bauhaus school in Dessau – the glazed Curtain Wall, the two-story Bridge and the overall impression of transparency, lightness and plane surfaces the new museum will embody a manifesto of contemporary culture that could most accurately be described as "low resolution at its best".

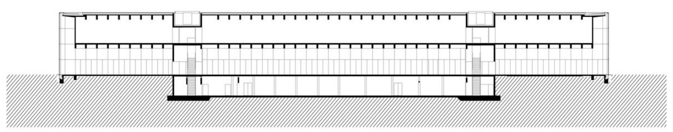


Figure 1.28 Facade of Bauhaus museum

Figure 1.29 Bauhaus museum

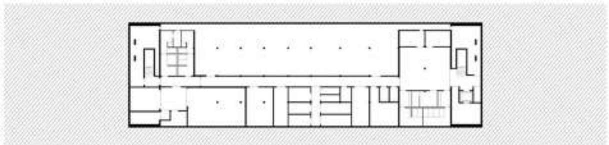


Figure 1.30 Plan of Bauhaus museum

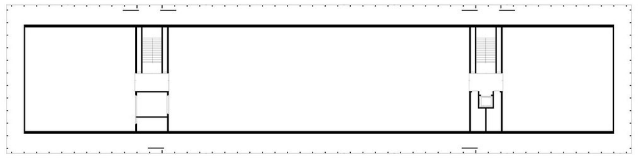


Figure 1.31 Interior of Bauhaus museum

The new Bauhaus Museum Dessau links an iconographic heritage ("Less is More") with a manifesto of contemporary culture ("The Age of Less"). The new Bauhaus Museum Dessau is a clear and simple volume located between city and Park, construction and nature. Its position, a little set back from the former historic building line, suggests a continuation with the city urban legacy. The building has an intermediate urban scale, between the size of a building and the size of a city block. Its position and dimension act as a city limit, which demarcates city and Park. Its four facades, oriented towards the four cardinal points, reflect the qualities of its position.

Thanks to its location and recognizable, quiet presence, the Bauhaus Museum will play a key role in Dessau's urban identity as an instrument to express activity and productivity, creativity and social interaction.

CHAPTER 02
ANALYSIS

2.1 URBAN ANALYSIS

2.1.1 Location

Dessau is a town located in Germany in the Bundesland (Federal State) of Saxony-Anhaltis with the area of 182.81 km2. It is situated on a floodplain where the Mulde flows into the Elbe. The south of Dessau touches a well-wooded area called Mosigkauer Heide. The highest elevation is a 110 m high former rubbish dump called Scherbelberg in the southwest of Dessau. Dessau is surrounded by numerous parks and palaces that make it one of the greenest towns in Germany.

2.1.2 Site

This hypothetical project is to be designed on a very real site in Dessau. Right between the iconic Bauhaus building by Walter Gropius and the new Bauhaus Museum. The site is a triangular piece of land of approximately 250m on its longest side and 180m and 200m on the other two, which can be considered flat. It is delimited by Bitterfelder Street on one side, Elisabethstraβe on another and the train tracks on the third. The Bauhaus museum is located approximately 600m to the east and the Gropius Bauhaus building another 600m to the north-west with the houses for the masters of the Bauhaus just a bit further in that same direction.

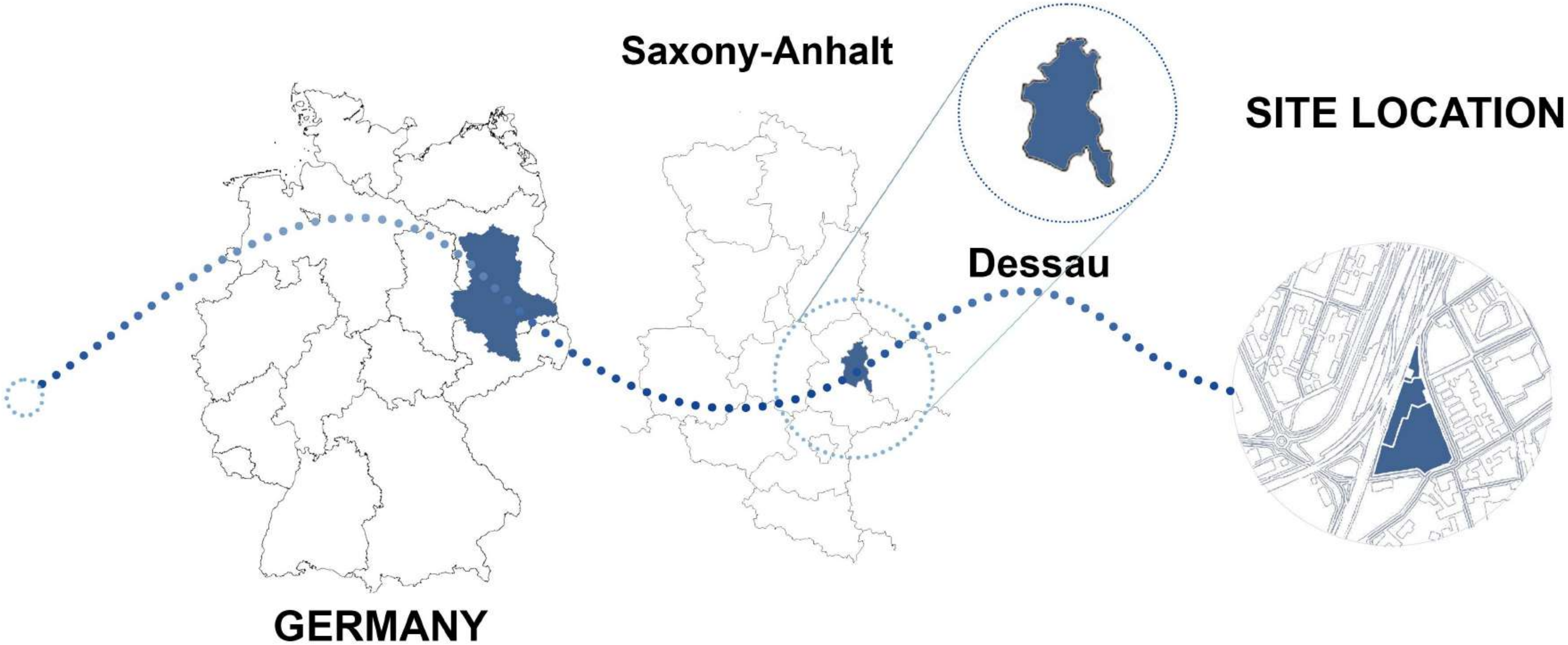


Figure 2.1 Collage of target location

2.1.3 Accessibility

2.1.4 Function

Bar, Restaurant

Hotel

Sport activities

School, educational center

Theater, concert hall

Hospital

Mall, supermarket

Green areas

Railway

Site

2.2 CLIMATE ANALYSIS

Germany is entirely located in the temperate climatic zone. In Dessau, the summers are comfortable and partly cloudy and the winters are long, very cold, snowy, windy, and mostly cloudy. Over the course of the year, the t emperature typically varies from -1.6°C to 25°C and is rarely below -10°C or above 31°C.

The warm season lasts for 3.3 months, from May 30 to September 9, with an average daily high temperature above 20.5°C. The hottest month of the year in Dessau is July, with an average high of 24.5°C and low of 14°C.

The cold season lasts for 3.7 months, from November 17 to March 9, with an average daily high temperature below 7°C. The coldest month of the year in Dessau is January, with an average low of -1.6°C and high of 3.5°C.

The climate analysis has been performed using the climate data from the leipzig halle, located 45km away from the Dessau, and at a very similar altitude.

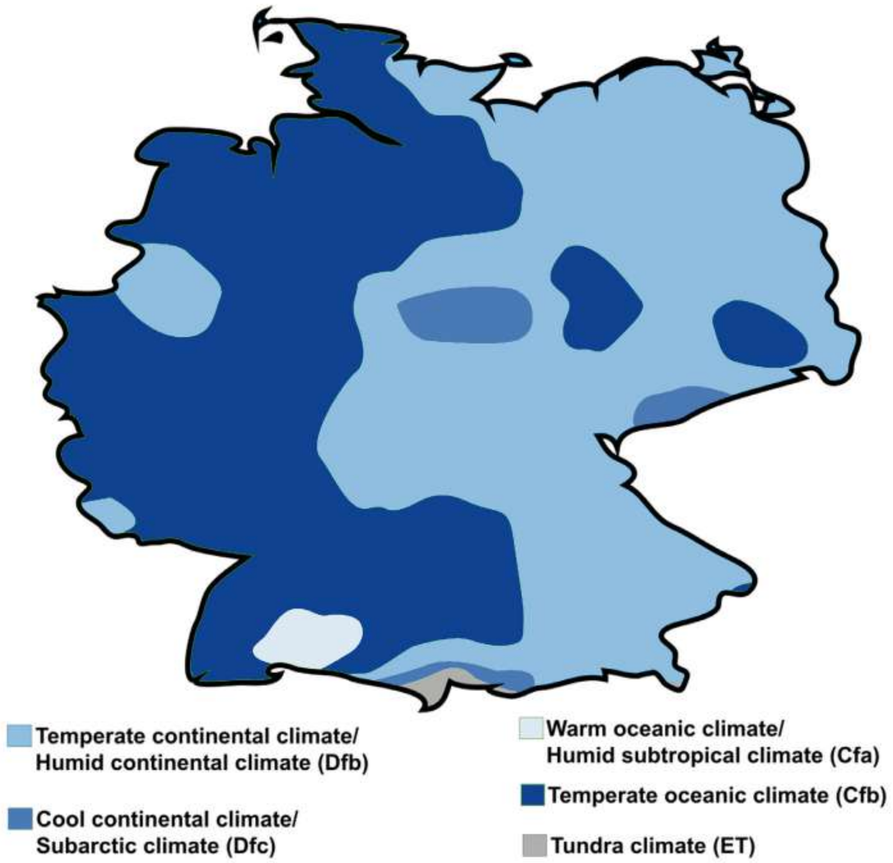
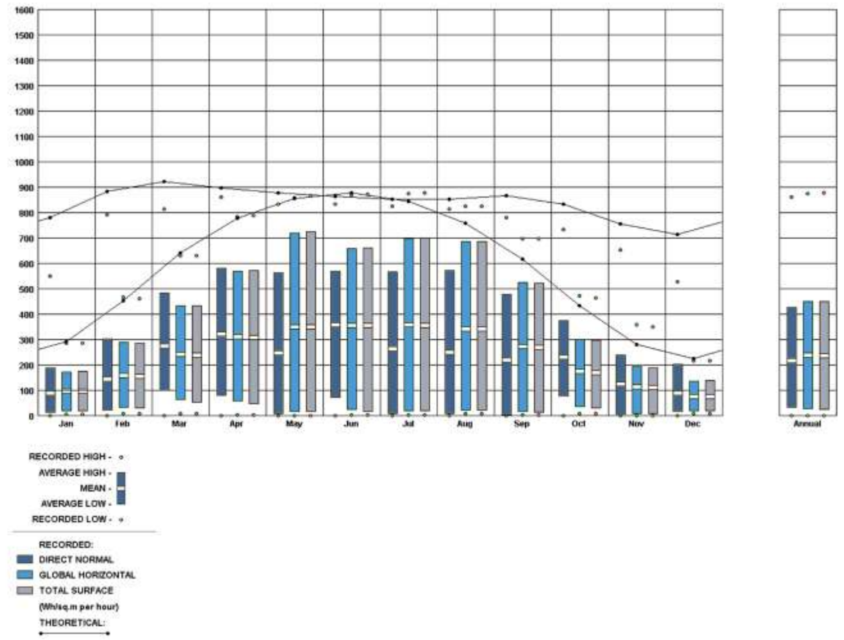


Figure 2.2 Climate classification

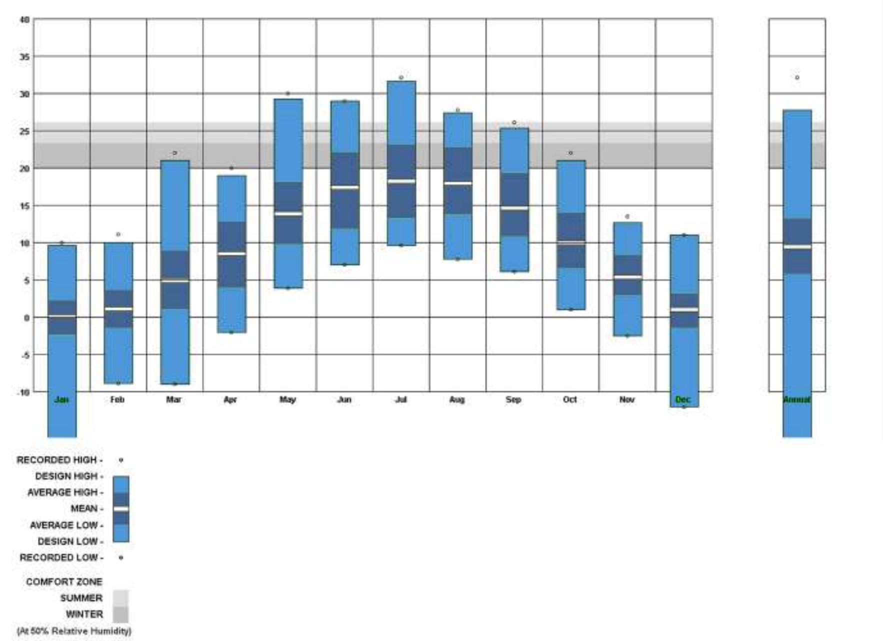
2.2.1 Radiation Range

This chart could be very useful in our further steps of our design to investigate the possibility of using solar photovoltaic panels or solar photovoltaic thermal systems according to the total surfaces and their angles and average energy can receive by them.



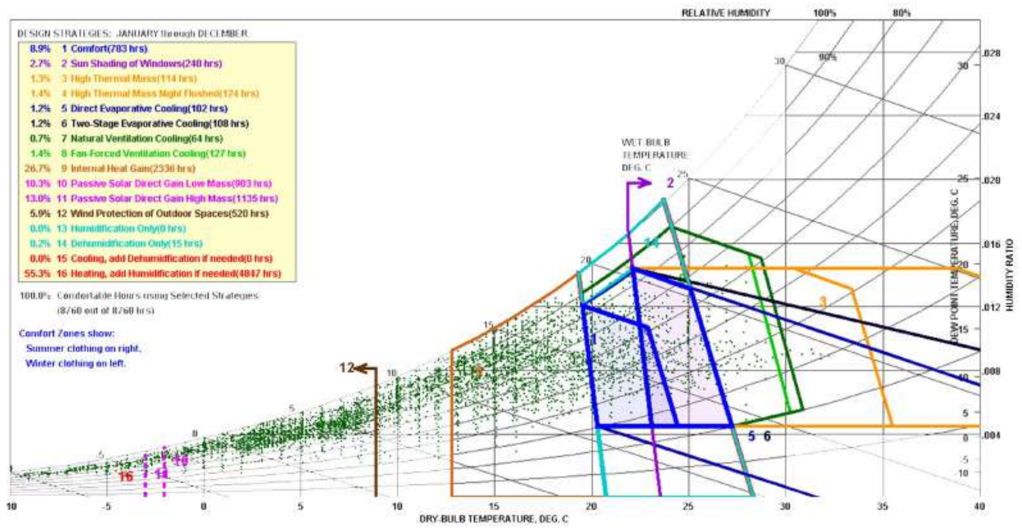
2.2.2 Temperature range

As we can observe from the chart the majority of the hours are below the comfort zone with a few hours above comfort zone.



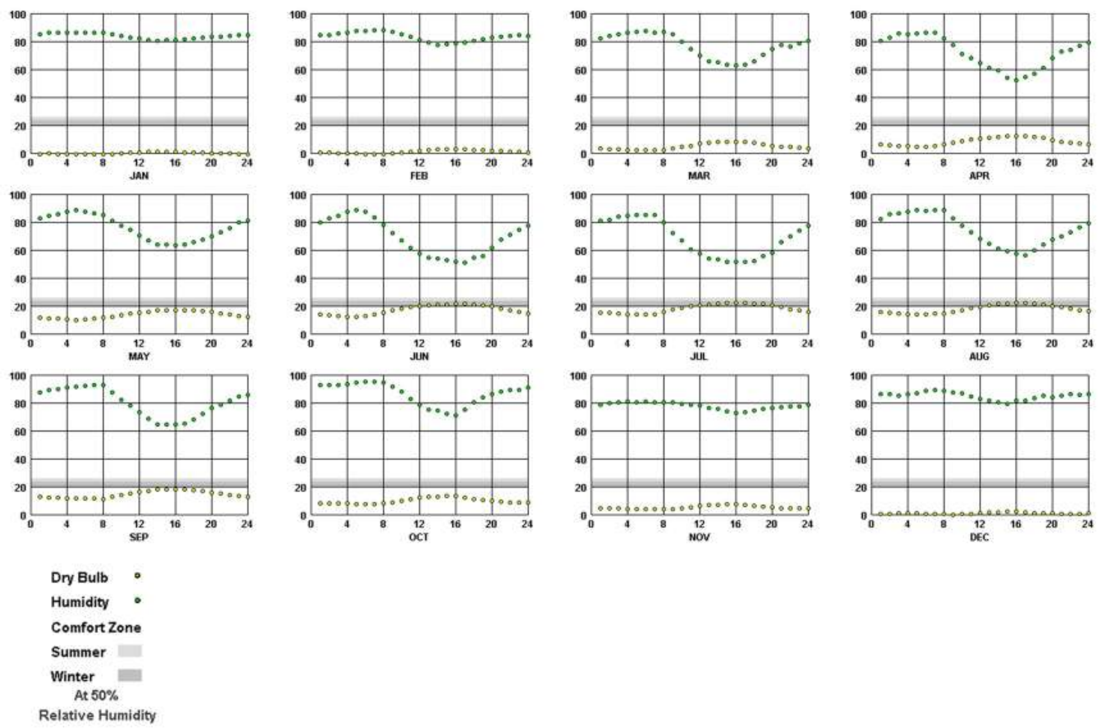
2.2.3 Psychrometric Chart

psychrometric charts present physical and thermal properties of moist air in a graphical form. They can be very helpful in troubleshooting and finding solutions to greenhouse or livestock building environmental problems. Only 9% of the yeat we are in comfort zone.



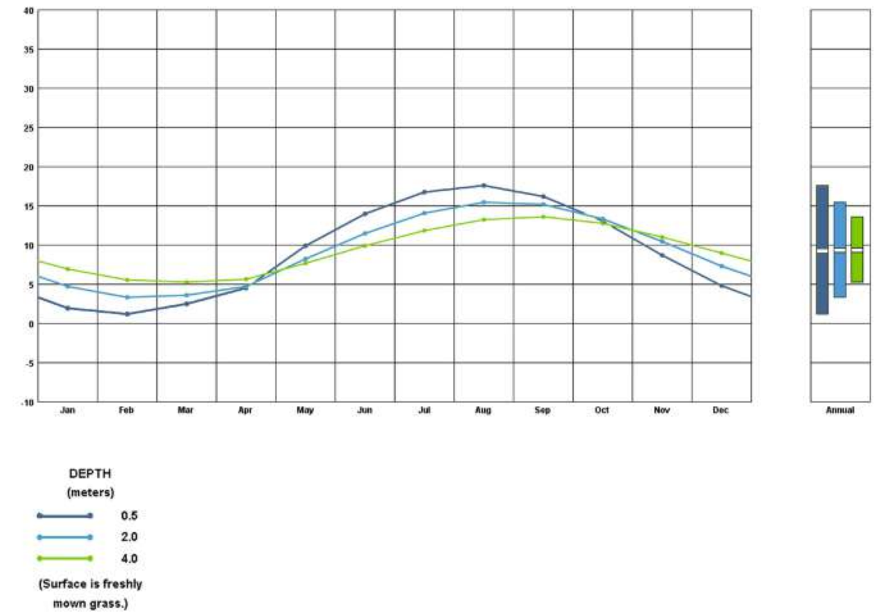
2.2.4 Dry Bulb Vs. RH

The reverse relation between Dry Bulb and RH shows us as we have higher T, we would have lower RH and reverse.



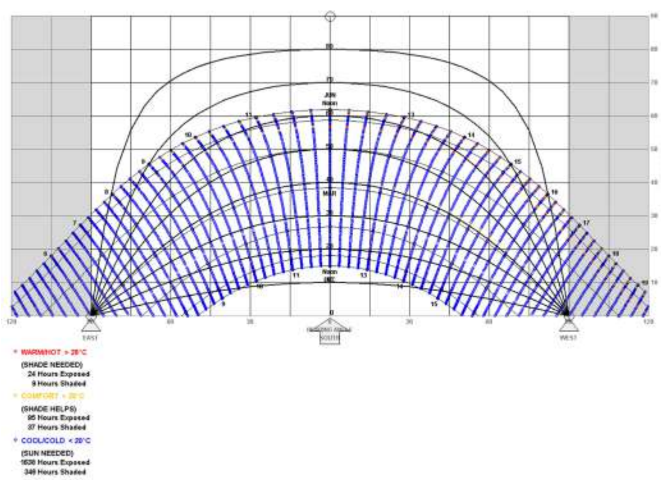
2.2.5 Ground temperature

This chart also could be very helpful if we going to consider basements or ground heat pump exchangers and as we can see in deeper part of the ground the curve is more constant and has less variety.

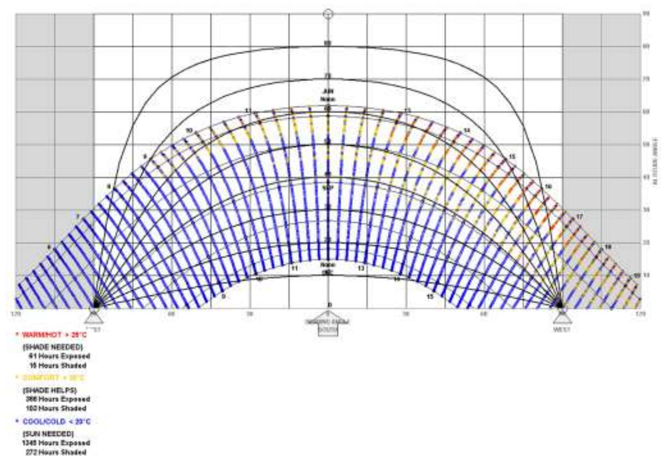


2.2.6 Sun Shading Chart

As we can observe from the chart in the winter, we are almost below the comfort zone and from June we have some hours above the comfort zone.



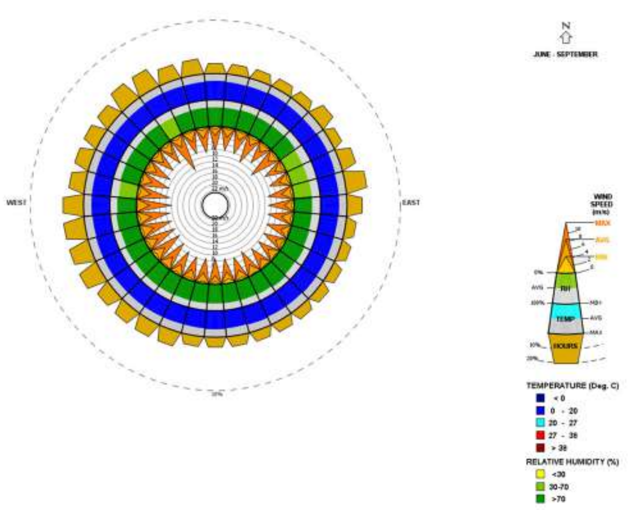
Wintwer Spring
21Dec-21Jun



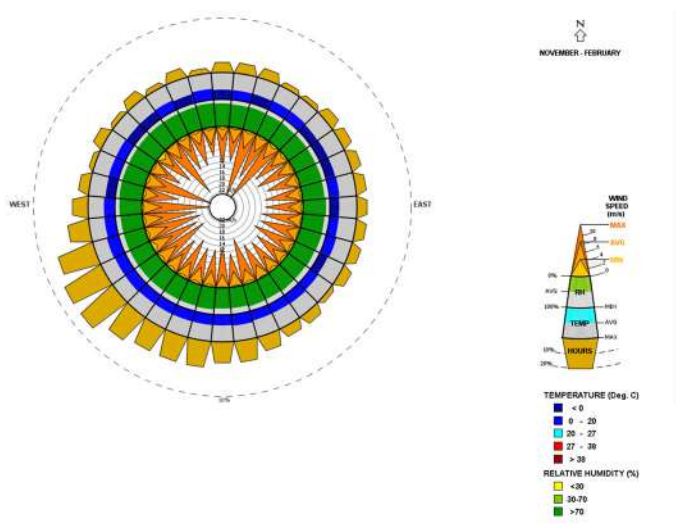
Summer Fall
21Jun-21Dec

2.2.7 Wind wheel

Wind weels are composed to state the direction, frequency and the wind speed in the area. As we can see the maximum wind speed is 20m/s and the dominant direction is from the west.



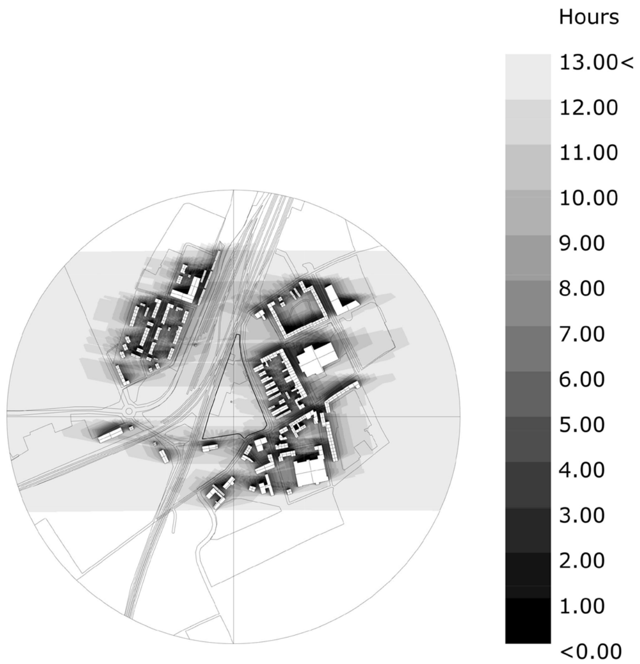
Summer



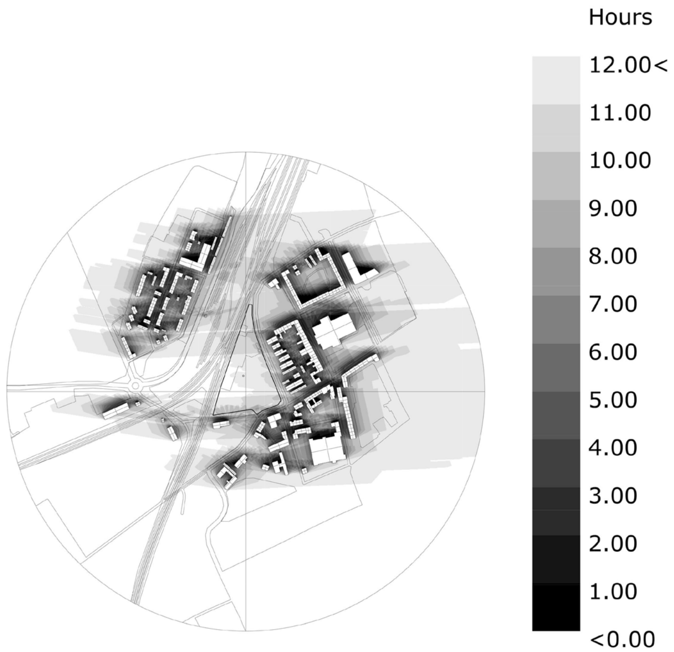
Winter

2.2.8 Shadow

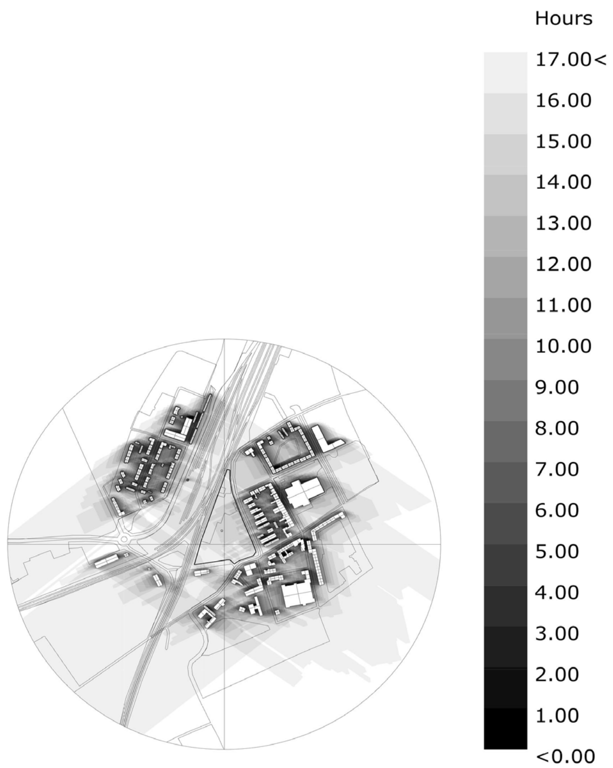
The shadow analysis for the main and surrounding buildings.



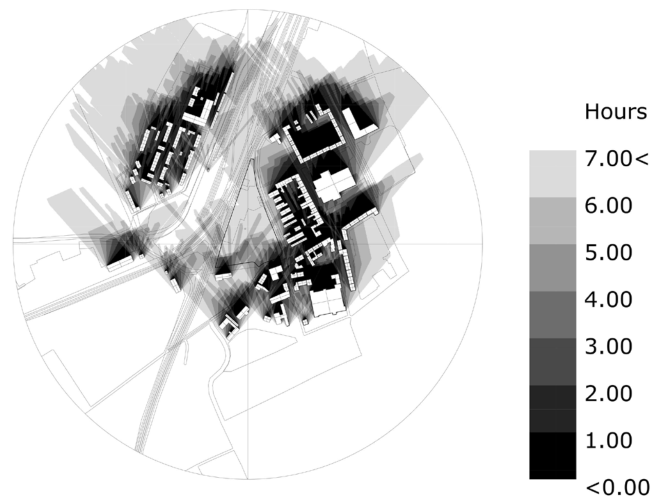
autumn 21 september



Spring 21 March



summer 21 june



Winter 21 december

CHAPTER 03
ARCHITECTURAL DESIGN

3.1 CASE STUDIES

3.1.1 Bauhaus School

Architects: Walter Gropius

Location: Dessau,Germany

Year: 1926

Area: 23,280 m2

The architecture of school was based on the relationship between art and industry which informed the use of modern materials and industrial processes across its various creative subjects. The campus features an asymmetric pinwheel plan, with dedicated areas for teaching, an auditorium and offices, and housing for students and faculty distributed throughout three wings connected by bridges.

The extensive facilities in the plans of the Bauhaus at Dessau include spaces for teaching, housing for students and faculty members, an auditorium and offices, which were fused together in a pinwheel configuration. From the aerial view, this layout hints at the form of airplane propellers, which were largely manufactured in the surrounding areas of Dessau.

The building is comprised of three wings all connected by bridges. The school and workshop spaces are associated through a large two-story bridge, which creates the roof of the administration located on the underside of the bridge. The housing units and school building are connected through a wing to create easy access to the assembly hall and dining rooms. The educational wing contains administration and classrooms, staff room, library, physics laboratory, model rooms, fully finished basement, raised ground-floor and two upper floors.

Technology Part

As a practiced architect, Gropius was interested in including structural and technological advancements as he designed this revolutionary school for architecture and design students. Among the innovative methods used in its construction were a framework made from reinforced concrete and brick a skeleton of reinforced concrete and brickwork, mushroom-like ceilings of the lower level, large expanses of glazing, and flat roofs covered with asphalt tiles that could be walked on

The Bauhaus Dessau's most striking features are its glass curtain walls, which wrap around corners and provide views of the building's interiors, and its supporting structure. The huge curtain window facade of the workshop building became an integral part of the building's design. Hoping to create transparency, the wall emphasized the 'mechanical' and open spatial nature of the new architecture. These vast windows enabled sunlight to pour in throughout the day, although creating a negative effect on warmer summer days. In order to preserve the curtain wall as one expanse, the load bearing columns were recessed back from the main walls.

3.1.2 Mälardalen University Campus

Architects: 3XNInterior Designers: AIX Arkitekter

Location: Eskilstuna,Sweden

Year: 2020

Area: 20000 m²

The new campus's main goal is to create a feeling of belonging between students and staff and to become a strong symbol for knowledge in the city. Effectivity and shared use were introduced in the disposition of the spaces. Eskilstuna is an old industrial city with many characteristic brick buildings. Brick and water. Keywords such as warmth, variety, and human-scale were the common thread through the design.

In terms of color, the concept has been based on the industrial façade of the industrial city, from the darkest iron oxide red to the lightest pale pink in the new areas. The workplace must encourage transparency and creativity where there is room for teamwork and individually concentrated work. On the entrance level, there is a library for publications, a place for exhibitions as well as study places and rooms for teamwork.

Technology Part

Wood Cladding - Linear Module is used in the interior part of the building. It has a very high Acoustic properties, and it is non-flammable, sustainable, pre-assembled, solid wood, customizable finish and spacing and very flexible in terms of size.

Acoustic Nano Panels is also used in this project.it has invisible micro-perforations giving it unique acoustic properties. When clad with Gustafs Nano panels, a room reduces not only the disturbing noise of conversations and other human sounds, it also absorbs the noise of machines and other mechanical equipment and thereby reducing the reverberation time to a very comfortable level.

3.1.3 Echo Education Building

Architects: UNStudio

Location: Delft,Netherlands

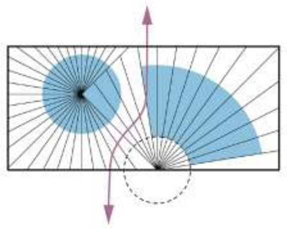
Year: Under construction

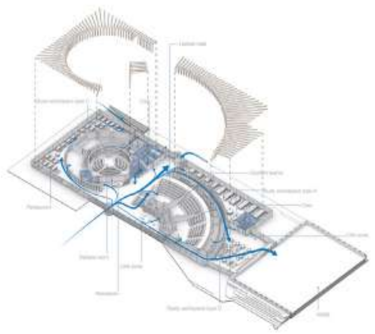
Area: 8,844 m²

Designed according to the new and future needs of the lecturers and students, Echo puts in place space for lectures and tutorials, group work, project-based teaching, debates, and self-study, for around 1,700 students. A centrally positioned grand stair facilitates and promotes physical movement through the building.

Designed to be a future-proof and active campus, Echo not only connects with the surrounding public space, but it also defines it. The ground floor, turned into a covered flexible public square holds two sculptural volumes that direct the flow of people. With a robust yet sleek exterior, the structure opens up to the activities taking place inside to the surroundings.

The Echo building teaches by example. In this highly compact building, the use of space is maximized, while bringing students from different disciplines in closer contact. Not only can they condense their learning experience and learn from each other, but they can also learn from the building itself.

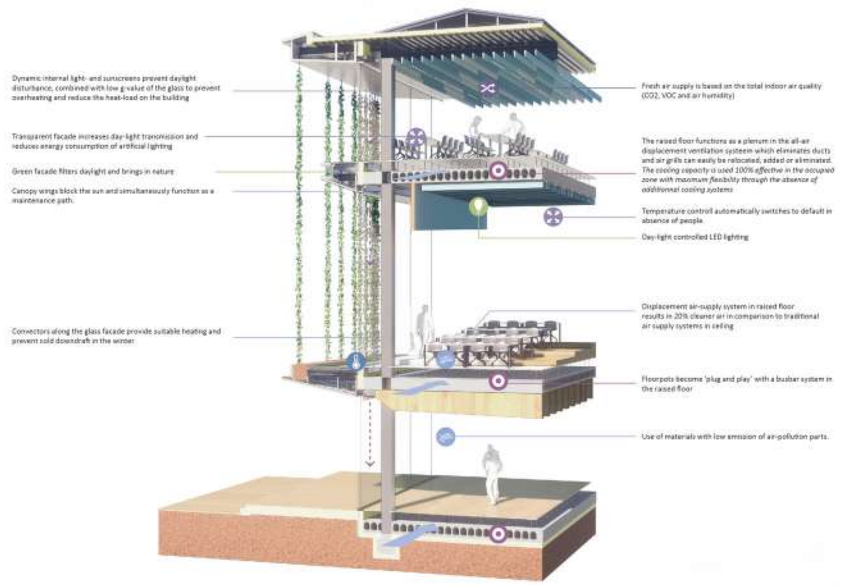


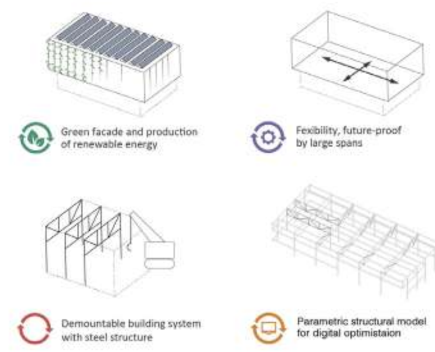


Technology Part

The design of Echo fulfills the progressive sustainability ambitions of the TU Delft. Transparency was essential to the design of Echo. It not only ensures maximum daylight inside the building, but also creates a visual connection to the wider campus and to surrounding nature.

The continuous glass facades are interrupted horizontally by deep aluminum awnings that play an important role in the composition of the facade and keep out excess solar heat.





In order to prevent excess sunlight penetration, a dynamic light barrier is used which provides indoor sun protection. Overheating of the building is prevented by a combination of sun protection and the low solar penetration factor of the glass.

In addition to floors that integrate ventilation and electrical facilities in a flexible and adaptable way, a building is created that not only has the flexibility to be adapted to daily use, but also to different, future programmatic interpretations.

1200 solar panels, smart installations, good insulation and a heat and cold storage system ensure that Echo will be able to provide more energy than it requires for its daily operations.

3.1.4 Columbia Business School

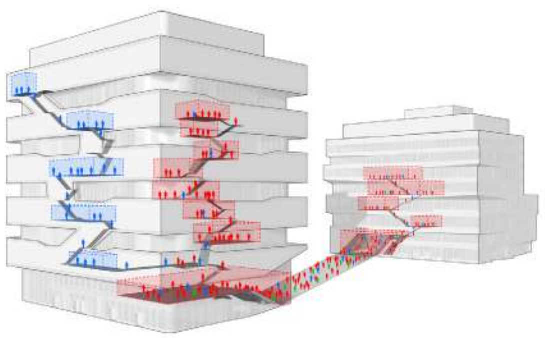
Architects: Diller Scofidio + Renfro, FXCollaborative

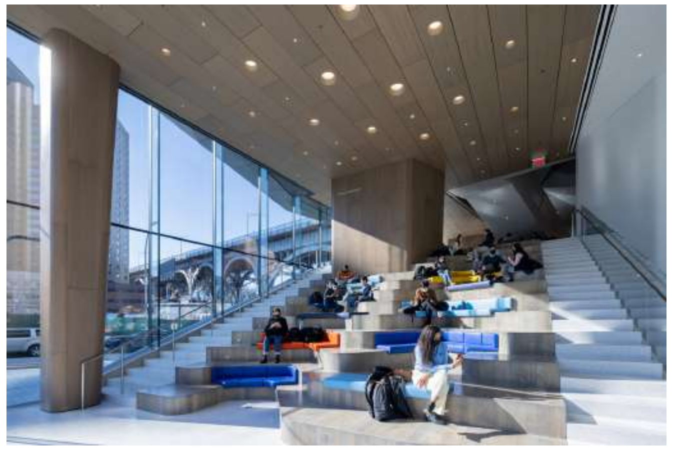
Location: New York, United States

Year: 2022

Area: 42,900 m²

Columbia Business School reflect the fast-paced, high-tech, and highly social character of the business in the 21st century. The resultant layer-cake design is expressed in each building's façade with systems tailored to the interior program. The school's internal spaces are organized around intersecting networks of circulation and collaborative learning environments that extend up vertically through each building, linking spaces of teaching, socializing, and studying, to create a continuous space of learning and interaction that remains vibrant 24 hours a day.



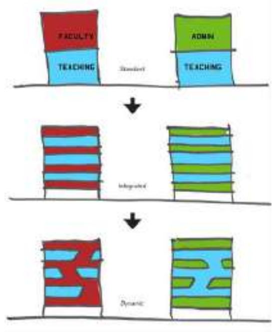


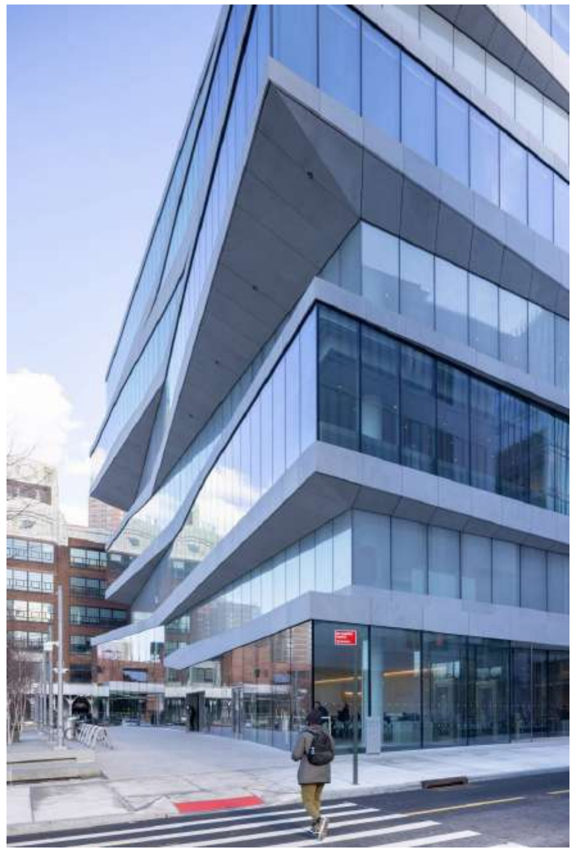
Engagement with the city and surrounding is a fundamental aspect of the new Columbia Business School's design. The school has a strong connection to the urban fabric of the neighborhood and the mid-block pedestrian axis of the Manhattanville master plan.

Every classroom provides a view of the city and landscape. A 40,000 square-foot public park and new retail spaces including a café featuring local products also connect Columbia Business School more closely with the surrounding neighborhood.

Technology Part

Façade: The building's skin expresses the shuffling of students, faculty, and administrative spaces. Student floors, the Network, and ground floor spaces utilize transparent glass exteriors inset from the edge of the floor plate, while Faculty floors utilize fritted glass. Each building façade features a custom curtainwall system and is regularized based on the geometry of the exterior building form. Geffen Hall's glass envelope is treated with a gradient from opaque to transparent, each panel having a bespoke and carefully calculated frit pattern.





Sustainability: Columbia Business School expects to achieve LEED v3 Gold certification. Knowing that students and faculty will spend long hours in the building, a particular emphasis has been placed on the quality of the indoor environment specifically air, light, thermal comfort, and materials.

The use of low-VOC materials, flushout before occupancy, increased ventilation rates, and outdoor air monitoring ensures high indoor air quality. Materials were specified with high percentages of recycled content from regional sources. Most of the wood was sourced from sustainably managed forests.

3.1.5 Polak Building

Architects: Paul de Ruiter Architects

Location: Rotterdam, Netherlands

Year: 2015

Area: 8400 m²

They approached was to design both the interior and exterior of the new university building. Students and visitors can freely to walk from the adjacent plaza straight into the atrium of the building. In this lively part of the building, there are opportunities to visit the hairdresser, go shopping or share experiences and ideas with each other in one of the cafés. A large platform staircase then leads to the heart of the atrium on the first floor,

where the teaching building begins.

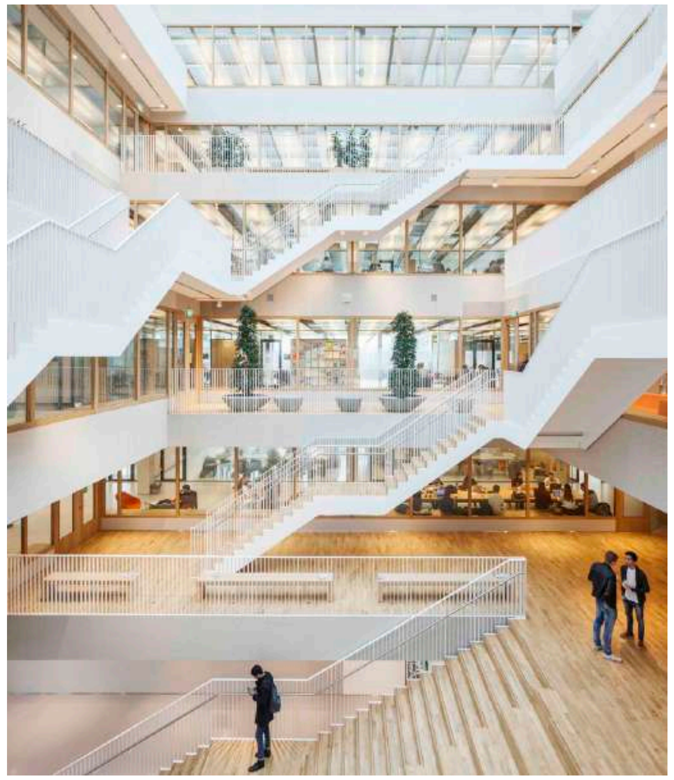
The glass top of the atrium has been designed to prevent sunlight entering directly. This enables users to gain maximum benefit from the daylight whilst keeping the temperature pleasantly cool.

The outfitting is playful and unconventional. The strip of wood separating the meeting area near the atrium from the walking routes is multifunctional. Along its length, this structure transitions from being part of the floor, to convenient seating, and even into functional work desks. Thanks to all of the wood and the bright colors encountered everywhere, the interior has a pure and warm look and feel. Of course, only natural and sustainable materials have been used here too.

Technology Part

The aim was to design a transparent façade that enhances the relationship between inside and out. In order to allow daylight to enter whilst preventing excessive heat from the sun, we designed special blinds. The blinds vary in depth depending on the wind direction, helping the glass to protect against direct sunlight and shade effects.

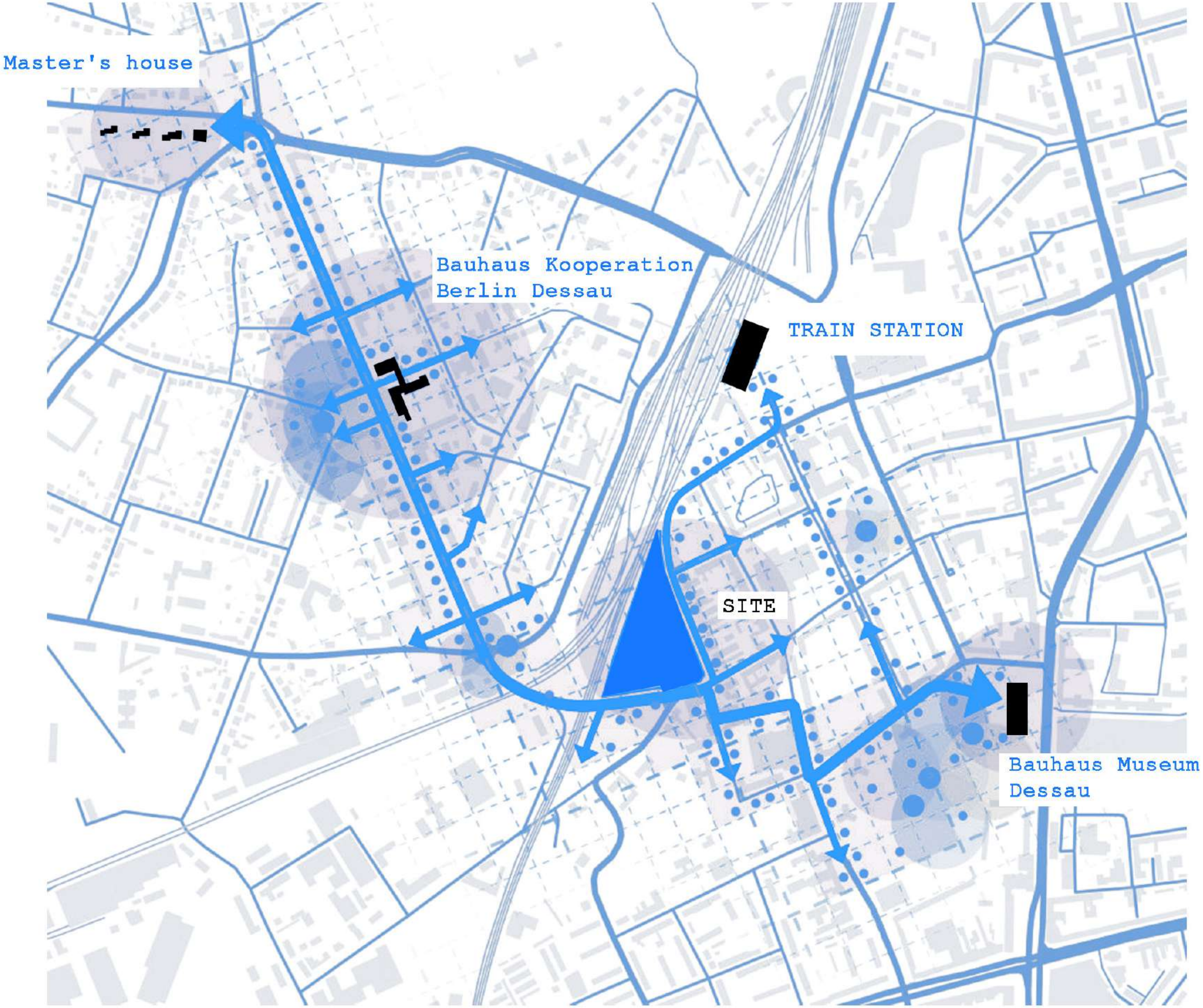
The vision is: natural where possible and mechanical where necessary. With a sustainable climate control system and optimal insulation, the university building is energy-efficient. By carefully making use of the flow of air, natural ventilation is created for the entire building. This even applies to the daylight, making artificial lighting redundant. It is also incorporated numerous sustainable technologies, including aquifer thermal energy storage in the ground and energy recycling.



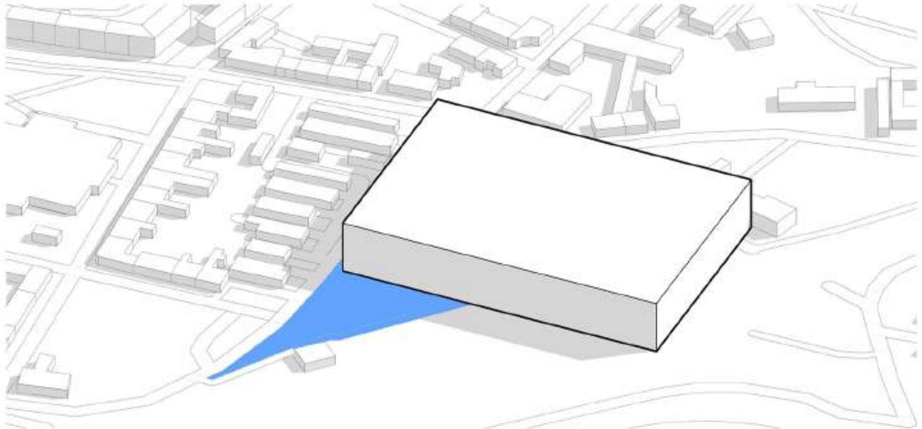
The design provided the aluminum multidisciplinary façade of Polak Building and created a slender aluminum profiling, whilst maintaining both the function of the aluminum blinds to protect the glass against direct sunlight and the function of the blinds to naturally ventilate the building.

3.2 URBAN CONCEPT

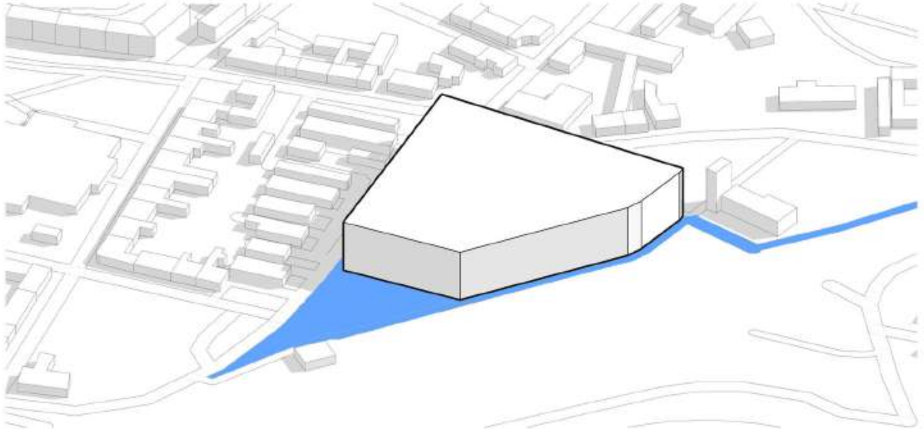
Our site has a distinctive location because it its located between the Bauhaus school and Bauhaus museum and we have railway which is a strong separation barrier between these two important building. We design a bridge not only with the purpose of connecting these two building but also for increasing the mobility in this area. People also can use this bridge for passingfromthestreet.We designed many bike ramps for keeping the connection.



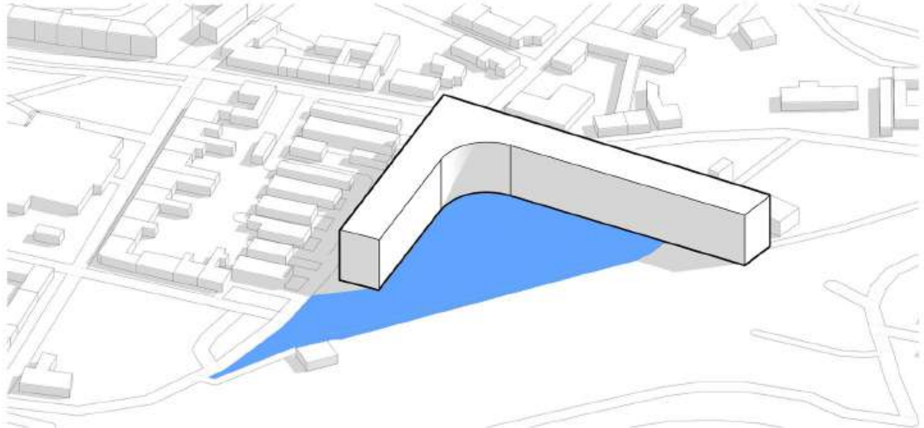
3.4 FORM FINDING



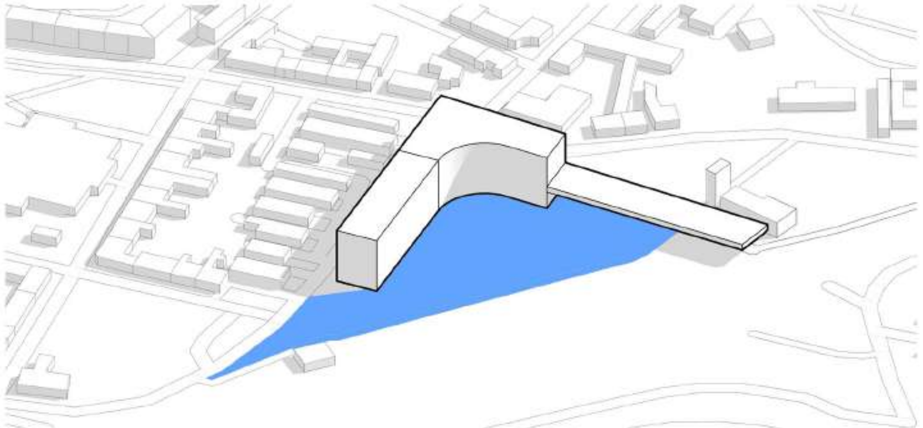
1.Volume covers the whole site



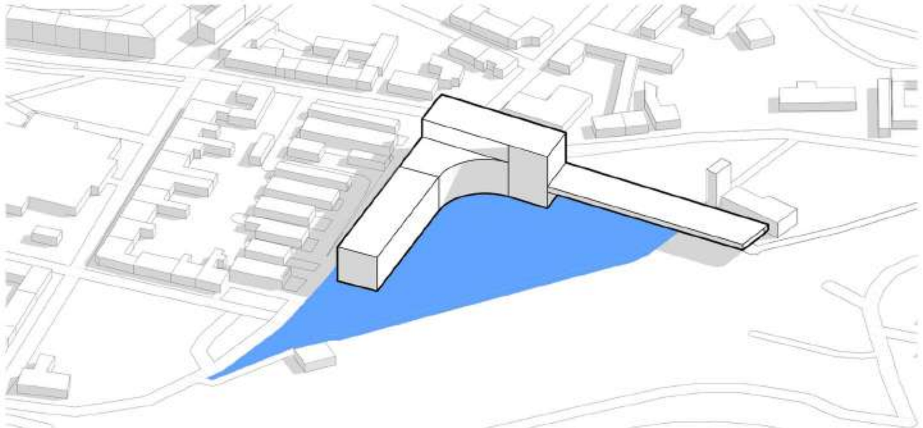
2. Cutting the volume by considering the constraints



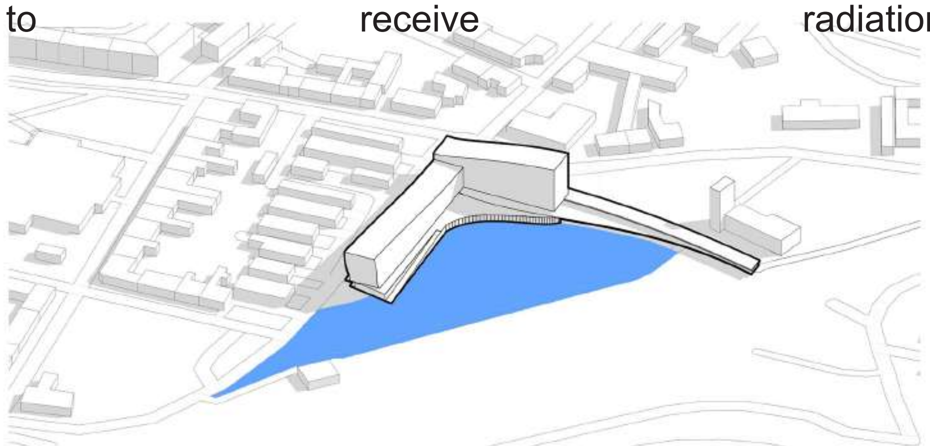
3. Apply idea in order to create roofs for outdoor activities and enabling more parts to receive radiation



4.Desing a bridge for Connecting the building with the urban for increasing the mobility



5.Modyfing the volume for enhancing roof activities

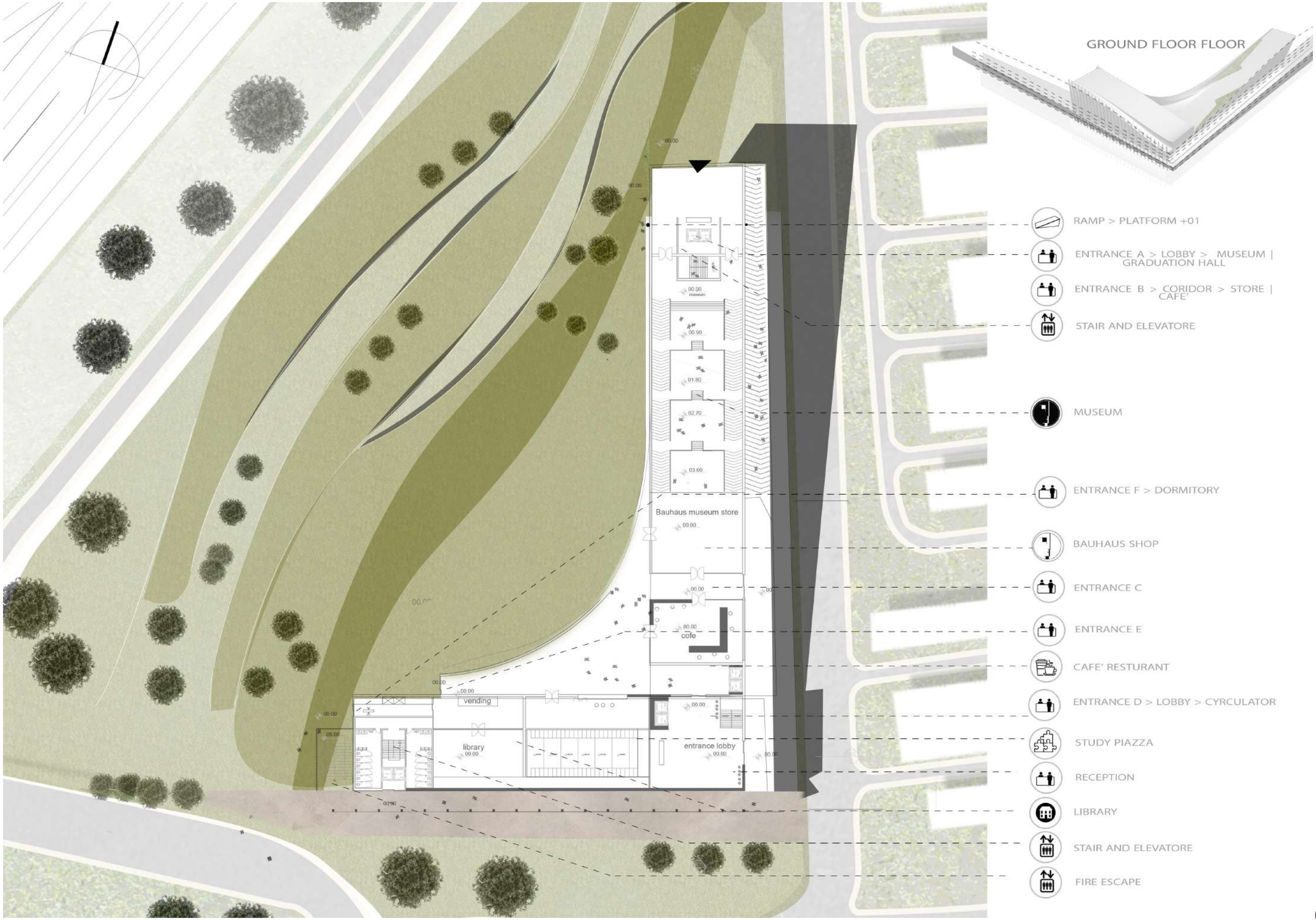


6.Matching the volume with mobilty access

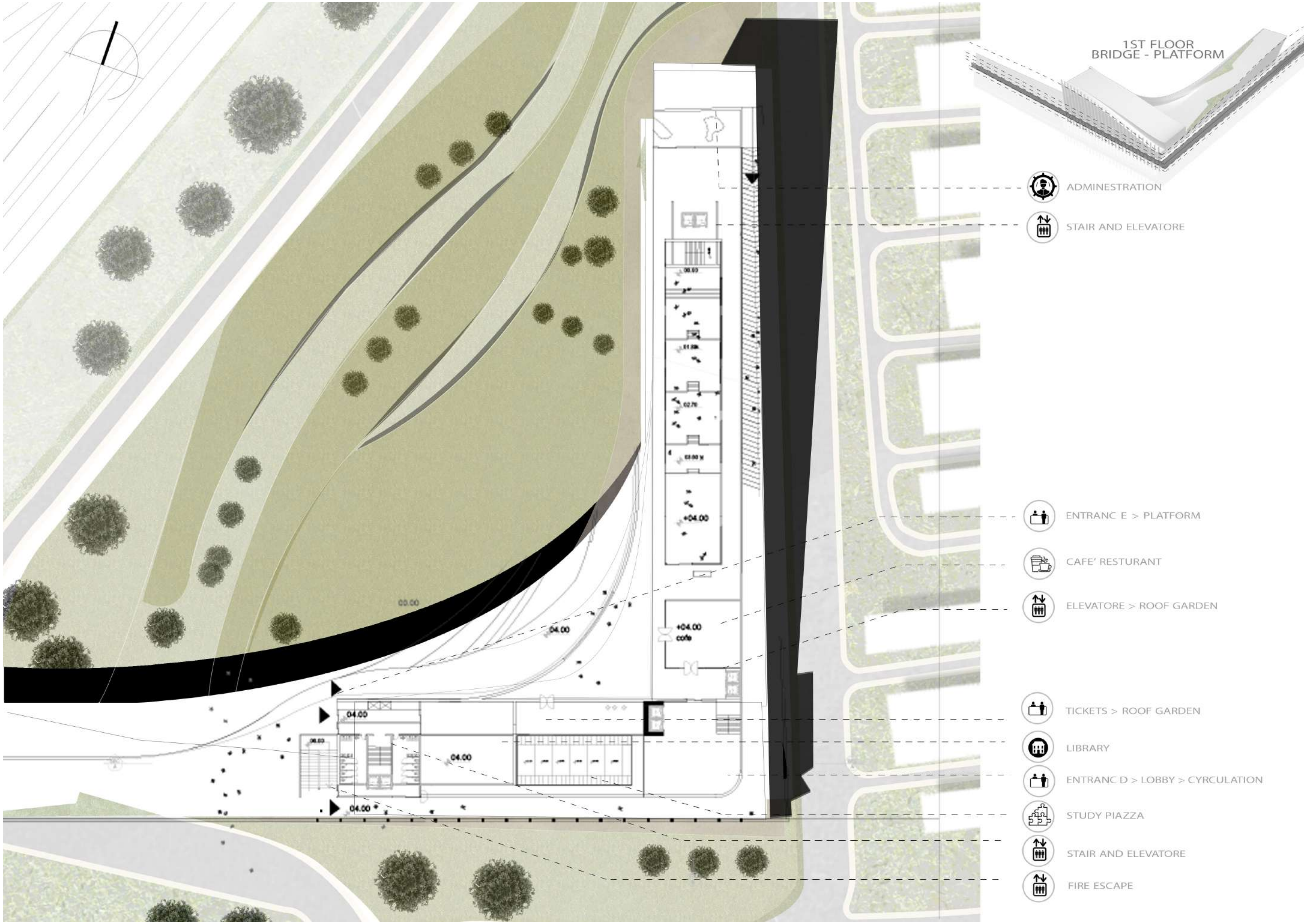
3.5 MASTER PLAN

3.6 PLANS

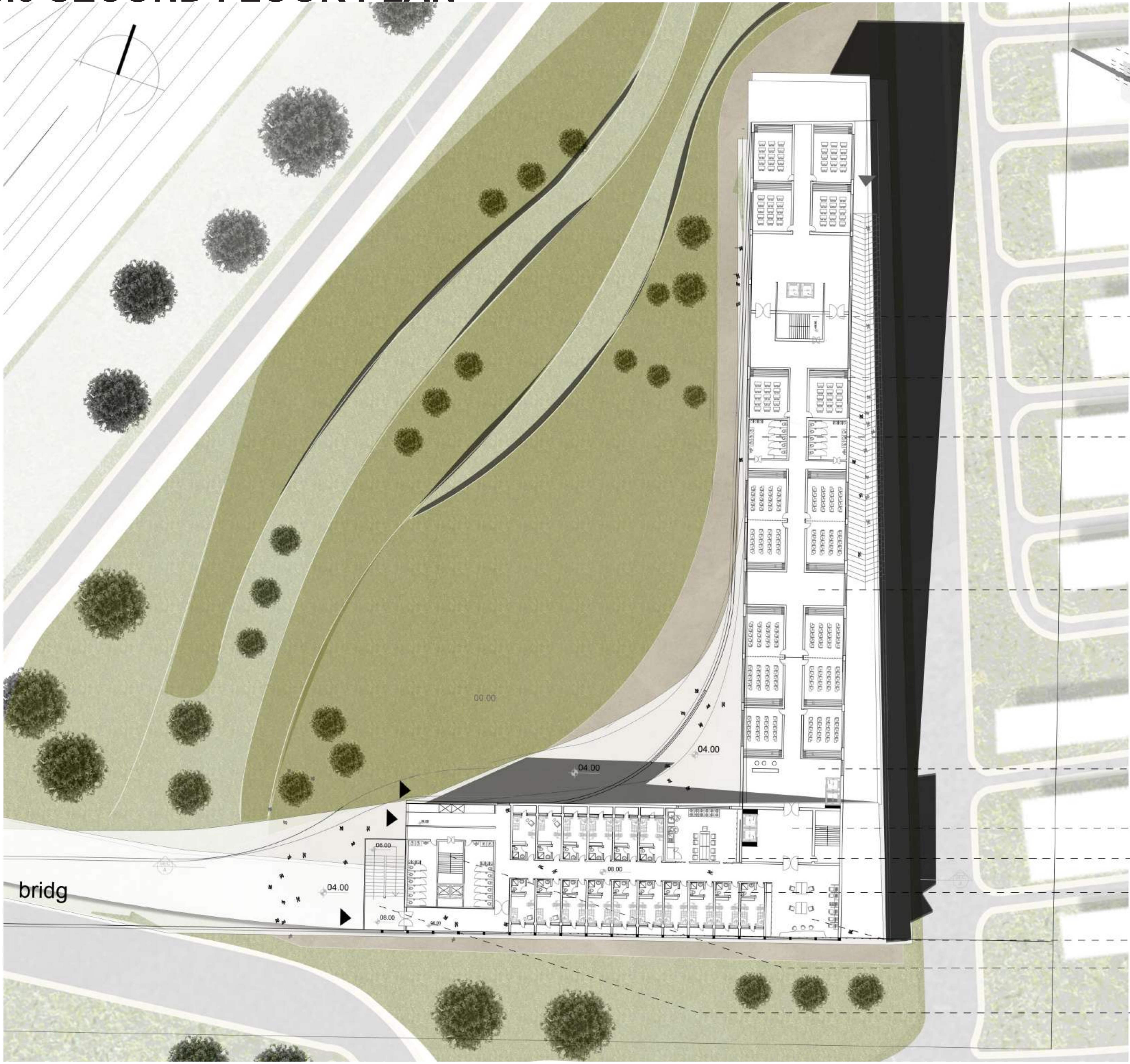
3.6.1 GROUND FLOOR PLAN

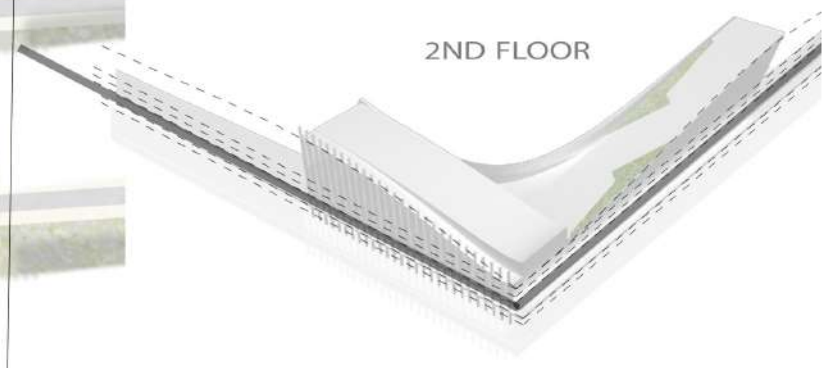


3.6.2 FIRST FLOOR PLAN



3.6.3 SECOND FLOOR PLAN





STAIR AND ELEVATORE

CLASSROOM

TOILET

COMMON AREA

LOBBY | EDUCATIONAL

LOBBY | RESIDENTIAL

KITCHEN

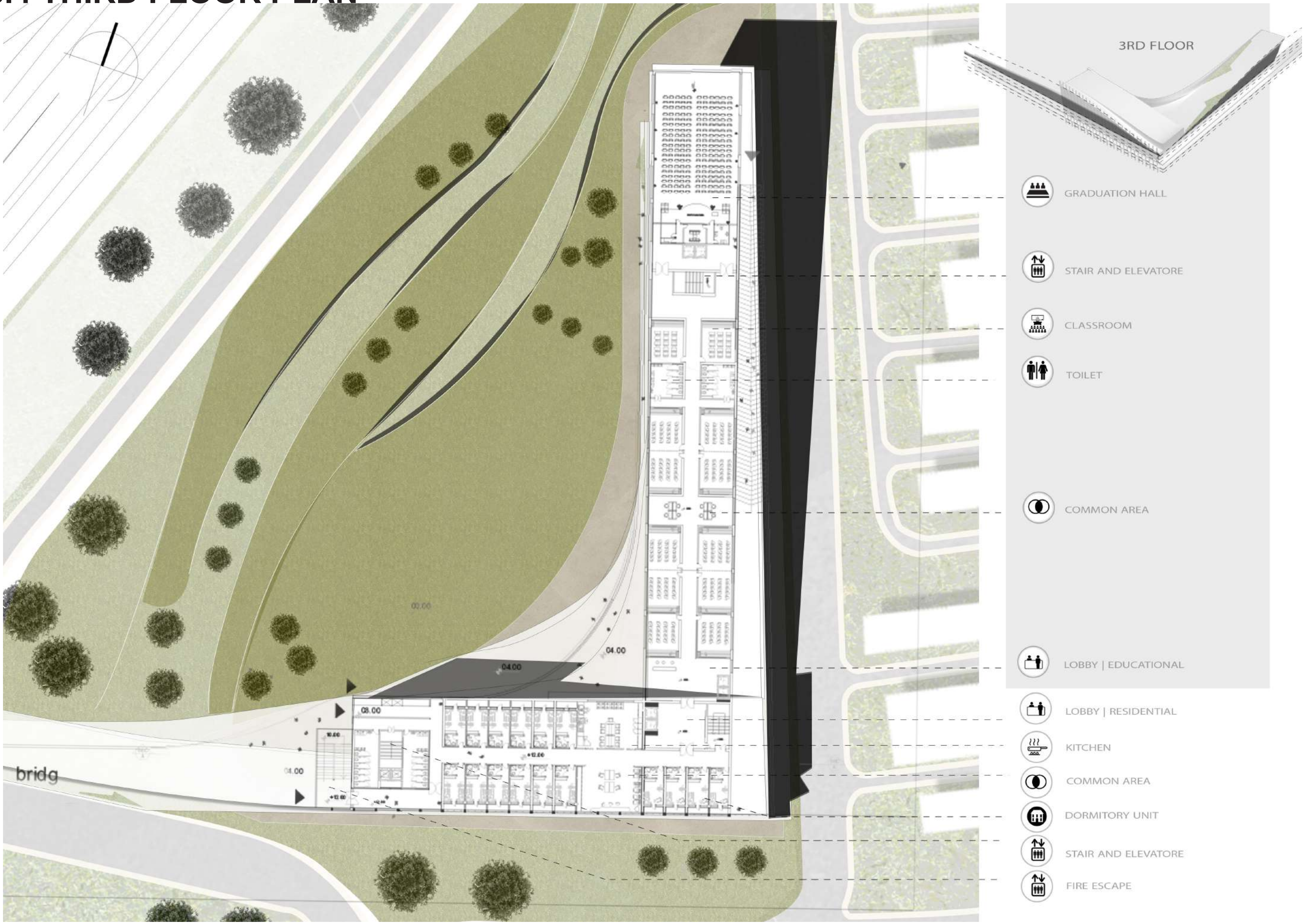
COMMON AREA

DORMITORY UNIT

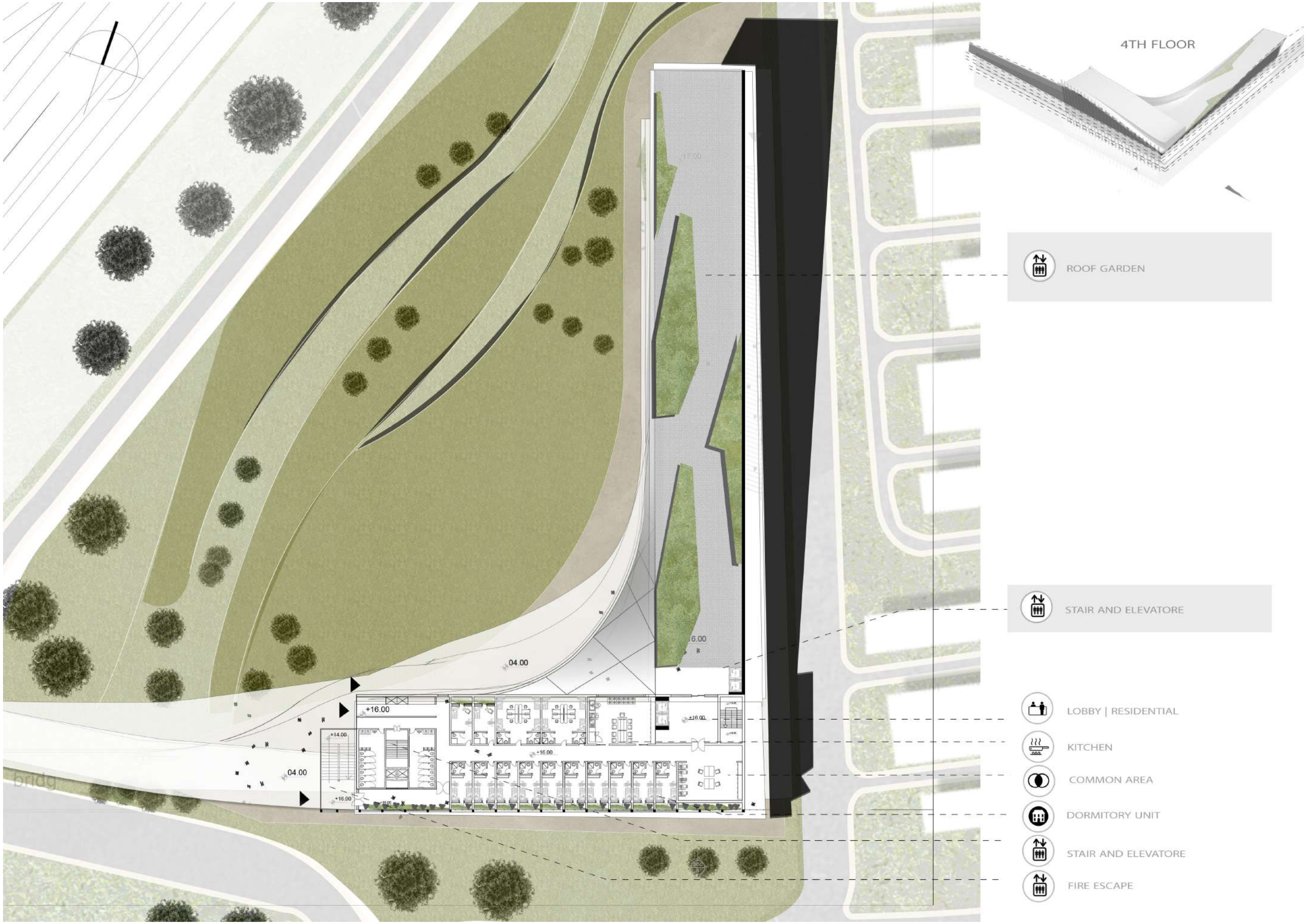
STAIR AND ELEVATORE

FIRE ESCAPE

3.6.4 THIRD FLOOR PLAN



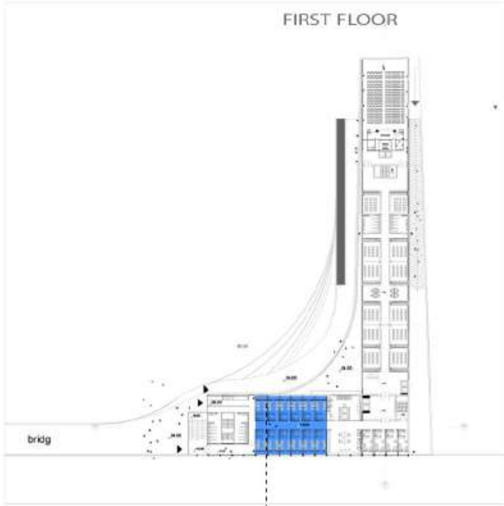
3.6.5 FOURTH FLOOR PLAN



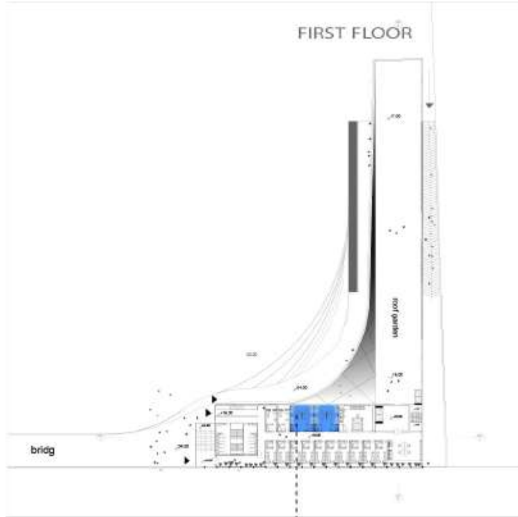
UNITS

Plan. Scale 1:100

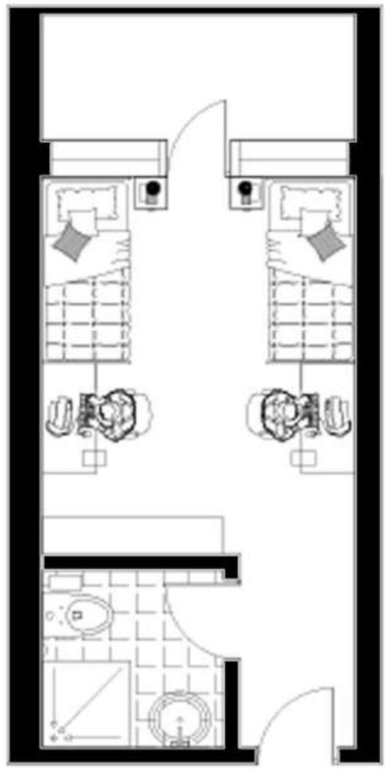
SINGLE ROOM

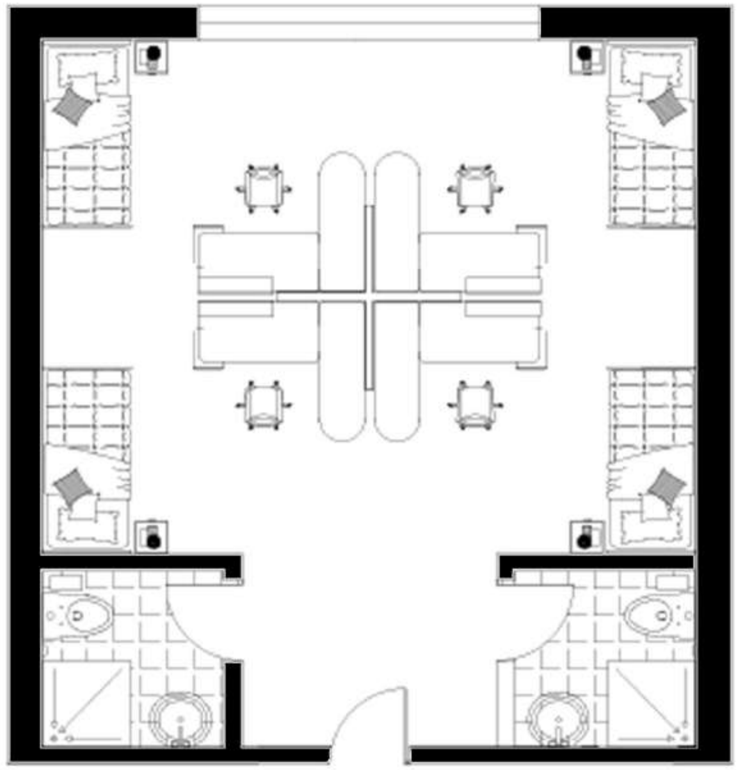


DUBLE ROOM



GROUPMATE ROOM
"OFFICE TYPE"





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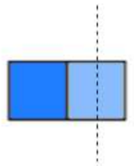
Composition: 

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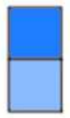
Composition: 

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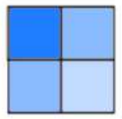
Composition: 

3.7 FACADES
3.7.1 SOUTH FACADE

3.7.2 NORTH FACADE

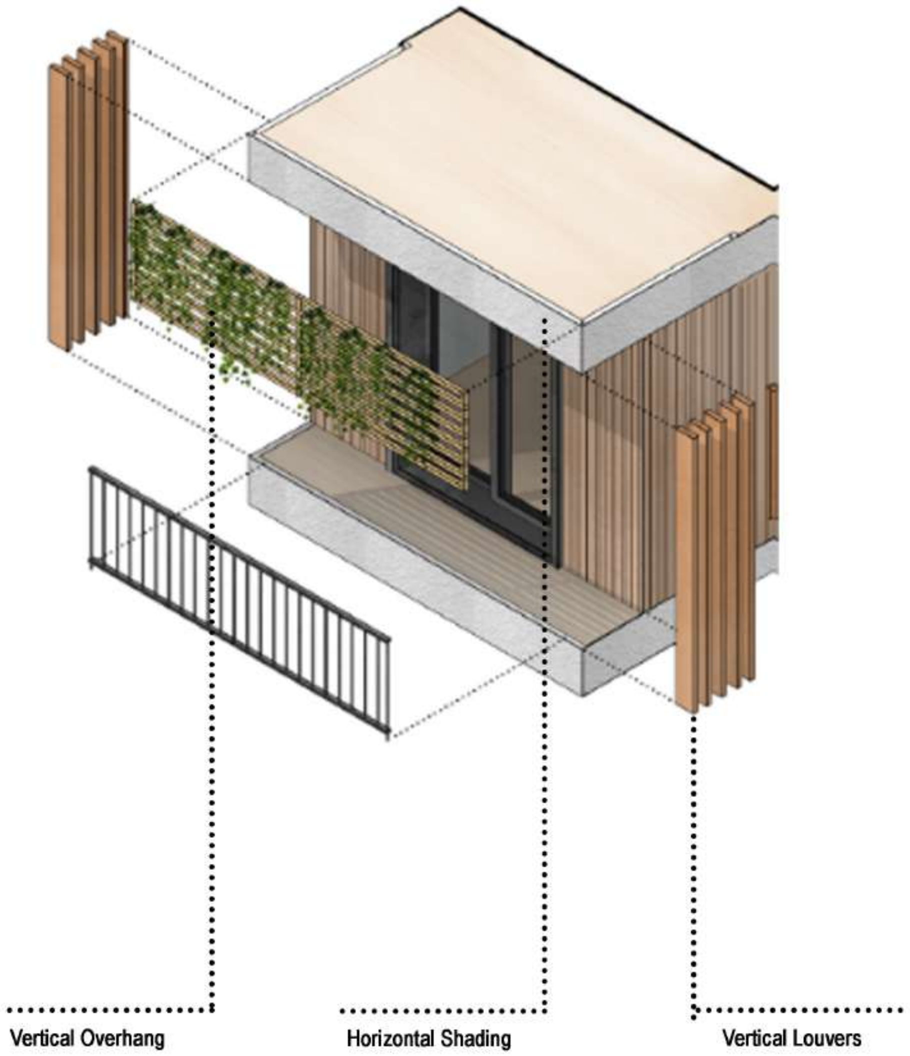
3.7.3 WEST FACADE

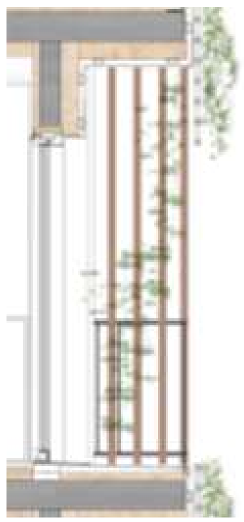
3.8 SECTIONS
3.8.1 SECTION A-A

3.8.2 SECTION B-B

3.9 RENDERS

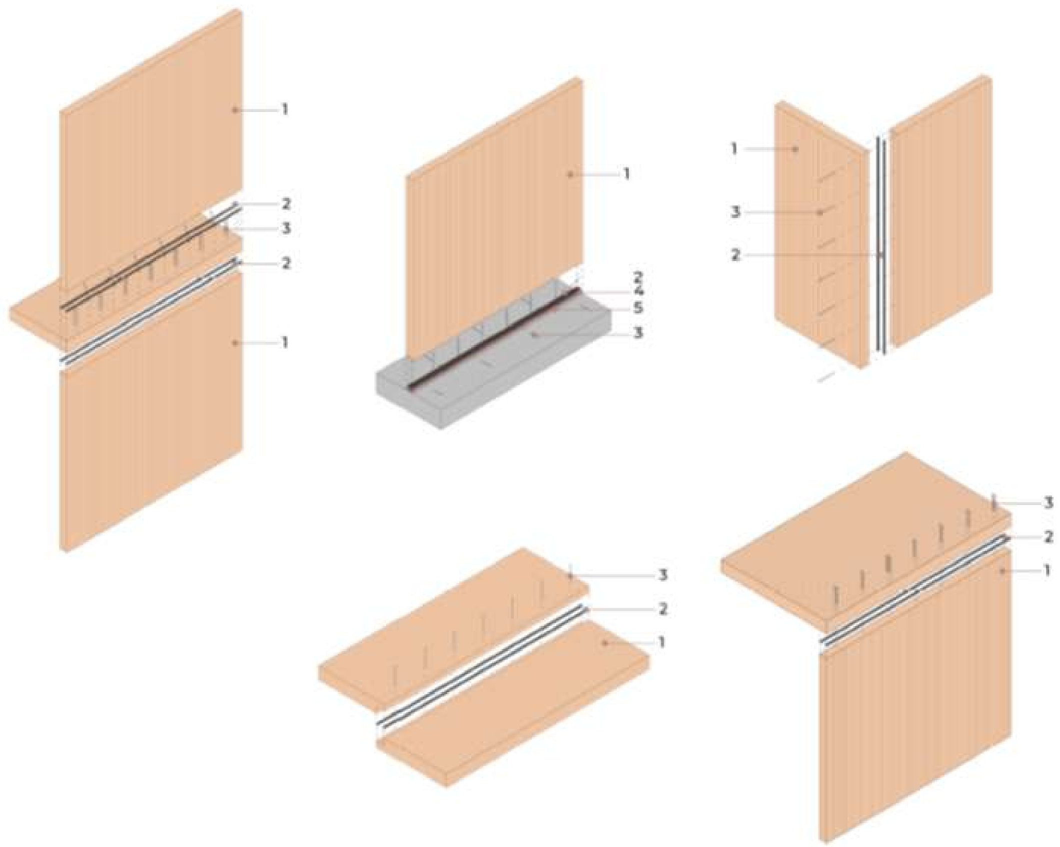
3.10 BLOW UP





STRUCTURAL CONNECTIONS

The CLT panels are joined with the use of self-tap-ping hardwood screws. The typical distance be-tween screws are determined by the structural de-signer. Position of the screws is designed to avoid thermal bridges, using internal points wherever possible. EPDM tape strips are used to create an airtight seal. The connection to the foundation uses a steel profile and guiding wood post to facilitate positioning of the panels and keep the CLT from directly contacting the concrete.



1. CLT Panel
2. EPDM Tape
3. Self-drilling hardwood screw
4. Guide Batten (Treated & Waterproof)
5. Steel Profile Base

CHAPTER 04
MATERIAL

4.1 MATERIAL

4.1 CLT

Cross laminated timber, CLT, is a highly engineered wood product that is excellent for all sorts of different structures. CLT's composition and method of manufacture offer huge opportunities, since the panel can be glued and worked into almost any shape and size. Since the raw material is fully renewable, CLT has a good environmental profile.

Cross laminated timber has excellent strength and stiffness properties, which mean that CLT panels can compete with other more traditional structural materials in high-rise buildings. In relation to their own weight, CLT panels have a higher load-bearing capacity than most other construction materials, which is why large structures can be built to withstand high loads.

CLT is already being used in many different types of structure: houses, high-rise blocks, halls, sports arenas and bridges. With suitable designs and detailing, plus protection from the climate, possibly with a surface treatment, CLT can be used for these and many other structures.

Figure 4.1 Kengo Kuma Unveils Cross-Laminated Timber Pavilion

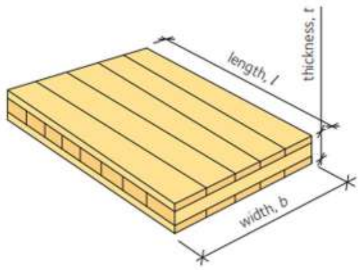


Figure 4.2 CLT panel

Parameter	Commonplace	Available
Thickness, t	20 – 45 mm	20 – 60 mm
Width, b	80 – 200 mm	40 – 300 mm
Strength class	C14 – C30	-
Width to thickness ratio	4:1	-

Table 4.1 Common strength classes and dimensions of boards used to

Parameter	Commonplace	Available
Thickness, t	80 – 300 mm	60 – 500 mm
Width, b	1,20 – 3,00 m	up to 4.80 m
Length, l	16 m	up to 30 m
No. of layers	3, 5, 7, 9	up to 25

Table 4.2 Common dimensions for CLT panels

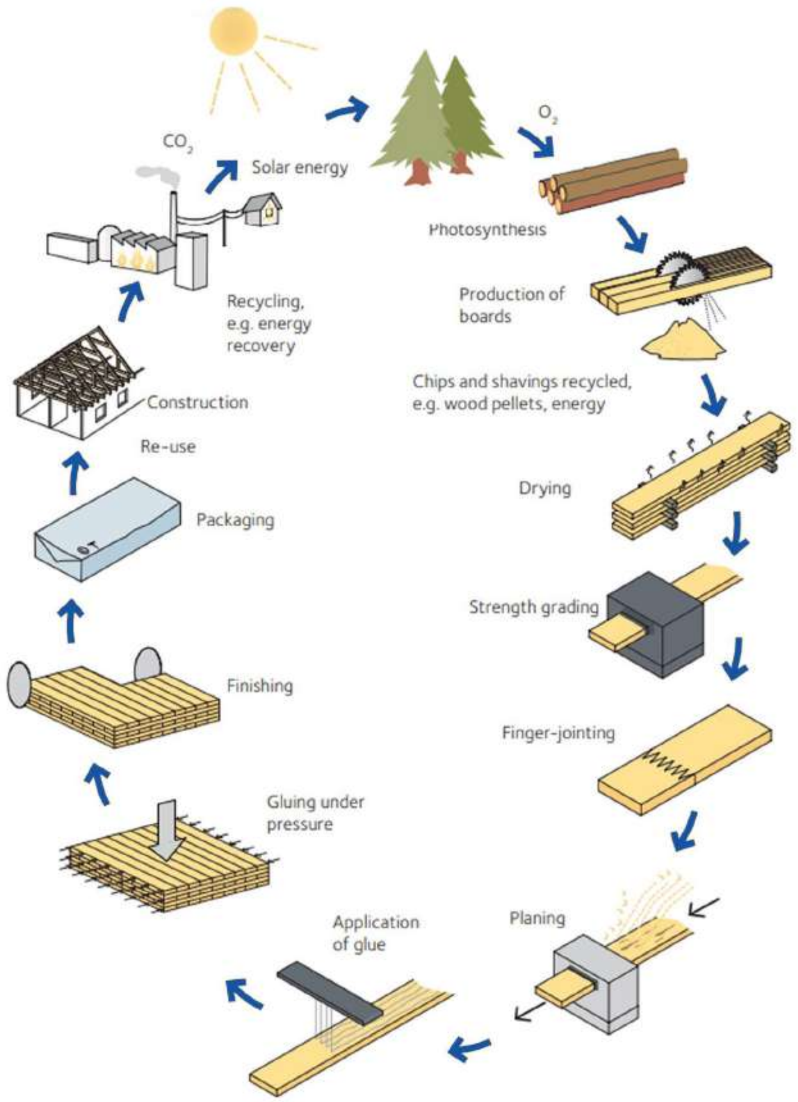


Figure 4.3 Schematic diagram of the CLT production process.

4.2 PROPERTIES

4.2.1 Strength properties

CLT displays major similarities with other wood products in terms of its strength properties:

- The strength varies according to the angle between the stress and the fiber direction, making it an orthotropic material.
- The strength falls as the moisture content rises.
- The strength falls as the length of time under load rises.
- The material properties vary both within one component and between different components.

The structure of CLT, with its perpendicular layered boards, evens out the variations in the wood and reduces the property differences. The strength of a CLT product is determined to a large extent by the composition of the cross-section. As with other structural components in wood and in a construction context, stiffness is often a design value. For CLT, the tensile strength of the surface boards and the rolling shear strength of the transverse layers are crucial in the breaking phase. In the use phase, the composition of the cross-section is an even greater determinant of what results can be achieved.

In comparison with wooden decks such as stress-laminated timber decks, which are often used in bridge designs, CLT exhibits lower stiffness in the main direction of load for panels of the same thickness. A CLT panel can, however, take substantially higher loads across the main direction of load. The basis for the static design of CLT and wooden structures in general is a characteristic strength or stiffness value, determined via testing under laboratory conditions and via a set number of samples. Normally, strength calculations in a design are based on the lower 5 % fractile, which is the value that is statistically undershot in 5 cases out of 100. Knowing the characteristic strength value, the design value for the individual case is then determined using various partial coefficients and conversion factors. Characteristic stiffness values such as modulus of elasticity and shear modulus are determined in a similar way, but taking the average value as the starting point, rather than the 5 % fractile.

4.2.2Moisture movement

CLT expands when the moisture content increases and contracts when the moisture content falls. The alternating layers of boards mean, however, that the wood in CLT panels expands and contracts less across the fiber direction than ordinary solid wood does. CLT is manufactured under controlled conditions from boards and planks with a moisture content of between 6 % and 15 %. The question of how much less the expansion and contraction will be compared with ordinary solid wood is determined by the number and thickness of the layers. Products made from CLT are usually manufactured with a target moisture content of 12 %. This means that individual CLT products are to have a moisture content of no more than 16 % on delivery. The moisture content of CLT will gradually achieve equilibrium with the ambient relative humidity (RH) and follow its variation over the year.

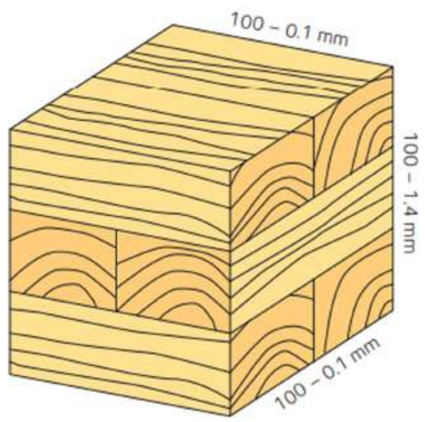


Figure 4.4 Approximate contraction and expansion of a CLT panel per 100 mm when drying from 20 % to 10 % moisture content

Figure 4.5 The United States' First Mass-Timber Highrise

4.2.3 Thermal properties

Wood has very small temperature movements, compared with many other materials. The thermal conductivity and thermal capacity of CLT is practically the same as for solid wood. The thermal conductivity, which describes the material's insulating capacity, is significantly better than for concrete and steel. wThe practical value for thermal conductivity for spruce is 0.11 W/(m °C) at a right-angle to the fibers and 0.24 W/(m °C) parallel with the fibers, while for pine the equivalent values are 0.12 W/(m °C) and 0.26 W/(m °C), respectively. In practice, a value of 0.12 – 0.13 W/(m °C) tends to be used for CLT. CLT has a relatively high specific thermal capacity, which is usually stated as around 1600 J/(kg °C). When building with CLT panels, the large quantity of wood influences the indoor climate by levelling out climate variations. The scale of this effect is determined by the other constituent materials, the ventilation system and the inbuilt regulation and control technology.

4.2.4 Fire properties

CLT and structures made from CLT have good, predictable properties when it comes to fire. CLT is a flammable material, but in combination with other materials, the required load-bearing capacity can be maintained during the fire. Wood is slow to catch fire and it burns slowly. The way the heat develops during a fire is often crucial in determining whether the fire will spread or burn out. The charcoal layer that forms on the surface of CLT in a fire protects the inner parts, and the penetration rate for wood is generally around 0.6 – 1.1 mm per minute.

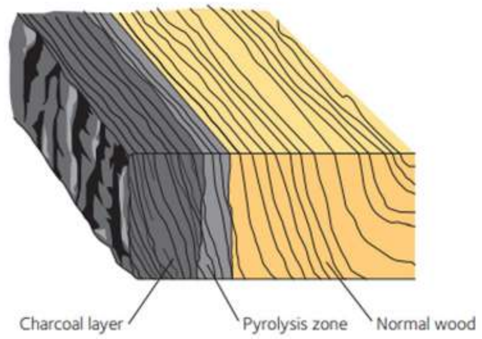


Figure 4.6 Fire penetration

Figure 4.7 Oregon state university peavy hall

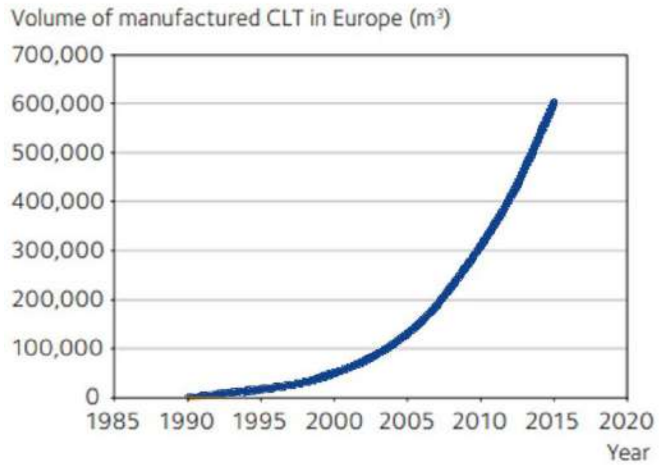
CHAPTER 05
STRATEGIES

5.1 USING RENEWABLE MATERIAL

Building with wood is positive for the climate. To minimize the environmental impact of construction and to contribute to a sustainable society, every opportunity to use renewable materials must be seized with both hands. For the construction and property sector, this means considering the production and operational phase, both of which affect the environment. As solutions in the operational phase become increasingly energy-efficient, the manufacturing and building process takes on greater weight when judging the environmental impact of a building over its entire life. Life cycle analyses of built objects have shown that emissions can be reduced by using wood in the structural frame instead ofothermaterials.

5.1.1 CLT in the eco-cycle

Use of wood is therefore beneficial from an environmental and climate point of view, compared with other construction materials. Firstly, manufacturing CLT is an energy efficient process. Secondly, the by-products (wood shavings and wood waste) are used to produce energy, which is used to heat the drying kilns, for example, thus reducing the need for fossil energy during manufacture. Sustainable forestry means that the extraction from the forest does not exceed growth, the raw material is constantly regenerated, and the wood can be returned to the eco-cycle without adding harmful greenhousegases to the climate.



Development of CLT in Europe

1990 – 1995	Concepts, patents and proposals presented in European trade journals.
1996 – 2000	Prototypes and components developed for the Swedish market.
2000 – 2004	First deliveries for small-scale projects in Sweden.
2004 – 2005	First taller wooden buildings in CLT built in Sweden.
2005 – 2014	More and more projects built using CLT.
2015 –	Forecast for the whole of Europe.

Figure 5.1 Volume of manufactured CLT in europe

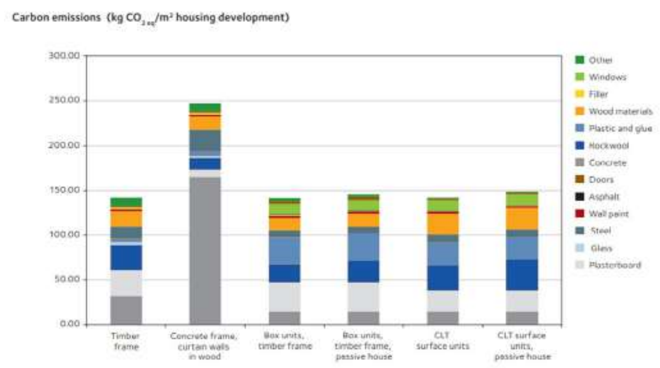
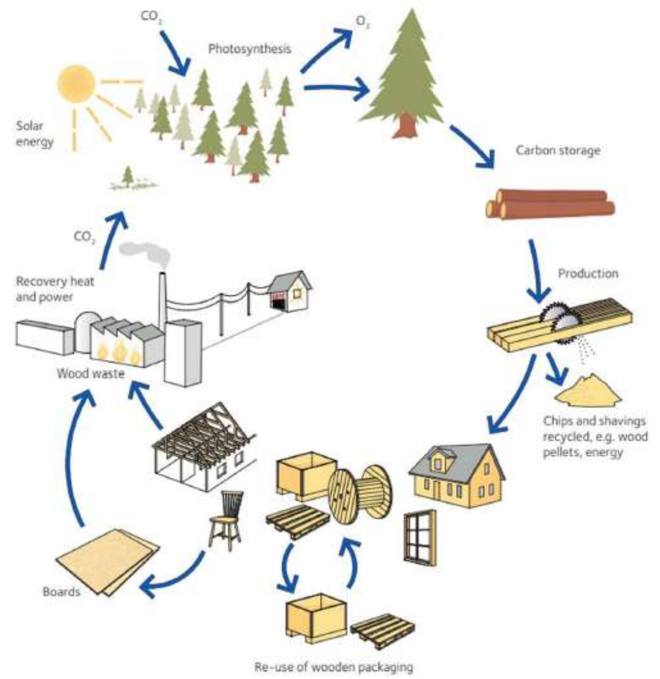
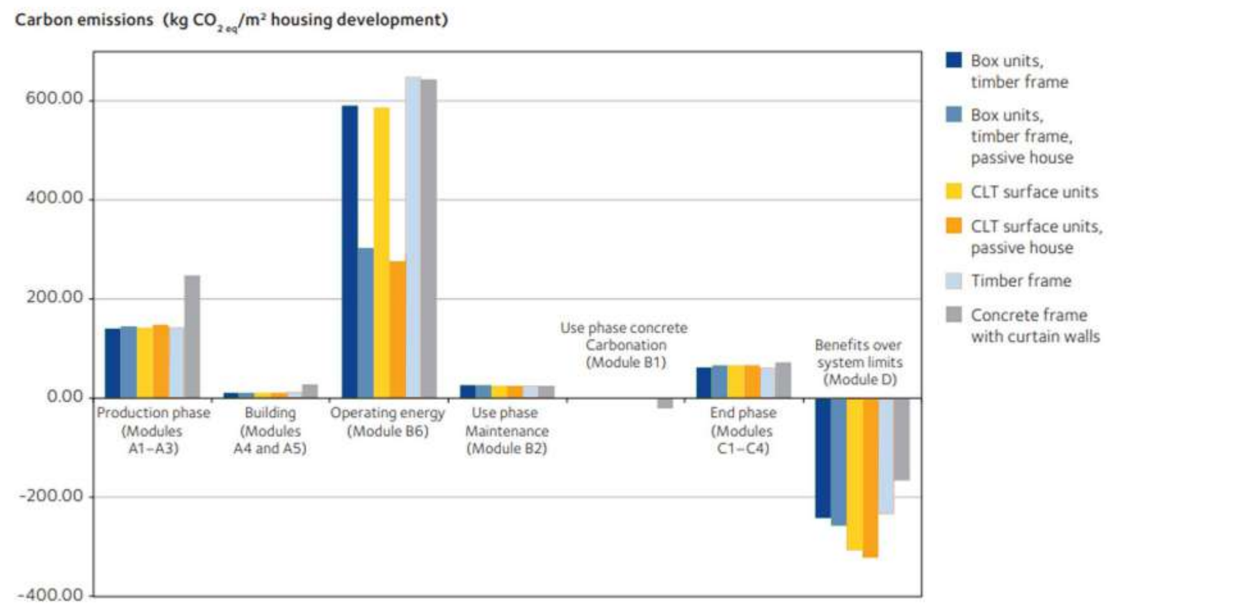


Figure 5.2 Greenhouse gas emissions (carbon dioxide equivalents, CO2 eq) from the production phase for six different designs of a four-storey building.

The eco-cycle comprises two parts. One relates to the forest and the other to the products. The forest gains its vitality from the sun. Through photosynthesis, solar energy is absorbed and reacts with carbon dioxide (CO2) to produce nutrients for the growing trees. The forest's products contain carbon (C) that has been absorbed by the trees in the form of carbon dioxide. The ecocycle of the products includes reuse, repair and recycling. When these products reach the end of their life, the carbon dioxide is released into the atmosphere as the waste decays or is recycled as bioenergy. The carbon dioxide is then again captured by the trees and converted into nutrients and new building blocks for their growth.



The bar chart also indicates major differences between buildings that meet the passive house standard and “normal” buildings. The parameters that are assumed to be different are amount of insulation, better airtightness and more low-energy installations.



5.2 THIN-FILM SOLAR CELL

Thin film solar cells are the new generation solar cells that contain multiple thin film layers of photo voltaic materials. The thin film solar cells (TFSC) are also known as Thin Film Photo Voltaic cell (TFPV). The thicknesses of thin film layers are very less as (few nano meters) compared to traditional P-N junction solar cells. According to the type of photo voltaic material used, the thin film solar cells are classified into four types. They are:

- Amorphous silicon (a-Si) and other thin-film silicon (TF-Si)
- Cadmium Telluride (CdTe)
- Copper indium gallium deselenide (CIS or CIGS)

Dye-sensitized solar cell (DSC) and other organic solar cells

5.2.1 Structure of Thin Film Solar Cell

The structure of thin film solar cell is shown below. The structure and functioning of thin film solar cells are almost same as that of normal silicon wafer cells. The only difference is in the thin flexible arrangement of the different layers and the basic solar substance used. The thin flexible arrangement of the layers helps to produce very thin form of cells that is much more efficient than the conventional silicon wafer cells.

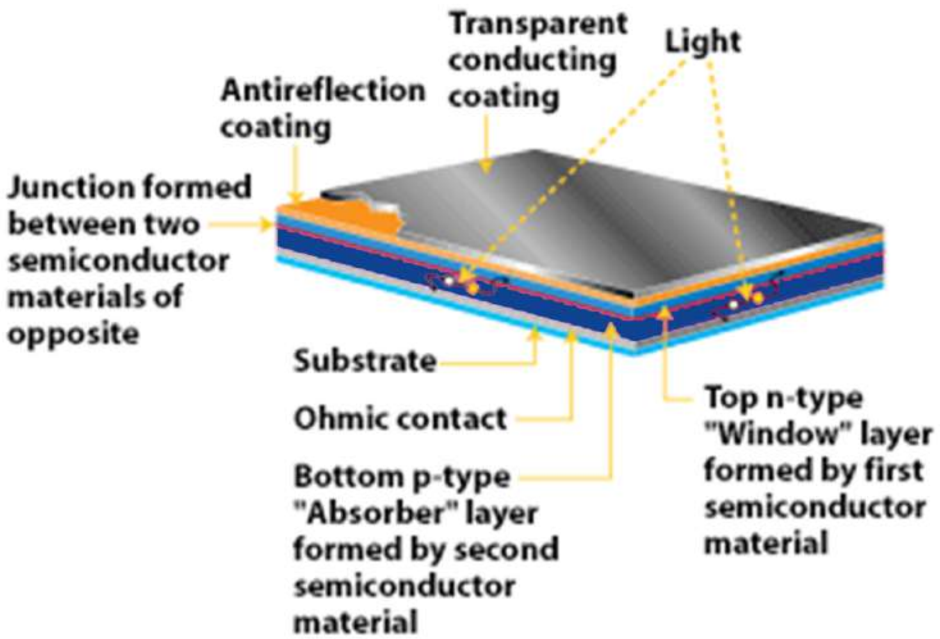


Figure 5.3 Layers of solar panel

5.2.2 Working

The basic substance of a photovoltaic cell is semiconductors. The semiconductor doped with phosphorus develops an excess of free electrons (usually called N type material) and a semiconductor doped with boron, gallium or indium develop a vacancy(called holes) and this doped materials known as P type materials. These n type and p type materials combine (join) to form a Photo voltaic cell. During the absence of light, a very small amount of atoms are excited and move across the junction. This causes a small voltage drop across the junction. In the presence of light, more atoms are excited and flow through the junction and cause a large current at the output. This current can be stored in a rechargeable battery and used for several applications .

The old solar panel technology use silicon semiconductor for the production of p-type and n-type layers and has several disadvantages. But in the case of Thin Film Layer technology , the silicon semiconductor materials is replaced by either cadmium telluride(CdTe) or copper indium gallium deselenide (CIGS).

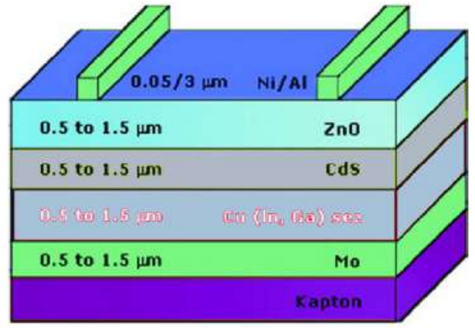


Figure 5.4 Layer arrangement of thin film solar cell

5.2.3 Advantages

- Easy to handle
- More flexible than conventional solar cells
- Available as thin wafer sheets

5.2.4 Disadvantages

- Less efficiency (20 to 30% of light converted into electricity)
- Complex structure

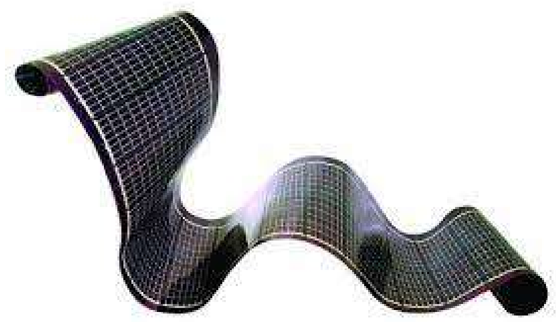


Figure 5.5 Example of thin film solar cell

CHAPTER 06
DESIGN
OPTIONEERING

6.1 INTRODUCTION

The quality and thermal comfort of the indoor has a direct affect on the human health and performance and help people to study, work more productive and also help them to feel safer. The indoor comfort depends on lots of factors and can affected by them. In this project we are trying to improve the level of life quality in the area. For meeting this goal, we should keep an eye on the :Thermal comfort, visual comfort and acoustic comfort during the different steps of the optimization.

6.1.1 Universal Definition of Thermal Factor

Thermal comfort is defined by the ASHRAE Standard 55-2010 and the EN ISO 7730 as “that condition of mind which expresses satisfaction with the thermal environment, and it is assesses by subjective evaluation”. Thermal comfort is assessed through an equation of objective and subjective variables, the first being controllable by the designers: air temperature, mean radiant temperature, relative humidity, and air velocity.

6.1.2 Universal Definition of Visual Comfort

We need to maintain and provide enough daylight to have a comfort environment for studying and learning and try to save the electricity which produced by the PV panels for the equipment such as fridge, Pcs, night lightning etc. An appropriate daylight in schools has proven to have effect both on the health and concentration of the students. According to a study conducted in European schools in December 2020, “classroom characteristics associated with daylighting do significantly impact the performance of the school children and may account for more than 20% of the variation between performance test scores”. Despite this, more light is not always desirable, as glare may occur. Appropriate shading devices must be provided in the learning spaces, especially the one with windows towards the northeast and West, where the low morning and late afternoon sun enters directly in the building. To reach a satisfying level of daylight three indicators have been used, sDA (Spatial Daylight Autonomy) and ASE (Annual Solar Exposure) and DF (daylight Factor) as suggested by the Leed v4 certification.

6.1.3 Setting up the model

The thermal comfort simulation has been performed using IES VE virtual reality. In order to perform a realist analysis, a building energy model of the project has been created. Other than the essential geometric information, other information contained regard the material properties, usage schedules, orientation, shading elements and local climatic conditions.

6.1.4 Weather Data

The climate data to perform the analysis has been taken from the dataset of the World Meteorological Organization, including the typical wheatear data of the past decades, referring to the close city of Leipzig Halle.

6.2 GEOMETRY

For energy analysis process, we model it in SketchUp and import it on IESve software. Each room has been modelled as an individual zone. This approach allowed to control the properties of each room depending on its actual use (classroom, cafeteria, services…), obtaining comfort result for each one.

6.2.1 Envelope Materials

During this step the building envelope including walls, roof, windows, floor, evaluated with different technologies. The envelope is the primary thermal barrier between outdoor and indoor. In this Step the main goal is to keep the building with high range of comfort.

OPTIONEERING

The last step of the optioneering is integrated process that studies the impact of opening size, position and shading devices on both the thermal comfort and daylight. Two parameters will be adjusted to find the best solution in both fields:

- Windows to wall ratio: the fraction of transparent surfaces over the whole wall.
- Extension of the shading roof: the size of the secondary roof will influence the amount of direct sun reaching inside the building, and consequentially the daylight and internal gains.

Both parameters are directly linked to architectural and structural topics. Regarding the structure, the openings should not exceed 50% of the wall in length according to the SADC ZW HS 983:2014 guidelines.

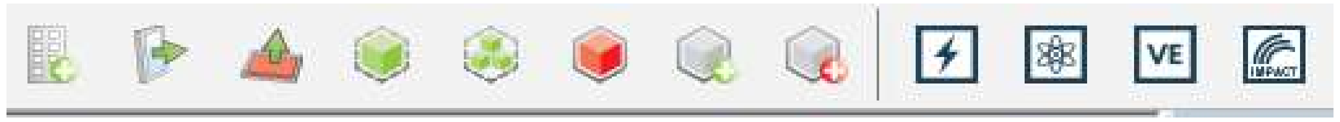
6.3 IESve FOR ANALYSIS

The IES Virtual Environment (VE) is a suite of building performance analysis applications. It can be used by designers to test different options, identify passive solutions, compare low-carbon & renewable technologies, and draw conclusions on energy use, CO2 emissions and occupant comfort.

The IESVE software provides a single platform that integrates with the BIM workflow to create and capture performance information during design, commissioning and operation ofabuilding.

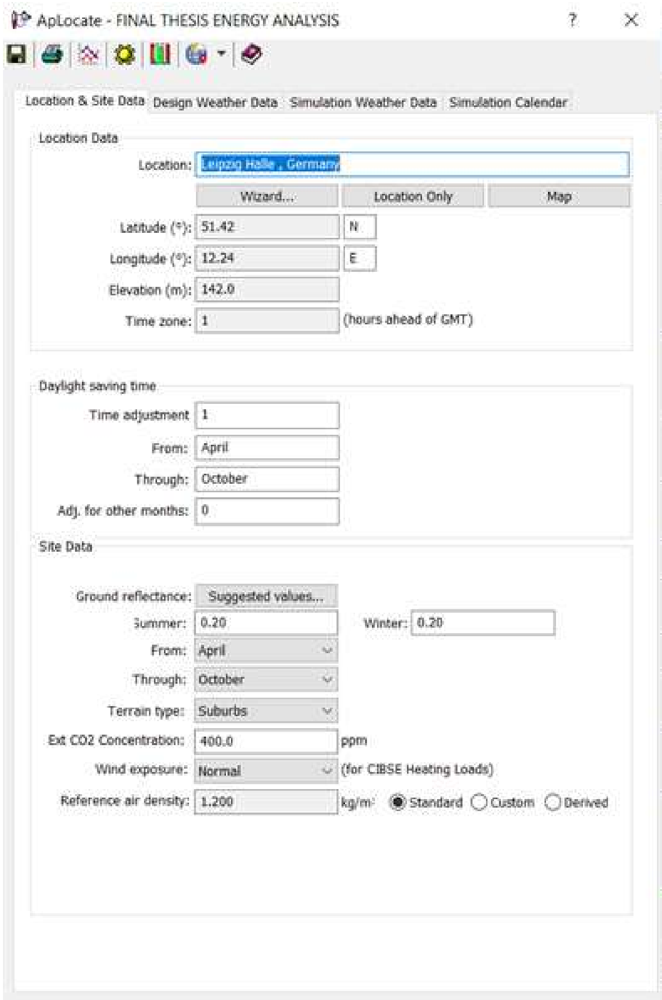
STEP 1

Model the building on SketchUp and use the IESve Plugin for importing it to IESve software. In this step we draw all elements such as shading elements on SkechUp.

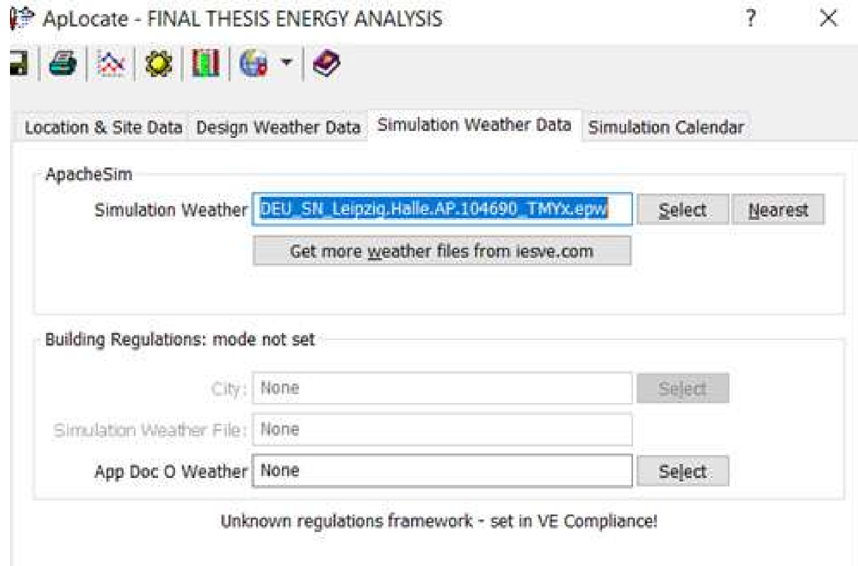


STEP 2

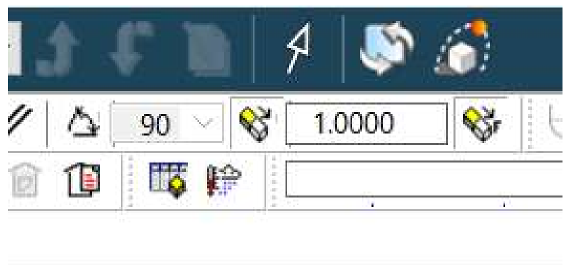
After importing the model we should insert the location and weather data. So, from the ApLocate menu we can change it from Location & Site Data tab



After that, with using Simulation Weather Data we can change the EPW file. What is EPW file? EPW's were developed by the United States Department of Energy (DoE) to be a standard weather data format, to which several other data formats could be converted. These have been derived from a wide range of sources which includes TMY2, TMY3, IWEC, and RMY. In our case we use Leipzig Halle file because it's the nearest city to Dessau.

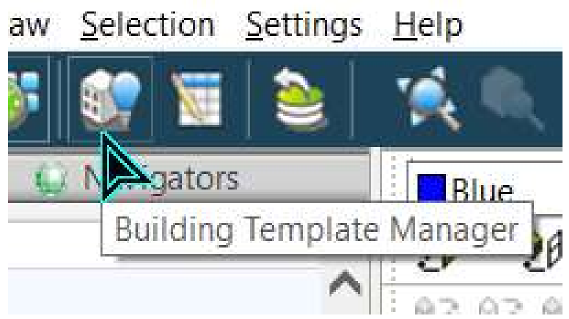


The last step of Location setting is to set the North on the software, By changing the north icon from top of tool bar.

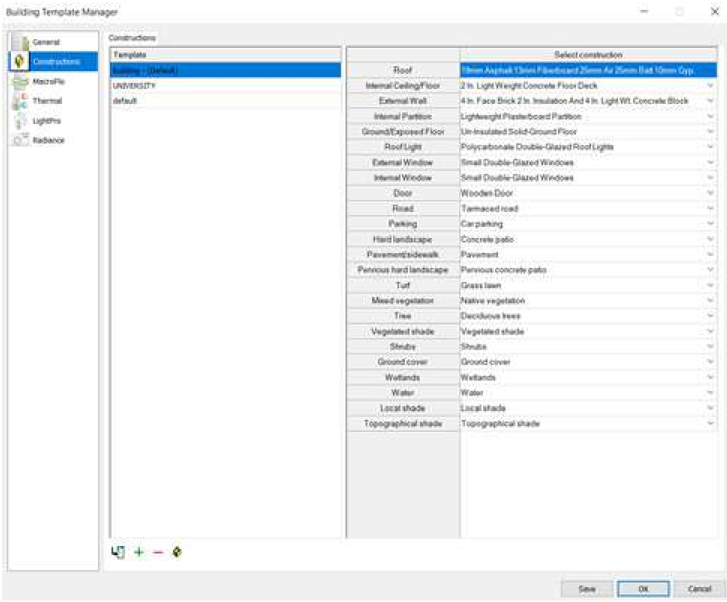


STEP 3

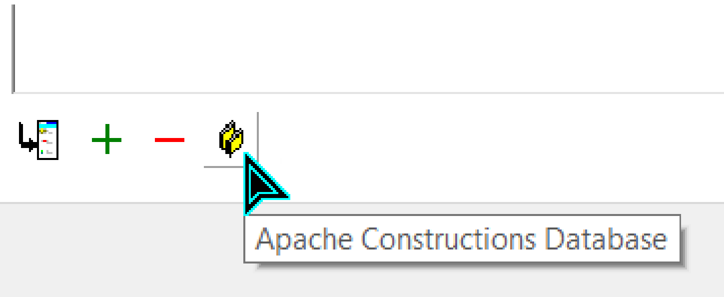
Now is the time for inserting the building characteristics by using the building template manager.



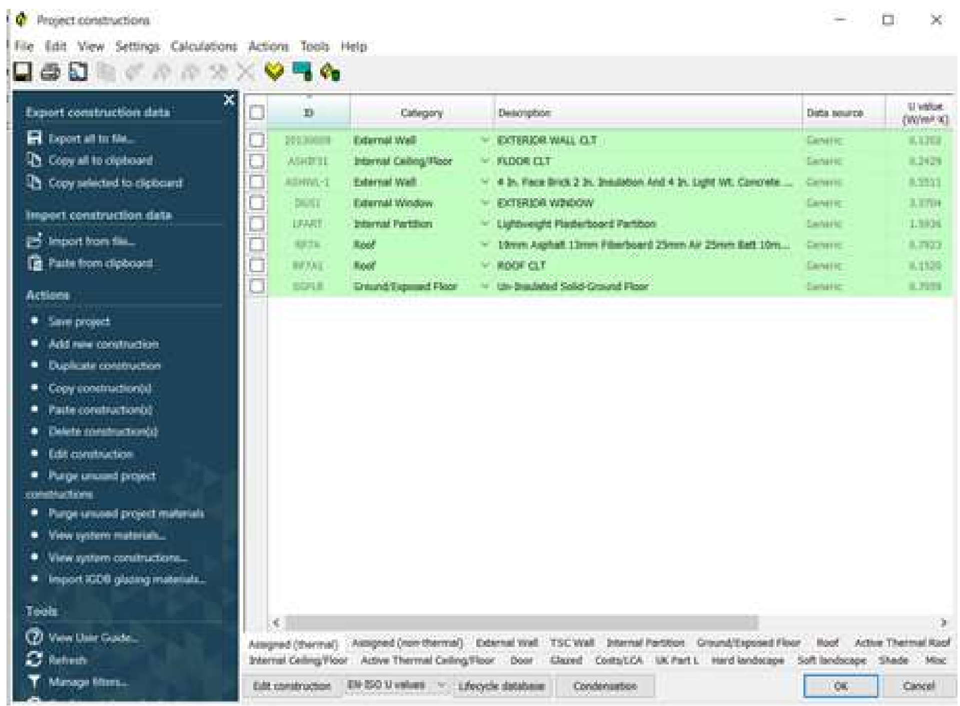
In this menu first, we should enter the elements which we use in our building such as the walls, windows, ceilings, etc.



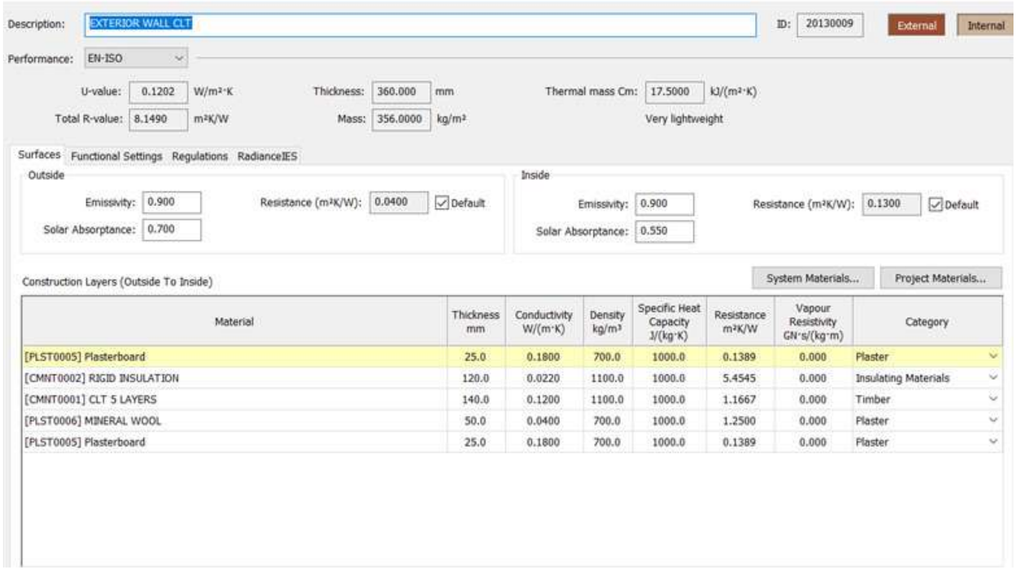
By using the icon we can add our specific elements.



In this menu, we can choose every type of element and change them.



All the characteristics of elements are editable like layers, Conductivity, Density, Thickness, etc.

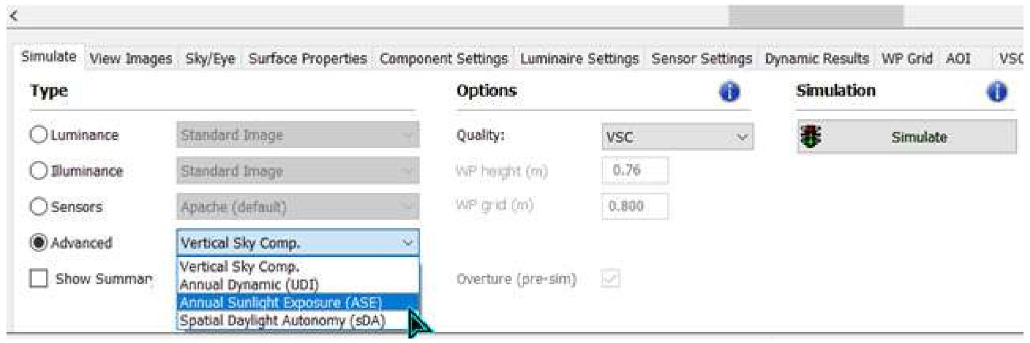


In the end, we have a specific element with a special U-value. After changing all the elements, we can start with the major part of the software.

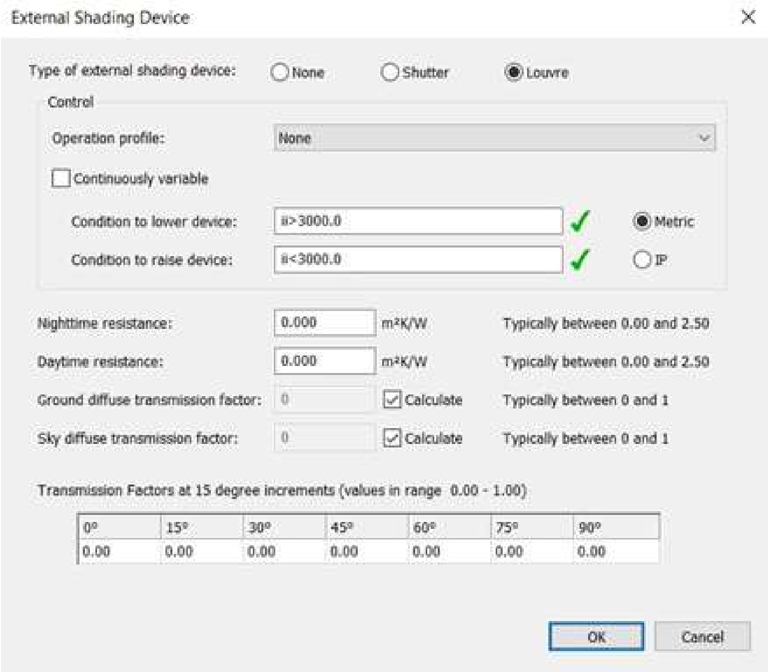
STEP 4

For daylight analysis, we should enter the RadianceIES part.

In this part, we can calculate the SDA and ASE of the glazing part.



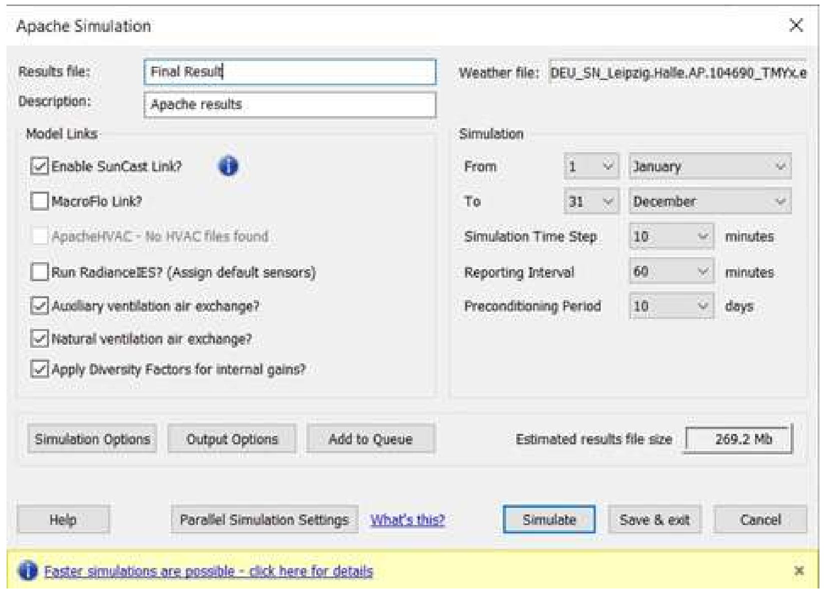
For this part, we consider 2 classrooms on the east and west side of the building (with 22-degree rotation) The results are in the daylight analysis part. In this software, we can put the shading part for glazing and it has a huge effect on SDA and ASE parts.



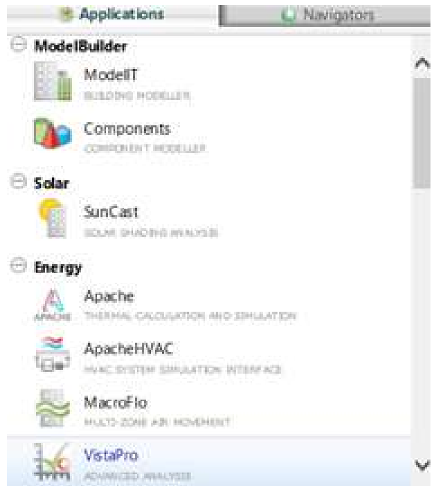
STEP 5

Another part of analyzing is calculating the load energy by entering the Apache part.

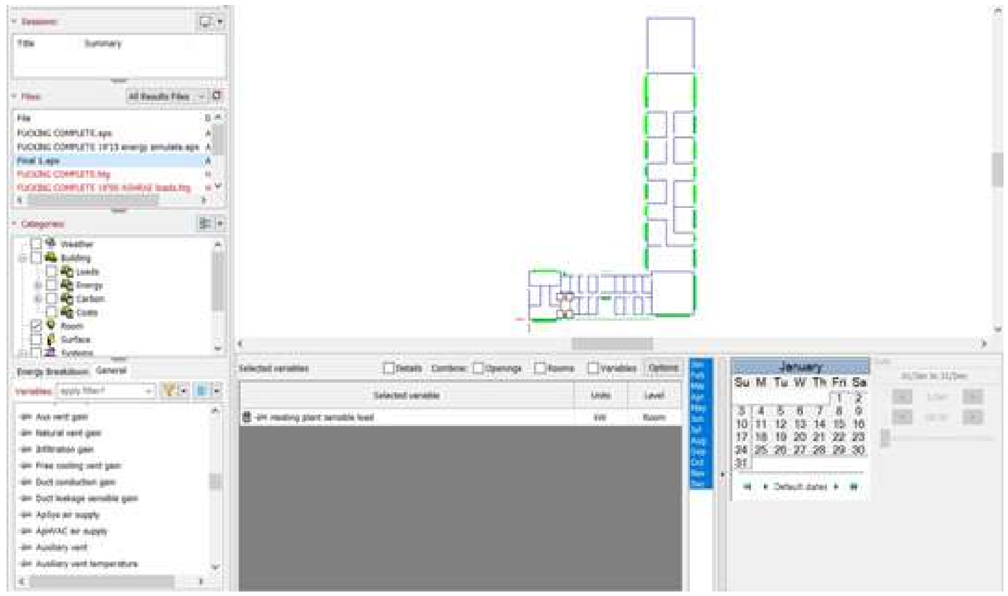
With all the elements which we give to software, it could be ready to give us the characteristics of consuming the load and other attitudes of energy part through the year.



Now we can go to VistaPro part and take all the information that we want.



With selecting the zones that we want the software gives us the table and graph.

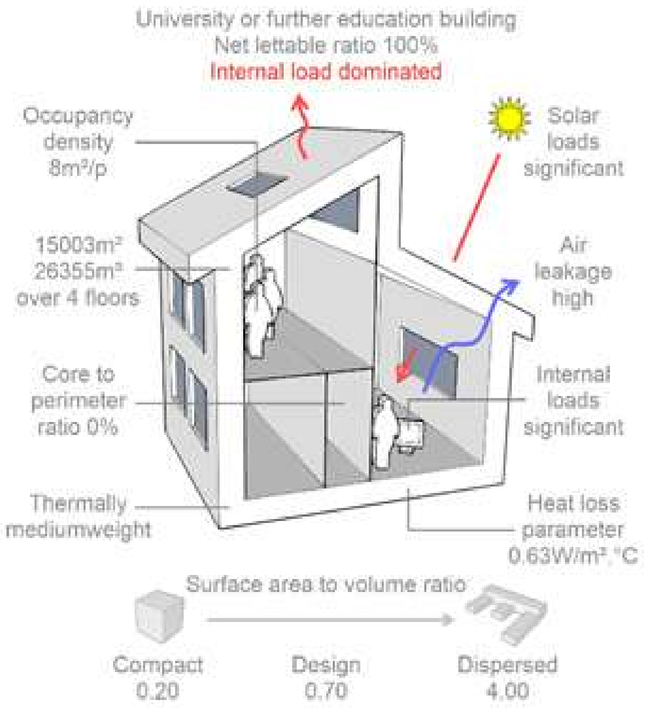


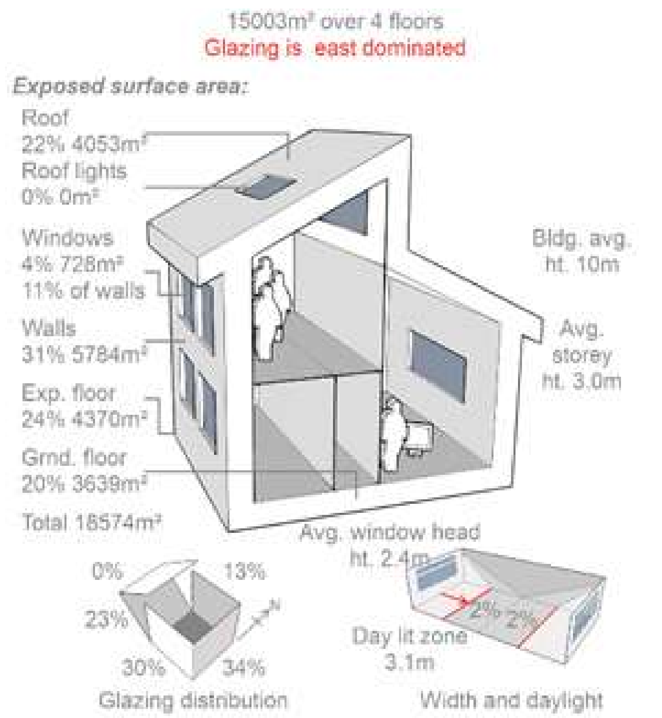
6.5 VE GAIA:EARLY STAGE DESIGN ANALYSIS

IESVE Gaia is the ideal tool for Helping to meet sustainable design goals and deliver efficient, low-carbon buildings.

- Climate / Bio-Climatic Interrogation
- Building Metrics / Materials Review
- Natural Resources / Water Analysis
- Energy / Carbon Simulation Heating / Cooling Loads Calculation
- Low / Zero-Carbon Technologies

6.5.1 Building Review





6.5.2 Climate Metrics

ASHRAE 90.11 (calculated) 5A Cool humid. Humid temperate (mild winters), Fully humid; no dry season, Warm summer (marine), Mild winters with heavy precipitation, warm/short/dry summers, on western continental coasts. Winter is potentially most dominant - the design must minimize heating energy. Latitude is mid - solar radiation on south/east/west walls is significant. Solar radiation on roofs is significant. Summer is cool. Summer also has a moderate diurnal range. Summer also has cool summer nights. Winter is mild. Winter prevailing winds typically from the north. Summer prevailing winds typically from the south. Wind patterns: Typically westerly winds.

6.5.2.1 Temperature

- Warmest month July
- Max annual temperature (Jul) 32.1 °C
- Warmest six months Jul Aug Jun Sep May Oct
- Coldest month Jan
- Min annual temperature (Jan) -18.9 °C
- Coldest six months Jan Dec Feb Mar Nov Apr
- Number of months warmer than 10.0°C mean = 6

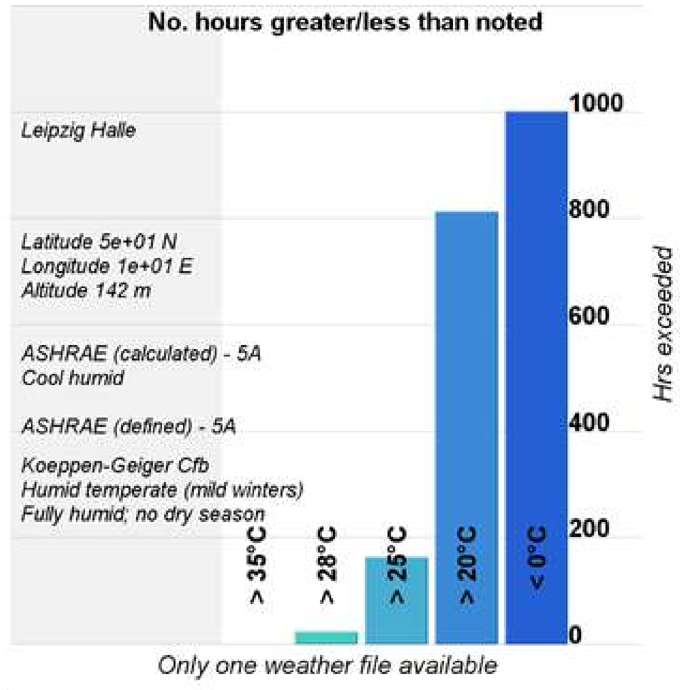
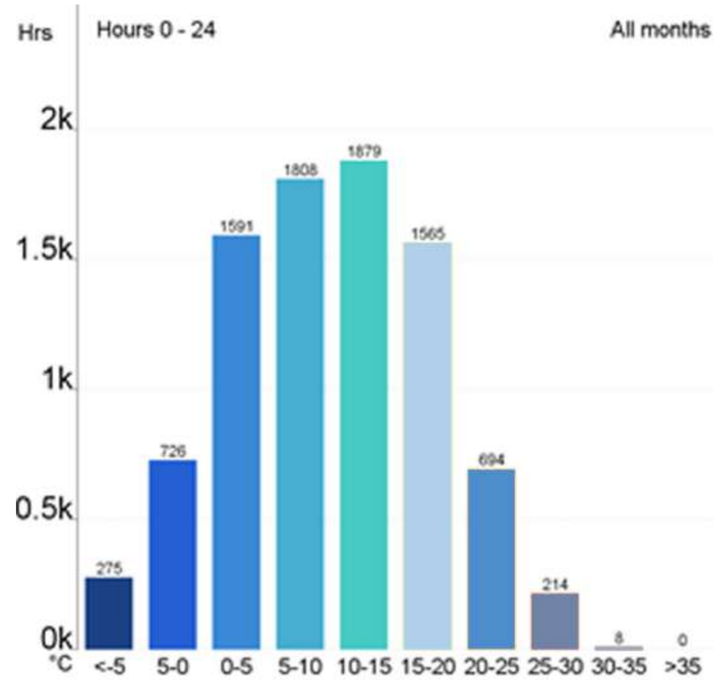


Figure 6.2 Temperature/hour ratio

6.5.2.2 Diurnal temperature swing

0 months swing > 20 °C, of which 0 are in the warmest 6M 0 months swing 15 to 20 °C, of which 0 are in the warmest 6M 1 months swing 10 to 15 °C, of which 1 are in the warmest 6M 9 months swing 5 to 10 °C, of which 5 are in the warmest 6M 2 months swing < 5 °C.



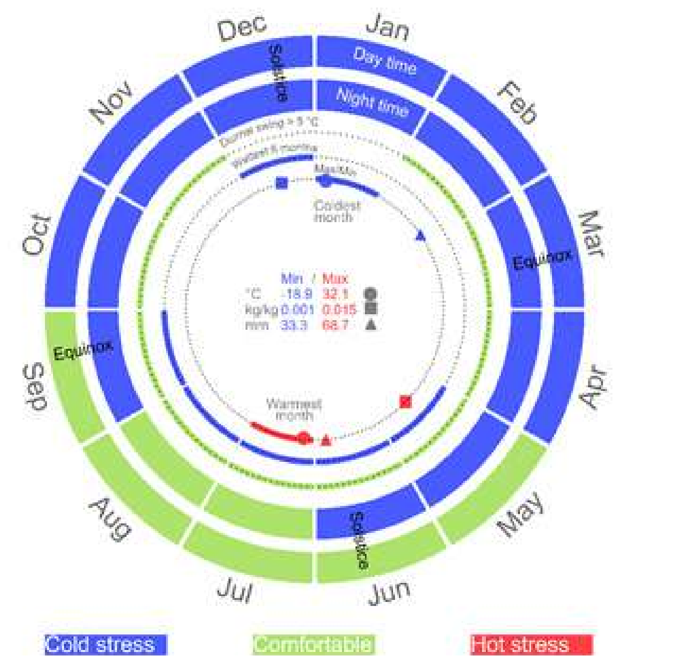


Figure 6.1 Temperature/hour ratio

6.5.2.3 Wind

Annual mean speed 4.7 m/s, Annual mean direction E of N 234.7.

6.5.2.4 Solar Energy

Annual hourly mean global radiation(a)130.9W/m2Meandailyglobal radiation(b) 3133.9 Wh/m2 Annual solar resource(c) 1147.0 kWh/m2 .yr Annual mean cloud cover(d) 5.4 oktas.

6.5.3 Natural Resources

- Annual solar resource 135 kWh/m2/yr.
- The position of this location (45 to 55 deg lat) means solar technologies are effective, although regional weather (cloud cover, humidity) can significantly reduce output.
- Annual mean wind speed 4.7 m/s.
- Annual weighted mean wind direction E of N 234.7°.
- Average wind speeds < 6.0 m/s means there is likely to be insufficient natural resource for standalone wind turbines.
- Average wind speeds < 6.0 m/s means there is likely to be insufficient natural resource for standalone wind turbines.

- Annual rainfall 571 mm.
- Annual rainfall > 500 mm indicates a climate with significant rainfall; dry seasons are possible.
- The baselines tested could deliver approximately.
- Solar 18% of annual building elec load.
- Wind 49% of annual building elec load.
- Rain 9% of annual building water load.

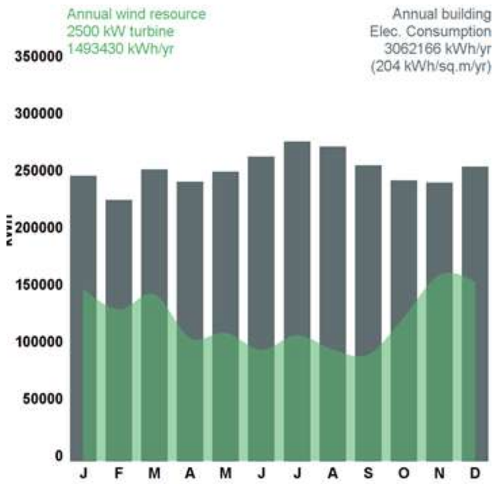


Figure 6.4 Annual wind resource

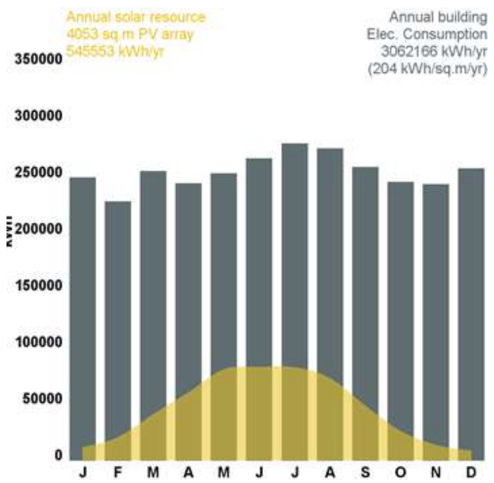


Figure 6.3 Annual solar resource

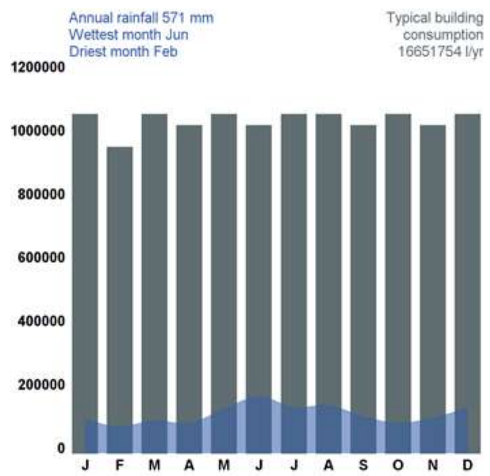


Figure 6.5 Annual rain fall

6.5.4 Climate Energy Index

The Climate Energy Index demonstrates the potential energy required in maintaining the CEI comfort zone based on climate alone excluding any consideration of building design or occupancy.The global charts graph the Climate Energy Index for the selected location and many global locations both for 24 hr and 9-5 hr occupancy for comparison purposes.

6.5.4.1 Global basket of climates

A summary is provided of extreme and average global locations on the charts and below.

kWh/yr	9-5 hours use	24 hour use
Extreme hot	30.93	78.28
Extreme cold	34.31	97.58
Benign	3.21	14.48
Average	14.52	42.44

6.5.4.2Monthly breakdown

The monthly breakdown chart illustrates the patterns of energy use (seasons) and the energy use breakdown. This is also summarised below.

kWh/yr	Hours in use
Sensible heating	9.93
Humidification	0.62
Sensible Cooling	0.06
Dehumidification	0

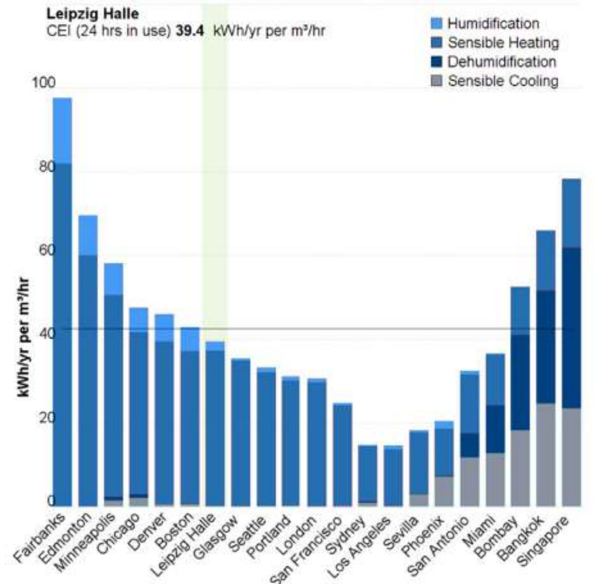


Figure 6.6 Used energy cities compration in 24 hours

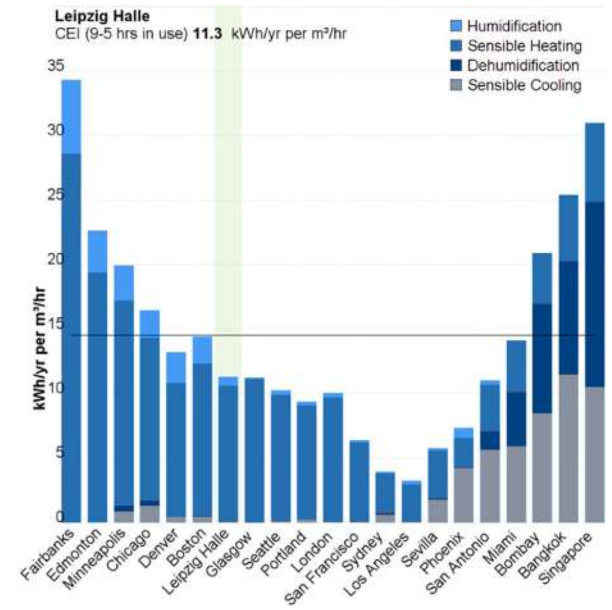


Figure 6.7 Used energy cities in 5-9 hours

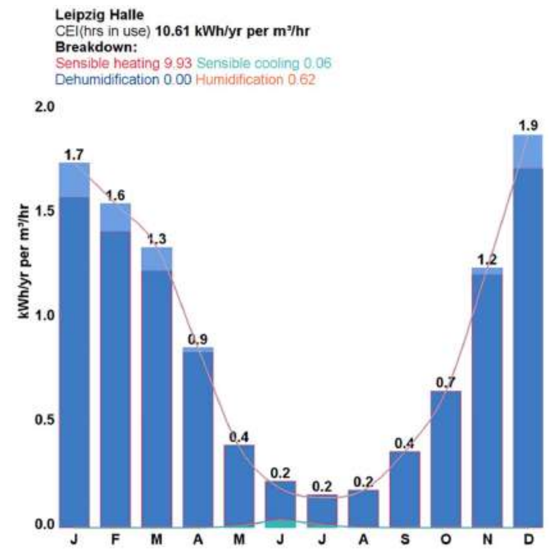


Figure 6.8 Use energy monthly

6.5.5Carbon reduction review

The selected technologies may not necessarily be utilized in combination. The choice of LZCT should be considered in the context of the preference hierarchy, the real use limit of each technology and in detail with a full load analysis.

6.5.5.1 Annual carbon emission analysis

Elements that together constitute the majority of emissions and therefore should be focused upon:

General electrical items	83.90%
Cooling demand	13.00%
Heating demand	3.20%

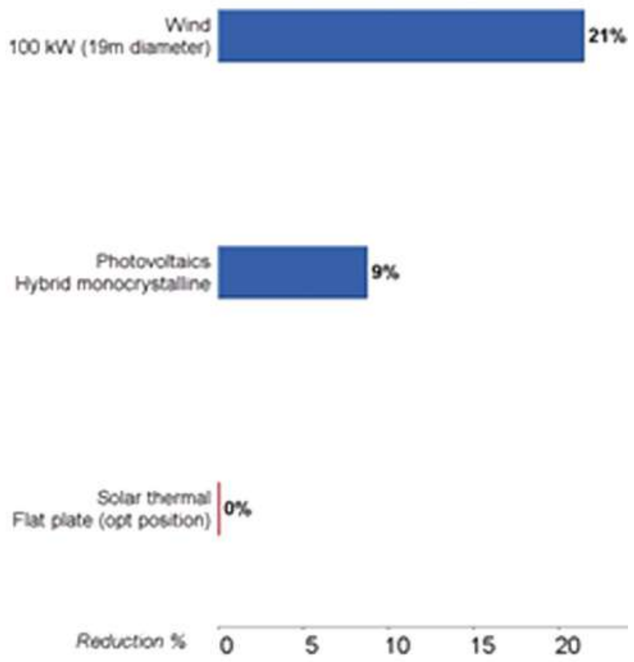


Figure 6.9 Energy reduction by using neutural resorces

6.5.5.2 Water Review

Proposed design for reducing water consumption:

WCs	Dual flush low flow	-1
Urinals	Waterless urinal, Auto Flush	(1.0), (0 / 50)
Hand Basins	Ultra low flow	-1
Sinks	Kitchen sink	-1
Cleaning Sink	Janitor sink	-1
Shower	Very low flow shower	-1

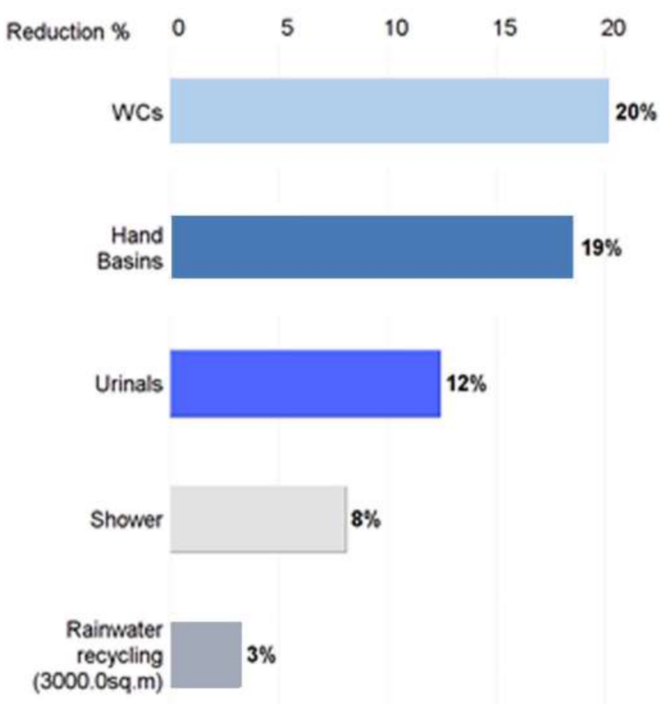


Figure 6.10 Water consumption reduction

6.6 HEATING AND COOLING LOADS

After all the data we insert in IESve, we export heating and cooling diagram.

6.6.1 Cooling load

In the charts below, you can see monthly and hourly cooling diagrams.

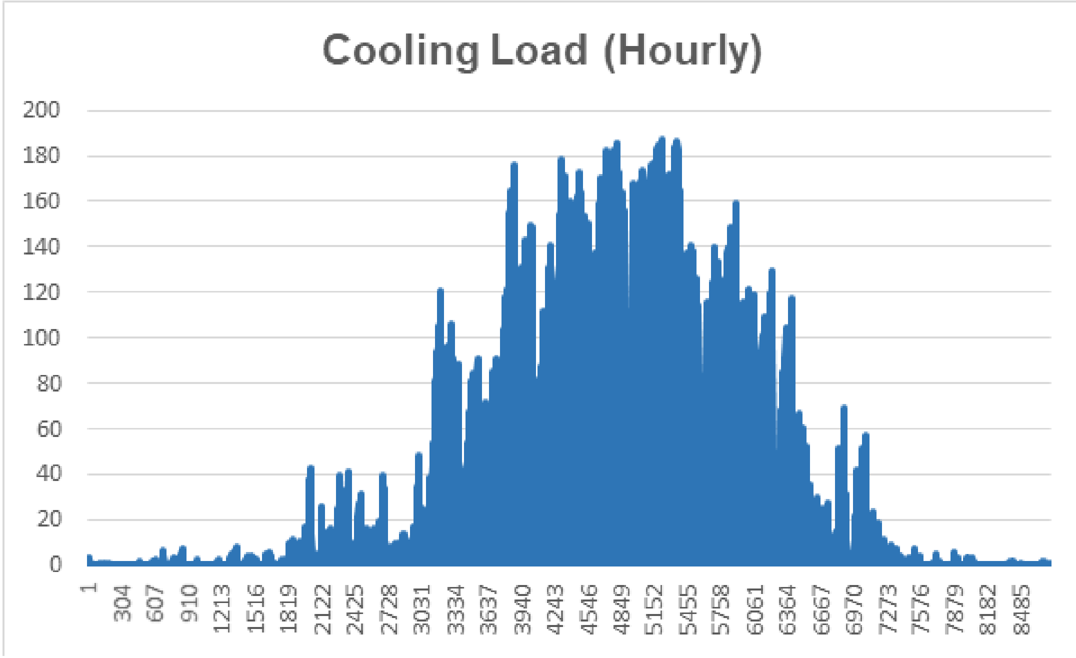


Figure 6.11 Cooling Load (Hourly)

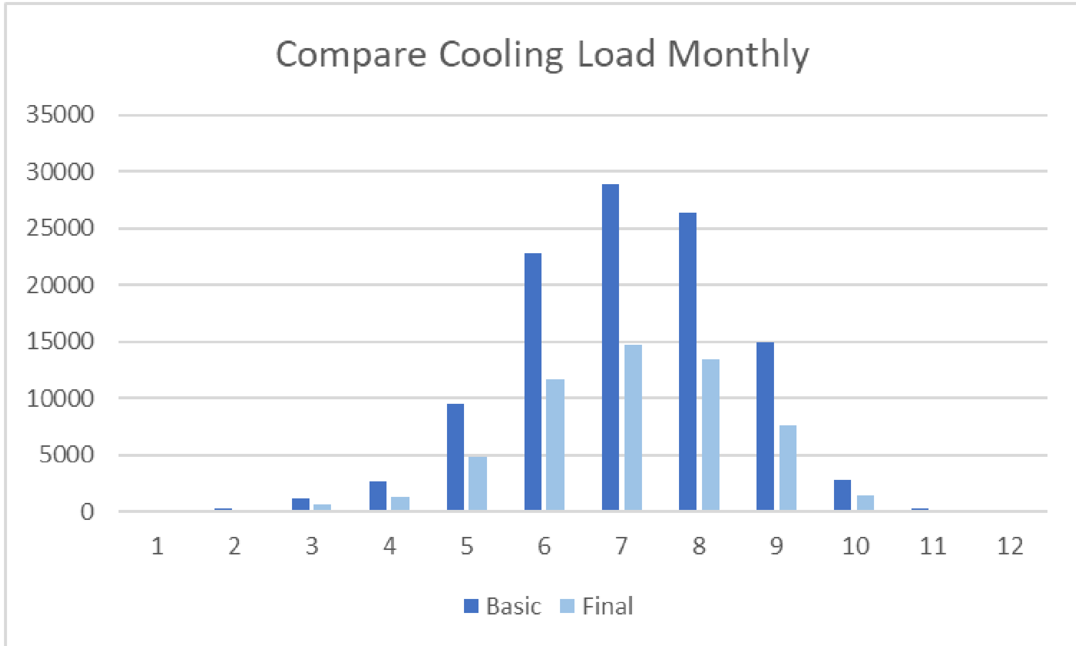


Figure 6.12 Cooling comparation (Monthly)

6.6.2 Heating load

In the charts below, you can see monthly and hourly heating diagrams.

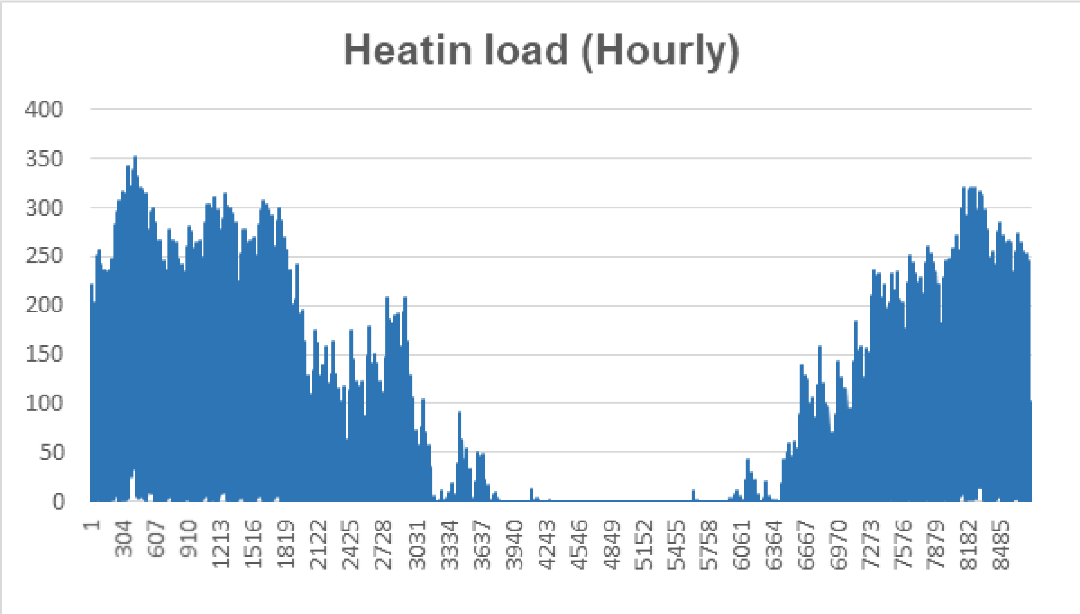


Figure 6.13 Heating load (Hourly)

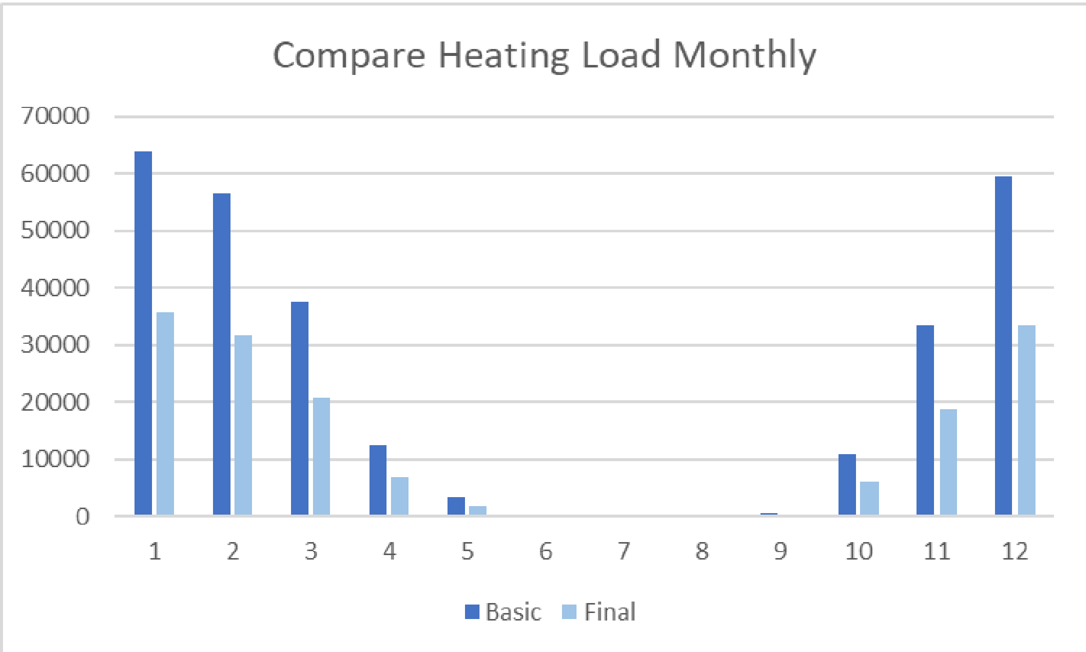


Figure 6.14 Heating comparation (Monthly)

By comparing the load in the Basic and Final model in the chart , we can see that the cooling load is 51% and the heating load is 56% reduced.

6.7 DAYLIGHT OPTIONEERING

The last step of the optioneering is integrated process that studies the impact of opening size, position and shading devices on both the thermal comfort and daylight. Two parameters will be adjusted to find the best solution in both fields:

- Windows to wall ratio: the fraction of transparent surfaces over the whole wall.
- Shadings: using vertical and horizontal shadings for reducing glare.

Both parameters are directly linked to architectural and structural topics. Regarding the structure, the openings should not exceed 50% of the wall in length according to the SADC ZW HS 983:2014 guidelines. The space in between them should be more than the width of the window itself. An adequate distance between the openings and the corner of the building should be kept to assure seismic resistance. The aim in this context is giving the importance of natural daylight in this context, the 55% limit of sDA must be reached by all the classroom. This is ok for all the classrooms and spaces but also it can be too high even with high potential of GDP if we go through this analysis, there may be the need to provide adequate shading devices. The glare potential (ASE) is a consistent problem in all the cases. High values are reached in all classes, way above 10% limit suggested by the LEED. The last step is providing net of bamboos around the Terraces to provide covered spaces and vertical shading to reduce the ASE as less as possible without reduction in the other factors.

6.7.1 Step 1

The first step of daylight analysis is the opening ratio of walls. We consider 4 types of opening ratios: 20%, 30%, 40% and 50%. In this step, we found that the best option due to the results of SDA and ASE is 40% for classrooms both on the west and east side (with 22-degree rotation). After that, we change the number of openings to the same percentage. In this case, the best result between the three options (1, 2, 3) is 2 in comparison to other options.

6.7.2 Step 2

The Second step is putting horizontal and vertical shading. These elements significantly decrease the ASE (glare), as the charts and tables show, the glare of classrooms without shading is too high. Even in the dormitory on the south part.

But in the north dormitory, we don't have any glare and SDA is not high, so we don't put any shading element on this area.

6.7.3 Step 3

The Last step is changing the length of shading in a critical area like south dormitories. The overhang length is 2 meters. We use 3 different shading sizes and mix the horizontal and vertical shading elements which we can see the results in the charts below.

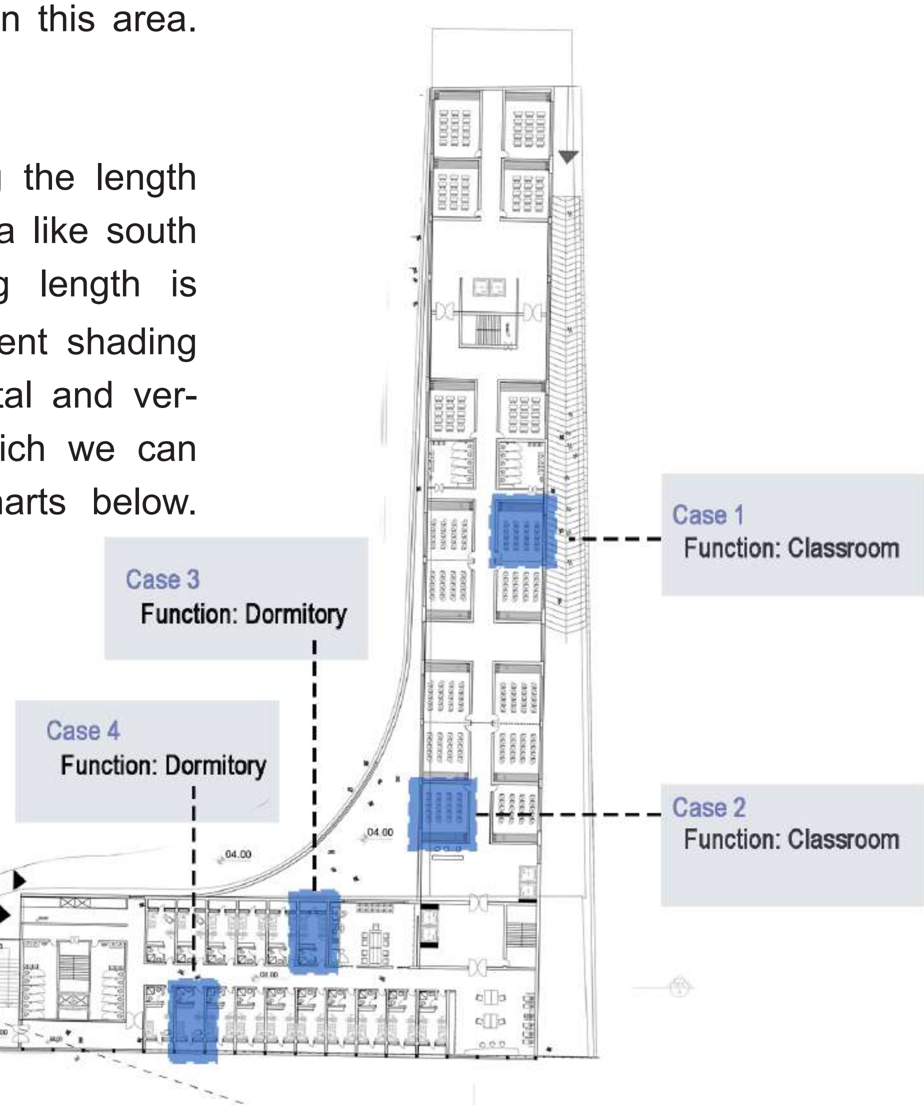


Figure 6.15 Daylight plan (cases)

6.7.4 Case 1

East classroom

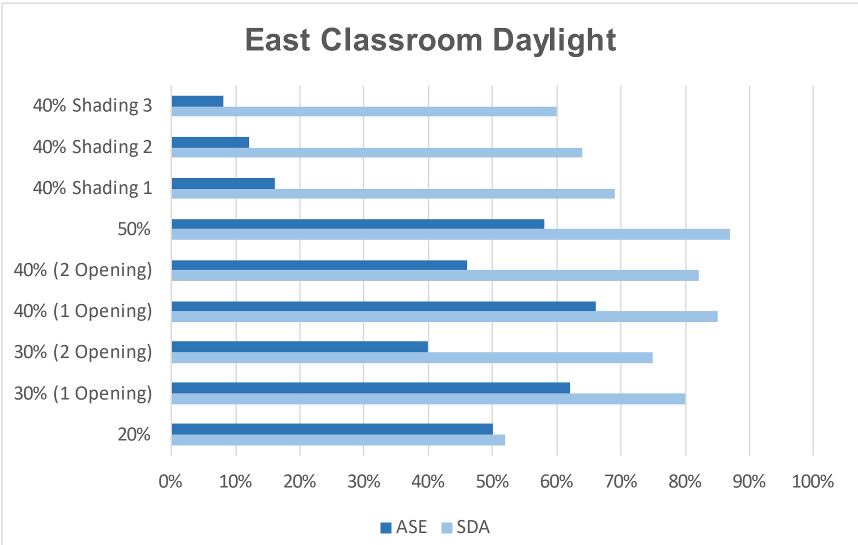
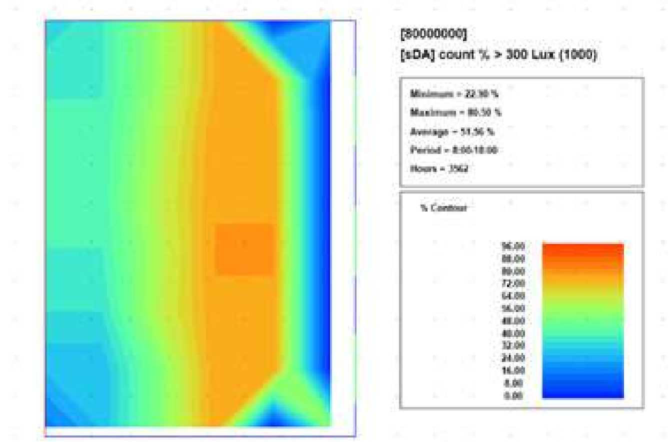
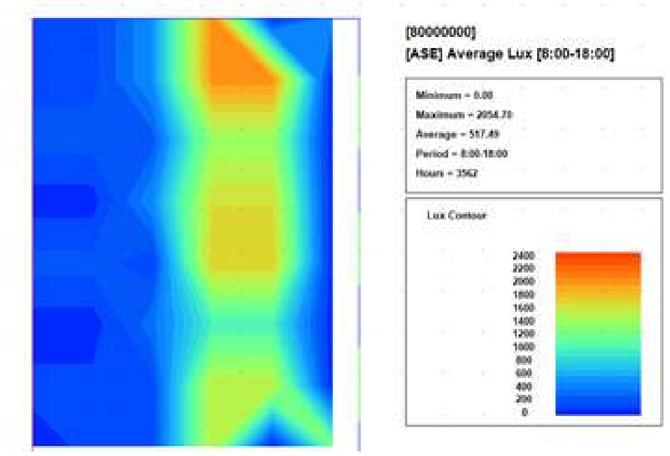


Figure 6.16 East classroom daylight

6.7.4.1 20% opening

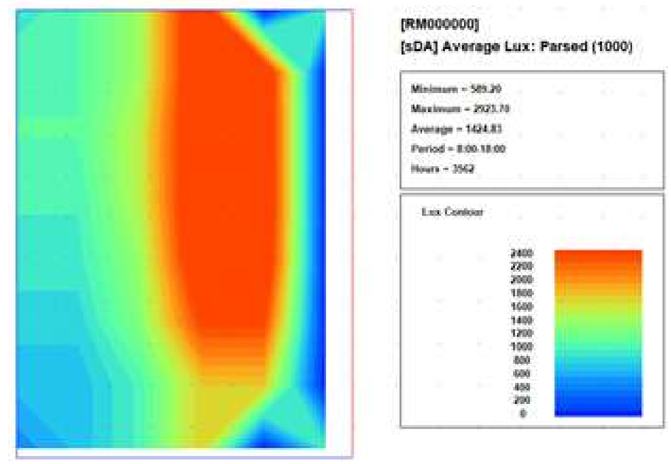


SDA: 52%

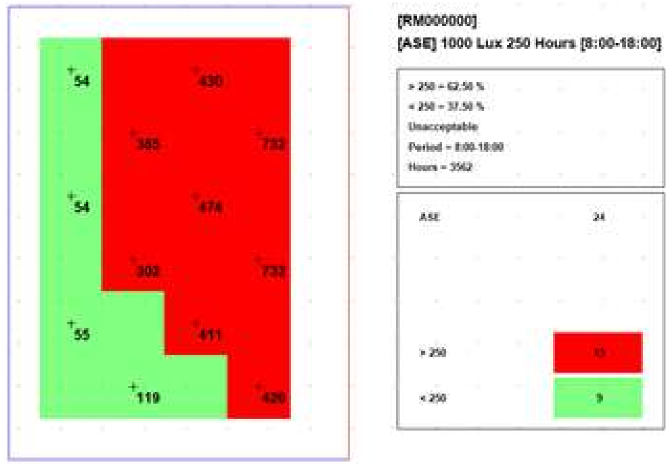


ASE: 50%

30% opening (one opening)

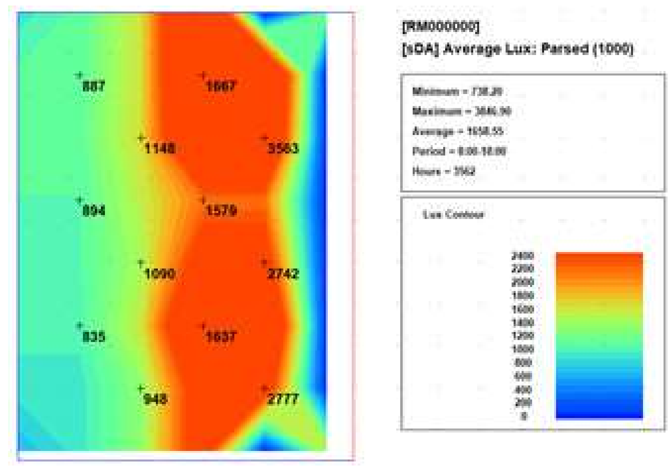


SDA: 80%

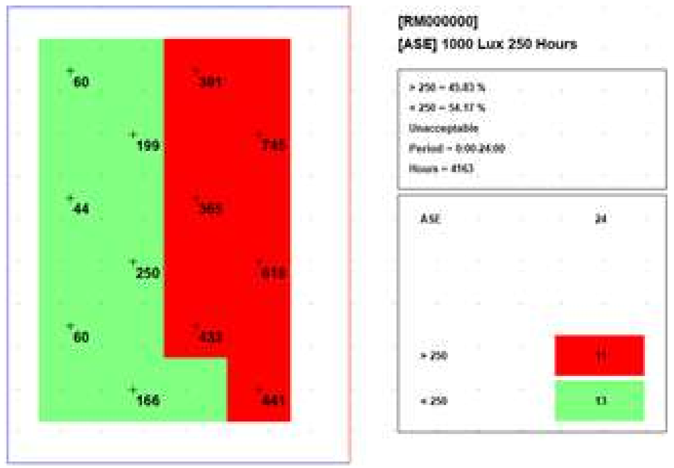


ASE: 62%

6.7.4.2 40% opening

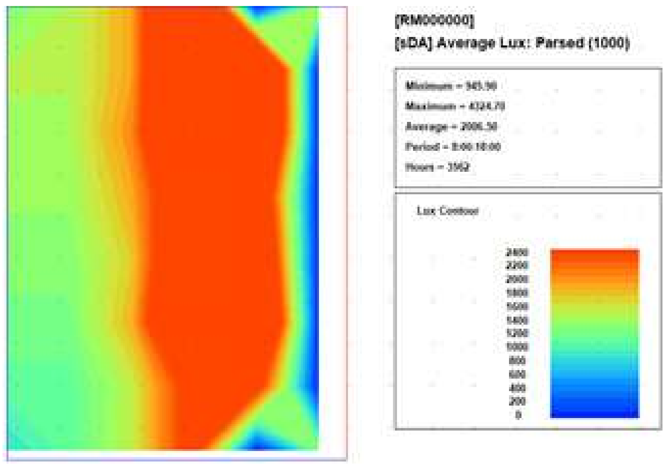


SDA: 82%

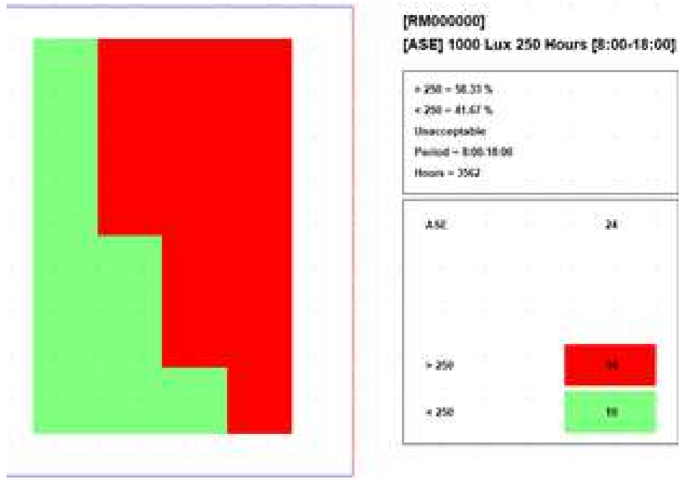


ASE 46%

6.7.4.3 50% opening



SDA: 87%



ASE: 58%

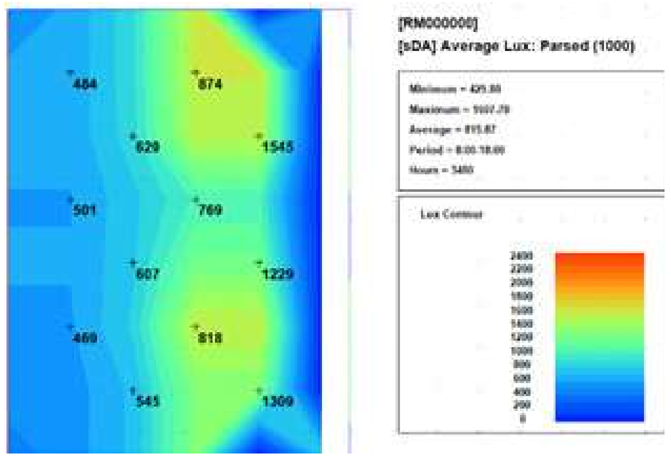
So the best result is the 40% opening wall ratio with 2 separate windows.

Now we are working on the shading part to make the ASE results better.

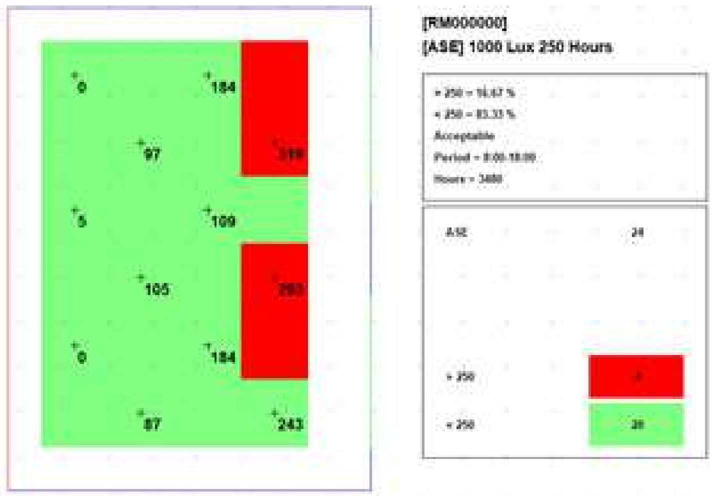
6.7.4.4 First Shading Option:

Horizontal shading 1.5m

40% opening



SDA: 69%

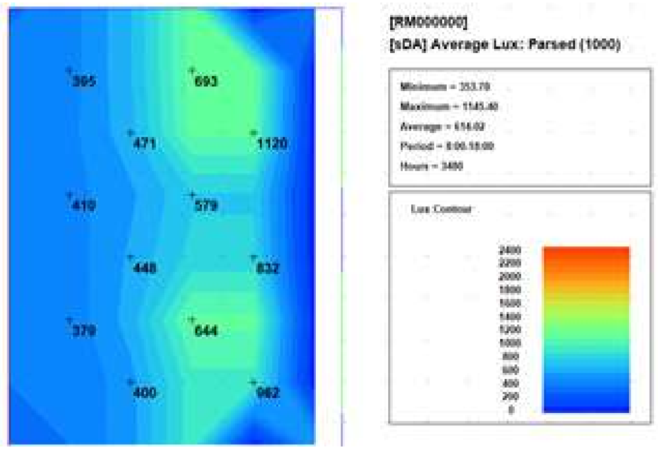


ASE: 16%

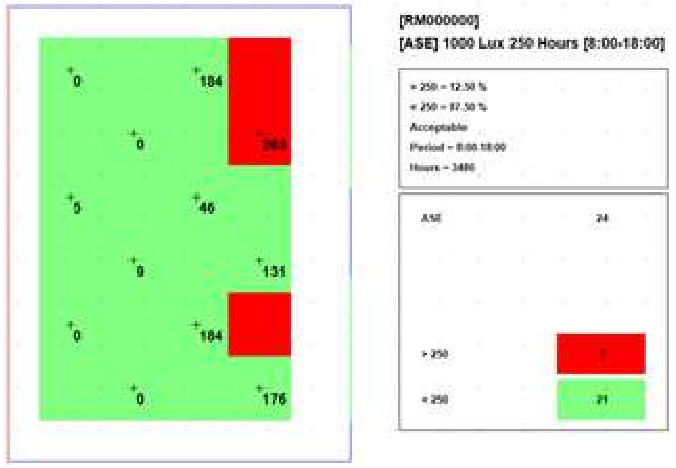
6.7.4.5 Second Shading Option:

Horizontal shading 1.5m
Vertical shading 1m

40% opening



SDA: 64%

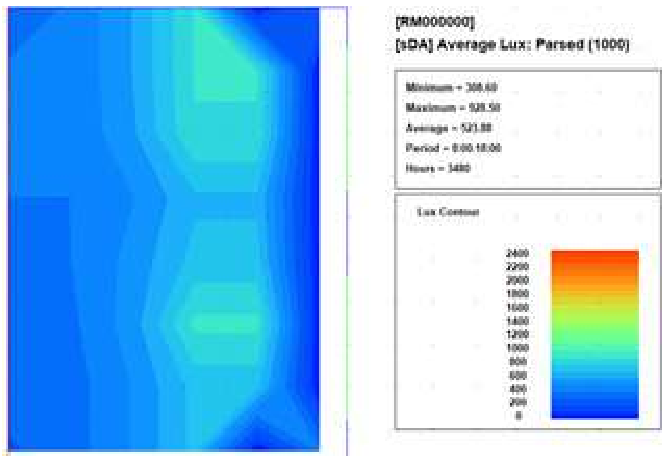


ASE: 12%

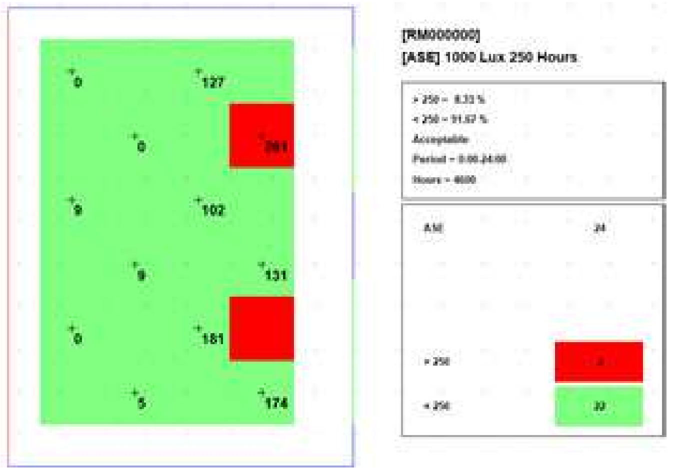
6.7.4.6 Third Shading Option:

Horizontal shading 2m
Vertical shading 1m

40% opening



SDA: 60%



ASE: 8%

6.7.5 Case 2

West classroom.

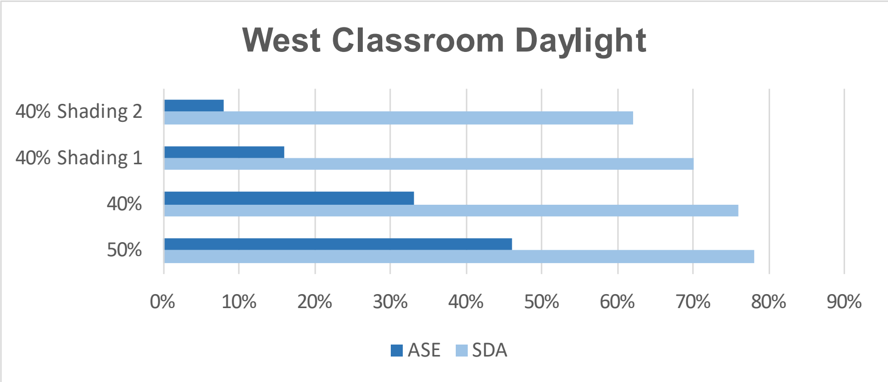
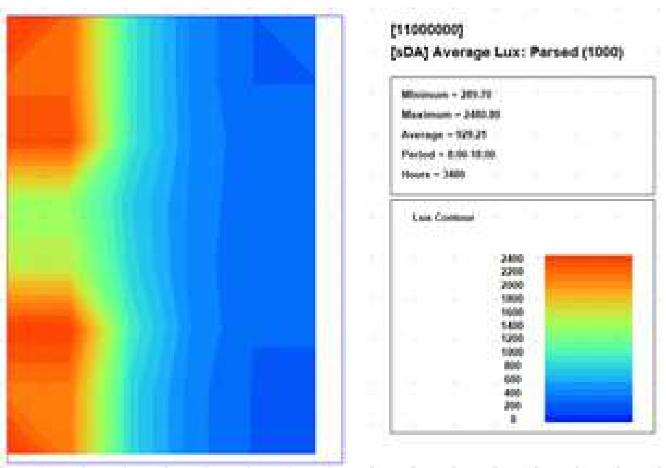
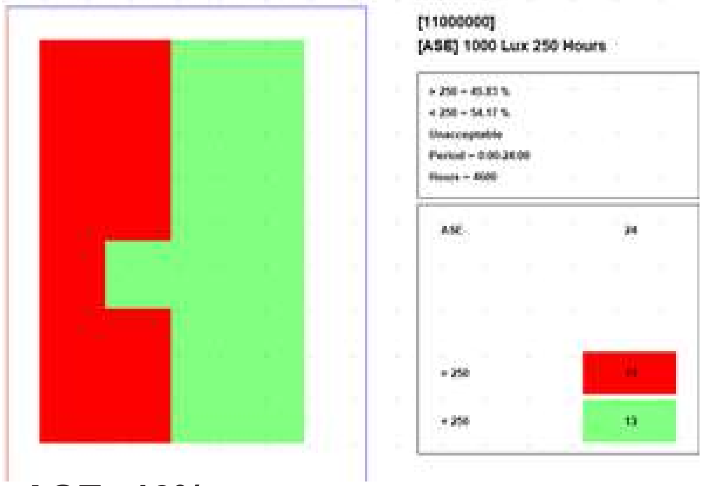


Figure 6.17 West classroom daylight

6.7.5.1 50% opening

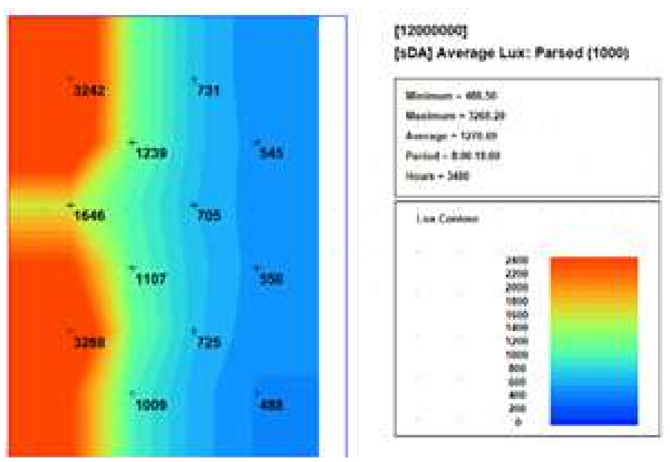


SDA: 78%

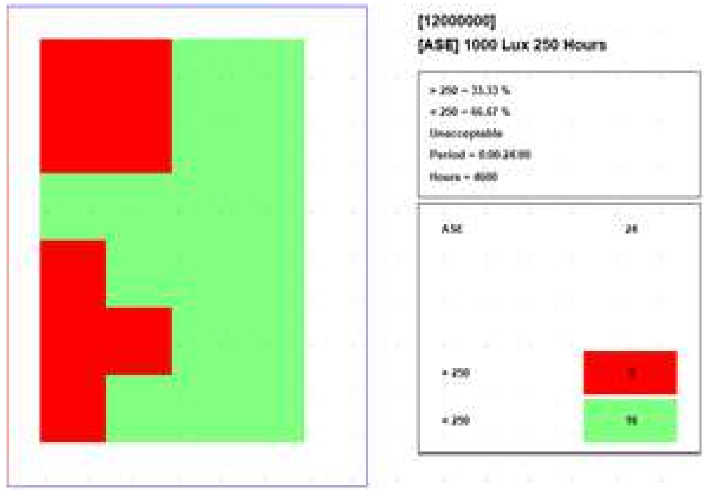


ASE: 46%

6.7.5.2 40% opening



SDA:76%

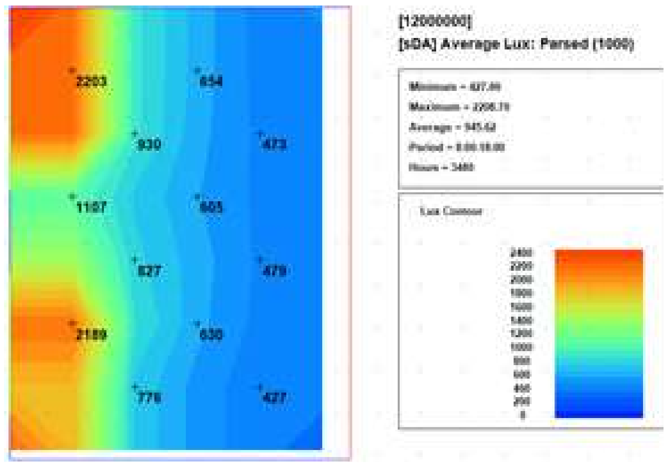


ASE: 33%

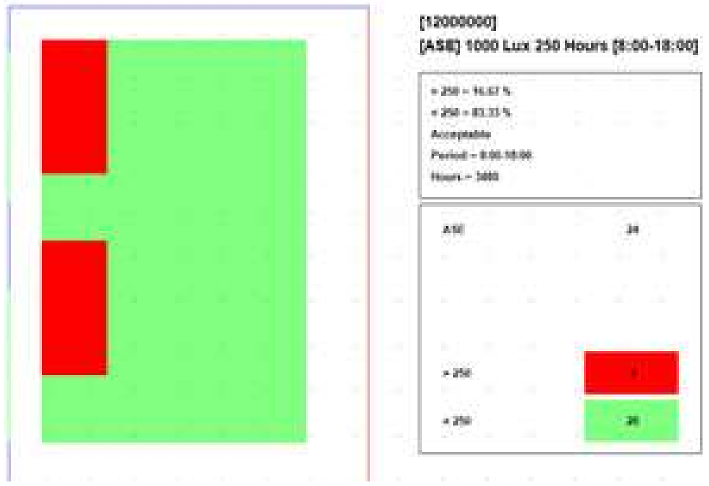
6.7.5.3 First Shading Option:

Horizontal shading 1.5m

40% opening



SDA: 70%

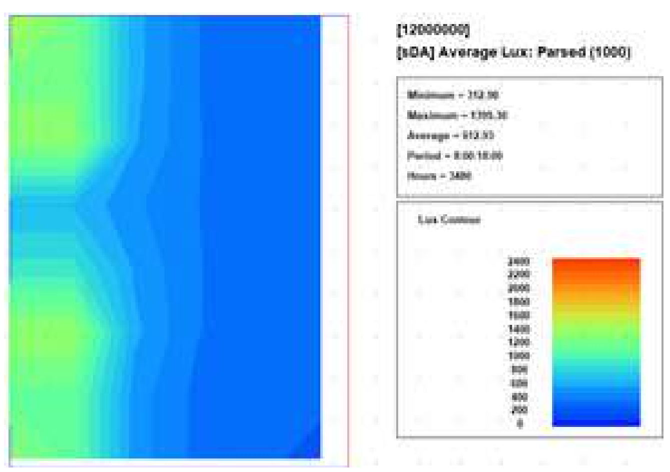


ASE: 16%

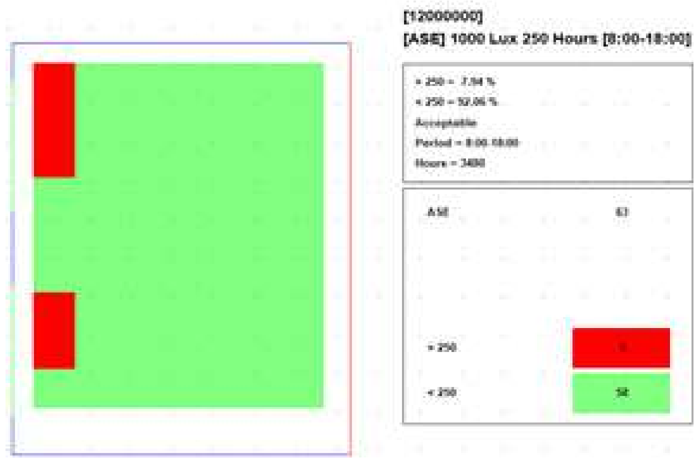
6.7.5.4 Second Shading Option:

Horizontal shading 1.5m
Vertical shading 1m

40% opening



SDA:62%



ASE: 8%

6.7.6 Case 3

North dormitory.

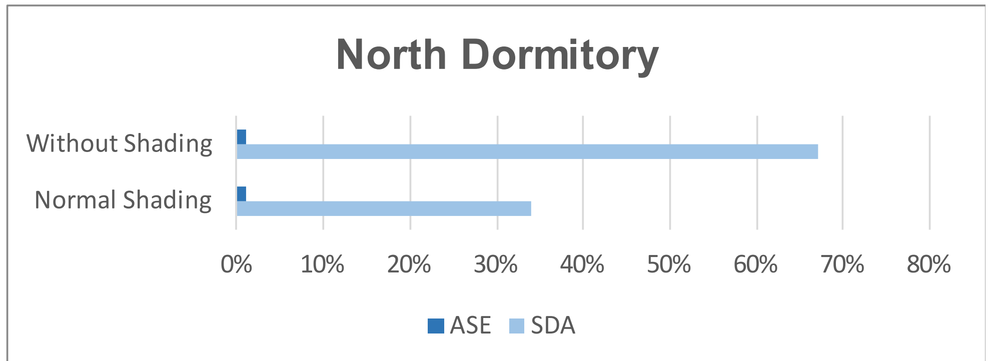
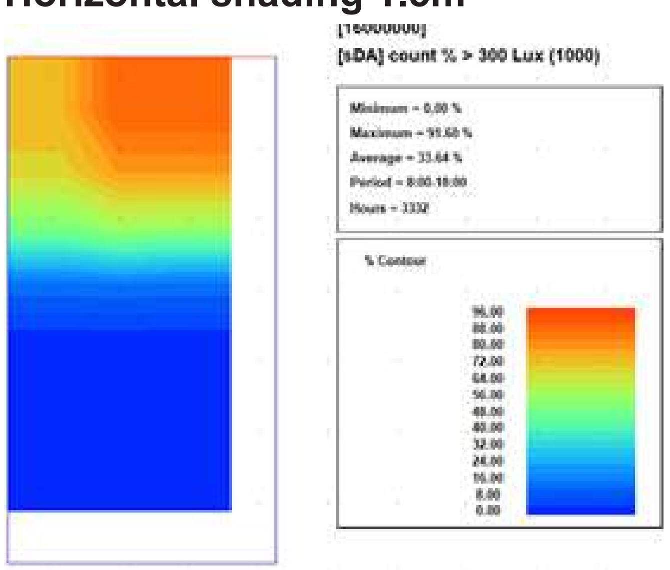
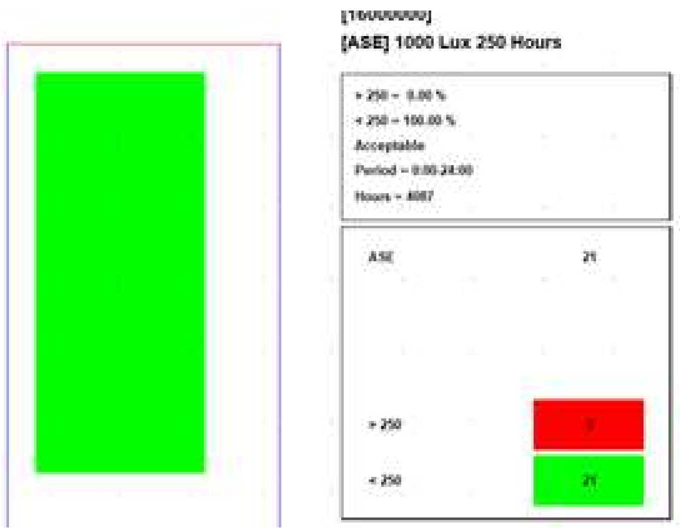


Figure 6.18 North dormitory daylight

6.7.6.1 First Shading Option:

Horizontal shading 1.5m



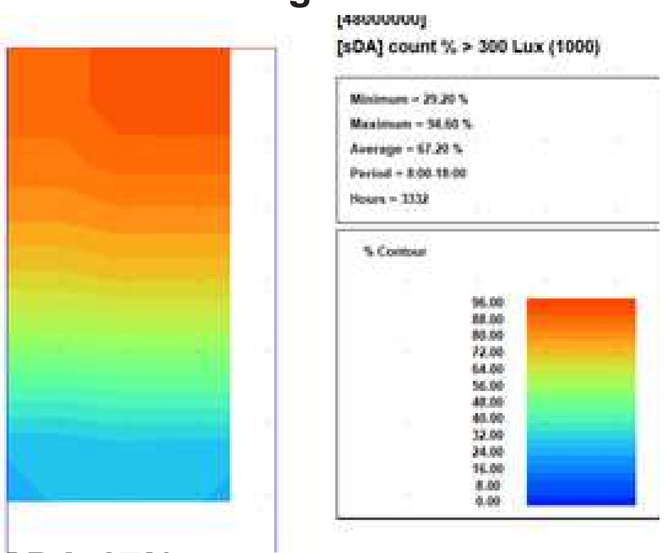


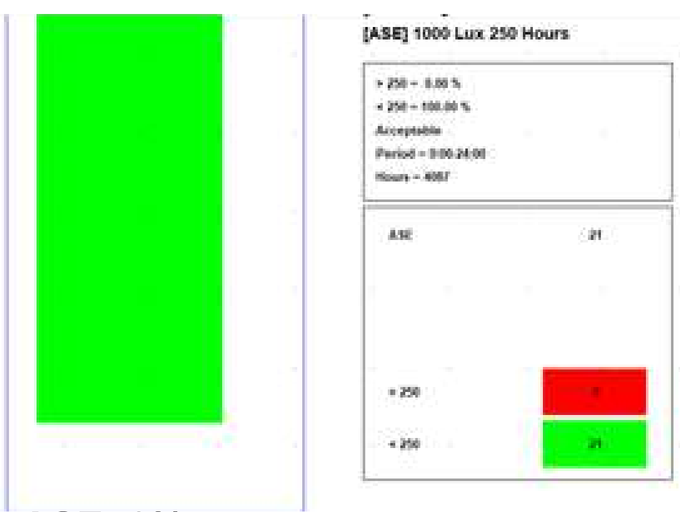
SDA:34%

ASE: 0%

6.7.6.2 Second Shading Option:

Without shading





SDA:67%

ASE: 0%

6.7.7 Case 4

South dormitory.

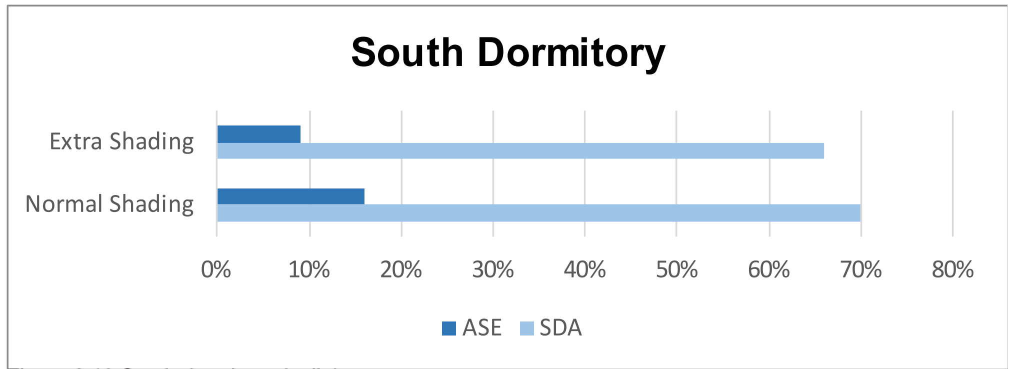
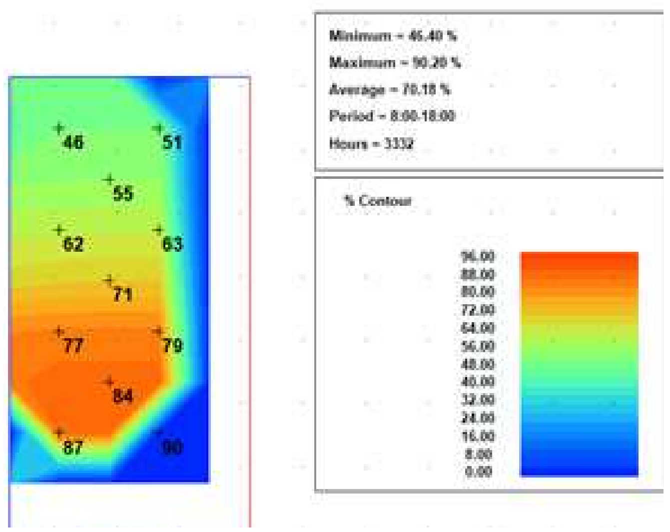
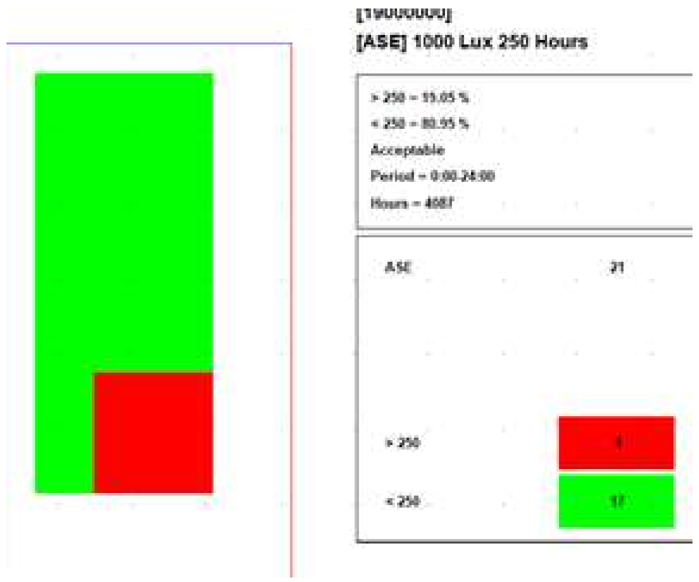


Figure 6.19 South dormitory daylight

6.7.7.1 Horizontal shading 1.5m

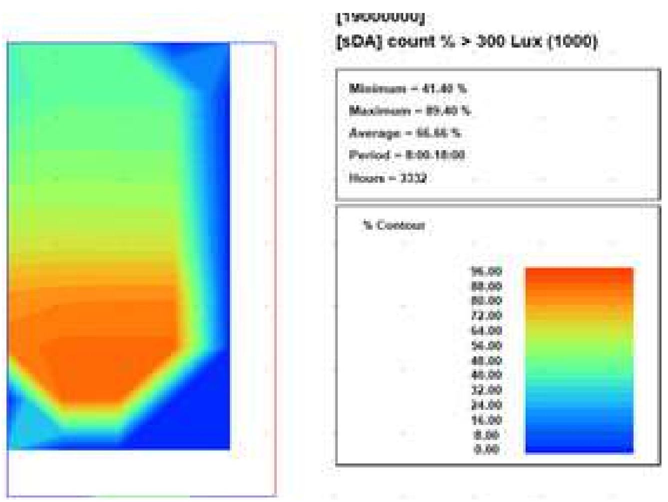


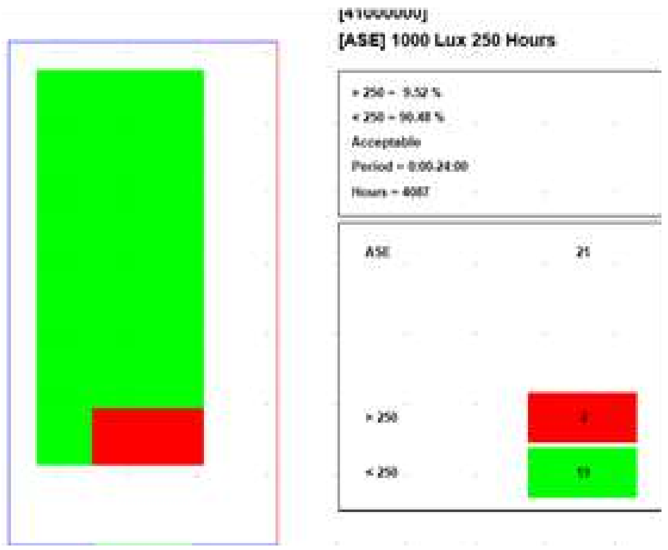


SDA:70%

ASE: 19%

6.7.7.2 Horizontal shading 2m





SDA:66%

ASE: 9%

CHAPTER 07
STRUCTURAL CONCEPT

7.1 CHOOSING THE CONSTRUCTION MATERIAL

Choosing the most appropriate structural system, as the bone of the building, is always an imperative and influencing step in the design process. There are several aspects to have in mind while deciding about structure, for example building function, site location, climate condition, building geometry, architectural considerations, manufacturer desire, local codes and regulations, etc.

Talking about this project, except mentioned aspects, some other factors also effect on material selection. In order to meet the needs of today and future generations and to build without harmful environmental and social impacts, sustainability considered a main factor in the whole building life cycle including the production of construction materials and building components. In this regard some other important aspects are; reduce carbon emission, environmental-friendly material, low waste-producing, durable, providing healthy and comfortable living conditions for occupants, high thermal behaviour.

After the rejection of other possibilities, cross laminated timber precast concrete, and steel, were investigated and their properties were compared in order to choose the best possible type of structure that can meet the needs of the building. teristics was adopted to the building.

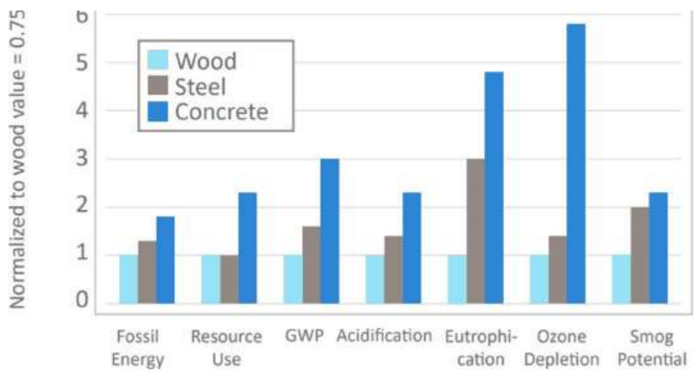
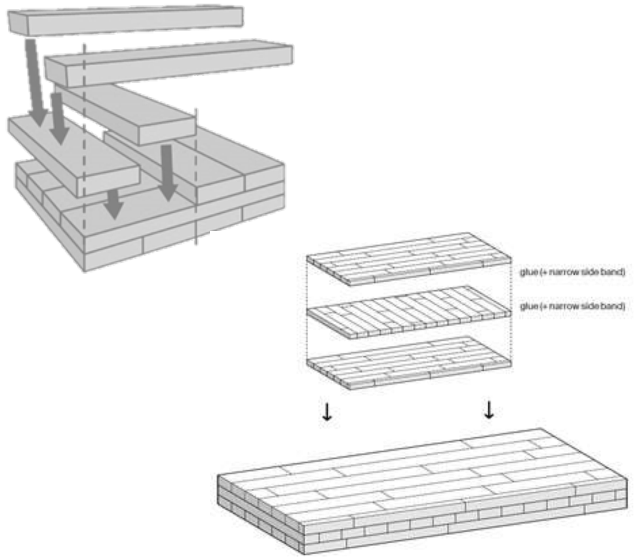


Figure 7.1 Comparing environmental impact of wood steel and concrete home (source: Dovetail partners using the Athena Eco-Calculator, 2014)

Finally, CLT structure, due to its specific characteristics was adopted to the building.

- CLT material also leads to a long service life and high-quality life cycle, due to:
- Shorter life time components are designed for replacement
- Long-term maintenance
- Load-bearing CLT structures located on the inside of the thermal insulation layers and thus protected from outdoor climate impacts
- High quality construction of the building, building elements and components



7.2 CLT

7.2.1 Definition

Cross-Laminated Timber (also known as CLT or X-Lam) is an innovative recent developed technology. It is a load-bearing wooden product made of multi layers of two-dimensional, solid timber elements, which are glued together on their surface, creating massive panels that are arranged in a box shape by using steel connections. Element can resist both vertical and horizontal loads and are completely prefabricated for walls, roofs and ceilings installations.

7.2.2 Manufacturing

CLT is a massive wood construction product consisting of bonded single-layer panels arranged at right angles to one another. Endless lamella strings are being created by finger joints. On request the cross layer can be edge glued. These single layer boards are being composed to a CLT panel, using face gluing, between each single layer board. Usually, the direction of the grain in the single layer boards are perpendicular to the adjacent layers. Top and bottom cover layers are usually oriented in the same direction.

Each layer is composed by several of 80-140 mm width which are combined together using polyurethane white glue or aluminium nails. According to the building's structural need the thickness and also the number of layers can vary but it should be at least three layer to ensure an effective mechanical property.

The most used row wood spicy is spruce wood of strength C24, the other common species are fir, pine, larch and Douglas fir.

- CLT structures are as resistant as other materials such as: concrete, steel and cement, but with notably lower weight.
- CLT system is the best choice for the buildings up to 10 floors, specifically is the best option for "green building" constructions.
- CLT layers are bonded with environmentally-friendly adhesives.

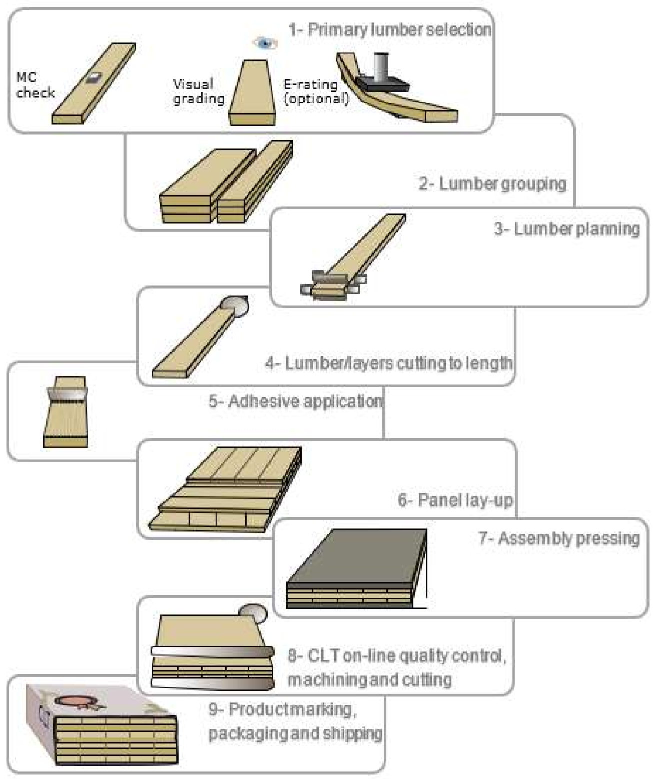


Figure 7.2 Manufacturing of CLT panels

According to the "Stora Enso" CLT company Handbook some main data is mentioned .

Application	Structural elements for walls, floors and roofs
Maximum dimensions	Length: 16 m / Width: 3.45 m / Thickness: 0.35 m
Invoiced widths	2.25 m / 2.45 m / 2.75 m / 2.95 m / 3.25 m / 3.45 m (on request up to 3.90 m)
Panel lay-up	3, 5, 7 or more layers depending on structural design requirements
Wood species	Spruce (pine, fir, stone pine/larch and other wood types on request)
Strength class	C24 according to EN 338, maximum 10% C16 permitted (other strength class compare with ETA 14/0349)
Moisture content	12% +/-2% on delivery
Adhesive	Formaldehyde-free PUR adhesive for finger jointing and surface bonding, approved for load-bearing and non-load-bearing components indoors and outdoors according to EN 15425; Formaldehyde-free EPI adhesive for narrow side bonding
Surface quality	Non-visual quality (NVI), Industrial visual quality (IVI) and Visual quality (VI); the surfaces are always sanded on both faces
Weight	5.0 kN/m³ according to DIN 1055-2002 for structural analysis 470 kg/m³ for determination of transport weight
Fire rating	In accordance with Commission Decision 2003/43/EC: Timber components (apart from floors) e Euroclass D-s2, d0 / Floors e Euroclass Dfl-s1
Thermal conductivity	0.12 [W/m2K]
Air tightness	CLT panels are made up of at least three layers of single-layer panels and are therefore extremely air-tight. The air-tightness of a 3-layer CLT panel was tested according to EN 12 114
Service class	Service class 1 and 2 according to EN 1995-1-1

Figure 7.3 Summary data of CLT

7.3 CLT CHARACTERISTICS

7.3.1 Environmental aspects

7.3.1.1 Sustainability

Wood is a renewable resource, which makes it more sustainable than any other construction materials. At end of their lifecycle, wood products can be re-used, recycled or used as none fossil fuels for energy production. Sustainability is also confirmed by the ISO 14000 LCA assessment.

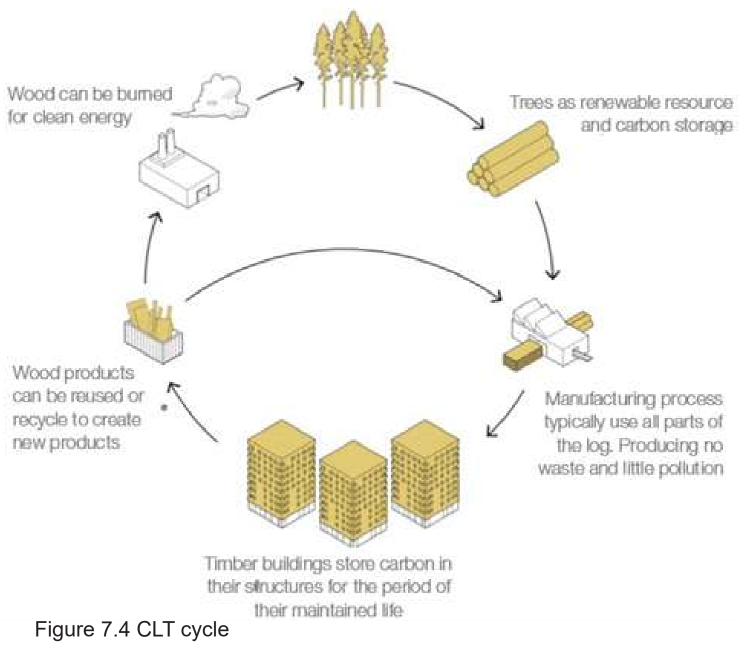


Figure 7.4 CLT cycle

7.3.1.2 CO2 Emission

Wood construction plays an increasing role in global warming mitigation as it helps to reduce the fossil carbon emissions. Wood construction materials store an amount of carbon and so wooden buildings are carbon storages during their lifetime. In comparison with concrete and steel, CLT has much lower energy use, and require less amount of water. It not only has lower carbon emission, but also convert CO2 into biomass by photosynthesis process.

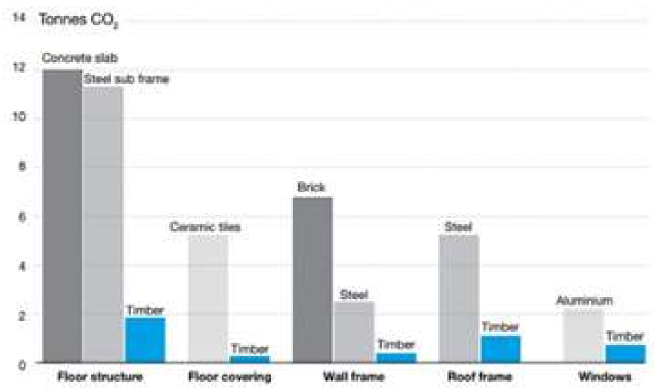


Figure 7.5 CO2 emission of different materials

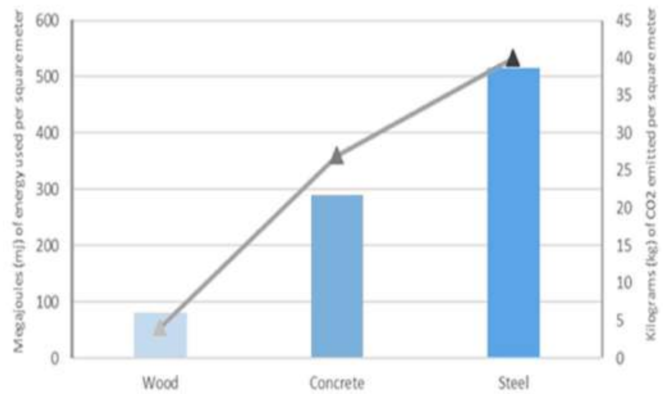


Figure 7.7 Energy use and carbon emission of building materials

7.3.1.3 Waste production

Due to prefabrication method of CLT, not only its waste production on site is very little, but also in the case, the waste materials can be reuse and recycle again.

7.3.2 Construction

7.3.2.1 Assembly time

Due to high level of prefabrication and dry assembly, CLT structure can be installed in shorter time compare to other kinds of structures. The components arrive on-site as a kit of parts, so it requires less storage.

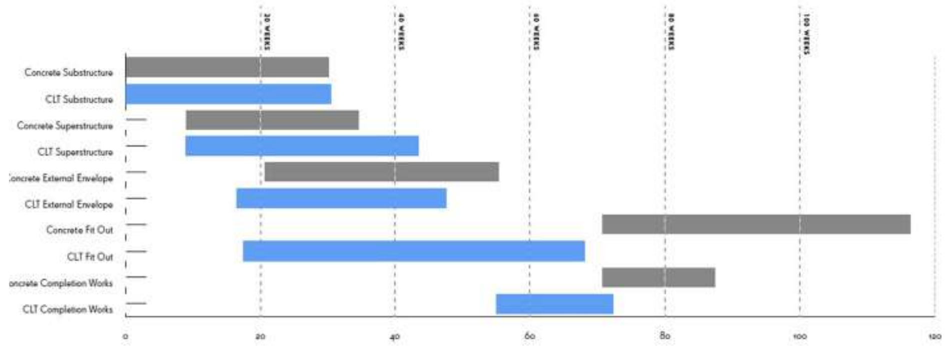


Figure 7.6 The Gantt chart of the approximate program adjustments for a CLT scheme compared to traditional reinforced concrete build

7.3.2.2 Quality

Since prefabricated CLT panels are controlled under industrial process, it makes it easier to better monitoring the whole process of producing and installing the products and to the higher quality of the final structure.

7.3.3 Durability

7.3.3.1 External exposure

Wood is a sensitive material and especially exposure to sun radiation, water (humidity), and biological agents (insects, fungi, moulds) may cause degradation. It is therefore very important to protect the material against external environment. Wood naturally tends to be in hygrometric equilibrium with its environment. After the proper drying process of structural timber, the relative humidity will decrease up to a level with no more risk of insects, moulds, and so on. in order to protect against sun exposure, the CLT panels will be covered by a series of membranes and barriers in the final technological stratigraphy.

7.3.3.2 Seismic behaviour

CLT structures are lower susceptible and more strength and durability against seismic forces. That is due to lightweight property, good traction and compression resistance, deformability (elastic modulus parallel to the fibres is smaller than the one of concrete).

7.3.3.3 Fire resistance

charring rate of structural wood is very low, according to [EN1995-1-2] it is 0.65 mm/min. under burnet layer CLT structure can resist efficiently strong and the smoke is not toxic. Also, in compare to steel, timber has shown more strength during the fire.

Figure 7.8 Fire resistance of CLT/ Outside layers of the sample are burnt while the inner core is still efficient from the structural point of view

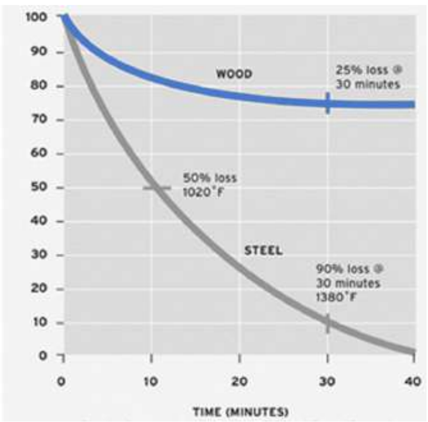


Figure 7.9 Comparative strength loss of wood vs steel

7.3.4 Comfort and health

7.3.4.1 Thermal comfort

Thermal 'sensation' is a parameter that reflects the thermal comfort in a building. Timber has a low thermal conductivity which determined by its bulk density and wood moisture content and can be calculated for CLT with a value of λ = 0.12 W/ m²K. So, it helps in improving the U-value of the envelope.

Thermal 'sensation' is a parameter that reflects the thermal comfort in a building. Timber has a low thermal conductivity which determined by its bulk density and wood moisture content and can be calculated for CLT with a value of λ = 0.12 W/ m²K. So, it helps in improving the U-value of the envelope.

In term of indoor climate, Cross laminated timber is dried to very low timber moisture values and has the capacity to absorb and buffer moisture from the surrounding room air. It therefore can provide a good thermal situation, without any moisture risks to have a comfortable and healthy atmosphere in the room.

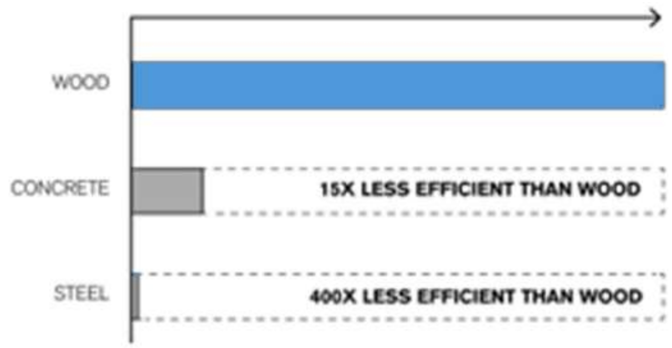


Figure 7.10 Thermal efficiency of different materials

7.3.4.2 Acoustic insulation

Providing adequate soundproofing is an important factor to ensure well-being in buildings. There are two types of noise in the buildings: Airborne sound which comes from traffic, voices or music, etc. and Structure-borne sound which comes from walking, banging, scraping furniture, etc. With CLT panels due to the elasticity and porosity of the wood, vibrations are less propagated and both kinds of sound diffusion are reduced in the building.

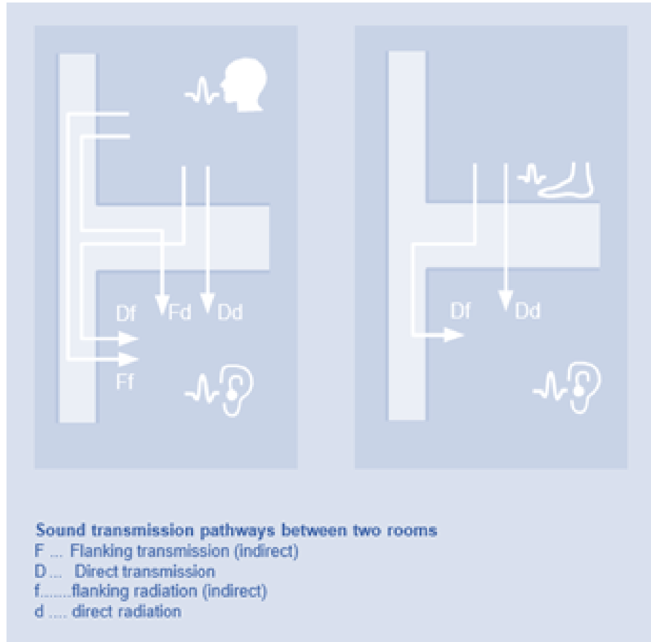


Figure 7.11 Soundproofing of CLT

7.3.4.3 Air-tightness

An air- and wind-tight building envelope prevents the penetration of damp air and is an essential requirement for an energy balance of buildings and quality and durability of the building's structure. The CLT elements naturally and due to preparing method have a great level of air-tightness and im-permeability.

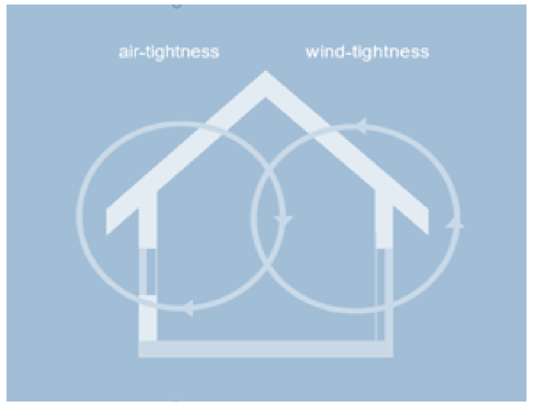


Figure 7.12 Air-tightness of CLT

7.4 CLT STRUCTURAL CONSIDERATION

In order to better adaption of CLT into the building structure some considerations must be noticed.

-Architectural considerations: Typology and scale of the building, unit and room layouts, customer demands or local market factors.

-Engineering considerations: Local performance requirements (acoustics, fire protection, thermal insulation, etc.), local code requirements (defined by relevant building authorities).

-Vertical load transmission and building bracing simultaneously.

-Horizontal forces are transferred through vertical shear walls into the foundations.

-Elements connect together with simple solutions.

-Biaxial state of floors (edge clamping of floor elements) leads to more reserve.

7.4.1 Mechanical behaviour evaluation

-The element with a mono-dimensional calculation: associate a value of effective inertia to the panel due to the different properties of the perpendicular layers, get the stresses inside the different layers.

-The element as a plate: distributing the loads in the two directions.

-The element as a sheet: walls are tolerating both the axial forces and the lateral forces, The rigidity is a combination of the different layers' properties

7.4.2 Load-bearing demonstration

CLT is made up of multi-layer solid wood, the overlapping of battens crosswise (orthogonal) layers avoid the shrinkage, that for wood is much greater in the longitudinal direction and very low in the transversal one, swelling and warping of the wood. The main direction (parallel to the top layer, as 0°) of load-bearing capacity is the one with higher stiffness, and the auxiliary direction (perpendicular to the top layer, as 90°) is the one with lower stiffness.

To calculate load baring performance only the layers with higher stiffness are included. The transverse layers are not assigned longitudinal stress, and usually the modulus of elasticity for transverse fiber is assumed with $E_{90} = 0$. In particular, the rolling shear failure ($F_{VR,k}$) occurs in the transverse layer since they are considered as pure spacers and are only subject to shear.

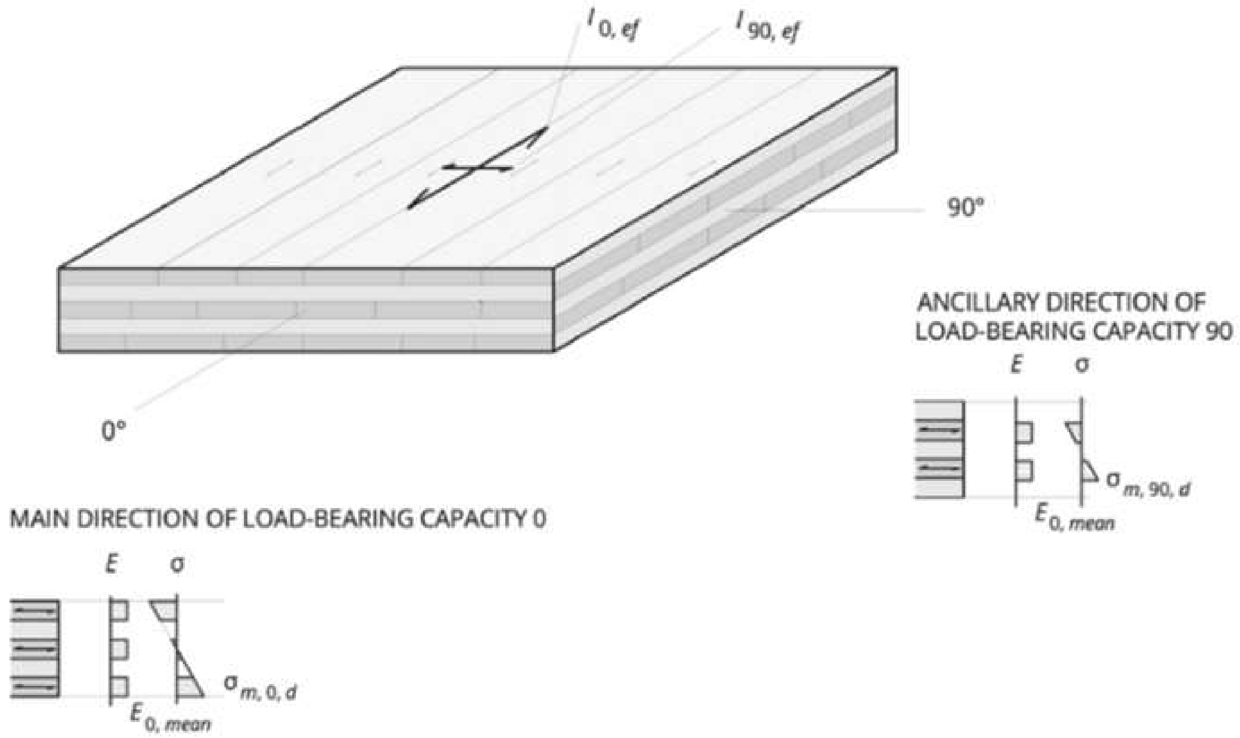


Figure 7.13 Cross-laminated timber element with main and auxiliary direction of load-bearing capacity

7.5 BUILDING GEOMETRY

The dimentions and configuarion of the building is as follows:

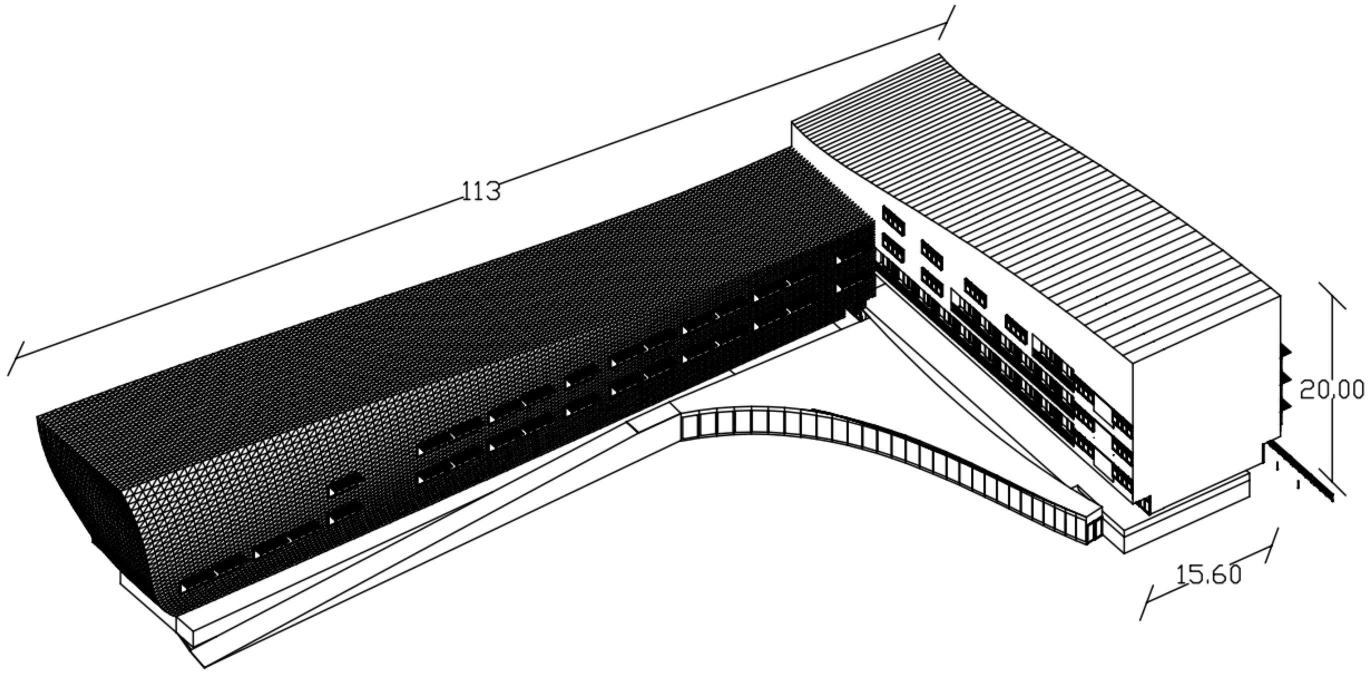


Figure 7.14 Building geometry

7.6 CALCULATION REFRENCES

In order to define the safety and resistance of the building the specific codes and regulations of European and Germany norms are considered to justify the coefficients and methods used for the following calculations.

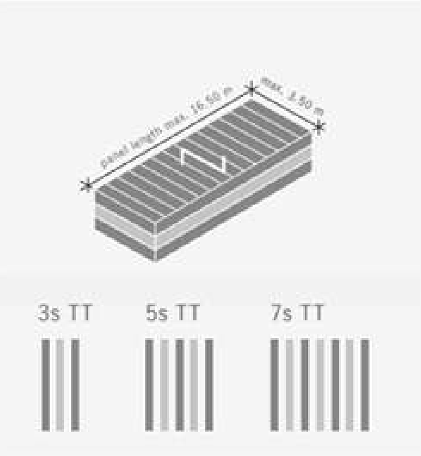
Code	Regulation
EN 1990	EN 1990 - Eurocode — Basis of structural design
EN 1991-1-1	Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings
EN 1991-1-3	Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads
EN 1991-1-4	Eurocode 1: Actions on structures - Part 1-4: General actions -Wind actions
EN 1995-1-1	Eurocode 5: Design of timber structures - Part 1-1: General -Common rules and rules for buildings
EN 1995-1-2	EN 1995-1-2 - Eurocode 5 — Design of timber structures — Part 1-2: General — Structural fire design
EN 338	EN 338 - Structural timber — Strength classes
CNR DT206	CNR-DT 206/2007: Recommendations for the design and execution of timber structures
DM18	NTC2018 - Italian standards for structural design of buildings and constructions - D.M. 14 Gennaio 2008

As well as the mentioned regulations, to have a realistic application of CLT panels a specific manufacturer has been chosen in order to define the product properties and geometries. The KLH manufacture provide the following panels classifications. The dimensioning and structural design follow Eurocode 5 (EN 1995-1-1 and EN 1995-1-2)

FOR THE WALL

Covering layer in the transverse panel direction TT

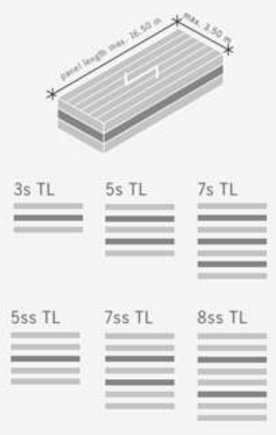
Nominal thickness		Layers|Type		Lamella structure in [mm]						
				T	L	T	L	T	L	T
KLH	60 mm	3s	TT	20	20	20				
KLH	70 mm	3s	TT	20	30	20				
KLH	80 mm	3s	TT	30	20	30				
KLH	90 mm	3s	TT	30	30	30				
KLH	100 mm	3s	TT	30	40	30				
KLH	110 mm	3s	TT	40	30	40				
KLH	120 mm	3s	TT	40	40	40				
KLH	100 mm	5s	TT	20	20	20	20	20		
KLH	110 mm	5s	TT	20	20	30	20	20		
KLH	120 mm	5s	TT	30	20	20	20	30		
KLH	130 mm	5s	TT	30	20	30	20	30		
KLH	140 mm	5s	TT	30	20	40	20	30		
KLH	150 mm	5s	TT	30	30	30	30	30		
KLH	160 mm	5s	TT	40	20	40	20	40		



FOR CEILING AND ROOF

Covering layer in the longitudinal panel direction TL

				L	T	L	T	L	T	L
KLH	60 mm	3s	TL	20	20	20				
KLH	70 mm	3s	TL	20	30	20				
KLH	80 mm	3s	TL	30	20	30				
KLH	90 mm	3s	TL	30	30	30				
KLH	100 mm	3s	TL	40	20	40				
KLH	110 mm	3s	TL	40	30	40				
KLH	120 mm	3s	TL	40	40	40				
KLH	100 mm	5s	TL	20	20	20	20	20		
KLH	110 mm	5s	TL	20	20	30	20	20		
KLH	120 mm	5s	TL	30	20	20	20	30		
KLH	130 mm	5s	TL	30	20	30	20	30		
KLH	140 mm	5s	TL	40	20	20	20	40		
KLH	150 mm	5s	TL	40	20	30	20	40		
KLH	160 mm	5s	TL	40	20	40	20	40		
KLH	170 mm	5s	TL	40	30	30	30	40		
KLH	180 mm	5s	TL	40	30	40	30	40		
KLH	190 mm	5s	TL	40	40	30	40	40		
KLH	200 mm	5s	TL	40	40	40	40	40		
KLH	160 mm	5ss	TL	30+30	40	30+30				
KLH	180 mm	7s	TL	20	40	20	20	20	40	20
KLH	200 mm	7s	TL	20	40	20	40	20	40	20
KLH	220 mm	7s	TL	30	40	30	20	30	40	30
KLH	240 mm	7s	TL	30	40	30	40	30	40	30
KLH	180 mm	7ss	TL	30+30	20	20	20	30+30		
KLH	200 mm	7ss	TL	30+30	20	40	20	30+30		
KLH	220 mm	7ss	TL	40+40	20	20	20	40+40		
KLH	240 mm	7ss	TL	40+40	20	40	20	40+40		
KLH	260 mm	7ss	TL	40+40	30	40	30	40+40		
KLH	280 mm	7ss	TL	40+40	40	40	40	40+40		
KLH	300 mm	8ss	TL	40+40	30	40+40	30	40+40		
KLH	320 mm	8ss	TL	40+40	40	40+40	40	40+40		



Special panel layups are available on request. By using double layers, for example the longitudinal or transverse stiffness of the panel can be further enhanced. The fire resistance of the KLH® solid wood panel can also be influenced by modifying the structures and can eventually be improved in relation to specific project requirements.

Invoicing widths
2.45 | 2.50 | 2.73 | 2.95 |
3.10 | 3.20 | 3.30 | 3.40 | 3.50 [m]

Maximum length 16.50 [m]
Maximum thickness 0.5 [m]

7.7 MATERIAL PROPERTIES OF CLT

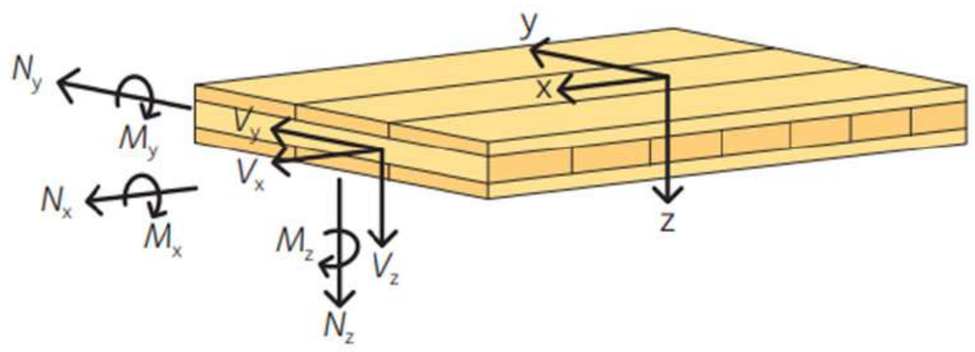
The chosen wood material for the panel is in the class C24. In the following the main mechanical properties for the chosen materials are listed for the calculation of the overall stiffness.

Characteristic strength value (MPa)		
Bending strength (MPa)	$f_{m,k}$	24
Tensile strength along the grain (MPa)	$f_{t,0,k}$	14.5
Tensile strength perpendicular to the grain (MPa)	$f_{t,90,k}$	0.4
Compressive strength along the grain (MPa)	$f_{c,0,k}$	21
Compressive strength perpendicular to the grain (MPa)	$f_{c,90,k}$	2.5
Shear strength (MPa)	$f_{v,k}$	4
Stiffness value (MPa)		
Mean value of modulus of elasticity, along the grain (MPa)	$E_{m,0,mean}$	11,000
Fifth percentile value of modulus of elasticity, perpendicular to the grain (MPa)	$E_{m,0,05}$	7,400
Mean value of modulus of elasticity, perpendicular to the grain (MPa)	$E_{m,90,mean}$	370
Mean value of the shear modulus (MPa)	G_{mean}	690
Mean value of modulus of rolling shear (MPa)	$G_{9090,xlay,mean}$	50
Density (kg/m3)		
Fifth percentile volume of density (kg/m3)	ρ_k	350
Mean density (kg/m3)	ρ_{mean}	420
Modification coefficient		
Combination coefficient- Load duration class: medium term	k_{mod}	0.8
Partial factor		
Safety coefficient- Italy	γ_M	1.25

Table 7.2 Material properties

7.8 CALCULATION METHODOLOGY

For this project, the whole process is cooperating with the Eurocode and related standards. There are many analysis methods that are applicable to CLT design but this project is based on the Beam Theory. If there is a clear main load direction, a CLT panel can be treated like a beam, as is often the case. The designing can then in principle apply beam theory.



7.9 LOAD ANALYSIS

Here the acting loads on structures are calculated based on the different definitions established in the Eurocode 1. The calculation approach classifies the different structural actions that considered in this project in the following way:

7.9.1 Permanent Actions

Permanent actions or dead loads are the actions that do not change over time and acting for all structural life of the building.

G1-Structural Loads: Refer to the structural elements of the building.

G2-Non-Structural Loads: Refer to all permanent loads except structural ones. Such as partitions, insulations, tiles, etc)

7.9.1.1 Structural Loads

Structural loads will be defined later according to pre-dimensioning tables. The table take into account the self-weight of the panels by considering the non-structural and variable loads.

7.9.1.2 Non-Structural Loads

The permanent Non-Structural Loads are reported in the table below according to the different materials self-weight acting on structural elements. For each material it is defined thickness and density to obtain each layer weight, and at the end the total Non-Structural weight were calculated in each stratigraphy.

The first table contains the permanent loads of the external wall, while in the second table are collected the loads acting on the roof, that is the one where solar panel are present.

Construction element		Layer	Thickness *(m)*	Specific weight (kN/m3)	weight (kN/m²)
FLOOR	1	Laminate flooring	0.08	17	0.13
	2	Gypsum-fiber panel (2x1,25cm)	0.025	10.4	0.26
	3	Floor heating system	0.04	0.2	0.012
	4	Granular dry screed	0.06	4	0.24
	5	Polypropylene protective sheet			
	6	Acoustic insulation (anti-footsteps)	0.02	1	0.02
	7	Structural slab in CLT	0.17	5	0.76
	8	Air	0.275	-	
	9	Insulation layer: rock wool	0.080	1.75	0.032
	10	Double cement board with vapor barrier	0.028	9	0.248
	11	Plaster rendering	0.002	15	0.03

Table 7.3 Floor stratigraphy

Construction element		Layer	Thickness (m)	Specific weight (kN/m3)	weight (kN/m2)
ROOF	1	Floating floor	0.02	5.5	0.11
	2	Air cavity	0.06	0.01	-
	3	Water proof polymer bitumen membrane	0.005	11	0.1
	4	Thermal insulation layer in wood fiber	0.1	0.3	0.03
	5	Vapor barrier	0.001	9.1	0.1
	6	Structural slab in CLT	0.17	5	0.76

Table 7.4 Roof stratigraphy

Construction element		Layer	Thickness (m)	Specific weight (kN/m3)	weight (kN/m2)
EXTERNAL WALL	1	Cladding in fiber cement boards	0.012	16.8	0.2
	2	Air cavity	0.040	0.01	
	3	Thermal insulation in wood fiber	0.100	1.4	0.14
	4	Structural wall in CLT	0.140	4.52	0.76
	5	Thermal and acoustic insulation in rock wool	0.050	0.4	0.02
	6	Double plaster board	0.013	6	0.11
	7	Vapor barrier	0.015	9	0.13
	8	Internal plaster finishing	0.003	14	0.04

Table 7.5 External wall stratigraphy

Construction element		Layer	Thickness (m)	Specific weight (kN/m3)	weight (kN/m2)
INTERNAL WALL STRUCTURAL	1	Internal plaster finishing	0.003	14	0.04
	2	Vapor barrier	0.015	9	0.13
	3	Double plaster board	0.013	9	0.11
	4	Thermal and acoustic insulation in rock wool	0.050	0.40	0.02
	5	Structural wall in CLT	0.140	4.5	0.76
	6	Thermal and acoustic insulation in rock wool	0.050	0.40	0.02
	7	Double plaster board	0.013	9	0.11
	8	Vapor barrier	0.015	9	0.13
	9	Internal plaster finishing	0.003	14	0.04

Table 7.6 Internal wall (structural) stratigraphy

Construction element		Layer	Thickness (m)	Specific weight (kN/m3)	weight (kN/m2)
INTERNAL WALL NON-STRUCTURAL	1	Internal plaster finishing	0.003	14	0.04
	2	Vapor barrier	0.015	9	0.13
	3	Double plaster board	0.013	9	0.11
	4	Thermal and acoustic insulation in rock wool	0.050	0.40	0.04
	5	Double plaster board	0.013	9	0.11
	6	Vapor barrier	0.015	9	0.13
	7	Internal plaster finishing	0.003	14	0.04

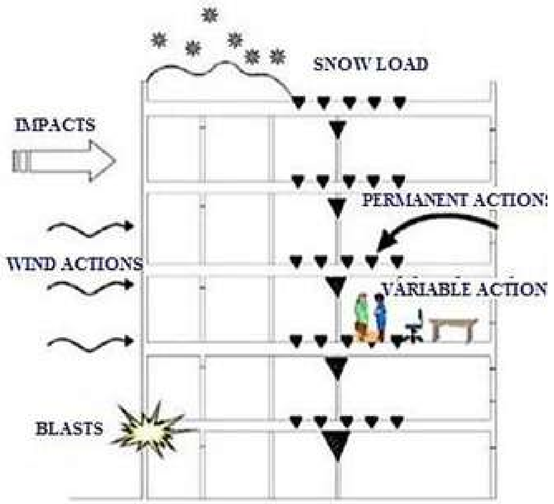
Table 7.7 Internal wall (non-structural) stratigraphy

Construction element		Layer	Thickness (m)	Specific weight (kN/m3)	weight (kN/m2)
INTERNAL WALL for SERVICES	1	Internal plaster finishing	0.003	14	0.04
	2	Vapor barrier	0.015	9	0.13
	3	Double plaster board	0.013	9	0.11
	4	Thermal and acoustic insulation in rock wool	0.050	0.40	0.02
	5	Non-ventilated cavity for the installation	0.100	0.001	-
	6	Thermal and acoustic insulation in rock wool	0.050	0.40	0.02
	7	Double plaster board	0.013	9	0.11
	8	Vapor barrier	0.015	9	0.13
	9	Internal plaster finishing	0.003	14	0.04

Table 7.8 Internal wall (for services) stratigraphy

7.9.2 Variable Actions

Variable actions or live loads are the actions that can change over the time. Q-Live Loads: associated to the dynamic forces from occupancy and intended use. Such as wind load, snow load, thermal load, people, furniture.



7.9.2.1 Categories of use

Regarding to the main function of this project, residential use is highlighted as a function of the building. According to the different functions located at each floor, a distinction has been made for the applied live load based on EC 1991-1-1 categories.

Categories of loaded area	Specific Use
H	Roofs not accessible except for normal maintenance and repair.
I	Roofs accessible with occupancy according to categories A to [AC1] G [AC1]
K	Roofs accessible for special services, such as helicopter landing areas

Table 7.9 Categorization of roofs

Imposed loads for roofs of category I is given in following table according to the specific use of our building.

Categories of loaded areas	q_k [kN/m²]	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

Figure 7.16 Imposed Loads on floors, balconies and stairs in buildings

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

Figure 7.15 Categories of Use

In the following scheme it can be noticed that:

-The residential apartments go under the A category.

-The shared ground floor, due to its higher occupancy density and multifunctional purpose, is under the category C1.

-One side of the roof top is accessible with occupancy (I) addressed to public use of the residents, according to the specific use of our building it goes under C1 category.

-Some Common activity spaces at the ground floor go under C4, even though the input values are the same of C1.

A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3
C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3

Figure 7.16 Categories of use in building section

Rif. NTC	Variable Loads	Unit	Category A. residential	Category C3. Common Spaces
qk	Vertical distributed loads	kN/sqm	2,0	4,0
Qk	Vertical concentrated loads	kN	2,0	4,0
Hk	Horizontal linear loads	kN/m	1,0	1,0

Table 7.10 Variable loads value

7.9.2.2 Snow load

EN 1991-1-3 with specifications according to the National Annex apply is applied. For the persistent / transient design situations the snow loads on the roofs shall be determined as follows [Expression 5.1-EC1-1-3]:

$$q_s = \mu_i \times C_e \times C_t \times s_k$$

where:

-sk Characteristic vaue of snow load on the ground
-μi Snow load shape coefficient
-Ce The exposure coefficient
-Ct The thermal coefficient

In our case, the snow load shape coefficient μi that should be used for mono-pitch roof with the angle less than 15o is equal to 0.8 based on EC 1991-1-3 (Table 5). And it is expressed in Eurocode with the following figures.

Angle of pitch of roof α	$0° \leq \alpha \leq 30°$	$30° < \alpha < 60°$	$\alpha \geq 60°$
μ_1	0,8	0,8(60 - α)/30	0,0
μ_2	0,8 + 0,8 α/30	1,6	--

Table 7.11 Snow load shape coefficients

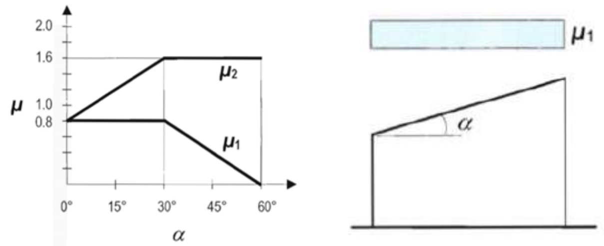


Figure 7.17 Snow load shape coefficients

The exposure coefficient Ce used for determining the snow load on the roof. The choice for Ce should consider the future development around the site. Ce depends on topography typology. Since Germany has a normal topography typology Ce is taken as 1,0.

Topography	C_e
Windswept [a]	0,8
Normal [b]	1,0
Sheltered [c]	1,2

[a] *Windswept topography*: flat unobstructed areas exposed on all sides without, or little shelter afforded by terrain, higher construction works or trees.

[b] *Normal topography*: areas where there is no significant removal of snow by wind on construction work, because of terrain, other construction works or trees.

[c] *Sheltered topography*: areas in which the construction work being considered is considerably lower than the surrounding terrain or surrounded by high trees and/or surrounded by higher construction works.

Figure 7.18 Recommended values of Ce for different topographies

By checking the European Ground Snow Load Maps (EN 1991-1-3:2003), Germany is in the Central East where the characteristic value of the snow load sk is calculated with the following formula.

Climatic Region	*Expression*
Central East	$s_k = (0{,}264Z - 0{,}002)\left[1 + \left(\frac{A}{256}\right)^2\right]$

-sk Is the characteristic snow load on the ground (kN/m)

-A Is the site latitude above sea level (m)

-Z Is the zone number given on the map

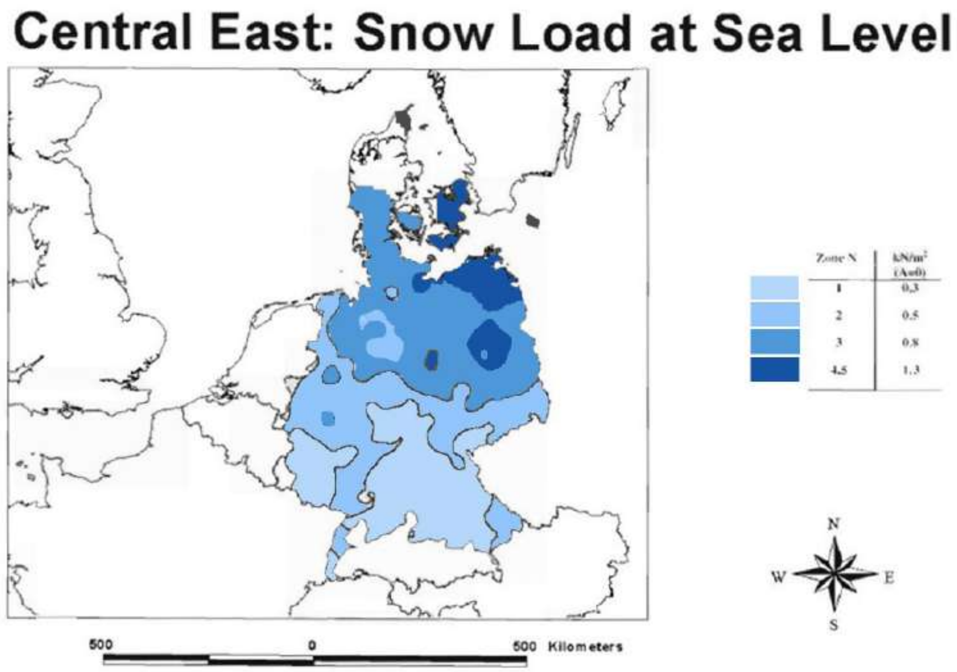


Figure 7.19 Snow load at sea level at Central East region

With considering the Germany region by using the above formula the characteristic value of the snow load is sk = 1.3 kN/m2. Finally, the snow load would be:

$$q_s = \mu_i \times C_e \times C_t \times s_k$$

$$q_s = 0.8 \times 1.0 \times 1.0 \times 1.3 = 1.04\ kN/m^2$$

$$q_k = q_L + q_s = 2.0 + 1.04 = 3.04\ kN/m^2$$

7.9.2.3 Wind load

According to EN 1991-1-4 the following procedure applies for the calculation of wind load. At the first step the basic wind velocity Vb needs to be defined according to EN 1991-1-4.

The basic wind velocity will be calculated from the below expression.

$$V_b = C_{dir} . C_{season} . V_{b,0}$$

where:

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

$v_{b,0}$ is the fundamental value of the basic wind velocity, see (1)P

c_{dir} is the directional factor, see Note 2.

c_{season} is the season factor, see Note 3.

NOTE 1 Where the influence of altitude on the basic wind velocity v_b is not included in the specified fundamental value $v_{b,0}$ the National Annex may give a procedure to take it into account.

NOTE 2 The value of the directional factor, c_{dir}, for various wind directions may be found in the National Annex. The recommended value is 1,0.

NOTE 3 The value of the season factor, c_{season}, may be given in the National Annex. The recommended value is 1,0.

NOTE 4 The 10 minutes mean wind velocity having the probability p for an annual exceedence is determined by multiplying the basic wind velocity v_b in 4.2 (2)P by the probability factor, c_{prob} given by Expression (4.2). See also EN 1991-1-6.

Figure 7.20 Basic wind velocity

By considering the definition of Vb,0 (EN 1991-1-4 4.2 (1), 2005): The fundamental value of the basic wind velocity, Vb,0, is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10 m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights. According to Eurocodes third Balkan:

Vb,0 = 25 m/s

Starting from the fundamental value, by means of two multiplicative coefficients Cdir and Cseason, which respectively take into account the influence of wind direction and seasonal weather factors, the basic wind velocity can be calculated as follows [Expression 4.1- EC1-1-4]:

Vb = Cdir Cseason Vb,0

The recommended values of Cdir = 1.0 and Cseason = 1.0 are used in accordance to the National Annex. Therefore, the basic wind velocity is:

Vb = 1.0 x 1.0 x 25 = 25 m/s

7.9.3 Wind actions

Wind actions on structures and structural elements shall be determined taking into account of both external and internal wind pressures. A summary of calculation procedures for the determination of wind actions is given in the following table.

7.9.3.1 The wind pressure

Acting on the external surfaces, we, can be obtain by the following expression [Expression 5.1-EC1-1-4]

We = qp(ze). Cpe

where:

-Ze is the reference height for the external pressure
-Cpe is the pressure coefficient for the external pressure
-Windward wall Cpe =0,8
-Leeward wall Cpe =-0,5

WW: We = 0.8 x 1054.7 = 843.76
LW: We = -0.5 x 1054.7 = -527.35

7.9.3.2 The wind force

Fw acting on a structure or a structural element may be determined by vectorial summation of the forces acting on their reference surfaces [Expression 5.5-EC1-1-4]:

Fw = CsCd Si Wei Ai

Parameter	Subject Reference
peak velocity pressure q_p	
basic wind velocity v_b	4.2 (2)P
reference height z_e	Section 7
terrain category	Table 4.1
characteristic peak velocity pressure q_p	4.5 (1)
turbulence intensity I_v	4.4
mean wind velocity v_m	4.3.1
orography coefficient $c_o(z)$	4.3.3
roughness coefficient $c_r(z)$	4.3.2
Wind pressures, e.g. for cladding, fixings and structural parts	
external pressure coefficient c_{pe}	Section 7
internal pressure coefficient c_{pi}	Section 7
net pressure coefficient $c_{p,net}$	Section 7
external wind pressure: $w_e=q_p\,c_{pe}$	5.2 (1)
internal wind pressure: $w_i=q_p\,c_{pi}$	5.2 (2)
Wind forces on structures, e.g. for overall wind effects	
structural factor: c_sc_d	6
wind force F_W calculated from force coefficients	5.3 (2)
wind force F_W calculated from pressure coefficients	5.3 (3)

Table 7.11 Calculation procedures for the determination of wind actions

where the structural factor Cs and Cd (separated into a size factor Cs and a dynamic factor Cd) is taken as 1.0 as recommended:

Ai-reference area perpendicular to wind direction

WW:Fw=0.86x1.0x843.76x1 =725.63kN
LW: Fw = 0.71 x 1.0 x (-527.35) x 1 = -374.42 kN

where the structural factor Cs and Cd (separated into a size factor Cs and a dynamic factor Cd) is taken as 1.0 as recommended:

7.10 Partial factors and combination factors

In this paragraph are reported the values of the partial safety factors for actions and combination factors that will be used later in the calculation.

Partial Safety factors for actions			
Coefficient	Action	Favourable	Unfavourable
γ_G	Permanent Loads	0.89	1.35
γ_Q	Variable Loads	0	1.5

Combination factors		
Ψ_0	Ψ_1	Ψ_2
0.70	0.50	0.30

7.11 PRE-DIMENSIONING

The pre-dimensioning is a preliminary step in which the main structural components are designed. The use of commercial tables from the KLH manufacturer of CLT panels is considered to support the choice of the panels thickness.

7.11.1 Horizontal Slab

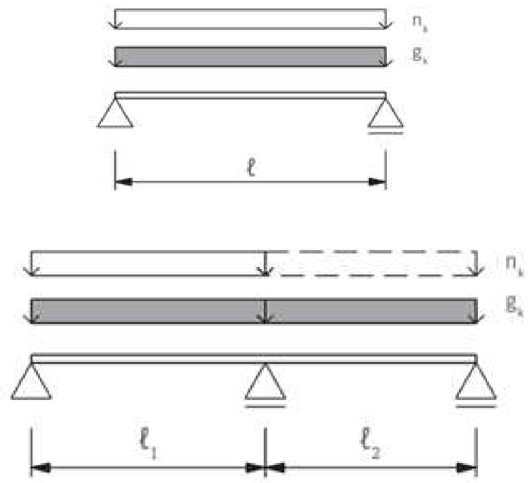
In order to select the appropriate horizontal structural element (Roof horizontal slab in our case were chosen) on the manufacturer table we need to first determine the dead weight and the imposed load of the building. Then based on the pre-dimensioning table and the span (4 meter in our case). We can find the appropriate thickness and layer of the panel according to our building design. Below the calculation of the Dead weight gk and the Imposed load nk is placed.

Horizontal slab					
Load	Non-structural kN/m2	Solar panel kN/m2	Building category A (q_L) kN/m^2	Snow load (q_s) kN/m^2	Total kN/m2
Dead weight g_k	1.19	0.11	-	-	1.31
Imposed Load n_k	-	-	2	1.04	3.04

Table 7.12 Roof non-structural dead loads & Live loads

gk = 1,31 kN/m2 (Roof non-structural loads+ Solar panels weight/m2) nk = 3,04 kN/m2 (Variable Loads based on A category+ Snow load) These values are the preliminary considerations included in the table. For some parts only two supports are considered. In other parts where another supporting wall is present under the limited span of the panel, the 3 supports and 2 span case is considered, using the related table.

Max Span (2 supports): 4m
Max Span (3 supports): 8m



Permanent load $g_{2,k}$ [kN/m²]	Imposed load n_k category	Imposed load n_k [kN/m²]	SPAN OF SINGLE-SPAN BEAM ℓ: 3,00 m	4,00 m	5,00 m	6,00 m	7,00 m
1,00	A / B / C	1,50, 2,00, 2,80 / 3,00, 3,50 / 4,00, 5,00	5s 130 TL	5s 150 TL	5s 170 TL	7s 220 TL	7ss 280 TL
1,50	A / B / C	1,50, 2,00, 2,80 / 3,00, 3,50 / 4,00, 5,00	5s 130 TL	5s 150 TL	5s 180 TL	7s 220 TL / 7s 240 TL	7ss 280 TL
2,00	A / B / C	1,50, 2,00, 2,80 / 3,00, 3,50 / 4,00, 5,00	5s 130 TL	5s 150 TL	5s 190 TL	7s 240 TL	7ss 280 TL
2,50	A / B / C	1,50, 2,00, 2,80 / 3,00, 3,50 / 4,00, 5,00	5s 130 TL	5s 150 TL	5s 200 TL	7s 240 TL	7ss 280 TL
3,00	A / B / C	1,50, 2,00, 2,80 / 3,00, 3,50 / 4,00, 5,00	5s 130 TL	5s 150 TL	5s 200 TL	7s 240 TL / 7ss 260 TL	7ss 280 TL

R 60 R 90 R 120

Table 7.13 Minimum panel thickness for a specific load-span-combination suggested by the company

By crossing the two input values of dead weight and imposed load with the span diameter, it is possible to find the suggested product. For the case of the roof, the matrixes give as a result the 5s150TL, intended as a longitudinal panel with 5 layers and thickness of 150mm. This is the Minimum panel thickness for a specific load-span combination suggested by the company. In some cases, more than one alternative is present, or the higher thickness and number of layers is suggested in other companies. In this case, it's the designer choice about the compatibility with the other structural elements.

Based on our investigation also in other company tables and information we decided to choose 5s160TL longitudinal panel with 5 layers and thickness of 160 mm as the appropriate panel for the horizontal slabs according to our design considerations.

7.11.2 Vertical Walls

The same approach is followed for the vertical structural elements by considering the dead weight and live loads in intersection with the height of the wall. Below the calculation of the dead weight gk and the imposed load nk of the wall is placed. Two different walls are considered for the calculation, one internal wall without opening and one external wall with two openings.

-Vertical wall height (net to floor): 4.00 – 0.16 = 3.84 m
-G1: Structural load of slab (CLT density x thickness x Interaxis)
-G2 = non-structural load x Interaxis
-Q = Live load x Interaxis
-W (load from above wall) = G1x thickness x wall net height
-Non-structural load (wall without openings- Internal) = 1.63 kN/m2
-Non-structural load (wall with openings) = 0.52 kN/m2

7.11.2.1Wall without openings-Internal

Floor	Slab Thickness (m)	Density (kg/m^3)	Interaxis (m)	G_1 (kN/m)	Non-structural Load (kN/m^2)	G_2 (kN/m)	Live Load	Q (kN/m)	Thickness of above walls	Wall Load (W)
4	0.12	450	6.0	3.24	1.63	9.78	2	12.0	0	0
3	0.12	450	6.0	3.24	1.63	9.78	2	12.0	0.12	1.34
2	0.12	450	6.0	3.24	1.63	9.78	2	12.0	0.12	1.34
1	0.12	450	6.0	3.24	1.63	9.78	2	12.0	0.12	1.34
0	-	-	-	-	-	-	-	-	0.12	-

Floor	$G_1 + G_2 + W$	Q (above the wall)	G (above the wall)	W (above the floor)	Product
4	13.02	-	-	-	-
3	14.36	8	13.02	1.34	140C5S
2	14.36	16	26.04	1.34	140C5S
1	14.36	24	39.06	1.34	140C5S
0	14.36	32	52.08	1.34	140C5S

7.11.2.2 Wall with openings

Floor	Wall Thickness (m)	Density (kg/m^3)	Wall Length (m)	G_1 (kN/m)	Non-structural Load (kN/m^2)	G_2 (kN/m)	Thickness of above walls	Wall Load
4	0.09	450	4.0	1.6	0.52	2.08	0	0
3	0.09	450	4.0	1.6	0.52	2.08	0.12	0.66
2	0.09	450	4.0	1.6	0.52	2.08	0.12	0.66
1	0.09	450	4.0	1.6	0.52	2.08	0.12	0.66
0	-	-	-	-	-	-	0.12	-

Floor	$G_1 + G_2 + W$	G (above the wall)	W (above the floor)	Product
4	3.68	-	-	-
3	4.34	3.68	1.2	140C5S
2	4.34	3.68	1.2	140C5S
1	4.34	3.68	1.2	140C5S
0	4.34	3.68	1.2	140C5S

Permanent load	Imposed load	HEIGHT WALL (buckling length ℓ)							
$g_{2,k}$	n_k	2,73 m				3,95 m			
[kN/m]	[kN/m]	R 0	R 30	R 60	R 90	R 0	R 30	R 60	R 90
10,00	10,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	20,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	30,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	40,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	50,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	60,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
20,00	10,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	20,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	30,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	40,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	50,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	60,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT
30,00	10,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	20,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT
	30,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 120 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT
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	50,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT
	60,00	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT
40,00	10,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT
	20,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT
	30,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT
	40,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT
	50,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT
	60,00	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT
50,00	10,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT
	20,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT
	30,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT
	40,00	3s 60 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT
	50,00	3s 70 TT	3s 80 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT
	60,00	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT
60,00	10,00	3s 60 TT	3s 90 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT
	20,00	3s 60 TT	3s 90 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT
	30,00	3s 60 TT	3s 90 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT
	40,00	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 90 TT	5s 110 TT	5s 130 TT
	50,00	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT	3s 70 TT	3s 100 TT	5s 110 TT	5s 130 TT
	60,00	3s 70 TT	3s 90 TT	5s 100 TT	5s 130 TT	3s 80 TT	3s 100 TT	5s 110 TT	5s 130 TT

R 0 R 30 R 60 R 90

Table 7.14 Minimum panel thickness for a specific load-span-combination suggested by the company

The same approach is taken for the wall CLT panel determination by crossing the two input values of dead weight and imposed load with the span diameter. For the case of the wall, the matrixes give as a result the 5s120TT, intended as a longitudinal panel with 5 layers and thickness of 120mm. This is the Minimum panel thickness for a specific load-span-combination suggested by the company. Based on our investigation also in other company tables and information we decided to choose 5s140TT longitudinal panel with 5 layers and thickness of 140 mm as the appropriate panel for the horizontal slabs according to our design considerations.

7.12 VERIFICATION

The verification calculations of structural elements are presented in this part to check if they can meet the statical analysis requirements in terms of load bearing behaviour. The structural safety verification is based on the calculation which consider that the applied loads on the elements are always lower than the corresponding resistance of the material, that is:

R (resistance) > S (solicitation)

7.12.1Design of floor structure

The floor structure comprises a 5-layer CLT panel with a thickness of 40 + 20 + 40 + 20 +40 = 160 mm. It is selected the thickness suitable for 4 m of span and with all the layers of boards in strength class C24. Service class 1, safety class 3 (γ_d = 1).
Loads:
Self-weight gk = 1.84 kN/m2
Imposed load qk = 3.04 kN/m2

With γ_m = 1.25 and kmod = 0.8, (Imposed load is leading action = medium load duration) the design strengths become:

$$f_{m,d} = \frac{k_{mod} \cdot f_{m,k}}{\gamma_m} = \frac{0.8 \, . \, 24}{1.25} = 15.36 \; MPa$$

$$f_{v,d} = \frac{k_{mod} \cdot f_{v,k}}{\gamma_m} = \frac{0.8 \, . \, 4}{1.25} = 2.56 \; MPa$$

Load	kN/m²	γ_g, γ_q	Load duration	Kmod	Ψ_0	Ψ_1	Ψ_2
gk	1.84	0.89 . 1.35	Permanent	0.6	-	-	-
qk	3.04	1.5	Medium Duration	0.8	0.70	0.50	0.30

Table 7.15 Loads and load factors

7.13 CALCULATIONS

7.13.1 1.One span (between F – G and 10 – 11 – 12)

Cross-sectional properties can be calculated for a strip bx = 1.0 m of the board using the table in the next page:

Design load combination for vertical load for a strip bx = 1.0 m:

$$q_d = \gamma_G \cdot g_k + \gamma_Q \cdot q_k = 0.89 \cdot 1.35 \cdot 1.84 + 1.5 \cdot 3.04 = 6.77 \; kN/m$$

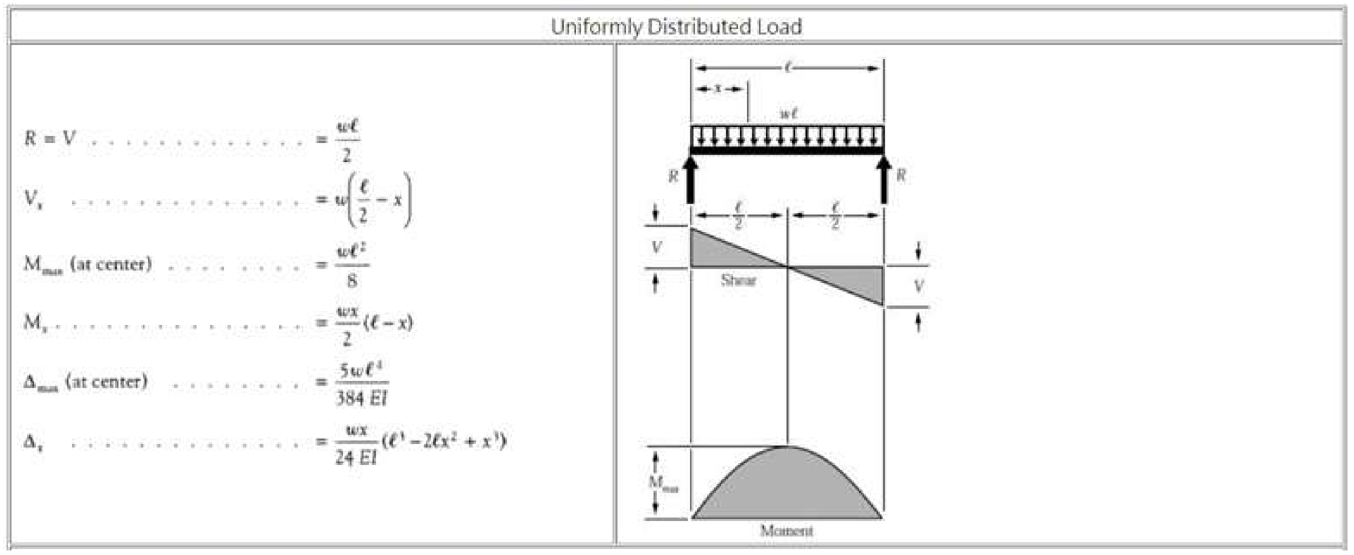
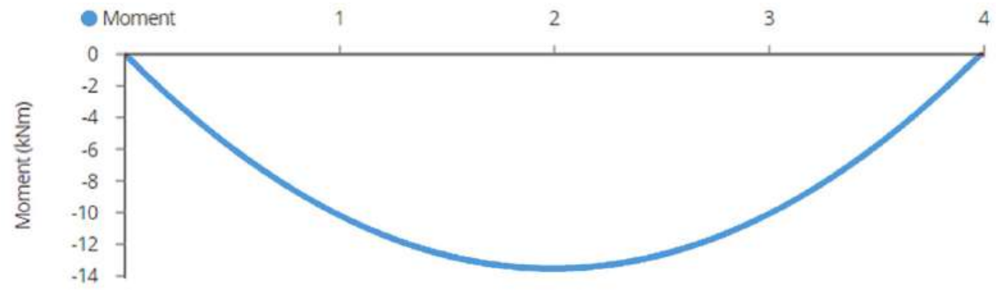


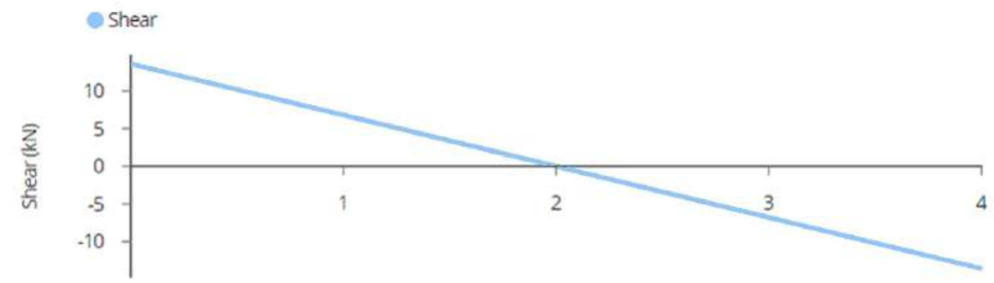
Figure 7.21 Uniformly distributed load

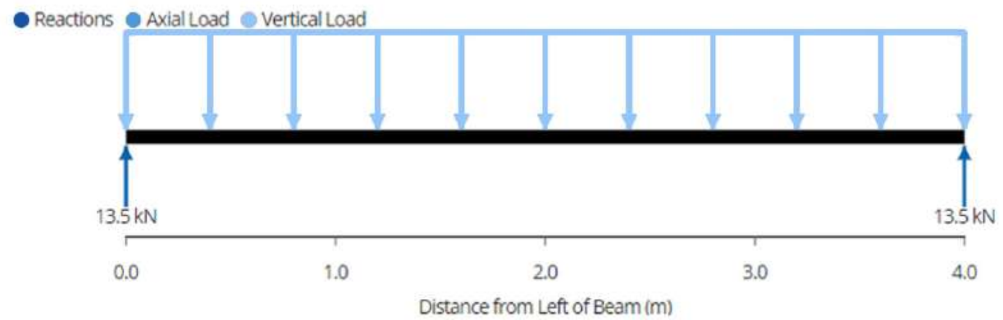
7.13.1.1 Moment

Design moment for a single-span beam of length L = 4 m:

$$M_d = \frac{q_d \cdot L^2}{8} = \frac{6.77 \cdot 4.0^2}{8} = 13.54 \; kNm$$







From the above figures:

Maximum bending moment M* = 13.54 kN.m

Maximum shear force V* = 13.54 kN

$$\sigma_d = \frac{M_d}{W_{x,net}} = \frac{13.54 \cdot 10^3}{2111} = 6.41\,MPa < f_{m,d} = 15.36\,MPa$$

7.13.1.2 Shear force:

Design shear force:

$$V_d = 0.5 \cdot q_d \cdot L = 0.5 \cdot 6.77 \cdot 4.0 = 13.54\,kN$$

$$\tau_d = \frac{V_d \cdot S_{x,net}}{I_{x,net} \cdot b_x} = \frac{13.54 \cdot 10^3 \cdot 1400 \cdot 10^3}{12677 \cdot 10^4 \cdot 1000} = 0.15\,MPa < f_{v,d} = 2.56\,MPa$$

$$S_{x,net} = b_x t_1 a_1 + b_x \frac{t_3^2}{4 \cdot 2}$$

$$\tau_{Rv,d} = \frac{V_d \cdot S_{Rx,net}}{I_{x,net} \cdot b_x} = \frac{13.54 \cdot 10^3 \cdot 1350 \cdot 10^3}{12677 \cdot 10^4 \cdot 1000} = 0.14\,MPa < f_{Rv,d} = 0.45\,MPa$$

Property	Calculation formula	Application to example
Net cross-section area (mm2)	$A_{x,net} = b_x \cdot 3 \cdot t_1$	$A_{x,net} = 120000\,mm^2$
Net moment of inertia (mm4)	$I_{x,net} = b_x\left(\frac{t_1^3}{12} + t_1 a_1^2 + \frac{t_3^3}{12} + t_3 a_3^2 + \frac{t_5^3}{12} + t_5 a_5^2\right) = b_x\left(3 \cdot \frac{t_1^3}{12} + 2 \cdot t_1 a_1^2\right)$	$I_{x,net} = 30400 \cdot 10^3\,mm^3$
Net moment of resistance (mm3)	$W_{x,net} = \frac{2 \cdot I_{0,net}}{h_{CLT}}$	$W_{x,net} = 3800 \cdot 10^3\,mm^3$
Static moment of rolling shear (mm3)	$S_{R,x,net} = b_x \cdot t_1 \cdot a_1$	$S_{R,x,net} = 2400 \cdot 10^3\,mm^3$
Static moment of longitudinal shear (mm3)	$S_{x,net} = b_x t_1 a_1 + b_x \frac{t_3^2}{4 \cdot 2}$	$S_{x,net} = 2600 \cdot 10^3\,mm^3$
Effective moment of inertia (cm4) for span L = 4 m	$\gamma_1 = \gamma_5 = \frac{1}{1 + \frac{\pi^2 E_{x,1} t_1}{L^2} \frac{t_2}{G_{9090,2}}}$ $I_{x,net} = b_x\left(\frac{3 \cdot t_1^3}{12} + 2\gamma_1 t_1 a_1^2\right)$	$\gamma_1 = \gamma_5 = 0.921$ $I_{x,ef} = 28125 \cdot 10^4\,mm^4$

7.13.1.3 Deformations:

Maximum shear force V* = 13.54 kN

$$\frac{L}{250} = \frac{4000}{250} = 16.0\,mm$$

$$w_{g,k} = \frac{5 \cdot g_k \cdot L^4}{384 \cdot E_{x,mean} \cdot I_{x,ef}} = \frac{5 \cdot 1.84 \cdot 10^3 \cdot 4.0^4}{384 \cdot 11000 \cdot 10^6 \cdot 11865 \cdot 10^{-8}} = 0.0047\,m = 4.7\,mm$$

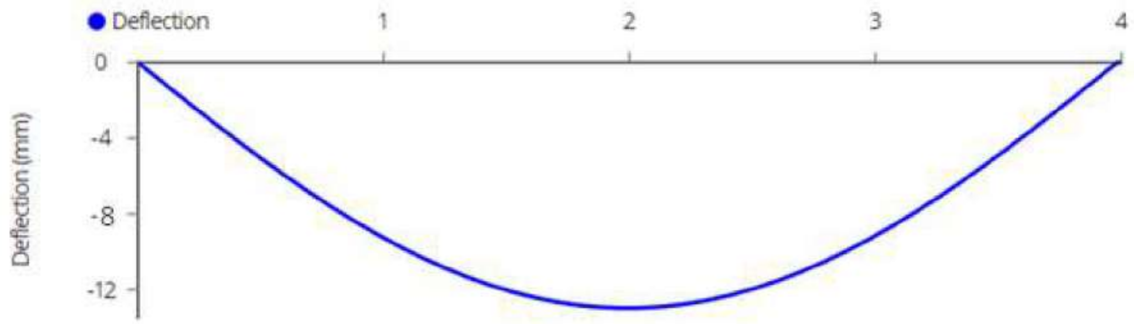
Where:

$$I_{x,net} = b_x\left(\frac{3 \cdot t_1^3}{12} + 2\gamma_1 t_1 a_1^2\right) = 11865 \cdot 10^4\,mm^4$$

$$w_{q,k} = \frac{5 \cdot q_k \cdot L^4}{384 \cdot E_{x,mean} \cdot I_{x,ef}} = \frac{5 \cdot 3.04 \cdot 10^3 \cdot 4.0^4}{384 \cdot 11000 \cdot 10^6 \cdot 11865 \cdot 10^{-8}} = 0.00776\,m = 7.76\,mm$$

Short-term deformation of characteristic load:

$$w_{inst} = w_{g,k} + w_{q,k} = 4.7 + 7.76 = 12.46\,mm < 16.0\,mm \quad \text{OK}$$



7.13.1.4 Vibrations:

The lowest fundamental frequency f1 for floor structure is calculated as:

$$f_1 = \frac{\pi}{2L^2}\sqrt{\frac{(EI)_L}{m}} = \frac{\pi}{2 \cdot 4.0^2}\sqrt{\frac{11000 \cdot 10^6 \cdot 11865 \cdot 10^{-8}}{110}} = 10.7\,Hz > 8\,Hz \quad \text{OK}$$

Control the stiffness by calculating the deflection w for a point load, F = 1 kN and compare with the largest permitted value a = 1.5 mm according to EKS:

$$w = \frac{FL^3}{48EI} = \frac{1 \cdot 10^3 \cdot 4000^3}{48 \cdot 11000 \cdot 11865 \cdot 10^4} = 1.02\,mm < 1.5\,mm \quad \text{OK}$$

Check the impulse velocity response v with b = 100 according to EKS. And with damping of 2.5 percent:

$$v = b^{(f_1\xi - 1)} = 100^{(10.7 \cdot 0.025 - 1)} = 0.034$$

Floor structures of width B = 4 m, simply supported along four sides:

$$n_{40} = \left[\left(\left(\frac{40}{f_1}\right)^2 - 1\right) \cdot \left(\frac{B}{L}\right)^4 \cdot \frac{(EI)_L}{(EI)_B}\right]^{0.25}$$

$$= \left[\left(\left(\frac{40}{10.7}\right)^2 - 1\right) \cdot \left(\frac{4.0}{4.0}\right)^4 \cdot \frac{11000 \cdot 10^6 \cdot 12667 \cdot 10^{-8}}{11000 \cdot 10^6 \cdot 1733 \cdot 10^{-8}}\right]^{0.25} = 3.12$$

Where:

IL, IB is the surface moment of inertia for bending about the y and x axis respectively:

$$v = \frac{4(0.4 + 0.6 n_{40})}{mBL + 200} = \frac{4(0.4 + 0.6 \cdot 3.12)}{110 \cdot 4 \cdot 4 + 200} = 0.0046 < 0.034 \quad \text{OK}$$

7.13.2 2.Two spans (between E - G and 10 – 11 - 12)

Cross-sectional properties can be calculated for a strip bx = 1.0 m of the board using table below:

Design load combination for vertical load for a strip bx = 1.0 m:

$$q_d = \gamma_G \cdot g_k + \gamma_Q \cdot q_k = 0.89 \cdot 1.35 \cdot 1.84 + 1.5 \cdot 3.04 = 6.77\ kN/m$$

Continuous Beam – Two Equal Spans – Uniformly Distributed Load

$R_1 = V_1 = R_3 = V_3$ . . . . $= \frac{3w\ell}{8}$

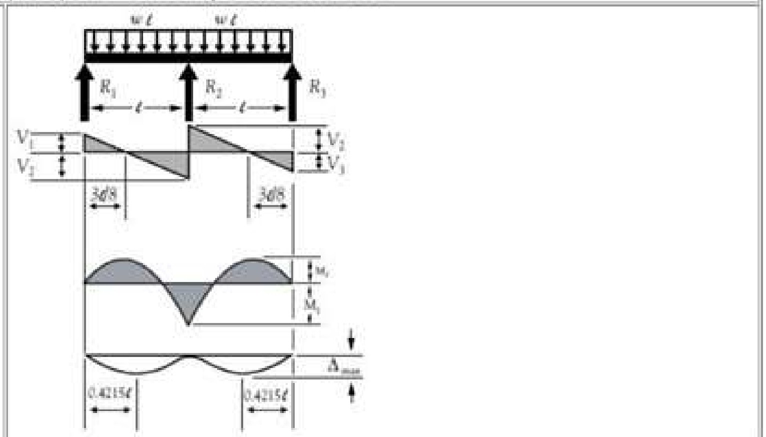
R_2 . . . . $= \frac{10w\ell}{8}$

$V_2 = V_{max}$ . . . . $= \frac{5w\ell}{8}$

M_1 . . . . $= \frac{w\ell^2}{8}$

$M_2 \left(\text{at } \frac{3\ell}{8}\right)$ . . . . $= \frac{9w\ell^2}{128}$

Δ_{max} (at 0.4215 ℓ, approx. from R_1 and R_3) . . $= \frac{w\ell^4}{185EI}$

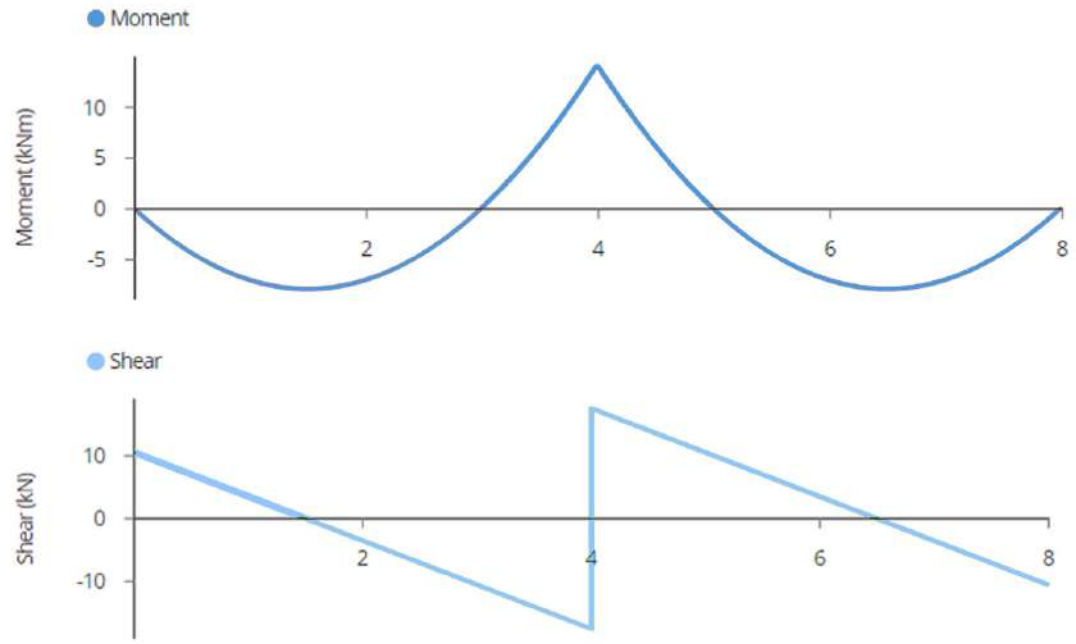


7.13.2.1 Moment:

Design moment for a single-span beam of length L = 8 m:

$$M_{max} = M_1 = \frac{q_d L^2}{8} = \frac{6.77 \times 4^2}{8} = 13.54\ kN.m$$

$$M_2 = \frac{9 q_d L^2}{128} = \frac{9.0 \times 6.77 \times 4^2}{128} = 7.62\ kN.m$$



From the above figures:

Maximum bending moment M* = 13.54 kN.m

$$\sigma_d = \frac{M_d}{W_{x,net}} = \frac{13.54 \cdot 10^3}{2111} = 6.41\ MPa < f_{m,d} = 15.36\ MPa$$

Maximum shear force V* = 17.5 kN

7.13.2.2 Shear force:

Design shear force:

$$\tau_d = \frac{V_d \cdot S_{x,net}}{I_{x,net} \cdot b_x} = \frac{16.93 \cdot 10^3 \cdot 1400 \cdot 10^3}{12667 \cdot 10^4 \cdot 1000} = 0.19\ MPa < f_{v,d} = 2.56\ MPa$$

$$\tau_{Rv,d} = \frac{V_d \cdot S_{Rx,net}}{I_{x,net} \cdot b_x} = \frac{16.93 \cdot 10^3 \cdot 1350 \cdot 10^3}{12667 \cdot 10^4 \cdot 1000} = 0.18\ MPa < f_{Rv,d} = 0.45\ MPa$$

Property	Calculation formula	Application to example
Net cross-section area (mm²)	$A_{x,net} = b_x \cdot 3 \cdot t_1$	$A_{x,net} = 120000\ mm^2$
Net moment of inertia (mm⁴)	$I_{x,net} = b_x\left(\frac{t_1^3}{12} + t_1a_1^2 + \frac{t_3^3}{12} + t_3a_3^2 + \frac{t_5^3}{12} + t_5a_5^2\right) = b_x\left(3 \cdot \frac{t_1^3}{12} + 2 \cdot t_1a_1^2\right)$	$I_{x,net} = 30400 \cdot 10^3\ mm^3$
Net moment of resistance (mm³)	$W_{x,net} = \frac{2 \cdot I_{0,net}}{h_{CLT}}$	$W_{x,net} = 3800 \cdot 10^3\ mm^3$
Static moment of rolling shear (mm³)	$S_{R,x,net} = b_x \cdot t_1 \cdot a_1$	$S_{R,x,net} = 2400 \cdot 10^3\ mm^3$
Static moment of longitudinal shear (mm³)	$S_{x,net} = b_xt_1a_1 + b_x\frac{t_3^2}{4 \cdot 2}$	$S_{x,net} = 2600 \cdot 10^3\ mm^3$
Effective moment of inertia (cm⁴) for span L = 4 m	$\gamma_1 = \gamma_5 = \frac{1}{1 + \frac{\pi^2 E_{x,1} t_1}{L^2}\frac{t_2}{G_{9090,2}}}$ $I_{x,net} = b_x\left(\frac{3 \cdot t_1^3}{12} + 2\gamma_1 t_1 a_1^2\right)$	$\gamma_1 = \gamma_5 = 0.921$ $I_{x,ef} = 28125 \cdot 10^4\ mm^4$

7.13.2.3 Deformations:

$$\frac{L}{300} = \frac{4000}{300} = 13.33\ mm$$

$$w_{g,k} = \frac{g_k \cdot L^4}{185 \cdot E_{x,mean} \cdot I_{x,ef}} = \frac{1.84 \cdot 10^3 \cdot 4^4}{185 \cdot 11000 \cdot 10^6 \cdot 11865 \cdot 10^{-8}} = 0.0019\ m = 1.9\ mm$$

$$w_{q,k} = \frac{q_k \cdot L^4}{185 \cdot E_{x,mean} \cdot I_{x,ef}} = \frac{3.04 \cdot 10^3 \cdot 4^4}{185 \cdot 11000 \cdot 10^6 \cdot 11865 \cdot 10^{-8}} = 0.0032\ m = 3.2\ mm$$

Short-term deformation of characteristic load:

$w_{inst} = w_{g,k} + w_{q,k} = 1.9 + 3.2 = 5.1\ mm < 13.33\ mm$ OK

Final deformation because of creep on quasi-permanent action:

K_{def} = 0.85 for service class 1

$w_{fin} = w_{inst} + w_{creep}$

$w_{fin,g} = w_{g,k} \cdot (1+k_{def})$ = 1.9 * 1.85 = 3.52 mm

$w_{fin,q} = w_{q,k} \cdot (1+\psi_2 \cdot k_{def})$ = 3.32 * (1+0.3*0.85) = 3.32 * 1.25 = 4.15 mm

w_{fin} = 5.1 + 4.15 = 9.55 mm < 13.33 mm OK

7.14 BEAM OVER OPENIN, SUPPORTED BY POSTS

With a reducing span to height ratio, linear stress distribution under beam theory no longer applies. Non-linear behaviour becomes noticeable in wall beams with around l ⁄ h ≤ 4, and must be taken into account at l ⁄ h ≤ 2. Edge stresses when calculating using plate theory depend on the load on the upper and lower sections of the panel and on the l ⁄ h ratio. In continuous systems, the shear deformation affects the internal forces. The moment at the supports reduces and the moment in the midfield increases. It is therefore recommended that moment and bending stresses are determined based on a simply supported beam along the longest span. Reaction forces and shear forces can be determined based on a continuous beam.

Load	kN/m2	γ_g, γ_q	Load duration	Kmod	Ψ_0	Ψ_1	Ψ_2
gk	32.54	0.89 . 1.35	Permanent (P)	0.6	-	-	-
nk	6.0	1.5	Medium (M)	0.8	0.7	0.5	0.3
Sk	6.12	1.5	Medium (M)	0.8	0.8	0.6	0.2

Table 7.16 Loads and load factors

A vertically and horizontally loaded wall panel, with two spans of lengths l1 = 2.0 m and l2 = 2.0 m and height h = 3.44 m.

7.14.1 Loads:

The floors over F and 4 to 9 has chosen for evaluation.

-The self-weight from the roof above the wall is gk = 8.07 kN/m and from the wall and floor structure along the lower edge it is gk = 7.85 kN/m.

$$g_k = \frac{(175.63 + 12) \times 9.81 \times 24}{4 \times 1000} = 11.04\ kN/m$$

$$g_k = \frac{175.63 \times 9.81 \times 24}{4 \times 1000} + 10.8 = 21.14\ kN/m$$

$$\rightarrow g_{k,tot} = 11.04 + 21.14 = 32.54\ kN/m$$

-The imposed load acting on the lower edge is nk = 6.0 kN/m.

-The snow load acting on the upper edge is sk = 6.12 kN/m.

$$g_k = \frac{1.04 \times 9.81 \times 24.0}{4.0 \times 1000} = 6.12\ kN/m$$

The wall comprises a 5-layer CLT panel with a thickness 140 mm and with all the boards in strength class C24. Service class 1, safety class 3 (γ_d = 1).

For CLT with boards only of strength class C24, the following applies:

$E_{0,x,0.05}$ = 7,400 MPa
$E_{0,x,mean}$ = 11,000 MPa
$G_{9090,xlay,mean}$ = 50 MPa
$G_{090,xlay,mean}$ = 690 MPa
and
$f_{m,k}$ = 24 MPa
$f_{v,k}$ = 4 MPa
$f_{c,0,k}$ = 21 MPa

With γ_m = 1.25 and kmod = 0.8, (Imposed load is leading action = medium term) the design strengths become:

$$f_{m,d} = \frac{k_{mod} \cdot f_{m,k}}{\gamma_m} = \frac{0.8 \,.\, 24}{1.25} = 15.36\,MPa$$

$$f_{v,d} = \frac{k_{mod} \cdot f_{v,k}}{\gamma_m} = \frac{0.8 \,.\, 4}{1.25} = 2.56\,MPa$$

$$f_{c,0,d} = \frac{k_{mod} \cdot f_{c,0,k}}{\gamma_m} = \frac{0.8 \,.\, 21}{1.25} = 13.44\,MPa$$

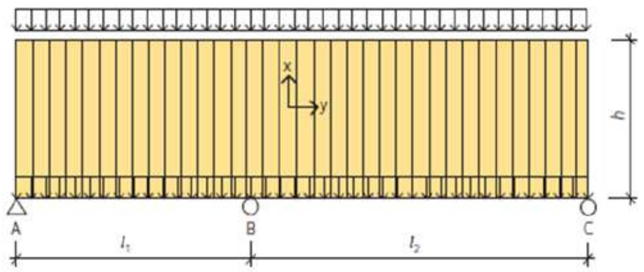


Figure 7.22 Wall panel on supporting posts

7.14.2 Calculations:

Design load combination for vertical load:

$$q_d = \gamma_G \cdot g_k + \gamma_{Q,n} \cdot n_k + \gamma_{Q,s} \cdot \Psi_{0,s} \cdot S_k =$$
$$0.89 \cdot 1.35 \cdot 32.54 + 1.5 \cdot 6.0 + 1.5 \cdot 0.8 \cdot 6.12 = 55.44\,kN/m$$

7.14.3 Moment:

Design moment for a single-span beam of length l1 = 2.0 m:

$$M_d = \frac{q_d \cdot l_2^2}{8} = \frac{55.44 \cdot 2.0^2}{8} = 27.72\,kNm$$

The cross-section during bending is calculated for the horizontal layers, i.e., only the layers of boards in the bearing direction:

$$W_{z,net} = \frac{d_z \cdot h^2}{6} = \frac{0.04 \cdot 3.44^2}{6} = 0.08\,kNm$$

with dz = total board thickness for the horizontal layers:

$$\sigma_d = \frac{M_d}{W_{z,net}} = \frac{27.72 \cdot 10^3}{0.08 \cdot 10^6} = 0.35\,MPa < f_{m,d} = 15.36\,MPa$$

7.14.4 Shear force:

Design shear force:

$$V_d = 0.625 \cdot q_d \cdot l_2 = 0.625 \cdot 55.44 \cdot 2.0 = 69.3\,kN$$

$$A_{z,net} = d_z \cdot h = 0.04 \cdot 3.44 = 0.14\,m^2$$

with dz = total board thickness for the horizontal layers:

$$\tau_d = 1.5 \cdot \frac{V_d}{A_{z,net}} = 1.5 \cdot \frac{69.3 \cdot 10^3}{0.14 \cdot 10^6} = 0.74\,MPa < f_{v,d} = 2.56\,MPa$$

Property	Calculation formula	Application to example
Net cross-section area (mm²)	$A_{x,net} = b_x \cdot 3 \cdot t_1$	$A_{x,net} = 90000\,mm^2$
Gamma values	$\gamma_3 = 1 \quad \gamma_1 = \gamma_5 = \frac{1}{1 + \frac{\pi^2 E_{x,5} t_5}{l_{ref}^2} \frac{t_4}{G_{9090,4}}}$	$\gamma_3 = 1 \quad \gamma_1 = \gamma_5 = 0.874$
Effective moment of resistance (mm⁴)	$I_{x,ef} = b_x \left(\frac{t_1^3}{12} + \gamma_1 t_1 a_1^2 + \frac{t_3^3}{12} + \frac{t_5^3}{12} + \gamma_5 t_5 a_5^2 \right) = b_x \left(3 \cdot \frac{t_1^3}{12} + 2 \cdot \gamma_1 t_1 a_1^2 \right)$	$I_{x,ef} = 13785 \cdot 10^4\,mm^3$
Radius of gyration $i_{x,ef}$	$i_{x,ef} = \sqrt{\frac{I_{x,ef}}{A_{x,net}}}$	$i_{x,ef} = 39.1\,mm$
Slenderness factor λ_y	$\lambda_y = \frac{l_k}{i_{x,ef}}$	$\lambda_y = 76.7$

7.14.5 Compressive force

Load spreading from supports is calculated for an angle 30° out from the support up to the height h/4.

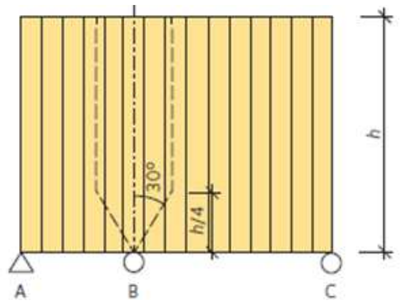


Figure 7.23 Load spread from support reaction

7.14.5.1 Support reaction:

$$M_B = -\frac{q_d l_1^3 + q_d l_2^3}{8(l_1 + l_2)} = \frac{55.44 \cdot 2.0^3 + 55.44 \cdot 2.0^3}{8(2.0 + 2.0)} = 27.72\,kNm$$

$$R_B = \frac{q_d l_1}{2} + \frac{q_d l_2}{2} - \frac{M_B}{l_1} - \frac{M_b}{l_2} = \frac{55.44 \cdot 2.0}{2} + \frac{55.44 \cdot 2.0}{2} - \frac{27.72}{2.0} - \frac{27.72}{2.0} = 83.16\,kN$$

7.14.5.2 Load spreading:

$$B = 2 \cdot \frac{h}{4} \cdot \tan(30^{\circ}) = 2 \cdot \frac{3.44}{4} \cdot 0.577 = 0.99\ m$$

This means that the load reaction spreads to a width of 1.04 m with a force of:

$$n_d = \frac{R_B}{B} = \frac{83.16}{0.99} = 84\ kN/m$$

Checks on buckling are made for a strip of 1.0 m, which gives the force:

$$n_{1,d} = \frac{n_d}{B} = \frac{84}{0.99} = 84.85\ kN/m$$

7.14.6 Control of buckling

The properties of the 5-layer panel are set out. Buckling is checked in the ultimate limit state:

$$\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} \leq 1$$

Reduction factor kc,y can be expressed as:

$$k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 - \lambda_{rel,y}^2}}$$

Where:

$$\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0.05}}} = \frac{76.7}{\pi}\sqrt{\frac{21}{7400}} = 1.30$$

$$k_y - 0.5(1 + 0.1(\lambda_{rel} - 0.3) + \lambda_{rel,y}^2) - 0.5(1 + 0.1(1.30 - 0.3) + 1.30^2) - 1.395$$

$$k_{c,y} - \frac{1}{1.395 + \sqrt{1.395^2 - 1.30^2}} - 0.526$$

$$\sigma_{c,0,d} = \frac{n_{1,d}}{A_{x,net}} = \frac{84.85 \cdot 10^3}{900 \cdot 10^2} = 0.94\ MPa$$

$$\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} = \frac{0.94}{0.526 \cdot 13.44} = 0.13 \leq 1 \quad \text{OK}$$

The wall is able to handle the compressive force, with a capacity utilization of 13.0 percent.

7.15 Wall panel with openings

A vertically loaded external wall on the ground floor has a height le = 4.00 – 0.13 = 3.87 m and a width b0 = 4.0 m. The wall has two windows and the effective wall width without windows is bef=1.6 m.

The design load from the roof structure above the wall is Fd = 3.7 kN/m. Wind pressure across the wall is qd = 1.86 kN/m. The wall comprises a 5-layer panel of CLT. Thickness 140mm, with all the layers of boards meeting strength class C24. Service class 1, safety class 3 (ɣd=1).

7.15.1 Calculations:

Cross-sectional properties can also be calculated for a strip bx = 1.0 m of the board. Buckling is checked in the ultimate limit state:

$$\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,d}}{f_{m,d}} \leq 1$$

The design strengths are:

$$f_{m,d} = \frac{k_{mod} \cdot f_{m,k}}{\gamma_M} = \frac{0.9 \cdot 24}{1.25} = 17.28\ MPa$$

$$f_{c,0,d} = \frac{k_{mod} \cdot f_{c,0,k}}{\gamma_M} = \frac{0.9 \cdot 21}{1.25} = 15.12\ MPa$$

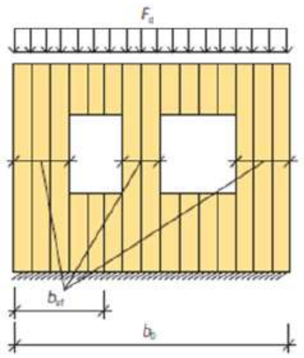


Figure 7.17 Wall panel with openings

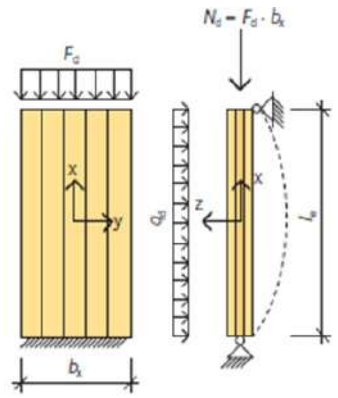


Figure 7.18 Part of a wall panel

Property	Calculation formula	Application to example
Centre of gravity (mm)	$Z_s = \frac{h_{CLT}}{2}$	Z_s = 45 mm
Net cross-section area (mm²)	$A_{x,net} = b_x \cdot 2 \cdot t_1$	$A_{x,net} = 60000\ mm^2$
Net moment of inertia (mm⁴)	$I_{x,net} = b_x\left(\frac{t_1^3}{12} + t_1 a_1^2 + \frac{t_3^3}{12} + t_3 a_3^2\right) = b_x\left(2 \cdot \frac{t_1^3}{12} + 2 \cdot t_1 a_1^2\right)$	$I_{x,net} = 5850 \cdot 10^4\ mm^4$
Net moment of resistance (mm³)	$W_{x,net} = \frac{I_{x,net}}{Z_s}$	$W_{x,net} = 1300 \cdot 10^3\ mm^3$
Gamma values	$\gamma_1 = 1 \quad \gamma_3 = \frac{1}{1 + \frac{\pi^2 E_{x,3} t_3}{l_e^2} \frac{t_2}{G_{9090,2}}}$	$\gamma_1 = 1 \quad \gamma_3 = 0.817$
Effective moment of resistance (mm⁴)	$I_{x,ef} = b_x\left(\frac{t_1^3}{12} + t_1 a_1^2 + \frac{t_3^3}{12} + \gamma_3 t_3 a_3^2\right) = b_x\left(2 \cdot \frac{t_1^3}{12} + (1 + \gamma_3) t_1 a_1^2\right)$	$I_{x,ef} = 5356 \cdot 10^4\ mm^3$
Effective radius of gyration $i_{x,ef}$	$i_{x,ef} = \sqrt{\frac{I_{x,ef}}{A_{x,net}}}$	$i_{x,ef} = 29.87\ mm$
Slenderness factor λ_y	$\lambda_y = \frac{l_e}{i_{x,ef}}$	$\lambda_y = 98.8$

Table 7.17 Properties of 5-layer CLT panel, strip of width bx = 1.0 m. Panel thickness 140 mm

Reduction factor kc,y can be expressed as:

$$k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 - \lambda_{rel,y}^2}}$$

Where:

$$\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0.05}}} = \frac{98.8}{\pi}\sqrt{\frac{21}{7400}} = 1.675$$

$$k_y = 0.5(1 + 0.1(\lambda_{rel} - 0.3) + \lambda_{rel,y}^2) = 0.5(1 + 0.1(1.675 - 0.3) + 1.675^2) = 1.971$$

$$k_{c,y} = \frac{1}{1.971 + \sqrt{1.971^2 - 1.675^2}} = 0.332$$

Openings in the wall cause larger loads on the remaining sections of the wall. As a rule, it is possible to assume an evenly spread load on the wall sections between the windows. Loads are The vertical load is calculated for a 1.0 m strip of effective width b_{ef}: distributed to the effective width bef with factor fb:

$$f_b = \frac{b_0}{b_{ef}} = \frac{4.0}{1.6} = 2.5$$

$$f_b = \frac{b_0}{b_{ef}} = \frac{4.0}{1.6} = 2.5$$

$$N_d = b_x \cdot f_b \cdot P_d = 1.0 \cdot 2.5 \cdot 3.7 = 9.3\ kN$$

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Moment of the wind load:

$$M_{y,d} = \frac{q_d \cdot l_e^2}{8} = \frac{1.86 \cdot 2.5 \cdot 3.47^2}{8} = 7.0\ kNm$$

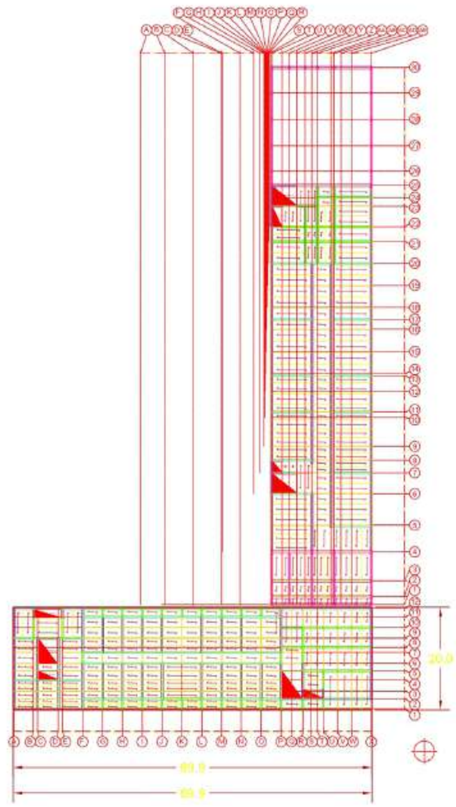
$$\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,d}}{f_{m,d}} = \frac{N_d}{k_{c,y} \cdot A_{x,net} \cdot f_{c,0,d}} + \frac{M_{y,d}}{W_{x,net} \cdot f_{m,d}} =$$

$$\frac{9.3 \cdot 10^3}{0.332 \cdot 600 \cdot 10^2 \cdot 15.12} + \frac{7.0 \cdot 10^6}{1300 \cdot 10^3 \cdot 17.28} = 0.03 + 0.31 = 0.34 \leq 1 \quad \text{OK}$$

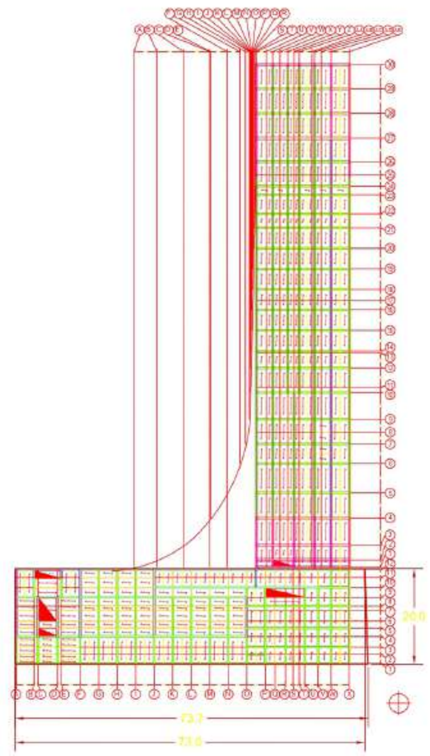
The wall can handle the stresses from the compression and moment, with a capacity utilization of 34 percent.

7.16 STRUCTURAL PLANS

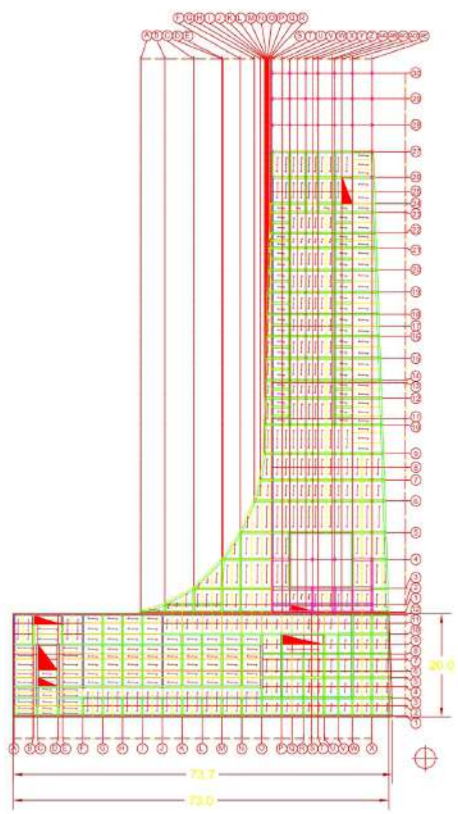
Ground floor



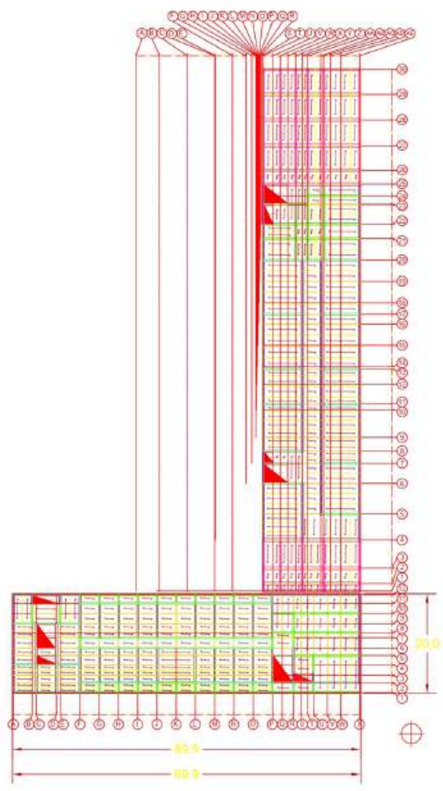
First floor



Second floor



Third floor



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