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Sustainable densification through wooden extensions. The case study of Sentralbygg 1 at Gløshaugen.

Master's thesis in Sustainable Architecture
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ABSTRACT

The increased demands of urban densification in combination with the ongoing rising amount of CO2 on atmosphere are calling for direct actions. As the buildings industry is accountable for about 40% of all GHG emissions, it is our duty to reconsider and develop the current built environment with zero-emission solutions that aim for sustainable growth.

A prominent solution that can tackle that problem is the wooden constructions as extensions on existing buildings. Wood can absorb and store significant amounts of CO2 and it can be easily reused after its end of life while the embodied energy of the current buildings stock cannot be underestimated.

This master thesis will focus on the wooden extension of Sentralbygg 1 at the Gløshaugen plateau in Trondheim, facilitating student housing. Recently, the campus is undergoing significant changes as the Dragvoll campus of NTNU will move into Gløshaugen and the built environment will change drastically. That will result to the creation of new needs and functions on the plateau. So the proposal aims to host some of the new needs.

The Nordic climate is key driver to the design along with the current socio-cultural environment of the campus. With emphasis to the users-residents and with respect to the existing structure, a three-storeys wooden extension is proposed to accommodate 36 students. The life cycle assessment (LCA) is conducted towards an optimal choice of materials. An important objective is to create a zero-emission wooden extension with possibilities for further energy generation.

The concept of energy synergy is proposed to upgrade the energy efficiency of the existing office building, Sentralbygg 1, while providing the necessary energy to the residential extension.

Norsk oversettelse

De økende kravene til fortetting i byområder, kombinert med stigende mengder CO2 i atmosfæren, krever direkte handling. Fordi byggebransjen står for omtrent 40% av utslippene av klimagasser, er det vårt ansvar å revurdere og utvikle det eksisterende bygde miljøet med nullutslippsløsninger som sikter på bærekraftig vekst.

En fremstående løsning som kan håndtere dette problemet er bygninger i tre som påbygg på eksisterende bygninger. Tre kan absorbere og lagre betydelige mengder CO2 og er enkelt å gjenbruke etter endt levetid, mens den forankrede energien fra den nåværende bygningsmassen ikke kan undervurderes.

Denne masteroppgaven setter søkelys på et påbygg i tre på Sentralbygg 1 på Gløshaugen-platået i Trondheim, med tanke på studentboliger. For tiden gjennomgår universitetsområdet betydelige endringer, ettersom Dragvoll-campus skal flyttes til Gløshaugen og det bygde området vil endres drastisk. Det vil føre til at det skapes nye behov og funksjoner på platået. Forslaget tar derfor sikte på å være vert for noen av de nye behovene.

Det nordiske klimaet er en viktig pådriver for designet, sammen med det nåværende sosiokulturelle miljøet på campus. Med vekt på brukerne (beboerne) og med hensyn til den eksisterende bygningen, foreslås et 3-etasjers påbygg i tre for å huse 36 studenter. Livssyklusvurderingen (LCA) gjennomføres mot et best mulig utvalg av materialer. Et viktig mål er å skape et nullutslippspåbygg i tre med muligheter for videre energiproduksjon.

Konseptet energisynergi er foreslått for å oppgradere energieffektiviteten til den eksisterende kontorbygningen, Sentralbygg 1, samtidig som det leverer den nødvendige energien til boligene.

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I would like to thank my supervisor Pasi Aalto as well as my co-supervisor Tomy Kleiven for their constructive guidance, remarks and their constant positive attitude.

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1| INTRODUCTION_CONTEXT

1.1.1 THE GROWTH OF URBAN HABITATS

Urban habitats originate from the first human settlements, the cities that arose around 3500 BC era in the valley of Mesopotamia; where agricultural innovation led to prosperity and expansion of human settlements. The first large dependence on agriculture was gradually replaced by merchandise and trade and as the settlements became larger, they transformed into socially complex urban societies (Greve, 2011). These *"processes by which agricultural village societies developed into socially, economically, and politically complex urban societies"* ("Urban revolution," 2016) are defined as urban revolution, a term which was enunciated by the archeologist V. Gordon Childe. The gradual transition to state-level urban societies resulted among others into the spatial transformation of the cities' boundaries and the rise of the total population from 14 million inhabitants during 3000 BC to 1 billion in the early 19th century (World population by year (2019) - Worldometers, 2019).

The 18th century is a benchmark for the urban development. The modern way of living has its roots back to that century, when the advent of Industrial Revolution made permanent changes in the global society. That does not imply that no significant changes have been made in the previous years, but the industrial era indicates the advent of mass urbanization. As Hannah Arendt rightly mentioned in *"The Human Condition"*, the things that owe their existence to people, continually define their creators (Arendt, 1958). That happened with the tools that were created in the industrial era; they reformed the human habitat and also introduced new ideas to the society. Mechanization, steam power, electrical power and the assembly line led to the development of the urban environment. Specifically, the development and expansion of roadways, railroads and all forms of transportation, allowed the redistribution of people and the goods that were produced that period (Greve, 2011).

So a huge number of people moved into cities in search of job opportunities and a better life which led to the rapid growth of urban population and therefore the urban environment. Since then, the world's population presented exponential increase and from around 1 billion in the advent of 19th century, rose up to 6.1 billion in the year 2000 (United Nations, 2019). However, all these years the urban population does not surpass that on rural areas. That happened only after 2007 (Roser, Ritchie, Ortiz-Ospina, 2013), where the post-industrial era, known as 'the Knowledge Age', presents a main shift in the economic growth that is based on the provision of services on the tertiary sector. Although the production of goods continues to play an important role in the contemporary society, knowledge and information are now the main source of economic growth. That affects the work patterns and the business practices are now orientated in even more specialized forms. With its turn, the new work patterns affect the urban growth as the majority of the work force is employed in the tertiary sector and therefore in urban habitats. Nowadays the total population is 7.72 billion persons and over a half lives in cities (United Nations, 2019). By 2050 it is expected to increase by 2 billion people, reaching a total of 9.7 billion persons, while 68% of them will constitute the urban population (United Nations, 2018).

According to United Nations, in the beginning of the 21st century, there were 371 cities with a population of at least 1 million each worldwide. In the course of the last 18 years the number of such cities reached to 548 while it is estimated that in 2030 there will be 706 cities with at least 1 million inhabitants. Moreover, the number of megacities-cities with more than 10 million inhabitants will present an increase of 10 megacities, from 33 that were in 2018 to 43 in 2030 (United Nations, 2018).

The spatial transformation of the urban habitats through the years is clearly illustrated in "The City as an Egg" from the architect Cedric Price (Fig.1). There the urban form of ancient cities resembled a boiled egg with clearly defined boundaries. The dense and compact center of each city was protected by defensive walls up until the medieval period. From 17th to 19th century the urban form is presented as fried egg.

The industrial revolution together with the new technologies led to the rapid growth of urban settlements and the expansion of them in residential and industrial areas, while interconnected through infrastructural networks that spread in every direction. Meanwhile the modern city resembles the scrambled egg. The current urban development is characterized by the modern ethics, where the term of stability is questioned and flexibility plays main role in the problem solving situations.

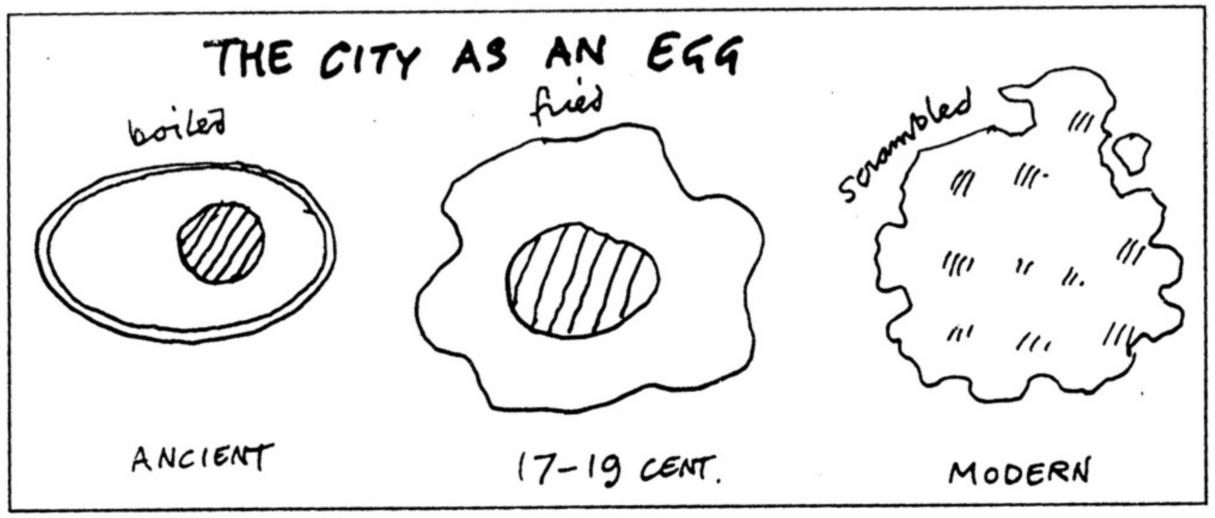


Figure 1 : "City as an Egg", diagram by Cedric Price (Brandon, 2016)

The main characteristics of this era are well described by Michel Foucault: *"The present epoch will perhaps be above all the epoch of space. We are in the epoch of simultaneity: we are in the epoch of juxtaposition, the epoch of the near and far, of the side-by-side, of the dispersed"* (Foucault, 1967).

A question that arises after that is how the cities' form will be transformed in the future. An answer may not be illustrated through a plan drawing as the different egg forms, but it may be presented as a section of a city's skyline. The tendency now is to move the urban sprawl into the vertical axis, which means to build upwards in the already dense urban environments, while using and developing the tools of modern times.

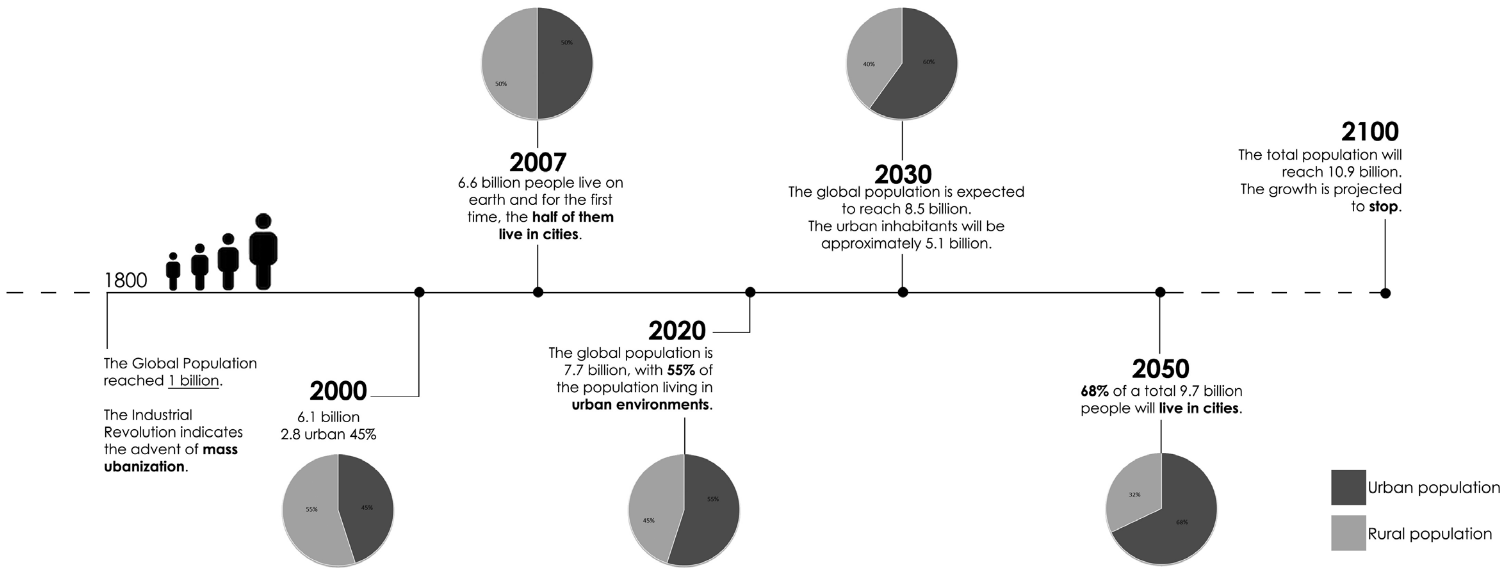


Figure 2 : Urban and rural population growth.

Figure 3 : United Nation's Sustainable Development Goals

1.1.2 CURRENT CHALLENGES

"While more and more people are pouring into urban areas, and while over-development is destroying higher fertile land and at the same time encouraging higher consumption of non-renewable resources, we have to ask ourselves: Where does this path lead?"

Chris Luebkeman

Parallel to the global trends of urbanization and the rise in population density, the new challenges, such as the augmentation of air pollution and the inadequate infrastructures, put even more pressure on the current world's resources, as nowadays humanity uses 1.75 times more the ecological resources that nature can regenerate in the course of a year (Earth overshoot day – Global Footprint Network, 2020). So, how sustainable can the urban growth be? In order to answer on 'how', it is first necessary to assure that the urban growth can be viable with the aim of an adequate environment for humans' health and well-being (WCED, 1987). Such development affects the social, economic, cultural and environmental aspects of urban environments. However, the concept of sustainability or sustainable development is not new. It originates from the "Report of the World Commission on Environment and Development: Our Common Future", also known as the Brundtland Commission, which was published in 1987 by the United Nations. In this report, sustainable development is defined as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This definition has profound influence on primary, secondary and tertiary sectors, from politics and economics to ecology, energy management, buildings infrastructure, transportation systems and so on. The multifactorial character of sustainable development is being addressed on the 2030 Agenda of Sustainable Development that was voted for all the member states of United Nations. There are 17 Sustainable Development Goals (SDGs) presented and urge all countries for actions under a global partnership that tackles poverty and improves well-being. All the strategies are interconnected and aim to deal with multiple issues, such as health, education, inequality and economic growth, while preserving the natural ecosystem and tackling climate change.

Although climate change can be described as a natural process of long-term alterations in climate system and weather patterns, the United Nations Convention on Climate Change (1992) defines it also as a change of climate due to human activities that change the composition of the global atmosphere.The main result is an increase in the concentration of greenhouse gases (GHGs) in the atmosphere that leads to a gradual increase of the average global temperature on earth. According to NASA Goddard Institute for Space Studies (GISS) the global surface temperature presents gradual increase since 1970 with an annual average anomaly reaching 0.98°C in 2019 (Global Temperature (2020)-Nasa, 2020). So the climate change has altered into a climate crisis. The importance of this issue is outlined in the Paris Agreement (2015), where 196 Parties of the UN Framework Convention on Climate Change (UNFCCC) adopted the global warming goal of this century: the global temperature rise should be well below 2°C above pre-industrial averages and even further to limit that increase to 1.5°C.

The focus of this report will be to tackle the challenges that are connected with the buildings industry in combination with the social aspects of sustainability. The construction as well as the operational energy of the buildings is accountable for consuming 50% of natural resources, 40% of energy use and 16% of water (Gauzin-Müller, 2002). With regard to the greenhouse gasses, in 2018 the buildings and construction sector accounted for 39% of energy- and process-related CO2 emissions (IEA,UN, 2019). However, the modern leaving standards in combination with the growth of population resulted in the expansion of floor area and the gradually increased demands of electricity within a decade. Until 2030, if no reduction measures are taken, global emissions from buildings are projected to increase by up to 1.7% per year or 53% overall from 2005 to 2030 (McKinsey & Company, 2009). Thus, one main approach of this report refers to the energy consumption and efficiency of the buildings.

The European Directive on Energy Efficiency in Buildings (Directive 2010/31/EU) emphasizes the necessity of transforming the buildings to nearly zero energy (NZEB) by 2020, which means that the total amount of annual energy use is almost equal to the amount of renewable energy created on the site or by sources elsewhere. Meanwhile the need to reduce the environmental footprint, led to the ongoing research and construction of plus energy buildings. Thus a surplus of energy can be transmitted to cover other energy demands and energy synergy between buildings can be achieved.

Another approach refers to the design through the architectural point of view. Sustainable architecture seeks to minimize the environmental footprint of the buildings through a holistic approach and the life cycle assessment. Energy efficiency and ‘smart’ buildings can be achieved through the current technology and the strengthening of the buildings envelope. Even though sustainable architecture uses a conscious approach to energy and ecological conservation in the design of the built environment, it is more than that. These words of Andrew Scott describe precise the definition of sustainability in architecture: “it is not just an environmental strategy but a means of making buildings that are more user responsive, more humane places to inhabit, more intelligent in the way the balance their energy flows, more respectful of nature and the resources it offers, and more understanding of buildings having a life span during which they undergo substantial change and adaptation…it simply equates to better designed places in tune with the environment.” (Scott, 1998).

1.1.3 THE CONTEXT IN TRONDHEIM _ A STUDENT CITY

Figure 4 : Expansion of Trondheim from 1915 to 2000.

Trondheim is a Scandinavian city with a fairly high urban expansion over the last 40 years. The geopolitical location in combination with the flourish of industry and education resulted in the rapid growth of the city. The expansion occurs mostly on the northeast and southwest part, where the main transportation axis leads to the capital and the majority of the cities in Norway. Currently Trondheim can be characterized by low density, as 200.000 residents occupy an area of 497 km^2. However, the population is constantly increasing and so has the urban density.

Figure 5 illustrates the number of dwellings that were into use since 1986 in Trondheim. As it shows, the number of dwellings presents significant increase the last twenty years. In the meantime, the blocks of flats (3 floors and more) and the student houses are the two types of dwelling that show significant growth only the last decade.

Even though the student housing is gaining more and more space after the millennium, there is still room for improvement. In Trondheim, the total number of students is approximately 42000, which means that 21% of the city’s population is students. Therefore it is wisely characterized as a student city. However the ongoing increased number of students at NTNU, puts even more pressure on the already limited number of students accommodations. In fact, in 2019, nearly 3000 students of NTNU, in Gjøvik, Ålesund and Trondheim, queued at SiT (Students in Trondheim) organization’s waiting lists, hoping to find student accommodation (Over 2300 studenter venter fortsatt på bolig hos Sit (2019) -trd, 2019). In addition, the student housing system in Trondheim will have to phase another challenge; the transfer of campus from Dragvoll to Gløshaugen. That will result in a denser Gløshaugen plateau and therefore more students will have to live nearby. The more students can live nearby this plateau, the fewer the emissions from long-term transportations and the more sustainable the development.

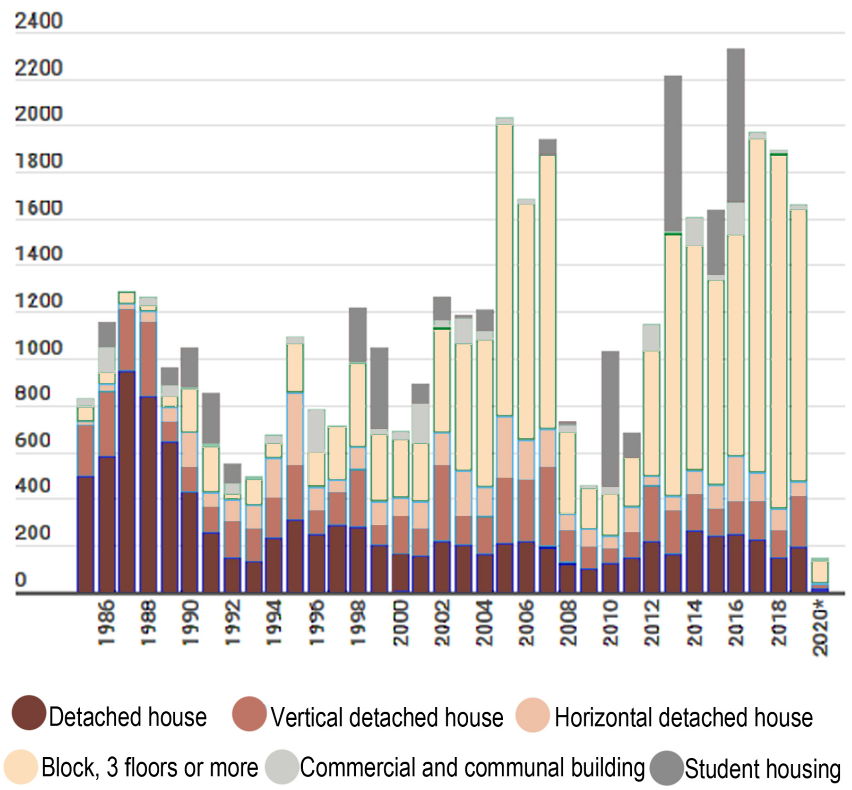


Figure 5 : Type of buildings in Trondheim.

1.2 SCOPE OF THE STUDY

The topic of a wooden extension on the top of Sentralbygg 1, at Gløshaugen, was first proposed by NTNU Wood and refers to the joint development of the master thesis under a multidisciplinary cooperation with master students from different engineering departments.

So the 'journey' of my master thesis will be done in cooperation with two students from the department of structural engineering. Anders Fjell and Jan Erik Edvardsen Holm are the engineers who will develop their thesis with the title *"Påbygg av tre i høyden på Sentralbygg 1"*. Therefore, below are two scopes, one for the group work and one that refers to this thesis. However, both of them were equally significant during the process of this thesis and they were always interrelated.

First, as a group, we do not aim to propose an optimal solution. We aim to explore the feasibility spectrum of the idea of a wooden extension on the top of Sentralbygg 1 through our different points of view and skills.

With regard to this thesis, the scope is to explore the design capabilities of sustainable urban expansion through the case study of Sentralbygg 1. Meanwhile, for the case study it was considered essential to set a further goal, that of designing a ZEB-OM (ambition level) extension with emphasis on social sustainability and the energy synergy that could be achieved with the reference building.

1.3 RESEARCH QUESTION

The main research question that seeks for an answer through this thesis is:

What is the scope of a wooden extension in a mixed use building in terms of environmental impact; the energy use and the CO2 emissions?

1.4 RESEARCH METHODOLOGY

The thesis is based on analysis and it is structured around the case study.

The case study explores the capabilities of a wooden extension on the top of Sentralbygg 1 in Gløshaugen. In cooperation with the two students from the department of structural engineering, we will explore this potential in terms of architectural design, structural analysis and energy generation from renewable sources. Under common understanding, we form different scenarios of 4 and 3 floors wooden extensions and analyze their capabilities according to our background and field of expertize. Therefore, architectural concepts will be tested in structural adequacy and vice versa, while each research will be based on the guidelines of sustainable development in urban habitats.

The focus of this thesis will be on the architectural concepts in combination with the energy generation. So each scenario will be composed by architectural solutions and energy simulations that will outline a sustainable approach on the problem.

2| CASE STUDY - SENTRALBYGG 1

2.1 THE SITE -GLØSHAUGEN

The site is located in the main part of NTNU campus in Trondheim and specifically in the center of Gløshaugen plateau. The area is of paramount importance for the city and is the main contributor to the development of Trondheim as a student city. The last years it is being subject of notable changes with the construction of zero emission buildings, such as the new ZEB laboratory on the south part of the campus. At the same time, the area will be transformed to accommodate the NTNU facilities, now located in Dragvoll. The additional functions will therefore serve even larger number of students and academic staff in Gløshaugen. The urbanization and densification of NTNU campus will have severe implications to the city. New areas for student accommodation will be sought, and public transport will be affected from probably shorter distances and more users. However, if we take into account the size of the city on that densification context, we can estimate that transfer to the campus will be mainly through walking or cycling. This means that public transport will be reduced and therefore the environmental emissions will be less. Of course, further research is needed, assessing the life cycle of infrastructures, new constructions, transportation and so on, that is out of the scope of this thesis.

The main advantage of the site is the fact that Gløshaugen is an important urban, educational, social and cultural node for the city. Consequently, location favors accessibility to all the main areas concerned with academia, student life and welfare, as all the facilities of NTNU in Trondheim are located in a walking distance of less than 5km. Laboratories, studios, lecture halls, offices and auditoriums are all accessible in a short walking distance inside the campus. Meanwhile, city center and Studentersamfundet, that have a vital role in the daily student life, can both be reached in less than 20' walking, 10' biking or 10' by public transport. Connection with the other facilities of NTNU in Trondheim such as in Dragvoll, Øya, Tyholt and Kalvskinnet, is also achieved through public transport that crosses the campus or by well-organized cycling tracks. These connections became even easier since the fall of 2019, as the transportation system was upgraded with new busses, the well-known metrobusses, and more frequent routes. At the same time, recreational activities that are well bonded with the Norwegian culture, such as cabin trips, hiking and skiing are also easily accessible by public transport.

The whole plateau is surrounded by green areas and parks that are often used by students and residents of the nearby areas. These vegetated areas have two significant roles. First, they lower surface temperatures during the months with high solar radiation, and second, they prevent high noise levels inside the university campus. Based on the noise map below, Gløshaugen plateau presents noise levels of 55-60 dB that makes it suitable for prolonged period of time, as noise levels above 70 dB and for prolonged period can damage the hearing.

Fig. 6 : Functions and main entrances to the site

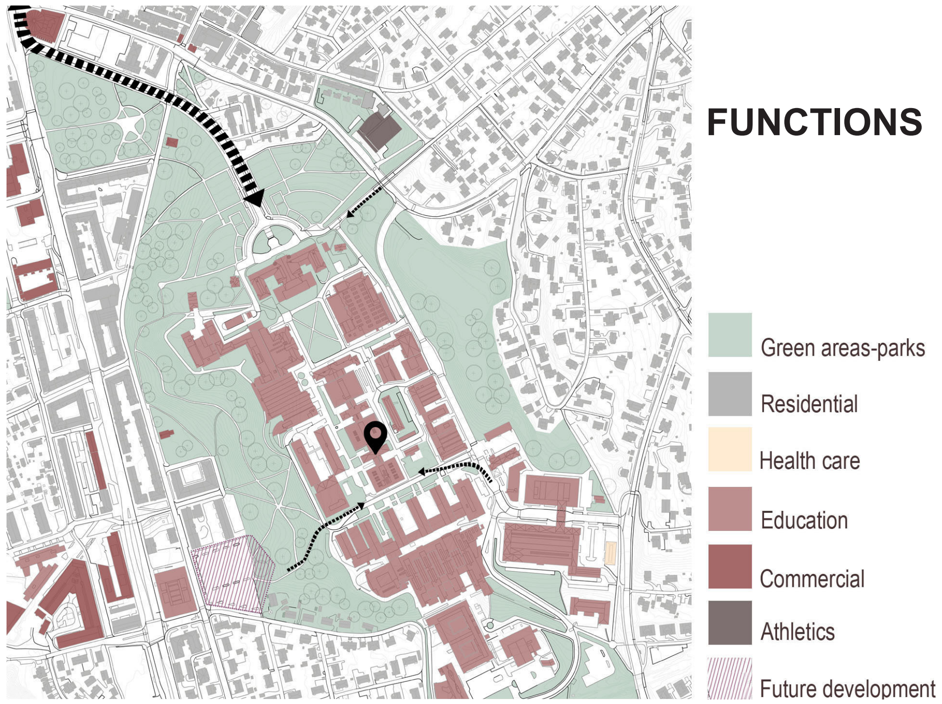
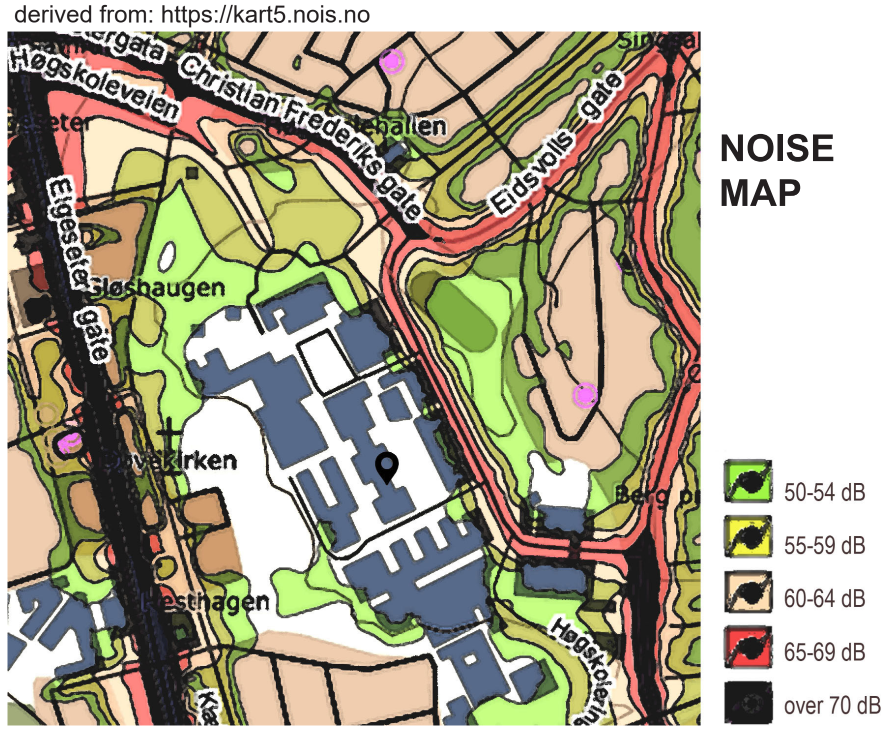


Fig. 7 : Green areas around Gløsaugen

Fig. 8 : Noise map of Gløshaugen, derived from: https://kart5.nois.no



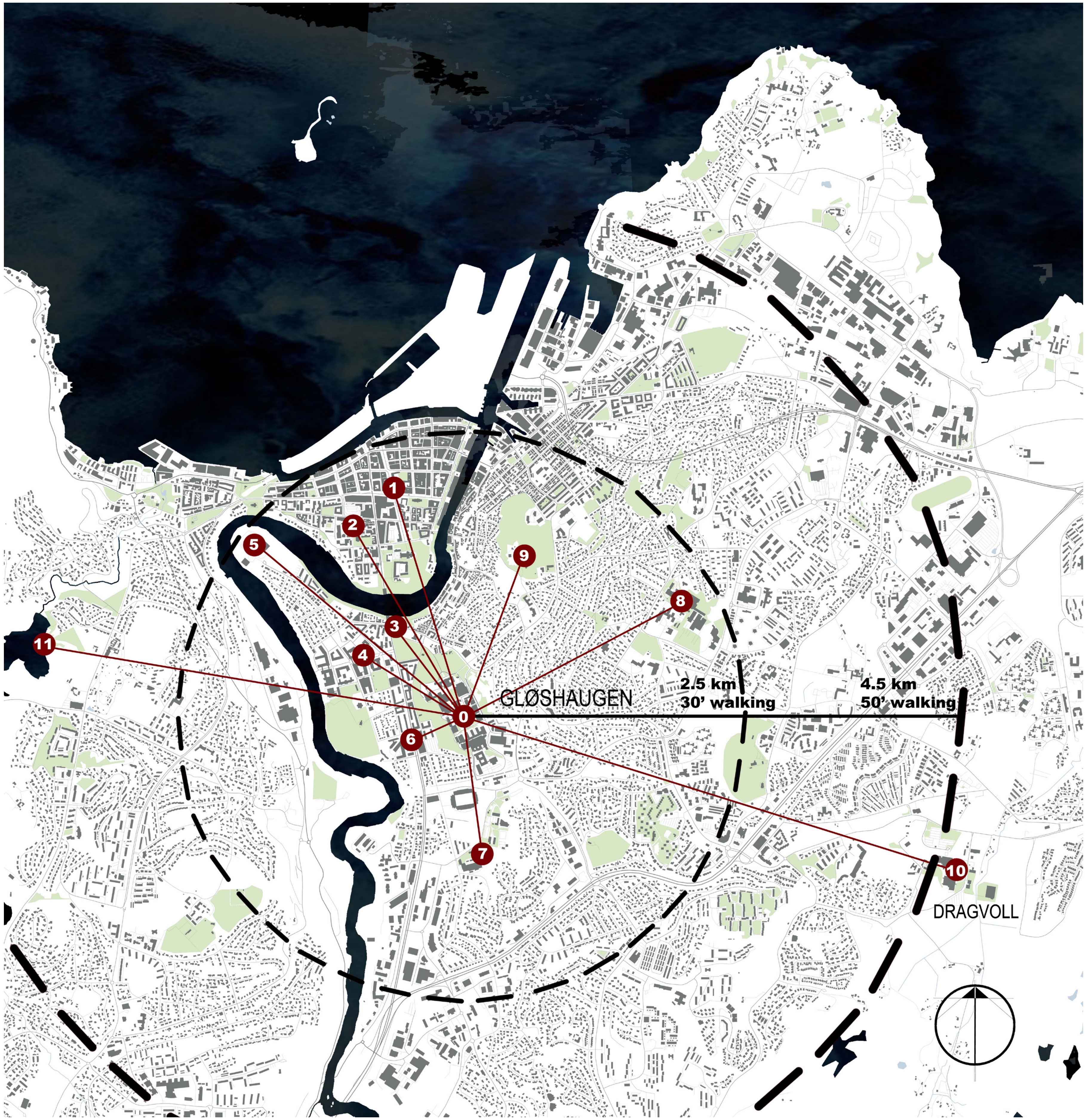


Fig. 9 : The map presents the site location in relation with the NTNU campuses in Trondheim and main areas of the city that are strongly connected with student life.

1. City center
2. Kalvskinnet campus
3. Studentersamfundet
4. Hospital - Øya campus
5. Trondheim Spektrum
6. Teknobyen student housing
7. Lerkendal
8. Tyholt
9. Kristiansten Festning
10. Dragvoll
11. Bymarka

2.2 MAIN CLIMATIC FACTORS ON THE PLOT

Trondheim_NO

Elevation: 56 feet Latitude: 63 28N Longitude: 010 56E
Köppen Classification : Continental Subarctic Climate [Dfc]

According to Köppen-Geiger Climate Classification system, Trondheim has continental subarctic climate (Dfc). In short, it is dominated by the winter season, although the maximum rainfall takes place during summer. June is usually the month with the highest amount of rain because “areas of low pressure accompanied by high temperatures, as opposed to the areas of high pressure accompanied by low temperatures that form in the winter” . Meanwhile, in an annual base, the temperatures fluctuate from -13 °C in winter to 23°C in summer, so the biggest part of the year, the climatic conditions are out of the comfort zone. However, the Gulf Stream creates a mild climate in the city and the areas near to the coast.

Due to the high latitude (above 60 degrees), the climate of Trondheim changes significantly with each season. To illustrate, during the summer solstice on 21st of June, the city is day lighted with a maximum of 20:31 hours, while during the winter solstice on 21st of December, it has a total of just 04:30 hours of daylight. The global radiation reaches a pick on June while the highest absolute values are observed from April to August. Spring and summer are periods where there is high potential for sufficient solar energy gains. However, on figure , it is obvious that the southwest part of the site in Gløshaugen is almost illuminated all year round. Specifically for Sentralbygg 1, the optimal orientation, the height and the unobstructed view to the south, offers sunlight to both south and west facade of it even in December, as long as there is sun in the sky. Such situation raises questions regarding energy perspectives of solar heat gains from the optimal parts of this building. One main question refers to the solar energy generation from the southwest part of the building. Could such gesture be profitable in terms of energy cover of Sentralbygg 1? The following section of this thesis seeks to answer such questions.

Another important climatic factor is the wind. The prevailing wind comes all year round from the valley on the southwest part of the city, where Heimdal lies, and has an annual average speed at 2.4m/s. The winter period though presents slightly higher values of wind speed. In the context of Gløshaugen campus, the wind has strong influence in the areas near Sentralbygg 1 and 2. The height of these buildings and the strong winter winds, create turbulent wakes on the ground level and therefore uncomfortable conditions (high wind speeds) at the entrances of the central building block. This feature creates design and structural challenges regarding the final height of an extension on the already high rise Sentralbygg 1. In the meantime, it raises questions about the hospitality of the ground level in this central part – the ‘heart’ of the campus.

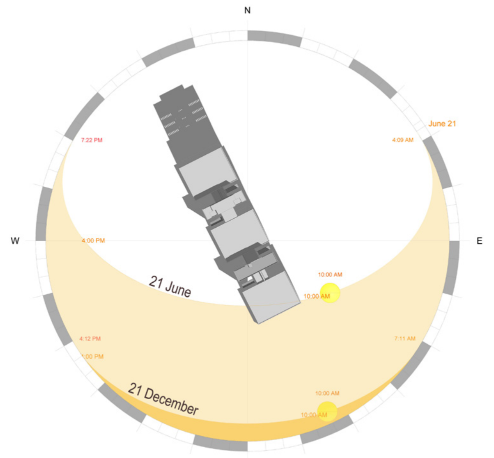


Figure 10 : Sunpath in December offers 04:30 hours of daylight, while in June the daylight lasts for 20:35 hours.

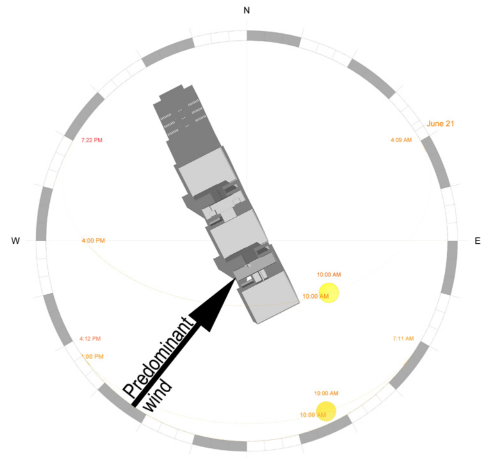


Figure 11 : Winter and summer predominant wind comes along the outer seaboard, S-W direction.

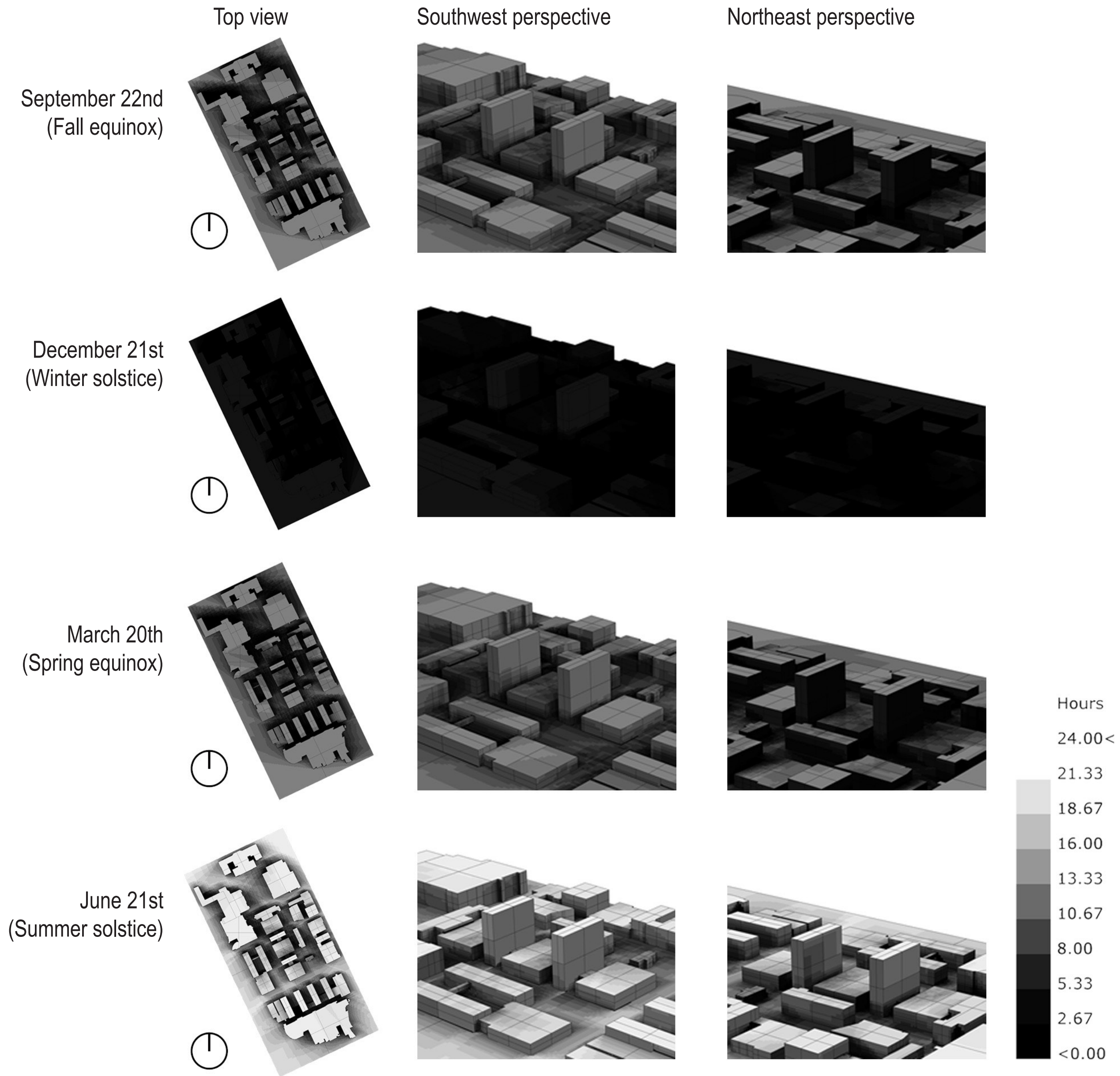


Figure 12 : Sunlight hours study of critical dates.

South facade- Current situation - View from the busstop
(personal archive)

2.3 THE HOST BUILDING - SENTRALBYGG 1

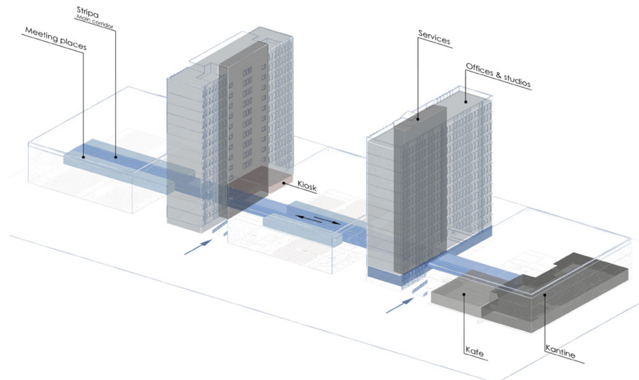


Figure 13 : Functions on Sentralbygg 1 and the main areas of the block.

Sentralbygg 1 is a high rise building that accommodates university facilities at Gløshaugen campus in Trondheim. It consists of total 14 levels, 13 floors above the ground level and one basement. Every weekday almost 250 people use its spaces from approximately 08:00 in the morning until 16:00 o'clock in the afternoon. Students, academic and administrative staff, workers and even more persons create a diverse and multicultural environment.

This host building was designed by the architect Karl Grevstad and it was built in 1961 and together with the equally high Sentralbygg 2 and the lower cubic volumes, form the central builings of the campus. Its form suggests strong influence of functionalism and the modern architecture that was the main architectural movement during 20th century. The height of approximately 41m, makes it one of the tallest buildings in Trondheim and has therefore become a landmark of the campus and the city.

The first three floors are connected with intermediate volumes that lead to the main corridor, 'Stripa', on ground floor level. There is connection with the café, the canteen, the kiosk and all the auditoriums of the whole central building block. In addition, the three first floors of Sentralbygg 1 shelter common areas, some studios and small lecture halls. From the 4th to 13th floor the building facilitates mostly cell offices and some open plan working areas. The majority of them faces south. The vertical circulation is located on the north part of the building and is achieved through two elevators, with a maximum capacity of 26 persons, and two spiral staircases. However due to the elevation of the building, many workers and academic staff are using mostly the elevators. So during rush hours, the elevators can be inaccessible or there is inconvenient waiting time.

With regard to the structure, this functionalistic tall building is constructed by reinforced concrete. The west and east facades, that are completely covered by concrete blocks, have significant role in the load bearing structure of the building and give the opportunity to the south and north façade to have all the openings. However, after in-situ investigation with the structural engineers, we discovered that the main central wall from 4th to 13th floor is a load bearing concrete structure that should be considered in further design.

As far as the energy context is concerned, Sentralbygg 1 uses NTNU's local district heating ring that is connected with the Trondheim district heating grid. A heat pump is placed in the basement and covers approximately 26% of the energy demand *(Woszczek, 2018)*. In addition, it receives excess heat from large computers. *(Kleiven, personal communication, March 2020)*

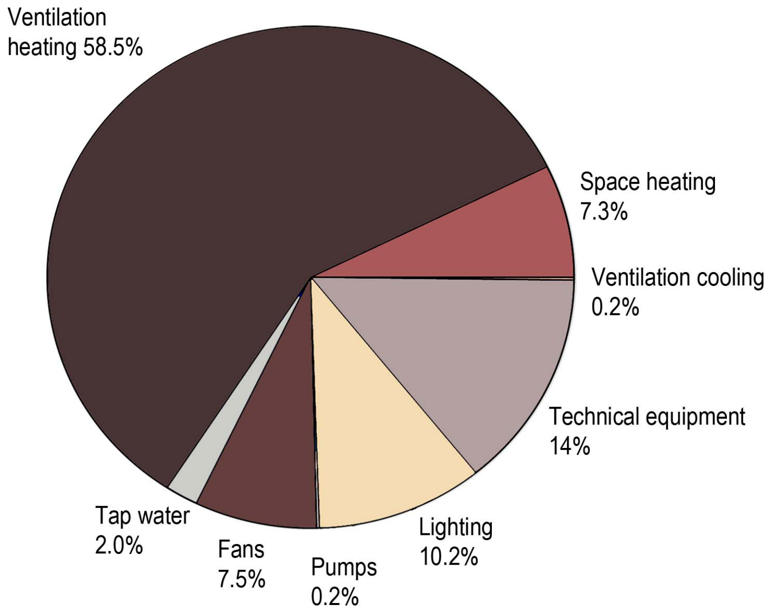
Sentralbygg 1 was built in 1961, so the building performance was expected to be really low. However, after we contacted the ‘Campus Service Department’, it was interesting to learn that the exterior windows have been replaced and the majority of them have a low U-value of 0,8W/m2K. The lower the U-value, the slower the heat transmittance through glass and therefore the lower are the heat losses. In the meantime more data we collected refer to the U-values of walls, roof and more. For example the concrete walls have approximately 10-15 cm insulation only on the inside and their U-values range from 0,3 W/m2K to 0,5 W/m2K. These data were used to calculate the energy use of Sentralbygg 1. According to simulations in SIMIEN, the total energy demand reaches almost 1270 MWh per year. On figure ... it is clear that over the half of it is used for ventilation heating.

With regard to the environmental emissions, almost 109 tons of CO_2 are released into the atmosphere every year that the building operates.

Figure 15 : Annual energy budget

5174 m² heated area	Simulated energy need	
Sentralbygg 1	**Energy need kWh**	**Energy need kWh/m²**
Space heating	92353	17.8
Ventilation heating	743294	143.7
Tap water	25923	5.0
Fans	95081	18.4
Pumps	2602	0.5
Lighting	129664	25.1
Technical equipment	178255	34.5
Space cooling	0.0	0.0
Ventilation cooling	2436	0.5
Total	**1269609**	**245.4**

Figure 16 : Annual energy budget



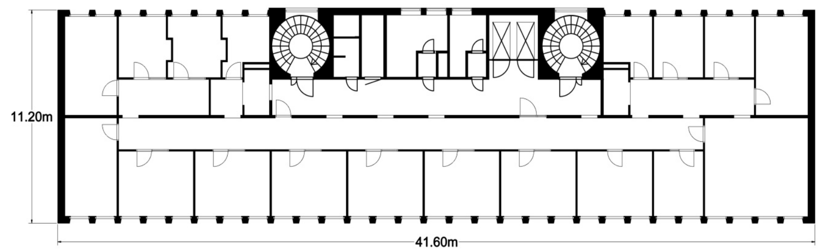
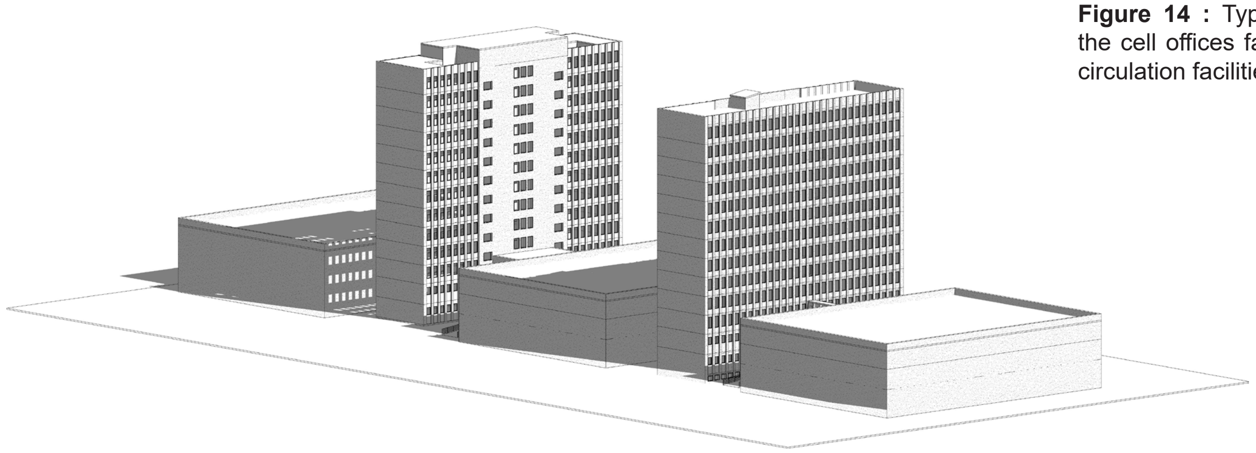


Figure 14 : Typical floor plan with the cell offices facing south and the circulation facilities at the north part.



2.2.1 SENTRALBYGG 1 - OPPORTUNITIES

The analysis on the existing situation of Sentralbygg 1 leads us to rethink its potential of transforming the area into a diverse student hub towards sustainable future. By knowing that NTNU already seeks for more space and infrastructures regarding academia, we decided to retain the current functions of the building and examine the potential for an extension on the top of it. In the meantime, the constant rising number of students seeking housing, urged us to design an extension that will shelter student accommodation.

The optimal location in terms of urban fabric and connection with the city of Trondheim, including all the tangible and intangible values corresponding to it (infrastructures, economy, education, environmental and sociocultural values etc.), creates opportunities to enhance the role of Gløshaugen campus as a student hub that operates not only during working hours, but is 'alive' all day long throughout the year.

Sentralbygg 1 has an imposing form with energy potential regarding renewable energy sources. Specifically, its design, height and orientation have advantages in the production of energy from photovoltaic panels - PVs. The radiation analysis as well as the shadow study, indicate that south and west parts of the building are having the largest amounts of solar radiation. For this reason, the whole west facade and the wall surface that is available from 3rd to 13th floor on the south façade, were selected to accommodate the PVs. The calculated performance is approximately 106 MWh per year. Although that amount corresponds to less than 10% of the buildings total demand, it could nonetheless cover the energy need for space heating, the fans and the ventilation cooling.

The combination of the existing heat pump and the proposed PVs would increase the onsite energy generation to almost 500 MWh per year. As a result, approximately 35% of the total amount of the buildings annual demand would be compensated by renewables.

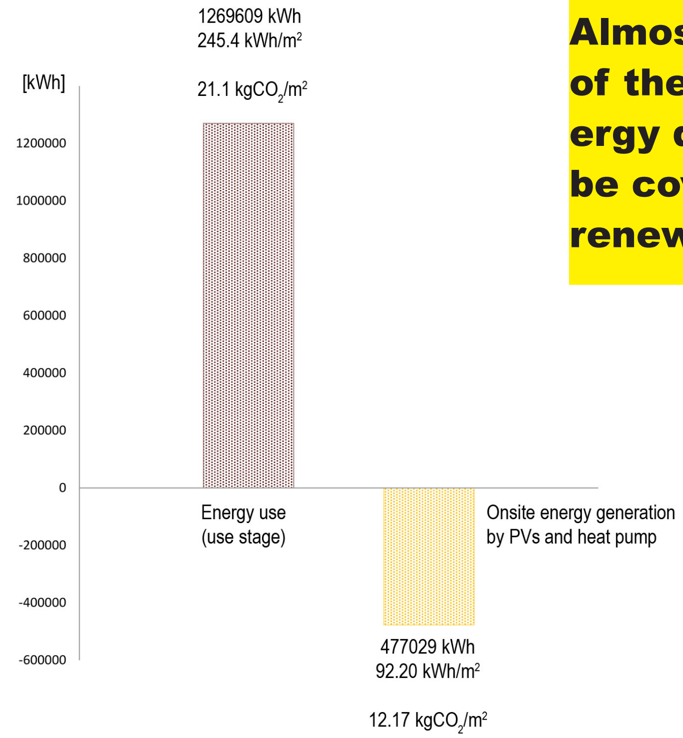


Figure 17: Energy balance of S1. The carbon emission factor 132 gr CO_2eq/kWh (Graabak and Feiberg, 2011) is applied for energy (electricity) use and generation.

Almost 35% of the annual energy demand can be covered by renewables.

Figure 18 : Current situation on the roof and views from the top, from north to west.

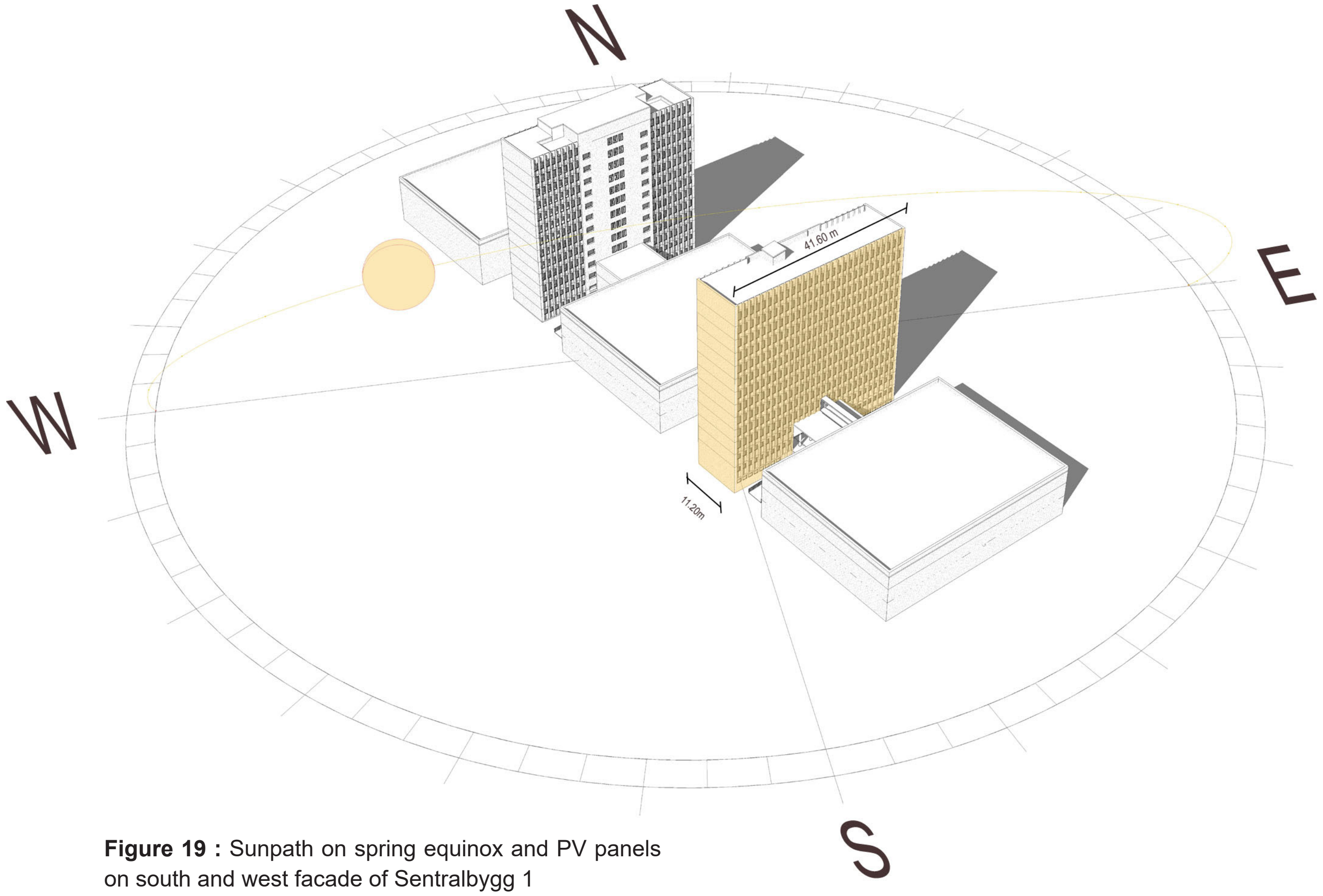


Figure 19 : Sunpath on spring equinox and PV panels on south and west facade of Sentralbygg 1

2.2.2 EXISTING PROPOSAL FROM TAG AND MULTICONSULT

sit TAG Multiconsult

In 2016 SIT organization cooperated with TAG architects to create student accommodation on the top of Sentralbygg 1 and 2 in Gløshaugen campus. The architects developed a design for Sentralbygg 1 and 2 that later Multiconsult Norge AS used to do a comprehensive study for the potential of these tall buildings. The aim was to transform the building in student housing and have a common-social area on the top of it.

In 2018 the report with the revision was published. The main outcomes concern fire safety requirements. The staircases are narrow for evacuation of so many people and the elevators do not comply with the current standards. The elevators shaft needs to be expanded and splitted vertically in half. In addition, the necessary sprinkling water would require a pumping station in the building. Moreover, the ventilation system should be decentralized and that would require two generators in each floor. The electrical system should also be replaced. In terms of energy consumption, such building cannot satisfy the energy requirements according to TEK14 but an exception could be done.

With regard to the architectural part of the proposal, this solution can accommodate a large number of residents (16 persons per floor) and seems efficient in terms of material use and economy of the structure. Also, that size of the elevators will be more suitable for an extension and could reduce the waiting time for the residents and the other users of the building.

On the other hand, that solution shows a lack of variety on spaces. There are three types of rooms that refer to individual persons or couples. A question that arises is: what happens in the case of a small family or two friends that want to live together? In addition, the two common areas that are located in the northeast and southwest corners of the floor plan are accessible from the main corridor after opening the doors next to the staircases. This gesture implies the entrance in a semiprivate space or a common space that refers directly to only a few residents. Also, the kitchen does not have sufficient cooking space for more than 3 people cooking at the same time and the long dining table creates a not friendly atmosphere as it resembles more to the big dining areas of canteens rather than a homey atmosphere.

Such spaces does not encourage gatherings or diversity and therefore the multicultural character that lies in the ground levels of the building is replaced by more individualistic manifestations on the top. For this reason, I chose not to follow this layout and suggest a different design that offers a variety of common areas and functions.

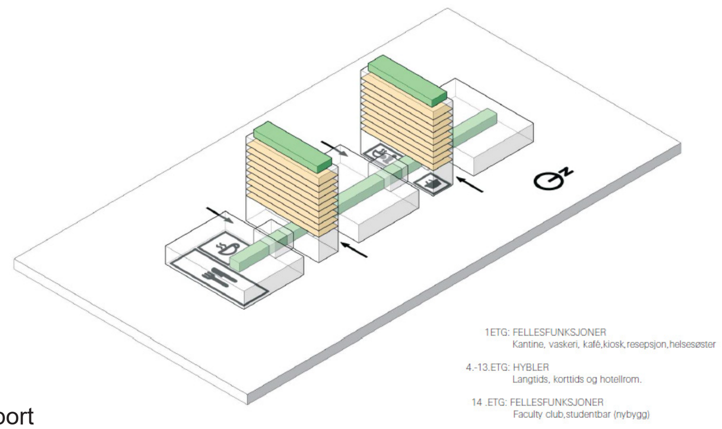


Figure 20: Illustration from the report (SIT, TAG architects and Multiconsult)

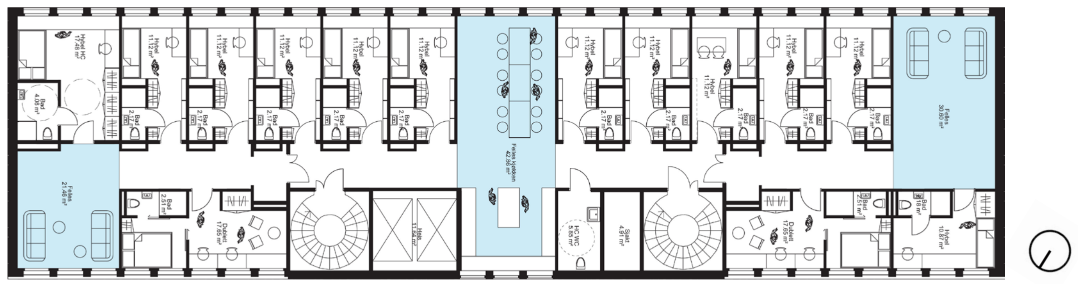


Figure 21 : Typical floor plan of the proposal from TAG architects

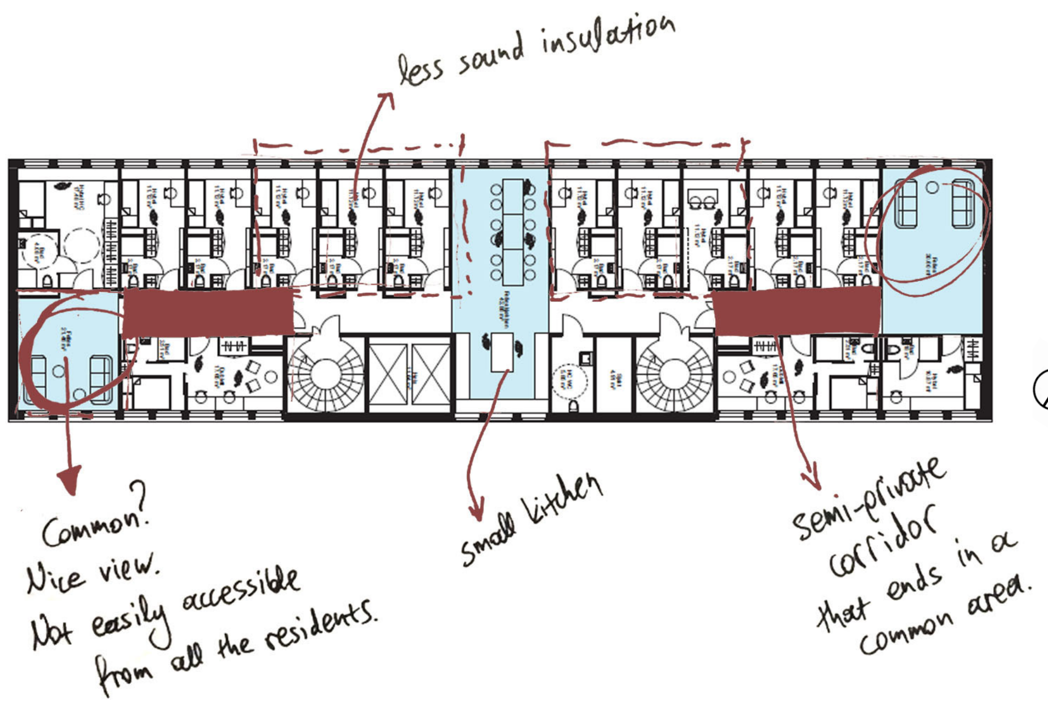


Figure 22 : Diagram with personal comments

2.4 COLLABORATION WITH ENGINEERS AND MAIN DECISIONS

The location of site in the 'heart' of Gløshaugen campus makes it unrivaled for student accommodation. The challenge is to find the scope of capabilities of a wooden extension on the top of Sentralbygg 1. To accomplish that, I had to cooperate, discuss and take common decisions with the two structural engineers.

The first proposal consists of 4 floors of wooden extension with residential areas on the first three floors and a common area on the top. The elevation of Sentralbygg 1 was the starting point of imagining the large common area on the top floor. The idea was to have a common space that can be used by everyone who has access on the campus. However, on that stage we had to set limitations to simplify the whole process. The engineers were categorical on a common top floor accessible by many persons. The quality of the structural materials of Sentralbygg 1 is questionable and therefore the final loads should be as less as possible. Also the fire restrictions would require enormous and costly solutions that would require more complicated processes. For these reasons we decided to create a common top floor that is accessible only by the residents of the extension.

On our following meeting we discussed about the design of a typical floor plan and the structural system. The design affected the choice of structural system and vice versa. An example is the structure in the central part of the proposal, which is made of columns instead of walls, so that I could have flexibility during the design process. At this point I was informed that the 4 stories on the top cannot be a realistic proposal. So we decided to make different scenarios of 4, 3 and 2 stories extension, with or without common areas on the top.

Important parts of the engineers work are also presented on this thesis to justify any further choices. The communication with them continued until the final outcome.

Scenario	**Piles**	**Columns**	**Beams**	**Shear walls (moment increase)**	**Horizontal displacement**	**Acceleration**
CLT						
2 stories	87 tons (+ 15 %)	+ 13,3 % compression + 29,0 % moment	+ 1,0 % shear + 13,7 % moment	+ 30,1 %	OK	Deviation 3 % OK
3 stories, residential	95 tons (+ 25 %)	+ 23,1 % compression + 43,7 % moment	+ 7,5 % shear + 20,5 % moment	+ 47,8 %	OK	Deviation 11,0 % Up for discussion
3 stories, common top floor	98 tons (+ 29 %)	+ 27,3 % compression + 50,3 % moment	+ 9,8 % shear + 23,2 % moment	+ 55,2 %	OK	Deviation 4,8 % OK
4 stories	108 tons (+ 42 %)	+ 40,0 % compression + 74,0 % moment	+ 17,4 % shear + 32,7 % moment	+ 79,9 %	OK	Deviation 12,1 % Not OK

Table 1 : Part of the work of structural engineers. The first (2 stories) and the third (3 stories with a common top floor) scenarios showed acceptable values on acceleration and therefore are potential solutions.

SOCIAL SUSTAINABILITY

The table ... shows the 4 different scenarios that were tested from the structural engineers, using cross-laminated timber (CLT) as the main structural system. Two of them presented acceptable values on acceleration and therefore are feasible. However, in this thesis, I will present the solution that is feasible and aspires high architectural qualities. That is the third scenario with total 3 stories extension (two residential and one common top floor).

The decision to present that solution is based on the aspects of social sustainability. The current way of living usually tends to create physical and emotional distance between individuals. In the case of student housing, the co-living with strangers can be challenging and either will isolate a person or it will develop its social skills. Climate can also affect the psychology and the social life of students. In the context of Trondheim, students have to cope with the long and dark winter, so that can be even more challenging.

By creating a common area (top floor) with different functions and a variety of spaces, I aim to deal with the problem of 'unhealthy' isolation and social distancing and provoke every individual to 'get out of the box' and enjoy the different atmospheres and qualities of the top floor.

2.5 THE EXTENSION - PARASITE

2.5.1 THE USERS

An accommodation on the top of Sentralbygg 1 refers mostly to students. However the idea is to create a multicultural environment where discrimination does not exist and all residents live together for a period, regardless of age, gender, nationality, educational or professional background and so on.

At this point I want to define the residence period which is no more than two years. This project refers to short term accommodation because of the environment. To clarify, the campus is firstly characterized as the work space for st udents, academic staff etc. and that is well imprinted in our daily lives. The transition from work to home has usually characteristics of catharsis and that implies the change of environments. Such transition is not clear when it happens in the same environment/campus, let alone when is happening in the same building. Therefore, for health, mental and physical, a student accommodation on the 'heart' of the campus is not recommended for extended periods of time.

The users can be students, exchange students, academic staff that seeks short term accommodation or even academics that are visiting NTNU's facilities for lectures, workshops, seminars or conferences. Accommodation refers mostly to individual persons but there are also possibilities of couple housing or even small families of 3-4 members, with young children. It is very common to see people with luggage or young parents with baby strollers crossing the main corridor-Stripa in the ground level. Meanwhile there are also many young couples that try to live together, regardless if they are foreigners who are trying to relocate with their loved ones or new couples that want to develop their relationship.

All these persons are users of the campus facilities and therefore should have the opportunity to stay on a potential extension on Sentralbygg 1.

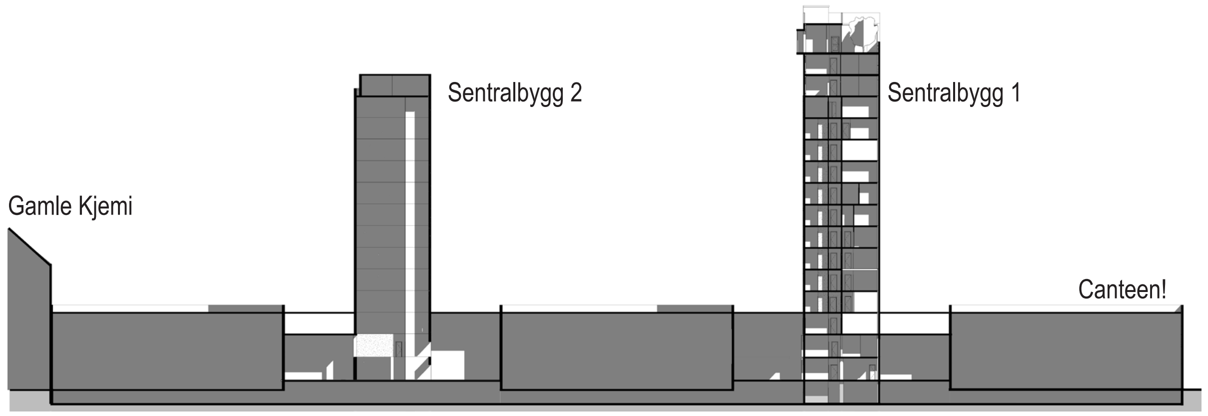


Figure 23 : Section A-A. Relation with the surrounding volumes.

Figure 24 : Masterplan of the proposal with emphasis on the green areas of the campus.

2.5.2 ARCHITECTURAL COMPOSITION

The extension on Sentralbygg 1 is also referred to as ‘parasite’, because it cannot exist without Sentralbygg 1. It uses the top level as a site and the existing infrastructures, such as the vertical circulation for accessibility and the technical rooms for the necessary equipment. Although in the beginning we tested different forms for the parasite, we decided to keep a simple layout, aiming to have the most of the efficiency in terms of architecture, structure, economy and energy. The parasite becomes a morphological continue of the host building and aims to differentiate on functions and materials, so the ‘light’ wood will be placed upon the ‘heavy’ concrete and homey atmosphere will be hosted upon workplace.

The strict outline of the site was the start of transforming the interior layout. The residential one accommodates maximum 18 persons. The rooms’ typology varies and aims to accommodate from individuals to families. Each floor hosts two clusters of rooms, on the east and the west sides, while all rooms are facing south and north. The entrance to the rooms is through the semi-private areas that are isolating each cluster of rooms and provide a quieter environment than the common area. Although the dining area is not enough for 18 people, there is the common area on the top floor that meets this need.

The ideas for the top floor derive from the multicultural environment of the campus. The intention was to combine different functions and create a common space that marks the meaning of student hub while encouraging the exchange of cultural goods between the residents. Thus, a communal sauna, as an important part of Scandinavian life, is combined with an open atrium, which is a common feature on southern cultures.

Figure 26 : Diagrams of the residential floor layout. The intention to have a central common space on each floor was the main idea of this composition.

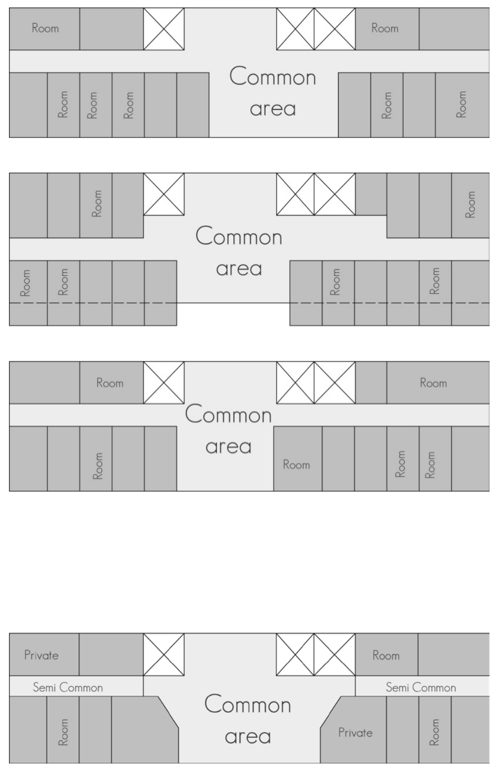
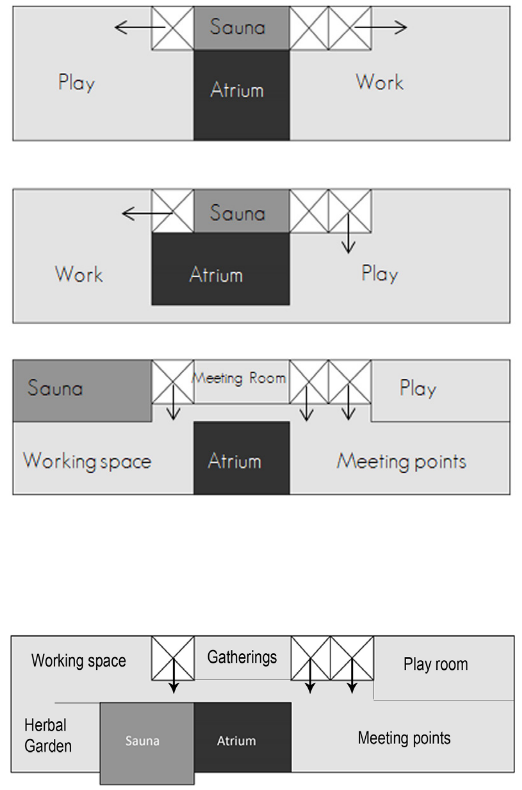


Figure 27 : Diagrams of the top floor. The main combination of spaces that were explored before the final outcome.



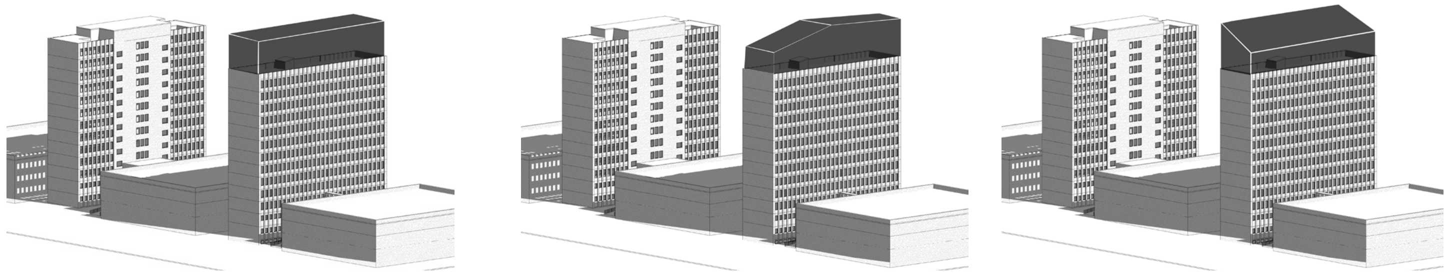


Figure 25 : Different forms of the proposal.

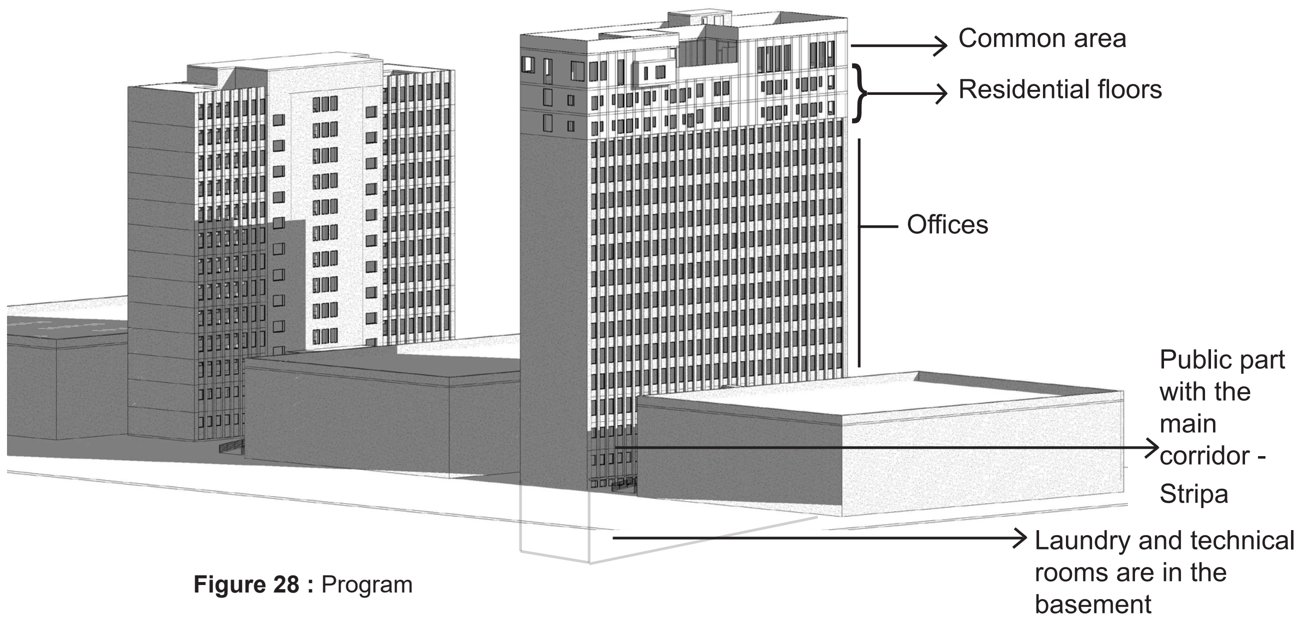


Figure 28 : Program

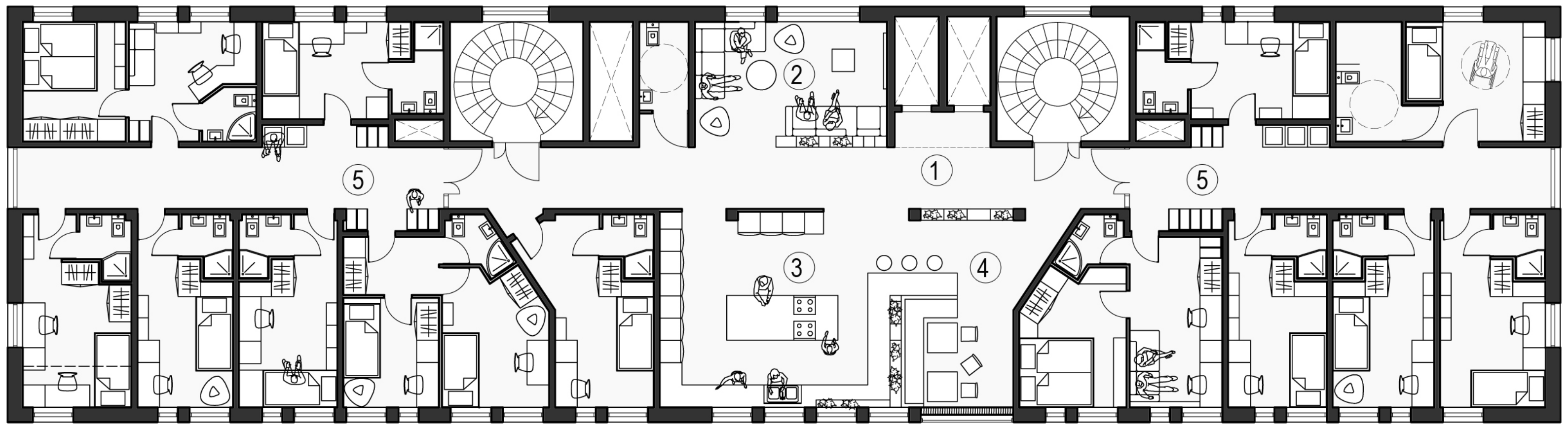
Residential floor plan

Scale 1:200

[13 rooms with maximum capacity of 18 persons]

1. Entrance from the elevators
2. Living room
3. Kitchen
4. Dining area
5. Semi-private space with wardrobes-lockers

14th and 15th level

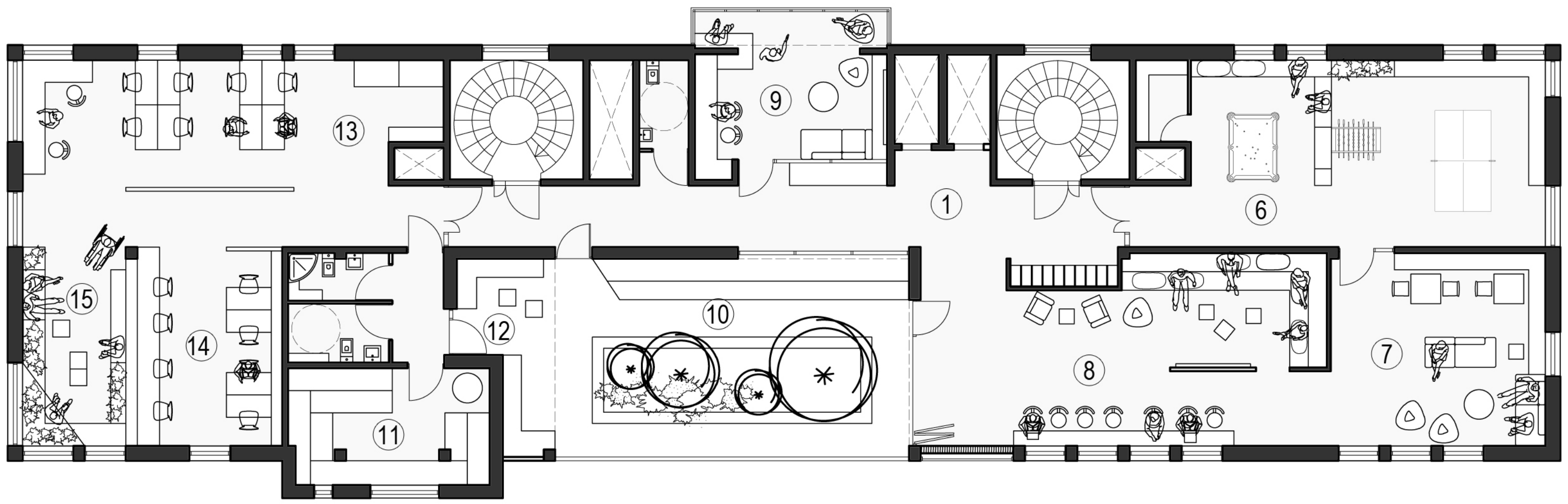


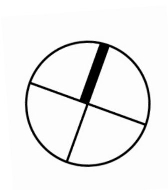
Top floor plan - Common area

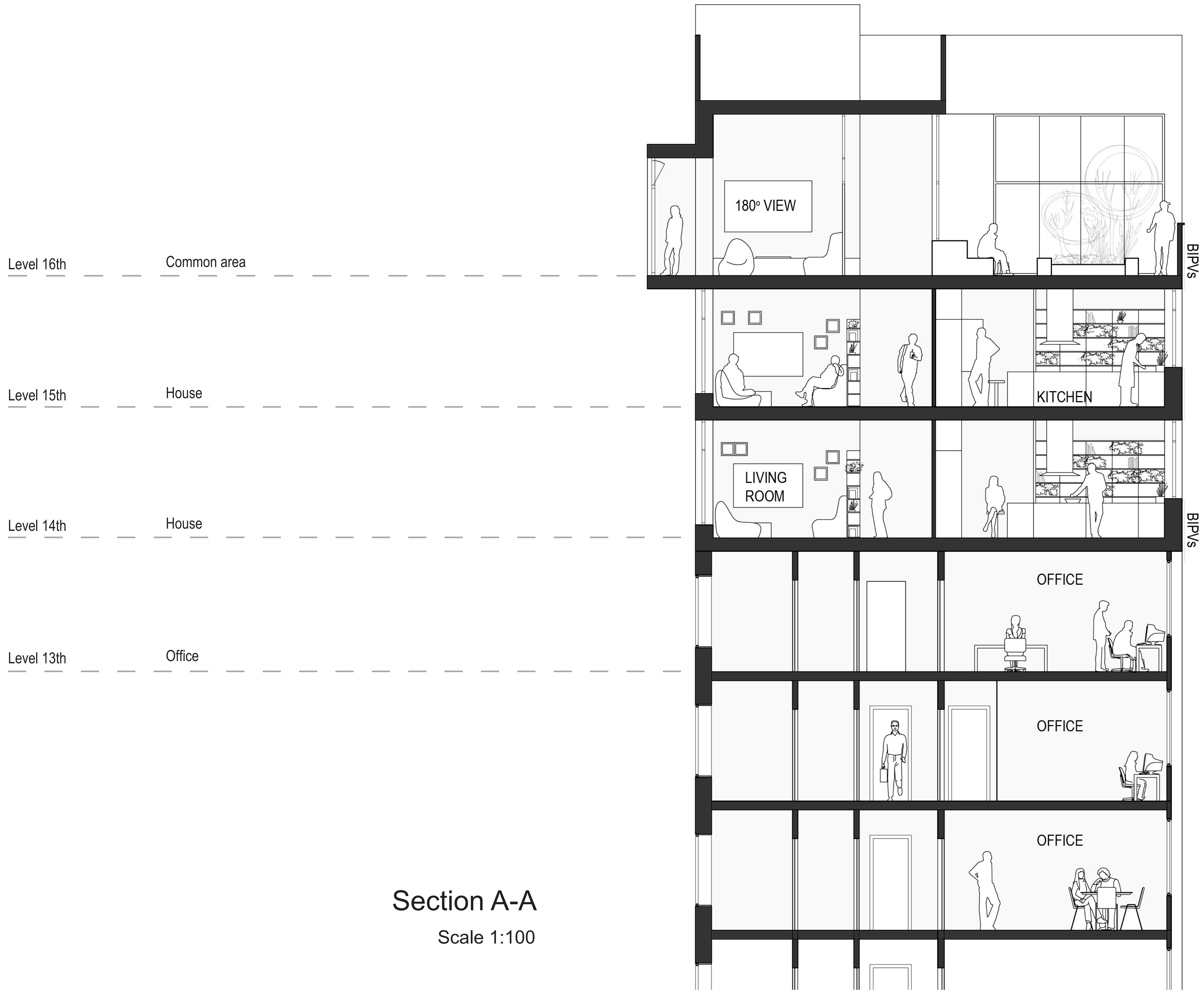
Scale 1:200

1. Entrance from the elevators
6. Play room
7. Meeting points
8. Common area with working bench and small ‘amphitheater’
9. The room with 180° view towards city
10. Atrium that is open in summer and closed during winter
11. Communal sauna
12. Covered space in the atrium - outer space of the sauna
13. Working area, ideal for groupworks, with printers and photocopy machines
14. Reading - working area
15. Small herbal garden with benches

16th level

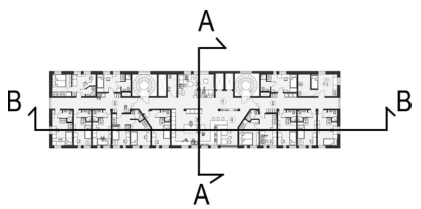




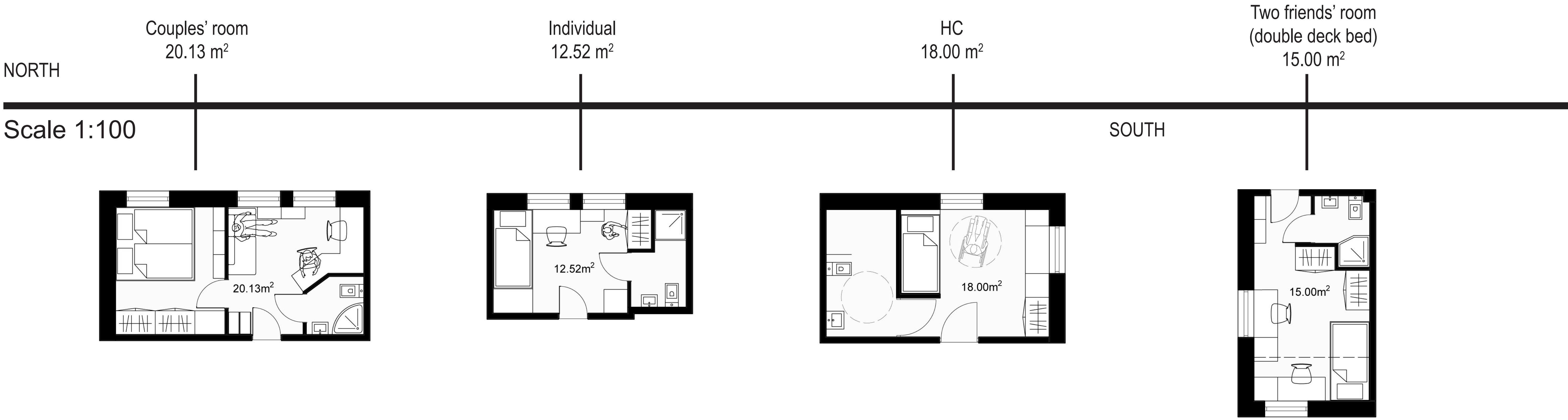


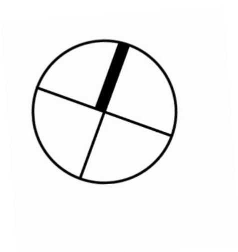
Section A-A

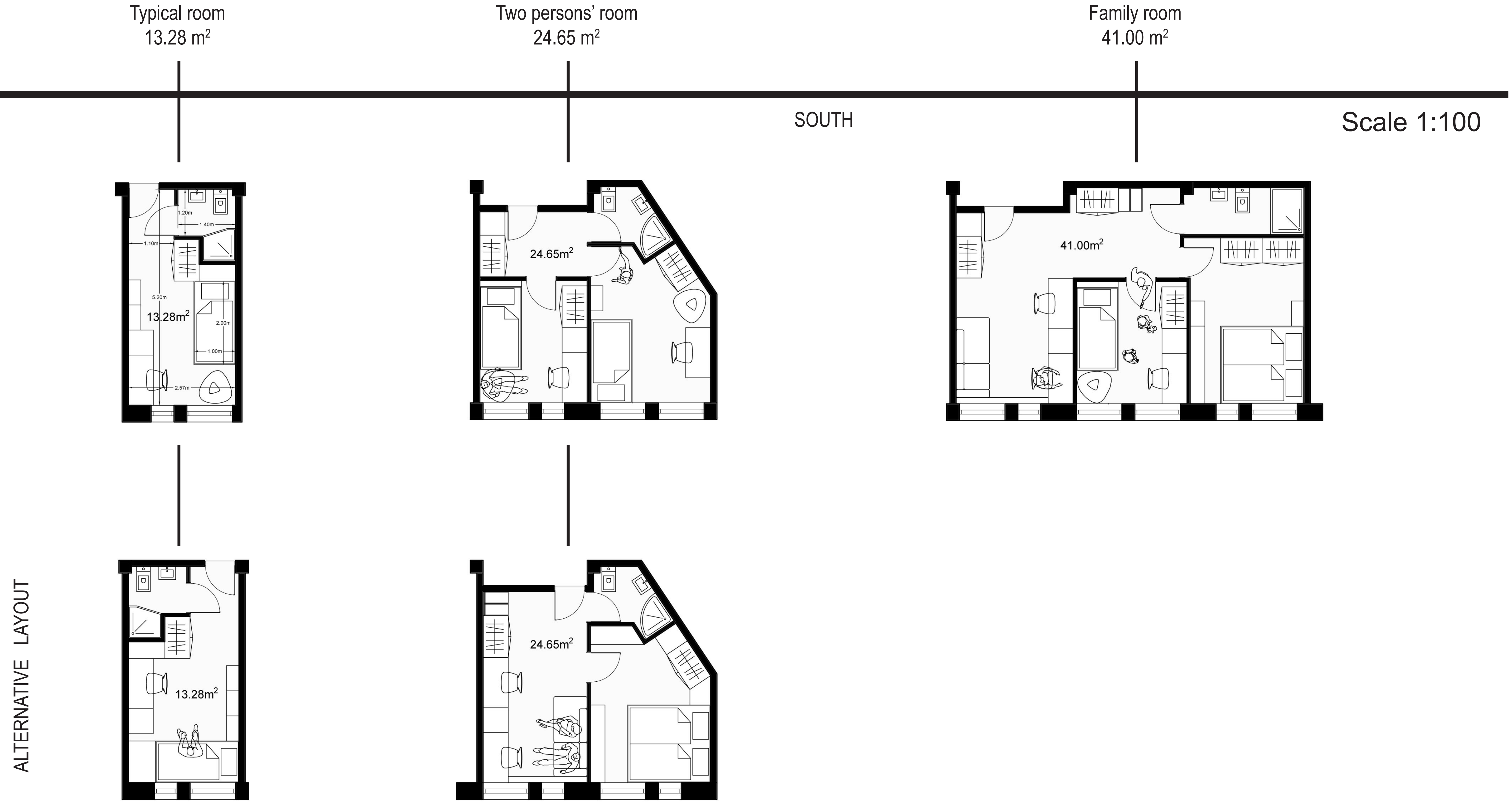
Scale 1:100



ROOMS TYPOLOGY



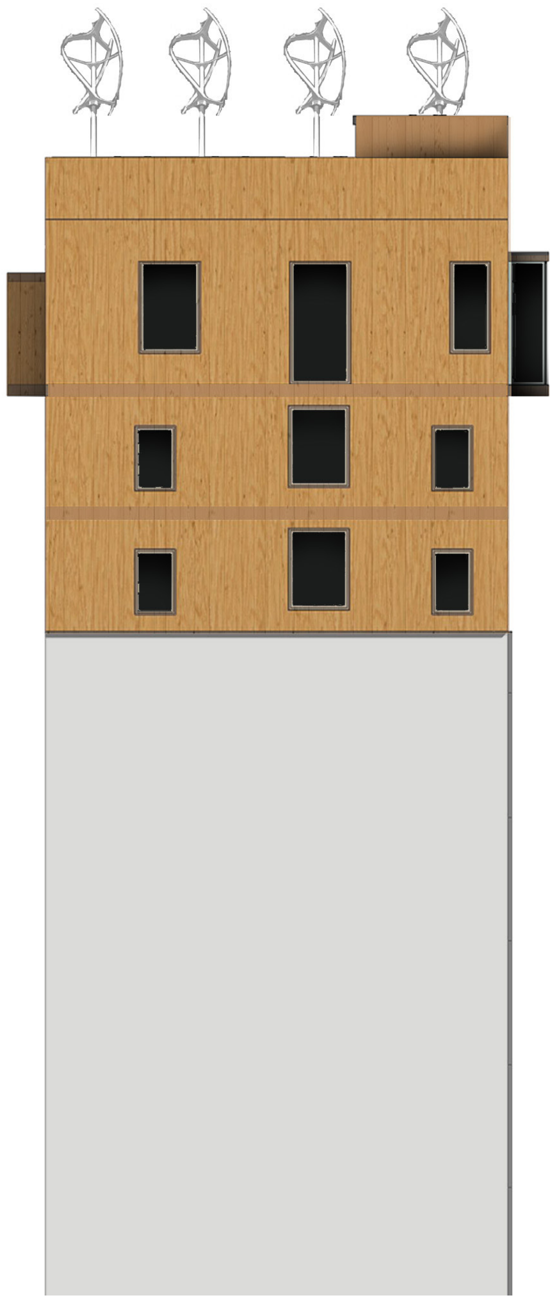



Typical room
13.28 m2
Two persons' room
24.65 m2
Family room
41.00 m2
SOUTH
Scale 1:100
13.28m2
24.65m2
41.00m2
ALTERNATIVE LAYOUT
13.28m2
24.65m2

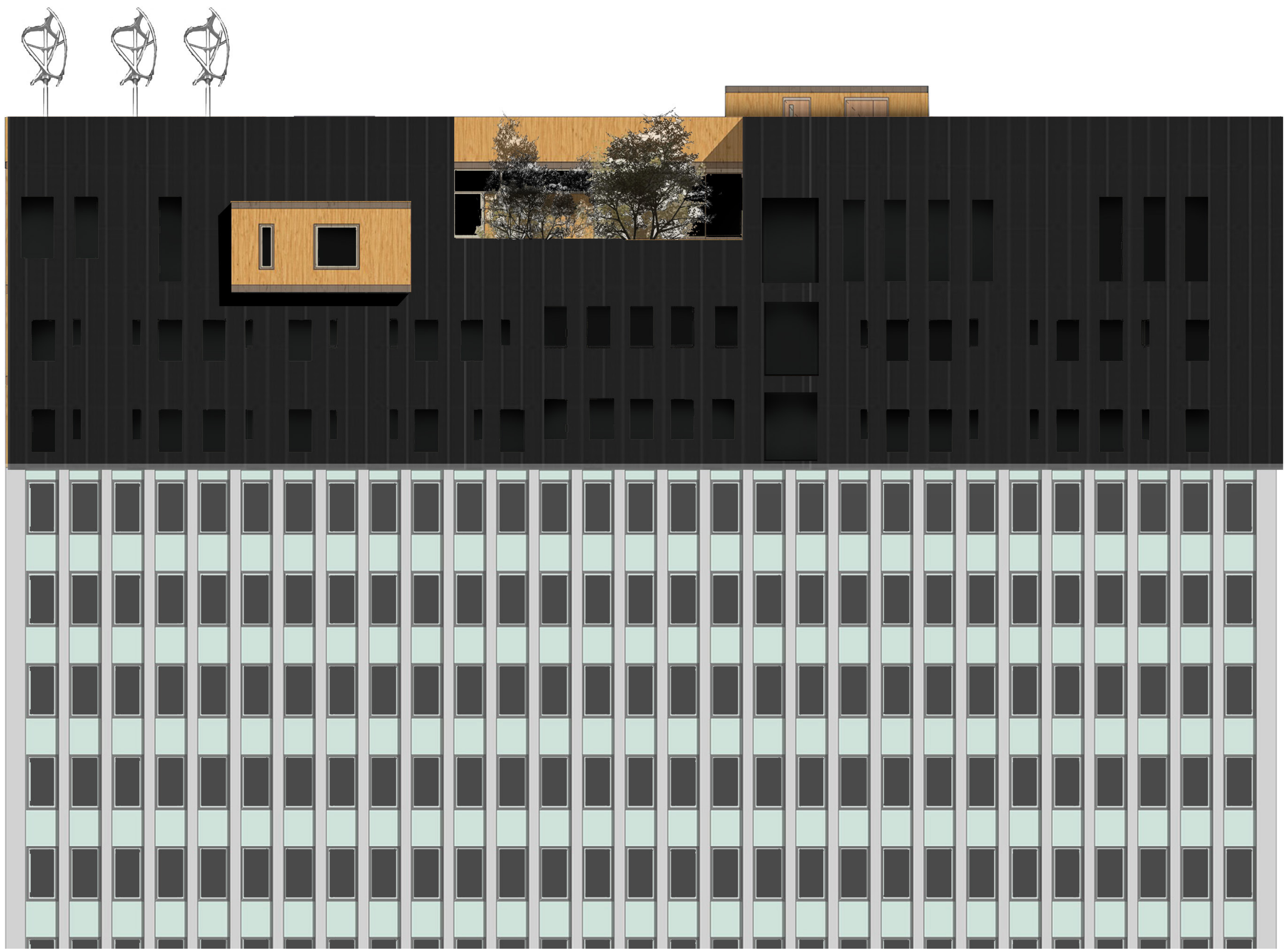
FACADES
SCALE 1:200

Emphasis is given on the extension. South and west facades are covered by PVs while east and north reveil their timber conctruction with timber cladding. Wind turbines are slightly visible from the ground level.

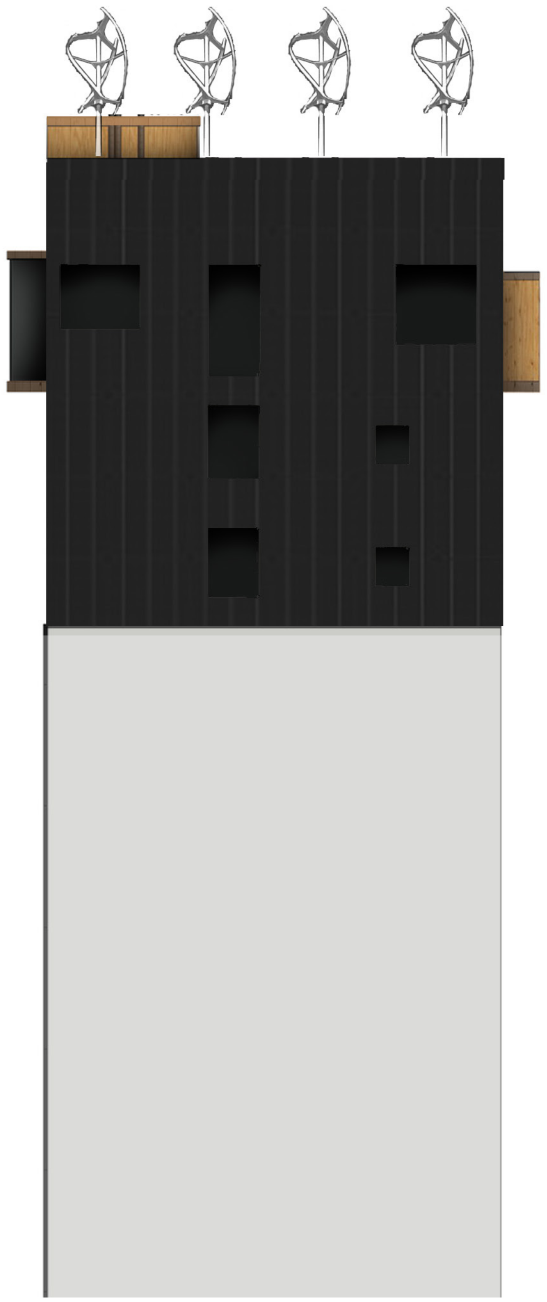
EAST



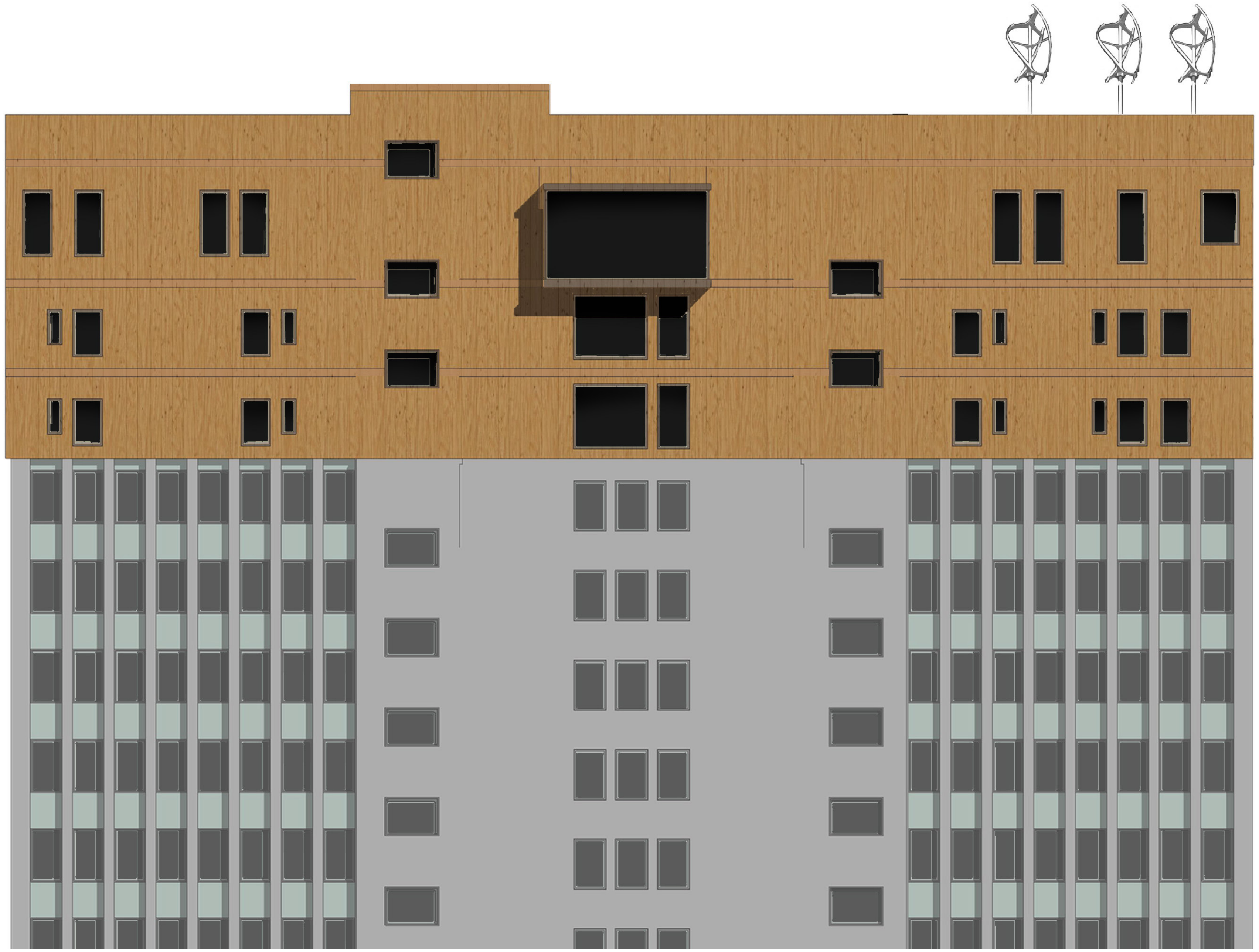
SOUTH



WEST



NORTH



The parasite has 1084 m2 of heated floor area (BRA). The residential floors have 2.5 m height while the top floor has 3.5 m. So the total heated volume reaches 3184 m3. In order to calculate the energy demand, this new structure should comply with the building codes of TEK17 and the Norwegian passive house standards NS3700/3701. So the simulation setup is based on their requirements. The result is 81572kWh or 75.3kWh/ m2 in an annual base. On the contrary with the host building, the parasite does not demand large amounts of energy on ventilation heating, but rather for space heating and domestic hot water. That is a sensible result considering that students are the largest consumers of domestic hot water. Both active and passive energy strategies were used to address the energy issue.

In order to accomplish the goal of a ZEB-OM extension, first of all, there must be onsite renewable energy sources to compensate for its operation. The orientation of the building and the unobstructed solar radiation are optimal for exploitation of solar energy. Thus both the south and the west façades are covered with building-integrated photovoltaic (BIPV) system. The panels are made of mono-crystalline cells that are ideal for conversion of direct radiation into electricity. Approximately 39081 kWh can be produced in a year, which means that PVs cannot even cover the half of the total energy demand.

1084 m² heated area	Simulated energy need	
Parasite	**Energy need kWh**	**Energy need kWh/m²**
Space heating	34463	31.9
Ventilation heating	2799	2.6
Domestic hot water	28481	26.4
Fans	5603	5.16
Pumps	1067	0.9
Lighting	9159	8.4
Technical equipment	0.0	0.0
Space cooling	0.0	0.0
Ventilation cooling	0.0	0.0
Total	**81572**	**75.3**

Table 2 : Annual energy use

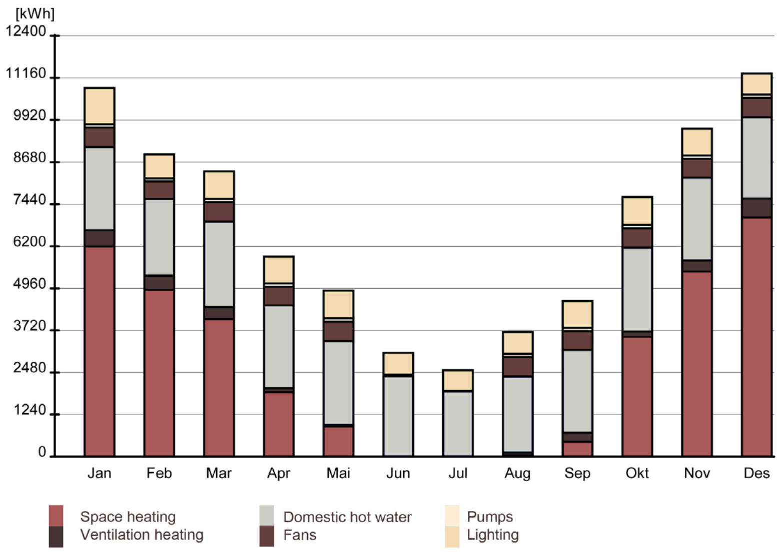


Figure 29 : Monthly energy use

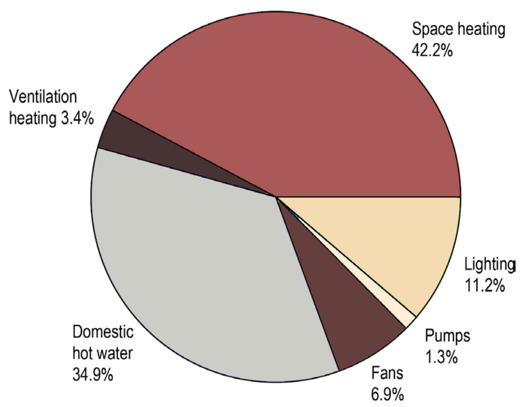
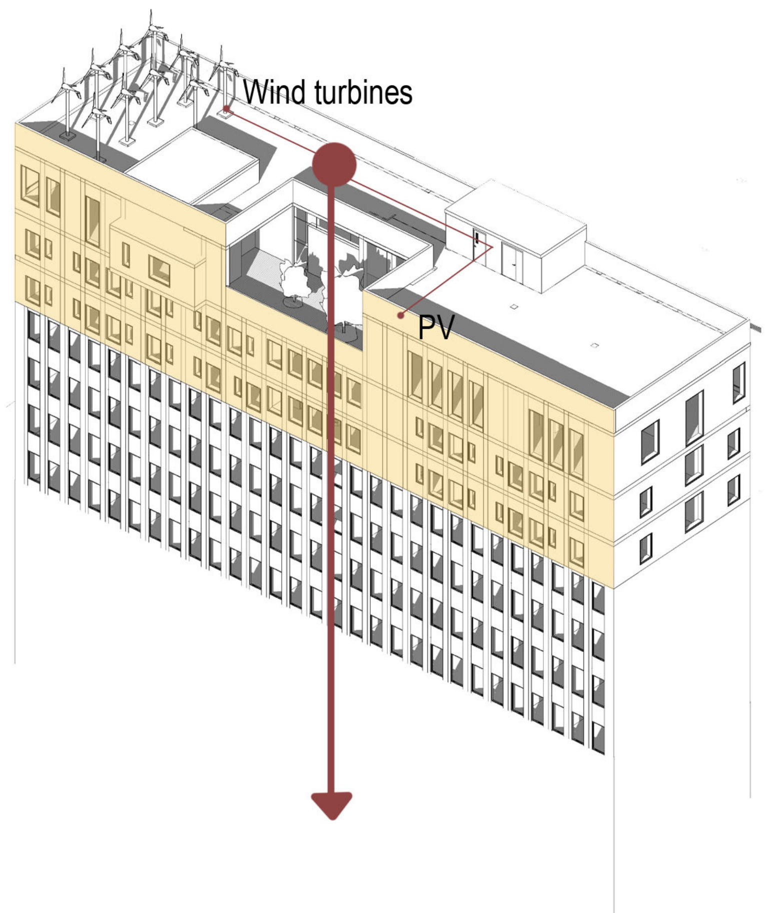


Figure 30 : Annual energy use

More efficient energy sources should be found. The second most important climatic factor on the site is the wind. The total height of S1 and the extension will be ..m and that would create even better conditions for wind exploitation. In fact, previous master student work demonstrated that a box-shaped extension on the roof of Sentralbygg is potentially exposed into doubled wind speed and therefore the power output potential could be multiplied by factor 8 (Haase, personal communication, March 2020). Under those circumstances, wind turbines could be placed on the top of the parasite. However, there are two main challenges on that decision. The first one is the total weight of the structure. Wind turbines are generally heavy constructions, so after discussion with the structural engineers, maximum ten wind turbines, of about 4600 kg each turbine, was acceptable. The second challenge is the noise they produce but, considering the latest trends of building-integrated wind turbines, that will be partially solved in the near future. In the meantime, the common area on the top floor could work as a noise buffer between the wind turbines and the residential zone. The selected wind turbine, Windside WS-12, meets these requirements amongst others, and can generate almost 10 MWh in a year.

The combination of energy production from PVs and wind turbines could result in about 139081 kWh per year. That amount could not only cover the energy demand of the parasite, but it also presents almost 58000 kWh/yr excess energy that could be transferred to the grid.

Figure 31 : Active energy strategies on the parasite



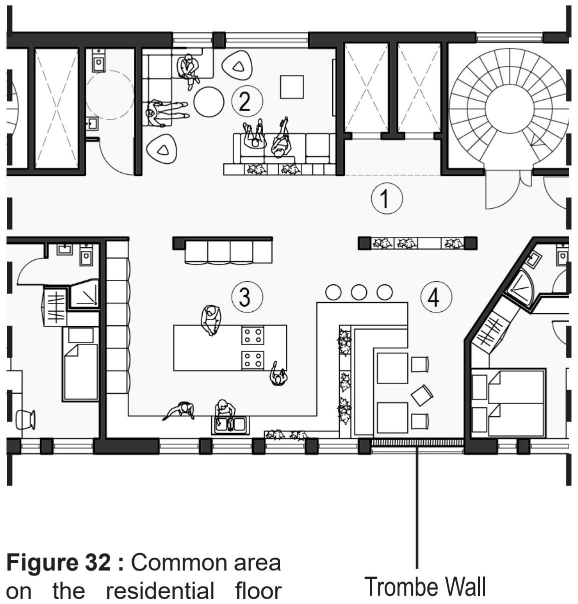


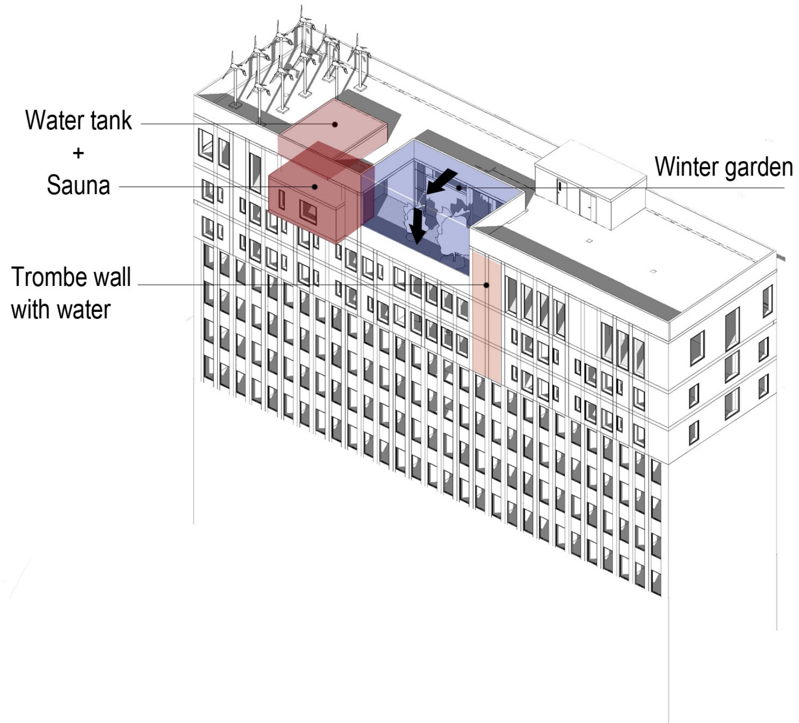
Figure 32 : Common area on the residential floor plan, indicating the Trombe wall position.

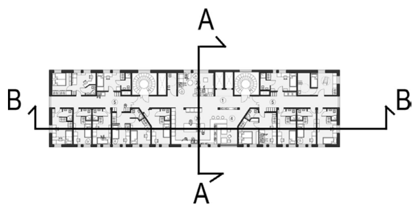
PASSIVE STRATEGIES

In addition to the active energy strategies, three passive strategies were also used. The layout of the residential floor plan and the south orientation offer the opportunity for passive strategies and specifically they inspire for designing a Trombe wall system (Figure ...). The dining area was firstly covered with large double glass windows that were later changed into the Trombe wall. It is proposed to be constructed by translucent material, such as water, so that it will provide sufficient daylight while preventing any glare issues. Although it could blur the view to the south, the top floor offers many different places where someone can enjoy that view.

Another important part of the design is the open atrium on the top level. Regardless the recreational use and the provision of daylight in the central part of the floor, it is also used as a winter garden. An automated glazed cover can transform it to a greenhouse that acts like a buffer zone on heat transfer during the winter season. Even though it would be an expensive installation, such cover could prevent snow and large amounts of rain on the garden and therefore make it vivid all year round.

The water tank is placed intentionally on the top of the sauna, as any excess heat from it could directly heat the water. The bigger height of the top floor is an advantage for the placement of the water tank as shown on the section below (section B-B).





Section B-B

2.5.4 ZEB-OM POTENTIAL

The environmental impact in terms of greenhouse gas emissions is calculated on this section. At this point I want to clarify the system boundary and the reference time for the life cycle assessment that was conducted on the parasite. The system boundary includes the production stage (A1-A3) of the buildings materials, including the photovoltaic panels, and the operational energy use on the use stage (B6) of the building. To illustrate, the environmental impact in terms of CO2eq emissions was calculated from 'cradle to gate' and includes the emissions from supply of raw materials, the transportation of them to the manufacturer and the manufacturing process for the final delivered product. Due to limited data regarding the construction materials of wind turbines, the calculations at this stage do not include them. The reference time of the buildings life span was set for 60 years.

According to the zero emission buildings definitions, the ZEB research center defines a ZEB-OM as the building where, "the building's renewable energy production compensate for greenhouse gas emissions from operation and production of its building materials." Thus, first the emissions are calculated from the renewable energy sources and later from the product stage of materials and the operation of the building.

According to the previous energy analysis, the parasite could generate annually 139.081 kWh from renewable energy sources. Although the wind turbines are not included in the product stage calculations, there are different studies showing that the carbon payback period for them is relatively short, ranging between 1,5 to 5 years and therefore their carbon footprint is considered minimum on that study. Thus, it is assumed that the renewable energy production derives from both PVs and wind turbines. The carbon emission factor of 132 grams CO2 (Graabak and Feilberg, 2011) was applied on the annual electricity generation, which means that total 18358 kgCO2eq can balance the annual emissions. Meanwhile, on the reference time of 60 years, the estimated payback of CO2eq, derived from renewables, is expected to be almost a million kgCO2eq (1101480 kgCO2eq).

With regard to the construction materials, the calculations were conducted through the BIM model and data derived from EPDs (Environmental Product Declaration) in the ZEB_Tool_2020-v_1_6, that was provided from previous courses at NTNU. The detail below illustrates some of the materials that were used for the LCA calculations. CLT (cross laminated timber) is the main structural material and it is used in both walls and floors constructions. The envelope of the parasite is insulated with a thick layer of wood fibre and has U-value 0.14 [W/m2K]. From the final calculations it turns out that the materials (construction materials and PVs) are responsible for 362468 kgCO2eq, while the operation of the building is responsible for 417420 kgCO2eq in a period of 60 years.

Under those circumstances the result may be an extension ZEB-OM at the top of Sentralbygg 1. The total 779888 kgCO2eq from the production phase of materials and the operation of the building, can be compensated by the final 1101480 kgCO2eq from renewable energy sources. However, this can only be achieved with the help of wind energy and the use of wind turbines. Otherwise, the on-site energy generation from renewable sources is insufficient and the result cannot be even a ZEB.

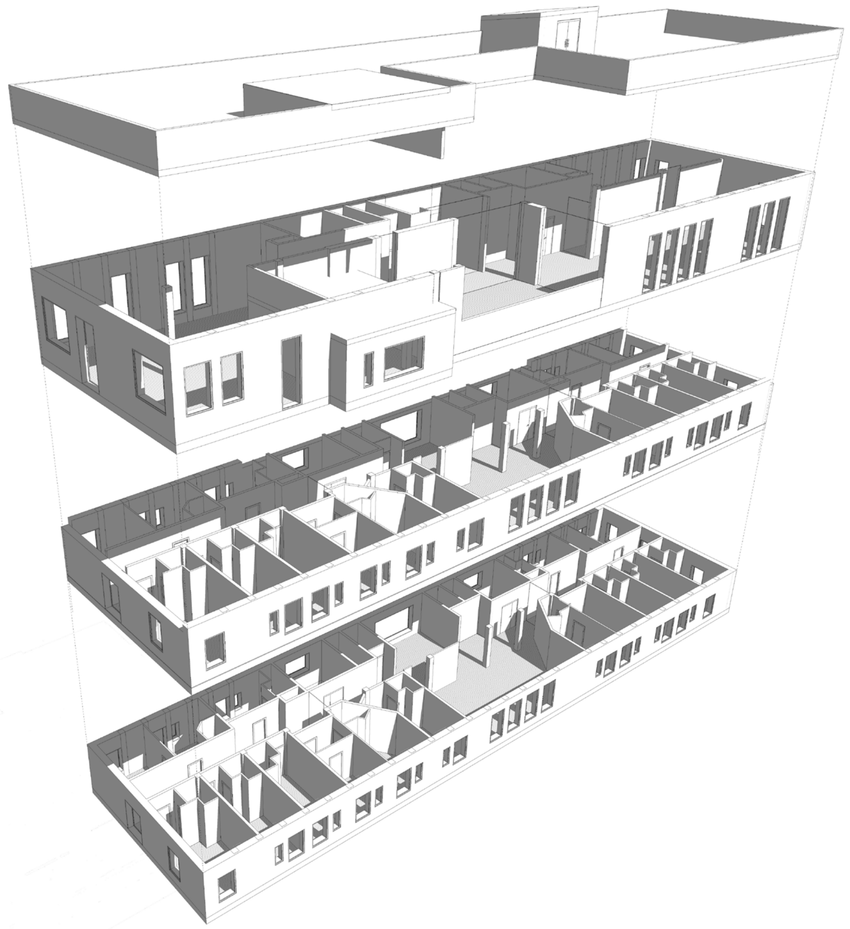


Figure 33 : 3D model -BIM.
This model was used for the LCA calculations. It includes the exterior walls as shown on figure below, with double glazed windows (U-value 0.60 W/m2K). All interior walls are made of wooden studs and panels, as well as acoustic insulation. Interior doors and basic partitions are also included in the calculations.

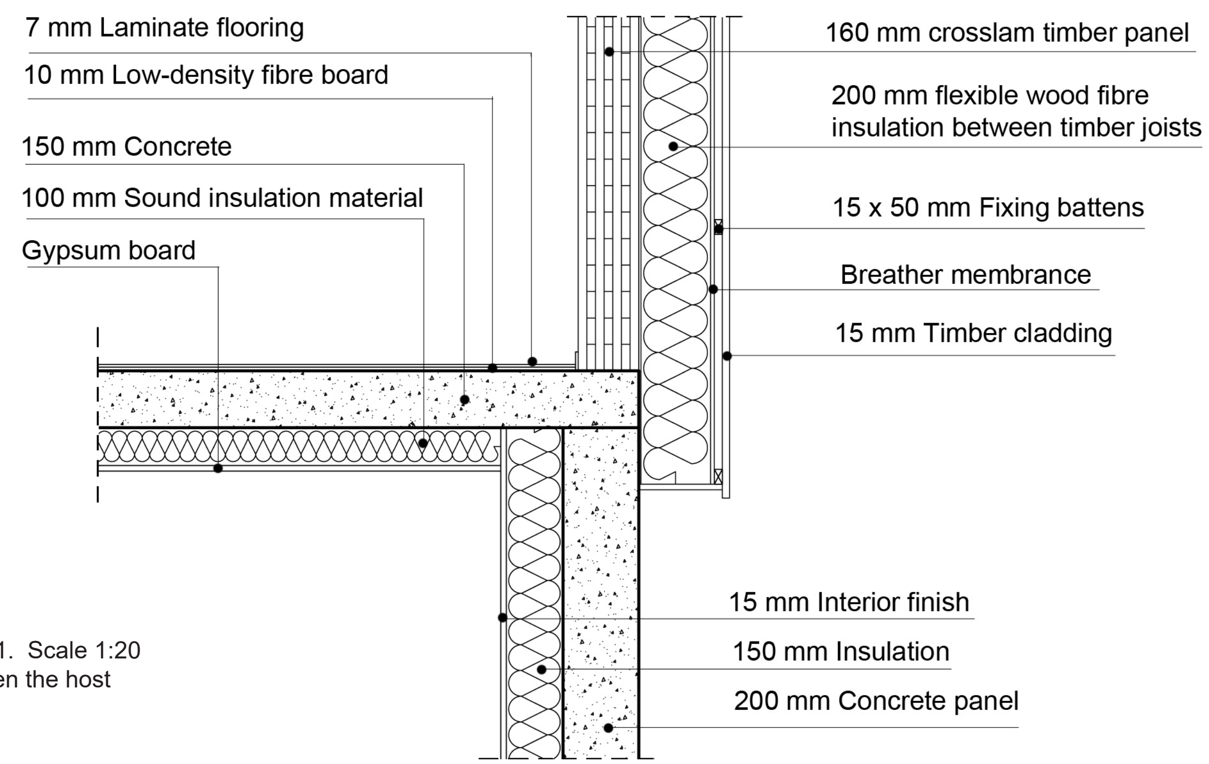


Figure 34 : Detail - D1. Scale 1:20
Wall conection between the host and the parasite.

PARASITE Heated area: 1084 m²	Superstructure	Outer walls	Inner walls	Inner floors	Outer roof	PVs
CLT [m³]	180	Included in superstructure	×	259	89	×
Insulation [wood fibre] [m²]	Included in outer walls	853	×	×	×	×
Rigid insulation [m²]	×	853	×	×	×	×
Timber Cladding [m²]	×	853	×	×	×	×
Glazing [m²]	×	443	×	×	×	×
Wooden frames [m²]	×	605	×	×	×	×
Timber inner finish [m³]	×	33	88	×	×	×
Door panels [m²]	×	×	379	×	×	×
Acoustic insulation [m²]	×	×	1120	1298	×	×
Flooring [m²]	×	×	×	1298	×	×
Bitumen [m²]	×	×	×	×	468	×
Wood, outdoor use [m³]	×	×	×	×	7	×
A1-A3 [$kgCo_2eq$]	299 468					63000
Total A1-A3 [$kgCo_2eq$]	362 468					

Table 3: Material take-off and total emissions from the product stage (A1-A3) of materials. Materials for wind turbines are not calculated.

Materials	
kgCO2eq	299468
kgCO2eq/yr	4991
kgCO2eq/m2	276.3
kgCO2eq/m2/yr	4.6

Figure 35 : LCA results of the construction materials. Product stage (A1-A3).

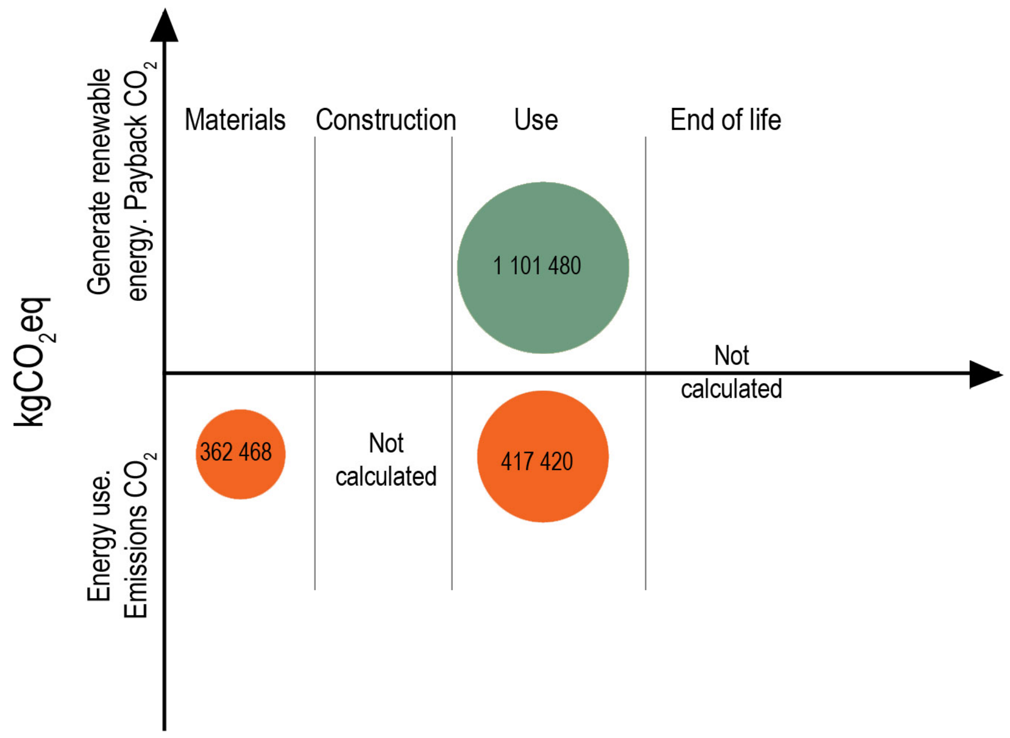


Figure 36 : The diagram illustrates the total kgCO2eq emissions. The renewable energy sources, PVs and wind turbines, can compensate for the production of materials and the energy use during the operation of the parasite in a period of 60 years.

2.6 ENERGY SYNERGY

An extension on Sentralbygg 1 does not only aim to create more space to solve the housing problem, but it also aims to ‘evoke’ the host building and develop the energy performance of it. Many construction built in the past have lack of energy efficiency as the building envelope does not comply with the current standards and the materials quality has been affected through time. That usually results in poor insulated envelopes that seek retrofitting as energy consumption could be reduced and the respectively emissions could also be less. On this study case of Sentralbygg 1, the parasitic extension should be seen as energy generator for the host building. Actually, in the energy context, the parasite could be better characterized as symbiotic organism and not manipulator of the host.

The concept of energy synergy should be developed. In short text, energy could be transferred from the parasite to the host and vice versa. As long as these two parts have different functions, the energy could ‘travel’ whenever and where there is need. It is a fact that the host building uses specific amounts of energy in specific hours and dates. In general, the majority of the university facilities functions during weekdays from 08:00 to 16:00, which means that the energy profile of Sentralbygg 1 is known. Also, the energy profile of the parasite, as student housing, can also be assumed known. When the university is open, the majority of the residents will be in the university facilities. So, when the host needs more energy, the parasite needs less and vice versa.

Table presents the main energy features for both the host and the parasite. The main outcome is the excess energy that derives mostly from wind exploitation. That amount results to additional 58 MWh per year, which means that another 10% of the total host’s energy demand can be covered from the excess energy of the parasite.

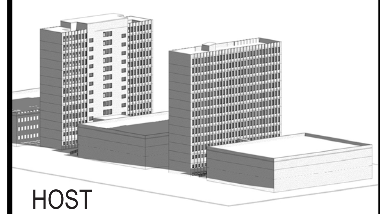
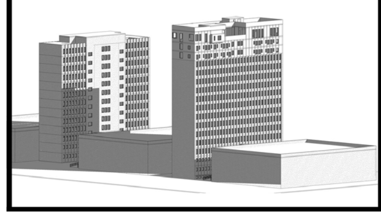
	FUNCTION	AREA [m²]	USERS	ENERGY DEMAND [kWh/yr]	ENERGY GENERATION from renewables [kWh/yr]	EXCESS ENERGY [kWh/yr]
 HOST	University facilities	5174	ca.250 persons	1 269 609	Heat pump: 330 097 PVs: 146 932 Total: 477 029	Not excess energy
PARASITE 	Student housing	1084	32 persons (max. 36)	81 572	PVs: 39 081 Wind turbines: 100 000 Total: 139 081	57 509

Table4 : Energy results of the host and the parasite

Almost 45% of the annual energy demand of Sentralbygg 1 can be covered from renewable energy sources.

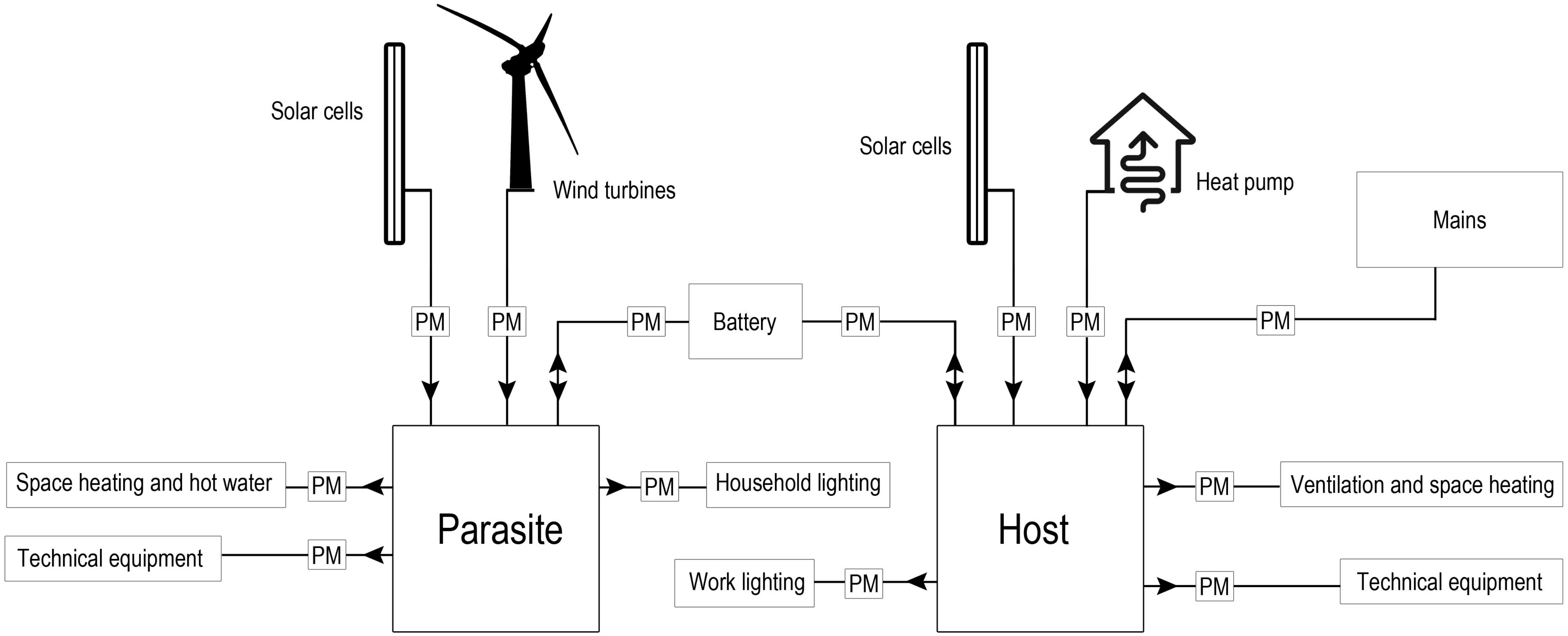


Figure 37: Energy synergy between the parasite (extension) and the host (Sentralbygg 1). The diagram represents the inputs and outputs of electricity. Batteries can store the excess energy when there is need and transfer it to either the residential or the office parts of this hybrid construction.

3| DISCUSSIONS

3.1 A COMPARISON WITH MOHOLT 50|50

The project Moholt 50|50, well-known as the ‘towers of Moholt’, was designed by MDH Arkitekter, and accommodates student housing since 2017. Sit organization commissioned this project to develop the existing student village in Moholt area. Although the area is approximately 15’-20’ walking distance from Gløshaugen, during winter seasons, the majority of the students use public transport due to low temperatures and the partially icy roads. However the interesting fact is that this project consists of nine-storey wooden towers that are all made of cross laminated timber (CLT), even the circulation vertical shaft with the elevators and the staircases. The use of CLT resulted in the significant reduction of CO2 emissions from materials. In comparison with a concrete construction, the CLT solution presented reduction of approximately 57% of CO2 emissions.

The first level on each tower is used for commercial functions while the other eight floors, accommodate the student houses. With regard to the floor plan layout, all rooms are circulating a big common area. Each floor consists of 15 single rooms and a big common area where residents share the kitchen, the dining area and the couch area with a TV. After discussions with some residents, the common area usually functions well as many Norwegian students tend to gather and eat together. However, for introvert persons, the kitchen area can be a challenge.

The heated area of each floor is approximately 360m2, which means that a whole tower has 3240 m2. The energy use of these buildings is calculated 76 kWh/m2/yr . So the total energy demand is 246240 kWh/yr. Meanwhile the energy demand of the parasite is 75 kWh/m2/yr or 81572 kWh/yr.

From the table below, it is clear that although there is significant difference in terms of total areas and residents, there are also very similar in terms of energy consumption per m2. With regard to the rooms typology, although the typical single rooms are very similar to both cases, the drawback of Moholt 50|50 is the availability in only one type. All the rooms can shelter just one person and that creates different qualities on the space and also the social aspects of student housing. Another interesting point was to observe the valuable-vital common areas on each project. The layout of an extension on Sentralbygg 1 shows greater variety on such areas.

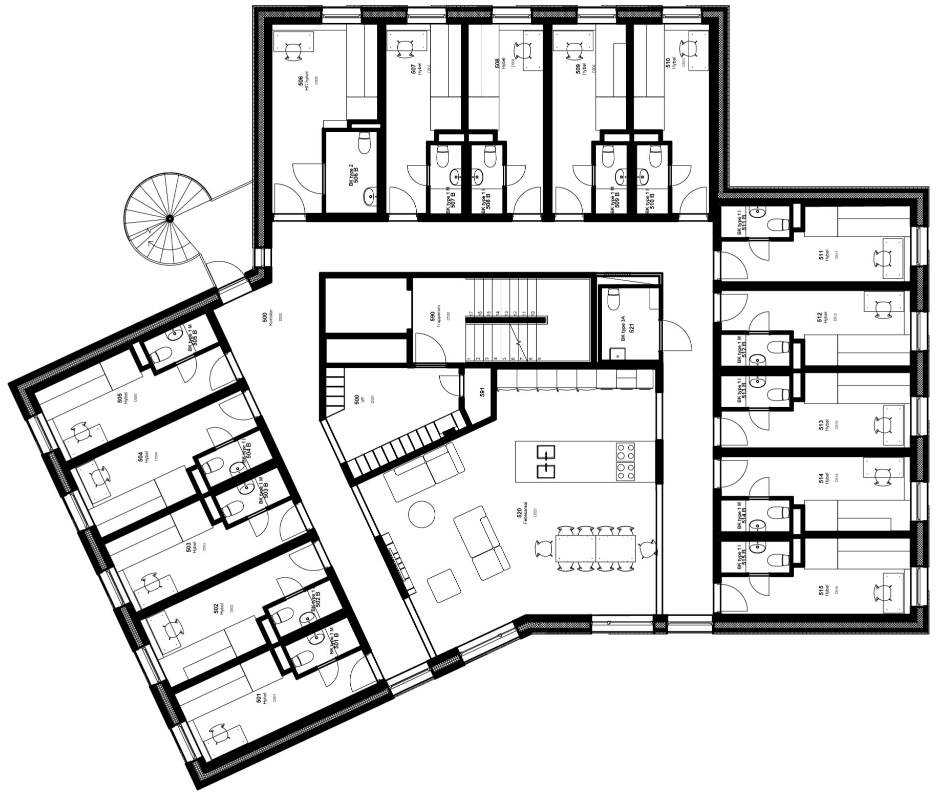
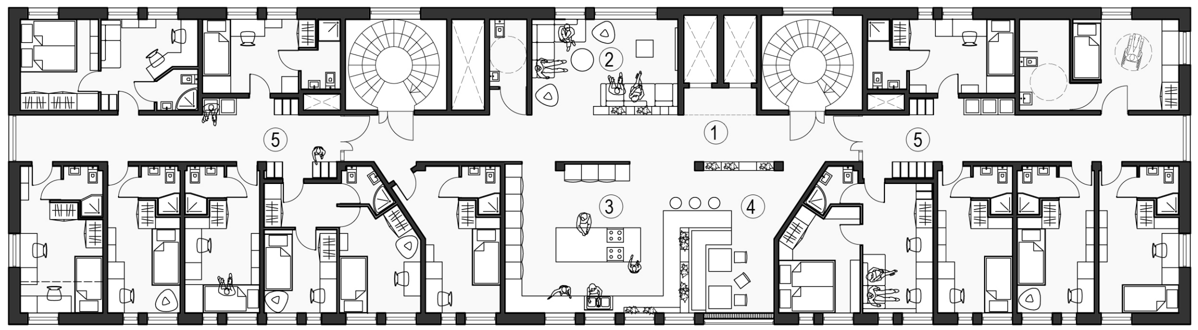


Figure 38 : Typical floor plan layout of Moholt 50|50.

Figure 39 : Typical, residential floor plan layout of the proposal-parasite.



	Area [m^2]	Residents	Common area [m^2]	Valuable common area* [m^2]	Typical room [m^2]	Energy demand [kWh/yr]	Energy demand [$kWh/m^2/yr$]
MOHOLT 50|50	3240	120	1206	621	12.97	246240	76
PARASITE	1084	32	282	465**	13.29	81572	75

Table 5: Main features of the two different student housing projects.
*Kitchen, dinning area and living room. (Excluding corridors and common toilets)
**Including the biggest part of the top floor. (Excluding shafts, sauna and atrium)

3.2 FINAL DISCUSSION AND FURTHER WORK

In the current context where the campus is on the verge of major changes, regarding the energy efficiency of the current building stock and the development of new constructions under the concept of sustainable urbanization, this thesis tried to investigate the capabilities and the scope of the synergy between the existing structures-infrastructures and the future needs-functions.

The initial scope was to explore the feasibilities of a wooden extension on the top of Sentralbygg 1. An extension on a high rise building that already has many years of life raises many questions. In the beginning we were all very puzzled of what we can do on a high rise building such Sentralbygg 1, but it seems that there is more potential than we believed. The cooperation into a multidisciplinary environment gave the opportunity to have a holistic approach on the topic. Based on the collaboration, as a team, we present the final table with all our data. From the table seems that two solutions are feasible. A two storeys extension and the three storeys with a common area on top. On appendix are drawings and data that were produced based on all these different scenarios.

The holistic approach on the topic required many backwards and later again forward steps and vice versa during the whole process of design. Architectural features and qualities were based on socio-cultural approaches that defined social sustainability on the context of student housing, promoting human interaction and personal development of the residents. The definition of residents-users affects the layout of the space and has significant role in the presentation of this proposal. Thus the final design provides typological variety on rooms and common areas that will invigorate the current multicultural environment.

Energy synergy is promoted to upgrade the current infrastructures that showed also a lot of potential. The on-site energy generation from renewable sources, and especially wind power, could provide energy to both, the wooden extension (parasite) and the existing infrastructures of Sentralbygg 1 (host). However, further work should investigate the challenges of wind turbines on the top of the residential zone.

The exceptional location of the site is the ‘ace up on the sleeve’ of this proposal. The accessibility to and from the site implies reduction of CO2 emissions from transportation. Specifically, such location favors handicap people. A decision to accommodate large number of HC would of course affect the available rooms’ space, because of higher requirements, and therefore the total number of residents, the heated area and volume and so on. Also, further work required for fire safety regulations and occupancy scenarios that could examine escape routes and evacuation scenarios of the whole building.

With regard to the environmental impact, the life cycle assessment presents sufficient results and ZEB balance can be achieved. The calculation of embodied emissions of Sentralbygg 1 would be a good indicator for further process.

Although in the beginning the question marks were many, the ideas that were raised through this thesis could evolve in the context of zero emission neighborhoods (ZEN) and achieve the goals of the major campus of NTNU in Trondheim.

Summary

Scenario	Piles	Columns	Beams	Shear walls (moment increase)	Horizontal displacement	Acceleration	Number of users (max.)	Energy need ($kWh/m^2/yr$)	Excess energy* (kWh/yr)	Emissions** ($kgCO_2eq/m^2/yr$)
Existing building	76 tons (744 kN)			26 241 kNm	OK	OK	250	258.3	-	21.1
Post and beam										
2 stories	84 tons (+ 11 %)	+ 9,9 % compression + 26,2 % moment	+ 1,5 % shear + 13,9 % moment	+ 22,4 %	OK	Deviation 6 % OK	34	73.09	70 357	Not calculated
3 stories, residential	90 tons (+ 19 %)	+ 17,9 % compression + 39,6 % moment	+ 7,1 % shear + 20,6 % moment	+ 35,7 %	OK	Deviation 15,9 % Not OK	51	73.45	55 155	Not calculated
3 stories, common top floor	93 tons (+ 22 %)	+ 21,3 % compression + 47,1 % moment	+ 9,3 % shear + 23,3 % moment	+ 41,3 %	OK	Deviation 7,8 % Up for discussion	36	75.25	57 509	Not calculated
4 stories	101 tons (+ 33 %)	+ 31,7 % compression + 72,5 % moment	+ 16,6 % shear + 32,1 % moment	+ 60,7	OK	Deviation 16,8 % Not OK	54	73.67	No excess energy	Not calculated
CLT										
2 stories	87 tons (+ 15 %)	+ 13,3 % compression + 29,0 % moment	+ 1,0 % shear + 13,7 % moment	+ 30,1 %	OK	Deviation 3 % OK	34	73.09	70 357	12.13
3 stories, residential	95 tons (+ 25 %)	+ 23,1 % compression + 43,7 % moment	+ 7,5 % shear + 20,5 % moment	+ 47,8 %	OK	Deviation 11,0 % Up for discussion	51	73.45	55 155	11.47
3 stories, common top floor	98 tons (+ 29 %)	+ 27,3 % compression + 50,3 % moment	+ 9,8 % shear + 23,2 % moment	+ 55,2 %	OK	Deviation 4,8 % OK	36	75.25	57 509	11.92
4 stories	108 tons (+ 42 %)	+ 40,0 % compression + 74,0 % moment	+ 17,4 % shear + 32,7 % moment	+ 79,9 %	OK	Deviation 12,1 % Not OK	54	73.67	No excess energy	Not calculated

* Excess energy is the energy difference between the energy demand and the energy production that derives from on-site renewable sources (PVs and wind turbines)

** Emissions derive from the product stage (A1-A3) of the construction materials and the PVs, and the operational energy use (B6) in the use stage with a life span of 60 years on each scenario

Table 6 : Final summary of group work

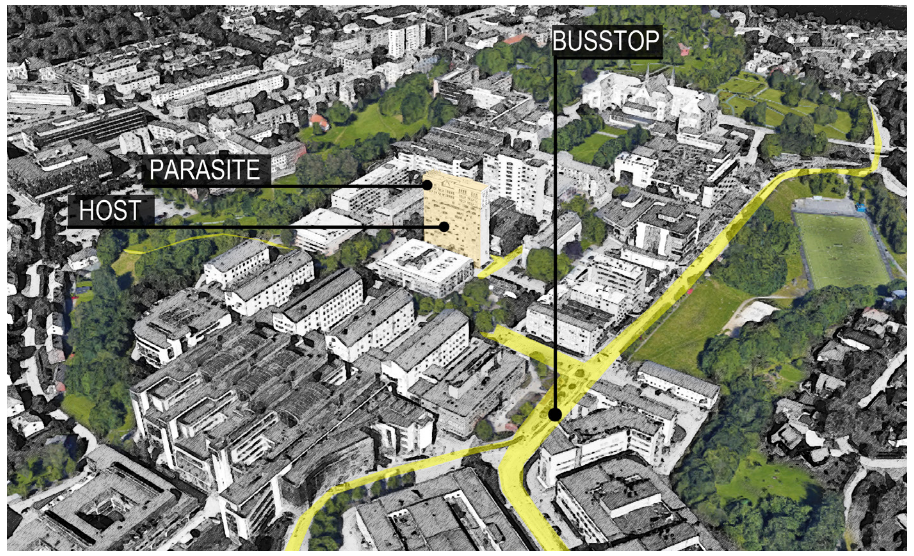


Figure 40 : The proposal in its urban context, on the Gløshaugen plateau.

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APPENDIX

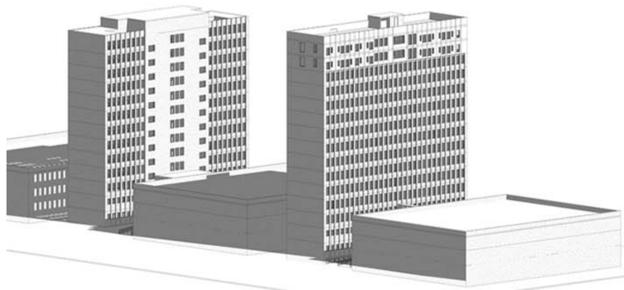
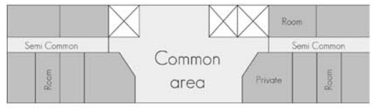
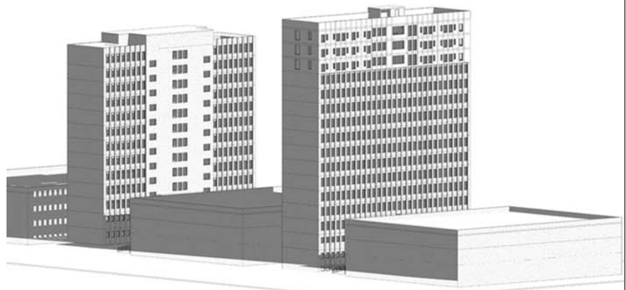
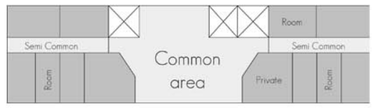
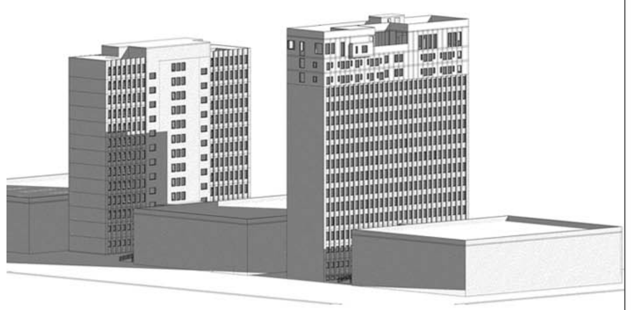
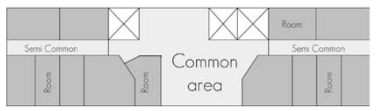
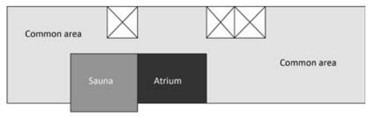
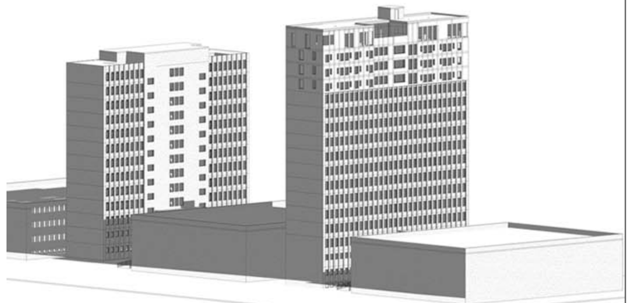
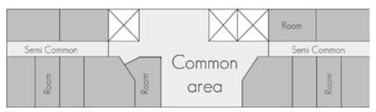
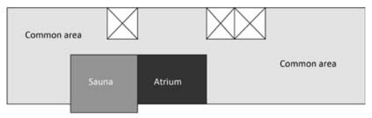
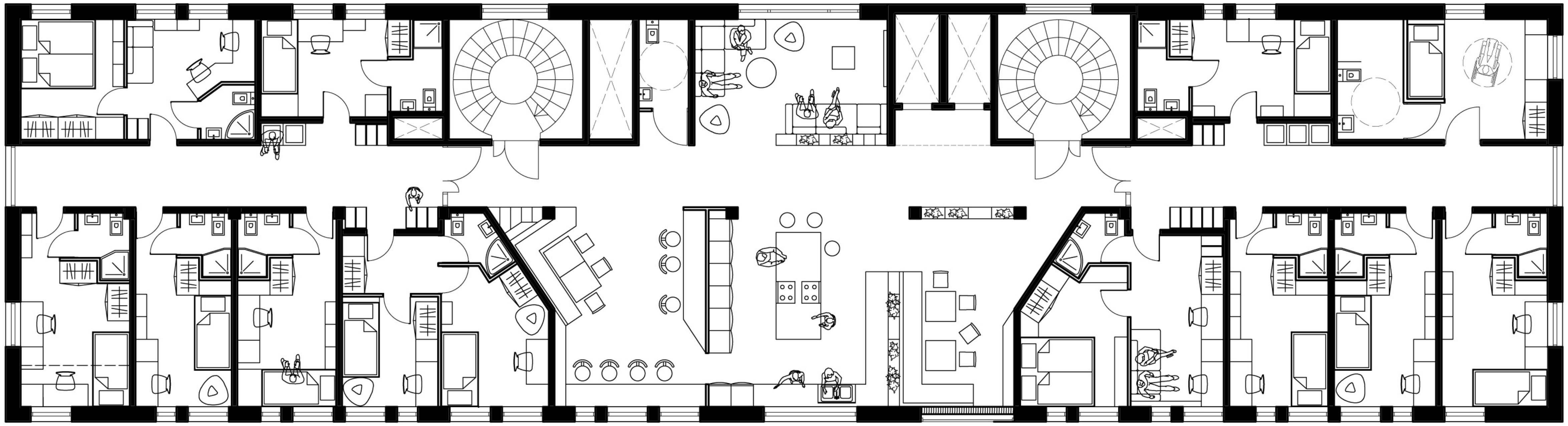
	Program		Residents	Energy Demand	Energy Production	Excess Energy
	Residential Floor Plan Diagram	Common Top Floor Diagram				
	2 Floors 	X	30 (max. 34)	55.697 kWh/year	_from PV: 26.054 kWh/year _from Wind turbines: 100.000 kWh/year Total = 126.054 kWh/year	70.357 kWh/year
	3 Floors 	X	45 (max. 51)	83.926 kWh/year	_from PV: 39.081 kWh/year _from Wind turbines: 100.000 kWh/year Total = 139.081kWh/year	55.155 kWh/year
	2 Floors 	1 Floor 	32 (max. 36)	81.572 kWh/year	_from PV: 35.182 kWh/year _from Wind turbines: 100.000 kWh/year Total = 135.182kWh/year	53.610 kWh/year
	3 Floors 	1 Floor 	48 (max. 54)	107.929 kWh/year	_from PV: 52.108 kWh/year _from Wind turbines: - Total = 52.108 kWh/year	-

Table: Final summary of all the solutions



Floor plan for two floors proposal

Scenarios	Function	Brutto Area	Residents	Annual Energy Demand		Energy production from renewales from PV	from wind turbines	Total Energy Production	Excess Energy -contribu	LCA for product stage A1-A3		LCA for product stage A1-A3 (PV panels)		(Total) LCA A1-A3	LCA for use stage B6 (60 years)		Total emissions
		m2		kWh/yr	kWh/m2/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr	kgCO2eq	kgCO2eq/m2/yr	kgCO2eq	kgCO2eq/m2/yr	kgCO2eq/m2/yr	kgCO2eq	kgCO2eq/m2/yr	kgCO2eq/m2/yr
2 Floors	Residential area	762	30 (max.34)	55697	73.09	26054	100000	126054	70357	218387	4.78	52500	1.15	5.93	282360	6.2	12.13
3 Floors	Residential area	1143	45 (max.51)	83926	73.45	39081	100000	139081	55155	298520	4.35	63000	0.92	5.27	422640	6.2	11.47
3 Floors	Residential and common area	1084	32 (max.36)	81572	75.25	39081	100000	139081	57509	299468	4.6	63000	0.92	5.52	417420	6.4	11.92
4 Floors	Residential and common area	1465	48 (max.54)	107929	73.67	52108	-	52108	-	-	-	-	-	-	553320	5.7	-

Final table with all the data

Energy demand of 2 floors, 3 floors (residential), 3 floors with common top and 4 floors repsectively