Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Architecture and Technology

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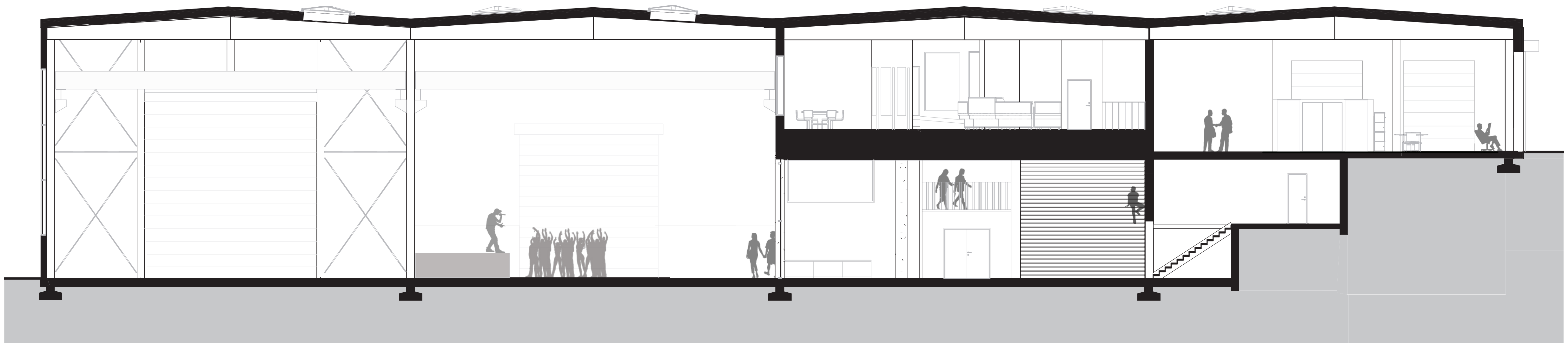
# Transformation of the Langland and Schei building

Master's thesis in MSc in Sustainable Architecture

Supervisor: Tommy Kleiven, Steffen Wellinger

Trondheim, May 2021



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Erik Hjelle Carlson, architect and friend, for his help and astute comments.

Lastly, we want to acknowledge our families and friends for their support and compassion during this project. Their encouragement has been a great support.

# ABSTRACT

This master thesis studies the possibilities of a transformation of the industrial building Langland & Schei at Reina in Trondheim. It is a building from the 1960's, which has served as a mechanical workshop. The thesis seeks to investigate the value of transforming and reusing the building, from a sustainable context. Building materials have large amounts of embodied energy and possible GHG emissions. Therefore, renovating and transforming existing buildings instead of demolishing, is critical in order to act according to environmental issues.

The framework is divided into an architectural concept and environmental assessment. The development the architectural concept is based on research, discussions and simulations, with a strong emphasis on environmental and social sustainability. The purpose of the environmental assessment is to evaluate the sustainability and consequences of the design choices. The method used is a Life Cycle Assessments (LCA).

The properties of the structure can be used as a guide for the transformation. Using principles such as design for disorder and adaptability can enhance the flexibility of the building. LCA results show that an adaptive reuse of the industrial building to a mixed-use building is favorable in terms of embodied GHG emissions compared to a new building in wood. The GHG emissions for the reference building are three times as large as the transformation design for A1-A3. The GWP is 12 % lower for designing according to NS 3700 Passive House standards compared to TEK17 for the office part of the building.

# SAMMENDRAG

Denne masteroppgaven som helhet ser på mulighetene ved en transformasjon av industribygget Langland & Schei på Reina i Trondheim. Bygget er fra 1960-tallet og har fungert som et maskinverksted. Oppgaven har til hensikt å undersøke verdien av transformasjon og gjenbruk av bygget, fra et bærekraftperspektiv. Bygningsmaterialer har store mengder klimagassutslipp bundet. Derfor er det essensielt å renovere og transformere eksiterende bygg i stedet for å rive, med konsekvens av at store mengder materialer sendes til deponi.

Rammeverket er delt in i et arkitektonisk konsept og en klima og bærekraftsanalyse. Utformingen av arkitekturkonseptet er basert på forskning, diskusjoner og simuleringer, med hovedvekt på miljøvennlig og sosial bærekraft. Formålet med klima og miljø analysen er å evaluere bærekraftigheten og konsekvensene av design valgene. Metoden for utredningene er livssyklusanalyser.

Egenskapene til konstruksjonen kan brukes som en veileder for transformasjonen. Prinsipper som tilpasningsevne og design for uorden kan brukes for å forbedre fleksibiliteten til et bygg. Livssyklusanalyser viser at en transformasjon av et industribygg til et flerbruksbygg er fordelaktig med tanke på klimagassutslipp i forhold til et nybygg i tre. Klimagassutslippene for referansebygget er tre ganger så store som transformasjonen for A1-A3. Videre er klimagassutslippene 12 % lavere for å utforme bygget etter NS 3700 Passivhus standarden i forhold til TEK 17 for kontordelen av bygget.

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# LIST OF ACRONYMS

BTA = BRUTTOAREAL /GROOS AREA
BRA = BRUKSAREAL / USABLE AREA
CFD = COMPUTATIONAL FLUID DYNAMICS
GHG = GREENHOUSE GAS EMISSIONS
GIFA = GROSS INTERNAL FLOOR AREA
GWP = GLOBAL WARMING POTENTIAL
LCA = LIFE CYCLE ASSESSMENT
L&S = LANGELAND AND SCHEI (COMPANY)
SDG = SUSTAINABLE DEVELOPMENT GOAL
VSC = VERTICAL SKY COMPONENTS
UN = UNITED NATIONS

# 1.INTRODUCTION

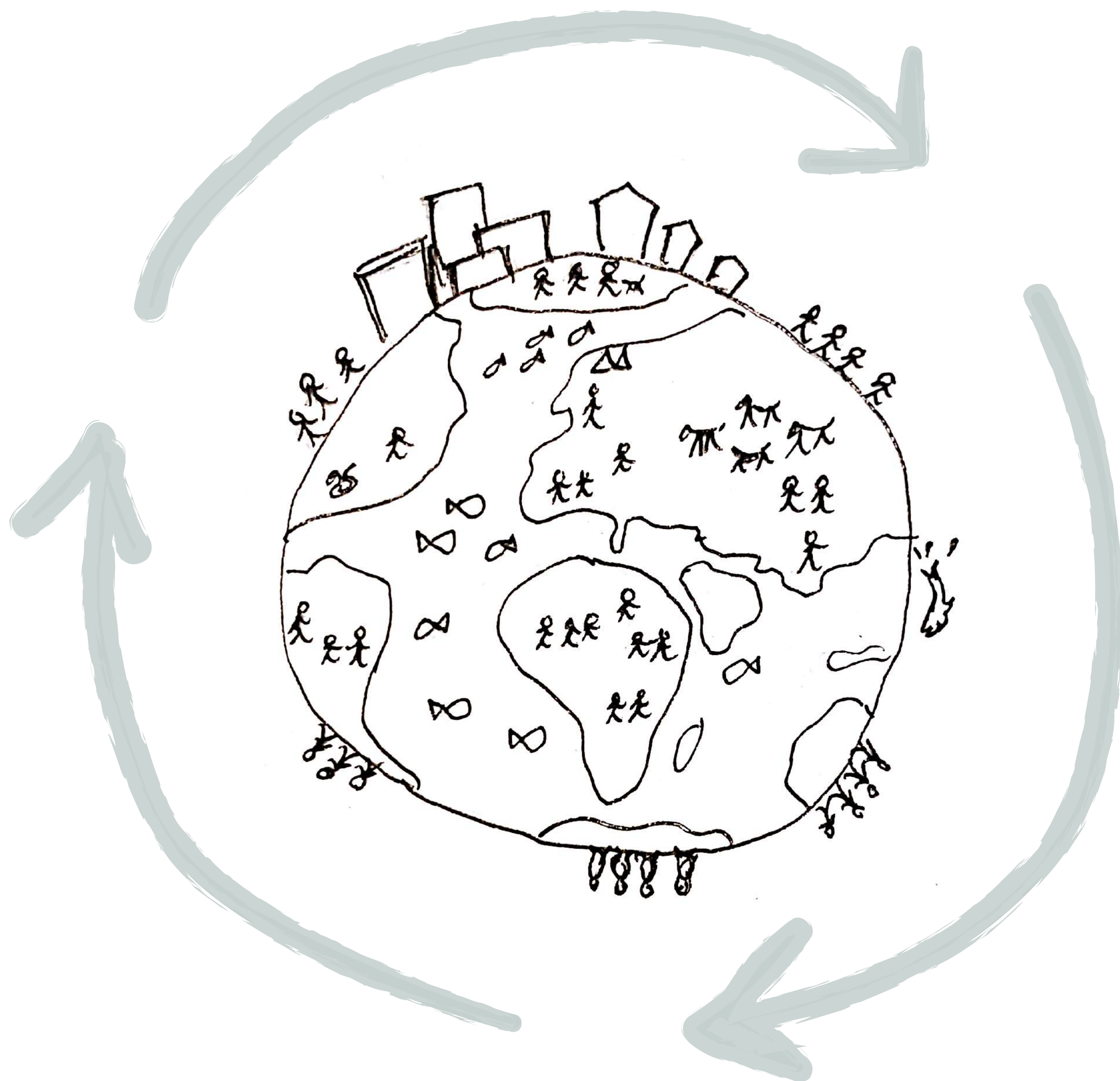
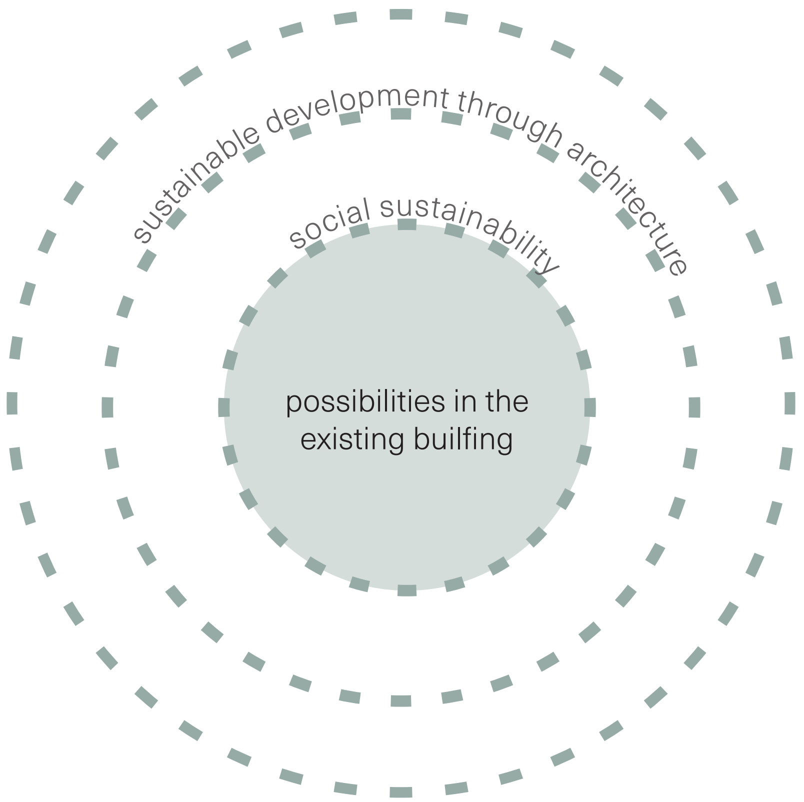



Figure 1: The UN Sustainable Development goals

Source: Adapted from [1] (https://www.un.org/sustainabledevelopment/news/communications-material/)




Fugure 2: Zoome levels

# INTRODUCTION

The introduction chapter will provide a context to this master thesis. It starts by discussing the context of the world today, followed by different aspects of sustainability. Then, the scope of the thesis is presented, succeeded by the problem statement and method.

# BACKGROUND

The context of the world today requires each and every one to take climate action. Sustainable development in the building sector can make a significant impact on greenhouse gas emissions. The UN's Sustainable Development Goals (SDG) guide us in the direction of a necessary change of practice in the construction industry. Particularly three SDG's are related to this master thesis; 11. Sustainable Cities and Communities, 12. Responsible consumption and production, and 13. Climate action [1]. However, it is important to mention that the building sector is not limited to these goals. As architect Natalie Mossin said "The built environment, planning architecture and design, interact with every goal" [2, p. 8] .

### "THE EARTH SYSTEM CHALLENGE"

According to Professor Katherine Richardson we need to understand the earth as a system, which she refers to as "the earth system challenge" [3]. It embodies the fact that we need to focus on the interactions within the systems of the earth. This is tied to the Sustainable Development Goals, and the importance of the interaction between them. Sustainability science should, according to Richardson, draw on all scientific disciplines and have a problem-solving approach. The key trade-offs need to be identified alongside the positive attributes of different strategies for sustainable development [3].

### RESOURCE CONSUMPTION

Sustainability in architecture has many aspects. One of them is the use of resources. According to economist Kate Raworth the economy is an open and linear system, with inflows and outflows of matter and energy, whereas the earth is a closed system with limited amount of resources [4]. The building sector needs to be understood as a closed circle, where resources and materials are conserved. Raworth calls it *doughnut economics,* where the outer circle represents the earth's resource boundaries and the inner circle represents the basic human needs. We need to be in the area in between these extremes. Materials that are already locked into existing buildings should remain in the building sector if the building is deconstructed or demolished. Redesign, reuse, recycle and design-for-disassembly are different approaches to material conservation. However, most products and materials are still designed for one-time use and often lack material declaration for a second and third time use [5]. Further, recycling of construction materials usually follow a downcycling, where the recycled material is downgraded in quality. Opposite of this is "upcycling", which architect Anders Lendager defines as "..taking a resource that's currently regarded as waste, or which is recycled in a process involving significant loss of value, and using it to create a new, high-value resource"[6, p. 47]. This process has possibilities to reduce resource consumption and embodied emissions in buildings. According to Lendager, an 80% reduction of CO2 emissions was achieved over the project lifetime of Ressourcerækkerne due to upcycling of reused brick facades, and the use of reclaimed concrete and wood [6].

### NORWEGIAN BUILDING STOCK

The building stock in Norway is increasing. From 1997 to 2021 the amount of individual buildings in Norway increased by 30 % [7]. From 2008 to 2019 an area of 540 $km^2$ was developed for buildings, and 60% of the area was built on land where the development had a negative climate effect, such as forest, farming- and march land [8]. It is well known that in the context of the climate crisis, we need to use and transform existing buildings and building sites. There is an ongoing densification in the cities. In Norway there are regulations for buildings worthy of preservation, usually for cultural reasons, which results in less demolition. However, we also need to more actively renovate and transform those buildings that are not considered to have a local, regional or national cultural value instead of demolishing them. These buildings need to be renovated in the context of sustainable cities with responsible consumption.

### PERSPECTIVES

Three zoom levels have been considered in this thesis. The largest scale is sustainable development through architecture. In order to take climate action, the concept of reuse, transform and design-for-reuse is vital to incorporate in every building project. The next zoom level is social sustainability. That is to consider the local area and community, and how the building can add value to the community. The last zoom level is the building site and the possibilities in the existing structure.

# SCOPE

The thesis seeks to investigate a possible transformation of the Langland and Schei (L&S) building at the Reina area in Trondheim. The aim is to design a multipurpose building with emphasize on achieving a low carbon footprint and providing functions for the inhabitants of Svartlamoen, Reina and Trondheim. An important design driver for this project will be the Life Cycle Assessment (LCA ).

A limitation of this project is energy simulations, which will not be performed as the thesis is in a schematic design phase, and the heating, cooling and ventilation systems are not designed. Therefore, it is decided that an energy simulation performed at this stage has many uncertainties which can lead to misleading results. Instead, the project will have an energy strategy and a premise note for the building physics and energy use of the building.

# PROBLEM STATEMENT

The problem statement was phrased as a result of discussions about transformations of buildings and reuse of materials. It is an open question, with possibilities for diverse answers. However, our approach is anchored in sustainability.

Is there a value in reusing/transforming the building? If so, how can we evaluate it, and how can we assign value?

Two viewpoints are considered in this question: outside-in and inside-out (Figure 3).

The outside-in viewpoint is reflected in the question; what is the "world" telling the building to be? This is a discussion about what we, as in the surrounding community and as designers, want the building to be, and what functions it should provide.

The inside-out viewpoint can be paraphrased as; what is the building telling us it can be? In this viewpoint lies the building's promise and restrictions. This is significant when considering reuse and transformation of a building.

# METHOD

This section describes the method of the project, which was a circular and iterative process. Feedback loops in terms of discussions, simulations and research altered the design throughout the project.

The first step in the project was to gather information about the site and existing building. It was important to understand the history of the site, and the city archives provided historical documents related to the site. A digital meeting with the municipality and local inhabitants of Svartlamoen was held in the beginning of the project, and a site visit with the property owner was organized.

The framework for the project is divided into two main parts: architectural concept and environmental assessment.

The method for developing the architectural concept is based on research, discussions and simulations, with a strong emphasis on environmental and social sustainability. That includes climatic factors, consideration of greenhouse gas emissions in design decisions, and energy performance. A set of questions were drivers for the process:

- The future is unknown. How can we allow for disorder and changes?
- What will happen to the building in 5 and 60 years?
- Can some functions or parts of the building be dynamic in periods of transition?
- Are there functions that are more suited to be placed in a dynamic or static part?
- Are there parts that can be left as is and others than can be developed more?
- Can we make meaningful changes to the building which "allow" for qualities in the selected functions?

The climatic factors on site were analysed with the use of Ladybug in Grasshopper. To consider the microclimate CFD simulations for wind patterns were performed with Butterfly in Grasshopper. Façade analyses were performed with Honeybee in grasshopper. Due to city regulation plans, consequences of densification were investigated in the microclimate and facade analyses.

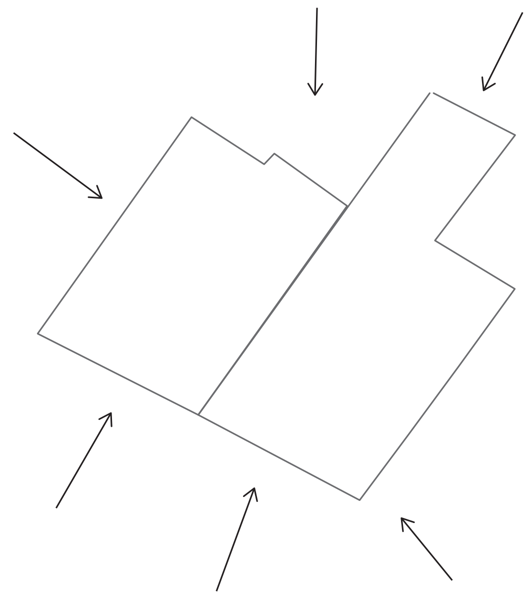
A requirement for the project was to introduce quality daylight into the building to create functional spaces. Concepts were tested and evaluated with daylight factor simulations with Honeybee in Grasshopper. Research was used to evaluate concepts for improving the energy performance and thermal comfort of the building.

The purpose of the environmental assessment is to evaluate the sustainability and consequences of the design choices. The method used is a Life Cycle Assessments (LCA), with a system boundary of A1-A3: Product Stage, B4: Replacement, C3: Waste Processing, C4: Disposal. The building lifetime is 60 years. Four different scenarios are compared in terms of greenhouse gas emissions:

A. New design
B. New design + existing building
C. New building as reference model.
D. Office requirements for TEK 17 and Passive house (includes B6: Operational Energy)

OneClick LCA is used to perform the LCA. Material quantities were collected from the Revit BIM.

This chapter will present the concept of the design project. It is followed by a discussion of dynamic and static structural systems. Then, viewpoints on the time perspective and principles of adaptability are presented.



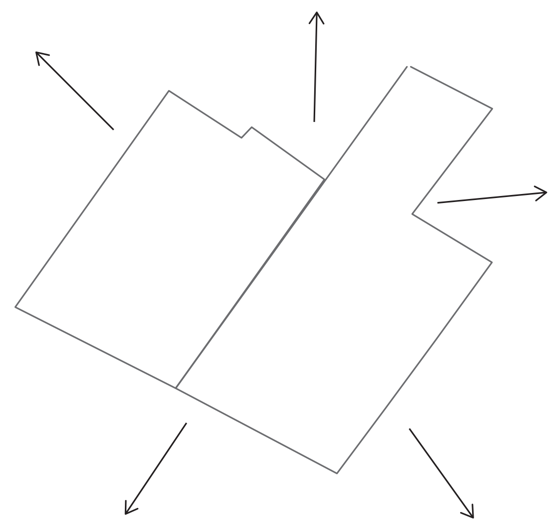
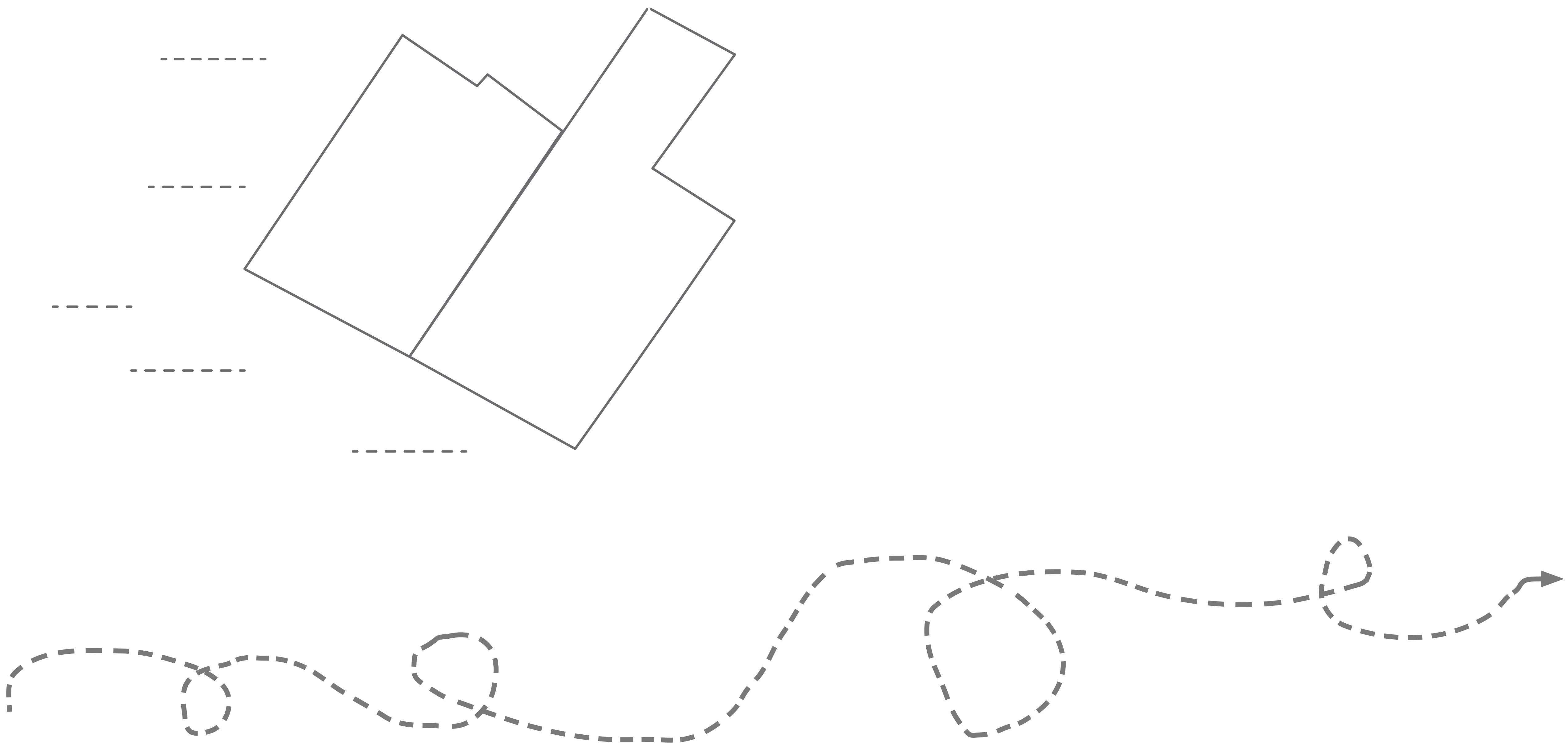


Figure 3: Outside-in and inside-out.

# 2. DESIGN FRAMEWORK



# DESIGN FRAMEWORK

## CONCEPT

The architectural concept is to use the characteristics of the structural system as a framework. To tailor for disorder and changes and introduce light into the darkness. “The quick processes provide originality and challenge, the slow provide continuity and constraint”[9]. The structure of the building is perceived as the slow, and the interior fittings and finishes are a part of the quick processes. The project seeks to preserve the structure and spatial robustness of the existing building and open up the building for daylight.

The concept and design process is inspired by Vassal and Lacaton’s statement “Never demolish, never remove or replace, always add, transform and reuse”[10, section 4]. The form follows the lifecycle of the building.


Figure 4: The West facade towards Strandveien.

Figure 5: The inside of L&S.

Source: Pfoto taken by Tommy Kleiven

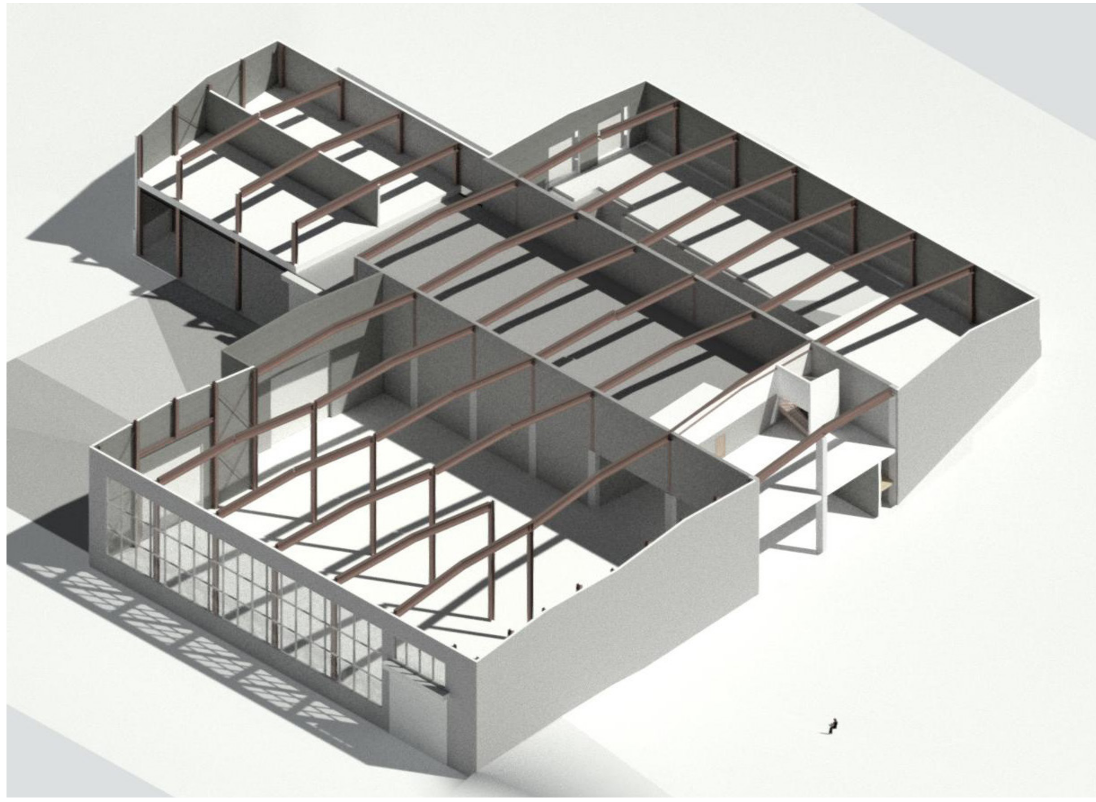


Figure 6: Model of the existing structural system.

# TIME PERSPECTIVE

Sustainable transformation is interconnected with the concept of time. As time passes there will be different kinds of needs for the building to cover. The future is perceived as indetermined. The probability tree in Figure 8 illustrates the fact that the future is hard to grasp. Architects, engineers, designers cannot predict with certainty the future needs for the building over its lifetime. However, this perspective leads back to one of the initial questions; what will the building be like in 5 and 60 years? And how do we get there? Spaces that absorb the uncertainty of time could lead to less renovation, transformation and demolition. Designing spaces that allow for changes and disorder can reduce the future environmental emissions. Richard Sennet talks about the built environment as an ontological process, and to leave projects unfinishable [11].

The time aspect of emissions lead to a discussion about energy use and embodied emissions in materials. A more ambitious energy target will in most cases result in a higher material emission. According to research in the ZEB Centre GHG emissions from production of materials can be as significant as the accumulated energy use of 60 years lifespan [12]. Embodied emissions in materials and emissions from energy use happen at different points in time. Hellweg, Hofstetter and Hungerbuhler state that “In general, LCA makes no explicit differentiation between emissions (and, ultimately, impacts and damages) at different points in time” [8, p.2]. The system boundary with respect to the lifetime selected for the life cycle assessment can affect the results, but this is not the same as explicit discounting. Further, Hellweg, Hofstetter and Hungerbuhler argue that “since LCA is a value-based decision support tool, it needs to address time-preferences if they are relevant in the context of future environmental damages” [8, p.2]. Their study concludes with “discounting is only applicable when temporally differentiated data is available. In some cases, such a temporal differentiation is necessary to take sound decisions, especially when long emission periods are involved” [8, p.1]. Based on this, Kristjandsdottir *et al.* argue that reducing the carbon emissions at the beginning of the building could potentially be more valuable than future predicted savings. One of the arguments is the effect of future decarbonization of energy supply [14].

Norway has agreed to be climate neutral in 2030 [15]. Powerhouse Brattørkaia will be “climate neutral” in 2073, as the embodied emissions are then paid back with solar power over 74 years [16]. That is more than 40 years after our “deadline”. In comparison, the refurbishment project Powerhouse Kjørbo is predicted to be neutral within 20 years of operation, around 2032. The promise of refurbishment is evident. The refurbishment of Kjørbo reduced the operational energy with 86 % [16]. However, emissions from the solar panels for Kjørbo accounted for approximately 35% of the material emissions. Meaning, that the embodied emissions could have been significantly reduced if the building did not have solar power. If the timeline of emissions is urgent, it might be more environmentally sustainable to dismiss or postpone the integration of photovoltaic panels.

An important aspect to consider when looking at the time perspective of a building is the lifetime of the building or its building parts. In [17,section 3] lifetime is defined as «the time the building or its parts are fulfilling its demand for the function.” This means that lifetime is not a “inherent characteristic trait”, but rather a way to measure functionality over time.

A last note about time; “Age plus adaptivity is what makes a building come to be loved. The building learns from its occupants, and they learn from it.”[9, p. 23] .

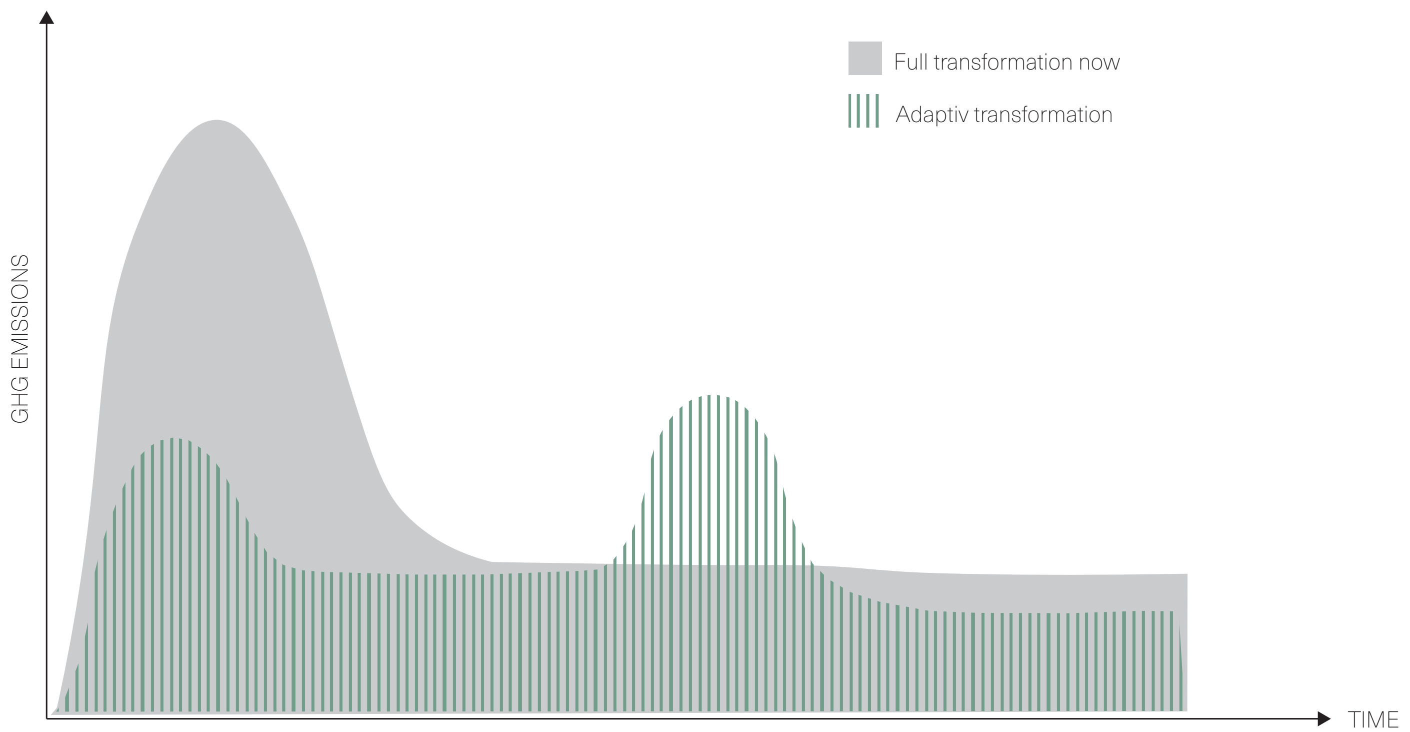



Figure 7: Building timeline for static and dynamic part.

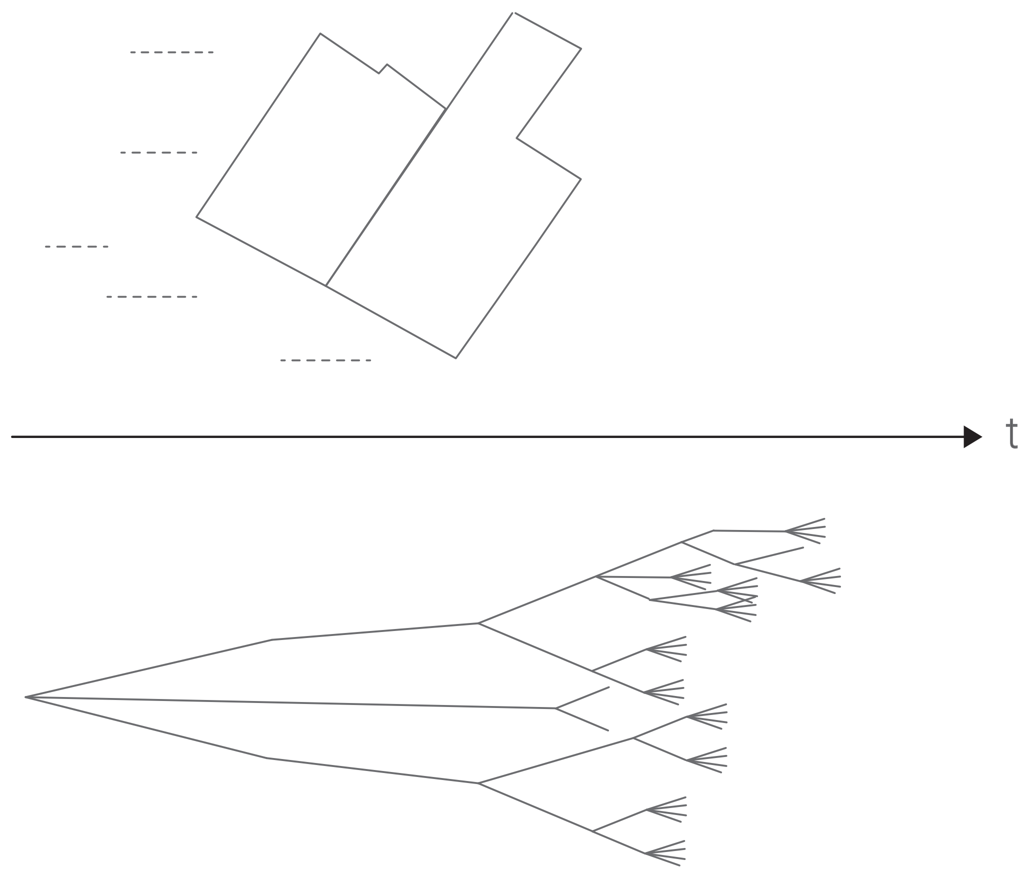



Figure 8: Building timeline

# PRINCIPLES OF ADAPTABILITY

Frank Duffy argued in “Measuring building performance” [18] that a building isn’t a thing, but rather layers of building components with varying longevity. Steward Brand built upon this notion in “How buildings learn” and split it into the six S’s [9], see Figure 9. Site, structure, skin, services, space plan and stuff. Brand concluded that these layers have different rate of change or lifetime, and buildings should be designed to allow for slippage between the layers, so they do not obstruct or interfere with each other.

Another principle of adaptability is oversizing. In a project report from 2002 “Generality, flexibility and elasticity in buildings” [19] Arge and Landstad points out that oversizing can mean spatial reserves, and extra capacity in the load-bearing system and technical services. The main principle for oversizing is that one allows for generality in the building. In this context, generality means the building’s capability to change its’ functional user requirement without larger changes in the building itself. For spatial reserves that means designing and constructing rooms that are bigger than intended use to allow for changes later. For example, having enough room height to fit in a new ventilation system. Arge and Landstad argues that oversizing has critical economic and environmental consequences when assessing new buildings. However, they conclude that old industrial buildings have shown to be very adaptable for new functions, mainly due to their generous volume and sizing.

In context of sustainability, the building needs spaces that allow for changes and disorder. The structure of the existing building consists of steel and concrete. The properties of steel allow for large spans, flexibility, and future reuse and recycling. In contrast, concrete is perceived as static and rigid. “The dynamics of the system will be dominated by the slow components, with the rapid components simply following along.” Steward Brand quoting Robert V.O’Neill’s “A Hiericichal Concept of Ecosystems”. Brand sums it up “Slow constrains quick; slow controls quick” [9]. The structure is a slow component. However, the properties of different structural systems indicate different speed within this slow component. Steel is moving more rapidly than concrete. Based on the existing building’s structural system, there are spaces than can be more flexible than others.

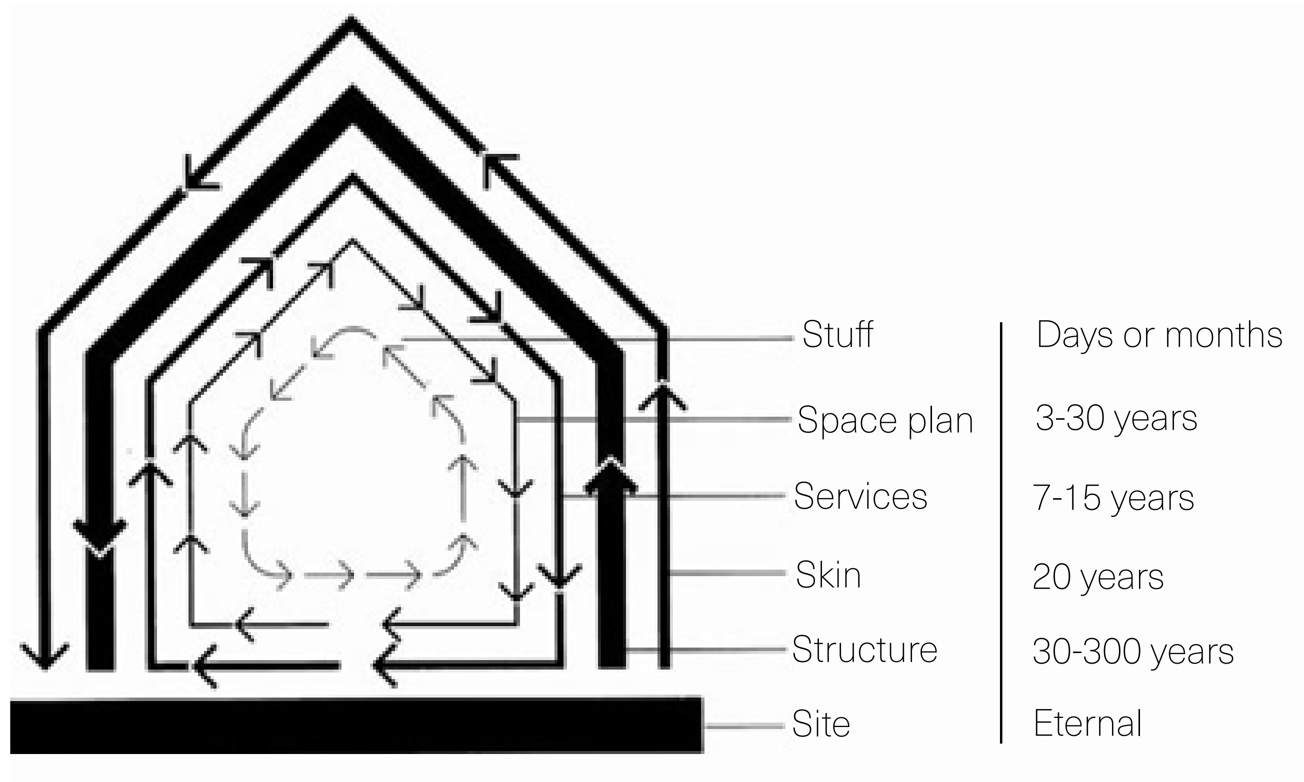



**Figure 9: Stewart Brand's six S's.**

Source: Adapted from [9]

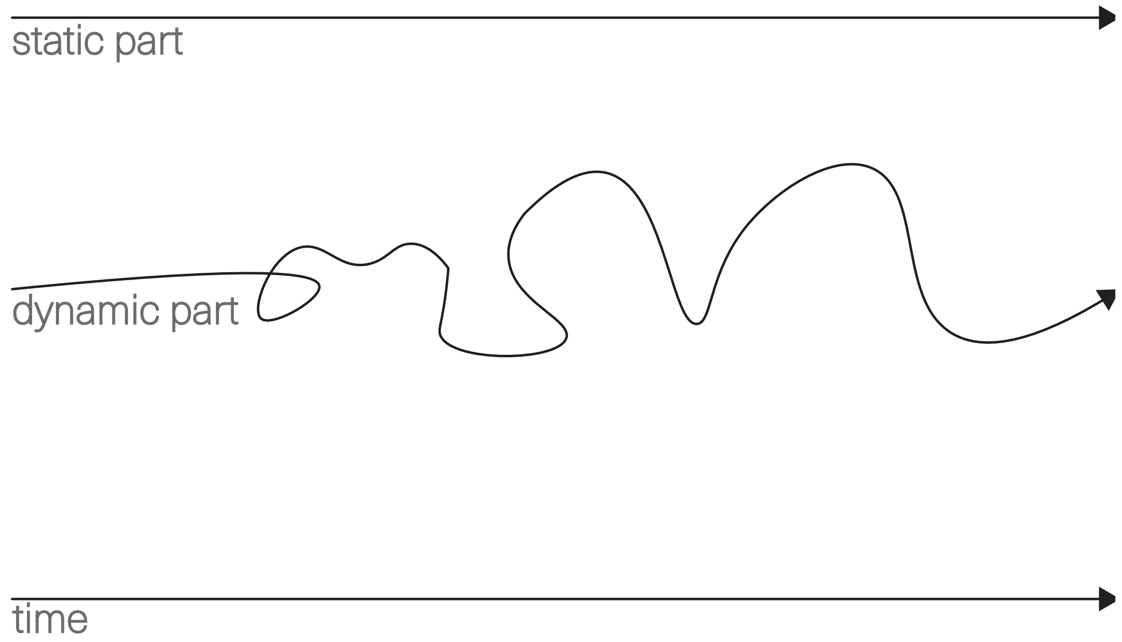



**Figure 10: Building timeline for static and dynamic part.**

# MATERIAL REUSE

There are several projects and some research done in reuse of building materials. The FutureBuilt project Kristian Augusts gate 13, initiated by Entra, is an office building from the 1950's, which was upgraded according to circular principles [20]. The project team wrote an experience report, with lessons learned from the pilot project. Some key lessons were that reuse demand high quality and long lifetime of building materials, and documentation of products is important and challenging. Further, it is complex and expensive to reuse structural elements in steel and concrete. However, here lies the possibility for the greatest environmental savings. Close cooperation between the architects, engineers, contractors and subcontractors is essential, and it is vital to start looking for recycled materials as soon as possible [5].

Another aspect of reused materials is to design for disassembly. If the product is difficult to remove, for example due to extensive use of adhesives, the product will most likely be destroyed during disassembly or demolition, and thus not possible to reuse. Therefore, design for reuse and disassembly demands more of the designers, engineers and contractors in the beginning of the project. To build it with the perspective of reversing it in the future. Adam Strudwick of Perkins and Will said " Rather than thinking of buildings or interiors as the end product, we have to think about every building as a kind of DIY store for the next project and the next project and the next project,"[21, section 3].

When reused materials are a part of the architectural expression the end product is unknown to a greater degree than conventional projects. The building will be defined by the materials that are available. The project "Rebeauty – Nordic Built Component Reuse" led by Vandenkusten explored and developed different prototypes for reused building components, from reused concrete to soft flooring [22]. For example, façade components by flattened ventilation ducts, interior walls of old windows, and sliced concrete slabs for facades. Stavneblokka is another element developed by Kennet Urdshals, Anne Sigrid Nordby and Kristin Støren Wigum, which can be used to create interior walls and spaces [23]. Another project, Villa Welpeloo used damaged cable rollers as façade elements [24]. Overtraders W and Bureau SLA designed the Pretty Plastic façade cladding tiles for the People's Pavilion, which is now a commercial product [25]. The tiles are made of recycled PVC products. These are just some examples of what is possible. The documentation of products is challenging, but apart from that there are endless opportunities to create interesting buildings with reused components.

Figure 11: Reused concrete as building component.

Source: Adapted from [22], Rebeauty

Figure 12: Old windows as interior walls.

Source: Adapted from [22], Rebeauty

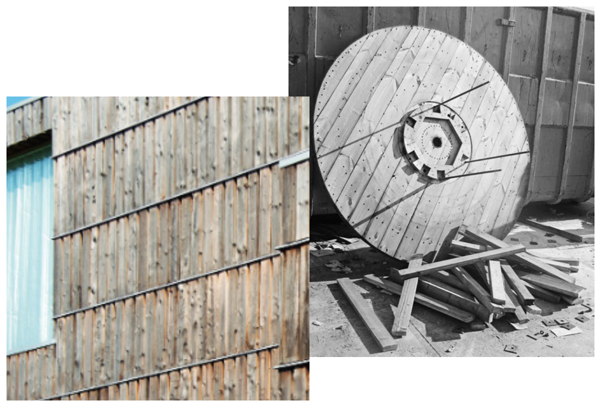


Figure 13: Old cable rollers as facade cladding.

Source: Adapted from [23], Villa Welpeloo

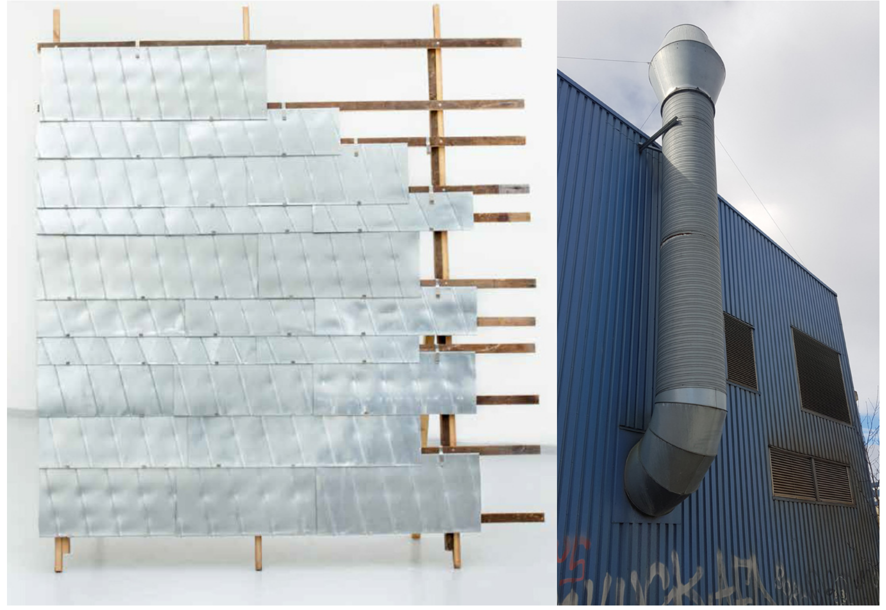


Figure 14: Reused ventilation ducts as cladding.

Source: Adapted from [22], Rebeauty

Figure 15: Pretty Plastic facade cladding tiles.

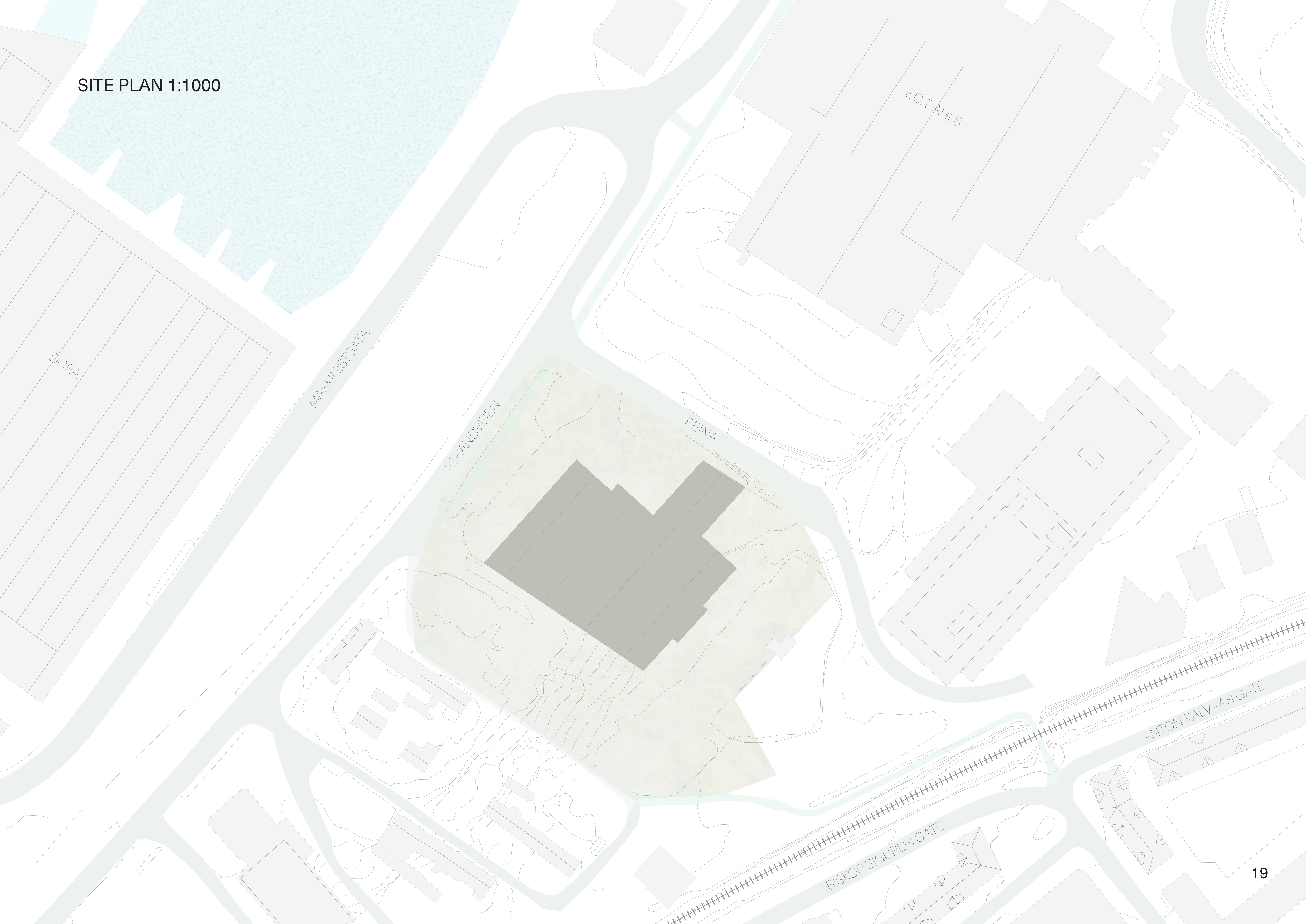
Source: Adapted from [25] and [21], Pretty Plastic

Figure 16: Stavneblokka

Source: Adapted from [23], Stavneblokka

# 3. SITE AND CONTEXT

# SITE PLAN 1:1000



# SITE AND CONTEXT

In this chapter the site and context of the design project is presented. It starts with the site and neighbourhood and is followed by the history of the Langland & Schei building, and a description of the conditions of the existing building. Then, the climate is presented with related simulations for the microclimate and façade analyses.

## SITE

The building adress is Strandveien 41. It is an industrial building located next to the port. There is easy access to public transportation and bike, and pedestrian paths providing connection to the city centre, Ladestien and Rosenborg (Figure 18). The building is called Langland and Schei (L&S), which is the company that had their mechanical workshop there for almost 50 years.

According to the current Reina zoning plan the existing building will be demolished and replaced with new housing units. However, local inhabitants wish to keep the existing building for, among others, historical reasons.

## NEIGHBOURHOOD

The site is in the city region Reina of Trondheim. It lies on the border between Reina, Nyhavna and Svartlamoen. There is a significant housing development ongoing at Reina. Nyhavna is Trondheim's main port and industrial area. Trondheim municipality has made a quality program for the development of Nyhavna from an industrial to an urban area [26]. Nyhavna is intended to develop into a zero emission neighbourhood. The Svartlamoen community is the closest neighbours to the existing building. They call themselves "Norway's first urban ecological experimental area [27]. This is reflected in the businesses that are located at Svartlamoen, with an emphasis on cooperation, community and acceptance.

A proposal led by Rodeo and Sanden + Hodnekvam show new housing blocks at the project site, and with increased densification [28]. The site is relatively large, and it is reasonable to assume densification in the future.

One of the strategies for Trondheim city east, which inludes Nyhavna, Lademoen, Reina, Møllenberg, is to facilitate for reuse and transformations of existing buildings. There are several historical buildings in the area, and the authenticity of Nyhavna shall be preserved. Another strategy is to strengthen the connection to the city centre with pedestrian and bike paths [29].


Figure 18: Mobility map

# HISTORY OF THE L&S BUILDING

This section is dedicated to the history of the site. The information was gathered from the city archives at DORA, where all historical building files related to Strandveien 41 were received from the archives. That resource gave an important insight to the history of the site.

The area was previously a residential neighbourhood in the early 1900s, but in 1947 the area was regulated for industrial use. That determined a shift for the neighbourhood. In 1945 Langland & Schei AS was allowed to use a former German workshop shed at Sødemannsgate for their operations. Most of their operations were still in the city centre by Trondheim Torg. However, this was the beginning of the L&S history at Strandveien 41.

At the L&S workshop they produced electric boilers for the industry and heating of residential buildings [30]. The work induced a lot of noise, and between 1961 and 63 neighbouring residents sent several letters to the municipality complaining about disturbance and unliveable conditions due to loud noises and "ugly" buildings that were built in the area. Since the area was regulated for industrial use, the complaints were not considered further.

The plot was a lot smaller at that time and was surrounded by residential houses. It started from Sodemanns gate 1, and then developed as L&S bought adjacent plots when the surrounding buildings were demolished one by one. First, the houses at Reina gate were torn down, then the ones at Sodemanns gate, and in the end Strandveien 41 stretched from Reina to Sodemanns gate.

The building has been extended six times. The first part of the building was constructed in 1963, which is the South-eastern part of today's structure. The structure consists of concrete and steel and covers 700 m². It was a mechanical workshop, with workshop functions in first floor and storage on second floor. At that time, the building was planned in a two-step construction process. In 1965 the municipality approved two additions to the building, which was step two in the original plan (Figure 20). This extension included a basement transformer room and a welding shop in first floor, with a total area of 113 m².

The third construction phase was in 1978, with a building addition of 360 m² (Figure 22). The additional building had a footprint of 120 m² and three floors. The exterior walls are of aluminium, and the floors are SH-plates. The existing building has a footprint of 1140 m². The first floor was used for storage, second floor was office space, meeting rooms, wardrobes and restrooms, and 3rd floor was lunchroom, wardrobes, restrooms and technical room.

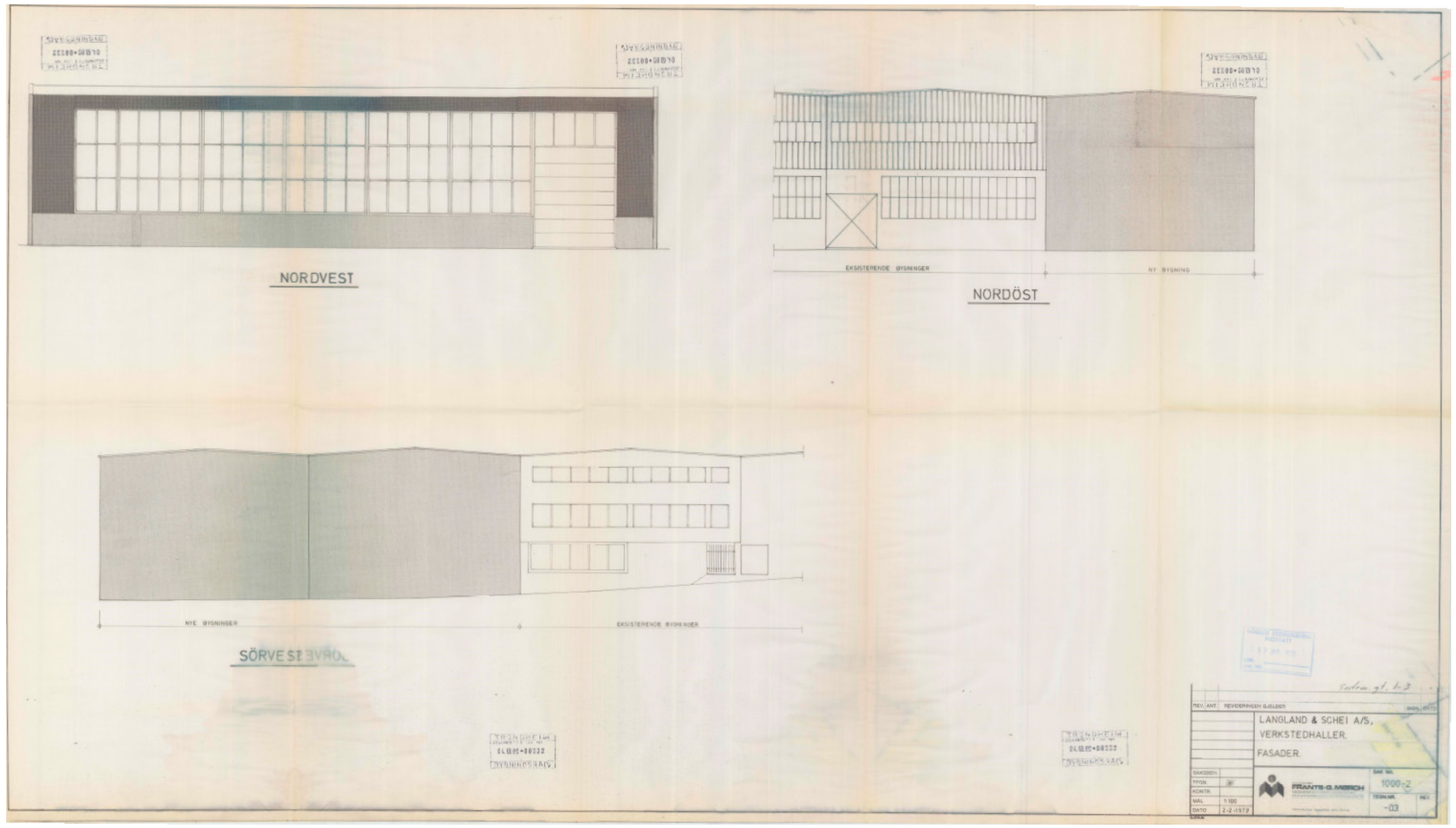



Figure 19: Construction documents from 1979
Construction phase 4 - elevation drawings.

The fourth construction phase was in 1980 (Figure 19 and 23). An additional building of 1180 m², which was a workshop over two floors, was approved for construction. It was built of insulated steel plates, except for the concrete parapet and gable walls in Leca blocks.

In 1996 the fifth addition was built. The application included extensions on all four building sections. However, that request was denied and only one hall could be extended. In 1998 the last building renovation was approved, which was an interior renovation of the upper workshop hall, with new slab on grade and interior floor as well as new concrete walls.

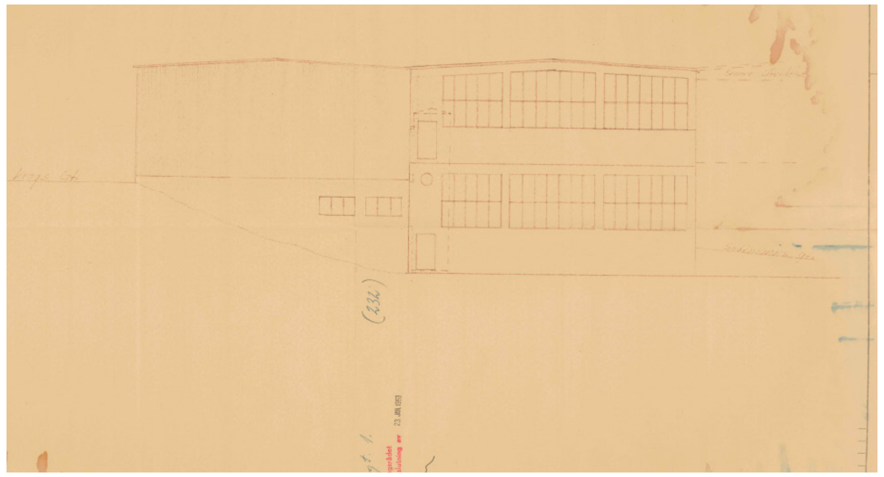


Figure 20: Construction documents from 1963.
Construction phase 2, east facade.

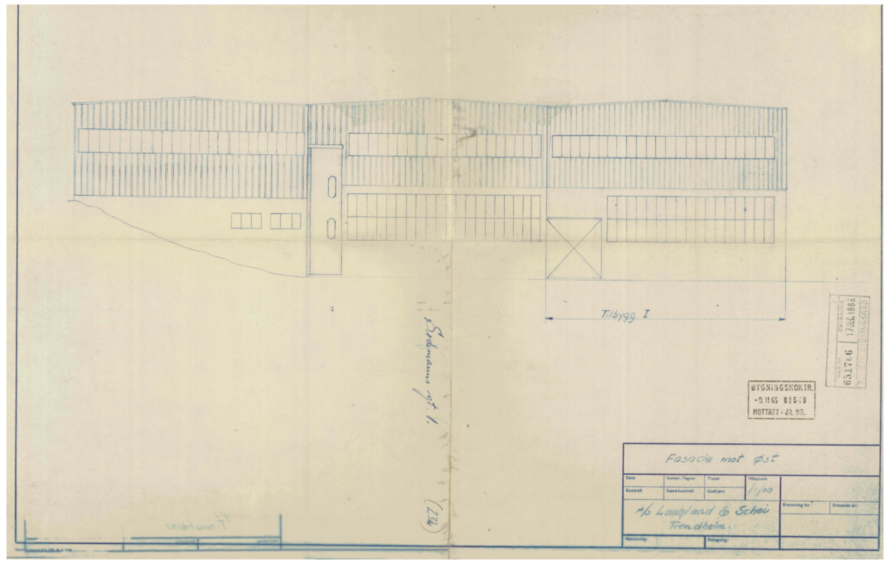


Figure21: Construction documents from 1963.
Construction phase 2 (1965), east facade.

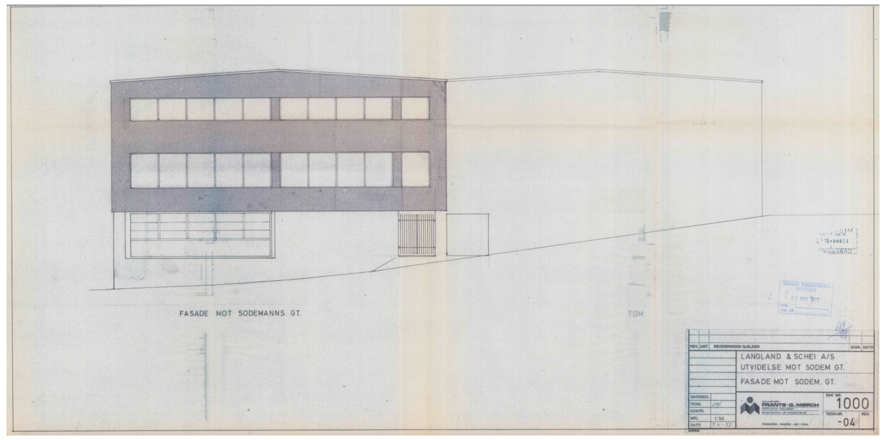


Figure 22: Construction documents from 1978.
Construction phase 3 - south facade.

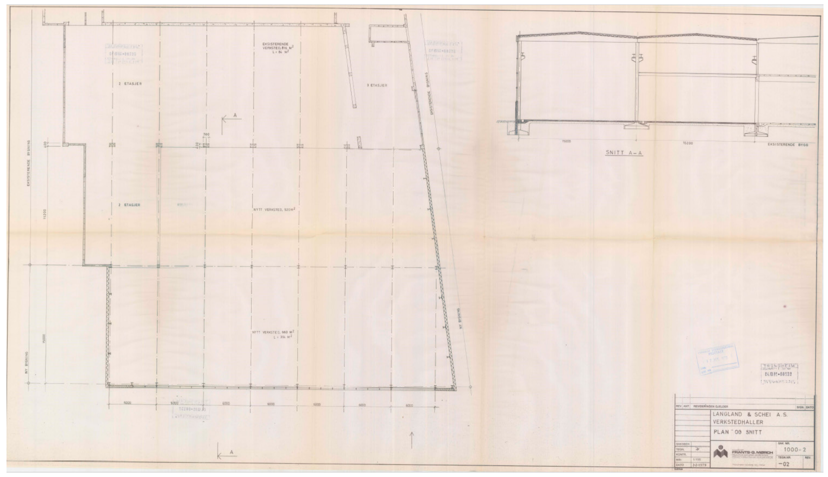


Figure 23: Construction documents from 1979
Construction phase 4. Floorplan and section.

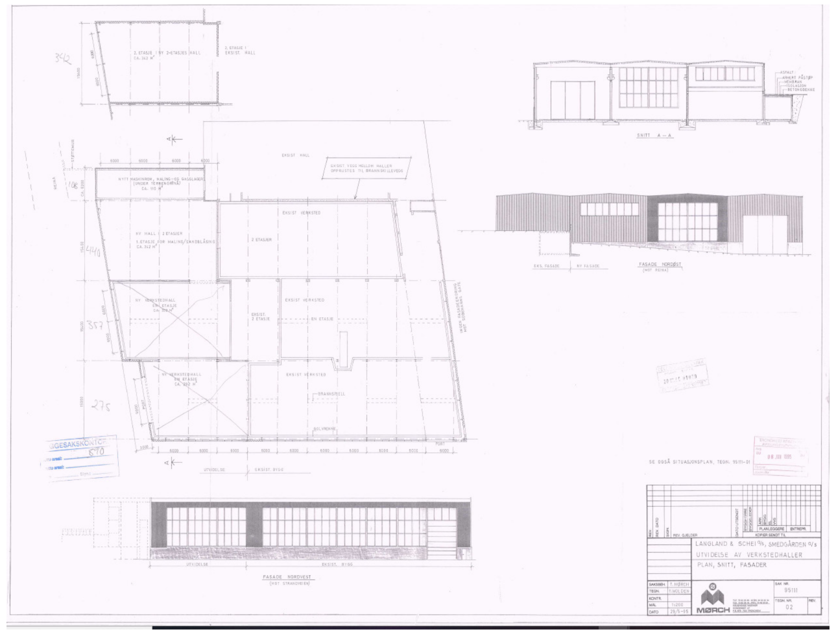


Figure 24: Construction documents from 1996.
Construction phase 5. Floorplan, section and elevations.

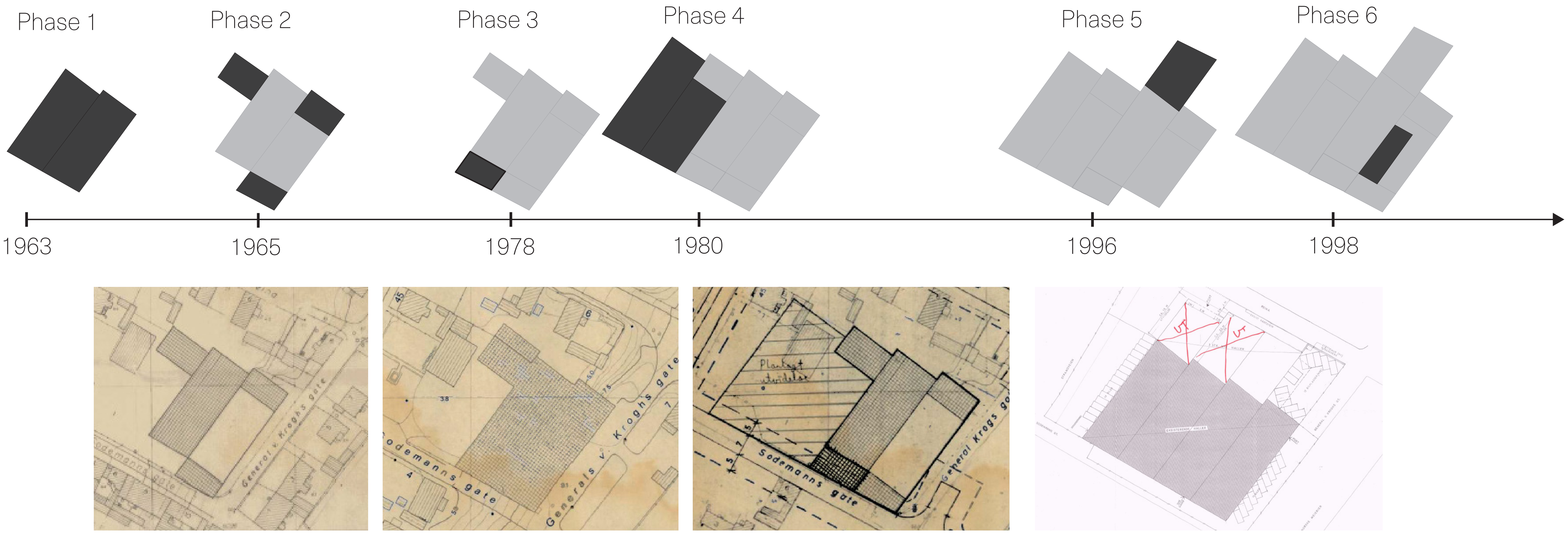



Figure 25: Construction timeline

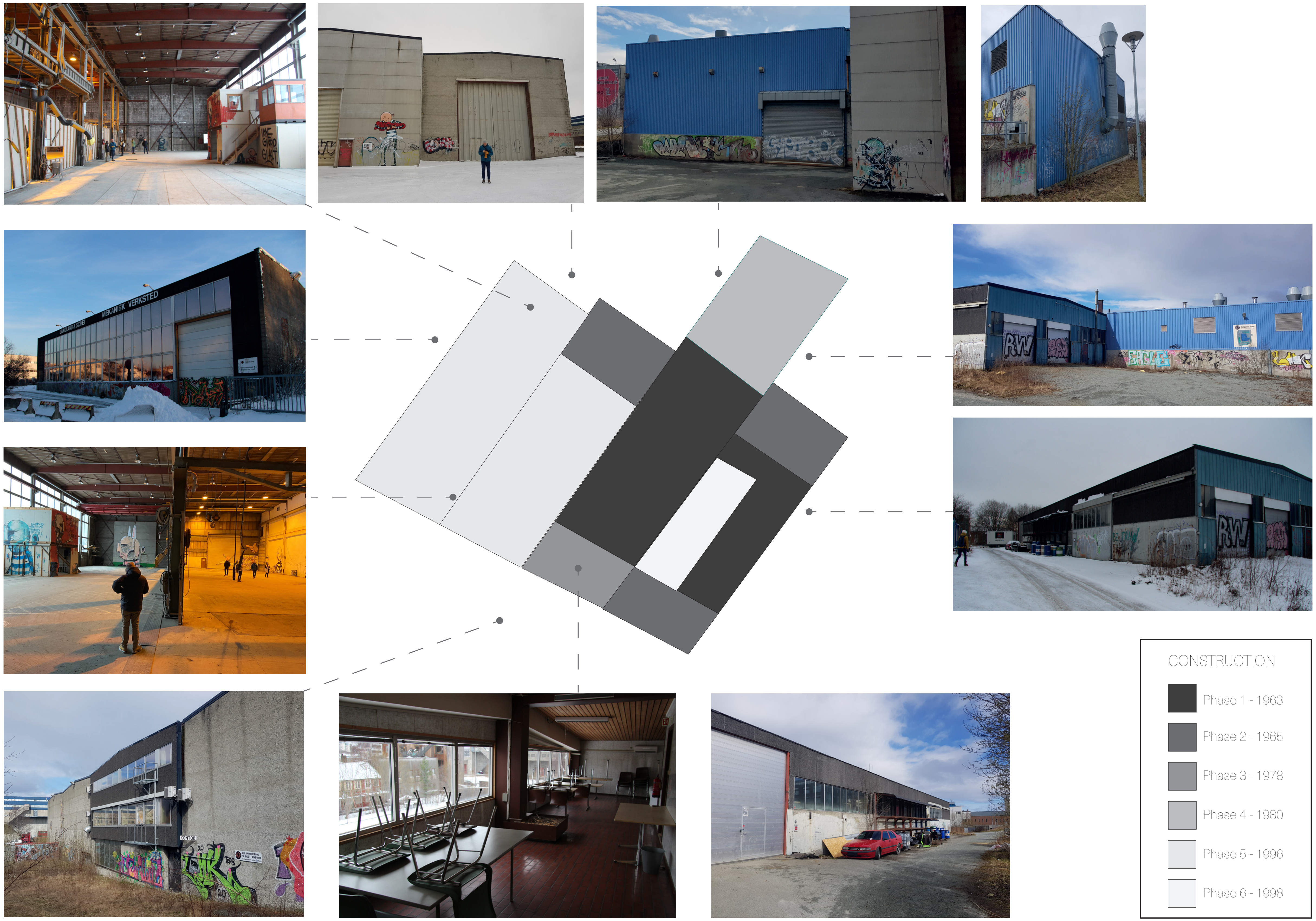



Figure 26: Existing building in construction steps.

# EXISTING BUILDING

The structural system is roughly from three time periods, the oldest components are 60 years old, the steel halls are 40 years old, and the newest addition is approximately 25 years old. The load bearing systems consist of a mix of steel frame and concrete walls and slabs. See Figure 27. Production hall 1 is constructed of steel beams and columns. This allows for large spans. The mounted transportation system is designed to handle 4 tons of vertical load. The top cover of the concrete flooring here has been set as +0m for the local elevation for this project.

Production hall 2 is constructed in the same manner but has an added floor at 6,78-meter (top cover) height. A concrete floor is spanned 15,4 meters between the steel structure, on top of steel beams that are welded between the columns. Connected to production hall 2 there is a concrete basement, fully subterranean and has a ceiling height of 4,1 meter. The structure between the main production hall and production hall 3, wall 1, is a mix between concrete columns steels beams and an infill of leca-blocks covered with plaster. The steel columns are mounted on top of concrete columns. Just like in the production hall 2, in production hall 3 there are steel beams welded between the steel columns that support the spanned concrete floor. The top cover height for the 3rd floor in this hall is 6,2 meters. Production hall 4 is also designed with a load bearing system of steel beams and columns for walls and roof. The floor is at 3 different heights. See section C-C. The floor is open to the lower part which has a local height of 2,27 meter. The eastern part for the floor has height at 5,0 meters at the top cover, where the southernmost floor area has a height of 5,28m. Wall 2 between production hall 4 and the volume for the office and production hall is assumed to be constructed similar to wall 1.

# CONDITION ANALYSIS

During the early phase of the design project students were granted a tour in the building with the owner at Dora eiendom. The tour however was limited to the production hall 1. This means that the condition analysis is limited to the visual inspection from the earlier mentioned visit inside, and from what can be inspected outside the building. Assumptions made for the condition of the building are very limited and general. During the visit inside one could observe signs of water leakage in the roof. However, the steel structure seems to be well coated with metal coatings, but with a few signs of rust. Since this is an old industrial building, the assumption is that one must handle some contaminated parts of the building. For the project this has been limited to laying a new cement screed over the old floors, and seal it off. On the exterior, the Eastern façade looks worn down. Around the perimeter of the foundation there are some cracks visible on the surface. From merely observation and inspection this seems to be limited to the plaster, and no rebars are exposed.

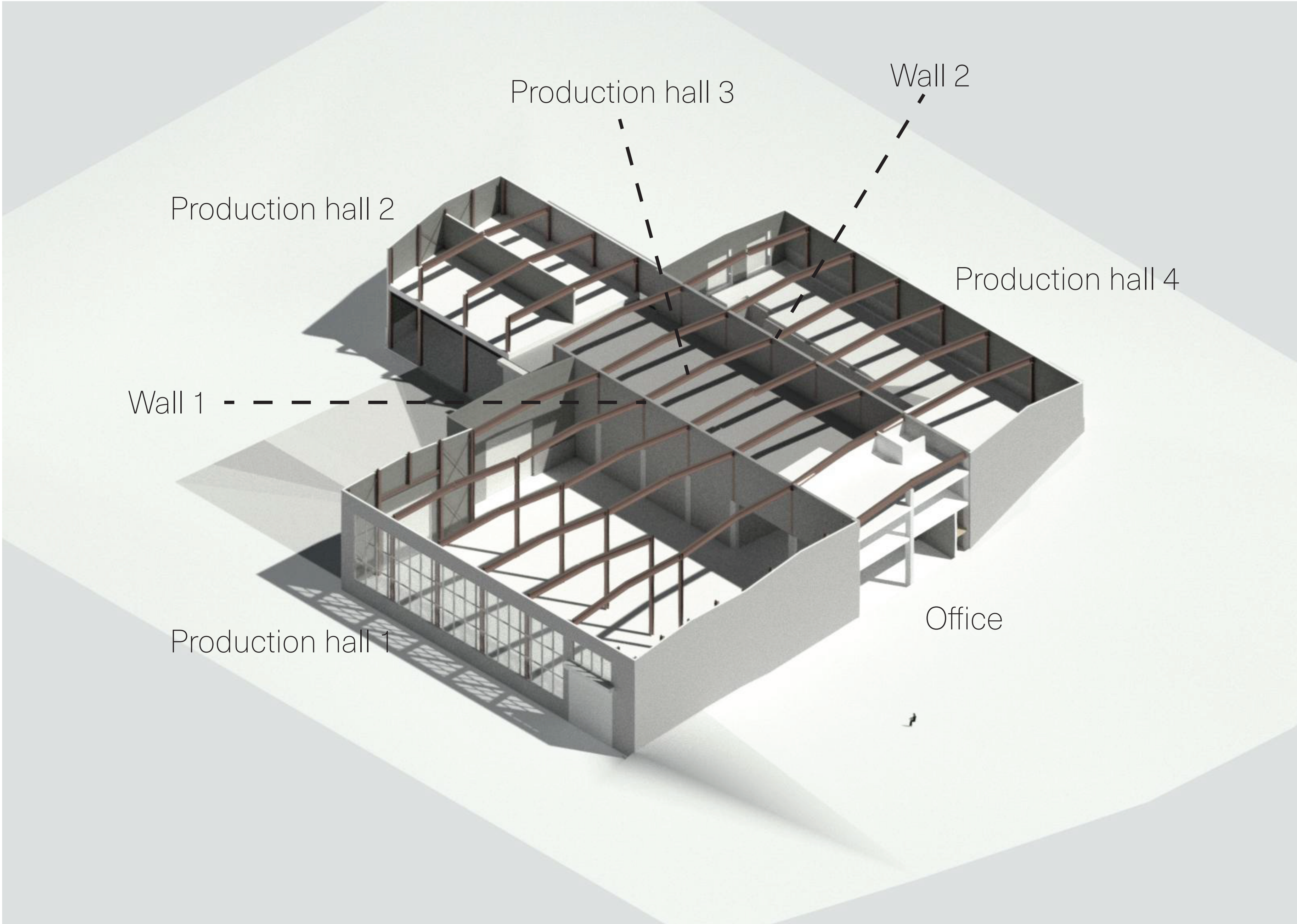
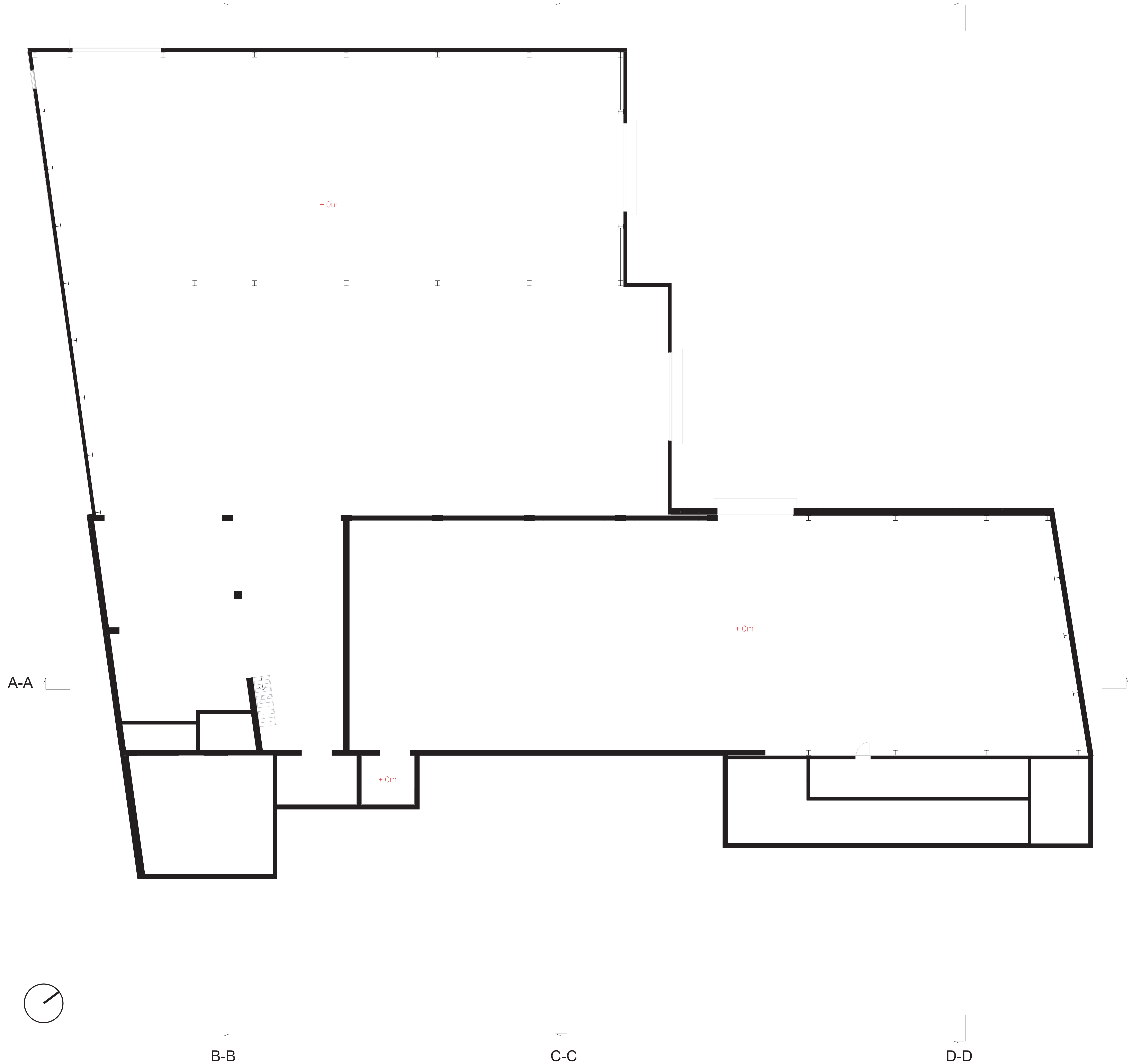


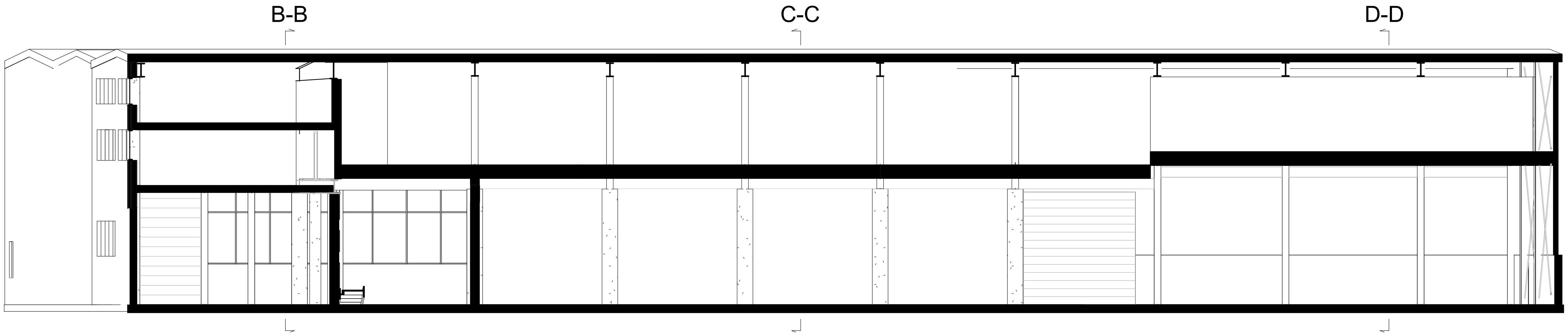

Figure 27: Structure of existing building



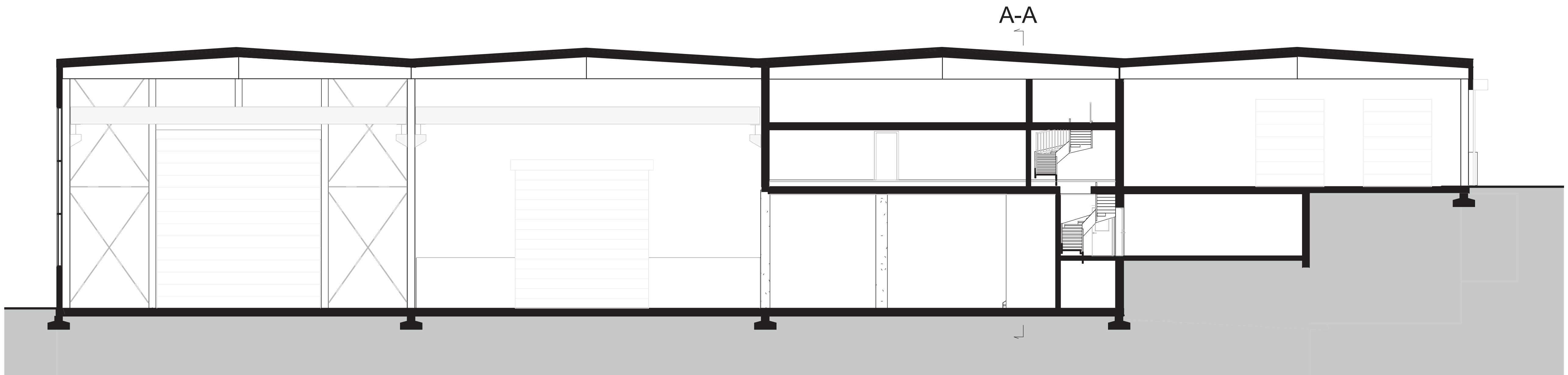

PLAN 1ST FLOOR EXISTING
1:200


PLAN 2ND FLOOR EXISTING
1:200

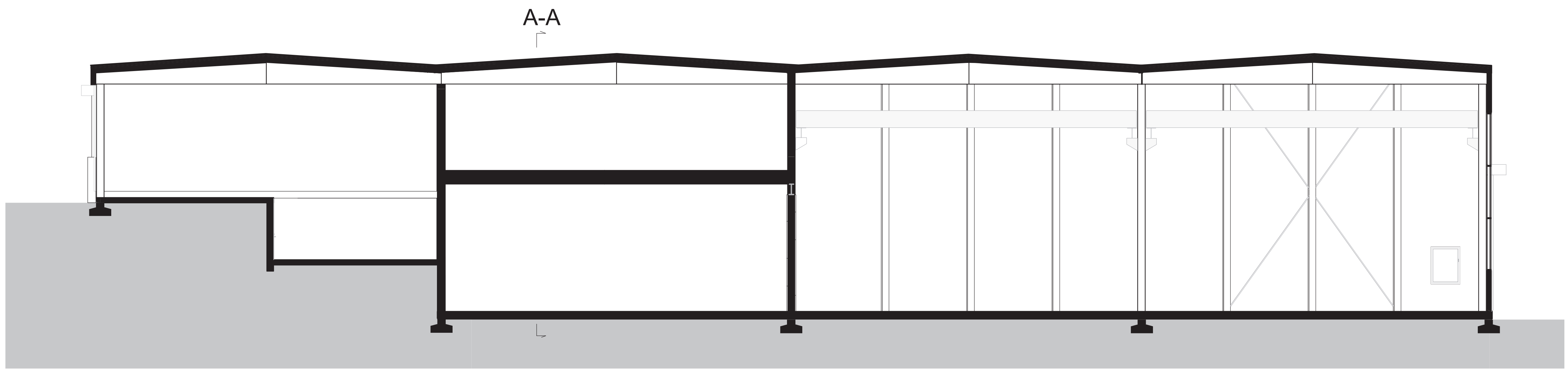

PLAN 3RD FLOOR EXISTING
1:200



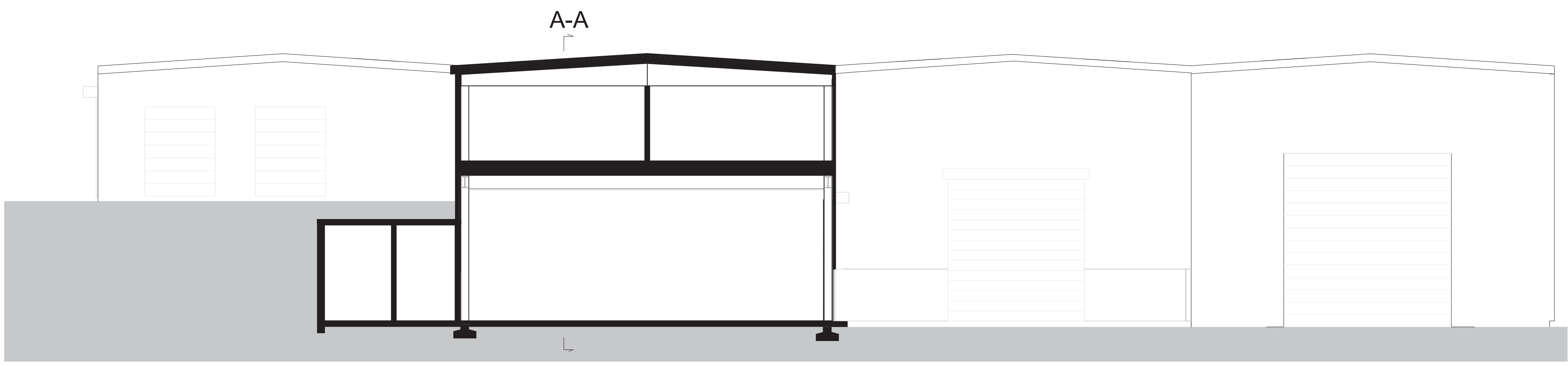

SECTION A-A EXISTING
1:200




SECTION B-B EXISTING
1:200




SECTION C-C EXISTING
1: 200




SECTION D-D EXISTING
1: 200

# CLIMATE

The climate of Trondheim is classified as Subarctic Climate (Dfc) according to the Kõppen Geiger Classification, and it is described as cold and temperate, with a high relative humidity (72-87%). The average annual temperature in Trondheim is 4,4°C [31]. January, the coldest month, has an average temperature of -4,5 °C, and July, the warmest month, an average temperature of 14,6 °C. April is the driest month in Trondheim with an average of 72 mm precipitation, and September is the wettest month with an average of 107mm precipitation. Figure 36 shows seasonal wind charts for Trondheim.

The prevailing annual wind direction is from 112,5 degrees, except for the summer months where the wind mainly comes direct from West (270 degrees). In Trondheim the wind is calm 150 hours during a year, or 1,7% of the time. Figure 35 shows the sun path during summer solstice, winter solstice and equinox. June 21$^{st}$ has a solar altitude of 50°, with about 20 hours of available sunlight. On December 21$^{st}$ the solar altitude is 3,4°, with 4,5 hours available sunlight hours, while 21$^{st}$ of March has 12 hours of available sunlight.

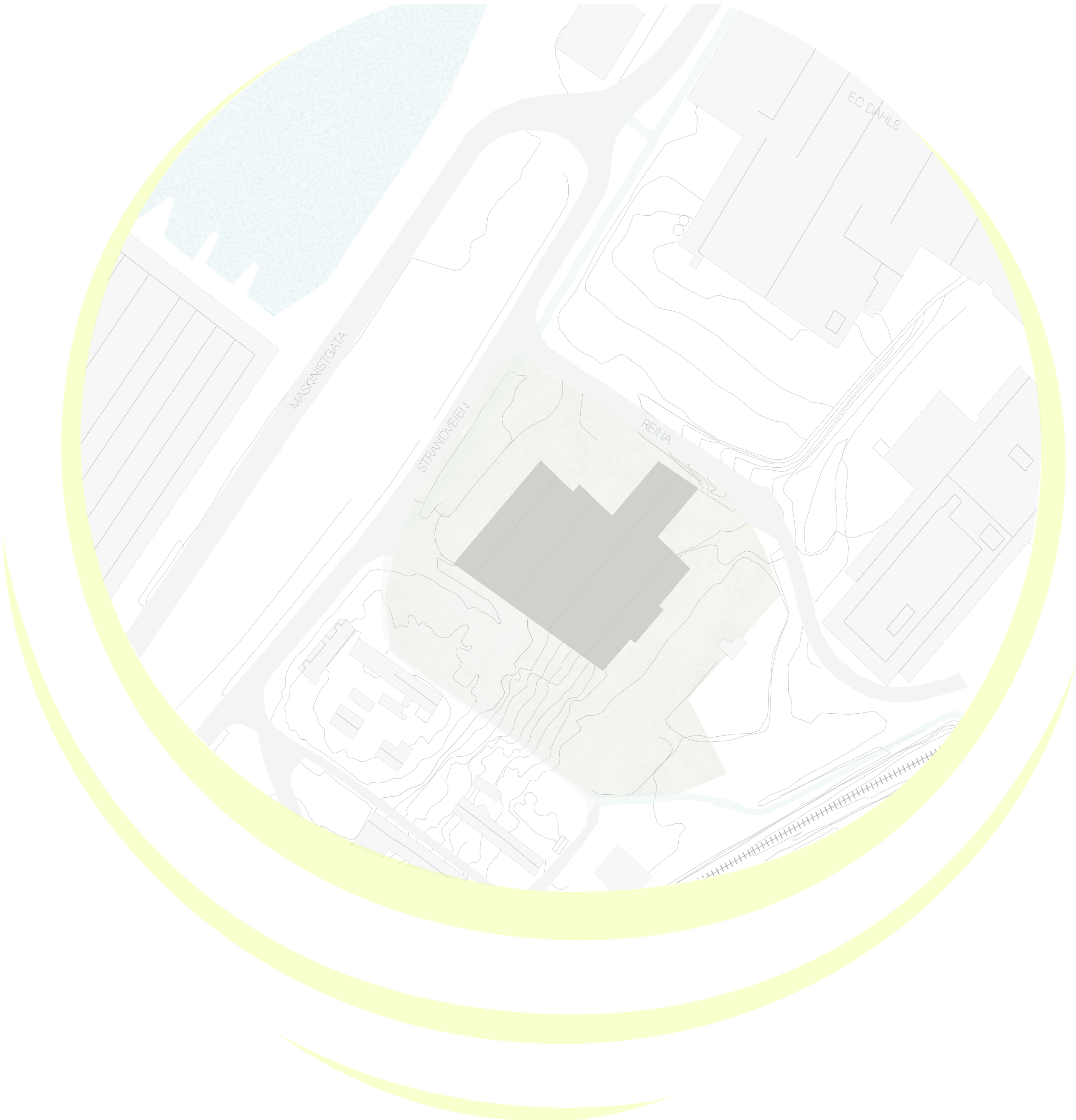
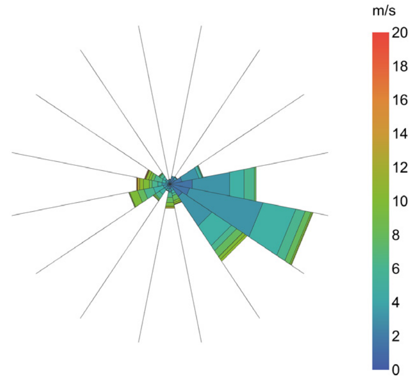
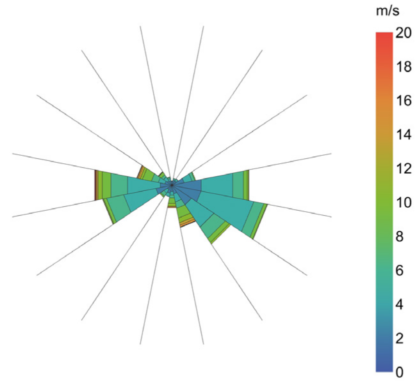


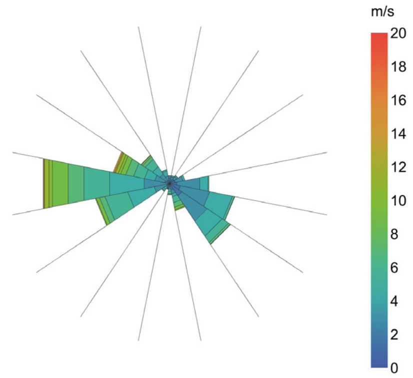
Figure 35: Sunpath



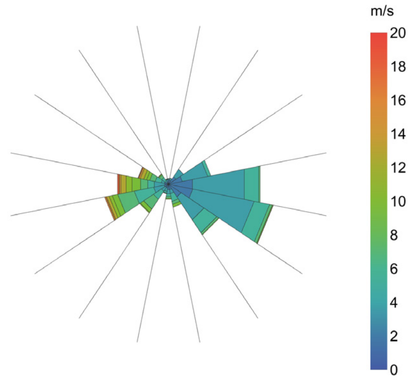

Winter wind direction.




Spring wind direction.




Summer wind direction.




Autumn wind direction.

Figure 36: Seasonal wind directions.

# FAÇADE ANALYSIS

The same configuration was used for the the analyses of radiation, vertical sky component (VSC), shadow range and computational fluid dynamics (CFD). The analyses were performed for three scenarios; (1) as it is today with the existing surrounding buildings and (2) a future scenario with densification on site (with three configurations of the buildings, D1, D2, and D3) where buildings are oriented on the North-South axis, and (3) a future scenario with densification where the buildings are elongated on the East-West axis. The scenarios are displayed in Figure 37. See Appendix B for scenarios details.

### RADIATION ANALYSIS

The annual radiation incident on the facades and roof was analyzed with the use of Grasshopper in Rhino, with a script provided by Multiconsult. It was measured in annual radiation incident on the façade in kWh.

The results indicate good radiation access for the building envelope as it is today. Figure 39 shows results for the facades as it is today, and the south façade receive 996 kWh/m² annually. In comparison, the north facing façade receives about 200 kWh/m² per year. Of the densification scenarios, (2) - D3 gave poorest results in terms of radiation. The south façade received 712 kWh/m² annually, which is a 29% reduction from the current situation.

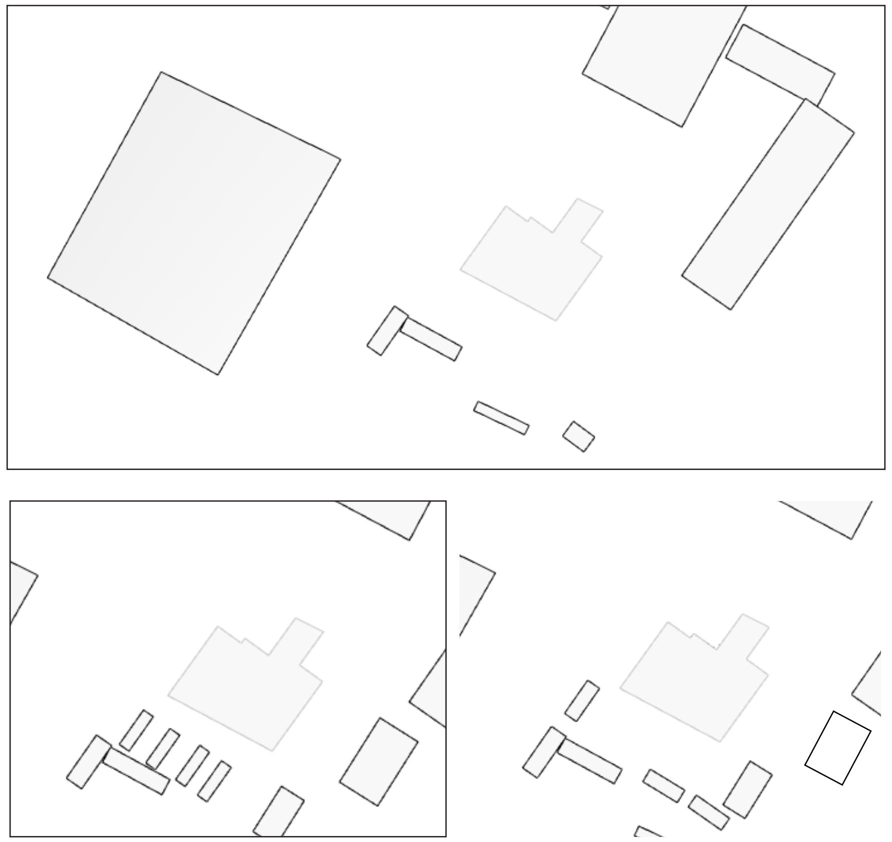
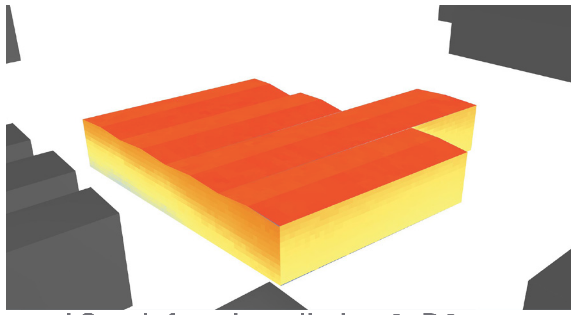


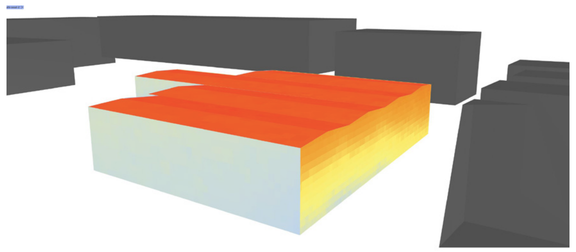
Figure 37: Overview of the facade analyses scenarios
The top figure represents the (1) as-is analysis, and the bottom left and right is analysis (2) and (3) respectively.

The results show possible use of solar gains as a passive heating strategy. The roof performs well for incident radiation, and the conditions are satisfactory for photovoltaic panels aligned east and west. Results are in Appendix B.

D3 - DENSIFICATION SCENARIO



East and South facade radiation 2- D3 scenario.



West and South facade radiation 2- D3 scenario.

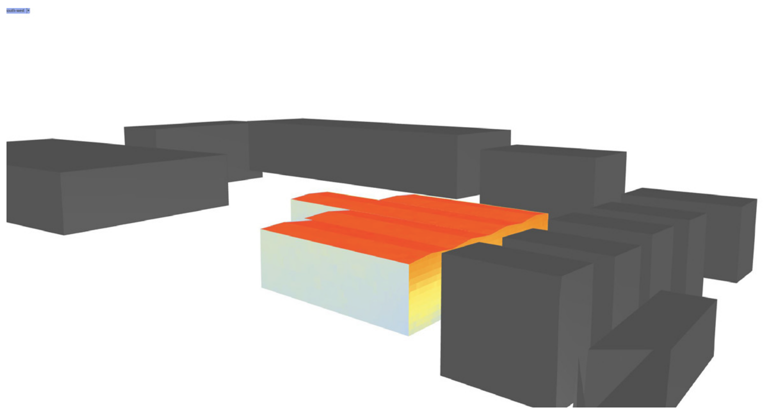
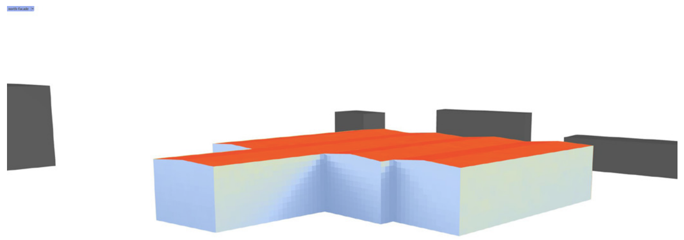
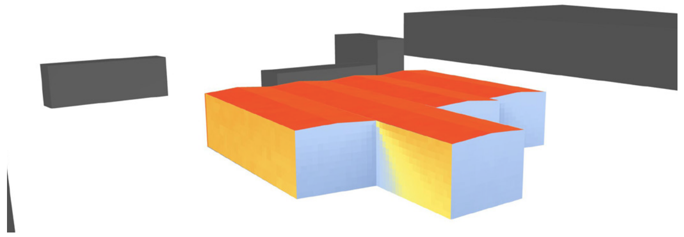


Figure 38. Radiation results scenario (2) - D3

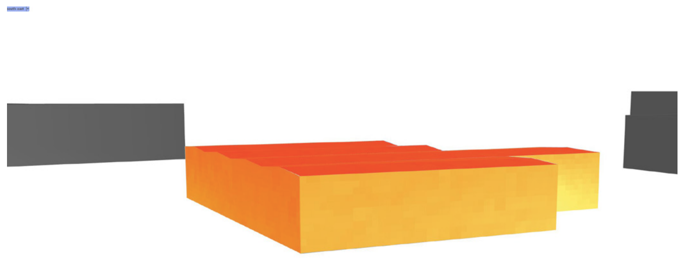
CURRENT SITUATION



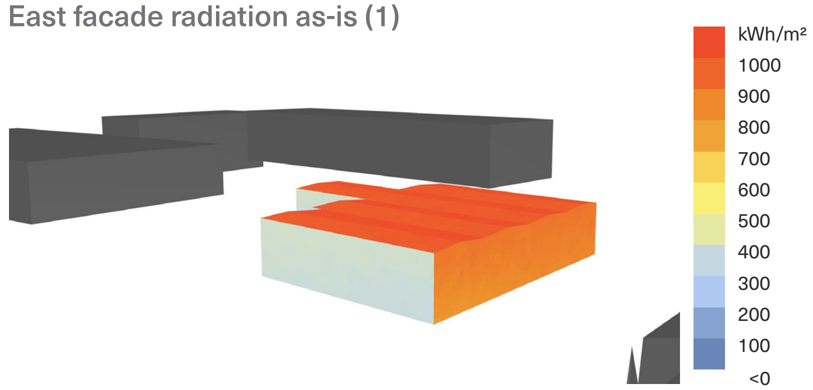
Northwest facade radiation as-is (1)



Northeast facade radiation radiation as-is (1)



East facade radiation as-is (1)




West facade radiation as-is (1)

Figure 39: Radiation results radiation as-is (1)

**VSC – VERTICAL SKY COMPONENT ANALYSIS**

In order to study the daylight access before the room layout and window sizes are designed, a vertical sky component (SC) analysis can help understand the daylight situation better. The vertical sky component (VSC) is defined as “the ratio of that part of illuminance, at a point on a given vertical plane, that is received directly from a CIE Standard Overcast Sky, to illuminate on a horizontal plane due to an unobstructed hemisphere of this sky.” [32]. The mathematical definition is: VSC = Vertical Diffuse Illuminance, L_dv / unobstructed horizontal diffuse illuminance, L_dh

The vertical sky component is maximum 40%. According to the report “Dagslys i bygninger” published by Rådgivende Ingeniørers Forening (RIF) the VSC results should be interpreted as following; if VSC is greater than 27% on the exterior façade, the interior space can be assumed to achieve satisfactory daylight levels. If the VSC is below 27%, it is most likely necessary to use larger windows or change the room layout to achieve desired daylight [33]. The analysis was performed in Grasshopper with a script provided by Multiconsult. CIE overcast sky was used.

The analysis was performed with the same three scenarios as for radiation; (1) as it is today with the existing surrounding buildings and (2) a future scenario with densification on site (the tallest version for building height) where buildings are oriented on the north-south axis, and (3) a future scenario with densification where the buildings are elongated on the east-west axis.

The results show good access to daylight. For scenario (1), 94 % of the facades had a higher VSC than 27%. Scenario (2) gave 83% and Scenario (3) had 93 %. The critical areas are outlined in black in the figures. The North, West and East façade remained unchanged for all scenarios, and the East and West façade both had 100 % of the façade area above 27 % of VSC. The north façade had three critical, but smaller areas. Detailed analysis gave point results down to a VSC of 19 % in the Northeast corner. For the South façade, scenario (1) and (3) gave optimal daylight access with the whole façade area achieving a VSC above 27%.  Scenario (2) resulted in only 59 % of the area achieving a VSC of 27%. This was due to obstruction from the densification on site. A detailed analysis of this area showed results down to a VSC of 21%, which is not too critical. However, it is worth noticing for developers when considering densification.

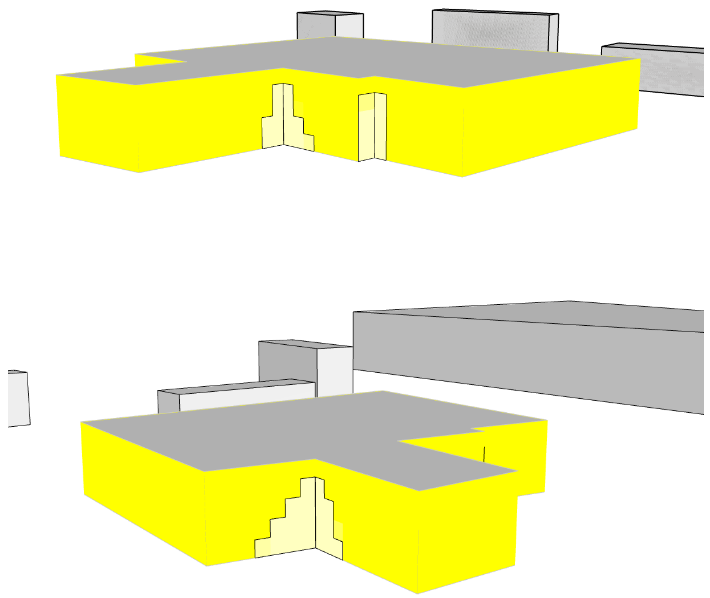


Figure 40: Analysis (1) results of north facade
Results showing critical areas on the north of the building.

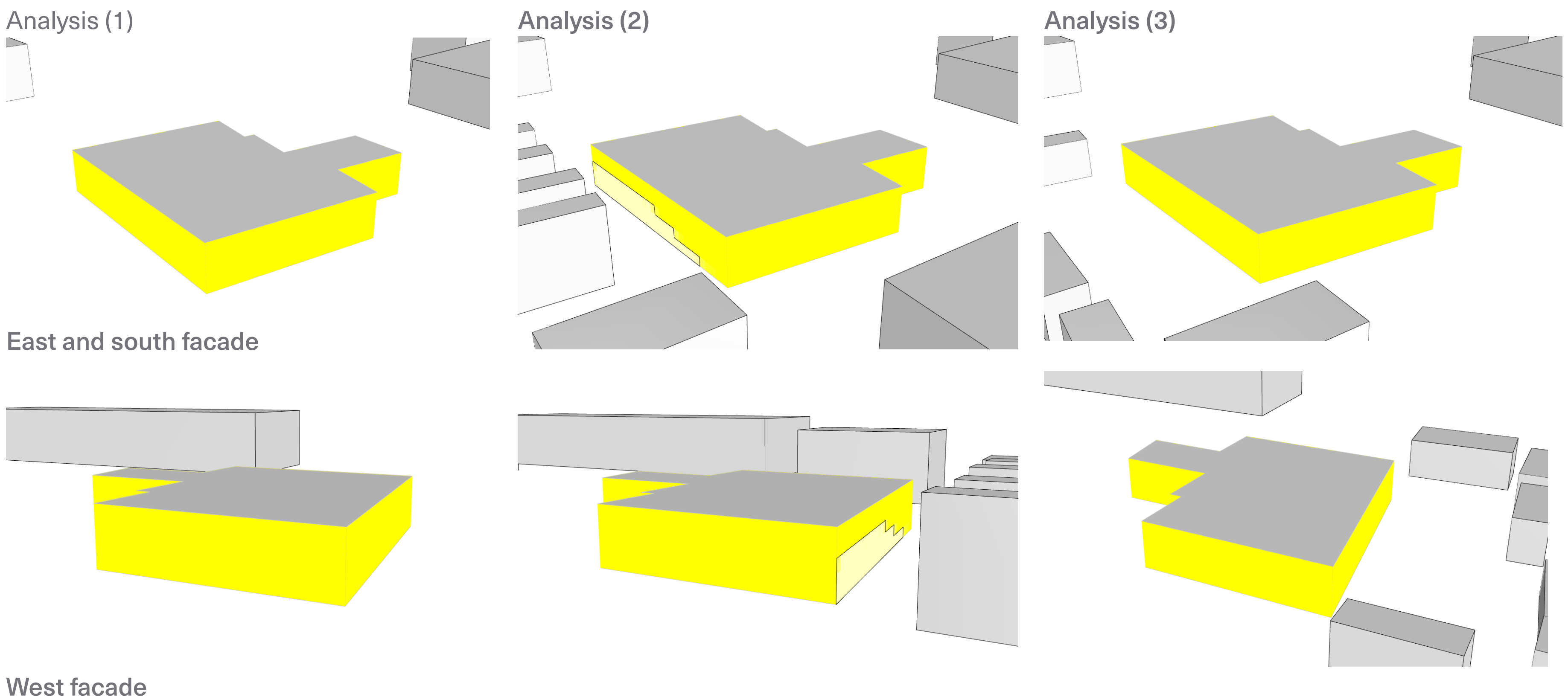



Figure 41: Analysis results for VSC

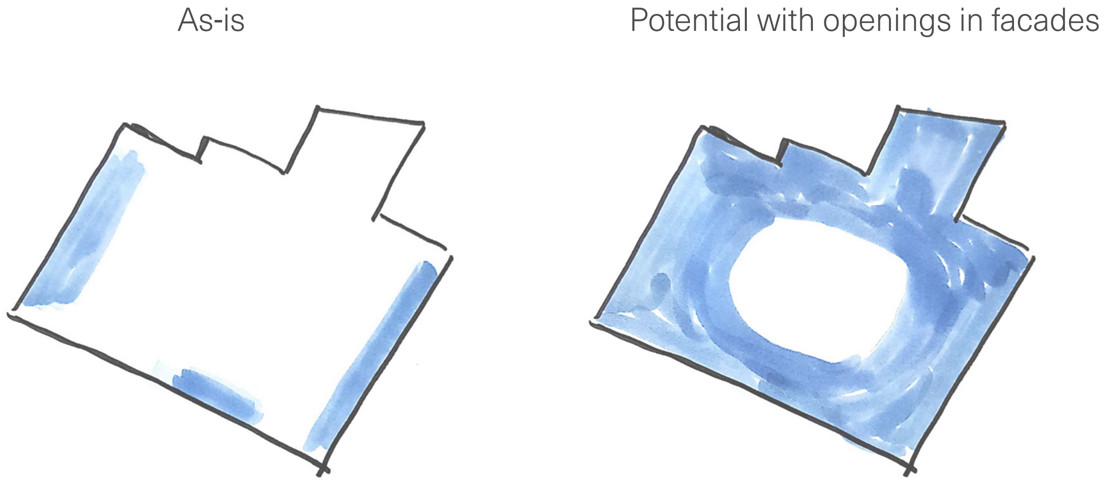



Figure 42: Shematic of daylight

Figure 43: Map of existing openings in the facade.

# PRELIMINARY DAYLIGHT ANALYSIS

The VSC analyses gave an indication of the existing conditions on the perimeter of the building. A preliminary daylight study was performed to assess the actual interior conditions. The daylight analysis was performed with Grasshopper, with a script provided by Multiconsult. CIE overcast sky is also used for calculating the Daylight factor.

The existing openings (windows and garage doors) were mapped in order to assess the possibilities for using these in the daylight strategy (Figure 43). The building is deep, and it is challenging to only rely on daylight from the facades. The results from the daylight analyses for the current situation show poor daylight conditions. Figure 44 shows how the building was understood in terms of possible daylight access.

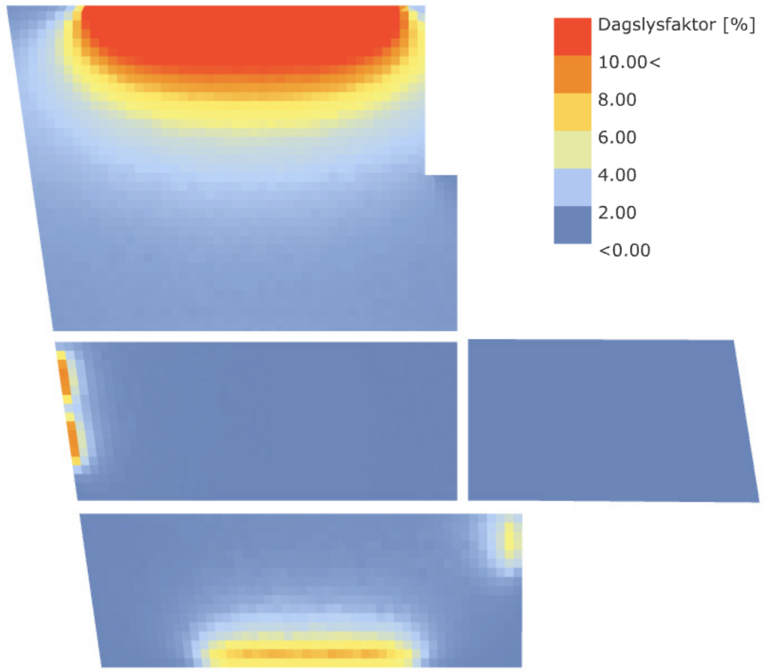



Figure 44: The current daylight factor situation.

# MICROCLIMATE

Based on the findings when investigating the climate and context for the location of the L&S, some analysis of the microclimate was done. This was to give a broader entry point to better understand the current situation for the surrounding area, and to investigate some of the consequences of a densification process. The following analyses were performed:

Shadow range analysis using the in the Ladybug Sunlight Hours Component in Grasshopper for Rhino. This was for summer solstice, winter solstice and equinox.

CFD (Computational fluid dynamics)-analysis was performed using the Butterfly plug-in in Grasshopper for Rhino. Th was done on a building scale with the most prevailing wind directions.

The findings from these analyses will be presented here.

# SHADOW RANGE ANALYSIS

The shadow range analysis uses the numbers from the Ladybug Sunlight Hours Component and shows the number of shading hours a surface is subjected to. Since radiation analysis and VSC analysis were performed on the facades, it was decided that the shadow range analysis should focus on the situation on the ground. It is important to note that to project meaningful and comprehensible test results the three different test dates will have different scales for Figure 45, 46 and 47. It is in correspondence with the actual available sunlight hours available on that given day. The legend shows the number of shading hours on the test surface. Analysis was done for 21. June (summer solstice), 21. March (equinox) and 21. December (winter solstice), and the simulation time step is 1 hour.

The current situation can be seen in Figure 45. As one can observe for 21. December, due to the low sun during winter, the building mass south of the L&S building cast a long shadow. For 21. March the shading around the building is from itself, except for the shading on the south that sets in around 15:00 until sunset at 18:20. At 21. June there are some shadings from the L&S building to the south and west during the low sun in the morning after sunrise, between 3 and 7 o'clock.

To better compare the test results Figures 46 shows the tallest configuration of scenario (2) and (3). Figure 47 shows the lowest configuration of scenario (2) and (3). The complete analysis can be found in Appendix C. For scenario (2), the four added stacked volumes to the west are causing shading for the south area throughout the whole day. Lowering the height has only a minor effect close to the Southern façade and allow for some more sunlight. However, the 2 larger volumes to the east are only casting shadow towards the Southern and Eastern area of the L&S building during two hours around noon. Changing the height of the two volumes allows for a larger effect on the shading situation on these two areas, specifically for 21. March and 21. June.

For scenario (3) during 21. June the southern area is having shading during the early morning hours. Also, during 21. March shading in the south is occurring during the morning, whilst rest of the day there is little shading from the surroundings buildings. Lastly it can be point out that around the densification to the east it is complete dark in the corner it shapes.

21.Des

21.Mar

21.June

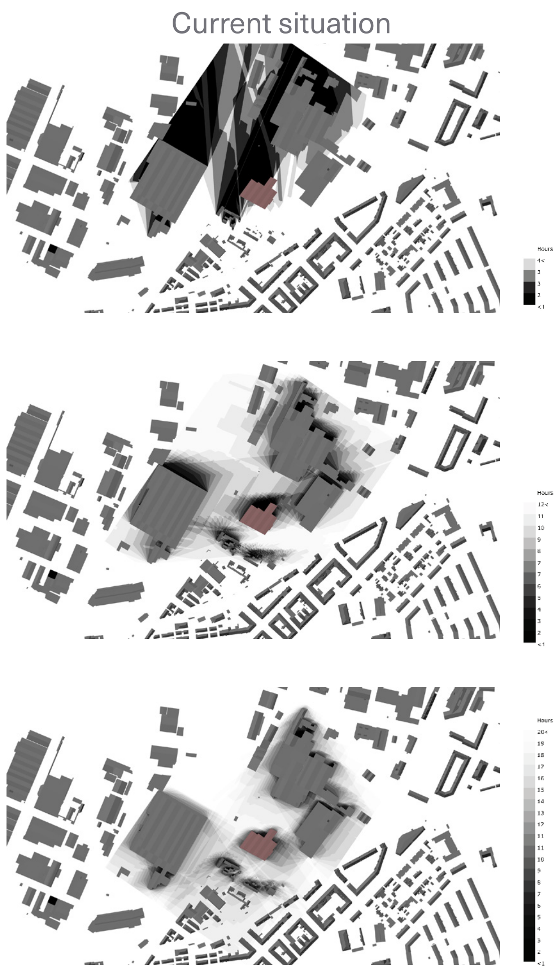


Figure 45: The current situation.

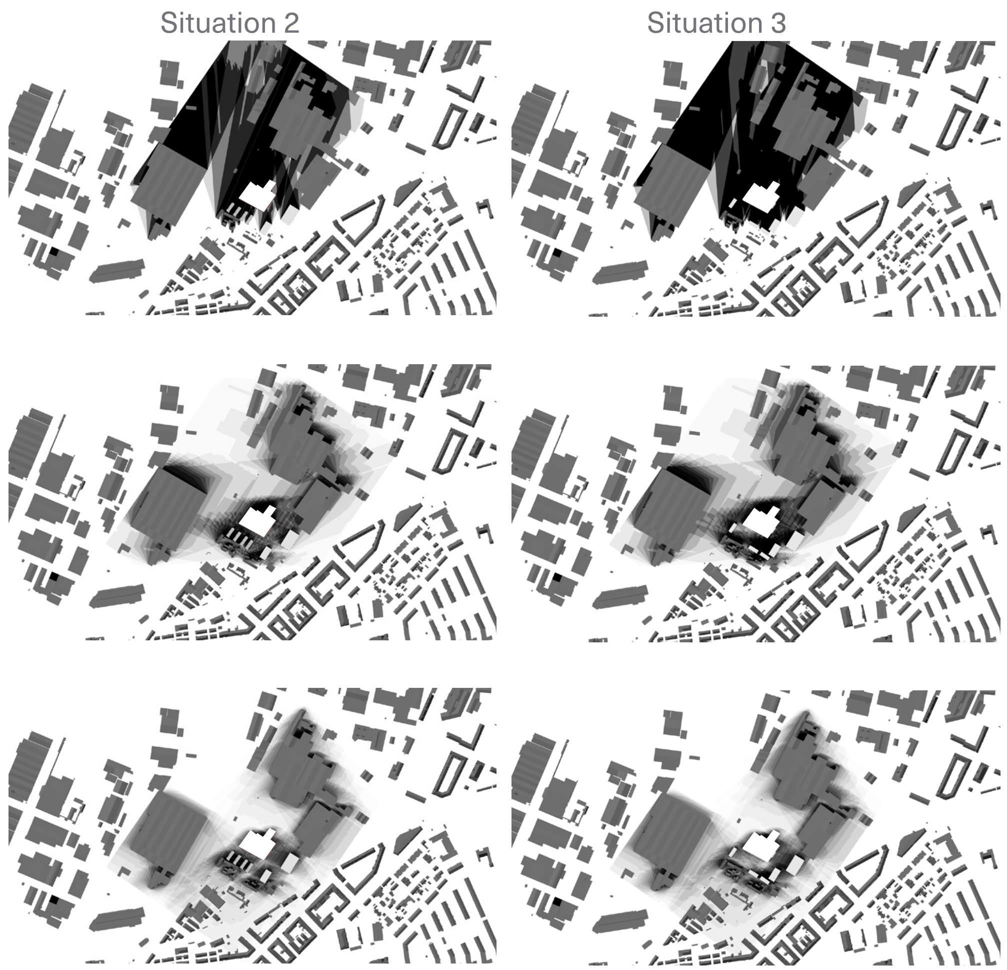


Figure 46: Tallest configuration.

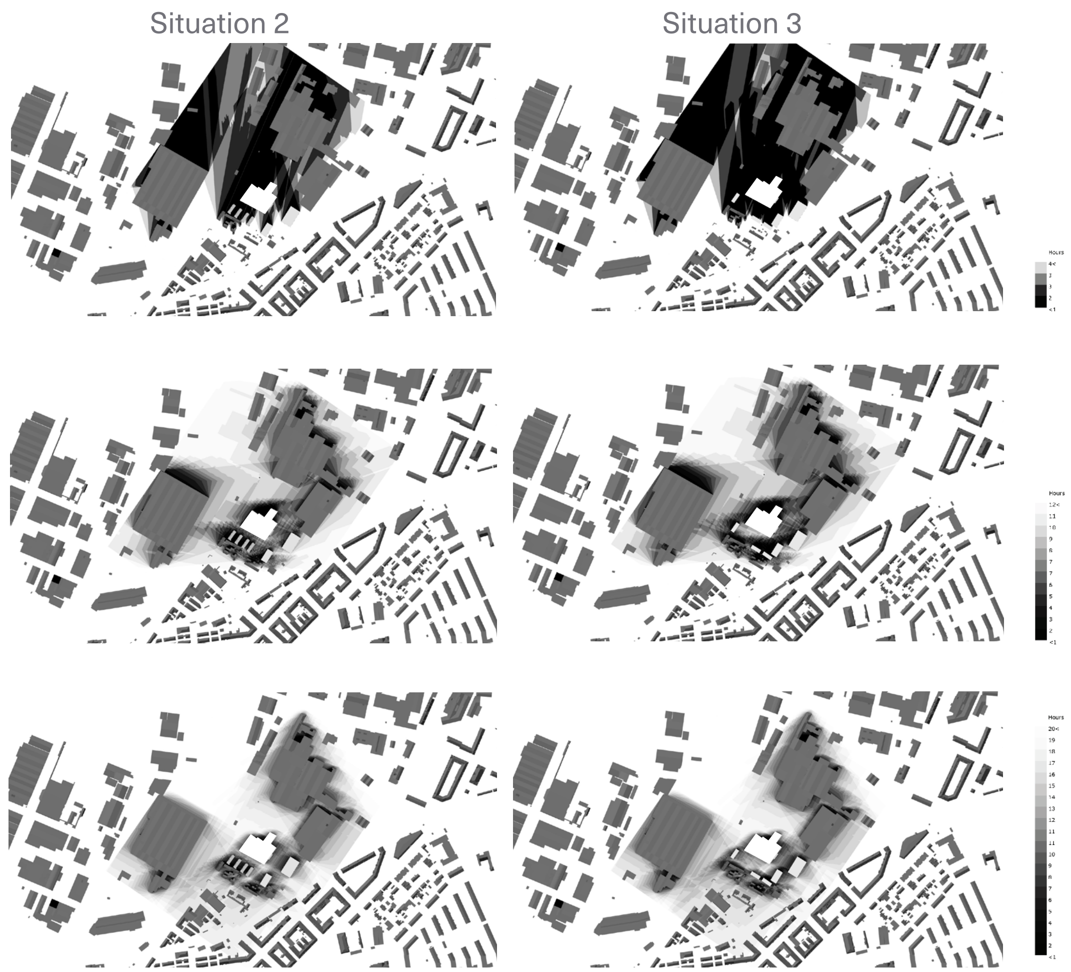


Figure 47: Lowest configuration.

# CFD

Due to relatively high demand for computational power and time, it was decided that the CFD-analysis should be done with a simplified model. These simpler iterations were done with the largest and closest building volumes, whilst the smaller surrounding volumes were discarded, which means that the analysis is restricted to a building scale size. As shown in the climate section, the prevailing wind directions for Trondheim are from 270 degrees West and 112,5 degrees Southeast. It is fundamental to note that since this analysis limits itself to these two wind directions, and a rather simple model, the results have a high degree of uncertainty. This means that it will not be given the same emphasis as other metrics. However, it is reasonable to respond to the feasible issues uncovered in the analysis.

In Figure 48 the result for the analysis is presented, in a zoomed-in version of a bigger test area. In the current situation the wind from 270 degrees West is funneled through the area between the South side of the building and Svartlamoen. When the wind hits the surrounding buildings on the windward side it is deflected clockwise. [34]

As pointed out in Heating, cooling, lighting [34, p. 343] a cluster or row of buildings most desirable to an shelter against the cold winter wind. And this appears to a be beneficial effect for scenario (3), when the wind is blow from East.

For both cases it is important to be aware of the channeling effect in narrow openings between the building volumes. Then there is an acceleration of the wind due to the Venturi effect.[34] As one can observe when the wind is blowing from the West, is the difference in the effect of building closest to Strandveien. In scenario (2) the building is pulled further back from Strandveien, and this leads to a stronger deflection and acceleration along the south façade of the L&S building.

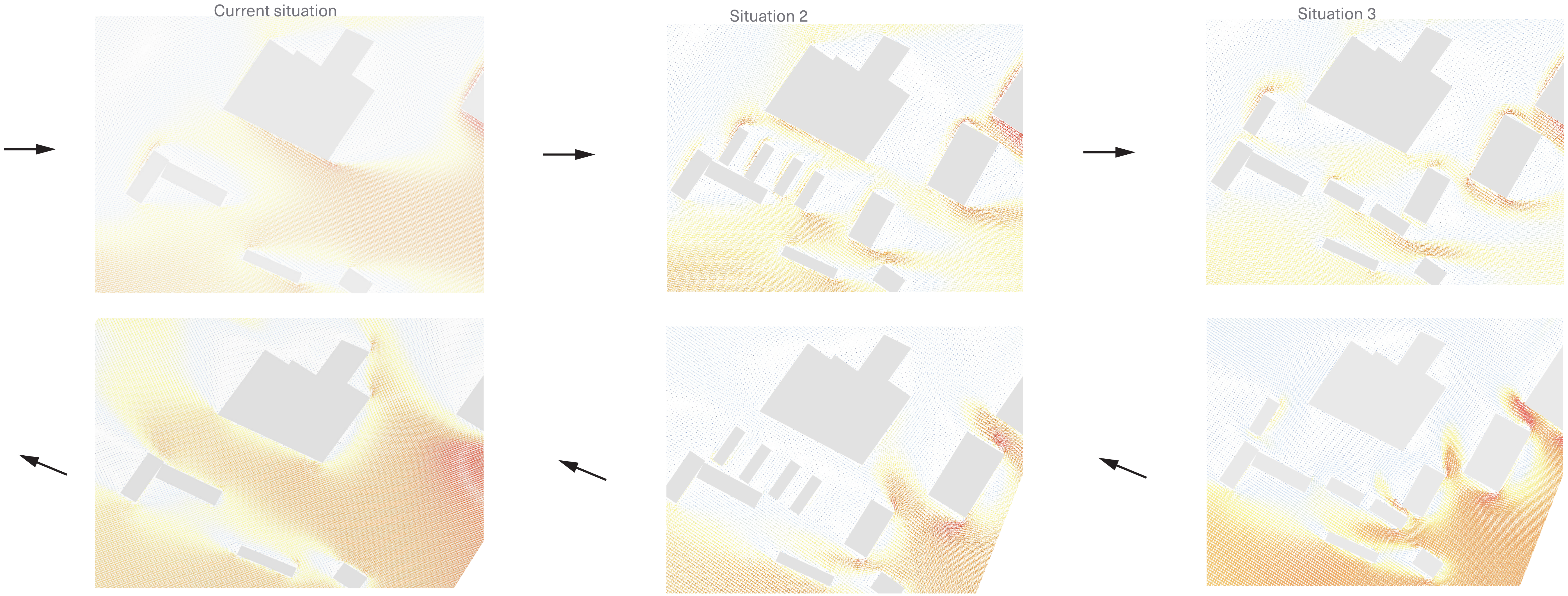
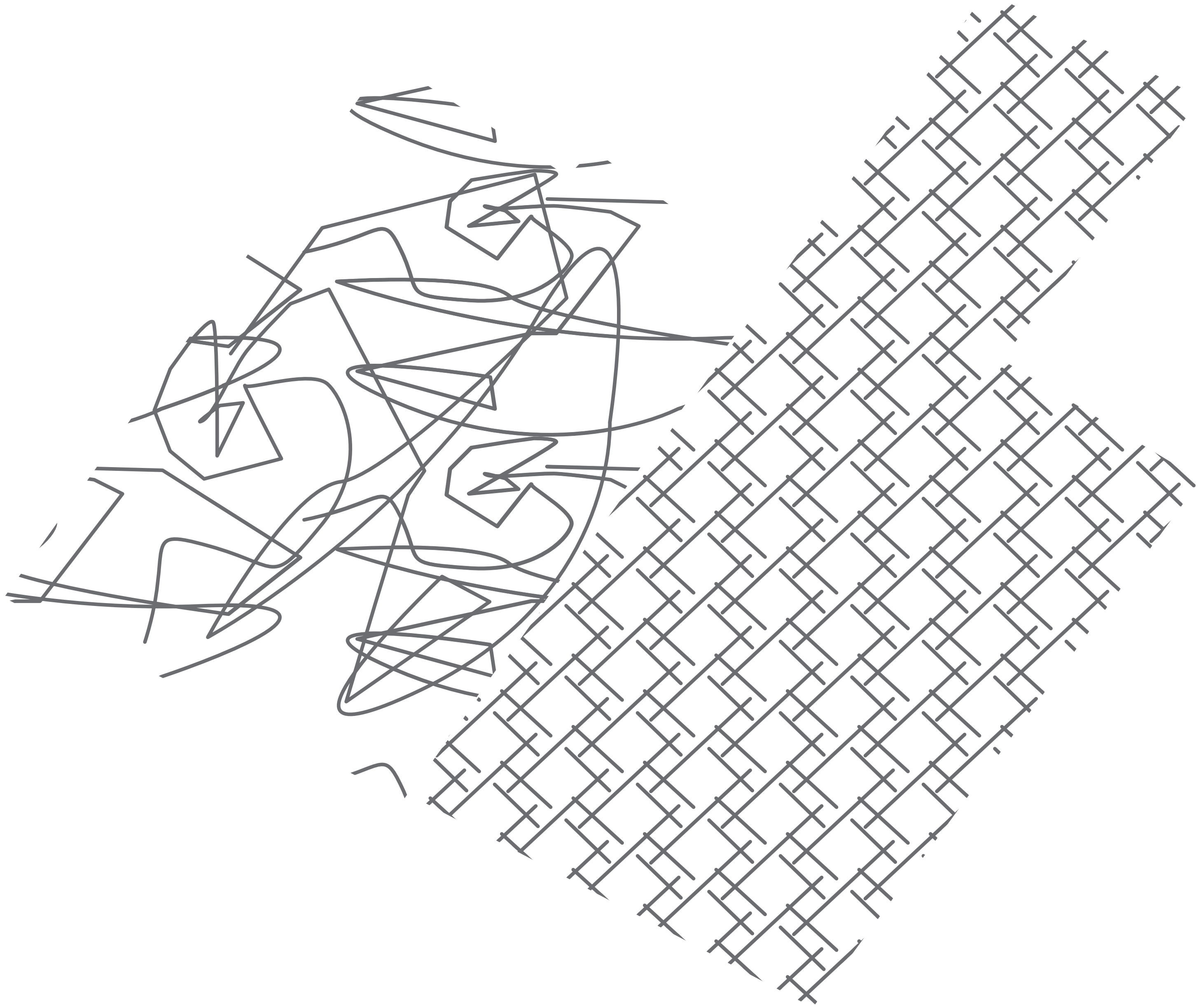



Figure 48: CFD analyses

# 5. TRANSFORMATION



# TRANSFORMATION

This chapter will describe and present the design for the project. It starts by providing the main design ideas and program. Then floorplans, sections and elevations are presented. A framework for the dynamic part of the building is presented, followed by the passive strategies and energy framework.

## DESIGN INTENTION

### DIVIDING THE STRUCTURE

In order to allow for future changes and flexibility, the structure is divided in two parts based on its structure: static and dynamic. This allows for a mixed-use building.

The static part has a structure mainly of concrete, with come inclusion of steel. It is transformed into an office space. The space will be fully climatized and have an upgraded envelope, much like a new down coat. The dynamic part consists of two large open halls in a steel structure. The spaciousness of the halls allows for flexibility in its existing form. Therefore, they will be kept mainly as is. As Vassal and Lacaton  said, “sometimes the answer is to do nothing” (Wainwright, 2021, section 2). This space is more like a light rain jacket, provides shelter and is not fully climatized

The structural qualities frame a design for disorder. The down coat and the light rain jacket cover different needs. Between them there is a permeable border. An interior glass wall between the two parts allows for visual connection, while providing an acoustical and thermal barrier.

### OPENING UP THE STRUCTURE

A main principle was to open up the structure and introduce daylight. This has been done with both exterior and interior changes. Larger openings in the façade allow for quality daylight. Where the floorplans are deep, skylights provide light access. The main staircase cuts the concrete slab of the darkest area in the building. The dense concrete is lightened, and skylights spread daylight into the darkness.

### ENTRANCE

The main entrance is on the South of the building. The intention is to create an entrance connected to a green outdoor space. It is facing Svartlamoen, and seeks to be welcoming.

### SIGHTLINES

Interior and exterior sightlines are considered. Visual connection between the interior spaces is emphasized with openings and interior glazing. The north part of the building has a view towards Trondheimsfjorden.

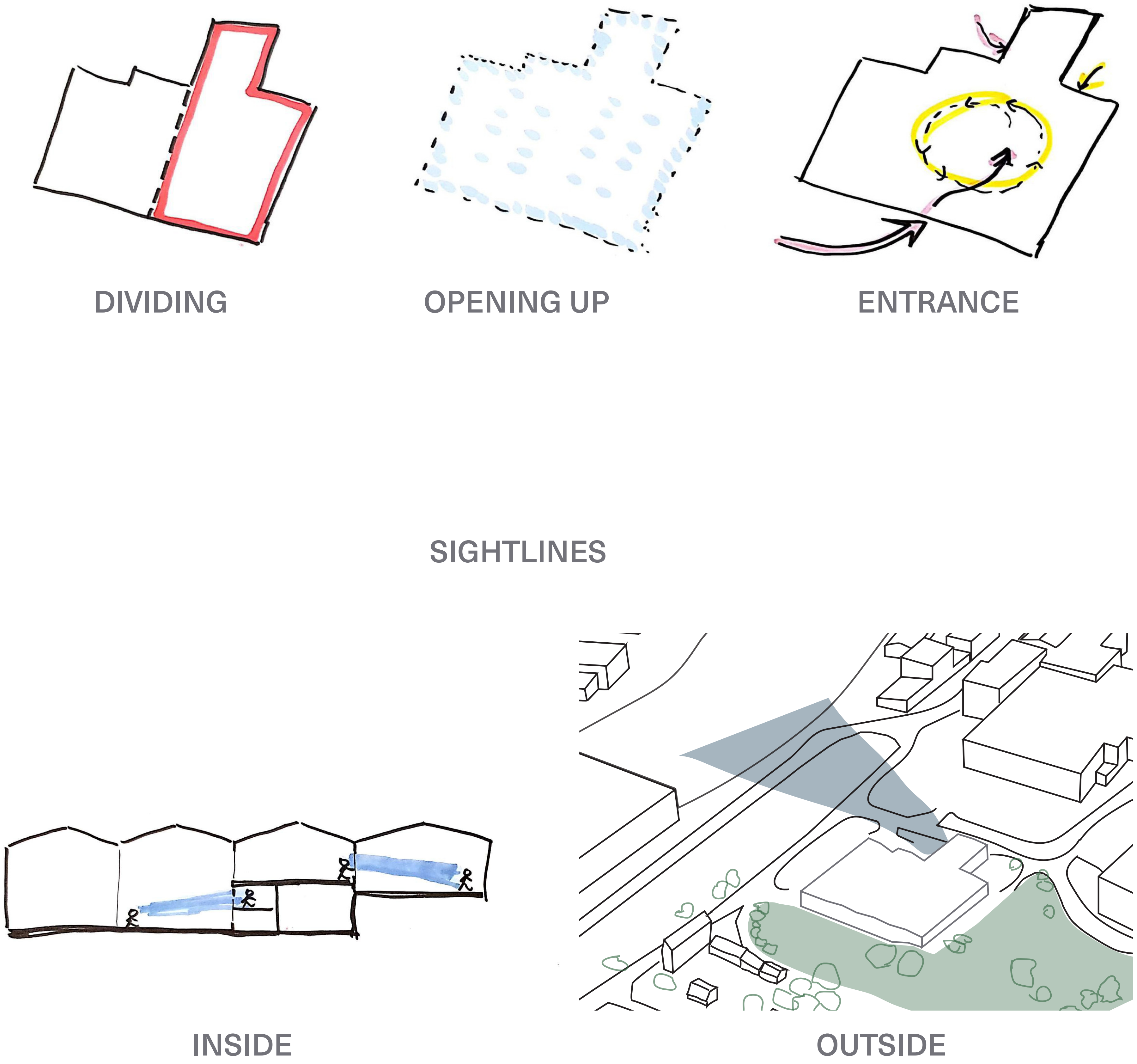



Figure 49: Concept sketches

# PROGRAM

It is a mixed-used building, with one part for office functions and one for flexible use. In the flexible part the program is determined by the needs of the users and neighbourhood. For example, the dynamic part can host concerts, exhibitions, workshops, and youth activities.

The office and dynamic area share support functions, such as restrooms, café and canteen.  They are located in the office part.

| | BRA ($m^2$) | People |
|---|---|---|
| Office | 3020 | 200 |
| Flexible area | 1160 | |

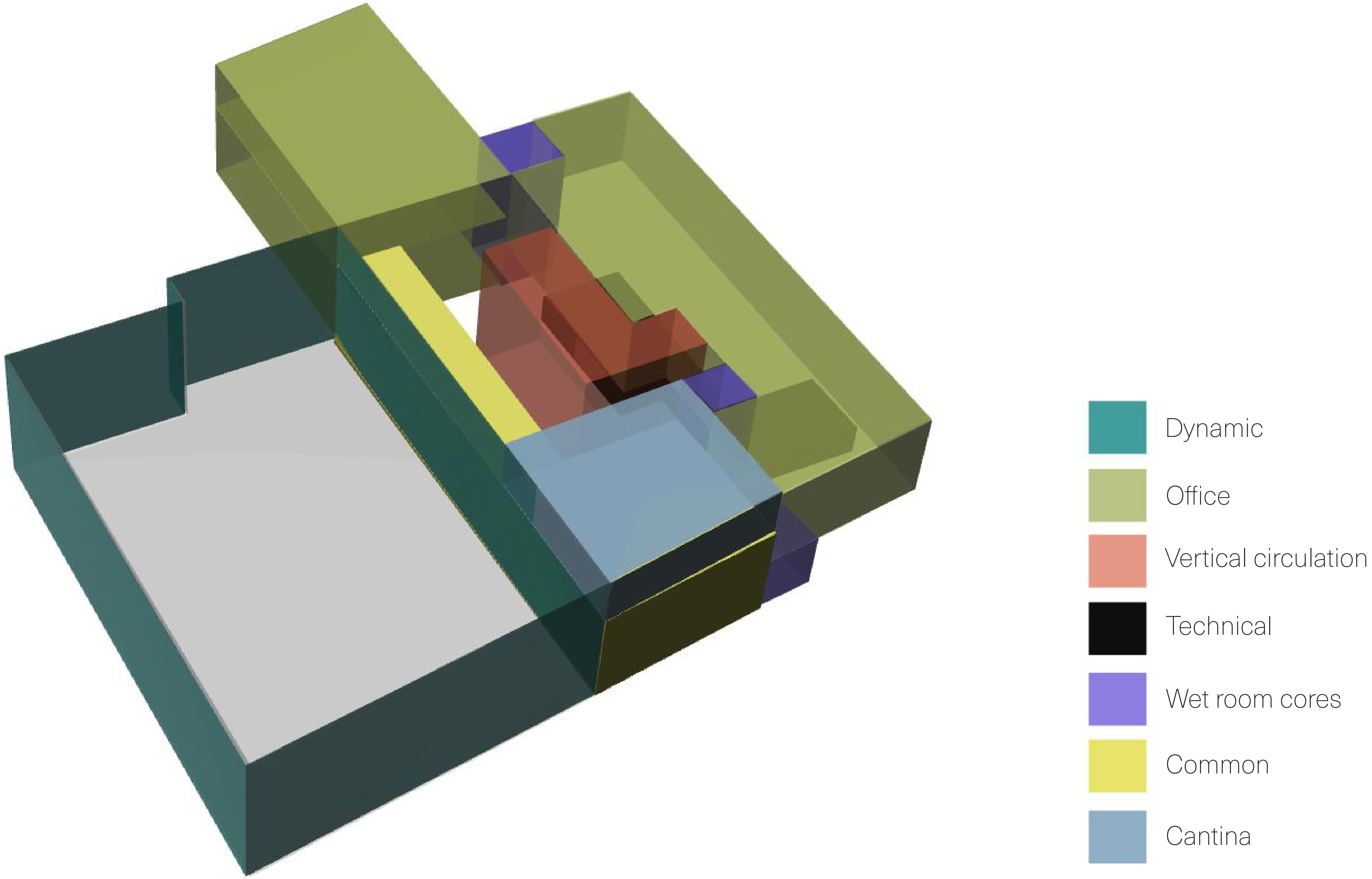



Figure 50: Program zoning

# FLOORPLAN

### ENTRANCES

The main entrance is located on the South façade. The intent is to enhance contact with Svartlamoen, and the entrance serves as a social area with a café and outdoor seating. This location is also based on the wish of having a green space south of the building. A supporting entrance is placed in the Northeast corner of the building, with entry level at 3rd floor. Another entrance is placed on the Northwest façade at 1st floor, with direct access into the connecting office area. The halls have existing garage doors available as entrance points.

### CIRCULATION

The main staircase is centred in the static part, and visible from the entrance. It is in the heart of the concrete structure. It allows a dark area to become functional. The elevator is placed with the stairs, and can serve all office floors.

Since the large halls are left more as is, it was desired to avoid interruption of this part in case of larger renovations in the future. Stairs in this section would interrupt future transformations. Thus, it is seen as more effective to include all main circulation in the fully upgraded part of the building.

### PLACEMENT OF CORES

The cores, wet rooms and elevator, are located in the centre of the concrete structure, together with the staircase. This allows for more flexibility of the steel structure. The perimeter space is free of interruption, and the areas with good daylight access are not compromised.

### DAYLIGHT INTRODUCTION

The daylight studies and sizing and placement of windows was an iterative process. The existing openings functioned as a starting point. It was desired to avoid unnecessary thermal losses, thus the glazing area should not be excessive. Due to deep floorplans skylight are used in several parts of the building.

### DAYLIGHT 1st FLOOR OFFICE

The average daylight factor for the office is 2,2 %, meeting the target of 2%. The West and North façade has large and tall openings to let the light flow deeper into the floorplan. The daylight access has to be provided by the West and North façade, as the West wall is under ground. Therefore, the work desks are placed accordingly.

The meeting rooms receive an average daylight factor or 2 %. The large conference receives 1,6 %. Since it is not a room of prolonged stay, a lower daylight factor is acceptable. Glazed area on either side of the rooms (towards the hallway and flexible area) provide daylight.

Figure 52: Progress model of the stairs

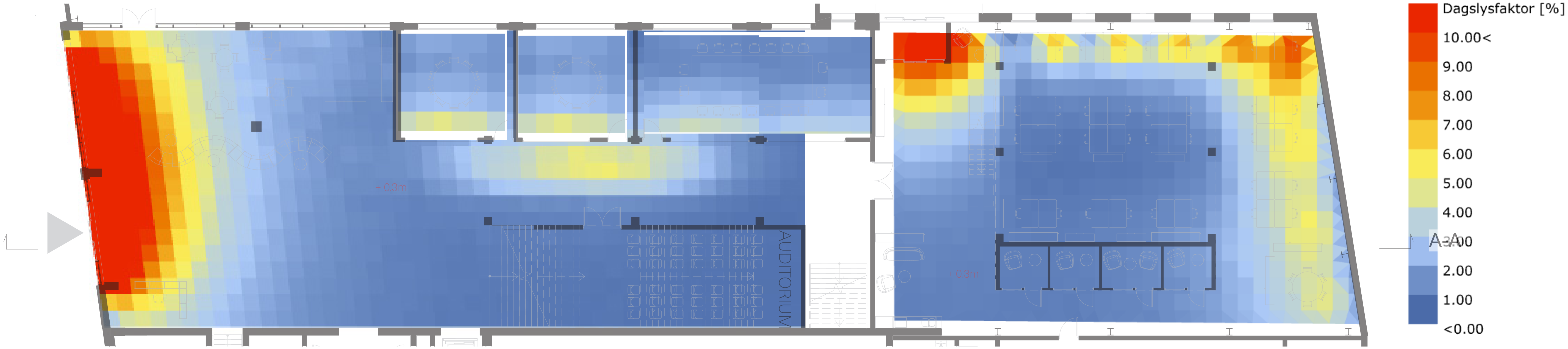
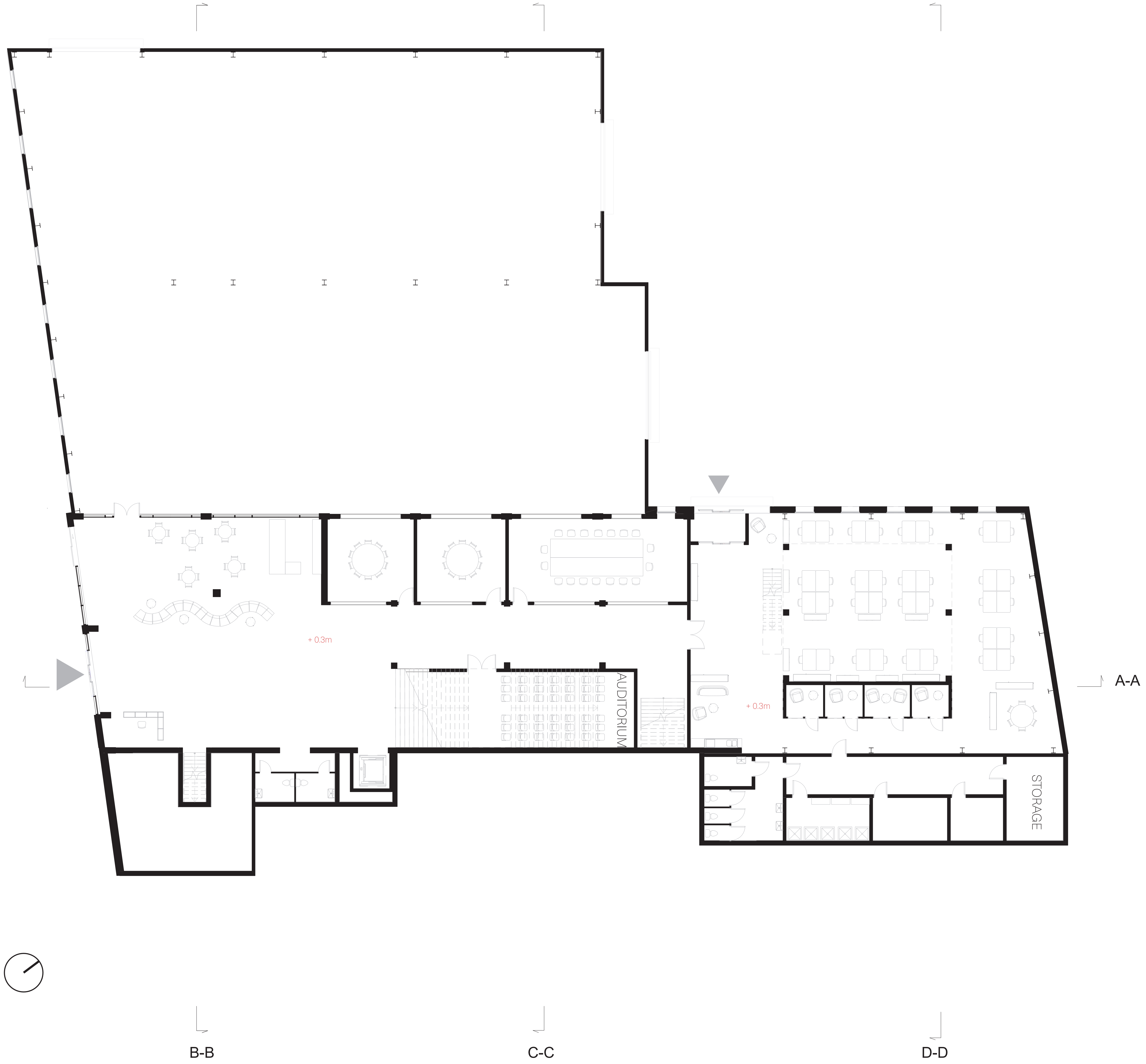
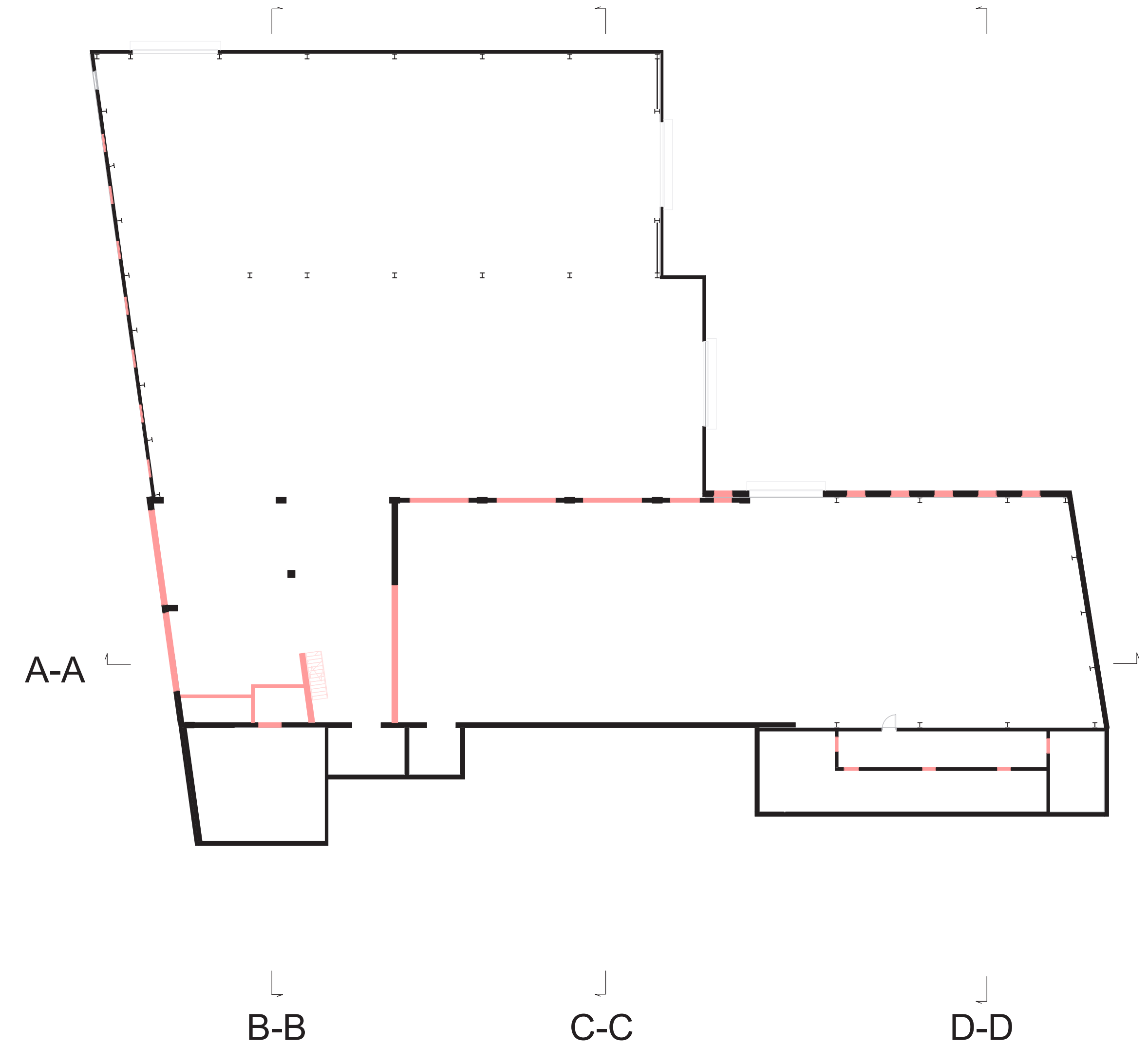



Figure 51: Plan 1st floor daylight factor 1:200




1ST FLOOR DEMOLITON PLAN 1:500

PLAN 1ST FLOOR
1:200

## NEW FLOOR ADDITION

The 2nd floor is a new addition to the building. It is built as a large-scale "table" in the north office section, hovering above the 1st floor. Wooden boxes (meeting rooms) create a 2nd level along the wall between the dynamic and static part, which are accessible by a ramp from the main staircase.

## DAYLIGHT 2nd FLOOR OFFICE

The average daylight factor for the office 2nd floor is 2,1 %. The 2nd floor is moved slightly out from the perimeter of the exterior wall to allow daylight down to first floor. The 2nd floor is open, without walls, to maximize daylight access. The height of the level was adjusted to ensure sufficient daylight beneath. The windows on 1st level go all the way up to the ceiling of 2nd floor.

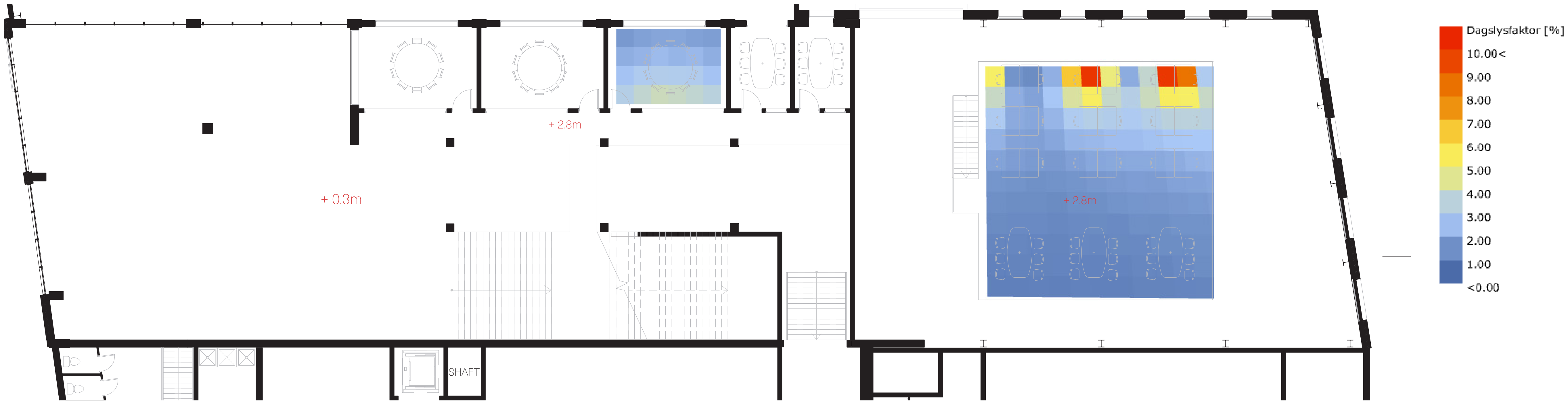
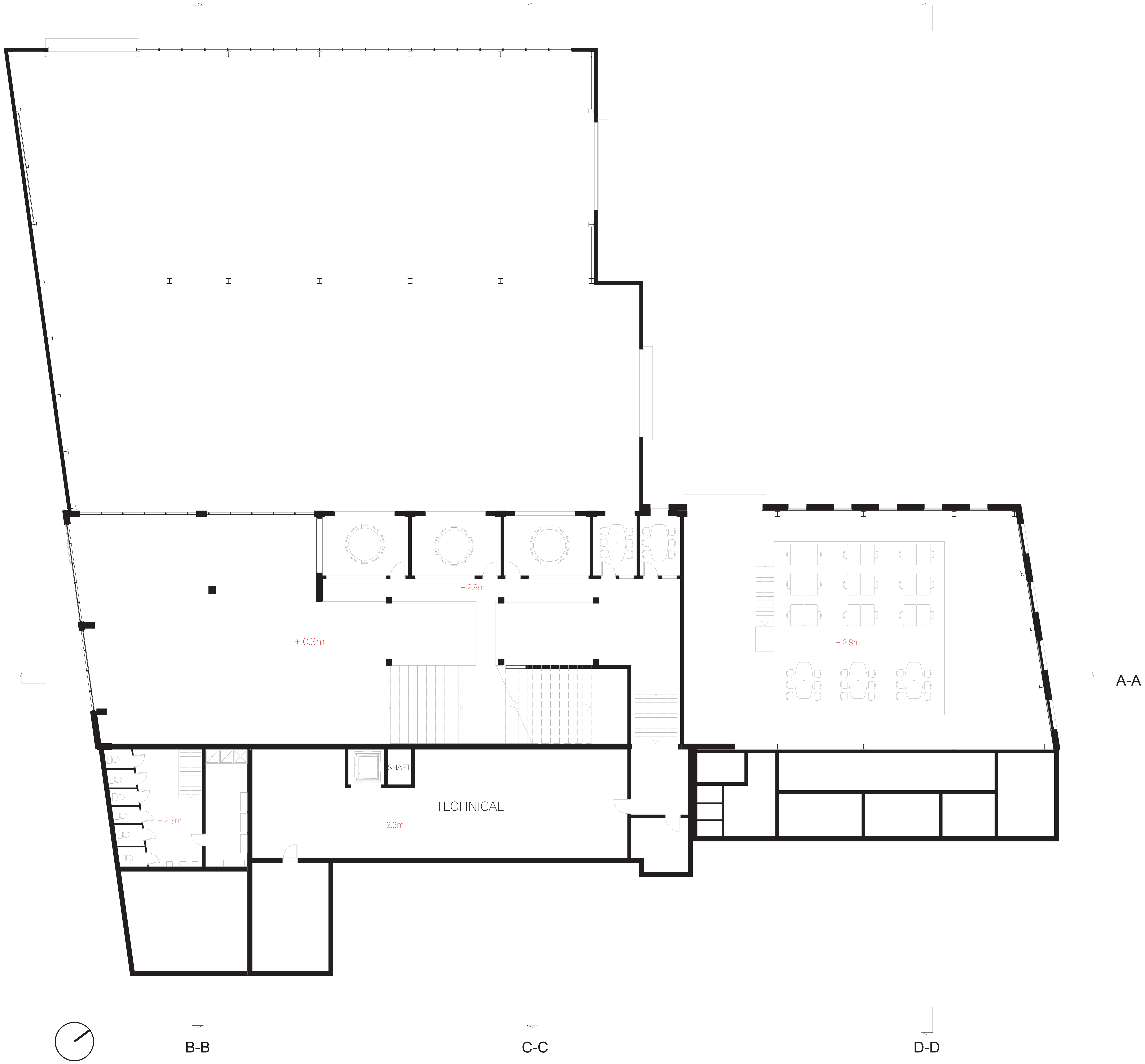
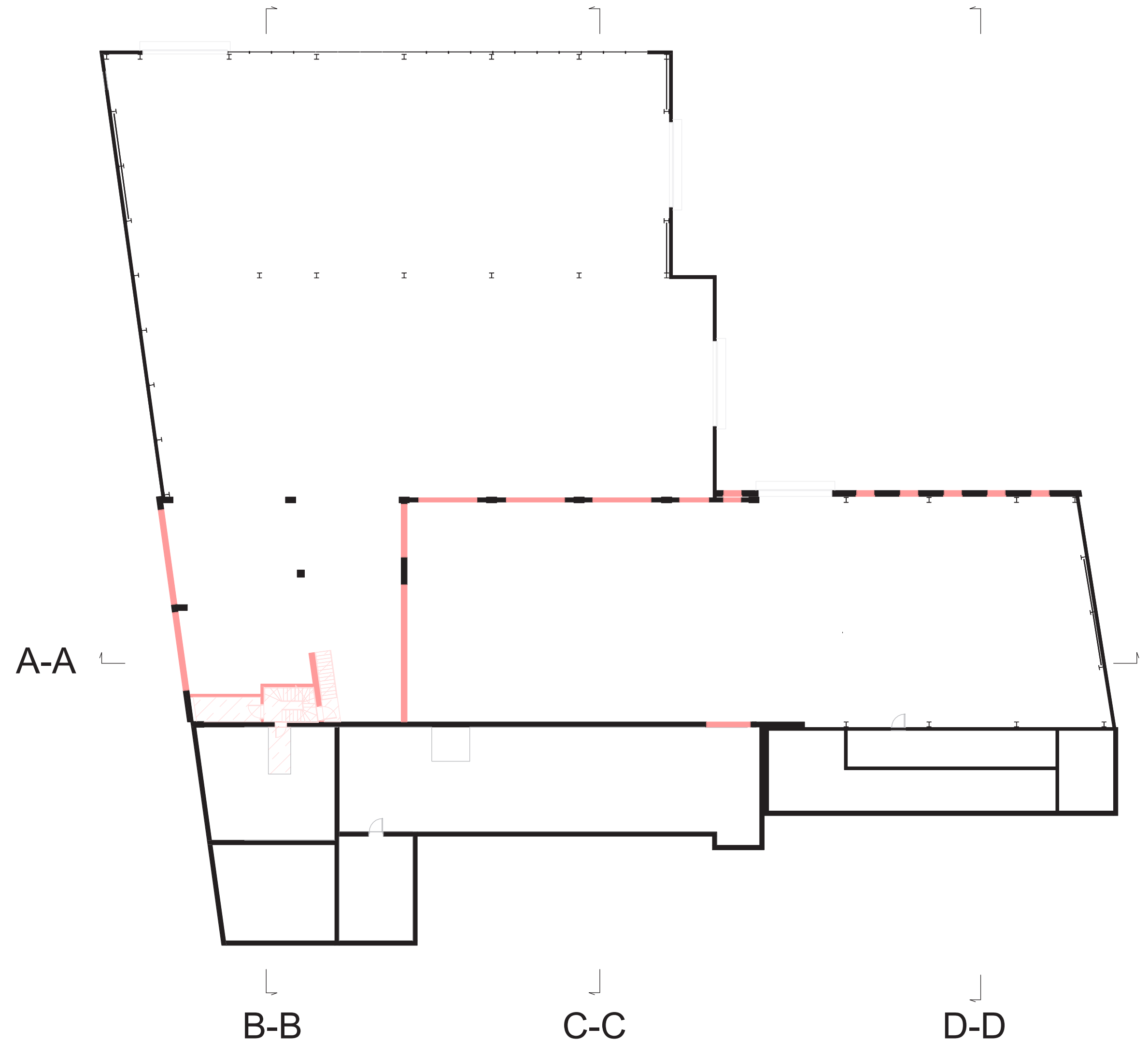



Figure 55: Plan 2nd floor daylight factor 1:200




PLAN 2ND FLOOR
1:200




2ND FLOOR DEMOLITON PLAN 1:500

**FLOOR PLAN**

The office has large open plans to allow for flexibility. This is possible due to the structure of the system with large spans and significant ceiling height. The workstations are placed along the perimeter to provide daylight and views.

**RAISING THE FLOOR**

To ease circulation on 3rd level, the floor has been raised certain places to improve accessibility. However, a few of the elevation differences are kept to create an interior landscape. Accessibility is then solved with ramps and elevators.

**DAYLIGHT 3rd FLOOR OFFICE**

The window sizes and placements were designed to meet a 2% average daylight factor, while also providing views. The average daylight factor for the North office part is 2%. Skylights are placed above the staircase to enhance daylight conditions both on 3rd and 1st floor.

The east office section has an average daylight factor of 2,7 %. The garage doors can be opened and closed and are glazed on the interior. The largest garage door has existing windows at the top. The smaller garage door (towards the south) is perforated to function as a shading device.

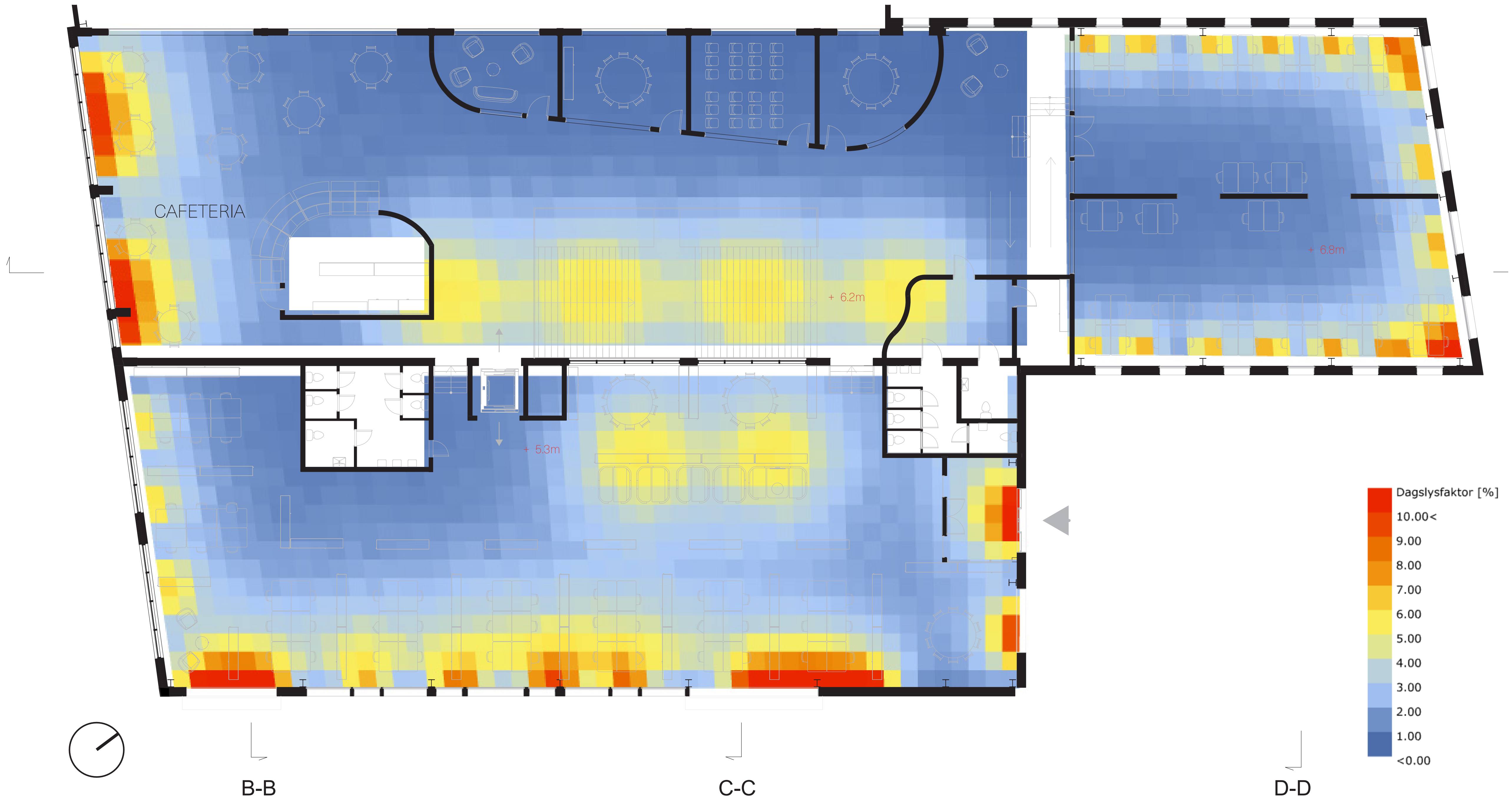
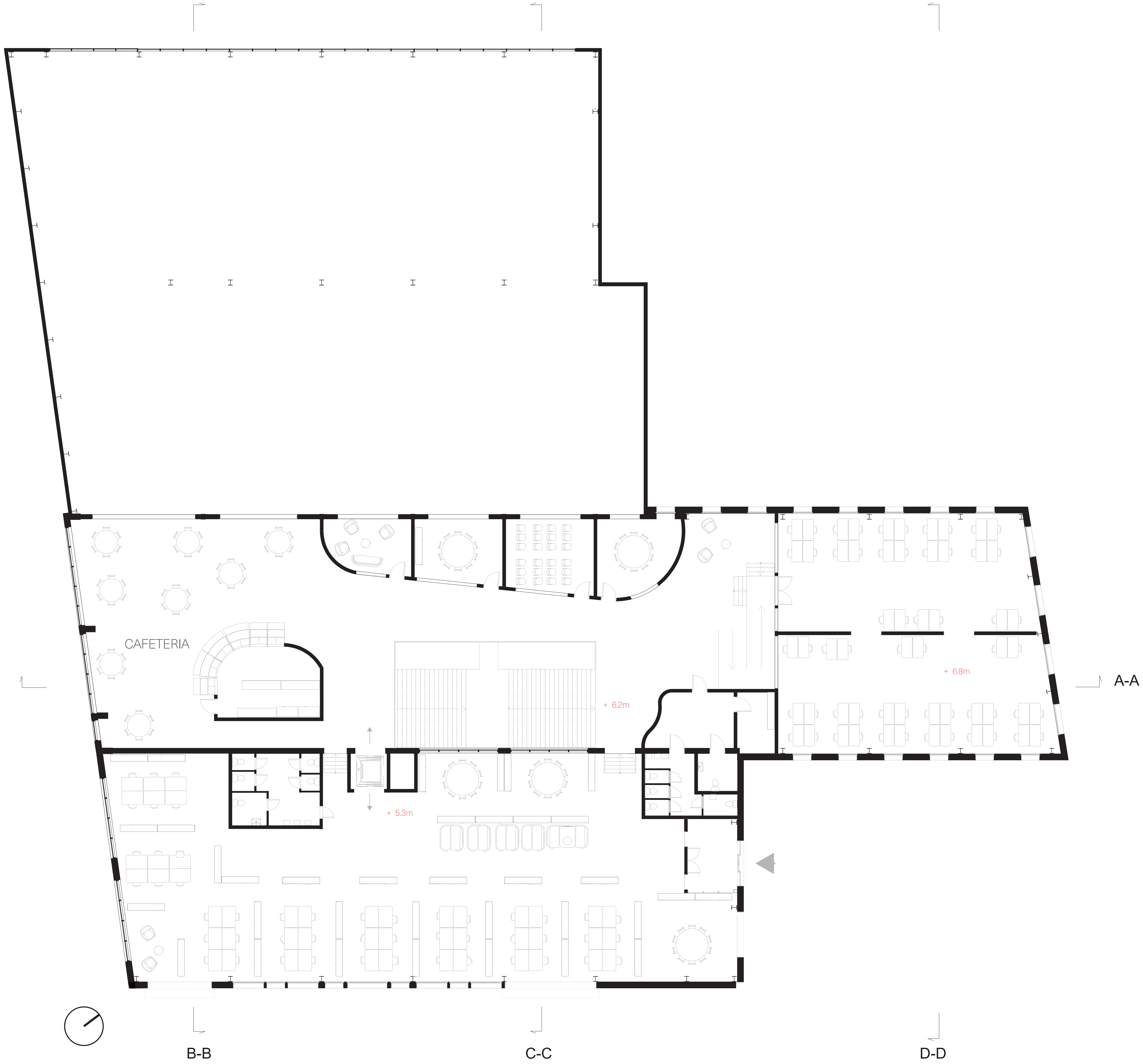
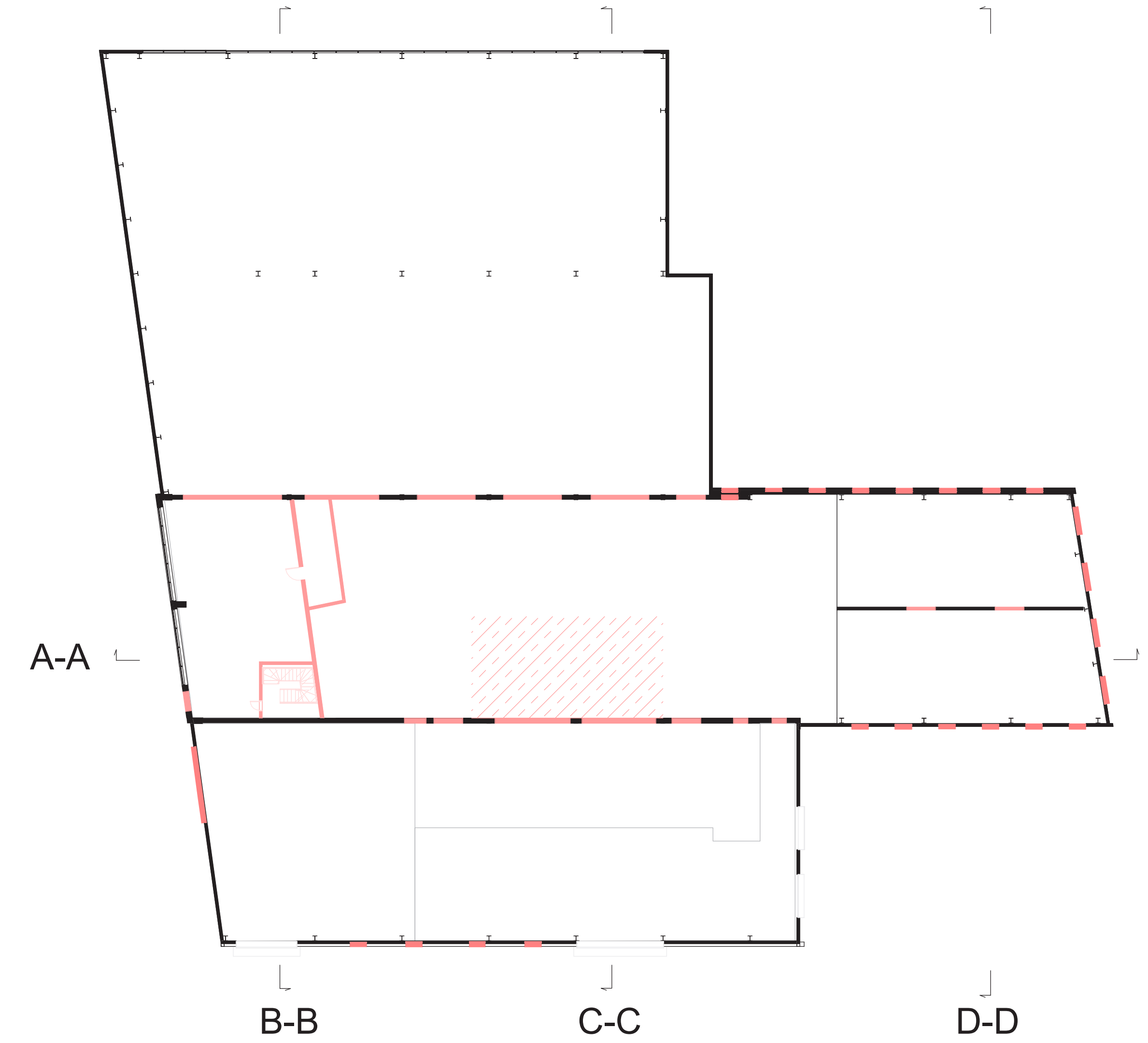


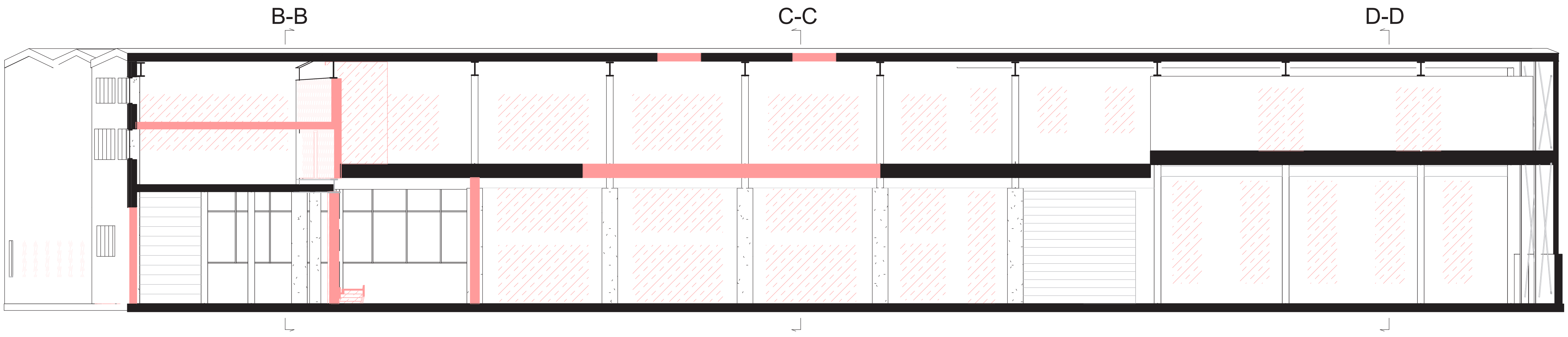

Figure 58: Plan 3rd floor daylight factor 1:200



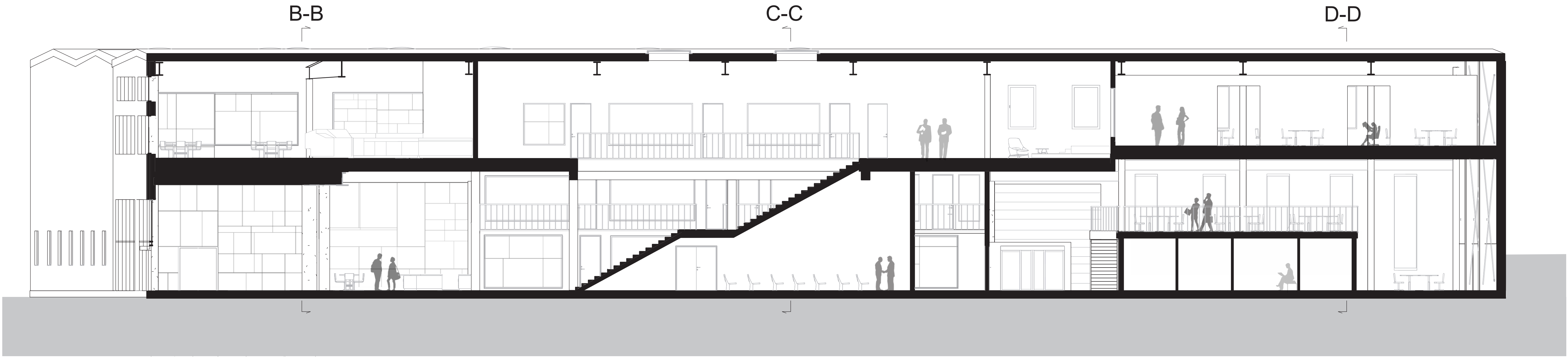

PLAN 3RD FLOOR
1:200



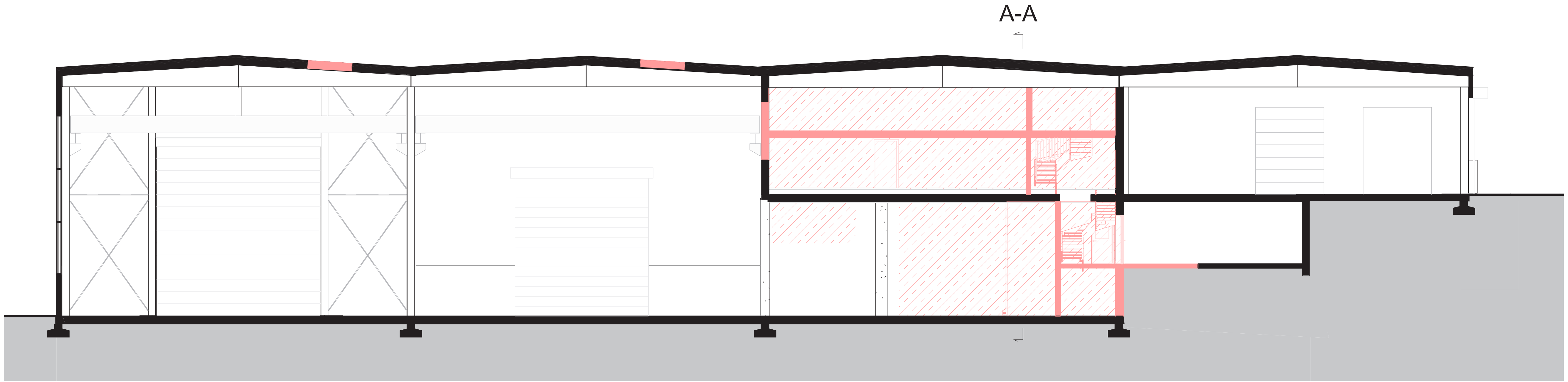

3RD FLOOR DEMOLITON PLAN 1:500



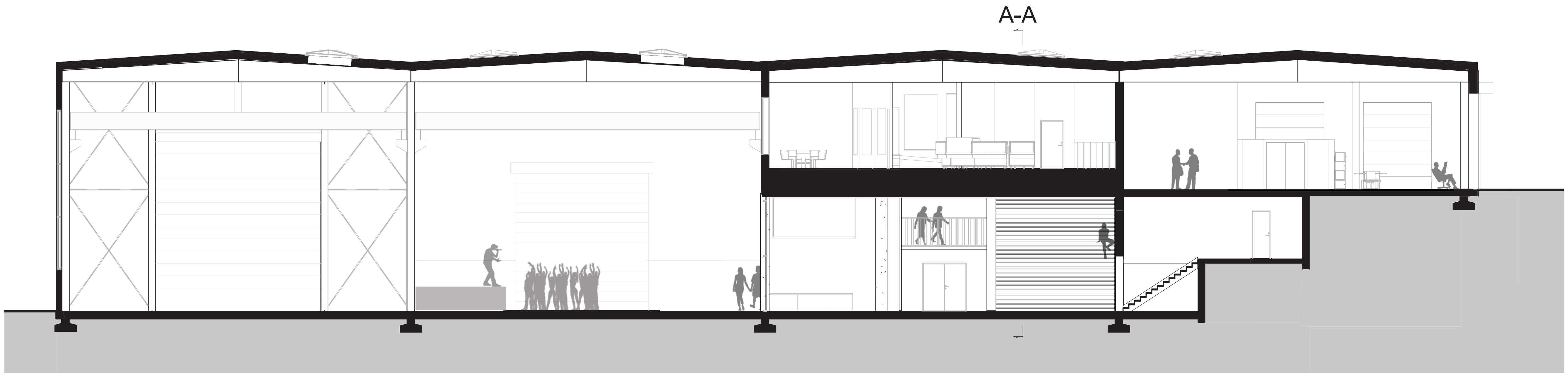

SECTION A-A DEMOLITON
1:200



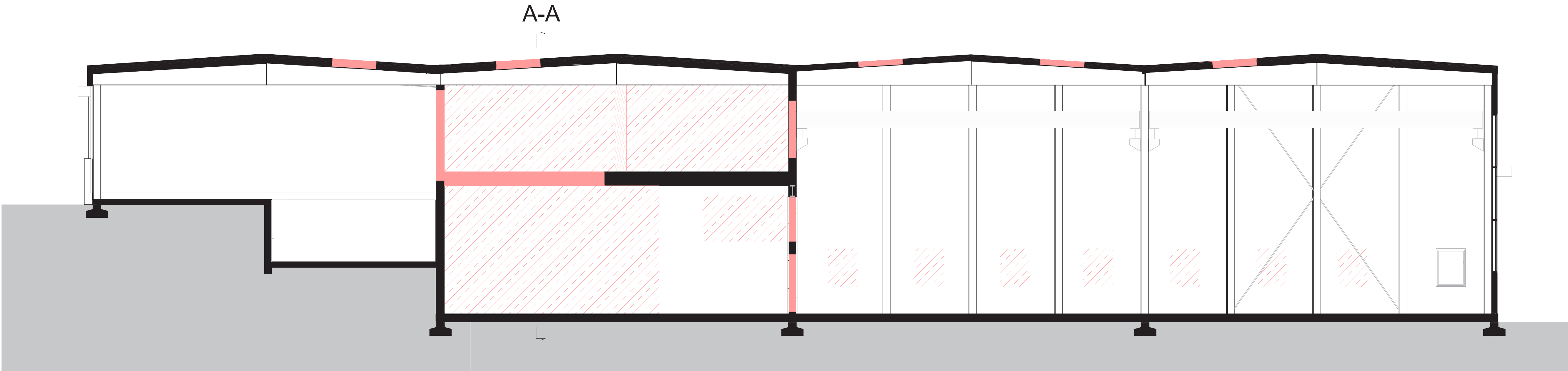

SECTION A-A NEW
1:200



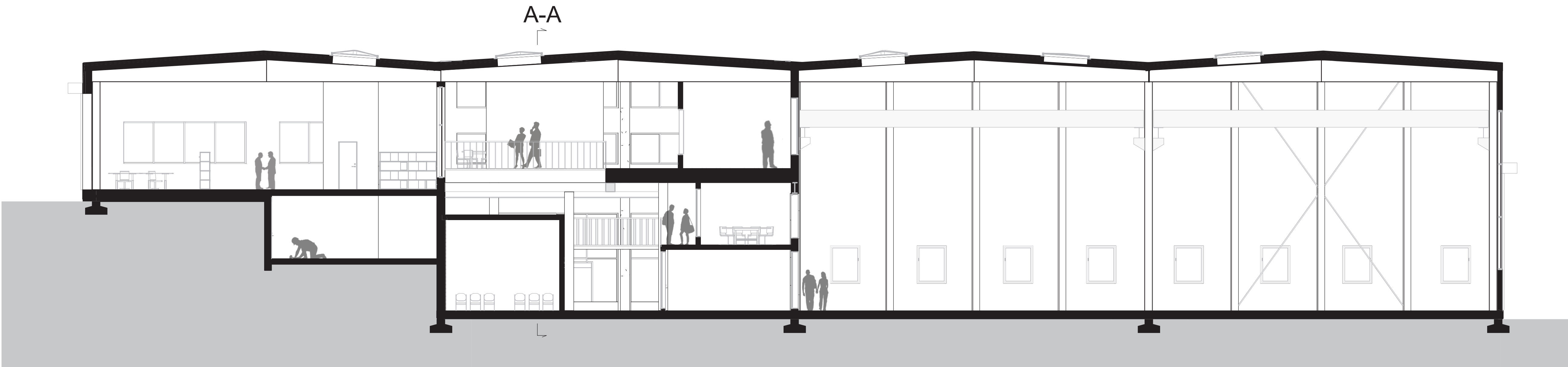

SECTION B-B DEMOLITON
1:200



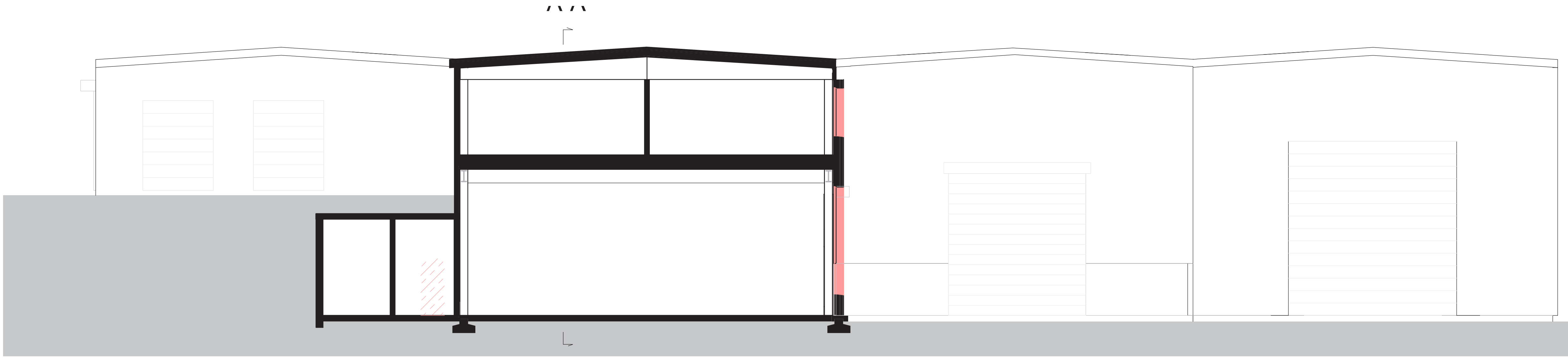

SECTION B-B NEW
1:200



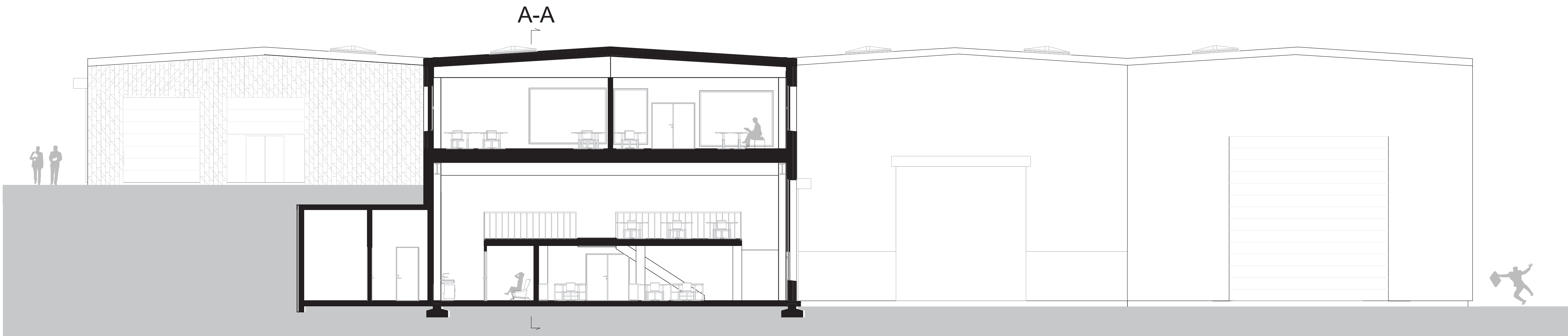

SECTION C-C DEMOLITON
1:200



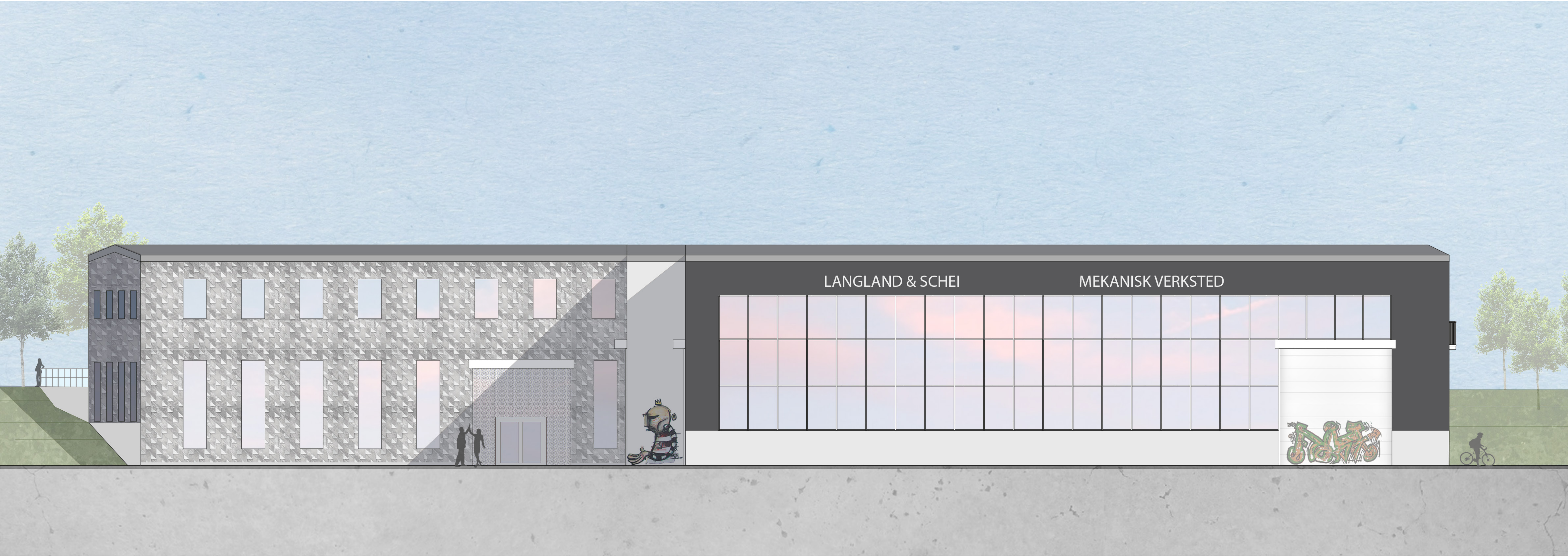

SECTION C-C NEW
1:200



SECTION D-D DEMOLITON
1:200




SECTION D-D NEW
1:200

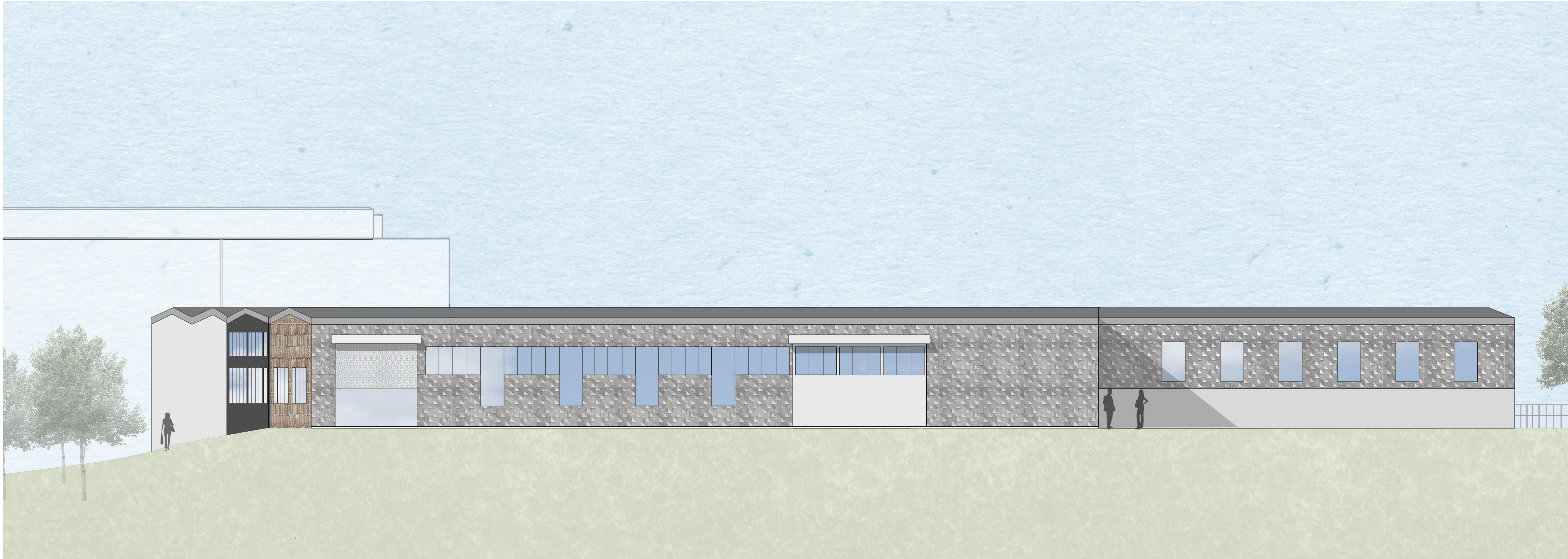



WEST ELEVATION
1:200

FAÇADE EXPRESSION

The local community explicitly stated the desire to keep the existing façade towards Strandveien. This is an iconic façade, which represents the history of the building and the area. Therefore, the expression of this façade is kept, as well as the shape of the building. The industrial expression represents its function since 1963.

The North extension has a new façade of reused metal sheets. As it is difficult to predict what reused materials are available, this is an example of possible upcycled facade material. The existing garage door serves as an entrance point, and is perforated to let in daylight.



EAST ELEVATION
1:200

FAÇADE EXPRESSION

The East façade has the same new façade cladding of reused metal sheets. The existing garage doors are operable with glazing behind. The Southmost garage door is perforated to introduce light while providing shade.

SOUTH ELEVATION
1:200

FAÇADE EXPRESSION

The expression of the South façade, towards Svartlamoen, is partially kept, with some new elements to manifest the transformation. Reused wood from damaged drum rollers serves as exterior cladding. Reused metal sheets was not used on the South facade due to high reflectance , and possible glare issues. The entrance point has larger openings, where Svartlamoen reflects in the glazing. Smaller windows provide glimpses of the activities inside the halls.

# PASSIVE STRATEGIES

The main passive strategies are; tight envelope, thermal mass, solar gains, quality daylight, and skylights for natural ventilation.

The existing building performs poorly in terms of energy use and envelope characteristics. Given that it is an industrial building with a relatively small area built for office functions, the envelope has minimal insulation. This project changes the function of the building, which also changes the demands of the construction system. Vaclav Hasik calls it "adaptive reuse", when a building is transformed from one type of use to a different one [35]. Changing the building category from industrial, with a small office area, to an office building introduce new building code requirements. These are necessary in order to satisfy the occupants in terms of thermal comfort. As a result, the envelope is fully renovated for the office section of the building.

A tight and well insulated envelope reduce thermal losses. In order to reduce thermal bridges, the insulation in the exterior walls are on the outside of the structural system. That allows for the steel columns to be visible on the inside. The foundation and basement is insulated on the exterior where possible, and on the inside where not possible. The windows are triple-pane windows with low-e coating. The roof is replaced with well-insulated roof elements.

Exposed concrete floors function as thermal mass and is coupled with solar gains through glazed areas. Enlarged openings in the façade introduce more daylight, while moveable shading devices reduce solar heating in the summer and possible glare issues.

Because of the deep floorplan skylights are used to provide daylight in the center of the building. The skylights are operable and can open and be used for natural ventilation, as exhaust outlets. Figure 72 and 73 show daylight and possible natural ventilation strategies for the office and flexible area.

The thermal zoning is divided between the static and dynamic part. The static part, office area, is fully conditioned, and the dynamic part is half climatized. That reduces the energy use as the dynamic hall include large volumes that would be challenging to condition with low energy use.

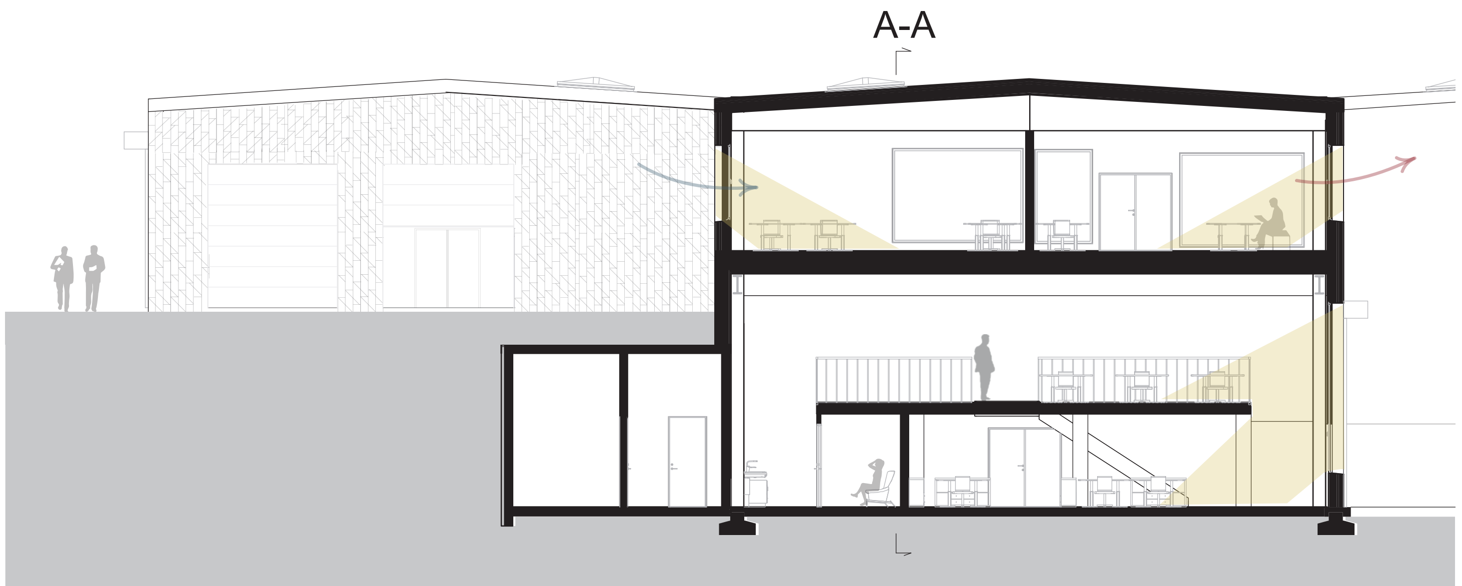



Figure 72: Section D-D with daylight startegy 1:200

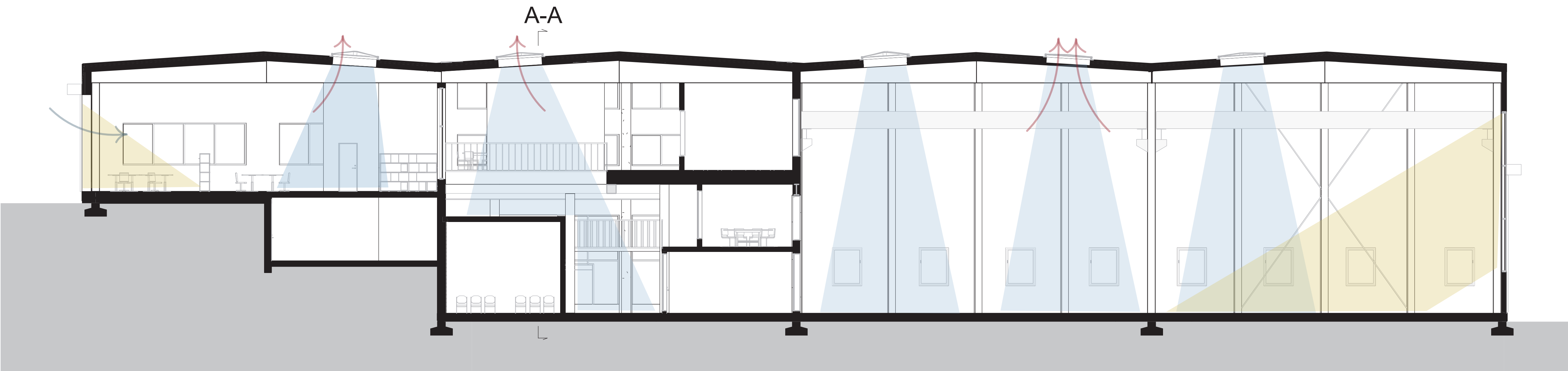



Figure 73: Section C-C with daylight startegy 1:200

# DYNAMIC FRAMEWORK

In the case of creating smaller spaces within the large hall, a framework is discussed in order to ensure adequate daylight access.

The large, glazed area on the West façade towards Strandveien provides significant daylight. However, the space is deep, and light cannot reach all the way back. Further, if interior boxes are assembled, they can block daylight access. Evenly spread, square, skylights ensure that the whole area is daylit, without depending on the glazed area of the west façade. The average daylight factor for the area excluding the west façade glazing is 2,2 %, and including the glazed area it is 6,4 %. The result indicates possible glare issues close to the west façade. This can be reduced with interior blinds. Based on these results it can be beneficial to vary the height depending on the location. Interior walls or boxes close to the West façade should be lower, in order to not block daylight deeper into the space. According to the daylight factor analysis, with the West façade glazing (Figure 76), the daylight contribution is most significant to the centre of the space. This area can have taller volumes to utilize the space more efficiently. Skylights provide sufficient daylight, but space between the volumes (Figure 77) is desired in order to keep a spacious and daylit environment. The area close to the static part should be lower (one floor) to not block visual connection and sightlines between the office and the flexible space. Lastly, this is only a suggestion and not a strict guide. The users' needs are the deciding factor for how to utilize the space.

Figure 75: Model for testing volume placement

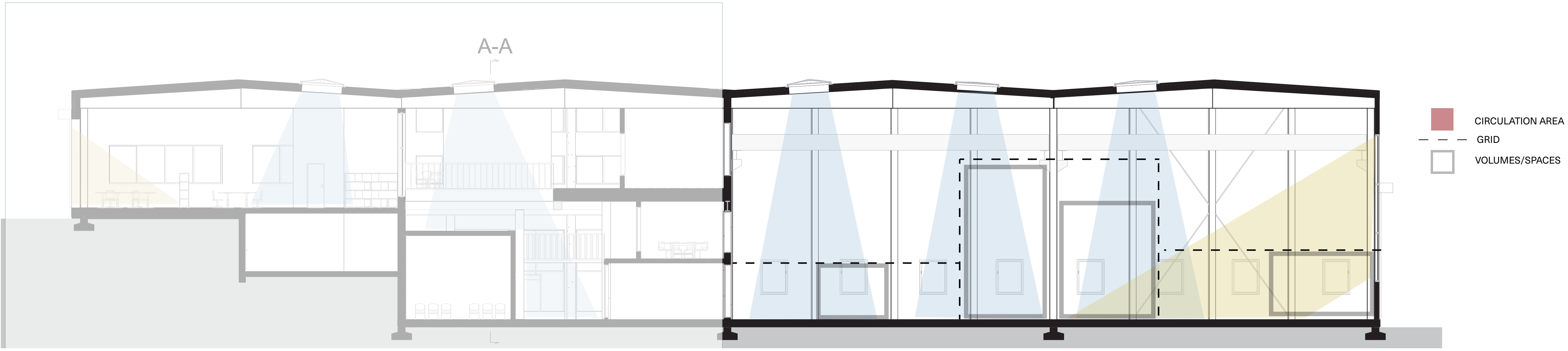



Figure 74: Section witth daylight strategy of dynamic space

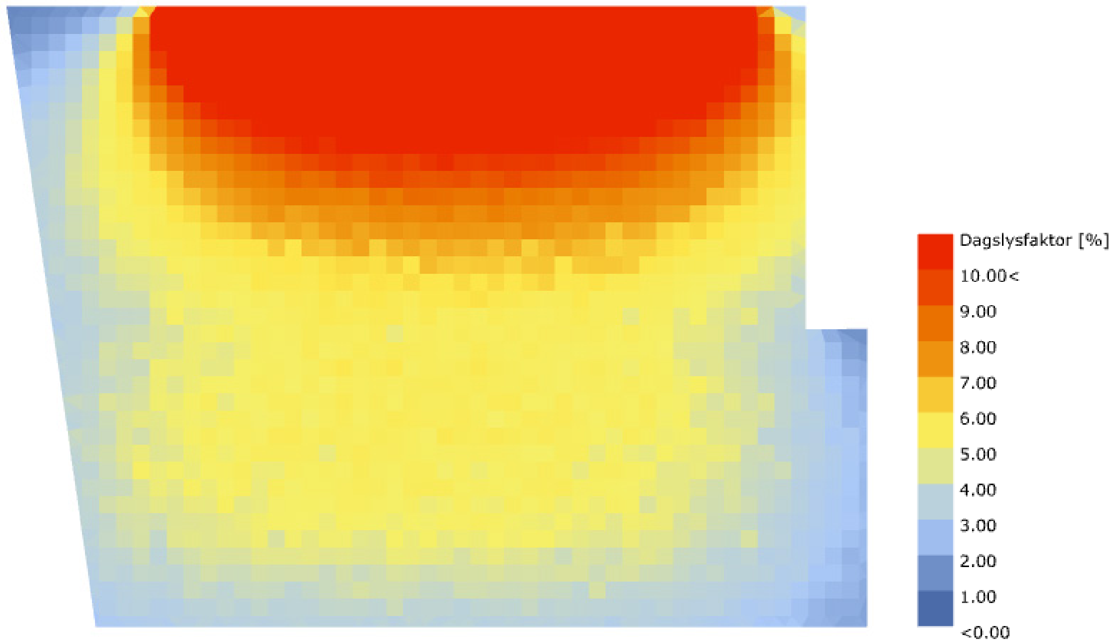
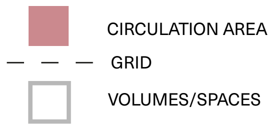



Figure 76: Daylight factor result with West glazing



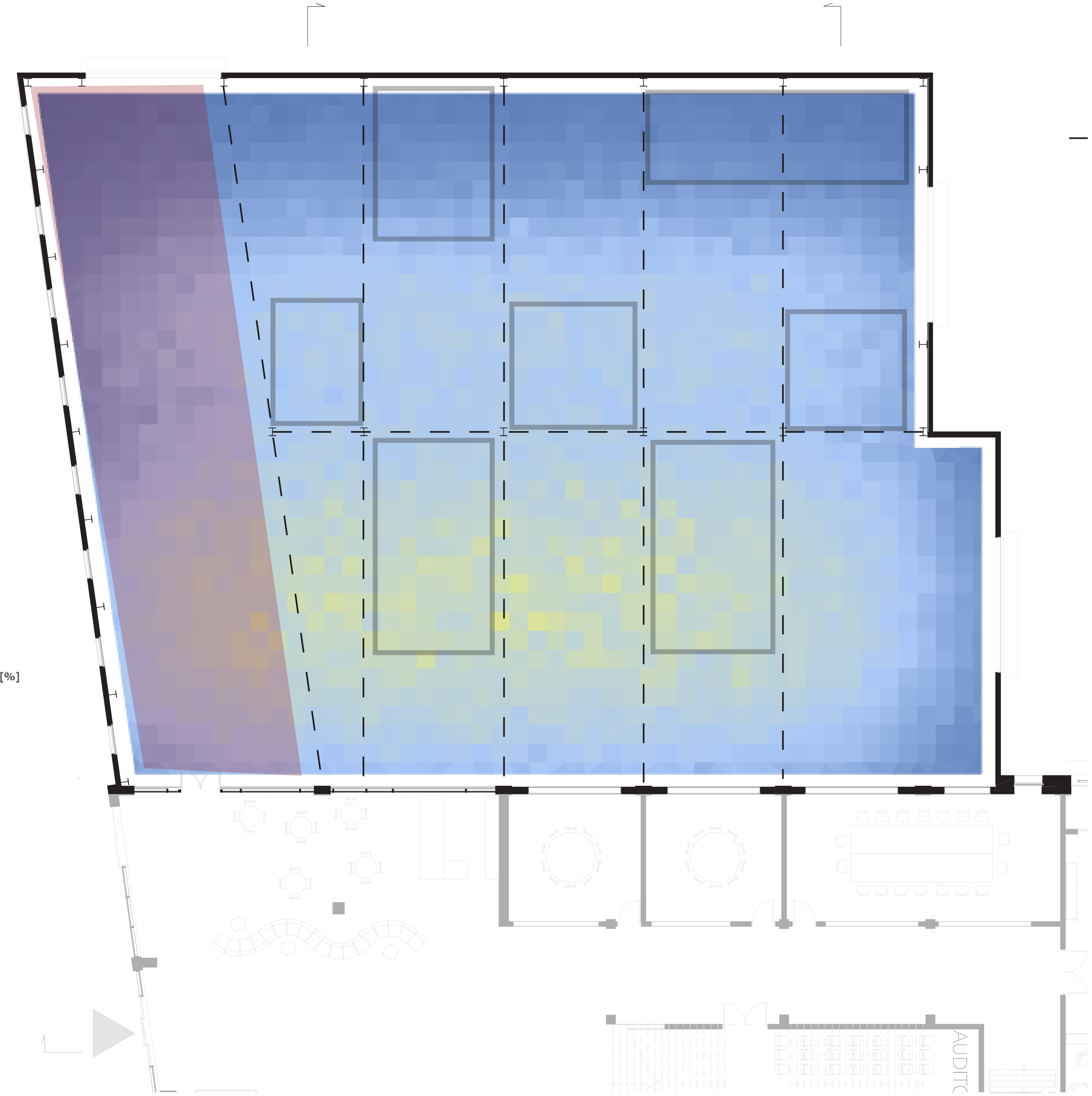



Figure 77: Daylight factor result w. grid

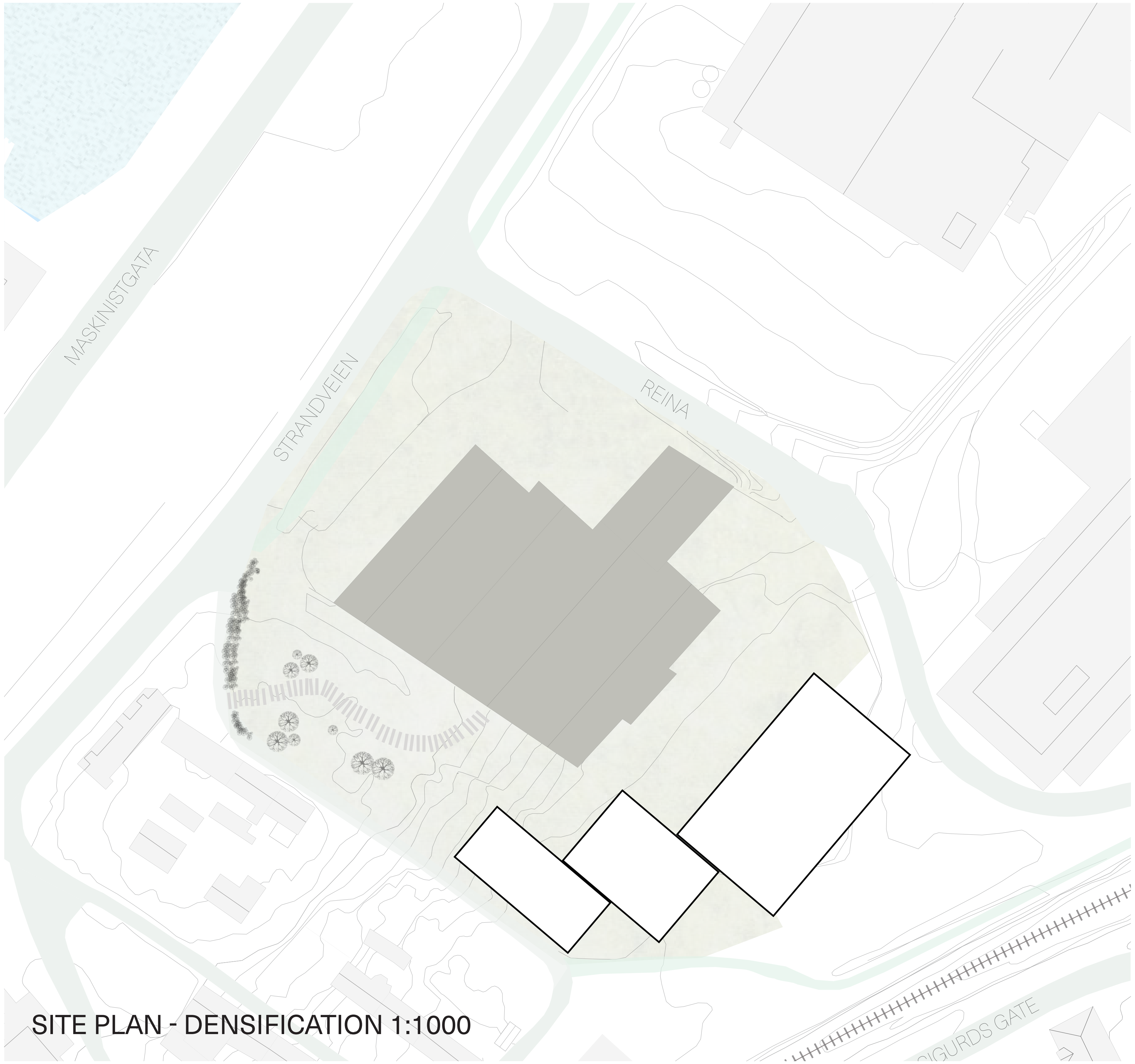
# DENSIFICATION

As mentioned in the introduction, a part of this thesis was to investigate some of the consequences of a most likely densification. Results from the shadow, wind (CFD), VSC, and radiation analyses are used to provide some suggestions for possible densification onsite. Possible consequences of densification are, among others, reduced incident solar radiation, daylight access, surrounding green areas, increased urban heat island effect, and reduced permeable surfaces for water management. This should be reflected in the design process and decisions. Therefore, densification on site should be designed with greenery on site.

The results from radiation and VSC analysis indicate that the best configuration in terms of available daylight for L&S and radiation is scenario (3), where the volumes on the south are elongated on the East-West axis and placed further away from the façade of L&S. However, if the buildings are limited to two or three floors for scenario (2), the daylight access is still adequate for the south façade.

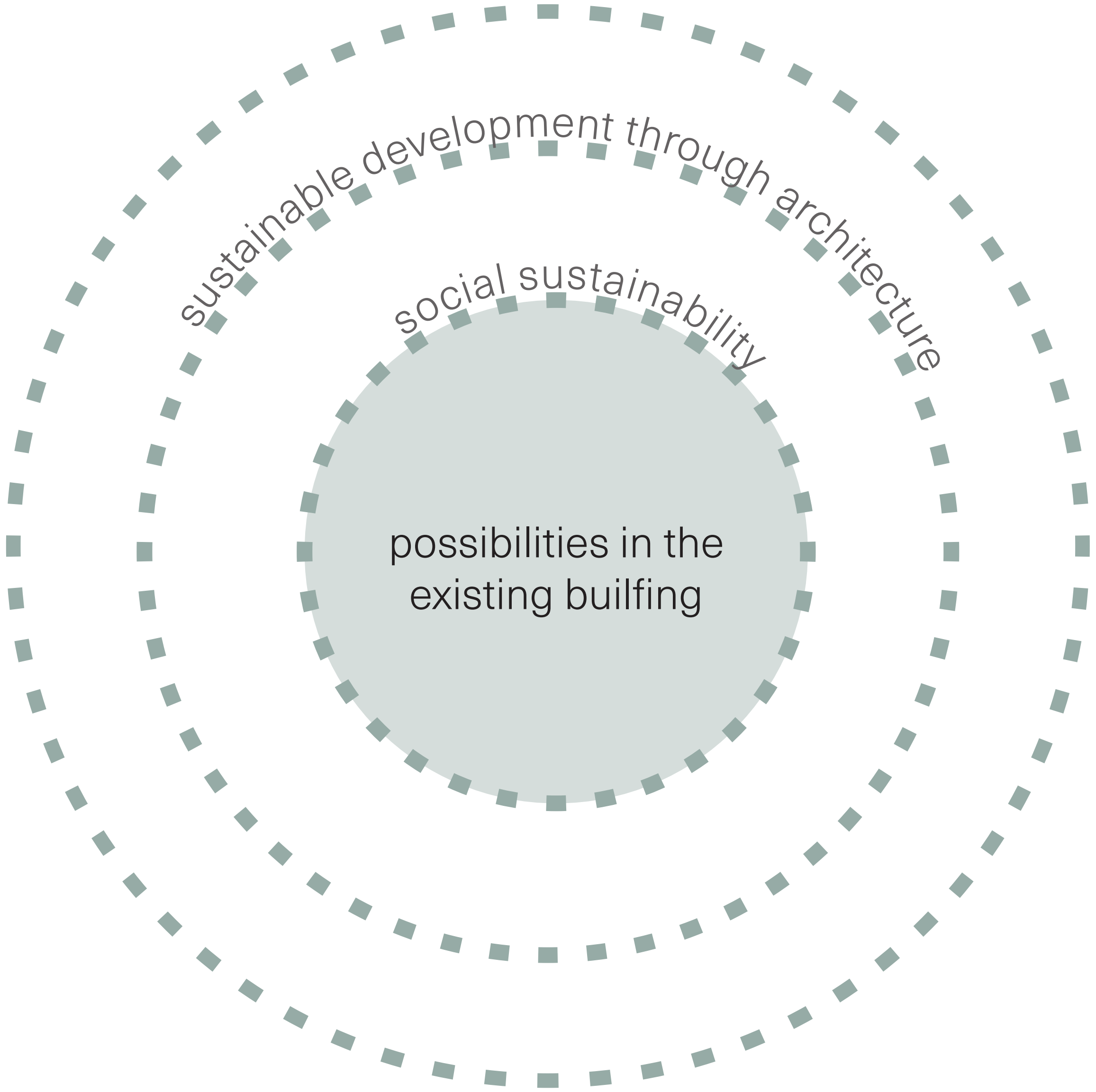
The shadow range analyses showed that scenario (3) is most beneficial in terms of shading on the South side of the building. In scenario (2), buildings were placed to close and made the South side of the building not adequate for an outside area.  The analyses suggest that a volume on the North-South axis, close to Strandveien, is not problematic in terms of shading.

As mentioned in the CFD-section, the analyses for scenarios (2) and (3) suggested that stacked volumes to the East gave a beneficial windbreak from the Eastern wind.  However, the placement configuration of the volumes is crucial to investigate further to avoid tunneling effects. The analyses show that sufficient windbreak from the Western wind during summer can be obtainable, but an incorrect placement of the building can also worsen the situation. An option is to plant trees with low canopies on the East side for windbreak, as suggested in [34, p. 347]




SITE PLAN - DENSIFICATION 1:1000

# 5. LCA


sustainable development through architecture
social sustainability
possibilities in the existing builfing

# LCA

In this chapter the life cycle assessment will be presented. It starts by explaining the LCA in detail with the system boundary and limitations. Thereafter, the results are presented and followed by a discussion.

The LCA is a tool to evaluate the environmental aspect of the adaptive reuse transformation. The LCA has two models, one with the new building materials and one with the new and existing building materials. The reason for the second model is to calculate the emissions embodied in the existing building. In order to compare the embodied emissions in the existing building with new buildings today the analysis is done with two types of concrete; low carbon A with 40 % of recycled binders in the cement and concrete without recycled binders. This is to see the variation within concrete, from worst to almost best-case scenario. For steel it is assumed a recycled content of 90% for beams and columns, and 97% for reinforcement bars. The actual components of the existing building most likely have lower recycled content.

These designs are also compared to a new reference building. To compare the transformation to an environmental option for a new building the reference building has a wooden structure. The reference building is mixed use with office and a large hall, to make it comparable with the project.

In the report “A Norwegian ZEB-definition embodied emissions” Kristjansdottir *et al.* recommend to not account for reused materials in the LCA, and that the lifetime of the refurbished building should be set back to zero and have 60 years after the restoration [14].

# SYSTEM BOUNDARY

The system boundary of the LCA is material production: A1-A3, replacement in use: B4, and waste process and disposal: C3-C4. The transportation (A4) and construction process (A5) are excluded because specific product manufacturers are not selected, and lack of data and knowledge of the construction process. According to Wiik et al., the construction phase of the ZEB buildings contributed between 2-15% of the embodied emissions [36]. The B6-operational energy use is excluded from the LCA as the HVAC system is not designed. However, it is included in a detailed analysis of the office. In the detailed analysis TEK 17 and Passive house requirements are compared for the office area.

# LIMITATIONS

The LCA does not include interior walls, interior doors, and floor finishes, as well as technical systems. Interior walls are excluded in order to make the reference models more comparable. If the new design and the reference models have the same quantity of interior walls, it would be comparable. However, it is intended to use recycled and reused materials for interior walls. Such as, old windows and reclaimed wood. As a result, the greenhouse gas emissions of these components are highly uncertain. Interior walls made up almost 25% of the total embodied emissions in the Kjørbo renovation project. That is including the use of reused glass façade in the interior walls [37]. The embodied emissions of interior walls are relatively large, and reused components can make a significant impact on the emissions. Stairs are excluded in the life cycle assessment. Energy use (B6) is only accounted for in the comparison between TEK 17 and NS3700 Passive House scenario for the office space.

A significant uncertainty parameter is repair of the structural system. The LCA excludes these emissions because the existing conditions are unknown. The lifetime of structural components, such as concrete columns, varies greatly and there are several influencing factors. For example, construction process and weather protection during installation, microclimate, mechanical tear, and quality of repairment [17]. For concrete, the reinforcement cover is particularly significant for the component lifetime to prevent corrosion of the rebars. As mentioned, the structural system is from at least three different time periods, the oldest dating to 1963. Visual inspections by a structural engineer are required to know the needed repair and replacements. In comparison, Kjørbo was 35 years old when renovated and all the original concrete structure was kept. Thus, the emissions from the superstructure and the foundations were insignificant [36].

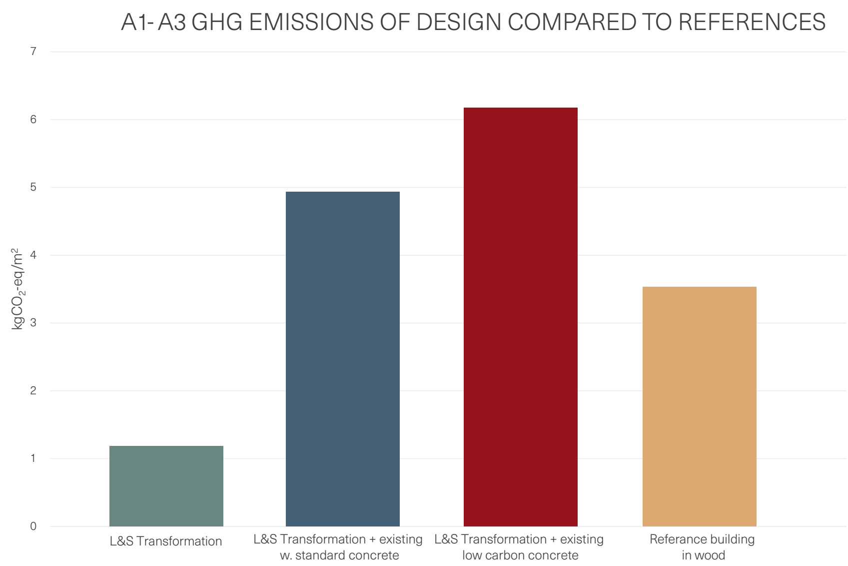



Figure 79: A1-A3 GHG Emissions of design and references

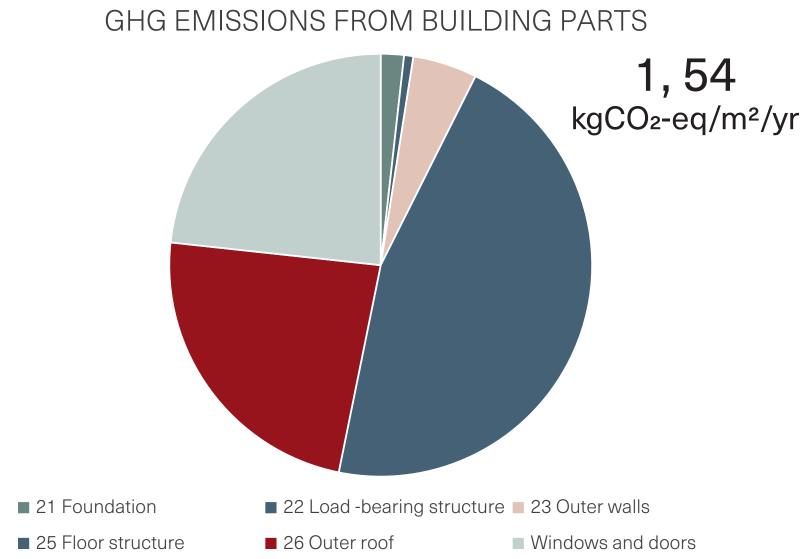



Figure 80: GHG emissions from different building parts

## RESULTS

The embodied emissions for the transformation, only looking at the new materials, result in 1,54 kg $CO_2$-eq/m²/year, where the floor structure accounts for 46 %. This is largely due to insulation and integral cast of the concrete slabs. The outer roof accounts for 24 % of the emissions. The results show that 68% of the GHG emissions are related to the upgrade of the office part, while 32% is from the large halls, called dynamic part. If these two parts are perceived as separate projects, the emissions for the office is 298 tonnes $CO_2$, which gives 1,41 kg $CO_2$-eq/m²/ year. The dynamic part has embodied emissions of 137 tonnes $CO_2$, resulting in 1,94 kg $CO_2$-eq/m²/ year.

The reference building in wood has almost three times as high GHG emissions for the product stage (A1-A3). The two scenarios accounting for the embodied materials in the existing building plus the new materials are significantly higher than the new reference building. That is as expected as the structural system consists of steel and concrete. The scenario with low carbon A concrete result in 20 % lower GHG emissions for A1-A3 compared to concrete with no recycled binders. However, both results demonstrate that the existing building has large amounts of embodied emissions that should not be disposed of as landfill. To build the L&S building today (including the transformation design) would induce 1527 tonnes $CO_2$. The new reference building in wood results in 734 tonnes $CO_2$, and the transformation reduces the emissions with 41 % compared to the reference building.

The analyses of the office transformation in terms of consequences of TEK 17 and NS 3700 Passive House requirements result in 12 % lower GHG emissions for the Passive House scenario. The embodied emissions are 21 % lower for the TEK 17 scenario, but the energy use is 30 % higher. See Appendix D for results.

## DISCUSSION

The results indicate low embodied emissions for the L&S transformation. However, the system boundary is limited. For a renovation project, from a beer bottling factory to a commercial building, Vaclav Hasik states that the largest contribution to GWP was finishes with 40 % [35]. For the renovation project Kjørbo interior walls accounted for almost 25 %, where old windows were reused as interior partitions [37]. Thus, the total embodied emissions are expected to increase significantly.

The assessment of the existing building plus the transformation shows that the embodied emissions in the existing building are large. That is an argument for transformation and reuse of the building. GHG emissions are already embodied in the building components, and several building parts are challenging to reuse or upcycle, such as concrete.

The comparison of TEK 17 and Passive House related emissions indicate a lower GWP for the NS 3700 Passive house standard. These two scenarios are not too different, and it could be favourable to compare it with a ZEB scenario. Also, the energy use for the two scenarios is simplified calculations and not based on detailed energy simulations. Thus, the results need to be understood as rough estimates.

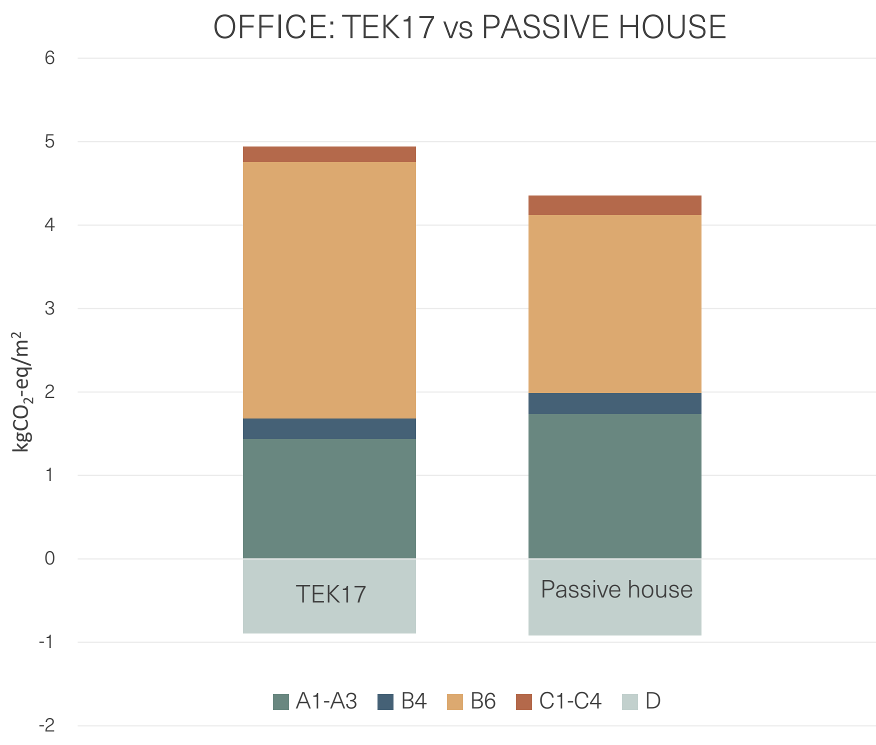



Figure 82: Comparison of TEK17 and Passive House requirements

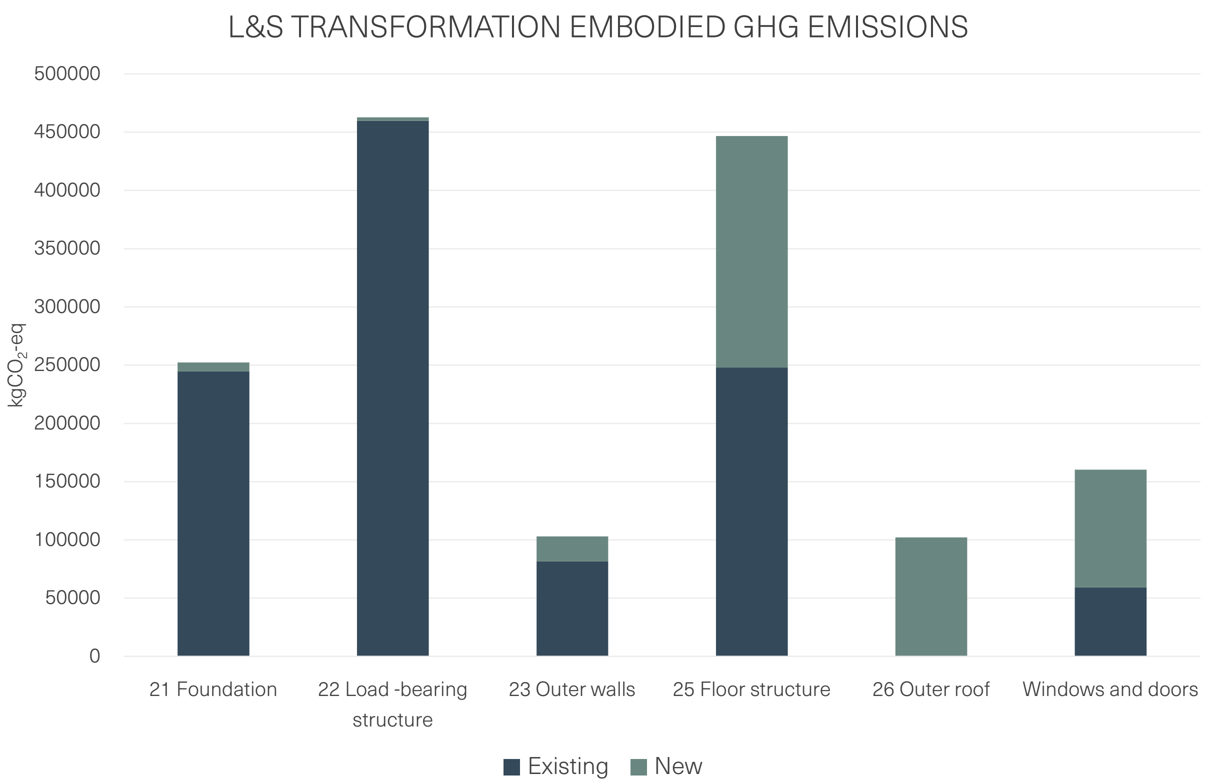
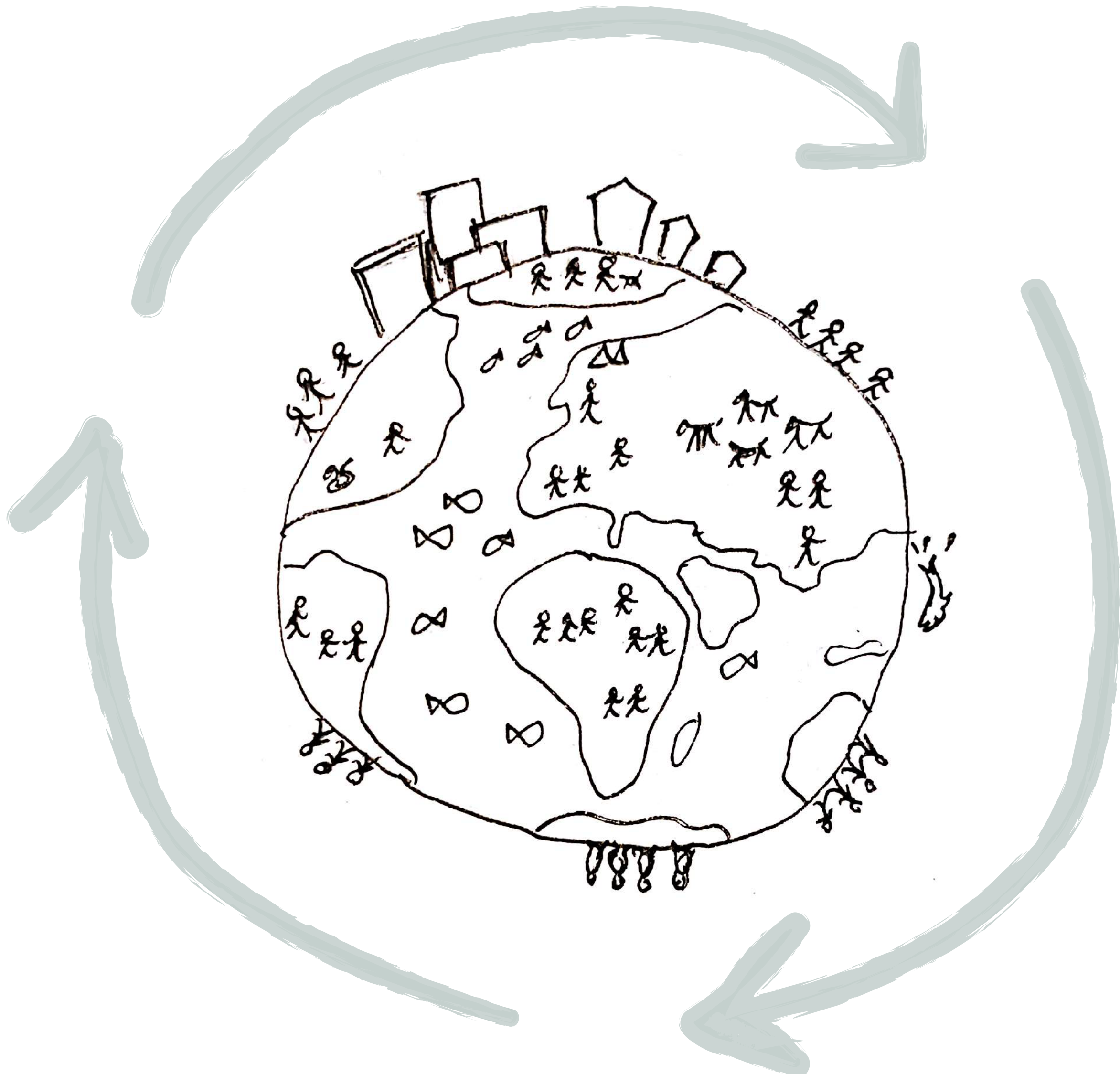



Figure 81: Embodied GHG emissions in new and existing materials. Existing concrete is assumed ti have no recycled binders.

# CONCLUSION



# CONCLUSION

The structural system was a deciding factor for the transformation and program of the building. Dividing the structure in a dynamic and static part allows for adaptability and to account for the unknown future to a larger extent. The dynamic part of the building is left as a space for the community and users of the building to develop and change according to their needs. The static part is fully renovated to a functional office space. The life cycle assessment indicate that the transformation (materials only) has a GWP of 1,54 kg $CO_2$-eq/$m^2$/year, where the floor structure accounts for 46 % due to renovation of the concrete slabs. The results show that 68% of the GHG emissions are related to the upgrade of the office part, while 32% is from the large halls, called dynamic part. Looking at the time perspective of GHG emissions, only fully renovating parts of the building, can be a sustainable option as the dynamic space is usable in its current state. The reference building in wood has almost three times as high GHG emissions for the product stage (A1-A3). Renovation projects have a large advantage in terms of reusing the structural system, which usually embodies the greatest emissions. The comparison of TEK 17 and Passive House related emissions indicate a 12% lower GWP for the NS 3700 Passive house standard. The material GHG emissions are larger, but the reduction of energy use is significant enough to “pay” back the embodied material emissions over the building lifetime.

During the process, it was discovered that the border between the static and dynamic part is not rigid, but rather fluid. The large volumes in the static part allow for open and flexible office spaces.

The spaciousness of the existing building and industrial expression with large volumes of concrete and steel provides architectural quality. As mentioned under “Principles of adaptability” these are qualities that are too “expensive” in terms of GWP and financial costs for a new building today.  Thus, preserving and transforming these buildings can allow for both architectural quality in spaces and environmental benefits. It might not be about optimizing the building, but rather about realizing the potential of the existing.

# FURTHER WORK

A natural continuation of this study would be to start assessing the necessary rehabilitation work needed on the structural system, and its consequences in terms of emissions. This is an emission post that has a large degree of uncertainty.  Further, detailed energy simulations are crucial to better understand the critical areas for thermal losses, and to improve the conditions. The life cycle assessment should be done in further detail when project details are known. A reference model including more phases than A1-A3 would be beneficial for comparing the design and assessing the environmental aspect.

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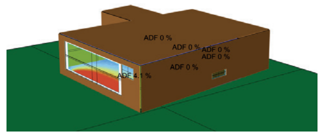
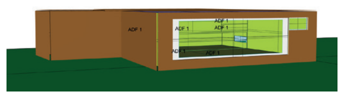
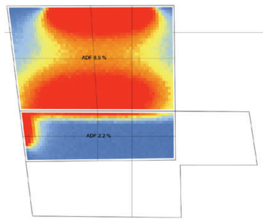
# APPENDICES

# APPENDIX A

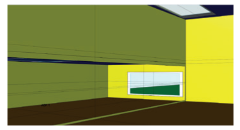
Model



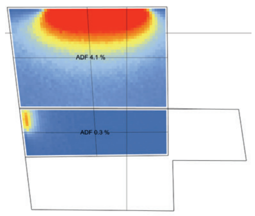




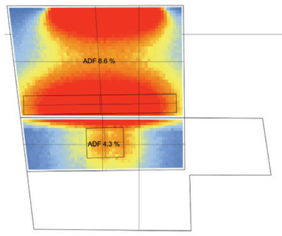
As built + 5 meter ceiling cut + 4x10 meter window on south entrance facade



Daylight 1

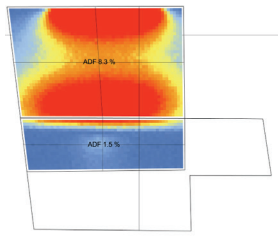


as -built

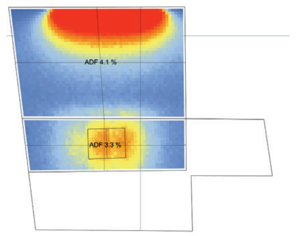


As built + 5 meter ceiling cut + 4x10 meter window on south entrance facade + 8x10 m cut in roof above stairs

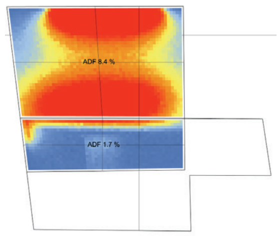
Daylight 1



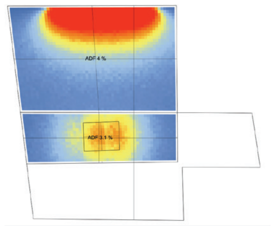
5 meter ceiling cut



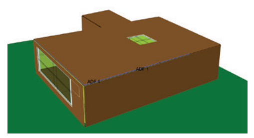
As built + 8x10 m cut in roof above stairs



As built + 5 meter ceiling cut



As built + 8x10 m cut in roof above stairs. Without glass wall between zones.



# APPENDIX B

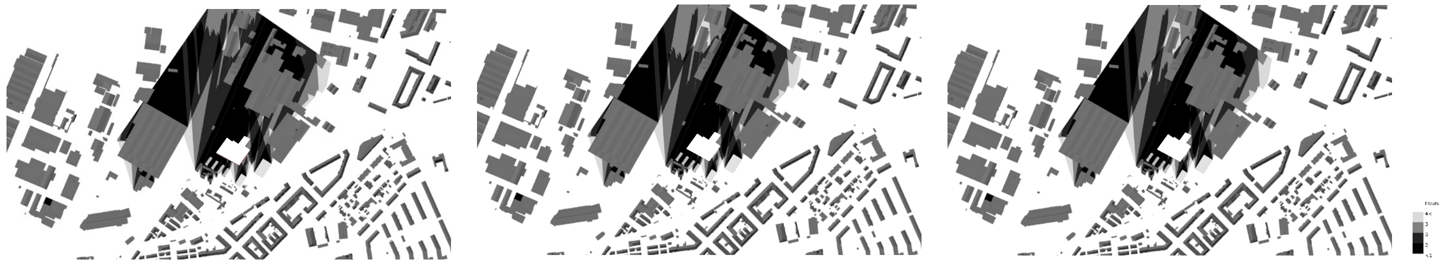
**Annual Radiation (kWh/m2)**

| Radiation | | | As-is | | D3-old | | D1 | | D2 | | D3 | | D-4 best scenario | | AS-is w/o-3 winter months- for roof | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | no | area | total | kWh/m2 | total | kWh/m2 | total | kWh/m2 | total | kWh/m2 | total | kWh/m2 | | | total | kWh/m2 |
| South | 0 | 712 | 708565 | 996 | 516889 | 726 | 650313 | 914 | 603586 | 848 | 515462 | 724 | 657954 | 925 | 679196 | 712 |
| west-facade | 1 | 505 | 164360 | 325 | 162533 | 322 | 163913 | 324 | 163271 | 323 | 161848 | 320 | 155937 | 309 | 160656 | 505 |
| North-facade-hall2 | 2 | 176 | 37090 | 211 | 37140 | 211 | 37176 | 211 | 37082 | 211 | 37134 | 211 | 35814 | 204 | 35751 | 176 |
| east-facade-utstikker | 3 | 239 | 118632 | 497 | 111920 | 469 | 115350 | 484 | 113926 | 478 | 111803 | 469 | 114867 | 482 | 115067 | 239 |
| North-facade-hall4 | 4 | 168 | 36211 | 216 | 35940 | 214 | 36084 | 215 | 36007 | 214 | 35958 | 214 | 35067 | 209 | 35109 | 168 |
| floor | 11 | 3091 | 6387 | 2 | 6143 | 2 | 6221 | 2 | 6225 | 2 | 6084 | 2 | 6043 | 2 | 6198 | 3091 |
| North-facade-utstikker | 12 | 185 | 43686 | 236 | 43774 | 236 | 43706 | 236 | 43789 | 236 | 43687 | 236 | 42238 | 228 | 42262 | 185 |
| East facade | 15 | 500 | 311365 | 623 | 262186 | 525 | 288848 | 578 | 277166 | 555 | 261911 | 524 | 289122 | 579 | 298017 | 500 |
| West-short-wall | 16 | 35 | 4639 | 131 | 4648 | 131 | 4622 | 130 | 4636 | 131 | 4641 | 131 | 4451 | 125 | 4471 | 35 |
| West-facade utstikker | 17 | 271 | 69754 | 258 | 69787 | 258 | 69847 | 258 | 69738 | 258 | 69828 | 258 | 68015 | 251 | 67957 | 271 |
| North-facade hall 1 | 18 | 174 | 37872 | 217 | 37831 | 217 | 37884 | 217 | 37912 | 217 | 37981 | 218 | 36648 | 210 | 36629 | 174 |
| Roof_1 | 5 | 319 | 288772 | 905 | 287870 | 902 | 289298 | 907 | 288565 | 904 | 287661 | 902 | 282646 | 886 | 282157 | 319 |
| Roof_2 | 6 | 336 | 337405 | 1004 | 335306 | 998 | 337441 | 1004 | 336680 | 1002 | 335775 | 999 | 328462 | 977 | 328778 | 336 |
| Roof_4 | 7 | 336 | 302124 | 900 | 300805 | 896 | 301924 | 900 | 302096 | 900 | 300710 | 896 | 294597 | 878 | 294301 | 336 |
| Roof_5 | 8 | 525 | 439921 | 837 | 438413 | 834 | 439589 | 837 | 439672 | 837 | 439003 | 836 | 429576 | 818 | 429478 | 525 |
| Roof_7 | 9 | 345 | 301938 | 876 | 300316 | 871 | 301718 | 875 | 301284 | 874 | 300744 | 872 | 294581 | 854 | 294874 | 345 |
| Roof_8 | 10 | 333 | 307246 | 922 | 304623 | 914 | 307171 | 921 | 306399 | 919 | 304842 | 915 | 300007 | 900 | 299586 | 333 |
| Roof_6 | 13 | 542 | 522187 | 963 | 520576 | 960 | 522199 | 963 | 522462 | 964 | 520476 | 960 | 509694 | 940 | 509562 | 542 |
| Roof_3 | 14 | 352 | 294113 | 836 | 292916 | 833 | 293983 | 836 | 293795 | 835 | 293295 | 834 | 287529 | 817 | 286987 | 352 |

| SITE ANALYSES | CONFIGURATION |
|---|---|
| SCENARIO 1 | AS-IS TODAY |
| SCENARIO 2 | 4 blocks stacked along South facade + 2 (1 large + 1 medium) blocks East of the building |
| 2 - D1 | D1: South blocks: 2 floors, East medium: 2 floors, East large: 3 |
| 2 - D2 | D2: South blocks: 3 floors, East medium: 3 floors, East large: 4 |
| 2 -D3 | D3: South blocks: 4 floors, East medium: 4 floors, East large: 5 |
| SCENARIO 3 | Buildings along edge of Svartlamoen (rotated 90 degress from scenario 2) - 4 floors |

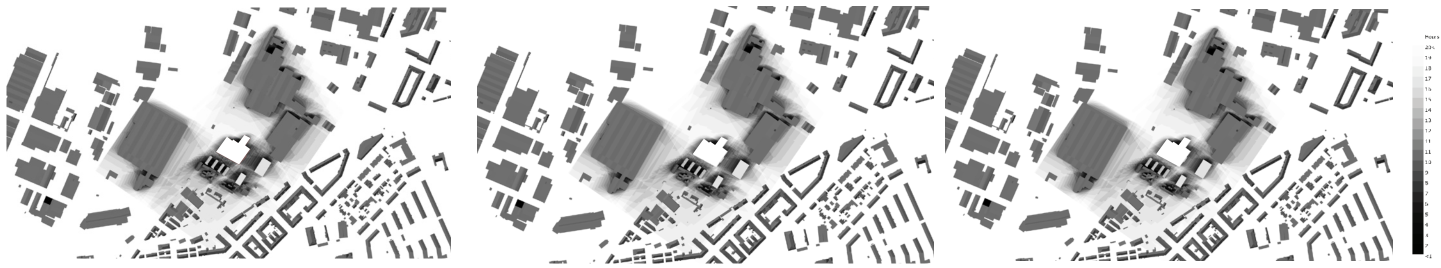
# APPENDIX C

21.Des

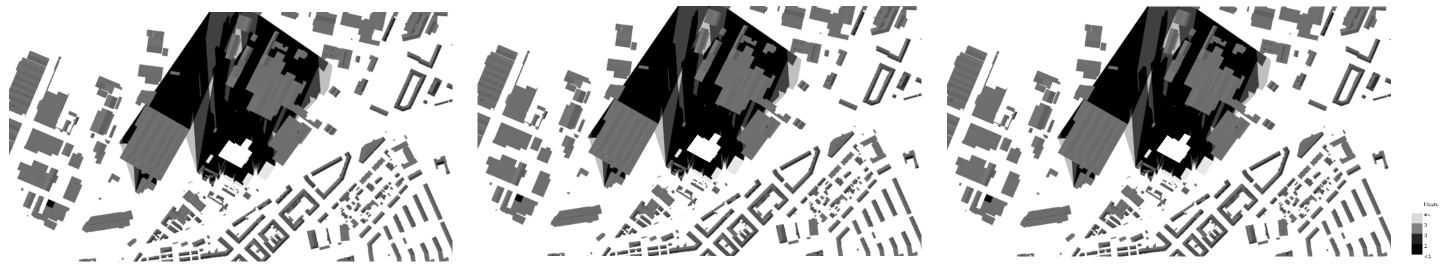


21.Mar

21.June



21.Des



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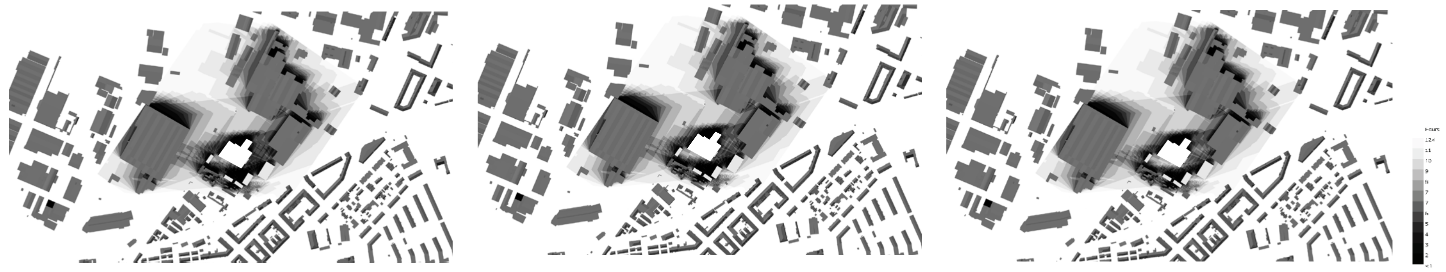
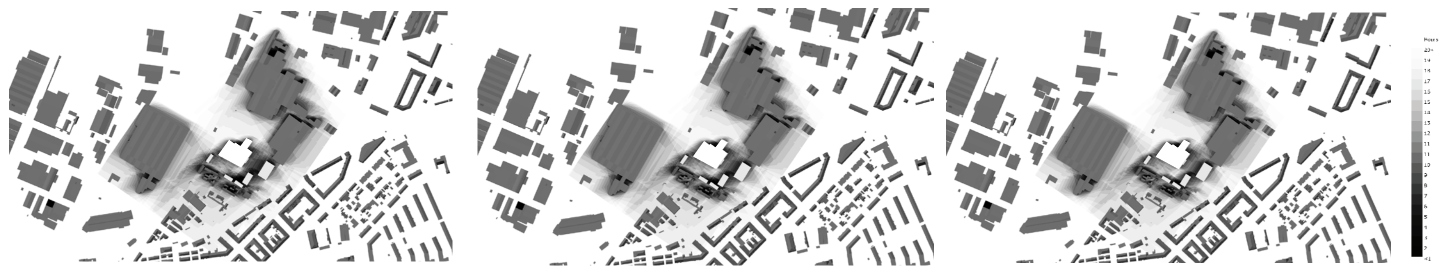


21.June



# APPENDIX D

| Lifecyle | Total renovation - only materials | | Renovation - Office | | Renovation - Dynamic | |
|---|---|---|---|---|---|---|
| 60 | | Pr BTA m2/year | | Pr BTA m2/year | | Pr BTA m2/year |
| | Total | 4696,0 | | 3513,0 | | 1183,0 |
| A1-A3 | 333323,61 | 1,18 | 217276,24 | 1,03 | 117127,35 | 1,65 |
| B4 | 52451,81 | 0,19 | 49734,28 | 0,24 | 2775,82 | 0,04 |
| B6 | | 0,00 | | 0,00 | | 0,00 |
| C1-C4 | 48324,62 | 0,17 | 30677,54 | 0,15 | 17448,55 | 0,25 |
| D | -193000,00 | -0,68 | -136000,00 | -0,65 | -54300,00 | -0,77 |
| Total GHG emissions (A1-C4) | 434100,04 | 1,54 | 297688,06 | 1,41 | 137351,72 | 1,94 |
| | | | | | | |
| | | | | | | |
| Per building element | | | | | | |
| 21 Foundation | 7679,20 | 0,03 | 7679,20 | 0,04 | | |
| 22 Load -bearing structure | 3077,94 | 0,01 | 3077,94 | 0,01 | | |
| 23 Outer walls | 21368,90 | 0,08 | 21501,47 | 0,10 | 513,50 | 0,01 |
| 25 Floor structure | 198748,41 | 0,71 | 135039,80 | 0,64 | 64002,29 | 0,90 |
| 26 Outer roof | 102155,35 | 0,36 | 56396,43 | 0,27 | 45758,92 | 0,64 |
| Windows and doors | 101069,63 | 0,36 | 73992,62 | 0,35 | 27077,01 | 0,38 |
| 32, 36, 39, 43, 44 Energy use | | | | | | |
| | | | | | | |
| Total | 434099,43 | | 297687,46 | | 137351,72 | |

| A1-A3 different scenarios | Total renovation | Total renovation + existing standard | Total renovation + existing low carbon | Office + dynamic in wood REFERENCE |
|---|---|---|---|---|
| A1-A3 | 1,183005415 | 4,935186022 | 6,177600668 | 3,483252681 |
| B4 | 0,18615775 | 0,241453989 | 0,322763431 | |
| B6 | 0 | 0 | 0 | |
| C1-C4 | 0,17150988 | 0,243886462 | 0,520555354 | |
| D | -0,684980125 | -1,465786485 | -4,746385805 | |
| Total GHG emissions (A1-C4) | 1,540673045 | | 7,020919453 | |

| Lifecyle | Total renovation + existing standard | | Total renovation + existing low carbon | | Office - TEK17 | | Office - Passive House | | Reference building office wood | | Reference dynamic hall wood | | Office + dynamic in wood |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | | Pr BTA m2 | | Pr BTA m2 | | Pr BTA m2 | | Pr BTA m2 | | Pr BTA m2 | | Pr BTA m2 | |
| | | 4696 | | 3513 | TEK 17 | 3513 | Passive house /ZEB | 3513 | | 3513 | | 1183 | 4696 |
| A1-A3 | 1390538,01 | 4,94 | 1302114,67 | 6,18 | 302790,85 | 1,44 | 366478,69 | 1,74 | | 2,00 | | 1,48 | 3,48 |
| B4 | 68032,08 | 0,24 | 68032,08 | 0,32 | 52451,81 | 0,25 | 52451,81 | 0,25 | | | | | |
| B6 | | 0,00 | | 0,00 | 647802,20 | 3,07 | 450645,01 | 2,14 | | | | | |
| C1-C4 | 68717,45 | 0,24 | 109722,66 | 0,52 | 38658,98 | 0,18 | 48806,95 | 0,23 | | | | | |
| D | -413000,00 | -1,47 | -1000443,20 | -4,75 | -188000,00 | -0,89 | -193000,00 | -0,92 | | | | | |
| Total GHG emissions (A1-C4) | 1527287,54 | | 1479869,40 | 7,02 | 1041703,84 | 4,94 | 918382,46 | 4,36 | | | | | |
| | | | | | | | | | | 10,61 | | 6,17 | 16,78 |
| | | | | | | | | | | | | | 0,00 |
| Per building element | | | | | | | | | | | | | 0,00 |
| 21 Foundation | 252330,76 | 0,90 | 232724,46 | 1,10 | 5753,01 | 0,03 | 7679,20 | 0,04 | 31000,00 | 0,15 | 11000,00 | 0,05 | 0,20 |
| 22 Load -bearing structure | 462850,59 | 1,64 | 456470,61 | 2,17 | 3077,94 | 0,01 | 3077,94 | 0,01 | 70000,00 | 0,33 | 1200,00 | 0,01 | 0,34 |
| 23 Outer walls | 102925,56 | 0,37 | 100017,45 | 0,47 | 20741,04 | 0,10 | 21367,53 | 0,10 | 153000,00 | 0,73 | 131000,00 | 0,62 | 1,35 |
| 25 Floor structure | 446725,63 | 1,59 | 428201,88 | 2,03 | 180351,08 | 0,86 | 201916,75 | 0,96 | 168000,00 | 0,80 | 169000,00 | 0,80 | 1,60 |
| 26 Outer roof | 102155,35 | 0,36 | 102155,35 | 0,48 | 82908,34 | 0,39 | 132625,79 | 0,63 | | 0,00 | | 0,00 | 0,00 |
| Windows and doors | 160299,04 | 0,57 | 160299,04 | 0,76 | 101069,63 | 0,48 | 101069,63 | 0,48 | | 0,00 | | 0,00 | 0,00 |
| 32, 36, 39, 43, 44 Energy use | | | | | 647802,20 | 3,07 | 450645,01 | 2,14 | 1814000,00 | 8,61 | 988000,00 | 4,69 | 13,29 |
| | | | | | | | | | | | | | |
| Total | 1527286,93 | | | | | | | | | | | | |

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