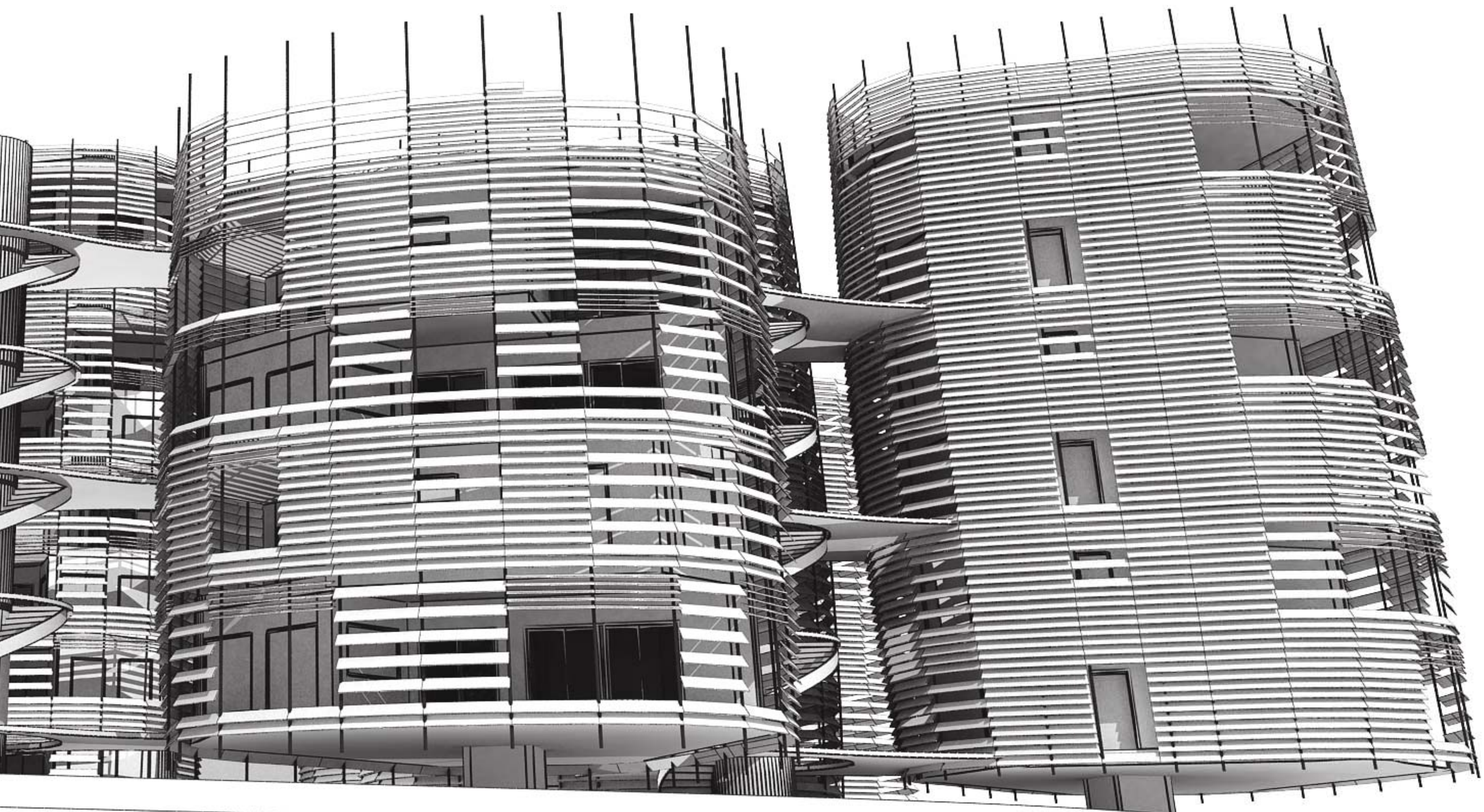
# SubDenCity

ma4 - ark13, Henriette F. Olesen, Nicki H. johansen, Susie R. Nørgaard, June, 2010



# Title Page

This master thesis has been completed at the civil engineering education at Architecture & Design, Aalborg University.

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# Summary


This master thesis deals with designing an energy neutral building in Nordhavnen, Copenhagen. It is based on the Bolig+ competition program.


# Synopsis

Nordhavnen in Copenhagen has in the last few years been a part of the climate vision, which the municipality has outlined for whole Copenhagen.

The area at Nordhavnen should be one of the first $CO_2$ neutral areas in Denmark - making Copenhagen one step closer the goal of being the first capital that becomes $CO_2$ neutral.

The vision is to create desirable apartments in a dense city area as an alternative to the large detached houses characterizing the suburbs.

This project deals with the theme "Zero Energy Building", using different sustainable principles to fulfill the demands for a zero energy building.

The focus is how to integrate different aesthetic-, functional- and technical demands without making a compromise of either.

# Reading Guide

The references in this report will be noted according to the Harvard method:

- Illustration references will be noted as [ill. X].
- References to appendix [see "title of appendix"].
- References to programs [see "programs name and the specific part"]
- References to drawings [see "drawing name"].

The list of used literature and illustrations is placed at the end of the report and illustrations are sorted according to the different main chapters.

The attached CD contains:

- IES Virtual Environment; result reports etc.
- Be06; original file, results- and documentation reports
- Further Appendix for the Be06-calculations
- Bolig+ competition program
- Bolig+ toolkit
- Pictures from the daylight studies of the final floor plan.
- The final report

# Table of Content

# Introduction

***"Around half of all non-renewable resources consumed across the planet are used in construction, making it one of the least sustainable industries in the world", [Rough Guide to Sustainability, 2010].***

For a long time human society has been living on the "capital" of the planet - not its interest. Now the planet has troubles supporting the current level of resource consumption associated with the construction and management of the buildings, which human civilization depends on for continued shelter and existence. As the world population and living standards are rising, the level of: resource consumption, pollution, $CO_2$ production and waste will continue to escalate.

To uphold and secure a high living standard for the next and future generations, it is clear that something must change and that architects - as leading building designers - have an important role to play in this.

Architecture though, cannot solve the environmental problems alone, but it can make a significant contribution to the creation of more sustainable human habitats. Design goes beyond creating habitats for more existence, it also involves generating happiness and a certain pleasure in living.

The challenge in this project is to create architecture that embodies a vision of how we should live and to materialise this vision through a sustainable way of construction.

The question of how we should live will be approached from a more environmentally concerned way of living - creating dense city areas and energy efficient dwellings, which will be regarded as alternatives to the inefficient and space consuming detached houses, which characterize the suburbs. The aim is to create buildings that are sustainable in terms of energy consumption but without compromising the architectural qualities. The building should likewise give considerations to social and human sustainability in order of creating an environment that will attract people - there is no point in making sustainable buildings, if nobody wants to use and live in them!

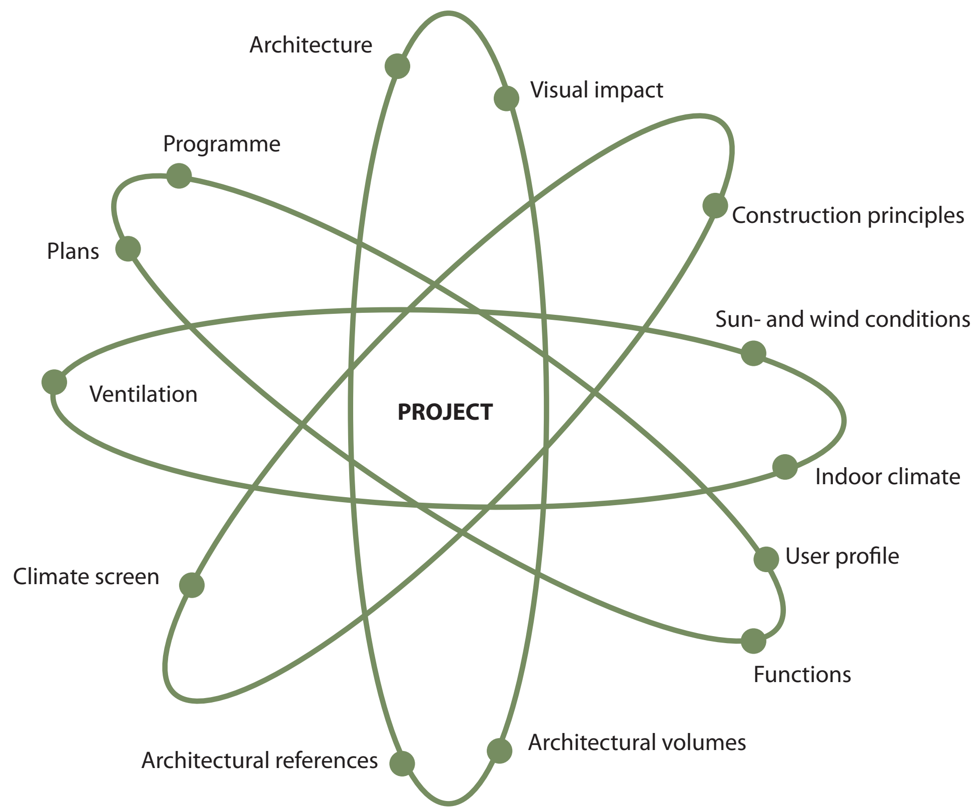
"Nordhavnen" or the northern harbour of Copenhagen has been chosen as the site in which the project will be developed. The area will in a relative near future, undergo a massive transformation from a commercial harbour and industrial area, to a new urban area. The intentions with Nordhavnen are very consistent with the aim of the project - to develop a dense sustainable city area with Zero Carbon Buildings.

This project though will focus on the development of a Zero Energy Building due to the program Bolig+ which is the name of a Zero Energy Building competition planned in Nørresundby, Denmark. The program will be used as a frame and guide for the project defining various elements such as: user, room program, architectural- and energy demands.

# METHODOLOGY
## INTEGRATED DESIGN

The project will focus on integrated design and use Mary-Ann Knudstrup's method as the overall structure of the design process to ensure that all necessary aspects of building are thought into the project [see ill. 1].

The method will have a holistic vantage point while customizing the project accordingly to different main priorities such as sustainability and user. Through the analysis different design principles will be determined, which should be integrated early in the sketching phase, and worked with simultaneously to create a balanced platform for the project to sit upon.




ill.1: "Integrated Design Process in PBL" by Knudstrup, Mary-Ann.

## Project structure

### Vision
A clear vision for needs to be defined, based on the main themes of the project. The vision can be change as new information is discovered during the analysis.

### Analysis / Program
Analysis and registration of context and site specific conditions.

Analysis and description of sustainability in general and as an environmental, social and economic theme to determine different architectural principles. Study of Zero Energy Building demands and the Bolig+ program to help navigating the terrain of the theme, and find an appropriate way for energy neutrality to be integrated into the project.

Analysis of trends in living. This analysis will help unravel the most important tendencies and desires in modern living and determine the needs of the users.

Analysis of new and upcoming technologies, which seem to have relevance, for creating "sustainable dwellings of tomorrow".

### Sketching phase
The sketching phase will be an iterative and "parallel" process, meaning that sketching will be done from multiple angles simultaneously, for instance on apartment configuration while also sketching on building concept. During the sketching phase, a multitude of different tools both digital, analogue, 3D and 2D will be used. Also in this phase technical tools will be used to evaluate the buildings performance.

What will be sketched on:

- Low detailed urban plan for the site and nearby context.
- Building expression and relationship with the context, directed by the vision expressed in the earlier completed analysis phase.
- Interior spaces, and how they relate to the building. In this stage, preliminary studies of daylight, energy use and comfort of the apartments will be done.
- Structural principles and the relation to both the building and the apartments.

### Synthesis phase
The synthesis phase will develop the conceptual ideas created in the sketching phase, into a final, logical and architectural whole accordingly to the initial intentions with the project.

In this phase detailed analysis of light, indoor climate and the performance of the building will be analyzed and the design will then be adjusted in order to optimize the building.

The building will be drawn in 3D, for use in a parametric analysis of the building, and to use for the later presentation phase.

### Presentation phase
The presentation will be a description of the final result through both physical and digital models, plans and sections.

## Tools to be used

Working holistically with architecture creates a need for tools which can deliver good results relatively fast, with the right accuracy for the current phase of the project, and which could possibly be integrated with each other.

### Rhinoceros 4.0/Grasshopper
*Grasshopper is a plugin for the 3D software package "Rhinoceros 4.0", which enables the user to create parametric studies using an interface of components, connections and drawn geometry. This enables the user to create rather complex geometry relative easy and most importantly - fast.*

### Revit Architecture 2010
*Revit is a relative new BIM tool, owned by the software giant Autodesk. Currently many architectural offices both domestic and foreign are moving from conventional 2D projecting, to this 3D BIM projecting. In the project it is a goal to use Revit in the later sketching phase, to become more familiar with the tool and hopefully create a stronger, and more thorough final concept.*

### 3ds Max Design 2010
*3ds Max will be used for both digital modelling and daylight simulations. One of the great advantages is the relative smooth workflow of importing Revit models into 3ds Max, which can be crucial in a fast paced design process.*

*The nature of 3ds Max Design as a comprehensive 3D package, makes the possibilities of testing far reaching, and even ranges to detailed material definitions.*

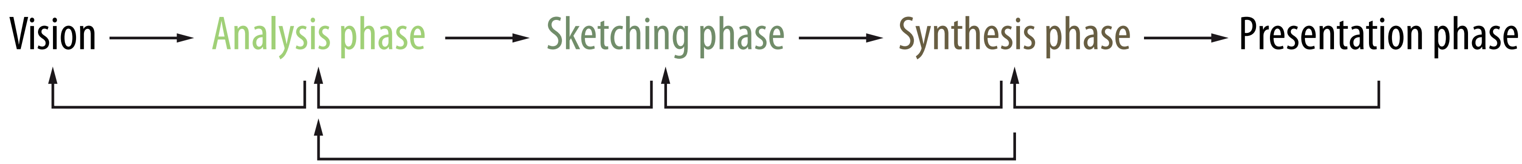
### VE 6.0 - Virtual Environment
*Virtual Environment is a tool created by the Scotland based firm, Integrated Environmental Solutions LtD. It is a quite powerful tool, which can perform a large array of tasks, such as: detailed daylight and solar investigations, airflow, ventilation, indoor quality investigations and so forth.*

*The advantage of this tool, compared to a tool such as BE06, is that BE06 is not really a simulation tool, whereas Virtual Environment can give much more accurate estimations of energy use and indoor climate.*

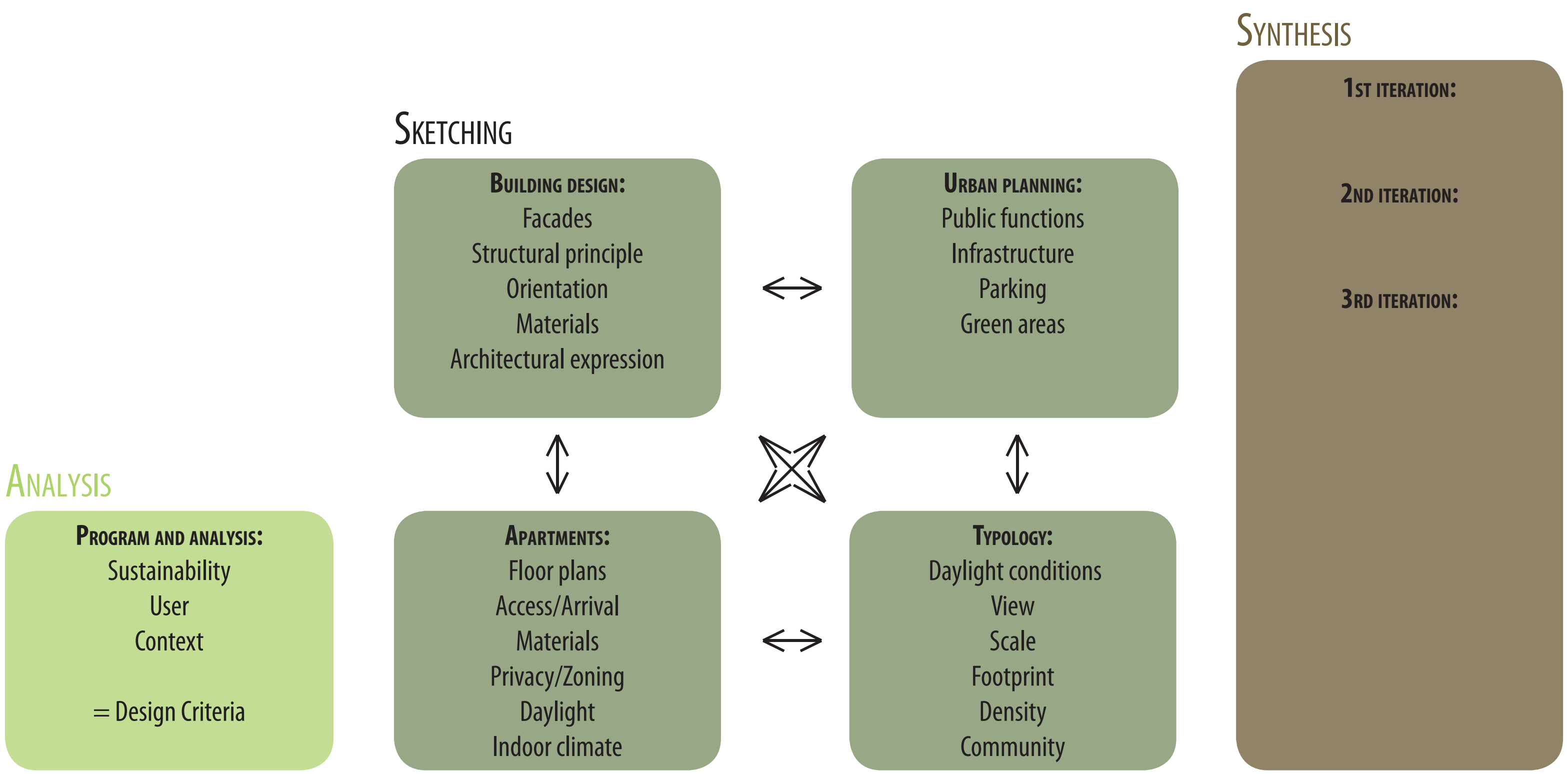
*Performance wise the program seems to create results in the same quality as Bsim, while being both faster and more user friendly. Furthermore, it can to some degree be integrated with both SketchUp and Revit.*

*The hopes are that by using this tool, it will be possible to do more tests, during the sketching and synthesis phase, hereby optimizing the integrated design process and the finally design based on more information.*

### BE06/Bolig+ toolkit
*The "Bolig+" toolkit is a BE06 toolkit, developed for the "Bolig+" competition, which will be used to investigate whether or not the current concept fulfills the demands for energy neutrality.*




ill.2: "Integrated Design Process in PBL" by Knudstrup, Mary-Ann.




ill. 3:Simplified diagram for project structure.

# Presentation

# The building

The buildings are intended to be a part of the future city development of Nordhavnen in Copenhagen, which are going to be developed during the next 50 years.

The vision for there future Nordhavn is to create a sustainable urban area for the future, and it is in this context, the settlement is developed.

To reach this goal calls for a rethinking the building as both a living space and at the same time an energy producing element for the whole area. This new way of thinking of the built environment calls for an evaluation of a new architectural expression, which is able to express, and embrace its new purpose.

## The design

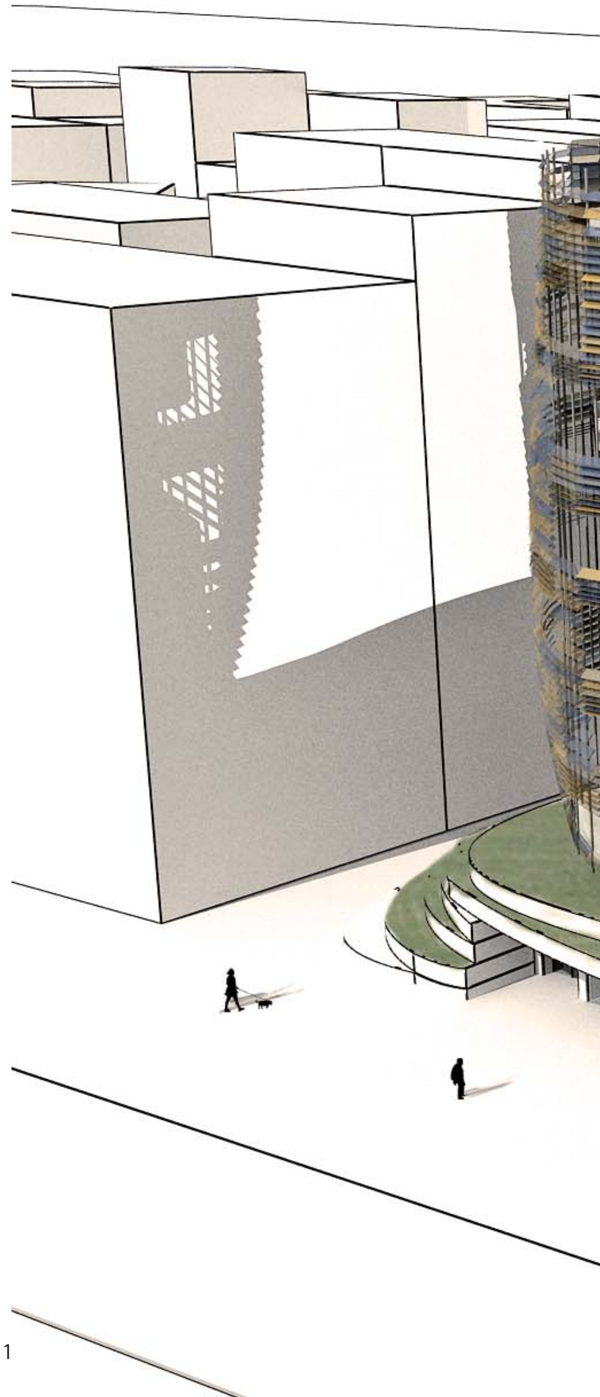
The building design is  a concept for of how an energy neutral building could appear focusing on the integration of livable dwellings and the energy producing elements.

The facades have been an important parameter for creating a clear truthful expression of how it has been achieved to design an energy neutral building. It consists of transparent warm colored louvres and dark blue photovoltaic louvers.

The unique and dynamic facades provide the area with buildings, which are characterized by ever-changing facades: A playful facade that conveys both the technological aspects of energy producing element along with the more warm expression gained from a combination of the orange/brownish colored transparent louvers and the green vegetation in the area.

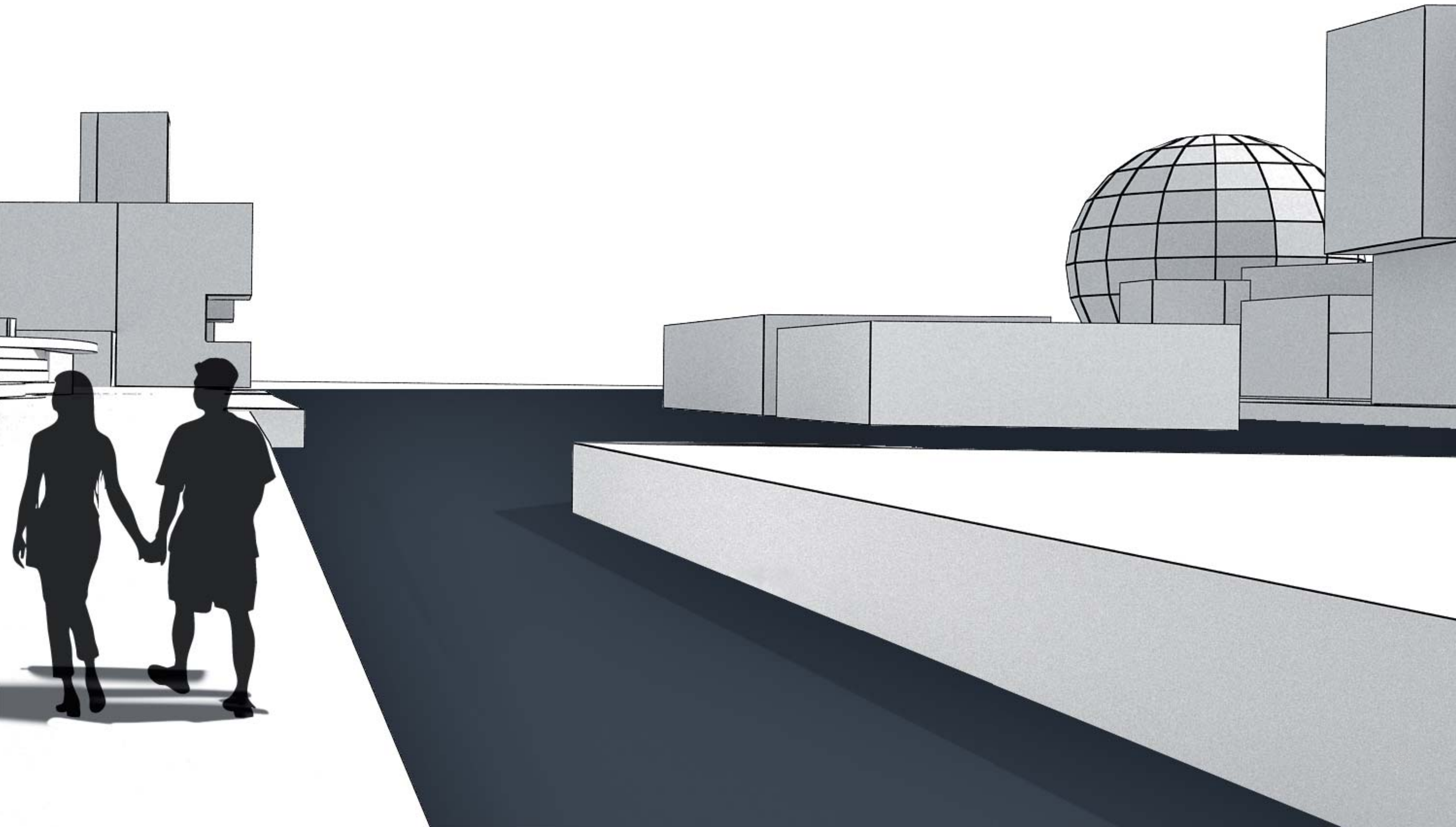
Apart from being the main energy producing element, the louver facade also has a number of other significant functions:

- Solar shading. The transparency of the louvers makes it possible to still gain from the daylight while preventing overheating during summer.
- Wind screening. To have the possibility of using the terraces through the year it is possible to move the louvers up and down according to the wanted comfort.
- A change of spacious perception. The possibility of moving the louvers up and down also provides the possibility of diversity in the perception of space. When lowering the louvers it is possible to gain a more intimate space and when having all the louvers down it is possible to get a more private enclosed space.

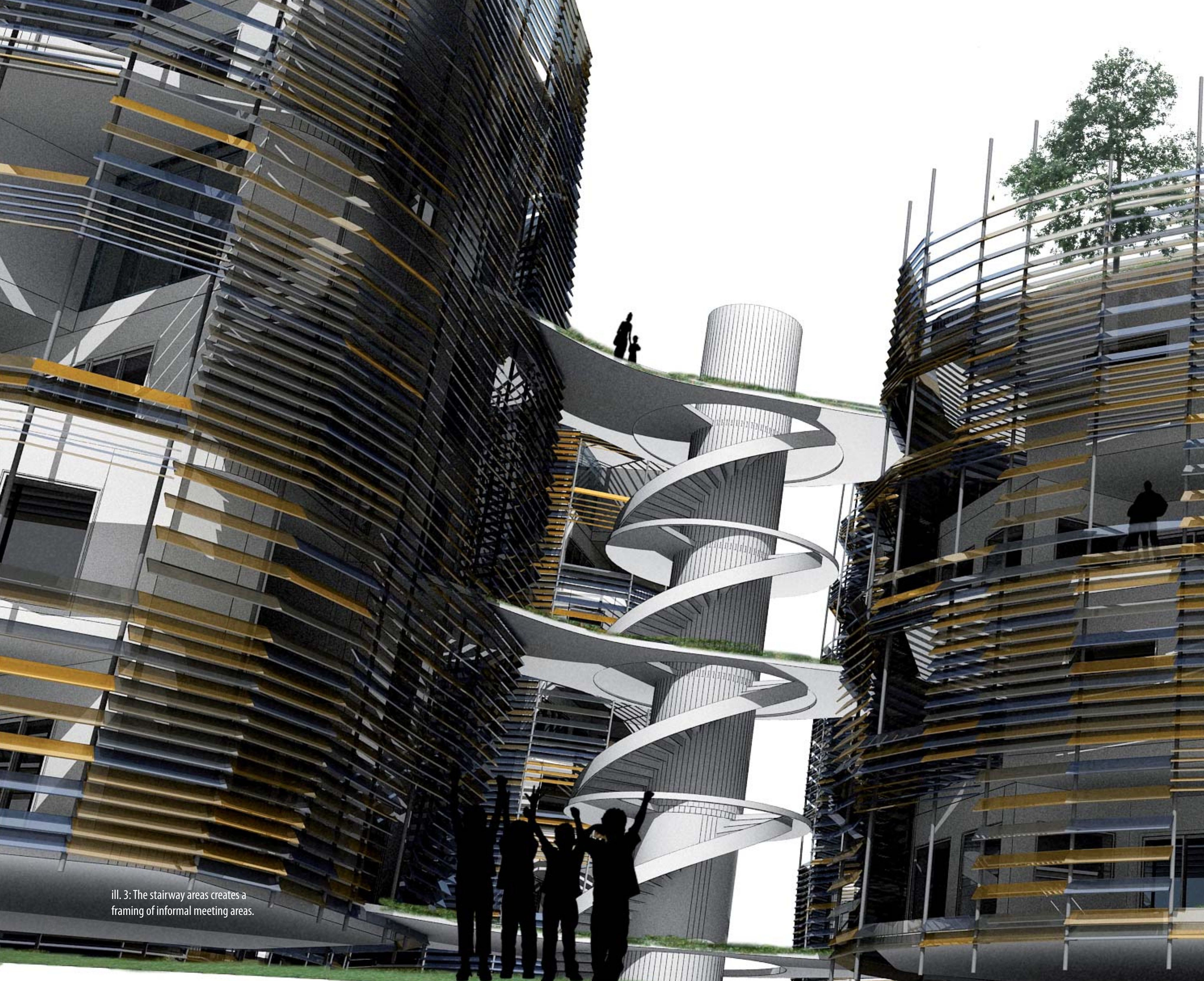


ill. 1

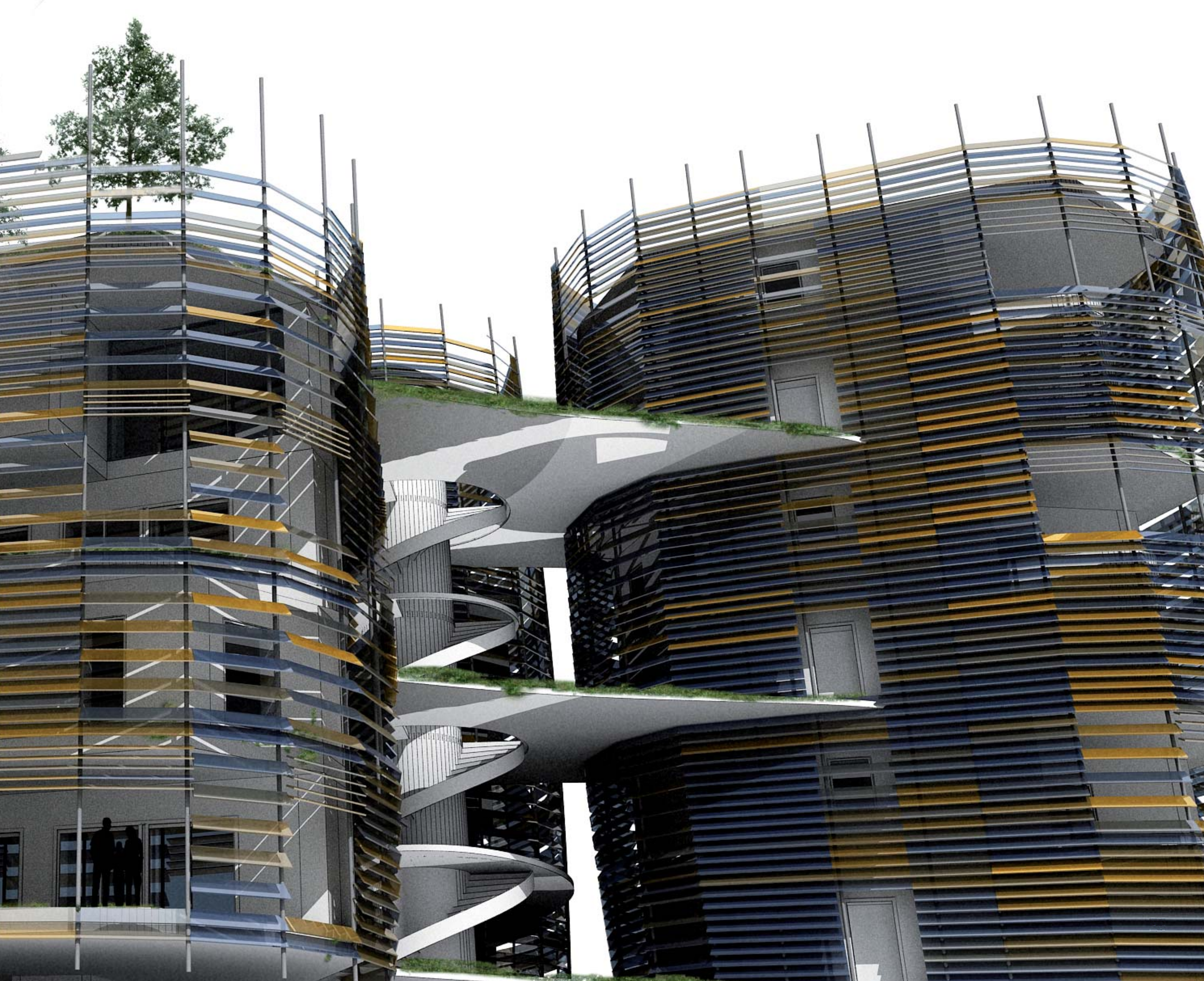

Shopping
Cafe

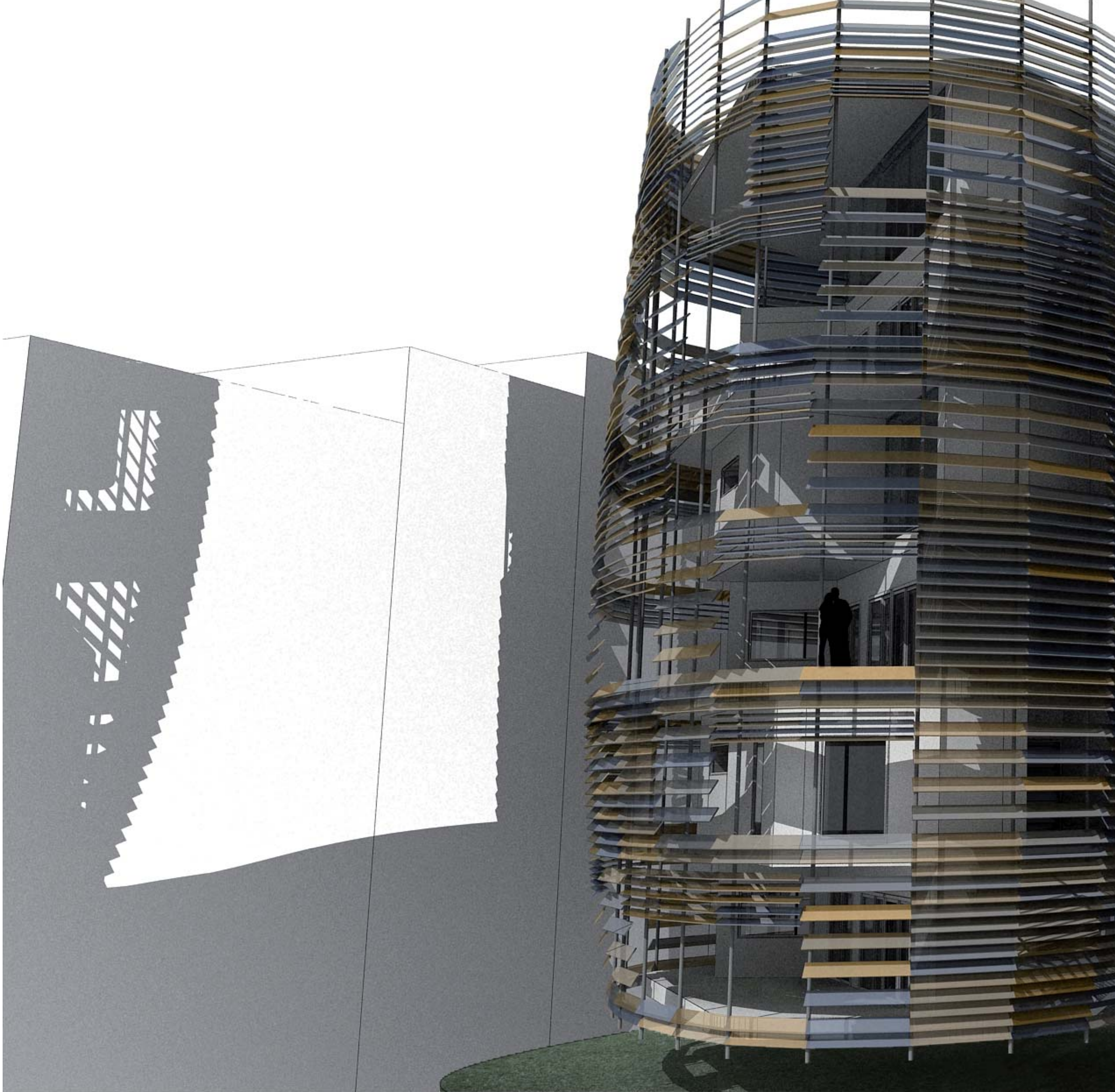


ill. 2: The waterfront with the shops in the base. The shops are going to contribute to activity in the area during the day.



ill. 3: The stairway areas creates a framing of informal meeting areas.





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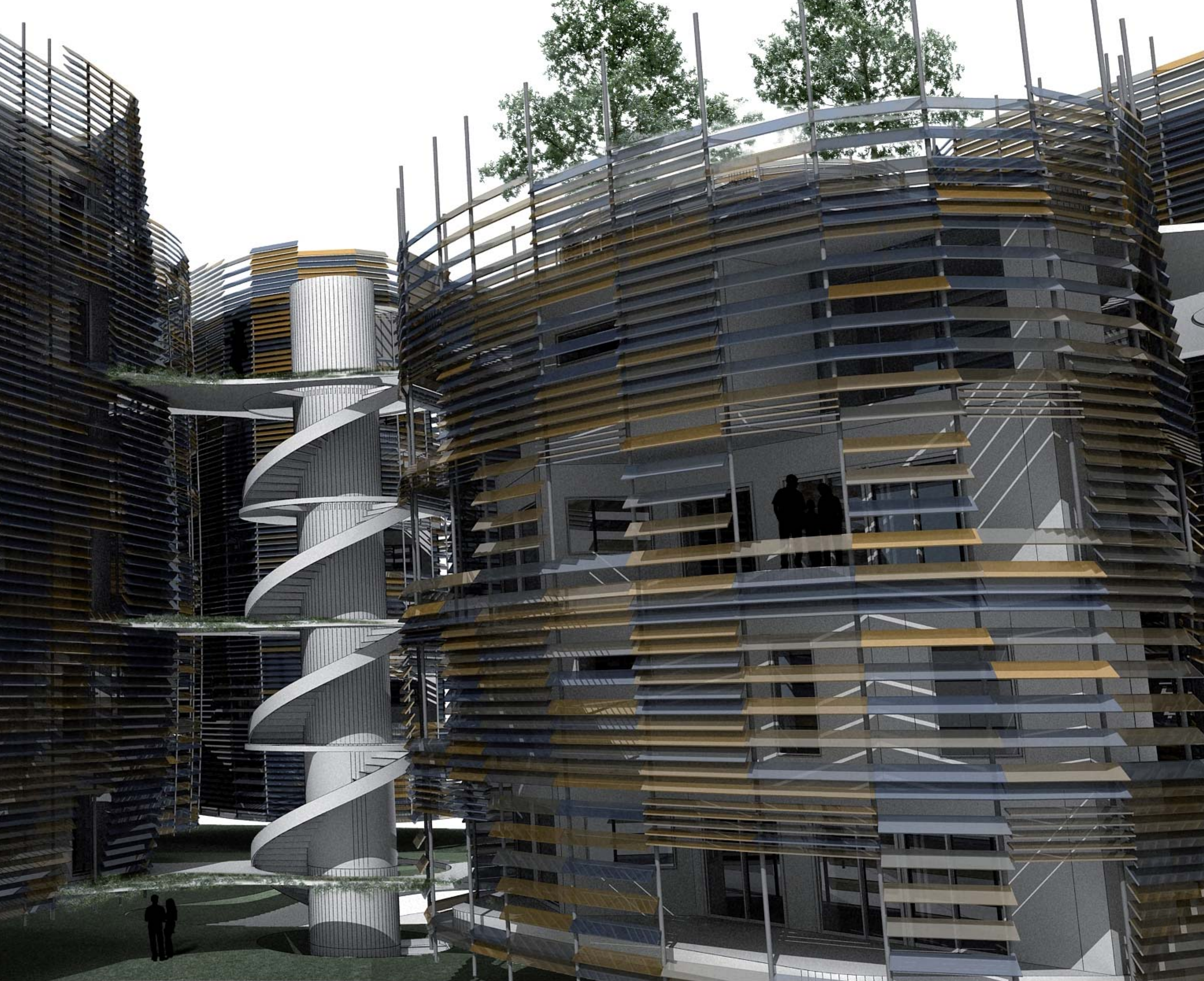

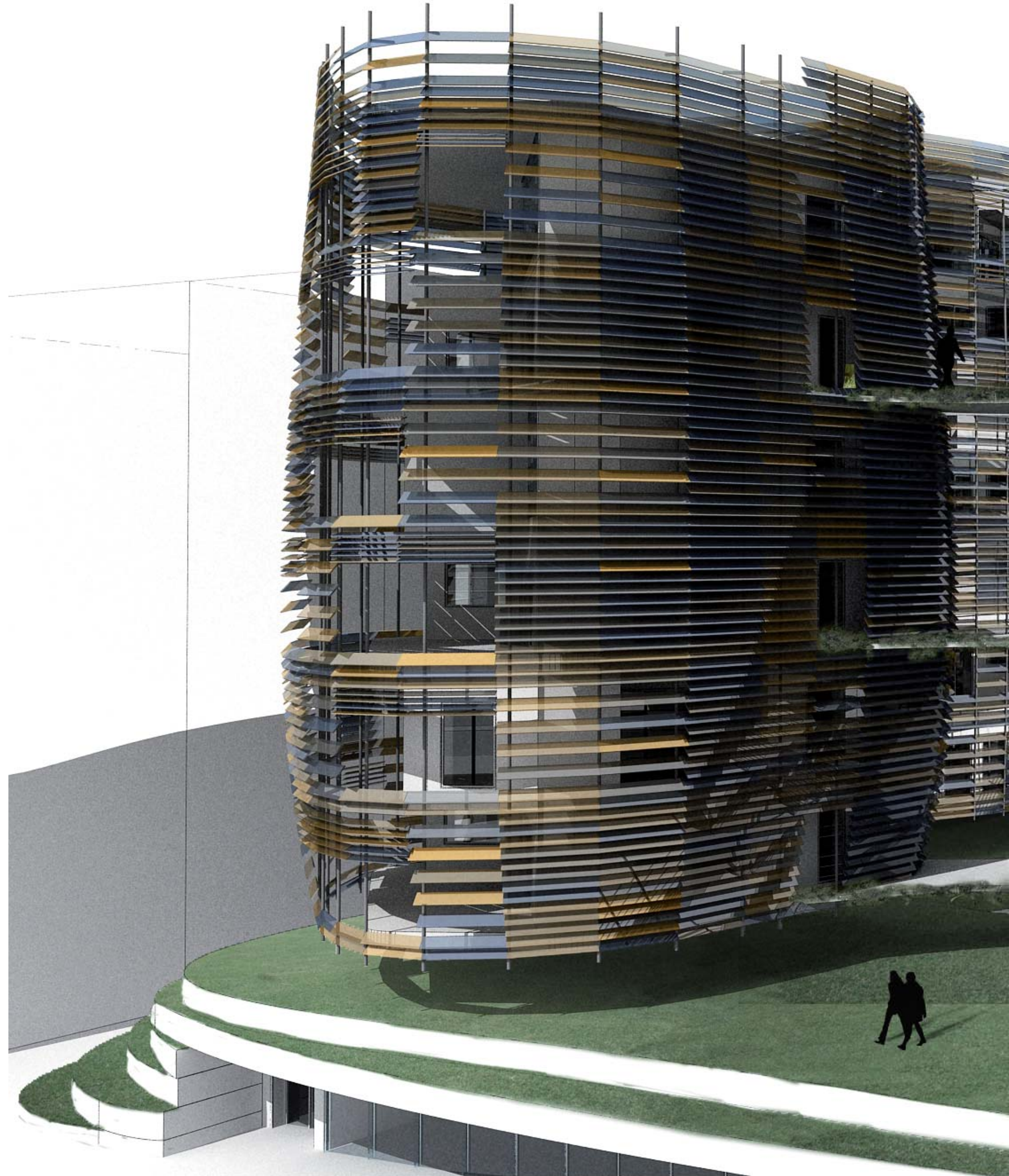

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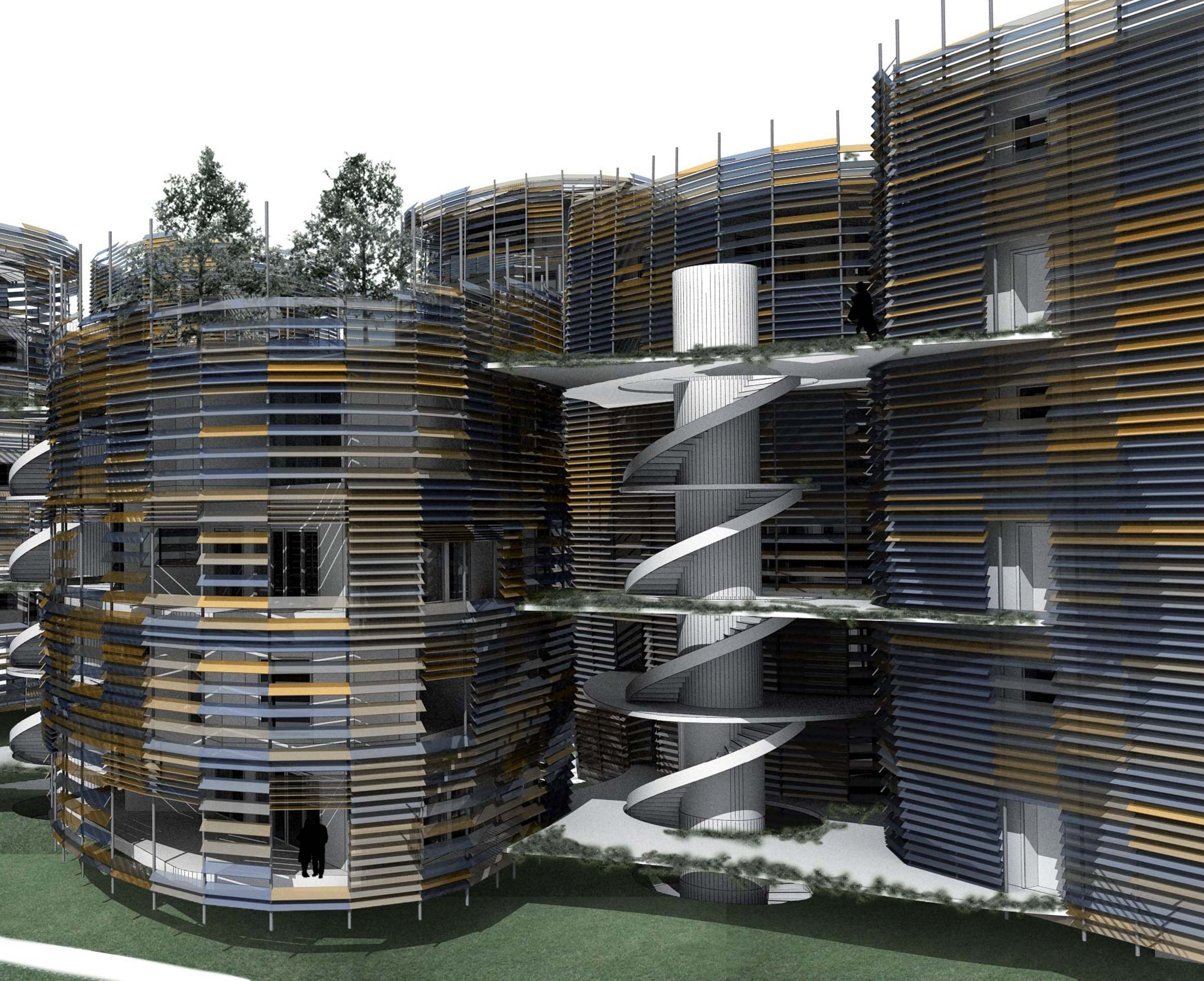

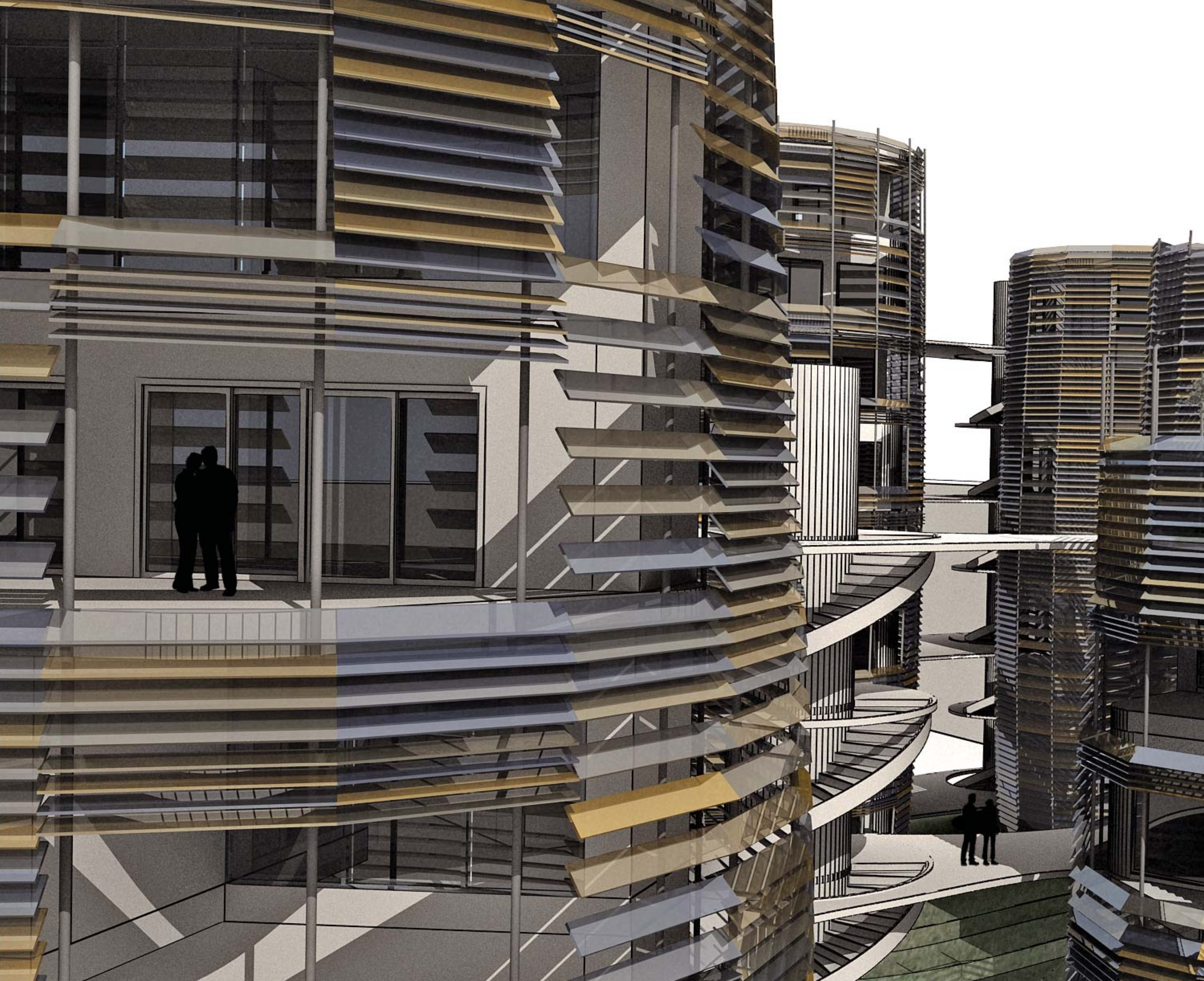

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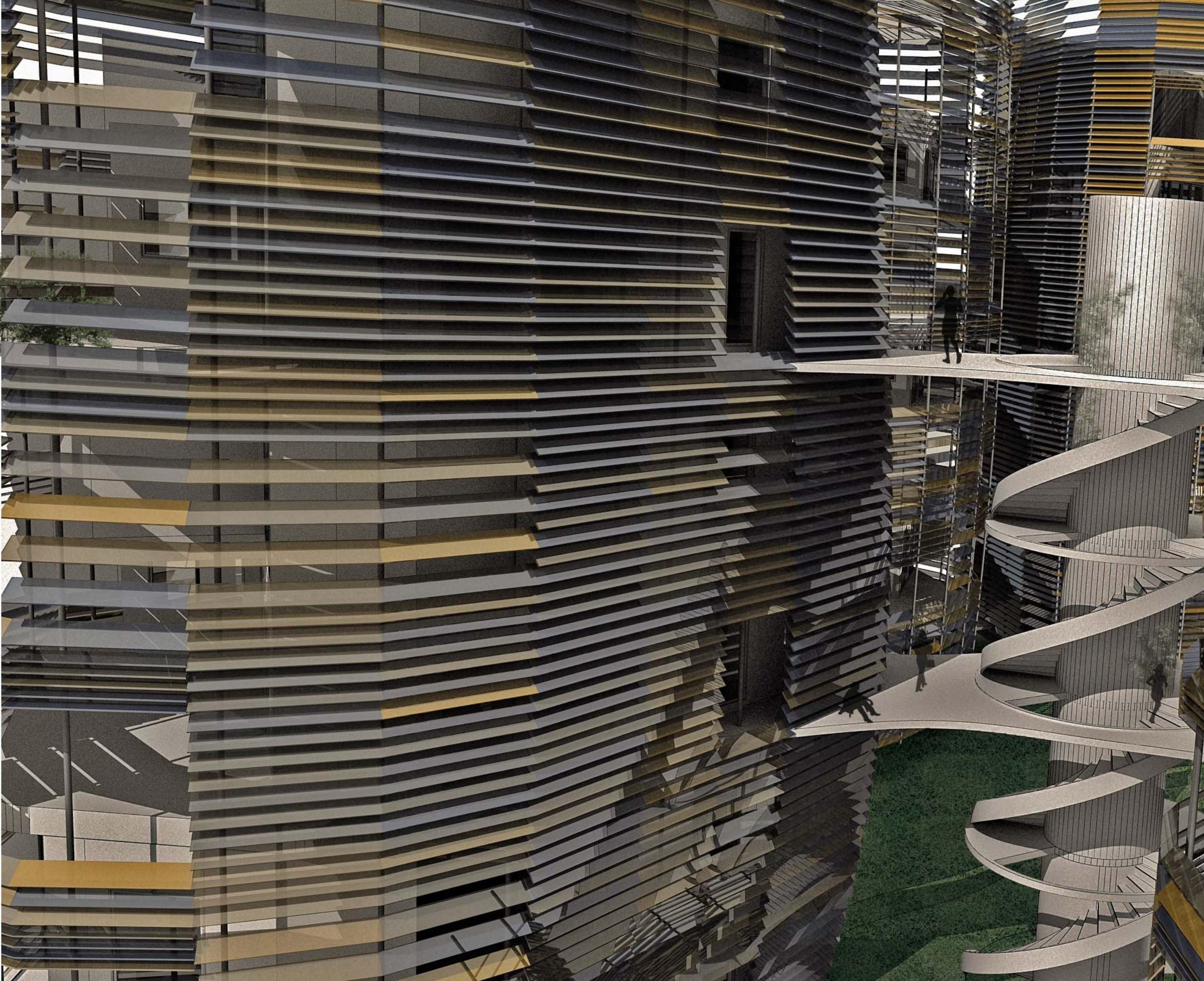
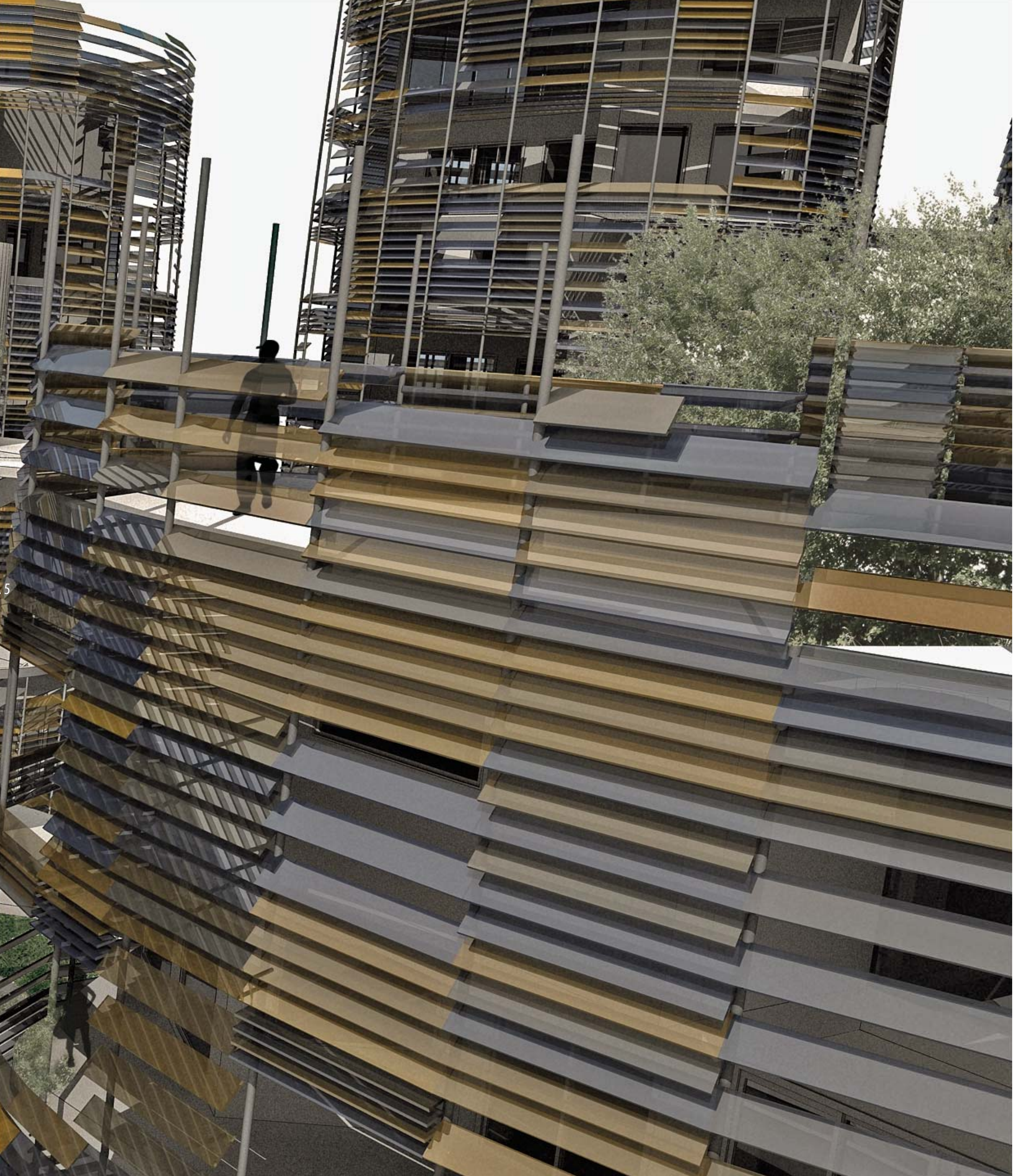
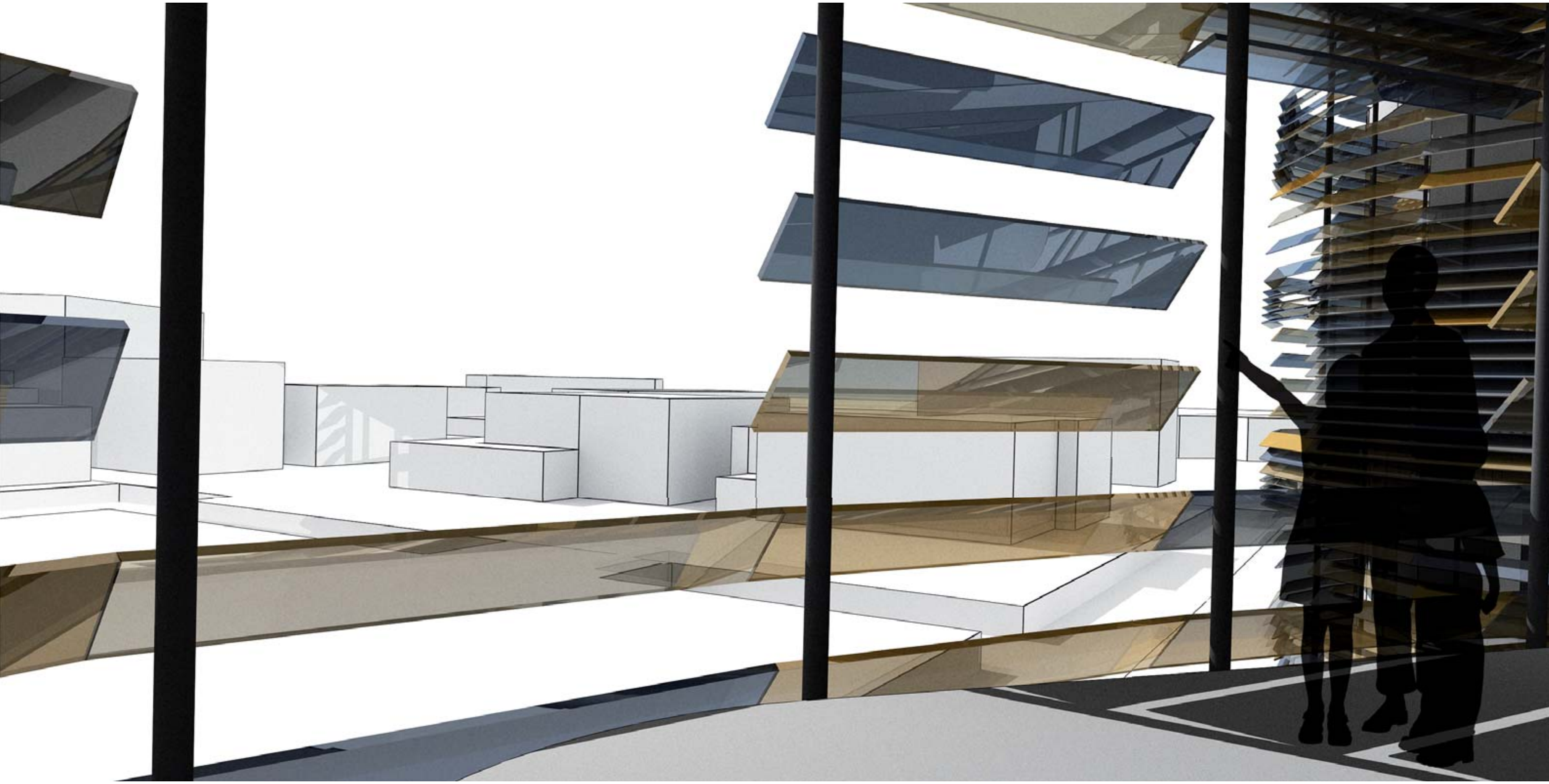




Ill. 7: The vertical connections between the dwellings and the different common areas, which both are to be found at ground level and in height.



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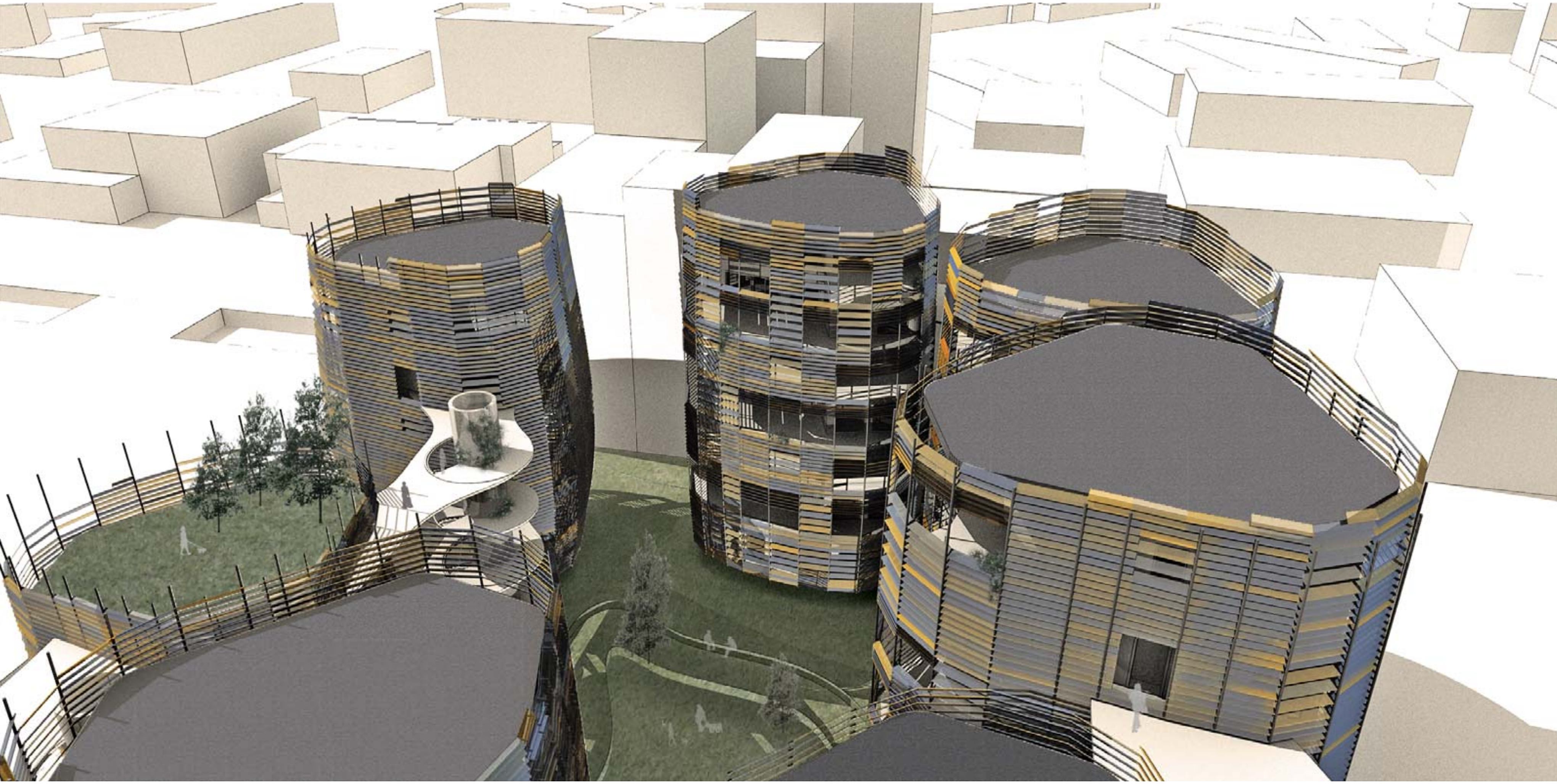


ill. 9: A cluster of the building complex seen from above. One of the common areas in height are illustrated towards the water front.

# Elevations 1:500

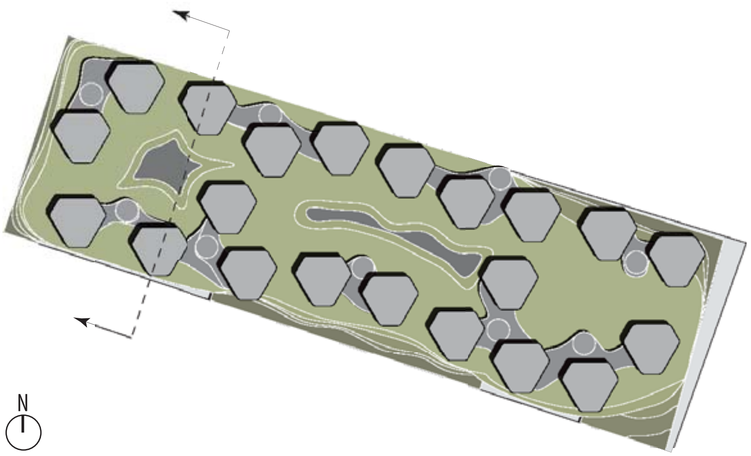
ill. 10: East-South-East

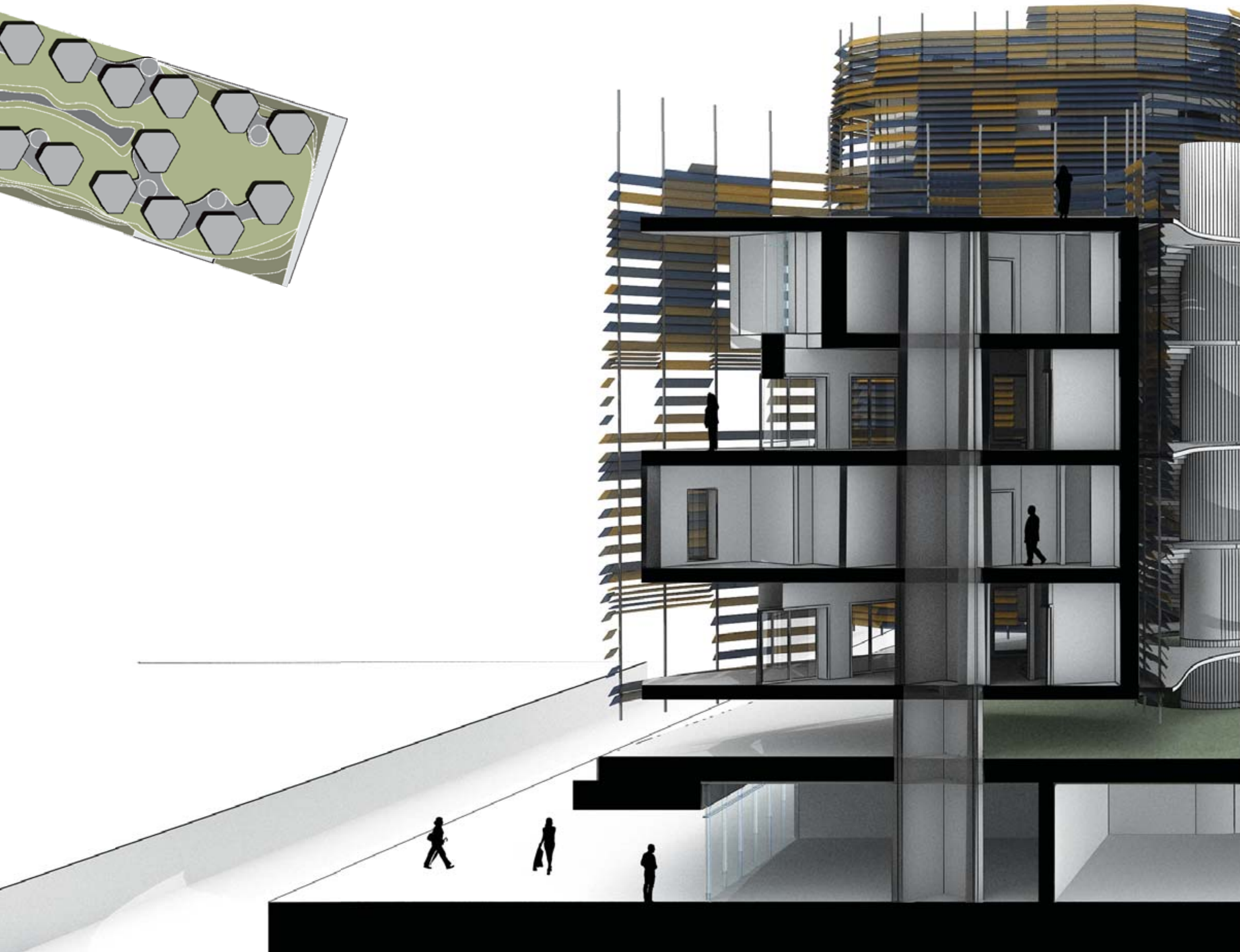
ill. 11: South-South-West

ill. 12: West-North-West

ill. 13: South-South-West

# Section ESE



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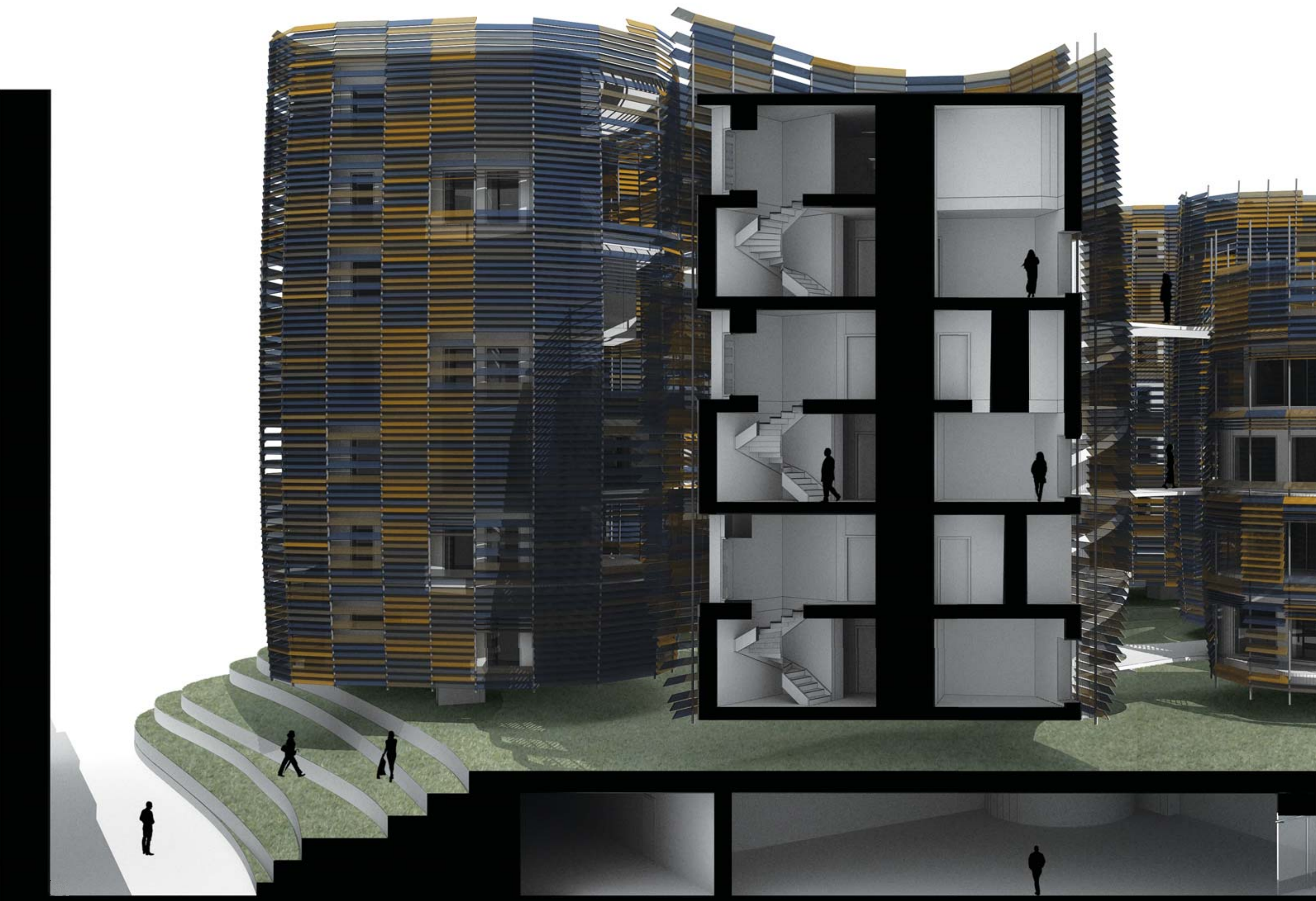
Toise

ill. 14



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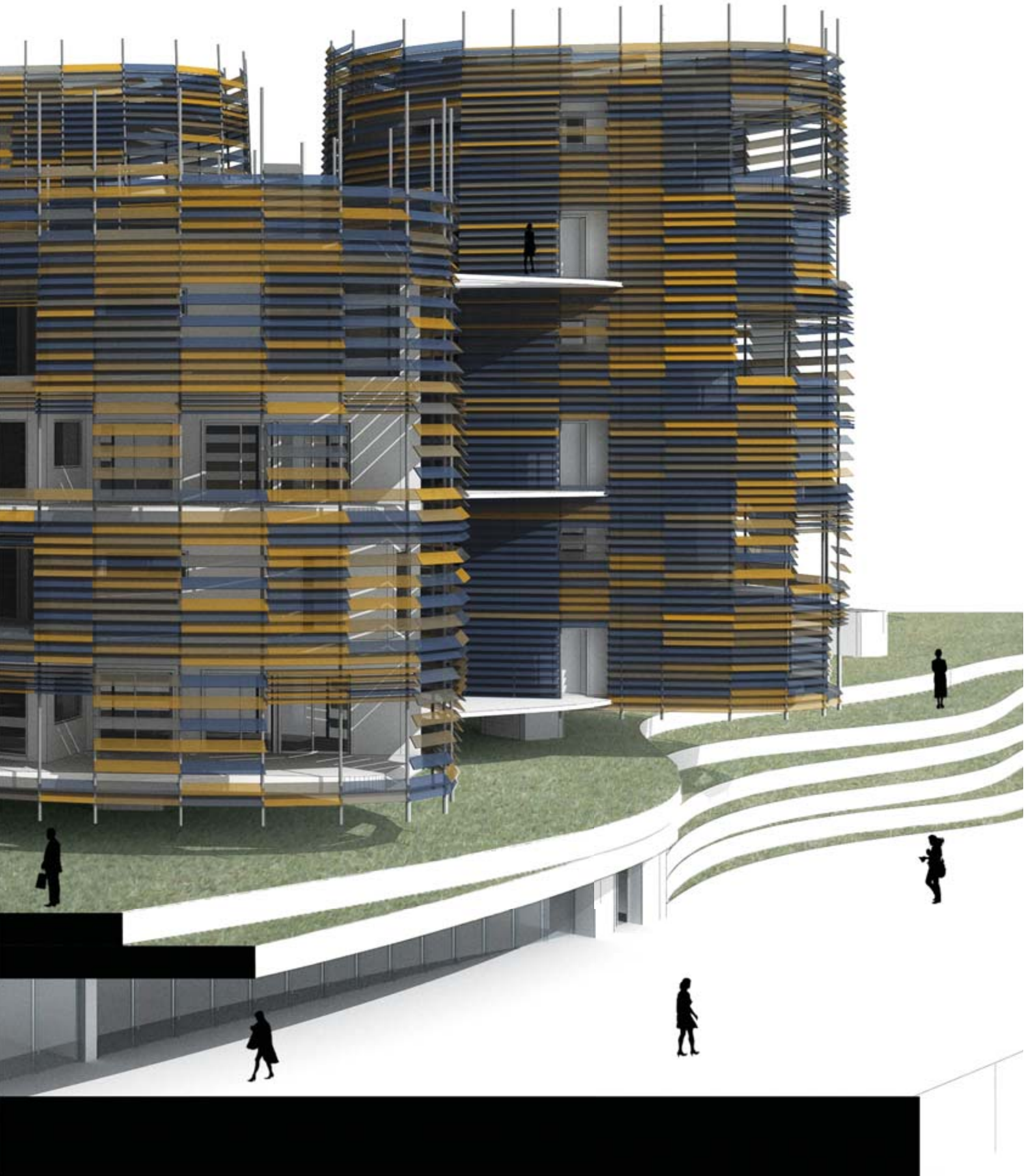
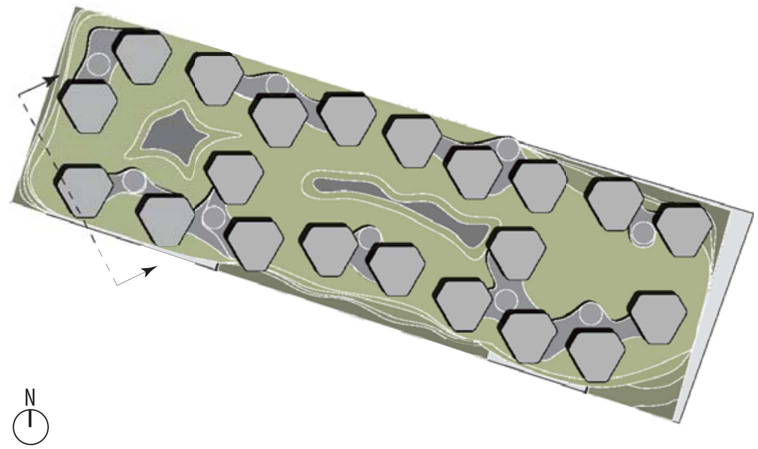
# Section SW



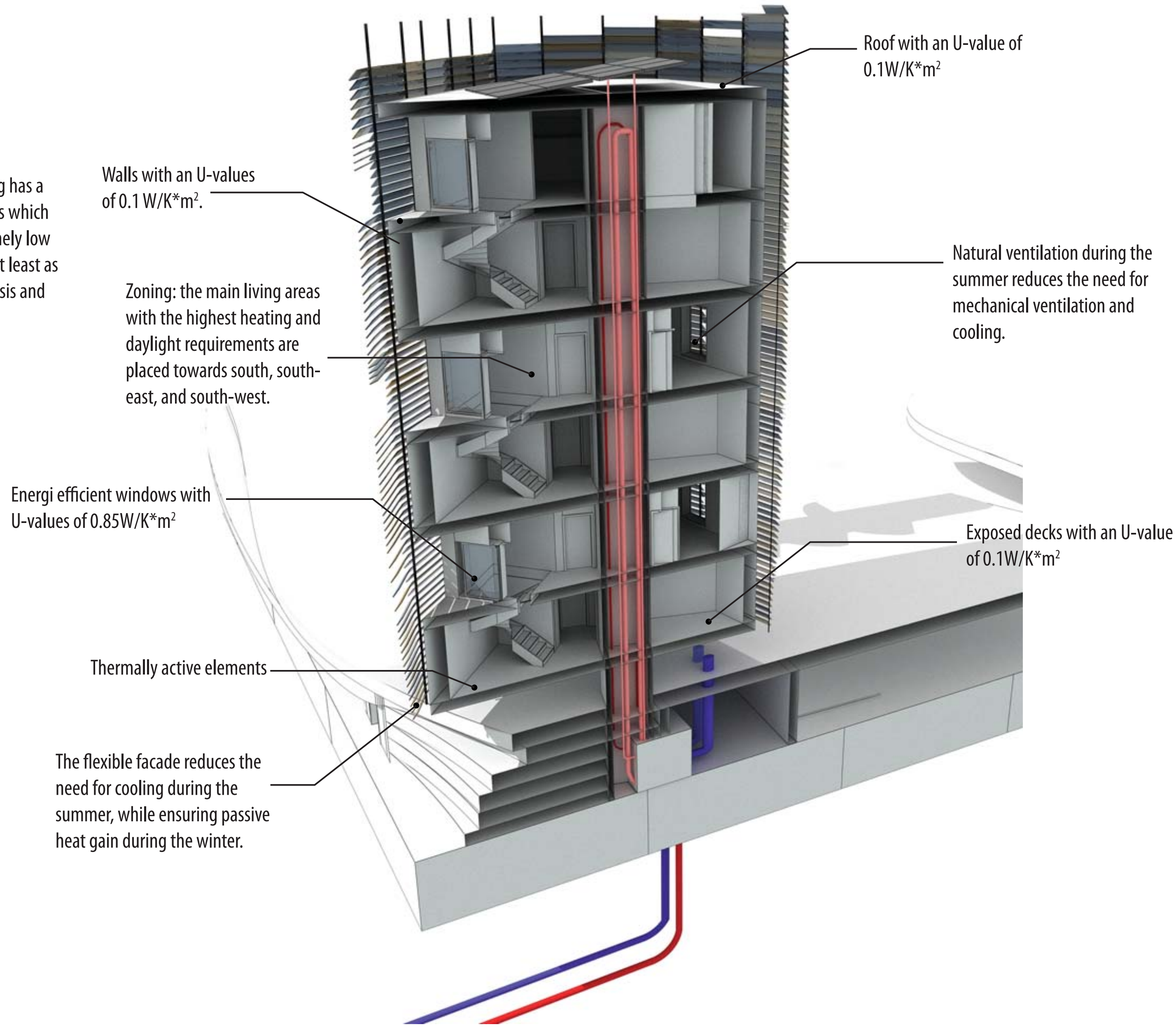


# Zero Energy

## Energy strategy

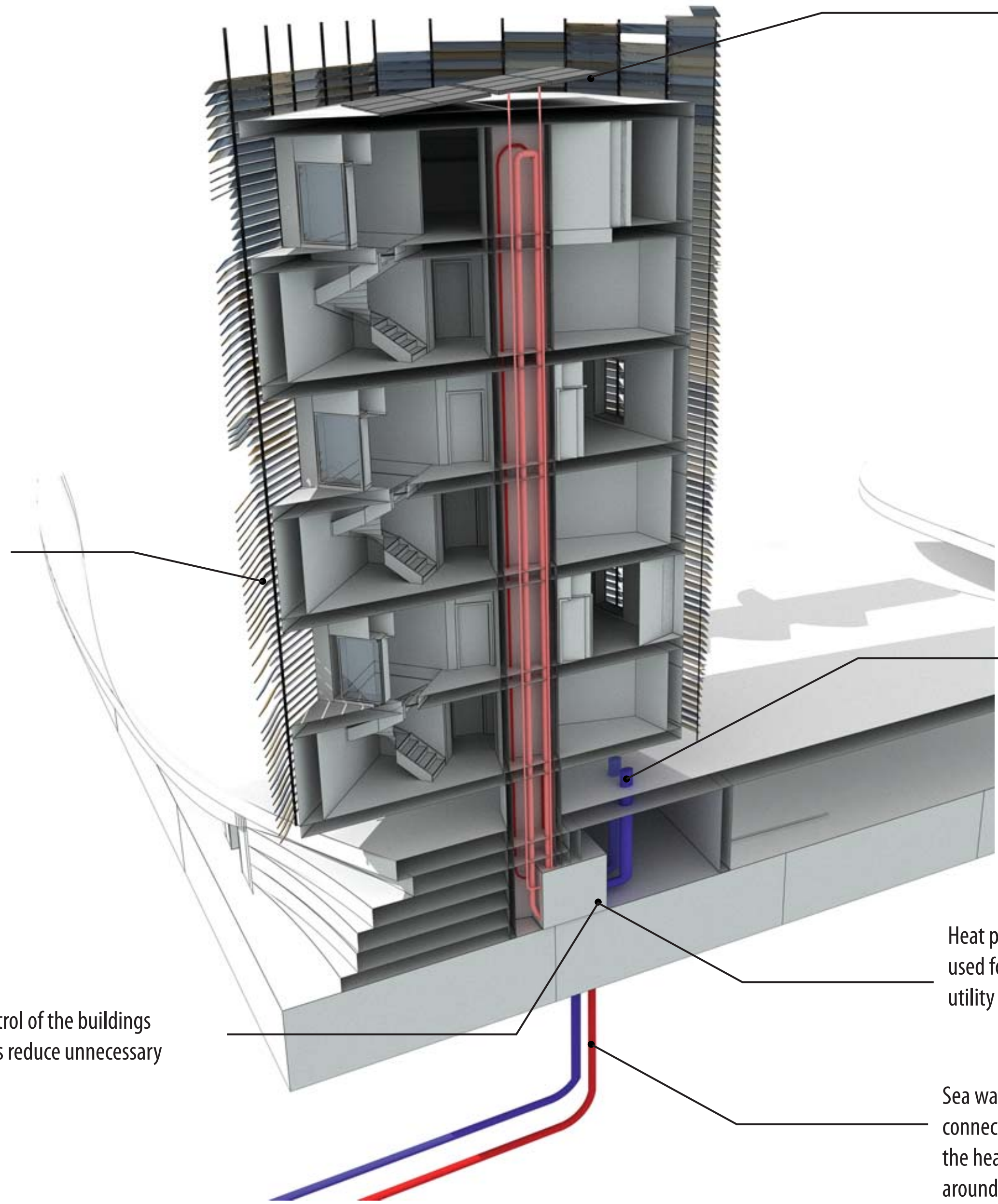
Being a "Bolig+" concept the building has a number of active and passive features which enables the design to have an extremely low energy use, and ultimately produce at least as much energy as it uses on a yearly basis and return this to the electricity grid.

## Passive technologies:




ill. 16: Passive energy features.

# Active technologies:




ill. 17: Active energy features.

# The apartments

In the design of the apartments the focus has been to attract the users, who would normally settle down in large suburban houses.

All the apartments consists of large terraces in different levels and directions. The indoor areas are based on a first floor, which consist of all the social areas. This is the framing of most of the daily activities in the dwellings and the different bedrooms are placed at the first floor and in the 1 storey dwelling it is placed in the back of the dwelling so it still is all the social activities, which is focused towards the primary views.

The diversity of dwellings enhance the social sustainability and create a dynamic environment. The diversity of apartments in sizes and spaciousness makes it possible to "move around" in the area according to the changing habitual needs e.g. marriage, divorce, children and so forth.

In the design of the apartments the focus has been to attract the users who would normally settle down in large suburban houses

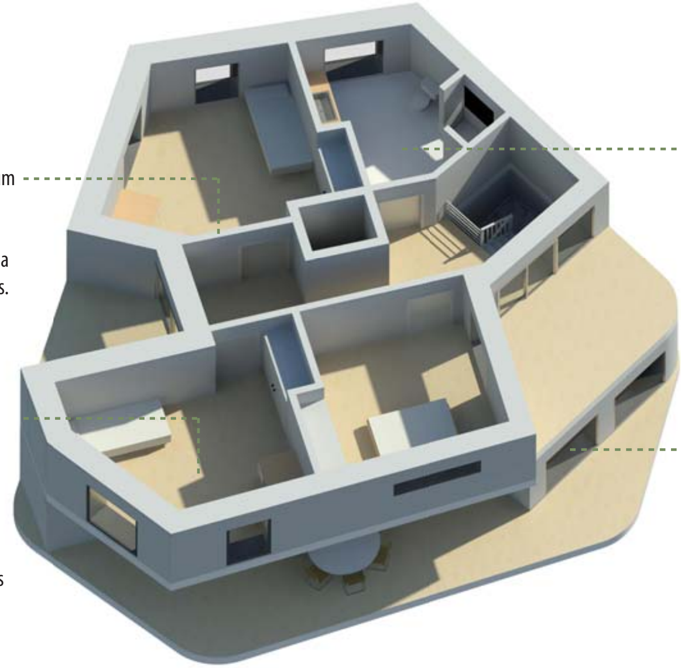
The criteria of building dense while fulfilling the qualities of the detached houses is rather contradictory especially considering the still increasing demand for more space and functions in the individual home.

# Materials

Interior walls. The walls are made of gypsum plates. The surfaces is painted white to decrease the need of artificial lighting. It also benefits the indoor climate by having a rough texture, which assure good acoustics.

Flooring. The floors spans from the core and out and carried by columns, which are integrated wall components in the outer facades.

The finish of the flooring is made of bamboo, which has a long lifetime and has a hard durable surface. The wood should be imported from a certified sustainable source. The bamboo is the flooring both inside and outside, which gives a better connection.



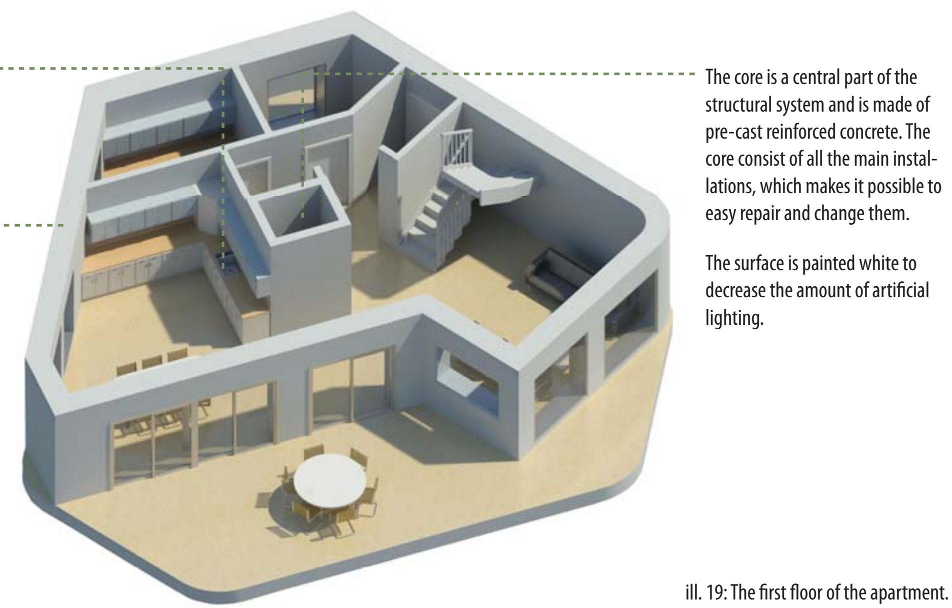
Walls, bathroom. The concrete and gypsum boards are painted white. The wet-zone in plastered with white tiles to achieve an easy cleanable surface.

Windows. The windows have a high g-value to ensure that the sun is lead through the glazing. The U-value should at the same time be as low as possible (in our case the U-value are 0,85 $W/m^2$ K).

ill. 18: The second floor of the apartment.

The service installations are distributed near the installation core to minimize the piping.

In the Bolig+ program it is requested to have some sort of flexibility according to the change of use during time. The exterior walls are therefore light, which makes it possible to change openings, connecting apartments and so forth.



The core is a central part of the structural system and is made of pre-cast reinforced concrete. The core consist of all the main installations, which makes it possible to easy repair and change them.

The surface is painted white to decrease the amount of artificial lighting.

ill. 19: The first floor of the apartment.

ill. 20: Interior view of the main living area, seen from the kitching/dining area in the 2 room apartment.

ill. 21: Interior view of the main living area seen from the living room in the 2,3, and 4 room apartments.

ill. 22: Interior view of the main living area, seen from the kitching/dining area in the 2,3, and 4 room apartments.

ill. 23: Interior view of the main living area seen from the living room in the 2,3, and 4 room apartments.

# Floor plans

## 4 room apartment

The apartment is mainly for families. The 1st floor decor is the same as the 3 and 2 room apartment but at the same time there are some differences according to the perceived space.

There are no double-high rooms inside the dwelling but on the terrace there are both double high and normal height. This gives a possibility to make different zoning of the terrace; more intimate at the coffee table and more spacious other places.

At the first floor one large terrace is orientated in two different directions. This gives a possibility of having outdoor areas which are exposed to the sun at different times during day, making it possible to move around according to the sun - an important quality from the detached houses and their large gardens.

**Facts**

Building area: 153 m²
Terrace area: 50 m²
Total area: 203 m²


ill. 24: The 1st floor, 1:100


ill. 25: The 2nd floor, 1:100

## 3 ROOM APARTMENT

The apartment is mainly intended to young/elderly couples or singles.

Inside the apartment it has a larger diversity of spaciousness than the 4 bedroom apartment. In the living room it has a double-high connection to the 2nd floor, which provides a visual connectedness between the two floors.

**FACTS**

Building area: 138 m²
Terrace area: 51 m²
Total area: 189 m²


ill. 26: The 1st floor, 1:100


ill. 27: The 2nd floor, 1:100

## 2 ROOM APARTMENT

The 2 room apartment is a luxurios egoist apartment, which has a great degree of spaciosness with an open connection to the bedroom area at the 2nd floor.

It has a large area of outside areas as well so even though it is one of the smallest apartments when looking at areas it is one of the apartments, which has the most spaciousness.

### FACTS

Building area: 114 m²
Terrace area: 53 m²
Total area: 167 m²


ill. 28: The 1st floor, 1:100


ill. 29: The 2nd floor, 1:100

## 2 ROOM APARTMENT, 1 STOREY

This apartment is mostly intended for disabled people but also as a cheaper solution than the 2 room apartment in 2 storeys.

The distribution of rooms are somewhat the same as in the other apartments but it has a more clear division in the living area, which is divided into a living room area and a kitchen/mixed area.

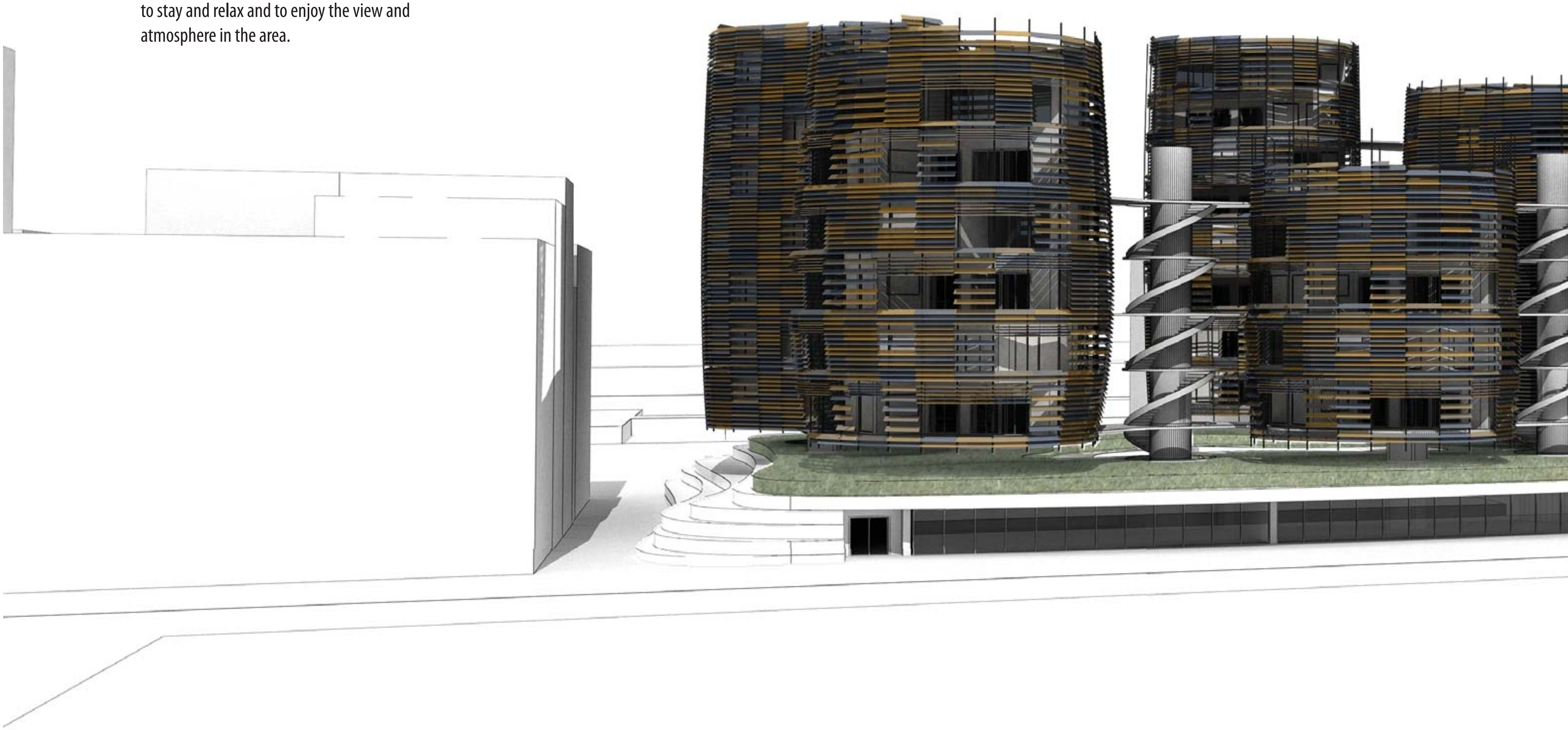
**Facts**

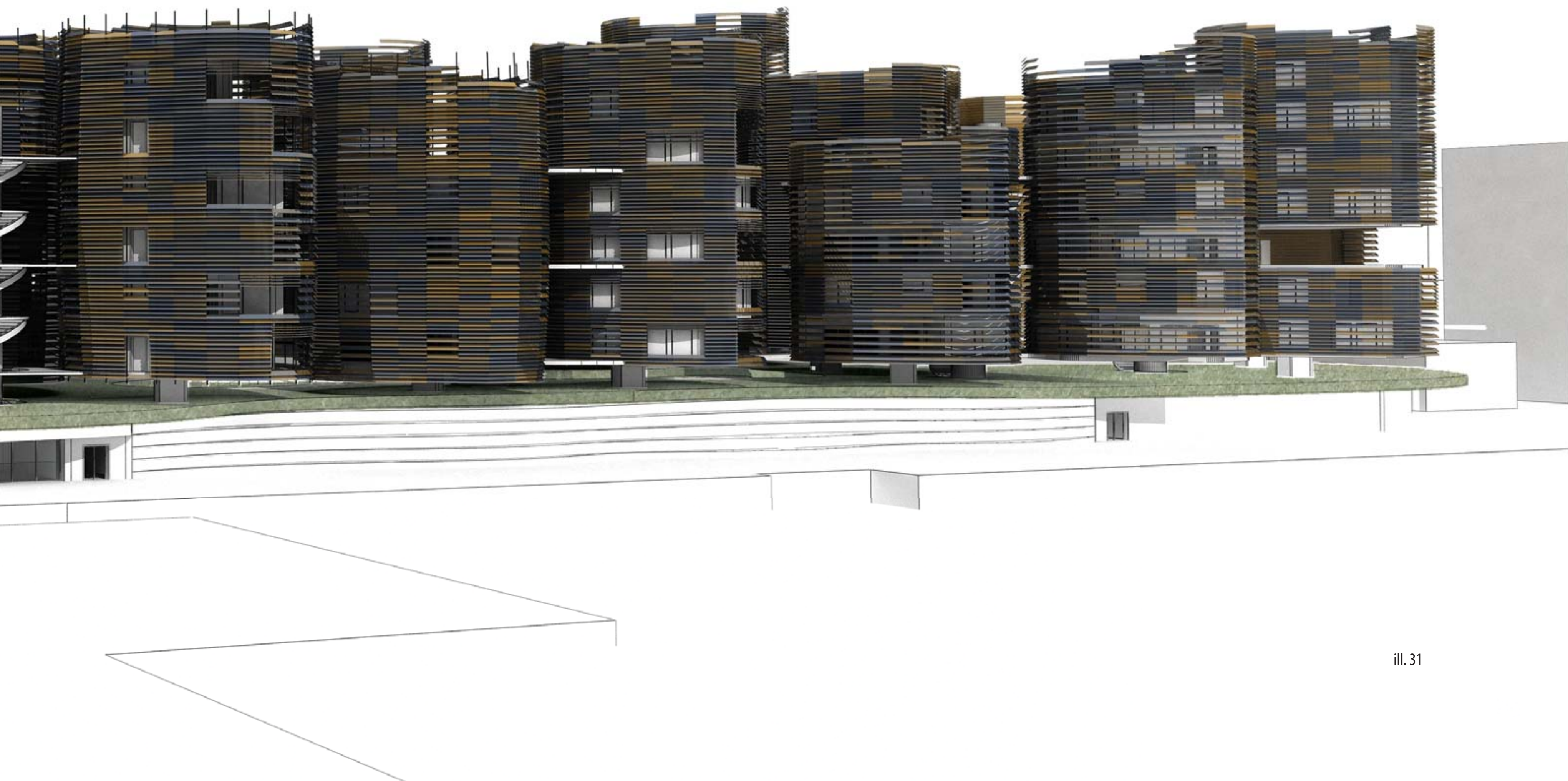
Building area: 91 $m^2$
Terrace area: 18 $m^2$
Total area: 109 $m^2$


ill. 30: Floor plan, 1:100

# The master plan

The master plan emphasize what is public and what is not by having a high base. The base gives the waterfront a continuous course past the site and at the same time it softens up at the middle and at the ends of the site.  At these areas there are places to stay and relax and to enjoy the view and atmosphere in the area.





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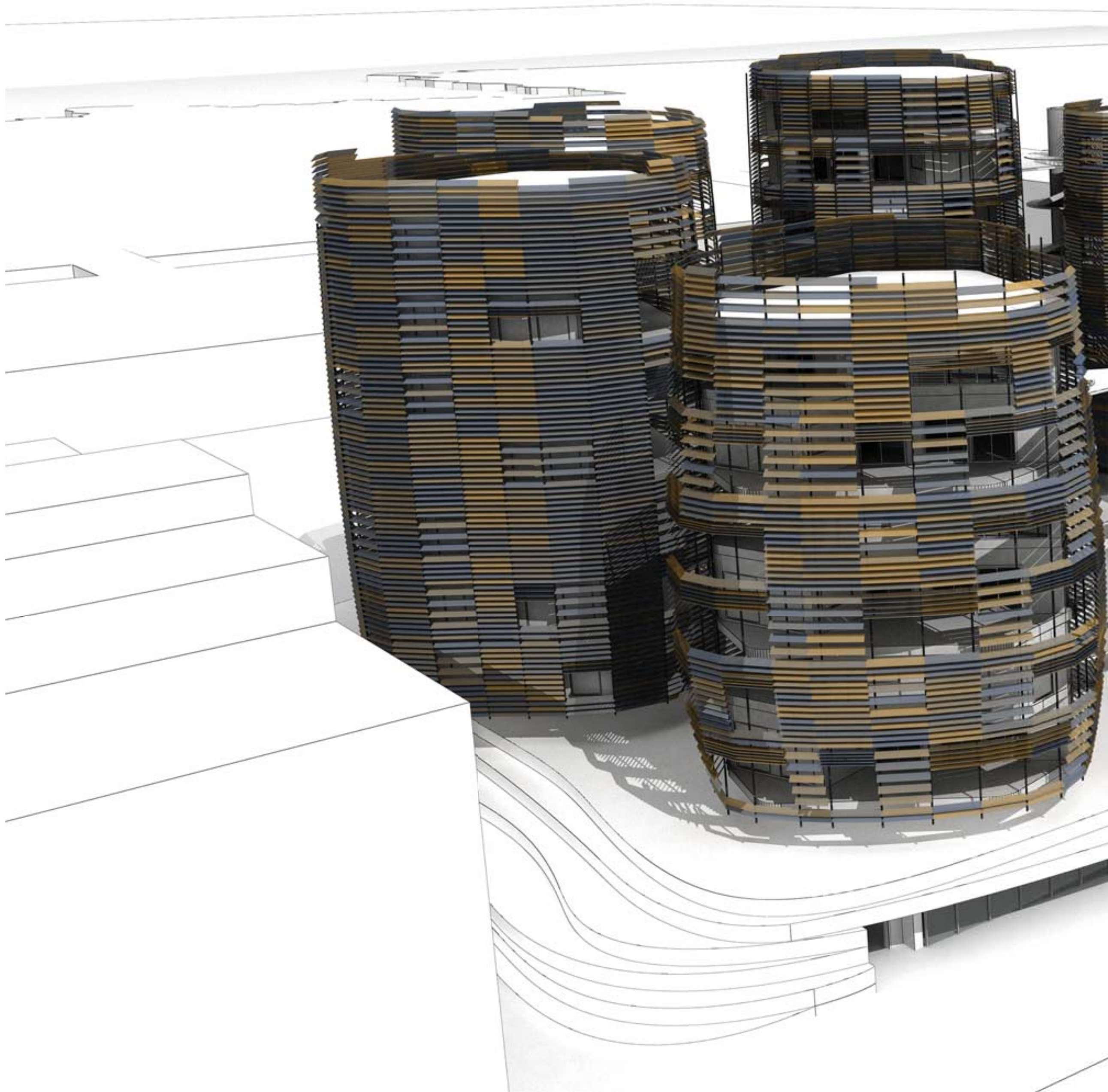
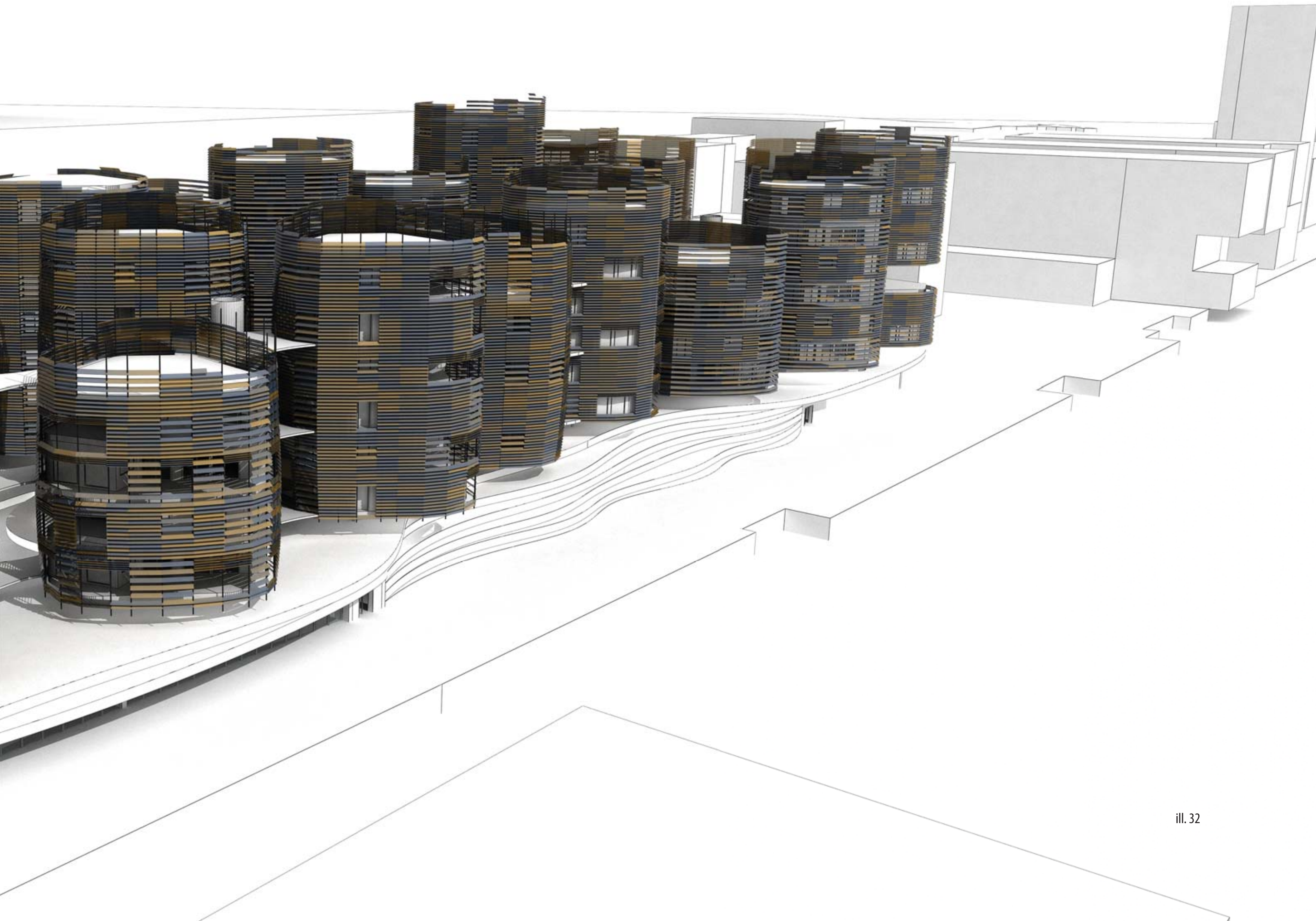




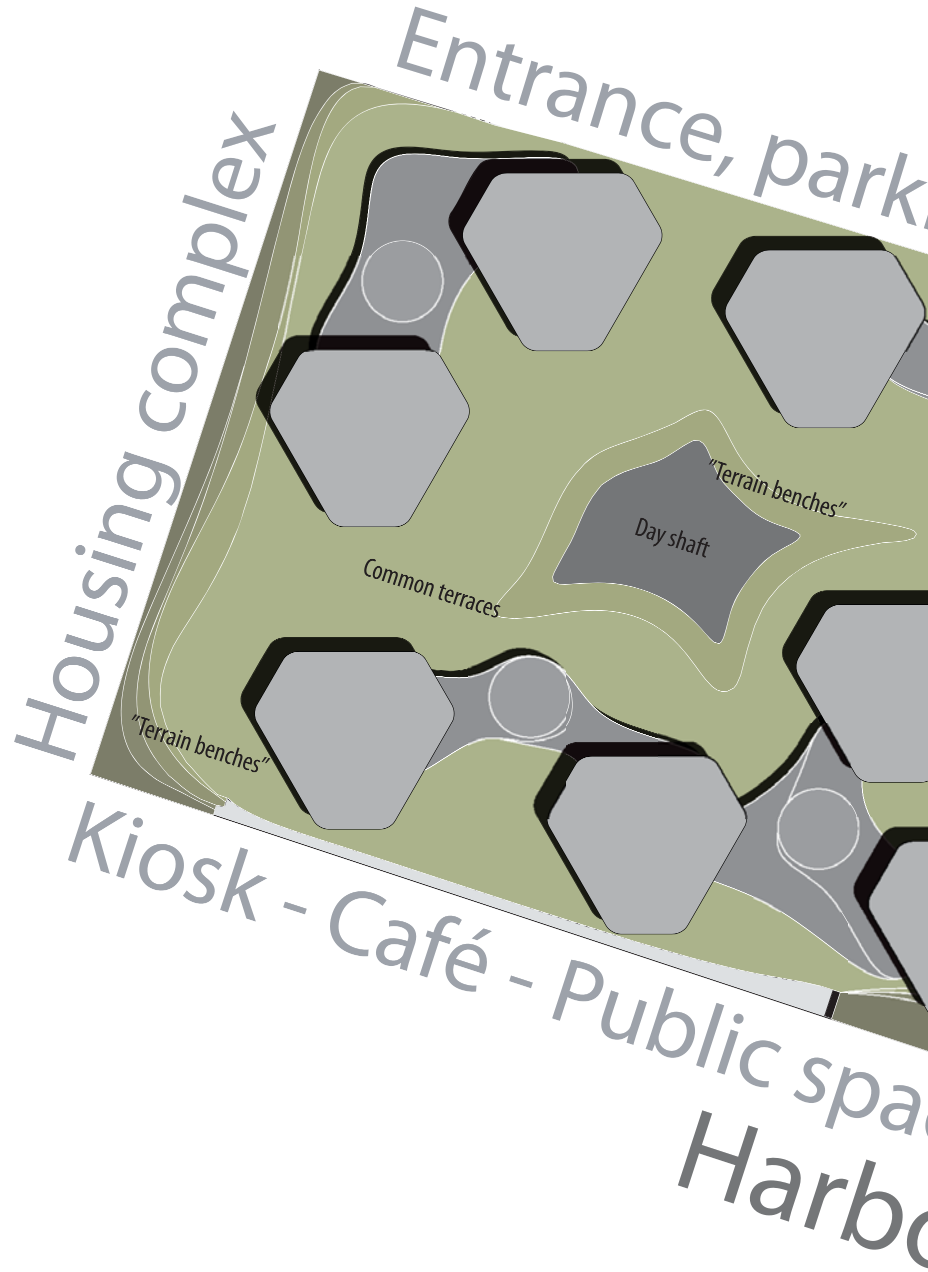
ill. 32

- The illustration shows the overall planning of the area with different spaces in between the buildings and at the same time a diversity of shops towards the harbour waterfront.

The area, surrounding the site, has a diversity of functions; large playground areas, a city square and many other different cultural offers. The site mostly includes activities and areas for the occupants caused by the already planned public activities in the area.

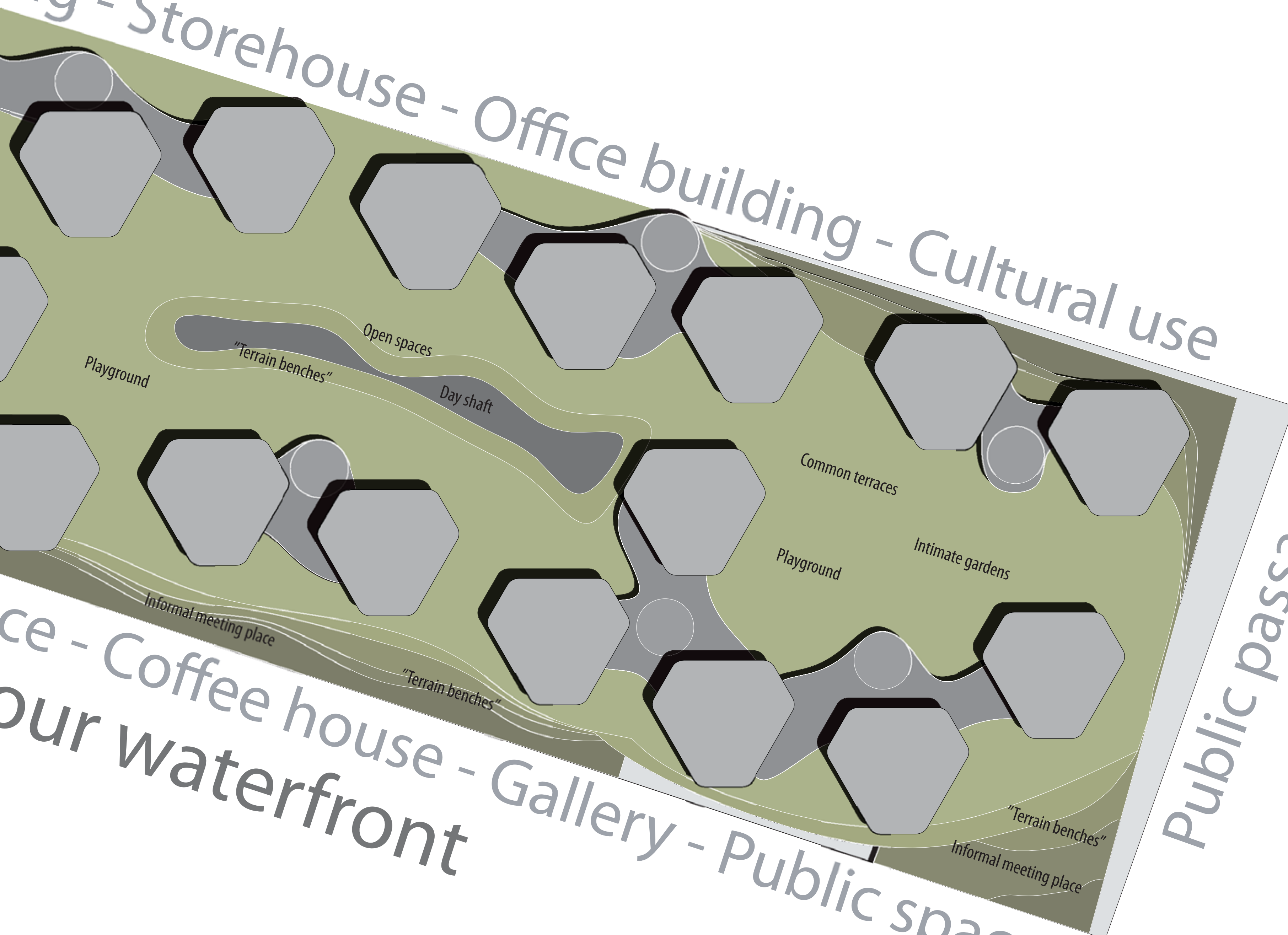
The sites contribution to the public area is the minor shops towards the public waterfront. The semi-public areas, which mostly are for the occupants, are raised to give the occupants a more private open space between the buildings.

The area consists of different degrees of openness and provides possibilities of having different places for long and short breaks.




ill. 33: Master plan, 1:500.

ing - Storehouse - Office building - Cultural use




Public passage

ce - Coffee house - Gallery - Public space

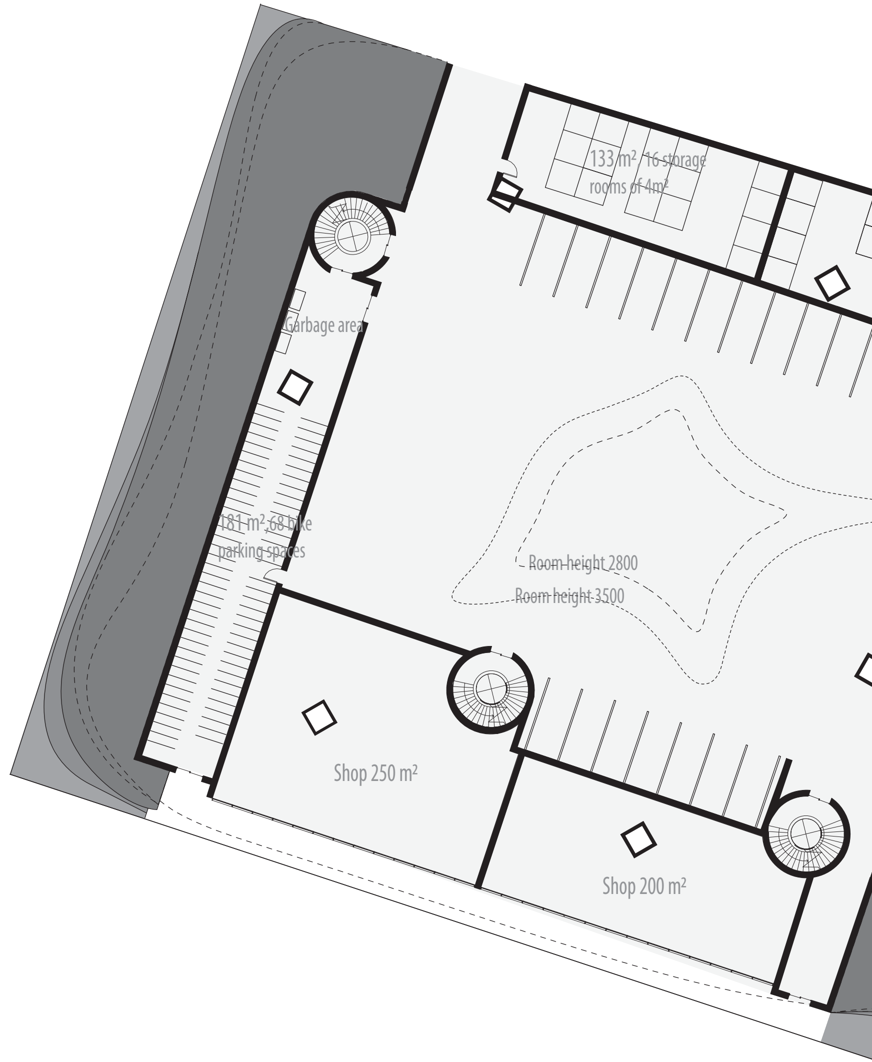
our waterfront

# GROUND FLOOR LEVEL

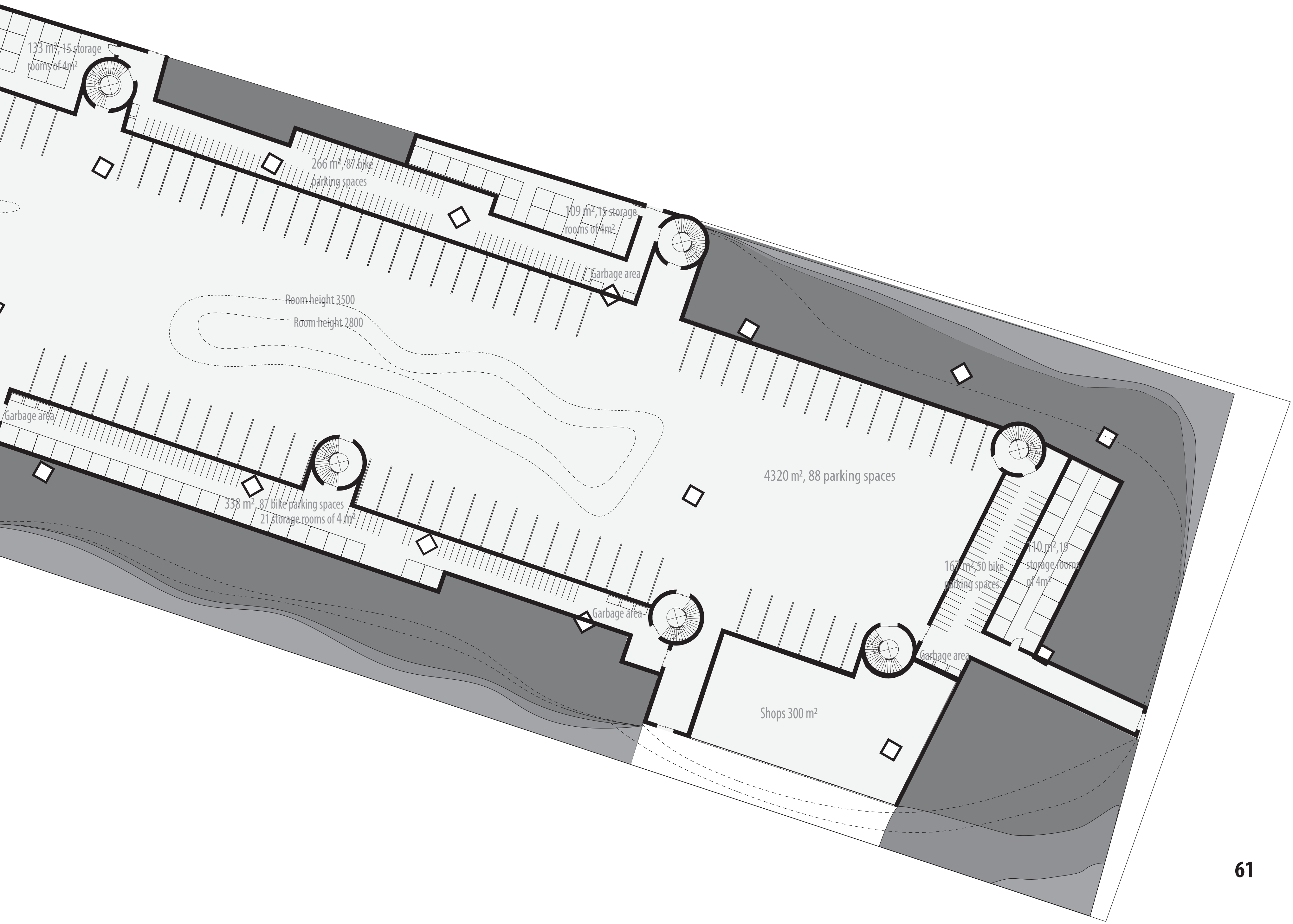
The ground floor level consists of:

- Shops towards the harbour waterfront.
- Parking for both the occupants and the public visiting the area.
- Storage and garbage areas for the occupants
- Bicycle parking for the occupants.

As seen in the floor plan the different functions, which apply for the occupants are placed near the different stairways to get a minimum of distance to the apartments.




Ill. 34: Ground floor level, 1:500


133 m², 15 storage rooms of 4m²
266 m², 87 bike parking spaces
109 m², 15 storage rooms of 4m²
Garbage area
Room height 3500
Room height 2800
Garbage area
4320 m², 88 parking spaces
338 m², 87 bike parking spaces
21 storage rooms of 4 m²
110 m², 19 storage rooms of 4m²
167 m², 50 bike parking spaces
Garbage area
Garbage area
Shops 300 m²

# Analysis

# Context Analysis
## Introduction

Copenhagen has in the last 10 years reduced the $CO_2$-emission with 20 percent and now they are aiming even higher by having a vision of being one of the world's first capitals that becomes $CO_2$-neutral in 2025. In 2005-2015 the goal is to have reduced the $CO_2$-emission by 20% [cphx.dk].

The goals outlined in the climate strategy should be reached by using known technologies, developing solutions for sustained energy and getting the citizens more aware of their way of living(cphx.dk). There has even been set up a homepage just to make the citizens more aware of the different things they can do to reduce the $CO_2$-emission: klimaKBH.dk. The goals of this homepage is to make the citizens realize that they will not only reduce the $CO_2$-emission but also save money by doing the things suggested.

The municipality's efforts are according to different scales within energy, green energy, alternative transportation and letting the citizens be aware of the different things they can do themselves to enhance the environment.

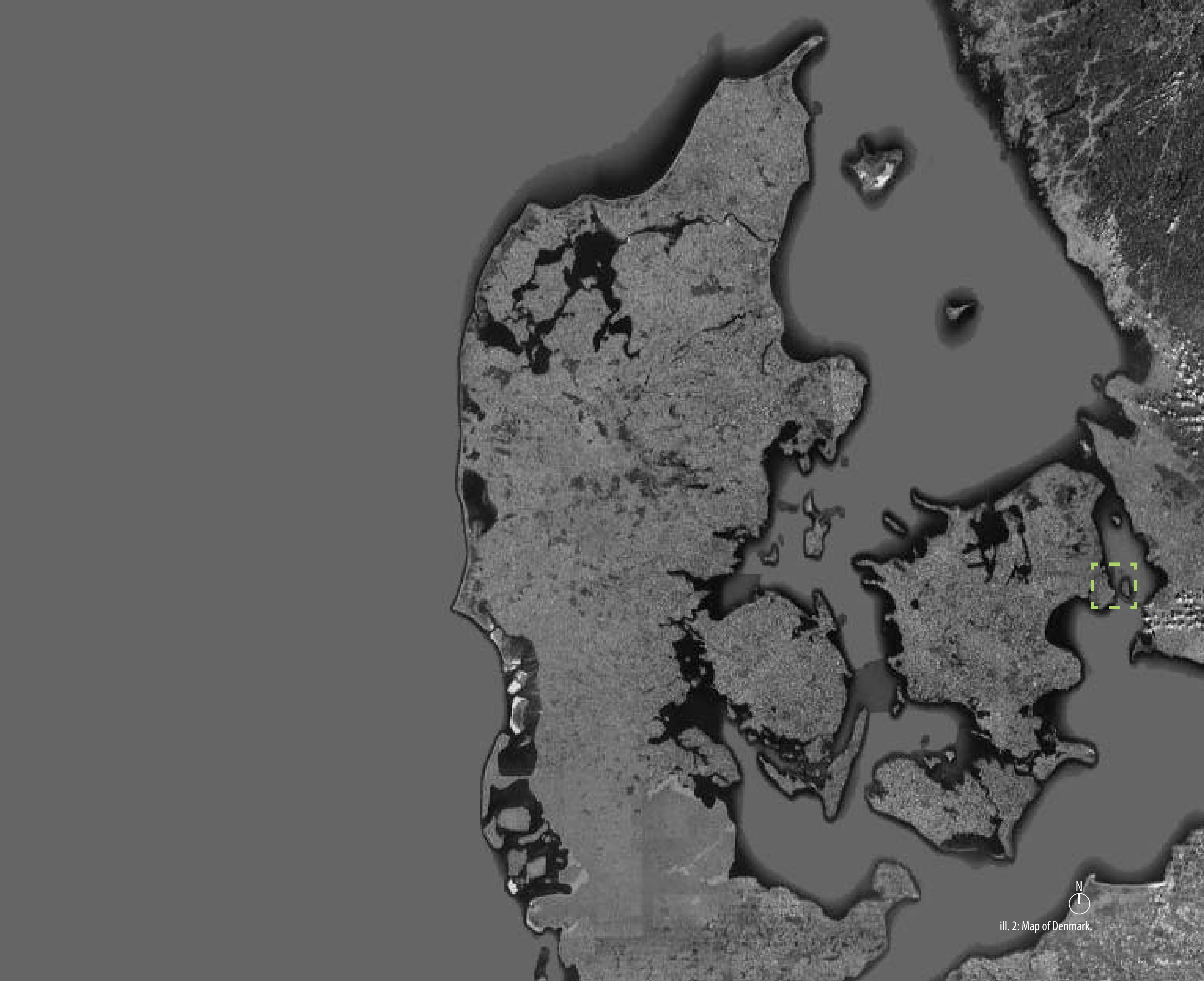
Different parts of Copenhagen are currently used for experimenting with new approaches for developing sustainable city areas. Among these areas, Nordhavnen is one of the largest. This area is during the next 40-50 years, going to be developed as a whole new sustainable city area.

*"Det er Skandinaviens største og mest ambitiøse byudviklingsprojekt til dags dato [cphx.dk]".*

*/ "It is Scandinavia's largest and most ambitious city development project of today."*

The intentions with the area at Nordhavnen is very consistent with the goal of the project, to develop a dense sustainable city area with $CO_2$ neutral buildings. For this reason the area is chosen as the context in which the project should be developed.

ill. 1: The Copenhagen, with the area "Nordhavnen" marked.



ill. 2: Map of Denmark.

# Nordhavnen - today

## The area

Nordhavnen is a large area (200 hectares) consisting of industrial areas and different harbour activities, such as Copenhagen's Container terminal and cruise quays (owned by By & Havn I/S).

Towards northwest lies the new Fiskerihavn along with Fisketorvet[nordhavnen.dk].

Towards west lies Kalkbrænderihavnen, which today has been almost fully developed into different business activities. Most significant buildings in the area are Paustians Møbelhus (furniture house) by Jørn Utzon/Kim Utzon [ill. 7] and the 100 meter high Svanemølleværk [ill. 6].

Recreative areas has been developed at Svanemøllehavnen/Svanemøllebugten by By & havn I/S. Svanemøllehavnen is most northern marina of Copenhagen and the largest in Denmark with approximately 1.100 berths.

Svaneknoppen has been taking over by different yacht clubs and facilities such as club houses, parking spaces and winter storage for yachts.

The other areas of the harbour has been rented out for different companies, though today many have left the area and freed up space - and thus increased the areas possibility and potential of becoming one of the first areas in Copenhagen, which will  be sustainable in all aspects (transportation, energy use etc.).

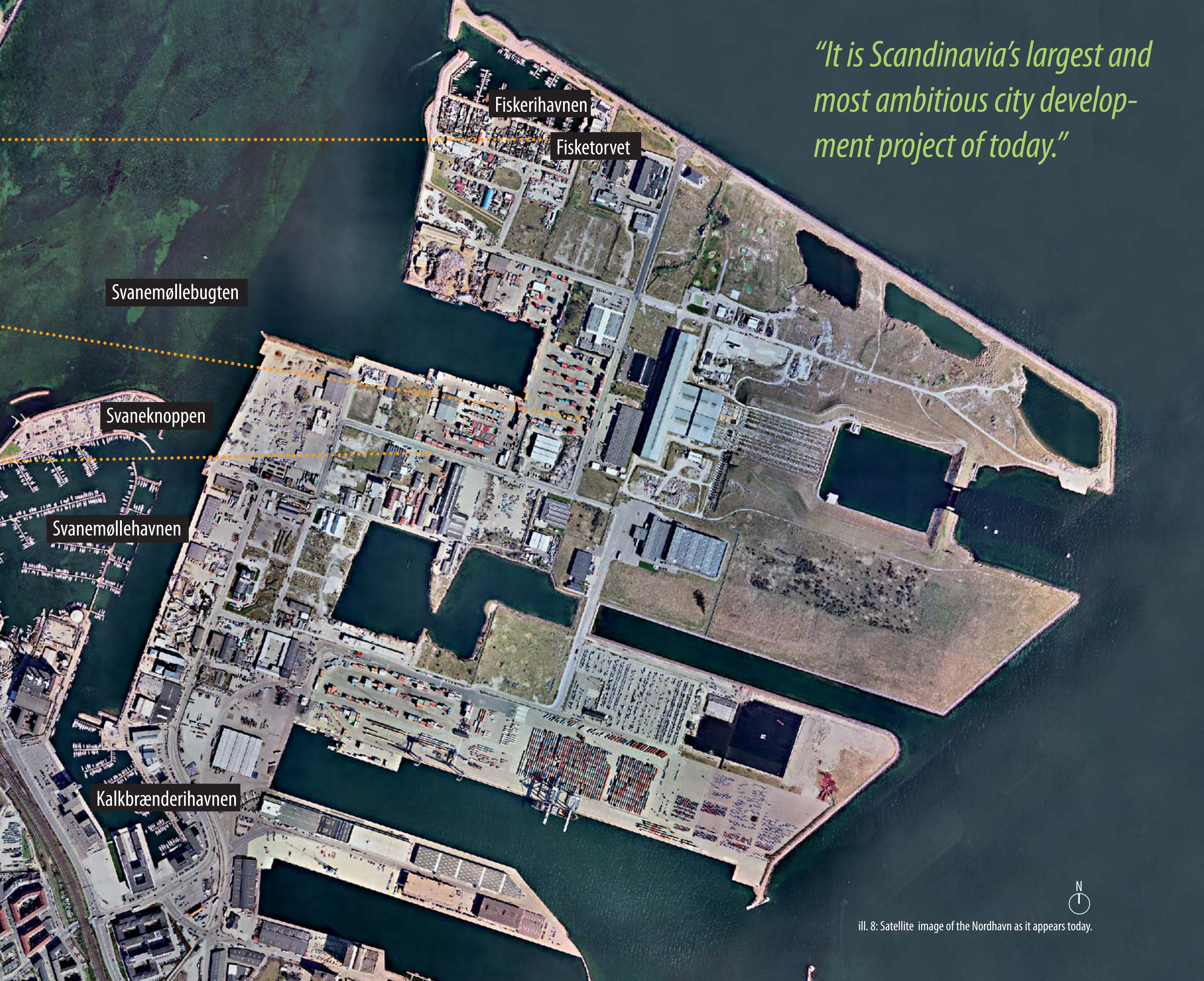

ill. 3


ill. 4


ill. 5


ill. 6

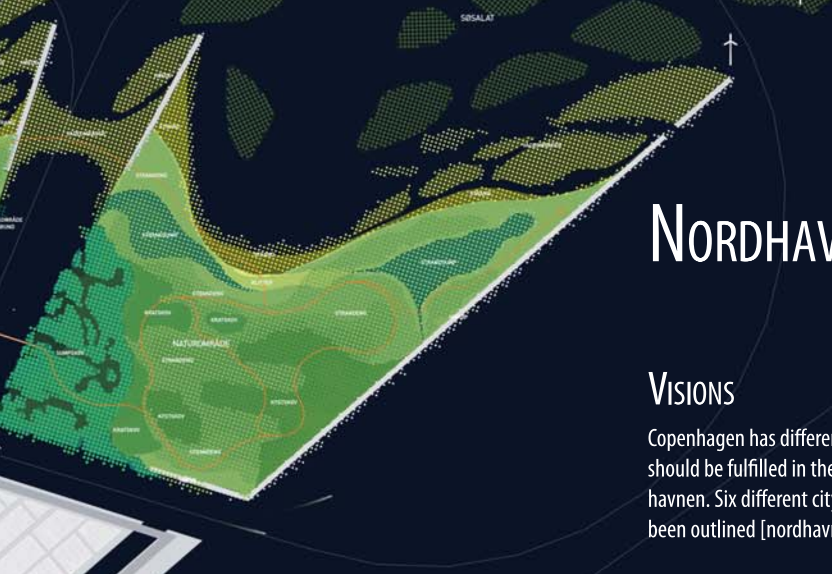
ill. 7




*"It is Scandinavia's largest and most ambitious city development project of today."*

ill. 8: Satellite image of the Nordhavn as it appears today.


ill. 9: The winning proposal for a masterplan, devised by the Danish Architectural office: COBE.



# Nordhavnen - future

## Visions

Copenhagen has different visions, which should be fulfilled in the planning of Nordhavnen. Six different city themes/visions has been outlined [nordhavnen.dk]:

**1] An eco-friendly city:**
- Focus on renewable energy and new energy sources.
- Optimum use and reuse of resources.
- Environmentally friendly modes of transport.
- Vivid, diverse urban nature on both land and water.
- A sustainable city and building structure.

**2] A vibrant city:**
- An attractive city district open to everyone in Copenhagen.
- Intensive urban life with a multitude of activities.
- A range of opportunities for experiences on the water or water front.
- A wide range of shops, cultural activities and sports facilities.
- Urban spaces that encourage experiences, enthusiasm and opportunities for everyone to engage in.

**3] A city for everyone:**
- Varied housing types at all price levels so that also people without high incomes can live close to the waterfront.
- Integrated mix of residential, commercial and business facilities.
- Diversity ensuring inclusion of all groups in society, including vulnerable groups.
- A friendly city district where both residents and visitors feel they belong.
- Dialogue with future residents and users on urban development of the district.

**4] A city at the water:**
- Housing and outward-oriented activities along the waterfront.
- Waterfronts, quays and urban coastal areas accessible to the public.
- City beaches, harbour swimming baths and sports activities at the waterfront and on the water.

**5] A dynamic city:**
- A wide variety of public institutions, shopping facilities and experiences.
- Basis for new workplaces and initiatives.
- Attractive environments for knowledge workers and students.
- Showcasing of Copenhagen as a prominent international city of knowledge.

**6] A city with sustainable mobility:**
- Bicycles and public transport should be obvious choices.
- A simple grid of roads and effective public transport.
- A fine-meshed network of comfortable bicycle routes and paths for pedestrians that connect the area's facilities, shops, squares, parks, water activities and recreational and cultural facilities, thus ensuring cohesion between districts.
- Development of urban districts on the basis of the needs of pedestrians and cyclists.

## The site - future

The city development of Nordhavnen is based on a competition from 2008, which had 180 different proposals handed in from all over the world. The project will develop a smaller area of Nordhavnen and the context will be based on the proposal of the winning suggestion.

The winning group consisted of COBE, SLETH and Rambøll, and were selected, along with Polyform (who was a part of another project group) to be advisors for the development of the city area.

It has not yet been decided how much of Nordhavnen that should be developed. Phase 1 gives the opportunity for 2000 dwellings and 200.000 square meter business area.
In the long run Nordhavnen will be able to accommodate approximately 40.000 citizens and workplaces.

One defining concept was the focus on how the area works as mediator between the historic city center and the city border of the ocean [sustainablecities.dk].

The proposal divides the whole area into different small islands and town entities. Thereby making a diversity in hierarchy and a gradual transition from the dense city to the open sea.

*"If you study a map of Copenhagen, it is obvious that the Sound is the city's heritage, and trade and properity occured in the heart of the city around Slotsholmen, which we all love [sustainablecities.dk]" said by Dan Stubbergaard (founder of COBE).*

## Character

Today the area, at Nordhavnen, appears in many different scales from sheds to large cranes while the view differs when there are large ships at the harbour and when there are none.

When the harbour is not full of big ships it appears as a great spatial experience. These differentiated views and feelings are some of the elements which the proposal tries to preserve. Also, as mentioned, the historic identity of the area has been preserved by ensuring that the some of the experiences of the old harbour, the cranes, the silo, the industrial buildings and the railway will still exist 20 years from now [sustainablecities.dk].

## Sustainability

The project has many different elements of sustainability. For instance the goal of getting the area to be self-sufficient in terms of energy.

During the process it became clear that Copenhagen did not need an area, which only focused on its own energy use. Nordholmene should be connected to the city's existing district heating and electrical systems. Through these systems it should supply Copenhagen with alternative energy from wind and geothermal sources - thereby the city area will not be $CO_2$ neutral but actually $CO_2$ negative. This bring Copenhagen's goal, of being the first $CO_2$ neutral city, closer.

All the houses in the area should have a low energy consumption and the car transportation should be replaced by other alternatives so the fuel consumption will be at a minimum. In the planning of the city area, metro stations should be placed so it will only take the residents 10 minutes to get to the city centre and require a maximum of 5 minutes walking time to a metro station from either part of the islands

The traffic systems will focus on the pedestrians and cyclists ("soft road users"). There are going to be high-speed bike lanes in the whole area and the different channels will give the sailing and kayaking clubs new ways of experiencing the city area.

To enhance the city feeling a pedestrian market street is planned as an continuation of Århusgade on the first island. This city feeling is concentrated closest towards the centre of Copenhagen (south) while towards north and the sea, the area should become more nature-like.

## Functions

The area should be a place of interaction, meaning that it should be lively with different nodes (obvious meeting points) scattered around. According to Dan Stubbergaard (founder of COBE) the small district of Christianshavn is conceived as the essence of Copenhagen, being an area with a lot of activ-

ill. 10

ill. 11

ity and possibilities to meet different people. A quality which is wanted at Nordhavnen as well.

The main function and program of the city development consists of mixed-use residential buildings, business areas and cultural buildings. The purpose is to design a city area with vary functions and thereby a place for both families, singles, elderly, children and young adults.

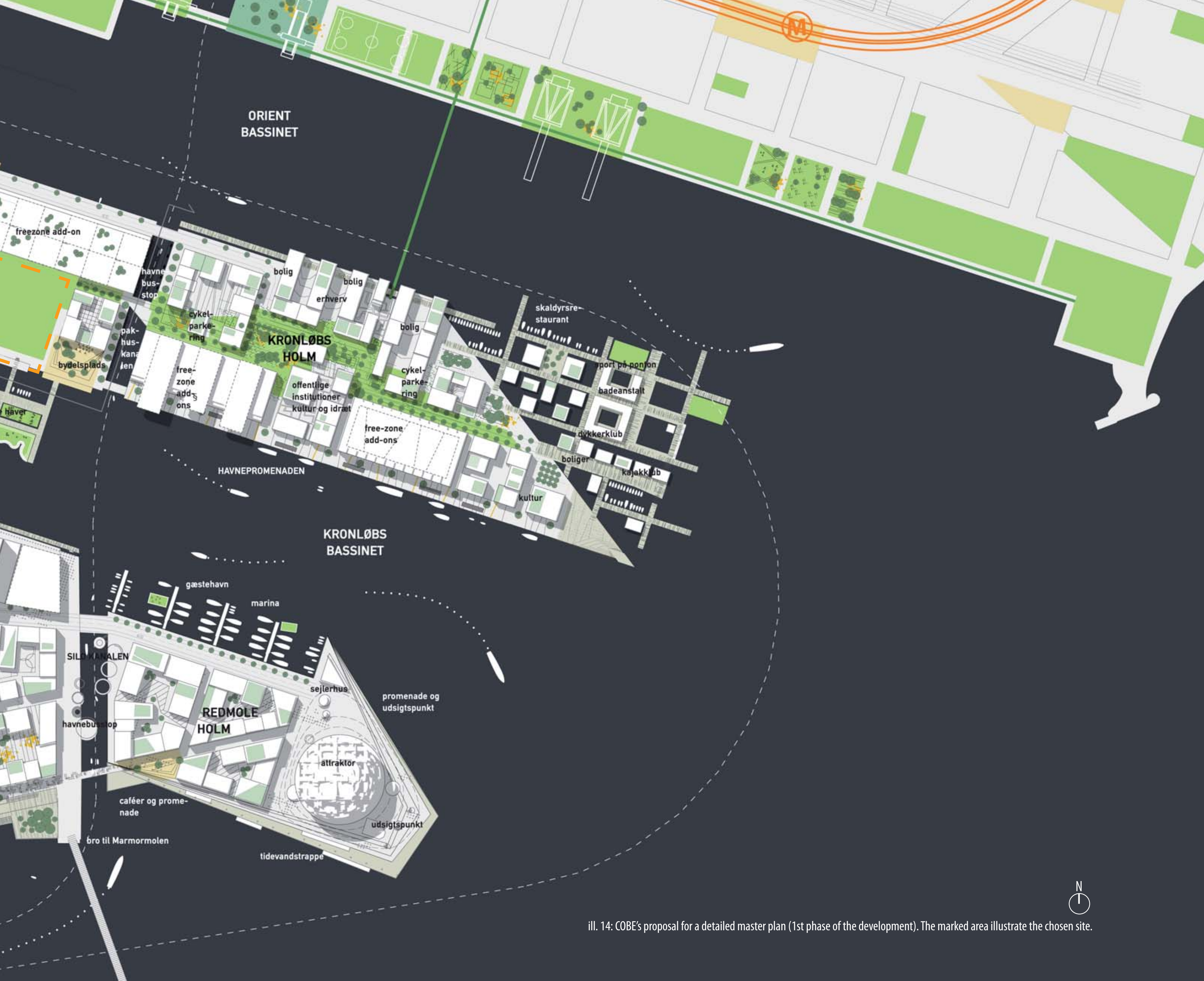
If the area is to succeed it is necessary to get a variation of accommodations; communal living, rented houses, housing cooperatives, private housing, home-office buildings. There should also be the opportunity to buy your own land and build your own house.

ill. 12

ill. 13

# Phase 1


byplads med sport
SOHO
opholdstrappe
flydende fodbold
detailhandel og erhverv
eks. pakhus
erhverv
erhverv og kulturinstitutioner
bolig
legeplads
promenade
erhverv
SKOLE HOLM
skole
legeplads
boldbaner
skolbasket, bordtennis, volley
SKOLEGÅRD
tidevandspytter
roklub og kvartershus
sandtrappe
erhverv
siddegrupper
SOHO
træbro
cykelparkering
spejlbassiner
handel, erhverv, bolig
SILOPLADSEN
SOHO
free zone, add-on
sport, siddemøbler, skøjtebane
hotel
siddegrupper
NORDHOLM
erhverv, detail
butikker
cykelparkering
klatrevæg og vertikal have på eksist. silo
lommepark
butikker
metrostation
detail
shopping
metroplads
café
gallerier
ÅRHUSGADEKVARTERET
bolig og SOHO
free zone, add-on
free zone, add-on
lommepark
udstilling
free zone, add-on
siloens havnebad
DET GRØNNE LOOP
bolig
bolig
udlejning af cykler, både mm
café
scenen
flydende marked
NORD




ill. 14: COBE's proposal for a detailed master plan (1st phase of the development). The marked area illustrate the chosen site.

# The site

The following analysis will involve a more detailed description and registration of the specific site, in which the project will be developed. The project will be placed in a not yet developed area and thus take its starting point in the master plan created by COBE.

The building volumes drawn in the 3D model are based on the conceptual volumes created by Cobe in their master plan. The buildings around the project site is determined to be more or less 5 floors high, adjusted with the 3D renderings created by COBE.

The chosen site, marked on the opposite page, consist of approximately 10.300 square meters, and is designated as an area primarily consisting of housing complexes. The near context will have a large diversity of functions, such as: school, different sports facilities, business areas, shopping, playground, parks and so forth. In the master plan COBE also introduces the concept of "free-zone add-on" [see previous page], meaning the possibility of adding to/on/in existing buildings - integrating the old with the new while adding value to the existing building stock, which is not as utilized as the new city area should become.

The desired building percentage of the site is not clearly defined, but an estimation of the master plan gives a building percentage of approximately 130% (13.390 square meters). This will merely be used as a guideline for the project though, as the main focus is to create a sustainable alternative to the suburban cities and not to create a high dense area.

The site has a single main road, leaving most of the area in the premise of pedestrians and cyclists, and makes public transportation an easy choice due to the nearby metro stations (300-500m).

ill. 15: Opposite page,3D model of context, based on renderings, descriptions, and the masterplan supplied by COBE.

ORIENT BASSINET
HAVNEPROMENADEN
flydende fodbold
pakhus
promenade
boldbaner
SKOLEGÅRD
tidevandshytter
SKOLE
HOLM

# Site registration


ill. 16

1. Following the old railway tracks, one arrive to the area.


ill. 17

2. The space opens up as you get closer to the chosen site, which today functions as parking zone.


ill. 18

3. The site appears very open, cold, rough and exposed to the elements of nature. The roughness is underlined by a very industrial appearance.


ill. 19

4. The horizontal space opens up towards south and gives view to the sea and high industrial buildings.


ill. 20

5. The buildings which should be preserved as "free-zone add-ons" are all characterized by the use of red bricks.


ill. 21

6. The road between the parking zone and existing building stock should, according to the new master plan by COBE, become a green zone/path with a minimum of private transportation.


ill. 22

7. The concept of "Free-zone add-on" deals with an integration between the old and the new. An important criterion in the development, are the preservation of different historical elements.


ill. 23

8. A challenge will be to bring back nature and green areas into the site which currently is characterized by a total lack of this.


ill. 24

9. Overview of the site.


ill. 25

10. The large building in the eastern part of the area is still in function as a warehouse containing different industries.


ill. 26

11. Inner part of the harbour, when following the future promenade in front of the site and looking towards west.


ill. 27

12. The area still functions as an important harbour for big cruise ships, bringing activity and variation in the urban space.

ill. 28: Satellite image of the site as it appears today.

# Macro-climate

As an initial investigation of the site, the local conditions of sun, shadows and wind has been investigated. First step in creating a sustainable building design is to exploit the natural settings of the area.

## Sun

Sun and daylight is important factors to integrate in the design, in order of creating apartments with a good indoor environment.

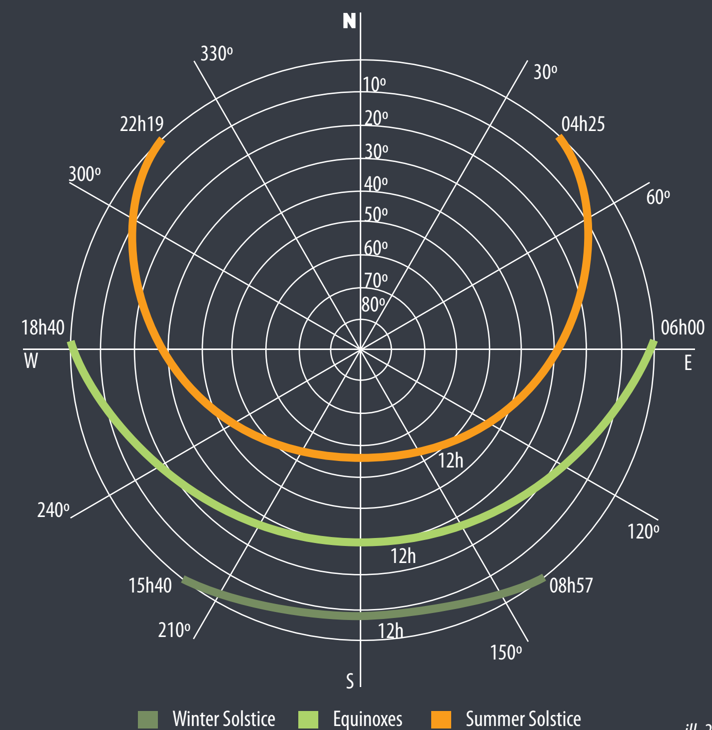
In the design of sustainable architecture, the use of natural sources of light has an even more important role in the design due to energy savings both on artificial lighting and heating.

The diagram illustrates the path and angle of the sun throughout the year and helps to understand how the building can be optimized in order of gaining natural light and passive solar heating.

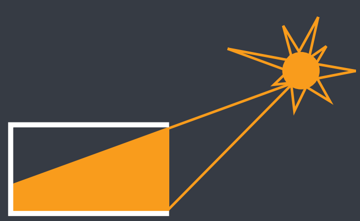
Solar heat gain is most important during winter time, where the heat demands are highest due to the low outdoor temperature. From November until February with the winter solstice is at the 21st of December, the angle of the sun is at its lowest, meaning the sun has the opportunity to easily penetrate deep into the building [see ill. 30]. Unfortunately the sun only has a short period of time to heat up the building.

In the summer time the opposite problem will occur. From April until August with the summer solstice at the 21st of June, the angle of the sun is at its highest, meaning the sun will have a hard time to penetrate deep into the building, while the many hours of daylight, can cause the risk of overheating.

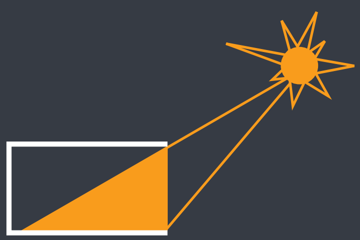
The design must be developed to fulfill the need for passive heating during winter, while being shaded to prevent overheating during summer. This will have an impact on both orientation/size of windows, building expression through the use of shading devices and in general the shape of the building.



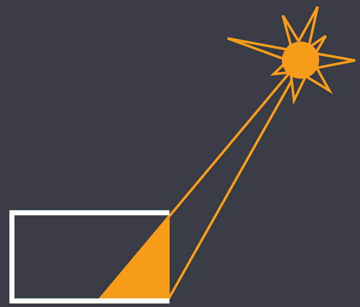

*ill. 29*



ill. 30: Winter solstice - 21st of june - 12am.



ill. 31: Equinox - 21st of March/September - 12am.



ill. 32: Equinox - 21st of December - 12am.

## Shadows

Another issue is the shadows cast from nearby buildings and the building/buildings on the site. In order to ensure a fair amount of daylight and heat gain in the apartments, the buildings should shadowed at least as possible. The site has been investigated with use of SkecthUp and a virtual model of the site, to explore the casting of shadows according to different time of the year and day.

The site has a very open and exposed position towards south, giving it a minimum of shading from surrounding buildings [see ill. 33].

Considerations during the design phase, should be given to the western and eastern part of the site, which are at most risk of getting shaded. Likewise should investigations be made accordingly to the position and distribution of volumes on the site, to prevent both shading of the existing building stock and the new designed volume/volumes.


ill. 33: Shadow studies based on the 3D model.

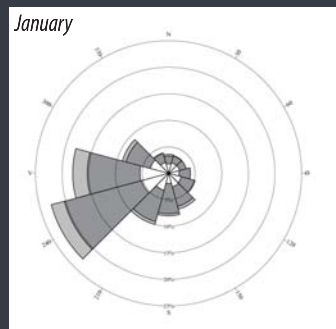
# Wind

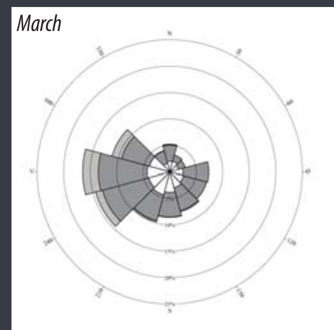
The wind charts illustrates the annual wind speeds and directions. The charts shows a slightly predominance of wind from east and west.

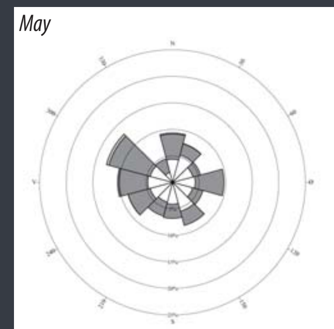
The main concerns regarding the wind conditions on the site, is the utilization regarding natural ventilation and the impact on outdoor areas.

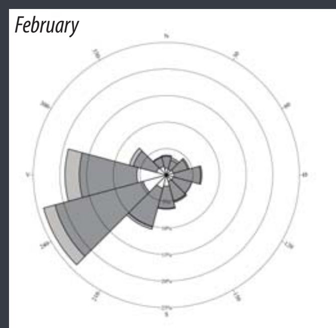
During summertime it would be advisable to make use of natural ventilation in order of saving energy, while mechanical ventilation should be used during winter to prevent any unnecessary heat loss.

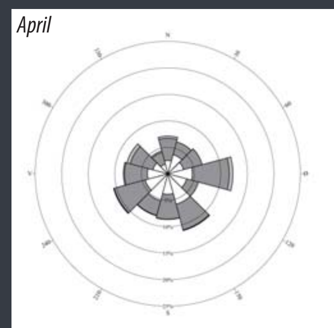
The dwellings should be designed and placed as to create sheltered outdoor areas, which could become an issue due to the south-west orientation of the sea and thus also the best view.  The outdoor areas though, will mainly be used during the summer, where the amount of wind and the velocity is a bit lower.

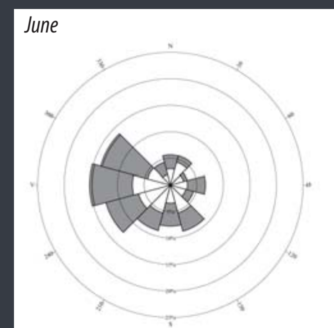


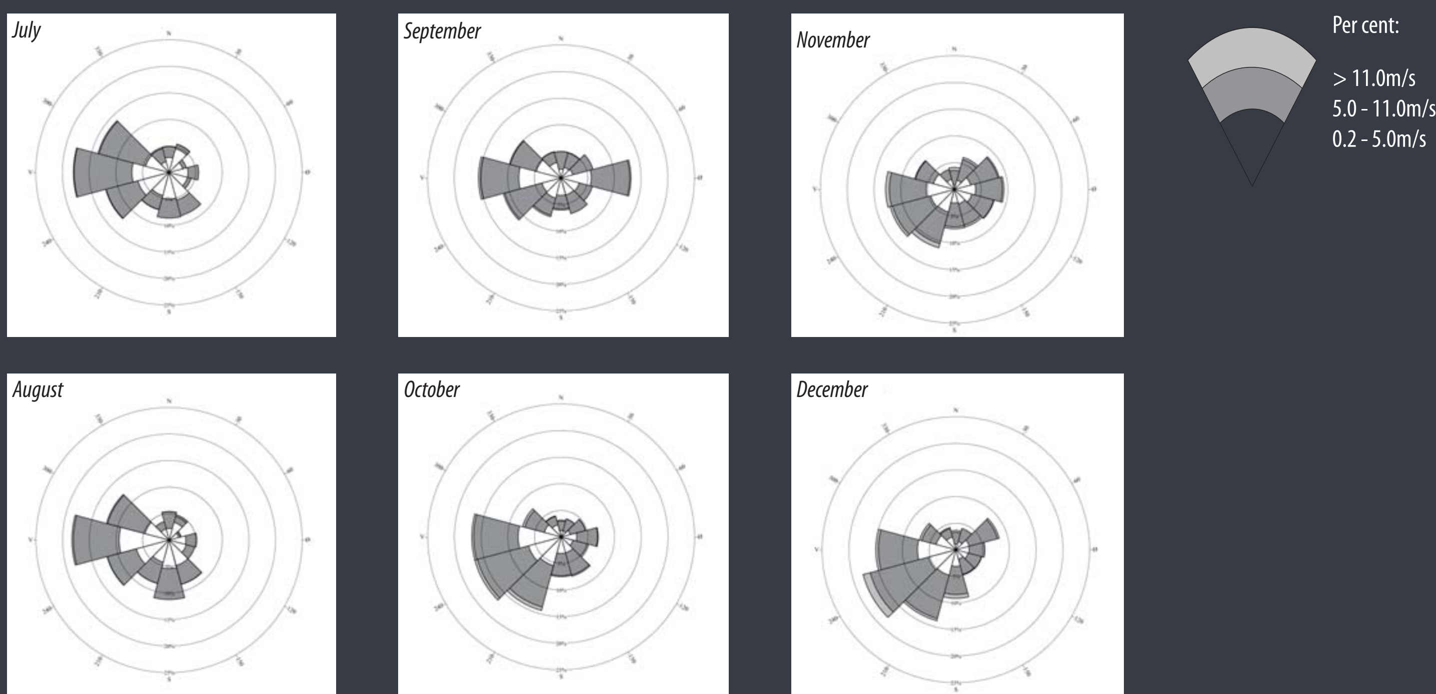






ill. 34: Wind charts from Kastrup Airport showing the intensity, and direction of the wind according individual months.

# Conclusion

As the goal for Copenhagen is to be one of the first capitals, which becomes $CO_2$-neutral, it is a quite interesting and obvious place to design a Zero Energy Building (ZEB), which in turn can be developed into a Zero Emission Building.

The desired goals for the area at Nordhavnen in Copenhagen are not small - and neither are the visions from COBE.

## The site

Nordhavnen is as discussed a vast and interesting area with many different potentials from sub-area to sub-area, which were all considered in the choice of the specific project site.

An area of approximately 10.300 square meters within the first phase of the urban development, has been chosen as the project site.

In and close to this area, a large diversity of functions, such as residential areas, business areas, shopping, playgrounds, sport facilities and so forth, is planned. Besides this, the unique qualities of the area is its placement towards south and the sea, which makes the natural conditions of the site quite favorable in respect to day- and sunlight. This creates the opportunity to harness passive heating, to utilise daylight and create amazing outdoor areas.

The wind charts shows a slightly predominance of wind from an eastern-western direction, which should be kept in mind when designing and placing the building, both according to the possibility of natural ventilation (summer) and sheltered outdoor areas.

How the building can exploit its natural settings in the development of a sustainable design, will be further discussed in the next chapter "Sustainability".


ill. 35: Masterplan with outlined project area

# Sustainability
## Definition

In a world with growing environmental concerns the term "sustainability" or "green" has become extremely familiar. Most people involved with building design in recent years, at least in the western part of the world, will have been confronted with the term and while a number of definitions exist, the term remains elusive to many.

Within the world of architecture, the Brundtland definition (see quote) has been the most commonly referred to as the "original" or "classic" formulation of sustainable development even though the definition gives little indication of how to apply principles of sustainability in practice and is more a description of the aim rather than the actual meaning.

The definition was intentionally made very vague to gain most chance of acceptance and cleverly captures two fundamental issues; the problem of the environmental degradation that commonly accompanies economic growth, and yet the need for such growth to alleviate poverty. But as World Bank economist Herman Daly points out, a sustainable development which considers the "expanding needs of a growing world population, implying a steady and necessary growth" is an inadequate development not requiring any leveling off to meet a carrying capacity. On the basis of this, Daly suggests three specific rules for society to meet in order to achieve (economic) sustainability:

*1. Harvest renewable resources only at the speed at which they regenerate.*

*2. Limit wastes to the assimilative capacity of local ecosystems.*

*3. Require that part of the profit be put aside for investment in renewable substitute resources. [McDonough W., p.29, 1992].*

This concept of an economic sustainable development can be directly transferred to environmental sustainability. In general sustainability can be thought of as three dimensions - environmental, economical and social.

Through history many examples has shown how considerations towards an economic wealth has compromised with social and environmental concerns.

***"The idea of sustainable development may bring people together but it does not necessarily help them to agree goals. In implying everything sustainable development arguably ends up meaning nothing", [Adams W.M., 2006, p.3].***

The importance of a common definition and understanding of sustainability is very apparent and the aim of the chapter will be to define a sustainable strategy for the project.

### Timeline:

**1900's:** Social consequences of industrialization.

***1960's:*** *Environmental consequences of industrialization.*

***1970's:*** *Climatic consequences of industrialization were an effect of the oil crisis - people became aware of that there were not unlimited resources.*

***1973:*** *First oil crisis prompted the governments to seek secure sources of energy and reduce dependency on imported fuel.*

***1979:*** *Second oil crisis.*

***1983:*** *The World Commission on Environment and Development was established by the United Nations as a result of the growing concern about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development.*

*In establishing the commission, the UN General Assembly recognized that the environmental problems were global in nature and determined that it was in the common interest of all nations to establish policies for sustainable development.*

***1987:*** *"Our Common Future", also known as The Brundtland Report, alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment.*

***1997:*** *Kyoto summit for Climate Change - terms for an internationally binding protocol to reduce greenhouse gas emissions are negotiated.*

***2006:*** *"An inconvenient truth" by Davis Guggenheim. American documentary about the consequences of global warming.*

***2009:*** *COP15 - UN Climate Change Conference. The intension was to make an agreement fighting the climate changes as follow up on the Kyoto-protocol.*

*"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". ["Our Common Future", Brundtland, 1987].*

Ill. 1: Earth seen from space.

## Main environmental issues:

***Global Warming*** *describes the process by which greenhouse gases accumulate in the atmosphere in abnormally high amounts, trapping the Earth's radiation and causing its temperature to rise. This is linked to environmental problems such as changes in rainfall patterns, rising sea levels and expansion of deserts.*

***Waste adds*** *pressure for more landfill sites, which pollute air, soil and groundwater and for more incineration, which pollutes the air and produces generally toxic residue.*

***Pollution*** *of air, water and land, resulting from burning of fossil fuels, industrial processes, agriculture and other human activities, is endangering human health, biodiversity and the built environment.*

***Soil degradation*** *caused by urbanization, construction, mining, war, agriculture and deforestation. Soil erosion, increased salination, altered soil structure, drainage capacity and fertilization can diminish crop yields, increase the risk of flooding and destroy natural habitats.*

***Water:*** *A third of the world population is still without access to safe water and, as the world population grows, the need for water will grow, as will waste and pollution which will increasingly threaten the quality of groundwater and rivers.*

***Ozone depletion*** *is caused by emissions of chlorofluorocarbons into the atmosphere. Increases in UV radiation are thought to be linked to a rise in skin cancer, damage of the human immune system and altered crop yields.*

***Resources:*** *Some non-renewable resources, including natural gas and petroleum resources, will eventually be depleted. Renewable resources, such as timber, are also at risk of overexploitation.*

***Deforestation*** *through commercial logging, conversation of forest land to agricultural use and other activities causes the destruction of natural habitats and extinction of plant and animal species and exacerbates the effects of global warming and pollution.*

***Extinction of flora and fauna*** *are the culmination of the environmental damage to our planet.*

***Population growth*** *is associated with increases in the human-induced environmental impacts mentioned above. [Sassi P., 2006, p.3].*

## Social sustainability

Social sustainability means to maintain social capital which equals investments and services to uphold the basic framework for society. The importance of social capital is not yet adequately recognized as can be seen in most western countries where the western-style capitalism has weakened the social capital to the extent where it promotes competition and individualism over cooperation and community. This is one of the main reasons for the high levels of violence and mistrust. Cohesion of community for mutual benefit, connectedness between groups of people, reciprocity, tolerance, compassion, patience, forbearance, fellowship, love, commonly accepted standards of honesty, discipline and ethics are some of the very important key words of social sustainability. Social (sometimes called moral) capital requires maintenance by shared value, equal rights, and by community, religious and cultural interactions.

Considerations can also be given to sustainability on a smaller scale - the individuals of society, also known as human sustainability. Human sustainability means maintaining human capital which is the private good of individuals such as health, education, skills, knowledge, leadership and access to services, [Goodland R., 2006].

## Economic sustainability

Economic sustainability is maintenance of capital, or keeping capital intact. The amount one can consume during a period and still be as well off at the end of the period, can also define economic sustainability, as it devolves on consuming value-added (interest), rather than capital. Historically, economics valuating things in terms of money has major problems valuing natural capital especially common access resources, such as air, which has resulted in an overcapitalization of manufactured capital, such as too many fishing boats and sawmills chasing declining fish stocks and forests, [Goodland R., 2006].

## Environmental sustainability

Environmental sustainability involves both reduction in the energy consumption during the operation phase, the design of the building envelope, the layout of the building, the selection of appliances for the building, reductions in the energy consumption during the production phase, the life cycle profile of the building, the integration of renewable energy sources and strategies for the flora and fauna preservation and development on the site [Hansen, H.T.R., 2007].

***"When the human economic subsystem was small, the regenerative and assimilative capacities of the environment appeared infinite. We are now painfully learning that environmental sources and sinks are finite. Originally, these capacities were very large, but the scale of the human economy has exceeded them. Source and sink capacities have now become limited [Goodland R., 2006]"***

Humanity must learn to live within the limitations of the biophysical environment. Environmental sustainability means that natural capital must be maintained, both as a provider of resources, and as a sink for wastes. This means holding the scale of the human economic subsystem (= population x consumption, at any given level of technology) within the biophysical limits of the overall ecosystem on which it depends. [Goodland R., 2006]

The three dimensions are not to be regarded as equivalent. Economy emerges from society as a mechanism or a set of rules to mediate the exchange of economic goods or value. The environment though is not created by society, but has an extremely high influence upon both social and economic sustainability. The resources available on earth and the solar system effectively present a finite limit on human activities. In many areas the capacity of providing basic resources is already close to its limits. Without these and an environmental sustainability, the social and economic sustainability cannot exist, [Goodland R., 2006].

The environmental sustainability will because of this have a higher priority, with focus on a reduction of the energy consumption during the operation phase, as the intension is to create a zero energy building. The project is a part of a greater scheme at Nordhavnen, which is intended to be developed into a lively and dynamic city area with room for many and different people. This should in some way be reflected in the project through different social considerations. The economic dimension will mainly be considered in relation to a low-cost production and maintenance.

The following pages will give a more specific introduction on how to approach environmental sustainability, based on different main concerns.

# Environmental sustainability

*"Not long ago a major part of the image of good architecture was a building that was suitable for its environmental context – one that would adequately protect the inhabitants from the climate. More recently it is 'the environment' that has been seen as needing protection", ["Understanding sustainable architecture", Williamson, Radford and Bennetts, 2003].*

## Main Concerns

Through history the meaning of the term sustainability has changed as a result of changing main concerns (climate, nature, culture and technology). This has obviously influenced the way to approach sustainability and the solutions within the world of architecture. In the PhD "Sensitivity Analysis" by Hanne T. R. Hansen a description of different approaches are given, based on the main concerns.

### Climate

Climate is a way of differentiating environmentally sustainable architecture from non-sustainable architecture. The climate definition is in a way more concrete than the others because it is based on the awareness of climate changes - rising temperatures, rain and dry periods, etc. It is everything that can be analyzed from the site, but also the general awareness of the changing climate.

### Nature

Concern for nature means to work with nature instead of against it, to understand, exploit and avoid damaging natural systems. This means being capable of recognizing what natural features (wind, sun paths, ground

and vegetation) that can be worked with and what to protect. The choice of materials should be natural and only with small human modifications; bale of straw, rammed earth and pressed mud bricks. Organic shapes are preferred instead of the hard and edgy shapes like earthly colors are preferred over brighter.

*"Neither does the building dominate its natural setting. Rather it expresses humility in the face of nature, its character coming as much from the play of sunlight and shade over its surface as from its own form (Hansen, 2007, p. 68)"*

### Culture

In architecture there should always be a meaning and reflection of the cultural context. Cultural sustainability means protecting and continuing the genius loci and working with the limitations and possibilities it provides. This approach to sustainability shows a concern for the local people, their way of living and interacting with their buildings. Materials, colors and building forms should be developed in relation to the local vernacular.

*"The new building is expected to rework rather than reproduce the vernacular, to be identifiably contemporary while eminently respectful of the past (Hansen, H.T.R., 2007, p. 68)."*

### Technology

Technical sustainability is solution of social, economic and environmental problems through the development of technical devices that neutralize or make benefits out of what may temporarily appear to be problems.

Success of solutions is seen as a matter of applying the tools of the social, economic and physical sciences to analyze the given situation. The key is rationality and efficiency in planning, material use and systems.

*"(. . .) The archetypical visual image is the high-tech corporate office in a city of similar offices: efficient people in efficient buildings, both in control, both responding to challenges through innovation (Hansen, 2007, p. 68)."*

## Approaches

In the PhD by Hanne T. R. Hansen six different ways to approach environmental sustainable architecture is given. The pictures on the next page illustrate how the theory has been developed into physical examples of  sustainable architecture through different approaches.

This project, which is mostly concerned about an energy production and reduction in order of achieving energy neutrality, will be approached from a combination of solar, bioclimatic and environmental sustainability - making use of the environmental conditions of the site and  applying both passive and active strategies. The strategies involve the use of different design principles, which are shown schematic on page 89. These principles will work as parameters to investigate and include during the design of the building.

Ill. 2: Dutch Pavillion,Hannover Expo 2000, MVRDV.

Ill. 3: The Nine Houses, Peter Vetsch.

Ill. 4: Tjibaou Culturcenter, Renzo Piano.

### 1. Self-sufficient

The original thought was that everyone should have access to food and shelter which resulted in the idea of self-sufficiency in order to design housing which could be placed anywhere in the world.

Self-sufficient buildings are commonly built in ecological communities by self-builders. An example of more modern self-sufficient buildings are the energy neutral buildings, which produce energy and are self-sufficient in order of energy consumption in the building. The energy neutral buildings are not necessarily self-sufficient in every aspect though, such as: collecting water, cleaning and building materials etc.

### 2. Ecological

The ecological approach has associations to the hippie culture of the late 1960's; people living in tune with nature. Ecological building has rarely been taken seriously by Danish architects and are therefore mainly associated with self-builders and are rarely seen in Denmark. One example though is the small community called Friland.

The designers of the ecological buildings combine the selection of natural materials with rules of thumb about passive and active solar heat gains, as well as local heat sources such as straw-bale or wood. The buildings reflect their creator's way of life which some might argue is not easily transferred to the lifestyle of the majority of the Danish population.

### 4. Environmental

There are two different approaches concerning environmental sustainability; the exclusive and the selective. This means that environmental architecture can either be used as an expression for architecture which considers the context in which it is placed, applying both passive and active strategies to control the environment and reduce the energy consumption, or it can be used as an expression for buildings with an artificial controlled environment, such as air-conditioned buildings with artificial lighting that works independent of the context in which it is placed.

Ill. 5: The EDITT Tower, Ken Yeang

Ill. 6: Heliotrop, Rolf Disch

Ill. 7: Arup Campus, Arup Associates.

### 3. Green

There are two diff erent approaches to green architecture: Green equals green as in nature and green as a result of the relationship between energy, ecology and environment.

*"Green architecture is a term used to describe economical, energy-saving, environmentally-friendly, sustainable development. These resources explore the relationship between architecture and ecology, and show how you can use concepts of green design in your own home [Hansen, H.T.R., 2007, p 45]."*

### 6. Solar

Solar architecture was one of the most popular terms of the 1990's, where it was used as a label for practically any building utilizing passive solar heat gains or any building with a solar panel or photovoltaics on the roof. Today the understanding of solar architecture has developed towards renewable energy. It is no longer enough to apply passive solar heating or small solar panels.

The approach is characterized by passive houses, energy efficient and low-energy buildings. The primary focus is on energy-efficiency during operation time and integration of energy producing elements. The secondary focus is the embodied energy. Solar design can improve: heat, cooling and lighting.

### 5. Bioclimatic

The bioclimatic approach can be traced back to 1963 to the writings of Victor Olgyay, but had a revival in the mid 90's caused by the writings and designs of Ken Yeang. These two writers are in fact from the pre and post energy crisis eras [Hansen, H.T.R., 2007]. Olgyay writes about how the climate affects the human environment, while Ken Yeang is concerned about how the human environment effect the climate.

The strategy in this approach consists of working with the natural forces around the building rather than working against them. The building's impact on its site, the energy and material used in a lifecycle and utilization of passive and low-tech solutions are also a part of this approach.

## Design principles

One of the most important criteria for making a sustainable building is to know how to exploit the environmental conditions of the site. Climatic design principles are essential to achieve an optimum energy and environmental building concept. To keep the energy use down there are some easy initiatives that can be made early in the process.

*"The desirable procedure is to work with, and not against, the forces of nature and to make use of their potentialities to create better living conditions (Heiselberg P., 2007, p. 9)".*

By working with a number of basic and climatic design principles the energy efficiency of the building can be dramatically increased and thereby reduce the energy consuming input of heating, lighting, ventilating and air conditioning systems. The principles will be investigated in relation to the development of the building concept, and in the making of parametric analysis of the different design proposals.

Many of the design principles are concerned with sustainability from an architectonic level and therefore concentrated about the design of the building. It is important to remember that sustainability also exist on an urban level and remember to work with principles such as: mixed programs, dense cities, good conditions for pedestrians and cyclists, reduction of private transportation, preserve or improve green spaces etc.

| | Self-sufficient | Ecological | Green | Bioclimatic | Environmental | Solar |
|---|---|---|---|---|---|---|
| Preserve/improve biodiversity | | | + | + | | |
| Life cycle assessment of materials | | + | + | + | | (+) |
| Reduce private transportation | | + | (+) | + | (+) | |
| Thermal mass of materials | + | + | | | + | + |
| Insulation of building envelope | | (+) | | | + | + |
| Window area to orientation ratio | | (+) | | + | (+) | + |
| Surface to floor area ratio | + | | | + | | + |
| Window to floor area ratio | | (+) | | | + | + |
| Utilisation of daylight | + | | | + | + | (+) |
| Zoning | + | (+) | | (+) | | + |
| Mobility (of building) | + | | | | + | |
| Ventilation: Natural | + | + | (+) | + | + | (+) |
| Ventilation: Mechanical | | | | | | (+) |
| Renewable energy sources | | + | + | + | | (+) |
| Energy producing elements | + | + | + | + | | + |
| Energy-efficient installations | | (+) | + | | + | + |
| Embodied energy of materials | | (+) | (+) | + | + | + |

Ill. 8: Design principles, Hansen H. T. R.

# Sustainable dense cities

Sustainability should not only be considered in connection with the single building. Far more significant is the role sustainability can play in city development from the viewpoint of resource-saving and $CO_2$-reduction.

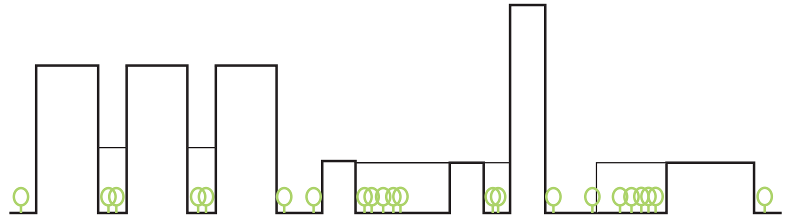
The increase of $CO_2$ production is a result of many factors: climate, land use patterns, density, lifestyle and population. Dense urban patterns with a diversity of land uses achieve significantly lower levels of emission than typical modern suburban cities. High density building optimizes the use of land, shortens the distance for supply channels, trash disposal and infrastructure required for transport and creates cities with intense, urban activity and increased social, cultural and economic exchange.

Compact urban development though, must not compromise with the architectural qualities and the living conditions. The current situation is that people are choosing to live in detached single family houses in the suburbs [see User p. 98]. To attract and make people live in the city, the architectural qualities and benefits must be likewise high or even higher, thus the challenge is to create compact buildings with a low energy consumption and a high degree of utilisation while having good daylight conditions, spatial qualities and attractive open and green areas.

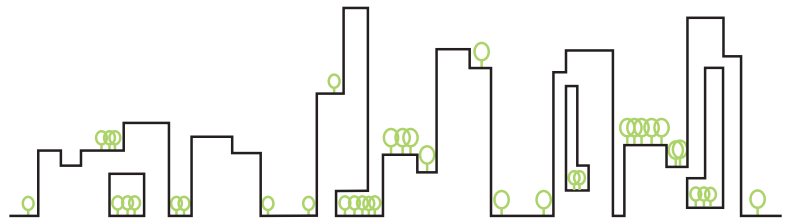
The diagrams shown to the right illustrate how typical dense cities have been developed with green spaces between the building volumes where daylight has a hard time to reach.

With "cutting for daylight" and introducing "vertical green" the city gains more optimized outdoor areas and new varieties of urban green spaces.

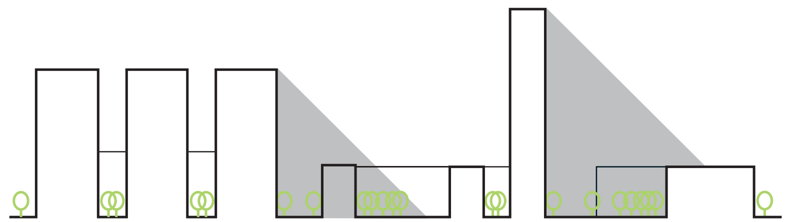
This creates a more dynamic experience of the city which is underlined by a mix of functions with dwellings in the upper storeys, offices in the mid/storeys and shopping at the bottom.



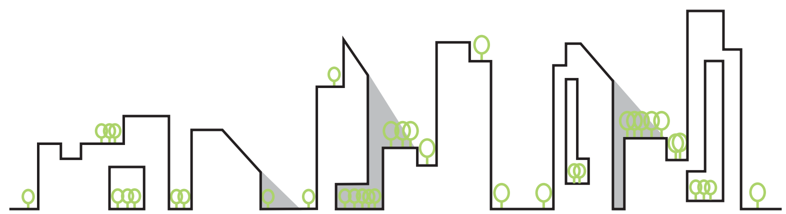
Ill. 9:The most common method in creating public green spaces in the city.



Ill. 10: By introducing "vertical green" the compact city gains new varieties of urban green spaces.



Ill. 11: Large areas shadowed by high and dense building.



Ill. 12: "Cutting for daylight" - by adjusting the building volumes through daylight analysis the city wins back some of its sunny squares.


Ill. 13: Mix of functions

# Zero Energy/Emission Building (ZEB)

*"Despite the excitement over the phrase "zero energy", we lack a common definition, or even a common understanding, of what it means", [Marszal, A. & Heiselberg, 2009, p. 6]*

In a fast developing world where success and wealth is often measured in physical property, the need for more energy efficient solutions is becoming increasingly important as the living standards will keep on rising – not only in the western countries but most importantly the third world countries will soon be demanding modern houses with district heating and electricity, furnished with all kind of electric equipment.

There is no exact definition for the way to construct or obtain a zero energy building. In principle it could be a traditional building supplied with a very large solar collector and solar photo voltage system. If the systems produce more energy within a year, than the building itself use, it is a energy neutral building. Different definitions are given based on what the building tries to solve and today the two main issues are the increasing energy use and greenhouse gas emissions from the building sector. For that reason one can distinguish between two different definitions:

*"**Zero Net Energy Buildings** - buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid.*

***Zero Carbon Buildings** - buildings that over a year do not use energy that entails carbon dioxide emission. Over the year, these buildings are carbon neutral or positive in the term that they produce enough $CO_2$ free energy to supply themselves with energy", [Marszal, A. & Heiselberg, 2009, p.9].*

Zero Carbon Buildings differ from Zero Energy Building in the way that they can also use electricity produced by $CO_2$ free sources, such as large windmills, nuclear power and PV solar systems, which are not integrated in the buildings or at the construction site.

The project will be based on the program of Bolig+ and thus focus on the development of a Zero Energy Building. Also the project do not wish to rely on an external supply of emission free, renewable energy.

To get a more specific definition of requirements, the project will be based upon the 5 dogmas formulated in the Bolig+ competition. The dogmas describe and define the performance requirements and objectives which the project should achieve (see page 92).

## Method

For the evaluation of the building's energy consumption IES - Virtual Environment is utilized through the sketching and synthesis phase, while Be06 and the Bolig+ toolkit will be utilized for the final documentation.

An evaluation in Be06 can be a very detailed and time consuming investigation due to the geometric limitations of the Be06 program. With Virtual Environment, which is a 3D building model, a part of the plotting work has been reduced. Furthermore the program can be utilized for analysis of wind, solar and daylight.

# Dogma 1

## Energy neutral

On an annual basis an energy neutral building does not use more energy than it can give back, meaning a zero energy building can consume energy from the supply grids during winter while having an overproduction during summer. The produced energy though must have same or higher quality as the used energy and with at least same usability. Energy neutrality can be reached through building design, construction and installations with utilization of solar energy.

The building must fulfill the Danish energy frame of a low energy building class 1 (or better) which are calculated in Be06 - not counting any  possible production of energy. The documentation of energy neutrality is carried out using a special Bolig+ toolkit working as a supplement to Be06. BE06 and the Bolig+ toolkit provide, on a monthly basis throughout the year, an energy balance showing:

- All energy consumption (excl. common outdoor lightning).
- Energy produced on the building or the site.
- Energy received from outside.
- Energy delivered back to the local net.

# Dogma 2

## Intelligent & user-friendly

To obtain energy neutrality the building should be equipped with systems supporting the daily management of electricity. The predominantly part of electric equipment only needs to be switched on when there is a need for it and only in the present of people. Optimized, intelligent control of heat and electricity not only reduce the energy consumption but also improve the indoor climate.

Constant information about energy consumption and production combined with a clear and intelligible interface helps to a changed usage pattern with better control/understanding of heat, ventilation and use of flexible components in the facade.

# Dogma 3

## Flexible in use & over time.

To reduce resource consumption on maintenance and conversion, the apartments should be flexible over time - offering the possibility of an individual lifestyle and changing needs of the users. A general usability of the different spaces and the possibility of change of functions should therefore be provided.

Attention should also be given to easy accessible and replaceable building and installation components. Since the completion often has a lower life span than the raw construction of the house, it should be performed as demountable elements made of light and durable materials that can either be disassembled and recycled or has a minimal environmental impact during construction and disposal.

If an apartment is expanded or reduced in relation to a neighboring apartment, partitions should be easy movable and installations and surfaces restored.

A way to gain energy neutrality is through the design of the climate screen. The building should have a flexible climate screen that can change accordingly to the time of the day and year. The facade function both as an active and passive building element in the production of energy while providing daylight, view and shade.

# Dogma 4

## Good & healthy indoor climate.

A good and healthy indoor climate includes temperature, air quality, natural daylight and acoustics.

1) The temperature is acknowledged as satisfying if the punishment of over temperatures in Be06 equals zero.

2) The air quality should be evaluated from health considerations and how people perceive the air quality. The air quality depends on the balance between the sources of pollution and the amount of air (ventilation) to dilute the pollution. Thus it is important to use building material and inventory which has a small release of contamination.

3) The natural daylight should be optimized accordingly to the usage of each individual space and contribute to the achievement of energy neutrality and the establishment of a good indoor climate. The amount of natural daylight in the main living areas should, during the winter (21. Sept.. - 21. Mar.), be no less than 5 percentage of the possible amount of sun hours within a year.

4) The acoustical demands are considered to be satisfying when they fulfill the demands of class C in DS 490 (sound qualifications of houses).

# Dogma 5

## High architectural quality customized the local context.

The building must express coherency between form and construction and meet both the functional demands and the energy demands in a convincing way. The design of the building must work over time and still relate to the time and area in which it is being constructed.

Opposite page: Proposals to a zero energy building in Nørresundby (Bolig+ Competition).

ill. 14: Rambøll

ill. 16: Team+

ill. 15: Vandkunsten

ill. 17: C. F. Møller

# Sustainable building design

In a fast developing world it can be extremely difficult to make buildings which will last 100 years, when technology, living conditions and lifestyle keeps changing even faster every minute – showing no sign to stop or slow down. The question is how can the need for future changes and adjustments be incorporated in the building design – giving the user the opportunity to modify the home in a continuous design process? One solution is to think of architecture more as a designed tool, which allows the user to create an individual and personal product.

To make a sustainable building is more than just making it energy efficient – it should most importantly be a place people wish to live. By giving the inhabitants the freedom and flexibility to change their home during time, the risk of the building to become outdated is minimized and the longevity is proportionally extended.

*" Boliger skal være unikke og fleksible – ligesom de mennesker, der skal bo i dem", "Præfabrikeret boligbyggeri", 2006.*

*/"Buildings should be unique and flexible – like the people, who are living in them".*

The idea is to perceive the building as a stratified system: the structure, the space plan, the skin and the services - each with a differentiated lifespan [see ill. 1].

Dividing the different parts of the building into separated systems, gives the opportunity to optimize and modify each layer individually while providing the user with a higher influence upon both functional and esthetical qualities – especially concerning the space plan and services which has the lowest longevity mostly caused by fast changing needs and trends.

The project will concern itself with how architecture *should* look, be used and built, with a strong personal angle, rather than how architecture is built and produced today.

**Examples on how changing living conditions creates new demands for the home:**

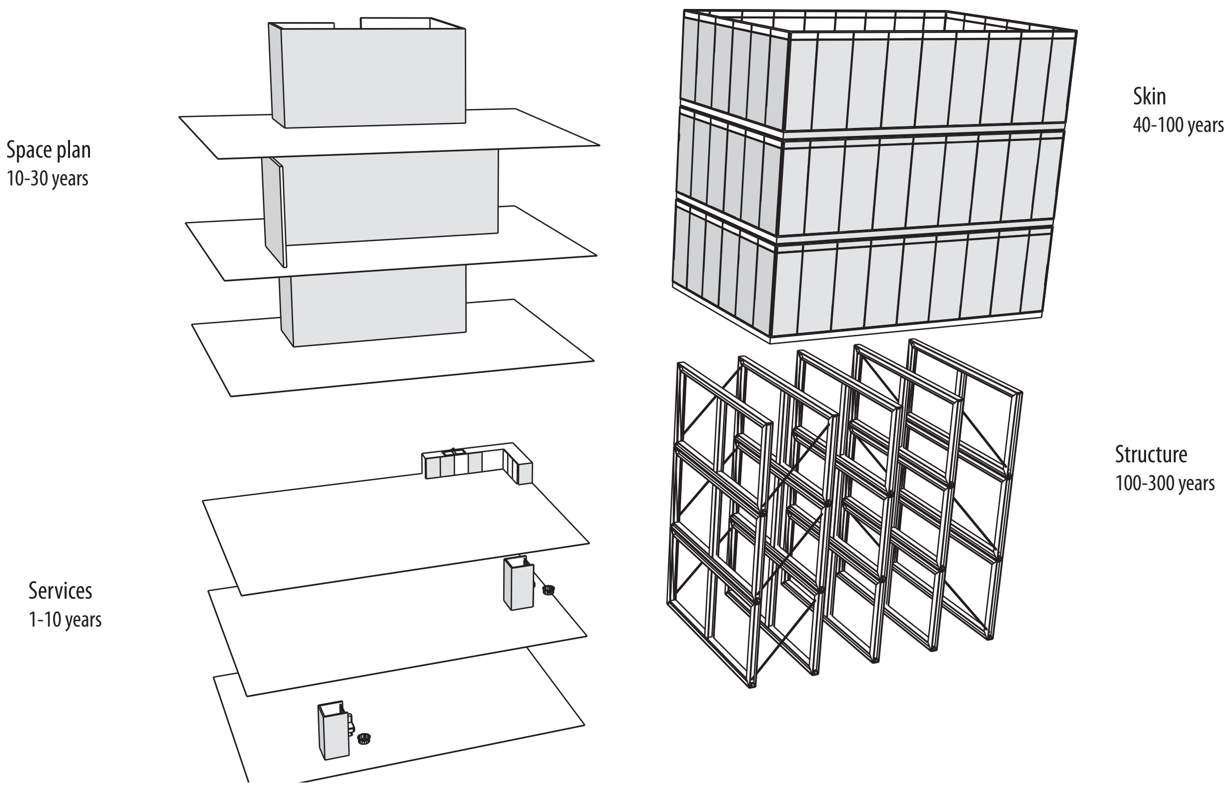
- *In 1955 every home had in average on more person than today.*
- *In 1955 only every third home had its own bath- today the percentage is 95. Same development is seen with central heating.*
- *The percentage of persons living alone has risen from 16 percent in 1960 to 38 percent today.*
- *In 1990 only 29 percent had a dishwasher – today the percentage is 63. In the same period the number of tumble driers has doubled from every fourth to every second family.*
- *In 1995 only every third home had a PC – today only 8 percentages are without.*

*["Præfabrikeret boligbyggeri, Byggeriets Innovation", p. 5, 2006].*

**Trends that will have an impact on the future building design:**

- ***Individuality** - people want something that is special, has a special history or quality, which reflect their live and values.*
- ***Electronic connectedness** - people are increasingly permanent online - through computers or mobile equipment. The boundary between work and spare time becomes illusive - like the interaction between real and virtual worlds becomes more advanced.*
- ***Accelerating changes -** the processor speed of computers is just one indicator of the still decreasing life cycle of technology. The fast alteration and replacement of equipment put forward new demands to the flexibility of the home.*
- ***Demographic changes -** elderly constitute an increasing part of society. What this means according to the nursing sector and the need for sheltering housing units for elderly is still uncertain. Also changes in the family pattern creates new demands for number, size and arrangement of houses.*
- ***Attention on resources -** there will be a more economic efficiency with many of the resources, which we build our wealth on. If not by desire than due to higher energy prices. Probably we have only witnessed the beginning of how sustainability will affect the building industry in the future.*

*["Præfabrikeret boligbyggeri, Byggeriets Innovation", p. 4, 2006].*




ill.18: Illustration describing the typical life time of different parts of a building.

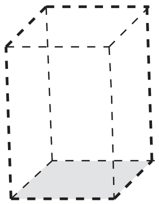
# Conclusion

## Strategy

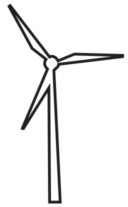
A growing concern about the climatic changes and scarcity of natural resources calls for new architectural solutions. Contemporary sustainable architecture should not compromise the qualities of life in the pursuit of an energy-efficient building, but instead enhance and improve the qualities while living more dense and eco-friendly.

The aim is to design a sustainable housing complex which has a higher production of energy than energy consumption. Opposite previous zero energy buildings, the project should count in the total energy consumption including the energy used by the household. To limit this consumption the use of energy-efficient appliances and intelligent controlled systems is of highest importance, especially when looking at the increasing development of electric equipment in the household. To achieve energy neutrality the right combination of available energy-efficient possibilities is essential. The most influential parameters are the development of technology and the geographic placement, meaning an optimal zero energy building will vary from place to place.

The strategy will both implement different passive and active design principles which should, as far as possible, be integrated early in the design process in order of avoiding any artificial adding to the design. Therefore the building design should first of all be optimized in order of reducing the energy consumption through the use of passive design principles and secondary implement intelligent technical solutions to achieve energy neutrality. Following list/icons, inspired by the different Bolig+ design proposals and the schema by Hanne T. R. Hansen shown on page 89, summons up the most important principles to incorporate in achieving energy neutrality and will work as a checklist during the design development.

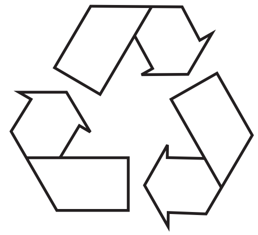


Surface to floor area ratio (compactness)



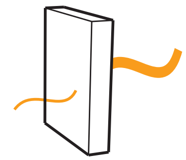
Energy producing elements:

Solar panels
Solar cells
Windmills/turbines



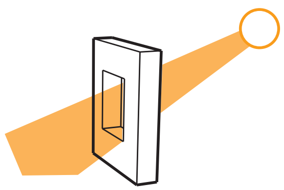
Recycling/reuse of materials:

Eco-labelled materials and surfaces
Utilization of waste- and rainwater

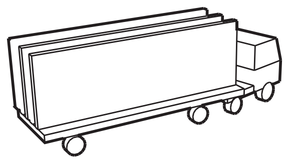


Insulation of building envelope:
(Passive house Standards)

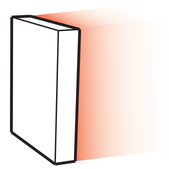
U-value (Walls): ≤ 0,1 $W/m^2K$
U-value (Windows): ≤ 0,8 $W/m^2K$
Linear thermal transmittance: ≤ 0,01 W/mK



Utilization of daylight & passive solar heating

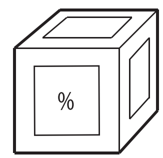


Mobility of building

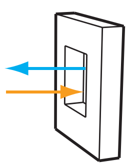


Thermal mass of materials:

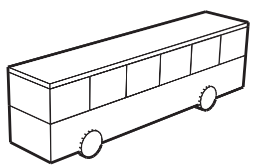
Heat accumulation > 120 $Wh/Km^2$



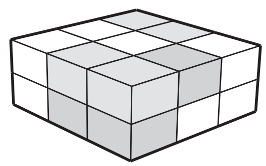

Window area to orientation ratio



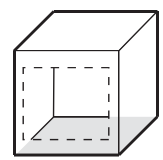
Ventilation:
Natural/hybrid ventilation during summer half
Ventilation with heat recovery



Transport:
Reduce private transport
Electric car charging



Zoning/orientation of rooms



Window to floor area ratio

ill. 19: Design principles.

# The User

## Introduction

Sustainability is, as mentioned in the chapter "Sustainable dense cities", not only to focus on the individual building but also the city development has a crucial importance. The high density of buildings makes it possible to achieve a more optimized use of land; it shortens the distance for supply channels, trash disposal and infrastructure for transportation and creates cities with a high intense urban activity and increased social and cultural exchange.

As it is today 70 percent of the Danish population, above the age of 15, wants to live in an owner-occupied home. 90 percent of them prefer living in a detached or terraced house. In the last 25 years this has been unchanged despite the different economical situations, [Center for Bolig og Velfærd, 2010].

To enhance a sustainable development, it should become more attractive to live in the dense cities. In this chapter the populations desire to live in the detached suburban house instead of the dense city (apartments) will be investigated. Why is this way of living preferred and is it possible to make a combination of living dense and having the advantages of the detached housing?

To get an understanding of why and how different people choose to live, there has been made an analysis of 4 different typical housing typologies (see next page). Of most interest are the open low and dense high buildings.

## The detached house

The detached house is somewhat a new trend, developed after the Second World War. Before this period most people lived in rented accommodations (both rich and poor), while during the 1950's and 60's the detached house became more and more normal. People had become aware of a new way to invest and create savings which gave them the possibility of economical freedom and life savings.

Today half of the real estate market consists of owner-occupied homes and the city has created a new urban development: the suburbs, consisting mainly of detached houses. According to different futurologists, the demand for the detached houses and owner-occupied dwellings will in the future be even larger, [Center for Bolig og Velfærd, 2010].

In general the trend is to build the detached dwellings larger and larger. The Danish people occupy an average of approximately 52 square meters each (average from detached houses, terraced houses, apartments and other dwellings). This might not seem very high but as an example, a family of five would have a house of 260 square meters which is not very common in Denmark today. The average for a family is around 30-40 square meters per person. The average of 52 square meters illustrates some tendencies in society, such as more and more adult people chose to live alone. The average is also highly affected by the fact that mid-aged couples chose to keep their, often large, detached house, in order to have room for when their children, and grandchildren visit, because of memories or for storing things with sentimental value etc.

Hedvig Vestergaard (an economist, who in the last 30 years has studied the Danish people's dwellings) is not enthusiastic about this trend at all. The detached suburban houses are placed far away from each other thus missing the relation seen between the denser city houses. She means that this result in a lack of urban life and community. The main reasons why people still choose and feel appealed by the thought of owning a detached house are:

- The opportunity to make changes on the house based on changing needs, economy and fashion.
- The feeling of privacy, spaciousness and quietness.
- The many possibilities of outdoor areas and activities.

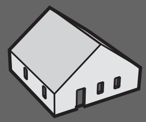
## The dwelling of tomorrow

One of the biggest challenges when designing dwellings in dense areas, caused by changing users, demands and fashion, are the flexibility. How is it possible to integrate flexibility in the dwellings, so that the dwellings of today will still be ideal tomorrow?

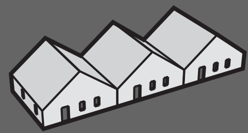
The development and change of working- and living situations, family structure and behavior are going faster now than ever. The challenge is to create dwellings which can cope with these changes. A dwelling that becomes the ideal setting to possibilities and choices. When talking flexibility according to the needs of the user there are two possibilities: Making spaces that has a general usability with rational floor plans or having an open structure with minimum of bearing inner walls. Peder Duelund Mortensen (architect) says this about the future dwelling:

*"Udformningen af fremtidens bolig vil handle om balancen mellem definerede rumligheder og ikke-definerede rumligheder", [Bolig og Velfærd, 2010, p. 107].*

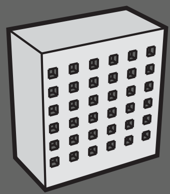
*/"The design of the future dwelling will concern the balance between defined and undefined spaces."*



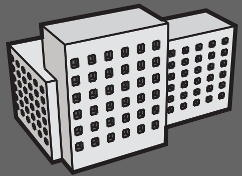
ill. 1: Open low buildings.



ill. 2: Dense low buildings.



ill. 3: Open high buildings.



ill. 4: Dense high buildings.

## Open low buildings

A majority of the Danish population would prefer this type of housing. Around 60% of the Danish population has lived in this type of housing at one point of their life. In many ways this type of housing is a synonymous for the nuclear family. They are known by their "soft traffic"-friendly traffic systems with child-friendly paths to schools, shops and different institutions. The majority of users are therefore also families with children.

Goals for this typology:

- The garden city
- A combination of the middle class house and the elder housing from the present villages with the presence of nature.

These users pay attention to:

- Similar norms.
- Privacy and quietness.
- Reputation of the area.
- Large amount of space
- Institutions nearby.

## Dense low buildings

Dense low buildings are characterized by having small gardens and individual housing with some degree of a social community. This type of housing is an often cheaper alternative to the open low buildings. The resident own the house but share walls with the neighbor. The area is more dense than the open low areas incorporating different facilities, such as common houses, common areas and other common facilities. Many who lives in these areas are single providers.

Goals for this typology:

- Create a community.
- Responsibility.

These users pay attention to:

- Closeness to other children families
- Closeness to family and friends
- Closeness to the city centre

## Open high buildings

This typology relates mainly to the prefabricated constructions, which were built during 1955 to 1975 caused by the large need for dwellings. The ideal for these areas were to be self sufficient with different public institutions (day care, schools and libraries), shops and common facilities.

Today the occupants of these buildings are divided into two different ownerships. The renters which are mostly families with a low income and owners which are predominantly young couples and single elders.

Many think of this way of living as a temporary station to something better and does not see it as a place for social networking.

Goals for this typology:

- Self-sufficient. One of the visionary projects according to this was the Unité d'Habitation by Le Corbusier. The building incorporates sports, medical and education facilities.

These users pay attention to:

- Size of the apartment
- Access to a balcony
- The view
- Common areas
- Public institutions.
- Public transportation
- Reputation of the area

## Dense high buildings

This typology refers to the dense city's tower blocks. The majority of occupants are single young people and younger couples. In general they like having a diversity of functions within a short distance.

These users pay attention to:

- Nearness to the city centre
- Mix of functions
- Cultural activities
- Shopping and other activities
- Public spaces such as parks and squares
- Public transportation

# Conclusion

## Target group

To enhance social sustainability and to create a dynamic, diverse and active area, the project aims for a heterogeneous population - providing different outdoor areas and apartments of varied sizes and prizes that appeals to different demographics. This also gives the possibilities of moving around within the area, should the habitual needs change by e.g. marriage, divorce, children, age - thereby creating a social sustainability within the community.

The project especially aims for users who normally would settle down in large detached suburban housing thus trying to integrate the qualities seen in these areas.

The criteria of building dense while fulfilling the qualities of the detached houses is rather contradictory especially considering the still increasing demand for more space and functions in the individual home.

The challenge is to build dense while still having the feeling of spaciousness, privacy, large (green) outdoor areas and a variety of public spaces and functions. Therefor the project will not aim for an extremely high building percentage, due to the risk of people not wanting to live in the area - choosing the inefficient detached house, but instead focus on the development of a true sustainable alternative to suburban city.

## Ownership

To create diversity in the area it is also necessary to look at ownership.

A newcomer in an owner occupied area will pay much more attention to the surroundings and the other occupants - trying to create social connections and a good reputation.

Looking at a residential complex, there generally is a lack of social cohesion and unity. Especially singles and couples without children consider the dwelling only as a temporary station.

Using a combination of both will be most reasonable in order of creating a diversity of residents which in turn will lead to a diversity of functions and activities.

In order of creating a social cohesion, the area should be organized in smaller communities and subdivided into private, semi-private and public spaces, to ensure the occupants do not feel too exposed despite the high density.

*"Modern man is a sociological paradox - an individualist that crave a social interaction - as long as its a casual non-binding relationship, which can be turned on and off as we like. A modern collective community should reflect this and should have a high regard to private versus community spaces, making sure the collective is a choice, not a demand - making people an integrated, not assimilated part of the community",*

*[The Eco Village Project, Europan 2010].*


- The dense city has a diversity of attractive offers; cultural, shopping, public transportation, jobs etc.

# Dense city vs. Suburban city qualities

- The suburban city represent the qualities found in the family housing areas outside the city; private outdoor spaces, green areas and similar suburban qualities.

ill. 5

# Room program

The room program is based on the user analysis, site analysis and the criteria formulated in the Bolig+ competition program. Therefore the dwellings will have an area of 95 $m^2$ as a minimum and a maximum of 150 $m^2$ (exclusive outdoor areas).

The Bolig+ program operates with an area of 4000 square meters, which should contain 60 dwellings and a total of 7000 square meter floor area (Building per cent = 175%). The chosen site at Nordhavnen constitute an area of 10.300 square meter and due to the wish of maintaining spaciousness, ensuring privacy, good daylight conditions, diversity of outdoor and green areas and so forth, the project will take its starting point in the estimated building per cent of 130% planned by COBE.

There will be four different apartment types, which will contain solutions for the family, elder couples, young couples, singles and disabled. Thus room programmes for a 2-, 3- and 4 bedroom dwellings will be defined.

- **Unit 1:** 2 bedroom dwelling (one-storey): Young couples, singles and disabled).
- **Unit 2:** 2 bedroom dwelling (two-storey): Young/elderly couples and singles.
- **Unit 3:** 3 bedroom dwellings: Small families/ single parents (with 1 child). This could also be relevant for seniors, wanting an extra room for an office or overnight guests/children.
- **Unit 4:** 4 bedroom dwellings: Families/ single parents (with 2 children).

By having these four different options there will be a larger diversity in the complex area underlined by the possibility of having both renters and owners. The percentage-wise distribution of apartments will be based on the criteria of having the largest apartments closest to the sea, as the sales prize and demand for apartments drop significantly when moving away from the waterfront [Bolig+]. To gain most families, which are the main target user due to their desire of living in the unsustainable suburban areas, a predominantly percentage of the apartments will be constituted by unit 4.

- Unit 1: 10%
- Unit 2: 20%
- Unit 3: 30%
- Unit 4: 40%

In the competition program from Bolig+, different demands are outlined and should be fulfilled in the organization and planning of the rooms.

- The rooms should be regular and easy to furnish.
- Functional kitchen with an open connection to the living room.
- One bathroom, but in the larger apartments there should be an extra.
- Minimum one terrace.
- Storage room in the basement.
- Elevators should continue to the basement.
- Parking for cycles near staircases/elevators.
- The terraces must not be joined to ensure privacy and should be sheltered for the wind.

Other functions, which might be connected to the dwellings, are:

- Common room with the possibility of sleep over.
- Common roof terrace.

# Zoning

### Orientation of rooms

When designing the floor plans, zoning can be used to optimize the arrangement and placement of rooms. Zoning is an important passive tool, both regarding an optimized use of daylight and heat gains, minimizing the dependency on active, energy consuming technologies.

Normally it is preferred to have the spaces which are active during the day towards south, east and west, to exploit the benefits from passive heating and daylight. This being spaces such as the living room, kitchen and dining area.

The spaces, which are used during the night are often preferred cooler and do not have the same requirements for daylight and heat gain. This being the bedrooms, entrance and bathrooms which should be orientated towards north.

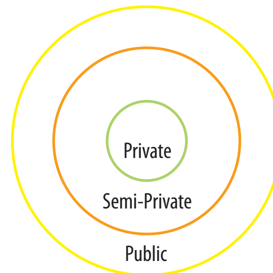
### Private >< Public

Another aspect to consider when implementing the qualities of the detached house to an urban compact context is the degrees of privacy.

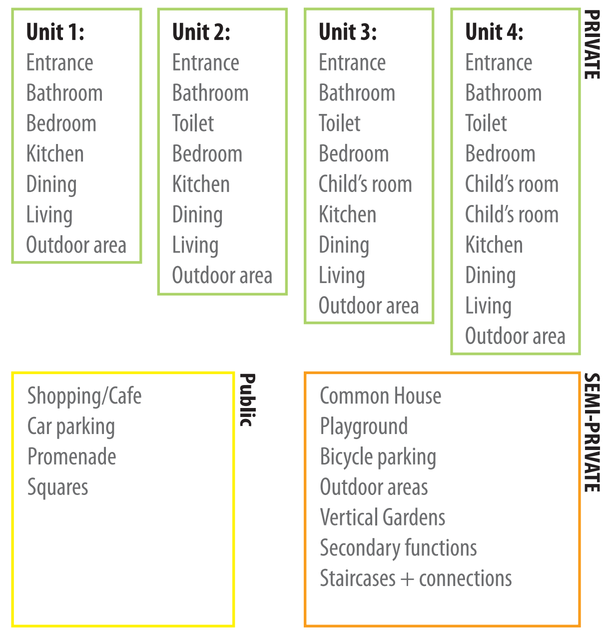
How are the privacy obtained in an area that has a high density? And how are the interaction between and the transition from the public and the private spaces?

These are some of the issues, which should be considered.

By adding common outdoor areas it is possible to gain buffer-zones to the private areas while creating places for informal meetings such as: squares, playgrounds, park areas and so forth. The division between public and private can also be done more significantly by either a physically or mentally division of the areas.




ill. 6: An example of how the zoning could be with buffers from the private zone to the public zone.



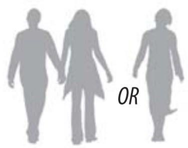

ill. 7: Scheme of functions according to private, semi-private and public areas.

The next schemes gives an overview of the needs of each room. The schemes is based on the demands there has been in the competition Bolig+ for the different sorts of rooms.

In the room programs there are some different informations outlined:

- **Area min. m²:** These square meters should only be seen as guiding.
- **Functions:** The usage of the rooms.
- **Activity level**: This ment as the activity during time as comparison measure. For instance it is clear that the children's bedroom is used just as much as the living room and so forth.
- **Light (lux)**: The necessary lighting to the room.
- **Ventilation:** The strategy, and requirements for the ventilation will be divided according to summer and winter.

# Unit 1 & 2 - room program




| Rooms | Area min. $m^2$ | Functions | Activity level | Light (lux) | Ventilation - summer | Ventilation - winter |
|---|---|---|---|---|---|---|
| Entrance | *5* | *Access, storage* | ▮▮▮ | *200* | *Natural* | *Mechanical* |
| Utility room | *6* | *Storage, laundry* | ▮▮▮▮▮ | *200* | *Natural* | *Mechanical* |
| Bathroom | *10* | *Shower, toilet* | ▮▮▮▮▮ | *200* | *Natural & Mechanical* | *Mechanical* |
| Living | *30* | *Entertainment, studying, relaxation, social* | ▮▮▮▮▮▮▮▮▮▮▮▮ | *200* | *Natural* | *Mechanical* |
| Kitchen | *10* | *Cooking, dining* | ▮▮▮▮▮▮▮▮▮▮▮▮ | *500* | *Natural & Mechanical* | *Mechanical* |
| Bedroom | *15* | *Privacy, sleeping, relaxation* | ▮▮▮ | *200* | *Natural* | *Mechanical* |
| Child's room | *15* | *Privacy, sleeping, relaxation* | ▮▮▮▮▮▮▮ | *200* | *Natural* | *Mechanical* |
| Outdoor area | *10* | *Relaxation* | ▮▮▮▮▮▮▮ | | | |

Gross min. : 95 $m^2$ - including outdoor area

## Unit 3 & 4 - room program

| Rooms | Area min. $m^2$ | Functions | Activity level | Light (lux) | Ventilation - summer | Ventilation - winter |
|---|---|---|---|---|---|---|
| Entrance | *5* | *Access, storage* | | *200* | *Natural* | *Mechanical* |
| Utility room | *6* | *Storage, laundry* | | *200* | *Natural* | *Mechanical* |
| Bathroom | *10* | *Shower, toilet* | | *200* | *Natural & Mechanical* | *Mechanical* |
| Toilet | *4* | *Toilet* | | *200* | *Natural & Mechanical* | *Mechanical* |
| Living | *30* | *Entertainment, studying, relaxation, social* | | *200* | *Natural* | *Mechanical* |
| Kitchen | *10* | *Cooking, dining* | | *500* | *Natural & Mechanical* | *Mechanical* |
| Bedroom | *15* | *Privacy, sleeping, relaxation* | | *200* | *Natural* | *Mechanical* |
| Child's room | *30* | *Privacy, sleeping, relaxation* | | *200* | *Natural* | *Mechanical* |
| Outdoor area | *50* | *Relaxation* | | | | |

Gross min. : 115 $m^2$/130 $m^2$ - including outdoor area

# Vision

The vision will describe the direction of the project in different areas: how should the building relate to the context and the urban fabric, an architectural vision both in expression outwards and inwards along with a sustainable vision for the project.

## Building and context

The building and context should form an almost 3 dimensional bond, where the building volumes relate to the site and the surrounding buildings/functions.

It is a vision that the site and building will merge together in some sense, creating different (green/public) connections and spaces also in the height thus the normally quite clear lines between site and building, becomes more elusive.

In a larger context, the vision is to bring affordable housing, with high architectural quality to the people.

## Architectural expression

The sustainable vision of the building should be revealed through the architectural expression. The building should be a meeting between nature and technology using both high and low tech solutions. This resulting in a slightly futuristic building, with a strong green element incorporated into the architecture.

The architecture should be multi-layered, incorporating many interesting facets and angles.

The project will concern itself with how architecture *should* look, be used and built, with a strong personal angle, rather than how architecture is built and produced today.

## Interior qualities

The apartments should be well lit, with a feeling of spaciousness. The apartments should have direct connection with an external space - a small garden, terrace or something similar.

The apartments should be designed with a combination of materials and surfaces, which give warmth and quality to the interior, but at the same time, allow for an efficient construction. Also the choice of materials should somehow reveal and relate to the sustainable nature of the project.

It is also the vision to create apartments which, despite the feeling of being spacious, are actually relative compact in order to underline the sustainable nature of the project.

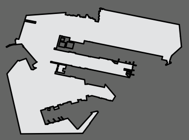
The vision for this master thesis project is to create a personal interpretation of an urban dwelling for tomorrow, which combines the advantages of living in the dense city, with those found in the currently preferred way of living - the detached house.

It is furthermore a vision that the dwellings have a strong sustainable character, both in appearance as well as "on the paper", in order to truly make an impact in the society of tomorrow!

# Design criteria

The final page of the analysis phase will be a summon up on the main design criteria to remember before starting the sketching phase.

The criteria is divided after the themes; site, user and sustainability.



## Site

- Optimize the access to and use of daylight, both regarding the dwellings and the surrounding outdoor areas and existing building stock.
- Provide a strong relation to the industrial and maritime history of the site and the nearness to the water.
- Relate the building with the history of the site.
- Create a strong connection between the building and the site, both visually and physically.
- Diversity in scale and functions of the area.
- Planning of an infrastructure that favours cyclists and pedestrians.

## User

- Diversity in functions.
- Diversity in users
- Private outdoor green areas.
- Zoning; Public-, semi private- and private areas. Creating areas for meeting and interacting with other people, while still having the desired privacy.
- Enhance the sense of community and "belonging" to the place.
- Mix of qualities found in the suburban way of living with living in the dense city.

## Sustainability

### Environmental

- The concept should obtain energy neutrality (Zero Energy Buildings).
- Use of passive and active technologies as well as intelligent installations/ equipment to minimize energy consumption.
- Use of active technologies to produce renewable energy (wind turbines, photo voltaic panels etc).

### Social

- Diversity in users
- Common areas; public, semi-public, and semi-private areas where people can interact.

### Economical

- Self sufficient in terms of energy (ZEB).
- Flexible solutions according to differentiated longevity of building parts.

# Sketching

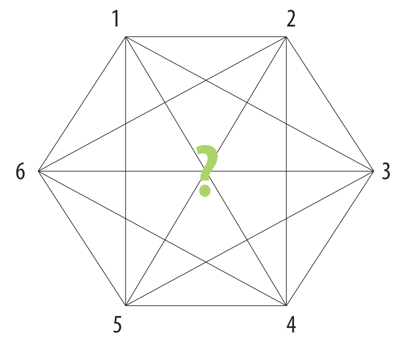
# Introduction

In the sketching phase,, initial concepts for the building design will be conceived based on the parameters and the studies performed in the analysis phase. The sketching phase is an iterative and integrated design process, which can be rather difficult to present, as many aspects of the building design is drawn and modelled simultaneously.   This should be kept in mind when reading the following description of the design process, which in the report is presented as linear [ill. 1].

The actual sketching is carried out using both analogue and digital drawing as well as digital and physical models.

The different initial concepts will be analyzed and evaluated in their potentials regarding the use of daylight and energy efficiency using Virtual Environment .

To initiate the sketching phase and gain a common understanding of the direction in which the project should be developed, the group started out writing down design principles (opposite page)and searching for references as inspiration [see page 112-113].




ill. 1: Illustration of the iterative design process and the different parameters of the sketching phase and their interaction. The final result should be a meeting and solution of all parameters.

1) Typology/density studies

2) Architectural expression

3) Apartments: spatial qualities, indoor climate and energy efficiency.

4) Structural and technical principles.

5) Climate screen: daylight/materials/intel-ligent or manual controlled.

6) Master plan: public functions/parking/ infrastructure.

? = Building design/Solution

# Design principles:

## (Urban planning)

### Mix of functions
The area should hold a large diversity of functions: living, working and leisure - bringing life and activity to the area. Nordhavnen should be a place for different people to live and meet, which will be underlined in the project by the use of different apartment types. The aim is, as mentioned earlier, to bring people from the suburbs to live in the dense city through the integration of the suburban qualities.

### Infrastructure
The area should favour cyclists, pedestrians and public transportation. This is already taken into consideration in the master plan by COBE (nearness to metro stations, highways for cyclists, minimum of traffic lanes etc), whereas the project will pay more attention to the experiences, when moving through the site as pedestrian/cyclist.

### Parking
Parking for cycles should be easy and close to the apartments. The area should reflect and invite for sustainable transportation, therefor car parking should be solved in a rather anonymous way.

### Green areas
The urban development will explore the creation of outdoor areas also in the height (vertical green) as part of: apartments (private), between apartments (semi-private) and larger green gardens (public). This will, besides bringing nature into the dense city and the possibility of outdoor activities, give a dynamic and green feeling to the area - underlining the sustainable approach to the project and give variation to the cityscape.

## (Typology)

### Daylight conditions
The access to sun- and daylight is the most important criteria to obtain energy neutrality. Besides this daylight is crucial for the well-being of the residents and the architectural experience. For this reason daylight studies will be made throughout the design phase, both sketching and synthesis.

### Scale
The building heights of the contextual area range from approximately 8 to 30 meters. To bring diversity to the cityscape the typology is visualized to be dynamic also in height, but without loosing connection and relation to the context.

### Density
The project should be a dense and more sustainable alternative to the detached house, thought it should not compromise with architectural or suburban qualities. For this reason the building percentage of 130% will merely be a guideline.

### Footprint
A low footprint will ensure the possibility of open green areas. Different footprints and typologies will be investigated as a starting point of the sketching phase.

### Community
In the placement and distribution of apartments, the development of smaller communities will be prioritized. This will enhance the social exchange and feeling of belonging to the area, which should be underlined by different common facilities such as common houses and gardens.

## (Building volume)

### Facades
The facades has an important role to play in both the architectural expression and in ensuring energy efficiency. The facades is thought of to consist various layers - a fixed insulating layer and a flexible layer which can be used both as a shading and energy producing device, integrating photo voltaic panels.

### Structural principle
The building design should have a clear logical construction. The idea of perceiving the building as a stratified system: structure, space plan, skin and services gives the opportunity to optimize the layers according to their life cycle. The challenge is to do so, while creating an architectural whole.

### Orientation
The orientation and shape of the building should be optimized accordingly to the sun and shadows - gaining most sunlit areas and facades.

### View
Both the placement at the waterfront and the degree of privacy/exposure, makes the view an important parameter to integrate, in the development of the building design.

### Architectural expression
The sustainable approach should be reflected in the building design through the use of photo voltaic panels, which will give the building a rather futuristic architectural expression. The design will be a meeting between nature and technology - using local conditions and basic design principles as well as energy efficient technical solutions.

## (Apartment)

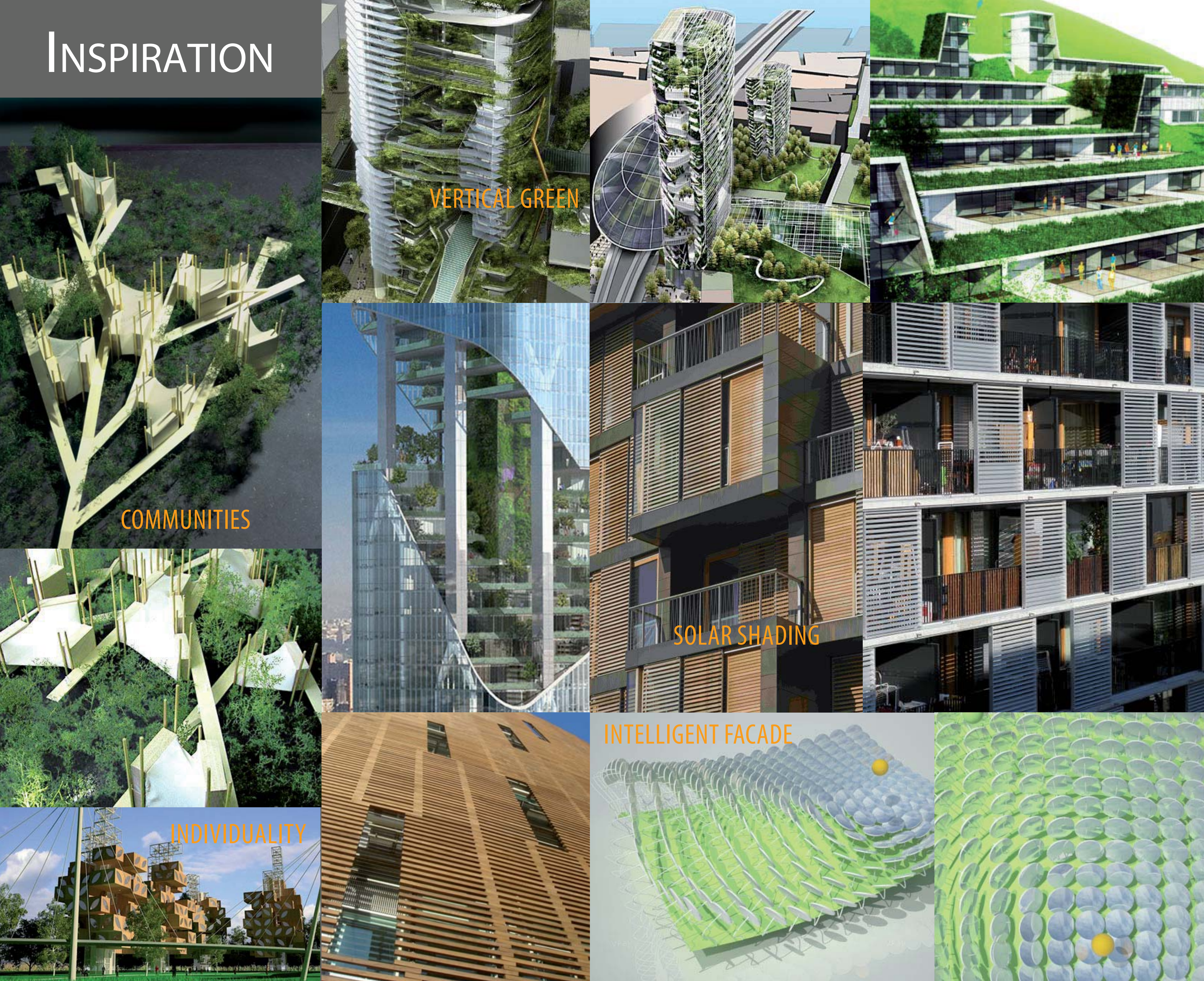
### Floor plans
The apartment should be rather compact to ensure a low heat loss, but without compromising the feeling of spaciousness and access to daylight. The layout of the floor plans should be rational and easy to furnish, making it adjustable to changing needs of the user.

### Outdoor areas
Each apartment should have access to outdoor areas either gardens, balconies or terraces. These should possess a curtain amount of privacy and thus not be joined together. Also the possibility of sheltered outdoor areas should be considered. As a starting point the outdoor areas are aimed to constitute 1/3 of the total floor area in the apartments.

### Materials
The building must integrate photo voltaic panels as a part of the architectural expression, as to make it energy neutral. The project will use this necessity to make a futuristic design, that reveals its sustainable approach to architecture. The rather technological appearance of the building from the outside should contrasted with a softer and warmer experience inside the apartments.

### Privacy/Zoning
The feeling of privacy is an important parameter to keep in mind throughout the design phase, due to the integration of the suburban qualities while building dense.

# INSPIRATION



ill. 1

# Design phase 1
## Typology studies

When designing a dense city area and larger building complexes, an analysis of different typologies and their specific qualities seems as an obvious starting point.

In this chapter some of the most typical typologies have been analyzed according to:

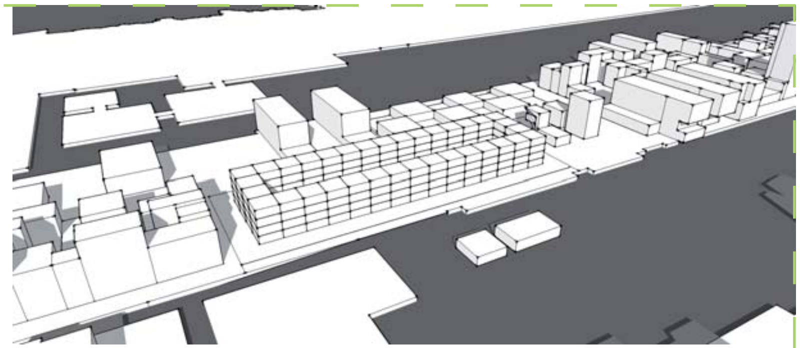
- Compactness
- Utility of daylight
- Views
- Degrees of privacy
- Quality of outdoor spaces

The typologies will be investigated using a FAR(Floor to Area Ratio) of 130%.

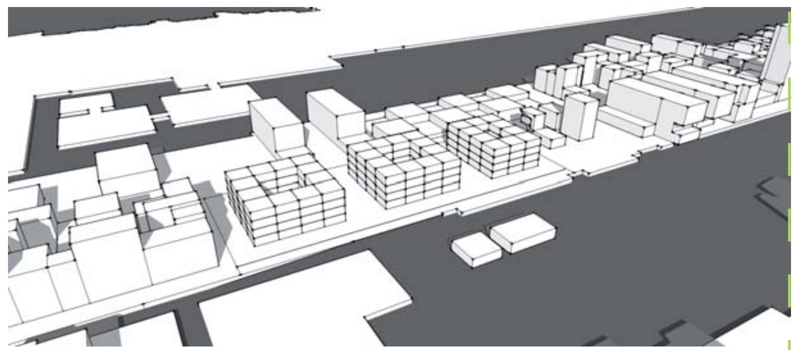
### The Block, in general

Pros:
- Defined communities and common areas.
- Continuation of the city grid.
- Very compact

Cons:
- The utility of daylight is poor in the corner-apartments of the building
- All the apartments have a two-way orientation, north-south or east-west.
- No buffer-zones between private and public spaces.
- An enclosed shape.
- Limited views from each apartment.



ill. 1: One large common area, no intimate spaces.

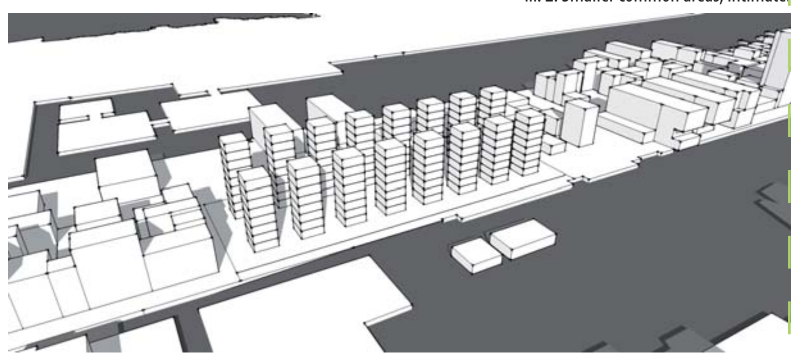


ill. 2: Smaller common areas, intimate.

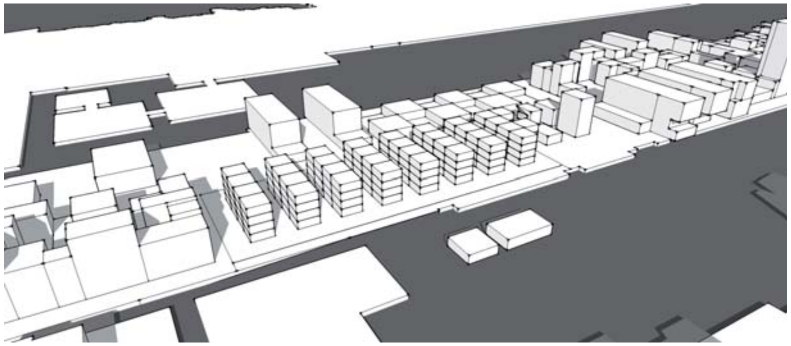
### The High-rise

Pros:
- Good daylight conditions.
- Possibility of more views.
- Small footprint.
- Relatively compact.

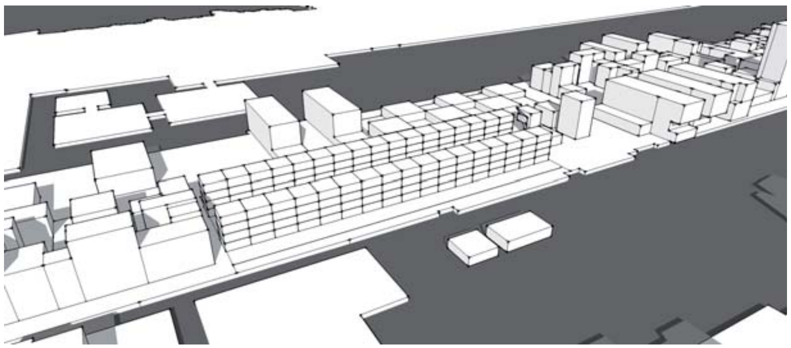
Cons:
- Lack of humane scale and defined common areas.
- No buffer-zone between public and private spaces.



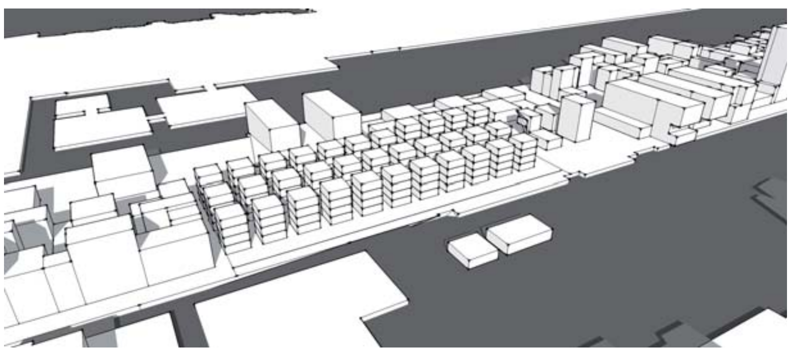
ill. 3: High-rise



ill. 4: Enables all the apartments to have views towards the ocean.



ill. 5: The two blocks obstruct each-others view towards the ocean.



ill. 6: The Urban Villa.

**The Slab, in general**

Pros:

- Compact.

Cons:

- Two-way orientation.
- Lack of defined common areas.
- Risk of exposure (lack of privacy).

**The Urban Villa**

Pros:

- Good access to daylight.
- More intimate spaces (in a humane scale).

Cons:

- Not very compact.
- No defined common areas.
- Risk of exposure.

## Further process

The high-rise and block have different possibilities and qualities, which are considered to be consistent with the vision of the project. Still different issues has to be solved in the further development:

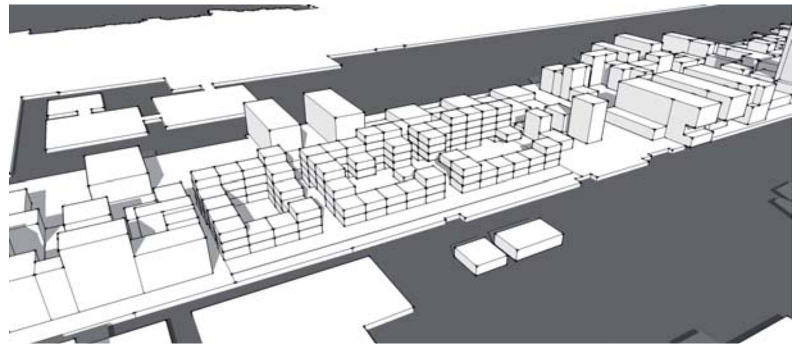
- View.
- Utility of daylight.
- Compactness.
- Definition and variation of common areas.
- Human scale.

# 1st Iteration

### Fragmented Block

Through a fragmentation the block starts to open up by creating paths into the enclosed areas. The division of the site into smaller communities is a strong feature in the block typology.

An optimization in access to daylight has been made by stepping up the block towards north while stepping down towards south. This also provides more apartments with a nice view to the sea.



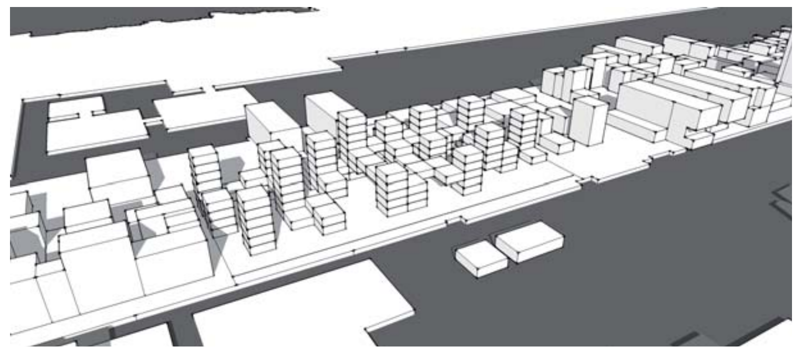
ill. 7

### Highrise-conglomerate

The highrise-conglomerate is a quite interesting typology in relation to "urban quality", partly due to the many varied outdoor areas who has become more defined, as well as the complex nature which bring dynamic and variation to the cityscape.

The compactness has been optimized, though still not being quite as good as the block typology.

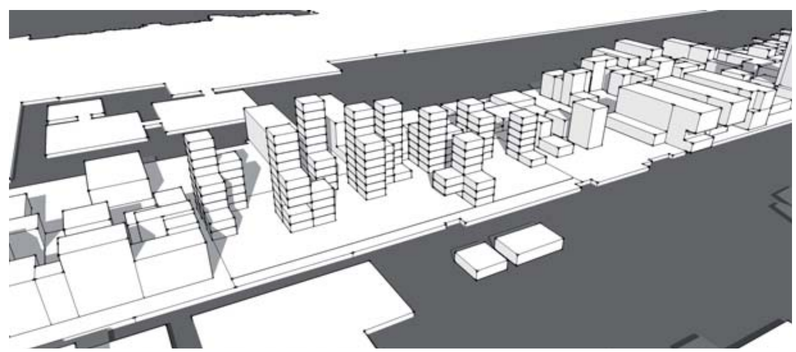
The differentiation in height gives the high-rise a more human scale.



ill. 8

### Stepped High-rise

The stepped high-rise has some interesting urban qualities with varied spaces and a good hierarchy in the urban space. Views and access to daylight is for most of the volumes quite good, though shadows could be a concern for certain small areas.



ill. 9

ill. 10: Mix between the high-rise and slab typology.

ill. 11: Mix between the high-rise and block typology and better definition of common areas.

ill. 12: Variation of heights gives the cityscape a more dynamic expression.

ill. 13: Experimenting with more organic typologies and varied outdoor areas.

ill. 14: The organic typology contains a large flexibility according to an optimization of views and access to daylight.

ill. 15: A more fragmented and open example of the block typology.

ill. 16: Merging the landscape and building typology.

ill. 17: Optimization of the block typology according to sun, common areas and view.

## Further process

At this point in the design process, a good overview of the different typologies, and their implications in relation to perceived urban quality, daylight conditions, density and so forth has been given.

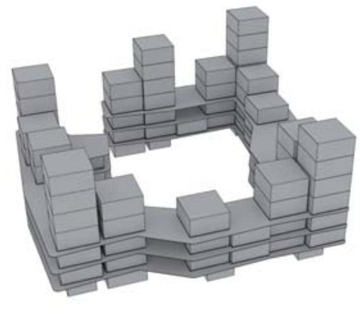
The next phase will explore how the qualities of the different typologies could be mixed in developing an area of smaller communities as seen in the block typology, but with the openness characterized by the high-rise. Also the qualities of a varied cityscape should be maintained in the further development with varied outdoor areas and experiences.

## 2nd Iteration

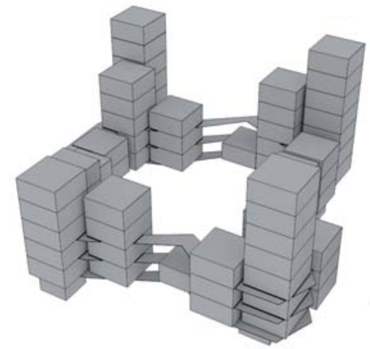
The 2nd iteration consist of some early volume studies, exploring the potential of a mixed and joined typology. A mix between the block structure and the high-rise  typology are further developed and tried out.

ill. 18 - 21: Different examples of a mixed block and high-rise typology. The intension has been to transform the traditional block typology and make it more dynamic and open, with out losing the overall shape and defined common areas.

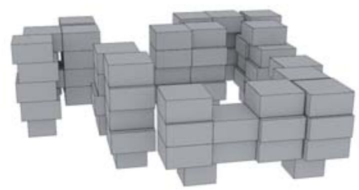
Eventually a good hierarchy was found by arranging the high-rises in smaller groups and connect them into a block-like structure. The connections are thought of to hold functions such as vertical gardens, access to apartments, balconies and so forth.



ill. 18

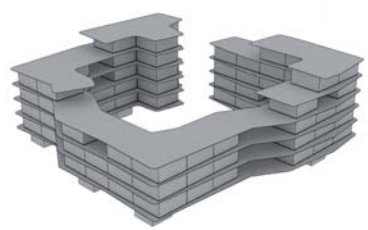


ill. 19

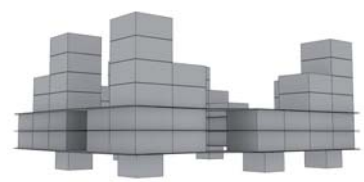


ill. 20

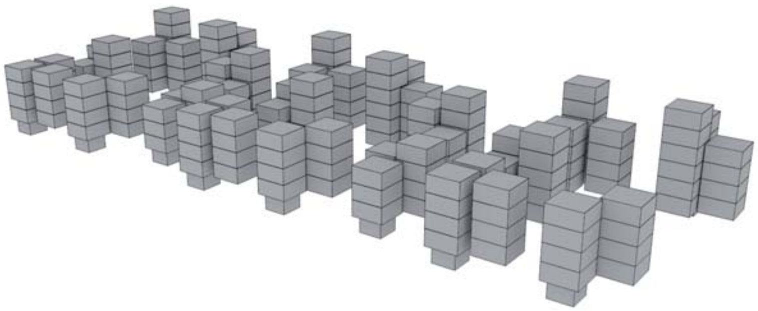
ill. 21



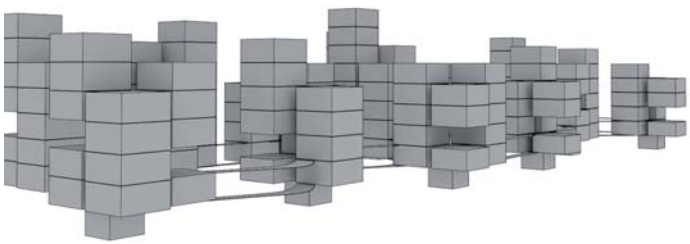
ill. 22



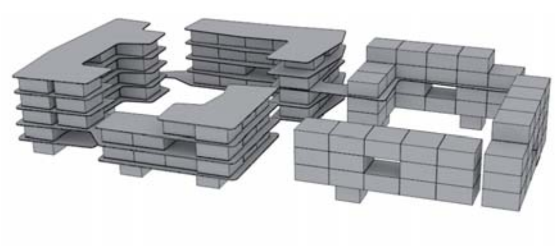
ill. 21



ill. 22: As a reaction to the very block-like typology, different high-rise typologies were tried out.



ill. 23: Some variation in the volumes have been made by cutting out modules and thus increasing the "airiness" of the concept. The cut-outs are thought to be green vertical gardens and common areas. Simultaneously connections between the high-rises have been made, in order to give the volumes an expression of a combined whole.



ill. 24:This study is a step back to the block typology. The intention was to investigate how the block could become less enclosed and create coherency with the surrounding building stock. In this specific case it is achieved by having simple walkways between the volumes.

## Further process

The good daylight conditions and spatial qualities makes the high-rise suitable for creating a sustainable building, which will attract the suburban families and provide them with the necessary privacy. To create a higher level of density and definition of smaller communities, the lower floors should in some degree be connected.

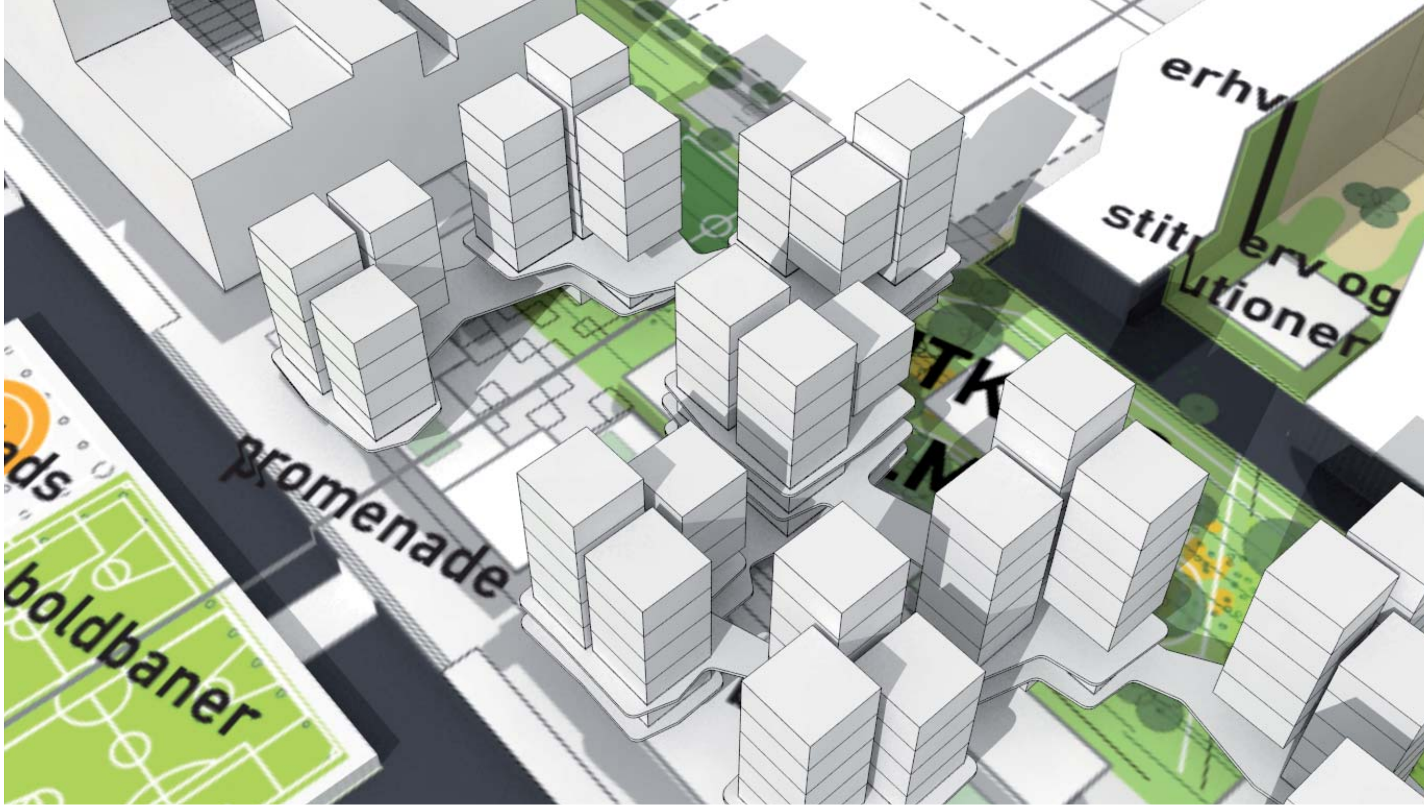
The next iteration will investigate a more detailed placement of volumes on the site according to shadow- and daylight conditions.

# 3rd Iteration

The 3rd iteration consist of placing and connecting the high-rises according to daylight investigations made i 3ds max design 2010, which has a built-in light simulation tool. With the use of this tool, it is possible to measure the amount of sunlight hitting on surfaces of both buildings and urban areas, and maybe mot importantly - the lack of sunlight due to shadowing.

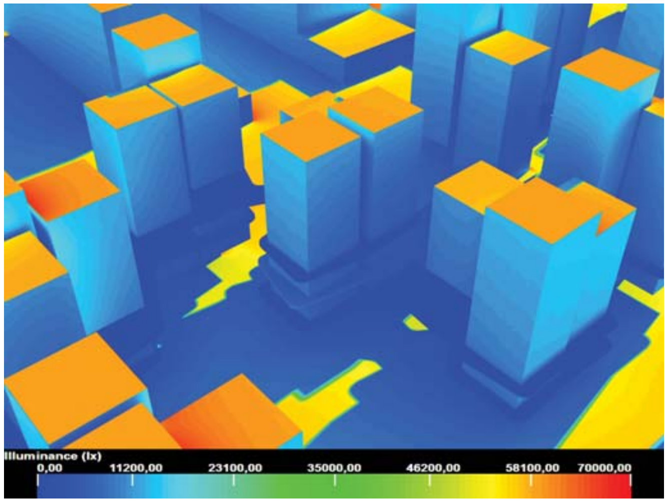
The investigations shown on the opposite page, are made the 21st of June from 08am - 14pm.

The high-rises are connected in the lower floors, creating coherency and defined spaces between the volumes, while providing an opportunity to experience the urban area from different levels.



ill. 25

ill. 26

1


ill. 27

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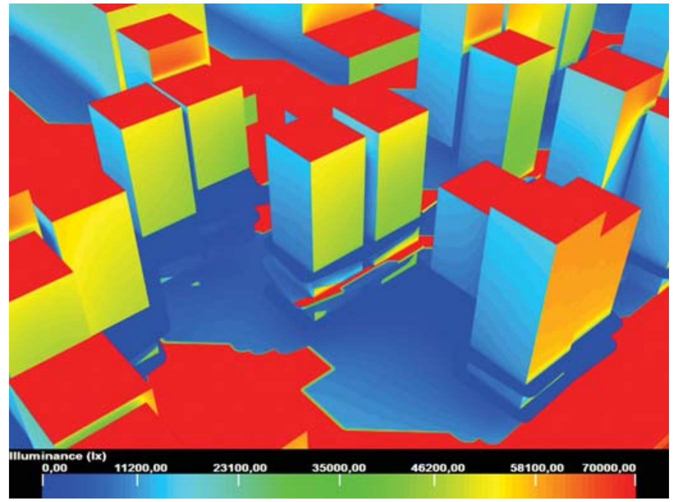
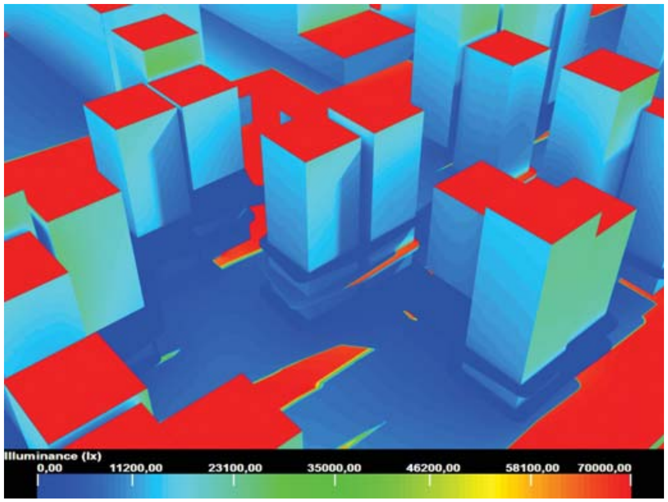


ill. 28

2


ill. 29

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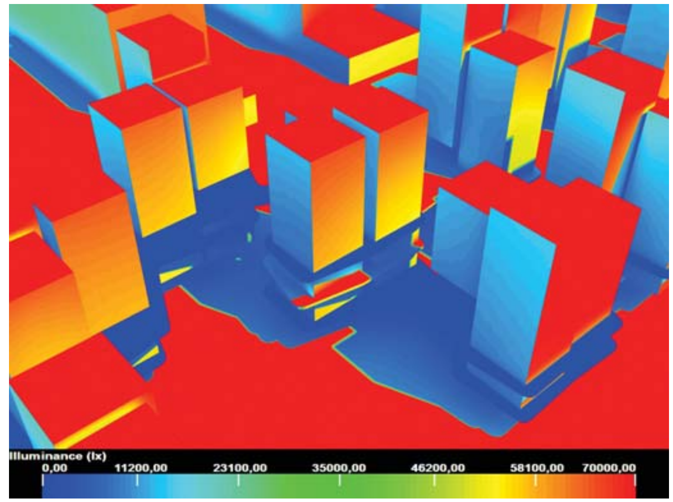
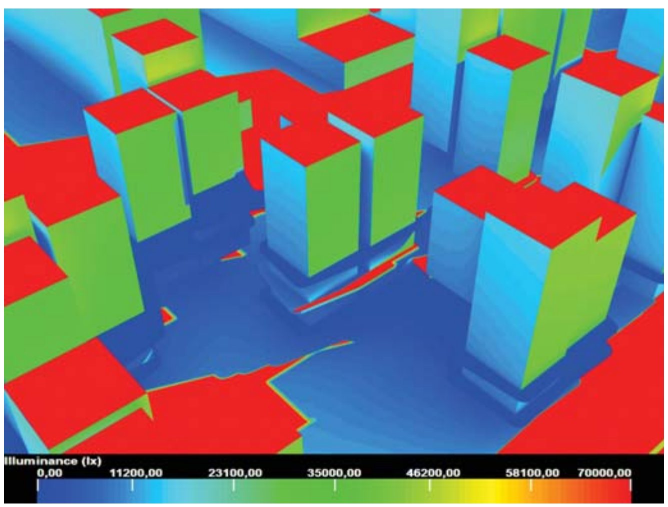
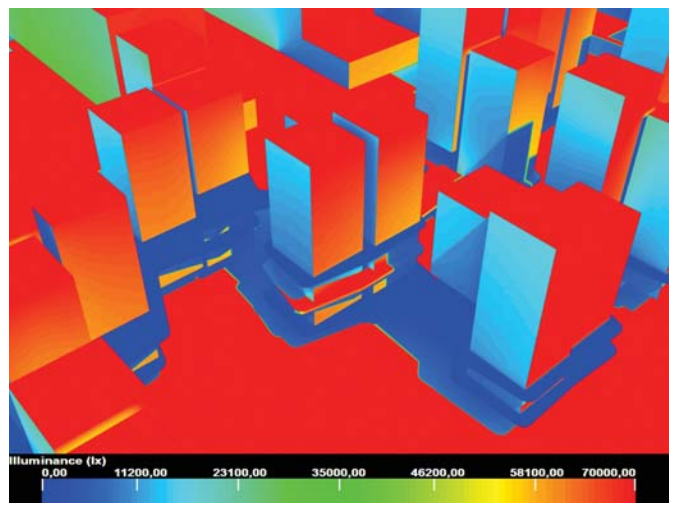


ill. 30

3


ill. 31

6


ill. 32


opholdstrappe
promenade
egeplads
boldbaner
KOLEGÅRD
evands
pytter
roklub og
vandtrappe


## Conclusion

A large range of different concepts and design parameters, for an urban plan and typology, has been tried out and investigated throughout design phase 1. At this point in the conceptualization the determining parameter is mostly based on personal preferences - since it is difficult to create meaningful quantitate evaluations of the individual studies. Factors such as access to daylight, outdoor areas, privacy and interesting views though, has been important determining parameters in a more qualitatively evaluation.

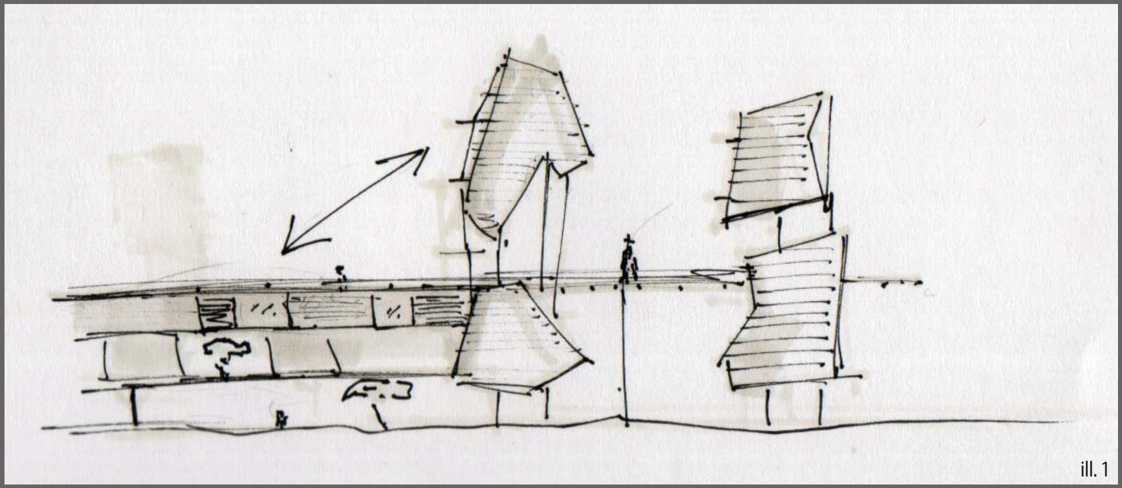
The final typology (shown to the left) functions as starting point for the further development. The concept is mainly based on the high-rise typology, with the high-rises arranged in small clusters and connected in the lower floors. The connections, besides giving cohesion between the high-rises and defining common areas, provides the area with a special 3-dimensional urban experience.

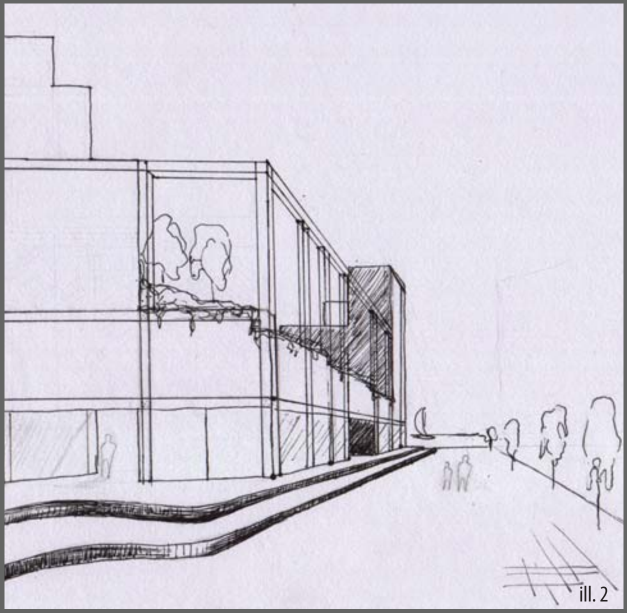
The overall intention, is to create an impression of a having the suburban dwelling in the heights, including both the important green outdoor areas and the feeling of spaciousness and privacy.

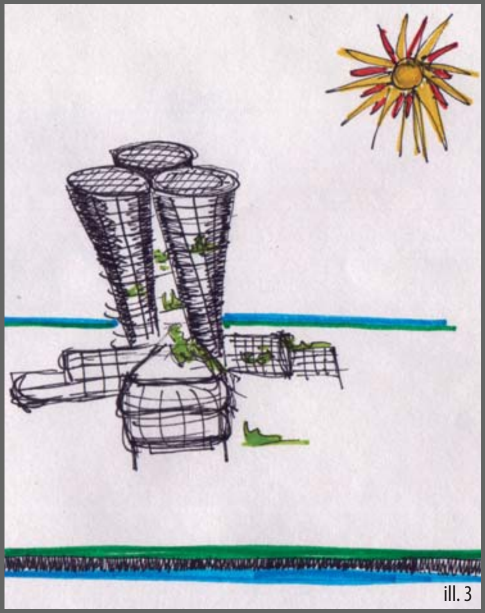
ill. 33: Overview and visual vision of the site.

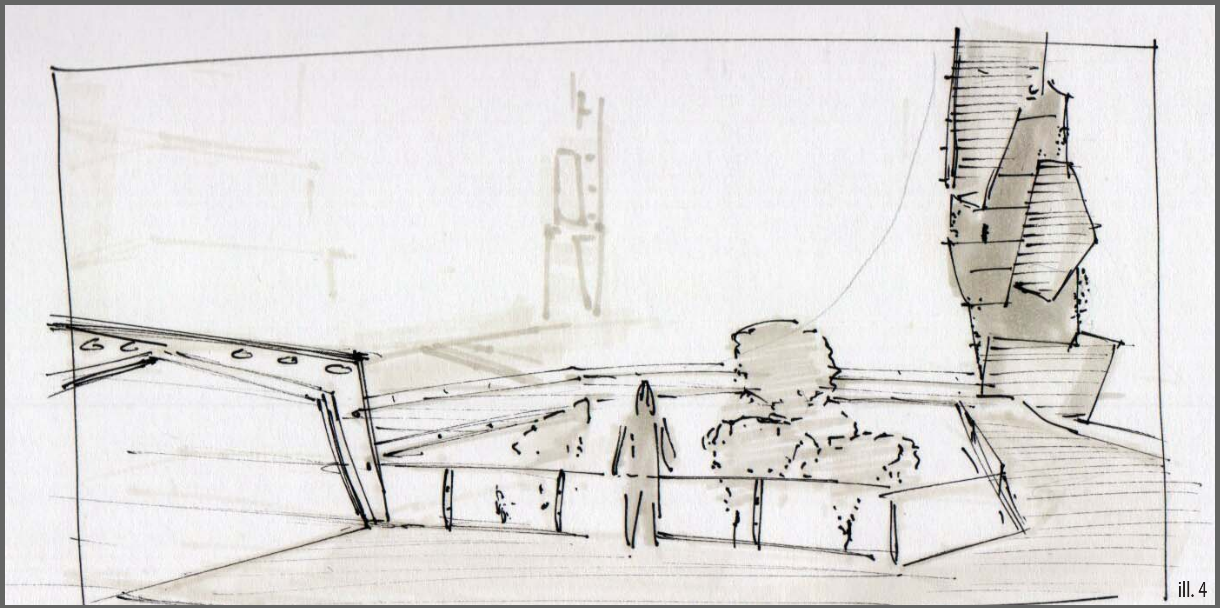
# Design phase 2
## Building concept

The first sketching on the building concept displays a large range of different ideas. The general theme of this phase, is a further development of the high-rises and the coherency between these. The result is a brainstorm of different architectural expressions.


ill. 1


ill. 2


ill. 3



ill. 4


ill. 5

ill. 1: An example of the high-rise with a more fragmented and layered expression. The concept seem more airy and in touch with human scale.

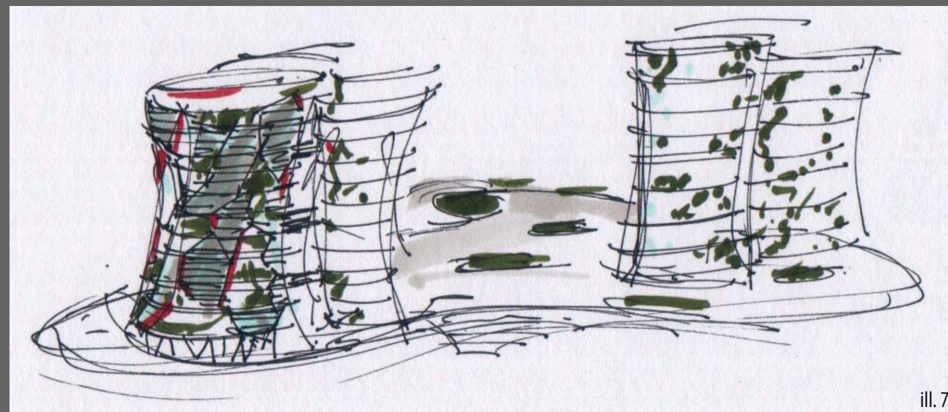
ill. 2: The high-rises are kept within an outer repeating structure. The freedom of the structure makes it possible to create openings for vertical gardens and paths into area.

ill. 3: Combining the high-rises through the use of a more heavy base which could be used for less expensive apartments and different public functions.

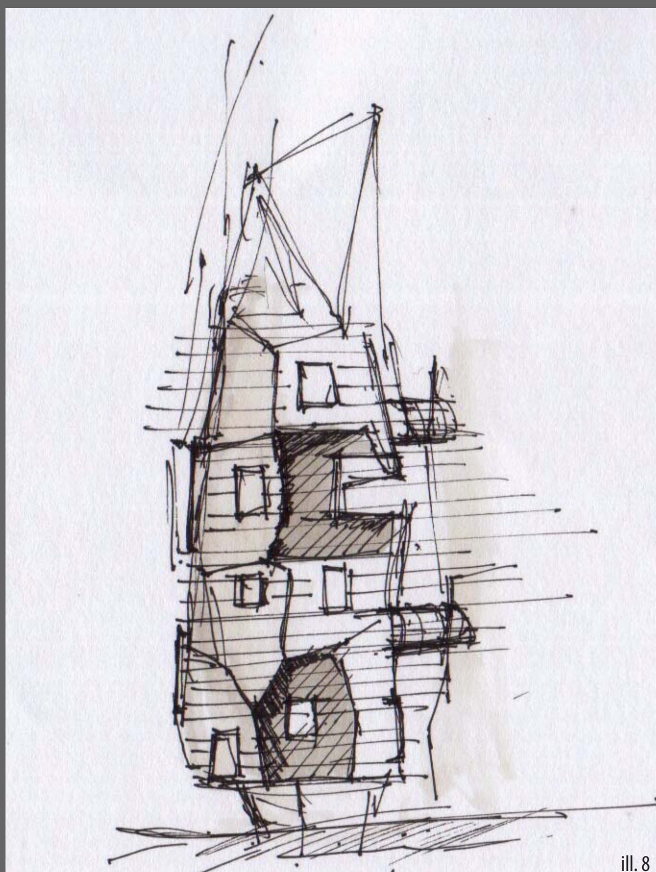
ill. 4: The high-rises are connected in the height with paths that offer a 3-dimensional urban experience.

ill. 5: High density with vertical green areas. Provides the cityscape with a nice variation and varied outdoor areas.

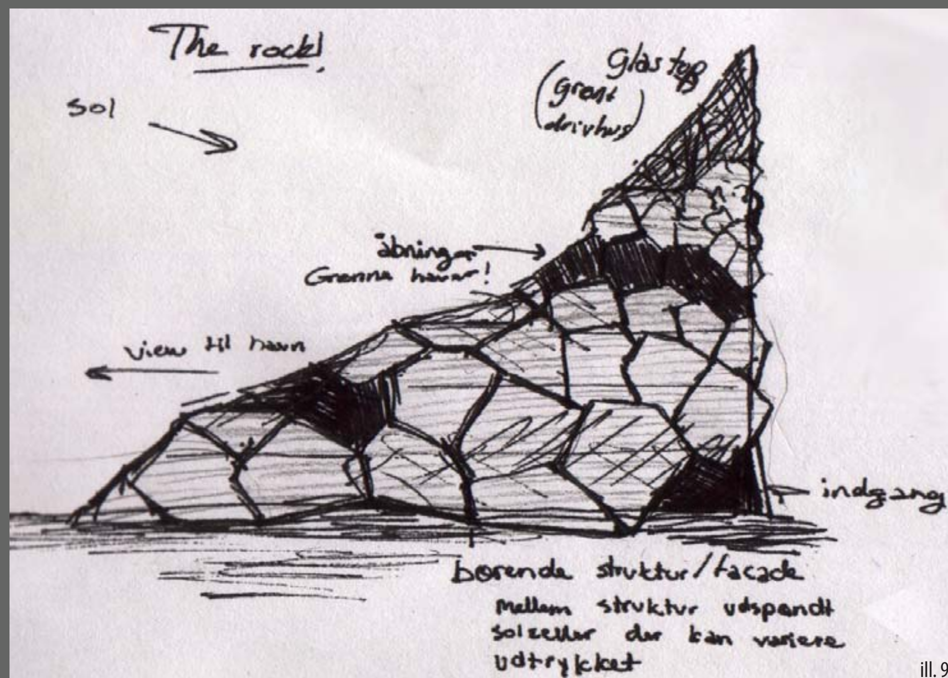
ill. 6



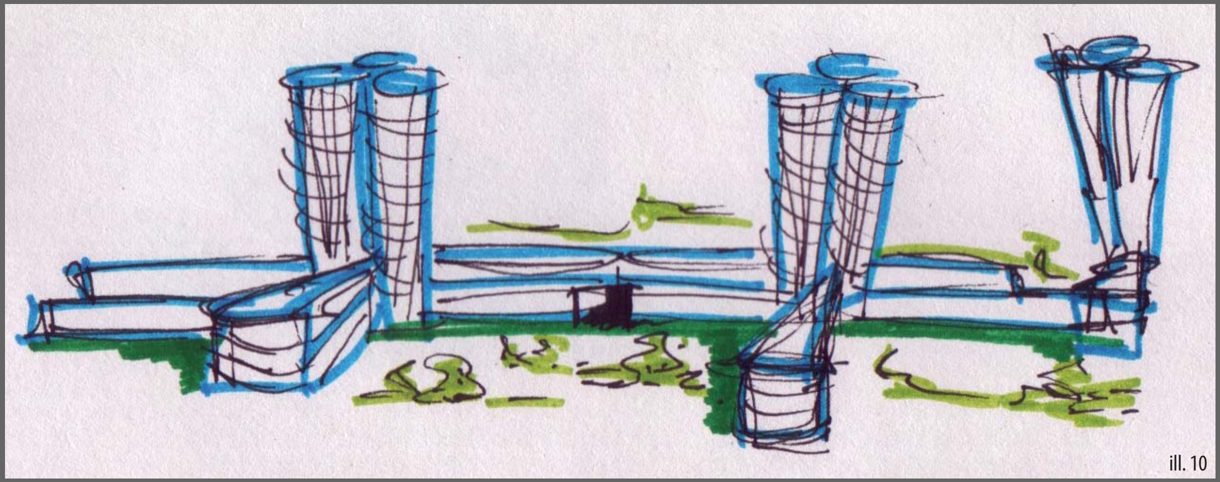
ill. 7



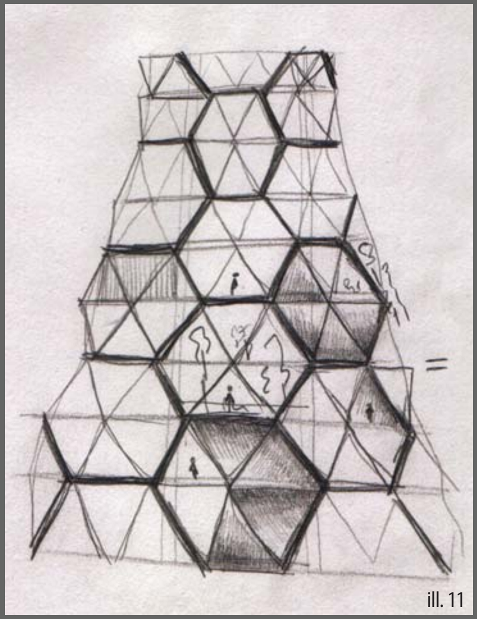
ill. 8



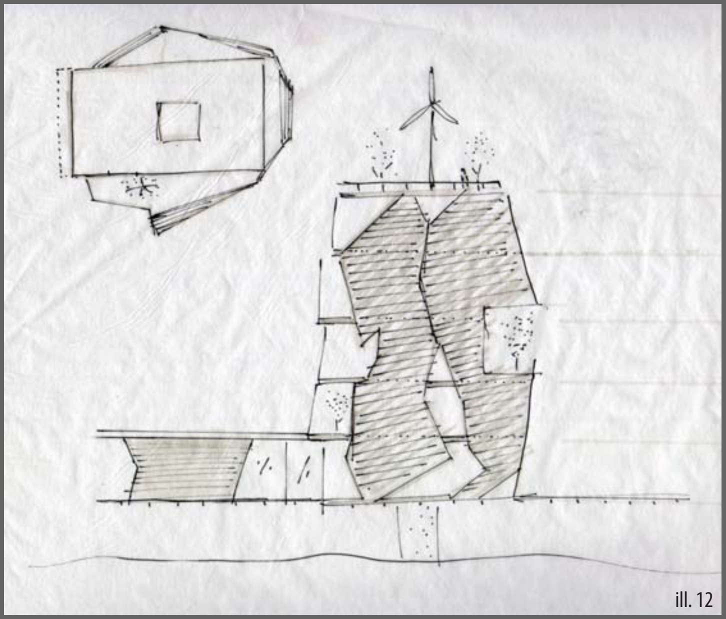

ill. 9



ill. 10



ill. 11



ill. 12

ill. 6: Concept of integrating the suburb within a structure while maintaining green areas = a more optimized and dense city area.

ill. 7: Dense high-rises with large open areas.

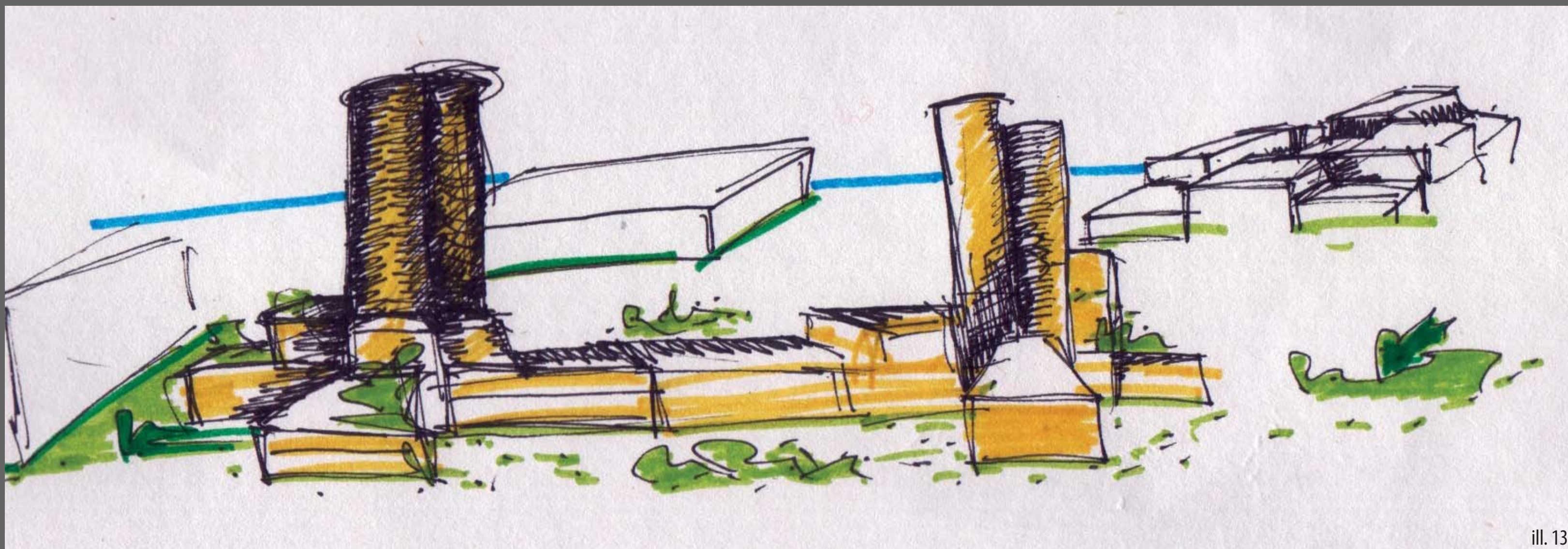
ill. 8: Further development of a more fragmented building structure and complex architectural expression.

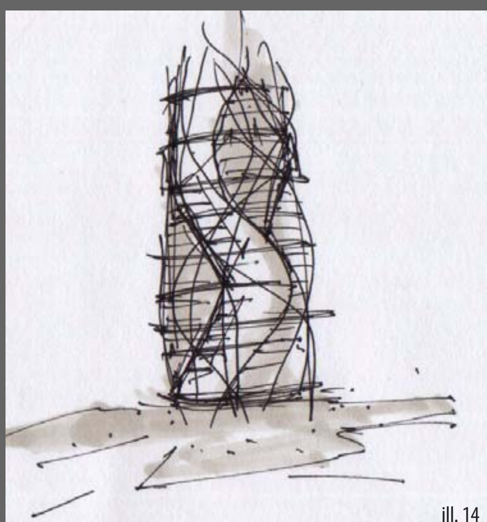
ill. 9: The concept gives associations to a mountain with the very edged structure, green openings containing various outdoor areas and a roof of glass used as a greenhouse.

ill. 10: The small footprint and arrangement of the high-rises in small "clusters", gives the opportunity of large open areas.

ill. 11: Example of a high-rise with a fixed facade-grid that allows for a flexibility in the use of photo voltaic panels and open views.

ill. 12: The facade/climate screen is seen as independent of the underlying building structure. This gives the facade the freedom to be placed according to the conditions of wind, sun and view.


ill. 13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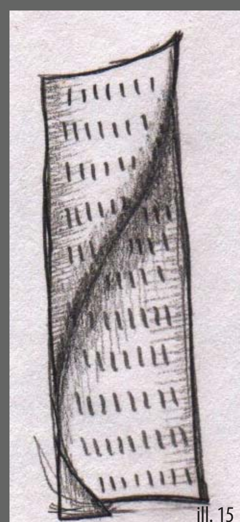
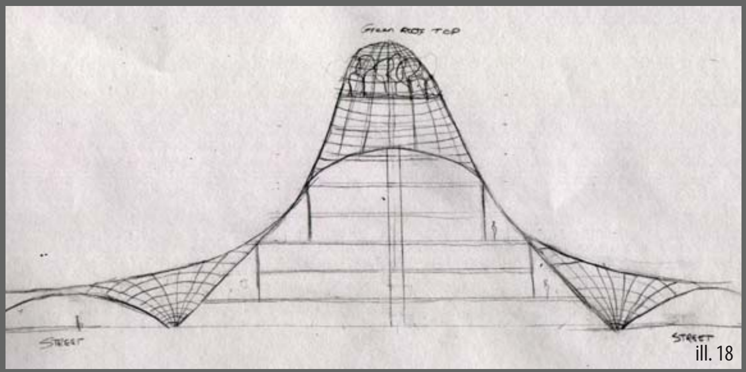

ill. 15


ill. 16


ill. 17

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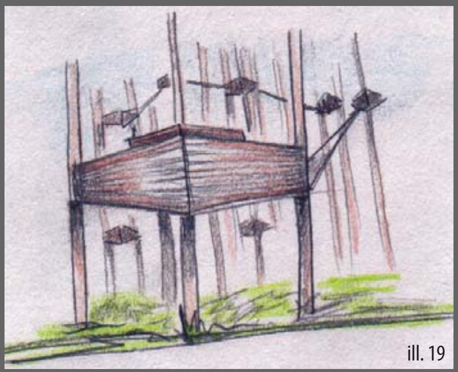

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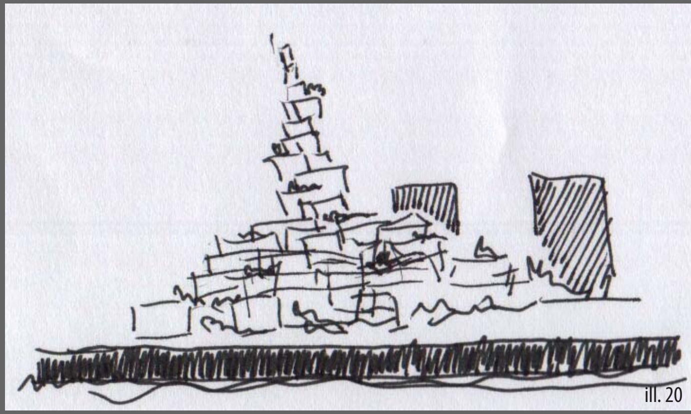
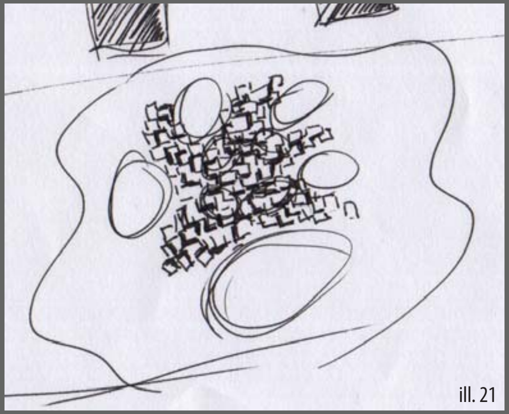


ill. 20



ill. 21


ill. 22

ill. 13: Various plateaus build up towards the high-rises - making a hierarchy from the lower human scale towards the a dense city-like scale.

ill. 14, 15 & 16: Experimenting with more organic expressions.

ill. 17: Stepping up the high-rise.

ill. 18: The concept of having a "net" stretched out between the building volumes, and integrating photo voltaic panels as a flexible facade solution also between the volumes as roofed streets.

ill. 19: Tree houses: an ecological concept of having the city in the heights, giving room for large green areas due to a simple grid distributed throughout the site.

ill. 20: The concept of the detached house as a building block, stacked into a tower.

ill. 21: Illustration 20 seen from above.

ill. 22: Same principle as seen in illustration 18. The continuous structure between the volumes creates a coherency of the area, while being flexible in the use of photo voltaic panels.

# Design phase 3
## The high-rise

To get a more realistic and detailed image of the apartments and the architectural expression, and to not least create coherency between the two, the ideas from the previous design phase is translated into more measurable floor plans and 3D-models.

The tools used are mainly: analogue sketching and digital sketching in Revit Architecture, Rhinoceros and 3ds Max Design.

After an investigation of typologies and sketching on building concepts, the need for inner spatial qualities and more detailed floor plans is present.

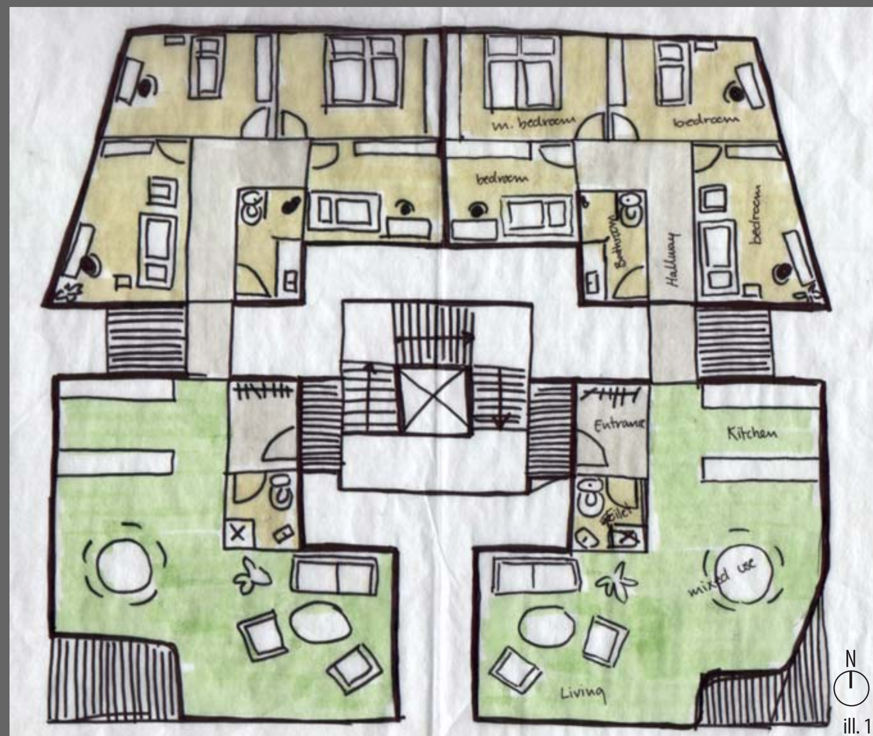
The main principles for the apartment:

- The apartments should be rather compact to ensure a low heat loss, but without compromising the feeling of spaciousness and access to daylight. Daylight from multiple directions will also be preferred.

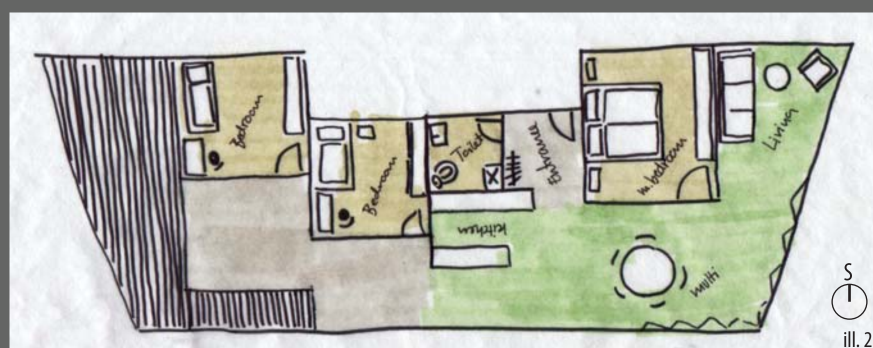
- The layout of the floor plans should be rational and easy to furnish, to make it flexible and adjustable to changing needs of the user.

- Focus on the social rooms (kitchen and living room), which should have a visual connection and be a central element in the ground floor.

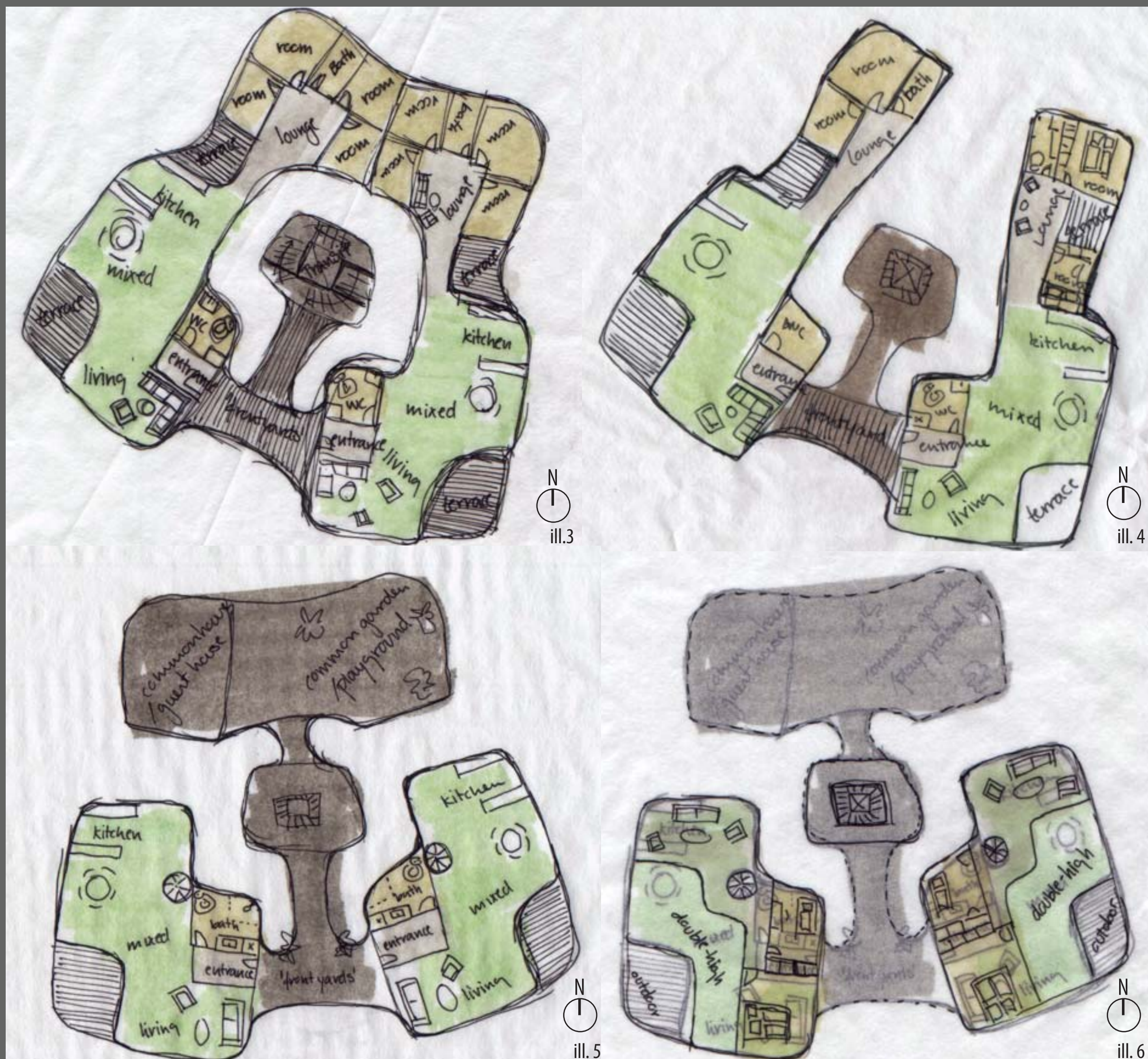
- Access to private outdoor areas should be an integrated part of the plan development.



ill. 1



ill. 2




ill. 1 & 2: The floor plan consist of two large apartments as seen on the sketch, or three apartments by replacing the bedroom-area with the apartment seen on illustration 2, while making the others 2 storey apartments. The flexibility of connecting apartments both vertical and horizontal is an interesting quality of this proposal, but the expression of having connections between high-rises gets lost due to the little spaces between the volumes. Instead the buildings appear as one rather large high-rise, not as light and airy as wished for.

ill. 3 & 4: Working with an organic shape to create a light outer expression underlined by large spaces between the apartments.

ill. 5 & 6: The volume dissolves and becomes more airy as the apartments is moved apart and made double-high. The integration of vertical common areas/gardens gives a dynamic variation and openness to architectural expression and the expression of connected high-rises also becomes more clear now.

# 1st Iteration

To visualize the coherency between floor plan solutions and architectural expression, different digital models are carried out.

The parameters which the models/plans will be evaluated by are:

- Flexibility - both in placement and orientation of apartments.
- Light, airy and spacious architectural expression (daylight an important necessary resource and quality of the apartments).
- Proportions, direction, dynamics and variety.
- Good plan solutions (outdoor areas, degree of privacy, inner spatial qualities, access to daylight etc.).
- The building should be a testimony of an environmental concern and approach to architecture.
- A somehow futuristic expression will be preferred, since the area at Nordhavnen will be developed into a new sustainable city area within the next 40-50 years.

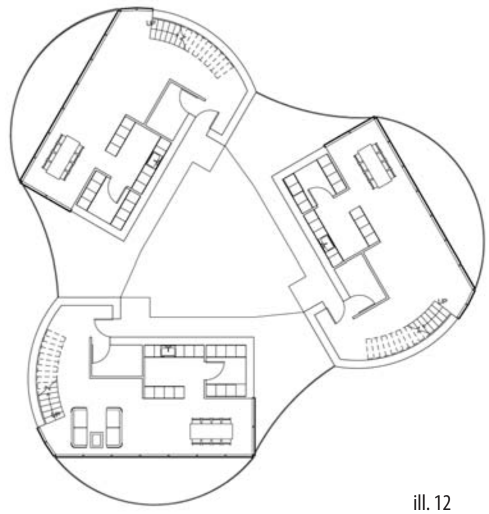
ill. 7

ill. 8

ill. 9

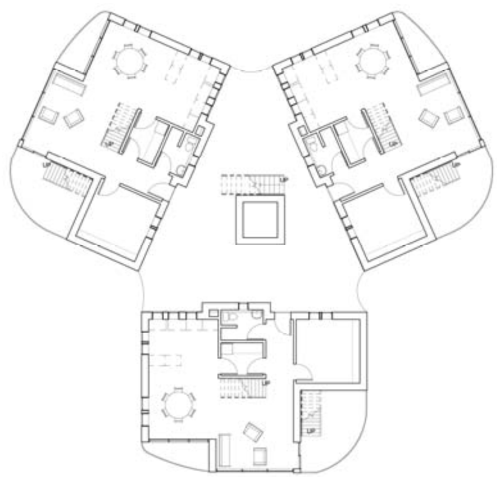
ill. 10

ill. 11



ill. 12

ill. 13



ill. 14

ill. 7, 8 & 9: Models from 3ds Max Design 2010.

ill. 10, 11 & 13: Models from Revit Architecture 2010

ill. 12: Ground floor [ill. 11].

ill. 14:  Ground floor [ill. 13].

All the examples shown to the left explores different architectural expressions of the high-rise.

The arrangement of the high-rises in smaller clusters appear rather heavy and massive [ill. 7, 11 & 13], whereas by decreasing the number of high-rises the expression becomes more airy and light [ill. 8, 9 & 10]. This brings back the dilemma of building dense while maintaining a feeling of spaciousness. It is decided though to work with a more free-standing high-rise, also due to its higher flexibility in orientation and placement on the site. Illustration 12 and 14 reveals the cons of the arrangement in smaller clusters, having always at least one northern orientated apartment.

## 2nd Iteration

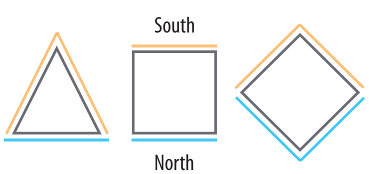
The development of the single free-standing high-rise will be evaluated by the same parameters as before (p. 132), but with more attention on the airy and light architectural expression and the flexibility in orientation/ placement on the site.

The sketched apartments are designed as to consist of: a living room, kitchen area, bathroom, sleeping room, two toilets and two children rooms.

The icons below [ill. 15] illustrates some thoughts about simple geometric shapes (footprints) and their possibilities:

- The triangle has the beneficial quality of having a 2/3 of the surface area southerly orientated and 1/3 northerly.
- The square: only has 1/4 or 1/2 of the surface area southerly orientated.

The importance of these assumptions are further investigated in the synthesis phase.




ill. 15

ill. 16: The apartment The architectural expression arise as a result of the plan solution which is constituted by the arrangement and adding of outdoor areas and rooms of varied sizes and functions [ill. 19 & 20]. The outcome is regular floor plans which are easy to furnish, but also a high surface area due to the complexity of the apartments. Another disadvantage is the apartments one-way orientation towards south [ill. 15 - square], which gives it a minimum of flexibility in orientation and placement on the site.

ill. 17: The floor plans are arranged within the boundaries of the triangular shape, which makes the apartment more compact than the example seen on illustration 16.

The quite good flow and distribution of rooms seen in illustration 19 and 20 is sought to be preserved in the triangular floor plans. The visual connections between the social rooms also allows the access of daylight from several directions.

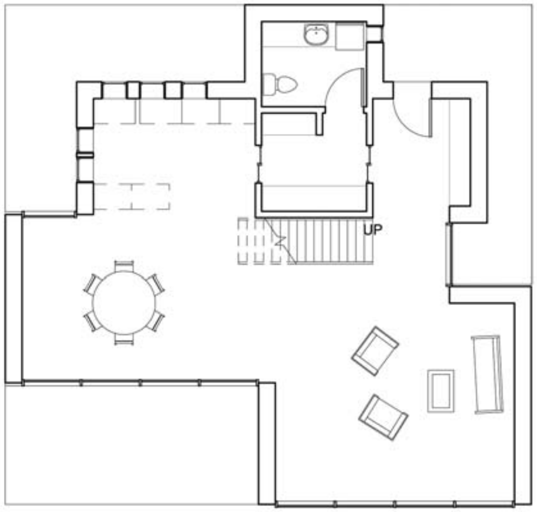
ill. 18: The apartments mainly have window towards south and is rather compact. The rooms though, needs to be optimized according to wasted areas and access to daylight and natural ventilation in all rooms.

The outdoor areas orientated in different directions gives good opportunity for always having privacy and sunlit terraces during the day.

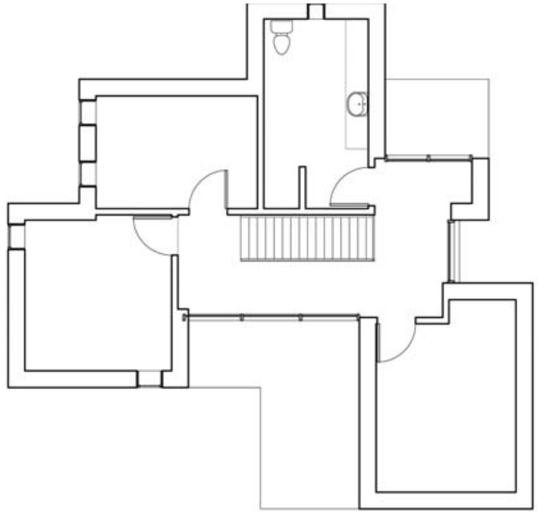
ill. 16

ill. 17

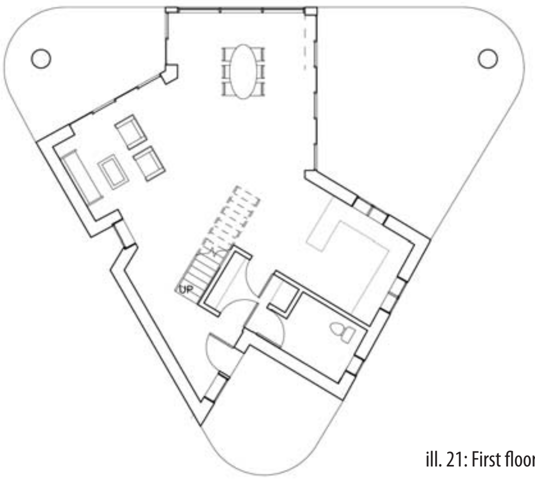
ill. 18




ill. 19: First floor.

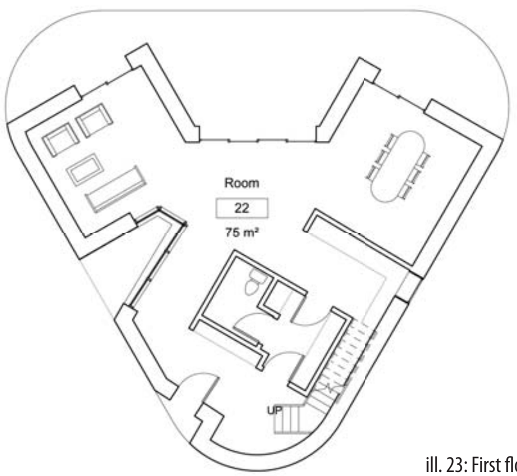


ill. 20: Second floor.

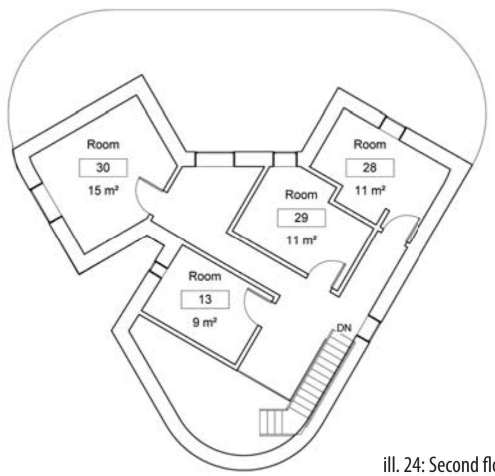



ill. 21: First floor.


ill. 22: Second floor.




ill. 23: First floor.




ill. 24: Second floor.

## Further development

The triangular shape has both architectural and sustainable qualities which will be investigated and developed on in the following sketching phases. Also the coherency between the inner and outer experiences should become better integrated. The clean white models [ill. 16, 17 & 18] has a resemblance to modernistic architecture, whereas the vision of the project is to be more futuristic. Trough a further sketching of the facades and floor plans, a more sustainable and futuristic architectural expression should be developed.

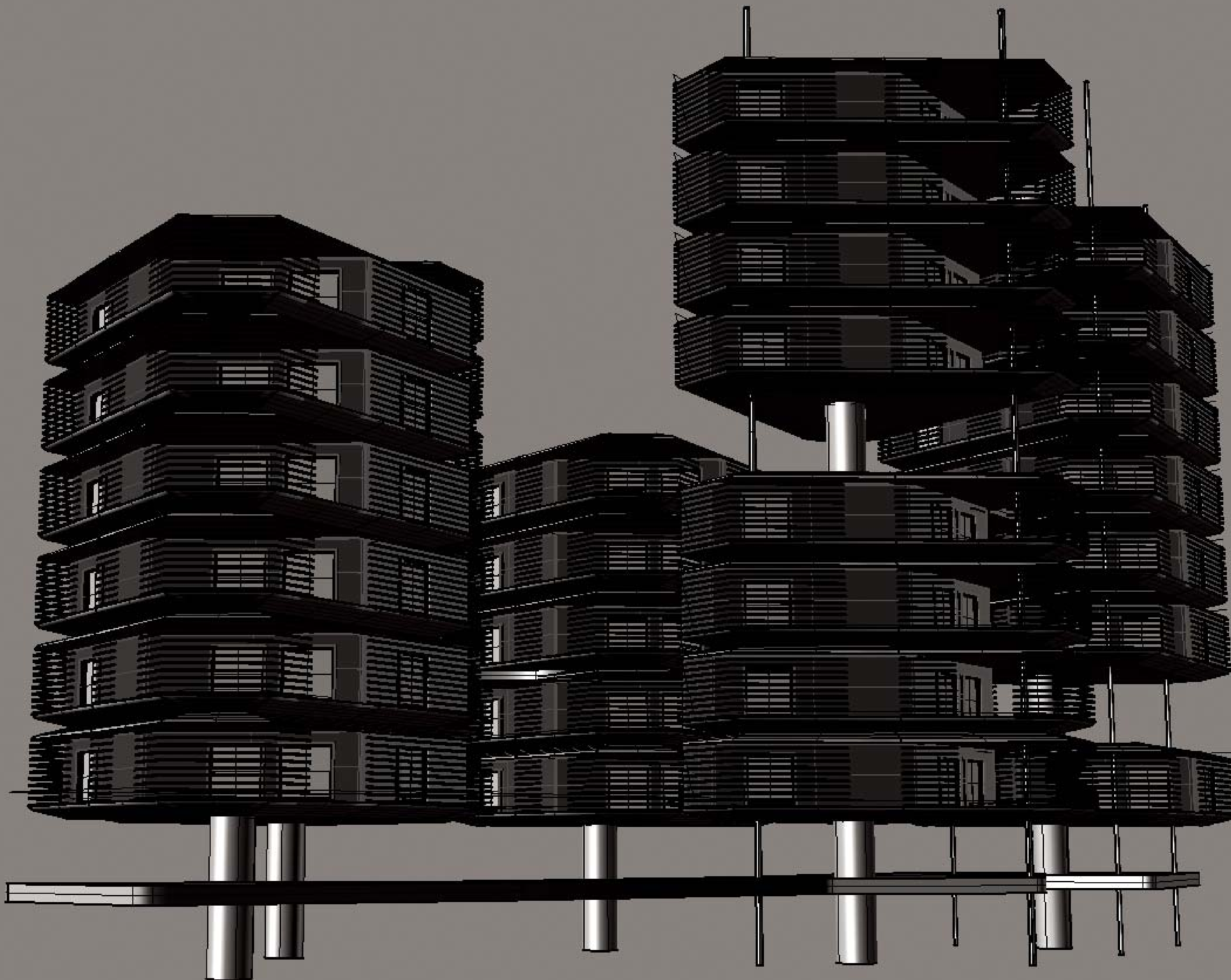
## 3RD ITERATION

The visualization on the opposite page illustrates a good example of the architectural vision.

The sustainable nature of the building is revealed in the architectural expression, by the use of an ever changing and flexible facade with integrated photo voltaic cells. This meeting between high tech solutions and basic design principles results in a slightly futuristic expression.

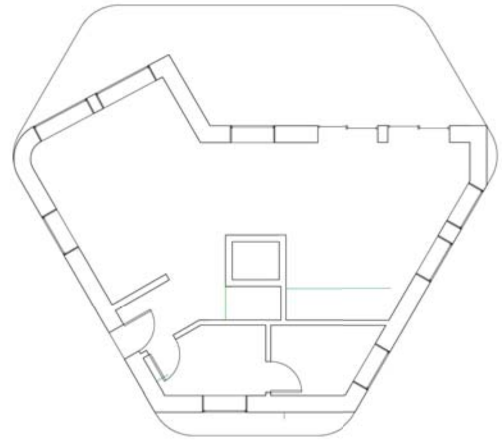
The architecture is multi-layered and incorporates many interesting facets and angles. The high-rises forms a whole despite the modular units constituting the apartments.

The concept, in agreement with the vision, concerns itself with how architecture should and could look like, be used and built - an example of the urban dwelling of tomorrow.

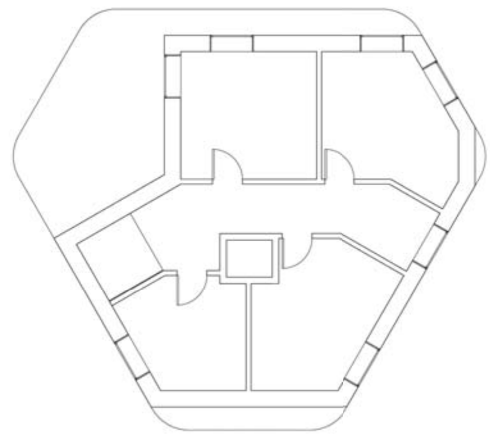


ill. 25: Concept of the high-rise with an evident futuristic architectural expression.

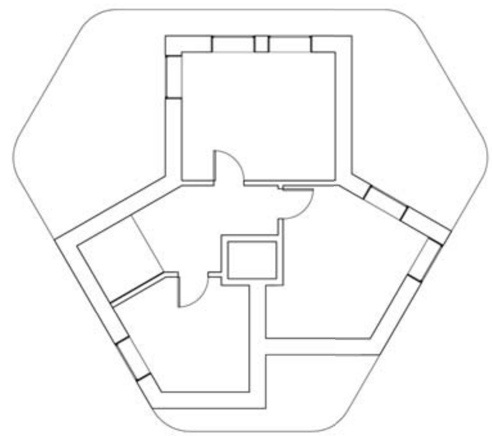
ill. 26



ill. 27: First floor.



ill. 28: Second floor - unit 4.



ill. 29: Second floor - unit 3.

## 4th Iteration

The picture to the far left is a physical model, which were used to investigate the flexibility of the floor plans [ill. 27, 28 & 29].

The floor plans now incorporates a central core used for installations, such as ventilation, electricity  and plumbing. The gathering of these makes reparations and maintenance much easier, while the core also can be used as a central load-carrying element.

The first floor is similar in all the apartments, while the second floor differ. The apartments can be reflected around the axis cutting through the core, providing an opportunity to give more variation and dynamics to the outer expression.

The apartments have been made more compact with better utilization of floor area. Different orientation of the outdoor areas expands the possible time of utilization.

## Further development

To ensure a relatively high density of the area and the interrelationship between the high-rises, a master plan should be developed. Also the access to the apartments, the common areas, parking and public functions should be detailed in the further development.

# Design phase 4
## Distribution of buildings

After having an overall idea of the building design, it is necessary to get an understanding of its relation and placement within the context.

The urban planning will be evaluated by:

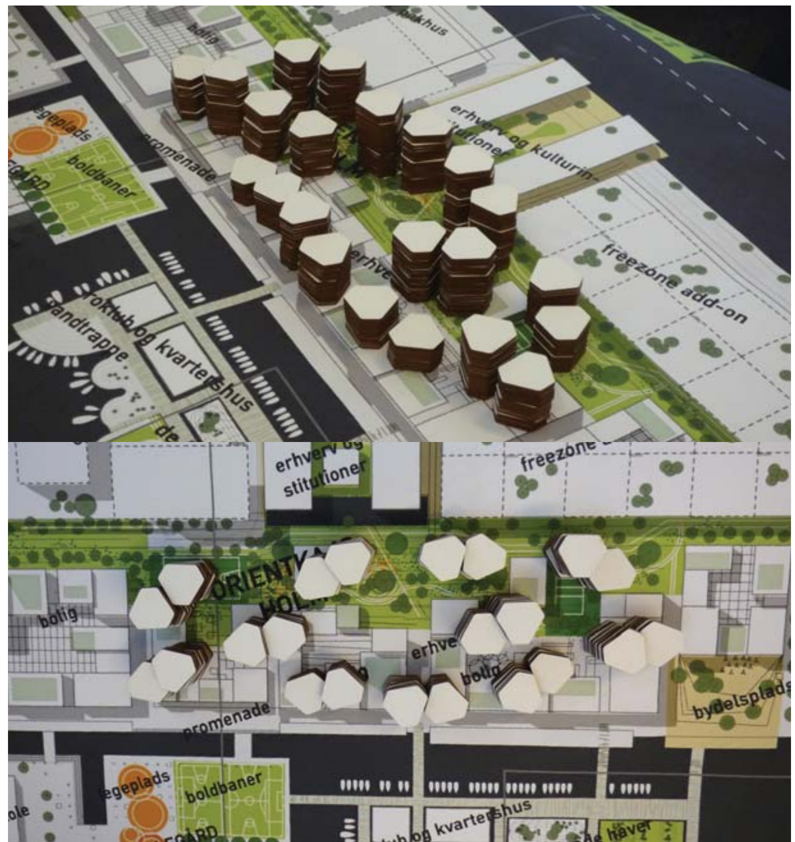
- The daylight conditions for each building.
- Relation to the area.
- The relation and spaces between the buildings.
- The access to each apartment.

Ill. 1:
Pros
- The buildings are higher towards north and lower towards south, ensuring better access to daylight, while providing nice views for more people.
- All the apartments have the opportunity of a southern orientation towards sea and sun.
- A lot of space for green areas between the high- and low-rises.

Cons
- The urban plan lacks a hierarchy between public and semi public areas.


Ill. 2:
Pros
- High buildings towards north and lower towards south.
- Outdoor areas is more defined with one large semi-public area in the middle of the site, and two public spaces towards the promenade.
- The buildings are grouped as pairs with possibility of shared entrances.
- A lot of space for green areas between the high- and low-rises.

Cons
- The vision of having detached houses in height is unclear, due to the arrangement of high-rises in pairs.





Ill. 3:
Pros
- The high-rises are arranged in smaller clusters of three, with semi public areas and access in between.
- Creation of public spaces towards the promenade.
- The buildings stands as individual high-rises, which underlines the vision of having the detached house in the height, with air and privacy around them.
- A lot of space for green areas between the high- and low-rises.

Cons
- The arrangement in smaller clusters with shared entrance, creates a larger shape, which do not correspond well with the context.
- No clear definition of public or the green areas. The outdoor arise randomly between the buildings.

Ill. 4:
Pros
- Well-defined semi-public areas inside the 'circles', as well as entrances.
- High buildings towards north, low towards south.
- The maximum height of the building complex are 4 floors, which gives it a more human scale.

Cons
- The zoning of public and private areas are not clearly defined.
- The green areas becomes smaller than at some of the other suggestions, due to the decrease of building height and thus a larger footprint.

## Further process

At this point the clear hierarchy of how the buildings should relate, to each other and the context, are still undefined.

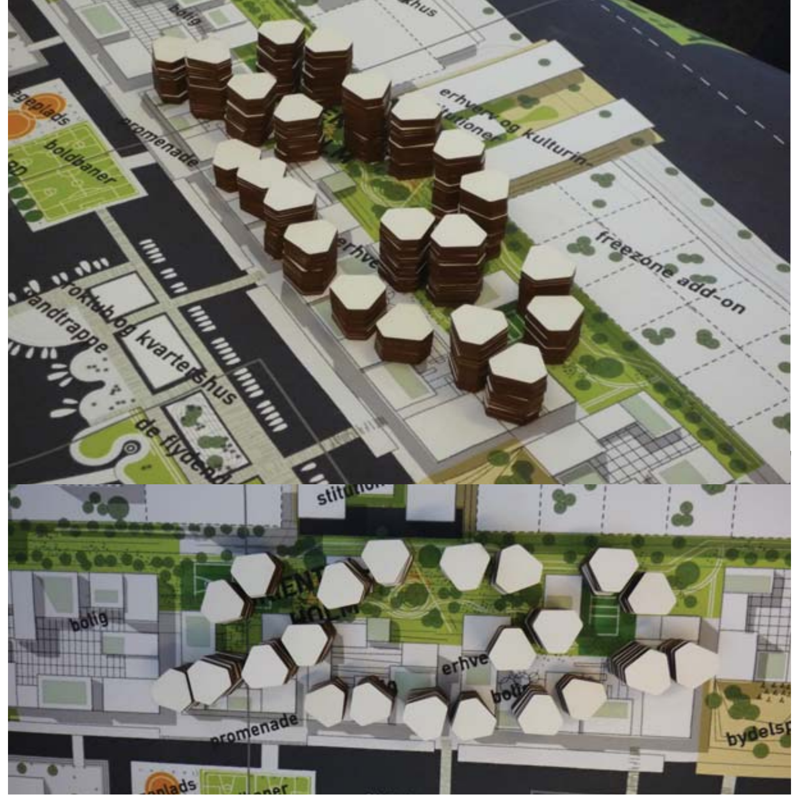
It is wanted to get more defined areas for the occupants - and clear public areas. This will be one of the main issues to solve in the next iteration.

# 1ST ITERATION

Ill. 5:
The plan has some of the same advantages as the examples shown on the previous pages:

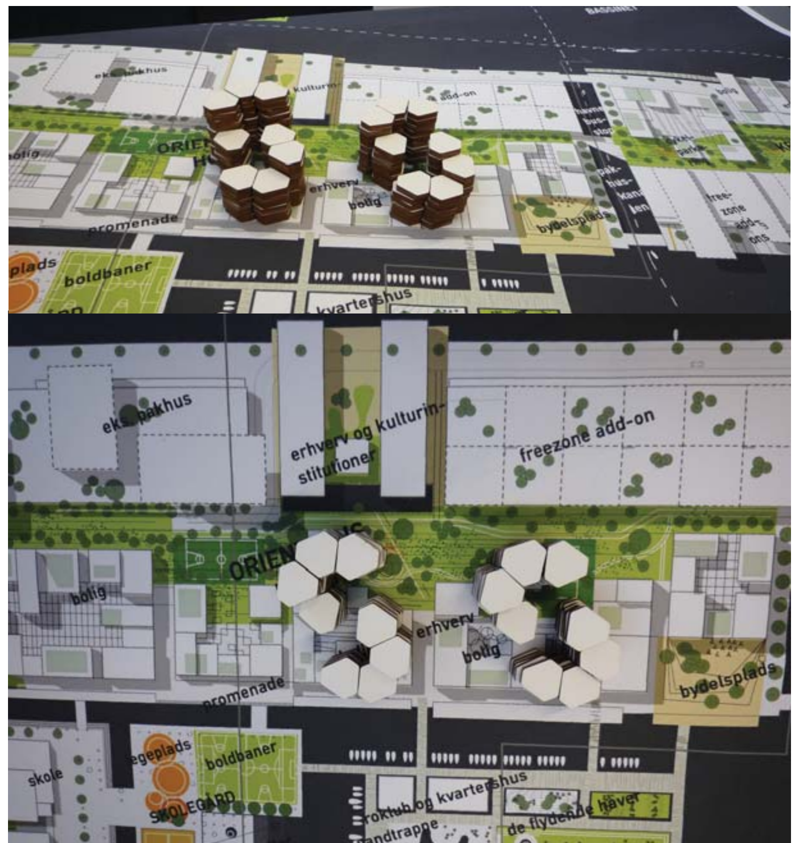
- The buildings are higher towards north and lower towards south.
- One large semi-public area in the center of the site.
- Two public spaces towards the promenade.
- Varied green areas between the high- and low-rises.

One of the main qualities are the clear reference to the vision of having the detached house in the height.




Ill. 6:
Pro's:
- A clear definition of smaller semi-public and entrance areas.
- The compact placement of the high-rises, gives room for large green areas on the site.

Con's:
- Some of the northern orientated apartments has little access to daylight.
- The high-rises does not correspond with the near context.
- The typology seem very enclosed due to the dense placement of the high-rises.




Ill. 7:
Pros
- The buildings surround two large semi public areas.
- Highest buildings towards north.
- Creates different public spaces towards the promenade and square.
- Air and space between the individual high-rises.

Cons
- There is still an undefined hierarchy when looking at the buildings orientation. The distribution of the high-rises appears random and unclear.


Ill. 8:
Pros
- One large semi-public area.
- All the high buildings are towards north.
- The differentiation of height gives the area a more human scale.

Cons
- A clear separation of public and areas are lacking.
- The green areas becomes smaller than at some of the other suggestions.
- The area appears as rather big, which compromises with the suburban feeling of small communities and the feeling of unity and belonging.

## Further process

When distributing the building complexes there appears a lack of relation to the surroundings, which are ordered in a regular city grid.

At the same time the characteristic shape of the building makes it possible to orientate all the dwellings optimal according to the sun and to gain from daylight.

The further process should develop better integrated common areas and a defined separation of public and private areas.

## 2ND ITERATION

One of the main criteria when integrating different common areas, is to provide the occupants with a diversity.

The variety of common areas in the height should be constituted by functions, such as:

- Common houses, which should provide both guests with the possibility for overnight stays and arrangement of private parties and so forth.
- Green gardens
- Playgrounds and so forth.

The integration of common areas will enhance the possibility of informal meetings and provide an opportunity for interaction between neighbors.

ill. 9: Integration of vertical gardens and common areas.


ill. 10: Examples of different outdoor activities, which could be a part of the common areas.

# 3RD ITERATION

Ill. 11:
As mentioned in the "2nd iteration" it is wanted to have a diversity of common areas. In this suggestion the lower floor plan as well as levels in the height, has been connected - defining different semi-public areas while separating private and public areas.

- The buildings are still higher towards north and lower towards south, providing more apartments with sunlight and better views.
- One large semi-public area in the middle of the site are defined by the surrounding buildings
- The edges towards the surroundings are very fragmented and seems quite random.
- Varied green areas between the high- and low-rises.


Ill. 12:
- The connected floor plan are divided into two with a large public passage through the area.
- Public paths through the site provides easy access to the waterfront, the town square and the playgrounds/sport facilities.
- The public appearance in the area is quite large.
- The division of the area gives the impression of two minor communities instead of one.
- The semi-public areas are only to be found on the connected floor plan.


Ill. 13:

- A well-defined base, which could consist of both shops, parking and so forth, gives a nice connectedness to the city grid of the context. When moving into the area the landscape of the base becomes more organic, relating more to the open green areas seen in the suburbs and dynamic expression of the building design.
- The one-way orientation of the buildings gives a clear indication of direction and a more restricted organization of the high-rises.


Ill. 14:

- This suggestion is quite similar with the one above. The main difference is the semi-public landscape between the buildings, which are a bit more dramatic.
- Towards the promenade the clear base dissolves in the middle to encourage to minor public stays, as well as towards the city square to the far right.

## Further process

The last two suggestions [ill. 13 & 14] gives a good indication of the wishes for the final master plan:

- A clear defined zoning between public and semi public areas.
- A definition of smaller communities.
- A dynamic and varied, yet integrated area.
- A large amount of green areas.

To figure out how the buildings relate to the context and each other in terms of accessibility to daylight, an overall investigation of shadows should be carried out in the further development.

# Conclusion

The chosen placement of the buildings provide a dynamic feeling to the area, which stands as a contrast to the planned rectangular building volumes of the surroundings.

**The context**
The buildings in the northern part of the area consists of offices, a storehouse and a new area, defined as a free-zone add-on by COBE. The term refers to the possibility of adding on/ to the existing building mass to both increase the density and bring more value/character to the new city area.

Towards northwest and southeast new building complexes will be created.

**The site**
The site should as mentioned before, be an area with both dwellings and businesses.

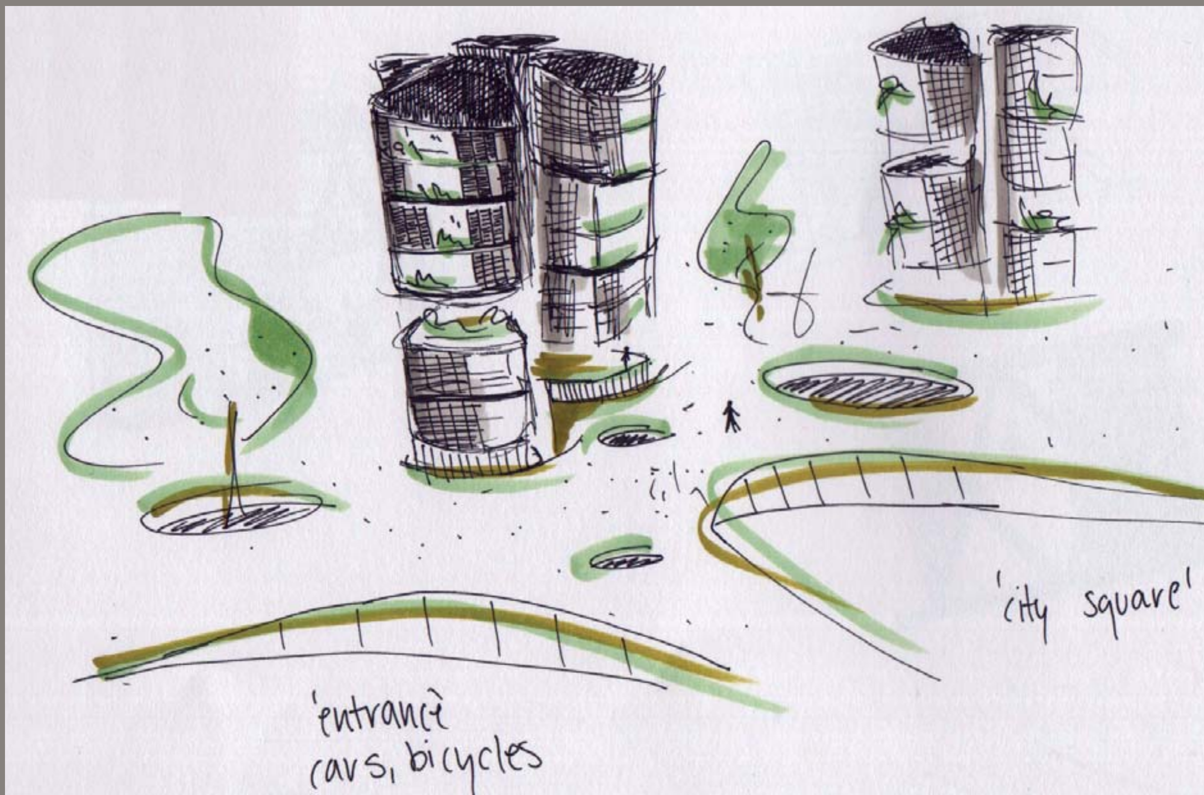
The area should provide the occupants, who normally prefer to live in the suburban areas, with a feeling of belonging and incorporate different suburban qualities such as; large green areas, privacy, air, gardens, playgrounds and so forth.

To provide the occupants with as much privacy as possible in the dense city area, the ground floor has been designed as a base containing: parking, shops and storage areas.

This creates a clear separation of public and semi-public areas. On top of the base a large green landscape with different elements from the suburbs, playgrounds and garden areas, is planned.

To give the area a more welcoming and human touch, vertical green areas should be added to break up the high continuos building masses, which surrounds the semi public areas.


ill. 15: Model of the urban plan.




ill. 16: Word picture of the urban plan .

## Further process

In the following chapter different detailing will be outlined, such as;

- The distribution of apartment types.
- The orientation of the apartments in each building.
- The definition of semi-public areas.
- The base.

# Design phase 5
## Shadow investigations

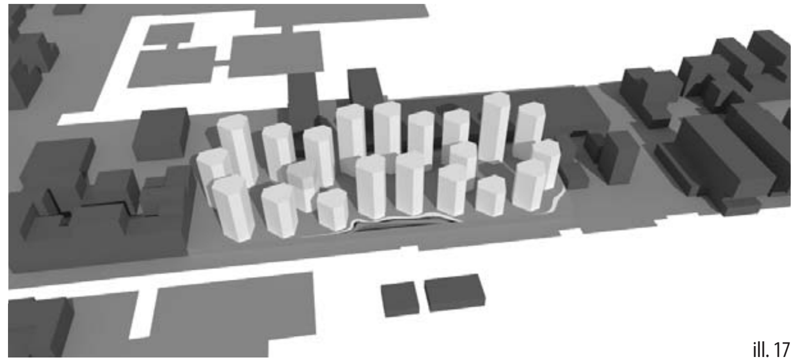
To get an understanding of how the buildings will be influenced by their own shadows and shadows from surrounding buildings, an investigation will be made to further optimize the placement and distribution of the high/rises.

From the previous design phase there has been chosen the specific placement of the buildings shown to the right [ill. 17, 18 & 19]. In the shadow scheme [ill. 20] it is possible to see how the graduation of height makes it possible for, most of the apartments, to gain daylight and passive heating from the sun during spring and until fall.

Caused by the shape of the buildings it is only at midday in summertime, that the semi-public areas are being exposed to the sun.

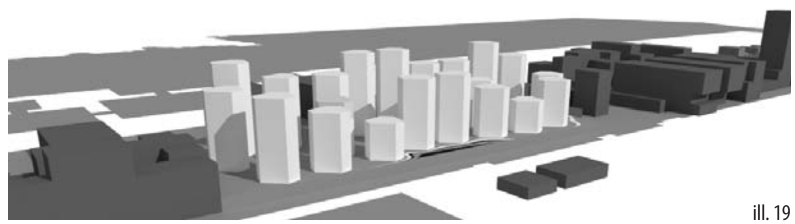
The buildings, which are placed towards northeast, has the least opportunity to gain heat and daylight from the sun at midday in wintertime. At summer, however, it is mainly in the afternoon that the buildings will be shaded.

- The building percentage including shops and dwellings with gardens= 156%
- The building percentage including; shops and dwellings without gardens=117%

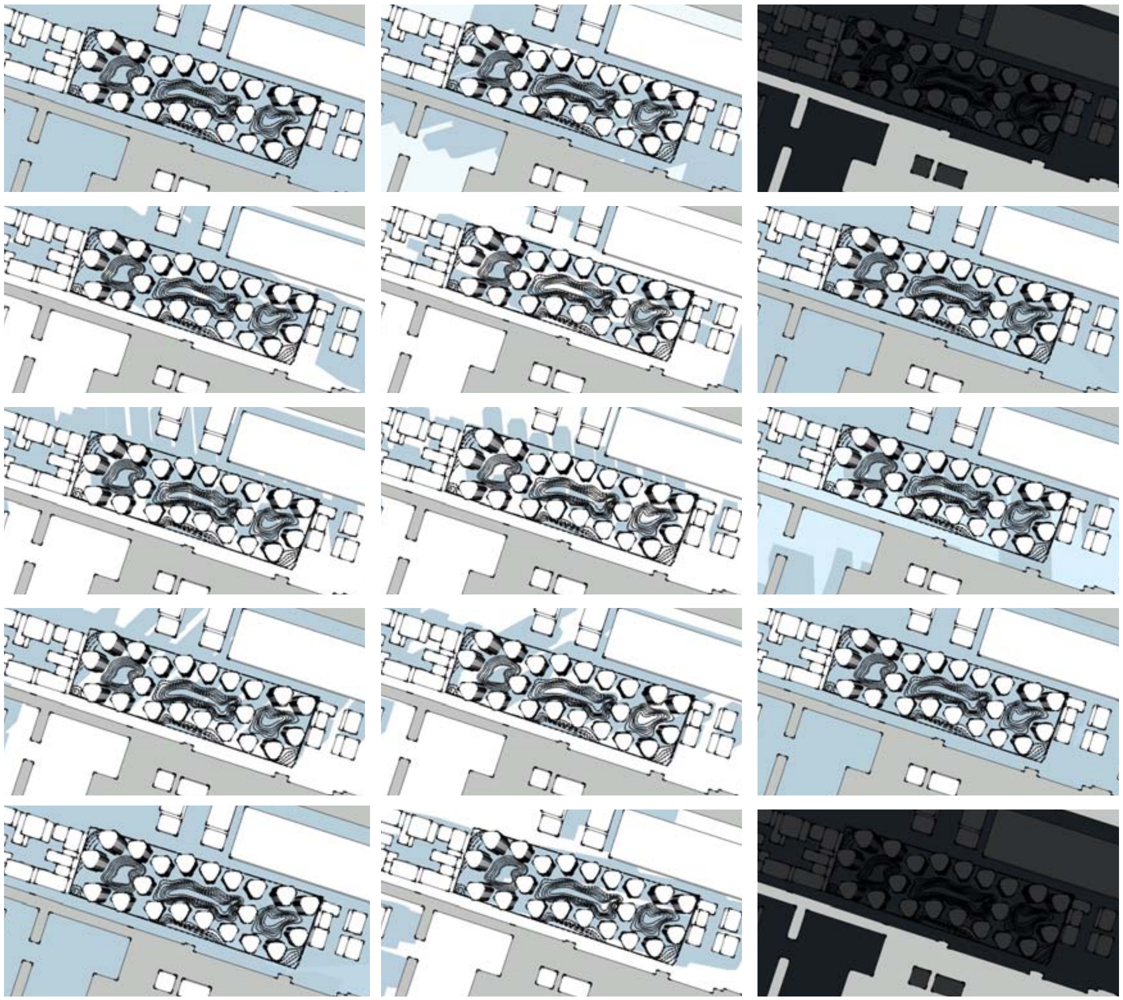


ill. 17

ill. 18



ill. 19




ill. 20: Shadow studies.

## Further process

When looking at the renderings the area seem very high in relation to the context, and when studying the shadow scheme, the lack of sunlit common areas is critical.

Because of this it is chosen to work with a lower building percentage, in order of not compromising with suburban qualities.

## 1ST ITERATION

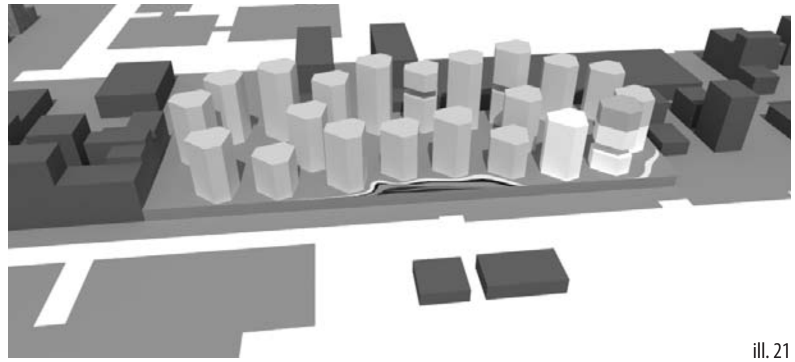
In the new plan [ill. 21, 22 & 23] there has been made some changes in the density to uphold some of the main criteria for the urban planning, which is to maintain many of the qualities from the suburbs while still building more dense.

In the new renderings the buildings seems more harmonic with the height of the surrounding building stock.

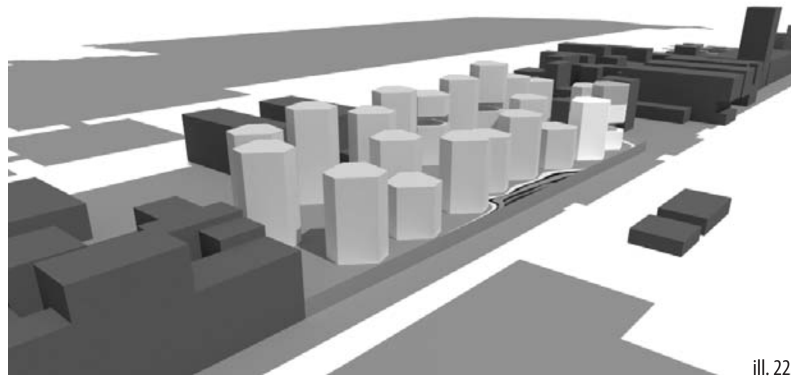
The buildings still scales down towards south and the plot is maintained the same but with a lower building percentage:

- The building percentage including shops and dwellings with gardens= 131%
- The building percentage including shops and dwellings without gardens=100%

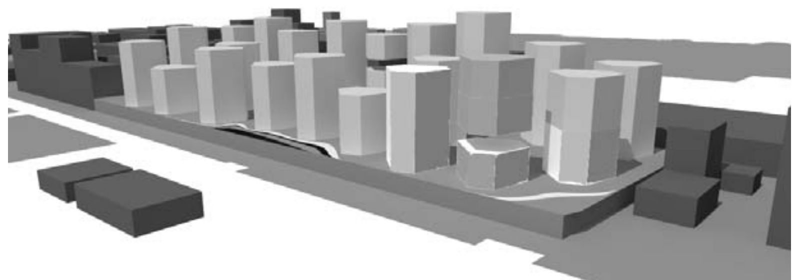
This is still a lot more when compared to the suburban areas, where the building percentage constitute only about 35%. This reduction gives the area a more welcoming human scale, not affected by shadings in the same degree as before [ill. 24].



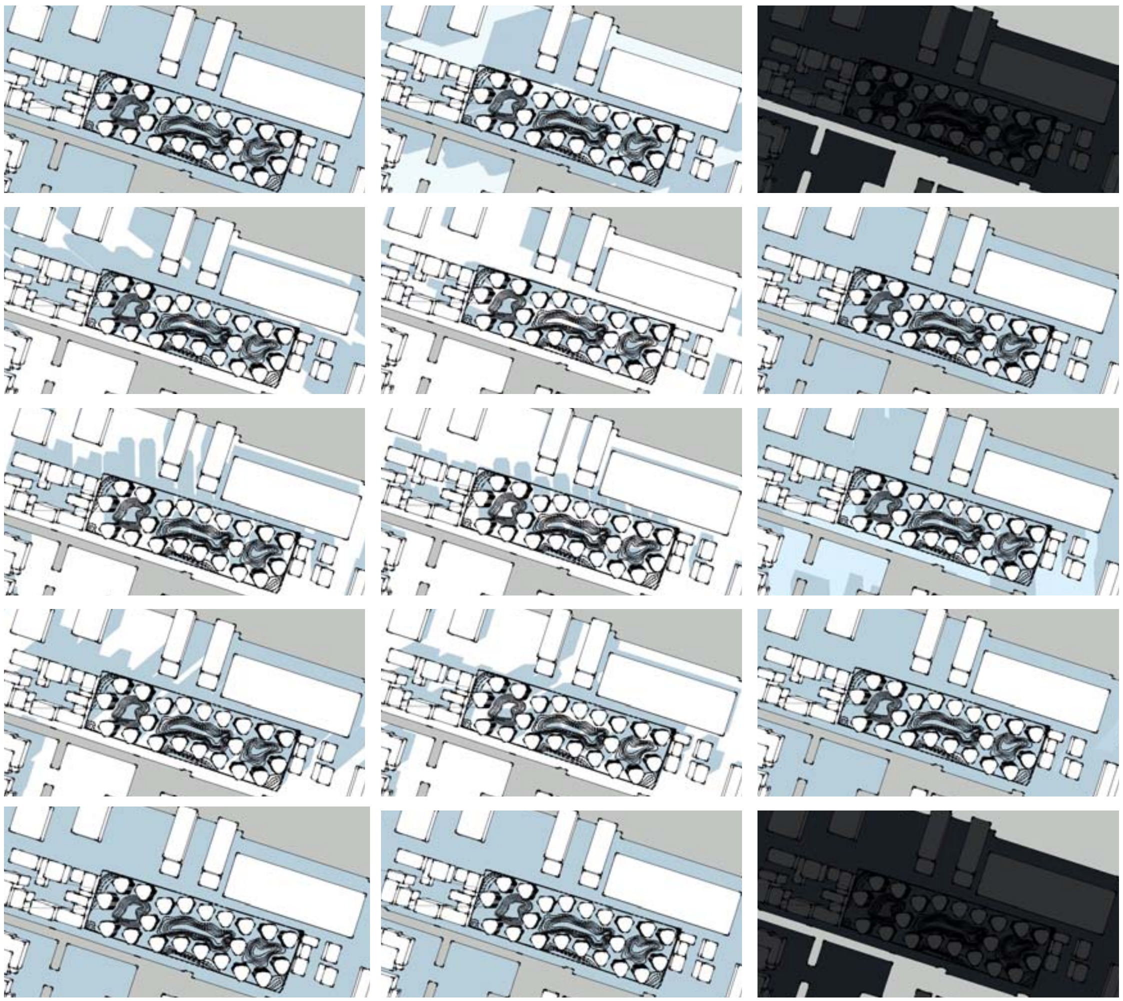
ill. 21



ill. 22



ill. 23




ill. 24: Shadow studies.

## Further process

The chosen placement of the high-rises and the functions of both public and semi-public areas, will be further detailed in the synthesis phase, concerning:

- Detailing of the base; parking spaces, storage etc.
- Orientation of apartments.
- Access and entrances to the apartments.
- Definition and distribution of common areas.

# Design phase 6
## Distribution of apartments

As mentioned in the room program the distribution of the different units in percentages*, will be as following:

- Unit 1 = 10% (13 apartments).
- Unit 2 = 20 % (13 apartments).
- Unit 3 = 30% (20 apartments).
- Unit 4 = 40% (26 apartments).

(*Percentage of total floor area).

This gives a total of 72 apartments and a building percentage of 131% (including the gardens and the shops at the base).

Unit 1 and unit 4 are both placed near the ground level. Unit 1 due to its design for disabled people and unit 4 mainly addressed for families, who wants near contact with the green areas. This leaves unit 2 and 3 at the top of the high-rises.

According to the criteria from Bolig+, which says that the dwellings between 110 $m^2$ and 150 $m^2$ should be placed towards the waterfront, a prevailing part of unit 3 and 4 has been placed along the promenade.

To give some variation in the building complex, a few smaller apartments has been moved near the waterfront.


ill. 25: Distribution of apartments.

ill. 26: Distribution of apartments.

ill. 27: Distribution of apartments.

## Further process

The density in the area is not very high, but because of the chosen user and typology, it is still necessary to investigate how the different apartments are placed and orientated in order to ensure privacy and good views.

When deciding the orientation of apartments, the placement of stairways and paths should also be considered.

# Orientation of the apartments

To get an understanding of how the different apartments relates to each other and how to access the apartments, the illustration to the right has been developed.

The main priority has been to provide all the occupants with a nice view towards either the water or the green semi-public areas, while trying to have as much distance as possible to the  nearby apartments.

Here the triangular shape really shows its worth, by having a high degree of flexibility in rotation and reflection of the floor plans.

## Paths and entrances

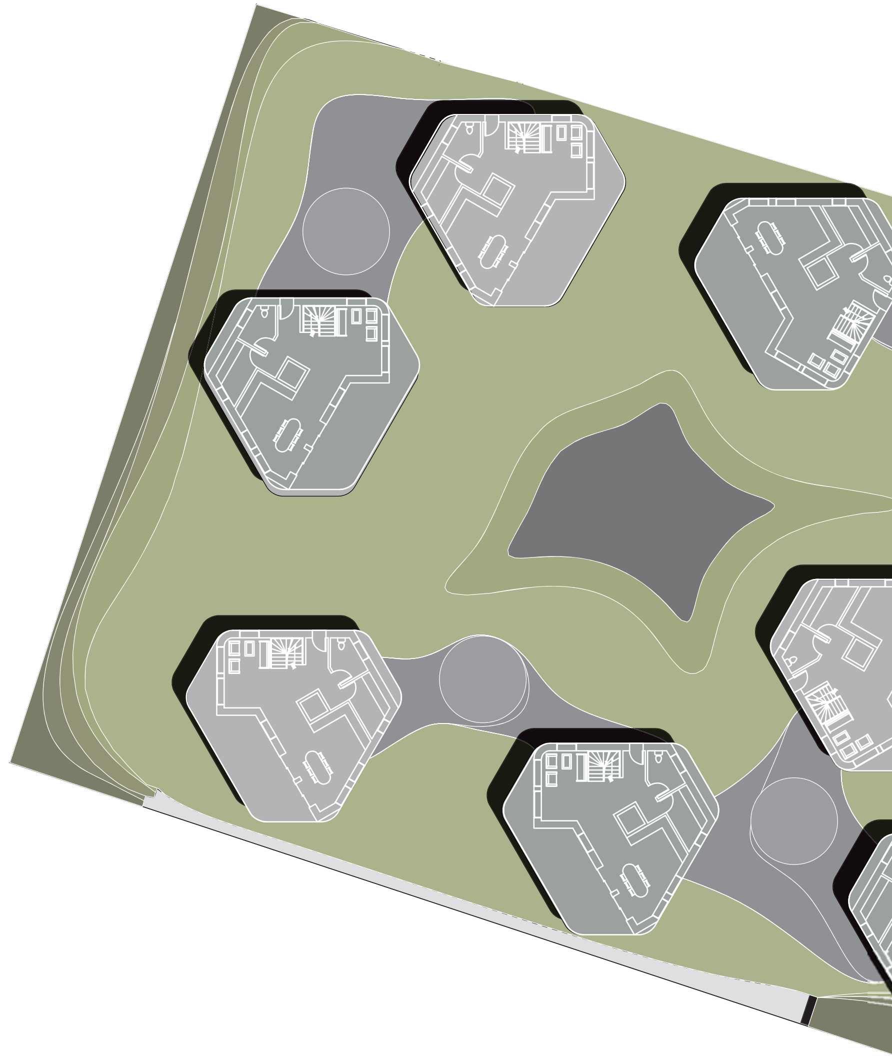
The entrances should be organic and sweep along the facades to be an integrated part of the architectural expression.

This provides the area with a connectedness between the different high-rises and common areas.

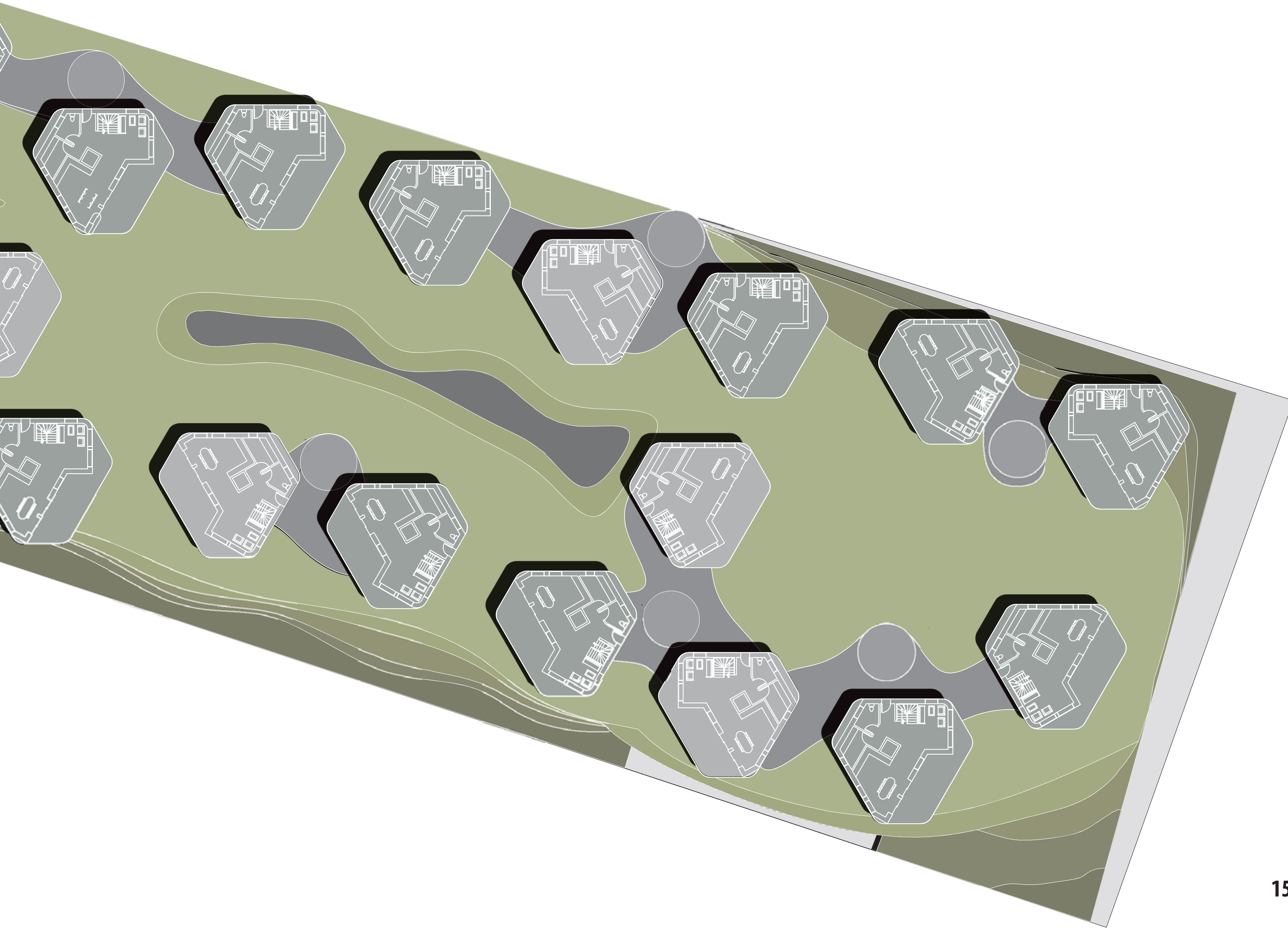
## Further process

The floor plans and the architectural expression should be developed into a coherent whole.

The concept is thought to have a flexible and energy producing facade, which will have a high and important influence on the architectural expression.




ill. 28: Orientation of apartments, 1:500.



# Design phase 7
## Facades

As a part of the early sketching phase, a large range of skinning and facade principles has been tried out, using both analogue sketching and 3D parametric models.

The intention were to identify different interesting concepts and discover methods for creating and visualizing such, hereby expanding the architectural language in the group.

At this time, the sketching is still very conceptual, and the facades is not thought in relation to a specific building design, due to the expectations, that the facade will have a great influence upon the building form and architectural expression. After a certain point though, this conceptualization should enter a dialogue between building form and interior plan dispositions.

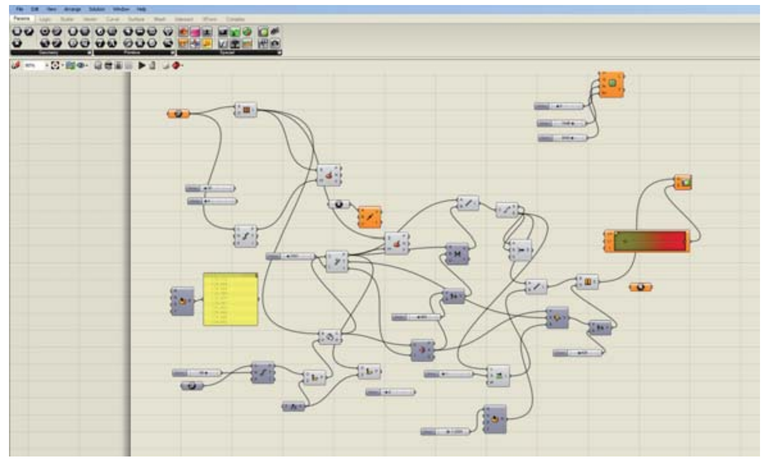
The facades/skins will be evaluated with parameters such as:

- Flexibility - in order to accommodate a non-static expression, but rather the image of a "living" building that respond to different inputs such as: user preferences, angle and movement of the sun (time of the year and the day) etc.
- Potential of incorporating energy converting elements, such as photo voltaic cells.
- Potential of having varied settings and individual shading factors on different parts of the building.
- Ability to have a differentiated openness in the building facade.

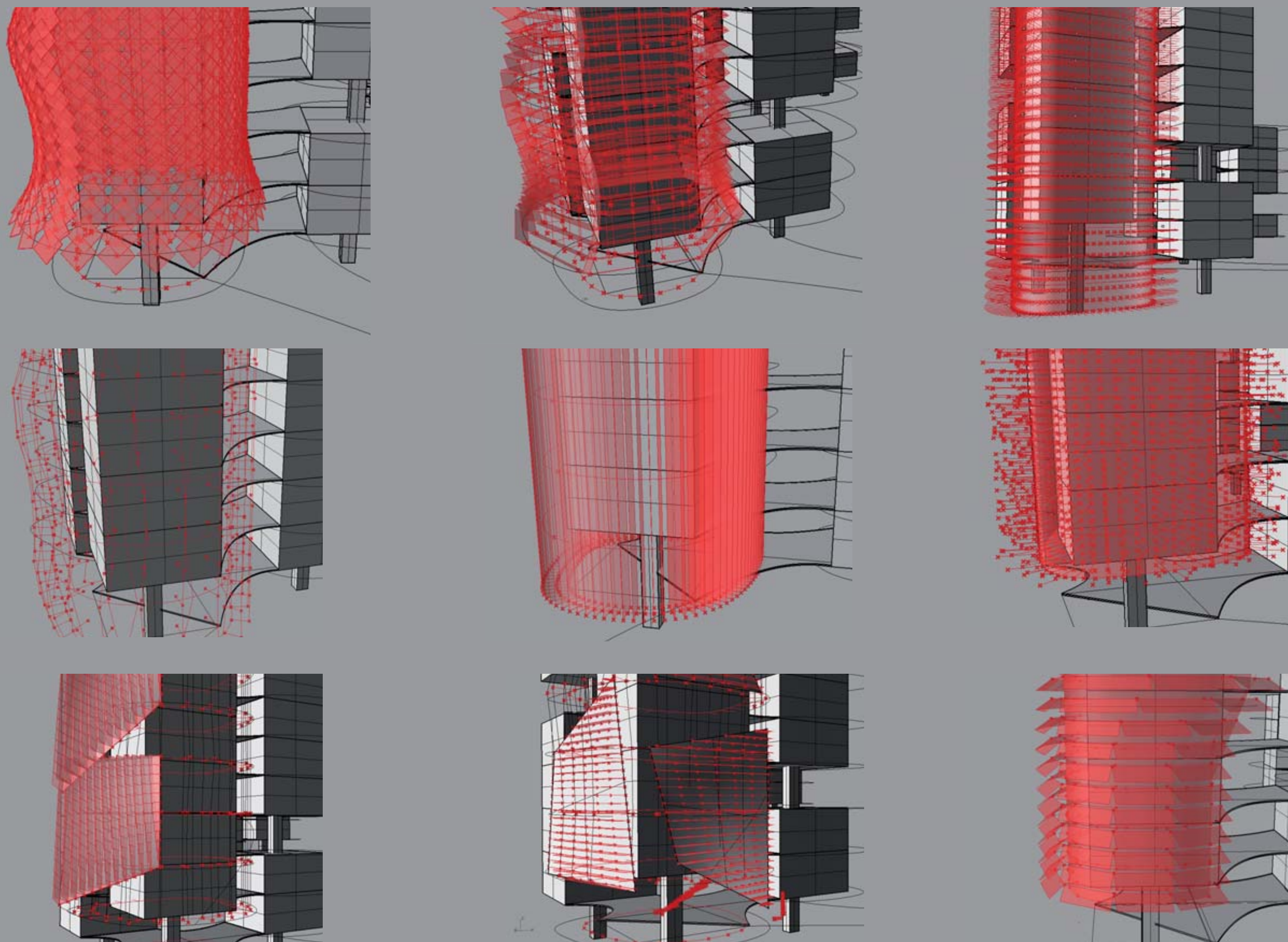
### Parametric design

Grasshopper is a plug-in for the 3D software package "Rhinoceros 4.0", which is used to carry out parametric studies trough an interface of components, connections and drawn geometry. This enables the user to create rather complex geometries, which otherwise would need some kind of scripting - or a fair amount of patience.

On the opposite page different examples is shown, of how parametric design has been used in the sketching and creation of various facade solutions.



ill. 1: Screen shot of the grasshopper interface.

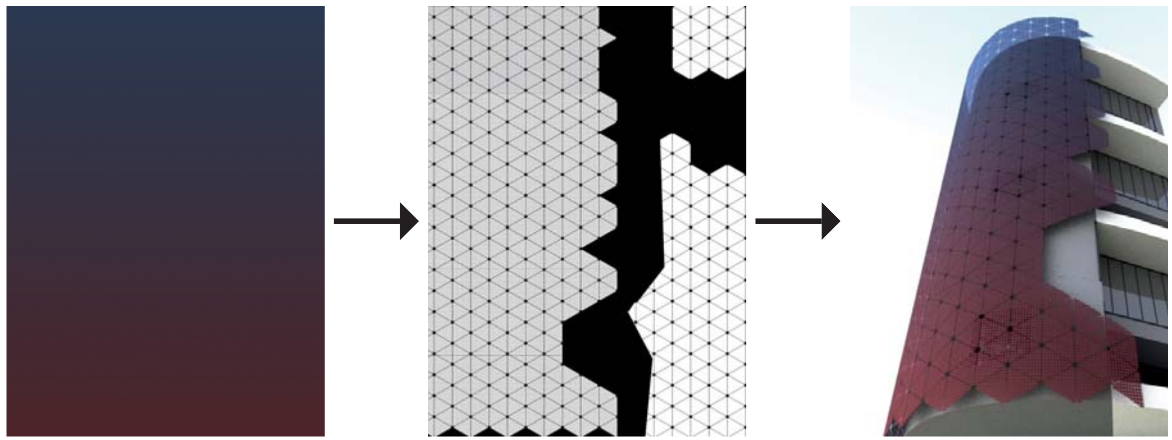


ill. 2: Facade experiments - Rhino/grasshopper.

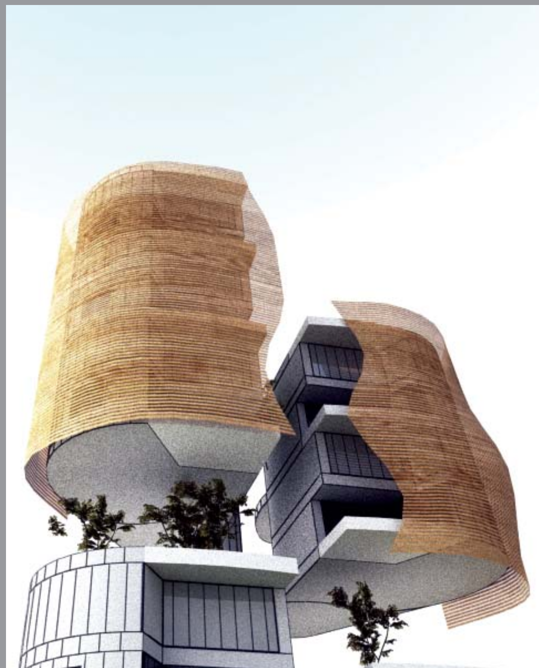
## Texture mapping technique

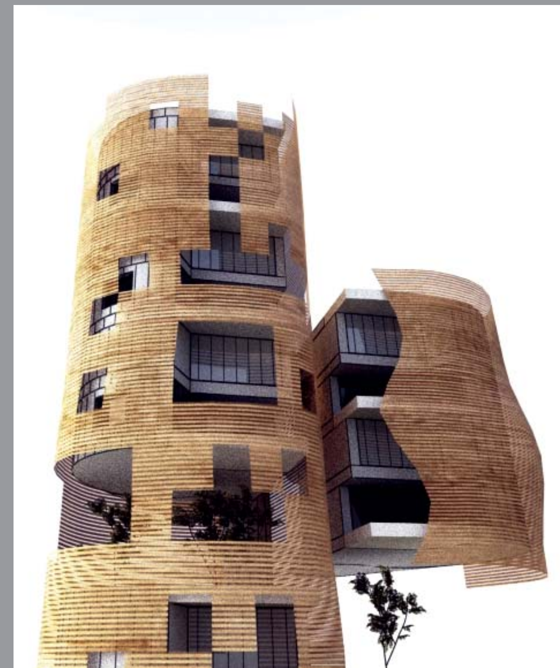
During the sketching on a skinning/facade principle, an idea arose on how to manipulate a simple surface into an easily rendered and slightly complex geometry.

The technique is executed by unwrapping the simple surface using 3ds Max Design, and exporting the wrapping coordinates to Photoshop. Here a diffuse map and a opacity map, are created on top of the exported coordinates. The diffuse map describes the color and material with whatever variation, while the opacity map which controls what is visible, and what is not. This technique allows for the creation of rather complex looking facades, while still retaining a large degree of control.




ill. 3: Work flow of texture mapping technique.



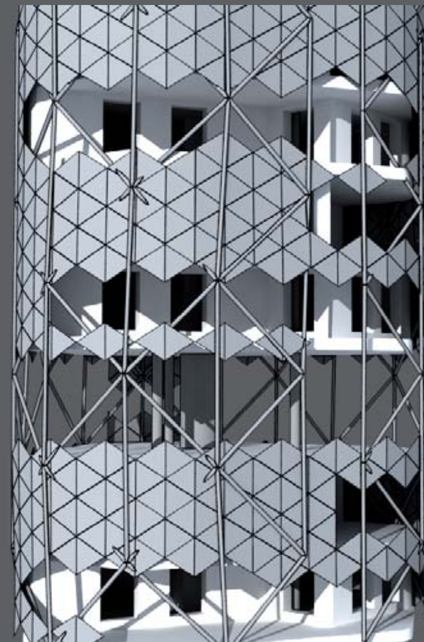



ill. 4, 5, 6, 7, 8 & 9: Facade experiments - 3ds Max Design/Photoshop.

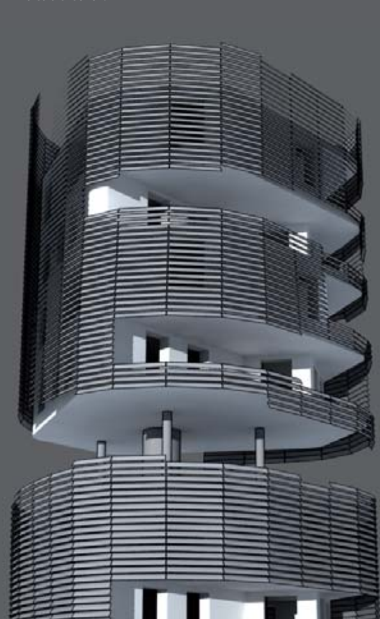
## 1st Iteration

The final tool of choice fell on Rhino and a plug-in called Rhino Paneling tool, due to the great flexibility it provided - though with the price of more manual work. The choice also marked a new phase in the facade design process.

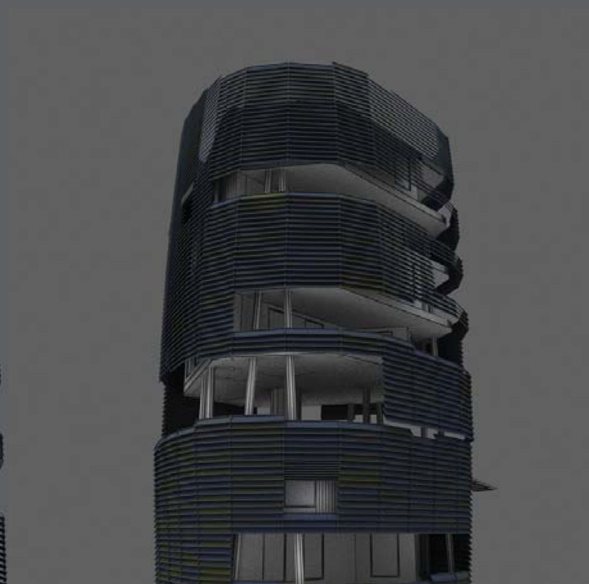
ill. 10 & 11: These are two early facade principles which experiments with different opening types and the facade color.



ill. 12: An investigation in the possibilities of the Rhino paneling tool, and the creation of another architectural expression.



ill. 13: The illustration is a proposal for using simple louvres, and how they could be combined with the raw building.



ill. 14: A further development of the proposal seen to the left. Some structural elements have been integrated, to see how they correspond with the architectural expression. There has also been some testing with a dark blue/green color scheme, where blue represents the use of photo voltaic cells.

ill. 15: Above a close up on how the flexible facade could work around windows and other openings.

The final facade concept is rather simple in its principle, consisting of a large number of louvres with integrated photo voltaic panels and varying density according to their placement.

The concept is thought as a part of an intelligent operating system which automatically optimizes the angle of the photo voltaic cells according to the sun, or opens up to gain passive heating, to reduce energy consumption . The concept though also hold a great flexibility for the occupants, who can adjust the louvres according to daylight, indoor climate, need for privacy and shelter for wind. The high amount of flexibility will make the facade a dynamic ever-changing and non/static element, which will add great variation and life to the architectural expression.

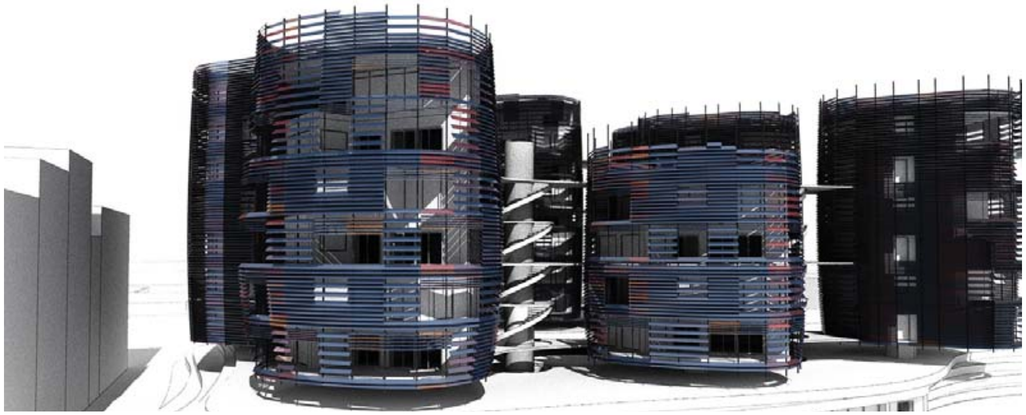
On the opposite page some different suggestions for color combinations are tested. At the top [ill. 17] a louver system of matt glass is used, which gives it a very light though a little boring expression. The effect of having a variety in degree of transparency seems to add interest and depth in the facade.

The second image [ill. 18] is a combination of dark blue louvres, which represent photo voltaic cells, and more warm reddish louvres which gives a nice variation of the facade.

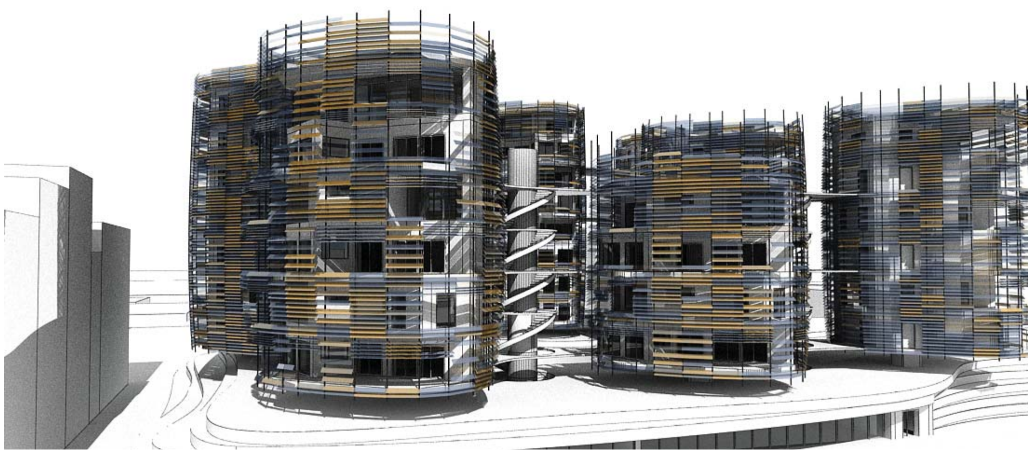
The last example [ill. 19], chosen for the facades, is a combination of the blue photo voltaic cells and a light brownish/golden color which adds a warmth to the facade. Also the facade has a general variation of transparency, which creates a nice play.

ill. 16: The final concept for the facade.

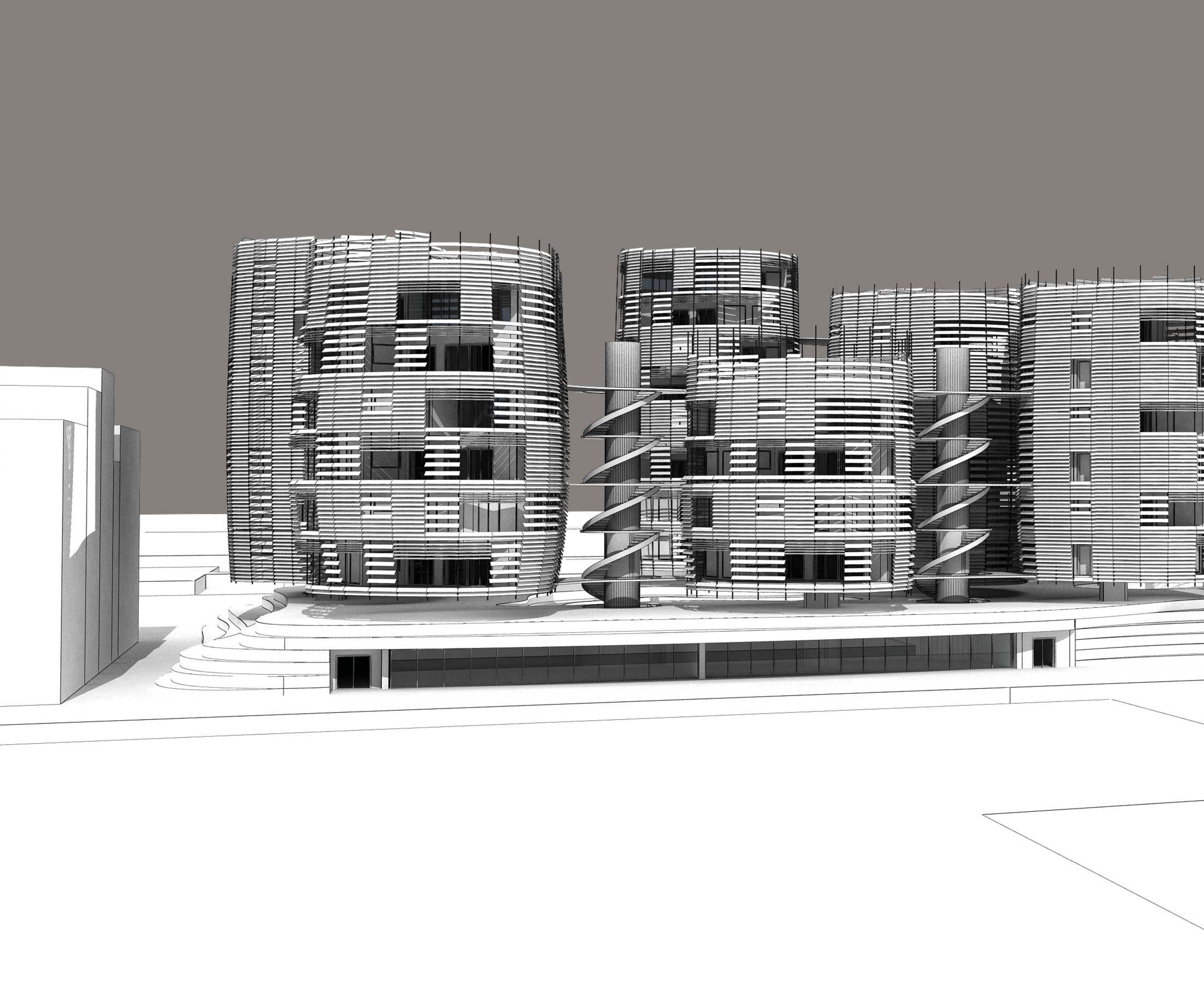
ill. 17: An investigation of material for the facade, using matt glass which gives lightness to the structure. The louvres have also been given a variation in degree of reflection to create a play in the facade.



ill. 18: A facade proposal with bluish photo voltaic cells, mixed with a reddish tone.



ill. 19: The choice of materials mixes the dark blue photo voltaic cells with a warmer brownish/golden material, which is thought to be colored glass. The transparency is varied to both give variation and more "openness" in the facade.



ill. 20: The final concept.

SYNTHESIS

# Indoor climate

From the Middle Ages until the beginning of the 19th century people began to have an awareness of that the air in a building should be good because if it was not it could result in diseases or discomfort.

During the late 19th century, thermal comfort became an issue according to the perceived climate. In addition a poor ventilated room result in bad air quality and indoor climate [Bluyssen, 2009].

Today, when talking about indoor climate, there are many factors, which play a role concerning the perceived indoor climate:

- Air quality; odour, indoor air pollution, fresh air supply.
- Visual comfort, lighting quality. This is determined by view, illuminance, luminance ratios, reflection and so forth.
- Thermal comfort; moisture, air velocity and temperature.
- Acoustical quality this concerns outside and indoor noises and vibrations (will not be considered in this project).

## Lighting qualities

When talking lighting qualities, daylight is one of the most important aspects of getting the wanted quality of lighting. Daylight is desired because it fulfill two important requirements ["Daylight in Buildings - A source book on daylighting systems and components, 2000]:

- To be able to see both a task and the space.
- To experience some environmental stimulation.

The daylight provides high illuminance and gives good colour reference, but at the same time there are also some difficulties concerning daylight, and it is therefore necessary to be aware of the aspects of lighting, which can result in discomfort.

### Over illumination

For good visibility a uniform distribution of light, across the task plane, is wanted. Poor visibility and visual discomfort occur for instance when the eyes have to adapt quickly to a wide range of light levels. For instance when working at a monitor the over-illumination will reduce or stop the visibility. When reading a book the over-illumination can result in glare.

To be able to achieve visual comfort it is necessary to be aware of elements, which can change the illumination level.

### Glare

*"Glare is produced by luminance within the visual field what are sufficiently larger than the luminance to which the eyes are adapted (thedaylightsite.com)."*

Daylight sources to glare could be the sun or the sky. The direct sunrays are disturbing. It has a luminance of 2 billion cd/m$^2$. The sky could be just as bright as artificial light or could be brighter.

During time of day and year the glare effect is changing. Caused by the change of daylight but also the different surfaces, which is present in a room.

The glare can be reduced by reducing the luminance, which means changes to openings or the luminance reflected on shiny surfaces.

### Daylighting

It has been proven that daylight gives a better visual environment than environments with artificial lighting (thedaylightsite.com). The advantages of using daylight are:

- Keeps the activation at a higher level than permanent lighting.
- The quality of work by dynamic lighting is better than by permanent lighting.
- Less tiring than permanent lighting.
- More pleasant than permanent lighting.

The average daylight factor (DF, %) gives an indication of how well lit a space without any artificial lighting are [Daylight as a sustainable lighting strategy, Merete Madsen]:

>5% Relatively high daylight level. Electrical light will normally not be needed during daytime.
2-5% Daylight is perceived in the space, but it would normally be necessary to add electrical light on desks and work areas.
<2% Electrical light will be needed almost all the time and it will be perceived as the dominating the space.

## Air quality

The ventilation rate is evaluated according to air pollutant to get a desired perceived air quality. The highest pollutant determines the ventilation rate, which normally is the thermal comfort (calculation of air pollutant according to $CO_2$ and olf - see "Indoor climate - air change calculations).

As well as the other different parameters concerning the indoor climate, the ventilation rate also has a limitation according to the defined category building (in this project, category B) [see ill. 1].

## Thermal comfort

Thermal comfort is a state, which is expressed by the satisfaction of the users concerning the thermal surroundings. This parameter is determined individually so if 90% expresses satisfaction it must be considered as fine, and if it is 80% then it is still acceptable.

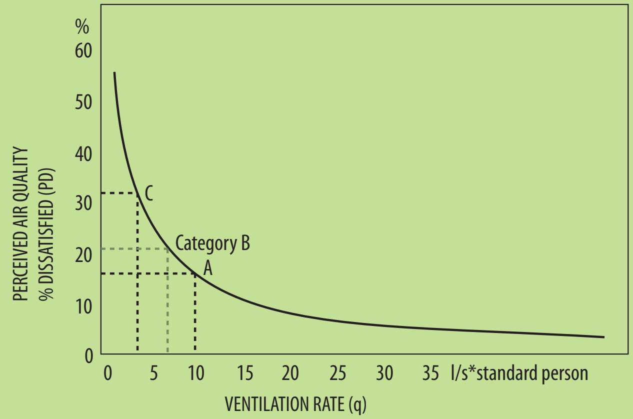
The human response to the thermal environment is expressed by the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD).

The PMV is an index from +3 to -3, which gives an indication of whether it is too hot or too cold in a room. There are six different parameters, which are able to affect the result:

- The occupants physical activity.
- The thermal resistance of their clothing.
- Air temperature.
- Mean radiant temperature
- Air velocity
- Partial water vapor pressure.

The last four are environmental parameters.

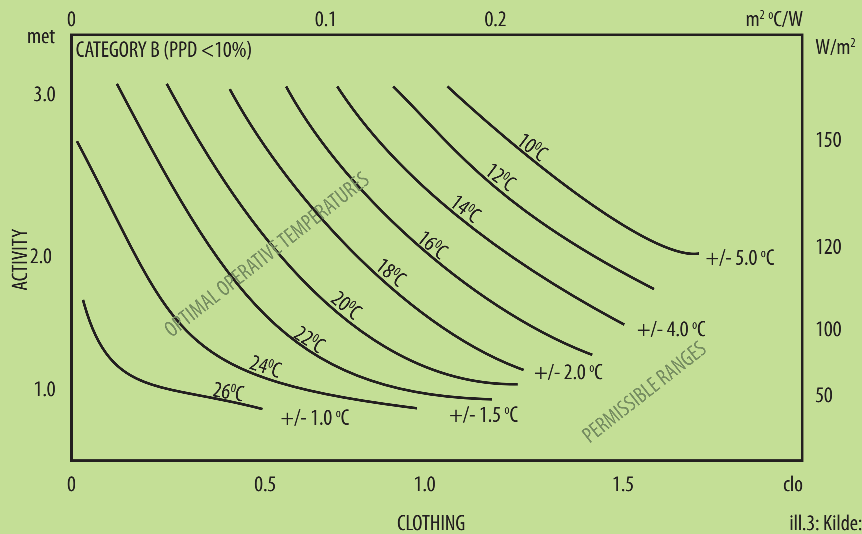
The desired thermal environment for a space can be selected according to three categories A,B and C [see ill.3]. In this project our goal will be to design a category B building.




ill.1: Kilde: CR1752

| | Thermal state of the body as a whole | | Local discomfort | | | |
|---|---|---|---|---|---|---|
| Category | PPD, % | PPD, % | Percent-age of dis-satisfied due to draught (DR), % | Percentage of dissatisfied due to air temperature difference, % | Percentage of dissats-fied due to warm or cool floor, % | Percentage of dissatis-fied due to radiant asymmetry, % |
| A | <6 | -0.2<PMV<+0.2 | <15 | <3 | <10 | <5 |
| B | <10 | -0.5<PMV<+0.5 | <20 | <5 | <10 | <5 |
| C | | -0.7<PMV<+0.7 | <25 | <10 | <15 | <10 |

ill.2: Kilde: CR1752




ill.3: Kilde: CR1752

# ENERGY & DAYLIGHT

During the sketching phase a general concept has been developed, by working simultaneously with both building volumes and plans. From this point on in the project, the aim is to further develop the building and floor plans through more detailed energy- and daylight investigations.

Due to the iterative and integrated design process there will be some overlapping between the sketching and synthesis phase, where some earlier plan solutions will be investigated despite the fact that another general concept has been chosen at the end of the sketching phase.

**WHY DESIGN FOR DAYLIGHT?**

It is well known that daylight has a profound influence on living organisms, and humans are certainly no exception. Daylight is therefore extremely important for our well being, daily rhythm, immune system, mood and so forth. New studies have even concluded that daylight, and the quality of being able to follow the shift in time according to both time of the year and day, has a significant effect on our ability to heal.

In architecture the use of daylight is also a major crucial part of how spaces are experienced and perceived, and thus an extremely important design parameter to work with.

Apart from these rather diffuse qualities, the use of daylight also has significant implications on a buildings energy efficiency. Using the natural resource of daylight instead of artificial lighting, and not rely on electricity - which in the Danish building regulations has a penalty of 2.5 times in primary energy (though at the time this is not the case for dwellings), the building will consume less energy and thus have better chances of becoming energy neutral.

Furthermore the use of artificial lighting, will in general generate significantly more heat, for the same amount of visible light obtained by daylight. This has implications for both office buildings and well-insulated dwellings, where overheating can be a critical issue.

**METHODS FOR EVALUATING DAYLIGHT**

In the evaluation of daylight levels, the tool of choice fell on 3ds Max Design 2010. The 3ds Max Design series have since the 2009 version, had an incorporated light simulation tool. The last conceptual plans developed in Designphase 3 were developed in Revit 2010, and imported into 3ds Max Design to evaluate the different daylight conditions.

The tool, and the quality of the results generated, has been evaluated in a paper written by Christoph Reinhart, National Research Council Canada. In the paper C. Reinhart evaluates the 3ds Max Design 2009 results, by comparing the generated data, with the program Daysim 3.0 and real life measurements of different test cases.

Reinhart concludes that:

*"The results suggest that the accuracy of both programs is sufficient for typical daylighting design investigations of spaces with complexity comparable to the five daylighting test cases [Reinhart, C., 2009, p. 3]."*

**ENERGY**

Energy efficiency is a major theme in this project due to the task of creating a Zero Energy Building, and will be thoroughly considered while designing the apartments. Throughout the sketching phase of the apartment design, the evaluation on how the different plan solution perform, has been discussed, and different problems/qualities has been highlighted. During the synthesis, simulation tools will be used to develop more specific and optimized solutions.

# Design Phase 8
## Daylight

### Plan
The plan is a development of the triangular shape [Designphase 3, ill. 21].

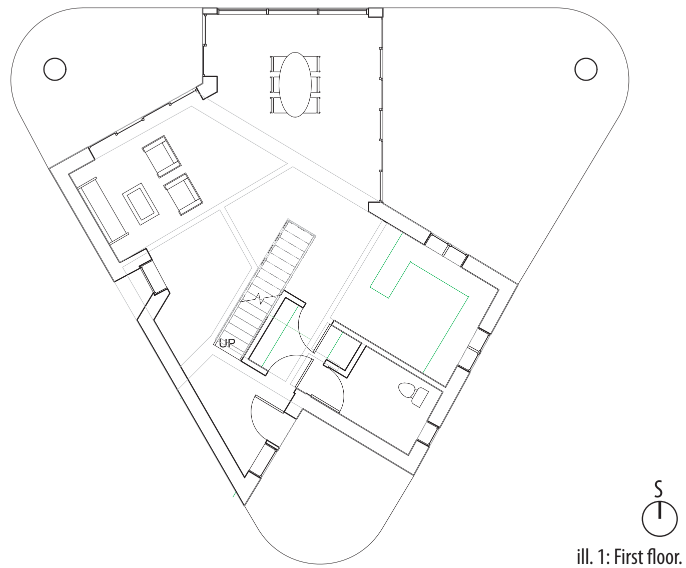
The main living areas are placed towards south, while the secondary functions are placed further towards north. The apartment is conceived as two-storey, having a second floor with the number of required bedrooms.

### Energy
The plan solution generally has some large window areas which in different periods could give problems according to both energy consumption and overheating. Depending on how the overhangs and shading devices are designed, the solar gain could especially during wintertime be significantly lower than the heat loss through these window areas.

### Daylight
The first tests of daylight conditions has been made on a preliminary plan, short after choosing the triangular shape as the final concept.

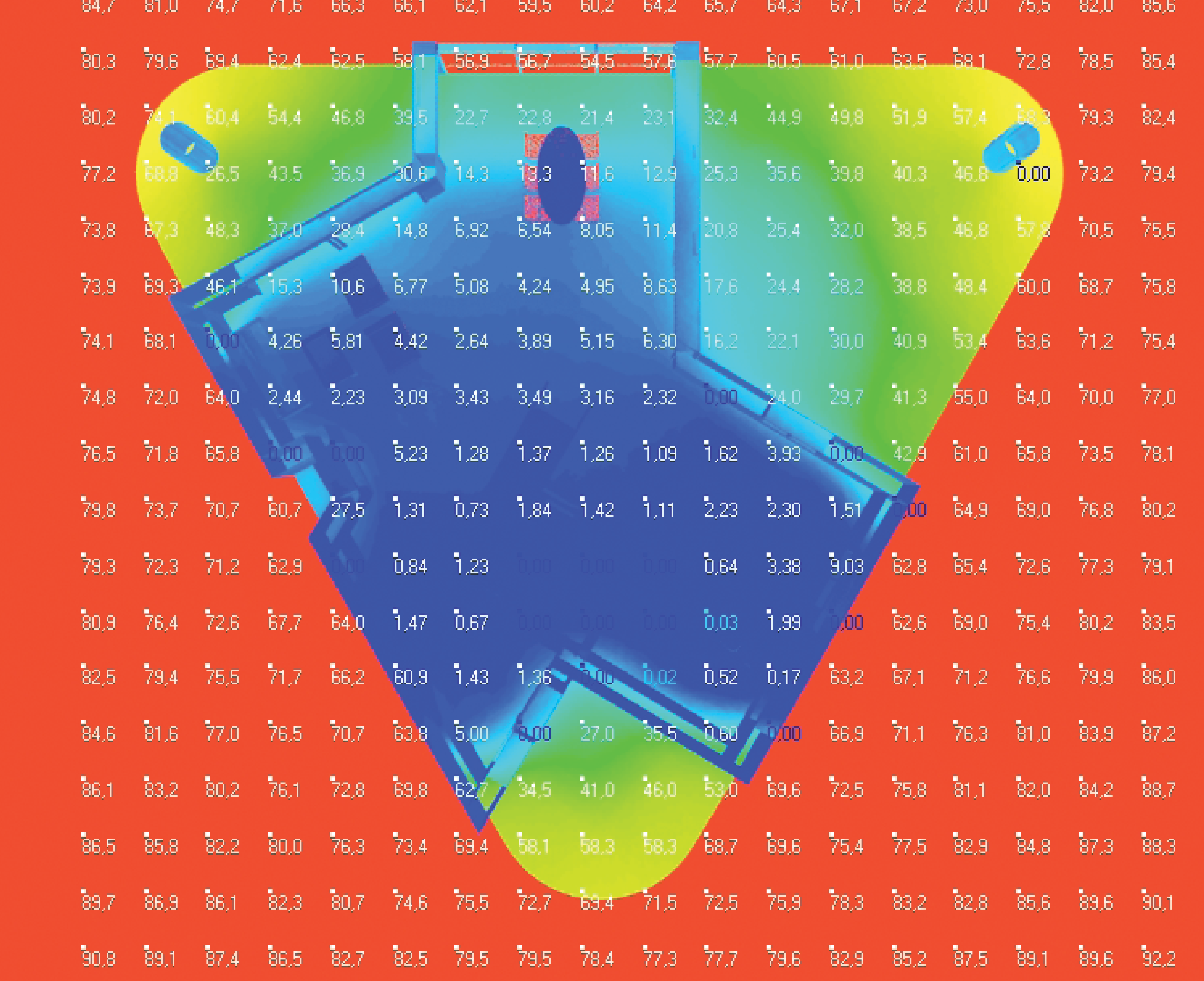
The plan has large window areas towards south, south-east and west. A large part of the windows are shaded by overhangs constituted by the apartment floor above. Towards north smaller window areas have been used.

In general this plan must be considered very well lit with light coming from several directions, but with a great risk of having glare. The results though will be affected by the integration of shading devices implemented in the facade/skinning solution.



ill. 1: First floor.

ill. 2 (opposite page): daylight study of ill. 1.


84,7 81,0 74,7 71,6 66,3 66,1 62,1 59,5 60,2 64,2 65,7 64,3 67,1 67,2 73,0 75,5 82,0 85,6
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80,2 74,1 60,4 54,4 46,8 39,5 22,7 22,8 21,4 23,1 32,4 44,9 49,8 51,9 57,4 68,3 79,3 82,4
77,2 68,8 26,5 43,5 36,9 30,6 14,3 13,3 11,6 12,9 25,3 35,6 39,8 40,3 46,8 0,00 73,2 79,4
73,8 67,3 48,3 37,0 28,4 14,8 6,92 6,54 8,05 11,4 20,8 25,4 32,0 38,5 46,8 57,8 70,5 75,5
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74,8 72,0 64,0 2,44 2,23 3,09 3,43 3,49 3,16 2,32 0,00 24,0 29,7 41,3 55,0 64,0 70,0 77,0
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79,3 72,3 71,2 62,9 0,00 0,84 1,23 0,00 0,00 0,00 0,64 3,38 9,03 62,8 65,4 72,6 77,3 79,1
80,9 76,4 72,6 67,7 64,0 1,47 0,67 0,00 0,00 0,00 0,03 1,99 0,00 62,6 69,0 75,4 80,2 83,5
82,5 79,4 75,5 71,7 66,2 60,9 1,43 1,36 0,00 0,02 0,52 0,17 63,2 67,1 71,2 76,6 79,9 86,0
84,6 81,6 77,0 76,5 70,7 63,8 5,00 0,00 27,0 35,5 0,60 0,00 66,9 71,1 76,3 81,0 83,9 87,2
86,1 83,2 80,2 76,1 72,8 69,8 62,7 34,5 41,0 46,0 53,0 69,6 72,5 75,8 81,1 82,0 84,2 88,7
86,5 85,8 82,2 80,0 76,3 73,4 69,4 58,1 58,3 58,3 68,7 69,6 75,4 77,5 82,9 84,8 87,3 88,3
89,7 86,9 86,1 82,3 80,7 74,6 75,5 72,7 69,4 71,5 72,5 75,9 78,3 83,2 82,8 85,6 89,6 90,1
90,8 89,1 87,4 86,5 82,7 82,5 79,5 79,5 78,4 77,3 77,7 79,6 82,9 85,2 87,5 89,1 89,6 92,2

# 1st Iteration

### Plan

The floor plan is a slight modification of the previous apartment [ill. 1]. Most noticeable some cuts have been made into the plan, breaking up the volume and make it seem less uniform in the facade - as well as to bring daylight deeper into the apartment.

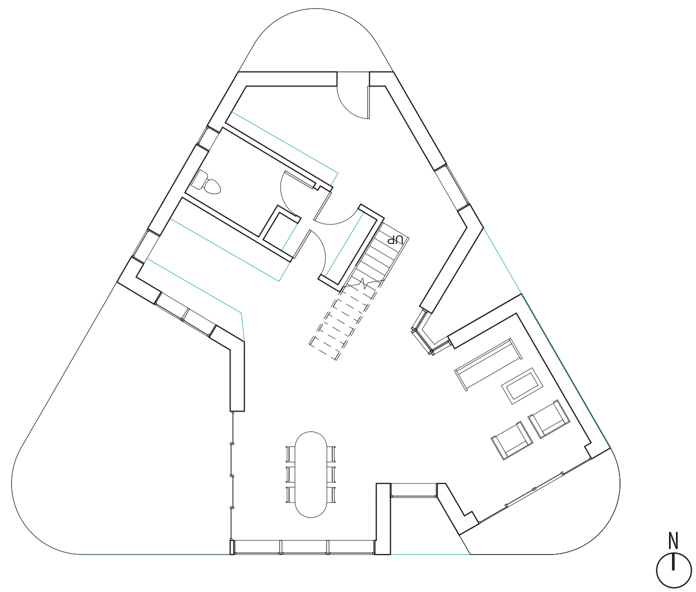
Apart from this, the new plan is also conceived as a two-storey apartment, with the 1st floor as the main living spaces and the 2nd floor primarily used for bedrooms.

### Energy

As with the former plan solution, this also has large window areas towards south. The cut into the eastern facade, done with the intention to bring daylight deeper into the volume, will however also lead to more heat loss.

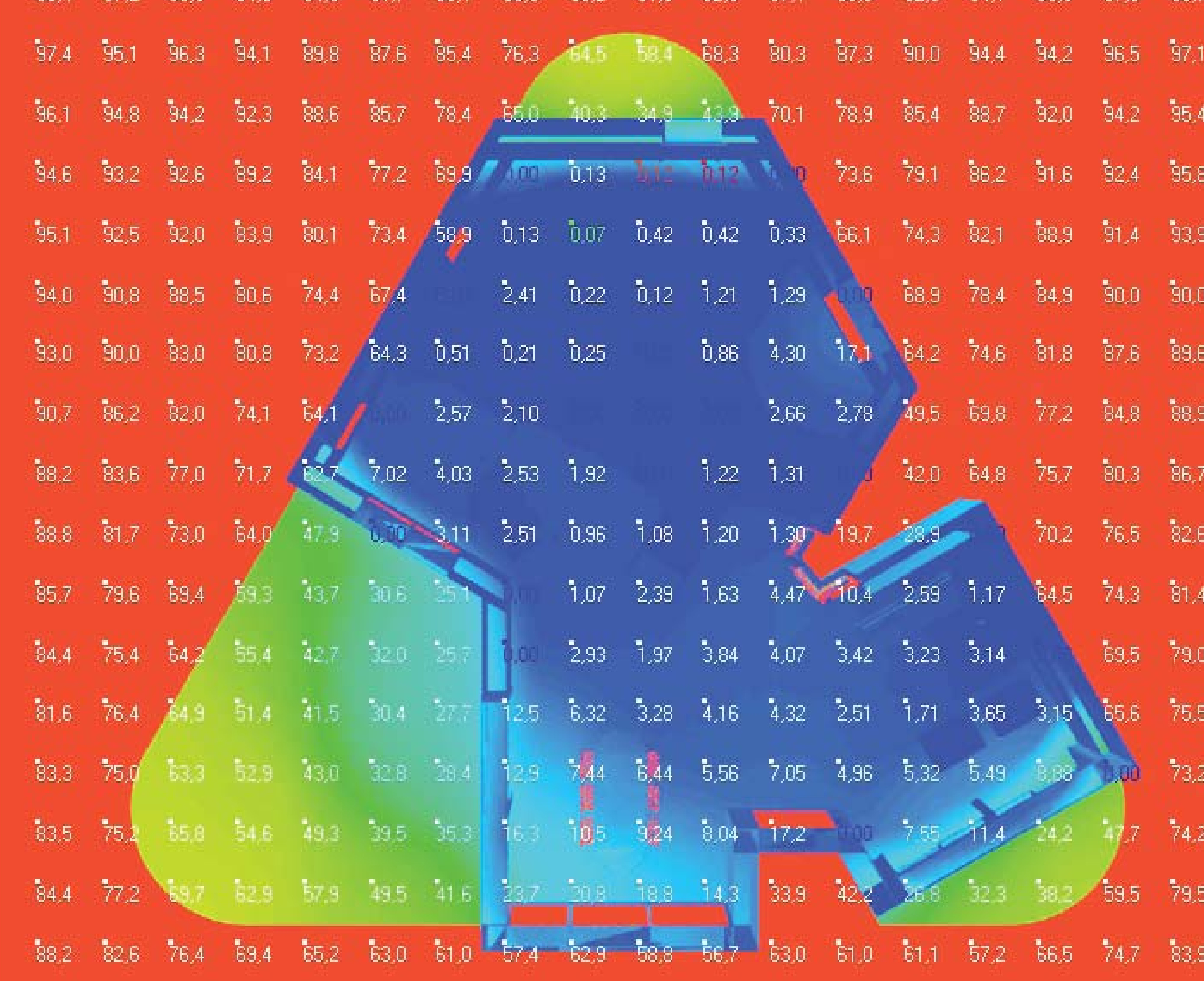
### Daylights

The cutting into the floor plan are made mainly to bring daylight deeper into the apartment, and as shown on the daylight rendering [ill. 4], they do have an effect, even though it is rather limited. Another observation is the impact, the overhang on the south-east facing living room seems to have on decreasing the difference between the highest and lowest daylight factor, but without compromising the amount of daylight in the center of the apartment.




ill. 3: First floor.

ill. 4 (opposite page): daylight study of ill. 3.


97,4 95,1 96,3 94,1 89,8 87,6 85,4 76,3 64,5 58,4 68,3 80,3 87,3 90,0 94,4 94,2 96,5 97,1
96,1 94,8 94,2 92,3 88,6 85,7 78,4 65,0 40,3 34,9 43,9 70,1 78,9 85,4 88,7 92,0 94,2 95,4
94,6 93,2 92,6 89,2 84,1 77,2 69,9 0,00 0,13 0,12 0,12 73,6 79,1 86,2 91,6 92,4 95,8
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88,2 83,6 77,0 71,7 62,7 7,02 4,03 2,53 1,92 1,22 1,31 42,0 64,8 75,7 80,3 86,7
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## 2nd Iteration

### Plan

This plan also has cuts made into it, to make the facade seem less uniform and increase the access to daylight in the center of the apartment.

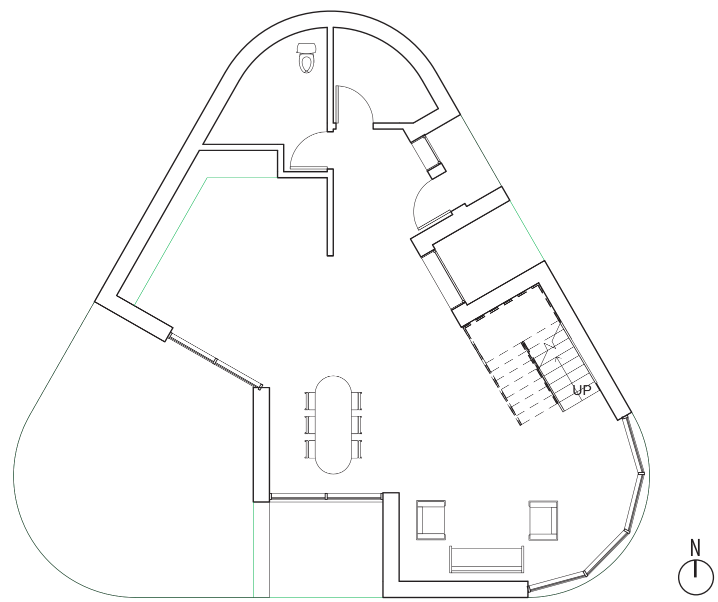
As with the former apartments, the living areas are centralized in the 1st floor while the bedrooms are placed on the not yet detailed 2nd floor.

### Energy

Again the large window areas are orientated towards south and should be shaded carefully in order to minimize extreme heat gain and heat loss. It is not at this point possible to determine exactly how the plan will perform in comparison with the earlier plans.

### Daylight

The daylight rendering reveals, that the cutting into the floor plan has a quite significant influence on a more uniform distribution of daylight - though the daylight factor is still quite high in the living room towards south-east.




ill. 5: First floor.

ill. 6 (opposite page): daylight study of ill. 5.


92,0 88,9 87,6 86,4 83,3 80,8 78,2 76,3 73,0 72,6 75,8 75,0 77,3 82,8 81,9 85,7 86,4 88,9
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79,0 75,3 66,9 53,7 43,1 33,9 26,6 22,4 4,51 0,00 5,31 4,16 3,30 5,04 6,32 0,00 69,4 77,6
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85,9 82,6 79,1 72,7 71,9 65,8 62,9 63,2 64,8 62,6 65,8 66,6 69,2 68,9 71,9 77,2 82,5 85,2

# Design phase 9
## Energy and daylight

### Introduction

The investigation of the floor plan in phase 1 was done on the conceptual apartments, developed in the sketching phase which paid great attention to both architectural expression and plan solutions.

While starting on the more detailed investigations of the synthesis phase, the floor plan still underwent a further development due to problems with the functionality and rationality of the plans. Even though it can be rather time consuming, this is the optimized way of working with the integrated design process - allowing the results from the more detailed investigations influence the building design and visa versa and making the project go through several iterations.

Eventually the new sketching of floor plans resulted in two different suggestions:

- An optimization of the triangular shape investigated in phase 1, with significant improvements on functionality.

A step back to the more rational and fragmented floor plan from the sketching phase [Designphase 3, ill. 19].

In order to aid the decision process, a number of more detailed analysis of the two floor plans were made. These analysis are rather detailed energy- and light studies performed in Virtual Environment, an approach which will be discussed in detail later.

Meanwhile, thorough considerations on the potential of the two concepts, both in terms of functionality, flexibility, and perceived architectural expression, were done.

## Energy simulation

In the 7th design phase, different plan solutions will be tested using Virtual Environment, which is a dynamic simulation tool, used to simulate energy use, indoor climate conditions, light conditions and air flow in buildings.

The reason for using VE at this point instead of using the monthly average spreadsheet or Be06, is due to the fact that it can to some degree be integrated with Revit Architecture, a tool which has been used throughout the sketching phase. Thus it seemed obvious to learn and develop a workflow that takes advantage of the interoperable qualities of the two programs - a learning process that has been quite time consuming.

The ambition with this considerable investment of time, was to develop a workflow that could relatively give fast feedback on a specific plan, or even a conceptual volume. Also the hopes were that the dynamic simulation tool would deliver results based more on geometry rather than numbers, which somewhat reflects the calculations made in the monthly average spreadsheet and Be06.

## Basic settings

Simple basic settings has been used, in order to approximate the energy consumption.

- General insulation conduction value: 0.037 w/(m*k).

**Construction:**

- Walls: Light- and non-bearing with a U-value of 0.12W/m$^2$K
- Internal partitions: Generic with U-value: 1.69W/m$^2$K
- Decks: 200mm thick prefab concrete element, with 350mm polystyrene insulation and a U-value of: 0.10W/m$^2$K
- Internal Decks: 200mm prefab concrete elements with 100mm insulation and a U-value of: 0.33W/m$^2$K
- Windows: Low-e generic triple glazed windows with net U-value: 1.45W/m$^2$K
- Roof: 250mm thick prefab concrete deck, with 350mm polystyrene insulation, U-value: 0.10W/m$^2$K

**Thermal conditions - Standard Dwelling (based on BE06):**

*Room conditions:*

- Heating: On continuously, setpoint 20 degrees.
- Cooling: On continuously, setpoint 24 degrees.

*System:*

- Min. flow rate (air change): 0.6*total volume/hour
- Internal gains: 1.5W/m$^2$ (people) and 3.5W/m$^2$ (equipment).

*Air exchange:*

- Infiltration: 0.13 l(s*m$^2$) *when in use, 0.09 l(s*m$^2$) *when not in use (as guided by BE08, the values can be lowered if the volumes perform better in a pressure test).
- Active air change.

*Heating system*

- Waste heat.
- Ventilation heat recovery effectiveness 78%.
- System specific fan power: 0,78 W/(L*s).
- Energy for lighting is not included.

# Triangular plan

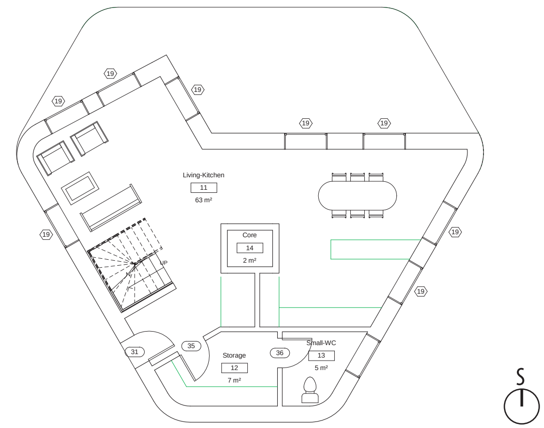
## Plan

The plan is a further development of the initial concept investigated in the 6th design phase [ill. 1, 3 & 5]. The round edges of the triangle have been cut, and instead a rounded 6 edged shape has emerged.

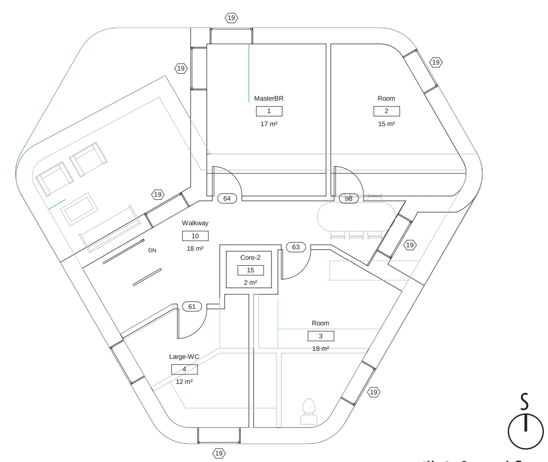
The plan is seems rather compact while still having a spacious quality. The rooms are quite large but with special corners which inhibits the flexibility of furnishing.

The planning of the apartment, has to a great extent been done with respect to a central core, which works as a structural element, but also provides the building with a flexibility for improvements, modifications and reparation of installations.

The plan also incorporates relative large out door areas on both levels.




ill. 7: First floor.




ill. 8: Second floor.

**Energy**

The energy tests have been performed with a basic profile created specific for the project. In this initial testing, a simulation on a detached 2 storey dwelling will be performed. This will most likely result in a higher heat loss, as when the dwellings are stacked and grouped, but will give an impression on the overall performance of the apartments.

At this point the apartments geometry, construction and service systems have not yet been optimized, and thus the energy consumption is quite high when compared to the low-energy class 1 buildings. To obtain energy neutrality the building should fulfill the energy frame of (35kWh+(1100kWh/A))/m$^2$ per year (low-energy class 1).

As seen on the schemes to the right [ill. 9,10 & 11], a large portion of the energy is used for heating. Despite the apartment generally has low U-values, the energy use for heating is still too high. A significant portion of this energy can very likely be attributed to infiltration, and to some degree also ventilation.

Summary

| Month | Heating (boilers etc.) | Cooling (chillers etc.) | Fans, pumps and controls | Lights | Equip. |
|---|---|---|---|---|---|
| A-Z | Hi/Lo | Hi/Lo | Hi/Lo | Hi/Lo | Hi/Lo |
| Jan | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Feb | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mar | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Apr | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| May | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 |
| Jun | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 |
| Jul | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 |
| Aug | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 |
| Sep | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oct | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nov | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dec | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 9.8 | 0.6 | 0.7 | 0.0 | 0.0 |



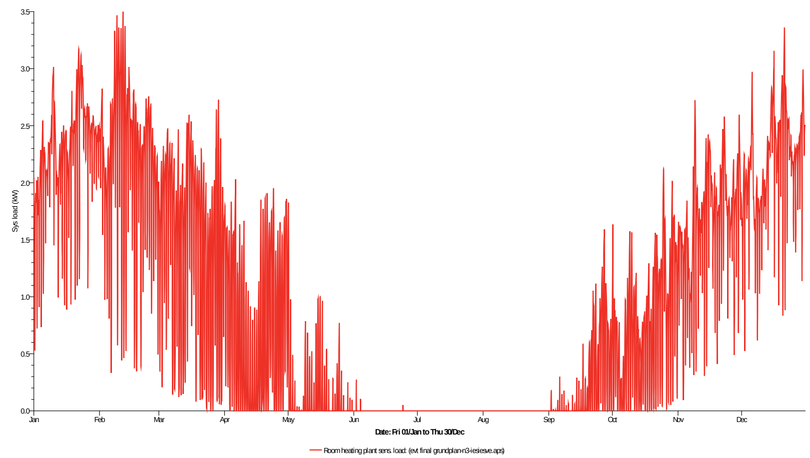
MWh

The maximum value in each column is highlighted in red. The minimum value in each column is highlighted in blue. More than one value may be highlighted

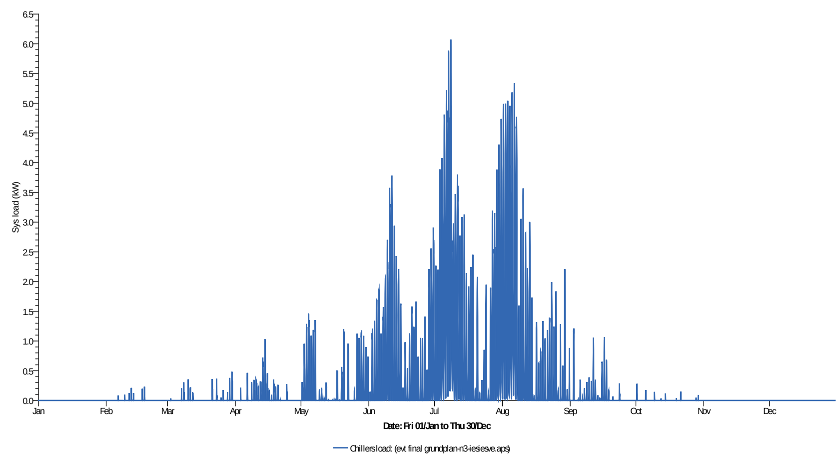
Total Yearly Energy Consumption = 11.1MWh

Total Yearly Energy Consumption per Floor Area = 70.5kWh/m$^2$

ill .9: Energy schedule.




ill .10: The heating demand over a yearly basis.

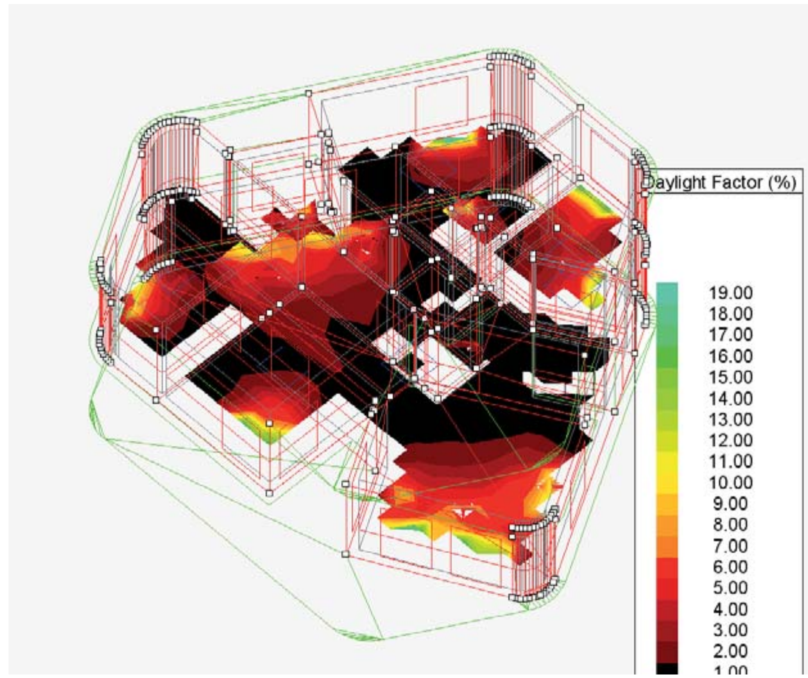



ill.11:The cooling demand over a yearly basis.

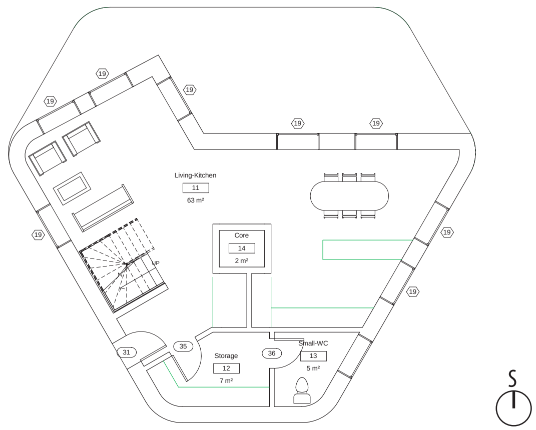
### Daylight

The daylight factor in the apartment are quite good in most of the areas . This indicates a general good placement and sizing of the windows.

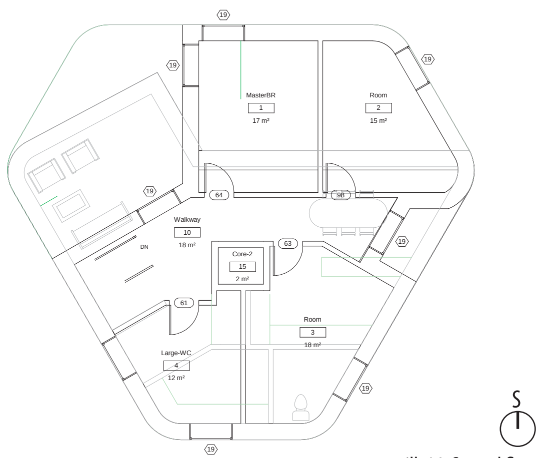
An area which could afford some improvements is the corridor on the second floor, where the average daylight factor is only around 1% - the space could therefore be perceived as being rather dim.




ill. 12: Daylight analysis.



ill. 13: First floor.



ill. 14: Second floor.

# Results of daylight:

Room: 1 - Master bedroom
Daylight factor: min. 0.4 %, average 2.5 %, max. 17.5 %.
Daylight illuminance: min. 46.22 lux, average 309.72 lux, max. 2138.79 lux.

Room: 2 - Child's room
Daylight factor: min. 0.1 %, average 2.0 %, max. 11.6 %.
Daylight illuminance: min. 6.37 lux, average 246.23 lux, max. 1411.17 lux.

Room: 3 - Child's Room
Daylight factor: min. 0.0 %, average 1.8 %, max. 18.9 %.
Daylight illuminance: min. 0.00 lux, average 220.65 lux, max. 2314.11 lux.

Room: 4 - Bath/Toilet
Daylight factor: min. 0.2 %, average 5.7 %, max. 17.6 %.
Daylight illuminance: min. 20.99 lux, average 695.18 lux, max. 2146.69 lux.

Room: 10 - Corridor
Daylight factor: min. 0.0 %, average 1.0 %, max 11.0 %.
Daylight illuminance: min. 0.02 lux, average 125.04 lux, max. 1339.79 lux

Room: 11 - Living/Kitchen
Daylight factor: min. 0.0 %, average 3.2 %, max. 17.7 %.
Daylight illuminance: min. 1.39 lux, average 393.34 lux, max. 2159.86 lux.

Room: 12 - Storage
Daylight factor: min. 0.0 %, average 0.0 %, max. 0.0 %.
Daylight illuminance: min. 0.00 lux, average 0.00 lux, max. 0.00 lux.

Room: 13 - Toilet
Daylight factor: min. 0.2 %, average 3.6 %, max. 11.9 %.
Daylight illuminance: min. 28.67 lux, average 440.73 lux, max. 1449.24 lux.

Room: 14/15 - Core
Daylight factor: min. 0.0 %, average 0.0 %, max. 0.0 %.
Daylight illuminance: min. 0.00 lux, average 0.00 lux, max. 0.00 lux.

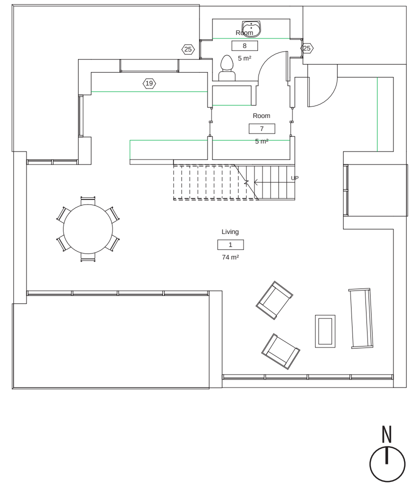
# Square plan

## Plan

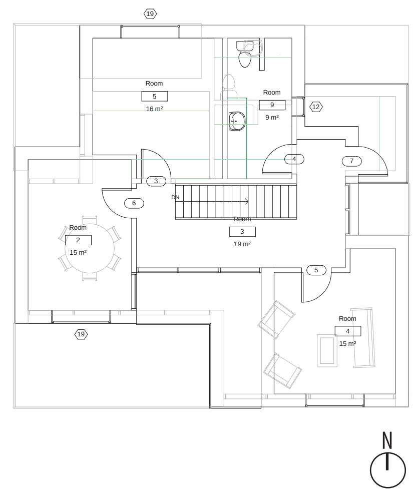
The 2nd suggestion for a plan solution focuses on creating rational floor plans for easy and flexible furnishing. This is a step back to an early suggestion from the sketching phase, made to investigate and compare the quite different concepts of the floor plan solutions.

The general distribution of rooms and functions are similar to the one found in the triangular plan. The flow of the floor plan is quite good, and the solution with the storage room between the entrance and the kitchen works very well. The floor plan also includes a number of terraces orientated in different directions, giving good opportunity for sunlit areas and outdoor activities during the day. The rooms however are generally smaller than those in the triangular floor plan.

Towards south, two large window areas have en been placed, which could be problem-atic according to energy consumption and overheating.




ill. 15: First floor.




ill. 16: Second floor.

## Energy

Both floor plans have been analyzed using Virtual Environment with the same construction, indoor climate, heating, and cooling profile, in order to compare them.

The results reveals that the square plan solution has a higher energy use for heating and cooling pr. m$^2$, which most likely can be attributed to a higher surface to floor area ratio and a bad distribution of windows.

This has resulted in a 14% higher energy use compared to the triangular plan proposal. Though at this point, it is of course difficult to foresee how both could perform after a further optimization.

Summary

| Month | Heating (boilers etc.) | Cooling (chillers etc.) | Fans, pumps and controls | Lights | Equip. |
|---|---|---|---|---|---|
| A-Z | Hi/Lo | Hi/Lo | Hi/Lo | Hi/Lo | Hi/Lo |
| Jan | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Feb | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mar | 1.5 | 0.0 | 0.1 | 0.0 | 0.0 |
| Apr | 0.8 | 0.1 | 0.1 | 0.0 | 0.0 |
| May | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| Jun | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 |
| Jul | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 |
| Aug | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 |
| Sep | 0.3 | 0.1 | 0.1 | 0.0 | 0.0 |
| Oct | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nov | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dec | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 11.0 | 0.9 | 0.8 | 0.0 | 0.0 |



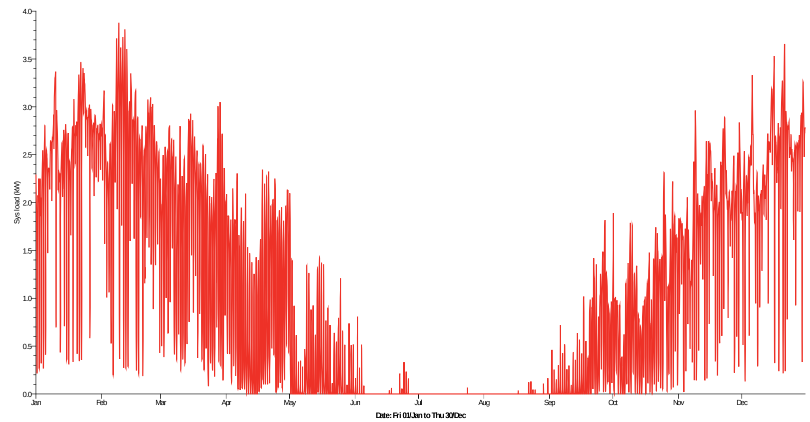
MWh

The maximum value in each column is highlighted in red. The minimum value in each column is highlighted in blue. More than one value may be highlighted

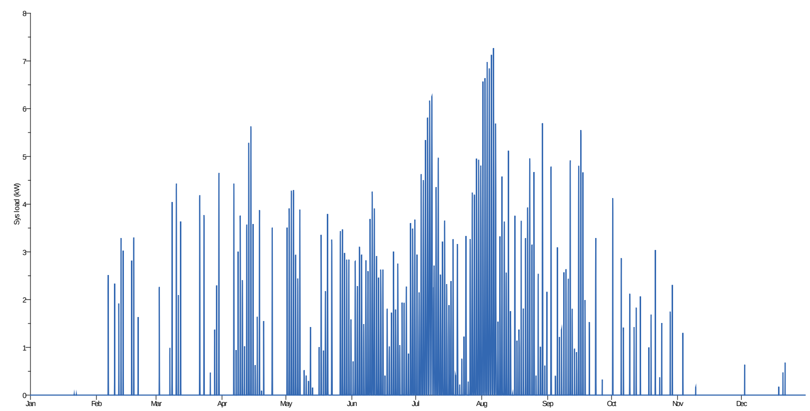
Total Yearly Energy Consumption = 12.7MWh

Total Yearly Energy Consumption per Floor Area = 80.2kWh/m$^2$

ill. 17: Energy schedule.




ill. 18: The heating demand over a yearly basis.



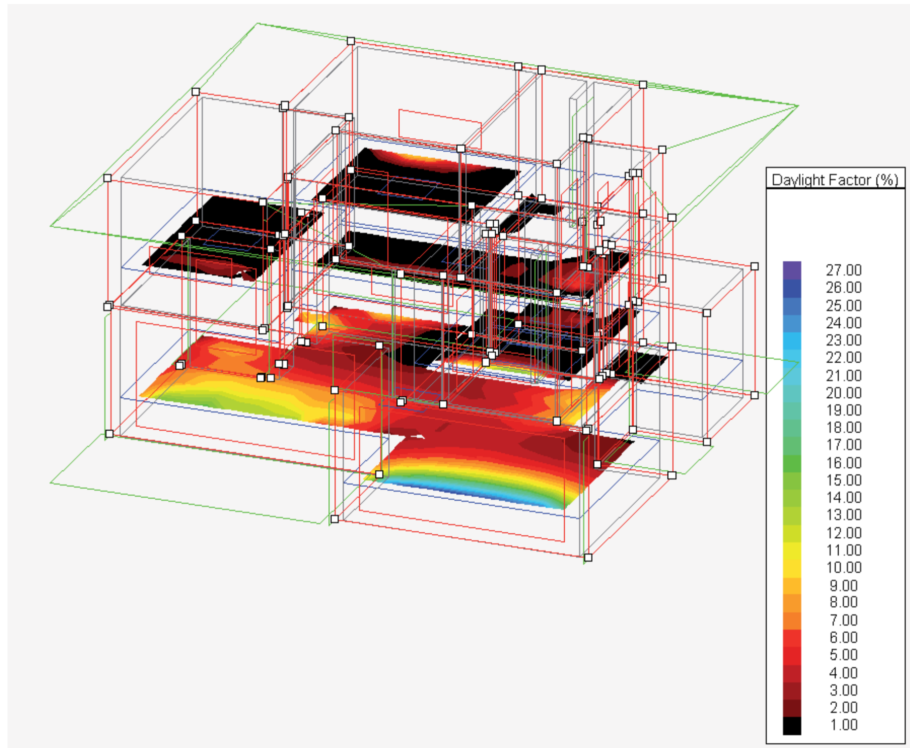

ill. 19: The cooling demand over a yearly basis.

### Daylight

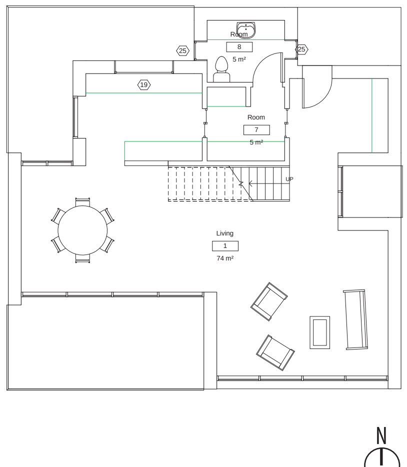
Similar daylight studies of the two plan solutions has been made. The studies were done using the same settings, which allows for a close comparison of the two proposals.

The results generally point towards the same conclusion as made in the analysis of the energy consumption, with rather poorly distribution and proportion of windows. In the main living areas, kitchen and living room, the daylight factor is quite high, creating a large range of the luminance, which will result in glare, and thus poor visual comfort.

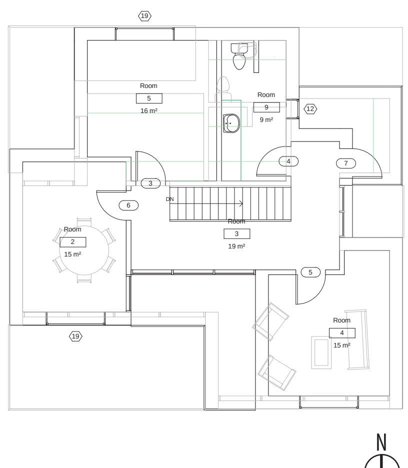
Furthermore the placement of windows and proportions of the rooms, seems to be inadequate in order to create well lit areas, and the rooms appear dim.




ill. 20: Daylight studies.



ill. 21: First floor.



ill. 22: Second floor.

## Results of daylight:

Room: 1 - Living/Kitchen
Daylight factor: min. 0.0 %, average 6.8 %, max. 26.3 %.
Daylight illuminance: min. 0.00 lux, average 825.86 lux, max. 3211.66 lux.

Room: 2 - Child's Room
Daylight factor: min. 0.0 %, average 0.6 %, max. 3.5 %.
Daylight illuminance: min. 0.02 lux, average 77.09 lux, max 426.03 lux.

Room: 3 - Corridor
Daylight factor: min. 0.0 %, average 1.3 %, max. 6.6 %.
Daylight illuminance: min. 0.00 lux, average 153.14 lux, max. 809.52 lux.

Room: 4 - Master bedroom
Daylight factor: min. 0.0 %, average 1.6 %, max. 15.4 %.
Daylight illuminance: min. 3.24 lux, average 196.26 lux, max. 1880.03 lux.

Room: 5 - Child's Room
Daylight factor: min. 0.0 %, average 0.9 %, max. 9.8 %.
Daylight illuminance: min. 0.00 lux, average 115.64 lux, max. 1195.80 lux.

Room: 7 - Storage
Daylight factor: min. 0.0 %, average 0.0 % , max 0.0 %.
Daylight illuminance: min. 0.00 lux, average 0.00 lux, max. 0.00 lux.

Room: 8 - Toilet
Daylight factor: min. 0.1 %, average 1.9 %, max. 4.8 %.
Daylight illuminance: min. 14.37 lux, average 232.36 lux, max. 582.62 lux.

Room: 9 - Bath/Toilet
Daylight factor: min. 0.0 %, average 0.1 %, max. 0.7 %.
Daylight illuminance: min. 0.00 lux, average 8.94 lux, max. 81.56 lux.

# Design phase 10
## Apartments

As a result of the investigations made in the previous design phase and the assessment of parameters such as functionality, flexibility, and perceived architectural expression, the decision was made to move forward with the triangular floor plan.

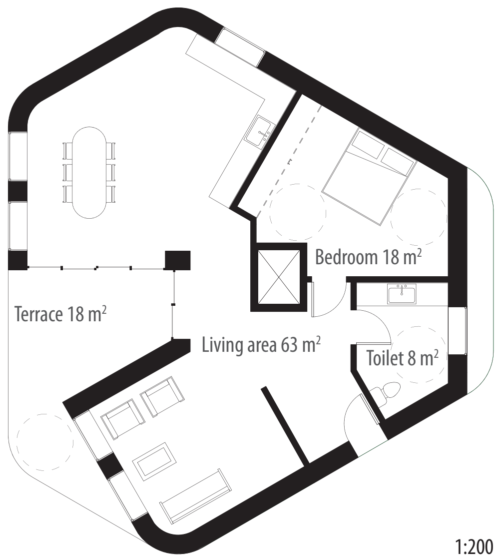
To fulfill the wish of having a diversity of users in the area, different apartments should be provided according to room program defined on page 88.

Through further sketching and synthesis, 4 apartment types has been developed:

- **Unit 1:** 2 bedroom dwelling (one-storey): Young couples, singles and disabled [ill. 1].
- **Unit 2:** 2 bedroom dwelling (two-storey): Young/elderly couples and singles.
- **Unit 3:** 3 bedroom dwellings: Small families/ single parents (with 1 child). This could also be relevant for seniors, wanting an extra room for an office or overnight guests/children.
- **Unit 4:** 4 bedroom dwellings: Families/ single parents (with 2 children).

Unit 2, 3 and 4 all the have the sane first floor, whereas the second floor adjust by the number of bedrooms.

### Unit 1:



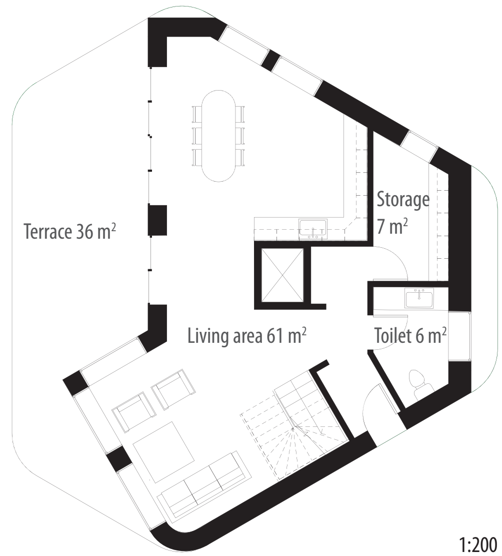

1:200

ill. 1: The apartment, having only one floor, is intended for disabled people as well as a cheaper alternative to the 2 storey apartments.

The distribution of rooms are somewhat the same as in the other apartments, but with a more clear division of the living and kitchen area.

The outdoor area has been decreased to gain more floor area inside the apartment.

### Unit 2, 3 & 4 - 1st floor:



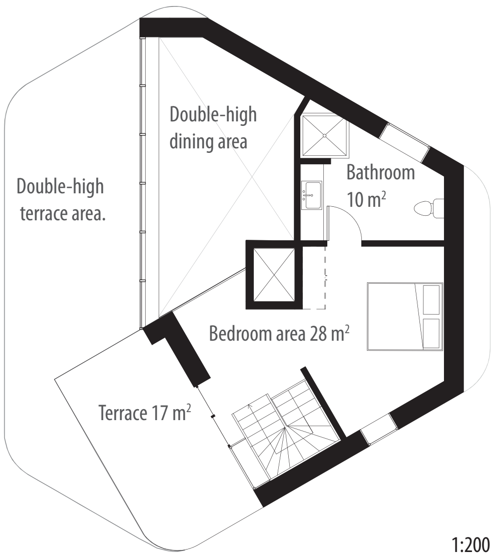

1:200

ill. 2: The first floor is repeated in all the 2 storey apartments. A main quality found in both first and second floor is the differentiated orientation of outdoor areas, which gives the possibility of always having sun exposed terraces.

The transition between inner and outer spaces, has been optimized with sliding doors, making it possible on sunny days to have an open connection between the two.

The entrance has been optimized with more wardrobe and better connections to both storage and toilet.

## Unit 2 - 2nd floor:

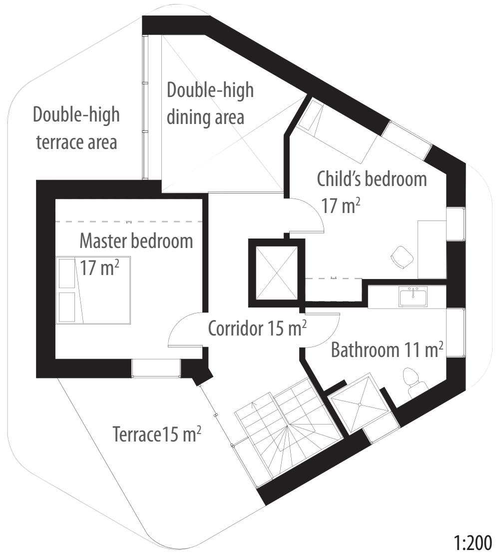



ill. 3: This 2 storey apartment with a private level on the second floor, is a quite luxurious egoist apartment intended for seniors, singles and couples.

Coming up the stairs one enters the single bedroom of the apartment which has its own terrace, bathroom and visual connection to the first floor.

The spatial qualities are quite good as the apartment takes up the same amount of space as the other 2 storey apartments, but with less floor area.

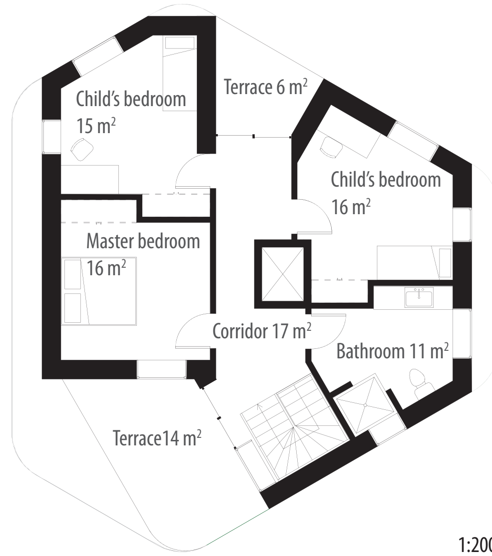
## Unit 3 - 2nd floor:




ill. 4: The first floor contains a bathroom and two bedrooms: a master bedroom and child's bedroom/office. The apartment is mainly intended for young/elderly couples or singles/single parents.

The apartment has a large diversity in spatial qualities, both inside and outside. The dining area is double-high with visual connection to the first floor. The outdoor areas is varied in both sizes and heights, having single- and double-high terrace areas at the first floor and a single-high terrace in connection with the more intimate and private second floor.

## Unit 4 - 2nd floor:




ill. 5: This apartment is the largest containing 3 bedrooms and is intended for families/single parents with two children. There are no double-high rooms inside, while the outdoor areas are diverse in both sizes and height, having to smaller terraces upstairs and one large downstairs. This gives the opportunity of activate the outdoor areas differently; having the more public terrace as a part of the social rooms at the first floor and more intimate terraces in connection with the more private second floor.

# Design phase 11
## Energy optimization

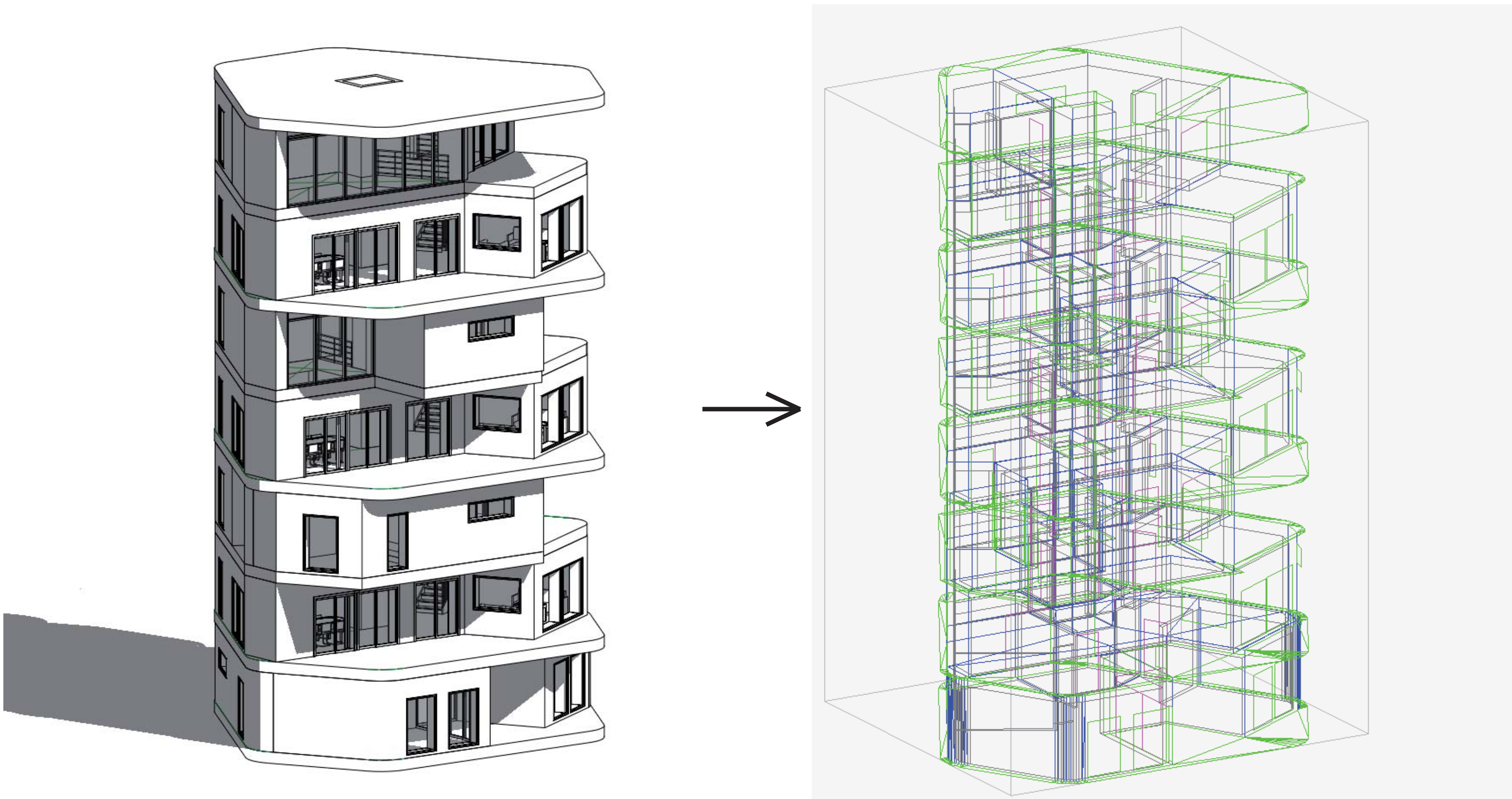
### Introduction

At this point a number of different apartment solutions have already been tested. These investigations has led to the final definition of the apartment types described in "Design-phase 8".

The earlier energy studies were done on single apartments, whereas in this chapter the whole building with the new 4 different apartments will be analyzed. This will give an insight on how the building could be optimized in respect to energy use, indoor climate and day-light, through an adjustment on construction, layout, heating- and cooling systems as well as the control of these.

This process will be iterative, and the actions taken will be clearly described during each step of the optimization. The aim is to modify the building and its systems until it reaches an energy use of 35kWh + 1100/Area, or less - which is the limit for low energy class 1 buildings as well as the demand from the Bolig$^{+}$ competition program in order of obtaining energy neutrality.

The studies have been performed by using the earlier described program Virtual Environment and exporting the geometry from Revit Architecture 2010.



ill. 1 Conversion of the geometry from Revit into a Virtual Environment model.

# Basic settings

Simple basic settings has been used, in order to approximate the energy consumption - the same as used for evaluating the initial floor plans according to daylight and energy in design phase 7.

### Construction:

- Walls: Light- and non-bearing with a U-value of 0.12 $W/m^2K$
- Internal partitions: Generic with U-value: 1.69 $W/m^2K$
- Decks: 200 mm thick prefab concrete element, with 350 mm polystyrene insulation and a U-value of: 0.10 $W/m^2K$
- Internal Decks: 200 mm prefab concrete elements with 100 mm insulation and a U-value of: 0.33 $W/m^2K$
- Windows: Low-e generic triple glazed windows with net U-value: 1.45 $W/m^2K$
- Roof: 250 mm thick prefab concrete deck, with 350 mm polystyrene insulation, U-value: 0.10 $W/m^2K$

### Thermal conditions - Standard Dwelling (based on BE06):

*Room conditions:*

- Heating: On continuously, set point 20 degrees.
- Cooling: On continuously, set point 24 degrees.

*System:*

- Min. flow rate (air change): 0.6*total volume/hour
- Internal gains: 1.5 $W/m^2$ (people) and 3.5 $W/m^2$ (equipment).

*Air exchange:*

- Infiltration: 0.13 $l(s*m^2)$ *when in use, 0.09 $l(s*m^2)$ *when not in use (as guided by BE08, the values can be lowered if the volumes perform better in a pressure test).
- Active air change.

*Heating system*

- Waste heat.
- Ventilation heat recovery effectiveness 78%.
- System specific fan power: 0,78 W/(L*s).

Energy for lighting is not included.

| Month | Heating (boilers etc.) | Cooling (chillers etc.) | Fans, pumps and controls | Lights | Equip. | |
|---|---|---|---|---|---|---|
| A-Z | Hi/Lo | Hi/Lo | Hi/Lo | Hi/Lo | Hi/Lo | Total Yearly Energy Consumption = 44.9MWh<br>Total Yearly Energy Consumption per Floor Area = 86.5kWh/m$^2$ |
| Jan | 8.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Feb | 7.2 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Mar | 5.8 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Apr | 3.2 | 0.0 | 0.1 | 0.0 | 0.0 | |
| May | 0.8 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Jun | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | |
| Jul | 0.0 | 0.5 | 0.3 | 0.0 | 0.0 | |
| Aug | 0.0 | 0.3 | 0.3 | 0.0 | 0.0 | |
| Sep | 1.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Oct | 2.9 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Nov | 5.8 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Dec | 7.4 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Total | 42.2 | 1.0 | 1.7 | 0.0 | 0.0 | |



ill. 2: Performance sheet from the first simulation.

## 1st Iteration

It is clear that the main problem in the first simulation [ill. 1], is a high energy use for heating. Thus the first task is to somehow reduce the need for heating.

At this point the need for cooling is suspiciously low, and the settings is checked in order to ensure that the results are correct.

U-values are lowered.

An error is found: Some of the doors, also the sliding doors at the terraces has been given a wrong construction type, and therefore have large U-values which is lowered to 1.25 W/m$^2$K.

Insulation in the walls is increased to 350 mm, giving the wall a U-value of 0.1 W/m$^2$K.

It should be noted, that the cooling system is driven by electricity and a factor of 2.5 is multiplied with the resultant energy use. This is done in order to compare the result with the Danish building regulations.

### Results

- Total Yearly Energy Consumption = 38.2 MWh.
- Total Yearly Energy Consumption per Floor Area = 73.4 kWh/m$^2$.
- Heating: 35.2 MWh.
- Cooling: 1.1 MWh.

## 2nd Iteration

It is suspected that the heat exchange system is not effective enough.

The heat recovery effectiveness is raised to 85%.

A thermal template, with a heating set point at 19 degrees, is applied to all bedrooms.

### Results

- Total Yearly Energy Consumption = 34.9 MWh.
- Total Yearly Energy Consumption per Floor Area = 67.1 kWh/m$^2$.
- Heating: 32.0 MWh.
- Cooling: 1.1 MWh.

## 3rd Iteration

Window U-values are decreased to a net U-value of 1.2 W/(m$^2$*K).

Storage heating is turned off.

An error is detected - the core was set to be an exterior facing wall.

### Results

- Total Yearly Energy Consumption = 39.0 MWh.
- Total Yearly Energy Consumption per Floor Area = 56.0 kWh/m$^2$.
- Heating: 35,9.0 MWh.
- Cooling: 1.2 MWh.

## 4th Iteration

The ventilation system is adjusted with a profile, meaning that it will deliver an air change of 0.6 times per hour, except between 9.00 to 16.00 where it will only ventilate at a rate of 50%.

### Results

- Total Yearly Energy Consumption = 38.3MWh.
- Total Yearly Energy Consumption per Floor Area = 55.0kWh/m$^{2.}$
- Heating: 35,3.0 MWh.
- Cooling: 1.3 MWh.

## 5th Iteration

U-values are changed to reflect passive house standards:

- Roof, walls, floors: 0.1 W/(m$^2$*K).
- Windows: 0.85 W/(m$^2$*K).
- Thermal bridges < 0.01 W/(m*K), (old value: 0.035 W/(m*K)).

### Results

- Total Yearly Energy Consumption = 28.1MWh.
- Total Yearly Energy Consumption per Floor Area = 40.4kWh/m$^2$.
- Heating: 24.2 MWh.
- Cooling: 1.9 MWh.

# 6TH ITERATION

At this point the construction has been optimized close to its limits, and it is therefore relevant to look at other areas, in order of further reducing the buildings energy consumption - one area could be the heating system.

## HEAT PUMPS

The interest for the use of heat pumps has been on the rise the last few years.

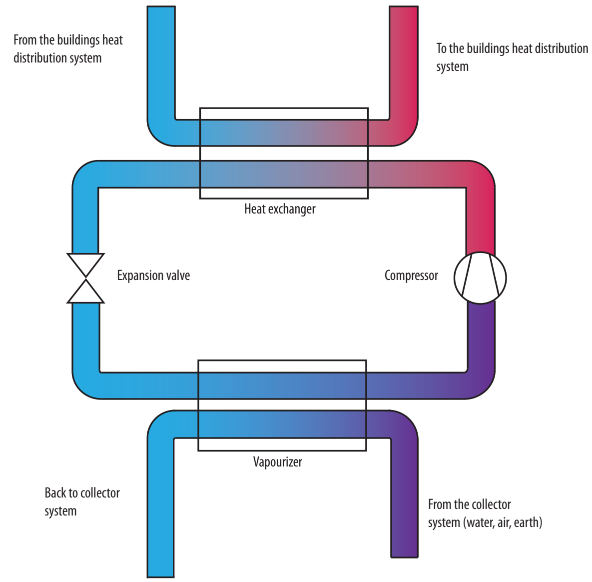
This project will not concern itself with a detailed description of the subject "heat pumps", merely provide a brief overview to determine if heat pumps could be an interesting part of the energy strategy. The benefit of using a heat pump system result from the utilization of energy sources such as: air, water and earth. The energy efficiency of such a system can be quite high, meaning that each watt putt into the system (usually in the form of electricity) one can receive as much as 4 watts of energy in the form of heat. Meaning that even when the electricity used for driving the system is multiplied with a factor of 2.5 (in order to get the equivalent primary energy, BE06), there is still a clear advantage in the total amount of used energy.

A great supply of heat pumps exist both in terms of size and how they are supplied with energy. In most cases the pump itself is driven by electricity, whereas the energy drawn into the building can come from a numerous of sources.

Examples of different types of heat pumps and their energy supply, [Poulsen, Claus S.]:

- Air/Air: the energy is retrieved from the outdoor air or possibly from a preheated air supply.
- Air/Water: works as the former principle though the energy is transferred into a water circulation system such as the traditional radiator system.
- Liquid/water: retrieves energy from tubes in the ground or ground water and exchanges this, with a water driven delivery system.

In relation to the project it is important to figure out, if a heat pump based system could be an improvement of the energy strategy, and if so, what kind of heat pump should be used as well as energy sources. The use of a liquid/water exchange system could be quite interesting in the light of the fact that the project situated near the sea. Also it is necessary to investigate whether to use individual heat pumps for each dwelling or a number of large centralized heat pumps.




ill. 3: Functional principle for at heat pump based on the slides by Claus S. Poulsen.

1) Refrigerant with low pressure absorbs energy at a low temperature from the energy source (water, earth, air, etc.)

2) The pressure and temperature is raised by the compressor.

3) A heat exchanger uses condensation to transmit heat to the buildings heat delivery system (radiators for instance).

**Energy sources**
As mentioned before heat pumps can draw energy from various sources such as: ambient air, exhaust air, ground water, ground source system, sea water etc.

In the investigation of different systems it is found viable to use a heat pump that utilize sea water as the main energy source, due to the placement of the project on the waterfront. The sea water based heat pump does not have the same problems with icing and significant drop in performance when the temperature drop, as an air based heat pump system because sea water in general has a constant temperature of 5-8 degrees at 25-50 m depth, [heatpumpcentre.org].

This is further supported by a case study published on heatpumpcentre.org, of a sea water energy based heat pump system used in Trondheim Norway. In this case a constant temperature of 5-6 degrees is determined, though not specified at what depth.

The ammonia driven system reaches a coefficient of performance (COP) of 4.0, and has a total performance of 3.900.00 kWh/year.

**Results**
- Total Yearly Energy Consumption = 9.7 MWh.
- Total Yearly Energy Consumption per Floor Area = 13.9 kWh/$m^{2}$.
- Heating: 5.8 MWh.
- Cooling: 1.9 MWh.
- Fans, pumps and controls: 2 MWh[1)].

[1)]All these functions are now driven by electricity, thus to compare the results to the demands of the Danish building regulations, the energy consumption must be multiplied with a factor of 2.5.

This adds up to a total of 13.9*2.5 = 34.75 kWh/$m^2$ which is under the desired (35+(1100/A)) kWh/$m^2$/year.

## 7th Iteration

At this point it is difficult to see how the energy use for heating could be significantly improved, without making large modifications on the concept. Instead it could be interesting to look at cooling which until now have not taken advantage of either natural ventilation, or shading.

A simulation is performed with settings that allow the users to use natural ventilation during summertime, having a set point of 24 degrees.

**Results**
- Total Yearly Energy Consumption = 9.1 MWh.
- Total Yearly Energy Consumption per Floor Area = 13.1 kWh/$m^{2}$.
- Heating: 7.1 MWh.
- Cooling: 0.6 MWh.
- Fans, pumps and controls: 1.5 MWh.

The results shows that the use of natural ventilation has had a positive effect, even though a contradiction in the heating and cooling profile is registered. The requirements for heating has gone up, even though the intention was to use natural ventilation only when overheating occurs.

## 8th Iteration

The mechanical ventilation is restored to have an air change of 0.6 times per hour, also in the periods where occupants are expected to be out.

Another approach to the natural ventilation is sets the estimated free cooling effect to an estimation of 0.3 l/(s*$m^2$) in the room thermal templates for all living- and bedroom areas.

**Results**
- Total Yearly Energy Consumption = 9.1 MWh.
- Total Yearly Energy Consumption per Floor Area = 13.0 kWh/$m^2$.
- Heating: 6.9 MWh.
- Cooling: 0.5 MWh.
- Fans, pumps and controls: 1.7 MWh.

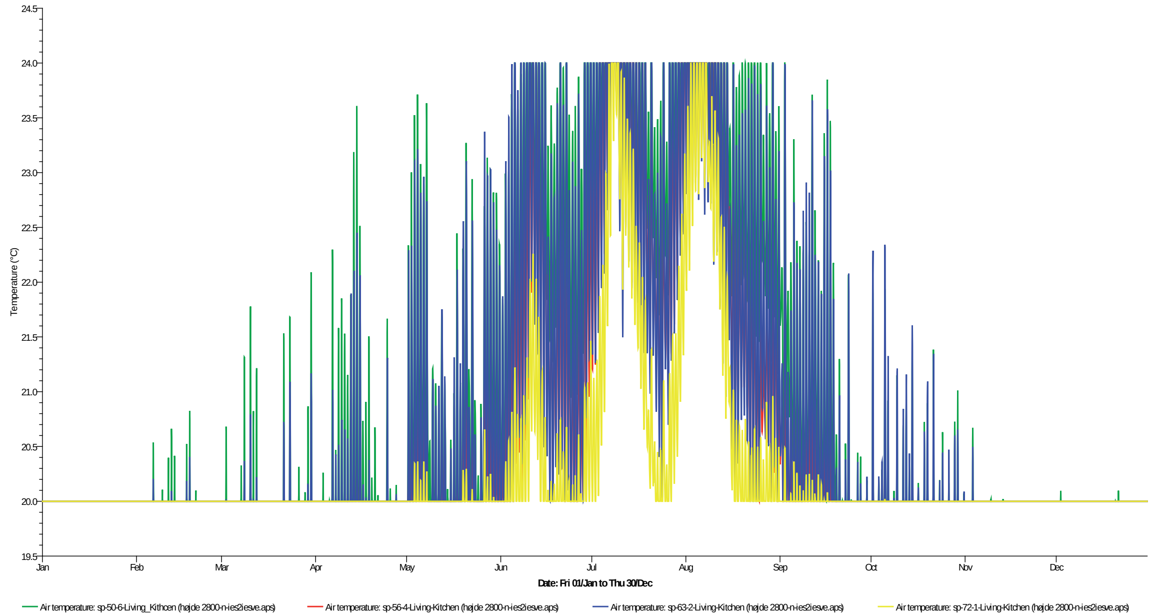
This adds up to a primary energy use of: 13kWh/$m^2$*2.5 = 32.5kWh/$m^2$.

## Final Results

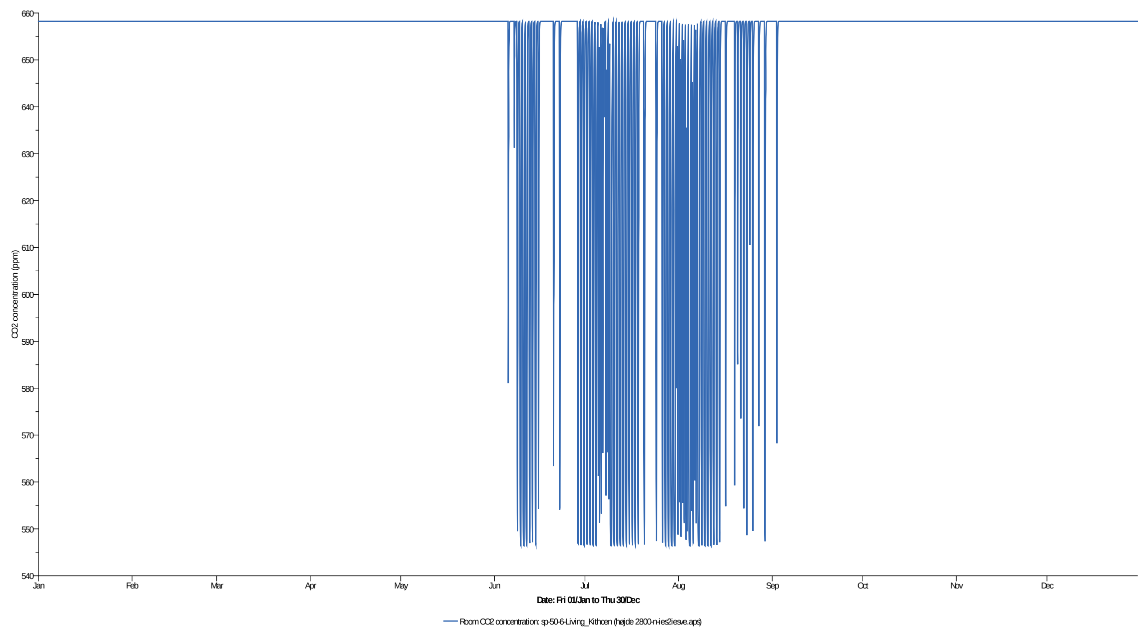
The graphs displayed to the right, show the key results from the simulation of 8th iteration.

ill. 4: The diagram graphically illustrates the annual air temperatures for the combined living rooms / kitchens of the four different apartment types. As the set point for heating is 20 degrees, the temperature does not drop below this. Likewise the temperature does not exceed 24 degrees, which is the cooling set point, where natural ventilation and if needed air conditioning will be used.

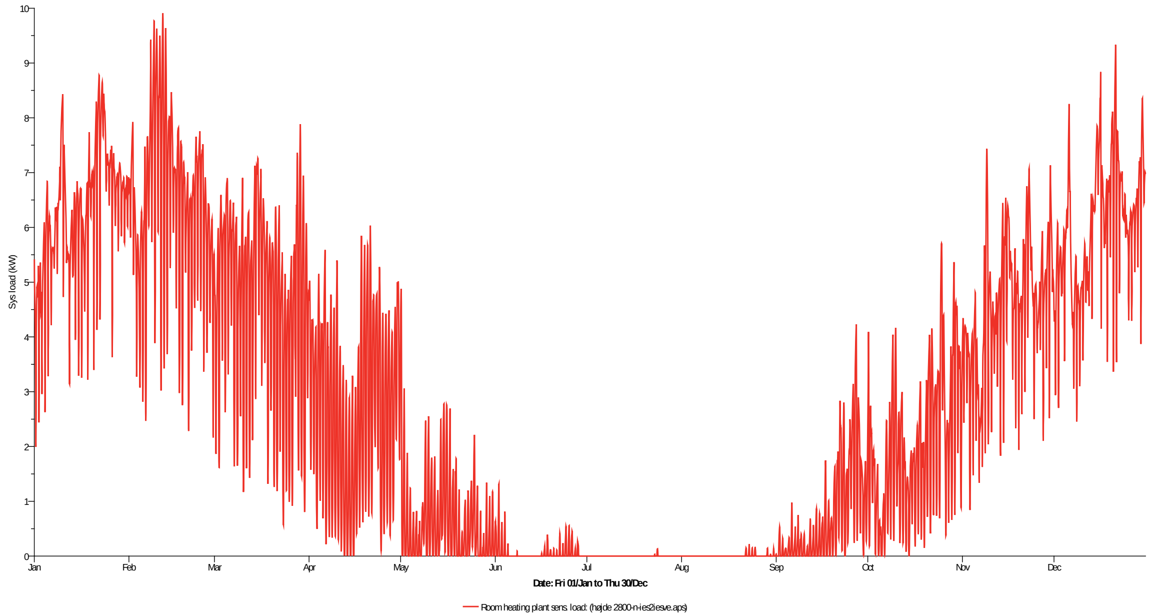
ill. 5: The diagram of $CO_2$ concentration gives an indication of the quality of the indoor climate and whether or not the ventilation rate is sufficient. The graph shows that the ventilation rate is just sufficient enough to comply with the desired level of 660 ppm (above outdoor $CO_2$ levels) which is a class B building, with a person density of 1 for every 30 square meter [CR1752, p 23.].



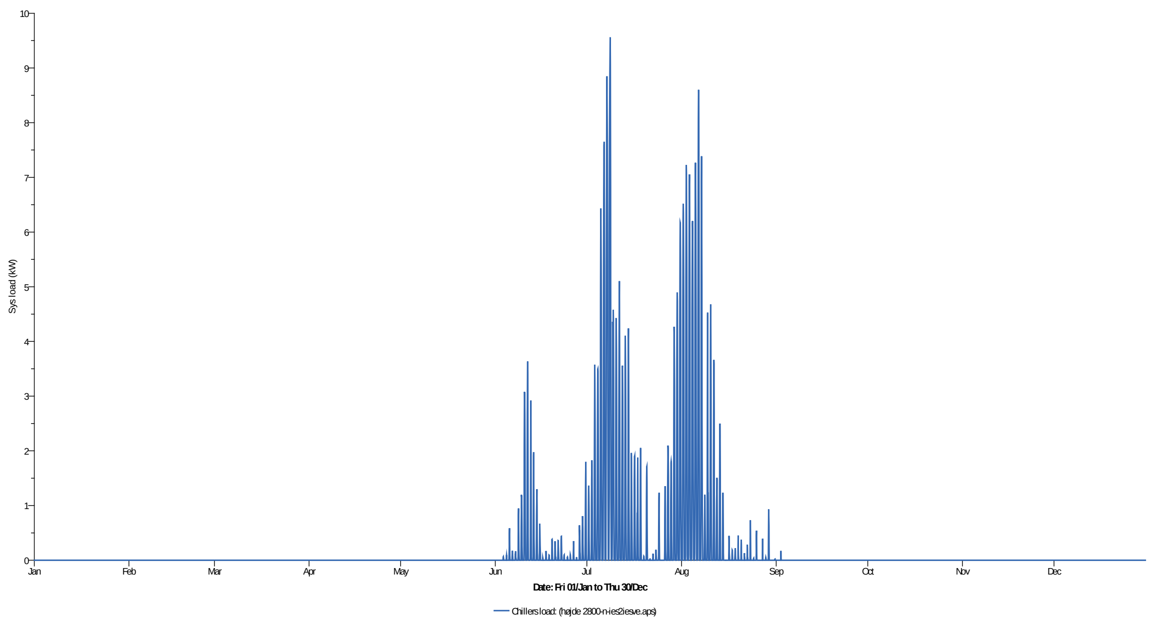

ill. 4: Annual air temperature in the combined living/kitchen area for the four apartment types.




ill. 5: Annual $CO_2$ concentration for a single apartment.




ill. 6: Graph displaying the annual energy consumption for heating in kWh (electricity).




ill. 7: Graph displaying the annual energy consumption for cooling (also electricity).

## Conclusion

Through this design phase it has been demonstrated how it is possible to optimize the building design by modifying primarily the construction and the service utilities. The process has revealed that in order to achieve the low energy class 1, it is necessary to:

- Insulate efficiently almost to the extent of passive house standards:

  Roof: 0.1 W/(m$^2$*K).
  Walls: 0.1 W/(m$^2$*K).
  Exposed decks: 0.1 W/(m$^2$*K)
  (Using an ordinary insulation would require an insulation thicknesses of approximately 350 mm).
  Windows: 0.85 W/(m$^2$*K).
  Thermal bridges < 0.01 W/(m*K).
  Infiltration < 0.13l/s/m$^2$.

- Use a heat recovery system, with an efficiency of approximately 85%.

- Ventilate with a rate of 0.6 times per hour, which is sufficient to meet the requirements of a type B building.

As the main source of heating, it has been found beneficial to use a sea water based heat pump system, with an efficiency of 4.0.

Natural ventilation is used during the summer to aid or replace air conditioning.

By using these different properties it was possible to obtain an energy use of 32.5kWh/m$^2$.

# Design phase 12
## Energy neutrality

The results from IES Virtual Environment imply that it is possible for the building to become a low energy building (class 1), which means:

35+(1100/(heated floor area))kWh/$m^2$ year.
In this case:
35+(1100/587)kWh/$m^2$ year =
36.9 kWh/$m^2$ year

(587 $m^2$ = heated floor area of a single building volume [ill. 1]).

To reassure that this is actually the case a further documentation has been made in Be06. In addition the prove of the buildings energy neutrality will be made through the use of the Bolig+ toolkit [see CD].

When testing the buildings energy neutrality it is necessary to first achieve a low energy 1 building in Be06, without implementing any energy producing devices, and first then transfer the results into the Bolig+ toolkit.

### Bolig+><The energy frame

When validating that the building is energy neutral it is necessary to look at the differences of how to obtain a low energy building, class 1 by using either the Danish Building Regulations or the method used by Bolig+.

In the Danish Building Regulations the energy frame includes the sum of the buildings necessities such as the energy used for: Heating, ventilation, cooling and domestic hot water. This means the energy which is contributed from the city grid.

Normally it is allowed to use renewable energy sources, such as photovoltaic cells to achieve the low energy class 1. According to the Bolig+ criteria this is not the case. The low energy class should be achieved without any sorts of contribution from photovoltaic cells. However, it is allowed to use a solar heating plant for the domestic hot water.

After achieving the low energy class 1 it is afterwards allowed to use photovoltaic cells to achieve the next goal, energy neutrality, which must be documented in the Bolig+ toolkit.

## Be06

In a calculation of the energy frame in Be06 different things are included:

- Heating
- Ventilation
- Cooling
- Domestic hot water
- The electricity consumption is multiplied with a factor of 2,5

The calculations include solar radiation, heat supply from persons and the buildings characteristics of heat storage.

### General input in Be06

The heat capacity of the building will be calculated as a medium heavy building, which means heavy parts, for instance concrete deck with tiles or clinker concrete walls. The usage time is 168 hours a week, which is the standard for dwellings.

Climate screen
The different U-values are based on the guidelines for passive houses.
At the windows different factors has been considered such as overhangs and different shading devices. It is assumed that it is possible to have shading devices all around the building.

Ventilation
During winter the building is mechanical ventilated with a heat-recovering system and a standard infiltration of 0,13 l/s $m^2$. In the summer time the ventilation will consist of natural ventilation.

Internal heat supply
- Persons=1,5 W/$m^2$ and applications= 3,5 W/$m^2$.

Domestic hot water
The solar heating plant contributes to the domestic hot water system.

The tank volume is defined to the amount of occupants in the building. In this building there are 13 occupants as a maximum. As a general rule 4-5 persons uses 123 liters per day, which gives a tank capacity of around 500 liters.

Solar heating plant
The solar heating plant contributes as mentioned to the domestic hot water. The different values are taken from a manufacturer, Buderus [see Be06 - Input].

The solar heating plant cover the whole roof and is connected to the solar heating tanks in the basement.

Heat pump
The values inserted are based on geothermal heat but caused by our location it is intended to use ocean thermal heat [teknologisk.dk].

The heat pump should be used for both the domestic hot water and space heating.

## The results

The results of the calculations in Be06 implies that it is achieved to reach the standards of a low energy class 1 building.

But the results from Be06 also imply that the designed building has a necessity to have low U-values, an effective ventilation system and alternative heating (heat pumps) otherwise it would not have been possible to achieve the low energy class 1 without any contribution from renewable energy sources, other than the solar heating plant for the domestic hot water.

It is now possible to begin the further documentation of the building, which means that it is necessary to figure out the amount of photovoltaic cells, which is necessary to implement on the building to fulfill the demands of the Bolig+ standards.

Ill. 1: The building, which has been used for the documentation. It consists of 2 apartments for disabled in the bottom, a 4 room dwelling, a 3 room dwelling and on top a 2 room dwelling.

## Input - Be06

**Transmission coefficient**
Windows: 0.85 W/m$^2$K and the solar heat transmittance: 0.65
Walls, roofs, floors: 0.1 W/m$^2$K

**Climate screen, areas**
Outer walls: 1428.2 m$^2$
Roof: 328.3 m$^2$
Floor: 496 m$^2$
Floor, terrain: 91 m$^2$

**Window areas**
Southwest: 117.8 m$^2$
Northwest: 14.44 m$^2$
North: 41,37 m$^2$
Northeast: 18.28 m$^2$
Southeast: 12,8 m$^2$
- A total of: 204,7 m$^2$

**Photovoltaic cells**
Panel area: 250 m$^2$
Orientation: Southwest
Slope: 45°
Peak Power [energiforumdanmark.dk]: 0,16 kW/m$^2$
System efficiency: 0,75

**Ventilation**
Mechanical ventilation, winter: 0,35 l/s m$^2$ = 0,5 h$^{-1}$
Heat recovery = 0,75
Infiltration, winter: 0,13 l/s m$^2$
SEL: 1 kJ/m$^3$
Natural ventilation, summer: 1,8 l/s m$^2$ = 2,3 h$^{-1}$

**Heat pump**
Heating for both space and utility water.
Nominal effect: 5.38 kW
Nominal COP (heat pump efficiency): 3,66

## Key results

Total energy requirement: 33,8 kWh/m$^2$ year
Total electricity consumption: 41,5 kWh/m$^2$

## Bolig+ toolkit

The Bolig+ toolkit is a supplementing spread-sheet, which uses the documentation and results reported in Be06.

The Bolig+ toolkit sets up an energy balance, which monthly shows;

- All the energy consumptions (exclusive common outdoor lighting).
- Energy produced by the building.
- Energy consumed from the grid.
- Energy, which is delivered back to the grid.

As mentioned earlier it is necessary to focus on the total electricity consumption from Be06. This sum indicates exactly how much the total consumption from the grid is.

In the Bolig+ competition program the definition of an energy neutral building, is:

*"An energy neutral building does not use more energy on a yearly basis from the grid, than it gives back.*

*The returned energy should be in the same quality or better, than the consumed energy from the grid and it shall have at least the same applicability (Bolig+ program)."*

## Conclusion

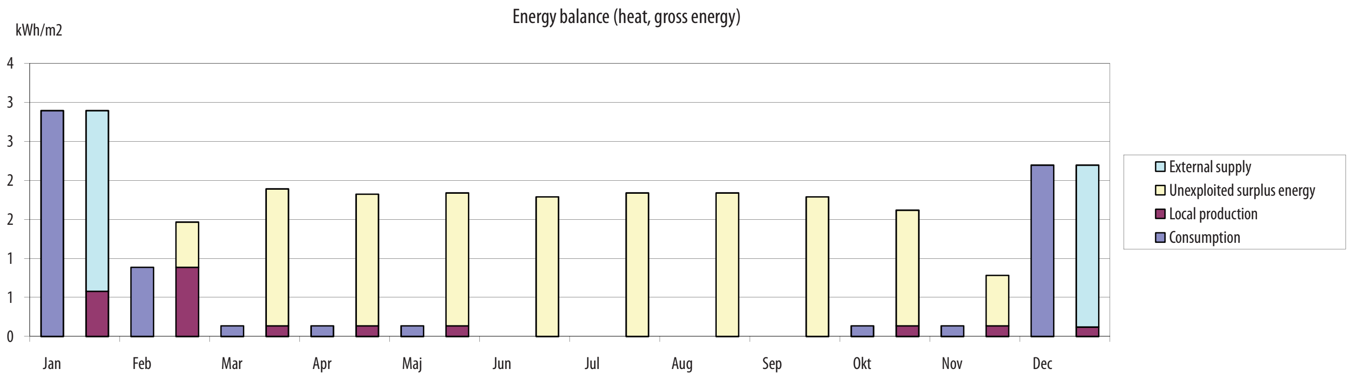
According to the shown diagrams, the goal to design an energy neutral building, has been accomplished.

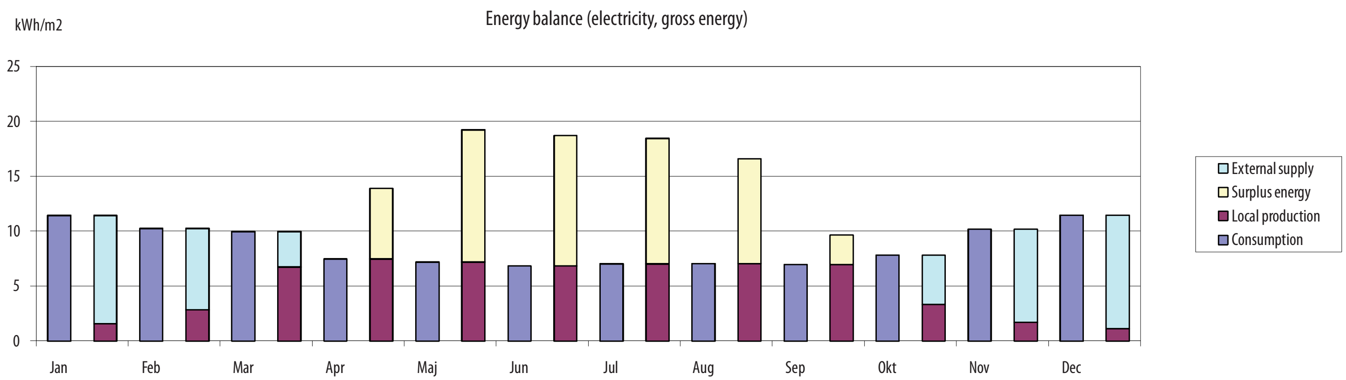
In the diagram "Energy balance (heat, gross energy)" it is possible to see that there is consumed energy from the grid for heating during winter.

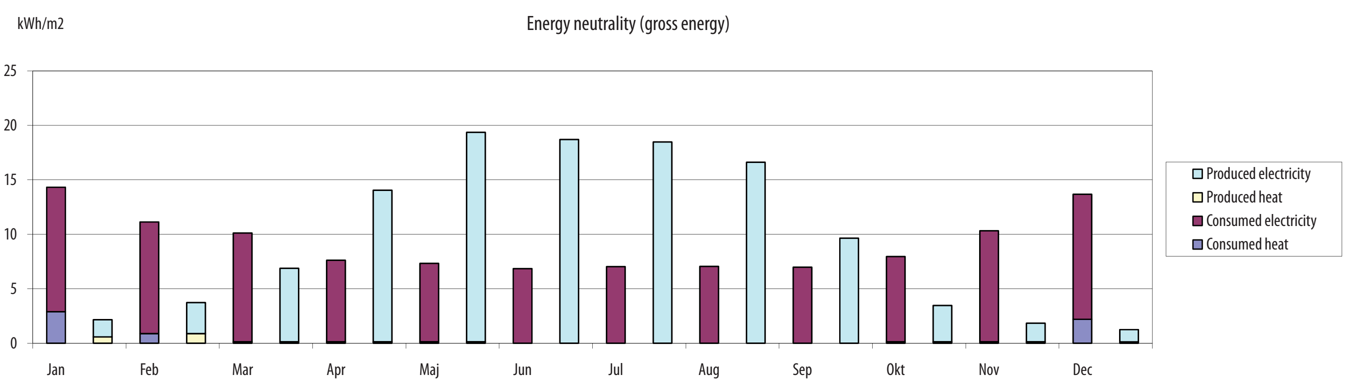
The "Energy balance (electricity, gross energy)" shows it is possible to see that the photo voltaic cells produces enough energy in the summertime to manage the consumption in the dwellings.

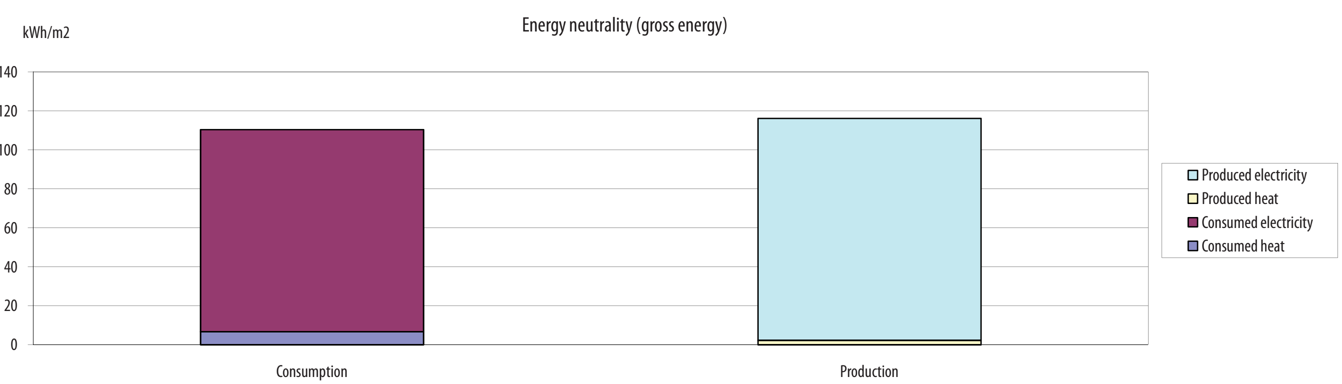
In the wintertime the produced energy on site has to be supplemented with energy from the grid. This is also illustrated in the "Energy neutrality (gross energy)" diagram, which shows that from April to September the site produces enough energy according to the total electricity consumption. It is producing almost twice as much energy in those months than it is using.

Through a whole year the building consume 110.4 kWh/m$^2$ year and it produces 116.19 kWh/m$^2$ year.


Energy balance (heat, gross energy)
kWh/m2
4
3
3
2
2
1
1
0
Jan
Feb
Mar
Apr
Maj
Jun
Jul
Aug
Sep
Okt
Nov
Dec
External supply
Unexploited surplus energy
Local production
Consumption


Energy balance (electricity, gross energy)
kWh/m2
25
20
15
10
5
0
Jan
Feb
Mar
Apr
Maj
Jun
Jul
Aug
Sep
Okt
Nov
Dec
External supply
Surplus energy
Local production
Consumption


Energy neutrality (gross energy)
kWh/m2
25
20
15
10
5
0
Jan
Feb
Mar
Apr
Maj
Jun
Jul
Aug
Sep
Okt
Nov
Dec
Produced electricity
Produced heat
Consumed electricity
Consumed heat


Energy neutrality (gross energy)
kWh/m2
140
120
100
80
60
40
20
0
Consumption
Production
Produced electricity
Produced heat
Consumed electricity
Consumed heat

# Design phase 13
## Daylight studies

Further daylight studies have been done using 3ds Max Design, to evaluate the final floor plans both with and without louvres, and with and without direct sun exposure.

As with the earlier daylight studies, focus will be on the main living areas on the first floor which is identical for the 4 -, 3 -, and 2 room apartments. The orientation of apartments differ, which will be relevant for the daylight studies with direct sunlight, but not for the daylight factor studies.

Some changes have been made to the plan since the last daylight studies [Design phase 6 ill. 1, 2, 3 & 4]. One of the main changes, in regard to daylight, is the deletion of windows in northern facade, which was done in order to conserve energy and to have more wall area used for furnishing. Also the internal apartment height  has been changed from 2.5 m to 2.8 m.

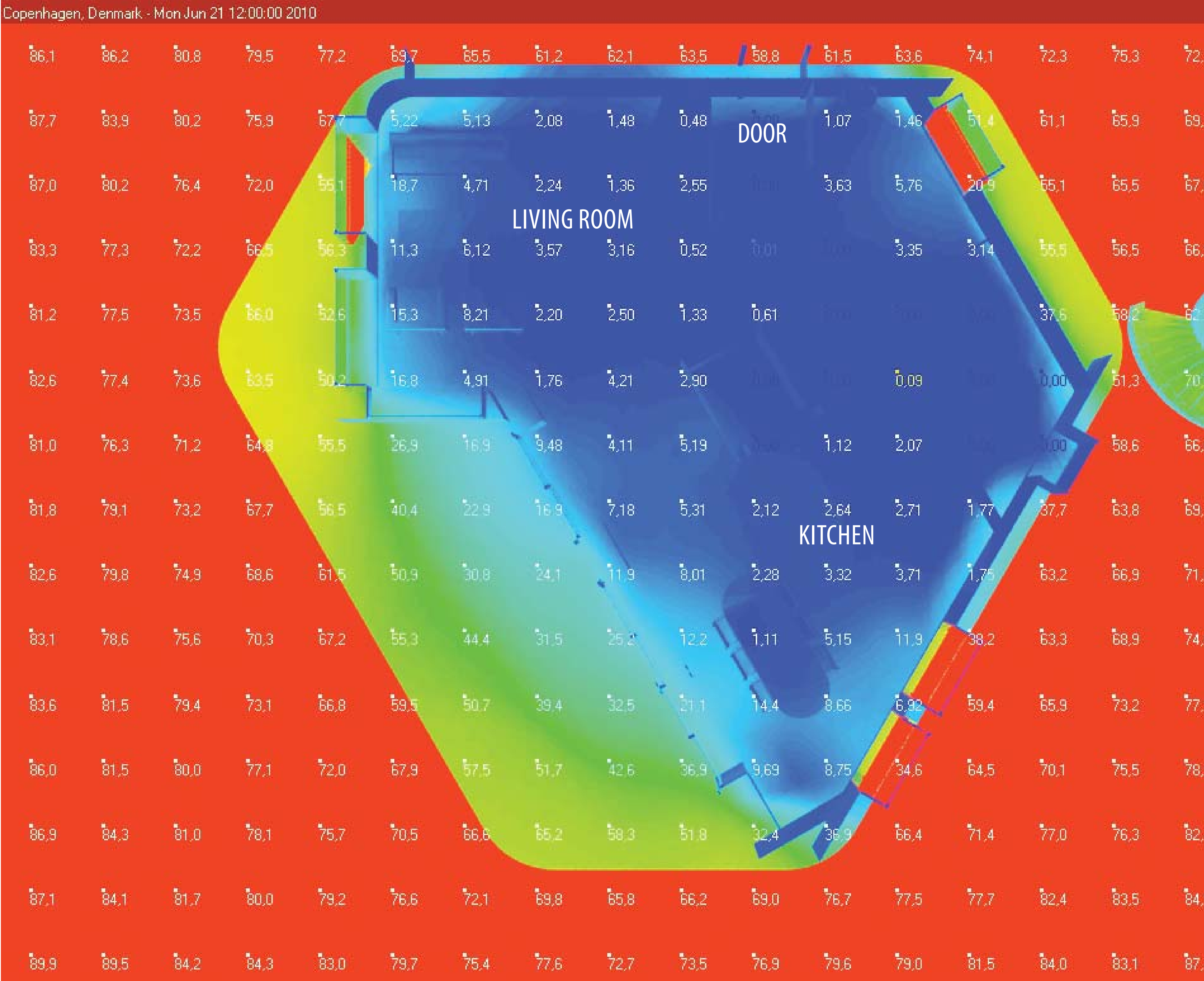
### Daylight factor

Daylight studies were done on the first floor both with and without the louvres.

On the opposite page the first daylight test is seen without louvres.

The result indicates that the plan has a decent amount of daylight in most areas, though some areas could benefit from more light such as the entrance and the far areas of the kitchen.

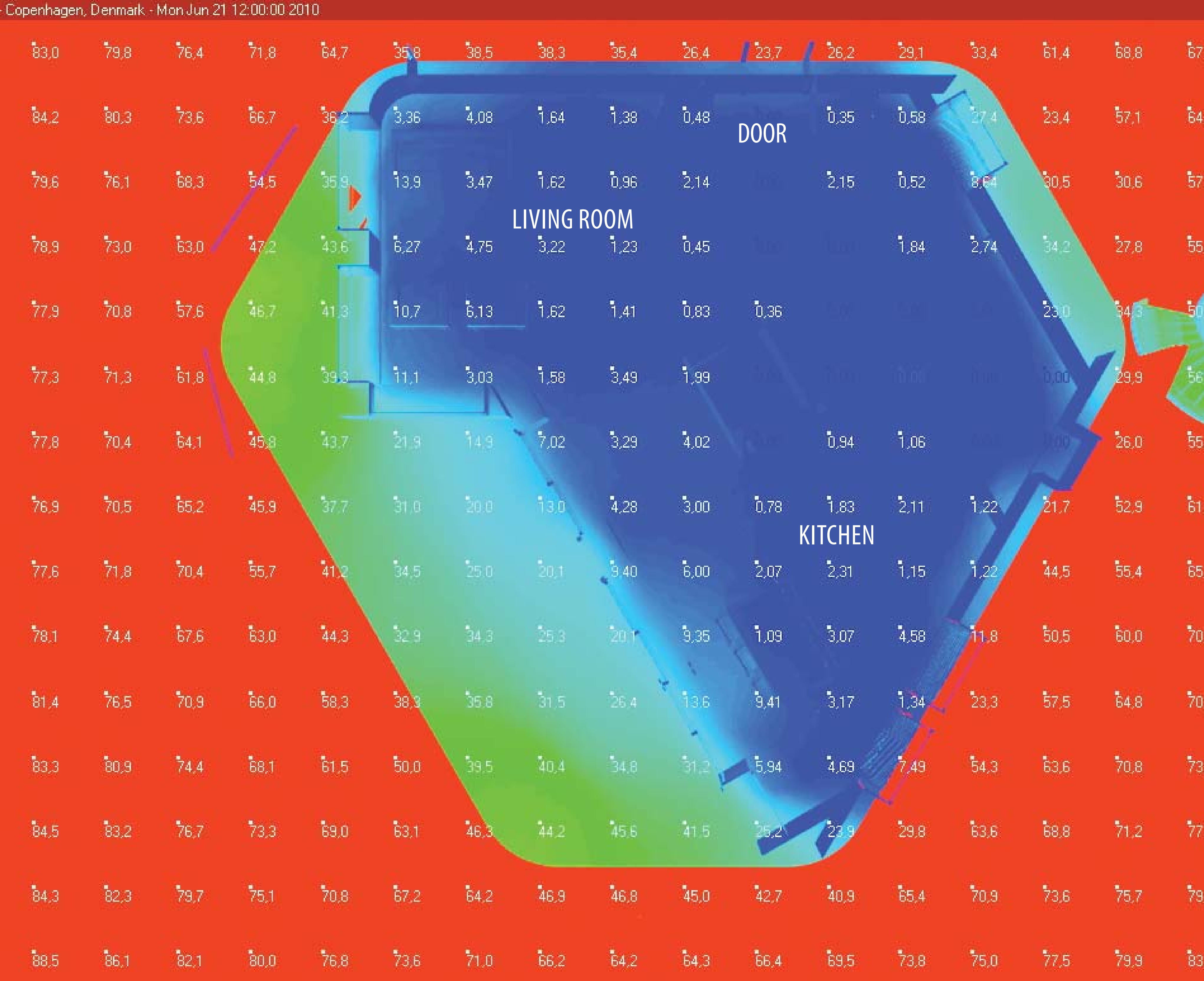
ill.1: Illustration with pseudo colors showing the daylight factor in the main living areas, when not having the facade applied.


Copenhagen, Denmark - Mon Jun 21 12:00:00 2010
DOOR
LIVING ROOM
KITCHEN

Opposite the results from the daylight simulation with the louvres are shown. The material used for the louvres is a semi transparent material, with matt glass-like properties.

The result reveals that even though large areas of the louvres have been opened, the daylight factor is reduced quite significantly - though still being decent in most parts of the floor plan. This indicates that a further optimization of the facade is necessary to get better daylight conditions.

ill.2: Illustration with pseudo colors showing the daylight factor in the main living areas when having the facade applied.


- Copenhagen, Denmark - Mon Jun 21 12:00:00 2010
DOOR
LIVING ROOM
KITCHEN

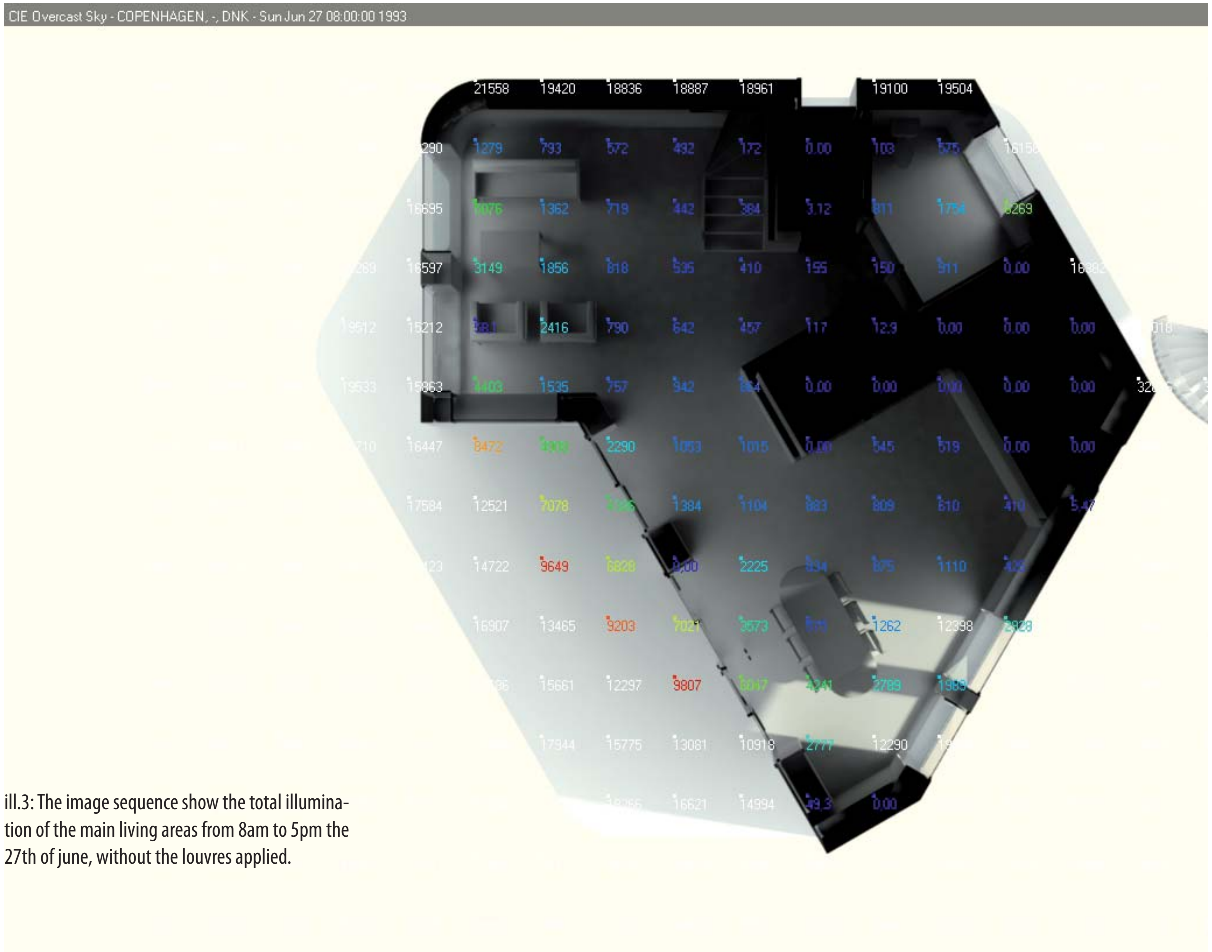
The daylight studies shown on this spread simulates the light conditions in the main living areas when taking both skylight and direct sunlight into account.

The first light simulation (shown on this spread) is done without the louvres to test the daylight conditions on a sunny day, the 27th of June from 8am to 5pm.

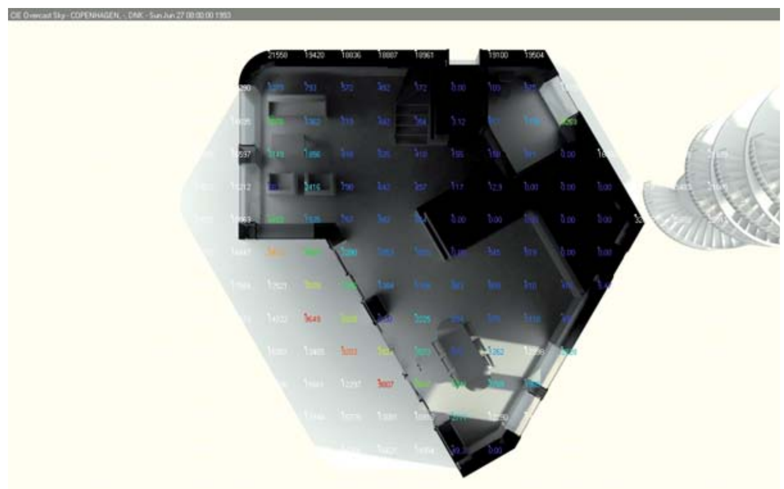
The simulations shows that the floor plan is well lit in most part of the day, though noticing a significant drop in the lux level between 4pm and 5pm, [for more detailed and larger plans see the attached CD].

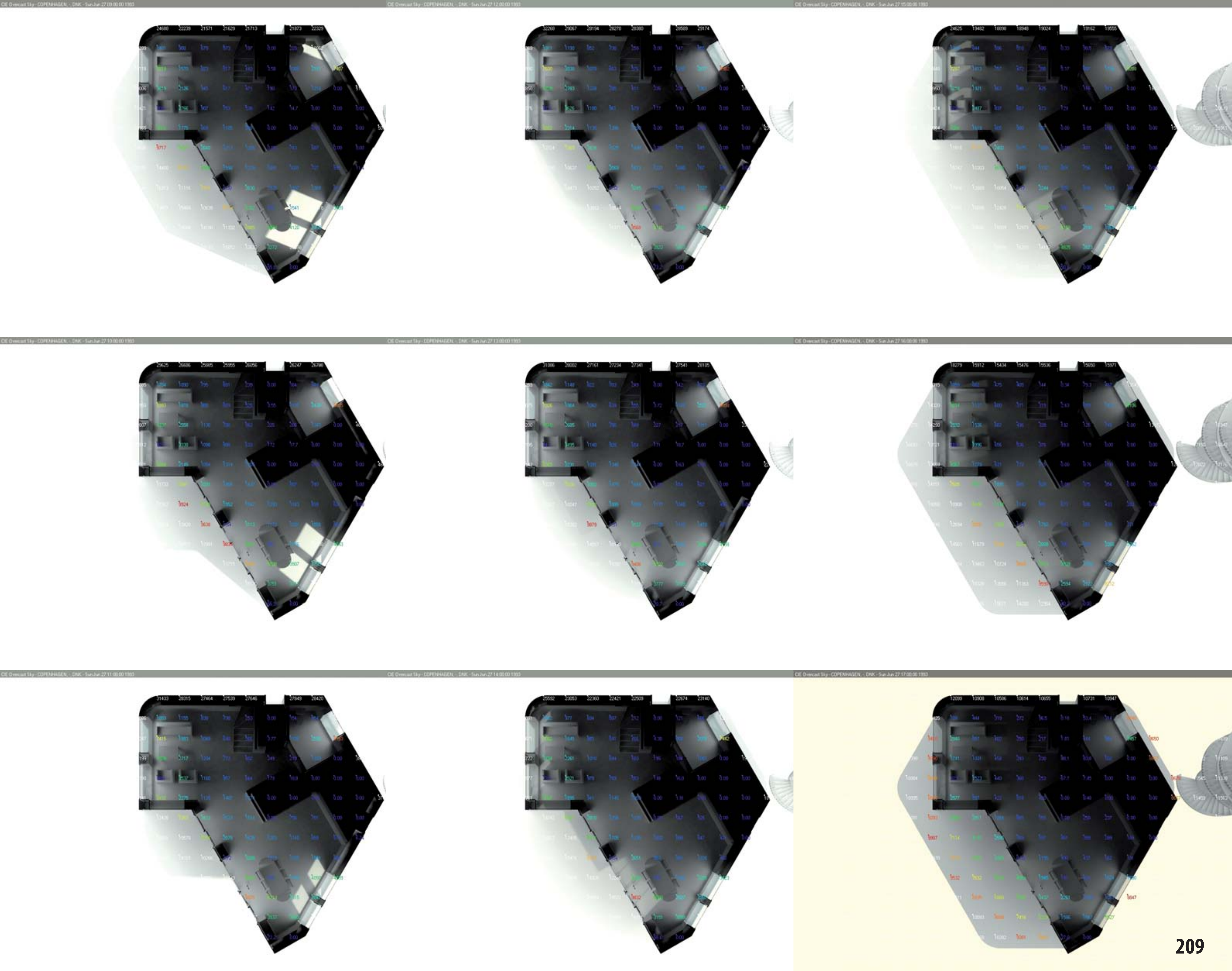
Certain times of the day shading of some sort is necessary in order to prevent glare, which for instance is the case in the living room during the afternoon.

It should be noted that the displayed range between light and dark, is not how the area would actually be perceived. Instead the numbers are the real indicators. In comparison with the daylight factor, the CIE overcast sky is defined as approximately 10.000 lux at the Danish latitude[Autodesk, may 5th]. Meaning that a daylight factor of 1% would equal approximately 100 lux, 2% would equal 200 lux etc.




ill.3: The image sequence show the total illumination of the main living areas from 8am to 5pm the 27th of june, without the louvres applied.



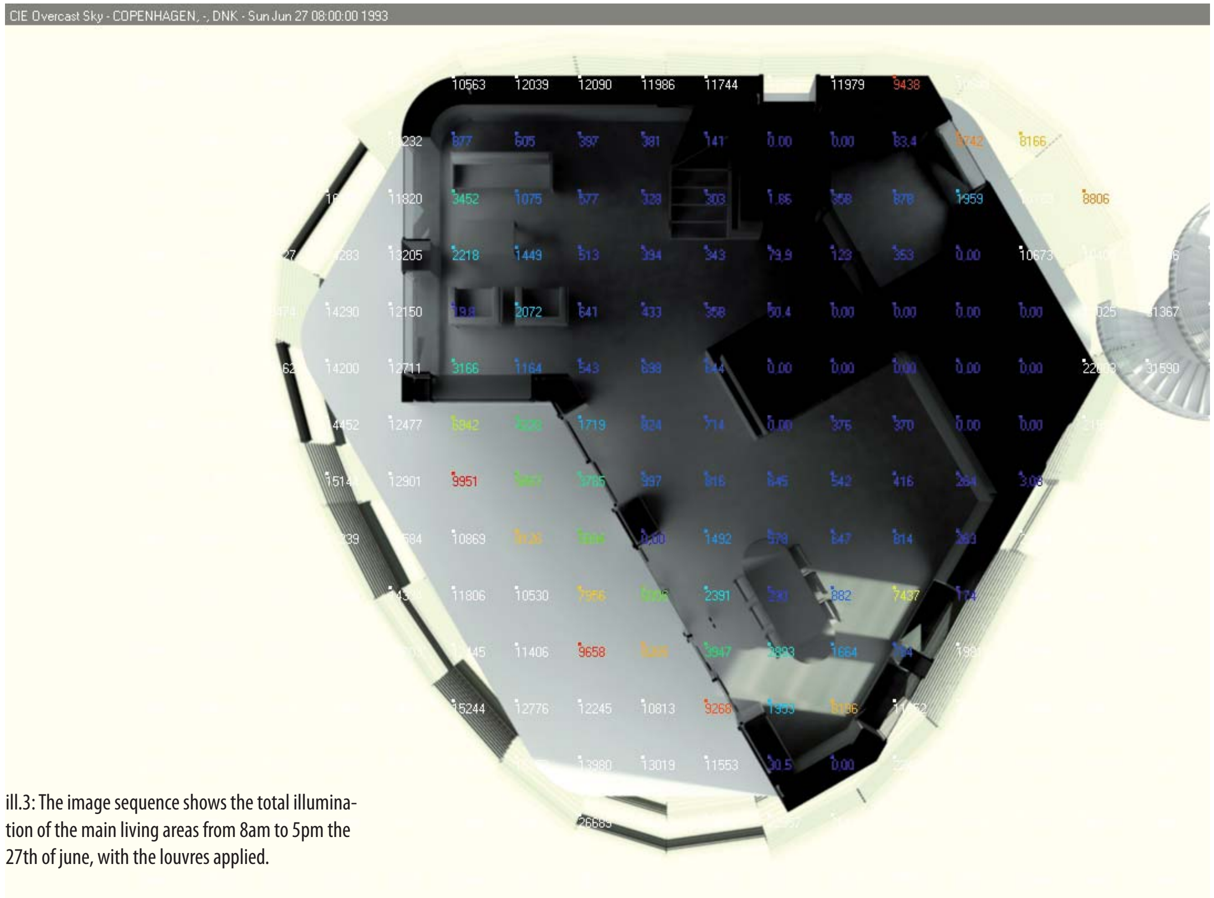


The simulation shown on this spread is performed similar to the one performed earlier, but now with louvres representing the concept of the facade, to test what effect these will have on lighting levels inside the apartment, on a bright summer day.

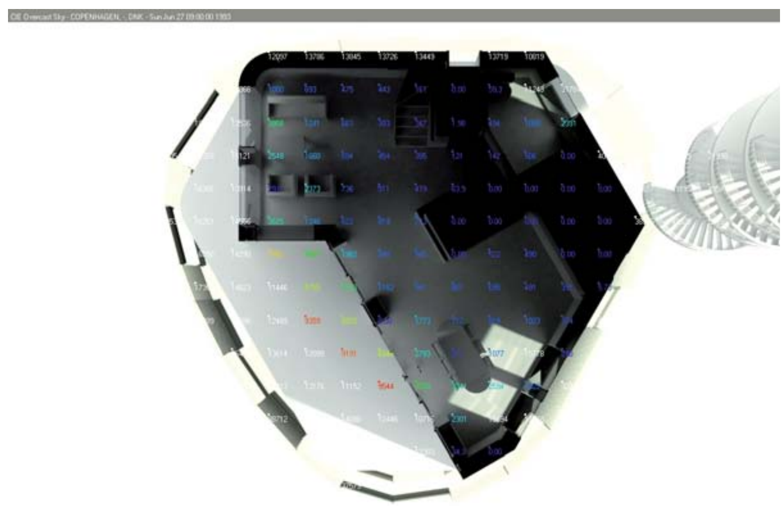
Even though 70% of the louvres has been opened there is a significant shading effect, resulting in lower lux values for the entire floor plan, but with the largest effect near the window areas - hereby reducing the risk of glare.

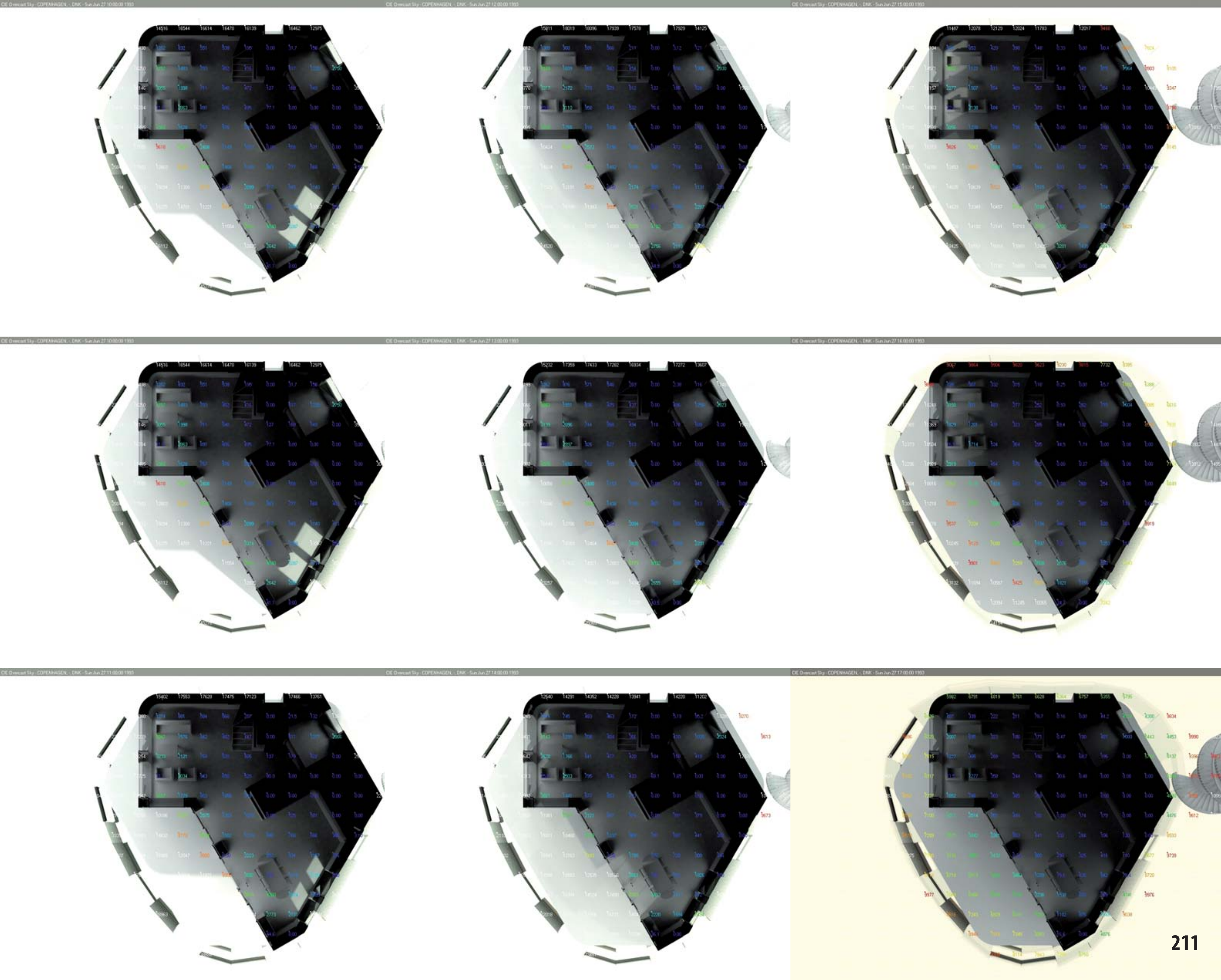
### Conclusion

The daylight studies has only been performed on a single facade position. In order to detail the facade, more studies would be necessary to see how it would perform in alternative positions and on a yearly basis. It is clear though that the lighting conditions could be improved in some areas, and in further process, this should be dealt with.




ill.3: The image sequence shows the total illumination of the main living areas from 8am to 5pm the 27th of june, with the louvres applied.





# Reflection

# Reflection
## Integrated design workflow

During this master thesis project, the themes of the project encouraged a great emphasis om integrated design in order to achieve a high degree of energy efficiency without comprising architectural quality, and the vision of creating an urban alternative to the surburban dwelling.

This vision also imposed the question: How freely is it possible to work with form and concept and at the same time keep the energy consumption according to the defined demands of a Bolig+ building?

During the conceptualization answers to this question were constantly sought, though without ever getting a definitive answer - mainly because of the rather complex nature of energy efficient buildings. This leads to one of the inherent problems of designing energy efficient buildings: How does one get the right information about the buildings performance, in a dynamic and ever changing process? It is this knowledge that will enable the architect to react proactive in the design phase.

Exploring solutions to this problem quickly became one of the hidden agendas of our master thesis, and in this chapter the experience gained from this project about tools and methods for integrating energy, and daylight considerations will be discussed.

### Sketching in 3D

During the design of the individual apartments, it quickly became necessary to be able to clearly visualize the spatial qualities of the plan - both in the individual apartments, but also in the volumes that the apartments form.

Earlier Autocad Architectural Desktop, or just ADT, and Google SketchUp has been used to create 3D models of apartments. ADT is known to be a bit to slow to become a part of the early sketching. Instead Autodesk Revit Architecture became an interesting program to investigate, to see whether or not it could be used in a fast moving design process, and what kind of freedom it provided against the freedom of ADT for instance.

After experimenting with Autodesk Revit Architecture 2010 it was integrated rather seamless into the design process, which aided the process in a number of ways. Apart from the direct benefits, a number of indirect opportunities also arose in the form of a higher degree of interoperability with some of the tested analysis programs.

### Energy and indoor climate

Energy and daylight have been two major themes in this project, but it is also themes, which in general can be difficult to evaluate in the architectural design process.

Throughout the Architecture and Design education, tools for evaluating and simulating building performance have been used, but most of these have been inadequate.

For evaluating a designs energy performance, tools such as Be06, Month average spreadsheets and Bsim have traditionally been used, but they all have inherent faults, which result in a poor use if these.

Be06 and the monthly average spreadsheets are both used by typing in data from different design proposals, data such as construction types, surface- and floor areas etc. By using the monthly spreadsheet, and BE06, there is generally a great risk, that a significant part of the building is "lost in translation" so to speak, and a more fluent link between building data, and BE06 is also missing. The nature of the monthly spreadsheet also implies that it is used in the very early stages of the design process.

In the more detailed simulation of buildings the program Bsim is often used, which is an extremely detailed energy, and indoor climate simulation tool. Bsim is useful for detailed studies of individual areas, which for some reason could be problematic. Bsim is though quite heavy to model in, adjust and is more relevant for the engineer, who will fix the problems the architect has created.

This generally leaves a gap in the design process - especially when one is designing highly energy efficient buildings, which to some degree can be perceived as highly tuned "living machines".

Because of this, time was invested in researching other tools or methods, which might could be used in a fast moving design process.

Ultimately two different tools were considered: Virtual Environment, by Scottish IES, and Ecotect, which is now owned by Autodesk. One of the advantages of both of these tools is that it is possible in some degree to be linked to the models from Revit.

Ecotect has won some ground in the architectural community, but has also met some critique regarding the validity of certain simulations. When comparing Virtual Environment (VE) and Ecotect, one will also find that Ecotect in general is more aimed at the earlier design phases than VE.

The final choice of simulation software fell on VE, which is a comprehensive, building simulation tool, that in general can perform the same kind of simulations as Bsim.

The advantage of using VE instead of Bsim is that it has a more intuitive, and more "hassle free" interface, a plug-in option for Revit and SketchUp, which speeds up modeling, and templates. This reduces retyping of parameters when testing different solutions with the same parameters, and hereby also reducing the risk of mistakes.

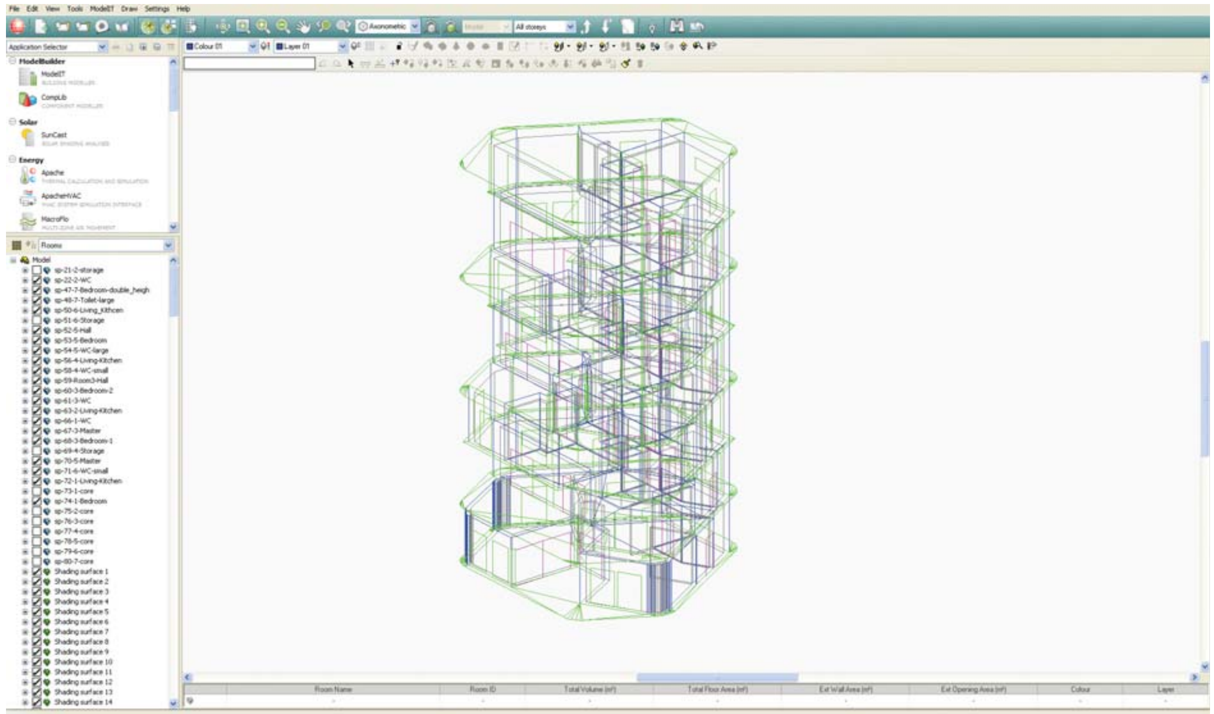
After understanding how Virtual Environment worked, and how it interpreted the Revit geometry, it was possible to make very detailed simulations in Virtual Environment, while not spending to much time on modeling because the most relevant design proposals were already modeled in Revit. Though some modifications, and some cleaning was necessary.

## Daylight

Daylight is an important element in most architecture, and this is of course also the case in this master thesis project.

During earlier semesters programs, such as Dial Europe and Ecotect has been used to evaluate daylight, usually as a daylight factor, but these methods have some drawbacks, which initiated research into alternatives.

The drawbacks of Dial Europe are the limited, and cumbersome modelling of simulation objects. Ecotect has some link capability with ADT and Revit, which could be handy, though earlier encounters with Ecotect gave a less than perfect impression, caused by time consuming simulation runs, and questionable results.



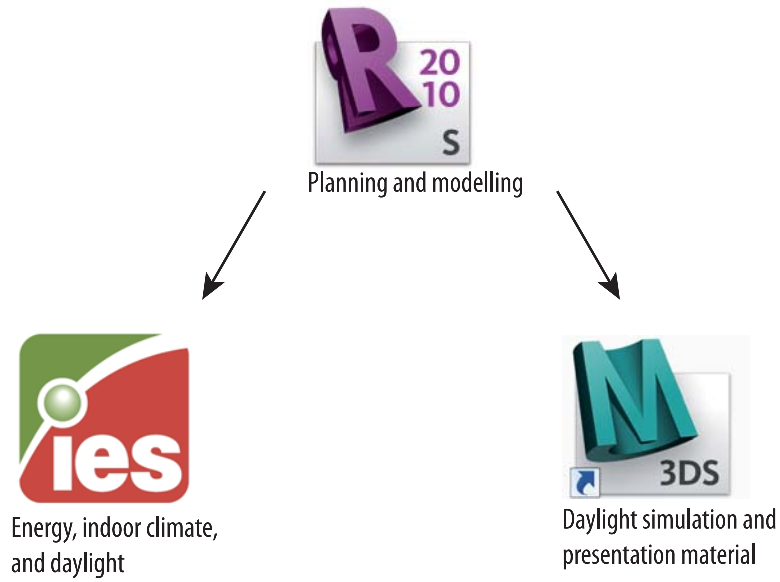
ill. 1: Screenshot of Virtual Environments interface.

During this project two different routes of evaluating daylight in buildings were tested. One of the methods was by using Virtual Environment, which apart from a energy and indoor climate module, also has advanced light study modules, as well as a simple CFD module.

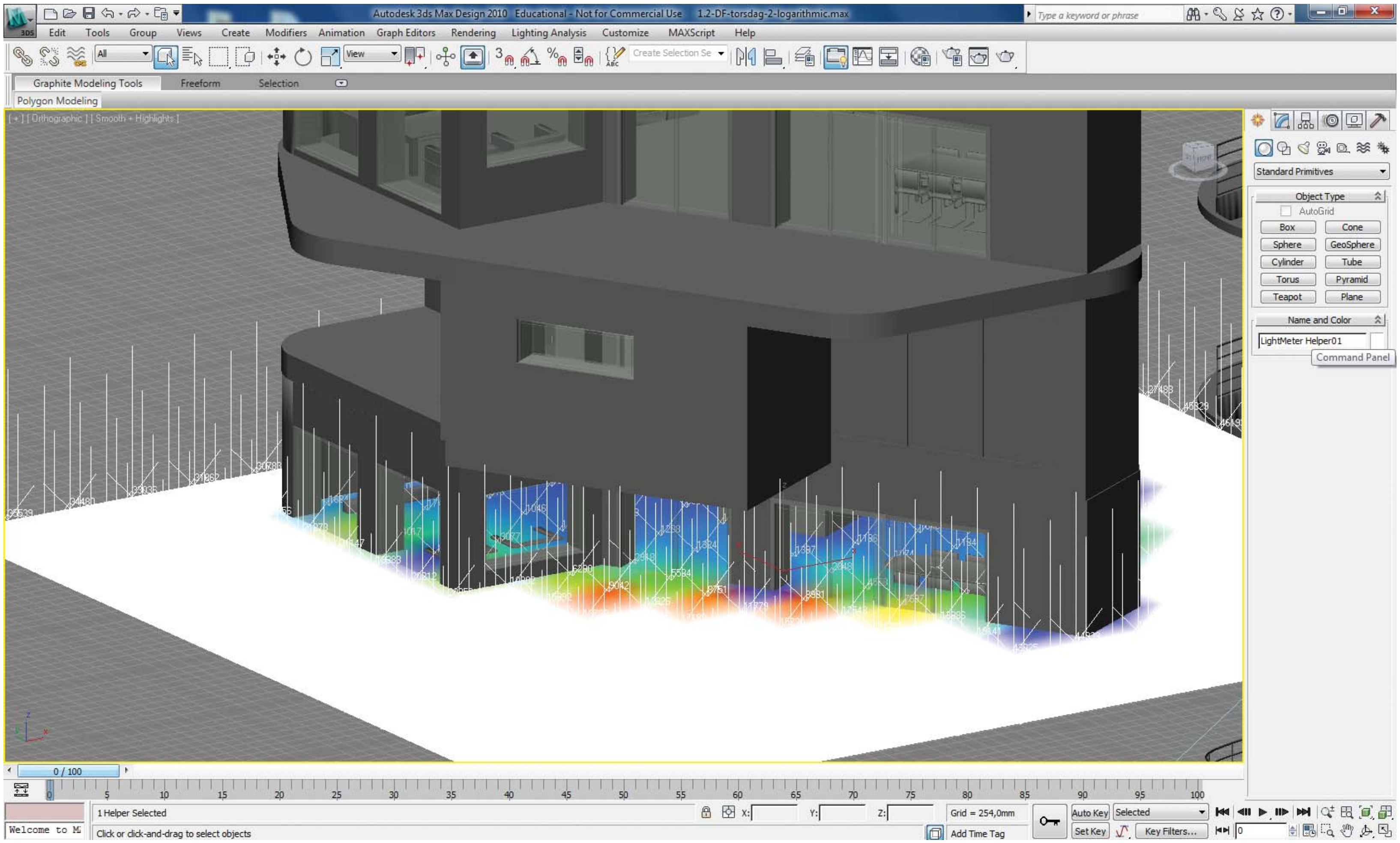
This approach seemed beneficial to use whenever time had been used to clean up a model for Virtual Environment in the first place. Virtual Environment could also export scenes to Radiance, which is generally accepted as being the leader in photo metric simulations - though this is also quite time consuming.

An alternative method used in the project, is by using 3D studio Max Design, which has a built in light simulator aimed at architects. The benefits of using 3Ds Max Design are many.

Being a comprehensive 3D package, it offers great flexibility, and interoperability - it can for instance fluently import Revit models, the 2011 version even allows a file link operation meaning that changes made in the Revit file could easily be updated in the 3Ds Max file. 3D Max Design is further more a software package which many architectural firms use in the first place to create presentation material. The challenge in 3Ds Max is to know how to set up materials and models in order to get valid results.




ill. 2: Diagram of the described workflow




ill. 3: Screenshot of the 3D studio Max Design interface

## Recapitulation - Integrated design workflow

The discovery and use of these methods during the project, definitely aided the decision making, though in order for the methods to have had a major impact on the project, they should have been in place before the design phase began.

**Energy and indoor climate**
In the early stages of the conceptualization, zoning, reasonable sizing of glazed areas, and a careful watch on the surface area to floor area, was the main points of focus.

Later in the process testing with monthly average spreadsheets aided the further design process, though this method seemed to distance itself from the geometry, and instead focus more on obtaining the right U-values in relation to the surface areas.

As a response the simulation tool, VE, was used for the further process, though unfortunately this was rather late, meaning that the benefits of the program were only slightly apparent in the project.

The main advantages of this program is that it makes it possible to further detail the input for the program during the process so it for instance focuses on daylight and an overall energy consumption at the early stages. When doing further iteration it is possible to still create a link between the different indoor climate parameters, and constantly go from overall, to more detailed energy parameters.

**Working with daylight**
In the early sketching phase, working with daylight, was done on multiple levels. The simple shadow diagrams, which can be created using SketchUp, did not seem sufficient to evaluate typologies in a satisfying degree partly because the shadow diagrams are not easy to quantify, meaning that it was difficult to evaluate when shadowing was acceptable and when they were not. The shadow studies alone are not sufficient to evaluate an urban area, to determine the lighting levels in planned settlements.

3Ds Max Design has the advantages of being able to use the different 3D models drawn in Revit and at the same time it is possible to make quick mock-ups in 3Ds.

The possibilities of working with the dwelling within accurate urban daylight conditions would give the possibility of creating an optimized design, which both focuses on the outdoor climate and the outdoor relations.

# The project

The vision for this master thesis project was to create a personal interpretation of an urban dwelling of the future, which should combine the advantages of living in the dense city, with those found in the currently preferred way of living - the detached housing areas.

Furthermore it was a vision that the dwellings should have a strong sustainable character, both in appearance as well as "on the paper", in order to truly make an impact on society of tomorrow. Therefore a choice to work with the Bolig+ programme.

This combination of visions challenged the assignment of designing an energy neutral building, and pushed the design in a direction, which may be considered alternative compared to the traditional way of thinking an energy efficient building.

## Bolig+ dogma

To design an energy neutral building the focus should not only be to build compact. To design good architecture should be about dealing with a lot of different parameters such as context, time, function and aesthetics.

As mentioned one of the groups visions were to design a building, which creates a strong sustainable character both in appearance and on paper. In this chapter, the final concept will be discussed according to its relation to the Bolig+ dogmas.

### Dogma 1: Energy neutrality

As documented in this report the final concept meets the energy requirements of the Bolig$^{+}$ program, which means that the building and its service systems use less than 35kWh + 1100 kWh/Area, per year, and produces more electricity than it consumes.

As mentioned in the process evaluation, one of the themes of this project was to design a dense alternative to the suburban dwelling which in some respects pushed the design in an interesting direction, while at the same time questioning the traditional approach to designing an energy efficient building where the mantra seems to be: "Build compact".

The concept developed during this project is not exceptionally compact in terms of floor area to exposed surface ratio. As a response to this, the building envelope needs rather low U-values, as those of passive houses, which is slightly more than the values for a typical low energy class 1 building.

This leads to the obvious conclusion, that it is not, at least in theory, necessary to build extremely compact in order to negotiate the energy requirements of the Bolig$^{+}$. The level of compactness though should be weighed against the amount of insulation, and the inevitable increase in costs. In relation to this question, one could say that the concept developed in this project, goes close to the limit of what is realistic with todays insulation technology.

Apart from the high degree of insulation, the energy concept also consists of an array of other features, which are necessary to meet the energy requirements, such as a heat pump, solar heating panels to collect hot water, effective ventilation and heat recovery system, and finally photovoltaic cells to produce electricity for the user. The use of such systems seems inevitable when designing a Zero energy building.

### Dogma 2: Intelligent and easy operable dwelling

As described earlier, the energy efficient dwelling can be considered a "fine tuned machine" and as such, and uninformed user intervention with the systems could mean a significant increase in energy use - this are one of the conclusions from the past experience with energy efficient buildings. The Bolig$^{+}$ program therefore asks for solutions that could inform, and motivate the users to act responsible, and in coherency with the service systems of the building.

In this project consideration about such systems have not been a significant part of the project.

### Dogma 3: Flexible in use, and over time

During the design process, flexibility has been a major concern, especially when designing the plan solutions, though at the same time it seemed that the flexibility was in a constant opposite interaction with architectural expression, alternative solutions and making the most of relative compact spaces.

Seen from a large perspective, the concept with its freestanding two plan volumes, are not extremely flexible for significantly changing uses, though of course one could imagine interesting add on solution if the structural system was flexible enough to support such a solution.

In the plan solutions there is definitely a struggle between great flexibility on one side, and more precisely programmed areas on the other, in order to achieve efficient, but still interesting spaces. Further more there has been some conflict in the process between architectural expression, and the requirements for flexibility which is also evident in the plan solution.

On of the major element in the plan, and in the building concept as a whole, is the fact that the plans have been designed around a core. This has to some negative impact on the flexibility of the plan itself, but was a trade-off in order to add more flexibility to the service utilities, making changes and renovations more practical. The core is also an important element in the structural systems, and is in this respect considered to add flexibility in the plan.

One of the more flexible elements in the building concept is the louvre facade, which has a number of uses, and therefore is required to be flexible. In this project the facade and the photo voltaic cells integrated into it is the main energy producing element, and has therefore been given the possibility to change in relation to the solar angle.

The facade is aside from the main energy producing element also important for controlling light conditions in the apartments, and the facade is therefore intended to retract in key areas to let in more daylight when needed.

The facade is also used to create diversity in outer spaces by changing the feeling of open spaciousness and the more compact and sheltered feeling.

**Dogma 4: Good and healthy indoor climate**

In the design of the dwellings the main priorities of getting a good healthy indoor climate has been acceptable temperatures, air quality and daylighting.

When looking on the results from Be06 it is possible to see that the good indoor climate has been achieved according to temperatures. The air quality of the rooms have been calculated in the appendix chapter "Indoor climate - Air change calculations", which provide the minimum of airchange that is necessary according to sensory pollution (olf) and air quality ($CO_2$). But when looking at the results achieved in both VE and Be06 it is possible to see that the ventilation rates are determined according to the temperature.

As mentioned earlier the program 3Ds Max Design have been used for the daylight investigations. In the earlier phases the investigations have been on the apartment volumes without the facade. It is clearly to be seen in the chapter concerning the final daylight investigations that when applying the facade skinning the results are less than desirable in some areas.

**Dogma 5: Architectural quality and adjustment to the local infrastructure, climate and nature content.**

What is the architectural quality of the project? Answering this question would be difficult without considering the context in which it is placed. The context is an old industrial harbor. Though in the near future the whole Nordhavnen will undergo a massive development, which is intended to convert it into a new visionary sustainable urban area.

This means that there is not much actual context to relate to, though COBE, the winner of the has proposed a master plan with inspiration found in Sydhavnen, also discussed in this project (see Appendix). The overall plan for the 1st stage of the development seems to suggest a quite "rational" layout and perhaps also style of the near by architecture.

Apart from these future planned buildings, there is also a large plot adjacent to the project site, with an old warehouse building, pointed out to include some kind of add-on architecture, which indicates a relative raw architectural expression to the north of the project site.

Seen from this perspective the concept of the project might not be perceived as very contextual related. Though one should remember that the proposed volumes around the area are still conceptual.

Instead the concept of the project has tried to relate to the vision for Nordhavnen by manifesting itself as a slightly futuristic concept for a sustainable area - an expression widely conveyed by the changing facade, with photovoltaic cells and the green elements found in the settlement.

# Appendix

# Case studies
## Architecture of the future

During these short case studies of architectural examples, which seem interesting and relavant, related to the three themes of; "Industrial Architecture", "Architecture of the Future" and "Dwellings", will be discussed, and later used for reference.

### EDITT TOWER

The EDITT Tower was designed by T. R. Hamzah & Ken Yeang as a expositon tower, for retail, exhibition spaces auditorium uses, etc. in Singapore.

The striking design set out with an ecological approach, and a goal to bring back green elements, and an ecological system to what yeang calls a "Zero culture" site. This is done by analysing the vegetation withing a mile of the site, and the introducing the found species to the building.

In EDITT Tower this vegation can be seen spiralling vertically up the building, and over the ramps connecting the building to the site. Accoring to Yeang, this has an ambiant cooling effect of the building.

Apart from the green character of the EDITT Tower, it also employs other "sustainable" elements, such as water recycling and water collection, which covers 55.1% of the buildings water use

The state of the art concept, is also planned to include photovolaics which were estimated to cover nearly 40% of the buildings energy use.

The building materials were chosen with a great concern for recycling, reuse, and intelligent selection of building materials, in order to reduce both embodied CO2. Further more the detailing an construction of the building is also conceived in such a way, that the resuse, and recycling of the building, at the end of its useful life.

Lastly the EDITT Tower features bith natural ventilation, mixed mode ventialtion and mechanical ventilation.

All i all, this concept has a lot of qualities that deserve some attention, when looking at the future of architecture. Especially the green nature of the building has a great appeal, especially in a future with increasing dense cities and increasing population levels. Somehow this way of building makes, the otherwise tehcnocratic expansion, and invasion of nature more beareble[trhamzahyeang.com].

ill.1: Editt Tower

## Housing for the 21st Century

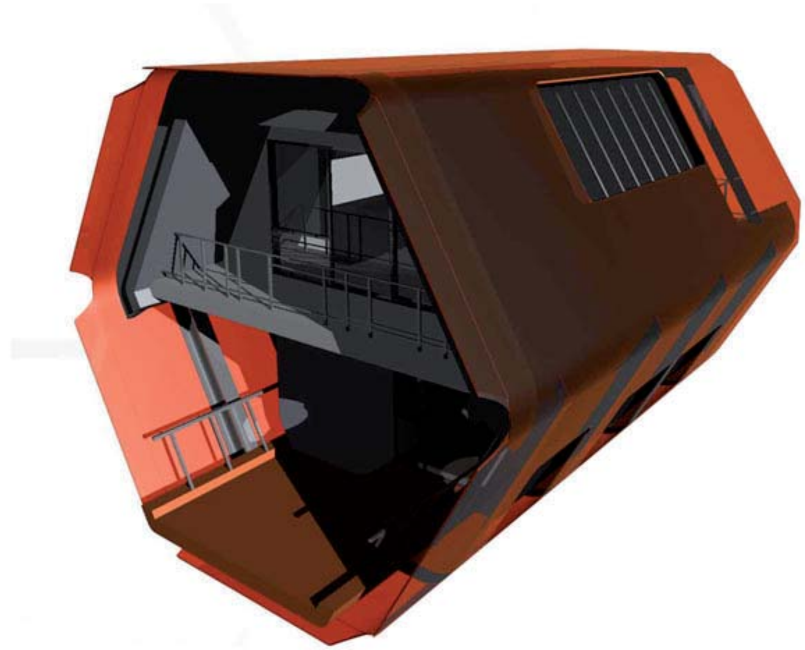
This project is created by Dan O'Riley, an is his solution to our problems regarding space, and ressource consumption.

The proposel is made up by hexagonal prefabricated units, which effectively transfers loads further down in the structure.

The volumes are conceived as volume-sized modules, with a frame construction. The idea is that all necassary functions are incorporated, and hidden withing the frame structure. This being the ventilation system, water supply and waste and so on. On top of this structure, a shell is constructed, to protect the living environment from noise, heat, cold, rain and other elements.

The modules are relative small, in order not to use more space, or ressource than are really necassary. To make up for this, the different zone are planned for flexible use, for instance the stairs can fold away, and the sofa, also functions as a bed.

To further enhance the industrial nature of the concept, the bathrom, and kithcen is conceived as a selvcontained fixture, or modules [evolo.us]



ill.2: Example of a future housing system

ill.3: Section of proposal

# Dwellings

The case studies explore different dwellings from today with attention on:

- How the floor plans are organized.
- The zoning around and in the different dwellings.
- The qualities of materials.
- The building/construction method.

Not all the mentioned elements appear in every case but they are the ones, which have been the main focus when choosing the different cases.

## The Mountain Dwellings

The Mountain Dwellings of BIG has in the last two years won several prizes.

**2008**
- World Architecture Festival Award for Best Residential Building.
- Forum AID Award for Best Building in Scandinavia.

**2009**
- ULI Award for Excellence
- MIPIM Award for Best Residential Development.

*"The Mountain Dwellings is located in Orestad city and offer the best of two worlds: closeness to the hectic city life in the centre of Copenhagen, and the tranquillity characteristic of suburban life [http://www.archdaily.com/15022/mountain-dwellings-big/]."*

The building is 2/3 parking area and 1/3 dwellings. The dwellings has been placed upon the parking area, which serves as a platform for the dwellings (see Ill. 1 and 2).

The mountain consists of 80 dwellings and 480 parking spots. The northern and western facades are covered by perforated aluminium plates, which image Mount Everest. These facades become the back of the dwellings and consist of the parking area. The southern and eastern facades consists of wooden boxes and green hedges.

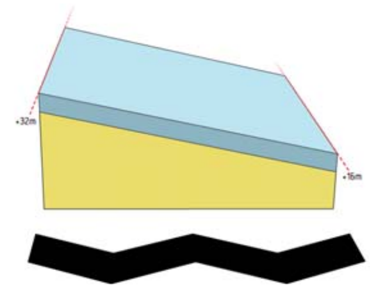
The inside of the dwellings is very anonomous in the choices of materials. The walls are painted white and the flooring is in wood.

**The apartments**

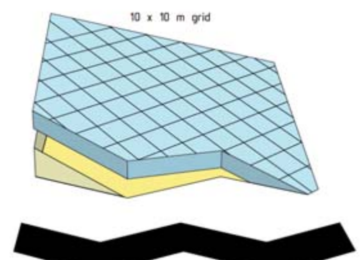
The apartments have a diversity in sizes ranging from 56 $m^2$ to 144 $m^2$.

In general the rooms are arranged according to the garden so that the kitchen, the dining area and the bedrooms are concentrated towards the view of the landscape of detached houses and the secondary rooms (bathroom, storage room) are placed towards north.

There are zoning around the dwelling both to the entrance and to the garden. When arriving to the apartment there are a small entrance area in front of each apartment. This area creates a small buffer zone for the common hallway. At the garden the privacy is best towards the dwelling and at the end of the garden it becomes more open and the garden gets more exposed for the other residents. The "hedges", which surrounds the garden, reassure that it is not possible to look down to the neighbour below. And it is thereby a part of the buffer elements, which have been used.




Ill. 1: The scaling down towards southeast. The w in the bottom indicates the VM-husene, which is the neighbour.




Ill. 2: The yellow is the parking area and the blue grid is dwellings, which lay on top.

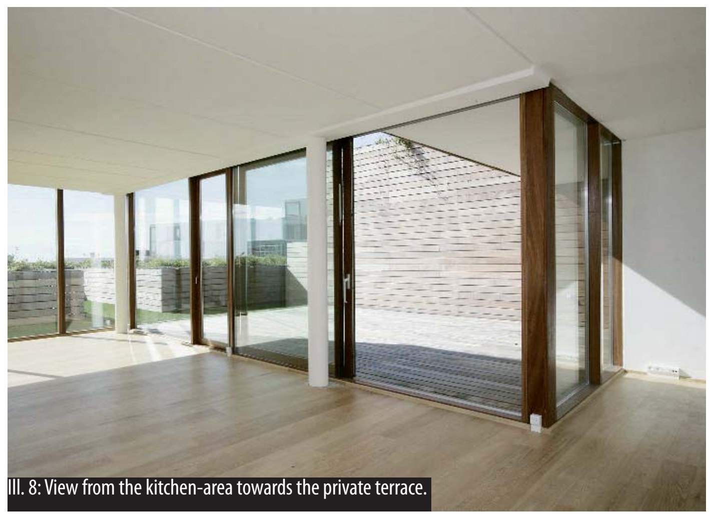
Ill. 3: An example of a floor plan of an apartment.

*Ill. 4: The Mountain Dwelling seen from northeast.*

Ill 5:The more semi-private part of the garden.

Ill. 6: The colourfull park area.

Ill. 7: View from the semi-private area at the garden towards the private area.



Ill. 8: View from the kitchen-area towards the private terrace.

Ill. 9: View from the bedroom.

# 8-TALLET

The complex has been designed by BIG and it is a complex, which consists of 501 different dwellings.

The whole complex consist a diversity of apartments from small townhouses to apartments to penthouses at the top of the complex.

The starting point for the design of this complex was the classical block building, which is found all over Copenhagen.

The block is divided into horizontal layers. In the bottom there are one layer of offices and on top of this there are townhouses, which are inspired by "Kartoffelrækkerne" in Copenhagen. On top there are a 3 floor layer, which consists of apartments and at the top there are penthouse apartments in two floors.

The dwellings are orientated according to the sun, air and the view. The offices are placed so that they are shaded and bring life to the street in the weekdays.

In the center of the complex there is a 500 m$^2$ common building. It becomes the vertical connection between the top and bottom.

The large variety of dwellings makes it possible to have different users in the building block and thereby also contribute to a diversity of use of the area.

The townhouses are characterized by their small gardens in front of the houses, which creates a semi-private zone before entering the house. The penthouses on top also have this semi-private zone before the entering of the dwelling. The apartments are the only ones, which do not have this buffer zone.

Ill. 10: A view from a townhouse from the inside towards the entrance.

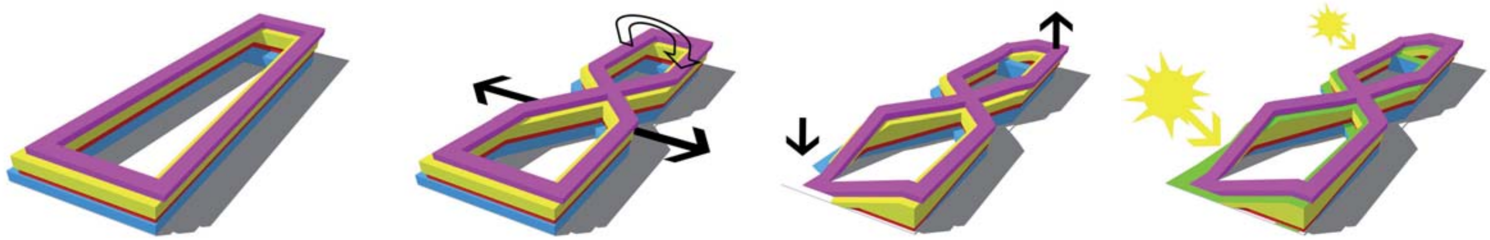
Ill. 11

Ill. 12

Ill. 13

Ill. 14

Ill. 15



Offices Townhouses Apartments Green area/Gardens Penthouse Apartments

Ill. 16

# The Flexible House

The flexible house is designed by Arkitema and is the product of much research relating to flexibility in living.

It all started in 1983 where the ministry of housing arranged a competition called "Det Nye Etagehus"/"The New High Building". Arkitema wins this competition and a research phase begins.

The focus has been to develop a construction principle, which indicates freedom for the user to change the apartment as they please. To tear down walls and add walls as they like. At the same time the focus has been the qualities of the family dwelling [Beim, A., 2007, p. 44].

- Multi-functional spaces, which makes the dwelling general practicable.
- A construction principle, which makes it possible to organise the rooms differently during time.
- Spatial qualities through trans-illumination, plan, sections and elevations.
- Healthy and eco-friendly indoor climate.
- There should be the possibility of getting outside directly from each apartment.
- Qualitative outdoor stays of private, semi-private and public character.
- Environmental zoning, which makes it possible to live according to the future demands of living.

### Construction principles

They develop a rational building system, which gives the residents the possibility to furnish the dwelling as they like. The construction consist of a column/slab system, which makes it possible not to have any bearing facades [see ill. 17]. Thereby the only function of the facades and walls are as room divider.

After the research period the housing association Kuben wanted the project realized in Ørestaden, Copenhagen (realized in 2007).

The vision of having all walls and facades as non-bearing elements cannot be realized because of the economic boundaries in the project. Therefor they had to rethink the construction principle.

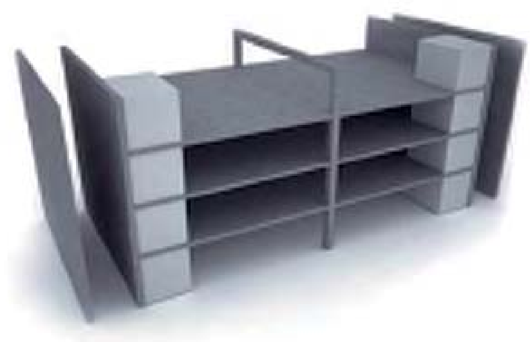
Instead of the very flexible outer facades it was necessary to have bearing walls and it resulted in a wall unit, which consists of bearing crosswise partitions with the installation cores placed at the wall [see Ill. 18].

The principle freedom becomes quite locked in the individual dwelling. The organizing of the dwelling gets decided once and for all by the geometry of the bearing construction.

In this case it has been tried to modify it. Between the bearing walls there is the possibility of different choices.

- It is possible to enclose with rooms to each side.
- It is possible to have a transilluminated room with rooms on both sides.
- It is possible to have an open diagonal connection.
- It is possible to choose an open floor plan.

Ill. 17: The column/slab system. It gives more freedom for the spatial organising.



Ill. 18: The illustration of the re-thought construction principle.

### Reflection - Arkitema

This project has through been developed through 22 years and is the result of a project, which had expectations but caused by the economic boundaries it had to evolve into a more common high-rise.

It had visions of rethinking the structure supported by ideas of which demands there would be for the future dwelling, the way of living and its contents. Some of these are still implemented in the dwelling but at the same time some has been left out, such as the visions concerning the common zones and common activities.

It is quite difficult to say whether the construction principle with no bearing walls had been an alternative according to economics. But if there had not been a boom in the building industry, at the time this project was realised then it had might been different.

This is one of the biggest issues of the building industry. As Rolf Kjær (from Arkitema) points out, the construction business often does not have the courage to evolve when things are going great, but at the same time when there are slump there are no resources to do so.

### Reflection - CINARK

The project consisted of many visions concerning the effectivity of the building process. It should have been a rational system and be optimized both functional, constructive and transportation methods.

The decks are thought as quadratic, which should give the opportunity to modify them at site. At first the focus was on one standard element and one edge element, but in fact there were many different variations, so one must think - is this way of making prefabricated elements on the building site that effective?

The techniques in 2006/2007 did not really create the possibility of trying the wanted structure. Today it might be possible with the different new technologies and mass-custumisation.

*Ill. 19*

# Flexible architecture

## Sluseholmen

Sluseholmen is a relative new urban area in the south-east part of Copenhagen, developed by Sjoerd Soeters (NL) and Arkitema (DK), which has been highlighted for its high urban quality.

Sluseholmen consists of eight islands covered with large housing"blocks".

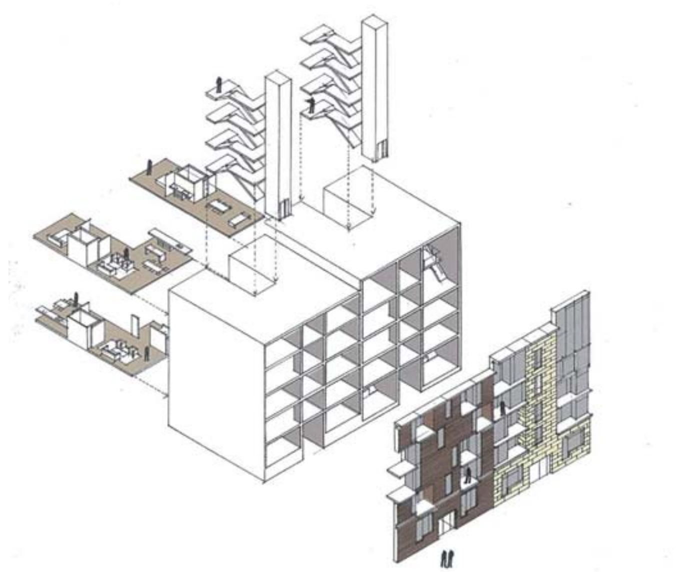
The interesting aspect of Sluseholmen, seen from an structural point of view, is the fact that even though the buildings look different, they are all based on the same raw structure seen on the sketch [see ill. 2] - an example on the concept of "skinning".

Arkitema and Sjoerd Soeters, who designed and managed the structure of the building complexes, invited over 20 other architectural firms to design the different facades - a dutch approach seen in many of Soeters other projects.

The variation in the facades evokes a completely other feeling than the one evoked by the modernistic, rational housing complexes of the 60'ties - by relating somehow much more with the viewer. It is warmer, more playful and has been called the modern "Nyhavn", an area known for its special urban quality.

Even though Sluseholmen is vastly more successful in the term of urban planning and quality, than for instance Ørestaden - another rather newly developed area close to Copenhagen, there are still critics. The concept of a hidden raw structure with a facade purely dealing with aesthetics, is claimed to be both dishonest, and a reduction of the trade of architecture. This problem relates the term "tectonics", and the lack hereof, which traditionally in a Danish context, with a long and proud history of functionalism and tectonic masters such as Utzon, equals bad architecture [ibyen.dk, 2010, Arkitektur DK, 4, 09].

ill.1: Sluseholmen in Copenhagen



ill. 2: Sketch of the construction principle for Sluseholmen

ill. 3: Sluseholmen in Copenhagen

# Indoor climate
## Air change calculations

In the following the air change will be calculated according to the sensory pollution load and the air quality. One example of the calculation will be outlined, but al the result and information for each apartment will be outlined in a scheme.

These calculations gives an idea of the necessary minimum of air change when only focusing on sensory pollution and air quality. But in most cases the determining factor are the temperature. This will be tested in the IES Virtual Environment and used in the Be06 as well.

### Calculation example, Living room, 4 room apartment

**General facts**

| | |
|---|---|
| Number of persons: | 4 |
| Activity level (normal): | 1,2 met/person |
| Hours of usage: | 168 (an assumption from Be06). |
| Clothing: 0.5 clo | (The calculations will be done for the hottest day of the year, a day in July). |
| Area: | 61 $m^2$ |
| Room height: | 2.8 m |
| Volume, $V_{room}$: | 170.8 $m^3$ |

**Assumptions**

Category B, building
Thermal comfort (PPD) < 10% (PPD; Predicted Percentage of Dissatisfied)
Experienced airquality (PD)< 20%, which means dp < or equal 1.4 dp.

**Sensory pollution load, olf**

$c=10*(q/V)+c_i$

- In the following calculations each element from the equation mentioned above, will be calculated, so it is possible to calculate the supplied air stream in the end.

q:
1 person: 1 olf/person (determined that the people are non-smokers).
Total load in non low polluting buildings: 0.2 olf/$m^2$ floor.

$q=1olf/person*4persons+0,2olf/m^2*61m^2= 13.52$ olf

$c_i$: This is a constant, which is given in the book "Grundlæggende klimateknik og bygningsfysik". In this book the value is given as; 0,3 dp, which is a building placed in a city with a moderate air pollution.

c: This is illustrated at a graph, where the experienced air quality should be according to the thermal comfort, and thereby: 1.4 dp

The supplied air stream, $V_l$, can now be calculated:

$V_l=(10*q)/(c-c_i)= (10*13.52olf)/(1,4dp-0,3dp)= 147,27\ m^3/h$

The wanted air change is thereby:

$n=V_l/V_{room}=(147.27m^3/h)/(170.8m^3)=$
$\underline{0.86\ h^{-1}}$

**The air quality, $CO_2$**

The attenuation equation is being used:
$c=(q/(nV))+c_i$
$c_i$ is a constant found in CR1752: 350 ppm "cities with a good air quality".

c is also found in CR1752 from a graph; Category B building: 660 ppm+350ppm=1010ppm

CO2 from people: 0,02 $cm^3/h$
and
$1000ppm=1000cm^3/m^3$

$q=4persons*0,02cm^3/h*10^6=$
8000ppm/h

The airchange:
$n=q/((c-c_i)*V_{room})=(8000ppm/h)/(975ppm-350ppm)*170.8m^3=\underline{0,71\ h^{-1}}$

| | | |
|---|---|---|
| **Category B building** | | |
| Thermal comfort (PPD)< | 10% | Perdicted Percentage of Dissatisfied |
| Experienced airquality (PD)< | 20% | Percentage of Dissatisfied |
| | | |
| **General input** | | |
| Total load in non low polluting buildings | 0,2 | olf/( $m^2$ floor) |
| Person load | 1 | olf/person |
| Clothing | 0,5 | clo |
| **Values to calculate the sensory pollution load, air change** | | |
| Perceived air quality outside, $c_i$ | 0,3 | dp — This is according to PD<20% |
| Perceived air quality in the room, c | 1,4 | dp |
| **Values to calculate the air quality, air change** | | |
| $CO_2$ concentration outside, $c_i$ | 350 | ppm — "Cities with good air quality", CR 1752 |
| $CO_2$ concentration outside, c | 1010 | ppm — CR 1752 p. 23, Category B building |
| $CO_2$ from people | 0,02 | $cm^3$/h |

| **4 Room apartment** | Childrens room no 1 | Childrens room no2 | Master bedroom | Bathroom | Toilet | Living space | Storage | Hall |
|---|---|---|---|---|---|---|---|---|
| Number of persons | 1 | 1 | 2 | 1 | 1 | 4 | 1 | 1 |
| Area ($m^2$) | 16 | 15 | 16 | 11 | 6 | 61 | 7 | 29 |
| Room height (m) | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 |
| Volume of the room ($m^3$) | 44,8 | 42 | 44,8 | 30,8 | 16,8 | 170,8 | 19,6 | 81,2 |
| Activity level (met) | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 |
| Hours of usage | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 |
| Clothing (clo) | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |
| Sensory pollution load (olf) | 4,2 | 4 | 5,2 | 3,2 | 2,2 | 16,2 | 2,4 | 6,8 |
| Supplied air stream, $V_l$ | 38,18 | 36,36 | 47,27 | 29,09 | 20,00 | 147,27 | 21,82 | 61,82 |
| Airchange, sensory pollution load | 0,85 | 0,87 | 1,06 | 0,94 | 1,19 | 0,86 | 1,11 | 0,76 |
| The total of source of pollution | 20000 | 20000 | 40000 | 20000 | 20000 | 80000 | 20000 | 20000 |
| Airchange, air quality | 0,68 | 0,72 | 1,35 | 0,98 | 1,80 | 0,71 | 1,55 | 0,37 |

| **3 Room apartment** | Childrens room no 1 | Master bedroom | Bathroom | Toilet | Living space | Storage | Hall |
|---|---|---|---|---|---|---|---|
| Number of persons | 1 | 2 | 1 | 1 | 3 | 1 | 1 |
| Area ($m^2$) | 17 | 17 | 11 | 6 | 61 | 7 | 29 |
| Room height (m) | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 |
| Volume of the room ($m^3$) | 47,6 | 47,6 | 30,8 | 16,8 | 170,8 | 19,6 | 81,2 |
| Activity level (met) | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 |
| Hours of usage | 168 | 168 | 168 | 168 | 168 | 168 | 168 |
| Clothing (clo) | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |
| Sensory pollution load (olf) | 4,4 | 5,4 | 3,2 | 2,2 | 15,2 | 2,4 | 6,8 |
| Supplied air stream, $V_l$ | 40,00 | 49,09 | 29,09 | 20,00 | 138,18 | 21,82 | 61,82 |
| Airchange, sensory pollution load | 0,84 | 1,03 | 0,94 | 1,19 | 0,81 | 1,11 | 0,76 |
| The total of source of pollution | 20000 | 40000 | 20000 | 20000 | 60000 | 20000 | 20000 |
| Airchange, air quality | 0,64 | 1,27 | 0,98 | 1,80 | 0,53 | 1,55 | 0,37 |

| **2 Room apartment** | Master bedroom | Bathroom | Toilet | Living space | Storage |
|---|---|---|---|---|---|
| Number of persons | 2 | 1 | 1 | 2 | 1 |
| Area ($m^2$) | 28 | 10 | 6 | 61 | 7 |
| Room height (m) | 2,8 | 2,8 | 2,8 | 2,8 | 2,8 |
| Volume of the room ($m^3$) | 78,4 | 28 | 16,8 | 170,8 | 19,6 |
| Activity level (met) | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 |
| Hours of usage | 168 | 168 | 168 | 168 | 168 |
| Clothing (clo) | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |
| Sensory pollution load (olf) | 7,6 | 3 | 2,2 | 14,2 | 2,4 |
| Supplied air stream, $V_l$ | 69,09 | 27,27 | 20,00 | 129,09 | 21,82 |
| Airchange, sensory pollution load | 0,88 | 0,97 | 1,19 | 0,76 | 1,11 |
| The total of source of pollution | 40000 | 20000 | 20000 | 40000 | 20000 |
| Airchange, air quality | 0,77 | 1,08 | 1,80 | 0,35 | 1,55 |

| **2 Room apartment, handicap** | Master bedroom | Bathroom | Living space |
|---|---|---|---|
| Number of persons | 2 | 1 | 2 |
| Area ($m^2$) | 18 | 8 | 63 |
| Room height (m) | 2,8 | 2,8 | 2,8 |
| Volume of the room ($m^3$) | 50,4 | 22,4 | 176,4 |
| Activity level (met) | 1,2 | 1,2 | 1,2 |
| Hours of usage | 168 | 168 | 168 |
| Clothing (clo) | 0,5 | 0,5 | 0,5 |
| Sensory pollution load (olf) | 5,6 | 2,6 | 14,6 |
| Supplied air stream, $V_l$ | 50,91 | 23,64 | 132,73 |
| Airchange, sensory pollution load | 1,01 | 1,06 | 0,75 |
| The total of source of pollution | 40000 | 20000 | 40000 |
| Airchange, air quality | 1,20 | 1,35 | 0,34 |

# Be06
## Input

In the Be06 it has been necessary to use different systems and information about different systems, these will be presented in this appendix or attached to the CD.

- Information about the ocean thermal heat system (see CD).
- Information about the solar heating plant (see ill.1, is also included on the CD).
- The documentation report from Be06 (see CD).
- The result report from Be06 (see CD).
- The report with key numbers (see ill. 2).

**Solvarmedata til Sbi beregningsprogrm Be06.**

| | |
|---|---|
| Beskrivelse | Logasol SKN 3.0, Buderus |
| Type | Brugsvand |

Solfanger

| | | | | | |
|---|---|---|---|---|---|
| 2,26 | Areal, $m^2$ | 0 | Horisont afskæring, ° | | Skygge, ° |
| 180 | Orientering | 0 | Skygge, ° Venstre | 0 | Højre |
| 45 | Hældning, ° | 3,68 | Varmetabskoefficient, $W/m^2$ K | | |

Rør til solfanger

| | | | |
|---|---|---|---|
| 16 | Længde, m | 0,17 | Varmetab, W/m K |

Effektiviteter

| | | | |
|---|---|---|---|
| 0,77 | Solfanger start, - | 0,904 | Solfangerkreds, - |

Beholder og el

| | |
|---|---|
| 250….500 | Beholdervolumen, liter *(input gives i "Varmt brugsvand")* |
| 30 | Pumpe i solfangerkreds, W |
| 3 | Automatik, stand-by, W |

Ill. 1: Data for the solar heating plant.

| Be06 nøgletal: 23/5 2010 | |
|---|---|
| **Transmissionstab, W/m²** | |
| Klimaskærm ekskl. vinduer og døre | 3,3 |
| **Energiramme, kWh/m² år** | |
| Lavenergibygninger klasse 1 | 36,9 |
| Lavenergibygninger klasse 2 | 52,7 |
| Samlet energiramme | 80,2 |
| **Samlet energiramme, kWh/m² år** | |
| Energiramme i BR, uden tillæg | 73,7 |
| Tillæg for højt luftskifte pga. BR krav om udsugning | 6,5 |
| Tillæg for særlige betingelser | 0 |
| **Samlet energibehov, kWh/m² år** | |
| Energibehov | -70 |
| **Bidrag til energibehovet, kWh/m² år** | |
| Varme | 6,7 |
| El til bygningsdrift, *2,5 | 10,8 |
| Overtemperatur i rum | 0 |
| **Netto behov, kWh/m² år** | |
| Rumopvarmning | 30,5 |
| Varmt brugsvand | 21,7 |
| Køling | 0 |
| **Udvalgte elbehov, kWh/m² år** | |
| Belysning | 0 |
| Opvarmning af rum | 0 |
| Opvarmning af varmt brugsvand | 0,9 |
| Varmepumpe | 7,8 |
| Ventilatorer | 2,1 |
| Pumper | 1 |
| Køling | 0 |
| **Varmetab fra installationer, kWh/m² år** | |
| Rumopvarmning | 2,1 |
| Varmt brugsvand | 8,6 |
| **Ydelse fra særlige kilder, kWh/m² år** | |
| Solvarme | 17,4 |
| Varmepumpe | 31 |
| Solceller | 41,5 |
| **Samlet elbehov, kWh/m² år** | |
| Elbehov | 41,5 |

Ill. 2: Key numbers from Be06.

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# Illustrations

The numbering of the illustrations are divided into the main chapters. Our own illustrations are not listed.

## Methodology

ill. 1, 2: Integrated Design Process in PBL" by Knudstrup, Mary-Ann.

## Analysis

### Context Analysis

ill. 1, 2, 8: Google Earth
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ill. 9, 10, 11, 12, 13, 14: Supplied to us by COBE
ill. 16-28: Google Earth
ill. 34: http://www.dmi.dk/dmi/tr99-13.pdf
ill. 35: Supplied to us by COBE

### Sustainability

ill.1: http://haft2.com/haft2know/blogimages/earth.gif
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### The user

ill. 5 (collage):
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## Sketching

### Designphase 4

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# Synthesis

**Indoor climate**
ill. 1, 2, 3: CR1752

# Appendix

**Casestudies**
Architecture of the future
ill. 1: http://www.trhamzahyeang.com/profile/yeang.html
ill. 2:http://www.evolo.us/2010/02/04/housing-for-the-21st-century-2/
ill. 3:http://www.evolo.us/2010/02/04/housing-for-the-21st-century-2/

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