SPACES FOR LEARNING

New Aarhus School of Architecture

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// Bjørn Bull Hansen & Jakob Feldager Jørgensen

TITLE SHEET

Title	Spaces for Learning
Theme	General
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ABSTRACT

The project seeks to design a new Aarhus School of Architecture as a proposal for a future architectural competition. The project is located in the centre of Aarhus at the Godsbane area, which today is an emerging creative area. The proposal integrates the context into the design; especially the unfinished axis from the city hall will be transformed into an architectural journey, climaxing in the centre of the building.

The proposal is a mix of creative workshops, studios, workspaces and a large public area, linking the school to the city. The proposal focuses on adaptability, effectiveness and the user experience. The functions will be designed based on modern theories of effectiveness and learning environment with an optimal indoor climate.

An integrated design process has been utilized, with a general awareness of construction, sustainability and the spatial experience throughout the project. The project takes its point of departure in: a pre-screening made by Signal, analyses of the context, a proposal for a development plan of the area and user interviews are used as point of departure, which will be referred to throughout the project.

FOREWORD

This Master Thesis contains a proposal for the new Aarhus School of Architecture, designed by Bjørn Bull Hansen and Jakob Feldager Jørgensen, two M.Sc04 architecture students from the Department of Architecture, Design & Media Technology at Aalborg University for the period of 2nd of February to 27th of May 2015.

The main theme of the master thesis is *General* with the underlying theme *Spaces for learning*. The main task was to design a new architectural school for Aarhus, Denmark, which have to be adaptive, efficient and integrated into context. The building will ensure a modern, inspirational learning environment and function as a creative driver for the area. The unfinished axis from the city hall will be completed and establish a connection between the area and the city centre.

READING GUIDE

The report for the proposal of a new Aarhus School of Architecture is divided into six chapters. The report addresses the different phases of the development of the design. It demonstrates an integrated design process, where the different parameters influence each other as the design develops.

The first captor presents the project and motivation for the design, as well as the methods being used and a Danish summary.

The second chapter analyses the different external inputs, affecting the design. Analyses are made of the context, learning environments and the users. Concluding in design parameters and a vision for the design.

The third chapter presents the finale design in form of text and illustrations. The presentation captor narrows the scoop of the design, starting with the masterplan and progresses into details.

The fourth chapter clarifies the design process. The chapter starts with two case studies and then narrows the focus on the different building components, informing and optimizing the design.

The fifth chapter concludes and reflects upon final design and the process of the project. Further consideration and issues are discussed as part of this chapter.

The sixth captor contains the appendix, with supporting material to the report.

The Harvard method has been used for both text and images throughout the project.

DANISH SUMMARY

Under temaet Rum for læring, undersøger projektet, hvordan gode læringsmiljøer skabes gennem arkitekturen. Med afsæt i eksisterende læringsmiljøer, der ikke længere er tilstrækkelige, tager projektet udgangspunkt i en ny arkitektskole til Aarhus. Aarhus arkitektskole har siden sin grundlæggelse i 1965 været midlertidig placeret ved Ringgaden i Aarhus. Med omkring 800 studerende og en spredt placering ved Ringgaden, har der fra skolens side været et ønske om nye lokaliteter. I 2013 blev godsbanearealerne bag Scandinavian Center og Godsbanegården udpeget som den fremtidige placering for skolen. Med en nylig offentlig gjort udviklingsplan for Godsbanearealer, samt en forventet udskrivelse af en idekonkurrence for den nye skole, tager projektet afsæt i en pre-screaning af arkitektskolens eksisterende funktioner.

Med afsæt i godsbanearealerne som ny placering for arkitektskolen, formstår projektforslaget som en bygning og skole der vil møde byen og blive en drivkræft for et nyt kulturalt centrum i Aarhus. Masterplanen for projektet og bygnings volumenerne tager afsæt i en uafsluttet akse der forbinder Aarhus rådhus med Godsbanearelerne. Da aksen på nuværende tidspunkt er uafsluttet forslår projektet en afslutning ved og i bygningens hovedindgang. Med placeringen af et auditorium og det omsluttende bygning volumen, indeholdende studioer, værksteder og kontoer, søger bygningen at lave en naturlig afslutning på aksen. Ved at bruge de gamle jernbane spor som en reference til en grøn kile, bringes naturen og den historiske kontekst ind i bygningen.

Gennem en integreret tilgang har analyser og studier informeret designprocessen. Projektet har under teamet Generelt arbejdet med tektoniske og bæredygtige aspekter, der har været med til at præge bygningens endelige udformning. Med fokus på studioerne og optimale forhold for de studerende med henhold på akustik, dagslys og indeklima, er bygningen blevet udarbejdet. Med studioerne orienteret mod nordvest og med højt og lavt placeret vinduer, opnås der her en atelier stemning hvor diffust lys giver optimale forhold for den kreative proces. Ved en kombination af lavt siddende vinduer sikres de studerendes udsigt, når disse er siddende. Med offentlige funktioner, så som udstillingsarealer, kantine og bibliotek central placereret i bygning, forslår disse områder et pulserende hjerte, der sikre en tilgængelighed fra hele bygningen og hvor offentligheden frit vil kunne færdes.

CONTENTS

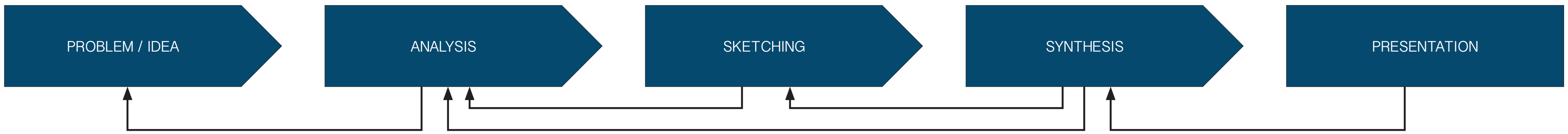
INTRODUCTION

During the last decade, spaces for learning have been in a rapid transformation. New learning approaches and technologies have set new requirements for the architecture. Existing facilities from the past are not seen as suitable anymore. Together with an increase in the number of students and with new goals for sustainability, the existing building stocks are renovated and new facilities are built. Aarhus School of Architecture is an example of a school - which is located in facilities - that is not suitable anymore. Since 1965 the school has been placed at a temporary location in the northern part of Aarhus city centre. [Arkitektskolen Aarhus, 2014]

Motivated by our background as students of Architecture and Design from Aalborg University, this master thesis will investigate how sustainable architecture can create spaces for learning. The project will take point of departure in a new architectural school for Aarhus. Aarhus School of Architecture has a vision to rethink the physical environment of an architectural school through the architecture. The thesis will investigate the field of sustainable architecture and spaces for learning. [Arkitektskolen Aarhus, 2014]

With preforming arts, visual arts and literature facilities placed on the old railway yard and in the old Godsbanegård, the appointed location for a new architectural school is in immediate connection to Godsbanen. The project will further investigate how this location can connect with the existing city and how the learning environment can invite its surroundings in. [Arkitektskolen Aarhus, 2014]

This thesis aims to create a good and modern learning environment, which will help the users preform their very best. The focus is on how the stimulation and over-stimulation of different senses affects the students and will help them increase their learning paste. A more effective learning environment is more sustainable in the long run and will help increase the overall level of knowledge.



Ill. 1 The integrated design process

This section describes the method, which has been used for the program as the initial part of the design process for the project Spaces for Learning.

Throughout the project Integrated Design Process, defined by Mary-Ann Knudstrup, will be used to integrate problems of spacial, aesthetic and technical character. The Integrated Design Process is defined in the paper *Nordisk Arkitekturforskning* as a synthesis between Problem Based Learning, architectural and engineering aspects. The Integrated Design Process can be seen as sequences and loops, where analyses are informing design proposals and leading to new synthesis, that may require new analysis and proposals. [Knudstrup, 2010]

The Integrated Design Process is divided into five phases: [Knudstrup, 2010]

- *The Problem / Idea Phase* outlines the project with an idea, an objective or a statement.

- *The Analysis Phase* is where relevant aspects and information, the project's preconditions are collected and evaluated. The analyses will underlie the framework for the project and collect principles, which will be used in the sketching phase. The analyses will be basis for the vision and main concepts of the project.

- *The Sketching Phase* outlines the framework with aspects of architecture and engineering, which will inspire each other and create integrated designs. Integrated design solutions seek to meet the goals for the project.

- *The Synthesis Phase* is where iterations from the Sketching Phase is reaching a point, where the building finds its final shape, that meets the framework. The synthesis phase will look at the optimization of the design proposal, which should result in solutions where architectural and technical qualities are integrated.

- *The Presentation Phase*; the material for the presentation of the project is produced, which clearly shows the qualities of the project.

Throughout the process, phenomenological and literature studies will be used to support the integrated design process.

The following program should be seen as a framework for the project, which will be basis for the continuing Sketching and Synthesis phases in the design process. In relation to the Integrated Design Process the program contains information related to the two first phases in the design process, the Problem / Idea phase and the Analysis phase.

ANALYSIS

Ill. 2 The Godbane area today

AARHUS

Aarhus is placed on the east coast of Jutland and facing Aarhus Bay. The city is placed in a valley, which was formed approximate 14000 years ago by melting ice of the latest ice age. A stream, Aarhus Å, is starting at Brabrand Lake to the west of Aarhus, passing the city centre and ending in Aarhus Bay to the east. The unique coastline, Aarhus Å and surrounding green areas are all contributing with qualities for the citizens. [Aarhus Kommune, 2012]

Copenhagen and Aarhus are two of the driving centres for development in Denmark. Aarhus is making an effort to develop new and more workplaces, student places and dwellings. During the last decade, Aarhus has been in a continuous transformation and development. Old industrial areas in the city centre have been converted into residential and business areas. The strategy is to develop and make the city centre more dense and to create new suburban areas. The vision for the city centre is to use the old industrial areas for new city areas, which will connect the city and expand the city centre. Areas include the old railway areas to the north of the train station and the transformation of the northern harbour.
The politicians in Aarhus have a vision to make Aarhus a good city for it's inhabitants and to create development. [Aarhus Kommune, 2013]

Aarhus has a long tradition for architecture. Architectural landmarks includes the City Hall by Arne Jacobsen and Erik Møller and the first university buildings and the surrounding park, which was designed by C.F. Møller, today both are included in the Danish Ministry of Culture's cultural canon on the top 10 as two of the most important buildings in Denmark. [Aarhus Kommune, 2012]

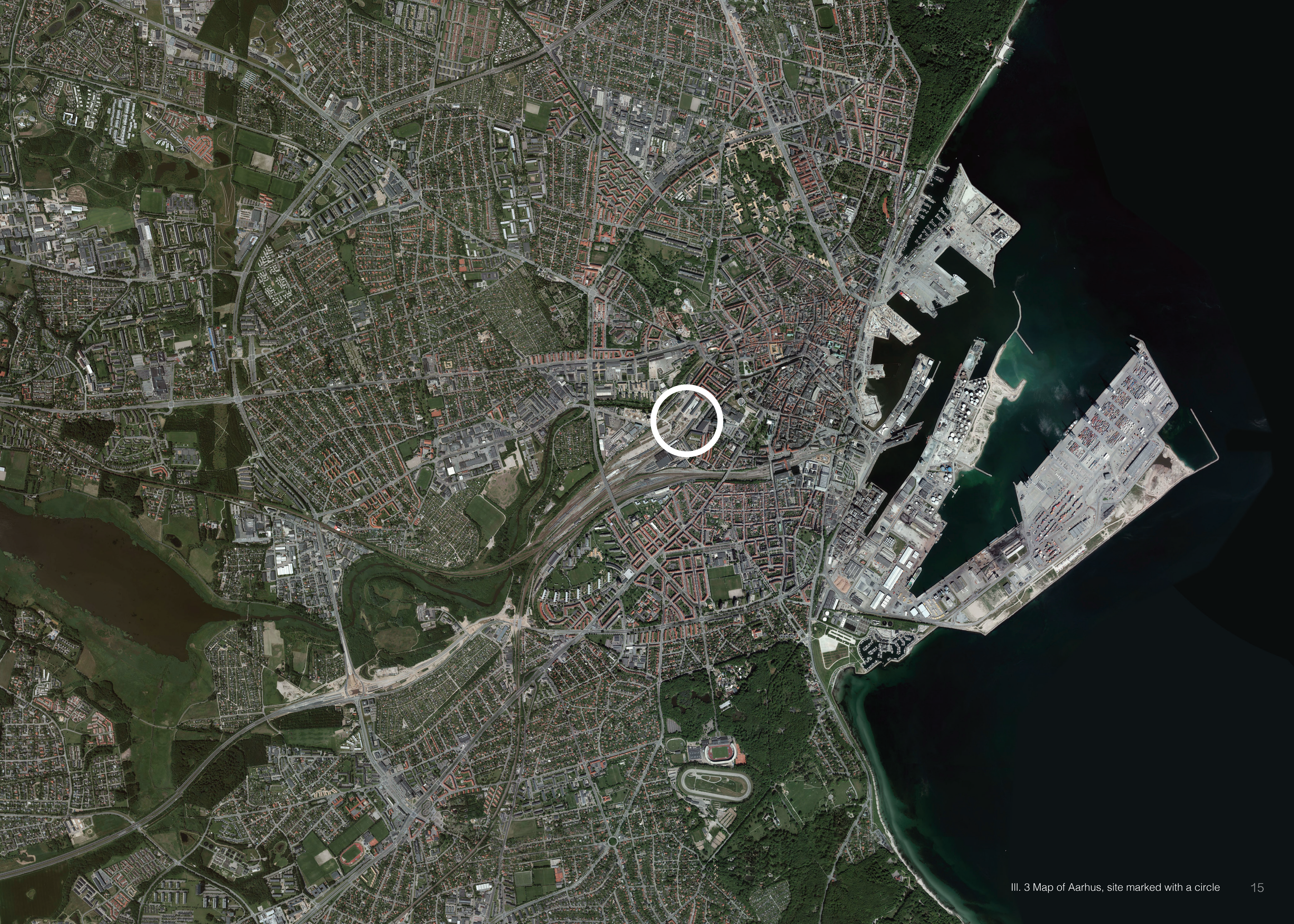
ARCHITECTURE POLICY

In 2012 Aarhus municipality defined their architectural policy. The goal for the architecture policy has been to retain and develop the existing qualities of the city and make Aarhus an attractive city for people to live and work in. The themes of the architecture policy concerns: Citizen involvement, Urban Development, Architecture, Resource Consumption and Infrastructure. [Aarhus Kommune, 2012]
A higher focus on the citizen involvement is noticed in the creation of Architecture, New Technology and Design – AND, a department seeking to involve the citizens in temporary activities as part of the city transformation and development in areas, such as Godsbanen. The goal is to increase the collaboration between educational research and the private sector. Topics regarding Urban Development, Architecture and Resource Consumption seeks to increase the urban density and raise the bar for future architectural competitions, so Aarhus will be internationally recognized for its architecture.

The field of Resource Consumption is further looking at how the existing building stock can be renovated without loosing the tactility of the worth preserving buildings, and with the field of Infrastructure is the municipality seeking towards infrastructural layouts, which will enhance the architectural interaction in urban spaces. [Aarhus Kommune, 2012]

SUSTAINABILITY

Aarhus municipality has an ambition for being CO_2 neutral in 2030, a key factor for achieving this goal is to reduce the CO_2 emission from buildings. The yearly reduction of CO_2 emission, electricity and heat consumption is target to 2% for the build environment. New buildings must at least meet Building Class 2015 requirements, however the vision is to reach Building Class 2020, without adding photovoltaic. New sustainable buildings must meet indoor climate class B without raising the energy consumption. The municipality has a focus on passive strategies, such as natural ventilation for night cooling, summer ventilation, exposed heavy structures, which will have a cooling effect, and an optimization of daylight conditions. The municipality is enhancing the use of certified materials, materials that have a recycling potential at end of life and materials that have a low CO_2 contribution.[Aarhus Kommune, 2013]



Ill. 3 Map of Aarhus, site marked with a circle

Ill. 4 Godsbanen in 1939

Ill. 5 Godsbanen container terminal in 1970

Ill. 6 Godsbanen in 2012

GODSBANEN'S HISTORY

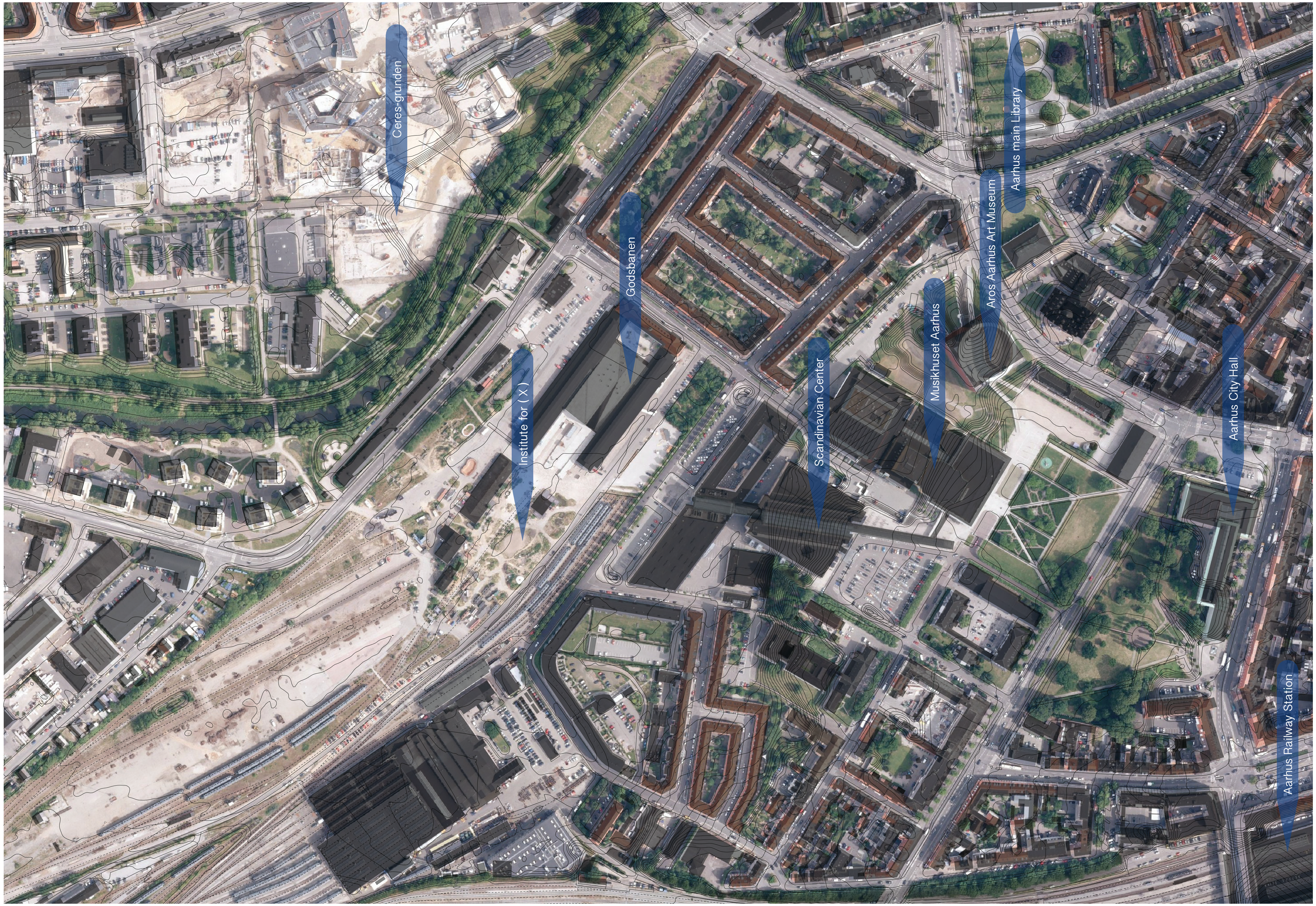
One of the areas Aarhus municipality would like to transform from closed industrial and rail areas is Godsbanearealerne on Mølleengen, west of the existing city centre. Godsbanen and the surrounding areas were used for loading and unloading rail carriers, but with the increase of road transportation and a new rail freight centre in the southern part of Denmark, the activities in Aarhus were shut down in 2006. Godsbanen and the surrounding area bought by Aarhus municipality in 2008. Based on the potential for a new western part of the city centre. With connections to cultural institutions such as Scandinavian Center, Musikhuset Aarhus and Aros Aarhus Art Museum, were the old Godsbanegård and the warehouses renovated from 2008 to 2012. [Dansk Center for byhistorie]

The placement of Godsbanen on Mølleengen was chosen as Hack Kampmann and Charles Ambts prescribed it in the master plan for Frederiksbjerg in 1898. Mølleengen was at that time placed outside the city centre with a location that would create minimal inconveniences for the citizens. However the project and final master plan was not decided before 1916 and 1919. [Dansk Center for byhistorie]

The construction of Godsbanen, including a main office building and warehouses, was finished in 1923. De Danske Statsbaner's chief architect Heinrich Wenck designed the building. Heinrich Wenk is known for Copenhagen Central Station, a reference, which is seen in the architectural stile chosen for the main office building of Godsbanen. The newest structural technologies, seen in the Hetzer-system, were used to create the needed span in the warehouses. [Dansk Center for byhistorie]

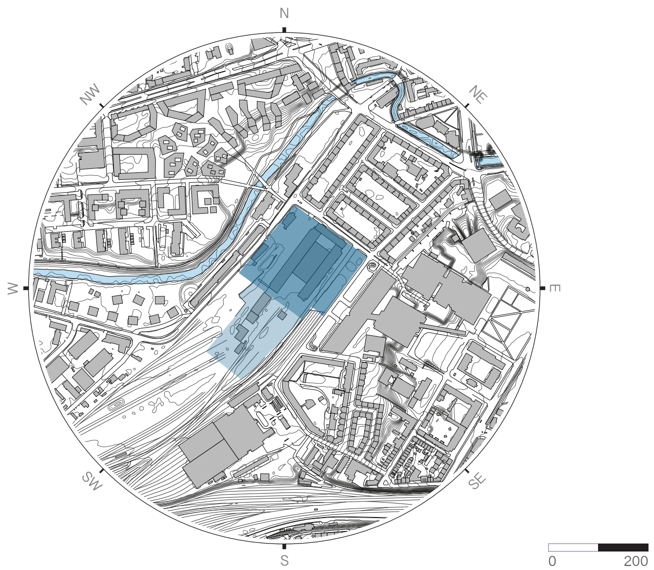
With an increasing number of freight containers was a new container terminal opened in the 1970's. The container terminal and its cranes were placed on the northern part of the railway yard in front of Godsbanegården. [Dansk Center for byhistorie]

A screening of Godsbanen regarding the history the site and its heritage recommendations was in 2009 carried out by the Dansk Center for Byhistorie. The heritage recommendations for the old rail areas was to maintain the feeling of the railway yards size, use some of the old tracks as guideline for new paths and roads in the area and preserve the view from the main building of Godsbanen towards southwest and the railway yard. [Dansk Center for byhistorie]



Ill. 7 Closeup map of the site with surrounding landmarks

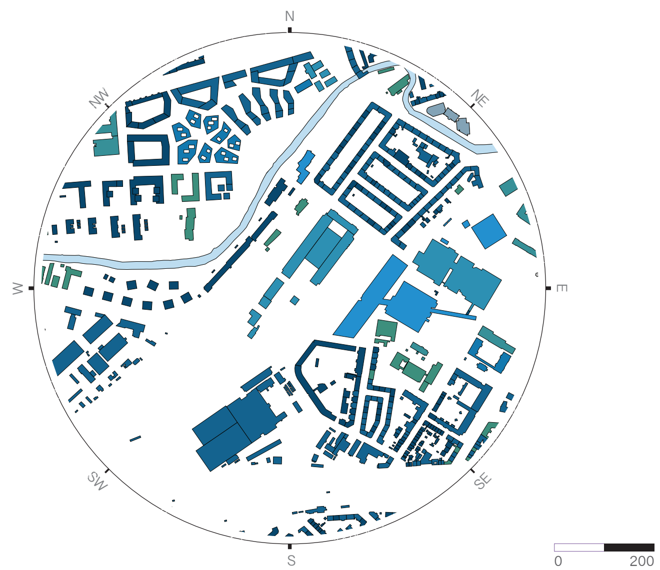
SITE
ANALYSIS



Godsbanen

Institut for (X) - (Site)

Ill. 8 Site and surroundings in a distance of 500 meters



Residential

Residential / Commercial

Commercial

Commercial / Educational

Cultural

Cultural / Educational

Education

Retail / Cafe / Restaurant

Cultural / Commercial

Ill. 9 Functions surrounding the site in a distance of 500 meters

Infrastructure, heavy traffic

Pedestrian and bicycle paths

Ill. 10 Infrastructure surrounding the site in a distance of 500 meters

GODSBANEN'S LOCATION

Godsbanen is located within 500 meters of the existing city centre and therefore an area for future urban development. Godsbanen was renovated and a new centre building with restaurant, exhibition space and scene for theatre was established. The buildings are production facilities with workshops for preforming arts, visual arts and literature.

Institute for (X) is located next to Godsbanen in the old customs warehouse, the carpentry shop, the old fruit marked and the tarpaulin house. Institut for (X) is a platform for upstarting designers, musicians, artists, entrepreneurs and craftsmen. [Institut for (X), 2014]

A new architectural school located on Godsbanen, where Institut for (X) is today, will connect with the existing cultural institutions in the area such as Aros Aarhus Art Museum, Musikhuset Aarhus with the musical conservatory of Jutland and Aarhus Art School. The area will also connect the new development of Ceres-grunden, north of the site, with the city centre. The new development on Ceres-grunden will contain mixed functions with education, commercial and residential areas.

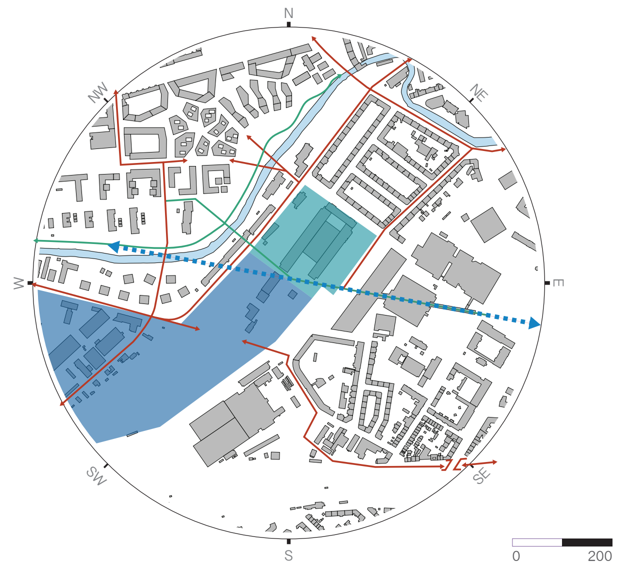
Main functions surrounding the site include residential and mixed-used buildings with residential and commercial activities. Southwest of Godsbanen the functions are mainly commercial. Rail activities for maintenance and repairmen of equipment are still placed southwest of the site.

Godsbanen and the old railway yard are bounded to the north by Carl Blochs Gade, which is connected with Vester Ringgade to the west and Thorvaldsensgade to the east. East of the site is the area bounded by Skovgaardsgade, which leads to the southern boundary Sonnesgade. The annual daily traffic for the surrounding roads varies from 4.600 to 5.300 vehicles. [Aarhus Kommune, 2015][Aarhus Kommune, 2015] Southwest of the site is Vestre Ringgade crossing the railway yard, with an annual daily traffic of 32.200 vehicles [Aarhus Kommune, 2015] and with the wind coming from southwest in large parts of the year, may noise be visible at the site.

(All nolly-maps are based upon the new master plan for Ceres-grunden.)

- Godsbanen
- Old industrial areas with possibilities for future development
- New / existing infrastructure for heavy traffic

Ill. 11 New roads (According to local plan 886 for Godsbanen)



- Godsbanen
- Old industrial areas with possibilities for future development
- Paths for pedestrians
- Paths for pedestrians and bicycles
- Axis through Scandinavian Center

Ill. 12 New paths and bicycle paths (Local plan 886 for Godsbanen)

- Sightline
- Axes

Ill. 13 Sightlines and axes from the past rail activities

DEVELOPING THE AREA

Due to the development of the site, a new proposal for the local plan republished in April 2015. However a local plan was made in 2010 for Godbanegården, in relation to its renovation and addition, the local plan predicts the main access road, Søren Frichs Vej, which will be connecting Vester Ringgade with Carl Blochs Gade. [Aarhus Kommune, 2010] However a suggestion for a development plan has been issued April 2015, but has still not been adopted.

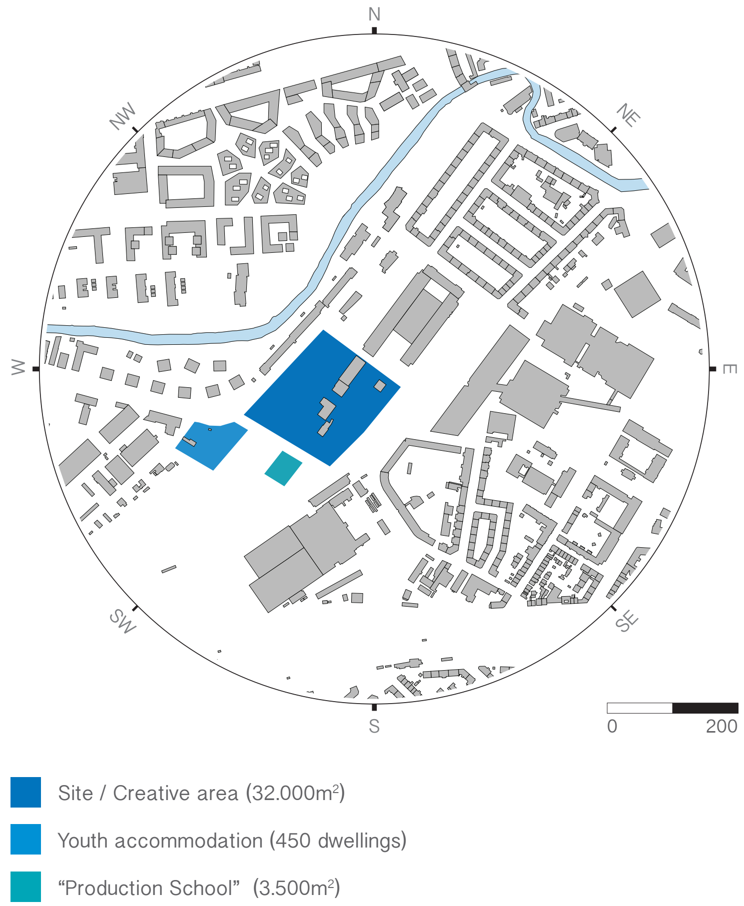
An unfinished axis from the town hall through Scandinavian Center to Godsbanen, is seen as one of the main pedestrian paths, should be developed and included in a future project. To the north of Godsbanen new bridges and paths on both sides of Aarhus Å are seen as main pedestrian and bicycle connections to the new development on Ceres-grunden. [Aarhus Kommune, 2010]
Godsbanen is placed on the low-lying terrain of Mølleengen creating long views towards southwest from Godsbanegården. This allows a panorama view of the railway yards, letting the user feel the impact of the scale. Dansk Center for byhistorie sees this worth protecting together with the axes marked by the old railway tracks. [Dansk Center for byhistorie]

AARHUS Å.

In 1932 Aarhus Å altered and covered, but in 1995, partly reviled again as part of a development of the city centre of Aarhus. [Aarhuswiki.dk, 2015]. Today Å'en is one of the most popular places and a signature of Aarhus. It functions as a gathering point all the way from Europaplads to Mølleparken with cafes and urban environment. Appendix 1.2 shows a map of Aarhus from 1796, where the stream can be seen before it was altered in 1932 and 1995. By comparing the map with a modern map. It can be concluded Aarhus Å was running through the area of Godsbanen.

By reviling Aarhus Å and letting it back through the site, the area might gain:

- Drain the area in case of a cloudburst or flood.
- Provide reservoir in case of flooding.
- Connect downtown to the cultural hub at Godsbanen.
- Enforce the Aarhus Å's symbol as one of the city's signatures.
- Reveal some of the city's history to the public.



Ill. 14 Site in context

GODSBANEN TODAY

Godsbanen in Aarhus is today's cultural centre with workshops for performing arts, visual arts and literature. 200 people are today working at Godsbanen on a daily basis and around 400 events are taking place every year. A new addition between the existing warehouses, drawn by 3XN, was opened in 2012. The building contains theatre, restaurant and exhibition halls. [Godsbanen, 2014]

The old Customs Warehouse (building 3 on Ill. 14), The carpentry shop (building 2 on Ill. 14), Aarhus fruit marked (building 1 on Ill. 14) and the tarpaulin house (building 4 on Ill. 14) is today used by Institut for (X). Institut for (X) is a platform where young innovative people can rent facilities. [Institut for (X), 2014] The old fruit marked, old carpentry shop and the tarpaulin house is characterized by its red wood facades. The old Customs Warehouse is standing out from the surrounding red wood buildings as the only brick building, build in the same architectural style as Godsbanegårdens main building.

MATERIALS

Red colours and red bricks characterize the site and the old buildings on Godsbanen. Materials are mainly wood and bricks for the buildings. Steel, concrete and wood characterized the old rails. The new building from 2012 is characterized by its use of rough materials, where exposed concrete surfaces are characterizing the interior. Galvanized steel facades and sloping concrete roofs characterize the exterior of the building. The sloping roof surfaces create a path to a lookout, where there is a free view of the railway yard towards southwest. The lookout is placed in a height of 19 meter. [Godsbanen, 2014]

RESTRICTIONS

According to the local plan for Godsbanen was the restricted height for a new central building 20 meter. [Aarhus Kommune, 2015] It is assumed that a future local plan for the developing area will have a similar restriction of 20 meter in height.

PRECAUTIONS

The site is potential polluted as an effect of the rail activities in the past. Recommendations for the area and soil is from the municipality to seal the ground with a hard surface or replace the upper 500 mm of soil with non-polluted soil. [Aarhus Kommune, 2010]

Godsbanen is located on Aarhus' lower-laying areas placing the water table near the ground surface. Values for a high and average water table shows that the water table is placed 0 – 1 meter below the surface with the current climate model from 1991 to 2010. The predicted average change in the water table is around 0 – 1 meter, when an average climate model for 2021 to 2050 is used. [Klimatilspasning, 2015]

The design should consider the high water table, contextual materials and become an engaging part of the existing cultural centre.

Ill. 15 Site views

INSTITUTE FOR (X)

Through interviews with both Mads Peter Laursen (the “manager” for institute for (X)) and Michael Troelsen (Supervisor for projects, department of Urban and Mobility), became the ideas and funding thoughts for the contemporary, creative community known as Institute for (X) clear.
Mads Peter Laursen is on of the founders and the anchor point for Institute for (X). He is the face of this contemporary community to the outside world; he handles with the local authorities, the press and the daily routine of the area.

Institute for (X) was founded in 2009 as a union on Godsbanen, owned by the communal authorities with a common understanding of temporary lease. The local authorities' idea of the society being temporary was not only regarding the site, but also regarding the tenants renting the different spaces. The authorities goal was to give start-up companies a good start by providing a good location, for a cheap rent and then the company should move on. At the moment there is a tendency for the tenants to stay, because they get to comfortable.

THE DOCKING IDEA

One of founding ideas for Institute for (X) is its idea of a dock, a place where developers can test and prepare their ideas, before the product gets shipped away. It is certainly not the intension for projects to stay and get permanent, there has to be a receiver for what ever you are doing at Institute for (X). Mads sees this as a way to motivate and prepare people for the real world.

EXPANDING/MOVING ON

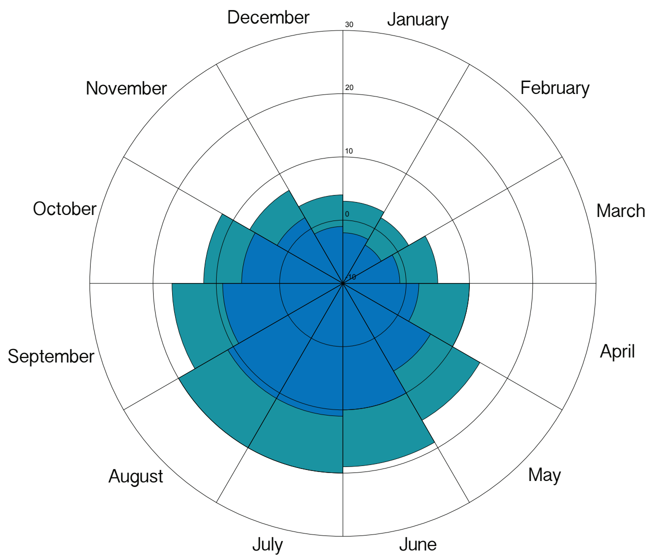
A symbioses exists between the authorities and Institute for (X). The area is put into good use and someone is responsible for it, instead of just becoming a left over space in the city and Institute for (X) has a good location for a low rent. Both parties have a common understanding of the current situation not being permanent, but are also both interested in keeping the arrangement. One of the options is to let Institute for (X) expand and develop into the future green areas to the east, letting go of its current location, evolving and adapting into a new location. Just like an organism moving slowing from one site to another and as the tenants are suppose to evolve.

INSPIRATION TO FOR THE FUTURE

By getting inspired by the dock-idea and the developing approach from Institute for (X), it would be logic, beneficial and a practical step to move Institute for (X). The obvious choice would be to let it grow on the green area and slowly, move out of its current location, to make room for a more permanent development of the site. This will allow the symbioses between the two parties to continue and let in a third party, the new architectural school. Together Institute for (X) and the Architectural school, might create a new creative hub for Aarhus, which Institute for (X) already has started. The tenants, who are ready to move out, might get inspired and move their business to a more permanent location and make space at the new location for new tenants. In this manner the idea and concept of Institute for (X) will become an inspiring testimony and keep on inviting new creative souls.

Ill. 16 New green area, possible expansion option for Institute for (X), and future buildings on the site

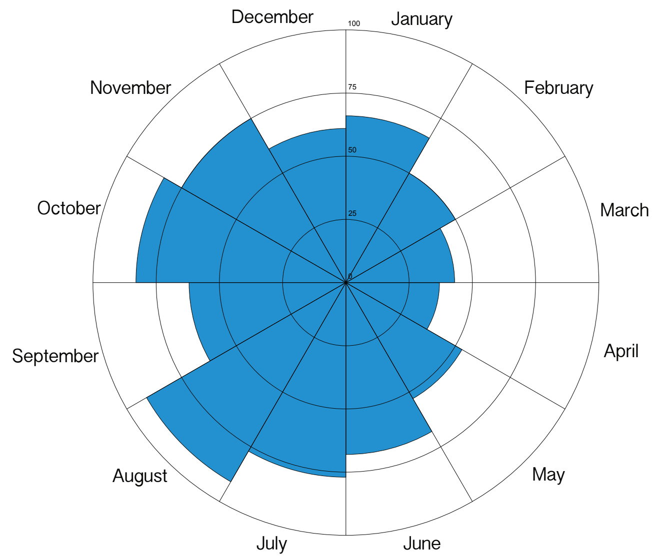
WEATHER
ANALYSIS



Average Minimum Temperature

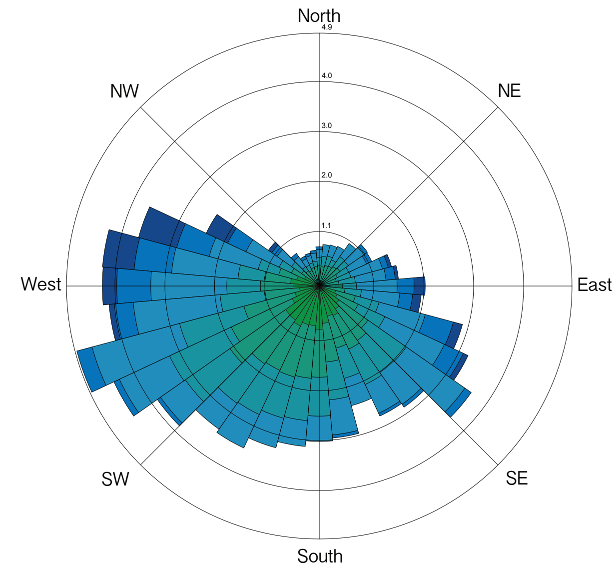
Average Maximum Temperature

Ill. 17 Average temperatures, maximum and minimum



Average Amount of Rain in mm/month

Ill. 18 Average rainfall



3 - 8	8 - 11	11 - 16
16 - 24	24 - 32	32+

Ill. 19 Wind

WEATHER ANALYSIS

Aarhus is located in a temperate climate with mild winters and summers, but with significant changes from summer to winter due to the location between the North Pole and equator. The location creates a large variety of daylight through the seasons.

In the winter the average temperature is between 2˚C and – 3˚C and only 6 hours and 56 minutes of sun at the 21th of December, whereas the summer temperature spans from 20˚C to 11˚C and 17 hours and 55 minutes of sun at the 21th of June. [Dmi.dk, 2015]

The amount of precipitation is almost equally distributed around the year, but from September to January is a notable increase of 3 days per month, compared with the rest of the year. As a result heavier rain will occur in months such as August. [Weather-and-climate.com, 2015] [Dmi.dk, 2015]

The wind rose is based on observation at the local airport, Thirstrup, located outside the city centre. The wind rose shows that the wind mainly comes from the west; with the highest speed in the west and the east, notable wind is also registered from the south. [akrherz@iastate.edu, 2015].

CLOUDBURST

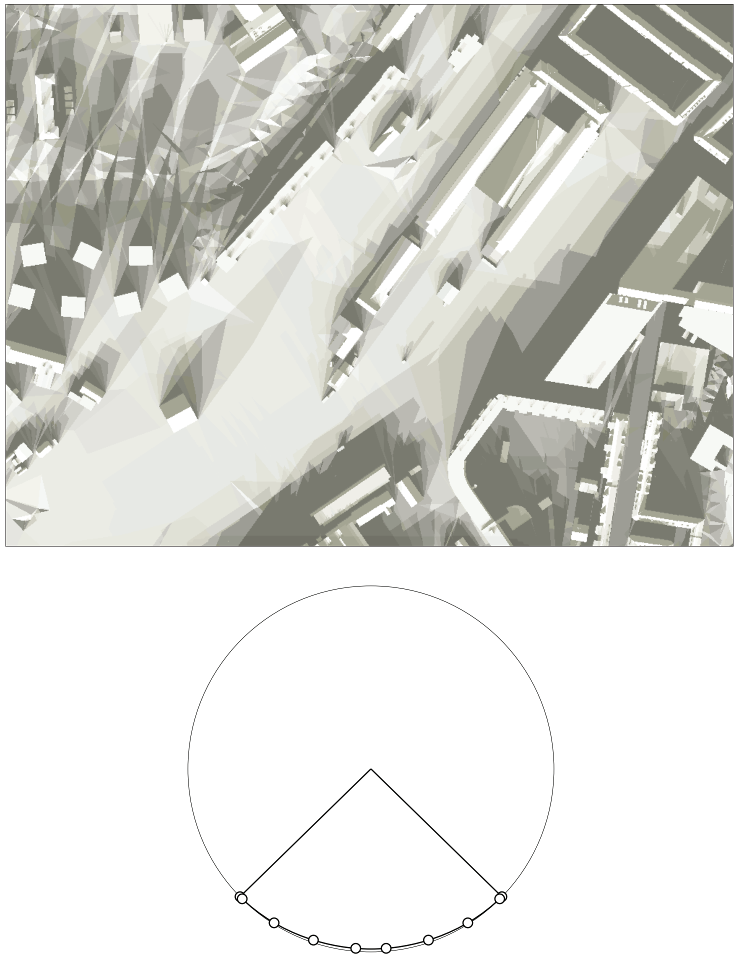
Due to the climate changes over the last couple of years Aarhus has experienced more frequent cloudburst and local floods. An effort is made to be prepared for the predicted climate changes in Denmark based on the A1B-senario for 2050. In the scenario the temperatures will increase, more rainy days will occur and a larger amount of rain will fall. The scenario is based on FN climate report, but has been altered to fit the Danish conditions by DMI. [Aarhus Kommune, 2014]

HOW TO HANDLE A FLOOD

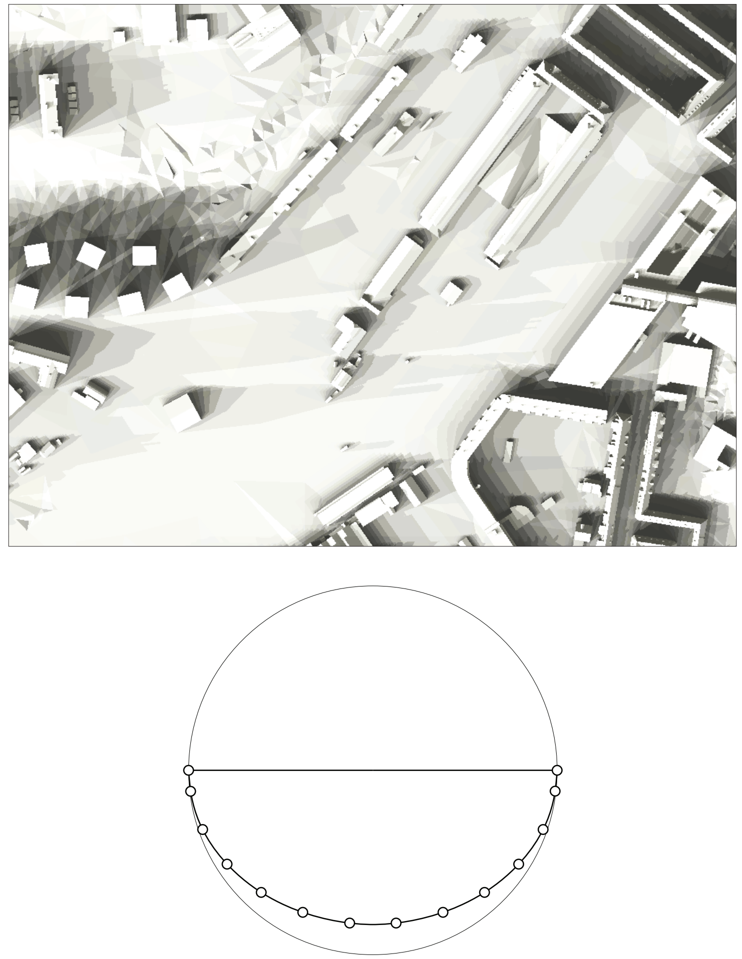
No innovative technology has been developed to save buildings in an instant flood scenario. Some of the options and ideas of today:

- The building adjusts to the water level within a frame.
- Build dams around the site
- Lead the water away through cannels or sewage systems.
- Build the building on poles above a presumed maximum water level
- Make a floating building
- Drainage

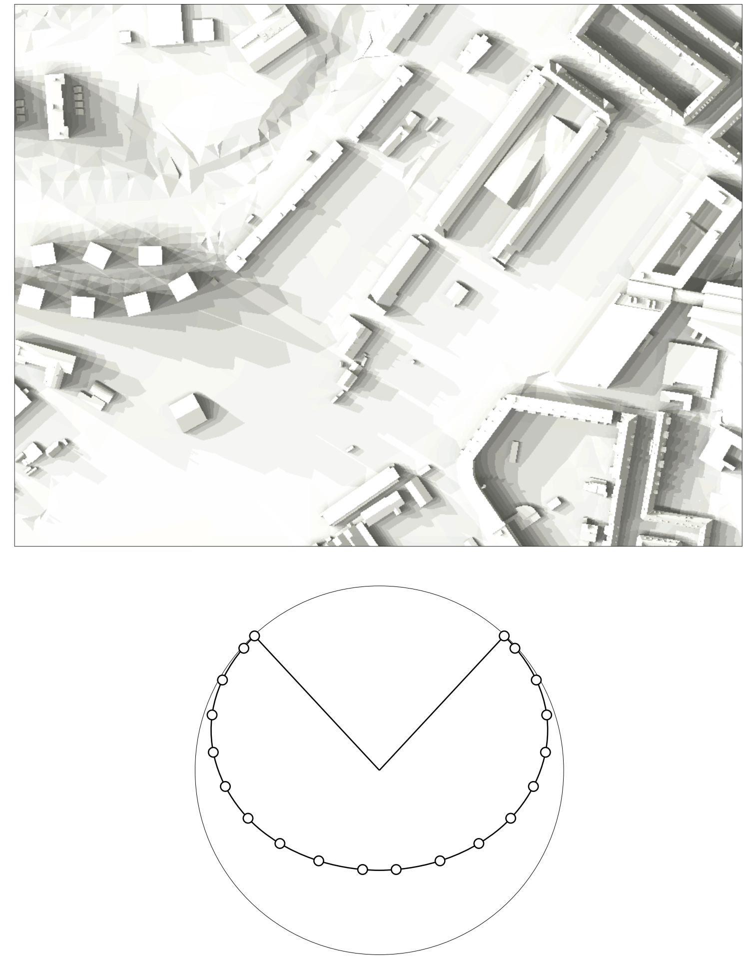
Many of these ideas and methods are expensive and some will always bring collateral damage, which can be taken into account as part of the design.



Ill. 20 Sun and shadows during winter solstice December 21st, 08:00 - 17:00



Ill. 22 Sun and shadows during spring equinox 20th March, 06:00 - 19:00

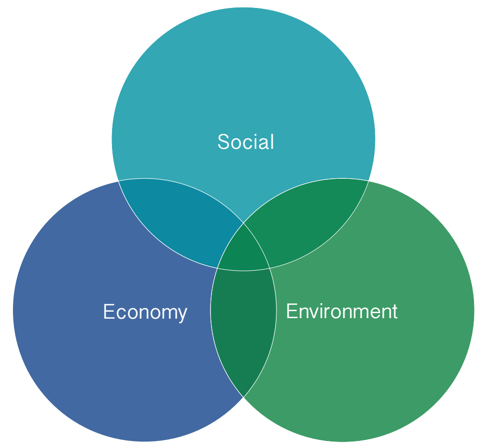


Ill. 21 Sun and shadows during summer solstice June 21st, 04:00 - 23:00

SUN ANALYSES

Aarhus is placed at the 56th northern latitude, giving a large variation in the sun inclination between summer and winter solstice. The sun inclination is at summer solstice in an angle of 58 degrees, whereas it at winter solstice is in an angle of 10 degrees. At equinox, where day and night will be at approximate the same length, the sun inclination is in an angle of 34 degrees.

The illustrations above show how the sun and surrounding buildings are shading the site during winter solstice, equinox and summer solstice. The illustrations show that shadows mainly affects the site for hours in the late afternoon and evening at equinox and summer solstice and that the shading effect from surrounding buildings is minimal at winter solstice, as the sun is coming from the south, where the buildings are low and placed at the same level as Godsbanen.



Ill. 23 Definition of sustainability

The definition of sustainability was first outlined in the report *Our Common Future*, also known as *The Brundtland-Report* from 1987. The definition relies on a holistic approach, where current development should not influence future generations possibilities for development. The definition was divided into three categories: Social, Environmental and Economic aspects. Sustainable buildings and architecture can in this relation be defined as: [Birgisdottir, 2013]

- Buildings where environmental impacts and energy consumption has been optimized over the lifespan of the building.
- Buildings where the use of chemicals has been limited.

- Buildings where the life cycle costs has been minimized.
- Buildings where high quality and flexibility ensures the value of the building for future use.
- Buildings where the useable area has been optimized.

- Buildings where well-being is enhanced by a good indoor environment.
- Buildings where the architecture and site plan supports its use and the local environment.
- Buildings placed to support sustainable (collective) transport.

Buildings are counting for approximate 40% of the total energy consumption in Denmark. [Bejder, 2014] The owner of the new Aarhus School of Architecture will be Bygningsstyrrelsen. Bygningsstyrelsen posses the most buildings in Denmark and are therefore focusing on sustainable buildings, which ensures the buildings low energy consumption and adaption for future use. [Universitets- og Bygningsstyrelsen, 2011]

> "A sustainable building meet demands and wishes in the present and contains a flexibility, which future-proofs its use."
> ***- Universitets- og Bygningsstyrelsen***
> p. 5 [Universitets- og Bygningsstyrelsen, 2011]

With 40-50% of the buildings energy consumption locked in the design, [Kongebro, 2012] and as studies shows that buildings with glass areas of more than 50% will have a bad indoor climate and an increased energy use, [Bejder, 2014] are early considerations of the architecture crucial for the building performance. On the other hand will considerations of ventilation, heating and shading (Passive and Active strategies) provide demands for the architecture. An integrated approach is therefore needed to ensure a design, which has low energy consumption and a good indoor environment. A good learning environment is essential for a school or university, as it will affect the learning and concentration ability of the users. Materials are here becoming important, as they have the ability to off-gas, which will affect the indoor environment, and as material in the exterior will be the visual expression of the sustainable approach.

With the characterization of sustainable buildings as energy efficient and with a good indoor climate, the aim for the project is to meet requirements for Building Class 2020 and at least Indoor Class B as outlined by Universitets- og Bygningsstyrelsen. The total list of requirements can be found on page 128 and in appendix 1.1.

PASSIVE STRATEGIES

Passive systems are low-tech, which requires no computers to function. They are based on knowledge to the site and simple physics to exploit the local conditions.

The knowledge allows the architect to make an integrated design by using geographically determined conditions. Common examples: using the wind as natural ventilation, collecting and reuse rainwater, earth cooling, allowing the sun to heat the building (thermal mass) or shelter the building from the sun. Research shows that plants and water lower the temperature in a room with a few degrees and affects the humidity. Water purifies the air and increases the comfort of the room as seen in Ministry of Foreign Affairs in Riyadh by Henning Larsen. The relation between cold a hot air is being used more and more to make natural ventilation, as seen by the use of solar chimney effect.

A normal passive energy building in Denmark will have walls with a high amount of insulation, a compact building mass and windows with a low U-value.

Ventilation is difficult to control due to the many variable factors, sun and wind. To insure the temperature and air values are within the limits of "comfort zone" a mechanical ventilation system has to be installed to ensure this, regarding school and office buildings. [Gonzalo, R. and Habermann, K., 2006]

ACTIVE STRATEGIES

Active strategies can be used to lower buildings energy consumption and provide an optimal indoor environment without excess temperatures. Studies shows that by using controlled isolated shutters, controlled sun shading, controlled natural ventilation and night cooling is it possible to lower an office buildings energy consumption to meet the requirements for Building Class 2020. [Brand, 2014]

Active strategies is characterized by mechanical systems, including sun shading, mechanical ventilation and cooling. However mechanical systems are often expensive and can be distracting for employees, as seen in adjustments of dynamic and automatic sun shading, which adjust to the sun several times a day. Those systems are often sabotaged by uses as they find the sudden adjustments distracting. [Brand, 2014]

Active systems does also include active ceiling panels, where the thermal mass is used to accumulate heat, giving a cooling effect. Active ceiling panels does contain embedded pipes in the buildings structures, where cool water is put into the system. However these strategies put demands on the used structures as light structures with their lack of thermal mass not will be suitable for those strategies. [Brand, 2014]

The envelope of the building is therefore becoming crucial for how the building will preform and which passive and active strategies it is possible to integrate in the design.

MATERIALS

Materials do not only express the architecture, but will also be the visual appearance of the buildings sustainable goal. With higher demands for energy efficient buildings, will materials in the future count for a higher energy consumption than the building it self. [Birgisdottir, 2013]

Building materials has the ability to emit Volatile Organic Compounds (VOC), which will influence the indoor environment badly and have an effect on the users productivity. [World Green Building Council, 2014] General requirements for materials used in university building is by Universitets- og bygningsstyrelsen listed as: [Universitets- og Bygningsstyrelsen, 2011]

- Materials in indoor environment must be Eco-labelled or have similar documentation.
- Materials and used products must not contain substances, which is on the Environmental Agency's list of undesirable substances.
- Materials and constructions must be robust and easily accessible. Possibilities for dust collections should be minimized and maintenance should be easy done, without detergents, which may influence the indoor environment.
- Wood used in public buildings must be documented sustainable sourced (FSC or PEFC certified) [Naturstyrelsen, 2014]

The project aim for a material selection, which compliment the architecture, it's surrounding context and is validated by analyses.

REQUIREMENTS

The building must meet *Building Class 2020* for schools and offices:

- The total energy supplied for heating, ventilation, cooling, domestic hot water and lighting must not exceed **25 kWh per. year per. m^2 heated floor area**. [Energi Styrelsen, 2015c]

- External wall: < 0,10 W/m2K
- Floor: < 0,08 W/m2K
- Roof: < 0,07 W/m2K
- Windows: < 1,00 W/m2K

The indoor environment must at least meet Indoor Class B and requirements stated in the building regulations: [Universitets- og Bygningsstyrelsen, 2011]

Thermal:	Operative temperature, summer:	21 – 26 ^{0}C
	Operative temperature, winter:	21 – 24 ^{0}C
	Tolerance:	100 h > 26 ^{0}C
	Tolerance:	25 h > 27 ^{0}C
Atmospheric:	CO^2:	< 1000 ppm
Visually:	Daylightfactor: [Energi Styrelsen, 2015b]	minimum 2 % in workzones
Acoustic:	Reverberation time: [Anvisninger.dk, 2015]	
	• Class rooms:	< 0,6 s
	• Class rooms for woodwork:	< 0,6 s
	• Rooms and corridors (study space):	< 0,4 s
	• Corridors (not study space):	< 0,9 s
	Absorption area: [Anvisninger.dk, 2015]	
	• Open learning spaces:	> 1,3 x floor area
	• Common rooms higher than 4m and room volume bigger than 300m^3:	> 1,2 x floor area
	Noise in offices from technical installations:	$L_{Aeq,30s}$ < 35 dB
	Noise in classrooms from traffic:	L_{den} < 33 dB
	Noise in offices from traffic:	L_{den} < 38 dB

CURRENT CONDITIONS

Aarhus School of Architecture was established in 1965 as a counterpart to the school of architecture in Copenhagen. In the beginning the school had 150 students [Denstoredanske.dk, 2015], but today it has around 800 students and 150 employees [Aarch.dk, 2015]. The school educates bachelor-, master- and phd-students in different disciplines within architecture, urban design, cultural legacy and design.

The schools location has always been temporary since the day the first students moved in. Instead of moving to a new location, the school has just grown and started to occupy the surrounding buildings as the need for space increased.

The students spend most of their time in the studio, where they make their work; whereas it is drawings, models or other ways of expressing themselves. It is also in the studio the students receive feedback from professors and mentors. Besides the studio they use the auditorium for lectures. Smaller rooms are located around the school for pinups and critics.

The education form is based on classes divided into units. The students stay with one unit at the time. At their 1st year, approximately 150 students are divided into 3 units. At the 2nd and 3rd year the students are mixed into 6 units across the semesters. Each unit has assigned it's own professors, studio and study plan, but are defined by the professors and their background. [Appendix 1.3]
At the master the students pick their own classes, this mean they can customize their education, fit to their personal interests.

Some students have been interviewed as part of the preparation for the new school. The students pointed out what they appreciated at the current location and what they problematic. They suggestion two additions to the existing program; such as model rooms closer to the studios, so they would not have to glue and cut at their own desk, more storage options for models and materials and a photo room.

The distribution of the buildings have created the need to cross Randersvej to get from one part to another. This was also a great issue for the students. The fragmentation creates a lot of courtyards between the buildings, which is greatly appreciated by the students, expect for when they had to moved material from the workshop back to the studio.

> "It should be a rough house, that can withstand use – a place with vibrant workshops and openness, where the students can express themselves, and where users experience the school as a fantastic place to be."
> *- Torben Nielsen, rector of Arkitektskolen Aarhus.*
> [Helbo, 2014]

A new proposal for Aarhus School of Architecture, should contain some of the aspects of the existing: the intimate smaller spaces, places to meet and have a spontaneous meeting, but be a more coherent building with an internal well designed flow between it's functions.

Ill. 24 Nolly map of Aarhus and Aarhus School of Architectural

SUMMARY OF SCREENING

The architectural firm Signal has made a screening of what will be needed for the new Aarhus School of Architecture . The screening has been validated and will function as a guideline for the suggestions presented with minor alterations and additions.

The screening indicates a room program of 12.000 m^2 net usable area and suggests a gross area of 16.900 m^2. Based on the screening, the vision is to develop a building, which include: [Signal 2015]

- Interacts with the city
- Exhibtion space
- Good working environment for the employees and optimal studying facilities, for the students to explore and develop themselves.

The building program has been divided into 5 different categories.

EDUCATIONAL SPACES [5.900m^2]

Primarily for the students and will be the space where they spent most of their time. It will be functions, which support and develop the student's competencies, with the option to receive feedback in smaller and larger groups. Primarily functions will be studios and educational rooms.
The screening indicates that more than 65% of the students currently spend 5 hours+ a day in the studios. The students appreciate the option to interact with other students, make mood boards and the option to focus and concentrate. 43% of the staff spent time in the studios on a daily basis and 16% spends more than 3 hours a day to give the students feedback.
Signal has assigned 7m^2 per student and has calculated with 800 students, plus other lecture rooms. [Signal, 2015]

BACK OFFICE [2.320m^2]

Primarily for the staff, with space to create, develop and share knowledge. Some of the key features are space for contemplation and spontaneous meetings. The access to knowledge should be easier to access in the new building.
An analysis of 64% of the staff indicates that on a typical day, they spend 40-60% of their time by the desk and about 18% is work, which requires a high level of concentration. The staff members themselves value an office to concentrate, with access to co-workers, privacy, to work on research and prepare lectures.
Signal has calculated with a workforce of 145 people with 15m^2 pr. office, with flexible rooms, guest apartments and more. [Signal, 2015]

INSPIRATIONAL SPACE [1.550m^2]

Is for all the school's users and invites the outside world into the school. The Inspiration Space is a showcase for the school and is characterized by a strong technical focus and is based on experiences, reflection and collaboration. One of the primary functions of inspiration space is the library.
55% of the students and 48% of the staff uses the library on a daily basis. [Signal, 2015]

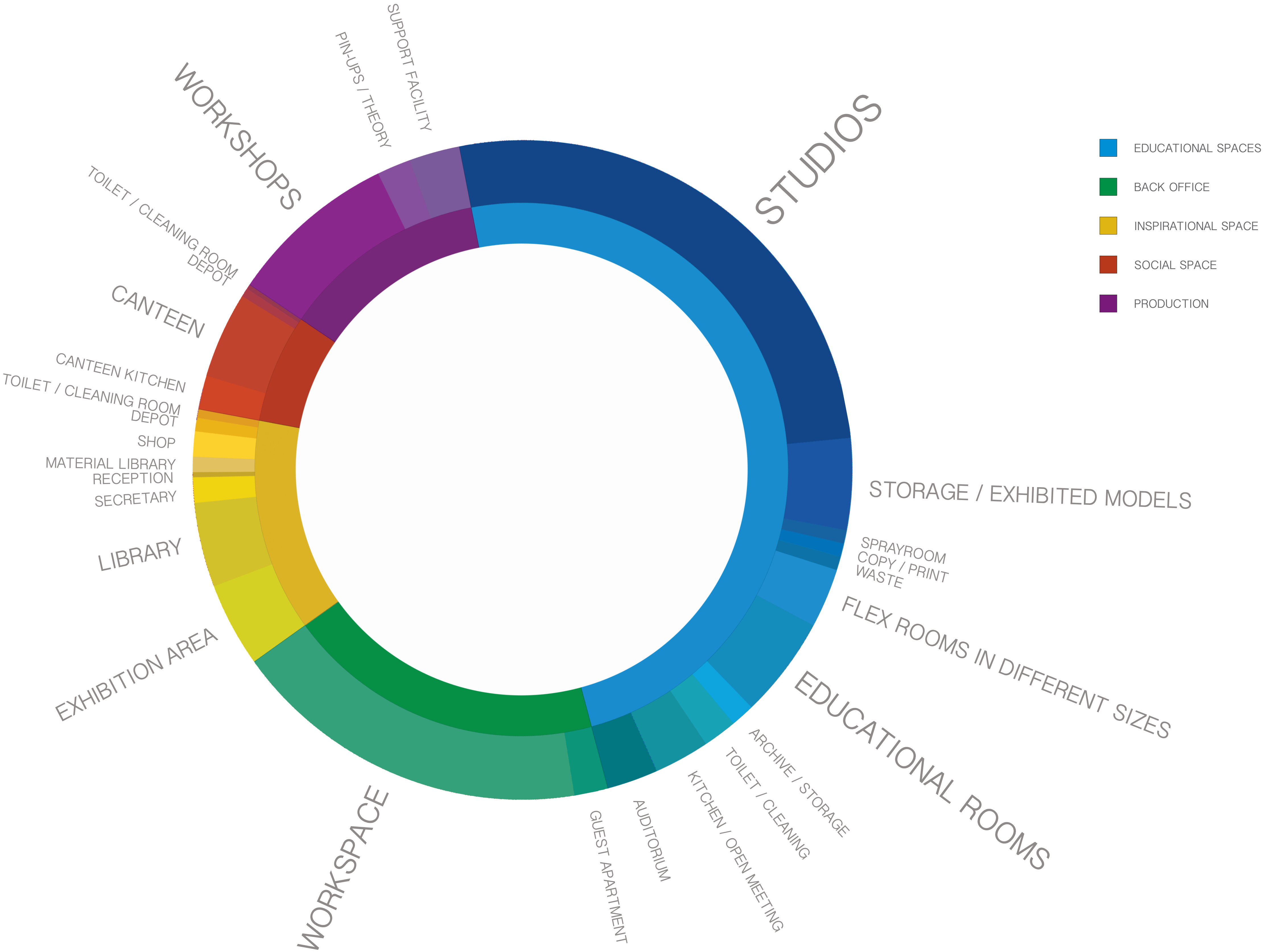
SOCIAL SPACE [790m^2]

The social space is for all school users and can be used by people from outside. The social space is the school's central meeting place and supports professional and social interaction. One of the primary functions is the canteen.
The current canteen is used almost by everyone every day for less than an hour.
Some of the good important features in the new canteen should be: a central location, related to some cosy outdoor spaces, spatial differentiation that allows you to sit invisible in a large room or choose an intimate niche. [Signal, 2015]

PRODUCTION [1.500m^2]

Production Space is for school staff and students. Performing relatively creative activities with physical artefacts that challenge the users. Primary functions are coarse- and fine-workshops and labs.
57% of the students do not use the current workshops and labs; this might be due to the period of the observation. Closer to an assignment's due date the workshop will properly be very busy.
The new workshops should be located close to the studios and have the option to open up to nature, with no noise pollution from the workshop and it should be easy to depose waste materials.
[Signal, 2015]

Complete room program is in Appendix 1.1.



Ill. 25 Diagram of Room program

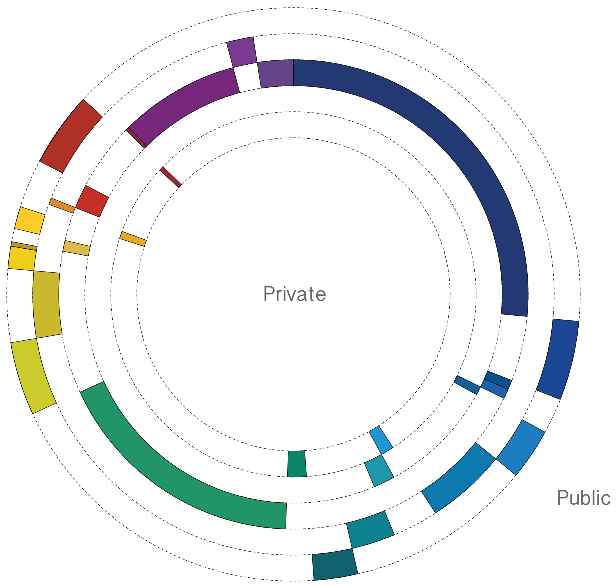
ROOM PROGRAM

ROOM	NUMBER	AREA EACH	TOTAL AREA
STUDIOS	800[1]	4[1]	3200
STORAGE / EXHIBITED MODELS	-	-	540
SPRAYROOM	-	-	80
COPY / PRINT	-	-	80
WASTE	-	-	80
FLEX ROOMS IN DIFFERENT SIZES	-	-	350
EDUCATIONAL ROOMS	-	-	600
ARCHIVE / STORAGE	-	-	140
TOILET / CLEANING	63[2] / 8[3]	-	200
KITCHEN / OPEN MEETING	-	-	330
AUDITORIUM	1	300	300
GUEST APARTMENT	-	-	200
WORKSPACE	145[4]	14,7	2130
EXHIBITION AREA	1	500	500
LIBRARY	1	500	500
SECRETARY	10	15	150

ROOM	NUMBER	AREA EACH	TOTAL AREA
RECEPTION	1	30	30
MATERIAL LIBRARY	1	90	90
SHOP	1	150	150
DEPOT	1	150	80
TOILET / CLEANING ROOM	-	-	50
CANTEEN KITCHEN	1	200	200
CANTEEN	1	510	510
DEPOT	1	50	50
TOILET / CLEANING ROOM	-	-	30
WORKSHOPS	-	-	1000
PIN-UPS / THEORY	-	-	200
SUPPORT FACILITY	-	-	300

[1] Number of squire meters required pr. Person
[2] 15 toilets pr. student / worker (10 appointed to Back Office) [Energi Styrelsen, 2015a]
[3] 5 handicap toilets for students (3 handicap toilet for Back Office) [Statens Byggeforskningsinstitut, 2014]
[4] 29 individual offices, rest as open offices

Table 1 Functions and area, for details see appendix 1.1.

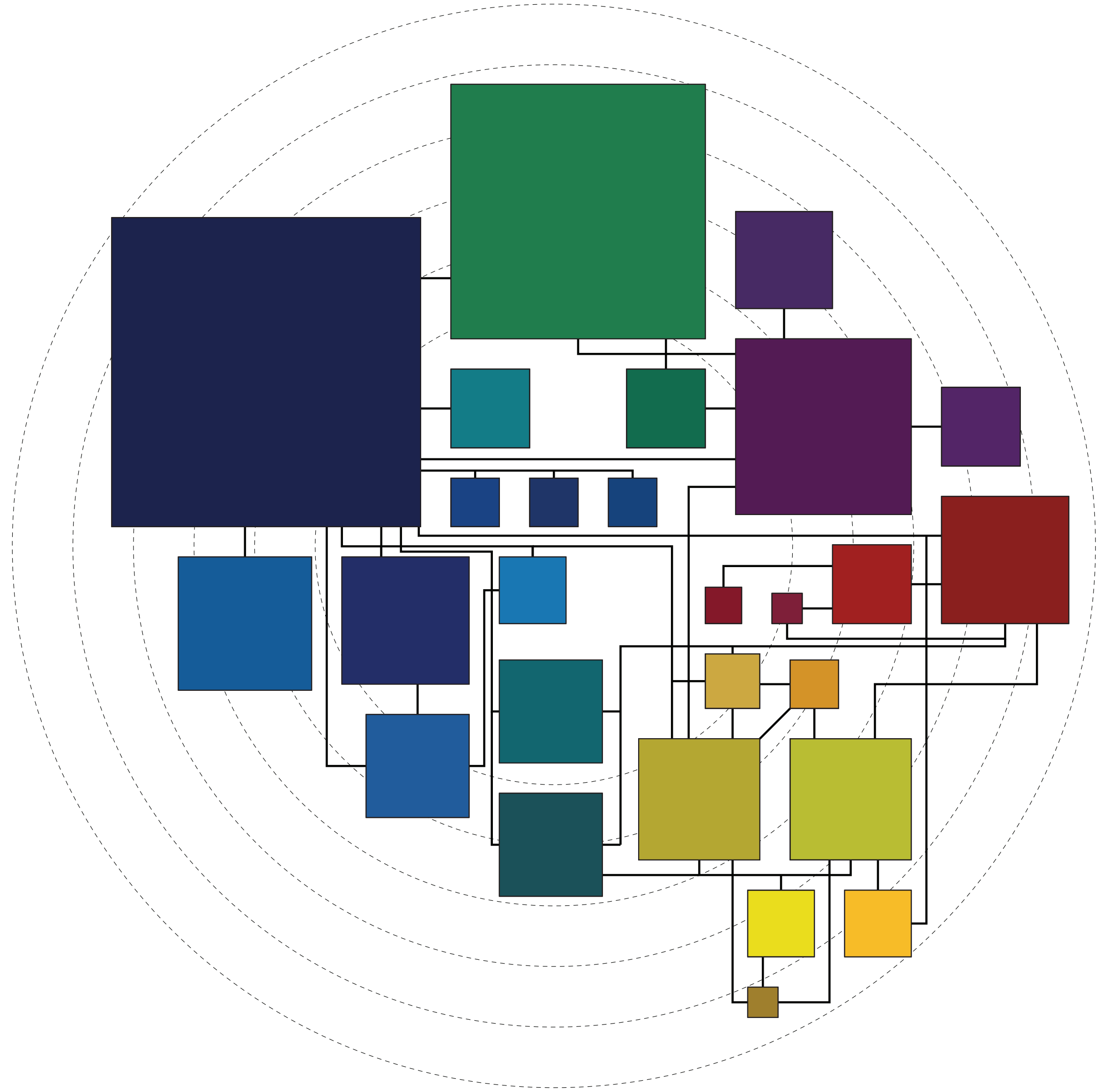


Ill. 26 Iteration of room privacy, orientated from private to public

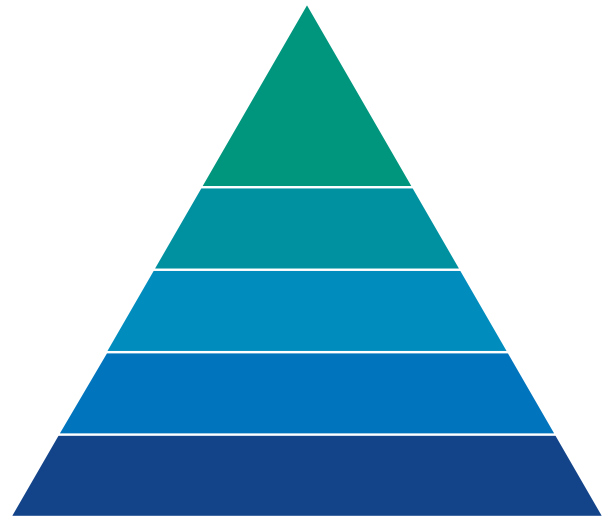
FLOW DIAGRAM

The visualised room program, shown in Ill. 26, suggests the rooms sizes in relation to each other. This illustration does not look at the internal relationships and the privacy of the rooms. By interpreting the wishes in the preprogram and by looking at aspects of learning, discussed in the next section, does Ill. 27 show an iteration for how private or public each room should be. Ill. 26 shows a further interpretation of the flow between each room and their orientation according to privacy and publicity.

Table 1 shows the room program with approximate number of rooms and total sizes. Workspace for students is divided with the total number of students, the overall definition of the required number of studios will be defined as part of the design process. For the room program including technical requirements, see Appendix 1.1.



Ill. 27 Flow-diagram, orientated from private to public



Ill. 28 Maslow's pyramid of needs

HERTZBERGER

Hertzberger has, in his book *Lessons for students of Architecture*, discussed and developed reasonable theories about people and their claim and relation to spaces, also in relation to learning environments.

To feel related to a specific place, you need to feel you have influence on the space, to be responsible in some level for it, if it decorating, maintaining or simply be an "exclusive" user. The way you feel a classroom is a private place, compared to the hallway and the school as private compared to the road. Hertzberger uses a middle school classroom as an example and focuses on the relation the students feel to the classroom, by decorating the walls and windows with their work. In this way they make their room unique and can recognise it from the outside as well as displaying their work. As a result the user feel more and more responsibility and will change from a user to a dweller. In this way the individual or a group can change their perception of a public space to a private space and start to feel at home at this place, users becomes inhabitants. [Hertzberger, 2009]

> "There can be no adventure without a home-base to return to: everyone needs some kind of nest to fall back on."
>
> - *Herman Hertzberger*
>
> p. 28 [Hertzberger, 2009]
>
> In relation to educational environments.

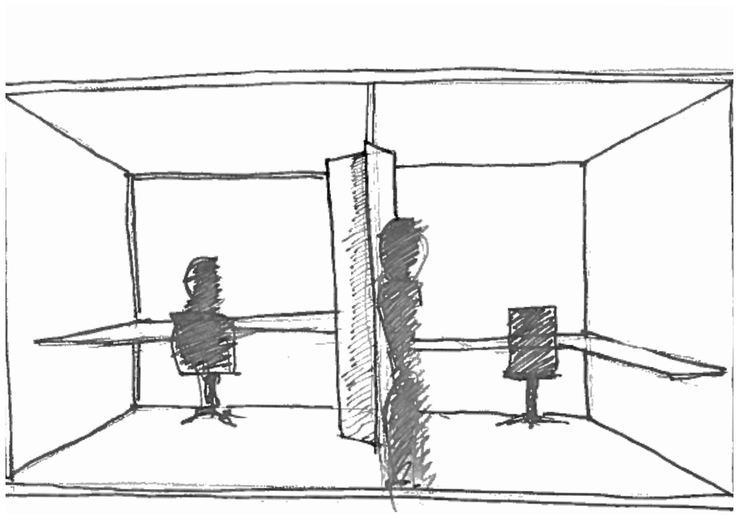
It is important for students, especially children, to be able to leave their workstation and display their work without fear of their things being destroyed. They should also be able to leave their unfinished work without a danger of it being moved or cleaned up by others. This can result in a feeling of "losing" your own space. [Hertzberger, 2009]

If a room has a multifunctional usage, it can have a negative impact to the relation the user has to the room. If, for example, furniture has to be moved in order to make space, they might not be put back in the right place, models might be damaged or broken and objects might disappear. [Hertzberger, 2009] A shared or multifunctional space will have a need to storage your work temporary, if needed. It should be easy to change to "your" settings to make it personal, this might be the seating height of the chair, make it possible and easy for the user to adapt the space to them to make the space personal.

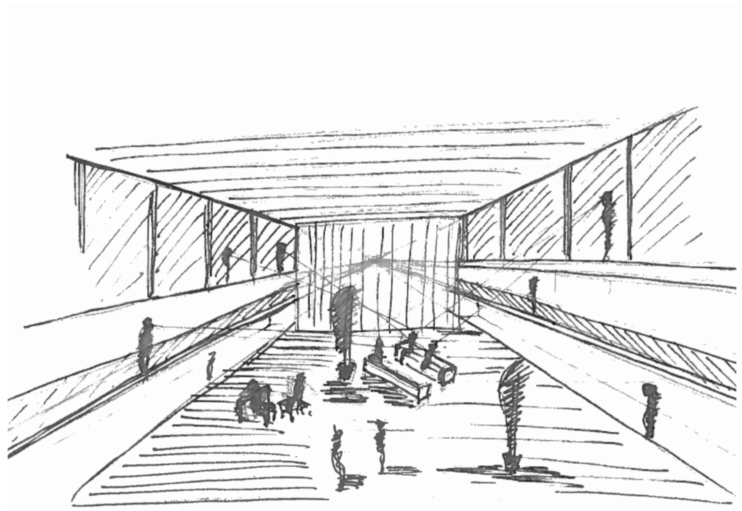
The student's current "home-base" or "nest" is their studio. From here they go to the lecture rooms, auditorium and workshops to explore their field of education or to get critic. Then they return to their studio to reflect and process the new impressions and knowledge they have gained.

When the students feel safe, they dare to take a chance, ask what might seem like a foolish question, explore a crazy idea and let it developed. All very important elements when you are in a learning process and developing your self and your skills. By a quick view at Marlow's pyramided of needs, which basically describes what "needs" you need fulfilled in order to advance towards the top. It goes from basic survival at the bottom, to intellectual development at the top. The need for a nest is especially important when developing and exploring your creativity (self actualisation).

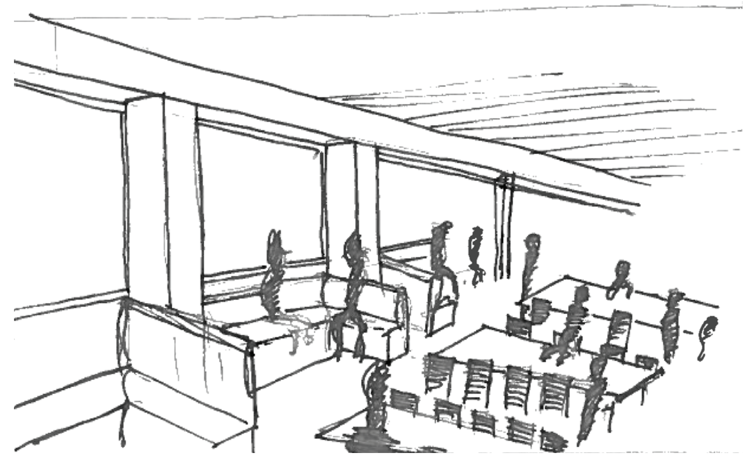
> "A 'safe nest' – familiar surrounding where you know that your things are safe and where you can concentrate without beings disturbed by others – is something that each individual needs as much as each group."
>
> - *Herman Hertzberger*
>
> p. 28 [Hertzberger, H., 2009]



Ill. 29 Adaptable workspaces



Ill. 30 Visual connections from offices



Ill. 31 Informal meeting places and canteen area

LEARNING ENVIRONMENTS

Like Hertzberger are Eva Gulløv and Susanne Højlund stating in their text *Materialitetens Pædagogiske Kraft*, that the ways we furnish our institutions have an effect on the social development of children. The rooms become the context for the users, making the relationship between the user and the room's important. [Larsen, 2005] Those statements are seen in relation to children institutions. However a similar need for a relationship between the users and the buildings are seen in the institutions for higher education. In 2003 a project, *Rum, Form og Funktion*, was carried out by Statens Forsknings- og Uddannelsesbygninger. The outcome of the project was a sketching program analysis, where five Danish architectural firms came with their ideas upon the configuration of future universities. The proposals were based on interviews with different employees and students from the universities. Here the interviews showed that the canteen played an important role as an informal place, where students and researchers could meet, but also that there was a lack and ability for the students to influence the spaces. [Rum Form Funktion, 2003]

> "Before the project room will work as a workplace, they must be able to make it their own."
> *- Lone Dirckinck-Holmfeld, research professor, Department of Communication, AUC.*
> p. 49 [Rum Form Funktion, 2003]

The future universities, and in this context a new architect school, should give the users the feeling that they are embedded with the room. A new flexibility in the spaces should give possibilities for those to adapt both the users and their needs, but also to future needs. [Rum Form Funktion, 2003]

> "On the future workplace there is a need for a place, where one feels embedded with the room as a place for concentration, contemplation, and where one can think and write"
> *- Sisse Siggaard Jensen, Associate Professor, PhD. Department of Communication, Journalism and Computer Science, RUC.*
> p. 56 [Rum Form Funktion, 2003]

The future buildings for higher education should in a higher degree promote user activities, such as specific rooms for contemplation. Rooms for deep contemplation should not only be dark rooms hidden away in a core, but also be rooms where people want to come. Rooms and facilities should promote use and social activities, so the institutions and the buildings in a higher degree would encourage the social life and knowledge sharing. [Rum Form Funktion, 2003]

> "Well, students should not only be taught, they should virtually perceive their place of study as their second home."
> *- Jakob Lange, Kontorchef, Copenhagen University.*
> p. 79 [Rum Form Funktion, 2003]

Canteens are in this relation not only becoming places for knowledge sharing, but also the place where the institution meets the city. As knowledge is not only subject to the Universities and educational institutions today, are the buildings in a higher degree becoming a urban driver for life, where the canteen plays an important role as the informal transition from the city to the institution. [Larsen, 2005]

The interaction between offices, canteens and informal meeting places are seen as a way for a higher knowledge sharing. Office corridors should be avoided as they are seen as a barrier. Flexibility is in this relation seen as one of the main focus points. Offices could be divided by sliding doors making sharing and discussions between researchers easier. A high level of flexibility should also be found in new educational rooms. A study showed that many of the educational rooms were only used 50% of the daily use time and that subject specific rooms, were used less than larger classrooms (30 – 60 persons) and auditoriums. The study, which was carried out at 10 universities, showed that the average size utilization where higher in subject specific rooms than in the compared large classrooms and auditoriums. [Rum Form Funktion, 2003] An easily transformation from classrooms to workspaces could in this relation be seen as a option if the students would have the possibilities to make the spaces their own, when the space would not be in use as a classroom.

CREATIVITY AND LEARNING

The needs for new learning spaces is also expressed by Jos Boys in the book *Towards Creative Learning Spaces, Re-Thinking the Architecture of Post-Compulsory Education*. Boys points out that creative educations are the place to start when implementing and exploring new learning environments, as those institutions are more open for new approaches and as they in their origin already are working within more flexible and informal learning environments. [Boys, 2011]

Likewise are Brian Lawson pointing out that creative educations are encouraging an approach of “learning by doing” not only theological studies. [Lawson, 2005] Creative educations are related to a high degree of self-exposure, the surroundings should therefore provide “safe” and “secure” environment, where the students feel relaxed and are able to take the risk of expressing and exposing themselves. [Boys, 2011] A “safe” and “secure” frame is therefore essential in architectural environments as architecture deals with personal expressions of external problems. [Lawson, 2005]
Optimal spaces for creativity have therefore been described as an un-interrupted and private space, where it is possible to work and “meditate”. Where others would argue that a space for creativity and learning is more of a mind-set, than an actual space. [Boys, 2011]
Optimal spaces for learning, and in this context improved spaces for creativity, can therefore be seen as subjective positions, some would argue that privacy creates the best frame, whereas others would find attention and attraction as the main driver for the creative process. [Boys, 2011]

> “A good learning space for me is a frame of mind, rather than an actual space. It is internal rather than external.”
> - *Quotation from tutor in art and design education, Person unknow*
> p. 8 [Boys, 2011]

CREATIVITY

To create optimal conditions for creative learning spaces is the understanding of creativity essential. Creativity is generally defined as: “*The use of imagination or original ideas to create something; inventiveness.”* [Oxford Dictionaries, 2015] Creativity can in this relation be seen as the rise of an original idea. The understanding of how this imaginative original idea rises is therefore essential for the framework. Thinkers and artists have expressed that their ideas have been floating, when they have been half asleep, completely themselves, in a relaxing moment in front of the fire or just after sleep. Those sudden emergences of original ideas are often referred as “Eureka” moments. [Lawson, 2005]

> “When I am, as it were, completely myself, entirely alone, and of good cheer – say travelling in a carriage, or walking after a good meal, or during the night when I cannot sleep; it is on such occasions that my ideas flow best and most abundantly.”
> - ***Mozart, composer***
> p. 148 [Lawson, 2005]

The creative process can be described as a more chronological process where the idea evolves in five phases. [Lawson, 2005]

- *First insight* reveals the problem and the commitment to solve it.
- *Preparation* uses a conscious effort to solve the problem. This phase is seen as an intense period, where various solutions are found.
- *Incubation* is a more relaxed period, where the mind can rest, while working on another things.
- *Illumination* where the moment where the original idea strikes, the “Eureka” moment.
- *Verification* where the idea is developed and tested, which might lead to new interpretations and problems.

However those five aspects cannot purely be seen isolated, Herman Hertzberger argues that gained knowledge and experiences is essential as a reservoir for creativity. [Lawson, 2005]

Likewise Hertzberger, is Peter Holdt Christensen in the book *Kreative rum* stating that creativity is normally associated with thinking-out-of-the-box, which requires an extensive knowledge within a specific field. Creativity is here described as a continuous process, which will emerge both at work and at leisure time, as described by Lawson as the Eureka moment. [Christensen, 2014]

Creativity has become a symbol for companies and a tendency has been to organize offices to improve creativity amongst the employees. Creative office designs have been associated with messy tables and colourful spaces, where open space planning is used as way for encouraging social relations and collaboration, which are found as cornerstones for creativity. However a lot of effort has been put in to create those creative spaces, only little has been done to prove that the spaces actually are stimulating creativity. [Christensen, 2014]
Where a stimulation of creativity has not yet been proven, diversity in the office layout has been proven to result in more productive employees. [World Green Building Council, 2014]
However where diversity and open space planning are seen as a way to improve collaboration and creativity within the office, are those layouts often associated with acoustical problems. A study in 1998 showed that distracting noises would lead to a 66% drop in performance and a study carried out in 2005 showed that 99% had a reduce in concentration when they where exposed to background office noise, from conversations and unanswered phones. [World Green Building Council, 2014]
Acoustics are therefore becoming import for the well-being of the employees and their productivity. Soft and absorbing surfaces are therefore essential for those large spaces. Plants and greenery can be used as absorption. There has in the past been an increase in the use of plants and greenery referred to as Biophilia design as natural elements has shown to improve cognitive functions, lower stress and improve creativity. Plants and greenery have also proven to enhance the indoor comfort, as plants filter the air and thereby absorb off-gasses from materials and room elements. [World Green Building Council, 2014]

> "Designing for a diversity of working spaces is key to a productive office."
>
> \- *World Green Building Council*
> p. 31 [World Green Building Council, 2014]

A survey, done for the carpet manufacture Interface, shows, that natural elements at the office could improve the employees' well-being with 13%. The study also showed that employees, who had access to sunlight, were up to 8% more productive than others. Interface concluded the survey with a top-5-list about what the architecture should include, based on the answers from employees asked. [Erhardsen, 2014]

- *Natural light*
- *Quiet working environment*
- *View to the sea*
- *Greenery*
- *Clear colors*

The studies show that natural light is essential for the well-being, also in relation to sustainability. A resent study carried out by Henning Larsen Architects shows that diversity in the daylighting strategy will influence how long the user wants to spend in the spaces. [Henning Larsen Architects, 2015] It is therefore import that technical requirements are combined with the architectural vision for the perception of the spaces.

DESIGN PARAMETERS
ANALYSIS

NATURAL ELEMENTS

Enforce the wellbeing of the users and the learning environment.

- Integrated naturel elements can improve wellbeing with up to 13%.
- Access to sunlight (8% more productive).
- Plants and greenery improves air quality.
- Trees and plants can be used as passive sun shading.
- Influence the microclimates.

ADAPTABLE

To be sustainable and secure the building's future, the design will have to be adaptable to new conditions and users/uses.

- Adapt to other users easily.
- Be transformable, change usage of a room.
- Flexible rooms.

DOCKING

Inspired by the thoughts from the Institute for (X), the idea of the dock will be integrated, providing:

- Options for 1:1 mock-ups.
- A place to prepare material before it is being shipped to the user.
- Encourage a more practical than theoretical approach.
- Inspire students to make subjects for a receiver.

MODERN LEARNING SPACE

A new perspective on learning environments, based on modern thoughts and ideas, considering the different factors influencing and improving the way we receive education:

- Optimal acoustics
- Views to water, trees, nature.
- Socialising
- Your own place to study
- Places for contemplation
- Flexible spaces

AARHUS Å

As a signature of Aarhus, it will be integrated into the site and the building.

- Enforce the learning effectiveness and productivity.
- Extend Aarhus Å's path, by leading it into the new cultural hub.
- Lead people from the harbour to the site.
- Prevent flooding, integrate with *Klimatilpasningsplan 2014*.
- Expands Aarhus Å's "atmosphere".
- Connect the city centre with the new cultural hub.

TECHNICAL

An integrated process will take point of departure in the architectural discipline with the technical aspects as guidelines:

- Indoor climate, minimum category B.
- Primary passive sustainable strategies.
- Material (sustainable, acoustics, phenomenological).
- Optimal acoustics conditions for workspaces.
- Diversity in daylight (minimum 2%).
- Flexible building (installations, walls, usage).

VISION

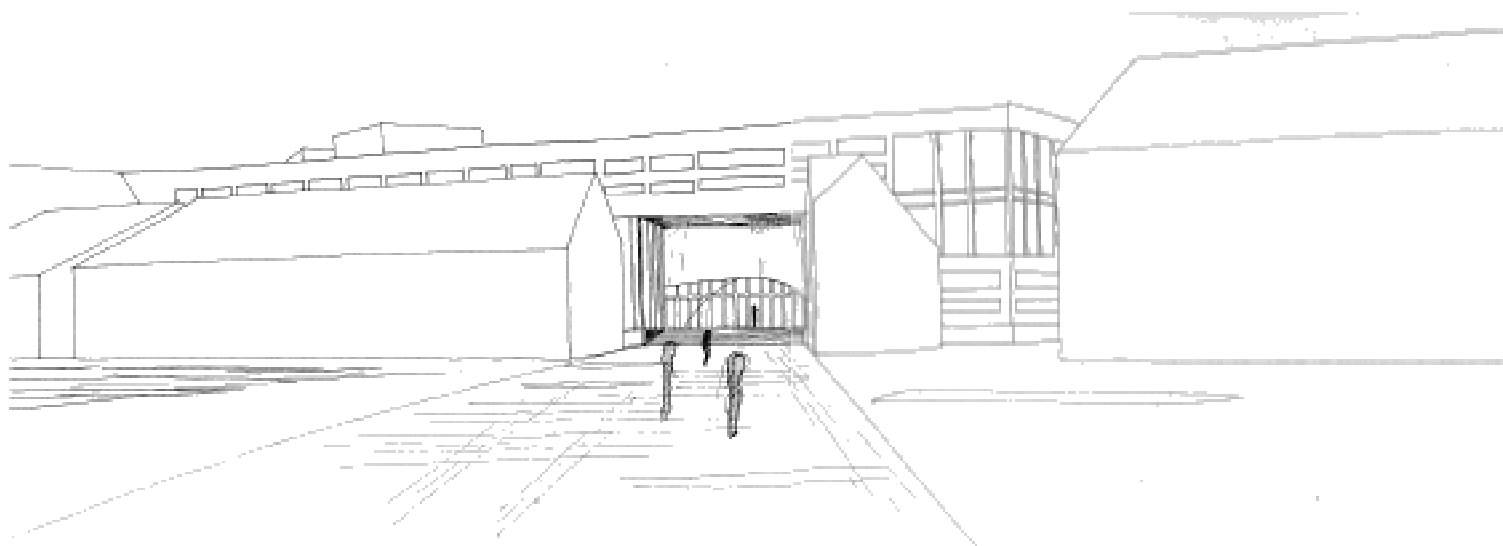
The aim for the project is to design creative learning environments, where the design will provide a rough setting for learning, knowledge sharing and individual contemplation. The building should be sustainable by being flexible and adaptable, allowing the user to interact and influence the building in the present and future.

The building should enhance the existing cultural and creative elements, by being a dynamic participant in a new cultural hub, which will connect with the existing city centre by ending the axis from the city hall.

Ill. 32 Picture of Institute for (X) - the site

PRESENTATION

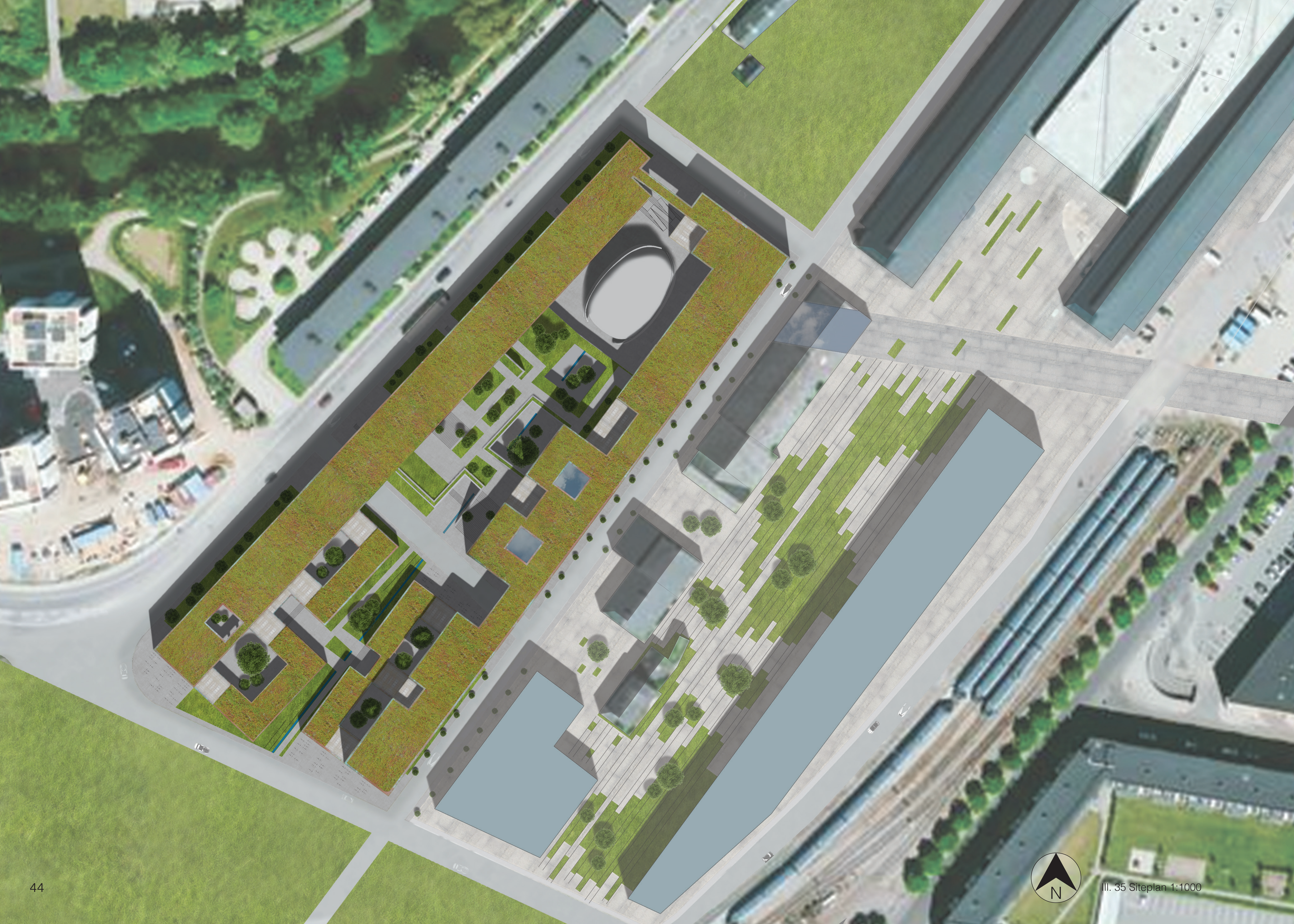
Ill. 33 Working model



ARCHITECTURAL JOURNEY

The finally to the axis started in the city hall, going through Scandinavian Center climaxing in the new creative centre of Aarhus, Aarhus School of Architecture. Along the axis is a progression of architecture, the city hall, a treasured, modernism work by Arne Jacobsen, the monumental post-modernistic Scandinavian Center by Friis og Moltke, by the transformation of Godsbanen originally a work of Wencks, transformed by 3XN. When the historic journey enters the architectural school, the flow pivots around the auditorium and continues south-west, through the building, guiding the architects of tomorrow, into a developing area.
The new axis will end undefined, to be defined by future projects in the area of development.

Ill. 34 Concept sketch



Ill. 35 Siteplan 1:1000

MASTERPLAN

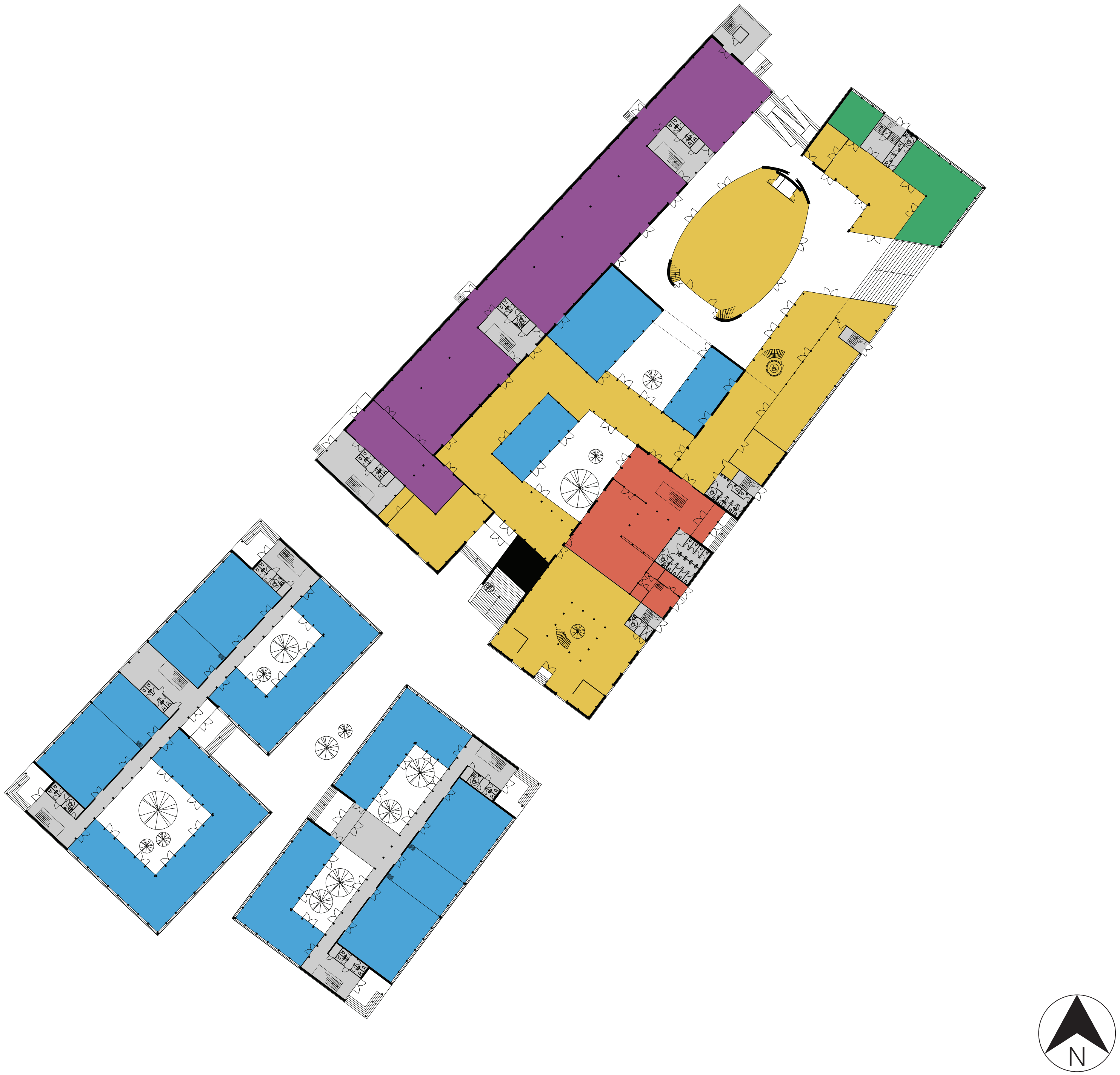
The masterplan is integrated into the context. Inspired by lines and flow from the existing roads and buildings. Especially the unfinished axis from the city hall and the old rails from the south have been two major factors determining the masterplan. A green wedge comes from south as a park, with the old rail integrated into the design. The green wedge splits just before entering the site and the major part continues all the way to the plaza in front of Godsbanen. The minor part of the wedge takes a left and runs between the building volumes and continues through the senior housing and where it connects to Aarhus Å.

The pavement and atmosphere in both parks have a historical relation to Aarhus and the area. The eastern park is related to Aarhus' use of railways and the historical impact this factor had on the city. The tracks end at the plaza, where they meet the axis from the city hall, as all railway tracks start and ends in Aarhus, no train runs through the city. The old railway will inspire the pavement and atmosphere of the park. The western park relates to the story of the origin of Aarhus and how one of the city's most significant brands carved the area out as a valley in the landscape.

As part of the plan from the municipality of Aarhus, the siteplan contains a 3 stories parking complex, a 4 stories building and is keeping the existing old buildings. The old buildings are indented to contain functions related to their original functions. The fruit marked might be established again and retail or restaurants in the old customhouse and the preserveable tarpaulin house. The 4 storey building, located in the east of the site, is intended to be mixed functions, with retail, cafes and living. The context-buildings are sketched on a conceptual level and has been designed completely from context lines and heights.

1ST FLOOR

Presentation



Ill. 36 1st floor, 1:1000

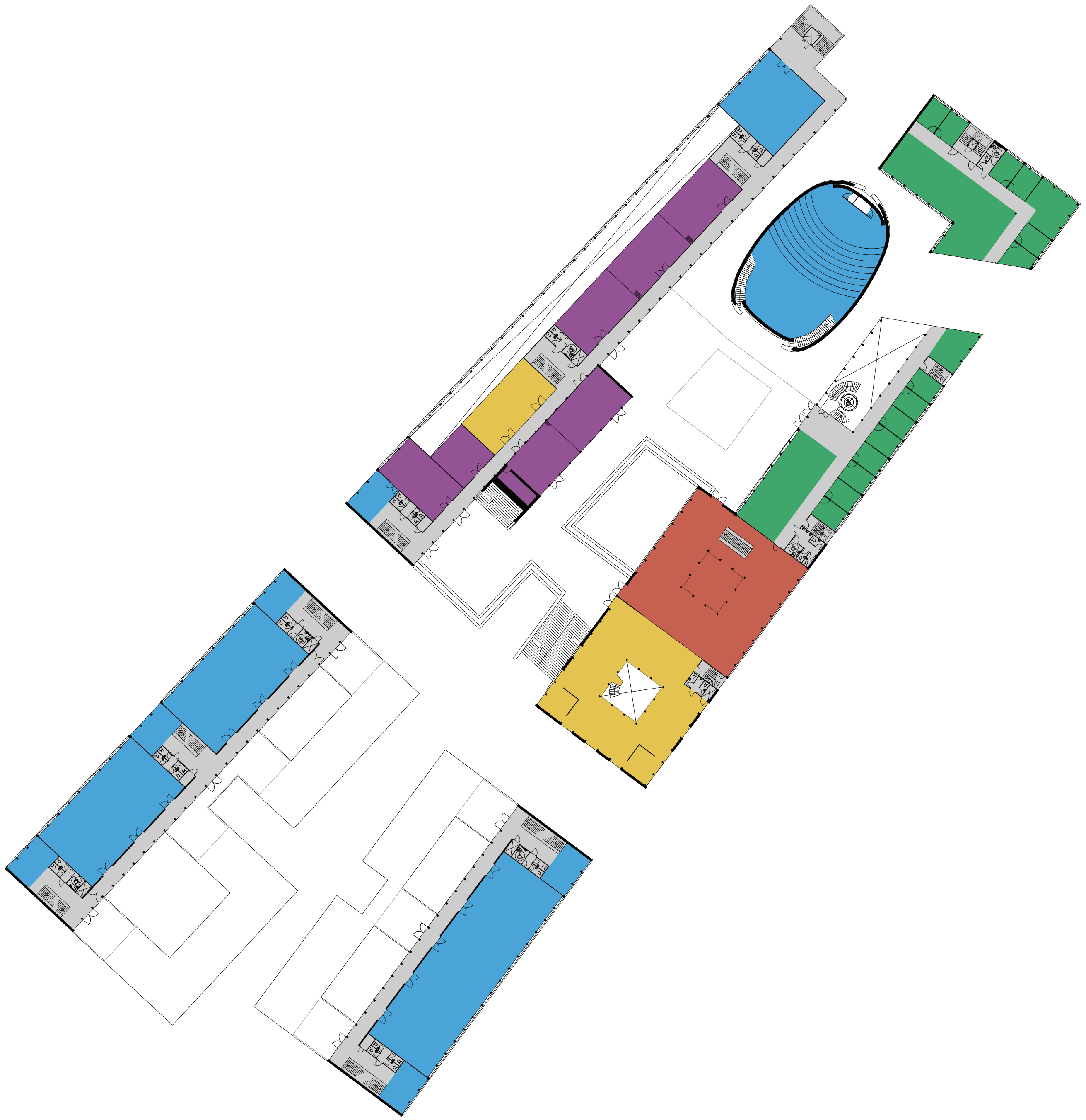
- Educational spaces
- Back office
- Inspirational space
- Social Space
- Inspirational space
- Additional spaces

AREA	7190m^2
EDUCATIONAL SPACES	**2432m^2**
Educational Room	555m^2
Flex Room	100m^2
Studios	1782m^2
BACK OFFICE	**202m^2**
Workspace	202m^2
INSPIRATIONAL SPACE	**2160m^2**
Achive	50m^2
Depot	37m^2
Exhibition	311m^2
Front Desk	43m^2
Internal Street (Exhibition)	978m^2
Library	432m^2
Secretary	158m^2
Shop	151m^2
SOCIAL SPACE	**369m^2**
Canteen	119m^2
Cateen Kitchen	203m^2
Canteen Depot	47m^2
PRODUCTION SPACES	**1240m^2**
Support / Depot	152m^2
Workshop	1088m^2
ADDITIONAL SPACES	**989m^2**
Elevator	21m^2
Gallery	252m^2
Restroom	157m^2
Stair	559m^2

2ND FLOOR

Presentation

- Educational spaces
- Back office
- Inspirational space
- Social Space
- Inspirational space
- Additional spaces

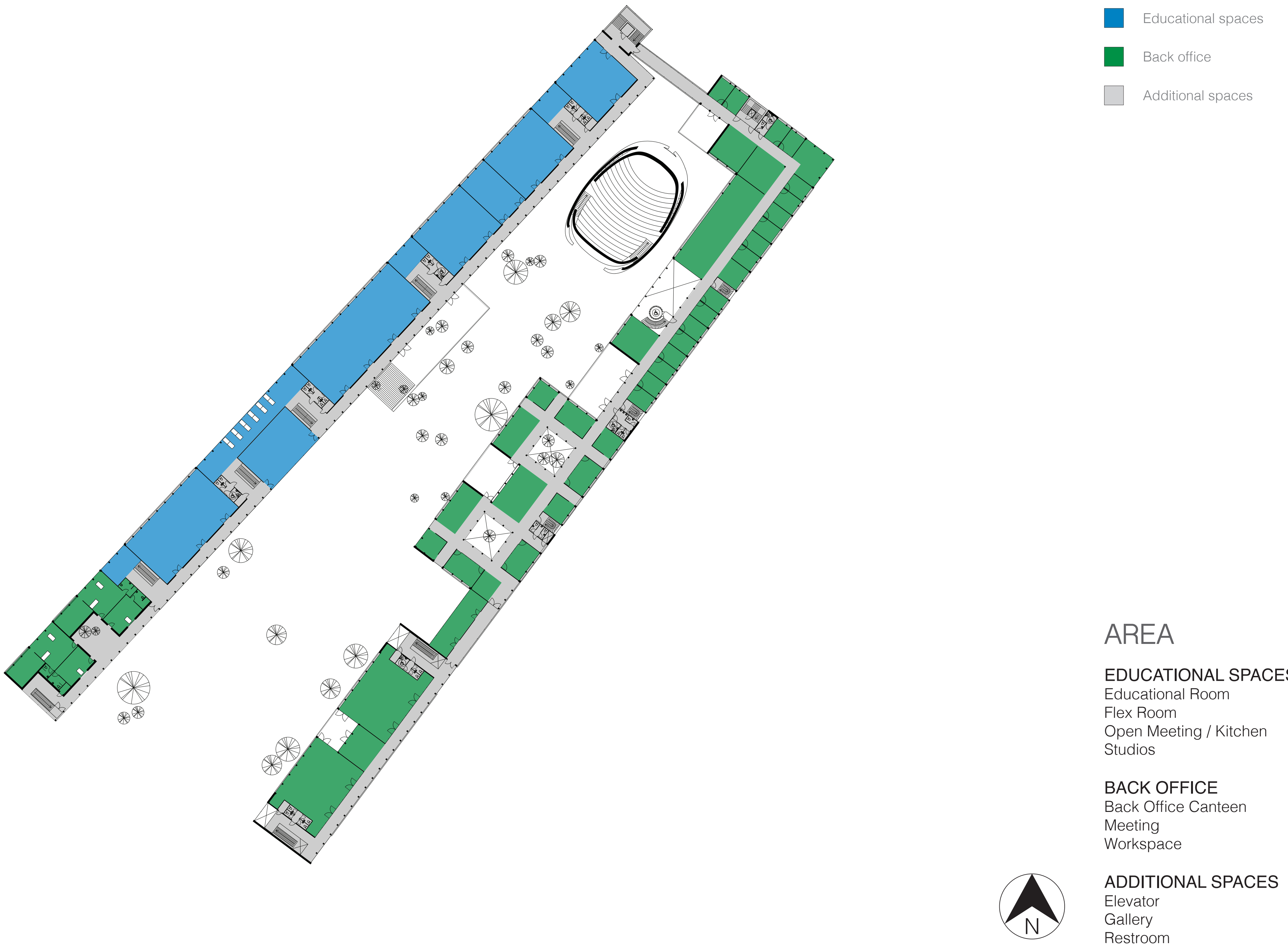


Ill. 37 2nd floor, 1:1000

AREA	4556m^2
EDUCATIONAL SPACES	**1519**m^2
Auditorium	311m^2
Open Meeting / Kitchen	134m^2
Storage	141m^2
Studios	933m^2
BACK OFFICE	**612**m^2
Meeting	89m^2
Workspace	523m^2
INSPIRATIONAL SPACE	**494**m^2
Library	390m^2
Material Library	104m^2
SOCIAL SPACE	**417**m^2
Canteen	417m^2
PRODUCTION SPACES	570m^2
Support Office	51m^2
Theory and Pinup	237m^2
Theory and Pinup Depot	22m^2
Workshop	260m^2
ADDITIONAL SPACES	**944**m^2
Elevator	21m^2
Gallery	420m^2
Restroom	103m^2
Stair	400m^2

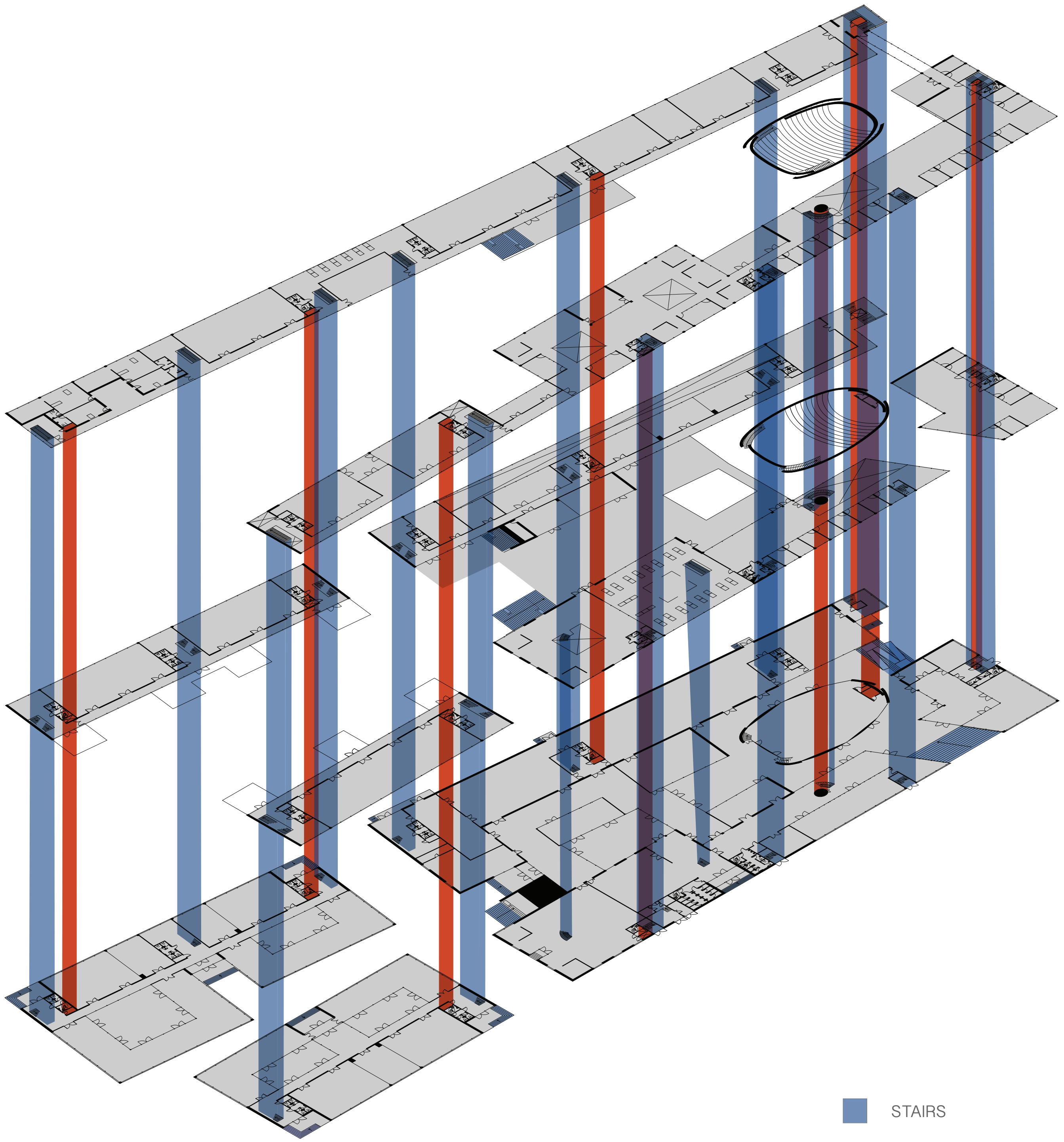
3RD FLOOR

Presentation

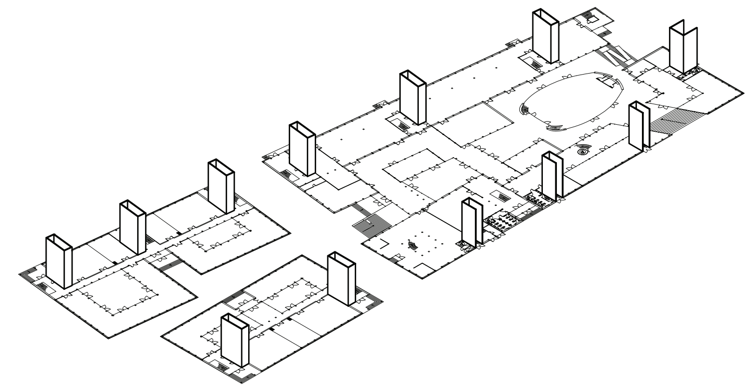


Ill. 38 3rd floor, 1:1000

AREA	3912m2
EDUCATIONAL SPACES	**1494m²**
Educational Room	84m²
Flex Room	138m²
Open Meeting / Kitchen	173m²
Studios	1099m²
BACK OFFICE	**1532m²**
Back Office Canteen	146 m²
Meeting	44m²
Workspace	1342 m²
ADDITIONAL SPACES	**886m²**
Elevator	21m²
Gallery	470m²
Restroom	96m²
Stair	299m²



Ill. 40 Stairs and elevators in the building

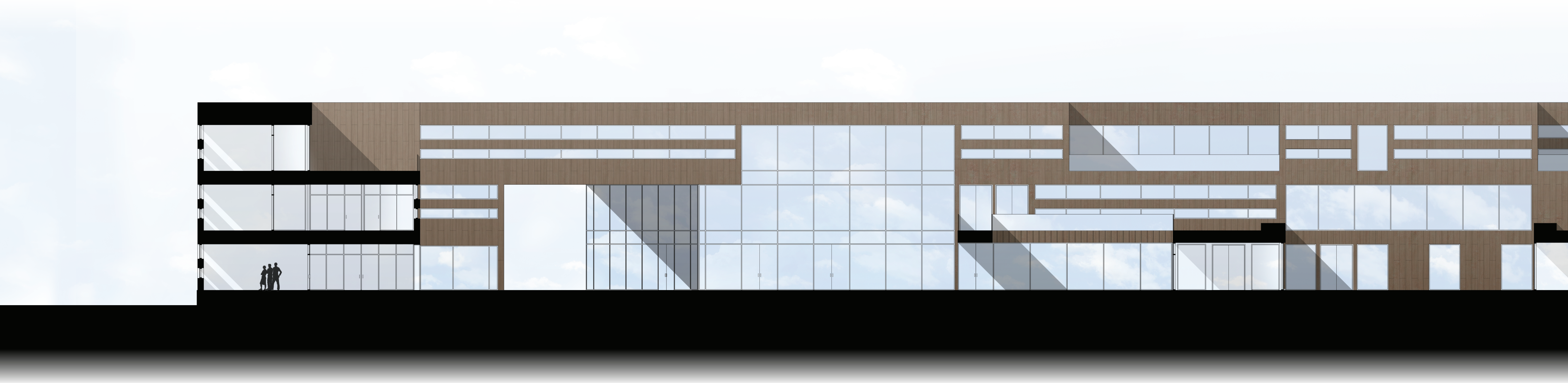

Ill. 39 Cores distributed throughout the building

The expression inside the building is characterized by exposed columns and beams, which reveal the structural principle of a column-slab system. Beams and columns will transfer the vertical load from the decks and its applied live load. To stabilize the structure for forces acting in the horizontal direction is 11 cores places throughout the building, as shown on Ill. 39. Besides the stabilizing effects of the cores, these also function as vertical shafts, which contains toilets and elevators.

The vertical connections and circulation of the building is located in close connection to the cores. Stairs are placed beside the cores in building North, South and West, with toilets and elevators inside the cores. For Building West does the cores contain fire escape stairs. The main vertical circulation path in Building West goes through the atrium near the entrance. Ill. 40 shows the vertical connections of stairs and elevators in the building.

FACADE BUILDING EAST

Presentation

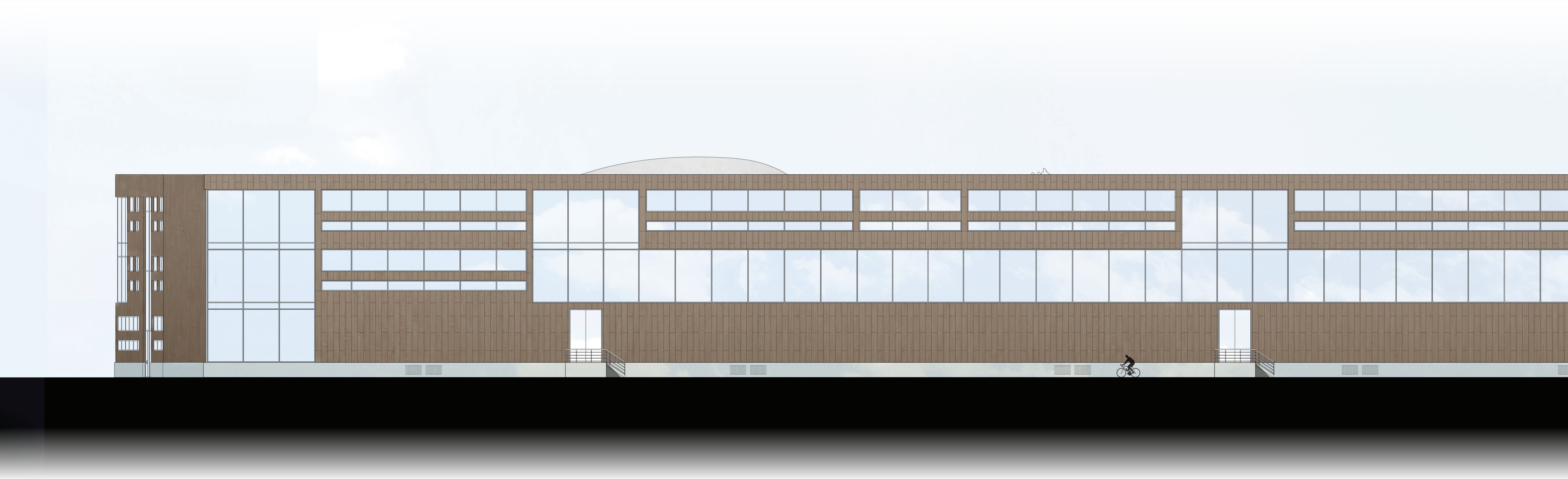


Ill. 41 Building East, western facade

Ill. 42 Building East, eastern facade

FACADE BUILDING WEST

Presentation

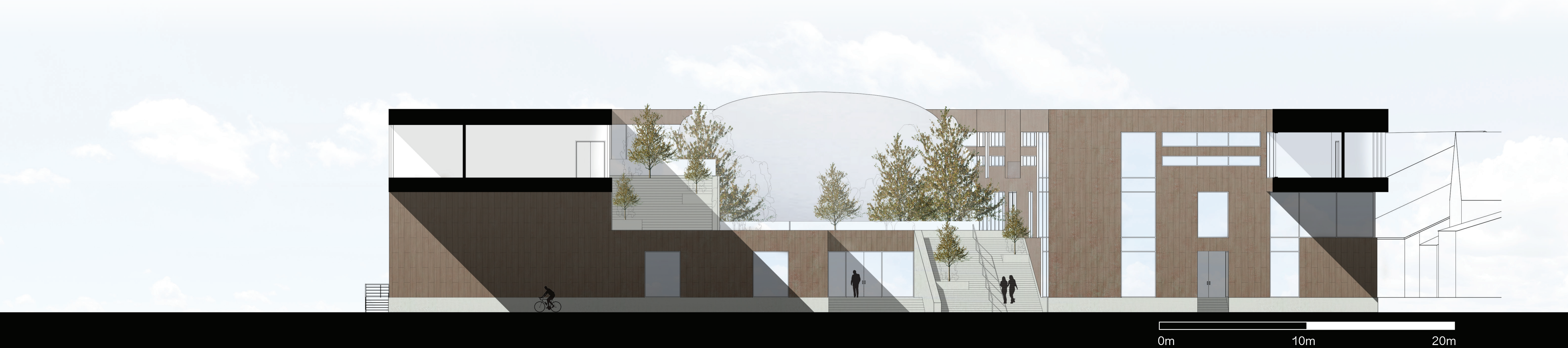


Ill. 43 Building North, north-western facade

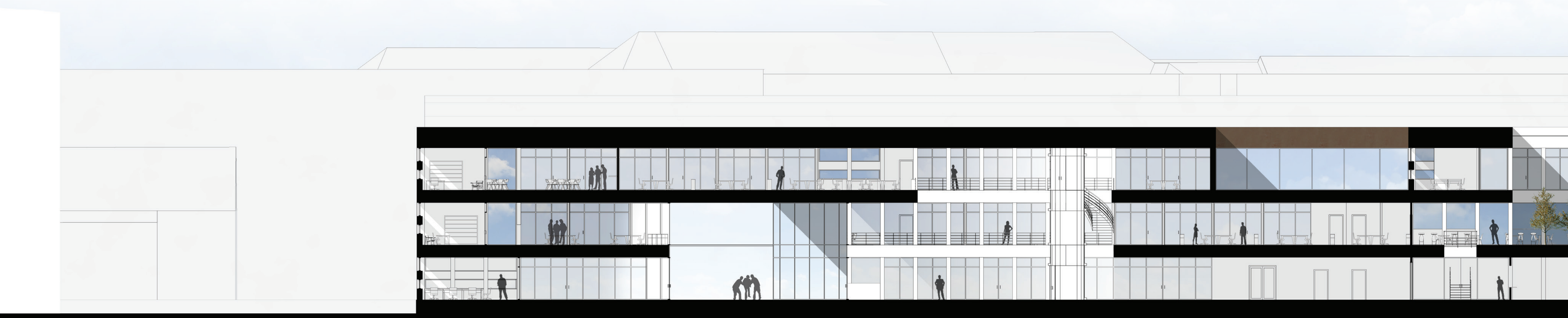
Ill. 44 Building North, south-eastern facade

FACADE AND SECTION

Presentation

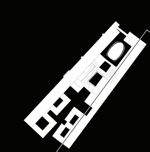


Ill. 45 Canyon, south-western façade



0m 10m 20m

Ill. 46 Building Complex, northern façade



0m 10m 20m

Ill. 47 Building East, section

BUILDING NORTH
Presentation

Ill. 48 Building West seen from Carl Blochs Gade, after the copper has oxidized

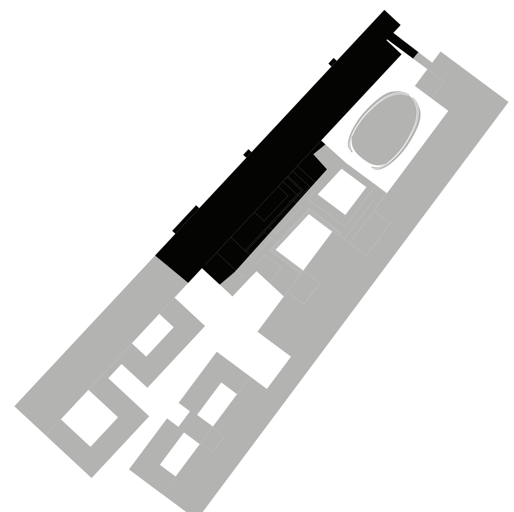
THE “WORKSHOP” BUILDING

The “Workshop-building” located in the north-western part of the site, along Carl Blochs Gade.

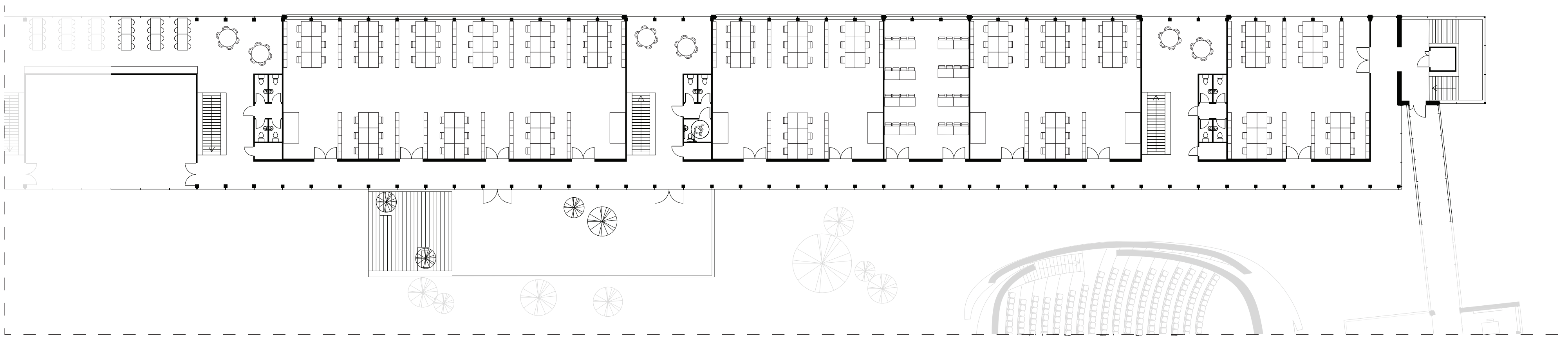
1ST FLOOR
The 1st floor contains a large workshop area, with space for larger machinery and the option of moving large objects in the double high room. Next to the workshop is a support room for the workshop, with storage space and easy access to the workshop. At the 1st floor is the shop (Archi-tegn) placed, near the centre of the complete building complex, to ensure good connection for everyone. This location allows students to easy access with materials to the workshop, larger materials can be delivered from Carl Blochs Gade.

2ND FLOOR
At the 2nd floor is a smaller workshop located, with smaller facilities and machinery. The material library is located in the south-western end of the building, being close to the centre of the building complex, making it more accessible for the students. Close to the material library are two “Theory and Pinup” rooms. In these rooms students can get feedback from workshops and become educated in different material properties.

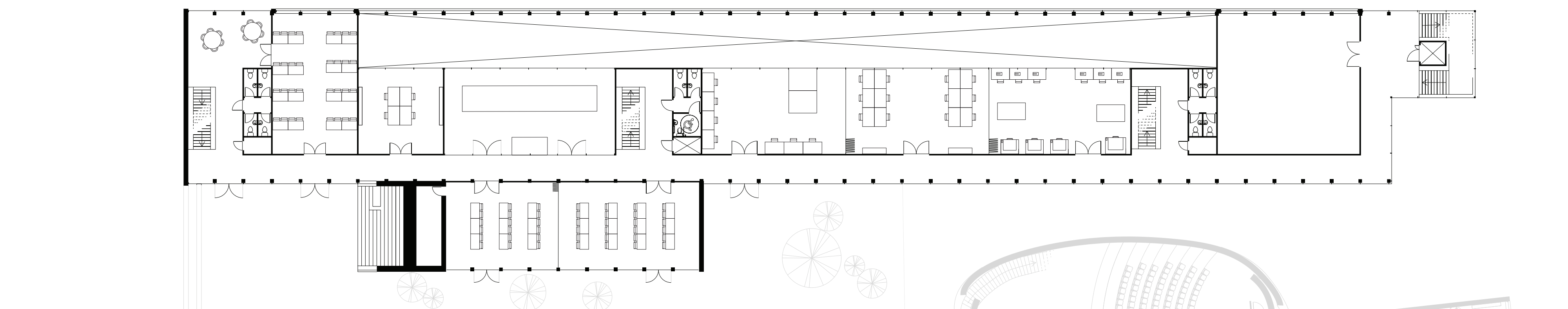
3RD FLOOR
The 3rd floor consists mainly out of studios, educational/flex rooms and some informal meeting areas in connection with the staircases. The building is connected to Building West by a cantilevered educational room, kitchen and meeting area. Creating a space between the two buildings, where students can meet and ensuring easy access from Building West to the workshop facilities.



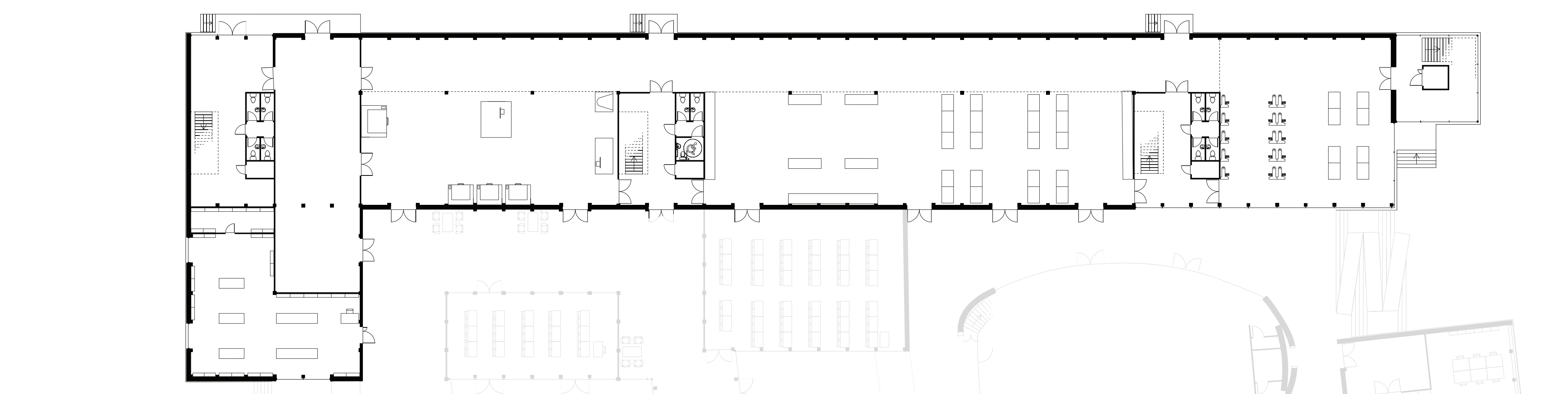
Ill. 49 Diagram of Building West



3rd floor



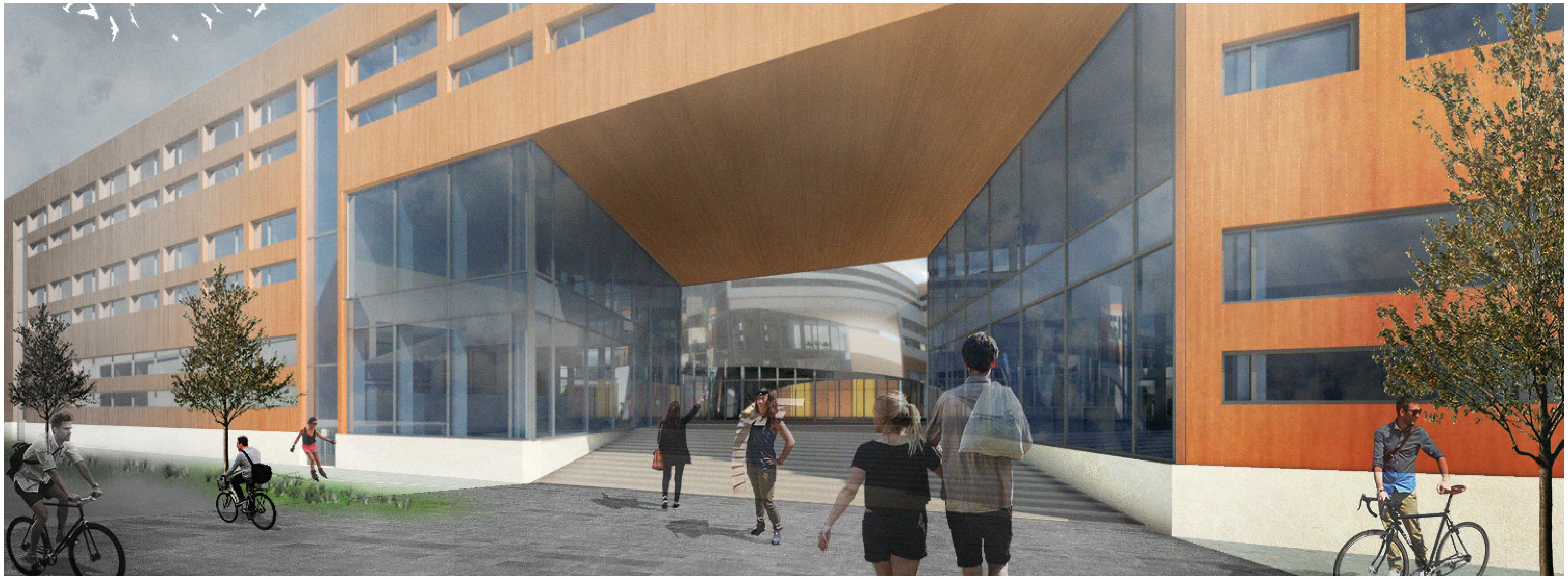
2nd floor



1st floor

Ill. 50 Plans of Building North's 3rd floor, 2nd floor and 1st floor, scale 1:500

BUILDING EAST
Presentation



Ill. 52 Building East, main entrance

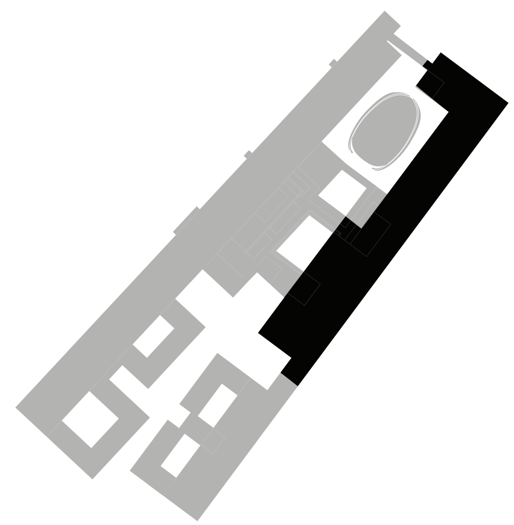
THE "ADMINISTRATIVE" BUILDING

The "formal" building contains functions as a front desk, canteen, library and workspaces for employees. The building is graduating from a public 1st floor to a private 3rd floor. In the lobby, at the main entrance, the user will walk into a triple high room, with the connecting circular staircase surrounded by exhibited models.

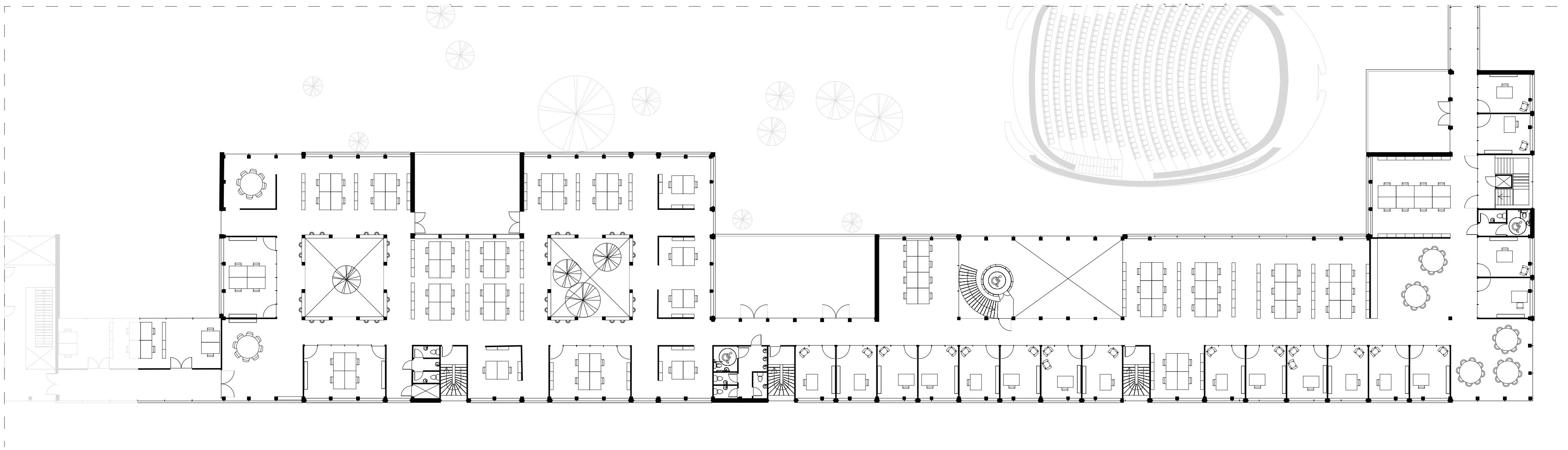
1ST FLOOR
The 1st floor contains public functions such as the main entrance, secretaries, front desk and a part of the exhibition, which also functions as an informal meeting place. The functions also include the library, the canteen and the canteen kitchen, which can be entered from the street and from the Canyon. The library and canteen are located near the centre of the building complex, to act as a gathering point for everyone using the school. In the northern end are workspaces located.

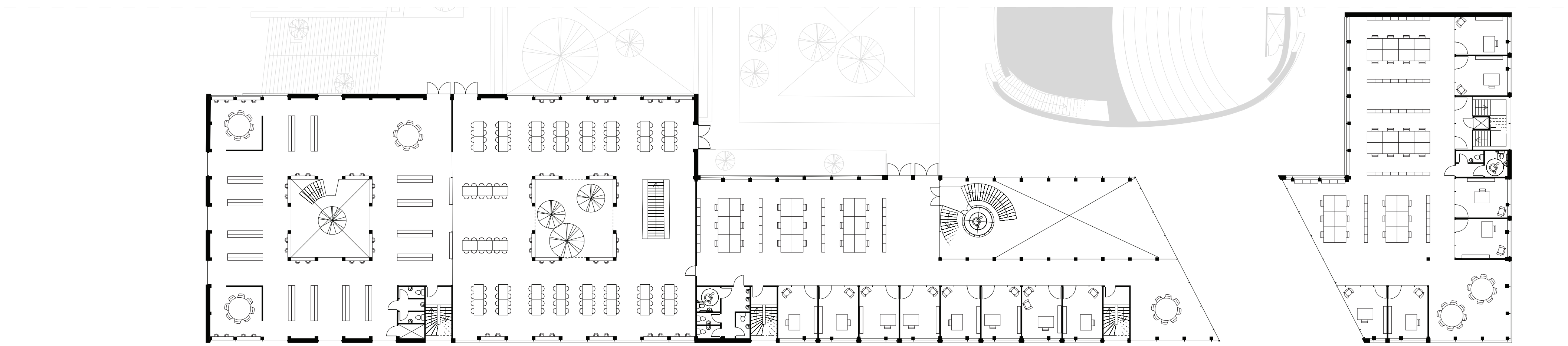
2ND FLOOR
The 2nd floor is more mixed between private and public. The canteen has a seating area on the 2nd floor, where the users can enjoy their meals. The library has places where the user can resign and study. When the weather is good, the user can bring their meal or books directly outside, to enjoy the nature meanwhile studying or eating. Among the private functions contains are meeting and workspaces for professors and assistants.

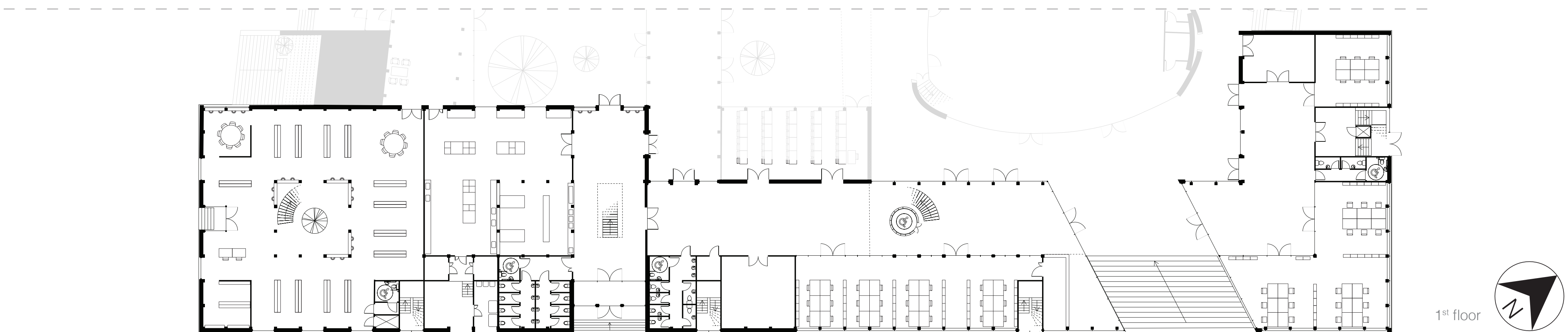
3RD FLOOR
The top floor is for employees and VIP only, the private section. Stretching across the main entrance and across the new street, connecting to the Building South. At the 3rd floor are several small terraces facing the Canyon, letting light in and allowing the people to go outside to refresh their minds.



Ill. 51 Diagram of Building East







Ill. 53 Plans of Building East's 3rd floor, 2nd floor and 1st floor, scale 1:500

Ill. 55 Courtyard in Building South

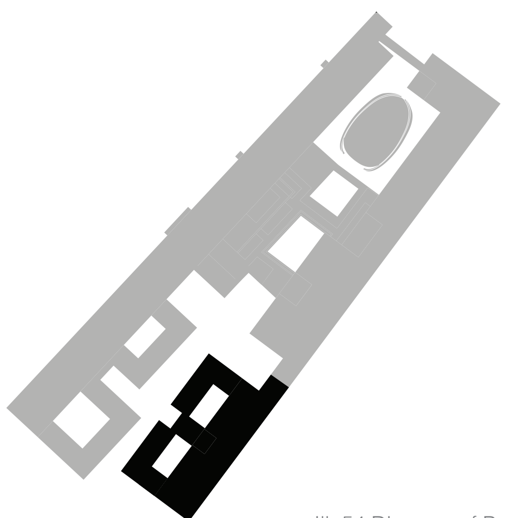
THE “MIXED” BUILDING

The Southern building is a mixed building, between Ph.D. student and bachelor/master students. The 1st floor and 2nd floor is for students, with a flexible educational room. At the top floor are open offices.

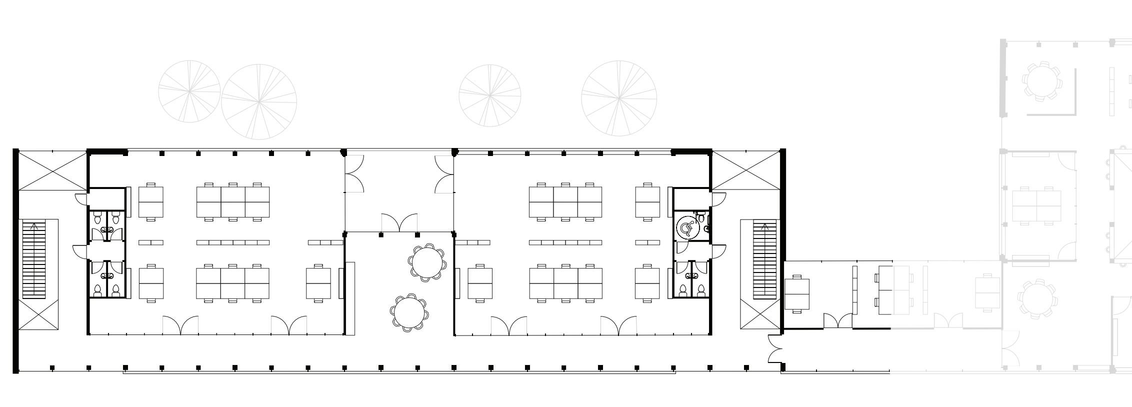
1ST FLOOR
At the 1st floor two courtyards has been placed surrounded by a curtain wall. Studios are placed on two sides of the courtyard, allowing a lot of light into the studios and providing a view on both sides of the studio. Gallery hallways are placed on the other sides of the courtyard, allowing other students to get a view into the studios, from and through the courtyards.

2ND FLOOR
On the 2nd floor is a larger studio placed. A gallery hallway ensures a pleasant flow into the studio, distributing the students closer to their workstations. From the gallery and roof terraces the user will have a view to the courtyards and the to the entire Canyon.

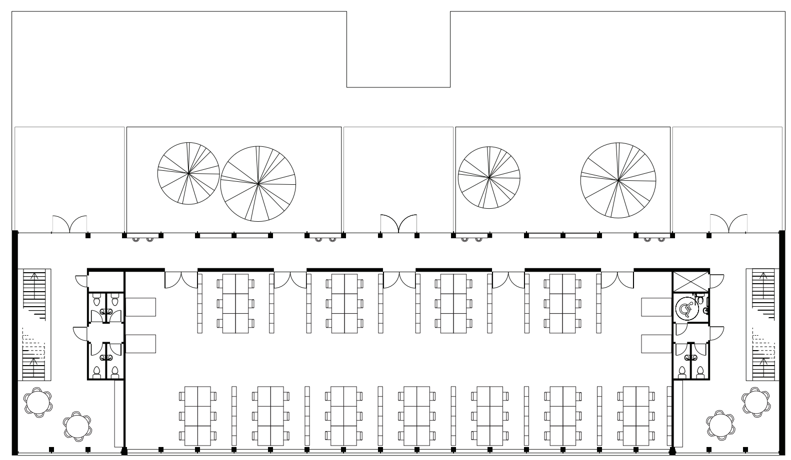
3RD FLOOR
At the 3rd floor are offices and Ph.D. students located, as an extension to Building East, connected above the road. The connecting building volume, allows an easy flow between the two buildings. The offices are open, to allow an easier sharing of knowledge. Between the two offices, are a roof terrace and a meeting area, which separates the offices, and at the same time make an informal space for socialization.



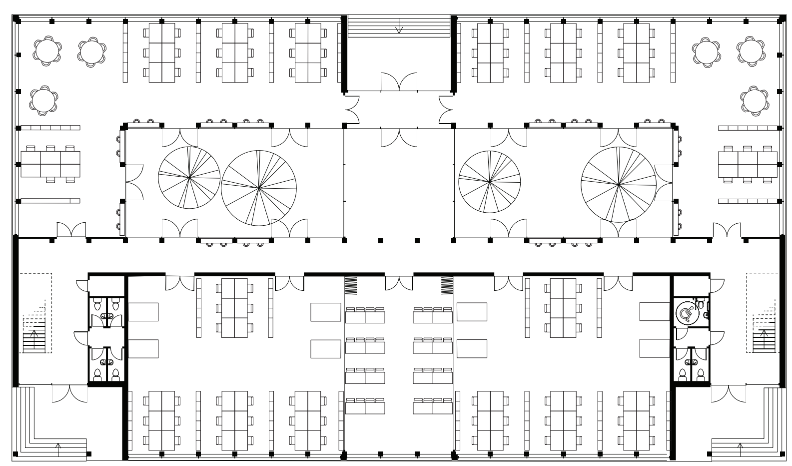
Ill. 54 Diagram of Building South



3rd floor



2nd floor



1st floor

Ill. 56 Plans of Building South's 3rd floor, 2nd floor and 1st floor, scale 1:500

BUILDING WEST

Presentation

Ill. 57 Central entrance to Building West

THE “STUDIO” BUILDING

Building West is similar to the Building South with studios, a few educational/flex rooms, but it also contains guest apartments at the 3rd floor.

1ST FLOOR

The 1st floor is mainly studios, but with two flexible educational rooms. It has two courtyards, which is surrounded by studios and gallery. The gallery functions as a hallway, with inspirational exhibited material. The courtyards allow light to enter the studios and create a visual connection into and across the courtyard.

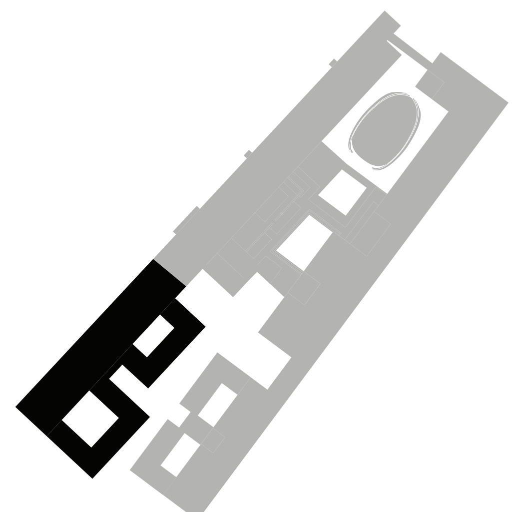
2ND FLOOR

Two studios are placed on the 2nd floor with large windows facing northwest. The northwest facing windows gives a pleasant diffuse light in the studios. A gallery-hallway provides the student with easy access to their workstation. From the gallery, the users can access the roof terraces and get some fresh air.

3RD FLOOR

At the 3rd floor is a connection to the Building North, connecting the students with the workshop, without the need to go outside. This is practical when you need to transport models or other fragile objects from one place to another.

For long-term visitors or VIP’s, such as guest professors, four guest apartments have been added to the buildings southern part. The guest apartments are located here, away from the offices, to make a change on venue, between work and spare time. This location also holds one of the best views of the old rails and Ringgadebroen (an old steel bridge, completed in 1938, crossing the railway tracks to southwest).



Ill. 58 Diagram of Building West

Ill. 59 Plans of Building West's 3rd floor, 2nd floor and 1st floor, scale 1:500

Ill. 60 South-west entrance to the Canyon

Ill. 61 Canyon, 1:500

JOINING THE BUILDING VOLUMES

Defined by the space between the two building volumes, is a mix of urban gardens, educational rooms and exhibition areas. The Canyon absorbs the deviation of the buildings grid lines. Inspired by the historic tracks, from the railways coming from the south-west.

1ST FLOOR

At the 1st floor is a large exhibition area, which also functions as an internal street. Connecting the two buildings with several educational rooms and courtyards along the path. The exhibition space is open to the public during office hours of the front desk and has several zones for seating to admire and reflect upon the exhibited material. The ability to exhibit is important for creative students, as it builds up confidence and they get used to get feedback on their work.

2ND FLOOR

The 2nd floor is a public urban garden from where, many of the schools functions can be accessed. The garden is sheltered from the wind; with a many places to enjoy the sun will it be an enjoyable place for the students to socialize.

STUDIO

The design for the studios is similar all over the building. All the studios provide light to the workspaces, good acoustics, efficient internal flow and workstations for the students to define as "their own space". The average daylight factor is measured to a minium of 3.7 in the darkest studio, which is 1.7 over the minimum, no workstations has a daylight factor lower than 2.

All workstations have a horizontal view to the nature and a more elevated view. The views are provided by two horizontal rows of windows in the external wall, placed at 80cm to 150cm (70cm) and 210cm to the ceiling (150cm). The lower window's main function is to provide a view to nature, which will enhance the productivity of the students and the work environment. The upper window also provides a view to the sky, which allows natural light to enter, providing higher daylight levels. The space between the two windows is assigned to drawings and pictures.

The beams are exposed from the ceiling to give the studio a characteristic expression. By letting the structural elements being exposed, a constant rhythm is created. With the beams exposed the spreading of acoustical rays will be reduced, improving the acoustical environment. The users will only hear the people nearby clearly and noise and voices from the distance is heard as an undefined, low, background noise. The acoustic environment makes it easier for the user to focus without being distracted from noises.

The studio is designed to be flexible, defining the individual workstations by the surrounding furniture. The usual workstation consists of a desk, 140 x 100cm, a shelving system, 30 x 150 x 70 cm, a pinboard, 150 x 70 cm, and a 120 x 80 cm hanging self for storage. All factors, which makes it possible for the students to create their own unique workstation.

Ill. 62 Visualization of a studio

SELECTED FUNCTIONS
Presentation

GALLERY

The galleries are the connecting elements of the building. Passing from function to function through a gallery with a glass wall on one side, with a view into the Canyon and to the Building North. The other wall has inspirational illustrations, details, drawings and pictures of ideas, models and buildings with a high architectural quality.

The gallery has a simple furnishing, not to distract the user from the inspirational illustrations. The furnishing is a wooden plank between two columns, set at two heights functioning as a bench or a table as an alternative space for reflection. The bench has a height of 50cm. The intention of the bench is a place for the students to sit and chat or a place to admire the illustrations on the wall. The table is placed at 120cm, if the students need to get away from their workstation or have a meeting outside of the studio.

Ill. 63 The gallery on the 3rd floor of Building West

WORKSHOP

The workshop is divided into two parts, which easily can be further subdivided.

One part of the workshop is for large objects and the rougher processing of materials. The second part is equipped with smaller machinery, for more detailed work.

The workshop has a large double high area, with wall on the lower half and windows on the top half. This solution allows natural light to enter the room and still being able to hang tools or drawing on the walls. The smaller workshop is benefitting from the large windows as well. They are pushed back from the facade, creating the double high room in the large workshop. This allows a visual connection between the two workshops and allows natural northern light to enter the workshops.

The workshops can easily be subdivided, if a studio is doing a workshop, requiring the studio to work on large models or mock-ups. The separation helps to isolate noise from other people using the workshop and provides the option of renting out sections to outside users.

Ill. 64 Section of workshop

LIBRARY

The library is located next to the canteen near the centre of the building complex. Its location is to ensure everyone the easy access to it, so the knowledge it contains can be used by everyone, also users from outside of the school.

The library is distributed on two floors, connected by a staircase in an atrium in the centre. The books in the library are located away from the natural light, to give the best conditions to preserve them. The space between the bookcases and the windows allows space for the users to take the material and study it, either by the atrium, the window tables or in the rooms, designed to resign and study.

Ill. 65 Atrium in the library

OFFICE

The school has three kinds of offices: open offices, shared offices and one-person offices. All offices have a pleasant environment with good natural lighting conditions, space and view to nature.

The open offices are assigned to for users working on research, to encourage a wider sharing of knowledge. Shared offices are assigned to specific research groups, to be able to collaborate about a subject without being disturbed. The single-person offices are for users, who need the office to focus or have personal meetings.
All offices are in the same area of the building, so the users easily can set up meetings, share ideas and give feedback.

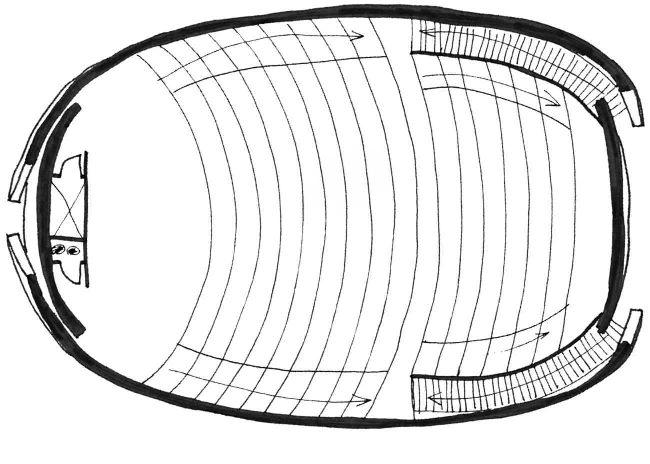
Ill. 66 Open workspaces in Building East

CANTEEN

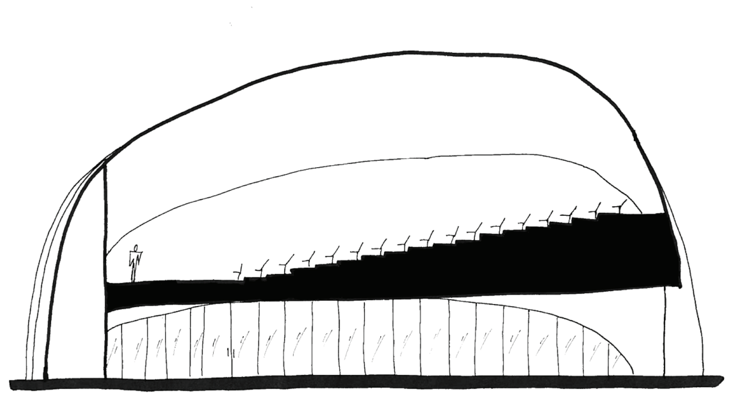
Located near the centre of the building, the canteen functions as a meeting point, easily accessed from all of the surrounding functions.

Practical functions, such as depot, restroom and kitchen are located at the 1st floor and the dining area is located at the 2nd floor. In the centre of the dining area, is an atrium, with indoor trees, which lets natural light and nature into the building.

Ill. 67 Canteen dining area on the 2nd floor



Ill. 68 Plan of auditorium



Ill. 69 Section of auditorium

Ill. 70 Rendering of auditorium

AUDITORIUM

The auditorium is placed where the two axis cross. As a focal point, physically disconnected from the architectural school, creating a rotation point for the flows created by each axis.

The auditorium is placed as the end the axis, stretching from the city hall, through the Scandinavian Center into the site, which ends out any closure since the Scandinavian Center was built in 1995. [Synligbeton.dk, 2015] The other axis is between the two building volumes of the architectural school, the centre of the Canyon. The auditorium is raised to 2nd floor, to allow an exhibition space below.

PLACEMENT

The auditorium is placed in the middle of the square and has a more organic and dynamic shape, than its context in order to stand out and emphasize its function as focal point. The placement of the auditorium and the exhibition space in located in central in the building's public and formal zone, accessible without having to go through any of the schools other functions. Therefor it is very available for the public and with glass almost 360 degrees around the exhibitions space, it becomes very public even outside opening hours. The option for lectures in the auditorium for the public is also very convenient, without the outsiders disturbing the daily routine at the school.

GOOD VIEW AND ACOUSTICS.

The floor of the auditorium is sloped in an angle and the seats are shifted to ensure a proper view of the speaker. The maximum distance from the spectator to the speaker do not exceed 24 meters; the distance a person can recognize mimics and facial expressions [Strong, J., 2010]. The ceiling is shaped to ensure good acoustics by focusing on reverberation time, Clarity and so the Haas Effect will not occur, to make the auditorium excellent for lectures.
The void between the shells are glazed to allow diffuse light to enter the auditorium.

The auditorium's design is on a sketch level, it needs structural and proper acoustic calculations in order to ensure the best performance.

Synligbeton.dk, (2015). Scandinavian Congress Center - synligbeton.dk. [online] Available at: http://www.synligbeton.dk/default.aspx?m=4&i=115&pi=3&pr=3 [Accessed 5 May 2015].
Strong, J. (2010). Theatre buildings. Abingdon, Oxon [England]: Routledge.
Rossing, T. (2007). Springer handbook of acoustics. New York, N.Y.: Springer.

THE HAAS EFFECT

Occurs when the difference of "direct" sound and "reflected" sound is so great, that the human ear can detect the difference and an echo will be created. The difference between direct and reflected sound may not exceed 50ms of impact or as a rule of thumb 17 meters.

CLARITY

Describes the how well every detail of the sound from a performer can be perceived, not becoming blurred and delayed. To ensure a clear sound, the difference between direct and reflected sound should not extend 50-80 ms. Clarity is a large extent to the property of *reverberance* (time the sound can be detected in the room). [Rossing, T. 2007]

Ill. 71 Auditorium, seen from terrace on 3rd of Building East

MATERIALS
Presentation

Ill. 72 White concrete

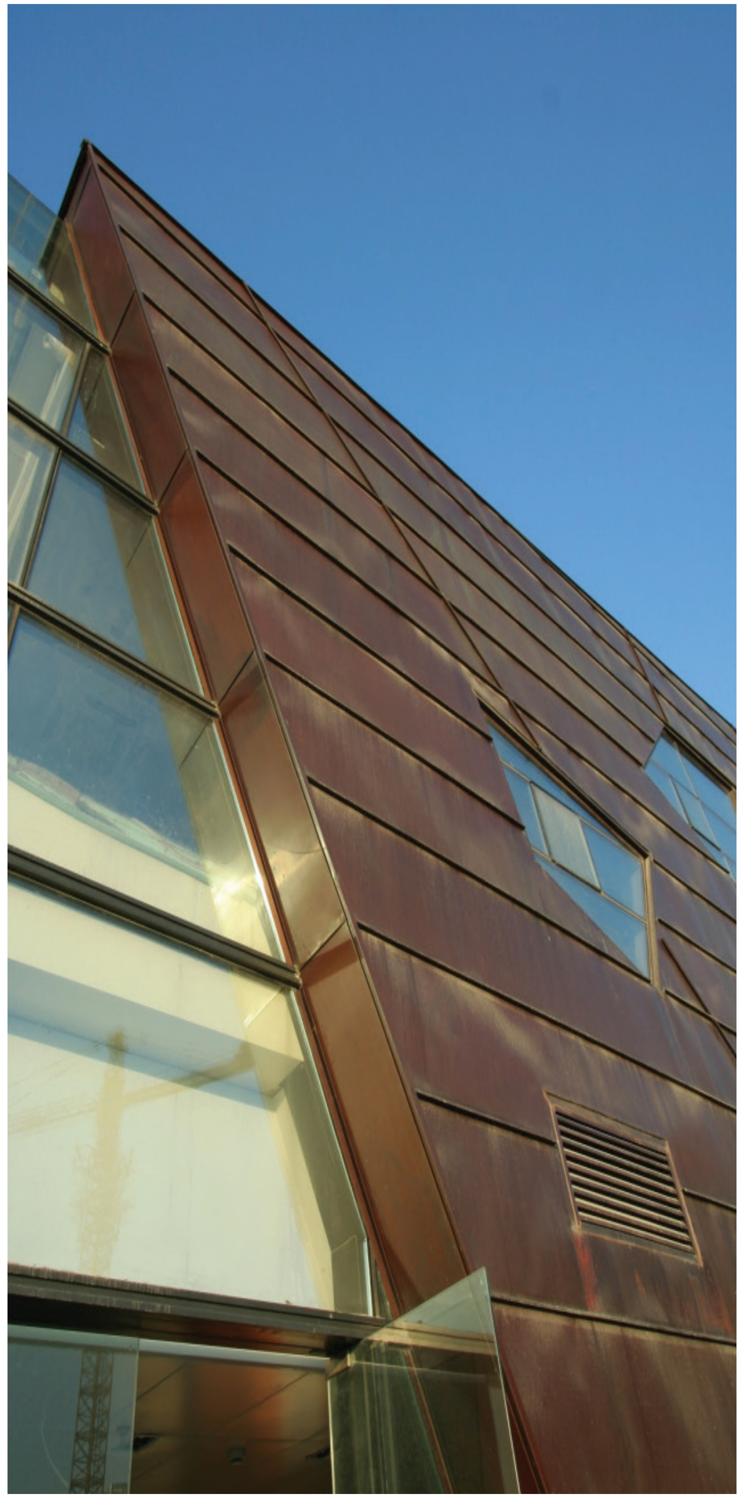
Ill. 73 Semi-oxidized copper

Ill. 74 Bamboo

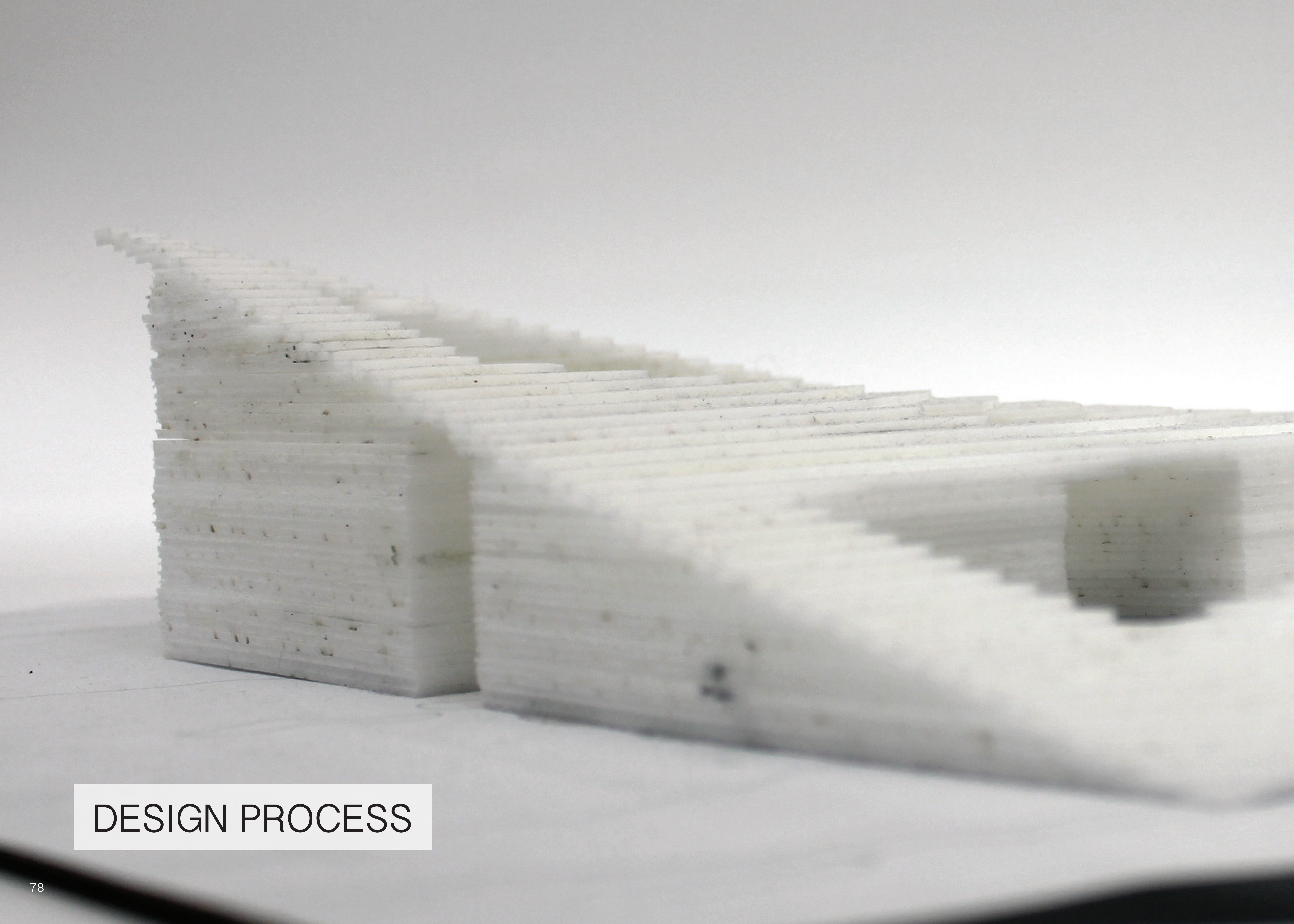
To emphasize the context of the old railway yards and make a reference to the surroundings, the building will meet the user as a red copper facade. The copper facade will age gracefully over time and create a patina, which with its green characteristics will correspond to the green wedge coming along the building. With the architectural intension of raising the building on a base, this is manifested by the use of white concrete. The white concrete surface will create a reference to the context and provide a surface, which will withstand impacts from everyday use, such as parked bikes.

For the interior surfaces will white painted walls create the frame for the students work in the studios. With sustainable aspects of bamboo and its warmer and softer characteristics, chosen as flooring material.

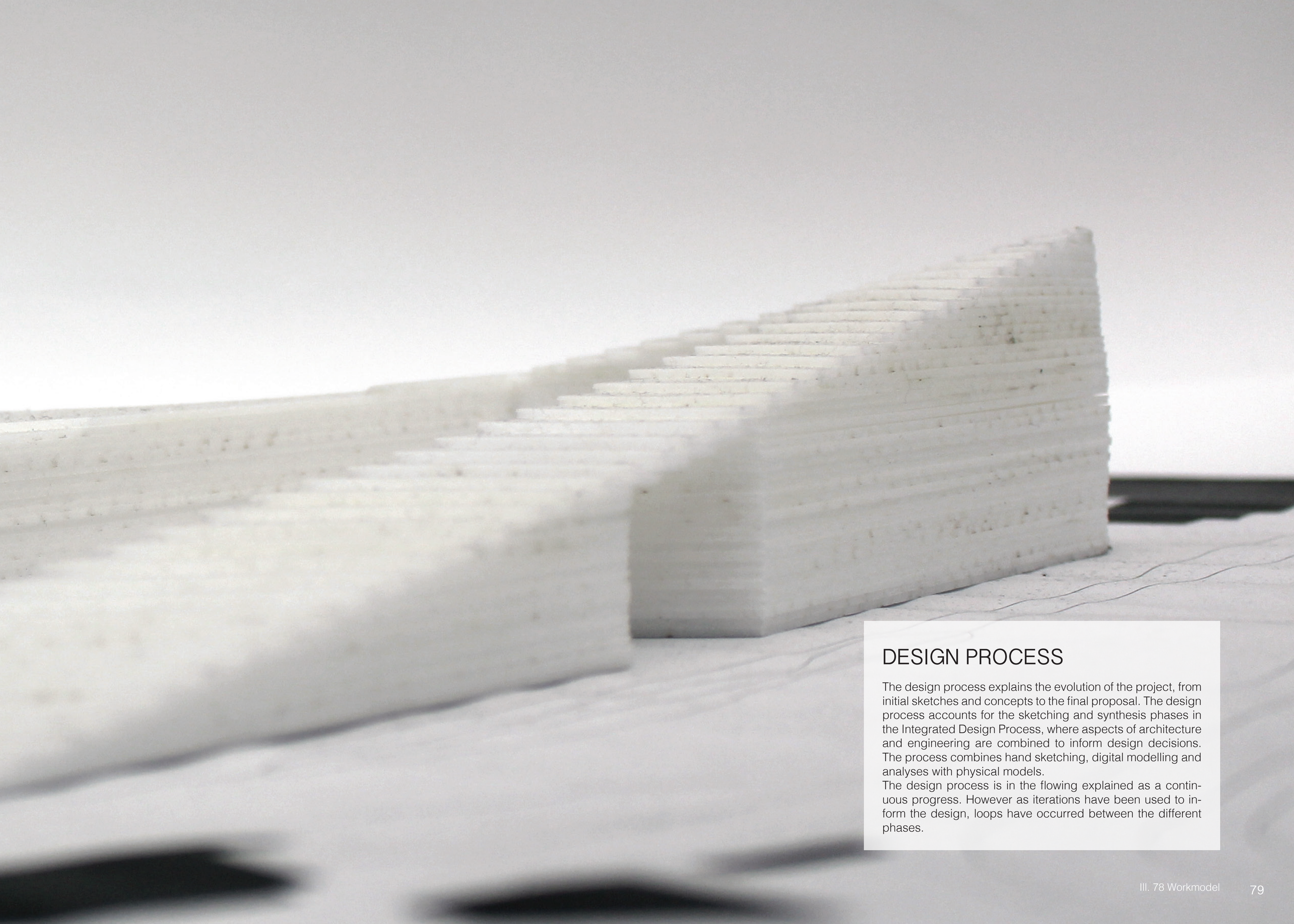

Ill. 75 Concrete in context, Naoshima, Tadao Ando


Ill. 76 Copper facade, Shanghai


Ill. 77 Bamboo flooring



DESIGN PROCESS



DESIGN PROCESS

The design process explains the evolution of the project, from initial sketches and concepts to the final proposal. The design process accounts for the sketching and synthesis phases in the Integrated Design Process, where aspects of architecture and engineering are combined to inform design decisions. The process combines hand sketching, digital modelling and analyses with physical models.
The design process is in the flowing explained as a continuous progress. However as iterations have been used to inform the design, loops have occurred between the different phases.

Ill. 78 Workmodel

CASE STUDY .01

Utzon Center by Jørn Utzon, Aalborg 2008

Ill. 79 The central courtyard of Utzon Center

Ill. 80 The internal colonnade of Utzon Center

UTZON CENTER, AALBORG

The Utzon Center was completed in 2008, designed to be a house of architecture, creativeness and learning, inspired by and in collaboration with Jørn Utzon. The building contains functions as an auditorium, a studio for architectural master students (originally a workshop), exhibition areas, a restaurant, front desk, library, offices and the Utzon archive. [Jørn Utzon om Utzon Center 2008]

The house can be entered from four sides; the main entrance faces Limfjorden, one of Utzon's most characteristic inspirational sources from his childhood. An atrium courtyard functions as a fulcrum, with a colonnade of concrete columns on all four sides. The squared colonnade connects the different functions of the building, separated from the courtyard with large windows and glass doors, decorated with drawings and illustrations of Utzon's work.

Several modules, as previous work of Utzon, combine the building. The structure is exposed to tell the story of the modules, the construction and how they enhance the quality of the spaces. The structure is a simple column-beam structure. The structure provides flexibility to the workshop and exhibition area by the option to construct walls fast and easy, between the beams and columns. Structural walls have on one side exposed bricks or watershed bricks, indicating which walls are permanent to the user.

An internal and external characteristic for the building is the roof. Externally the roof creates and icon with its curved zinc, internally the different shapes provide daylight in the different rooms. Glulam is used to give the roof their iconic shape; the 150cm glulam structure is used as decoration in some rooms, providing an atmosphere of greatness.

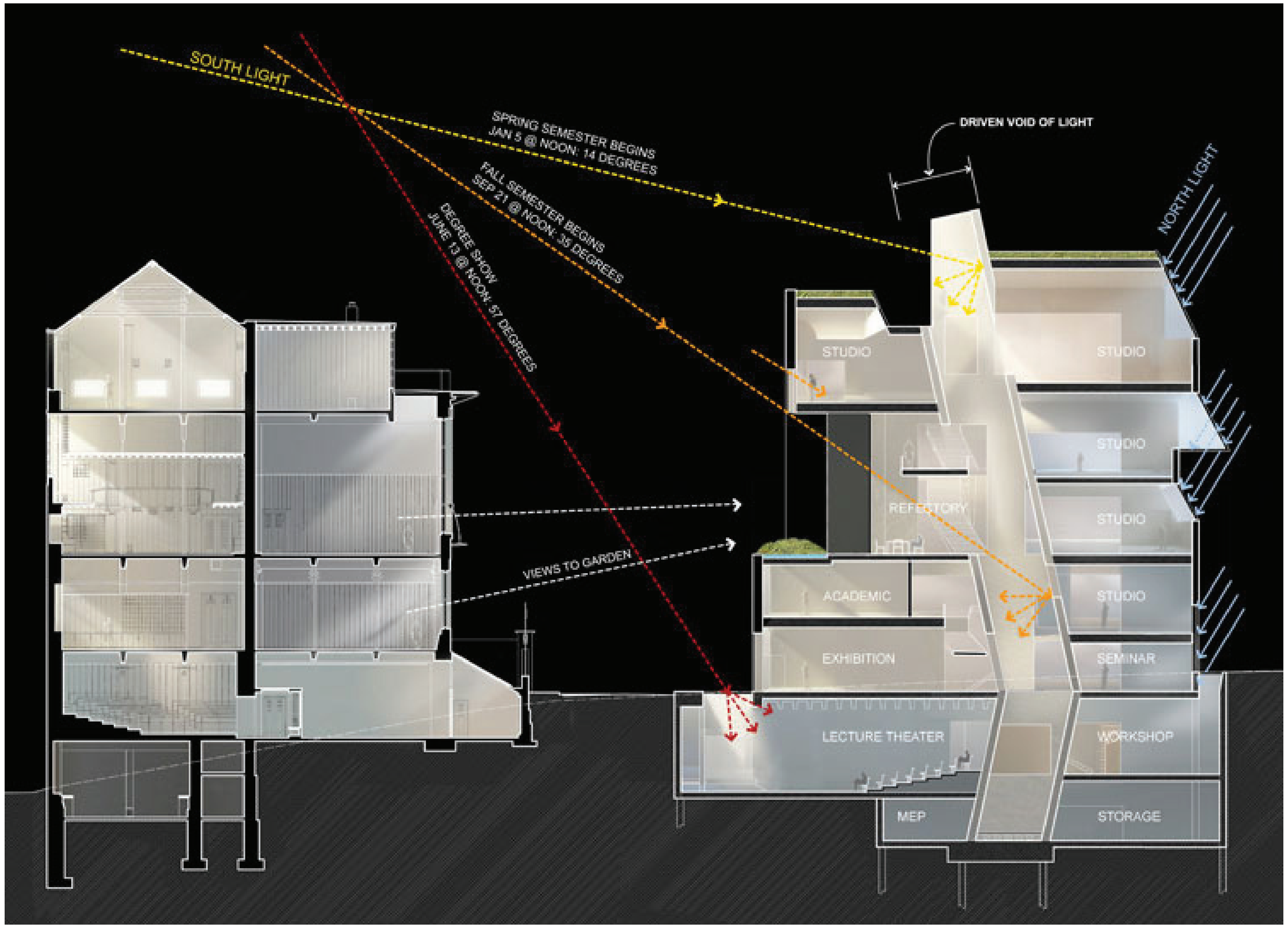
Jørn Utzon used the modular approach to design in much of his work. The module can be prefabricated and minimising the construction time and cost. Through repetition and rotation, the module can create various and diverse forms and shapes. Providing freedom for the architect on large projects. [Jørn Utzon om Utzon Center, 2008]

Ill. 81 The "library" of Utzon Center

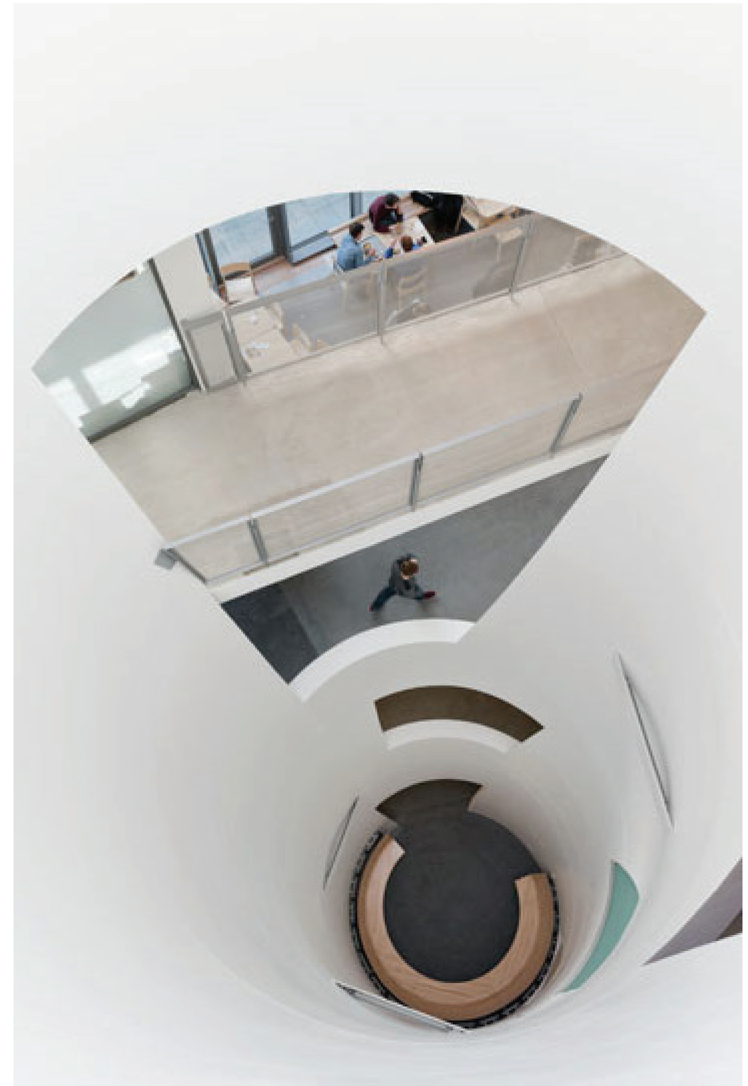
Ill. 82 Main entrance, Utzon Center

CASE STUDY .02

Extension by Steven Holl, Glasgow, 2014



Ill. 83 Section of Reid Building with sun rays.



Ill. 84 A “void” of the Reid Building

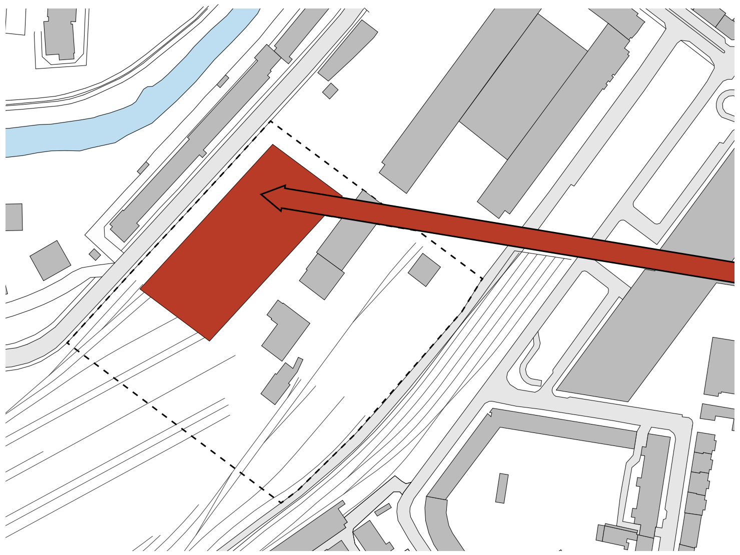
REID BUILDING, GLASGOW

The Reid building by Steven Holl was completed in 2014. The building is located in Glasgow as an extension to the original Glasgow School of Art designed by Charles Rennie Mackintosh. The program of the building consists of studios, project spaces, lecture theatre, seminar rooms, a café, exhibition and administrative spaces.

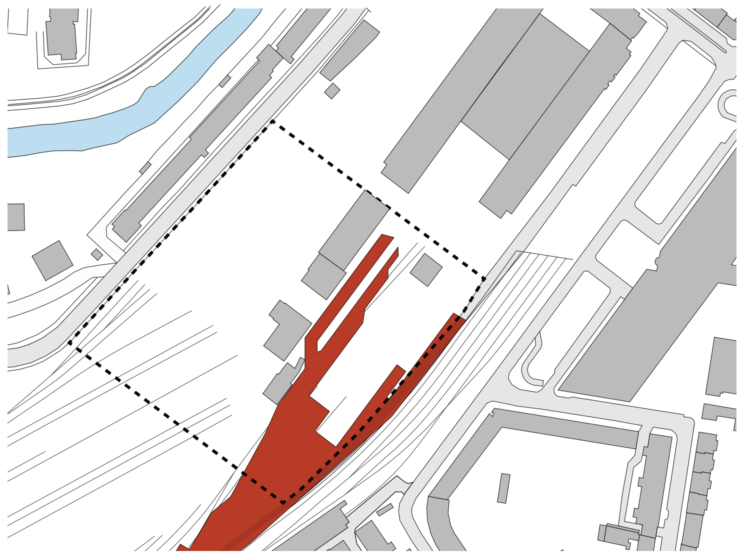
The building is an expression of Holl’s desire to work with different focus points. Studios and spaces, which have strict require¬ments for natural light, are facing north, whereas functions such as administrative spaces are facing south. Elevated windows, which have been slightly inclined, ensuring diffuse, north light in the studios and wall space for the students to put op their work. Towards south and the existing building a landscaped terrace provides green views from the inside. An exterior cladding of thin translucent panels provides a contrast to the existing masonry build¬ing. With the transparency the building makes a connection to the existing Mackintosh building and the city.

Inside the building, three vertical voids ensure the vertical cir¬culation as part of a connecting circuit. The voids function as light channels, which brings light to the lower-lying levels of the building. In addition/additionally, the voids function as structural elements, and as a part of the buildings ventilation strategy. Centrally placed in the building is a connecting circuit of ramps and stairs, which provides views inside the building. [Steven Holl Architects, 2015]

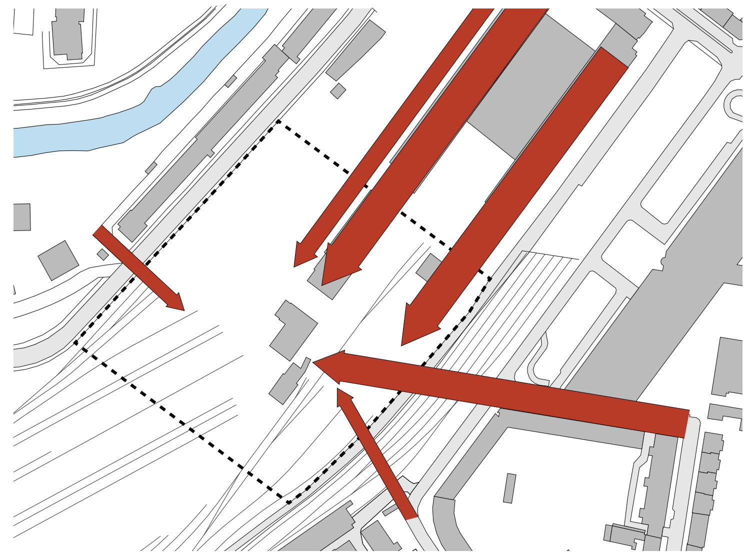
Ill. 85 A studio in the Reid Building



Ill. 86 The axis from the city hall enters the site



Ill. 87 The green wedge inters the site, according to the development plan



Ill. 88 Context lines and flows

ZONING

The masterplan for the site takes point of departure in the vision, which aims to connect the existing city with the new creative area at Godsbanen. The unfinished axis stretching from the town hall through Scandinavian Center to the site is used as the main driver for the zoning of the site, in combination with a green wedge coming along the old railway tracks.

The intended plot ratio on the site i,s by the municipality of Aarhus, estimated to 125 – 150%, equalling a gross area between 40.000 – 48.000 m². Existing buildings accounts for approximate 2000 m².

THE AXIS

The axis from the town hall is considered unfinished. The concept for the masterplan should therefore finish the axis and create a counterpoint to the city hall in the end. Known axes as Amalienborg-axis in Copenhagen and the axis from Louvre to Grande Arche de la Defense in Paris is used as inspiration for the concept. A plaza is therefore considered as a natural end to the axis. This new plaza will make a counterpoint to the existing plaza in front of the town hall in the beginning of the axis. The axis is seen as the dominating element, which will cut through existing buildings, and at the end on the plaza. (IIll. 86 and Ill. 89)

THE GREEN WEDGE

Natural elements are important for the productivity and wellbeing of people. The green wedge coming along the old train tracks, which is accessing the site from southwest, is seen as the element connecting the site with its historical past. Considerations of the old railway tracks and their course are used as a guideline for the placement of the green wedge. (Ill. 87)

LINES THROUGH THE SITE

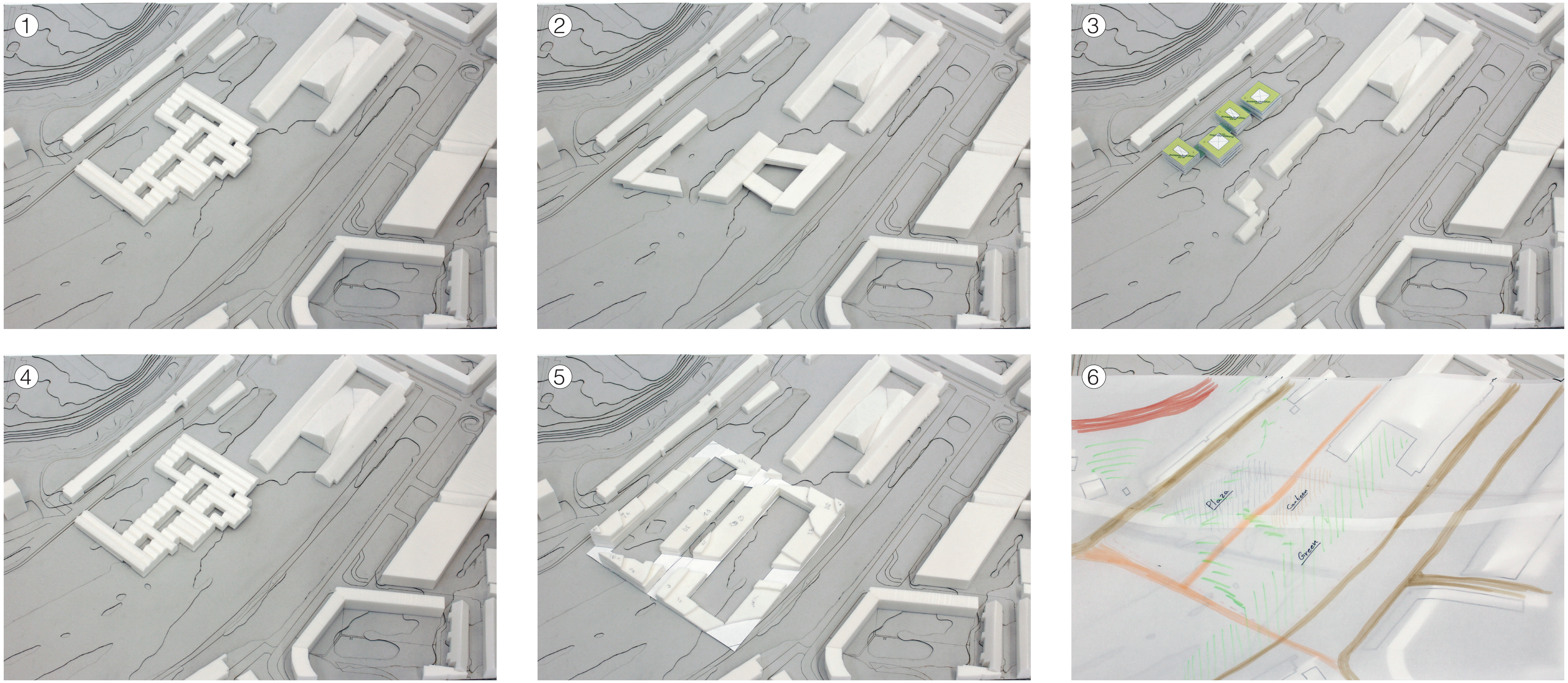
Adjacent buildings and roads are considered as basis for additional lines, which will define building plots, accessing roads and paths on the site. Lines from the buildings of Godsbanen and the line from Carl Blochs Gade are used to define the building plots. Adjacent roads (Sonnesgade, Gebauersgade, Lundbyesgade) are used, as cutting edges, which will cut the site creating a system of the roads and paths.

Ill. 88 shows how the adjacent lines, the axis and the green wedge is cutting through the site and creating the zoning of the masterplan.

Ill. 89 The axis from the city hall into the site

INITIAL CONCEPTS

Design Process



Ill. 90 Initial concept models

FUNCTIONS AND EXPRESSION

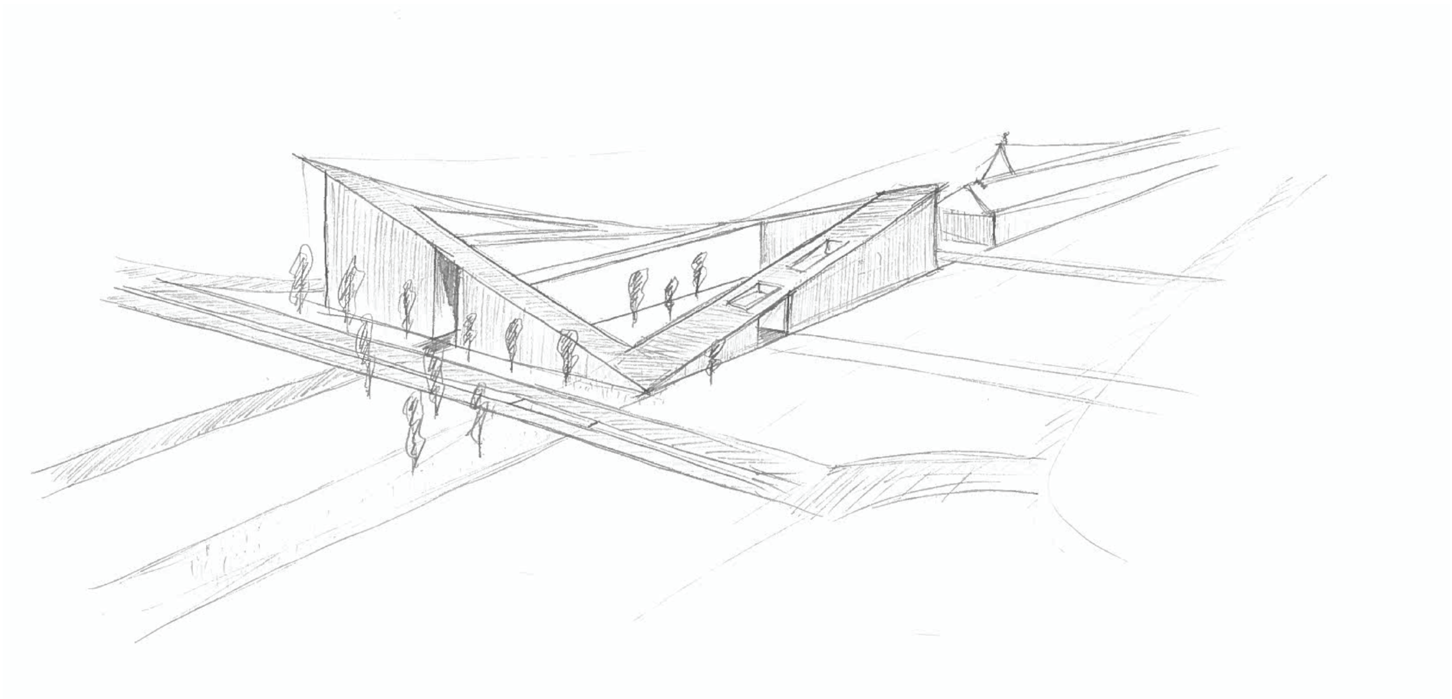
Ideas for the initial concepts work with principles from the conceptual masterplan, where the axis and the green wedge are used as drivers. Different proposals work with aspects of adaptability and fragmentation, which will frame the settings and divide the site into different zones. Several of the concepts take point of departure in the adjacent lines from Godsbanen, as a definition for the building volumes. Along with the sketching and modeling are studies of the building programs placement on the site used as a guideline for the iterations.

Design parameters, based on the analysis:

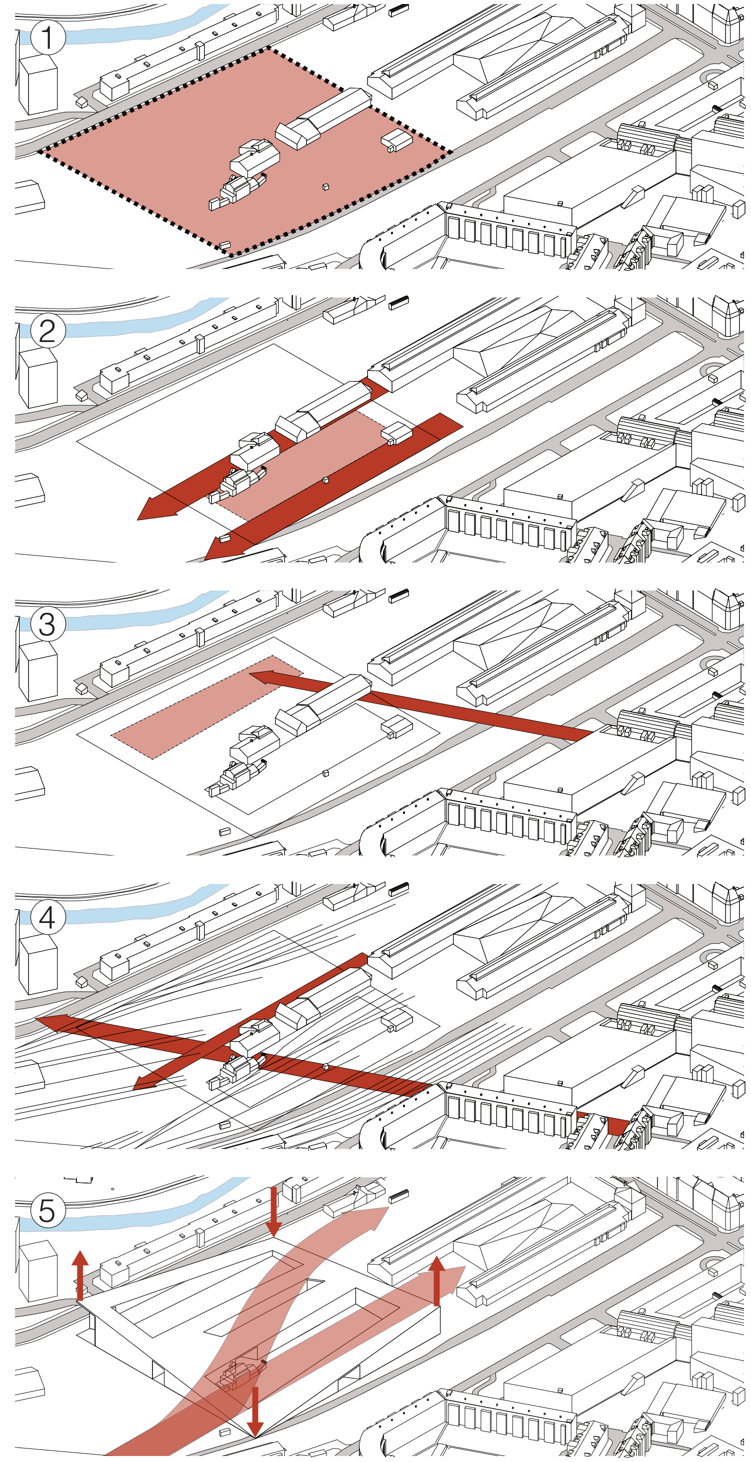
- The axis coming from the city hall.
- The framing of a plaza at the end of the axis.
- The green wedge coming along the train tracks.
- How the old train tracks can be used for the buildings orientation.
- Adaptability
- Flexibility
- Narrow volumes, makes it easier to get light into the building.
- The possibility of connecting the site with Aarhus Å.

However the different concepts showed a high fragmentation, which would divide the site into different parts. To get a more connected and uniform expression of the site, the idea of the building covering the entire site (as shown in Ill. 90, 5) with different cutouts in the volume, was taken to further development.

Ill. 91 Distribution of functions on the site



Ill. 92 Sketch of The Green Wedge building



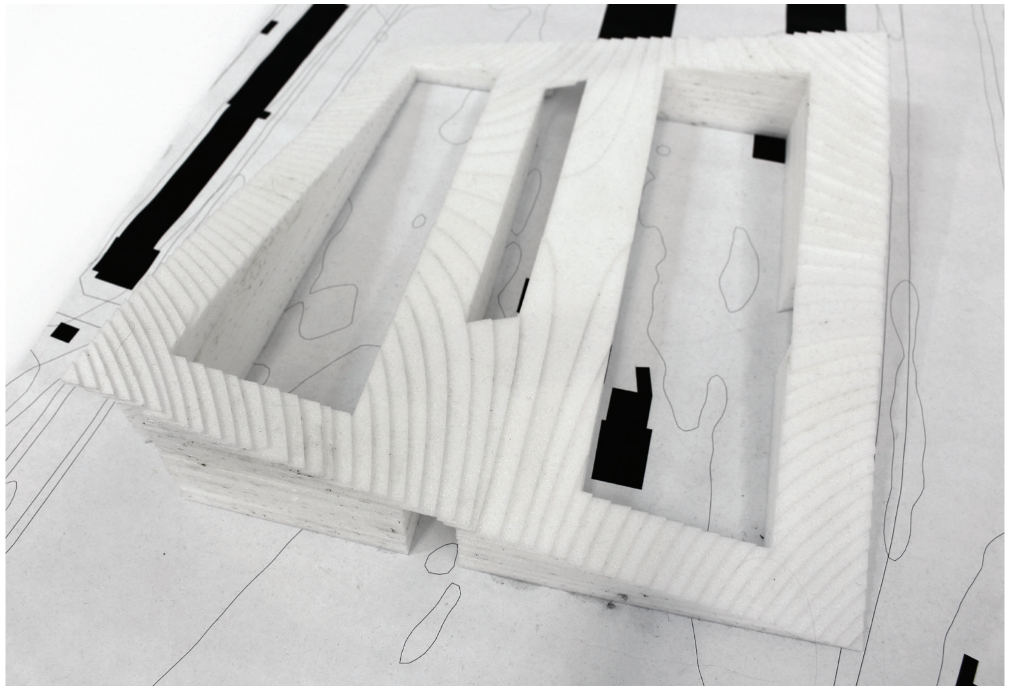
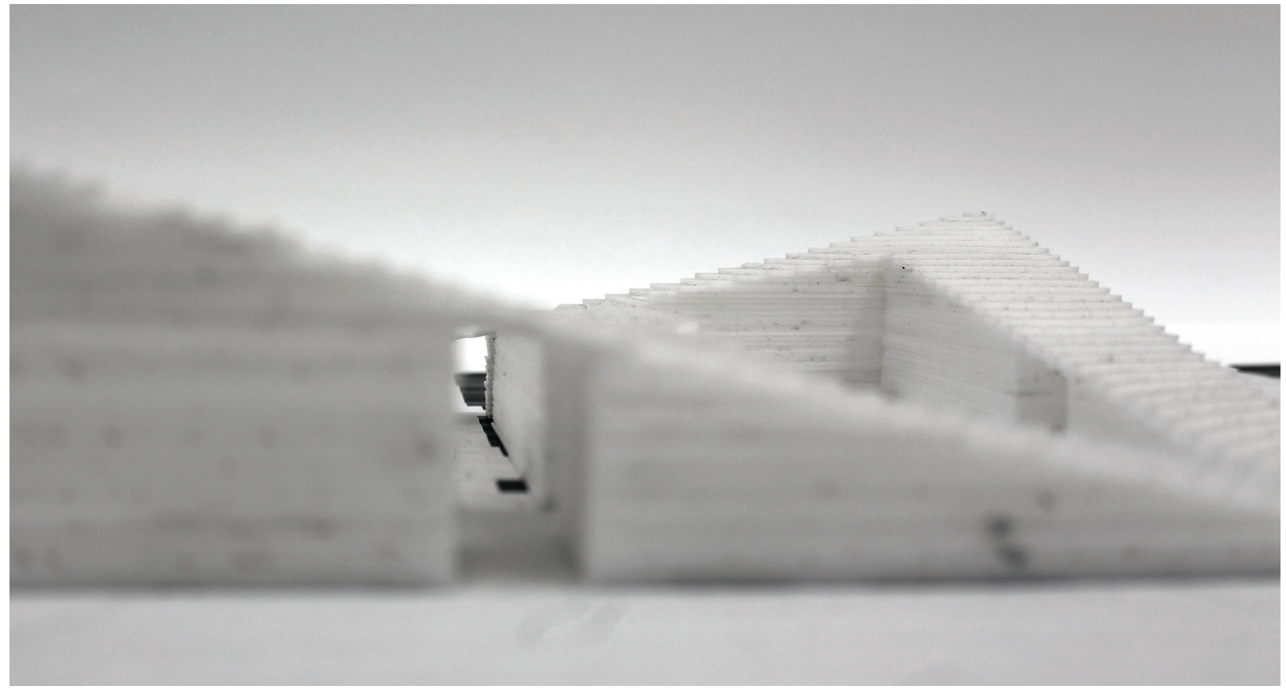
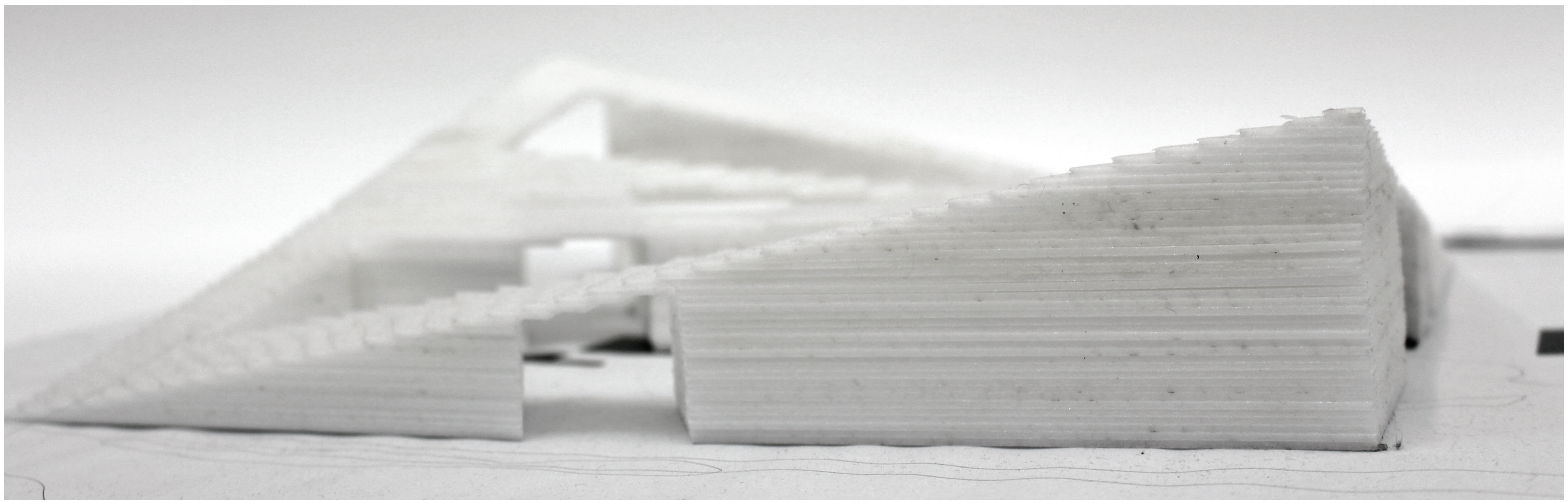
GREEN WEDGE BUILDING

With point of departure in the axis, lines in the context and the green wedge are volumes created which would connect by a roof warping over the volumes. The roof should in this way reflect the green wedge and connect this with a path going through the adjacent building to the green belt coming along Aarhus Å opposite Carl Blochs Gade. With its unique form framing two plazas the building would make a modern reference to the nearby karre structures. The effect of the double-curved roof would let sunlight access the plazas without a big self-shading effect from the buildt. The plazas would create a natural environment in within the building, providing nature and views from the inside. The two elevated corners of the roof, was inspired by the Åhusene (30 meters) in one end and the high point of the Godsbanen (20 meters) in the other.

The form also has several disadvantages:
- Long distances between functions, would create long travel paths for users.
- Volumes at the ends of the courtyards would create a barrier for the connection between the green wedge and Godsbanen. Views of the railway yards from Godsbanen would be limited.
- The height of the building along Carl Blochs Gade, the eight stories would be out of proportions and from time to time shade adjacent buildings.
- The building would not create enough gross area and other building might have to be placed in the courtyards, ruining the view and spaces created.

The number of unfavourable effects was higher than the favourable effects of the concept, was a step taken back. This step would investigate possible plans and how a modular system would create a frame for a repetitive system, which would become the basis for the main concept.

Ill. 93 Diagrams showing the architectural concept of the Green Wedge building

Ill. 94 Model of The Green Wedge building

MODULES AND PRINCIPLE

MODULES AND PRINCIPLE
With the aim of creating an optimal studio environment, the studio unit was developed with focus on the interior. With point of departure in the existing studios environments, lots of inspiration was found in Jørn Utzons, Utzon Center.

"The age of a person gives a certain richness, and in the same way, I hope that the courtyard provides a wealth for the place."
- Jørn Utzon
[Utzon Center, 2015]

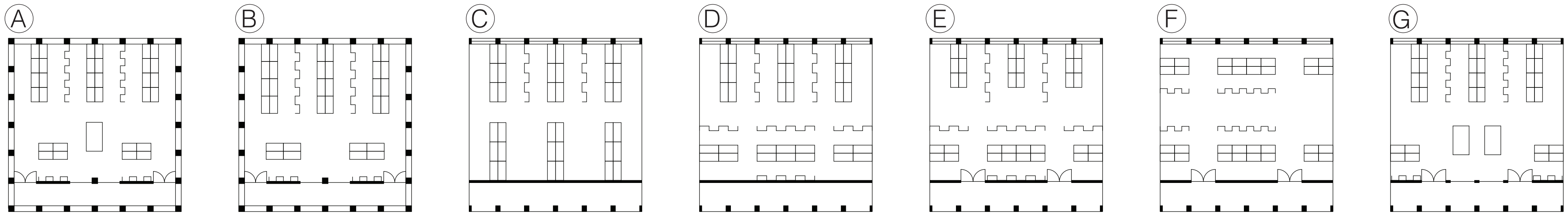
From this inspirational source, a modular system was studied. Studies showed how modules could create the frame for a studio environment and other functions. For easy adaptability and fabrication units were developed from a grid with dimensions of 22,50 x 22,50 m, 15,00 x 15,00 m, 7,25 x 15,00 m and 7,25 x 7,25m, based on an initial survey.

FURNISHING AND UTILIZATION DEGREE
Modules and furnishing was studied from the inside out with the architectural intension of giving students views from their desk. Concepts were later evaluated according to:

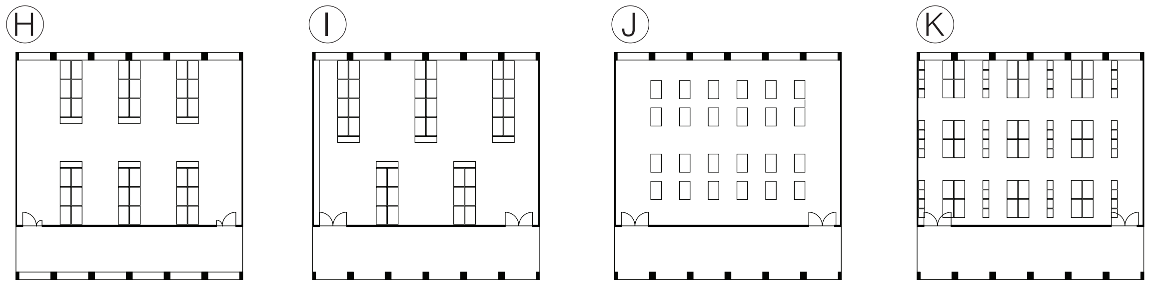
- How workspaces will be accessed, both inside and from outside into the studio.
- How the plan would create views from workspaces.
- Utilization degree and number of students.

The studies showed that an open floor plan would lack the ability of privacy, which was important according to the analysis. Additionally plans with a closed studio unit and a gallery hall were studied, those modules would create intimate studios and an open gallery hall. Having the intension that different parts of the build would create the frame for different practices was the intention for the gallery hall to create interaction. A wall between the studios and the gallery hall would provide space for exhibition and create intimacy and privacy for the studios.

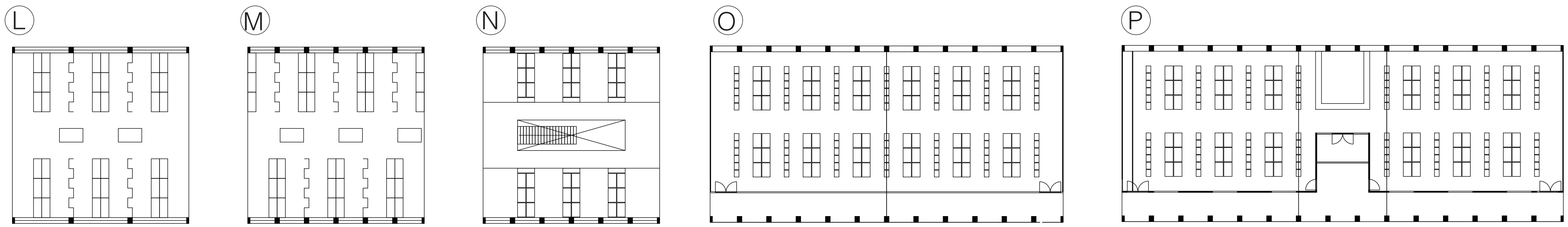
With values found in the modules consisting of a studio and a gallery hall, as found in proposal C, D and M, those layouts were taken into further development of the plan, see Ill. 95.



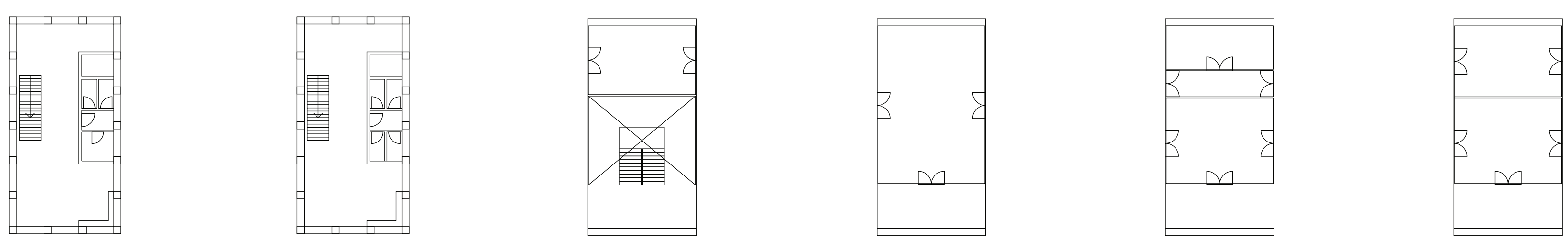
Square meter Studio:	165,7	165,7	177	177	177	177	177
Number of students:	32	32	36	32	32	32	32
Squire meters per student:	5,2	5,2	4,9	4,9	4,9	4,9	4,9



Square meter Studio:	162,4	162,4	162,4	162,4
Number of students:	36	32	24	36
Squire meters per student:	4,5	4,5	6,8	4,5



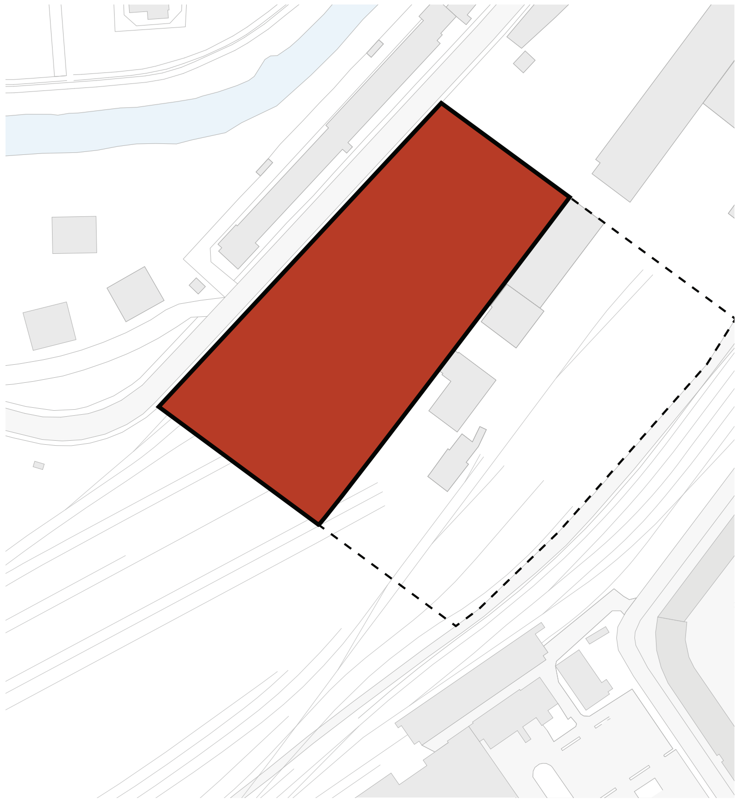
Square meter Studio:	210	210	126	355,8	422,2
Number of students:	36	36	36	72	72
Squire meters per student:	5,8	5,8	3,5	4,9	5,9



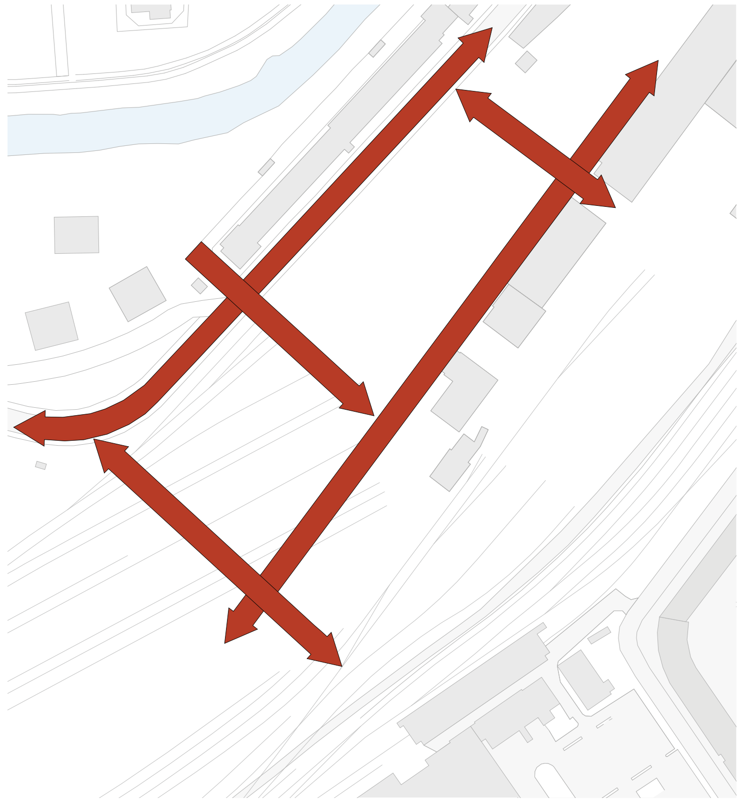
Ill. 95 Iterations: How to furnish a studio module and its utilization degree , additional modules for stairs and educational rooms.

SHAPING THE BUILDING

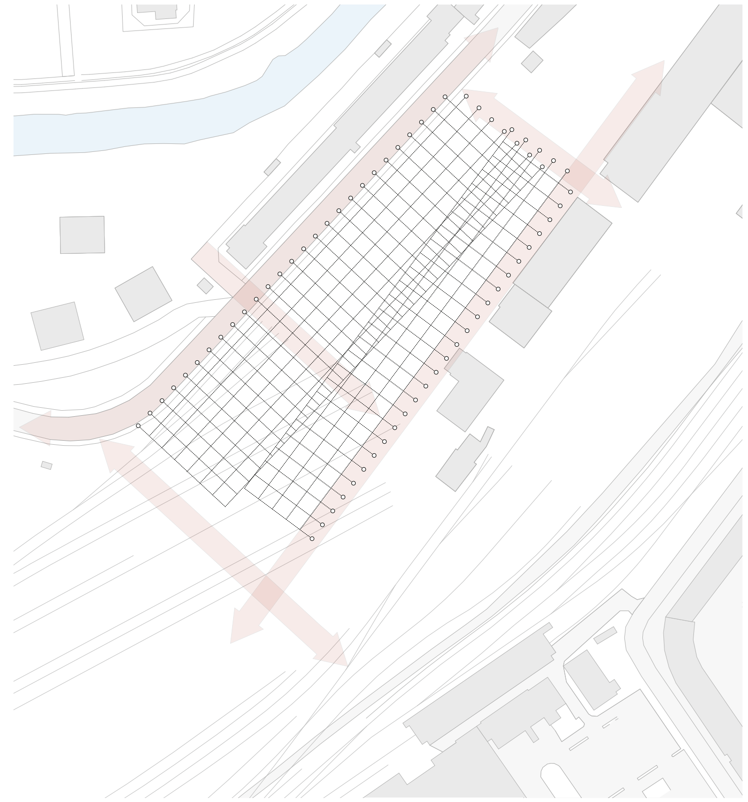
Design Process



Ill. 96 The building revised building lot



Ill. 97 Adjacent roads and new roads in the area are defining the site



Ill. 98 Gridlines for modules, defined by the site

GRID AND FUNCTIONALITY

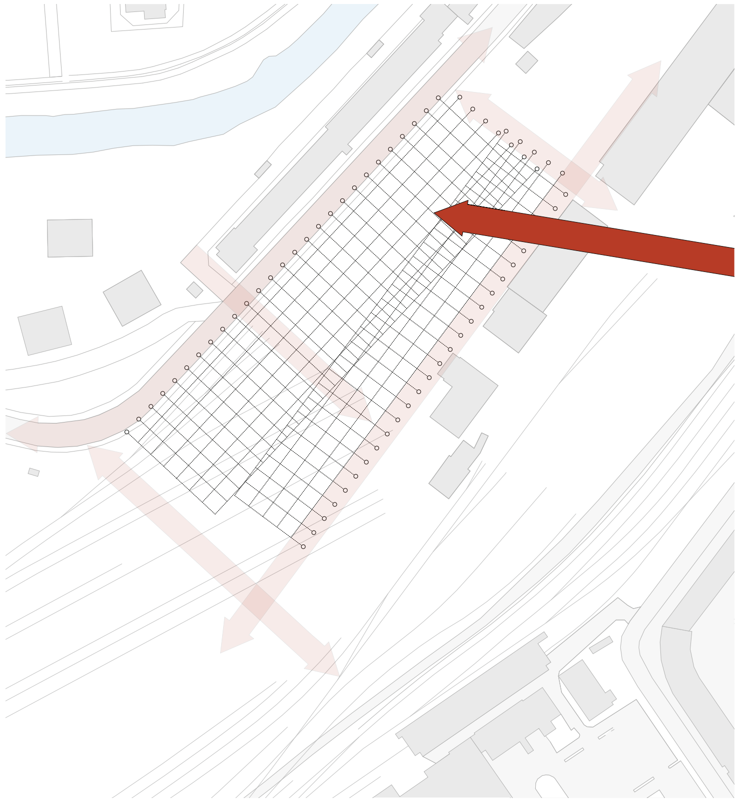
Having the modular system in mind and the configuration of the modules the masterplan was reconsidered. By looking at the axis and the intension of ending this in a plaza surrounded by the building was the site for the new school delimited to the north-western part. This delimitation would also make space for smaller building volumes on the south-western part. The south-western part would be orientated around the green wedge, whereas the north-western part would be orientated around the axis and the old railway tracks.

DEFINING THE SITE

Observing the surrounding roads and buildings, with the concept of using lines from the context would the site be delimited and cut by the flow of adjacent roads. Surrounding roads would create a flow around the site and the cutting roads would break the long straight line along Carl Blochs Gade.

GRID

Having the architectural idea of a repetitive modular system in mind, a grid was developed along from Carl Blochs Gade and the new road on the site. For structural and daylight reasons within the plan, the grid lines have an offset with a distance of 7,25m.



Ill. 99 The axis is ending in and cutting through the grid lines

Ill. 100 Distribution of functions of site

AXIS

Having the intension of finishing the axis from the town hall, the axis when entering the grid, would overrule the gridlines. By overruling the grid, the axis would be natural surrounded and make an end on the axis. In same way the lines from the old train tracks will be used for a new green belt, which absorbs the difference between the rotations of the two main grid lines.

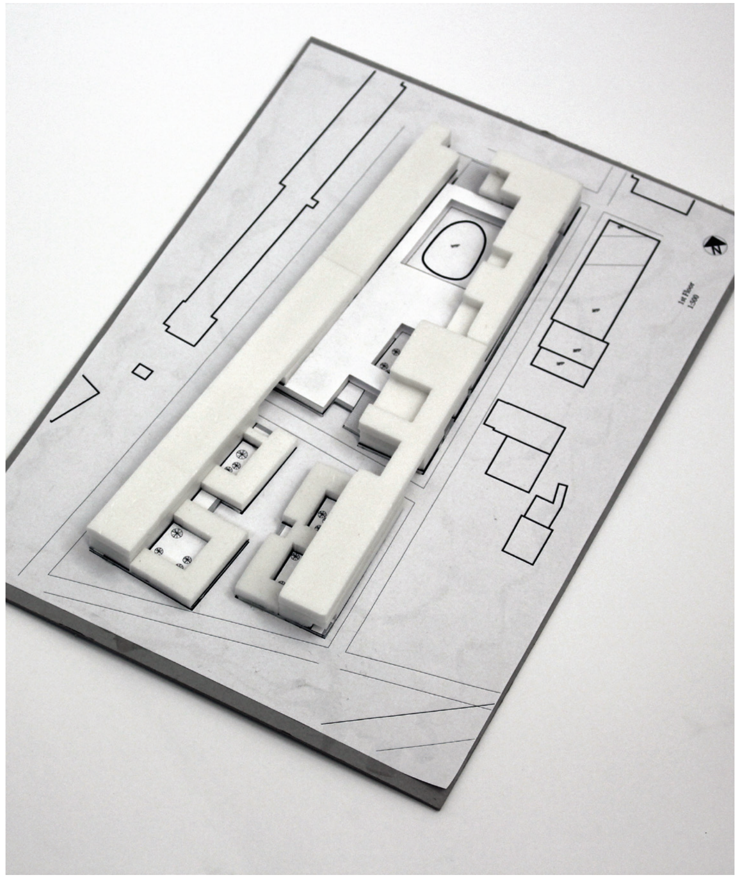
FUNCTIONS

Having defined the boundaries for the site, the placement and flow between functions are studied; the functions are defined in the building program. The studies investigate, how the program can be distributed to form a transition from public to private functions and spaces.

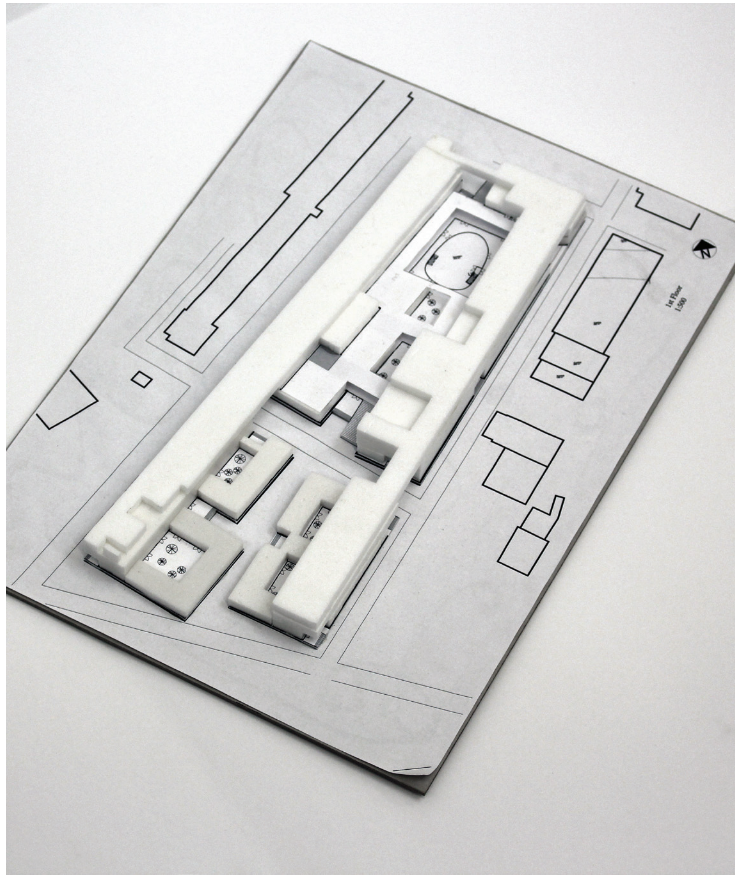
The main factor for the distribution of the functions is the accessing roads and the axis. To create a counterpoint and a public space at the end of the axis, the studies show how functions can be placed around a central exhibition space and an auditorium. The studies show how the exhibition, auditorium along with the library and canteen will become the heart in the building. Considerations of orientation and views along with the internal flow between functions are used to define their location.

SHAPING THE BUILDING

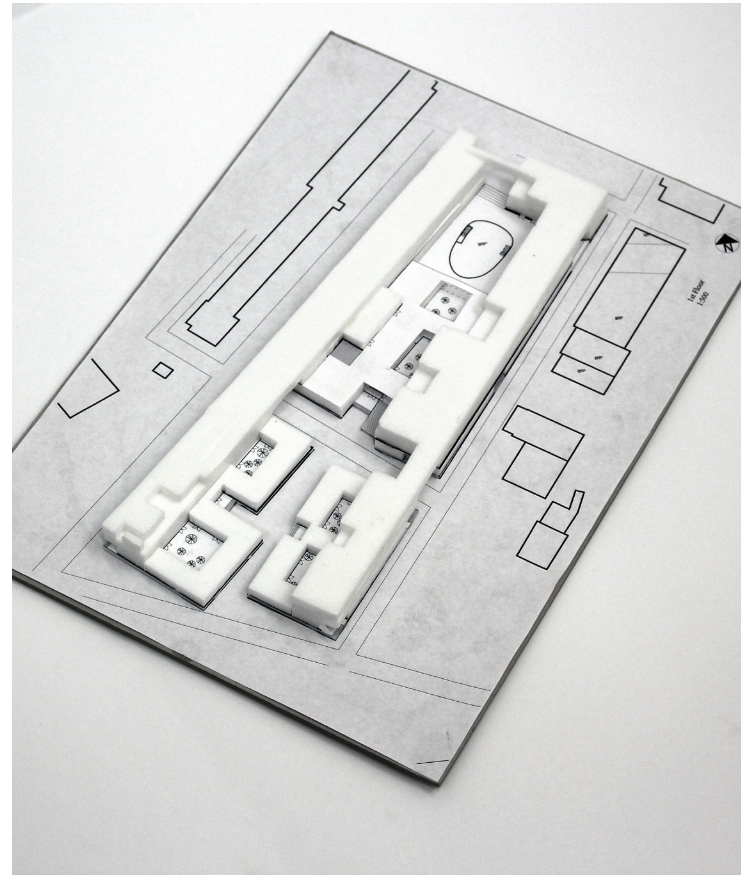
Design Process



Ill. 101 First iteration



Ill. 102 Second iteration



Ill. 103 Third iteration

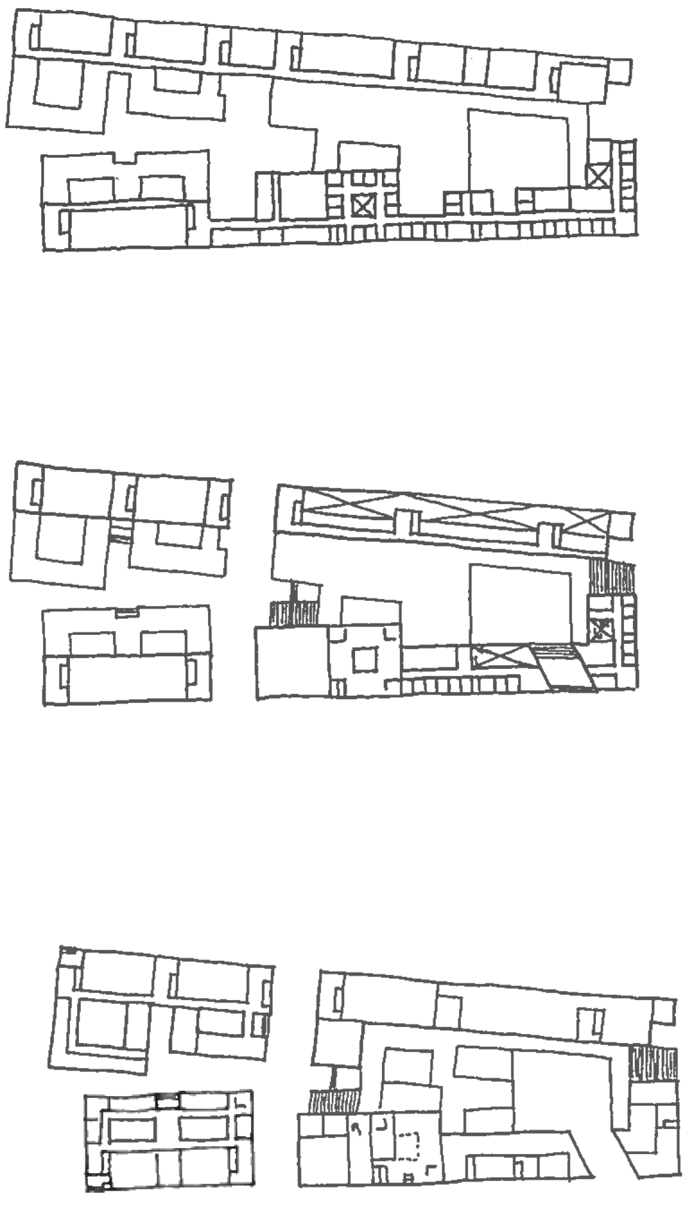
FORM AND PLAN

Having the grid and functions placed, repetition is used for developing the plan. By introducing the old train tracks for a green belt inside the building the difference between the grids would be absorbed. With the risk for flooding and the reference to the adjacent Godsbanen the building would be raised on a 1m high base.

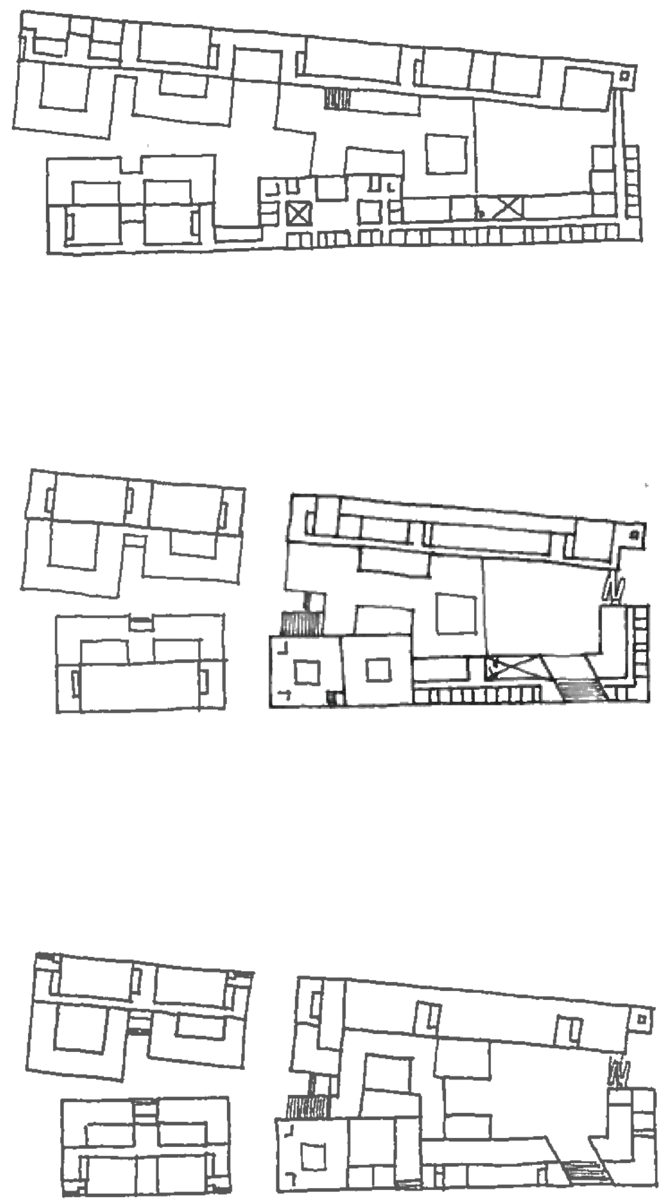
The models and sketches, presented above (Ill. 101 to Ill. 106), show how the grid along with lines from the context is used to shape the volumes of building. By placing the previous studied modules with the gallery hall along the inside of the building, an interaction between the volumes is created. In the plan, public functions such as offices and administrative functions would be places near the end of the axis, making a main entrance to the building. Workshop and studios would mainly be placed along Carl Blochs Gade, as this volume is placed north-west of the plot, it would give the functions a higher privacy. By placing the canteen, library and gallery hall in the centre of the building those functions would be easy accessible, and create a heart in the building.

Iterations studied how cuts and indentations in the building volumes would create spaces for terraces and a reference to the idea of a canyon. Initial sketches where the auditorium and the exhibition hall are surrounded by a gallery walk. However in order to make the statement of the axis ending in a plaza with the auditorium was this later removed, to simplify the plan.

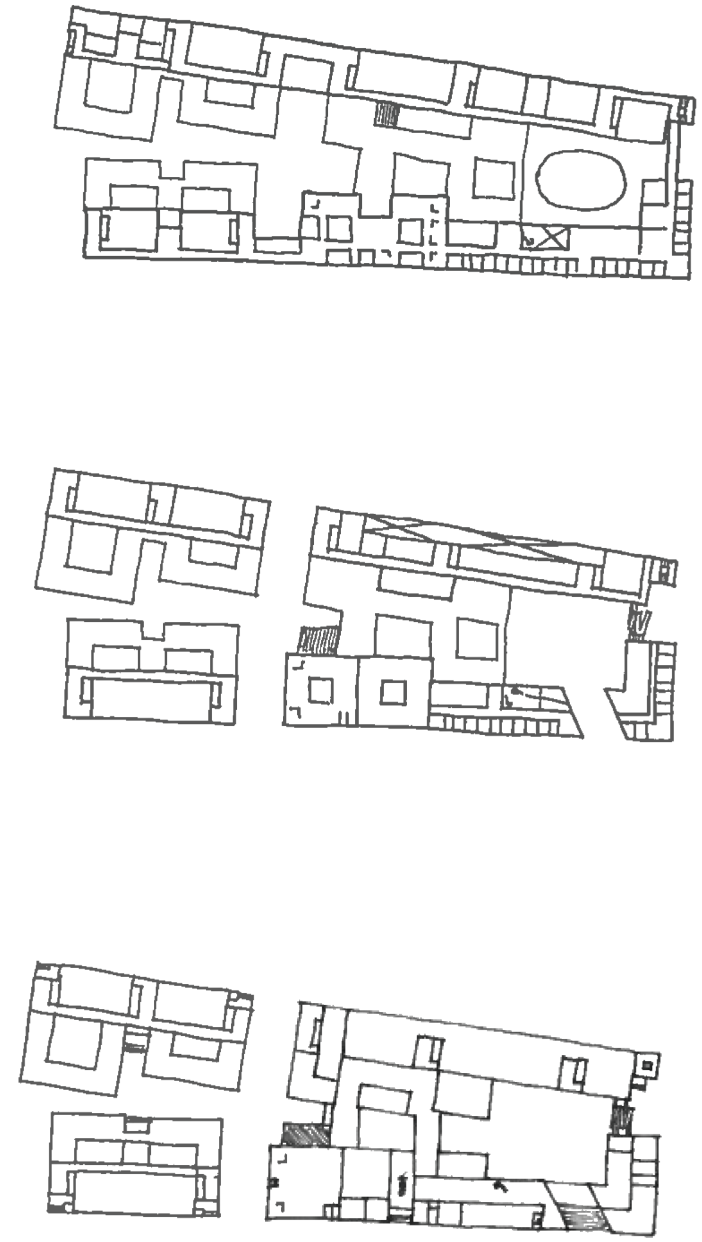
The sketches illustrate how two different modular systems were used for the studios. Having the possibility for cross ventilation in the studio module M. By installing in-wall aggregates (Inventilate), would the studios be natural ventilated in summer and mechanical ventilated during winter. As the design progressed, this concept would not work and the ventilation strategy was changed to a mechanical system with aggregates placed in the base of the building. By the need of a place for the ventilation ducts, studios were later switched to module C and D and the floor height was altered from 3,5m to 4m.



Ill. 104 First model



Ill. 105 Second model



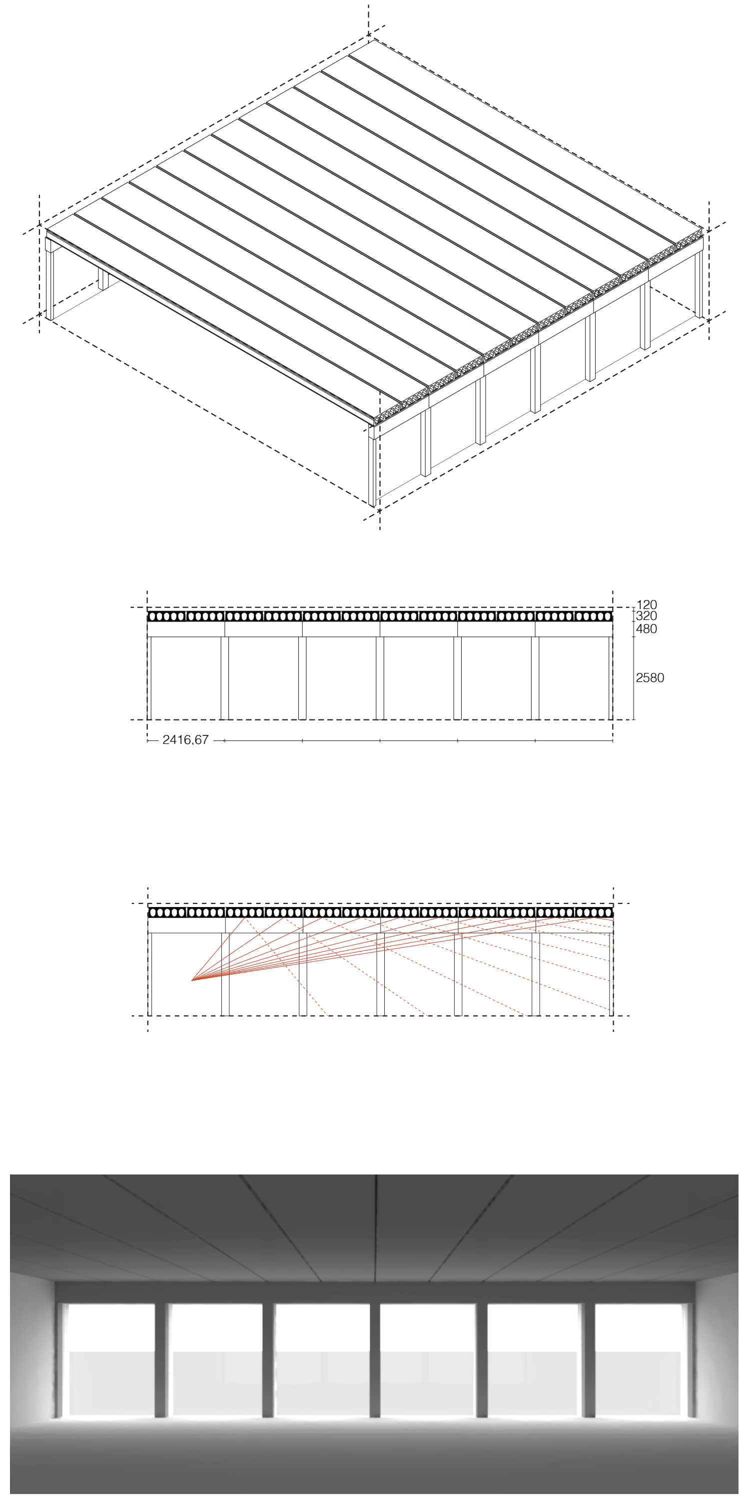
Ill. 106 Third model

STRUCTURE

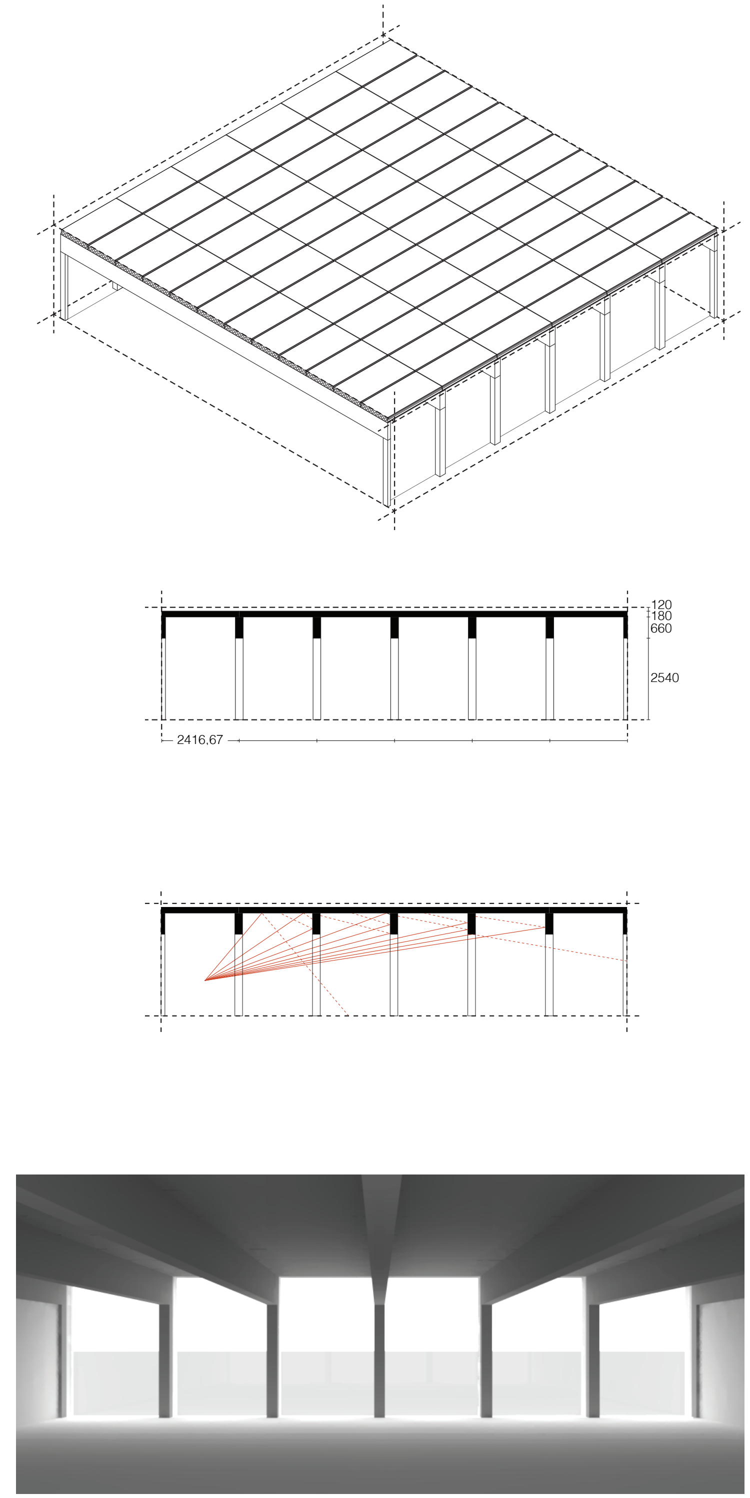
Having the intension of adaptability and a low-tech approach in mind, different structures were evaluated. With the idea of a low tech approach in the form of night cooling, used for additional ventilation and cooling in the summer season was a structural system of concrete considered instead of structures made of wood or steel.

By studying the element sizes in different column-plate systems, their aesthetic qualities, when exposed, and their acoustic performance by ray tracing, a structure as seen on Ill. 108 was chosen. This structure would have exposed beams for night cooling and acoustically prevent sound from spreading. By spanning the beams across the building, the possibility of higher windows in the modules was created.

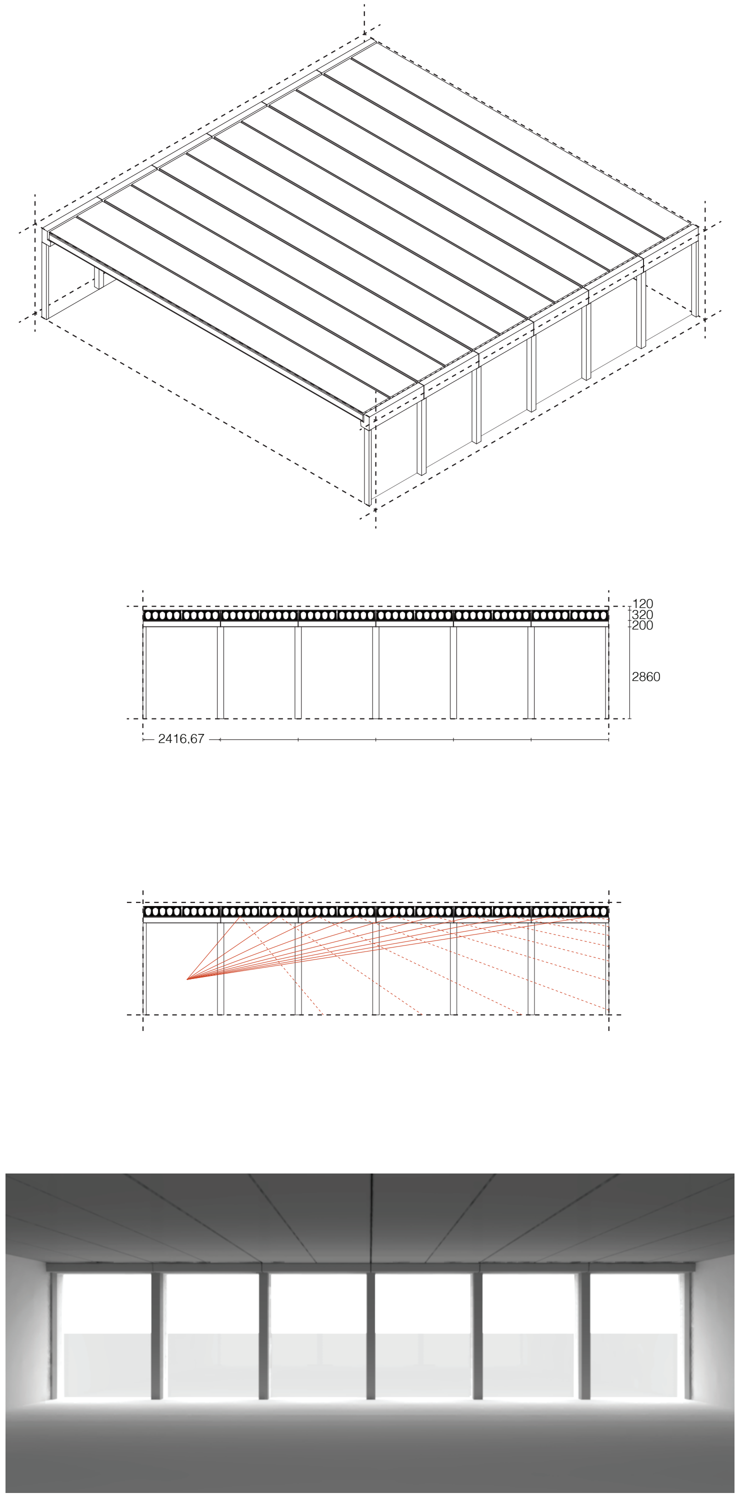
The initial studies worked with an internal floor-to-floor height of 3,5m, as this would provide the minimum requirement room height of 2,5m. To ensure a proper feeling of the space the free ceiling height was set to a minimum of 2.8 meters.



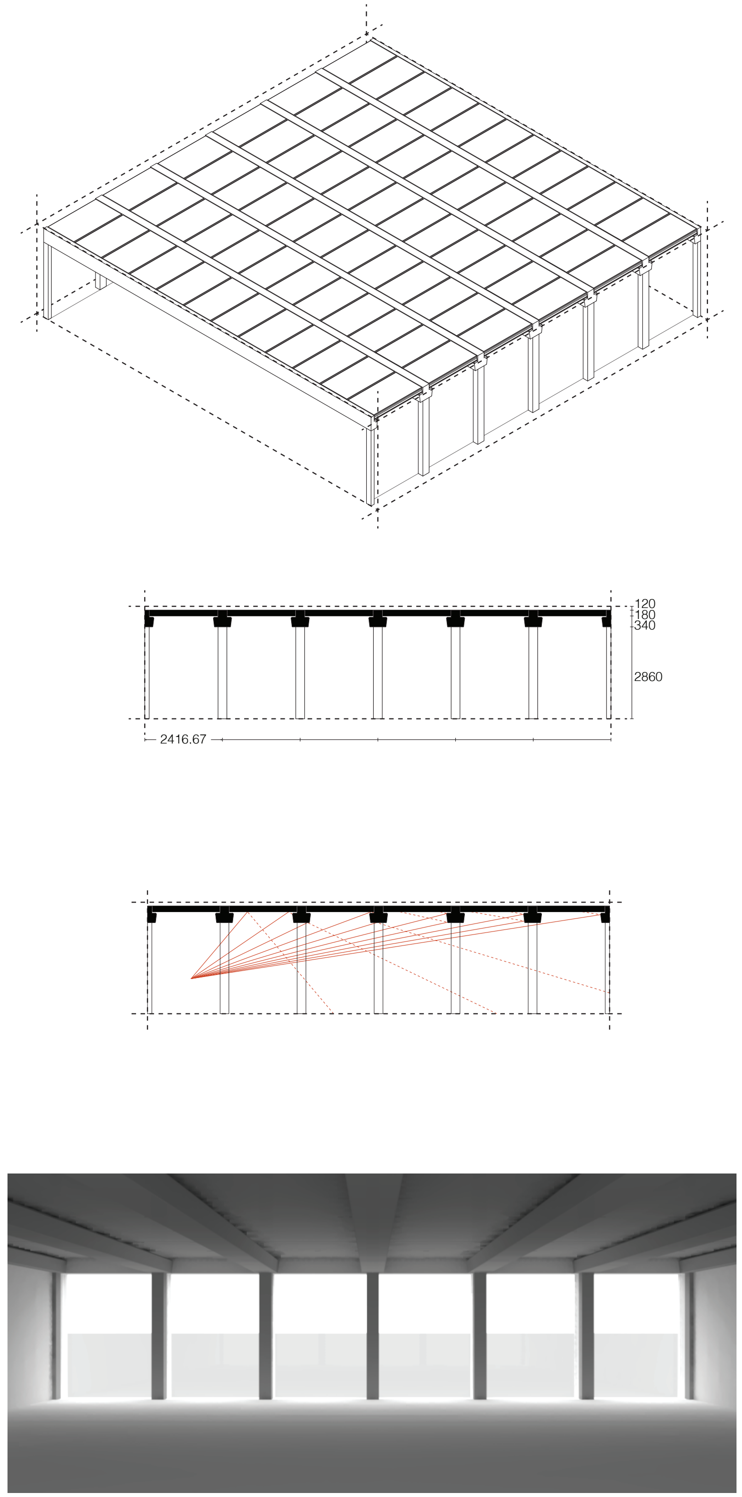
Ill. 107 Structure 1: Deck EX32 spanning 14400 mm; beam RB 2400mm



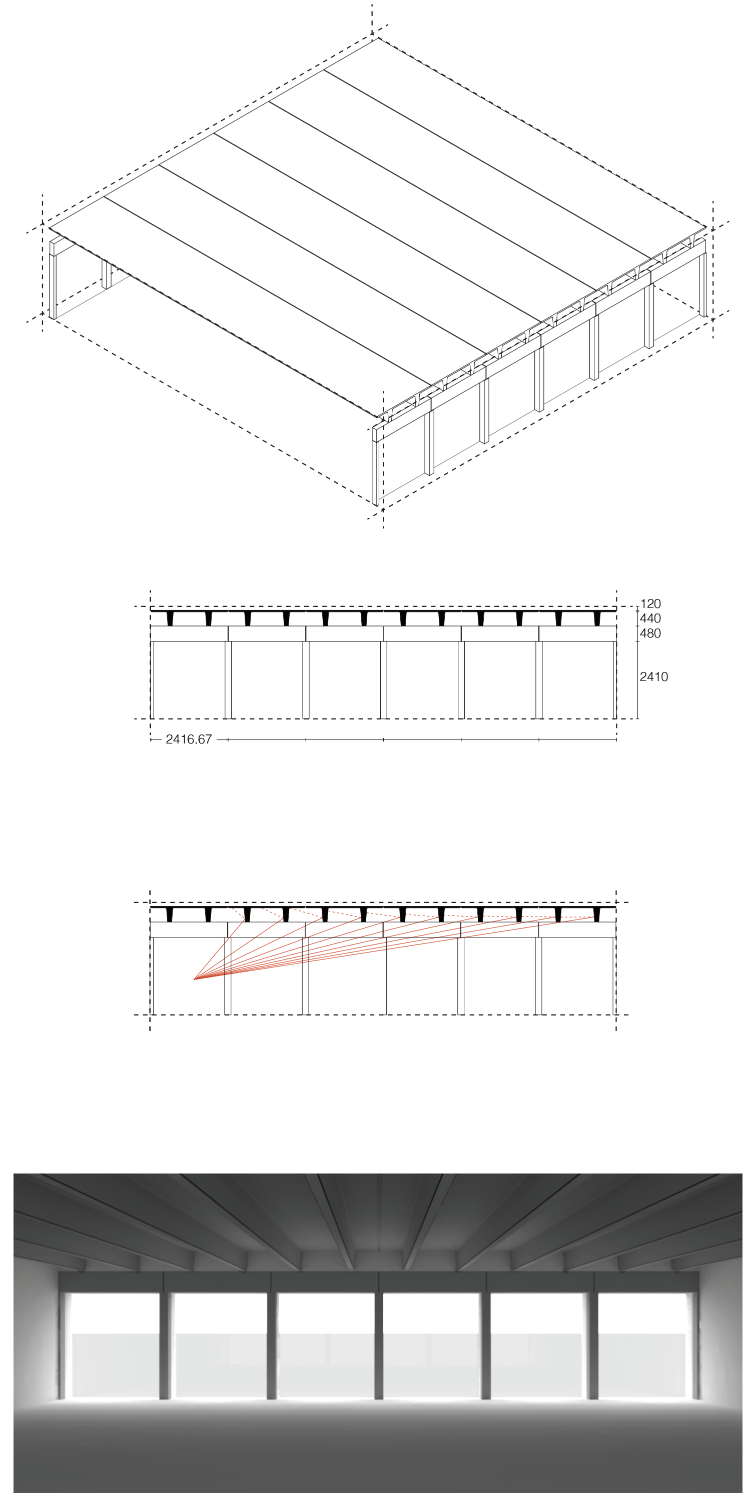
Ill. 108 Structure 2: Deck EX18 spanning 2400 mm; beam RB 14400 mm



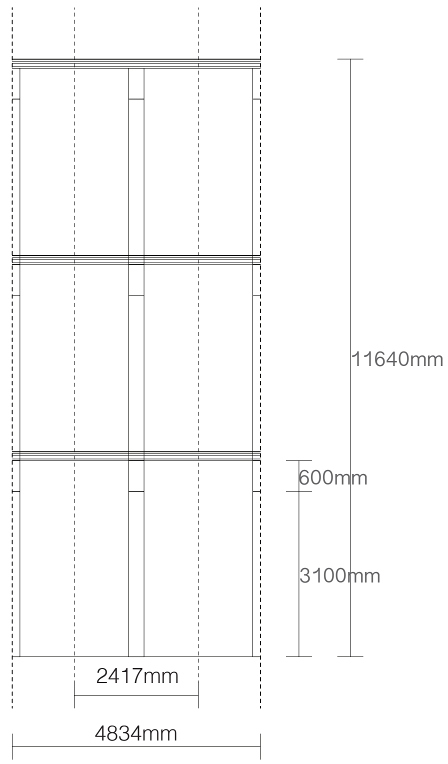
Ill. 109 Structure 3. Deck EX32 spanning 14400 mm; beam KBE 2400 mm



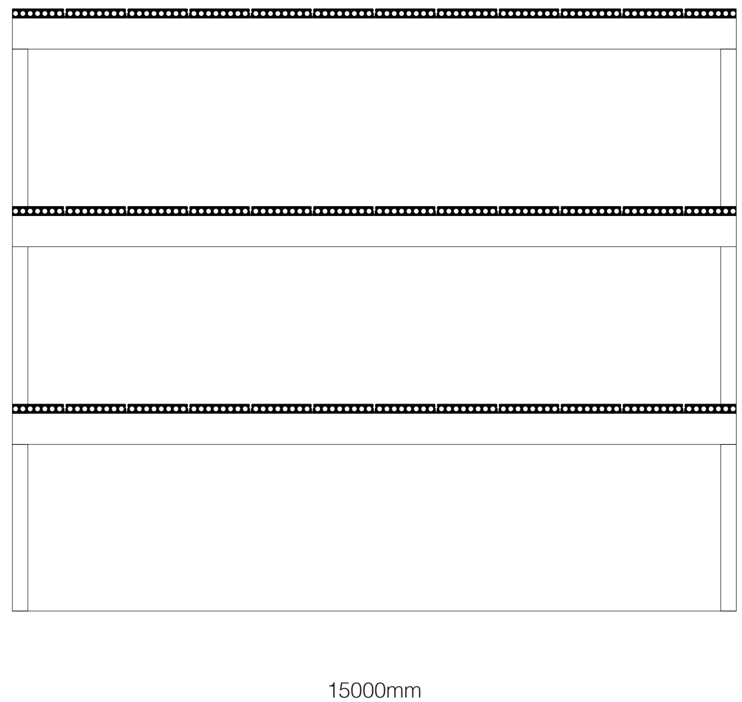
Ill. 110 Structure 4. Deck EX18 spanning 2100 mm; beam KB 14400 mm



Ill. 111 Structure 5. Deck TT40/240 spanning 14400 mm; beam RB 2400mm



Ill. 112 Construction: column, beam and deck



Ill. 113 Construction: column, beam and deck

Through with the development of the plan, were the different structural systems evaluated. With a low-tech building in mind, a heavy concrete structure was further investigated.
With point of departure in the studio and the expression of the structure, were the study used to evaluate dimensions for floor slabs, beams and columns. In order to find approximate dimensions for the structural elements were carrying capacity tables used.

When developing the plan, the placement of cores in relation to stability and circulation in accordance with fire requirement been incorporated. The development of the structure focussed on the vertical forces applied to the structure; applied load, the deflection and carrying capacity of the different elements. By investigating different rotations of deck and beams was the expression later evaluated. Following pages, explains the dimensioning process of the study for the later chosen.

The calculations for the deck and beam are illustrated on this page. For further calculations for the column, see appendix 1.4.

LOADS

The study investigates the decks, beams and columns. The deck is carrying an installation floor with a load of 0,5 kN/m² and a live load of 2,5 kN/m², according to live load for offices. [Eurocodes 1, Tabel 6.2]

The load for the deck is found as an area load and for the beam as a line load. The line load is for this example found by adding the width of the deck. Ill. 112 and Ill. 113 shows the structure seen from the front and from beside. As the calculations are focuses on an internal deck on the second floor, the calculation only take the permanent and live load into account.

	Load	Partial Factor	Permanent Load	Service Limit State	Ultimate Limit State
	kN/m²	-	kN/m²	kN/m²	kN/m²
Floor Covering	0,5	1	0,5	0,5	0,5
Live Load	2,5	1,5	0	2,5	3,75
Total Load	-	-	0,5	3,0	4,25

Loads on deck

	Load	Partial Factor	Permanent Load	Service Limit State	Ultimate Limit State
	kN/m²	-	kN/m	kN/m	kN/m
Floor Covering	0,5	1	1,21	1,21	1,21
Deck	3,06	1	7,40	7,40	7,40
Live Load	2,5	1,5	0	6,04	9,06
Total Load	-	-	8,60	14,65	17,67

Table 2 Loads on beams

DECK

Table 2 shows the load on the deck in Ultimate Limit State is 4,25kN/m². The span between the carrying beams is 2400mm as shown on Ill. 112. It is assumed that a deck with a span of 2400mm and a thickness of 180mm can withstand the load, as the minimum span in the carrying capacity tables from Consolis Spæncom is 4200mm with a carrying capacity nearly four times the load used in the design.

egv i kN excl. fugebeton		Pr. plade		14,8
		Spændvidde		4,2
5 L9,3	M_{Rd}	58,90 kNm	$q_{,Rd}$	**19,2**
	V_{Rd}	63,26 kN	$q_{,vRd}$	22,0
	MmREI60	49,24 kNm	qmREI60	15,5
	MmÅbnFak0,02	34,77 kNm	$q_{mÅbnFAk0,02}$	**10,1**
	MmÅbnFak0,04	42,03 kNm	$q_{mÅbnFAk0,04}$	**12,8**
	MmÅbnFak0,06	47,84 kNm	$q_{mÅbnFAk0,06}$	15,0
	VvBrand	42,49 kN	q_{vBrand}	13,8
	MmREI120	19,20 kNm	qmREI120	**4,2**
	Mrev	60,37 kNm	q,rev	19,8
	Mbal	18,28 kNm	q,bal	3,8
	flev i mm		f_{lev}	2,9
	fe1 i mm		f_{e1}	0,3
	Egensvingning	Hz	$f_{,1}$	20

Table 3 Carrying capacity table for Spæncom EX18 5L9,3

The other deck used in the design is spanning 14400 mm, therefor will this deck have to be thicker. Table 3 shows that in order to withstand the load is 320 mm thick needed. As the deck will be spanning 14400 mm is a calculation of the deflection of the beam found, In order to ensure the expression of the structure and adjacent structures must the deflection not be higher than l/500 and l/250. Flowing calculation shows the deflection of a deck with a permanent load of 0,5kN/m² and a live load of 2,5kN/m². Decks from Spaencom are prestressed concrete elements, meaning that the deck will have a delivery camber of 9,1mm and a deflection fe1 of 9,2mm pr. kN/m².

First is the deflection from the resting permanent load found:

$$\text{Deflection}_p = \text{Fe1} \cdot \text{q}$$

$$0{,}5\frac{\text{kN}}{\text{m}^2} \cdot 9{,}2\frac{\text{mm}}{\frac{\text{kN}}{\text{m}^2}} = 4{,}6\text{mm}$$

0,3

Next is the deflection for the live load found:

$$\text{Deflection}_l = 2{,}5\frac{\text{kN}}{\text{m}^2} \cdot 9{,}2\frac{\text{mm}}{\frac{\text{kN}}{\text{m}^2}} = 23\text{mm}$$

Over time will shrinkage take place, calculated by:

$$\text{Residual deflection} = \left(\text{q}_{\text{bal}} - \text{q}_{\text{p}}\right) \cdot \text{fe1} \cdot \frac{9\text{mm}}{7\text{mm}}$$

$$0{,}2 - 0{,}5\frac{\text{kN}}{\text{m}^2} \cdot 9{,}2\frac{\text{mm}}{\frac{\text{kN}}{\text{m}^2}} \cdot \frac{9\text{mm}}{7\text{mm}} = -3{,}55\text{mm}$$

The total deflection with an permanent load and a live load becomes 22,05 mm as shown in Table 4.

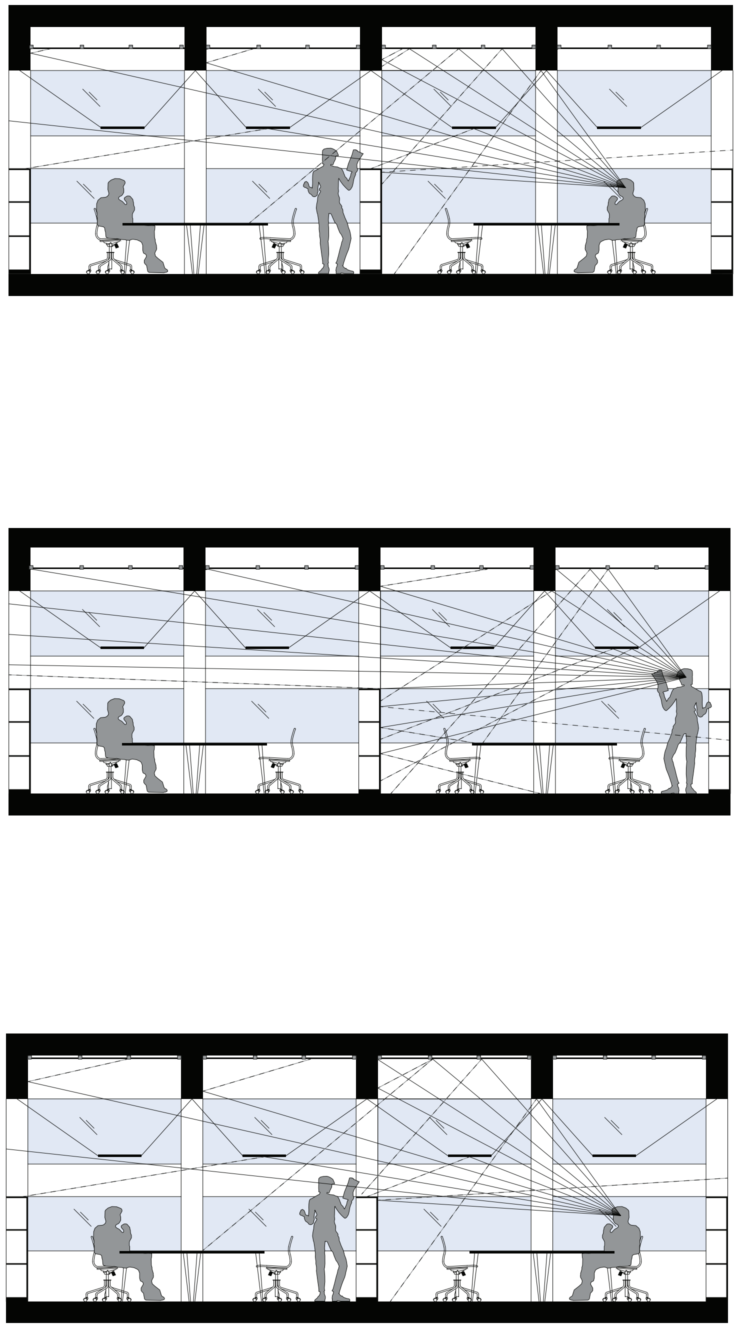
		mm
1.	Delivery Camber	9,1
	Deflection from resting permanent load	-4,6
2.	After completion	4,5
	Shrinkage	-3,6
3.	After shrinkage	1,0
	Deflection from live load	-23,0
4.	Deflection when totally loaded	-22,0

Table 4 Deflections in different stages

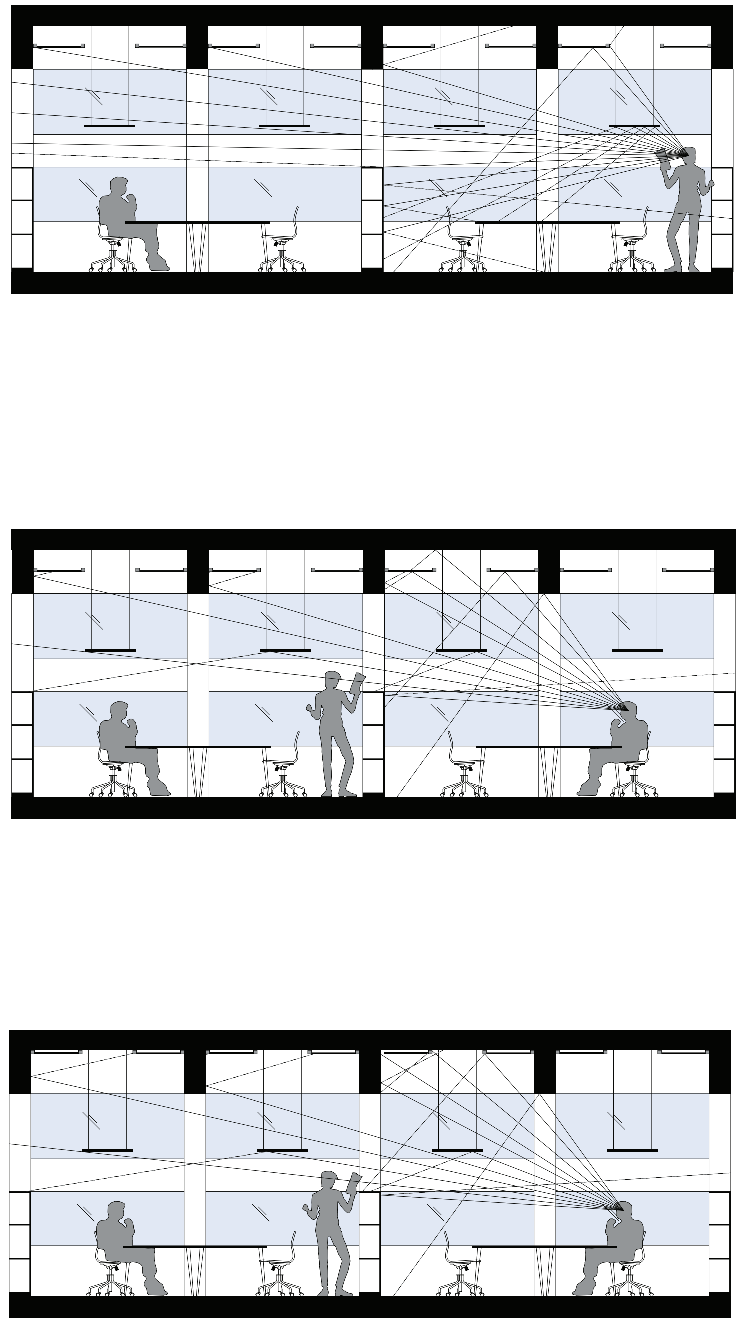
STRUCTURE AND RAYS

To get an understanding of the chosen structure and how sound waves would spread inside the studio, further ray-tracings were used to investigate the section. The initial idea was to have the beams from the structure exposed in the entire building. However as later iterates would include a fully mechanical ventilation system with aggregate in the base, the structure in areas with workspace would be rotated, as shown on Ill. 107. By rotating the structure, acoustic requirements in those areas would be met by a suspended acoustic ceiling and subdivision of the rooms. However the concept of exposed beams would still be used for areas with studios.

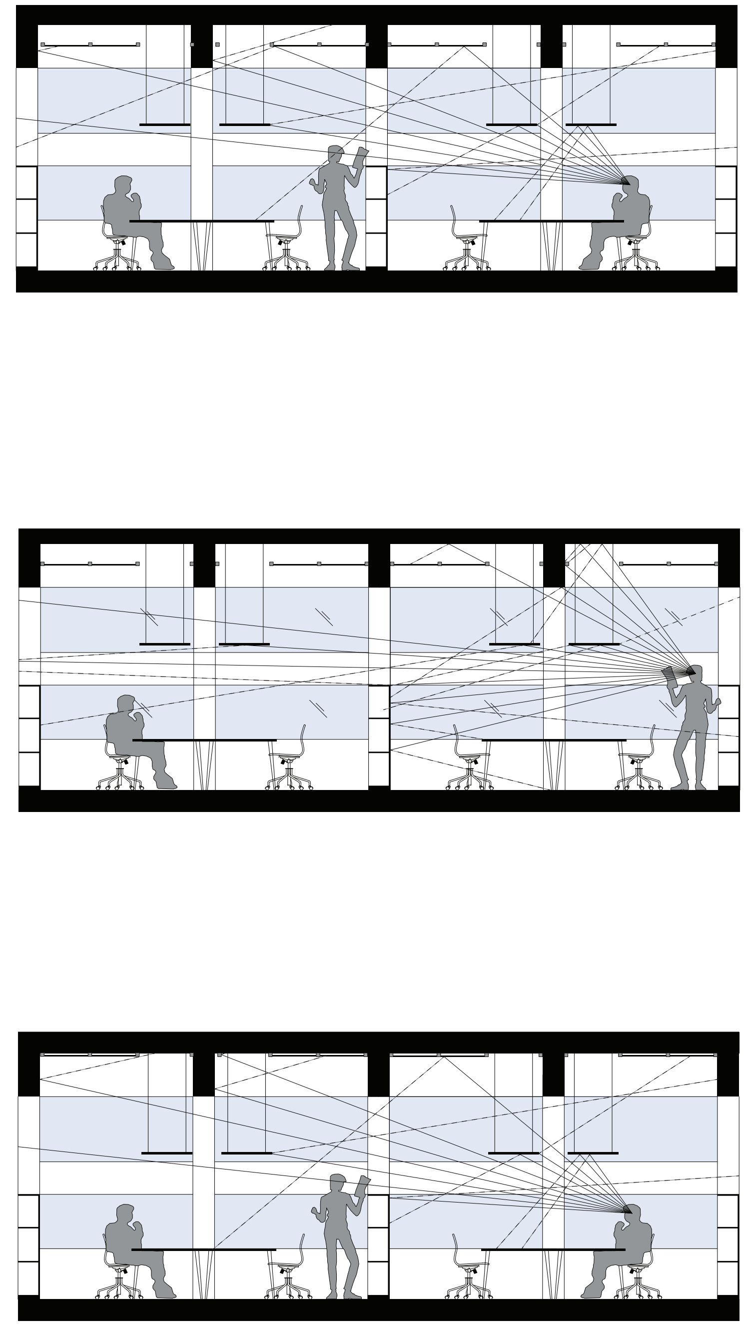
The studio section shows a furnishing arrangement, where the students will have an overhanging shelf for storage of large cardboard and models. The previous analysis found the importance of ways for the students to define their own space. A fact which earlier was used to create the plan for the modules. With the need for storage near the students and the opportunity for them to personalise the space was a storage system created. By giving each student his or her own storage, the required amount for storage found in the program for the studios would be allocated to each student. By studying the ray-tracing the placement for the overhangs and the height of the shelving system was found. Ill. 114 to Ill. 116 shows the iterations. Having the intension of the students being able to personalize their workspace the placement was studied along with the acoustic considerations. By placing the overhanging storage over the student, it will be easier for the student to adjust the surrounding acoustics by changing the height of the overhanging storage.



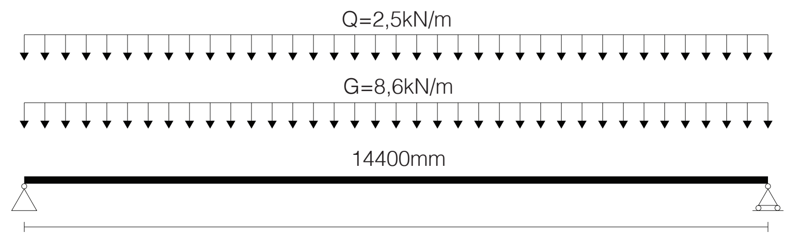
Ill. 114 Ray tracing studio with storage alternative 1



Ill. 115 Ray tracing studio with storage alternative 2



Ill. 116 Ray tracing studio with storage alternative 3



Ill. 117 Structural system

BEAM

Similar is the carrying capacity and deflection for the beam found. The beam is loaded with 14,65kN/m in Service Limit State and 17,67kN/m in Ultimate Limit State. The span of the beam is 14400mm as shown in Ill. 117. Carrying capacity tables from Spaencom are again used to estimate a beam dimension of 300 x 600mm.

MRd	772,6	kNm	Lgd m	3,6	4,8	6,0	7,2	8,4	9,6	10,8	12,0	13,2	14,4	15,6
Mrevne	525,4	kNm	qRd kN/m					83,3	62,7	48,7	38,6	31,2	25,5	21,1
Mbal	266,7	kNm	qrev kN/m					55,3	41,3	31,7	24,9	19,8	16,0	13,0
Egenvægt	4,32	kN/m	qbal kN/m					25,9	18,8	14,0	10,5	7,9	6,0	4,4
			flev mm					21,2	26,3	31,3	35,8	39,6	42,2	43,3
14 L12,5+	4 L 12,5		f10 mm					3,6	6,1	9,8	14,9	21,8	30,9	42,6
			Egenf Hz					8,2	7,1	6,2	5,4	4,8	4,3	3,9

Table 5 Carrying capacity table for Spæncom EX18 5L9,3

The table shows that the beam has a higher carrying capacity (16,0 kN/m), than the load, which is applied to it (14,65 kN/m).

Ultimate limit state (ULS)

The bending moment for the beam must be higher than the designed moment capacity:

$$M_{Sd} < M_{Rd}$$

The design value for the moment capacity is found by:

$$M_{Sd} = \frac{1}{8} pl^2$$

The moment capacity for the load combination in ultimate limit state is used (Load from floor, deck and live load):

$$M_{Sd} = \frac{1}{8} \cdot 17{,}66 \frac{kN}{m} \cdot 14{,}4^2 m = 457{,}75kNm$$

The moment capacity for the beam is 772,6 kNm, which is higher than the moment of 457,75kNm caused by the load.

Service Limit State (SLS)

The maximum deflection must not exceed:

For expression and general use:

$$\frac{l}{250} = \frac{14400mm}{250} = 57{,}6mm$$

For ensuring adjacent construction parts:

$$\frac{l}{500} = \frac{14400mm}{500} = 28{,}8mm$$

The total deflection for the beam is calculated with a camber of 42,2 mm. The deflection for 10 kN/m (fe10) is listed in the carrying capacity Table 5 to 30,9mm. The deflection for the resting permanent load and live load is calculated.

Deflection from resting permanent load is found:

$$Deflection_p = \frac{8{,}61 \frac{kN}{m}}{10kN} \cdot 30{,}9 \frac{mm}{10kN} = 26{,}35mm$$

Deflection from live load is found:

$$Deflection_l = \frac{6{,}04 \frac{kN}{m}}{10kN} \cdot 30{,}9 \frac{mm}{10kN} = 18{,}48mm$$

A residual deflection will occur after shrinkage:

$$Residual\ deflection = (q_{bal} - q_p) \cdot \frac{fe10}{10} \cdot \frac{9mm}{7mm}$$

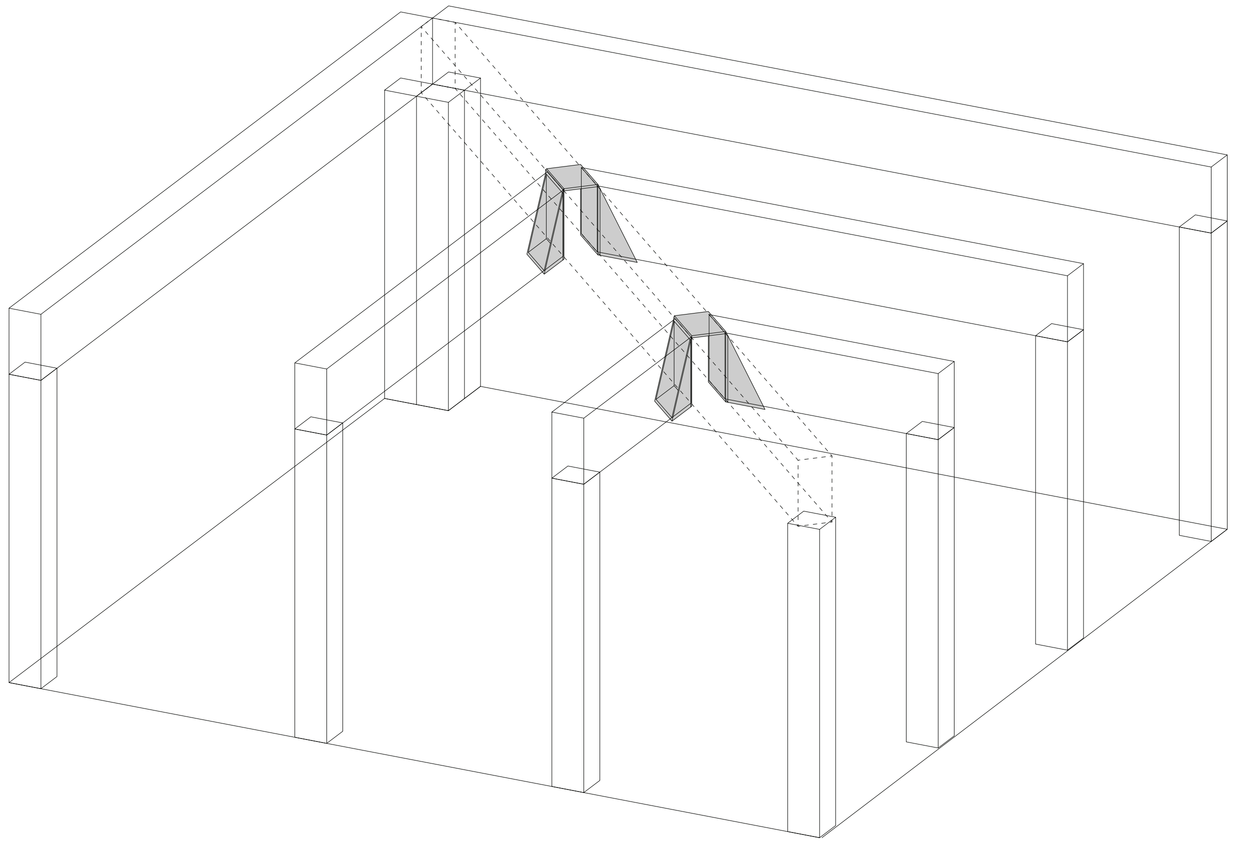
$$Residual\ deflection = \left(6{,}04 \frac{kN}{m} - 8{,}61 \frac{kN}{m}\right) \cdot \frac{30{,}9}{10} \cdot \frac{9mm}{7mm}$$

$$= -10{,}21mm$$

The calculation shows that the deflection will be less than the 28,8mm allowable for ensuring the adjacent construction. Table 6 shows the deflections with the total deflection of 12,9 mm.

		mm
1.	Delivery Camber	42,2
	Deflection from resting permanent load	-26,4
2.	After completion	15,8
	Shrinkage	-10,2
3.	After shrinkage	5,6
	Deflection from live load	-18,5
4.	Deflection when totally loaded	-12,9

Table 6 Deflections in different stages

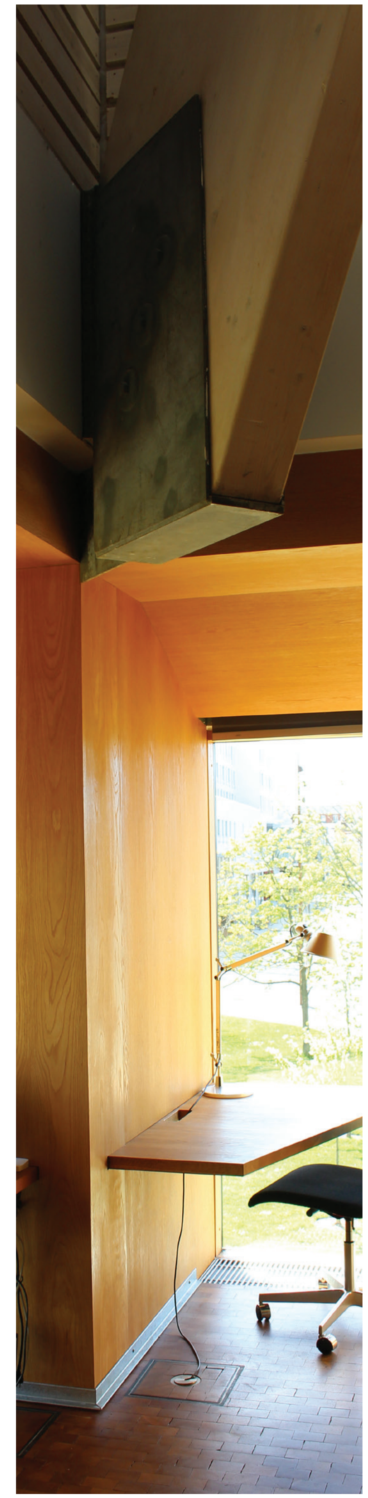


Ill. 118 Joining the beam with a steel-shoe.

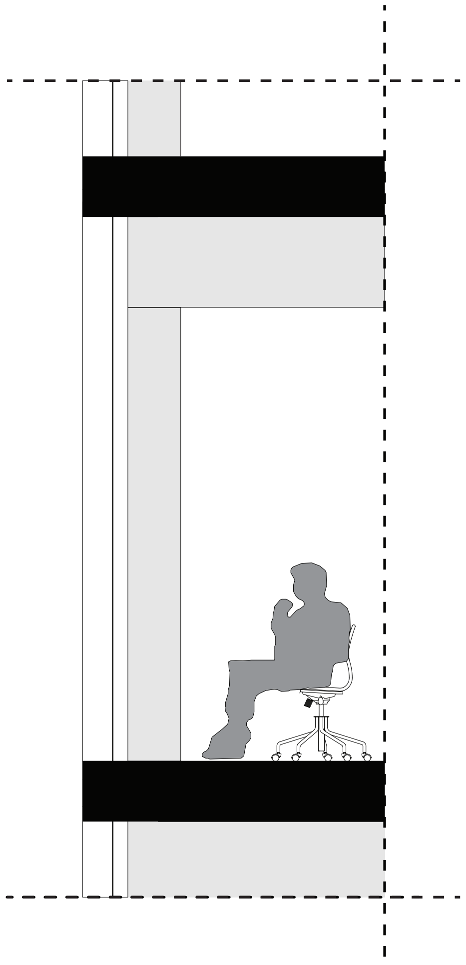
JOINING BEAMS

A special beam and shoe was designed for the corner structure, to ensure floor area with no columns in the middle of the room. The beams is dimensioned to the same size as the regular beams, but with more reinforcement to withstand the larger load. For calculations see appendix 1.5. According to the calculations the beam meets the requirements of deflection (l/250 = 41mm) ensuring a pleasant user experience, calculating cross-section of an un-cracked beam (39,5mm). A cracked cross-section of the beam's deflection is slightly too large according to the calculations (42,3mm). This issue will be solved with further reinforcement.

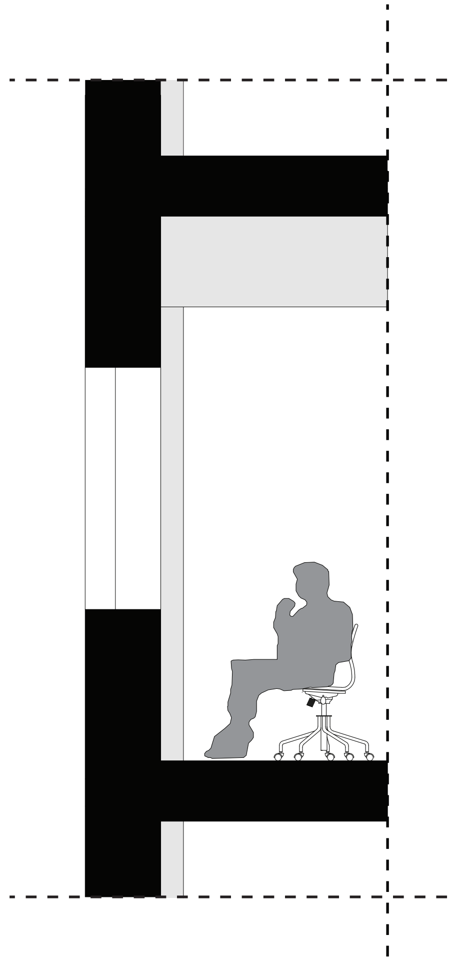
To join the beams, a steel "shoe" has been designed to transfer the load from the beams onto the corner beam. The steel-shoe has not been calculated, but existing steel-shoe carrying an approximately larger load has been used as a reference. The intention of the steel-shoe is to give the user and impression of the structure and how the loads are transferred. Principle illustrated on Ill. 118 and Ill. 119.



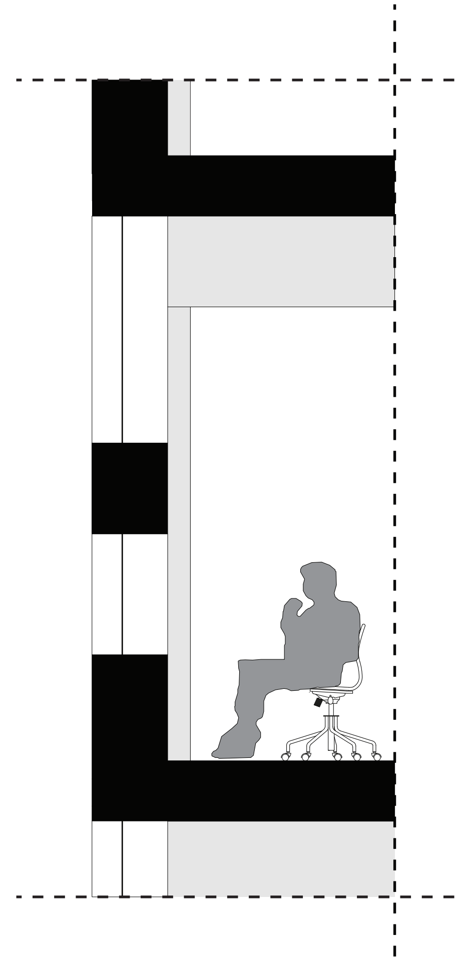
Ill. 119 Reference of a steel-shoe handling the load of a glulam beam.



Ill. 120 Principle A: Curtain wall



Ill. 121 Principle B: Middle placed window



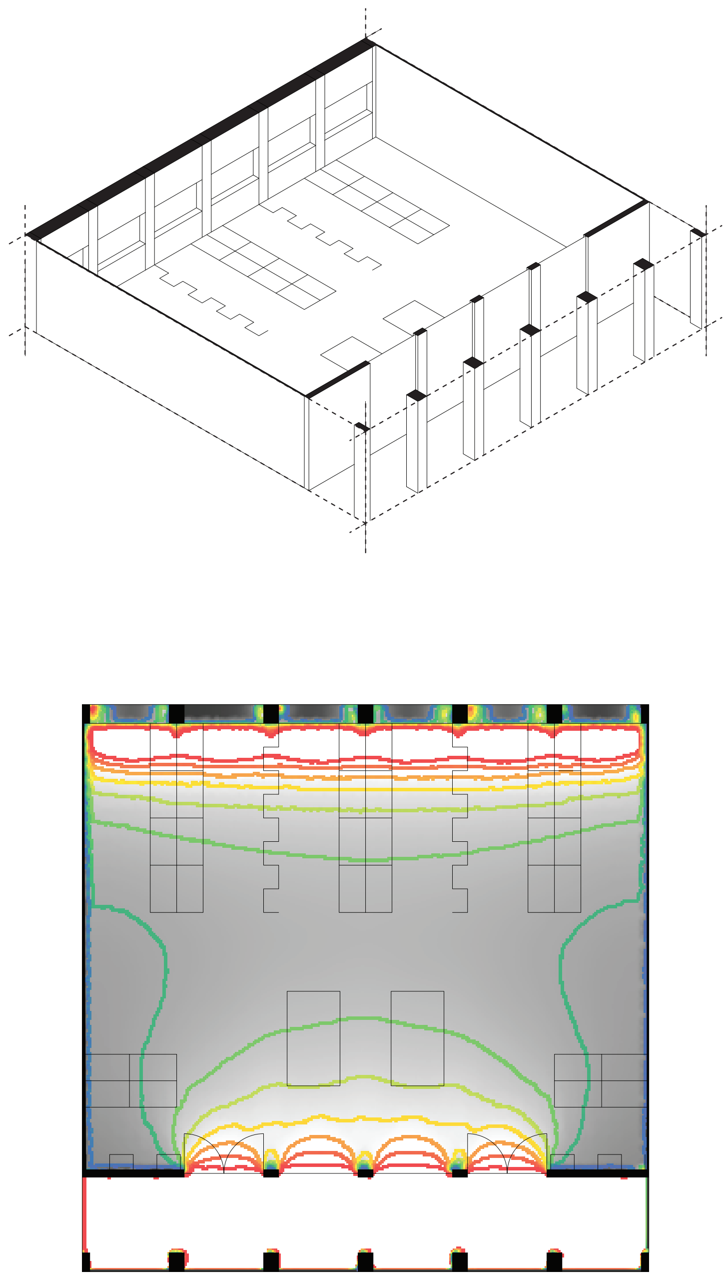
Ill. 122 Principle C: High and low placed window

WINDOWS AND ENTRANCES

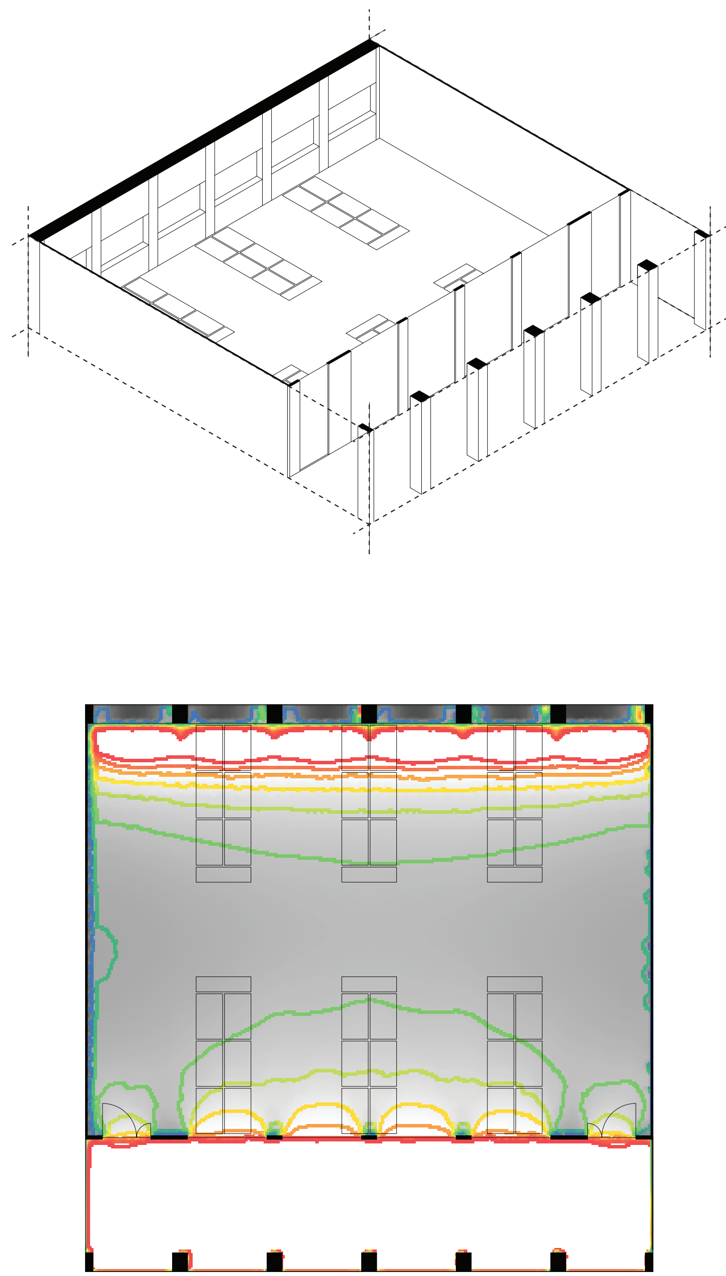
Along with acoustical and furnishing principles for the studio, considerations of views, daylight and ventilation are taken into consideration for the placement of windows. Ill. 120 to Ill. 122. shows the section of different window placements and the viewing angle from a seated student. The window placement was evaluated by the fact of views to greenery and natural element would increase the productivity of office employees. Having this fact in mind and studies of a curtain wall versus a window in the middle of the wall was the idea developed of a higher and a lower placed window. With most of the studios facing north-west, the higher placed windows would provide light as in an atelier and let daylight deeper into the room. The qualities of the concept would give students the ability to look out when seated and the spacing between the windows to put up sketches and drawings. The window configuration would also allow possibilities for natural ventilation and night cooling with higher and lower placed windows, discussed further in next section.

STUDIO ENTRANCES

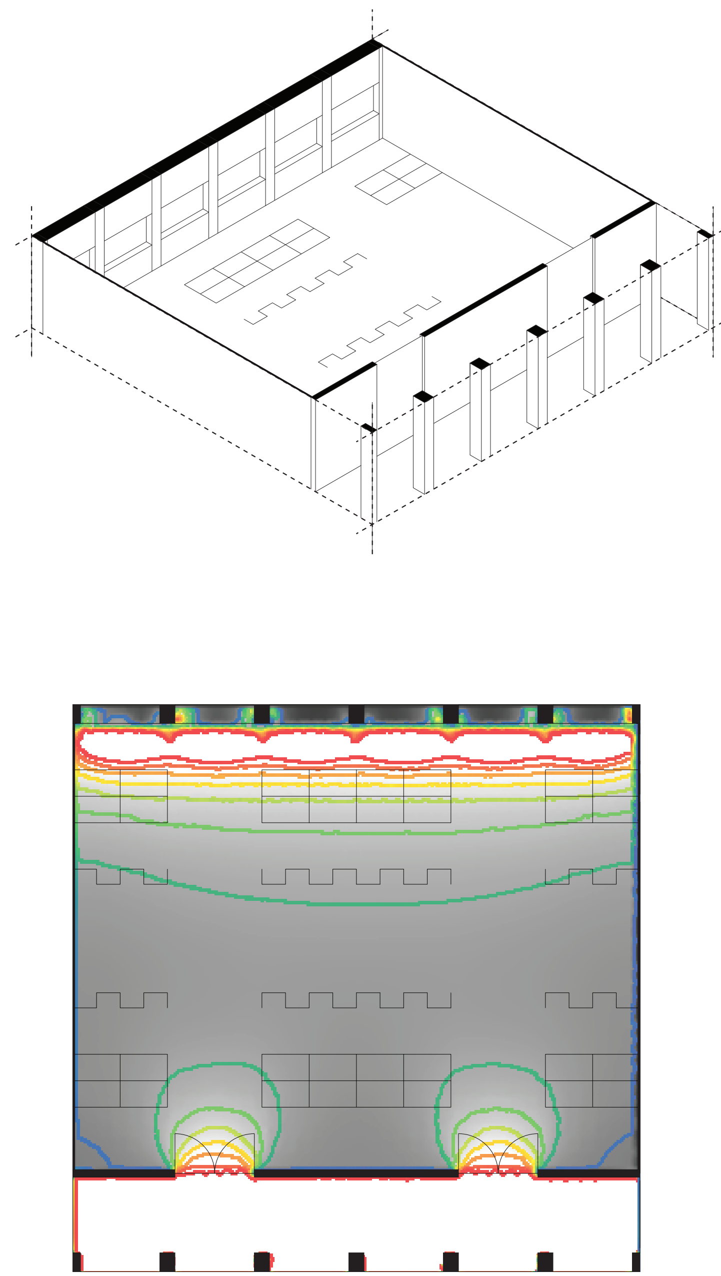
For the idea of a gallery, a wall between the gallery and the studio would be needed. Different principles for entering the studio were therefore studied according to flow and light. Since the wall would block for daylight coming form the side of the gallery hall, additional daylight simulations were used to study which effect the placement of entrances and windows in the wall would have. The desired effect of intimacy, views and daylight in the studio were found in Principle C, Ill. 125.



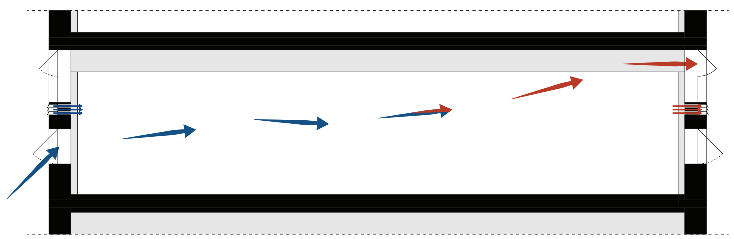
Ill. 123 Principle A: Glass doors and multiple windows



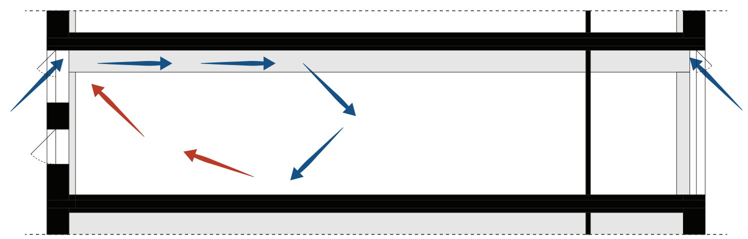
Ill. 124 Principle B: Glass doors small and multiple windows



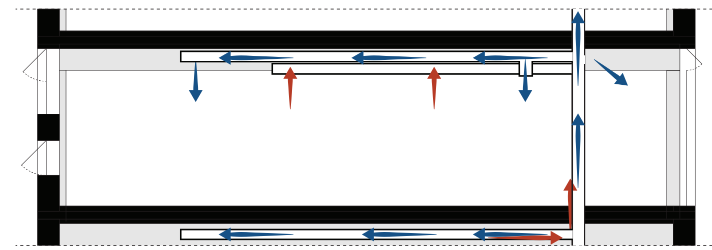
Ill. 125 Principle C: Glass doors



Ill. 127 Principe A: Cross ventilation and Inventilate



Ill. 126 Principe B: Single sided ventilation and Inventilate



Ill. 128 Principe C: Mechanical ventilation

VENTILATION

Along with window and daylight studies, different ventilation strategies were evaluated.

The initial idea of hybrid ventilation would use natural ventilation for night cooling in the summer time and mechanical ventilation in winter in the studios. However with different areas in the building requiring a high airflow and extraction, such as the canteen and canteen kitchen, those areas would be ventilated only with the use of mechanical ventilation. Having the intension of giving the studios, workspaces and offices a higher degree of flexibility. Those areas would be ventilated by in-wall mounted aggregates, manufactured by InVentilate. By placing InVentilate units in the wall the need for ducks would be eliminated. The units would be placed in the area between the lower and higher placed windows, shown in Ill. 127. By evaluating the system, further studies show that the concept would only be useable in cross-ventilated rooms. Single sided studios would be to deep for the units to ventilate. InVentilate would also require a high placement, meaning that the units had to be placed no further than 30 cm from the ceiling to use coanda-effect to give a longer casting length and avoid cold drafts. The high location would not correspond with the architectural intension of high windows. Another downside for the units was their need for a foreclosure in front of the air intake on the facade.

With more negative than positive factors for the concept, more traditional principles of mixing and displacement ventilation were considered:

Mixing ventilation:

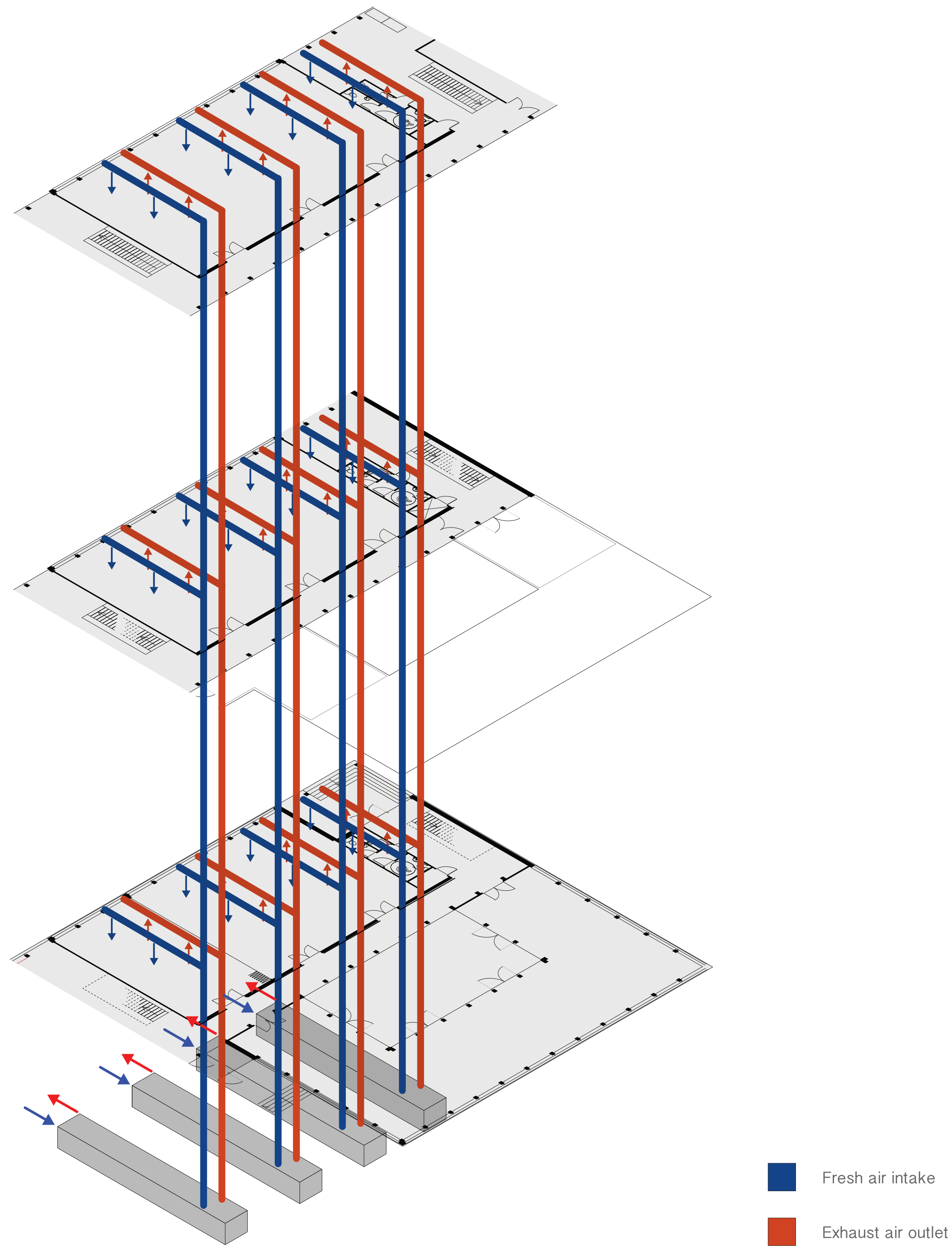
Air at a high velocity will be delivered in the room from above outside the occupied zone. The high air velocity is creating an overpressure, which will drag room air towards the supplied air. [KE Fibertec, 2015a]

Displacement ventilation:

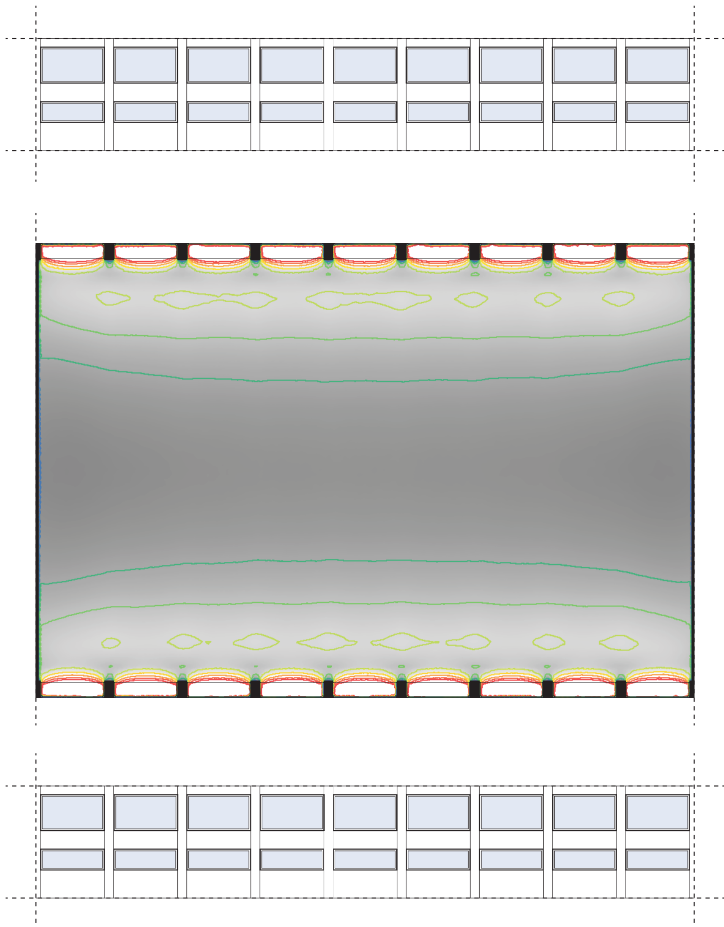
Displacement ventilation works as a layered supply. Air is supplied at floor below the warm air inside the room. The air is moved by convection flows caused by heat emitting processes and activities in the room. [KE Fibertec, 2015b]

An evaluation of the two systems indicated by using mixing ventilation could the walls between studio and gallery hall be used for supply and exhaust pipes. For the displacement ventilation could the air be supplied though an installation flooring, however this system would also need exhaust pipes in the ceiling. With the intension of having the beams exposed in the studios, mixing ventilation was chosen as the optimal solution. However by changing to mixing ventilation it would require a higher floor-to-ceiling height and a rotation of the structure in areas with offices and workspaces, as penetration for pipes in the concrete beams would not be possible.
The ventilation system was then placed in the ceiling, between the beams with ducts in the wall and behind a suspended ceiling. By using a phase shifting suspended ceiling, the ceiling also improves the acoustics and the climate of the room, by being located as close to the floor slab above as the ventilation ducts allow. To make space in the ventilation ducts in Building East, the complete floor-to-floor raise by 300mm. This alteration changed the height from floor to beam in the studios from 2,8m to 3,1m, which improved the spatial qualities of the room.

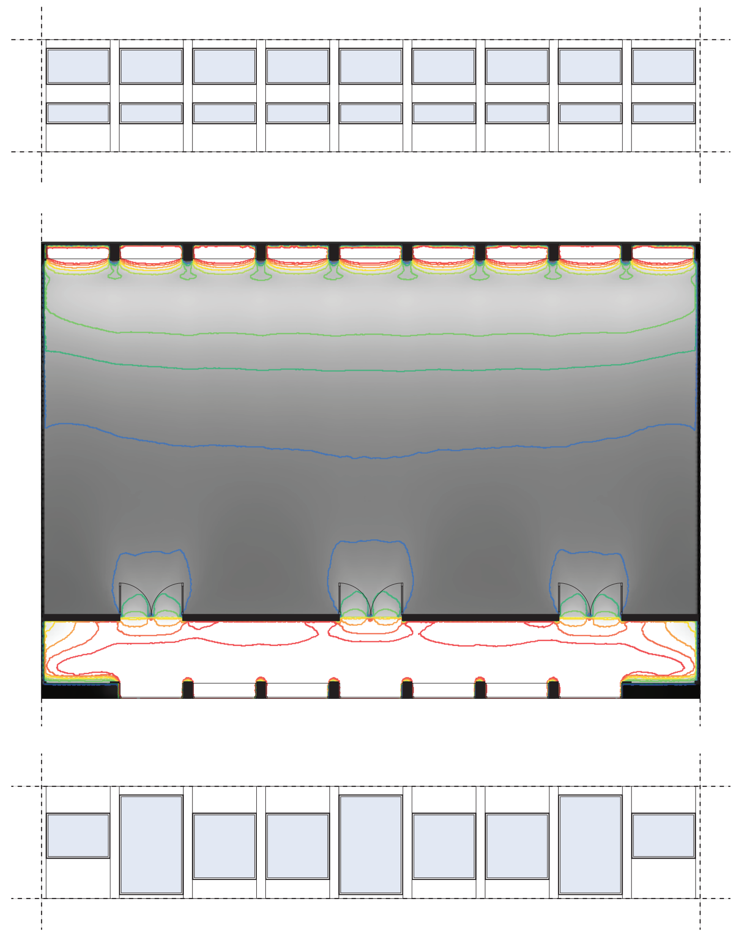
Ill. 128 and Ill. 129 shows the concept for the studios, which include night cooling. Having the higher windows, which can open and a heavy structure will night cooling be used at summer. Higher placed windows will open and cool air will cool the beams, mechanical extraction is used to aspirate the air and give a continuous airflow. Similar principles are used in the offices and workspace areas. Ill. 129 shows the principle for the ventilation.



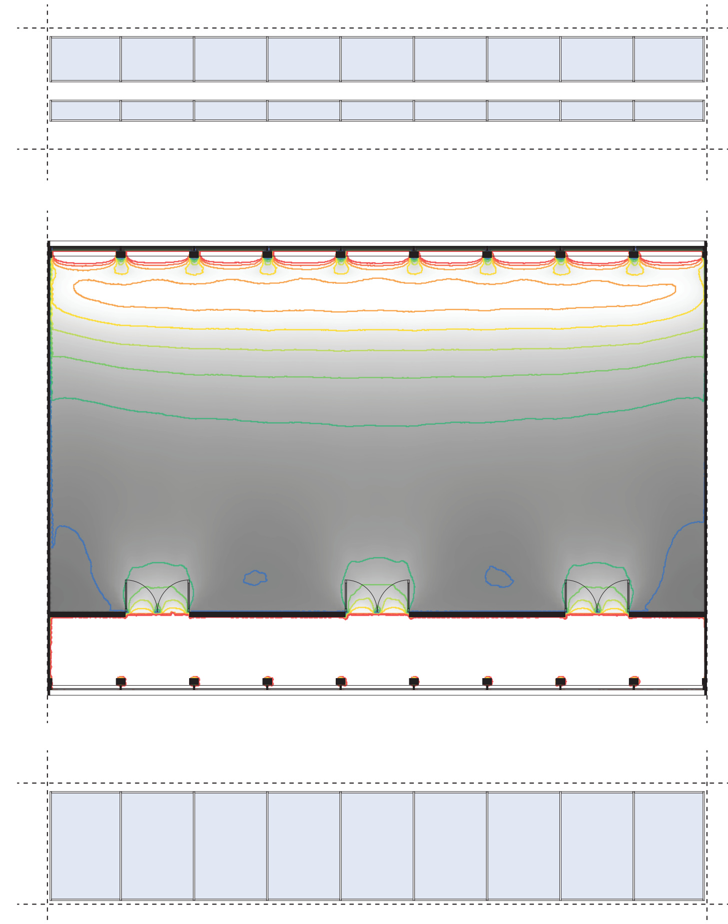
Ill. 129 Diagram of ventilation strategy, aggregates placed in the base with connecting ventilation ducts for diffuser in the studio placed inside the walls.



Ill. 130 Daylight study of studio without gallery



Ill. 131 Daylight study of completely informative facade

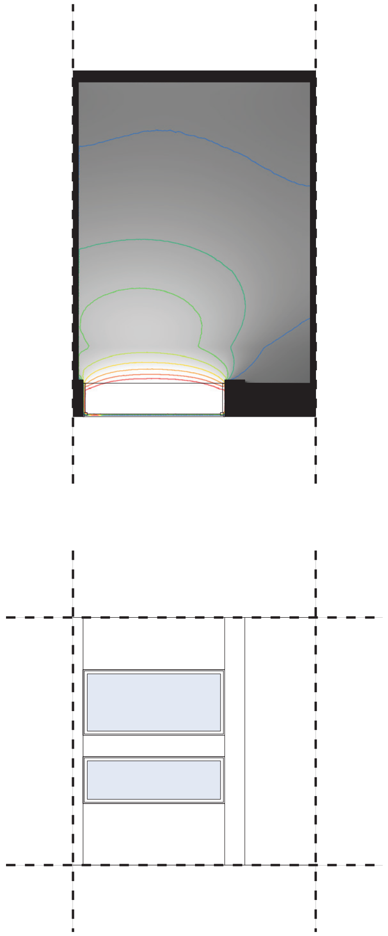


Ill. 132 Daylight study of modified informative facade

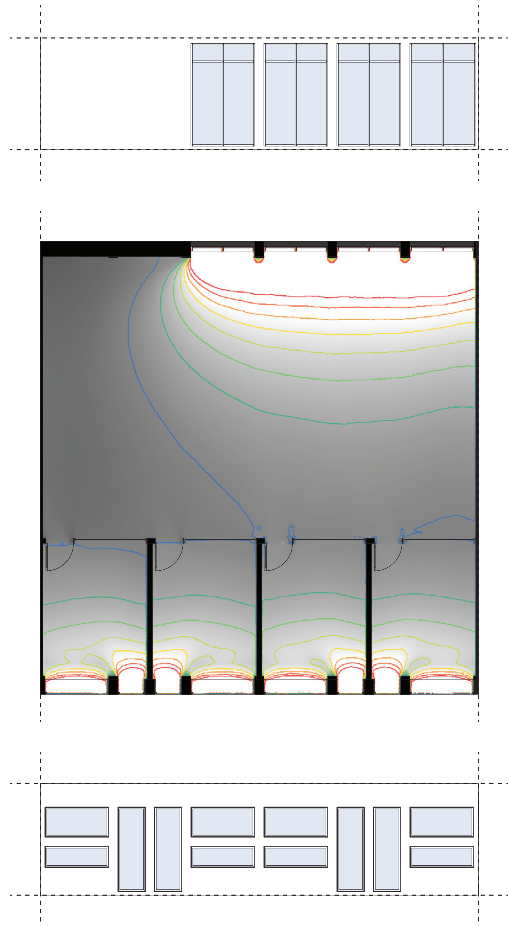
STUDIO

Previous daylight studies of the studios did show, that the plan of a cross-ventilated studio would have a proper amount of daylight. However similar studies of the chosen studio type with gallery hall on one side and studio on the other, showed difficulties in letting enough daylight into the plan. The options for letting more daylight into the room would therefore be to raise the ceiling level, which was placed at 3,4 m (between the beams), or to make more windows in the wall separating the studio from the gallery hall. Other studies investigated how an angling of the uppermost windows would let more light into the center of the plan, however those iterations did not fit with the desired architectural intension for the facade. With the need for a higher floor-to-ceiling height, caused by the mixing ventilation, the solution was to increase the room height with 300 mm, which showed to be enough for the daylight Ill. 132.

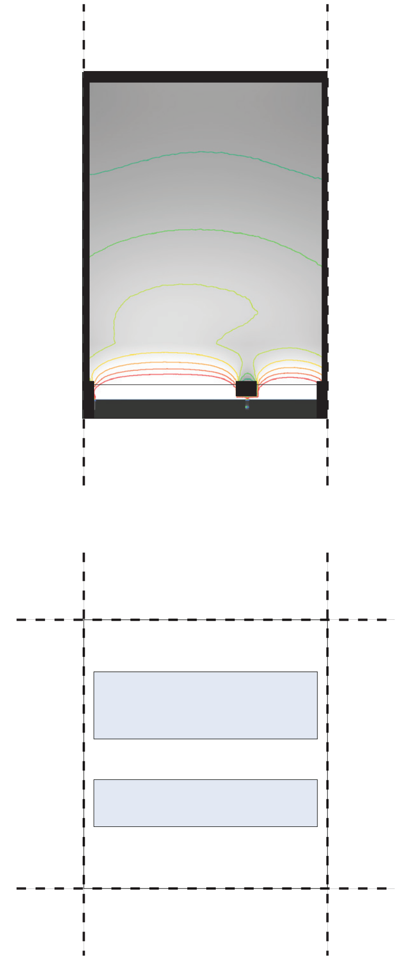
Concepts for the window layout in the gallery hall were rooted in a high transparency with niches in the windows, where students would have the opportunity to sit and read or have smaller meetings. This transparency would create an interaction between the users, and show the flow on the inside, Ill. 131.
Basic building simulations studies in BSim were used to evaluate the thermal indoor climate. Analyses found that the big window areas and the heavy occupation load would create more hours with temperature over 26°C and 27°C than allowed. Similarly did studies of the buildings energy consumption in BE10, show a lot of energy was used for heating and in relation to excess temperature. Essential factors for changing those results and lowering the energy consumption, was to look at the windows and ventilation. By using low energy windows, with a u-value on 0,52 w/m^{2}K and a g-value for the northern facing windows on 0,5 and for the southern 0,25, it was possible to lower the results. Higher g-values was chosen, as those would let more passive solar heat into the rooms, meaning lower energy consumption for heating. To avoid excess temperature, additional external dark blinds would be placed on the exterior of the window. Those would be automatically controlled.



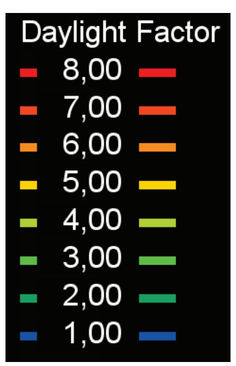
Ill. 133 Initial windows layout for office



Ill. 134 Daylight study of office in context



Ill. 135 Daylight study of offices



Ill. 136 Scale of daylight factor

OFFICES

Similar did studies of the offices show, that the original floor-to-ceiling height would be too low to let enough daylight into the rooms. Initial studies were therefore working with how vertical windows could contribute and increase the daylight. However as the architectural intension of the facades resulted in a cluttered expression, the solution was to higher the ceiling height in addition with a longer horizontal window, which would span the width of the offices. With the use of natural ventilation in the form of night ventilation and mechanical ventilation would the hours of 26ºC and 27ºC be under the allowed limit specified according to Indoor Class B. [Universitets- og Bygningsstyrelsen, 2011]

Ill. 133 to Ill. 135 show the facades and corresponding daylight analyses. Windows are in those analyses placed as horizontal ribbons, which shows the last iteration.

For complete daylight factor analysis of the final floorplans, see appendix 1.6.

As previous discoursed was building simulations done in BSim studying the indoor climate of the studio, gallery hall and an office. For the simulations the required air change and airflows were found according to thermal and atmospheric comfort.

Required ventilation rate for single offices and open floor plan offices are 12 l/s pr. occupant. However the rate for Educational and Computer rooms are in Climate Class B defined as 1,4 l/s pr m^2 and 6 l/s pr. Occupant. [Universitets- og Bygningsstyrelsen, 2011]

$$q_{tot} = n \cdot q_p + A \cdot q_B$$

$$q_{tot} = 1{,}4\frac{\frac{l}{s}}{m^2} \cdot 253{,}66m^2 + 6\frac{\frac{l}{s}}{person} \cdot 32occupant = 547{,}12\frac{l}{s}$$

$$V_L = n \cdot V_R$$

$$n = \frac{547{,}12\frac{l}{s} \cdot 0{,}001\frac{m^3}{l} \cdot 3600\frac{s}{h}}{896{,}71m^3} = 2{,}2h^{-1}$$

Additionally to the requirements the ventilation rate for atmospheric and thermal comfort has been calculated. Early iterations for the facade showed an air change of $3h^{-1}$ in the studios and $6h^{-1}$ in the offices was needed in order to avoid excess temperatures. Following Calculation shows the required airflow in relation to the pollution from 32 people in a studio (atmospheric comfort).

$$n = \frac{q}{(c - c_i) \cdot V}$$

V = Volume
C_i = 350ppm
c = 850ppm (350ppm + 500ppm)

$$n = \frac{32\ occupants \cdot 19\frac{l}{(h \cdot occupant)} \cdot 0{,}001\frac{m^3}{l}}{(850ppm - 350ppm) \cdot 10^{-6} \cdot 894{,}276m^3} = 1{,}36h^{-1}$$

The highest values measured to acquire thermal comfort, displayed in Table 7, were used for the simulations.

Early simulations showed that the thermal comfort inside the rooms would be highly affected by the glass areas. This would increase the hours above 26°C and 27°C, more than permitted. With the intension of the window placement, and a high transparency, were the studies used to investigate how blinds, natural ventilation and the windows thermal conductivity and g-values would affect the results.
Developing the ventilation strategy further, showed that night cooling combined with energy efficient windows could help to solve the problem. Further iteration, using Velfac 200 windows, for the southern facade; with a low g-value (0,25) and for the northern have a higher g-value (0,50), proved to be beneficial. However this configuration and additional BE10 studies indicated, this configuration would have high-energy demands for heating. Daylight studies additionally showed some of the windows with a low g-value, would have to low a light transmission (Lt) value to let enough light into the room.

With the intension of a high transparency from the gallery hall towards the canyon, a big area of windows would need additional solar shading. In order to maintain the transparency, was external dark blinds added, which would lower the excess hours above 26°C.

STUDIO TYPE 1		HALLWAY IN FRONT OF STUDIO		OFFICE	
Equipment					
Heat Load: 0,32 kW	Profile: A Hours: 08 - 17		Ill. 137	Heat Load: 0,1 kW	Profile: A Hours: 08 - 16
Part to air: 0,7			Ill. 138	Part to air: 0,7	
Heating					
MaxPow: 0,5 kW	Profile: B	MaxPow: 0,5 kW	Profile: B	MaxPow: 0,5 kW	Profile: B
Fixed Part: 0		Fixed Part: 0		Fixed Part: 0	
Part to Air: 0,6		Part to Air: 0,6		Part to Air: 0,6	
Factor: 1		Factor: 1		Factor: 1	
Set Point: 20^{0}C		Set Point: 20^{0}C		Set Point: 20^{0}C	
Design Temp.: -12^{0}C		Design Temp.: -12^{0}C		Design Temp.: -12^{0}C	
MinPow: 0,05 kW		MinPow: 0,05 kW		MinPow: 0,05 kW	
Te Min.: 17^{0}C		Te Min.: 17^{0}C		Te Min.: 17^{0}C	
Infiltration					
Basic Air Change: 0,1 /h	Profile: C	Basic Air Change: 0,1 /h	Profile: C	Basic Air Change: 0,1 /h	Profile: C
Lighting					
Task Lighting: 0,576 kW	Profile: A Hours: 08 - 17		Profile: A Hours: 08 - 17	Task Lighting: 0,018 kW	Profile: A Hours: 08 - 16
General Lighting: 2,03 kW		General Lighting: 2,36 kW		General Lighting: 0,128 kW	
Gen. Lighting Level: 200 Lux		Gen. Lighting Level: 200 Lux		Gen. Lighting Level: 200 Lux	
Light Type: Fluorescent		Light Type: Fluorescent		Light Type: Fluorescent	
Solar Limit: 0 kW		Solar Limit: 0 kW		Solar Limit: 0 kW	
Factor: 1		Factor: 1		Factor: 1	
Lower Limit: 2 kW		Lower Limit: 2 kW		Lower Limit: 2 kW	
Temp. Max.: 25^{0}C		Temp. Max.: 25^{0}C		Temp. Max.: 25^{0}C	
People Load					
Number of People: 32	Profile: A Hours: 08 - 17	Number of People: 32	Profile: A Hours: 08 - 17	Number of People: 1	Profile: A Hours: 08 - 16
Heat Gain (Pr. Person): 0,1 kW		Heat Gain (Pr. Person): 0,1 kW		Heat Gain (Pr. Person): 0,1 kW	
Venting					
Basic Air Change: 0,5 /h	Profile: D Hours: 08 - 17 23 - 05			Basic Air Change: 0,1 /h	Profile: D Hours: 08 - 16
SetPoint: 23^{0}C				SetPoint: 23^{0}C	
SetPoint CO^2: 850 ppm				SetPoint CO^2: 850 ppm	
Factor: 1				Factor: 1	
Ventilation					
Input / Output: 0,227 m^3/s	Profile: A Hours: 08 - 17	Input / Output: 0,05 m^3/s	Profile: A Hours: 08 - 17	Input / Output: 0,09 m^3/s	Profile: A Hours: 08 - 16
Pressure Rise (Input): 1200 Pa		Pressure Rise (Input): 1200 Pa		Pressure Rise (Input): 1200 Pa	
Pressure Rise (Output): 600 Pa		Pressure Rise (Output): 600 Pa		Pressure Rise (Output): 600 Pa	
Total Eff. (Input / Output): 0,7		Total Eff. (Input / Output): 0,7		Total Eff. (Input / Output): 0,7	
Part to Air (Input / Output): 0,5		Part to Air (Input / Output): 0,5		Part to Air (Input / Output): 0,5	
Heat recovery (Max. / Min.): 0,85 / 0,70		Heat recovery (Max. / Min.): 0,85 / 0,70		Heat recovery (Max. / Min.): 0,85 / 0,70	
Heating Coil: 0,5 kW		Heating Coil: 0,5 kW		Heating Coil: 0,5 kW	
VAV max factor: 3		VAV max factor: 3		VAV max factor: 3	
Inlet Temp. (Min. / Max.): 18^{0}C / 24^{0}C		Inlet Temp. (Min. / Max.): 18^{0}C / 24^{0}C		Inlet Temp. (Min. / Max.): 18^{0}C / 24^{0}C	
SetPoint (Indoor Air / Cooling / CO^2): 20^{0}C / 25^{0}C / 850 ppm		SetPoint (Indoor Air / Cooling / CO^2): 20^{0}C / 25^{0}C / 850 ppm		SetPoint (Indoor Air / Cooling / CO^2): 20^{0}C / 25^{0}C / 850 ppm	

A: January - June, September - December 100% 8-17, 25% 12
B: Heating Season (Week 1-19, 39-53)
Ill. 139 C: Alltime, FullLoad 100% 01 - 24
Ill. 140 D: April - September

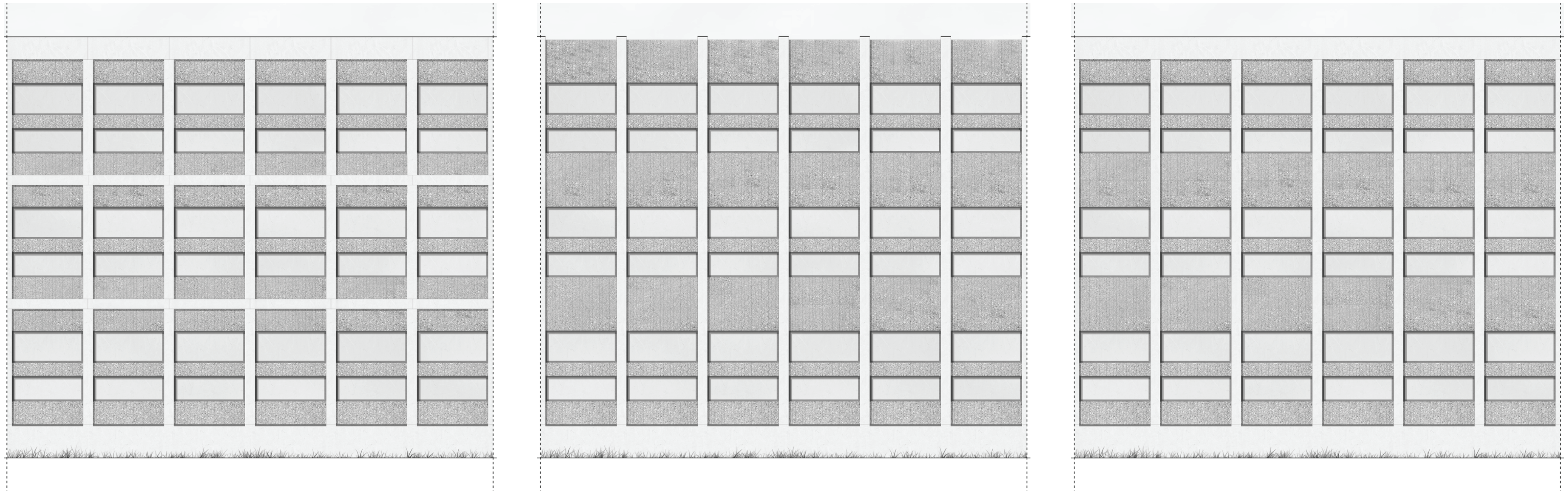
A: January - June, September - December 100% 8-17, 25% 8, 25 % 12, 25% 16
B: Heating Season (Week 1-19, 39-53)
C: Alltime, FullLoad 100% 01 - 24
D: April - September

A: January - June, September - December 100% 8-16, 0 % 12
B: Heating Season (Week 1-19, 39-53)
C: Alltime, FullLoad 100% 01 - 24
D: April - September

Table 7 Table of imputs for BSim

FACADES

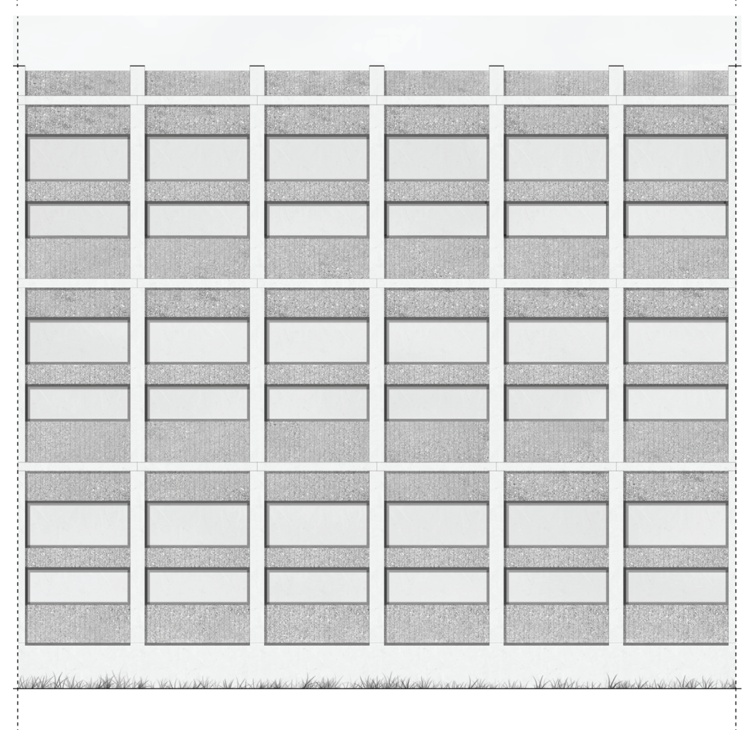
Design Process



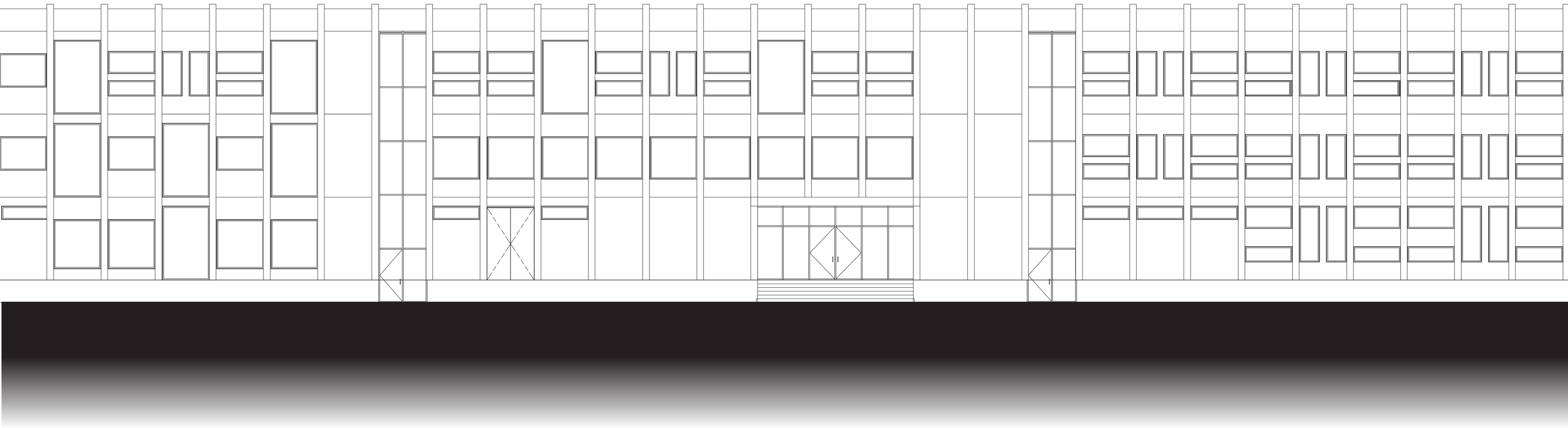
INFORMATIVE FACADE

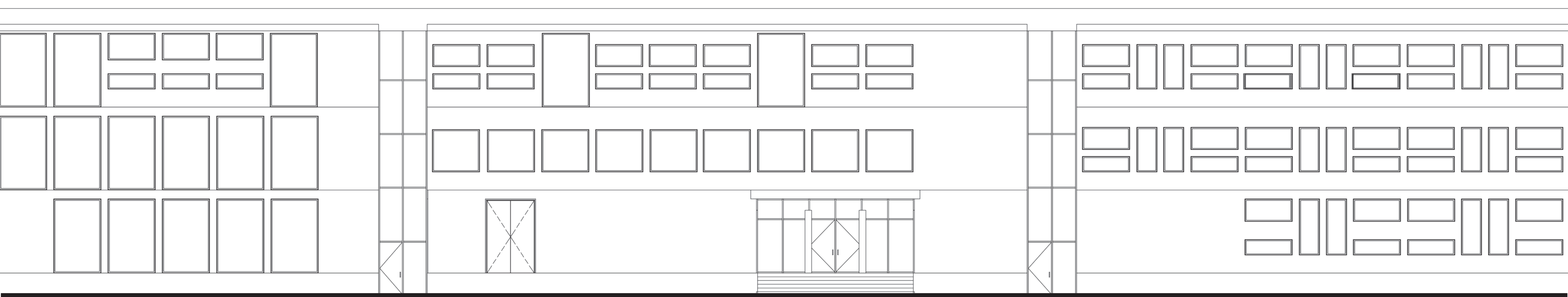
The initial idea of the facades is an informative facade related to the functions. The informative facade displays the functions inside the building by changing as the function might change. The intention was a playful and varied expression of the facade, revealing the gridlines to tell the story of the columns. The facade would be easy to change related to possible changes of interior function, by replacing one facade element with another. The facade elements were placed between columns, which were pushed out of the facade to underline the rhythm.

But when the idea was executed, it proved to be messy and confusing. The idea was simplified and iterated with different alterations regarding optimizing the indoor climate, material and placement of windows: The columns were pushed into the facade to make it more calm and through several iterations to get a simple and modern expression. Still having a consistent informative design, executed in a minimalistic way with less categories of facades elements. The result is long and large windows, only interrupted by mullions and perpendicular walls.



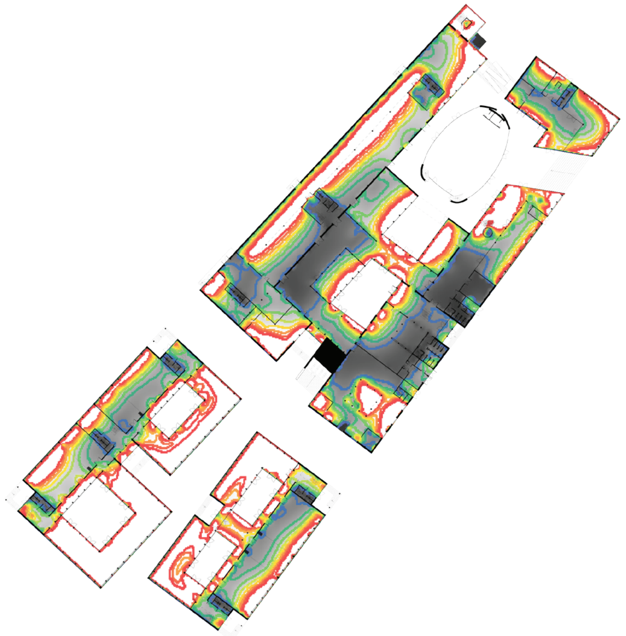
Ill. 141 Facade iterations



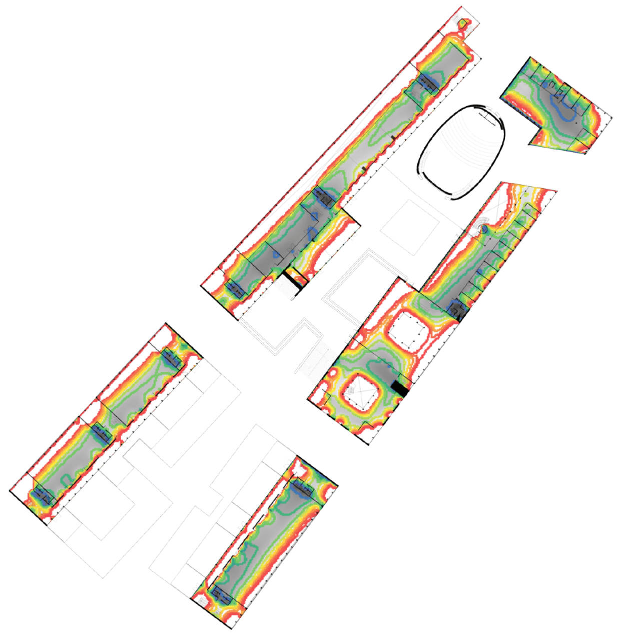


Ill. 142 Examples of iterations of the facades

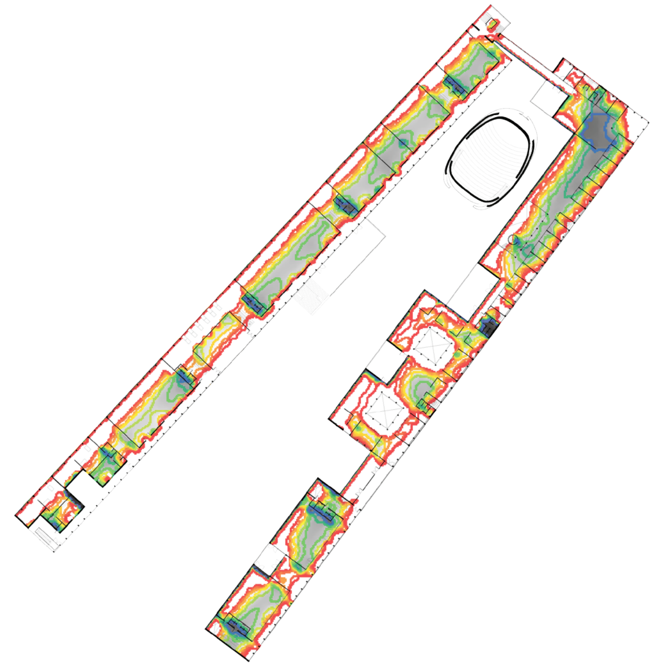
INDOOR CLIMATE
Design Process



Ill. 143 Dayligt factor for 1st floor



Ill. 144 Dayligt factor for 2nd floor



Ill. 145 Dayligt factor for 3rd floor

During the facade studies the buildings energy consumption was studied and optimized. Initial studies of the energy consumption did show that a lot of energy would be used for heating and cooling. Part of the optimization focused on the energy efficiency of equipment. Other aspects focused on the structures and an optimization for those to get as low a thermal conductivity as possible. Table 8 shows results of the building, with the initial window layout and maximum table values for the structural parts. Table 9 shows the optimized result. With the large areas of south and northwest facing windows did later studies, the balance between solar heat, light transmission and the thermal conductivity. By using windows with a low thermal conductivity, U-value of 0,5 W/m2K (Scandia-Windows, 2015) and at the same time have a higher G value, the lowered the needed energy for heating. In order to bring down the energy in relation to excess energy and previous BSim studies, was the effect of blinds investigated. By applying blinds and a thermic film to the southern-faced windows, (Reduce2day, 2015) around studios and gallery hall, was the energy consumption lowered.
The final result shows the building comes close to the 2020-requirements, further applications has to be installed to meet the requirements.

Main data inputs

Heated floor area: 17239 m^2
Heat capacity: 120 Wh/K m^2
Rotation: 320
Normal usage time, 45 hours/week 8 - 17 (usage time is assumed as normal office hours)
Heat supply: District heating

External walls, roofs and floors [Isover, 2010]

External Walls	*4784,71 m^2, U 0,09 W/m^{2}K*
Roof	*8446,83 m^2, U 0,059 W/m^{2}K*
Ground slab	*7719 m^2, U 0,066 W/m^{2}K*
Floors under bridges	*544 m^2, U 0,059 W/m^{2}K*

Foundations etc. [Isover, 2010]

External Wall Foundations	*1140,35 m, Loss 0,02 W/mK*

Windows

South (East, West)	*U 0,52 W/m^{2}K, G 0,25 W/m^{2}K*
North (West)	*U 0,52 W/m2K, G 0,50 W/m2K*

Ventilation

The categories of ventilation, Internal Heat Supply and Lighting are divided into zones. Functions with similar use or functions, which are using the same ventilation unit is placed in the same zone.

Offices
Workspace open + meeting areas + support
Auditorium
Educational Rooms + Theory Rooms + Flex Rooms
Canteen Kitchen
Canteen Library
Studios
Toilet
Storage
Workshop
Gallery + Open Meeting
Stairs + Fire Escapes
Shop
Exhibition
Guest Apartment

Use Factor F_o is assumed:

0,4 for auditorium
0,6 for Offices, Canteen and Toilet
0,8 for educational rooms including Workshop and Canteen Kitchen.

Rest of the rooms is assumed to be used during the entire use time.
Temperature efficiency and Specific electrical energy consumption for moving air SEL:

Temperature Efficiency: 85 %
SEL: 1,44 kJ/m^3.

An air supply temperature of 18^{0}C is assumed according to SBI 213. [Aggerholm, 2008]

Respective airflows have been found according to room pollution and CR1752. With a strategy of hybrid ventilation with mechanical ventilation at winter and a mix of natural ventilation and mechanical ventilation at summer time has the air flows been found. Airflow values for night cooling in the offices and studios are assumed to 0,6 l/s pr. m^2 according to SBI 213. The assumption has been made as the studios have a top hinged window of 0,6 m, which will have an effective opening area higher than 2% of the floor area (effective opening area is defined as 40% of the frame area according to SBI 213). Same scenario is seen in the offices.

Lighting

Lighting has been applied to zones as defined in the ventilation section. General minimum power is estimated to 0,2 W/m^2 as sensors are running all the time. General maximum power is estimated to 7 W/m^2. An additional effect of 0,3 W/m^2 from work lighting is applied in workspaces. Level of lighting should be 200 lux in workspaces, in areas, which not requires high lighting levels, is 50 lux applied. Daylight factors between 2 and 6 has been applied according to final simulations of the plan, Ill. 143 to Ill. 145 The applied lightning control is continuous automatic (K).

Internal heat gain

Internal heat gain is for other building than dwellings defined by SBI 213. The heat gains as been applied to zones as shown in the ventilation section:

People 4 W/m^2; Equipment 6 W/m^2

As guest apartments will be for living is this zone calculated as dwelling also defined by SBI 213:

People 1,5 W/m^2; Equipment 3,5 W/m^2

Domestic Hot Water

Assumptions for domestic hot water according to SBI 213

Hot-water consumption 100 l/year/m^2;
Domestic hot water system 55^{0}C

Energy frame in BR 2010		
Without supplement	Supplement for special conditions	Total energy frame
71,4	0,0	71,4
Total energy requirement		117,1
Energy frame for low energy buildings 2015		
Without supplement	Supplement for special conditions	Total energy frame
41,1	0,0	41,1
Total energy requirement		112,9
Energy frame Buildings 2020		
Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		89,8

Contribution to energy requirement		Net requirement	
Heat	21,1	Room heating	21,1
El. for operation of building	27,0	Domestic hot water	5,3
El. for operation of building	28,5	Cooling	0,0
Selected electricity requirements		Heat loss from installations	
Lighting	17,0	Room heating	0,0
Heating for rooms	0,0	Domestic hot water	0,0
Heating of DHW	0,0	Output from special sources	
Ventilators	10,0	Solar heat	0,0
Pumps	0,0	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	41,0	Wind mills	0,0

Table 8 Be10 results; before optimization

Energy frame in BR 2010		
Without supplement	Supplement for special conditions	Total energy frame
71,4	0,0	71,4
Total energy requirement		37,0
Energy frame for low energy buildings 2015		
Without supplement	Supplement for special conditions	Total energy frame
41,1	0,0	41,1
Total energy requirement		34,0
Energy frame Buildings 2020		
Without supplement	Supplement for special conditions	Total energy frame
25,0	0,0	25,0
Total energy requirement		26,6

Contribution to energy requirement		Net requirement	
	15,0	Room heating	15,0
El. for operation of building	6,2	Domestic hot water	5,3
El. for operation of building	6,4	Cooling	0,0
Selected electricity requirements		Heat loss from installations	
Lighting	1,4	Room heating	0,0
Heating for rooms	0,0	Domestic hot water	0,0
Heating of DHW	0,0	Output from special sources	
Ventilators	4,8	Solar heat	0,0
Pumps	0,0	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	20,2	Wind mills	0,0

Table 9 Be10 results; optimized

AESTHETICS AND FUNCTIONALITY

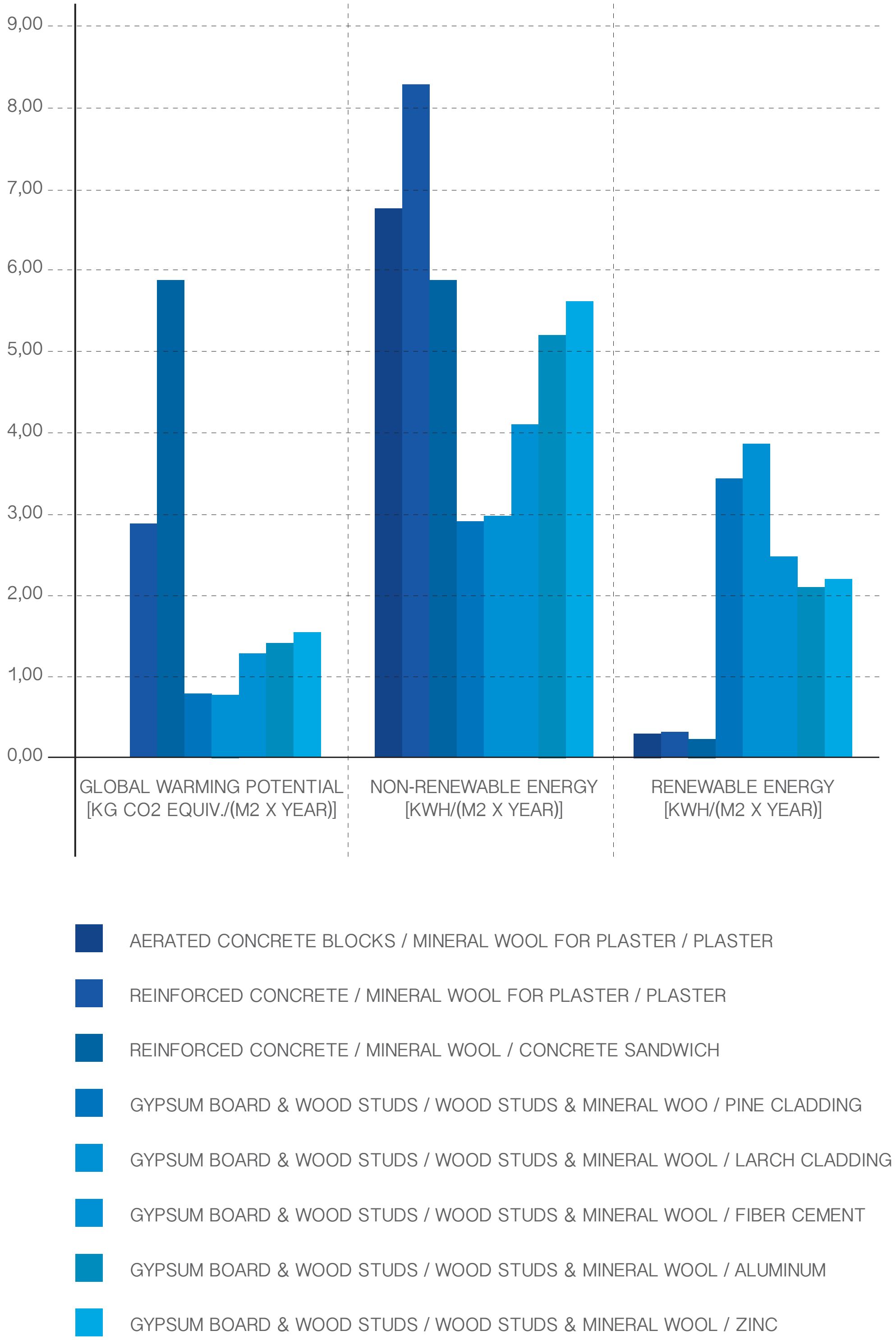
With point of departure in the context, materials for the facades were investigated. With the old railway areas and a reference to industrial buildings in the area materials such as concrete, bricks, wood and metal cladding were taken into consideration.

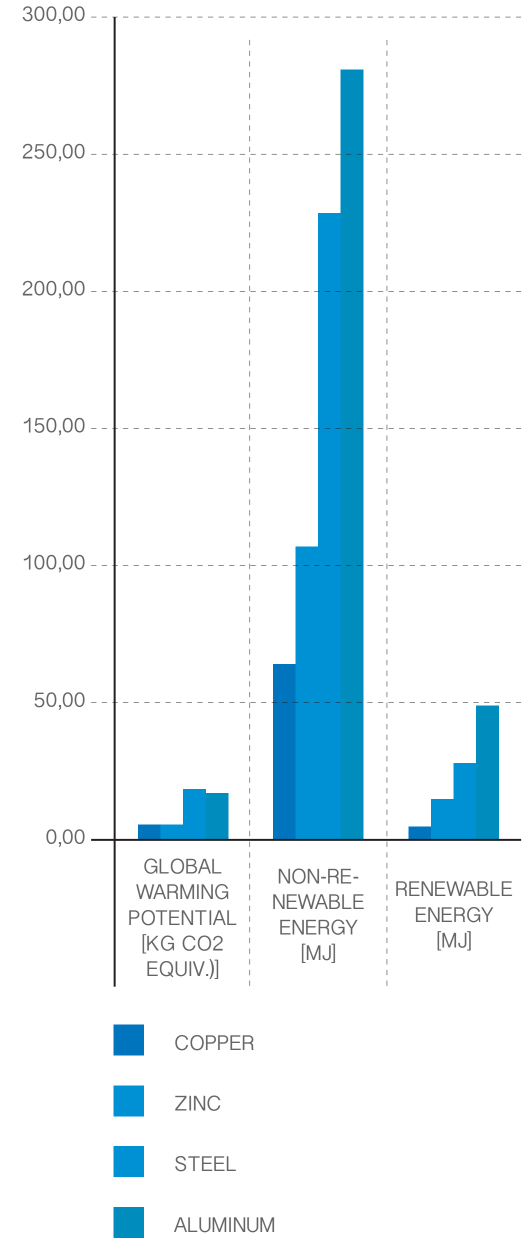
Along with questions of adaptability aspects of environmental impacts from different wall types were studied. Studies did show that a heavy structure, such as concrete sandwich elements would have a high global warming potential, where as light walls would have a lower impact. With the idea of a higher possibility in adaptability in the lighter wall structures were further analyses done to evaluate the materials. Further analyses did study the structure of the wall and the impact of the facade cladding. Structures with gypsum, wood studs and different facade claddings were investigated. With low environmental impacts found in wooden claddings, initial studies investigated the expression of wooden materials such as cork. Cork was chosen for its highly sustainable aspects, low maintenance and it's visual appearance when placed near a white surface (here white concrete surfaces). However the materials were found out-of-context and reconsidered

By looking at the contextual materials raised the idea of a metal cladding. With the tactility of metals, such as weathered steel and copper, a connection and reference to the context will be made. Ill. 147 shows the environmental impacts from the metals with copper seen as having the lowest environmental impact cause its minimal use of energy in the manufacturing processes. [Mansfeldt, 2015] The low environmental impacts correspondent with cooper, is caused by a high use of recycled content in the production. This means that the production of copper facade cladding require 80 – 92 % less energy when compared with metals extracted and produced directly from the ores. [Institut Bauen und Umwelt (IBU), 2012] Copper can in this context be seen as a sustainable material. However copper does also have the ability to cause environmental impacts. Copper is a potential flower pollutant, and a pollutant for aquatic environments. This means that rainwater coming from copper facades or roofs have to be collected and cleaned [Mansfeldt, L., 2015]

With both positive and negative factors of copper, the material was evaluated and chosen because of its aesthetical qualities and low environmental impacts. In order to eliminate impacts for the aquatic environment it is desired to collect and filter the rainwater from the facades before percolation.

For interior, material considerations of the flooring were made. With the need for a high reflection of daylight, white surfaces were considered. However in order to create a warmer feeling in the room and with sustainable aspects of bamboos, this material was chosen for the flooring based on these qualities.





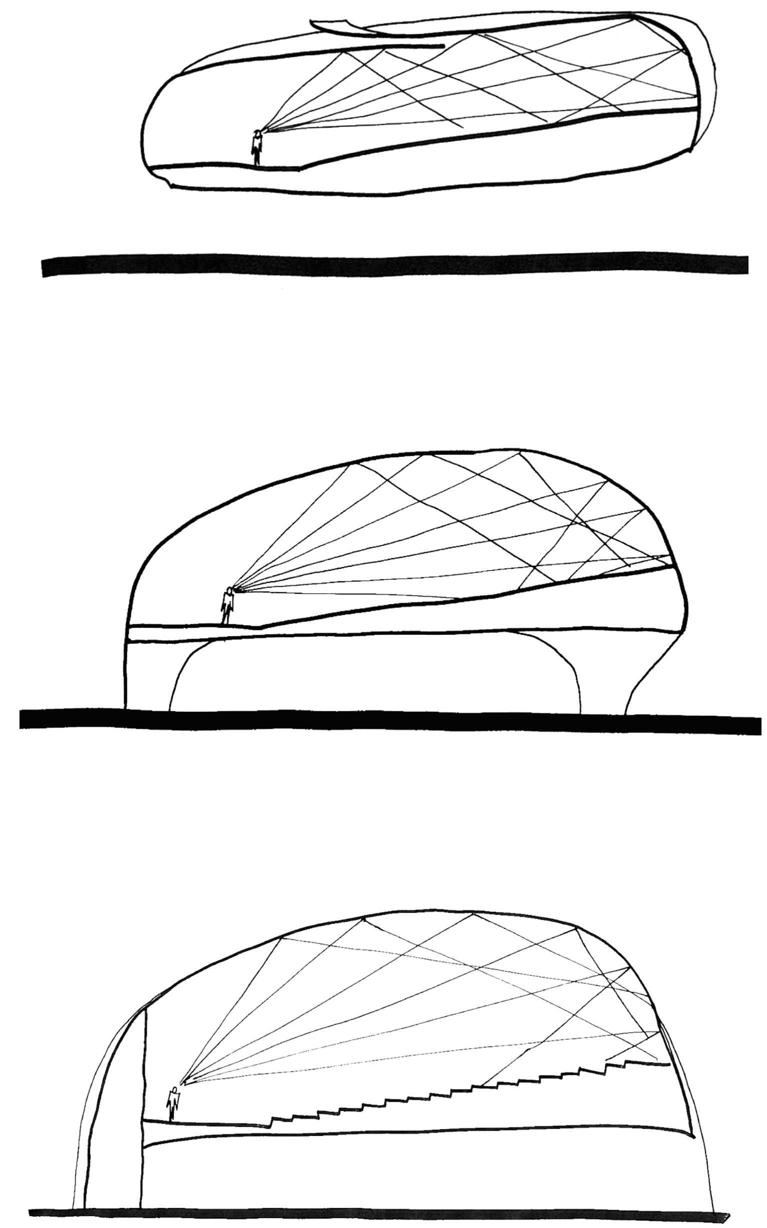
Ill. 146 Analyses of environmental impacts form wall structures

Ill. 147 Analyses of environmental impacts from metals

AUDITORIUM

Design Process

Ill. 148 Diagram of sight angles



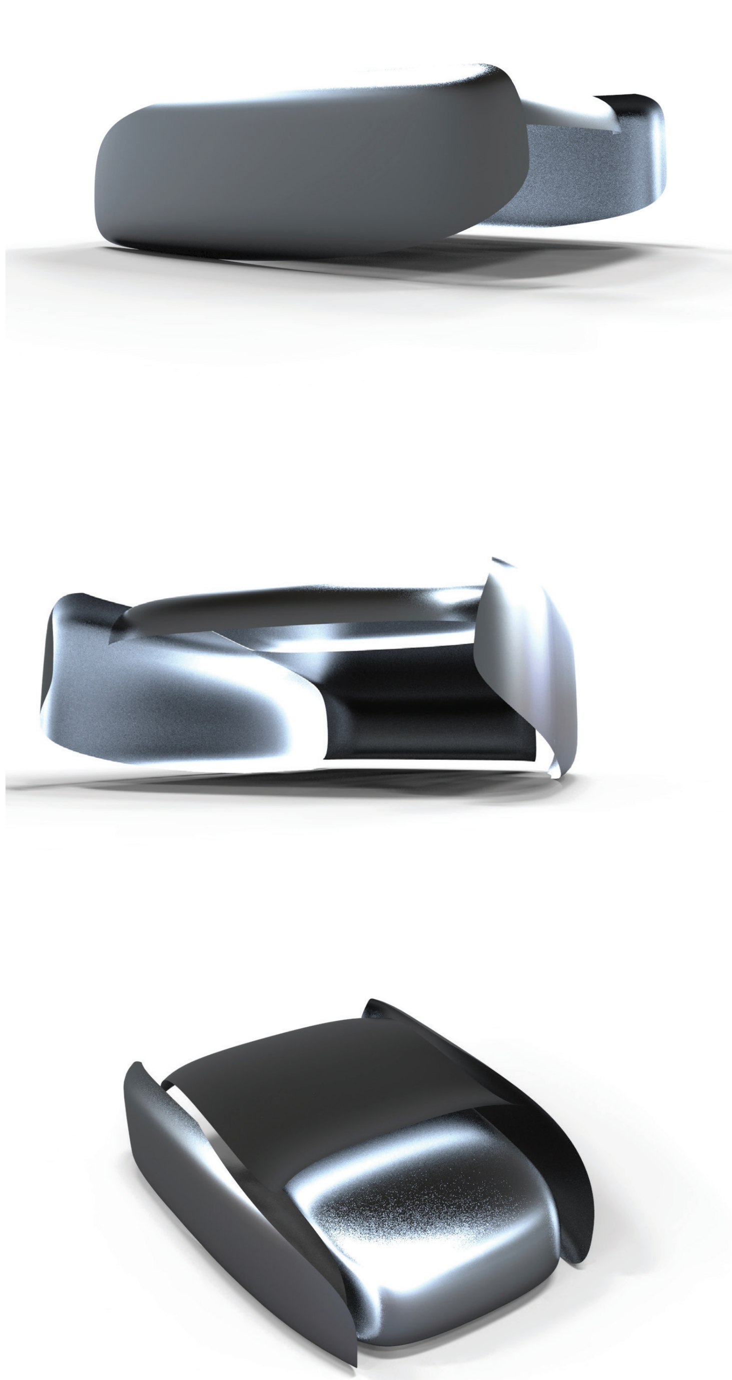
Ill. 149 Ray tracing of different iteration

The initial idea for the auditorium is to create an end to finally to the axis from the city hall. As a focal point where the two axis cross and be closely connected to a public exhibition area.

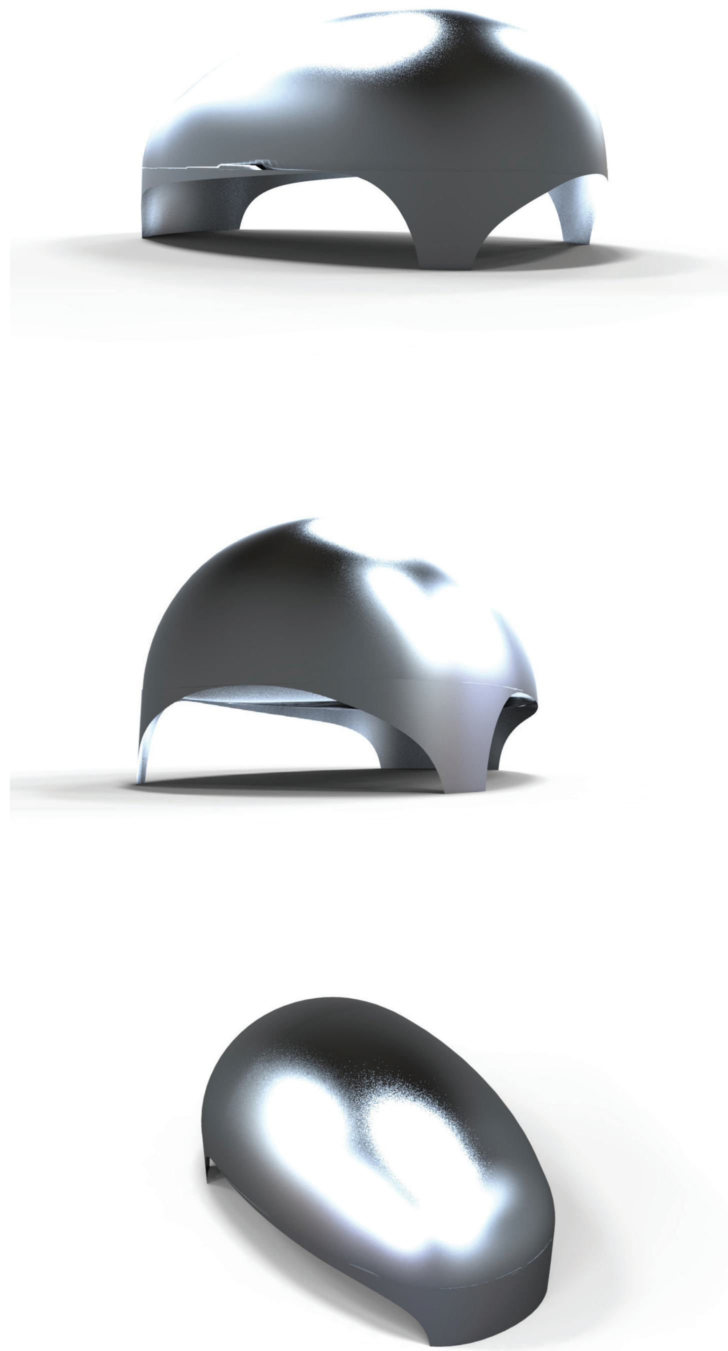
The footprint of the auditorium is formed by the surrounding buildings, with a clear distance of a minimum of 5 meters to ensure proper space between the auditorium and the surroundings.
The next step is to work from the inside to the outside, ensure view lines, seating, access, and acoustic performance. To satisfy the parameters, inspiration and theory from theatres has been used. A maximum of 24 meters distance between the performer/speaker to the audience, ensuring the spectators can see mimics and facial expressions of the performer. Sloping the floor to create a clear view for everyone in the audience, but no more than 45 degrees. 45 degrees being the combined angle of untroubled vertical head rotation (30 degrees) and vertical view angle (15 degrees) for a person. The seats are rotated towards the stage, not to expend the limit of 60 degrees horizontal view, 45 degrees horizontal rotation and 15 degrees untroubled view angle. The view angle ensures the audience to have a pleasant physical experience watching a lecture. The seating has been placed a meter apart, a distance where the user can pass others, without the need to stand up.

To make simple tests for the acoustics, the method known as ray-tracing gives a good idea of how the sound is distributed in the room. The feedback is then used to alter the design of the roof to a more satisfying design. For a room designed for speeches, it is very important for the design to avoid the Haas Effect and enforce Clarity and the Sound Strength. The auditorium is a work in progress, the preface studies has been made, but the next move would be to assign materials and run simulations of the performance of the acoustics.

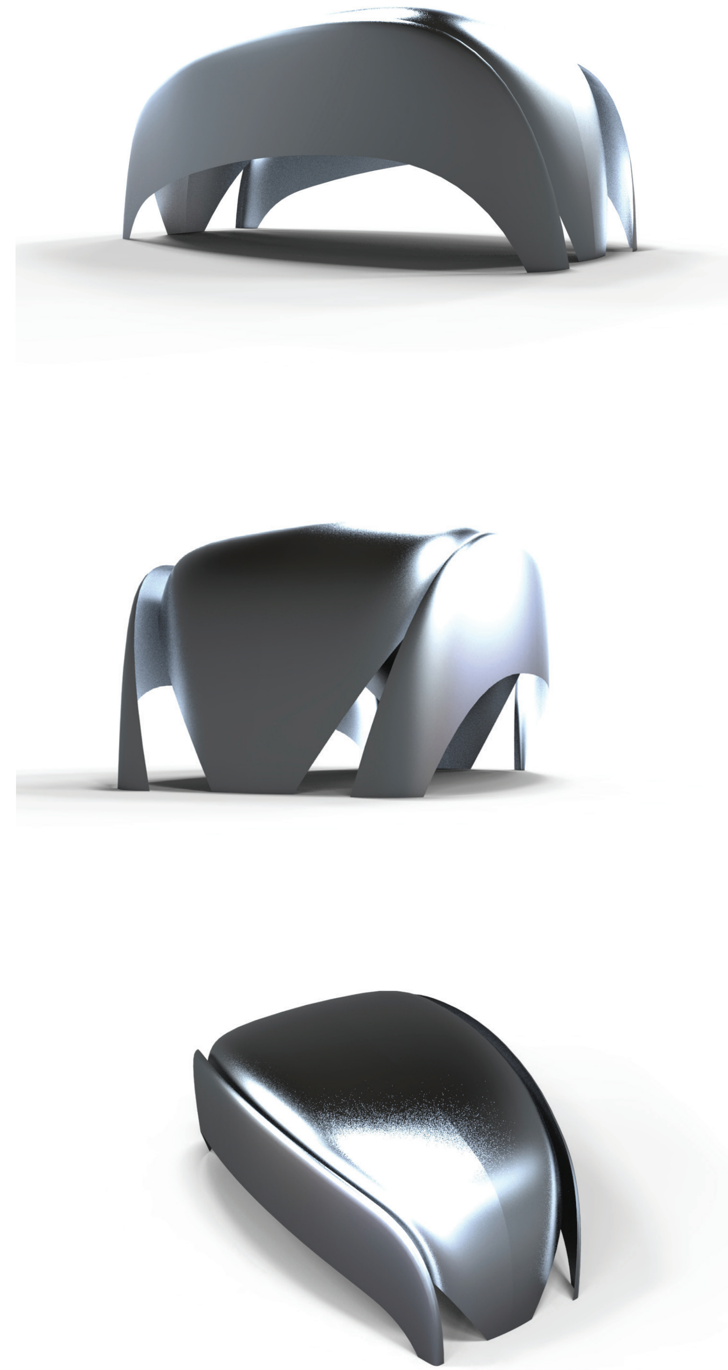
The exterior of the auditorium footprint is shaped from the courtyard; the intention of the design was to stand out from the building. To counteract the static and geometric design of the major building volumes, the auditoriums design is more dynamic and organic.



Ill. 150 Initial design, being too dynamic.



Ill. 151 One of many design ideas, this one being too static.



Ill. 152 Conceptual design for further development.

PROLOGUE

Ill. 153 Site today, view from Godsbanen

CONCLUSION

Since the foundation of the Aarhus school of architecture has its location has been temporary. The project provides a suggestion for a new school, which fulfils the needs described by Signal in the pre-screening done in 2013. The design has incorporated ideas and wishes from the students and professors and integrated them into a modern, low-tech building, with an efficient flow and optimal conditions for learning.

The building relates to the context of the site by its height and integrates lines and flows in the area. Especially the currently unfinished axis from the city hall has got a finale in a meeting with green wedge from of the old rails from the south, symbolised by the location of the auditorium. Existing roads and flows have been continued through the site, helping to define the footprint of the building and the sketched proposal for the masterplan.

The functions of the building have been distributed to provide the optimal flow and logistics of the building, integrated with the existing and future functions and zones in the area. The result is grouping of functions, so the users will not have to go from one end of the building to another for a minor task. Therefore the main functions are essential for all occupants, located near the centre of the building. Those functions include the canteen, the library and the shop. Functions such as studios, educational rooms and the workshop are located close together. Similarly are offices, secretaries and the main entrance grouped and located near each other.

The different functions have been designed to fit into a squared grid. The rooms where then designed individually and then positioned. To ensure a high quality of rooms all over the building, they were adapted and integrated with their location. The rooms were designed to fulfil the local standards and to optimize the efficiency of the user, based on the latest research. Therefore rooms have views to nature, natural daylight and a good indoor climate, with fresh air and ideal acoustics.

Space to reflect, for meeting people and focus have been some of the key elements while developing the design. The hallways were made into a gallery of reflection, inspiration and conversation. Inspiring the user subconsciously while they move from one location to another or when they sit in the hallways on the benches and table suspended between the columns. The gallery encourage the users to meet and share knowledge and ideas, by the places to sit and work, but also with the visual contact along and across the Canyon. The library, canteen and Canyon have been designed with the same motivation, to enforce the positively learning effect of the school and letting the studios be a more quite space. In this way the inevitable hallways have been transformed into a function, which benefits the users.

The sustainable approach of the building is not to be a zero-energy building, rather a focus of being adaptable to the future and raise the effectiveness of the time the users spend at the school. The design enforces their productivity, creativity and minimizes time waste by well-considered logistics and applying factors improving effectiveness. The design is seen as adaptable as the structure is easy for change. The aim from the architectural school to have fewer students will be handled with the possibility to separate parts of the building to other users. If the building would have to change its purpose completely, structural elements can be reused and the copper facade can be recycled.

The New architectural School for Aarhus will be one of the main drivers in a new creative hub in Aarhus. Letting nature and regular people into the building that will open up the school making it a centre for ideas, creativity and life. The adaptable approach will ensure a lasting building, which will be able to change and adapt to future needs.

REFLECTION

With the scope of creating a new architectural school to Aarhus, the intension for the master thesis was to study learning environments and create new thoughts on the subject. The project, in this case, has studied scenarios for the learning environment related to studios. The scale of the program and the time consuming aspect of getting the flow and circulation in the building, changed the focus from the intension of studying learning environments in detail to a less detailed overall plan.

The project has been developed through an Integrated Design Process, where aesthetic and technical considerations compliment each other. Looking back on the process phases informing each other, with the quality of architecture as the main evaluation point. This fact is seen in early decisions for the ventilation strategy with InVentilate. Had further and more detailed studies been made of the system could an intervention early in the process have been made. By solving the problem regarding ventilation, other issues where solved at the same iteration of the project. In this way solving one problem allows other issues to be reviewed and changes at the same time. An un-solved issue is the area around the auditorium; the sketch-proposal became too tall and wide, leaving too little empty space around it. The design fulfils the program regarding square meters, but iteration with balconies would have solved the issue of the surrounding space.

With the near context of Aarhus Å and the environmental aspects of copper, could other facade cladding materials, such as white plaster be used. A white plaster facade would have created a more neutral building. However this cladding would require more maintenance and not age as gracefully as seen with the copper cladding and as the copper oxidizedes it will fit more into nature with its green colour.

The sustainable angle on the project in focussed on adaptability, effectiveness for the user and modern low-tech aspects. The project is very close to meet the requirements of 2020 according to BE10. The many large windows causes the missing 2 kW/h. The windows create a conflict between heat gain in the summer and heat loss in the winter, to compensate for this conflict the building consumes energy. To reach the 2020 requirement the building would have to gain energy or alter the façade. An option to gain energy is solar panels. The most effective position is on the roof, but due to the 10 story buildings (Åhusene) close to the site, the roof is considered an 5th façade and is therefor not an option. Alternatively solar panels can be integrated into the facade or investing in the future parking garage next to the architectural school, to gain energy from this building into the school. The other option is to alter the facade and minimizing the window area. This option has to be executed carefully not to create a complex and messy facade and still create a coherent and pleasant internal experience.

One of the initial intentions of the design was to incorporate Aarhus Å as a symbol, to lead rainwater away from the site and for waters spatial effects. With the decision of copper as facade material the site could not be connected to Aarhus Å any more, because of particles from the copper, which have to be filtered.

Defining the limitations of the project more clearly, would have allowed working with all parameters in detail instead of working on a general level. Changing the scale of the project and defining either an area of the building or a subject of the design would have made it easier and less time-consuming to design the project.

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Ill. 147 Mansfeldt, L., 2015. Kan en kobberfacade være bæredygtig? byg Bæredygtigt Byggeri NR. 2 2015. Copenhagen: Arkitektens Forlag.

Ill. 148 IZENOUR, G. (n.d.). Theater design. Yale University Press.

Ill. 149-153 Own illustration.

Ill. 154 Own illustration.

Ill. 155 Flickeflu.com, (2015). Købstadskort fra Rigsarkivet a set by Rigsarkivet - Danish National Archives. [online] Available at: http://flickeflu.com/set/72157626682809504 [Accessed 23 May 2015].
Ill. 157-164 Own illustrations.

APPENDIX

Ill. 154 Godsbanen

APPENDIX 1.1

ROOM PROGRAM

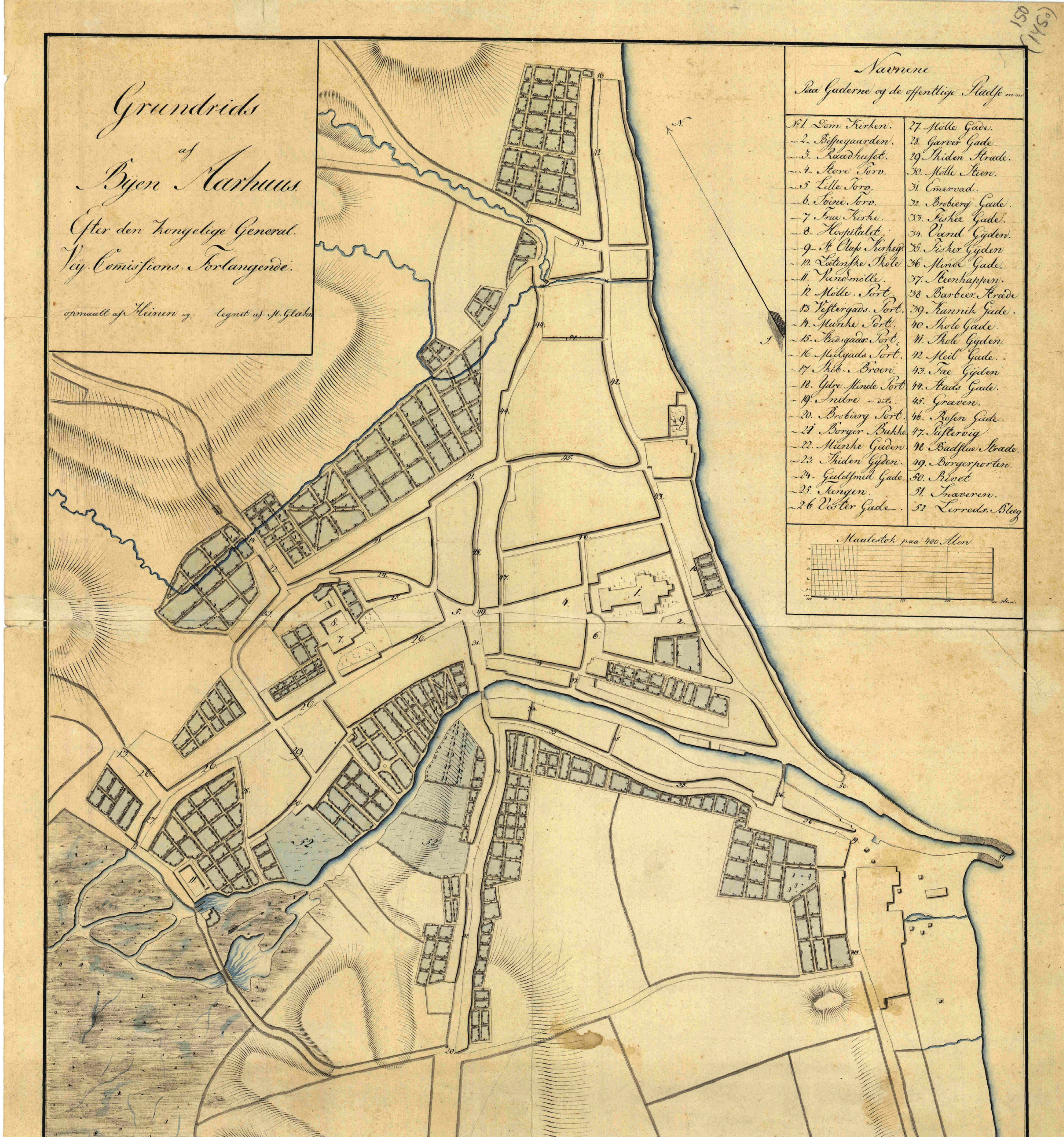
	Description	Number	Area Each	Usable Area	Usable Area
			[m²]	[m²]	[m²]
Student Workspace					
Workspace	Tables, Personal Storage, Chair, Waste	800	4	3200	3814
Storage / Exhibited Models	-	-	-	540	141
Sprayroom	-	-	-	80	-
Copy / Print	-	-	-	80	-
Waste	-	-	-	80	-
Flex rooms in different sizes	-	-	-	350	238
Educational Rooms	-	-	-	600	639
Archive Storage	-	-	-	140	-
Toilet / Bath / Cleaning	-	63 / 8	-	200	340
Kitchen / Open Meeting / Tables	-	-	-	330	307
Auditorium / Multi Room / Performance	(Potential connected to a can)	1	300	300	311
Sub Total (Usable Area)	-	-	-	5900	5790
Sub Total (Gross Area)	-	-	-	8260	-
Back Office					
Guest Apartment	Living quartos for VIP guests	-	-	200	257
Workspace	Individual / Open Office Area	29 /	14,7 / 2115,3	2130	2346
Sub Total (Usable Area)	-	-	-	2330	2603
Sub Total (Gross Area)	-	-	-	3262	-
Inspirations					
Exhibition Area	-	1	500	500	974
Library	Collection / Workspaces	1	500	500	801
Back Office	Secretary	10	15	150	158
Reception	-	1	30	30	43
Material Library	-	1	90	90	104
Shop	Archi-Tegn	1	150	150	151
Depot	-	-	-	80	136
Toilet / Cleaning Room	-	-	-	50	16
Sub Total	-	-	-	1550	2383
Sub Total (Gross Area)	-	-	-	2170	-
Social Spaces					
Canteen Kitchen	-	1	200	200	203
Canteen	-	1	510	510	536
Depot	-	1	50	50	47
Toilet / Cleaning Room	-	-	-	30	43
Sub Total	-	-	-	790	829
Sub Total (Gross Area)	-	-	-	1106	-
Production Spaces					
Workshop / "Mock Up"	-	-	-	1000	1348
Theory & Educational Space	Introduction, Course, Workshop	-	-	200	237
Support Facility / External Collaboration	Office, Toilet, Depot, Hotel-Work-Space	-	-	300	203
Sub Total	-	-	-	1500	1788
Sub Total (Gross Area)	-	-	-	2100	-
Total	-	-	-	12070	13393
				16898	

	Temp. Summer [⁰C]	Temp. Winter [⁰C]	CO^2 Level [ppm]	Ventilation Rate [1/s x m²]	Ventilation Rate [1/s pr. Pers]	Light (Direct) [Lux]	Light (omni) [Lux]	Sound Pressure [dB]
Student Workspace								
Workspace	21 - 26	21 - 24	1000	-	12	500	200	40
Storage / Exhibited Models	-	-	-	-	-	-	-	-
Sprayroom	-	-	-	-	-	-	-	-
Copy / Print	-	-	-	-	-	-	-	-
Waste	-	-	-	-	-	-	-	-
Flex rooms in different sizes	21 - 26	21 - 24	1000	1,4	6	-	200	35
Educational Rooms	21 - 26	21 - 24	1000	1,4	6	-	200	35
Archive Storage	-	-	-	-	-	-	-	-
Toilet / Bath / Cleaning	-	-	-	-	-	-	-	-
Kitchen / Open Meeting / Tables	-	-	-	-	-	-	-	-
Auditorium / Multi Room / Performance	21 - 26	21 - 24	1000	4,2	6	-	200	33
Sub Total	-	-	-	-	-	-	-	-
Back Office								
Guest Apartment	-	-	-	-	-	-	-	-
Workspace	21 - 26	21 - 24	1000	-	12	500	200	35
Sub Total	-	-	-	-	-	-	-	-
Inspirations								
Exhibition Area	-	-	-	-	-	-	-	-
Library	21 - 26	21 - 24	1000	1,4	6	-	200	-
Back Office	-	-	-	-	-	-	-	-
Reception	-	-	-	-	-	-	-	-
Material Library	-	-	-	-	-	-	-	-
Shop	21 - 25	16 - 22	-	3	-	-	-	45
Depot	-	-	-	-	-	-	-	-
Toilet / Cleaning Room	-	-	-	-	-	-	-	-
Sub Total	-	-	-	-	-	-	-	-
Social Spaces								
Canteen Kitchen	-	-	-	-	-	-	-	-
Canteen	21 - 26	21 - 25	1000	-	12	-	200	45
Depot	-	-	-	-	-	-	-	-
Toilet / Cleaning Room	-	-	-	-	-	-	-	-
Sub Total	-	-	-	-	-	-	-	-
Production Spaces								
Workshop / “Mock Up”	-	-	-	-	-	-	-	-
Theory & Educational Space	21 - 26	21 - 24	1000	1,4	6	-	200	35
Support Facility / External Collaboration	-	-	-	-	-	-	-	-
Sub Total	-	-	-	-	-	-	-	-
Total	-	-	-	-	-	-	-	-

Table 10 Table of room program and requirements.

APPENDIX 1.2

Aarhus Å



Ill. 155 Map of the historic path of Aarhus å

Ill. 156 Map of the historic path of Aarhus Å, merged with a map of today

APPENDIX 1.3
INTERVIEW 1

As a fellow up question to an interview of a few students, Simone Stellô Stelsø Lauridsen answered a few clarifying questions.

Interview:
Simone Stellô Stelsø Lauridsen. 2015. Clarifying questions. Interviewed by Jakob Feldager Jørgensen [facebook chat]. Aarhus and Aalborg 11-02-15.

Jakob Feldager Jørgensen: *Hey Simone! Tak for hjælpen i mandags! Vi har lige et opklarende spørgsmål, hvordan fungere jeres unit-koncept? Det virker lidt forvirrende ude fra...*

Simone Stellô Stelsø Lauridsen: *Det var da så lidt. Super hyggeligt! Unitsne fungerer jo som en slags klasse/hold. På første år er der ca 150 studerende fordelt på 3 units. Hvert Unit har deres egen tegnesal, faste vejledere og studieplan.*
På 2./3. år er der 6 units, da disse årgange er blandet. Ellers fungerer det på samme måde som på første år, bortset fra at vi arbejder på tværs af årgangene. Hvert Unit har lidt forskelligt fokus alt efter vejledernes baggrund. På kandidaten er det lidt anderledes. Der er der jo massevis af forskellige studios/ "studieretninger". Fx Urban design, building design, theory mm. Giver det mening?

Jakob Feldager Jørgensen: *Men skifter man så imellem units på 2/3 eller er man holder man sammen i klynger?*

Simone Stellô Stelsø Lauridsen: *Når man starter på 2. år bliver man bare placeret på tilfældigt Unit. Fx er jeg nu op Unit med lidt landskabelige fokus.*
Når jeg så skal på 3. år, kan jeg ønske om at komme på et andet Unit med et andet fokus. Ellers fortsætter man på samme Unit.

Jakob Feldager Jørgensen: *Hey Simone! Thanks for the help on Monday! We have just a clarifying questions, how to operate your unit-concept? It seems a bit confusing for an outsider ...*

Simone Stello Stelsø Lauridsen: *No problem. It was very cozy! The units work well as a kind of class / team. In the first year there are about 150 students spread over 3 units. Each unit has their own studio, fixed supervisors and curriculum.*
On the 2nd / 3rd years, 6 units, as these volumes are mixed. Otherwise, it works the same way as the first year, except that we work across cohorts. Each Unit has a little different focus depending on the supervisors' background. On the candidate is a little different. There are of course lots of different studios / "study". For example, urban design, building design, theory etc.. Does it make sense?

Jakob Feldager Jørgensen: *But change as between the units of 2/3 semester or is clustered together?*

Simone Stello Stelsø Lauridsen: *When starting the 2nd year one will be placed at random Unit. For example, I am now up Unit with little landscape focus.*
When I then in the third year, I wish to come on another unit with a different focus. Otherwise, continue on the same Unit.

LIVE LOAD

The functional program of the building consists of functions such as: Studios, Educational Rooms, Shop, Guest Apartment and Access Ways. The following calculation will take point of departure in areas with studios and workspaces, the live load is therefore defined in Category B Offices, giving a live load of 2,5 kN/m. [Eurocodes 1, table 6.2]

The beams are placed with a distance of 2416 mm, center to center, giving a live load of 6,04 kN/m on the beams as shown on figure ….

$$2{,}5\frac{\mathrm{kN}}{\mathrm{m}^2}\cdot 2{,}416\mathrm{m} = 6{,}04\frac{\mathrm{kN}}{\mathrm{m}} \qquad ()$$

The column which later will be calculated will be placed on the first floor in the building having the load of the two stories on top as shown on Ill. 158 The live load applied on the two upper floors is reduced with the reduction factor: [Eurocodes 1, 6.3.1.2(11)]

$$\alpha_n = \frac{1+(n-1)\psi_0}{n}$$

n = number of floors above
ψ_0 = 0,6; load reduction factor category B:Offices,DS/EN 1990

The reduction factor for the live load on the column becomes:

$$\alpha_n = \frac{1+(2-1)\cdot 0{,}6}{2} = 0{,}8$$

SNOW LOAD

Snow load found as a continuous temporary design value:

$$s = \mu_i C_e C_t s_k$$

μ_i = 0,8 (form faktor $(0° \le \alpha \le 60°)$)
C_e = 1,0; (Exposure factor in an area with normal topography)
C_t = 1,0; (Thermal factor)
S_k = 0,9 kN/m2 (Charteristic terrain value)

Calculated snow load:

$$s = 0{,}8\cdot 1{,}0\cdot 1{,}0\cdot 0{,}9\frac{\mathrm{kN}}{\mathrm{m}^2} = 0{,}72\frac{\mathrm{kN}}{\mathrm{m}^2}$$

WIND LOAD

The total resulting wind load on the structure is a summation of the exterior wind loads ($F_{w,e}$), interior wind loads ($F_{w,i}$) and the frictional forces (F_{fr}).

Exterior wind loads:

$$F_{w,e} = c_s c_d \cdot \sum w_e \cdot A_{ref}$$

Interior wind loads:

$$F_{w,i} = c_s c_d \cdot \sum w_i \cdot A_{ref}$$

Frictional forces:

$$F_{fr} = c_{fr}\cdot q_p(z_e)\cdot A_{fr}$$

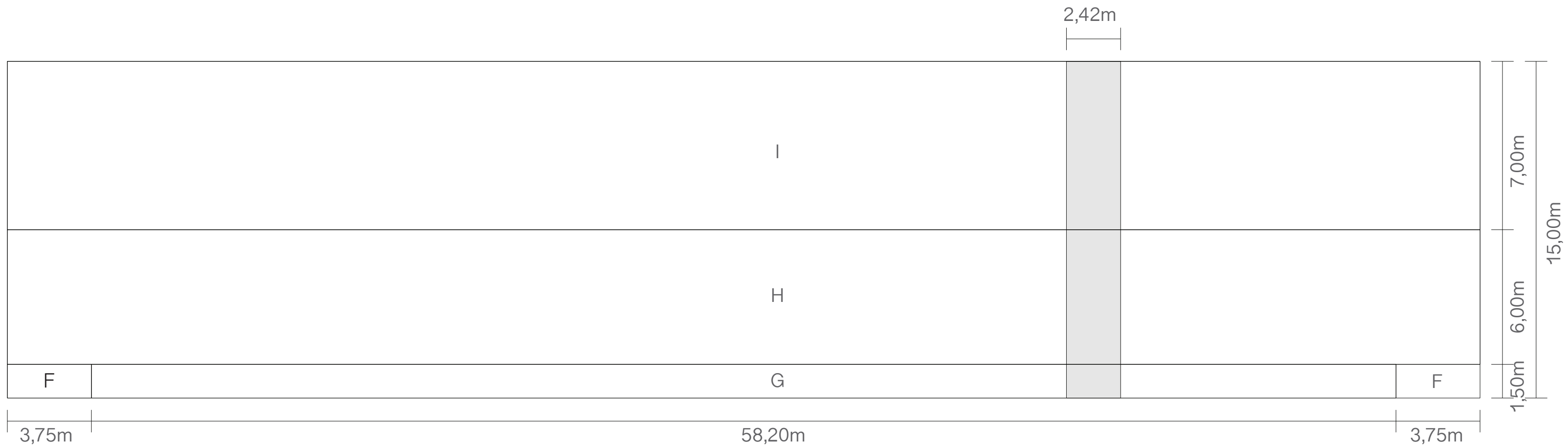
In the formulas is W_e and W_i respectively the external wind pressure and the internal wind pressure found by:

$$w_e = q_p(z_e)\cdot c_{pe}$$

$Q_p(z_e)$ = Peak velocity pressure in the reference height
C_{pe} = Form factor for external pressure

$$w_i = q_p(z_i)\cdot c_{pi}$$

$Q_p(z_i)$ = Peak velocity pressure in the reference height
C_{pi} = Form factor for internal pressure



Ill. 157 Zones for form factor on roof, grey area of the roof is carried by the column later calculated.

MEAN WIND VELOCITY

The mean wind velocity is needed to find the peak velocity pressure. Mean wind velocity is calculated by:

Cpe =Form factor for exterr

$c_{r(z)}$ = Roughness factor
$c_{0(z)}$ = 1, orography factor according to Eurocodes 1.
V_b = 24 m/s, basis wind velocity according to Eurocodes 1 and the Danish annex.

The roughness factor $c_{r(z)}$ is calculated by:

calculated by:

k_r = Terrain factor dependent on the roughness factor z_0.
Z = Height over terrain
Z_0 = Roughness factor

K_r is determined by:

The roughness factor cr(z)

$$c_r = (z) = k_r \cdot \ln\left(\frac{z}{\,}\right)$$

With the building placed in an urban area is the terrain category assumed to be IV. The terrain factor becomes:

Z0 = roughness factor

Kr is determined by:

The roughness factor c_r becomes:

$$k_r = 0{,}19 \cdot \left(\frac{\,}{z_{0,II}}\right)$$

The mean wind velocity can now be found:

$$v_m(z) = 0{,}60 \cdot 1{,}0 \cdot 24\frac{m}{s} = 14{,}4\frac{m}{s}$$

WIND TURBULENCE

In order to find the peak velocity pressure is the winds turbulence needed. The turbulence is found by:

$$I_v(z) = \frac{\sigma_v}{v_m(z)}$$

The component for spreading is calculated by:

$$\sigma_v = k_r \cdot v_b \cdot k_I$$

k_I = 1,0, turbulence factor according to Eurocode 1

$$\sigma_v = 0{,}23 \cdot 24\frac{m}{s} \cdot 1{,}0 = 5{,}52\frac{m}{s}$$

The wind turbulence becomes:

$$I_v(z) = \frac{5{,}52\frac{m}{s}}{14{,}4\frac{m}{s}} = 0{,}38$$

PEAK VELOCITY PRESSURE

The peak velocity pressure $q_{p(z)}$ can now be found:

$$q_p(z) = [1 + 7 \cdot I_v(z)] \cdot \frac{1}{2} \cdot \rho \cdot v_m^2(z)$$

$\boldsymbol{\rho}$ = Wind density, put to 1,25kg/m^3

$$q_p(z) = [1 + 7 \cdot 0{,}38] \cdot \frac{1}{2} \cdot 1{,}25\frac{kg}{m^3} \cdot 22{,}8^2\frac{m}{s} = 474{,}34\frac{N}{m^2} = 0{,}474\frac{kN}{m^2}$$

EXTERNAL WIND LOADS

The form factor for the flat roof has been found according to Eurocodes. The study looks at the wind load on the roof in building West. Ill. 157 shows the division, the colored boundary shows the roof area resting on the section, where a column later will be calculated. As the wind load will be used in relation to the calculation of the column, is the load found as area load and point load. Used form factor is for a flat roof.

Table 11 shows the wind loads on the roof in the different zones, and Table 12 shows the load in the colored section.

	$C_{pe,10}$	Load	Area	Load
	kg/m	kN/m²	m²	kN
F	-1,8	-0,85	11,26	-9,61
G	-1,2	-0,57	87,30	-46,66
H	-0,7	-0,33	394,20	-130,80
I	0,2 -0,2	0,09 -0,09	492,75 492,75	46,71 -46,71

Table 11 Wind loads

	$C_{pe,10}$	Load	Area	Load
	kg/m	kN/m²	m²	kN
G	-1,2	-0,57	3,63	-2,06
H	-0,7	-0,33	14,50	-4,81
I	0,2 -0,2	0,09 -0,09	18,23 18,23	1,73 -1,73

Table 12 Wind loads in section

INTERNAL WIND LOADS

According to Eurocodes are the most unfavourable load calculated with c_{pi} +0,2 and -0,3 used. For the calculation is the area of the section shown on Ill. 157 used (15m x 2,42 m).

$$F_{w,i} = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref}$$

$$F_{w,i} = 1 \cdot 0{,}2 \cdot 0{,}474 \frac{kN}{m^2} \cdot 36{,}25m^2 = 3{,}43kN$$

$$F_{w,i} = 1 \cdot (-0{,}3) \cdot 0{,}474 \frac{kN}{m^2} \cdot 36{,}25m^2 = -5{,}15kN$$

FRICTIONAL FORCES

The roughness of the sedum roof is assumed to be 0,02 and the reference area for flat roof are found according to Eurocode 1:

$$A_{fr} = 2 \cdot d \cdot b = 2 \cdot 15{,}00m \cdot 2{,}42m = 72{,}6m^2$$

The frictional force of the area becomes:

$$F_{fr} = 0{,}02 \cdot 0{,}474 \frac{kN}{m^2} \cdot 72{,}6m^2 = 0{,}69kN$$

The total wind load becomes the sum of $F_{w,e}$, $F_{w,i}$ and F_{fr}.

$$F_{wind} = (-6{,}88kN) + (-5{,}15kN) + 0{,}69 = -11{,}34kN$$

The total wind load on the roof, here shown as a point load is -11,34kN. This means that there will be suction on the roof. By dividing the point load by 2, is the load on one column in the structure found to -5,67kN. This means that the wind load is favourable for the structure. The wind load will in this relation reduce the load on elements, such as the column.

LOAD COMBINATIONS

Load combinations are found for Service Limit State (SLS) and Ultimate Limit State (ULS) in order to dimension the decks and beams, as shown earlier in the report. Following will the load combinations for the columns placed at first floor be found. Load combinations are made according to Eurocodes and the Danish Annexes:

$$K_{FI}\gamma_{G,j,sup}" + "K_{FI}\gamma_{Q,1}Q_{k,1}" + "K_{FI}\gamma_{Q,i}\Psi_{0,i}Q_{k,i}$$

$$K_{Fi} = 1{,}0;\ (\text{Load safety class CC2})$$

$$\gamma_{G,j,sup} = 1{,}0$$

$$\gamma_{Q,1}(\text{Unfavourable}) = 1{,}5$$

$$\gamma_{Q,i}(\text{Unfavourable}) = 1{,}5$$

The load combinations for the structure and the building are calculated with dominating live load, wind load and snow load. Table 13 shows the combinations.

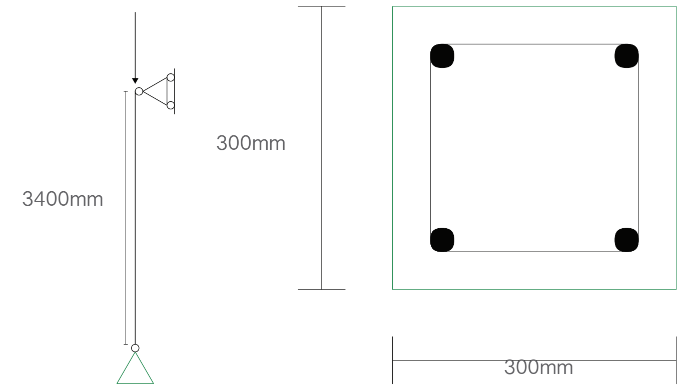
Formula	G	L	W	S	D
	-	-	-	-	-
(6.10a)	1,0 · 1,2	-	-	-	-
(6.10b)-4	1,0 · 1,0	1,0 · 1,5 · 0,8	-	-	-
(6.10b)-1	1,0 · 1,0	1,0 · 1,5 · 0,8	1,0 · 1,5 · 0,3	1,0 · 1,5 · 0,3	L
(6.10b)-2	1,0 · 1,0	1,0 · 1,5 · 0,8 · 0,6	1,0 · 1,5	1,0 · 1,5 · 0,0	W
(6.10b)-3	1,0 · 1,0	1,0 · 1,5 · 0,8 · 0,6	1,0 · 1,5 · 0,3	1,0 · 1,5	S

Table 13 Load combinations for the structure.

APPENDIX 1.4

LOAD COMBINATIONS AND COLUMN

Ill. 158 Section of structure, column which will be calculated marked with red.



Ill. 159 Cross-section of column

Ill. 158 shows the structural section of the building. The calculation for a column will look at a column placed on the first floor, marked on the figure. Table 14 shows loads from the structural elements above the structure.

	Density	Load	Load	Load
	kg/m³	kN/m²	kN/m	kN
Column (300 x 300 x 3400)	2400	-	-	2,40
Total Load (two columns)	-	-	-	4,81
Spæncom RB 30/60	-	-	4,32	31,10
Total Load (two beams)	-	-	8,64	62,21
Spæncom EX 18 5L 9,3	-	3,06	7,20	53,24
Flooring	-	0,50	1,21	8,70
Total Load	-	3,56	8,60	61,94
Total Load (two floors)	-	-	17,21	123,89
Green Roof	-	0,98	2,37	16,61
Insulation	128,00	0,50	1,22	8,51
Total Load	-	3,06	3,67	4,41
Total Load	-	-	7,26	29,52
Total Load on column	-	-	27,30	220,43

Table 14 Loads on conlumn

The following table shows the load combination for the resulting loads in Ultimate Limit State (ULS). The loads are calculated for load safety class CC2 with live load, snow load and wind load calculated as point loads.

Formula	G
	[kN]
(6.10a)	264,52
(6.10b)-4	290,03
(6.10b)-1	327,92
(6.10b)-2	274,56
(6.10b)-3	299,31

Table 15 Load combinations for load on bottom column

COLUMN

Following calculation is proving that a beam with a dimension of 300 x 300 x 3400mm (Ill. 159), will withstand the load from two floors on top, as shown in Ill. 158. The column is calculated as a centrally loaded column with adjacent beams and plates. The column must therefore withstand a load of 2,0 x the calculating load. The column is prefabricated with concrete C25 and reinforcement diameter of 25mm with a steel strength of 400MPa.

Partial factors for materials, according to Eurocodes 2, for prefabricated elements:

$$\gamma_c = 1{,}40\gamma_3$$

$$\gamma_s = 1{,}20\gamma_3$$

According to Eurocodes 2 are factors for control class found to 1, as control class is normal.

Design values for concrete and reinforcement steel:

$$f_{cd} = \frac{f_{ck}}{\gamma_c} = \frac{25\text{MPa}}{1{,}40} = 17{,}86\text{MPa}$$

$$f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{400\text{MPa}}{1{,}20} = 333{,}33\text{MPa}$$

Cross section area of concrete:

$$A_c = w \cdot d = 300mm \cdot 300mm = 90000mm^2$$

Cross section area of reinforcement steel:

$$A_s = n_{reinforcement} \cdot \pi \cdot \left(\frac{d}{2}\right)^2 = 4 \cdot \pi \cdot \left(\frac{25mm}{2}\right)^2 = 1963{,}50mm^2$$

Reinforcement ratio:

$$\rho = \frac{A_s}{A_c} = \frac{1963{,}50mm^2}{90000{,}00mm^2} = 0{,}022$$

Radius of gyration:

$$i = \sqrt{\frac{I}{A}} = \frac{h}{\sqrt{12}} = \frac{300mm}{\sqrt{12}} = 86{,}60mm$$

Slenderness:

$$\lambda = \frac{l_0}{i} = \frac{3400mm}{86{,}60mm} = 39{,}26$$

Modulus of elasticity:

$$E_{0crd} = \min\begin{cases}1000f_{cd}\\0{,}75E_{0d}\end{cases}$$

$$E_{0d} = \frac{51000}{\gamma_c} \cdot \frac{f_{ck}}{f_{ck} + 13}$$

$$E_{0crd} = 1000 \cdot 17{,}86MPa = 17857{,}1MPa$$

$$E_{0rd} = 0{,}75 \cdot \frac{51000}{1{,}40} \cdot \frac{25MPa}{25MPa + 13} = 17974{,}6MPa$$

Concrete stress:

$$\sigma_{crd} = \frac{f_{cd}}{1 + \frac{f_{cd} \cdot \lambda^2}{\pi^2 \cdot E_{0,crd}}}$$

$$\sigma_{crd} = \frac{17{,}86MPa}{1 + \frac{17{,}86MPa \cdot 39{,}26^2}{\pi^2 \cdot 17974{,}6MPa}} = 15{,}46MPa$$

Ratio of modulus of elasticity between concrete and reinforcement is specified according to table value:

$$\alpha = 24$$

Concrete contribution to the bearing capacity:

$$N_{crd} = \sigma_{crd} \cdot A_c$$

$$N_{crd} = 90000mm^2 \cdot 10^{-3} \cdot 15{,}46MPa = 1391{,}4kN$$

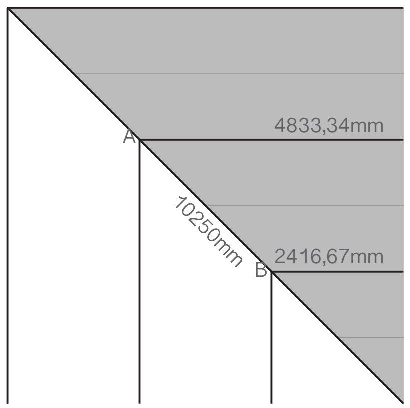
Load-bearing capacity with reinforcement:

$$Ncrd = \min\begin{cases}\sigma_{crd} \cdot A_c \cdot (1 + \alpha \cdot \rho)\\ \sigma_{crd} \cdot A_c + f_{yd} \cdot A_s\\ \sigma_{crd} \cdot A_c \cdot (1 + 0{,}04\alpha)\end{cases}$$

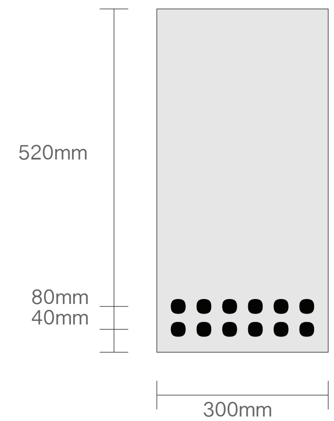
$$Ncrd = \min\begin{cases}15{,}46MPa \cdot 90000mm^2 \cdot 10^{-3} \cdot (1 + 24 \cdot 0{,}022)\\ 15{,}46MPa \cdot 90000mm^2 \cdot 10^{-3} + 333{,}33MPa \cdot 1963{,}5mm^2 \cdot 10^{-3}\\ 15{,}46MPa \cdot 90000mm^2 \cdot 10^{-3} \cdot (1 + 0{,}04 \cdot 24)\end{cases}$$

$$Ncrd = \min\begin{cases}= 2126{,}06kN\\ = 2045{,}89kN\\ = 2727{,}14kN\end{cases}$$

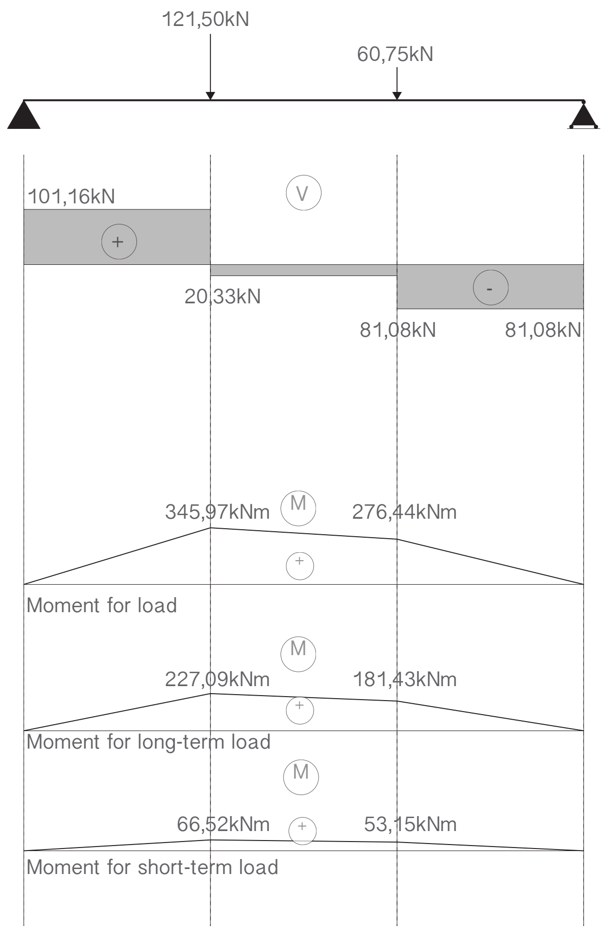
The calculations profs that the column will withstand the load, which is 327,92 kN, the column can also take the load when multiplied by 2 (655,84), which is the case here, where the column is calculated as a centrally loaded column.



Ill. 161 Beam for corner



Ill. 160 Cross-section of beam



Ill. 162 Cross-section of beam Shear and moment curves

BEAM

The diagonal beam, discussed at page 103, will be investigated, to see if it can withstand the load from the roof and adjacent beams which it will be carrying. The loads are calculated as point loads, with the load from the roof of 4,54kN/m² and the two point loads from the adjacent beams as 20,88kN and 10,44kN. Load combinations on the beam is calculated with dominating live load and snow load, it is seen that the load from the dominating live load is the biggest. Table 17 shows the load combinations and Ill. 162 shows the forces on the beam.

Formel	Load beam [2,4m]	Load beam [4,8m]
	[kN]	[kN]
(6.10a)	44,34	88,69
(6.10b)-4	53,05	104,61
(6.10b)-1	56,40	112,80
(6.10b)-2	60,75	121,49

Table 16 Load combinations for load on bottom beam

The reactions at R_A is 101,16kN and at R_B 81,08kN. Shear and bending moment are found according to shear and bending moment curves shown on Ill. 162. Additionally have the moment curves for the short-term load and long-term load been found.

The following calculations will look at the deflection for the beam in Service Limit State, when cracked and uncraked and its bending strength in Ultimate Limit State.

Reactions in R_A And R_B are calculated, as the sum of the moments in A will be 0:

$$\sum M_A = 0$$

$$(121{,}49\text{kN} \cdot 3{,}42\text{m}) + (60{,}75\text{kN} \cdot 6{,}84\text{m}) - 10{,}25\text{m} \cdot R_B = 0$$

$$R_B = 81{,}08\text{kN}$$

$$\text{Total load} = R_A + R_B$$

$$R_A = \text{Total load} - R_B$$

$$R_A = (121{,}49\text{kN} + 60{,}75\text{kN}) - 81{,}08\text{kN} = 101{,}16\text{kN}$$

Ill. 160 shows the cross-section of the beam with reinforcement. Information's for the beam is:

Reinforcement: 12 x d 25mm A_s=5890,49mm²

Concrete:

$$f_{ck} = 45\text{MPa}$$

$$f_{cd} = \frac{45\text{MPa}}{1{,}4} = 32{,}14\text{MPa}$$

Reinforcement:

$$f_{yk} = 550\text{MPa}$$

$$f_{yd} = \frac{550\text{MPA}}{1,2} = 458,33\text{MPa}$$

Distance from concrete edge to center of gravity for reinforcement:

$$c_s = \frac{6 \cdot 40mm + 6 \cdot 80mm}{6+6} = 60mm$$

Useable height:

$$d = h - c_s$$

$$d = 600mm - 60mm = 540mm$$

The deflection for is for a long-term load effect and a short-term load effect is found. For the permanent long term load is the quasi-permanent load in both points calculated. Here is the load in point A calculated:

$$q_1 = p + \psi_2 Q_l = 73,75kN + 0,2 \cdot 29,20kN = 79,75kN$$

The characteristic load in the point is found:

$$q_2 = p + Q_l = 73,91kN + 29,2kN = 103,11kN$$

The characteristic load is used to find the short-term load, which will be the difference between the quasi-permanent load and the characteristic load:

$$q_0 = q_2 - q_1 = 23,36kN$$

Similarly is the load in point B found to 39,87kN for the quasi-permanent load, 51,55kN for the characteristic load and 11,68 for the short-term load. The moment curves for the short-term load and the long-term load is shown in Ill. 162. The maximal moments in the two cases become 227,09kNm and 181,43kNm:

In the calculations is shrinkage taken into account, the effective modulus of elasticity for concrete C45 is 7,2 for a long-term effect and 29 for a short-term effect. [Jensen, C. J., 2008]

$$\alpha\rho = \alpha \frac{A_s}{b \cdot d}$$

Where ρ is the reinforcement ratio, known as the geometric reinforcement degree.

$$\alpha\rho = 29 \cdot \frac{5890,49mm^2}{300mm \cdot 540mm} = 1,05$$

The stress in the concrete is found by:

$$\sigma_c = \frac{M}{\varphi_b \cdot b \cdot d^2}$$

φ_b is a dimension less size, which can be found by:

$$\varphi_b = \frac{1}{2} \cdot \beta \left(1 - \frac{1}{3}\beta\right)$$

Beta β takes the duration of the load into account. The stress in the drag reinforcement is found by:

$$\sigma_s = \alpha\gamma\sigma_c$$

β γ φ_b is here found in “Teknisk Ståbi” φ_b =0,279, γ=0,352 and β=0,740. [Teknisk Ståbi Tabel 5.23, p 190] The stresses in the concrete becomes:

$$\sigma_c = \frac{227,09kNm \cdot 10^6}{0,266 \cdot 300mm \cdot 540^2 mm} = 9,63MPa$$

The stresses in the steel is found:

$$\sigma_s = \alpha\gamma\sigma_c = 29 \cdot 0,352 \cdot 9,63MPa = 98,30MPa$$

Similarly is the stresses found for the short term load found according to the moment curve, Ill. 162. The moments for the short term load becomes 66,52kNm and 53,15kNm. The dimensioning is done with the biggest moment 66,52kNm:

$$\alpha\rho = \alpha \frac{A_s}{b \cdot d} = 7,2 \cdot \frac{5890,49mm^2}{300mm \cdot 540mm} = 0,26$$

β γ φ_b is here found in "Teknisk Ståbi" φ_b=0,211 γ=0,974 and β=0,507. [Teknisk Ståbi Tabel 5.23, p 190] The stress in the concrete becomes:

$$\sigma_c = \frac{66{,}52kNm \cdot 10^6}{0{,}211 \cdot 300mm \cdot 540^2mm} = 3{,}6MPa$$

The stresses in the steel is found:

$$\sigma_s = \alpha\gamma\sigma_c = 7{,}2 \cdot 0{,}974 \cdot 3{,}6MPa = 25{,}25MPa$$

The total reinforcement stress is found by addition of the stress from the long- and short-term load:

$$\sigma_s = 98{,}3MPa + 25{,}25MPa = 123{,}55MPa$$

The total reinforcement stress is lower than:

$$0{,}8 \cdot f_{yk} = 0{,}8 \cdot 550MPa = 440MPa$$

The deflection for the long-term can be found when the neutral axis x is know:

$$x = \beta \cdot d = 0{,}740 \cdot 540mm = 399{,}6mm$$

The beam is calculated as a simply supported beam, the deflection is found by:

$$u = \frac{1}{10} \cdot \alpha \cdot \frac{\sigma_c}{E_s x} \cdot l^2 = \frac{1}{10} \cdot 29 \cdot \frac{9{,}63MPa}{2 \cdot 10^5 \cdot 399{,}6mm}$$

$$\cdot 10250^2mm = 36{,}71mm$$

The deflection for the short-term load becomes:

$$x = \beta \cdot d = 0{,}507 \cdot 540mm = 245{,}7mm$$

$$u = \frac{1}{10} \cdot \alpha \cdot \frac{\sigma_c}{E_s x} \cdot l^2 = \frac{1}{10} \cdot 7{,}2 \cdot \frac{21{,}47MPa}{2 \cdot 10^5 \cdot 245{,}7mm}$$

$$\cdot 10250^2mm = 5{,}54mm$$

The total deflection is found by addition of the deflection from the long- and short-term load:

$$U = U_\infty + U_0 = 36{,}71mm + 5{,}54mm = 42{,}25mm$$

To ensure the expression and look of the structure, must the deflection not be higher than:

$$\frac{l}{250} = \frac{10250mm}{250} = 41mm$$

To ensure adjacent construction must the deflection not exceed:

$$\frac{l}{500} = \frac{10250mm}{500} = 20{,}5mm$$

The calculation shows that the deflection for the beam will exceed the requirements, when calculated as a cracked cross-section. Additionally is the beam calculated as uncracked.

THE DEFLECTION CALCULATED AS A UNCRACKED

The moment of inertia is needed, before the deflection can be found. An increased stiffness will be taken into consideration, as the cross-section will be uncracked. First is the distance from the reinforcement to the center of the cross section found:

$$c = \frac{1}{2} \cdot h - c = \frac{1}{2} \cdot 600mm - 60mm = 240mm$$

The cross section area of the concrete beam is found as:

$$A_c = 300mm \cdot 600mm = 180 \cdot 10^3mm^2$$

In order to find the moment of inertia for the beam should the center of gravity be known. For a beam with reinforcement (in this case as shown on Ill. 160) is this found by:

$$a = c\frac{(A_{s2} - A_{s1})}{A_c + \alpha(A_{s1} + A_{s1})}$$

$$a = 240mm \cdot \frac{29(5890{,}49mm^2)}{180 \cdot 10^3mm^2 + 29(5890{,}49mm^2)}$$
$$= 116{,}86mm$$

The moment of inertia for the beams cross-section is found by:

$$I_t = \frac{1}{12}bh^3 + A_c a^2 + \alpha A_{s2}(c-a)^2$$

The moment of inertia for the beam with reinforcement becomes:

$$I_t = \frac{1}{12} \cdot 300mm \cdot 600^3mm + 180 \cdot 10^3mm^2$$
$$\cdot 116{,}86^2mm = 7{,}86 \cdot 10^9mm^4$$

$$\alpha\rho = \alpha\frac{A_s}{b \cdot d} = 29 \cdot \frac{5890{,}49mm^2}{300mm \cdot 540mm} = 1{,}05$$

β γ φ_b is here found in "Teknisk Ståbi" =0,279 γ=0,352 and β=0,740. [Teknisk Ståbi Tabel 5.23, s 190] φ_b The moment becomes:

$$x = \beta d = 0{,}740 \cdot 540mm = 399{,}6mm$$

The moment for the concrete is now calculated:

$$M_{cr} = \frac{I_t}{y} f_{ctm}$$

f_{ctm} is the concrete mean tensile strength:

$$0{,}30 f_{ck}^{\frac{2}{3}} = 0{,}30 \cdot 45^{\frac{2}{3}}MPa = 3{,}8MPa$$

$$M_{cr} = \frac{7{,}86 \cdot 10^9mm^4}{(239{,}76mm - 60mm)} \cdot 3{,}8MPa \cdot 10^{-6}$$
$$= 166{,}16kNm$$

The deflection equaling the cracking moment is found:

$$u = \frac{1}{10}\alpha\frac{M_{cr}}{E_s I_t} l^2$$

The deflection becomes:

$$u = \frac{1}{10} 29 \frac{166{,}16kNm \cdot 10^6}{2 \cdot 10^5MPa \cdot 7{,}86 \cdot 10^9mm^4} 10250^2mm$$
$$= 32{,}2mm$$

Beta for long-term load is 0,5. It is now possible to calculate the deflection for an uncracked beam.

$$\zeta = 1 - \beta\left(\frac{M_{cr}}{M}\right)^2 = 1 - 0{,}5\left(\frac{166{,}16kNm}{277{,}09kNm}\right)^2 = 0{,}73$$

Beta for long-term load is 0,5. It is now possible to calculate the deflection for an uncracked beam.

$$\alpha = \zeta\alpha_{II} + (1-\zeta)\alpha_I = 0{,}73 \cdot 42{,}25mm$$
$$+ (1 - 0{,}73) \cdot 32{,}2mm = 39{,}54mm$$

The calculation shows, that the deflection for the beam is under the allowable l/250 (max. 41mm) for the expression, when the beam is calculated as uncracked. As no adjacent structures will be underneath the beam, is the limit of l/500 (max. 20,5mm) not taken into consideration.

ULTIMATE LIMIT STATE

The bending strength of the beam is evaluated to see if the beam can withstand the moment caused by the load. Parameters for the concrete are the same as used for calculating the deflection.

The calculating value for the strain in the reinforcement is found:

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{458{,}33MPa}{2 \cdot 10^5 MPa} = 2{,}3 \cdot 10^{-3}$$

The reinforcement degree in the beam must be lower than the value for the reinforcement degree in the balanced cross section:

$$\omega < \omega_{bal}$$

The reinforcement degree is found:

$$\omega = \frac{A_s \cdot f_{yd}}{b \cdot d \cdot f_{cd}}$$

$$\omega = \frac{5890{,}49mm^2 \cdot 458{,}33MPa}{300mm \cdot 540mm \cdot 32{,}14MPa} = 0{,}519$$

The reinforcement degree for the balanced cross section is found:

$$\omega_{bal} = 0{,}8 \frac{\varepsilon_{cu3}}{\varepsilon_{cu3} + \varepsilon_{yd}}$$

$$\omega_{bal} = 0{,}8 \frac{0{,}35\%}{0{,}35\% + 0{,}23\%} = 0{,}489\%$$

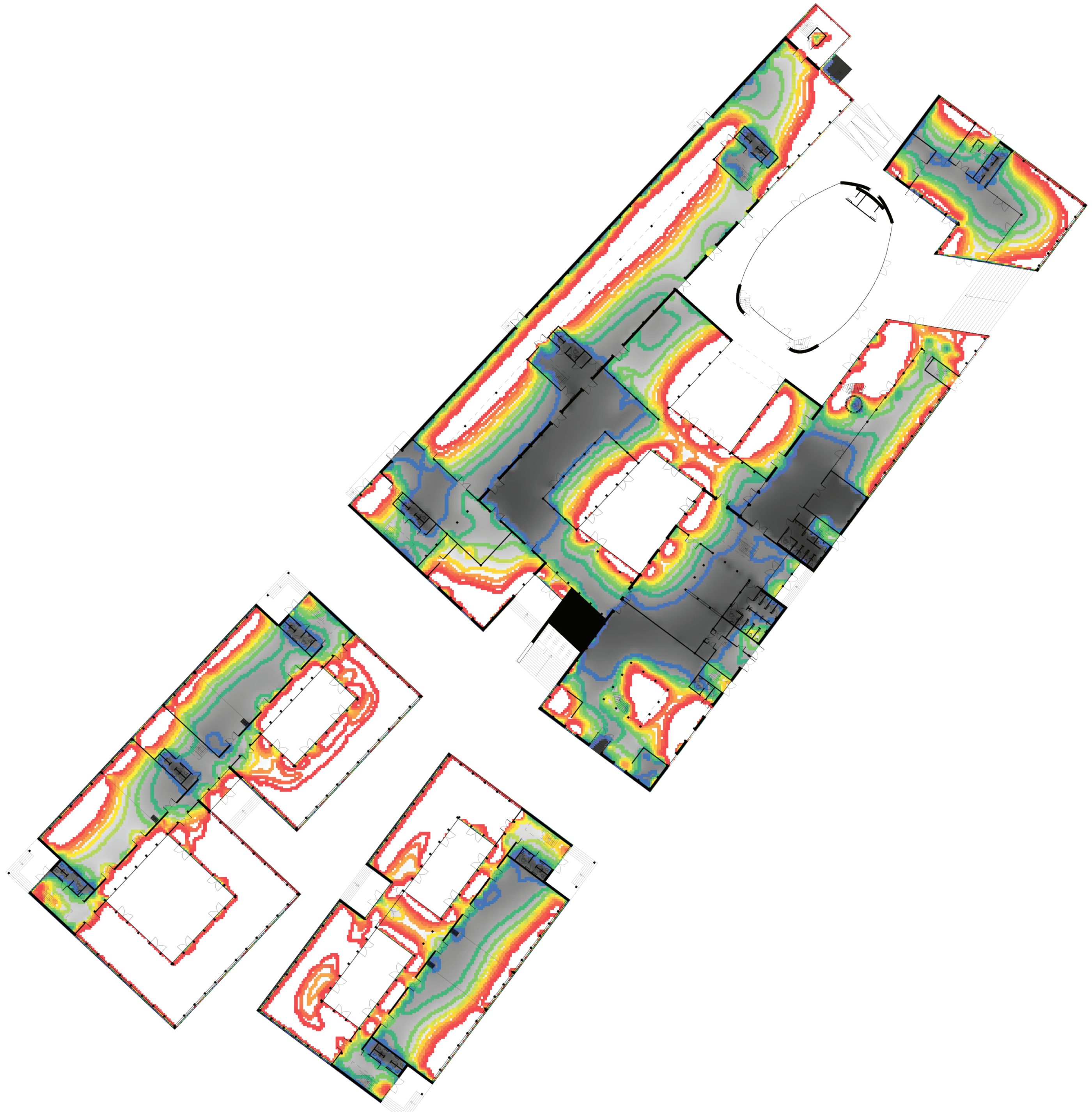
The reinforcement degree is near the reinforcement degree for the balanced cross section, 0,519 > 0,489%. As the concrete strength is below 50 MPa is the bending moment strength for the beam found by:

$$M_{Rd} = \left(1 - \frac{1}{2} \cdot \omega\right) \omega \cdot b \cdot d^2 \cdot f_{cd}$$

The bending moment strength for the beam becomes:

$$M_{Rd} = \left(1 - \frac{1}{2} \cdot 0{,}519\right) \cdot 0{,}519 \cdot 300mm \cdot 540^2 mm \cdot 32{,}14MPa \cdot 10^{-6} = 1080{,}56kNm$$

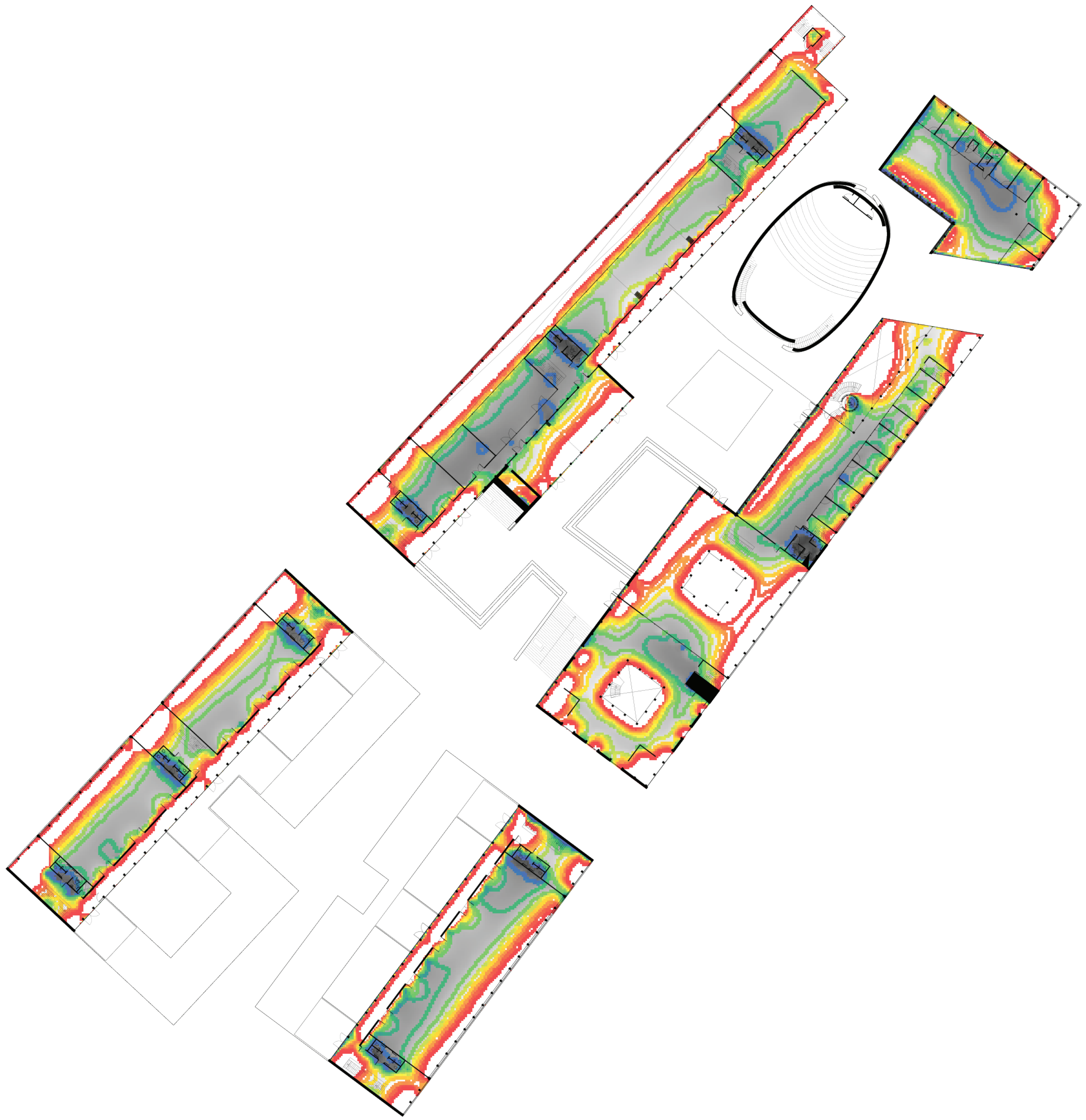
The bending strength of the beam can resist a moment of 1080,56kNm, which means that the beam will withstand the moment caused by the loads.



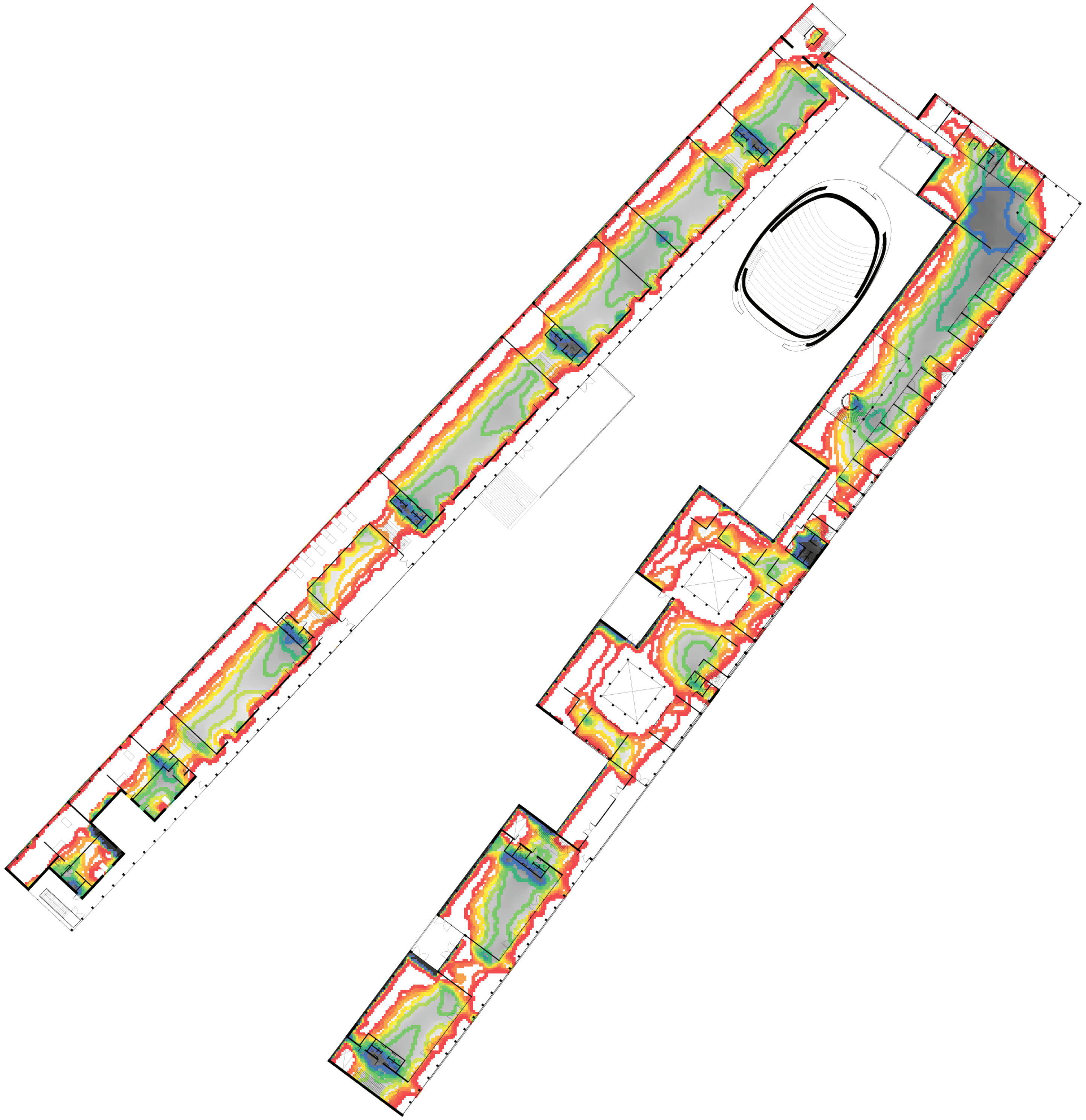
Ill. 163 Daylight factor for the final 1st floor

APPENDIX 1.6

Daylight factor of the final plan



Ill. 164 Daylight factor for the final 2nd floor



Ill. 165 Daylight factor for the final 3rd floor