FACULDADE DE ARQUITETURA
UNIVERSIDADE DE LISBOA

AN NZEB APPROACH TO A PROPOSED COLLECTIVE HOUSING COMPLEX IN A CONSOLIDATED CITY BLOCK IN COPENHAGEN

FINAL MASTER PROJECT TO OBTAIN THE MASTER'S DEGREE IN ARCHITECTURE

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DEFINITIVE DOCUMENT
LISBON, FACULDADE DE ARQUITETURA DA UNIVERSIDADE DE LISBOA
JULY 2022

Abstract

This work presents a proposal for a housing complex with a "Near Zero Energy Building" (NZEB) performance, incorporated in the consolidated urban fabric of the city of Copenhagen (Denmark).

The motivation for this work stems from my interest in sustainability and in this specific country (where I did my Erasmus, during the whole academic year of 2019/2020).

The development of this project implied:

- The selection of an adequate plot in terms of location, size and unresolved problems to be addressed. The plot chosen (formerly occupied by a gas station, in Sundholmsvej street) is located in a consolidated neighborhood, faces a relevant street, has several unresolved facades and an incomplete adjacent public garden;

- Site visits, analysis of the surrounding buildings and of an official (unrealized) proposal for the plot, allowing for the formulation of the brief, including the definition of the type and size of the apartments.

- Enquiries to Danish citizens and a report on all the apartments experienced during my Erasmus stay, to get a better grasp on the specific aspects of the Danish way living;

- Volumetric studies to optimize the positioning of the building (dealing with noise, wind, sunlight and shadowing);

- Studies of relationships with the surrounding buildings in terms of form, volume and materials, resorting to drawing (hand sketching and digital modeling), scale models and site photographs;

- Studies of the organization and characterization of the typologies and other spaces, considering "typical" Danish living practices, while pursuing a meaningful and adequate architectural solution;

The result of this process is a proposal that strives to address the challenges of designing in a Nordic context (including the need to respond to its environmental performance requirements) as a Portuguese trained architectural student.

Keywords

Near zero energy building | Sustainability | Housing | Copenhagen

Resumo

(Nota: Este resumo vem a satisfazer o número 7 do artigo 20º do Regulamento de Estudos de Pós-Graduação da Universidade de Lisboa, ao qual o Regulamento de 2º ciclo da Faculdade de Arquitetura da Universidade de Lisboa se subordina e que determina que com a regulamentação específica, o trabalho final escrito em língua estrangeira, deve ser acompanhado de um resumo desenvolvido em português, com uma extensão compreendida entre 1200 e 1500 palavras).

Este projeto final de mestrado apresenta uma proposta para um complexo residencial com uma performance energética equivalente a "NZEB" (um edifício com um consumo energético perto de zero), inserido no tecido urbano consolidado na cidade de Copenhaga, Dinamarca.

A motivação para este projeto deriva do meu interesse no conceito de sustentabilidade e neste país (Dinamarca) em particular, onde realizei o meu Erasmus durante o ano académico 2019/2020.

O projeto procurou dar resposta ao desafio que é construir no contexto Nórdico (incluindo a necessidade de responder aos requisitos específicos de desempenho ambiental e energético) como uma estudante portuguesa habituada a projetar para Portugal.

Os objetivos definidos para este projeto passaram por:
- Projetar um edifício com uma boa performance energética (NZEB) ao mesmo tempo que se procurava responder às necessidades da cidade de Copenhaga. Copenhaga possuí um clima bastante diferente de Lisboa, com temperaturas amenas durante o ano com bastante humidade e verão ameno;
- Perceber o que é um edifício NZEB e de que maneira é que o conceito poderia influenciar as escolhas de projeto. O conceito de NZEB não tem uma única definição pois esta é estabelecida por cada país através de valores máximos que se apliquem e façam sentido a cada país. No entanto, é possível definir estratégias para se obter um edifício NZEB: as estratégias passivas, que estão diretamente relacionadas com a arquitetura do edifício e devem ser o primeiro foco para se obter um NZEB, medidas como, a orientação do edifício, ventilação natural, a otimização do envelope térmico, etc.; as estratégias ativas, que passam por sistemas que são adicionados à arquitetura e ajudam a melhorar a eficiência do edifício, sistemas como, bombas de calor, painéis térmicos ou fotovoltaicos, etc.
- Perceber a dinâmica de um bairro "típico dinamarquês" para se escolher um local adequado e com problemas por resolver;
- Entender o que seria o "modelo de vida dinamarquês" para relacionar estas necessida-

des com as características de um design NZEB;
- Procurar uma resposta que fosse para além de uma resolução prática dos problemas e encontrar uma resolução poética para as necessidades do local;
- Por fim, analisar e avaliar a performance energética do edifício através de simulações digitais.

Responder a estes objetivos implicou:
- A escolha de um terreno adequado em termos de tamanho e localização. De princípio, havia quatro opções possíveis de terreno, que acabaram por ser eliminadas ou por não se introduzirem num bairro que fosse considerado ideal, ou por não terem a área desejada ou até por não existirem aspetos morfológicos por resolver.
- Várias visitas ao local escolhido. Análises aos tipos de edifícios em redor do local e uma análise à tipologia de casas encontradas nesses edifícios.
- Uma análise ao projeto urbano proposto pela câmara municipal (não realizado) para o local escolhido.
- Estudos de forma e volume do edifício (complexo) propostp para que este tivesse uma posição otimizada em relação a elementos exteriores como o ruído, os ventos, a exposição solar, o sombreamento causado pelos edifícios vizinhos e pelo próprio volume.
- Foi realizado um inquérito a cidadãos dinamarqueses tal como uma análise às casas que foram experienciadas por mim durante o meu Erasmus para se perceber o que seria viver como um dinamarquês.

Foram estas análises que tornaram possível a definição de um programa.
- Foram também definidos três pontos chaves para a resolução deste projeto: As fachadas cegas por resolver adjacentes ao terreno, em que duas delas derivaram da escolha em manter o edifício isolado existente no terreno (Sundholmsvej 57), o jardim adjacente em desuso e a paragem de autocarro existente no terreno.
- Um programa habitacional focado nas tipologias T1 e T2, pois são estas que parecem ter a maior procura no local. A tipologia T3 é também introduzida no complexo, para as eventuais famílias que procurem viver perto do centro da cidade.
- Zonas de comércio localizadas no piso térreo, permitindo que o trajeto entre a paragem de autocarro e o jardim seja mais apelativo aos transeuntes e para trazer mais atividade ao local.
- Áreas de escritórios. O programa de escritórios é mais uma forma de trazer atividade ao local e, para além disso, esta parte do complexo não reunia as condições básicas (ventilação cruzada e exposição solar) para se ter habitação com um bom ambiente interior.

A solução de forma e volume do complexo composto por três blocos distintos, acaba

por conseguir responder às necessidades, problemas e programa definido através de um conjunto de atributos:
- Todo o complexo descansa sobre plataformas que permitem a definição de espaços públicos e espaços privados coletivos enquanto definem um trajeto entre a paragem e o jardim e protegem a proposta do possível risco de inundações.
- Era crucial que houvesse uma subida gradual de alturas entre blocos (mais baixo a sul e mais alto a norte) de modo que houvesse o maior aproveitamento da luz solar.

O Bloco A (a Norte) acolhe o programa de escritórios e a maior parte das zonas de comércio. Este bloco resolve uma das fachadas cegas do edifício existente no terreno e relaciona-se com o edifício do outro lado da rua, através do seu sistema distributivo (Esquerdo/Direito) e da sua linguagem. Este é também o edifício mais alto do complexo, que acaba por decrescer de altura para ter uma menor altura (e menor impacto) no seu topo, diretamente virado para o jardim, a Leste.

O Bloco B, através da rotação que realiza para conectar as outras duas fachadas cegas (a fachada a sul de Sundholmsvej e a fachada a oeste do Complexo Vibo) adjacentes ao terreno, permite que este bloco esteja diretamente orientado a Sul, aproveitando assim a exposição solar mais favorável. É também este bloco que permite relacionar a paragem de autocarros com o jardim existente, pois o seu piso térreo é atravessável. A distribuição do edifício é resolvida através de galerias abertas acabadas com revestimento em tijolo que permite uma conexão expressiva e visual da proposta com a envolvente. As caixas de escadas foram colocadas em contacto com os edifícios existentes e permitem a transição de linguagem entre proposta e os edifícios existentes. A cobertura deste edifício é na sua maioria plana, com exceção dos toques com os edifícios envolventes.

O Bloco C é o bloco mais baixo e mais a sul, este relaciona-se com edifício existente entre Sundholmsvej e Telemarksgade. É neste bloco que se localizam os T3 em forma de "Town House", organizados como moradia em banda.

As fachadas dos edifícios são constituídas maioritariamente por tijolo reutilizado e a sua estrutura é em CLT. Para trazer "veracidade" a esta escolha de construção (estrutura leve- madeira, revestida com um material pesado- tijolo), o piso térreo é construído em betão pigmentado a cor de tijolo (para dar continuidade à cor do material) de modo a suportar o peso desta escolha de fachada. O uso do betão está também associado com o uso publico do complexo (zonas de comércio e zonas coletivas do programa residencial).

Os apartamentos foram a base da organização do edifício, com uma base modular no

seu comprimento (3 m por 3 m) e respeitando sempre a dimensão de profundidade dos edifícios envolventes (nunca superior a 12 m). Esta organização modular permite a que haja uma troca entre os dois módulos que perfazem um apartamento T1 (módulo sala/cozinha e módulo quarto/casa de banho), o que permite a manipulação da expressão do edifício, evitando uma repetição determinada pela montagem dos fogos. A organização interna dos apartamentos é regulada pelos princípios de design para se obter um NZEB, sendo que as divisões de permanência (sala e quarto) localizadas nas zonas em que existe mais exposição solar (fachada sul), para aproveitar o máximo de luz para o aquecimento das mesmas. As zonas de águas (cozinha e instalações sanitárias não necessitam de tanta exposição solar, daí a sua localização adjacente às fachadas nortes. Era necessário que existisse ventilação cruzada dentro do apartamento, daí a cozinha e a sala têm uma disposição de "open space" (correspondendo também à preferência por "open spaces" por parte dos dinamarqueses – inquérito). O tamanho dos vãos procura também a este aproveitamento da luz solar, daí os vãos virados a sul/sudoeste aproveitarem a dimensão das paredes quase por inteiro e os vãos a norte serem de dimensões mínimas, para diminuir as perdas de calor através das mesmas.
A materialidade do interior dos apartamentos pretende corresponder ao tipo de ambiente preferido pelos dinamarqueses (cores claras para compensar a falta de luz solar e refletir a existente; e uso de materiais naturais como a madeira).

O resultado desta proposta pretende dar uma resposta aos desafios propostos pelo design Nórdico (incluindo a necessidade de responder às necessidades energéticas dos edifícios), como também procura encontrar uma resposta sensível e adequada ao que o local precisa. Na minha opinião, os objetivos definidos foram atingidos, ainda que o uso de ferramentas digitais que confirmassem o desempenho energético do complexo como "NZEB" tenha ocorrido apenas na fase final do processo de trabalho e apenas nos apartamentos situados no sítio mais critico da proposta. Os resultados das simulações revelam que mais de metade da energia utilizada pelo edifício provém de energias renováveis. No geral, acho que agora seria interessante, "olhar" de novo para a proposta e tentar encontrar uma resposta que fosse menos "convencional" do que a obtida. No entanto, penso que a proposta é consistente e responde às necessidades do terreno introduzindo uma nova vivência ao bairro, através da sua resolução geométrica e organização. Tanto o conceito como o local eram pouco familiares, o que trouxe alguns desafios interessantes sobretudo pelo facto de estar a projetar para um local tão diferente e, para além disso, estar a fazê-lo a partir de Portugal. Penso foi uma excelente oportunidade de aprendizagem, preenchendo as expetativas existentes quando o tema foi escolhido.

Palavras-Chave

Near zero energy building | Sustainability | Housing | Copenhagen

Ackowledgments

This work wouldn't have been possible without the help and guidance of Professor Antonio Jose Damas Lobato dos Santos and Professor Carlos Filipe Chambel Duarte. Thank you for all the time and effort dedicated to help me complete this project and consequently, this stage of my life.

A special thank you to my mom and dad, for all the patience, understanding and support you gave me throughout these six years of university (and my whole life). To my big brother, who showed me how to take things with ease and to breath in once in a while. To the rest of my family that always showed so much love and enthusiasm about my university path.

Last but certainly not least, a big thank you to all my friends that "walk this road". You made all the hard work a little bit easier.

Muito obrigado a todos.

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All of the figures were made by the author, except when the contrary is mentioned.

1. Introduction

2. Challenges

Ill. 7 - World Map of Köppen–Geiger Climate Classification.
Source: http://koeppen-geiger.vu-wien.ac.at/present.htm
Consulted: February 2021

3. The Proposal

1. INTRODUCTION

1.1 Theme and Motivation

With this project it is intended to develop a proposal of a near Zero Energy Building (NZEB) inserted in a city block in the city of Copenhagen.

In today's world sustainability is becoming a topic that is addressed more on the day to day. The topic has been gaining popularity in every sector ever since the consequences of climate change have been felt more each year. The construction sector has not been blind to the subject, as it contributes to 40% of the global carbon emissions (architecture2030.org, 2019). The desire for buildings to respond to the need of lowering their carbon footprint has been growing.

A large part of European cities is already aware that global warming can be fought through measures that are usually applied on a broader scale (the city), including the incentive of using alternative means of transportation to the car or even through the reorganization of the city traffic. However, what if the buildings that start appearing around the city contribute to the "war" against climate change? That is where the concept of NZEB can make a difference.

Denmark is one of the countries that has been in the front line of building these types of constructions. However, most of the NZEB'S/ZEB's around the country don't correlate to the language of the "traditional" city.

This project was developed in a plot in a consolidated city block in Copenhagen, to explore how these two themes, the new NZEB's and building in the "traditional" city, can connect to each other. It is important to clarify that the building developed is focused on housing to respond to the Copenhagen's city need is being faced with, as more and more people are moving / are expected to move into the city (according to the city's website) there is a need to house all the new coming residents.

The main aim of the project was to design a **near zero energy building while also responding to the existing conditions of the "traditional" city.**

First, it was necessary to **understand what a near zero energy building (NZEB) is**. It was then necessary to define which of the possible directions (associated with the main concept) would be taken and applied to the project, considering that the project strives to give an answer to the city and the user's needs.

It was then necessary to **understand the dynamics of a "typical" Danish block** so that the choice of the exact location could be made. The goal was to choose a site (within the traditional city) where the building would solve existing problems and bring benefits to the location.

A brief research was conducted to **understand the "Danish way of living"**, so that the design could correspond to the needs of the users, and **correlate the design of the houses to the strategic building characteristics of a net zero energy building.**

Then, it was essential to **develop a proposal that strives to surpass the resolution of practical issues and searches for a poetic response** to what the chosen site needs and its possible to accomplish.

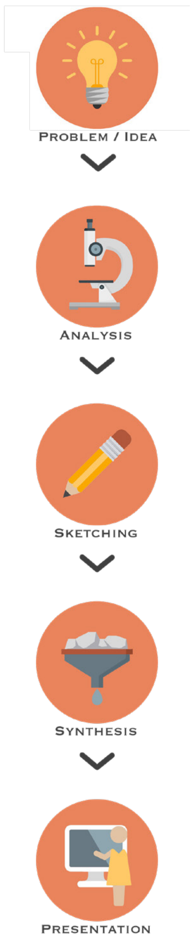
And lastly, the use of digital tools and software to **analyze and evaluate the performance of the building**, was crucial to make sure that the building was as close as it could be to the qualification of a net zero energy building.

1.3 Methodology

The methodology applied throughout the whole project has as its base the "Integrated Design Process" (Knudstrup, 2005). This process is divided in five different stages that interchange with each other: the problem, the analyses, the sketching, the synthesis, and the presentation. The Integrated Design Process is an interactive way of designing where the different stages of the process are constantly analyzed and readjust to address the discoveries made in every part of the process (Ill.1). In this way the project is developed and optimized, striving to achieve a solution that addresses everything proposed. This was not a linear process, however. To have a better notion of time and content, there was some "focus points" organized in phases, bearing in mind that this methodology goes back and forward between topics:

1. As a starting point, it was necessary to find an adequate location for the project. After analyzing the city, a site was chosen and the search for the cartography and the history of the location started. Then, the treatment of the information acquired and the analysis of the location was done. It was important to identify the problems that existed in the chosen location, so that they could be considered when developing the project. It was also important, to perform solar and climate analyses in the initial phase. After the production of these drawings and analysis, it was necessary to formulate some preliminary strategies.

2. Then it was necessary to formulate a functional brief for the project, having in mind that this was a housing program. To accomplish this, it was imperative to analyze the area surrounding the plot to know what made sense to build in the designated area. It was also important to look at the plan the city of



Ill.1 - The Integrated Design Process, Knudstrup, 2005.

Copenhagen has regarding the future growth of the city. Then, it was crucial to study the dimensions of the typologies to know what type of houses should be designed, due to the fact that the city and the site was unfamiliar. Only then, was possible to elaborate a "local urban design proposal" for the project, taking into account the urban context and alterations that were essential to the area.

3. As a last topic, it was necessary to mention the production of technical drawings and models, to test what was best for the project. The conjunction of these elements with simulations in different software's were made on the different designs produced to make sure that the designs performance correspond to the NZEB objectives.

4. In a final stage of the project, the final elements were produced for the final presentation in conjunction with a final revision of the written document.

1.4 Structure

This report is going to be divided into four different chapters.

01 Introduction:

The thematic of the project is explained as well as its objectives, the methodology of work and structure.

02 Challenges:

The concepts of the project are explored to substantiate the work bases. This chapter is divided into two parts (NZEB and Copenhagen), incorporating case studies to inform the proposal.

03 Proposal:

As it focuses on giving an answer to the theme problematics, this chapter is split into two parts. The first part prioritizes the characterization of the chosen site and the formulation of the brief, while the second part of this chapter illustrates the urban proposal as well as the building organization and formal aspects.

04 Final considerations:

Finally, conclusions were made regarding the final design proposed and the answer it gives to the work thematic.

2. CHALLENGES

2.1 NZEB

According to the European Performance Building Directive (EPBD), 2017 a "near zero energy building" is defined as "*… a building that has a very high energy performance (…) the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*". The definition of this concept has been debated by several authors, as it is a very broad and undefined definition. It was implemented by all the member states since the 31 of December of 2018 for new public buildings and on the 31 of December of 2020 for new buildings and big renovation constructions.

The definition of NZEB was left in a "broad" manner by the EPBD, so that every member state can adapt its requirements to the country's reality. By doing this, every member state has the possibility to define the boundaries and indicators that define a NZEB. With this information in mind, it is understandable why the EPBD did not give a thorough method to calculate the energy performance, nor it gave minimum values to qualify a building as a "near zero energy building". Such values depend on each member state, **so the definition of NZEB is inconsistent from country to country**.

Based on the submission of the different national plans to incorporate and increase NZEB by the member states, it is possible to summarize the definition of NZEB (D' Agostino, D; Zangheri, P and Castellazi, L 2017) as:

"*- included energy uses are heating, domestic hot water (DHW), ventilation, and cooling. Auxiliary energy and lighting are taken into account in almost all countries. Several Member States also include appliances and central services;*

- the most common choice regarding the energy balance calculation is the difference between primary energy demand and energy generated, over a one year period, and considering annual constant weightings/factors (e.g., primary energy factors);

- single building or building unit are the most frequent indicated physical boundary for the calculation, but the overall impression is that the differences among building unit/site/zone/part need to be better addressed;

- the most common considered Renewable Energy Sources (RES) option is on-site generation, but many countries also consider external generation and nearby generation (but not always with the same meaning);

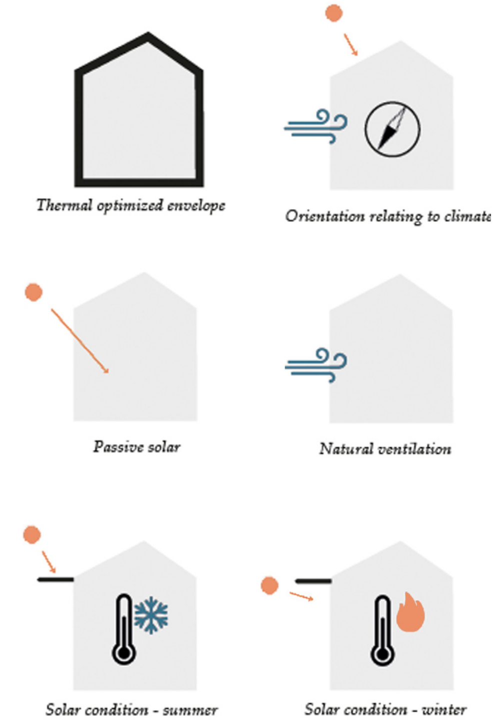
- almost all Member States prefer the application of low energy building technologies and available on-site RES. The used technologies are PV, solar thermal, air and ground-source heat pumps, geothermal, passive solar, passive cooling, wind power, biomass, biofuel, micro combined heat and power (CHP), and heat recovery."

The measure of energy performance of each building does not only depend on each member state but also on the type of building, physical boundary, type and period of balance, including energy uses, renewable energy sources, metric, normalization and conversion factors (table 1).

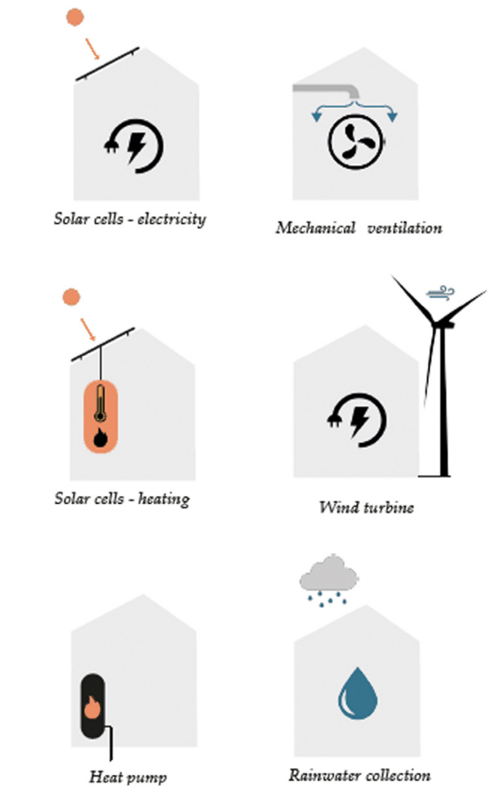
Country	Residential Buildings (kWh/m^2/y or Energy Class)		Non-residential Building (kWh/m^2/y or Energy Class)	
	New	Existing	New	Existing
Austria	160	200	170	250
Belgium	45 - Brussels region 30 - Flemish region 60 - Wallon region	~54	(95-2.5) x (V/S) - Brussels region 40 - Flemish region 60 - Wallon region	~108
Bulgaria	~30 - 50	~40 - 60	~30 - 50	~40 - 60
Cyprus	100	100	125	125
Czech Republic	75% - 80% PE	75% - 80% PE	90% PE	90% PE
Germany	40% PE	55% PE	n/a	n/a
Denmark	20	20	25	25
Estonia	50 - Detached House	n/a	100 - Office buildings 130 - Hotels, restaurants 120 - Public buildings 130 - Shopping malls	n/a n/a n/a n/a
	100 - Apartment Buildings	n/a	90 -Schools 100 - Day care centers 270 - Hospitals	n/a n/a n/a
France	40 - 65	80	70 - Offices without AC 110 - Offices with AC	60% PE n/a
Croatia	33 - 41	n/a	n/a	n/a
Hungary	50 - 72	n/a	60 - 115	n/a
Ireland	45 (Energy load)	75 - 150	~60% PE	n/a
Italy	Class A1	Class A1	Class A1	Class A1
Latvia	95	95	95	95
Lithuania	Class A++	Class A++	Class A++	Class A++
Luxemburg	Class AAA	n/a	Class AAA	n/a
Malta	40	n/a	60	n/a
Netherlands	0	n/a	0	n/a
Poland	60 - 75	n/a	45 - 70 - 190	n/a
Romania	93 - 217	n/a	50 -192	n/a
Spain	Class A	n/a	Class A	n/a
Sweden	30 - 75	n/a	30 - 105	n/a
Slovenia	45 - 50	70 - 90	70	100
Slovakia	32 - Apartment building 54 - Family house	n/a n/a	60 - 96 - Offices 34 - Schools	n/a n/a
Uk	~44	n/a	n/a	n/a

Table 1 - Energy requirements defined by EU Member States for NZEB levels. PE: primary energy; and n/a: not available.

As it is possible to conclude by looking at table 1, every country adopts its own NZEB requirements. In this project, there will be a focus on the definition adopted by Denmark which will be looked at in more depth in the chapter 02.2.2.



Ill. 2 - Diagram of the **passive strategies** that can be applied in a project to help reach NZEB.



Ill. 3- Diagram of the **active strategies** that can be applied in a project to help reach NZEB.

The concept of a NZEB is, much like the concept of a zero-energy building (ZEB), the result of a continuous evolution of other low-energy and passive building designs (Kylili and Fokaides, 2015). Therefore, some of the same strategies used in passive designs are applied to ZEBs, with the addition of resourcing to technologies to exploit renewable energy sources, so that the energy demand of the buildings can be reduced. According to Berardi (2018) to achieve a ZEB or, in this case, a NZEB, it is necessary to think of three fundamental steps:

The optimization of the building design, through passive strategies:

To achieve a NZEB/ZEB, there should be first a focus on passive strategies and only after doing the most to reduce the energy demands of the building, should the active strategies be approached. Passive strategies depend on the architecture of the building, so the implementation of these measures will impact the exterior look of the building, as well as the organization of the interior and floor plans. Measures such as the building envelope, natural ventilation, the maximized utilization of solar orientation and shading mechanisms to control undesired solar gains are a priority (Ill. 2).

The maximization of energy efficient systems to minimize the energy demand of the building, through active strategies:

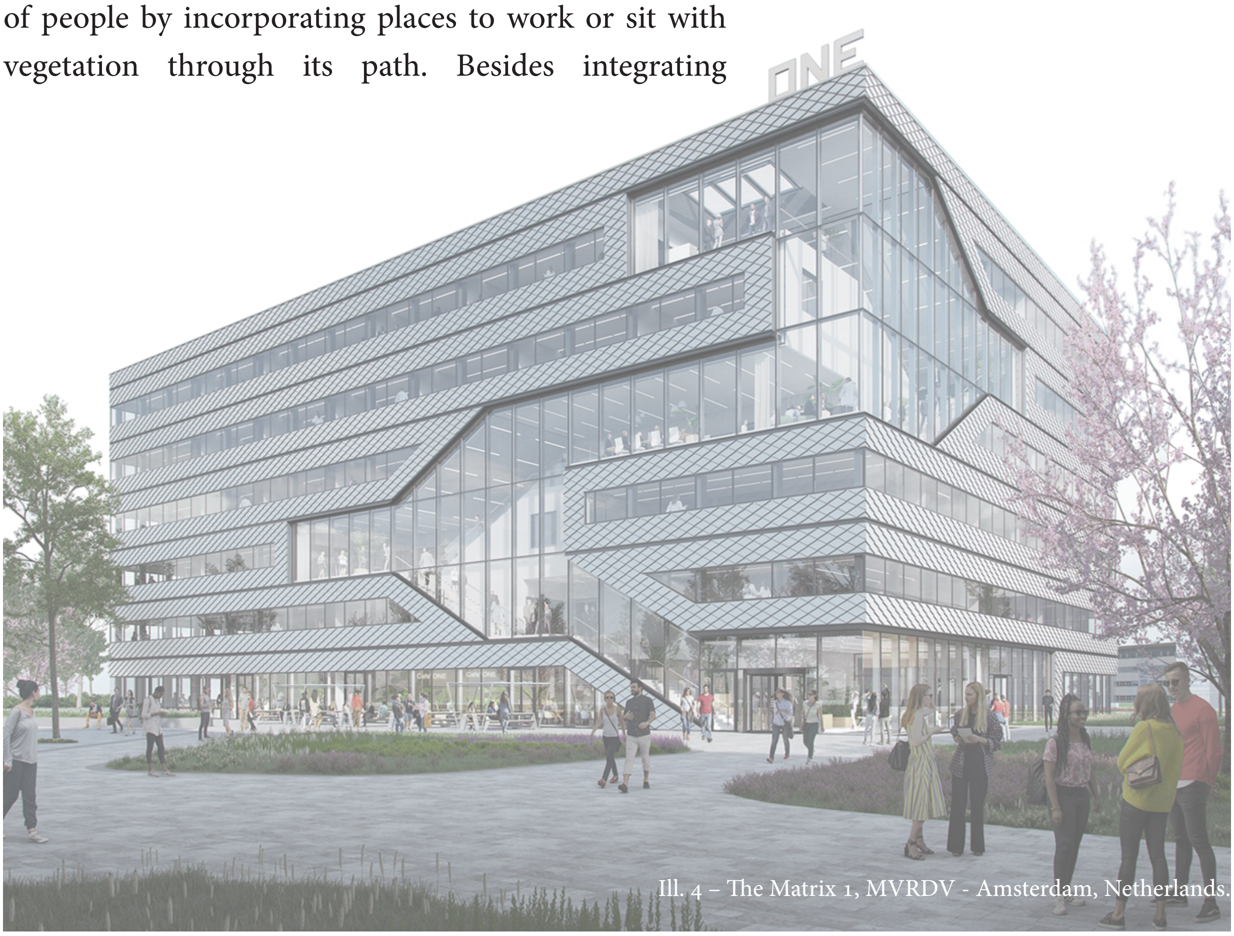
Active strategies that help reach the goal of NZEB/ZEB, consist of systems that improve the efficiency of the buildings capacity to heat, cool and ventilate, combined with lighting systems and high-performance controls to use the energy supplied as efficiently as possible (Ill. 3).

__To provide on-site energy renewable energy generation:__
Finally, to reach a zero-energy demand, there should be renewable energy sources to supply and counterbalance the residual energy demand of the building.

Concluding, the correct approach to a NZEB/ZEB should first consider passive strategies, then active strategies and, finally, provide on-site energy renewable sources. An example on how to implement these strategies on a practical level is "The Matrix 1", an office building in Amsterdam, Netherlands by MVRDV completed in 2019(Ill. 4).

This building focuses on maximizing its energy performance, as well as the social aspect of the building through its design.

The staircase combines these two aspects: it allows for natural ventilation to roam through the whole building, while also promoting the meeting of people by incorporating places to work or sit with vegetation through its path. Besides integrating



Ill. 4 – The Matrix 1, MVRDV - Amsterdam, Netherlands.

passive strategies, the architects also used active strategies, for example, the floor cooling and mechanical ventilation to counterbalance the sun heat that the staircase receives.

The overall building embodies the “sustainable” concept, for example the building envelope creates spaces for animals to make their nests, or the fact that its structure can be disassembled and reused.

The building complies the ambitious Amsterdam’s energy targets while also contributing to the life surrounding it.

2.1.2 NZEB in Denmark

Even though the implementation of the NZEB definition was scheduled to be implemented in 2018 for new public buildings and 2020 for new buildings, Denmark’s has had a mandatory NZEB definition implemented into the Danish building regulations since July 2016.

The first energy requirements were actually implemented into Danish building regulations in 1961, making the energy consumption of new buildings decline at a steadily pace ever since. In 2008, the Danish government announced an energy agreement to reduce the energy of buildings by 75% by the year 2020 compared to 2006. These new and more strict restrictions were introduced in 2011 as a voluntary “Building Class 2020” with the intent of having time to develop new technologies to use in the future. The “Building Class of 2020” is equivalent to NZEB level, and, since 2020, these are the current minimum performance levels to be met on account updated primary energy factors.

Requirements set by the NZEB 2020 for new buildings:

The integration of Renewable Energy Sources (RES) is taken into consideration as a primary energy factor (such as ventilation, heat recovery, thermal heating, heat pump efficiency, solar gains, shading) so that the electricity necessary to operate the building, can be lowered.

The energy frame for the NZEB 2020 is :

-20 [kWh/m2 per year] for residential buildings.
-25 [kWh/m2 per year] for non-residential buildings.

The building must have a good indoor thermal climate throughout the whole year. The inside temperature must not exceed 26ºC for more than 100hours per year and 27ºC for more than 25 hours per year. The Danish Building Regulations include requirements for a wide range of technical building systems: the individual elements must ensure that the values of heat losses through them don't exceed the values in table 2. Even though these requirements are important to obtain a NZEB, issues such as form, volume, building orientation and implementation, and the conditions of the surroundings are determinant for these requirements to have an effective impact.

Building Element	U-value (W/m²K)
External walls and basement walls in contact with the soil	0.30
Suspended upper floors and partition walls adjoining rooms/spaces that are unheated or heated to a temperature which is 5ºC or more below the temperature in the room concerned	0.40
Ground Slabs, basement floors in contact with the soil and suspended upper floors above open air or ventilated crawl space.	0.20
Suspended floors below floors with the underfloor heating adjoining heated rooms/spaces.	0.50
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.20
External doors without glazing.	1.40
External doors with glazing.	1.50
Doors and hatches to the outside or to rooms/spaces that are unheated and these as well as glass walls and windows to rooms that are heated to a temperature which is 5ºC or more below the temperature in the room concerned.	1.80
Skylight domes.	1.40
Insulated sections in glazed external walls and windows.	0.60
Suspended upper floors and walls against freezer rooms.	0.15
Suspended upper floors and walls against cold stores.	0.25
Building Element	**Linear losses**
Foundations around spaces that are unheated to a minimum of 5ºC.	0.40
Foundations around floors with underfloor heating.	0.20
Joint between external wall and windows or external doors and hatches.	0.06
Joint between roof structures and roof lights or skylight domes.	0.20

Table 2 –Maximum U-value and linear losses of individual constructive elements.

2.2 Copenhagen

Copenhagen is the capital city of Denmark and its history can be traced back to the 11th century and, at that time, it was referred as Portus Mercatorum (Merchants' Harbour), which in Danish of the time, was translated to Købmannahavn, giving the name to the city of today, København.

2.2.1 The Past, the Present and the Future

The Scandinavian countries have always been one step ahead when it comes to renewable energies and city planning. Denmark, and Copenhagen specifically, is no exception to this. To understand how Copenhagen became the city of today, it is necessary to understand its history and what the city plans to do in the future.

Renewable Energies

Denmark was a country of farmers and fishermen, with no national natural resources, such as oil or gas. The only raw material Denmark had was wood, because of its geographical position and its climate. Natural resources had to be imported, which proved to be a problem in at least two well documented occasions: the second world war (1939-1945) and the oil crisis (1973), where there was a shortage of natural resources that caused a very sudden price increase. It was the later that propelled the change in the energy sector in the country. When the crisis surfaced, 90% of Denmark's energy consumption was based on oil and imported from the Middle East. When the need for oil could not be met, a national energy policy and a regulating framework was implemented, so that the country did not have to depend on external sources. One of the main points was to diversify the energy suppliers. That was when Denmark started to bet on renewable energy sources, not knowing at the time (1979) it would become the world-leading country in wind-based energy production. But if, at the time, this need to turn to alternative energy sources grew out of fear, today the choice to invest and develop these sources even further is made because of the climate/environment awareness. This is the reason to why its NZEB requirements (Chapter 2.1.2) are one of the strictest in the world.

Today, 50% of Denmark's electricity is supplied by wind and solar power and, in March of 2012, the government announced an Energy Agreement that had three main goals:

-By 2030, coal is to be eliminated from power production;

-Electricity and heat production should be fossil--fuel-free by 2035;

-Renewable sources should provide 100% of Denmark's energy requirements by 2050.

Copenhagen has been setting an example for the rest of the country. Even though the city is in Constant growth, the municipality of Copenhagen has been able to comply with the country's requirements as off-shore wind farms, solar and biomass power supply most of Copenhagen's energy needs.

In 2017, the city was able to reduce its carbon emissions by 42% compared to 2005 and now aims to become carbon neutral by 2025. After achieving this goal, Copenhagen aims to become completely fossil-free by 2050. It also has the goal that all municipal buildings should be emission free by 2030.

Architecture and City Planning

As many European cities, Copenhagen architecture is characterized by a mixture of styles that can date back to the 12th century. At that time, churches were being built in granite and limestone, while the houses were still being built in timber. Brick production started in Denmark in the middle of the 12th century and after that, the buildings were being built predominantly in brick.

During the 20th century, Copenhagen's urban development was heavily influenced by Industrialization and the municipality adopted Fordism[1] as

[1]Fordism is a concept born after the WWII. Named after Henry Ford, Fordism is based on the standardization of mass production and mass consumption, it serves as model for the economic and social systems.

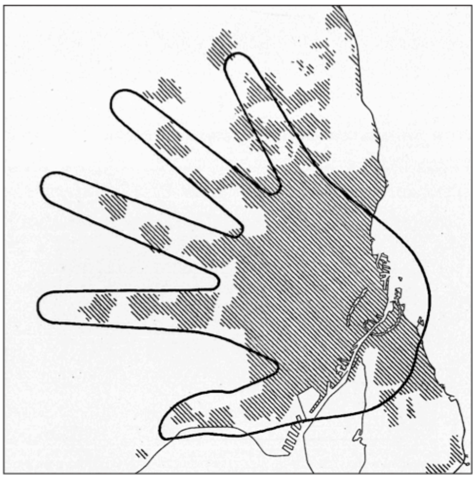
a way of living. The urban planning of that time was characterized by "zoning", which meant that housing, commercial areas, and industrial areas were all separated.

In 1947, an innovative urban project based on the "Garden City"[2] concept was developed for the city of Copenhagen by Danish Architects and town planners Peter Bredsdorff and Sten Eiler Rasmussen, with the name "The Finger Plan". The combination of this plan with the contemporary view of the Danish architect Jan Gehl[3] on how the quality of life can be defined by how the space between the buildings is used, is what now defines the urban planning of the city of Copenhagen.

"The Finger Plan" (Ill.5) had two main goals:

- -To guarantee that there was an efficient public transport network between the new suburbs and the historical city;
- -To ensure easy access from urban to rural areas;

These two main goals were to be achieved through a plan that assumed a "hand form" (Ill.5), the palm of the hand rested on the existing city center, the fingers pointed out future areas to develop and the space in between the fingers should consist of mainly green areas.



Ill. 5- First sketch of the Finger Plan for the city of Copenhagen, made by the Regional Planning Office in 1947.

Through suburbanization, Copenhagen became a bigger city, with low density housing, using semi-detached and detached houses. This extension of the city allowed the city center to maintain its buildings with an average of five to six-story buildings. Today's social and city structure of Copenhagen is the outcome of two main occurrences:

[2]Garden City, initialized in 1898 by Ebenezer Howard in the United Kingdom, the garden city movement is a form of urban planning, where areas of residence, industry and agriculture are contained by green areas and well-proportioned between each other.

[3]Jan Gehl is a danish urbanist and architect. Author of the book: "Life Between Buildings: Using Public Space", that focuses on the need to build cities for the people, defining the spaces between buildings as places that should increase the quality of life of the people.

-The urban expansion to rural areas, from 1940 trough 1980. Around 350 000 citizens exchanged the life in the city for new and modernized houses in the suburbs, more than 200 000 houses were built during this time;

-The duality of the Danish housing market (houses were either privately own or belong to non-profit housing associations);

In the present, Copenhagen strives to achieve diversity in urban areas. New urban areas and developments in existing urban areas should have a diverse character in terms of function, housing sizes and types of ownership. It is essential that all new constructions (buldings or urban spaces) are developed with the users in mind and can relate to the specific character of Copenhagen.

One example of how this can be achieved is the "Krøyers Plads" building complex developed in the historical center of Copenhagen by Cobe architectural office in 2016 (Ill.6).

Ill. 6 – Krøyers Plads, Cobe - Copenhagen, Denmark.

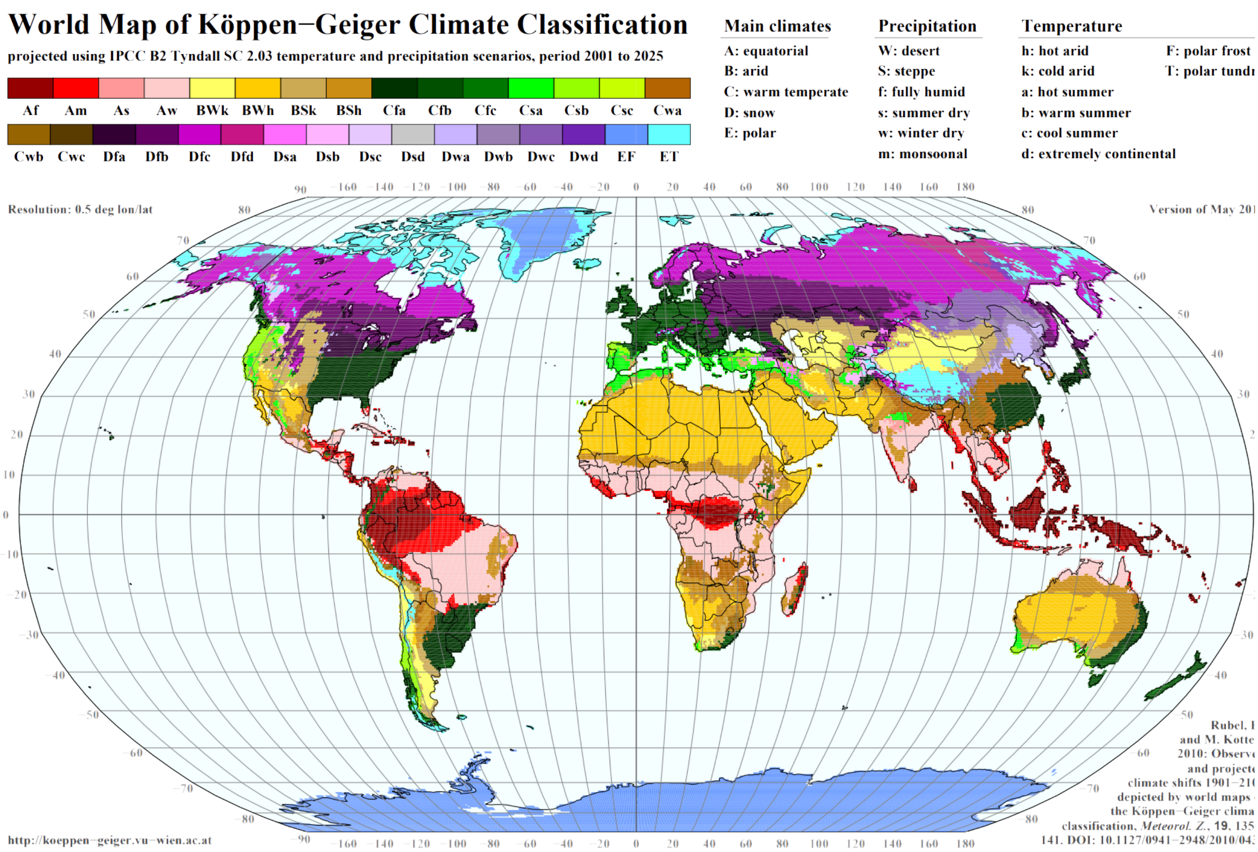
The Krøyers Plads complex building is product of an architectural and political battle that lasted for over a decade. It is in a historical site on the harbor with a waterfront view. The approach promoted by Cobe was based on the reinvention of the industrial warehouses adjacent to the site. The result was three "residential warehouses" on the harbour, the design of the building relates to its surroundings though its form as well as through the materials and colors used in the facades.

The Krøyers Plads was the first housing project to receive the "Nordic Swan" Ecolabel, which makes references to high standards of indoor climate, energy use, minimizing toxic additives in building materials and high lifecycle demand.

2.2.2 The City's Climate

To have a better understanding of the Copenhagen's weather, it was necessary to look at its climate, so that it was possible to respond to the climate necessities. By observing the world map of Köppen–Geiger climate classification (Ill.7) it was possible to indicate the Danish climate as a "Cfb", meaning that it has a warm temperature, humid with warm summers climate.

It was then, necessary to understand what this meant for the city of Copenhagen. A more thorough analysis was conducted to see the variation of temperature, precipitation, winds and daylight throughout a year.



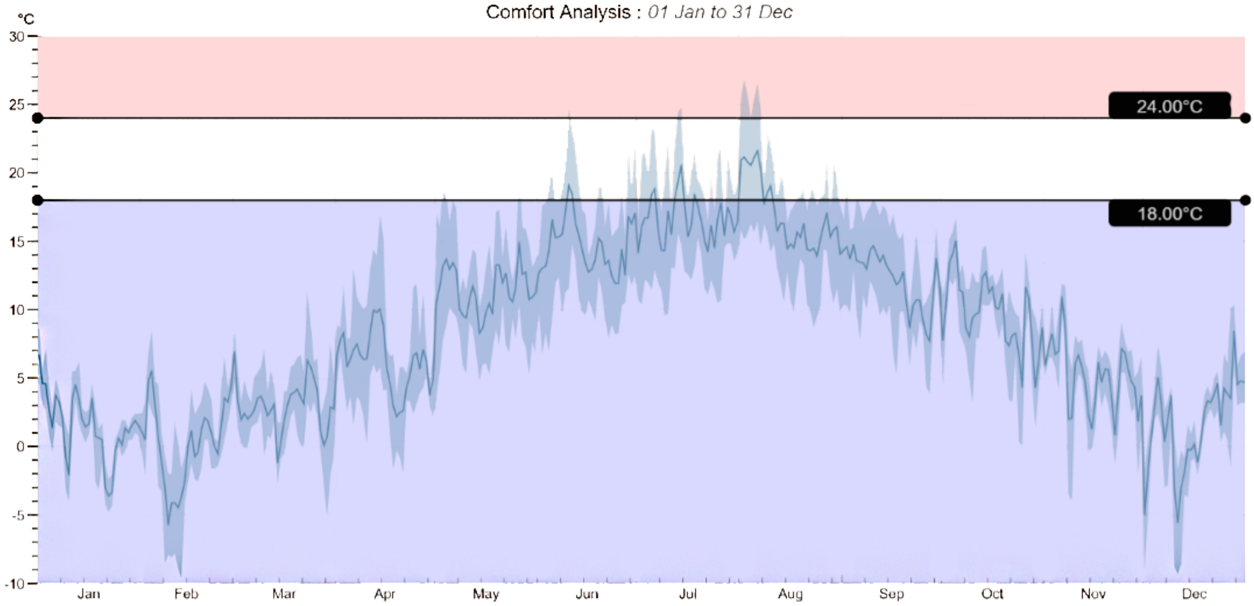
Ill. 7 – World Map of Köppen–Geiger Climate Classification.

Temperature

From observing the graphics of annual temperature variation and indoor confort temperatures (Ill.8), it is possible to observe that the temperature variation throughout a year can go from -9.6ºC in the winter to the 26.8ºC.

Regarding "annual comfort", the window of time that the temperatures are within the comfortable temperatures for human comfort (18ºC-24ºC) is small, only occurring during the summertime.

From this graphic (Ill.7) it could be deduced that the homes designed would have to be prepared to face the cold temperatures throughout the year (93% of the time).

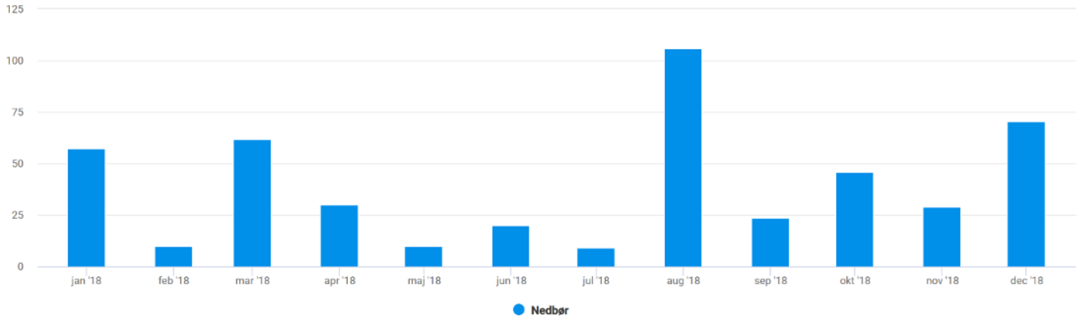


BELOW COMFORT			WITHIN COMFORT		ABOVE COMFORT		
Hrs	Deg.Hrs	Percent	Hrs	Percent	Hrs	Deg.Hrs	Percent
8139	86250.5	92.9%	574	6.6%	47	52.0	0.5%

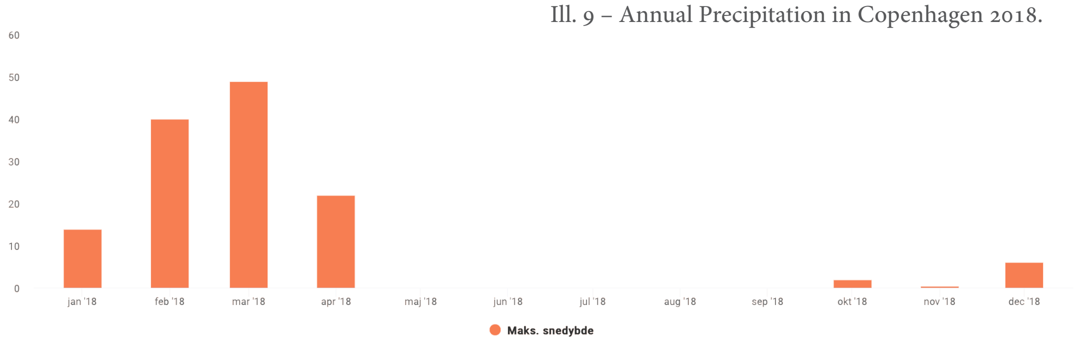
Ill. 8 – Indoor Comfort Analysis in Copenhagen 2017.

Precipitation

It is also possible to observe (Ill.9), Copenhagen (and Denmark in general) has a lot of rain. Precipitation can occur throughout the whole year and in the winter, combining with the cold temperatures the precipitation can occur in the form of snow. (Ill.10).



Ill. 9 – Annual Precipitation in Copenhagen 2018.

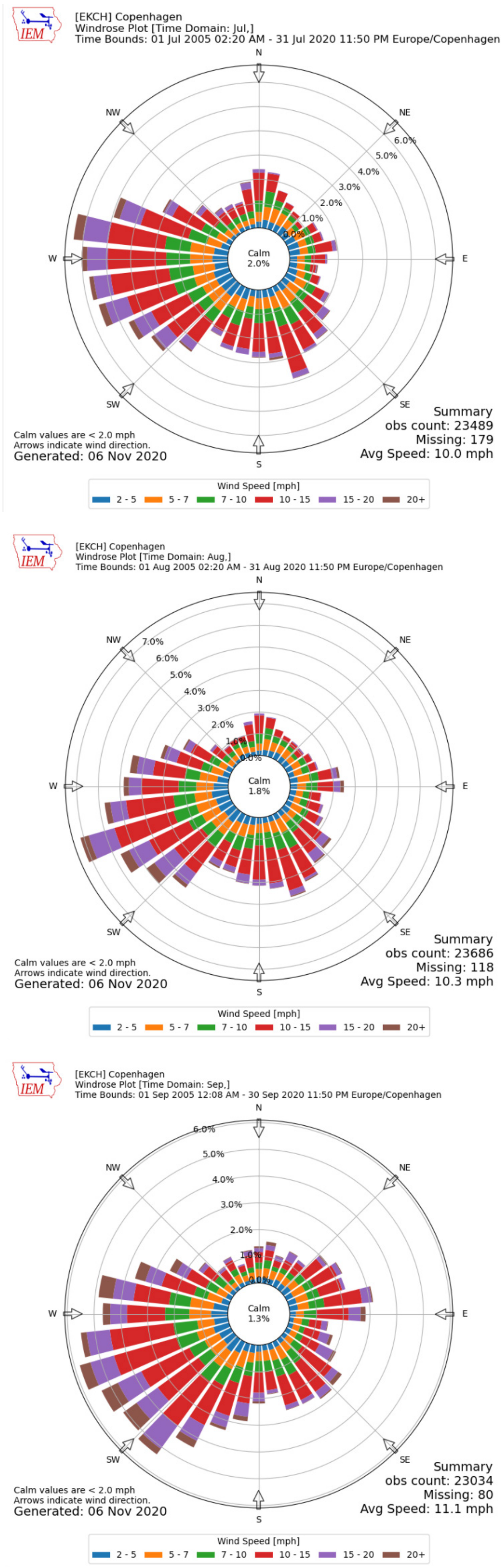


Ill. 10 – Annual Snowfall in Denmark 2018.

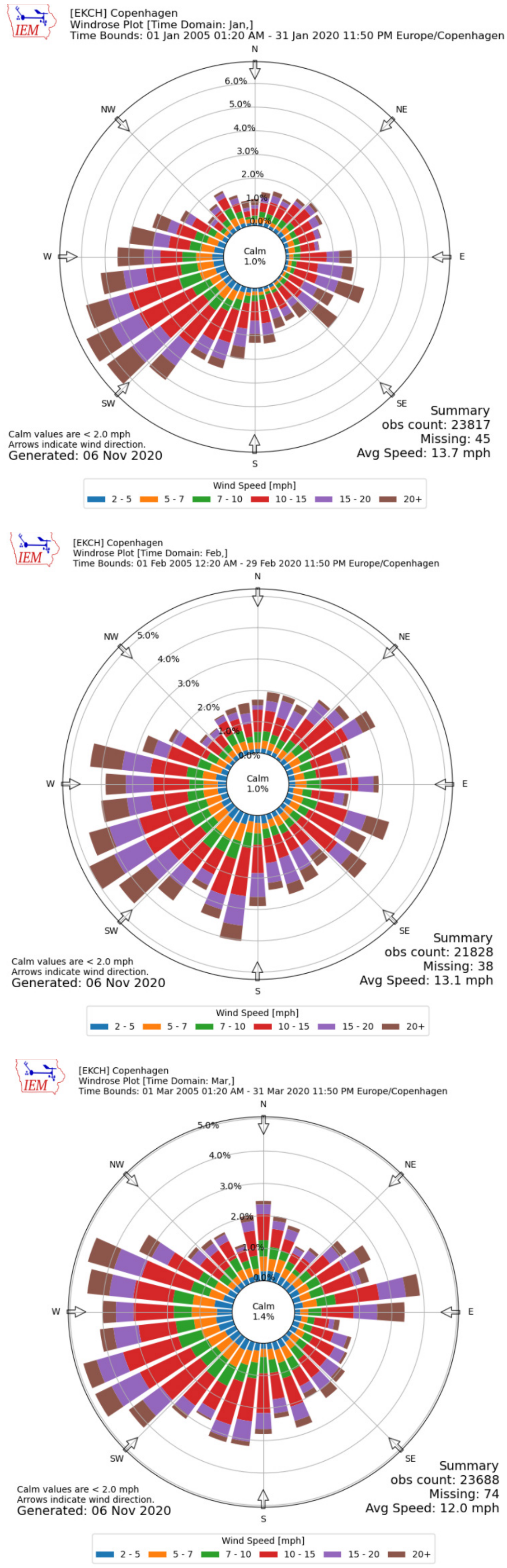
Wind

According to the Iowa State University website, the winds in Denmark exist from almost every direction. However, during the Summer they are predominantly from the west and southwest, with some occurrences from south and southeast. (Ill.11).
During the Winter, they are predominantly from the west and southwest but, comparing to Summer, they also are predominant from the southeast and east. (Ill.12)

The winds are very strong from every direction, and it is important to mention that the topography of Denmark is mostly flat so there are not a lot of obstacles that dimmish its impact.



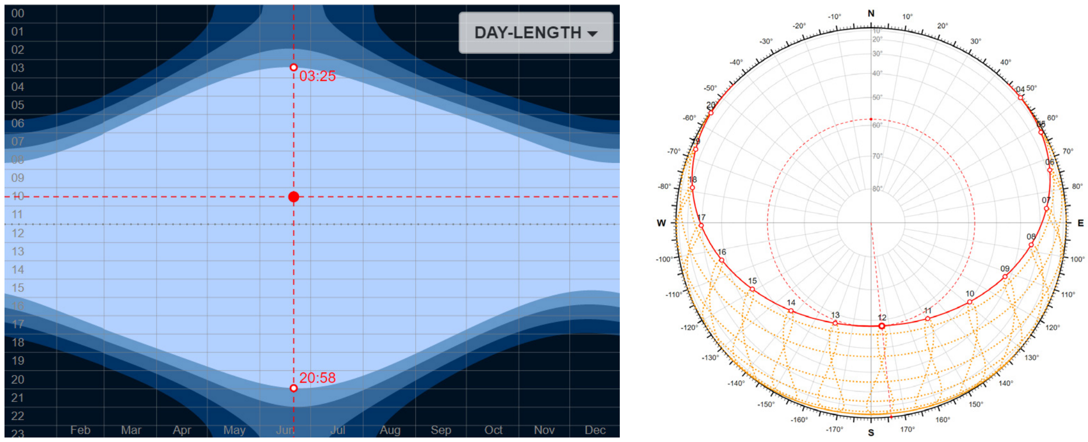
Ill. 11 – Wind roses, annual average data (2005-2020).
July (top), August (center) September (bottom).



Ill. 12 – Wind roses, annual average data (2005-2020).
January (top), February (center) March (bottom).

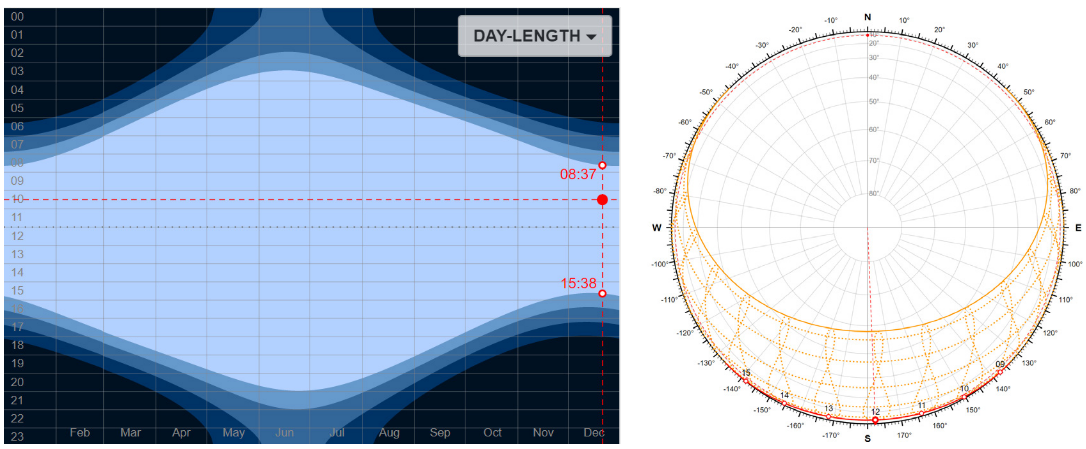
Daylight

Regarding daylight, during summer the days are long. On the longest day of the year (summer solstice - 21 of June), the sun rises around 3:20h and it goes down around 21:00h. The highest angle with the earth's surface is 57º (Ill. 13).



Ill. 13 – Sun hours (left) and sun position (right), during the Summer solstice, 21 of June.

During winter, the days are small. On the shortest day of the year (winter solstice - 21 of December) the sun goes up at around 8:40h and sets at around 15:40h. The sun is low during the winter, with its lowest point around 11º (Ill. 14).

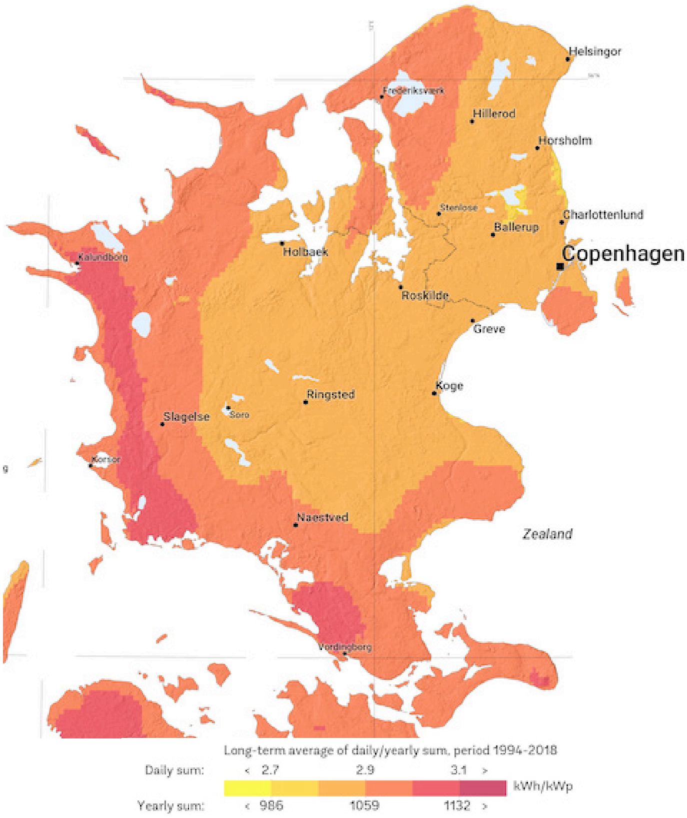


Ill. 14 – Sun hours (left) and sun position (right), during the Winter solstice, 21 of December.

Photovoltaic Power Potential

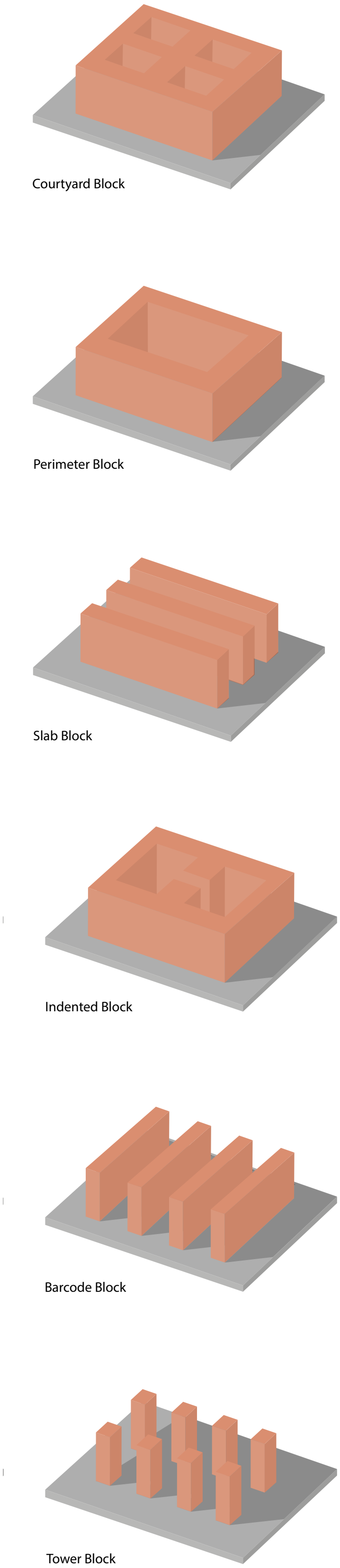
Denmark is not considered to have a strong condition to have a good photovoltaic power potential (PVOUT), according to the Global Solar Atlas website. Its PVOUT average is below 3.0 kWh/kWp (a good PVOUT average would start at 3.5 kWh/kWp). However, this does not mean that Denmark should not consider the use of PVs, as the difference between the potential for PV power in lower performing countries is not dramatically less than the top performing countries (Ill. 15).

Aside from this fact, the Danish government promotes the use of renewable sources for electricity production by awarding a premium tariff and net-metering, to those whom actively use renewable sources. So, there are economic incentives to use PV power even though the country's solar power is not as effective as in countries with more sun hours.



Ill. 15 – Photovoltaic Power Potential in Copenhagen

2.2.3 Building the City



Ill.16 –The six different types of blocks that can be found in the city centre of Copenhagen.

In Copenhagen it is possible to observe the density of the buildings decreasing as you get further from the city center. The different traditional building typologies that exist in the city of Copenhagen are (Ill.16): the *"Courtyard Block"*, the *"Indented Block"*, the *"Perimeter Block"*, the *"Barcode Block"*, the *"Slab block"* and the *"Tower Block"*. The one that can be seen the most is the *"Perimeter Block"*. These buildings, typically occupy the whole plot defined by roads, they can look heavy and hard form the outside, however, the courtyards created are frequently very appealing, with greenery and spaces for different types of activities. These are only be possible because the buildings are commonly "thin" and organize, with only a central staircase serving no more than 12 dwellings at a time, allowing for all dwellings to have access to both sides of the building. This also creates opportunity for cross natural ventilation and good daylight inside the dwelling. One question arises: Is the *"Perimeter Block"* typology suitable to design a building that aims for energy efficient building? A study comparing the six different typologies on how its urban form and density[4] can affect energy use and daylight, was conducted by P. Sttrup and J. Stømann-Andersen, in the city of Copenhagen. The study concluded that the "Perimeter Block" is the overall better typology, so using this traditional typology as a base for a more contemporary approach to the project can be very beneficial.

The "79&Park" building in Stockholm, Sweden built by BIG in 2018 is a good example on how to use the traditional typology of a "*Perimeter block*" as a base for a contemporary project (Ill. 17).

This is a building based on the addition of 3.6m by 3.6m modules organized around a courtyard. This module approach allows for the building to be constructed in a

[4] plot ratio - in the central districts of Copenhagen the average plot ratio of the buildings is between 150%-200%, in this study a 200% plot ratio was considered.

“mountain like” form that takes the most advantage of daylight. The south-west corner is lowered so that the northern part of the building, as well as the courtyard, can receive direct sunlight. The modules also give a unique approach to every house, almost all the dwellings are different, which allows for a big variety of users, from singles to couples to families. Every house has access to a private or shared terrace, which is a valuable attribute for families that want to move from the suburbs to the city and are used to their own outdoor space.

Besides this, the building is mainly constructed with natural materials, from its wooden cladding to the interiors of each house, that consist of mainly wood and natural stone, with greenery all over the terraces and courtyard.

When walking around the city it is possible to observe some tendencies when it comes to the different elements that make up a façade, especially in “*Perimeter Blocks*”. On the outside part of the block, windows and doors are, usually, on the same plane as the rest of the façade, while on the inside of the courtyard, there are usually balconies on the higher floors, and places to enjoy the courtyard on the ground floor, of course there are exceptions to these tendencies, buil-

Ill. 17 – 79&Park, BIG - Stockholm. Sweden.

dings where the facades are more intrigued and were there was more attention on detail, can have more than one plane to its façade. The location of the windows without any type of solar protection is justified by the need of solar light inside the dwellings.

The facades of the majority of the buildings in the city are made out of red and yellow brick. The tendency to use brick in Denmark sees no slowing down, the production of the material has become more and more "green" throughout the years and the variety of colors and textures that are possible to give the bricks, make them very versatile. Besides this, the brick is very appropriate to the Danish climate, as it is very durable to harsh climate, such as wind and snow, and time, it also as good insulating qualities. The city of Copenhagen as the authority to demand the use of sustainable building materials, for example, the material should have a DGNB certification and due to this fact, wood structures and materials, have begun to enter the building sector. Contrary to popular belief, the use of wood does not mean deforestation, on the contrary the use of wood as actually helped expanding the forests, as the wood used is resourced from sustainable sourced forests. Wood has very good thermal, acoustic, electrical and mechanical properties, besides this it is also a renewable material and can contribute to the reduction of the CO_2 levels inside a building.
To conclude, it is possible to understand, that Denmark in general has very well defined numerical and value judgments that should be taken into consideration when developing this project.

The project will be based on the numerical values found in the most recent "Executive Order on Building Regulations (BR18)", while the value judgments will be based of the "Copenhagen's Municipal Plan 2019".

[5]The DGNB system used to optimize and recognize the sustainability of building methods. It is based on three fundamental factors: life cycle assessment; holistic approach and emphasis on performance.

3. PROPOSAL

3.1 Location

The choice of the location for the project was a challenge itself. Copenhagen is a very dense city with very defined city blocks. With the goal of designing the project integrated in an existing city block, there were not a lot of choices of terrains around the city. So, a search for vacant plots through Google Earth was made.

Ill. 18 – Location of the different possible terrains. 1- Søllerødgade; 2- Julius Bolms gade with Holtergade; 3- Gammel Køge Landevej; 4- Sundholmsvej.

The first terrain (Ill.19) was considered because it appeared to be missing a building to close the block. However, after analyzing the city in a more detailed way, it was obvious that this is a situation that occurs in plenty of different locations. The spaces in between buildings sometimes exist to open the inside of the city block to the public, while other times (such as this one) the residents of the block take advantage to park their bikes or build a collective area for the people living there to meet. Even though these functions could be incorporated into a new design, this terrain was not chosen, as the area of intervention was small, and the


Ill.19 – Possible terrain on the Søllerødgade, Copenhagen.

Ill.20 – Possible terrain on the Julius Bolms gade with Holtergade,Copenhagen.

Ill.21 – Possible terrain on the Gammel Køge Landevej, Copenhagen.

Ill. 22– Possible terrain on the Sundholmsvej, Copenhagen.

aim was to choose an area of intervention around 4 000m². Also, the solution for the design was obvious and there weren't any big problems in this area to be solved by the proposal.

Much like the first terrain, the second one (Ill.20) also had an obvious solution and was already occupied with a playground for children in the area. Even though the area was bigger, there wasn't enough reasons to replace the existing program for the terrain.

After realizing that these types of terrains were not adequate, a more intense search was conducted in the outskirts of the city.

The third terrain considered (Ill.21), was completely different from the previous two. This one had a bigger area and was located in an industrial area near the railways. However, the terrain was not inserted in the desired type of background for this project as it was not inserted in an existing city block.

The fourth and final option (Ill.22) was the terrain chosen for the project. It was a terrain that had a connection to a "standard" Copenhagen's city block and that had various unresolved problems. The terrain is on the "Sundhomsvej" street with the plot number being the 59. There is an isolated building in the terrain (plot number 57), different types of buildings in the direct proximity, a connection to be solved between the interior of the existing city block as well as a connection to be solved to the park on the outside of the existing city block. The terrain had around 3 600m² which fitted the desired area of 4 000m².

3.1.1 Amager Vest District

The terrain is located in the south of Copenhagen, more specifically in the district of Amager Vest (Ill.23). It is the largest of the existing ten administrative districts of the city of Copenhagen, at the same time it has the smallest population. Besides that, the terrain is also included into the school district of "Amager Fælled Skole". It is considered a safe place to live, with a low risk of burglary.

According to the geodemographic classification, developed by Geomatic, the Danish population can be divided into 9 groups and 36 types (DinGeo website). The typical residents that live in this area are mostly considered the type "Familiebænd", meaning:

- The residents consist mainly of single people of different generations, without children or without children living at home.

-About 40% of the residents have a non-Danish origin;

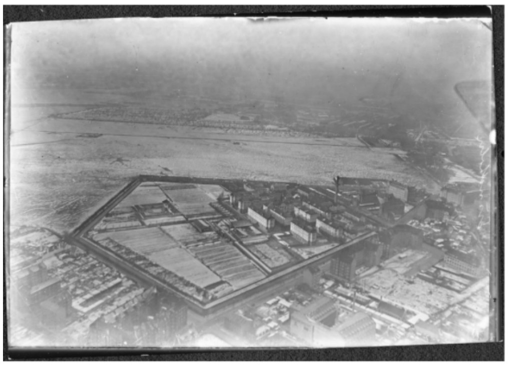
- It is a neighborhood of low-income residents, with some being unemployed, others being retired and others being students;

- Most people live in non-profit rental housing apartments between 40 to 80 m2;

- 2/3 of people do not own a car, they use public transportation and/or a bike to get around the city.

- Finally, the "Familiebænd" type are considered to have a quiet and calm lifestyle, they spend more time at home than out.

Ill. 23– Amager Vest district,4Copenhagen.



Ill. 24– Aerial Photographs of Sundholmsvej, 1920. Looking from South-East.

Ill. 26– Office Building in Telemarksgade and Sundholmsvej.

Ill. 27– Sundholmsvej Heat Central.

Ill. 28– Sundholmsvej 57, viewed from the front.

The plot Sundholmsvej 59 is part of the 2015 Copenhagen's plan for the city to provide more 60,000 homes to create space for 100,000 new Copenhageners by the year 2031. The space is classified as able to build a high-density residential building. Another goal for the city presented by the 2019 plan is for new buildings to have a variation in housing sizes, so that different types of users (families, couples, or singles) can settle in the city, so:

-50% of the floor area of the new constructions must be of dwellings of 95m2 on average, to meet the needs of families, couples or people who want to share a house;

-The other 50% is designated for singles and others, with a minimum size of 50m2 or 40m2 in developed urban areas;

According to an analysis made by the city of Copenhagen, the neighborhood where the site is inserted is characterized by buildings with 5 to 6 floors, with saddle roofs and well-defined streets and courtyards spaces.

Ill. 25– The terrain: Sundhomsvej 59 and the surrounding streets.

Even though the area is now considered a residential area, it was considered an industrial area in the 1970-1980. It is still possible to see those origins though the existing buildings surrounding the terrain. The site itself, used to have a gas station until 2019. On the crossing between Sundholmsvej and Telemarksgade is a 1915, 3 story building that was a former office or storage building (Ill. 25), while on the other side of the road of the site is the Sundholm Heat Central (Ill.26). Besides these two buildings, there is a five-story residential building from 1907, that has two unresolved facades, Sundholmsvej 57 (Ill.27 & Ill.28).
The two big housing blocks on Kornblomstvej and Øselsgade belong to the VIBO's public housing association, they are both from the early 1980 (Ill. 29 & Ill.30). The unresolved existing garden between Øselsgade and Råsøgade is in direct connection with the site (Ill.31).

As previously mentioned, the chosen site is part of the city's' plan to build more housing to house the foreseen growth of the Copenhagen's population. Therefore, there is already a local plan to the designated terrain that was analyzed and reviewed (Appendix V).

3.1.2.1 Terrain Analysis

Acessibility & Amenities

-The chosen site is located in a residential area in direct connection to one of Amager district main roads, Sundholmsvej street.

-There is a green park on the other side of the terrain opposed to the main road with an under--ground parking lot underneath it. The entrance to this parking lot creates a barrier between the site and the green park. There are also parking spots in front of the VIBO's complex.

Ill. 29– Sundholmsvej 57, viewed from North-west.

Ill. 30– VIBO Complex, central division.

Ill. 31– VIBO Complex (left), Sundholsvej 57 (front), Unused Garden (right).

Ill. 32– Part of the unused park.

- On the green park there is also a day care. between the two buildings of the VIBO complex.

-There are no street shops on the ground floor of the surrounding area. However, Amagerbrogade (the main road that connects the Amager district to the city center) has a lot of shops on the ground floor and it is only a 5 min away walk from the terrain.

-There is a bus route that stops in front of the terrain (Bus 77 that does not connect the terrain to the city center). There is a metro station that connects the airport to the city center and goes further to the out-skirts of the city, only a 7 min walk away (Amagerbro Station).

-The terrain is a 10 min walk away from the IT University of Copenhagen main campus.

Ill. 33– Map of Acessibilities and amenities.

Types of Dwelllings

Along the Amager district it is possible to identify at least three different types of building blocks: the “Perimeter Block”, the “Barcode block”/ ”Slab Block” and a great variety of “Town Houses”. The majority of the buildings surrounding the terrain are considered “Perimeter Blocks” and a more in-depth analysis (Appendix IV) was conducted on some of those buildings. Some of the conclusions that can be taken from the analysis are:

-All of the buildings are organized in a “left-right” scheme;

-The areas of each typology[6] vary through the buildings:

T1 go from 44,7 m2 to 65,8 m2;
T2 go from 77,3 m2 to 101 m2;
T3 go from 90,5 m2 to 116 m2.

-Most of the houses are T1 and T2 which means that, there isn’t a lot of big families living here/wanting to buy a house around the area.

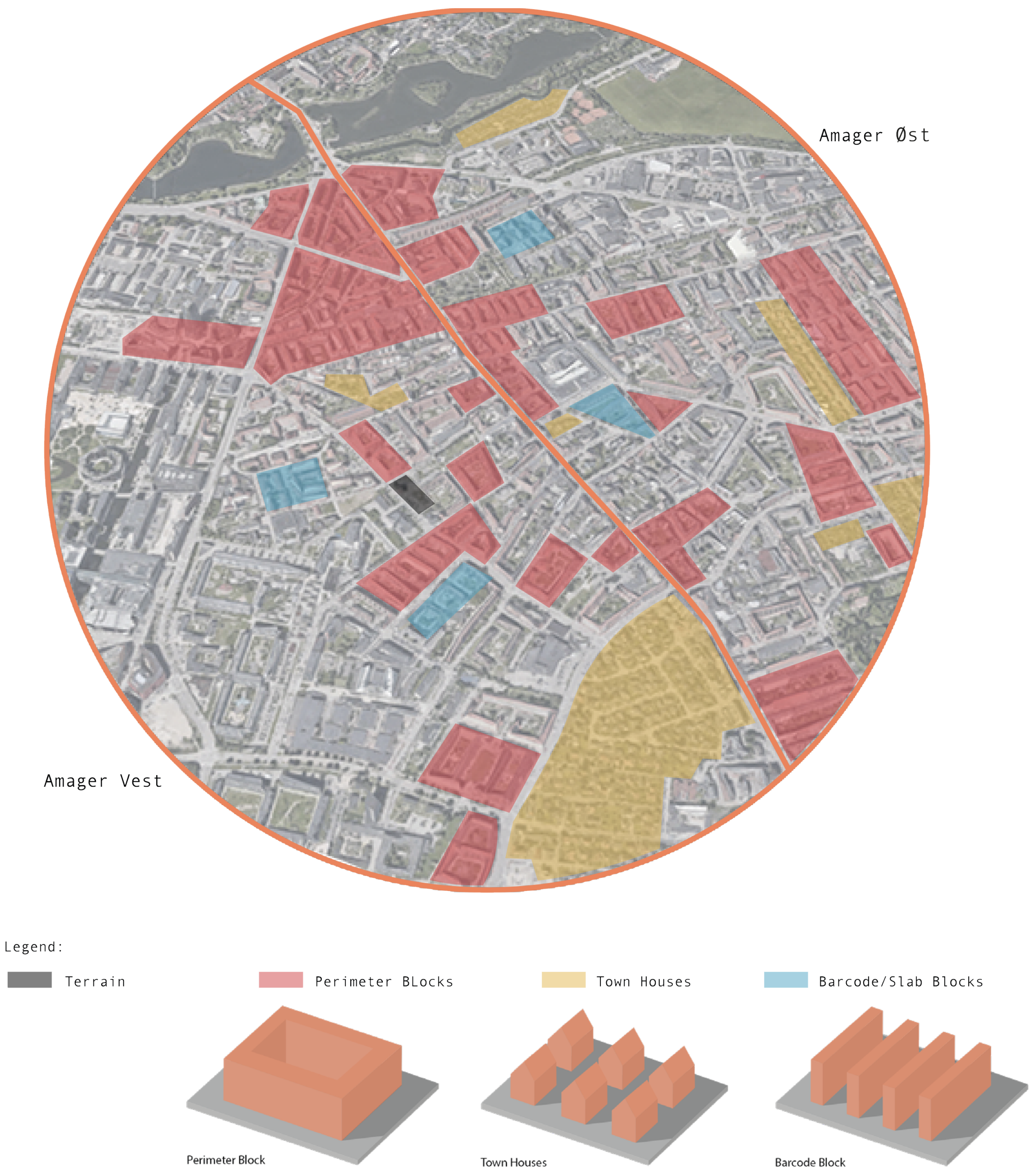
-Each house is connected to both facades of the building, allowing for cross ventilation and access to more daylight, as most of the houses studied are part of “Perimeter Blocks”.

-The smaller rooms are always located to where it seems to be the least important view of the apartments;

-Housing on the ground-floor is very common in the area (instead of shops/services);

-The ground-floors of the existing buildings are closed to outside users and do not offer a crossable path from one side of the block to another without going around the building.

[6]The typologies in Denmark are designated in a different way from Portugal. A T1 in Portugal is considered a T2 in Denmark (and so on) as they also count the living room as a room.

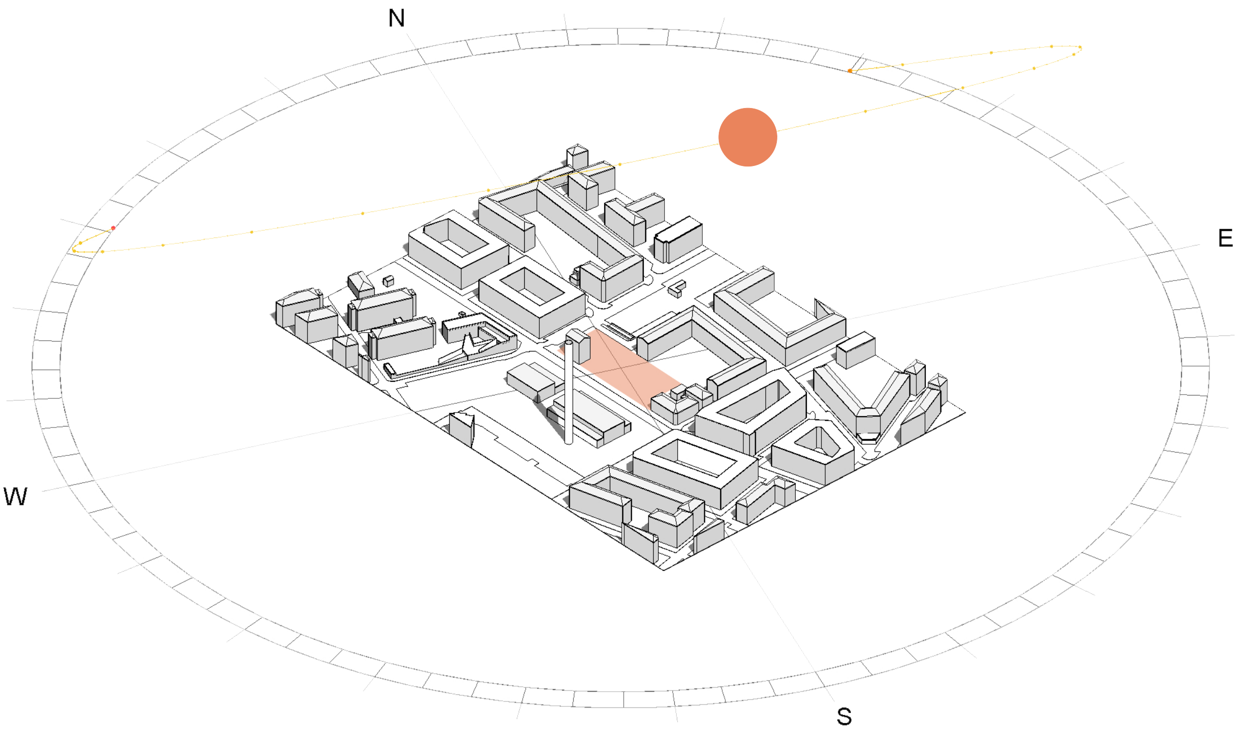


Ill. 34– Map of types of buildings in the surroundings of the site .

Daylight Exposure

To understand the existing challenges in the chosen terrain, it is necessary to perform different analysis.

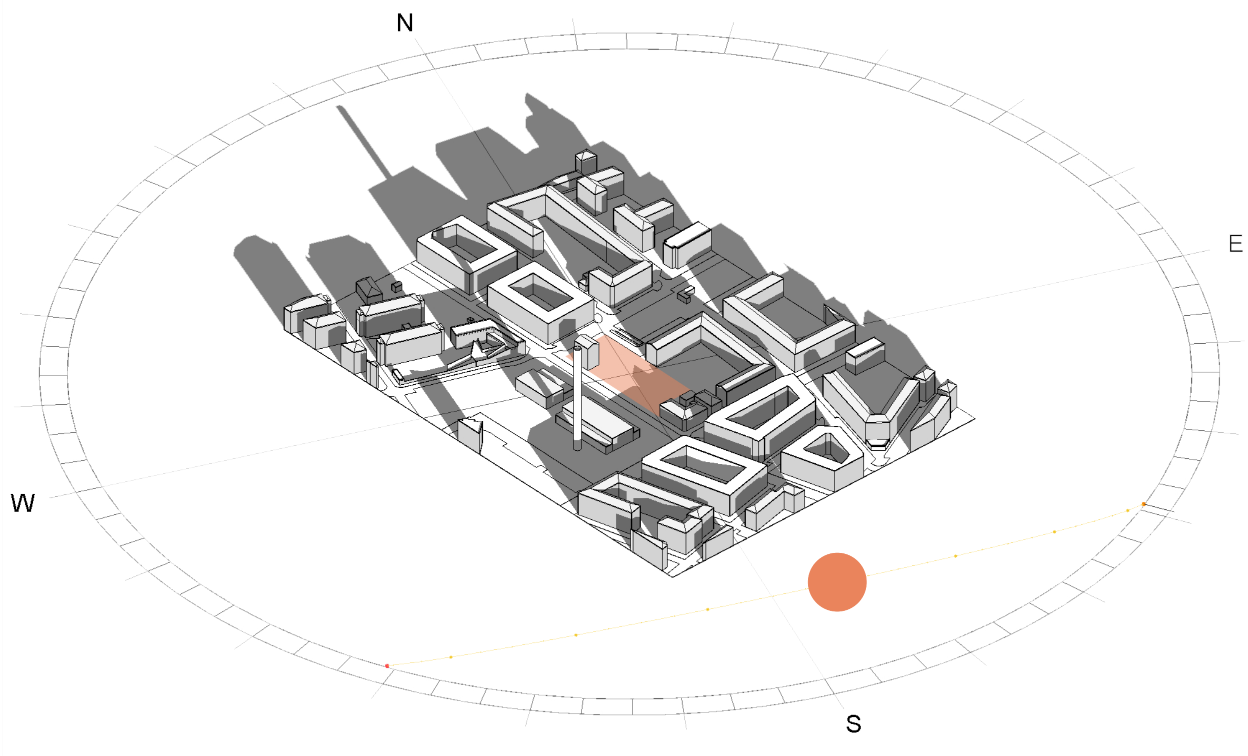
At 13:00 of the summer solstice (21st of June) the longest day of the year, the projected shadow by the 12-meter-high adjacent building is 4 meters long. Still the majority of the terrain is completely lit by sun in the summertime (Ill.35).



Ill. 35– Shadows caused by the sorrounding buildings in the terrain, during the summer solstice, 21st of June at 13:00 h.

On the other hand, during the winter solstice at 13:00 (21st of December), the projected shadows by the same building can be almost 18 meter long. The more problematic area is the south of the terrain (Ill.36).

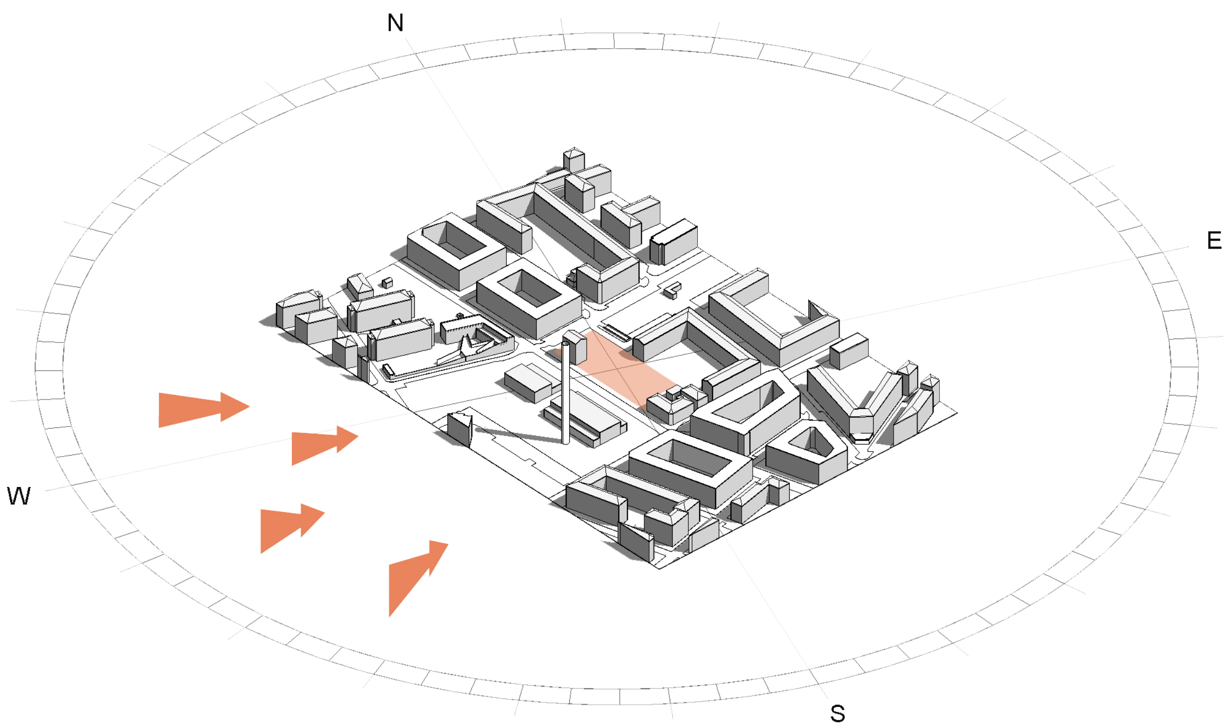
For the proposal, it was necessary to consider that the south part of the terrain is shadowed by the surrounding buildings, especially during the wintertime when the sun is lower.



Ill. 36– Shadows caused by the sorrounding buildings in the terrain, during the winter solstice, 21st of December at 13:00 h.

Wind

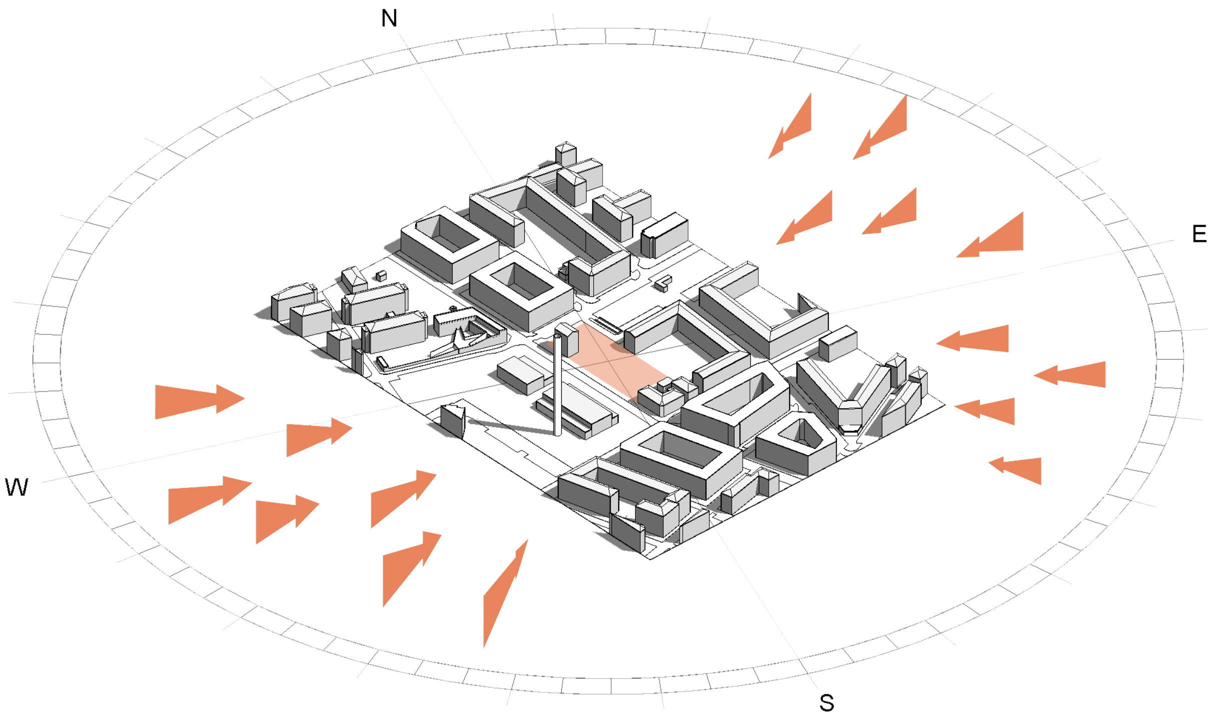
During the summer (Ill.37), the winds are predominantly from west and southwest. Which can be an opportunity to use it for natural ventilation, since there is low rugosity level (no big elements that could slow down the wind coming to the terrain in that direction).



Ill.37 – West and Southwest wind representation affecting the terrain during the Summer.

During the winter (Ill.38), the winds from west and southwest get stronger while there are also predominant winds from east, with lighter winds coming from south. The southwest winds can be a problem due to the low rugosity level. The terrain is more protected from east because of the existing building complex.

In conclusion, it was necessary to protect the terrain from the wind mainly from west, southwest and east during the winter, while during the summer these winds can be used to accomplish the natural ventilation of the building.

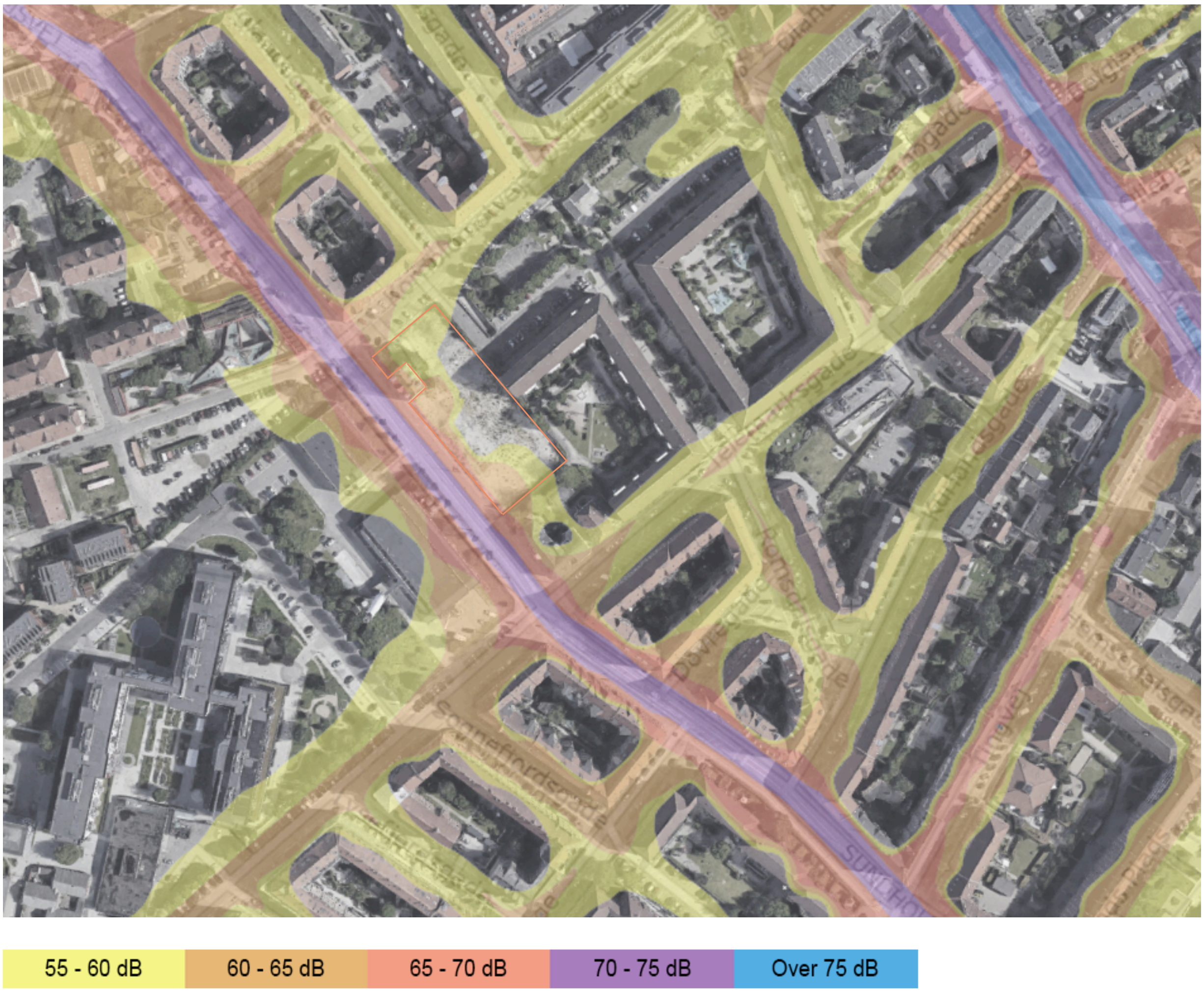


Ill.38 – West, Southwest, and East winds representation affecting the terrain during the Winter.

Noise

The plot is directly connected to a primary street with a noise volume of 70-75 dB, which means that there is a lot of traffic that goes through it. The terrain is also connected to a secondary street where the noise volume is considerably less, 50-60 dB (According to the Noisy Planet website sounds below 70 dB are considered safe) (Ill. 39).

A strategy to protect the building from the noise made on the street had to be implemented by the sitting and shape of the building, the use of adequate building solutions and, if possible, by vegetation.



Ill. 39 – Noise representation on the streets surrounding the terrain.

Water Level

Denmark is in general a flat country, with an average elevation of 64 meters (https://en-gb.topographic-map.com/maps/dft/Denmark/). Copenhagen is in average 10 meters above sea level and the chosen terrain is only about 2 meters above sea level. This analysis shows that if the sea level were to rise 2 meters as a worst-case scenario for the future, the terrain would be partly flooded (Ill. 40).

It was necessary to design with this information in mind, so that the proposal could be protected from this possibility.

Ill. 40 – Water level rise representation affecting the terrain.

The program for this project results from the analysis of the existing urban plan for this location and on the study of the residential buildings surrounding the terrain, using information available at the Dingeo website[7].

The existing official urban plan (Appendix V) proposes a residential building for the site, as this site is part of city's plan to increase the number of "beds" in the city (Copenhagen Municipal plan 2015).

The site is in a residential area, where houses are mostly of T1s and T2s typologies (Appendix IV), leading to the conclusion that these typologies must be the most sought after in this area. Besides this the terrain is a 10min walk away from the IT University of Copenhagen, meaning that there was the possibility for students to be looking around this area for accommodations. Both aspects, allowed for the conclusion that the proposal should consist mostly of T1 and T2 typologies (allowing some apartments the possibility of having a second bedroom) with the inclusion of some T3 houses for bigger families.

It was very relevant to consider the existing bus stop (Ill.41) and public garden (Ill.42) adjacent to the site. These two elements justified the choice to have the ground floor dedicated to the public, with the purpose of reactivating the unused garden to the north, connecting it to the bus stop through a commercial area in order to bring more life and activity to this part of the city. The public garden had to be reorganized for the connection to the building to be stronger.

My proposal considered that the parking lots that used to exist in the entrance of the VIBO's complex were deactivated and included in the extend underground parking lot. The access to the underground parking, had

Ill. 41– Bus stop located on the terrain.

Ill. 42– Public garden adjacent to the site.

Ill. 43– Day care center in located in the public garden.

[7]The Dingeo website is a danish website that colletcs the geodata of all Denmark. In this website it is possible to know all the relevant information about an allotment. From its history (with the documents relating to the buildings - past, current and future plans, facades, sections), to the type of soil of the terrain or even about how that part of the city ussualy votes (in the elections).

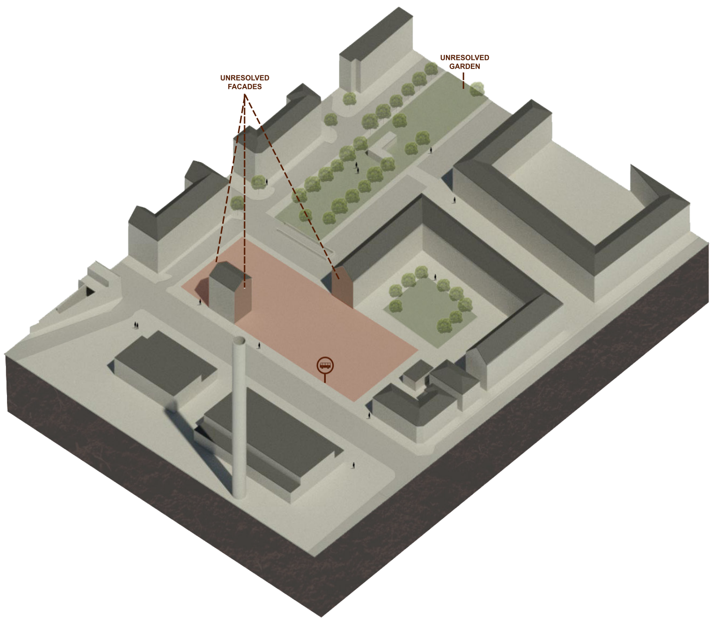
Ill. 44– Entrance to the under-ground parking lot; the site (on the right); VIBO complex (in front).

to be relocated so that it wouldn't break the connection between the garden and the building. The existing day care center (Ill.43) was also relocated. This and the new entrance to the parking lot (Ill.44) were aggregated in the same polygon and relocated to the side of the garden closest to the road, so that the space infront of the VIBO's complex also would become more pleasant.

Part of the proposed complex was dedicated to office space. It is also seen as one more way to bring people to visit and enjoy the site.

3.3 The Plan

The master plan anchors itself on to three different features that were already part of the site (Ill.45): the bus stop, the adjacent public garden and the three unresolved facades (Ill.46 & Ill.47).



Ill.45 – The unresolved problems of Sundholmsvej 59.

Ill. 46 – Sundholmstvej north-west unresolved facade.

Ill. 47– Sundholmstvej south-east unresolved facade (left); VIBO-Complex unresolved facade (right).

When discussing what should be done with the existing building on the plot (Ill. 48 -Sundholmsvej 57), there were three different approaches that were taken into consideration:

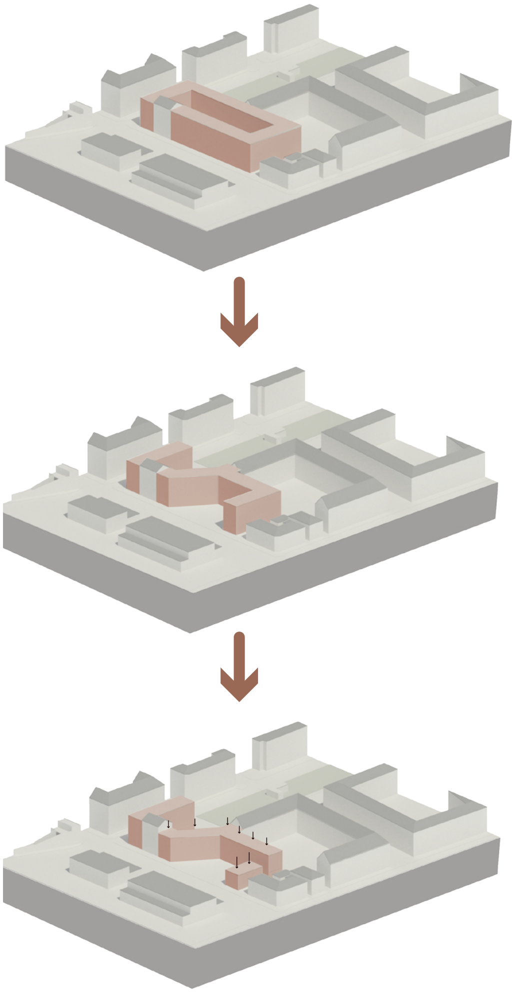
-Keep the building and integrate it;
-Demolish it;
-Or, move the building to another part of the site, an extreme but technically possible option.

The second one was rapidly abandoned as after some research, it was found that the Copenhagen's municipality did not want that to happen, so it was necessary to incorporate the building into the proposal. After doing some volumetric studies to understand if it made sense to move the building around, the conclusion was that there were no advantages. So, this meant that there were three different unresolved facades that needed to be solved, as well as the back side ofthat isolated building and its backyard.

Different volumetric solutions were tested using Revit, to understand how the forms would dialogue with the surroundings and how each form would have the better energy performance, sun exposure and shadow casting. In the end, the solution chosen was the one that would not only take better advantage of the sites positioning (taking advantage of the sun's orientation) but would at the same time resolve the existing facades and alignments with the surrounding buildings, resorting to a non-orthogonal form.

The chosen proposal can be seen as a *"Perimeter Block"* that offers its courtyard to the city as public space and it is divided into two, by the rotation of the central body that connects two of the unresolved facades (Ill. 49). The "courtyard" space created a separation between the building and the main street, this in conjunction with

Ill. 48 – The existing building on the terrain, Sundholmsvej 57.



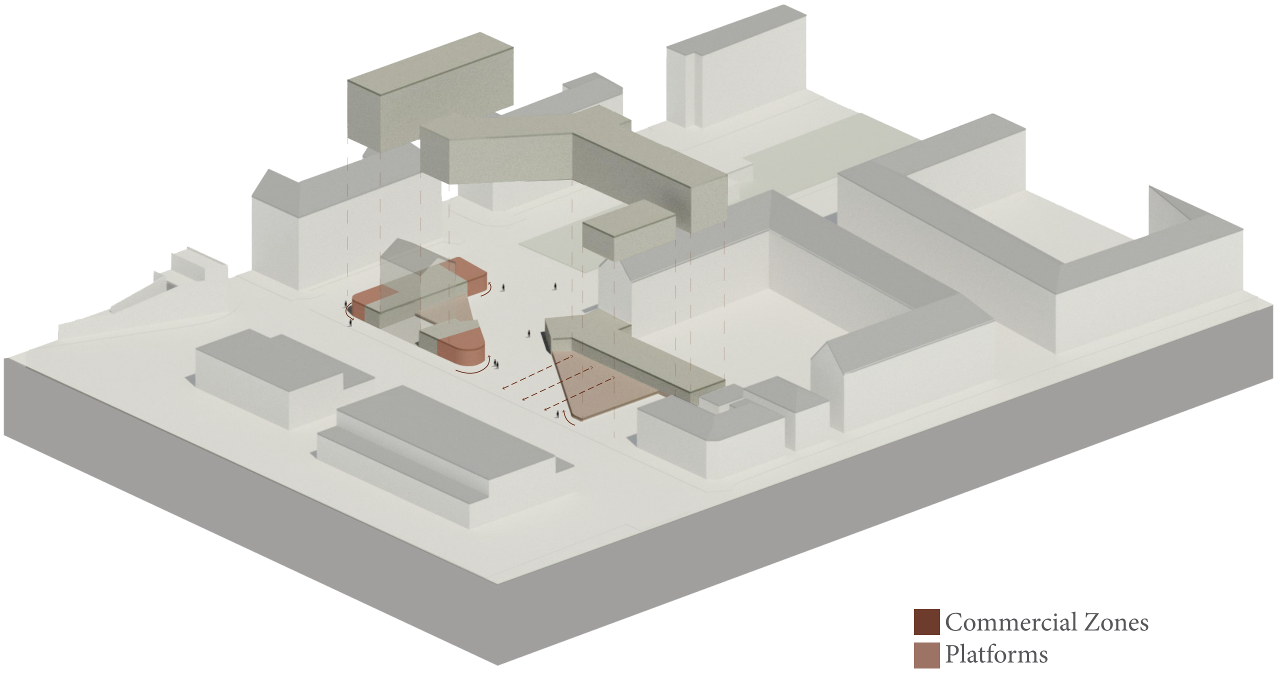
Ill. 49 – The evolution of the proposed volume.

the trees planted and the building envelope, helped protecting the majority of the houses from the noise made by passing traffic and, giving more emphasis and space to the bus stop and to be a key moment of meeting.

During the process of studying the form the project should take, it became evident that the public garden (existing on the northern side of the terrain) should be involved in the overall experience of the building. Because of this intention, part of the ground floor became a passageway that would connect the bus stop to the garden. Commercial zones (restaurant/caffes and/or stores) were placed in direct connection with the street and garden for the users experience of this connection to be more pleasant, as having different types of uses connected to the street can bring more security to the area (Jan Gehl, Life Between Buildings 1971). The corners on the ground-floor of the building complex were rounded allowing for the flow of walking around the building to be more fluid and inviting to the users (Ill. 50).

The housing portion of the complex is manly elevated from the street level. The creation of a platform on the south side helped creating a private garden that would resolve the privacy that the residents of the existing building were used to have, as well as maintaining the existing trees. This platform allowed for the creation of collective and private areas for residential users to use on the outside of the building. It also protects the building from possible water rise (Ill. 50).

On the south part of the terrain, the building complex takes on the scale of the office building adjacent to the site, in the form of a row "*Town Houses*".

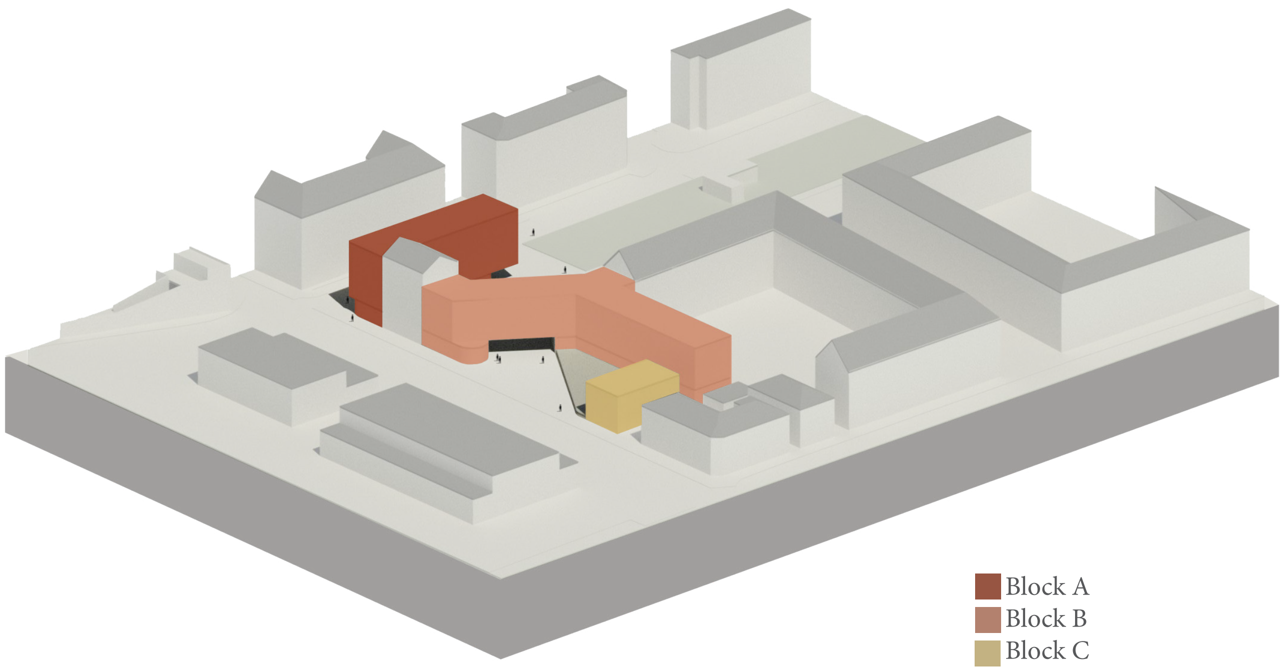


Ill. 50 – The organization of the Ground-floor.

3.4 The Building Complex

The organization of the complex is dictated by the modular approach that was taken when developing the apartments. The modular aspect was, however, only taken in terms of width of the apartments, as the depth of the buildings are not only defined by the existing unresolved facades, as well as the maximum size (12 meters) residential buildings can have according to the Danish Building Regulations, to allow for good cross ventilation and sunlight exposure.

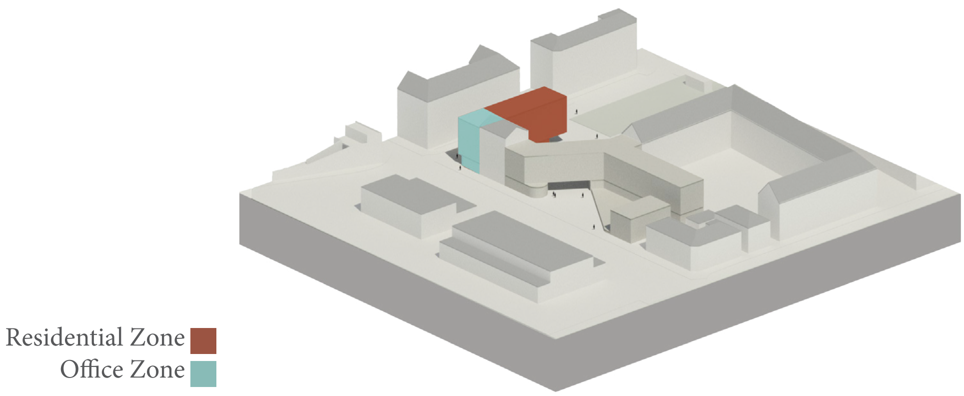
The building can be divided into three different parts (Ill. 51):
Block A – the north body;
Block B – the central body;
Block C – the south body.



Ill. 51 – The three different blocks of the building complex.

3.4.1 Block A

This body of the building has two different uses: residential and offices (Ill. 52).

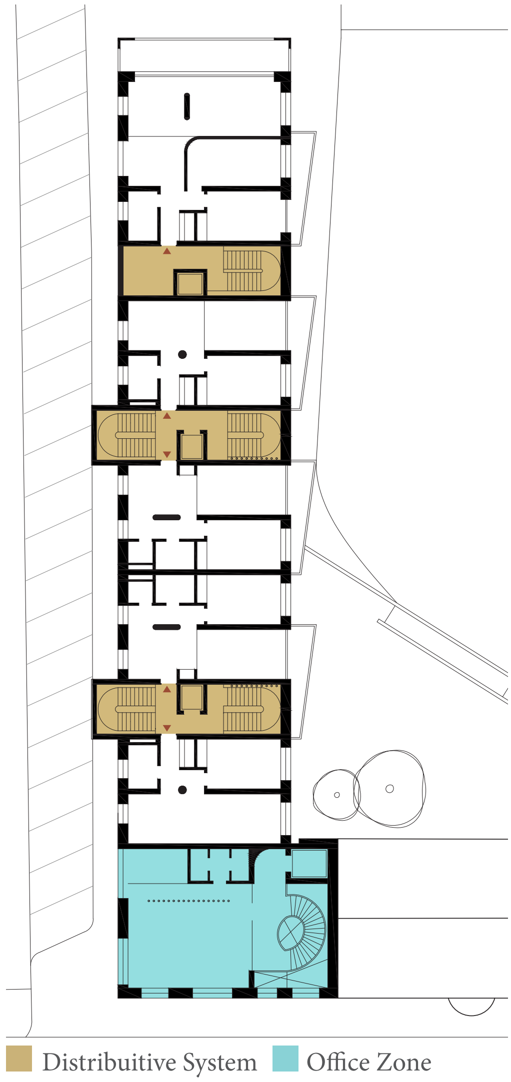


Ill. 52 – Block A: Distinction between the office and the residential part.

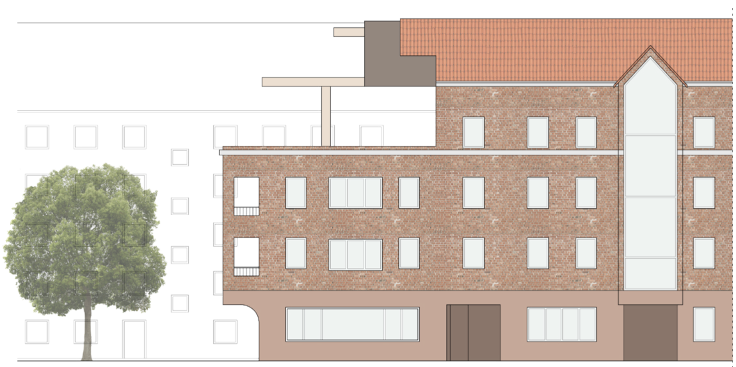
In its overall organization and expression, it connects with Sundholmsvej 57 and the existing building on the opposite side of the street. The office part (that is adja-cent to Sundholmsvej 57) of the building maintains the existing floor height of Sundholmsvej 57, so that their expressions can communicate. But, after turning the corner it goes back to the proposal floor heights, so that it can relate to the platform created.

On the top of the building (façade that faces the garden), the height decreases. This was made with the conscious choice of having a more human scale approach to the building from a big outside open area. It also allowed for the creation of a terrace on the top of the building, that the apartment users can enjoy (Ill.53).

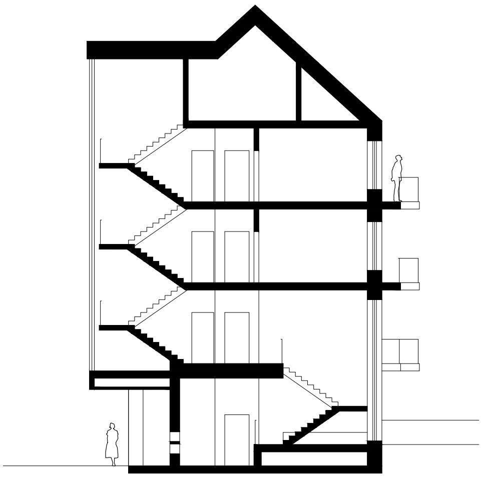
The residential part was organized in a left/right distribution scheme, taking inspiration in the same way most of the existing surrounding buildings, allowing the apartments to have a connection with both façades of the building facades. The staircases start from being in direct connection with the south facing façade but then, from the 1st floor up, change to connect with the north façade (except for one staircase) (Ill. 54).
The staircases are then incorporated into volumes that jut out of the main volume. This volumetric decision gives space for the stairs to develop and it also connects to the volumetric solutions of the existing building in front. The staircases change frees up enough space for having another room facing the preferable climate orientated façade in the apartments. The choice to have



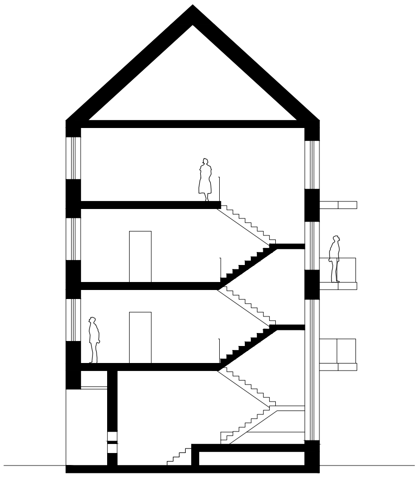
Ill.54 – Distributive system of Block A and the Office Zones.



Ill.53 – Part of the façade that faces the Kornblomstvej street and is in direct contact with the garden.



Ill. 55 – Staircases that jut out of block A.



Ill. 56 –Exception staircase block A.

these volumes in mostly glass (to the north) allows for by passers to have a peek inside the building and how it is organized (Ill. 55).

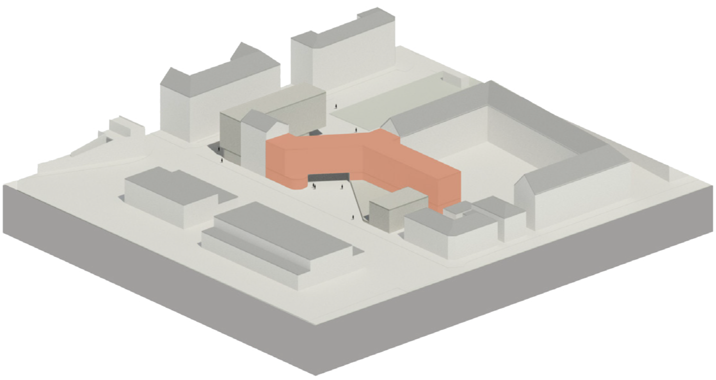
The staircase that never changes from the south façade to the north façade, helps maintain a certain rhythm and regular organization of the façade. These apartments are also an exception and are located in the lowest part of the building that faces the public garden, having three free façades(Ill. 56).

The office space is located in the corner of the building that faces a crossroad (between Sundholmstvej and Kornblomstvej). This part of the building did not meet the minimum conditions to be considered habitable since the cross - ventilation and sunlight received were little, so it rapidly change from having a residential program to an office one, bringing more diversity in terms of users and use throughout the day. There was an intention of associating a different solution of the staircase shaft to the different use of this part of the building.

The ground floor of this block is where most of the commercial zones are located, all of them connecting directly to the main street, Sunholmstvej, or to the south part of the plot. Besides this, a communal area was also proposed where the residents of the building can meet up and enjoy this space connected with the elevated garden provided by the platform created.

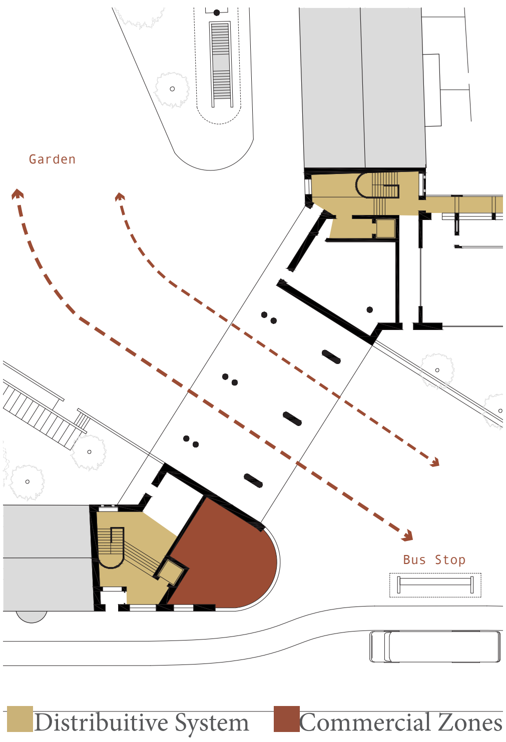
3.4.2 Block B

This block (Ill. 57) connected to two of the unresolved facades that are in contact with the site. This meant that it would have to have a strong relation to Sundholmsvej 57 façade that faced the main road, as this block would be solving most of the plan facing this road and it should also respect the façade rules on the Kornblomstvej building.



Ill. 57 – Block B.

This is also the part of the complex that allowed for the direct connection between the bus stop and the public garden, through a passageway created by "removing" part of the ground floor. For this passageway to work, the horizontal circulation system had to change from a left/right organization to exterior galleries (Ill.58).



Ill. 58 – Connection of the bus stop and garden trough the ground-floor; Main distributive cores of Block Block B.

The galleries were placed on the less preferable side (colder side) of the building, to the North, as it is a passageway and not a place of permanence. They had to be open to the exterior to allow for the apartments to have cross-ventilation, however a brick wall was proposed along the whole gallery façade with big openings. This allowed for a more coherent unitary perception of the overall building and easier connection with the existing buildings facades.

The vertical distribution cores (stairs and elevators) for this part of the building, were positioned side by side with the facades of the adjacent buildings to the project, to solve the connection between building facades as the proposal had the floor levels on different heights relatively to the existing buildings because of the elevated platform on which the proposal rests on. So, for the façades to have a better communication with the existing buildings it was decided that the windows in this vertical cores, should be aligned between the existing and the proposal. This was only possible by pushing the stairs away from the façade, having a continuous empty space from floor to top height and installing the windows in those places (Ill.59).

Ill. 59 – Alignment of the windows from Sundholmsvej 57 (left) and thecores of the proposal (right).

There is a third vertical core, that consists of stairs only, to respect the maximum distance (30 meters) of an apartment door to a possible fire escape (stairs) placed near Block C, this staircase is directly connected to the outside garden.

The ground floor of this building has different characteristics throughout its extension. It has a shop directly connected to the street level, bus stop and passageway. Then, it has an indoor parking space for bicycles also on the street level. Lastly, it has apartments and a collective space for the residents with a communal laundry space, all connected to a collective private garden on the platform level on the West side.

When the block “rotation” happens , there is a change in the language of the façades. In the corner where this change is made, there was a need to create separation (balconies were implemented) between the facades so that there was a clear reading on the building. From the moment the building rotates, the balconies of the proposal are grouped into two and mimic the painted brick arched expression Sundholmsvej 57's front façade has in its 1st and 2nd floor. However, in the proposed building, these two floored arches can happen in every two floors, and have more depth to incorporate the balconies, but also maintain the different toned bricks on the inside of the arch (Ill.60).

Ill.60 – Appropriation of elements from Sundholmsvej 57 into the proposal.

The roof on this block was a challenge as, there was a need to resolve the top part of the existing facades, a need for people to enjoy the top floor of the building, as well as a need for the building to be as low as possible for the sun to be able to reach the greatest amount of Block A's southfaçade. This last need was inspired by the way BIG resolved their need to have sunlight in the courtyard and northern part of their building, 79 & Park in Sweden. This project is a *"perimeter block"* with a big courtyard and to allow for the sun to "get in" this courtyard and hit the opposite facade, they lowered the south part of the building and rose the northern part.

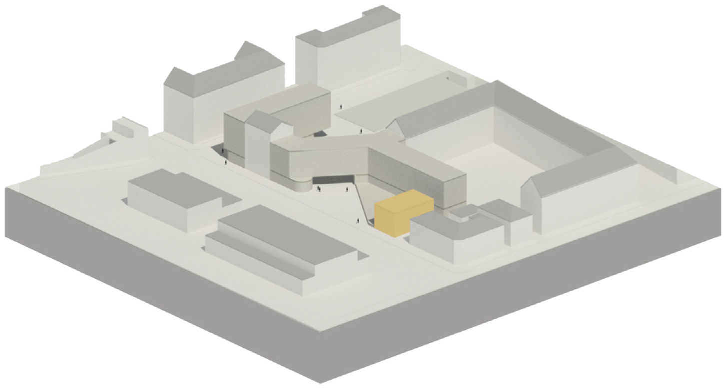
The result on this proposal is, however, also inspired by the way Carlo Scarpa solves the roof in the Castelvecchio museum in Verona, Italy, when the main building "touches" the stone wall (Ill.61). So, two separated deconstructed roof structures, that only exist in the connection of the proposal with the existing buildings were designed. It was to look like they are reaching for each other and finish the connection between buildings. This allows for the vertical cores to reach the roof giving building users the opportunity to enjoy this outside space.


Ill.61 – Castelvecchio Museum by Carlo Scarpa, 1957.

3.4.3 Block C

Ill.63 – Three-story existing office building.

Block C (Ill. 62) is dedicated to bigger families, it consists in three townhouses in a row, all of them with the same layout and a T3 typology. The houses have an entrance floor that connects both with the private garden on the platform level, and the street level where there is space for one car per family. The rest of the house is organized into two other floors. The fact that this building has 3 floors, allows for it to relate with the three-story existing office building to the South (Ill.63), having the floor levels and windows aligned with each other.



Ill.62 – Block C.

3.4.4 Building Materials

In terms of building materials, there was a debate on what to use and how to use it for the building to have a better energy performance, an adequate life cycle and to be able to fit in with its surroundings.

CLT was used in the structure of the building. This choice came from the fact that CLT has a good energy performance and life cycle (The CLT Handbook, Swedish Wood 2019). However, it was a hard decision to make, as it was known that brick would be used for the facades of the building. CLT is a light material (wood), and brick is a heavy looking material, so having a heavy look onto a light structure could interfere with the “truth” of the building’s construction. It was not a case of being possible to do it or not, COBE’s Kroyders Plads in Copenhagen used light steel framing with brick facades, but they had to find a balance between these two materials. Their solution was the production of “brick shingles” (Ill.64) this would allow for the building to connect with the surrounding materials, but it still gave a lighter feel to the building and an insight on what the building structure could be. It was a case on how the building can be presented in a way that lets the users and the outside people know how the building was built.

Using the same strategy as Kroyers Plads was considered. However, even though brick production is striving to become more sustainable, it is still a material that uses a lot of energy to be produced and releases great amounts of CO2 during the process. So, the decision of using reclaimed bricks from old buildings that were demolished was taken[1] (Ill. 65).The strategy was having a concrete ground-floor that would support the brick facades and give a heavy looking support to the building. Concrete is not the best material to use when thinking from a sustainable point of view. It is an extremely durable material, but it cannot be reused nor recycled. However, it isused in only around 15-18% of the building’s envelope, it is associated with the public use of the building (Commercial zones and the buildings public route that need to be more durable) and it can protect the rest of the building in case of floods (Ill.66 & 67).

To make sure that it was perceptible for people to know how the building was built, the vertical cores (Block A) and galleries (Ill.66 - Block B) are coated in wood panels, this allows for users to be in direct contact with

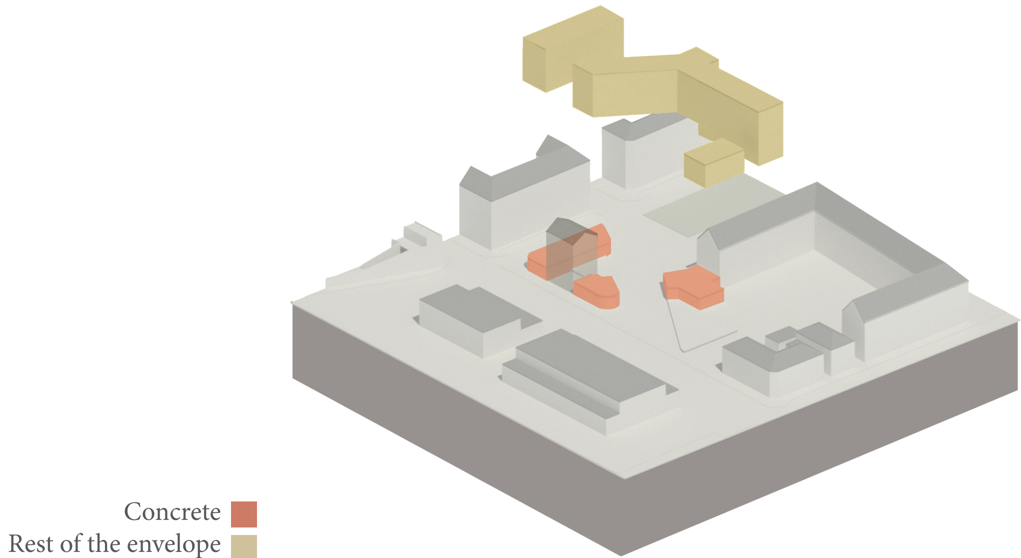
Ill.64– Kroyders Plads brick shingles (left); Existing roof tiles (right)

Ill.65 – Siza-Pavillon Insel Hombroich, Neuss-Holzheim by Álvaro Siza Vieira.
Built in reclamed bricks.

Ill.66 – Concrete use on the ground-floor; Observing the inside of the galleries from the street level (Block B).

[6] Recycling bricks from demolished buildings can be dated to World War II in Berlin. As young women were not being called to play part in the war, they were left behind to clear up the cities and help rebuild them. These women were called the Trümmerfrauen, in english, the rubble women (https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/197658/trummerfrauen-women-of-the-rubble/).

the material used for the structure and for passersby to see the wood from the outside of the building. The footers of the galleries are 90 cm high and are the same materials as the floors (ceramic paneling) to protect the walls from shocks and to allow for easier cleaning as it is in direct contact with the outside.



Ill.67 - Differentiation between where concrete was used and the rest ofthe envelope.

3.5 The Apartments

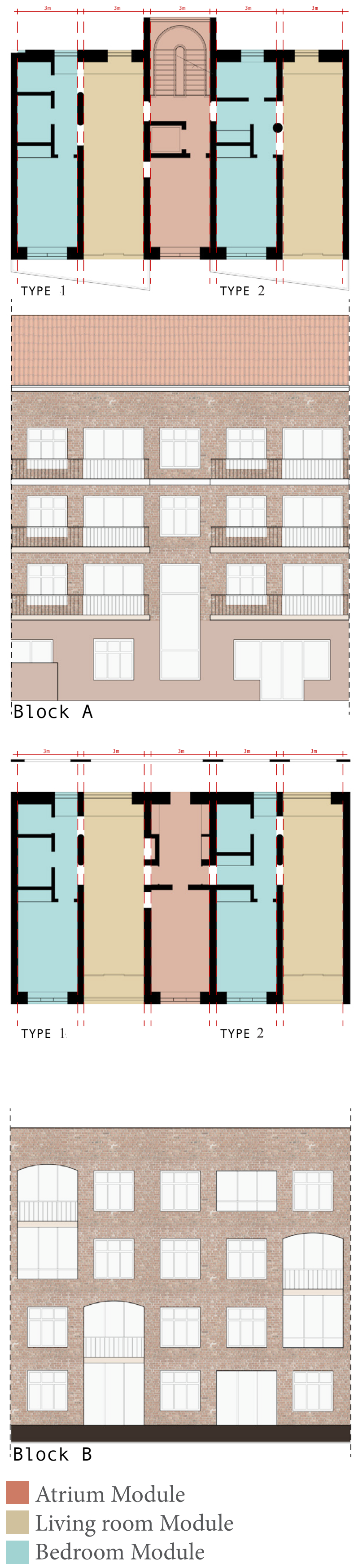
Only the apartments in block A and block B are going to be described. Block C has a different nature than these two other blocks, as it consists of townhouses and not apartments. This was decided because they are considered an exception when compared to the number of apartments there are in the complex (3 townhouses vs. 43 apartments). However, it can be assumed that the materiality of these houses is going to be similar to the materiality used in the apartments.

The apartments organization is a combination of information collected through my Danish experience (Appendix I), the enquires made (Appendix III), the analysis of the surrounding buildings (Appendix IV), and on the optimization of the floor plan regarding the climate conditions. The size of each typology respects the average surface of different typologies in the surrounding buildings (Appendix IV).

The apartments were the key element to the overall organization of the building. As mentioned, there was a modular approach taken when designing them, each apartment is the junction of two 3 meter (plus structure) modules, where one module is dedicated to private spaces (bedroom and bathroom) and the other to communal spaces (Livingroom and kitchen). This, combined with the positioning of the piping infrastructures on the partition walls (between apartments and between, apartments and atriums), allowed for the creation of two different organizations for the same typology, which subsequently permitted the south façade on Block A to have more of a regular language, while on the block B allowed for it to have a more dynamic expression (Ill. 68).

The entrance to the apartments is different in each block. In block A the entrance is made directly from the vertical cores to the apartment. In block B however, the entrances to every two apartments are made by small atriums that connect the gallery space with the apartments. These atriums allow for the users to open their home doors to a more controlled environment, decreasing the heat changes between the inside of their homes and the outside air. The atriums also work as spaces for the users to take off their outside shoes and taking of their jackets before getting into the comfort of their homes, as it is a common habit of Danish people having their shoes by the door or even outside their houses.

There are some exceptions to this conjoined entrance of the atriums in Block B. The exceptions happen when



Ill.68 – The regulation/ de-regulation of the façades because of the apartments organizations.

the apartments are also an exception to the standard configuration. The entries to these apartments are either made through the vertical cores or through the gallery itself.

The standard apartment is of a T1 typology and there are two possible organizations for these apartments (Ill.68):

Type 1 - where the users enter directly to the collective spaces of the house (living room and kitchen);

Type 2 - where the users enter to a hallway connected to the more private spaces (bedroom and bathroom).

The difference between type 1 and type 2 is that in type 2 the positioning of the bathroom switches with the storage room and the storage room becomes the entry to the house.

Both types have the same logic (Ill. 69):

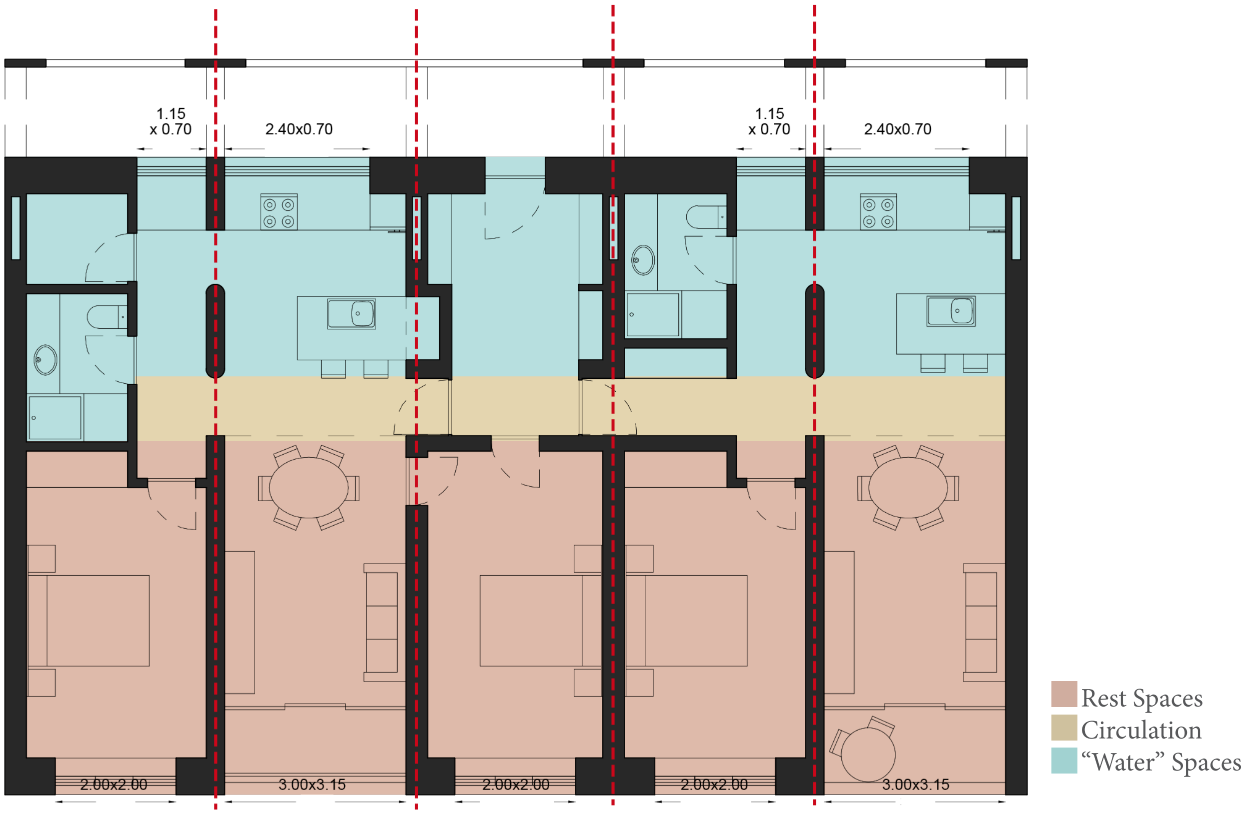
-The kitchen and the living room should be connected; the living room should have a direct contact with the outside through a balcony (as outside area was important for the Danish people enquired) and should have a continuous look (outside/inside) to make the apartment look bigger.

-There should be a clear separation between the private areas (bedroom and bathroom) and the common areas (living room and kitchen).

-The kitchen and the bathroom (the "water" spaces) should be in the colder parts of the apartment, meaning that they should be connected to the facades that receive less sun light (in block B this also meant that these were the places that were in direct contact with the galleries, which solved the problem of having rooms facing the galleries). While the bedroom and the living room should be facing the sun exposed facades, as these are the spaces where the users spend most of their time.

-The windows facing the south façade should be maximized to receive more heat and light from the outside while the openings facing the north facades should be minimized to allow the less possible heat exchanges with the outside.

Besides this, there is one independent room that can be acessed directly through the entry atriums that has the possibility to connect to the type 1 apartments to become an extra room (or office).



Ill.69 – Organization of the apartments

Ill.70 – Perspective of the galleries (top) and Atriums (bottom) and its materialization.

Regarding the materialization of the apartments, it is the same in both types and in both blocks. To be more succinct only a "type 1" apartment in Block B is going to be described, including the materialization of one entry atrium of Block B.

The use of neutral and light colors is associated with the Danish way of living. As the country has little sun light, the houses tend to use lighter colors to reflect the sunlight and give a sense of lightness compared to the outside. Natural materials, as wood and wools are also used frequently, to bring a sense of comfort to the houses. This information influenced the decision of what materials should be used inside the apartments.

The galleries floors and baseboards are equivalent to the inside atriums; however the difference is that on the inside of the atriums instead of using wood paneling on the top half of the walls (the baseboard begins by being 90 cm tall and then decreases to 50 cm to go along with the bench height), painted plaster is used. In the atrium niches, the CLT structure is exposed, and wood benches are used. Wood is associated with comfort; this principle will also be used on the inside of the apartments (Ill. 70).

On the inside of the apartment, the floors are continuous throughout the living room, kitchen, corridor, and storage room. Only changing in the bedroom and bathroom from linoleum to wood and ceramic tiles, respectively.

In the kitchen, the walls are of the same materiality as the atriums. With a 90 cm ceramic baseboard that gets the height from the kitchen counters, and the kitchen top creates a connection from the gallery baseboard, that "gets in" the apartment through the windows, and the kitchen baseboard. The top half of the walls are painted plaster, in a light color paint as the kitchen is on the least sun exposed side of the apartment.

The bottom kitchen cabinets are painted the same color as the baseboards, connecting the two, while the top kitchen cabinets are made of wood for the eye of the user to meet a warm surface when looking from the living room to the kitchen. A suspended ceiling is installed in the kitchen area and elongates itself to the rest of the apartment besides the bedroom and the living room. This suspended ceiling allows for a differentiation between the kitchen and the living room, it also allows for the needed infrastructures
to be hidden.

The living room walls and ceilings are exposed CLT this allows for the apartment users to have a direct connection with the building structure. It was decided to leave it bare in the living room, because, as previously said, wood is associated with comfort and places of rest and permanence. The living room connects directly to the balcony, there was an intention of having a continuous look from the inside of the living room to the outside balcony. This look is achieved through the flooring, not by using the same materials but using the same color on different materials (Ill.71).

Ill.71 – Materialization of an apartment. From gallery (left) to balcony (right).

Ill.72 – Perspective of the apartment seen from the living room to the kitchen.

The dividing wall (Ill. 72 - left) between the common and private spaces of the apartments is finished in plaster with the color of the outside brick. This choice was made to bring inside the apartment an exterior element and consequently it is the only "pop" of color in the apartment. The configuration of the tops of walls also reminisces on the fluidity of the public ground floor, with its rounded edges, it invites the user to have a more fluid experience around the dividing wall.

In the bedroom, the 90 cm baseboard is once again present, however it is in wood as well as the floors. This, once again, gives the user a sense of comfort when laying in their bed and walking around in the bedroom. The top half of the wall is painted plaster. There is a wood bench directly connected with the bottom of the window, offering a niche to the user inside of their own bedroom, with a connection to the outside.

The bathrooms walls and floors are finished in ceramic tiles. This connects with the use of ceramic in the more exposed (to water and/or damage) spaces of not only the apartment but as well as the galleries and atriums.

The apartments organization is mostly based on how it can optimize the overall thermal and acoustic experience of the space, while also making it a comfortable and place to live.

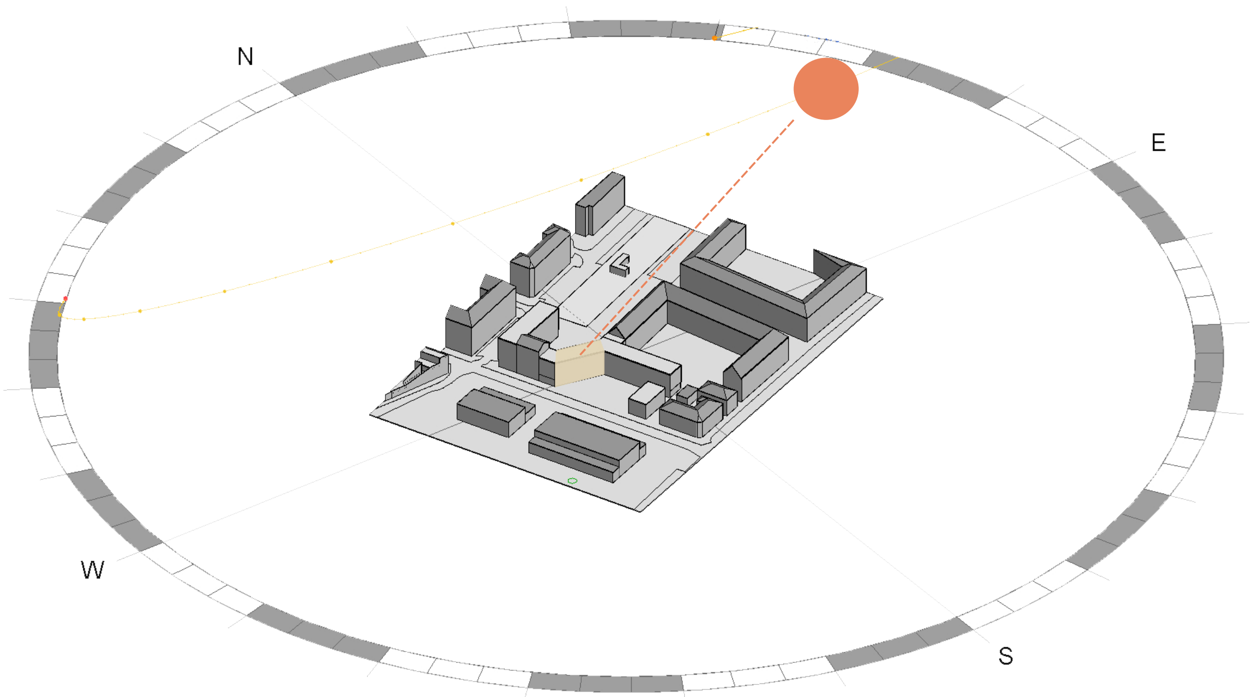
3.6 The Building Design for NZEB

When designing the complex, the design directives to design a NZEB building were always taken into consideration. Firstly, the building is optimized through passive strategies and then, some active strategies could be used to enhance the performance. Due to the climate of the city of Copenhagen (and country) the strategies were used mainly to address needs of heating the building complex.

3.6.1 Active and Passive Strategies

Orientation relating to climate

The preferred orientation when designing a good performance building would be North-South, to take advantage of the sun path. However, the site was orientated North-west – South-east and there were buildings that were already built, affecting the space. As mentioned, the solution was to rotate parts of the complex to face this direction (Ill.73), while the rest of the facades would respect the terrain and street layout. However, the terrain geometry allows for most of the complex to take advantage of the direct winds coming from east and west.



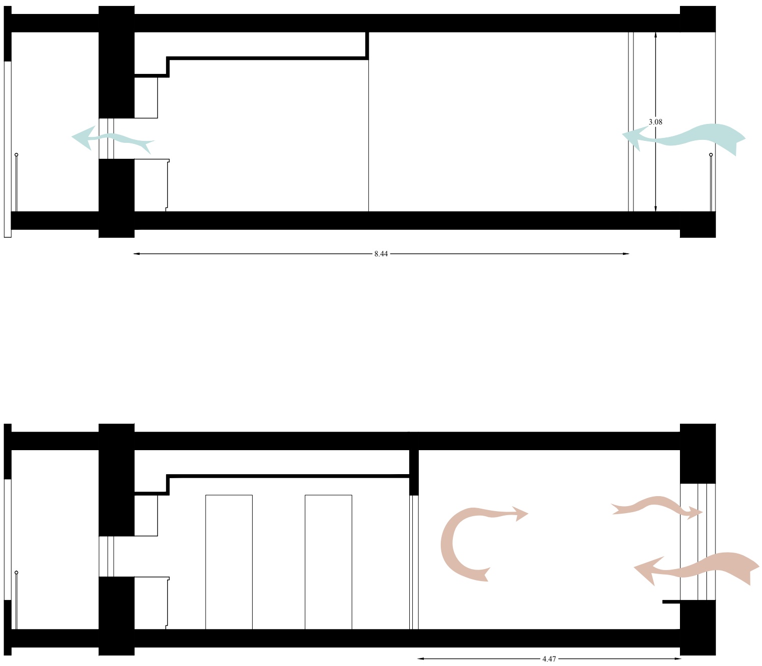
Ill. 73 – Rotation of the central block to face the exact direction of South.

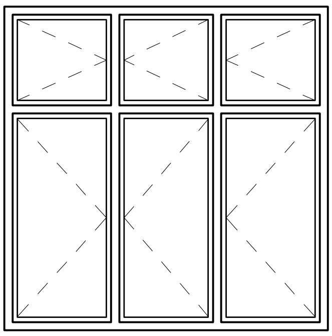
Natural Ventilation

It was assured that the rooms where most of the time would be spent (living room, kitchen, and bedroom) could have cross-ventilation and when this wasn't possible (when the door to the bedroom is closed) one sided-ventilation should be possible.

The unobstructed connection between the living room and kitchen allows for cross-ventilation, as the distance between the windows is less than five times the height of the spaces.

In the bedroom, when the door is closed, the one-sided ventilation is granted through the apportioned windows (Ill.74) used, so that the air could circulate through the room and have a different way out. The room is smaller than 6 meters to allow for one-sided ventilation. When the bedroom door is open, it can cross-ventilate with the corridor/kitchen windows (Ill.75).





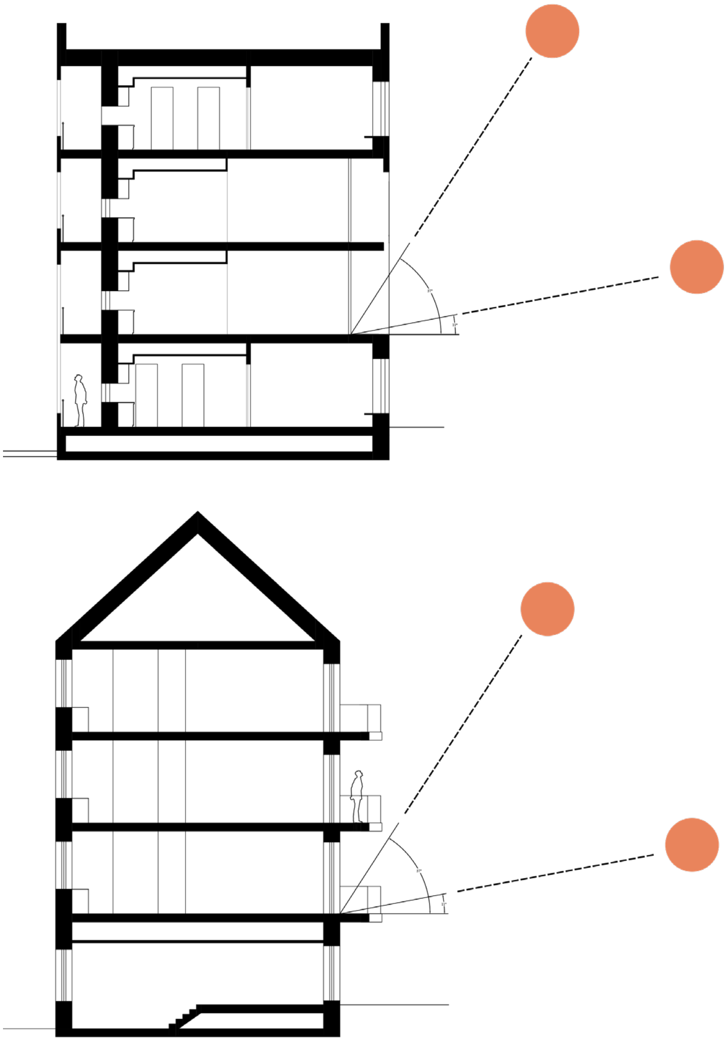
Ill.74- Apportined windows in bedroom.

Ill.75 – Cross-ventilation in the living room/kitchen (top); One sided ventilation in the bedroom.

Passive Solar

The orientation of the complex, the dimension and type of windows used contribute to control the passive solar (heating) gains the building has. It was necessary to maximize these gains in the winter minimizing them during the summer. This can be achieved through the positioning of the window in the envelope and balconies.

The dimension of the windows to the south were maximized to be almost the size of the wall. The curtains used should be of a translucid material to allow the daylight to penetrate but still give some privacy to the users.



Ill.76 – Balconies allow to receive the most amount of sun in block B (top) and block A (bottom). During the sun the sun's highest is 57ºC. During the winter the sun's lowest angle is 11ºC.

Thermal Optimized Envelope

This was determined by the structural and building systems used in the external walls, the roof, the ground-floor slab, and the windows/ doors used. The construction elements were chosen to respect the parameters required by the Danish Building Regulations (BR18) - "Building Class 2020".

It was also necessary to have a continuous layer of insulation throughout the whole complex to prevent any thermal bridges and maintain the indoor temperatures at a comfortable level.

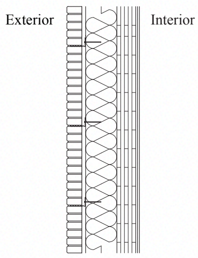
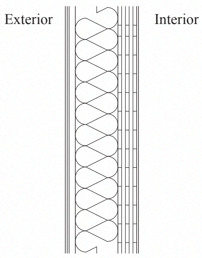
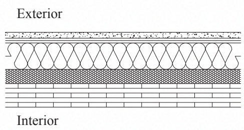
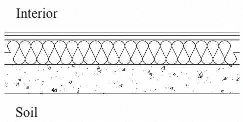
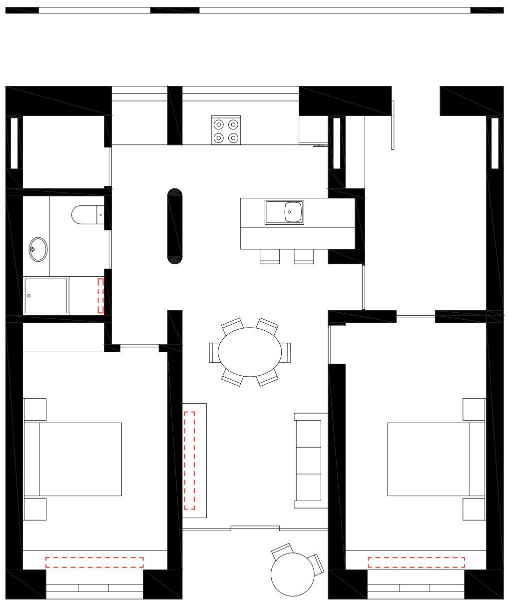
Construction Elements		Materiality	U-Value of the Element (W/m²K)	U-Value "Building Class2020" (W/m²K)
Brick Exterior Wall		Brick 12 cm Air Space 3 cm Wood Fiber Insulation 27cm CLT Panel 15 cm Plaster Cladding 1,5 cm	0,12	0,30
Wood Exterior Wall		Wood Cladding 1,5 cm Air Space 3 cm Wood Fiber Insulation 34 cm CLT Panel 15 cm Plaster Cladding 1,5 cm	0,11	0,30
Flat Roof		Paving Stone 3 cm Air Space 3 cm Hard Wood Fiber Insulation 6 cm Wood Fiber Insulation 16,5 cm Gravel 12 cm CLT Panel 20 cm	0,19	0,20
Ground-floor Slab		Linoleum Flooring 1,5 cm Plywood 1,5 cm Air Space 3 cm Hard Wood Fiber Insulation 6 cm Wood Fiber Insulation 14cm Concrete 30 cm	0,18	0,20
Triple Glazed Wood Windows		$U_g = 0,53$	0,80	0,80
Glazed Doors		$U_g = 0,53$	0,9	1,00

Table 3 – U-values of the elements chosen for the building envelope.

Active Strategies

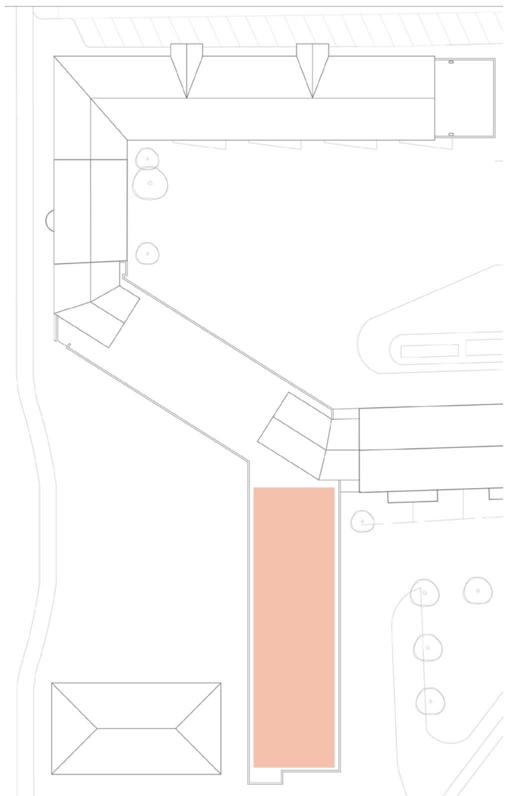
To heat the air and the water inside the apartments, an air--to-water heat pump system would be used. This system is powered by photovoltaic panels installed in the roof of the complex (72m2 of photovoltaic panels were estimated to be necessary to power the heat pumps in the complex), and then it heats up the rooms through radiators (Ill.77): The radiators were placed in the bedroom and in the living room the closest possible to the windows, as this is the coldest part of the room and can help counteract the possible drafts. In the bathroom, the radiators appear as a towel heater.



Ill.77 – Location of the radiators in the apartments.

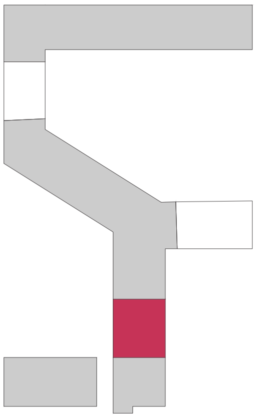
The hot water heated up by the heat pumps is stored in centralized boilers in the designated technical spaces on the ground-floor, that is then distributed to each apartment.

The electricity required to meet the needs of the building is produced through photovoltaic panels that are also located on the roof of the building. The space determined for both the solar and the photovoltaic panels is around 400m^2 (Ill.78). If the solar panels take up to 72 m^2, there is still around 380 m^2 that can be used to put up photovoltaic panels. This area can fit 160 panels (each module occupies 2m^2 and has an installed potential of 4.5kWP) and produces 749 645.90 kWP annually (Appendix VII) .



Ill.78 – Space on the flat roof for the solar and photovoltaic panels, around 400 m^2.

The photovoltaic panels and solar panels would be placed of the flat part of the roof so that they can be set to the most desirable angle (perpendicular to the sun), in Copenhagen it would be around 40º.



Ill.79 – Location of the two apartments the simulation was made.

To know how the building would behave with regards to its energy performance, a simulation was conducted in the software ArchiCAD. The process that shows how the simulation was made is in Appendix VII.

The evaluation was made in two apartments located on the ground floor of Block B, with a gross floor area of 161,91 m2. This was assumed to be the most critical part of the project because their orientation is not ideal (North-East to South-West) and on the South-West façade, they're overshadowed by Block C.

Key values of the evaluatio:

Buidling Shell Performance data - 1,56 ACH

Energy Consumption - 123,04 kWh/m2a

Primary Energy - 174,15 kWh/m2a

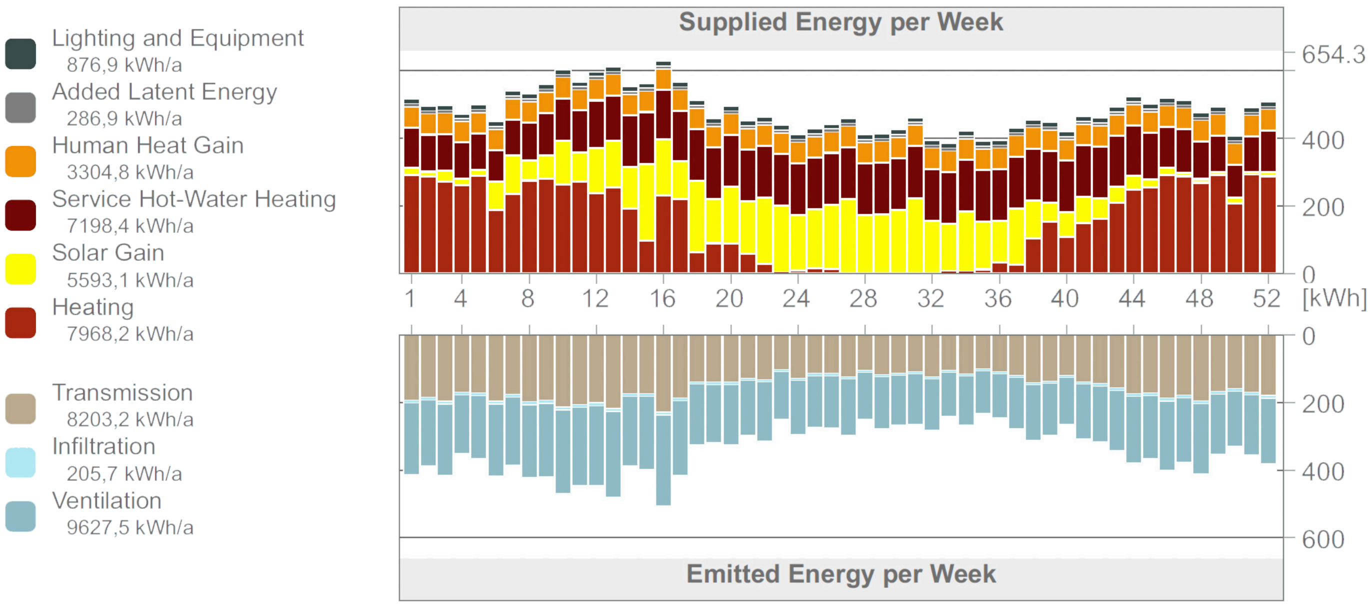


Table 4 – Thermic gains and losses along the 52 weeks of the year.

On top (Table 4), it is possible to observe that during the summer (week 20-36) there are more solar gains than during the winter (week 48-52 | week 1-5). During this time there are almost no solar gains, due to the shadowing of Block C and the orientation of this part of

Block B. The heat needed to warm the apartments goes up as there is little sun light to provide heat. On the bottom (Table 4), it is possible to conclude that there are almost no losses due to air infiltration. The transmission and ventilation losses are consistent throughout the year.

Energy Consumption by Targets

Target Name	Energy Quantity kWh/a	Energy Primary kWh/a	Energy Cost GBP/a	CO_2 Emission kg/a
Heating	7968	11274	0	317
Cooling	0	0	0	0
Service Hot-Water	7198	9220	0	194
Ventilation Fans	19	49	0	2
Lighting & Appliances	876	2192	0	126
Total:	**16063**	**22737**	**NA**	**640**

Table 5– Energy consumed by each type of system.

The heating and service hot-water are the systems that consume the most energy (Table 5).

In the table below (Table 6) it is possible to understand that 49% of energy consumed is for heating and 44% of energy consumed is for the heating of water. The main source of the energy consumed for heating comes from "External air" (free energy) due to the heat pump installed.

The energy needed to heat the water comes mostly form the PV panels and heat pump installed.

Only 5% of the energy consumed is for electricity.

In table 6 it is possible to observe that most of the CO2 emited is from heating.

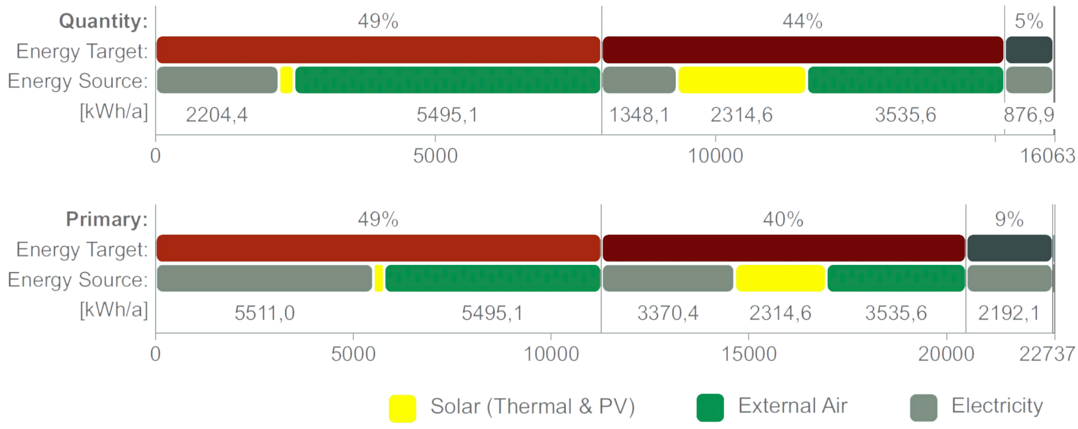


Table 6 – Energy consumption by targets.

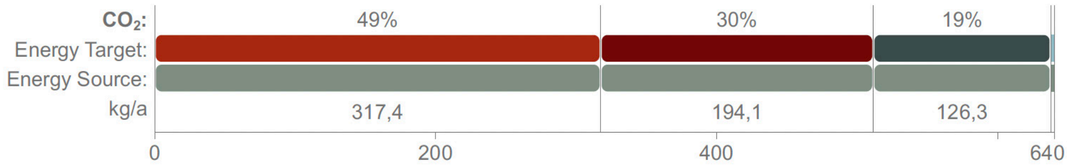


Table 6 – CO2 issued from the different systems.

Energy Consumption by Sources

Source Type	Source Name	Energy Quantity kWh/a	Energy Primary kWh/a	Energy Cost GBP/a	CO_2 Emission kg/a
Renewable	Solar (Thermal & PV)	2583	2583	NA	0
	External Air	9030	9030		0
Secondary	Electricity	4449	11123	--	640
	Total:	**16063**	**22737**	Not Applicable	**640**

Table 7 – Energy consumed by the each type of sources.

The majority of energy consumed by the building comes from renewable sources (16% + 56% = 72% - Table 8). The main source being “External air” - the heat pump (Table 7).

The “Primary table” it is possible to see that when the energy conversion factors are taken into account, only 50% of the energy consumed comes from renewable sources (Table 8).

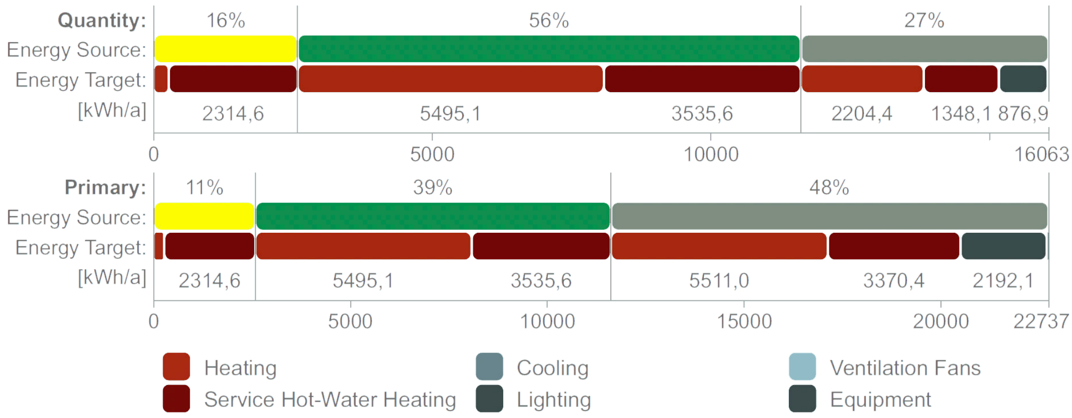


Table 8 – Energy consumption by sources.

To conclude, there is still some room for improvement with regards to the energy simulations.

However, it is important to reinforce that this is the situation in the most critical two apartments of the whole complex, meaning that the rest of the complex should have a better energy performance.

This energy simulation results combined with the PV potential calculations (It was calculated the electricity produced for the simulated area, and then generalized to the whole complex. The conclusion was that the electricity produced by the PV panels covers up to 94% of the building needs - Appendix VIII), allows to denominate the building as NZEB, as more than 90% of the energy needs of the whole building complex is covered by renewable sources.

4. FINAL CONSIDERATIONS

The aim of this project was to design a NZEB building in a consolidated city block in Copenhagen with a sensible approach to the NZEB buildings, focusing not only on the energy performance of building but also on the connection with the surrounding city. It can be concluded that the NZEB ambition of this project would be achieved mainly through passive strategies and complemented by some active strategies. The building complex is inserted within the city block through many architectural strategies, it responds to the needs of the site by having a "unusual" volumetric approach to the "traditional" city block, but without disrupting the reading of this part of the city of Copenhagen as its materiality and language allows for the connection between the two (the building complex and the surrounding city).

Throughout this process there were some things that didn't correspond to the initial methodology or objectives. Energy simulations were made, however, they were only made at the end and not during the whole design process and egarding two apartments (considered the most critical ones). The ideal was to simulate with the whole complex, but because of time management and program malfunctions, it couldn't be accomplished. The results could be improved. However, it is still possible to classify it as an NZEB building as it was always designed within the NZEB design methodologies (passive and active strategies) and the final simulations corroborate this affirmation . Besides this, all the elements that make the building are within the parameters defined in the Danish Building Regulations (that have NZEB parameters as a base line since 2020, encoded as the "Building Class of 2020").

The configuration of this complex and its language is an interpretation of the "typical perimeter block", even though the courtyards were "given" to the public realm, and it is possible to cross the building through the ground-floor. The façades that make up the shell of what would be the "typical perimeter block" are still very regular and closed off, while the inside of the courtyards has a more dynamic feel (with the balconies and gardens that allow for the connection between users). However, I think it could have been interesting to invest more time into having the parts of the complex that don't relate directly with the surroundings (the open courtyards), to be more contrasting with the parts that did need to dialogue with the surrounding buildings (the shell).

Even though the apartments combine the needs of the users with the design strategies of an NZEB I think it might have been interesting to have them organized in a less conventional way. This was something that I was aiming for in the beginning of the design process, but it got lost along the way, due to the fact that were so many influencing factors on the design of the apartments (the recommended area per unit, the type of users and the NZEB design strategies).

I think the volumetric configuration and organization of the budling complex is the strongest asset of the proposal. The ground-floor layout articulates different points of interest in the project, and the spaces created by the platforms have a possibility to bring life to a site where there is not a lot of activity but has a lot of potential. The overall organization of the building takes advantage of the spaces (gardens, connection to the existing garden, views to the street) of the site created by the ground-floor layout, while also allows for the connection between the surrounding buildings and the proposal. The inspiration that the proposal takes from the surrounding buildings allows for an easy reading of the whole complex and how it relates to the adjacent constructions (from the height differentiation to vertical distribution cores and street

alignments).
Overall, I think that the project was ambitious and there were a lot of things to take into consideration and choices of be made. I knew it wouldn't be an easy process specially because this was a big project, and I wasn't familiar with all the concepts or ways of designing and especially, working in Portugal for a site in Denmark. Even though this was not the first project experience in the area of NZEB (during my Erasmus the first semester was centered around this subject) there is a big difference in relation to a year and a half long solo project where there is not only a focus on designing a NZEB for the city, as well as designing with the city. Especially a city (Copenhagen) that is unfamiliar with a different language, ways of building and climate to where I have spent most of my life (Lisbon). Nonetheless, I think it was a very good learning opportunity and it fulfilled the expectations had when deciding this was the theme I wanted to explore.

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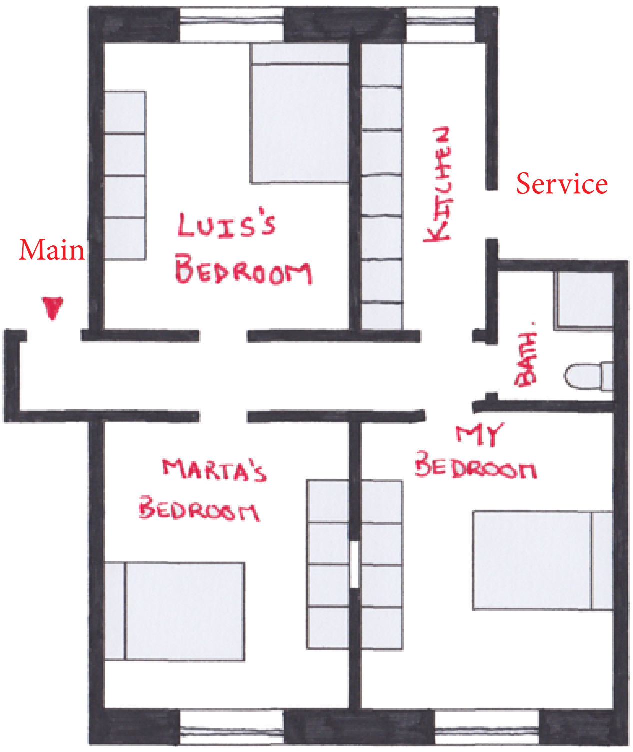
Appendixes

I lived in Aalborg, Denmark for about 10 months during my fourth year of university (2019/2020). I went there as an Erasmus student to complete only the first semester, but I ended up falling in love with the city, the people and the culture so I prolonged my stay for one more semester and even considered finishing my masters there (which ended up not happening but gave me the motivation to do my final master project in Denmark). For a while I considered doing the final project in Aalborg but ended up choosing Copenhagen as the location since Copenhagen is a much more defined city, meaning that the urban planning and typology of the city blocks is more evident than in Aalborg, that is now going through a big growth. So, this is my testimony as a person who lived a very happy year in Denmark.

I arrived in Aalborg on the 25th of August, and I had two surprises when I stepped foot out of the airplane, the first being how windy Denmark really is, which, after thinking about it made sense, as they are called "the country of winds" and are one of the worlds pioneers of wind power and the first country in the world to install an offshore wind farm. The second surprise was how hot and sunny it was. Even though I arrived in the middle of the summer I was not expecting temperatures of 27º-28º degrees, maybe because here in the south of Europe we are taught that the north is so very cold and cloudy, which it is but mostly in the winter or it can be due to the climate warming though, as I was told by the danish people I met. After this initial shock I had a big problem to solve; I still had no house for the next few months only, an Airbnb rented for the following seven days and the best Airbnb host ever, Esben, he had been helping us (me, my parents and my unknown Portuguese house mate, Luís, that I had just met through Facebook and was arriving in two days) searching for a house for the past week before arriving, has we had no luck in the previous months of searching (Aalborg is a university city with a lot of people moving in and out in the beginnings and ends of the semesters). So when we got there we had a visit to look at a house the next day that Esben had arranged us, but the house renter was not being very collaborative and we had to abandon that house, something to note, Danes can be mischievous. So now we had 5 days to find a house before my parents leave and Luís arriving the next day with no place to stay, which was solved, Esben let him stay with us without charging, Luís slept on the couch and no one knew each other. To understand how strange this whole

Esben's house

living situation was, here is a plan from Esbens house. When we got into the house there was a nook to leave the shoes and the coats at the door, then because the house had an open floor layout, it was possible to see pratically the whole house (besides the bedroom from the entrance point). My parents were sleeping the bedroom while I was sleeping in a air matress next to the kitchen table. When Luis arrived there was no other option then for him to sleep on the couch and share a small bathroom in a house full of strangers. Our quest to find a house started with the hopes of going to renting offices to see if we could find one. To our surprise, in Denmark this is an online task not a "talk to somebody face to face process", so it was a bit harder to get instant responses and plausible conversations. After two days of searching, Luís found a place for us to visit the next day, which left us only one day to make a decision, sign a lease and do the moving. So, on the 30th of August, we when to see a three bedroom apartment in the main pedestrian street of Aalborg, an amazing location and for our surprise at a very good price. We decided that we had no other options, it was the best decision to make, and we could even find a third person to share the house with making the price go down even more, the next day we signed the lease and moved



Our house

into an empty apartment which Esben furnished with things he had from his other house, for a very fair price. That was how we find our amazing home in Aalborg.

This house was very different from Esbens. Besides being more recent, it was also in a four-story building, the height of each floor was considerably higher then the height from Esbens building and it was definitely prepared to receive students as the renter had placed three big wardrobes in each room, leaving no space for a living room. Our house had a corridor circulation system, so when we got into the house we got directly into the corridor, with not a lot of space to put the shoes, (but we actually got used to leave them there anyway) even though we were two Portuguese and an Italian girl, (Marta, the girl that ended up renting the third room). Then at the end of the corridor there was the door to the bathroom, that had no ventilation at all and was always getting dusty event though we cleaned it every week, while along the corridor there were the doors to the rooms. On the opposite wall of the entrance door there was a the door to a Marta's room and after it the door to the assumed "living room" (my room). On the wall of the entrance door of the corridor, the first door was Luis room, and the second door was the corridor like kitchen. In the kitchen there was a door to a shared staircase that led to the private courtyard shared by three different buildings, but this staircase was actually out of use. My room and Marta's room had really big windows to the main street, which was always really quiet after 18:00 as stores had closed, besides Fridays and Saturdays because we lived 1 minute away from the "party street", and there were no cars allowed there. A combination between the big windows and an approximately six-meter width main street, meant I could see my front neighbours' houses, which I actually did not mind. It was pretty entertaining and I would sometimes speculate what was their living situation. This also happens because they do not really use curtains (besides the bedrooms), to enjoy most of the daylight possible during the Winter as they have very short and dark days and the curtains/ blinds they use are not opaque at all, so they only use them for privacy purposes. Our house had gas heating in all of the rooms and the ventilation was only assured through the windows, so even in the winter we had to open parts of the windows (they were sectioned so that different parts of the window could be open for different purposes. In the winter we only opened the higher little windows and during the

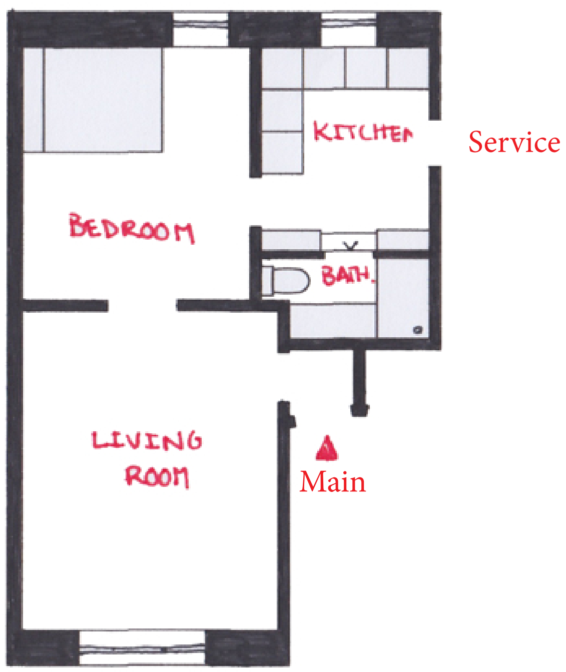
The window in my bedroom,
for comparison Diogo is 1,78m

warmer days we would open all of the windows). After finding our little home in Denmark, we were now ready to discover its culture. The first big step to mix with the Danes was getting a bike. The bike culture is something that is very present in everyone's life, it is rare to meet someone who doesn't own one. Every road has bike lanes in each direction, there are traffic lights for bikes, bikes are compared to cars, the pedestrian streets even have schedules for bikes (normally from 21:00-8:00, during the night) so you had to get out of the bike and take it by the hand to go through the pedestrian streets and you could get fines for the exact same reasons you could get fined when using a car. I remember the first time I really felt part of the city was when I was riding my bike home from the main university campus and I found myself in a queue of 5 or

6 people all riding their bikes. A place to leave your bike safety is pretty essential in the streets of Denmark and the places that exist in the centre are normally overloaded. The bikes, normally, have their own lock system in the back tire so that you don't have to carry a lock and attach it to other things. Yes they can be easy to steal but it doesn't happen very often, danish people are very trustworthy. That is very easily observed when you walked through the street we lived in. There were stores on the ground floor of almost all the buildings in our street and all the stores had things on display outside of the store, very easy to take but no one took them. With the use of a bike comes comfort, besides using very comfortable shoes everywhere, comfort is present in their space of work, which made total sense to me. We are spending almost all of our day at university, so we should get comfortable there. Running around with only socks on was something seen every day at university and at libraries, they even bring their own coffee makers to their workspace. The fact that the indoor spaces are really warm in the winter time is probably the best factor that contributes to the comfort of the work space, as well as the living space. Even in very big open spaces, such as the architecture faculty, they are able to obtain the thermal comfort. I used to only dress a light long sleeve and a big warm jacket every day, so that I wouldn't be to hot inside and cold outside, the envelope of the building playing a huge factor in the thermal comfort.

Something that really stood out to me and taught me a lot while living there, was the importance they gave to personal time, they have their work life and their life outside of it, most people work from 8:00-16:00 whit a short lunch break around 12:00 and when they said 16:00, it is 16:00, no less and no more (besides exam time). What you do before and after work it is up to you, so most people have hobbies, exercise, or do both. The best example of an "extreme Danish person" I know is my friend Anne, she woke up at 5:00 went for a 10km run or to the gym before going to university ate lunch around11:00, left at 16:00, ate dinner around 17:00, worked on her drawings and paintings, drank a tea around 21:00 and was most definitely in bed at 22:00. The schedules change a lot when it gets to the weekend. Danes are party people, at 14:00 on a Friday, a lot of people are out of the office to start their weekend and meet their friends. This phenomenon can be best observed on a sunny Friday. If the sun is out danish people are out in the parks playing games and enjoying their time with friends and family.

I got to know Anne's house and her house was different from mine and Esbens (it is worth to notice that Danes leave their parents' house around



Anne's house

18 years old).

Her house was a small one-bedroom apartment near the train station. The buildings there are higher, around five-stories with apartments in the basements

that had windows to the street. When you entered her house you had a little place to put your shoes and jackets and would enter straight into the living room, there was a double door to the right connecting it to the bedroom,
from the bedroom you had a door also to your right to the kitchen, which also had a connecting door to an out of service stair case that led to the courtyard, and lastly, when entering the kitchen there were two steps and a door to your right leading up to the bathroom. Something that I should refer is that my house was the only house of the three that a place to wash our clothes because the owner placed a washing/drying machine in our kitchen. Otherwise, self-service laundry places are very common around Aalborg and I assume in all of the danish cities.

During lockdown (March 2020) I got to know another house really well that showed me how young danish people live in a community. My other Portuguese friend, Diogo, lived in a student residence about 20 min away from the city centre, so the bicycle ride there was our daily trip to get fresh air and then we could just hang out with a small group of people living at the residence. This resident was part of a student housing complex that was made of 4 buildings that looked the same and were grouped into groups of two that were connected through a staircase. There were 12 rooms and one kitchen within each building floor and each building had two floors. The students were of various ages and were almost all danish, with about two rooms for international students in each floor. How the system there worked, was that every week one of the students living there was responsible for cleaning the kitchen and the corridor, they also had to take the trash out, but every person had to clean their dishes and put them away every day. Then there was one person responsible for the overall organization of the kitchen and other one responsible for buying the common items that everyone could use in the kitchen (like paper towels, salt, ...) and then there was a person that supervised every kitchen so that people would not slack out. Besides this, every now and then they had deep cleaning days, where everyone would have their own chore. Each group of buildings had their own laundry space and bicycle storage in the basement, that was when I discovered that danish people also air dry their clothes besides the cold and rain. They air dried it in the basement, where there was little windows on the top of the wall to the outside. Then, connecting these two groups of two buildings was an outside green space where they had a volleyball net and a space for fire pits, which is something they use a lot when spring and summer comes around (I would say almost Friday or Saturdays, and then they would just hang around the fire). They also had an indoor common space, with a gym, a music room and a space for parties, where they were also responsible for cleaning every now and then. Danish people really like to hangout, so this space had a lot of use to them. The bedrooms of the residence had a very simple layout, they were basically a rectangle that could fit a single bed, a desk and two deceant sized dressers. The rooms had their individual bathroom.

This was a resume of my experience in Denmark, the things that stood out to me and the houses I got to know while living there. It was a country that really surprised me in a very positive way, people are very happy there and just smile at you for no reason in the middle of the street, I just felt very well received and at home and that is one of the motives why I felt drawn to make my final master project in the country that taught me a lot of things.

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Sundholmtvej 57


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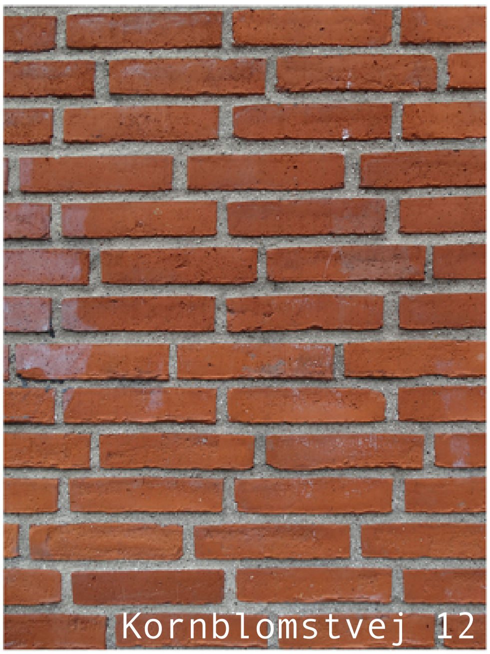
Kornblomstvej 12

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-It is located in a very calm zone, it is even possible to hear birds singing. Which is a big difference from the main street of the Amager district (Amagerbrogade) which is only a 5 minute walk away, because all of the stores and bussiness are located there;

-It is a completetly residential area, there is almost no one walking, cycling or driving through Sundholmsvej (which can be a little contradictory from the sound analysis available);

-Even though there is almost no movement in the area, it still feels like a very safe area to walk around, with no sense of emergency to get anywhere or to be seen by someone;

-The terrain feels like it is situated in a frontier between an older part (Amager Øst) and a new part of the city (The university campus, located in Amager Vest), this can also be seen in the morphology of the buildings sorrounding the terrain;

-The garden located near the terrain has an abandoned look and it is not used by the residents of the area. It would be nice to bring some movement to it. However, there is a parking ramp and a storage shed that create a bit of a "thrench" feeling between this garden and the terrain;

-It is also possible to see that there are some bycicle parking spots missing in the building adjacent to the terrain (Kornblomstvej 12), so that the bycicles don't end up being pilled next to the windows and entry doors of the building.

-The building that stands alone in the site (Sundholmsvej 57) has a different "feeling" than the rest of the buildings that sorround the area. It's expression is richer and it's more detailed than the rest of the older buildings.

This questionnaire was made in March of 2020. Eight people answer it and it was made through the Google Docs questionnaire form.

YOUR UP BRINGING HOUSE

How many people lived in your house?

- 3 - 25%
- 4 - 75,5%
- 5 - 12,5%

How did the circulation of your house worked?

- Distributed through a corridor -25%
- The rooms were connected to an open space -37,5%
- Circulation between rooms -12,5%
- Two story home, rooms up top, living room and kitchen down-stairs -25%

Where did you spend most of your time when you were at home?

- Living room -37,5%
- Bedroom -37,5%
- A mixture between the both -25%

Where did you study?

- Bedroom -62,5%
- At the dining Table -12,5%
- A mixture between both -25%

Where was the washing machine?

- Kitchen -12,5%
- Bathroom -25%
- Separate room/building -37,5%
- Hallway -12,5%
- In the basement -12,5%

Did you had a destined place to leave your shoes at the entrance of your home?

- Yes -87,5%

No, but left the shoes at the door -12,5%

What is something you valued in your house?

-The living room is viewed as a main space for the family to hangout and it is a very valued space.

<u>YOUR LIVING HABITS</u>

At what time did you leave the house during the school days?

Between 7:00-7:30 -62,5%

Between 7:30-7:50 -37,5%

Did you had any activities before or after school?

Yes -75%

No -25%

At what time did you arrived home?

15:00-15:50 -50%

16:00-16:30 -37,5%

17:30 -12,5%

At what age did you leave the house you grew up in?

18 -50%

19 -37,5%

21 -12,5%

How did you use to get around the city?

Bike -62,5%

Public Transportation -37,5%

If your household had a car how many cars did it had?

1 -33,3%

2 -50%

3-16,7

Something I should know about the danish way of living:

-Danish people are very punctual;

-They leave the house early (age), the earlier they leave the house the more monetary help they receive from the government (SU);

-Independent but really like to spend time with family and friends, in the winters and rainy days inside (play a lot of board games), in the summers they spend a lot of time outside.

How would you describe the relationship between danish people and their home?

-It is possible to identify two main themes through the answers given. Danish people like to make their house comfortable and personal and they also chose their houses because of the life style it can bring to the family.

LIVING PREFERENCES

Is a closed space, private to the building to park your bike an important feature?

Yes -25%

Yes, but only if it has access to the outside -37,5%

No -37,5%

Would you prefer to have a laundry room common to the apartment building or have it in your private home?

Common to the apartment -37,5%

Private home -12,5%

It doesn't matter -50%

Is it having a gym facility in the apartment a valuable thing to you?

Yes -12,5%

No -25%

It doesn't matter -62,5%

Would you like to have a common space to the apartment building for the neighbours to meet?

Yes -100%

No -0%

Maybe -0%

What would you value the most in a house:

A spacious bedroom:
- I wouldn't mind -37,5%
- I could live without it -62,5%

A spacious living room:
- Essential -62,5%
- I wouldn't mind -25%
- I could live without it -12,5%

A spacious kitchen:
- I wouldn't mind -87,5%
- I could live without it -12,5%

An open space layout:
- Essential -25%
- I wouldn't mind -50%
- I could live without it -25%

An office room:
- Essential -12,5%
- I wouldn't mind -37,5%
- I could live without it -50%

A place to wash your clothes:
- I wouldn't mind -87,5%
- I could live without it -12,5%

What would you value the most in a possible living place?

A sense of community:
- Essential -37,5%
- I wouldn't mind -50%

A sense of safety:
- Essential -62,5%
- I wouldn't mind -37,5%

Closeness to the supermarket:
I wouldn't mind -100%

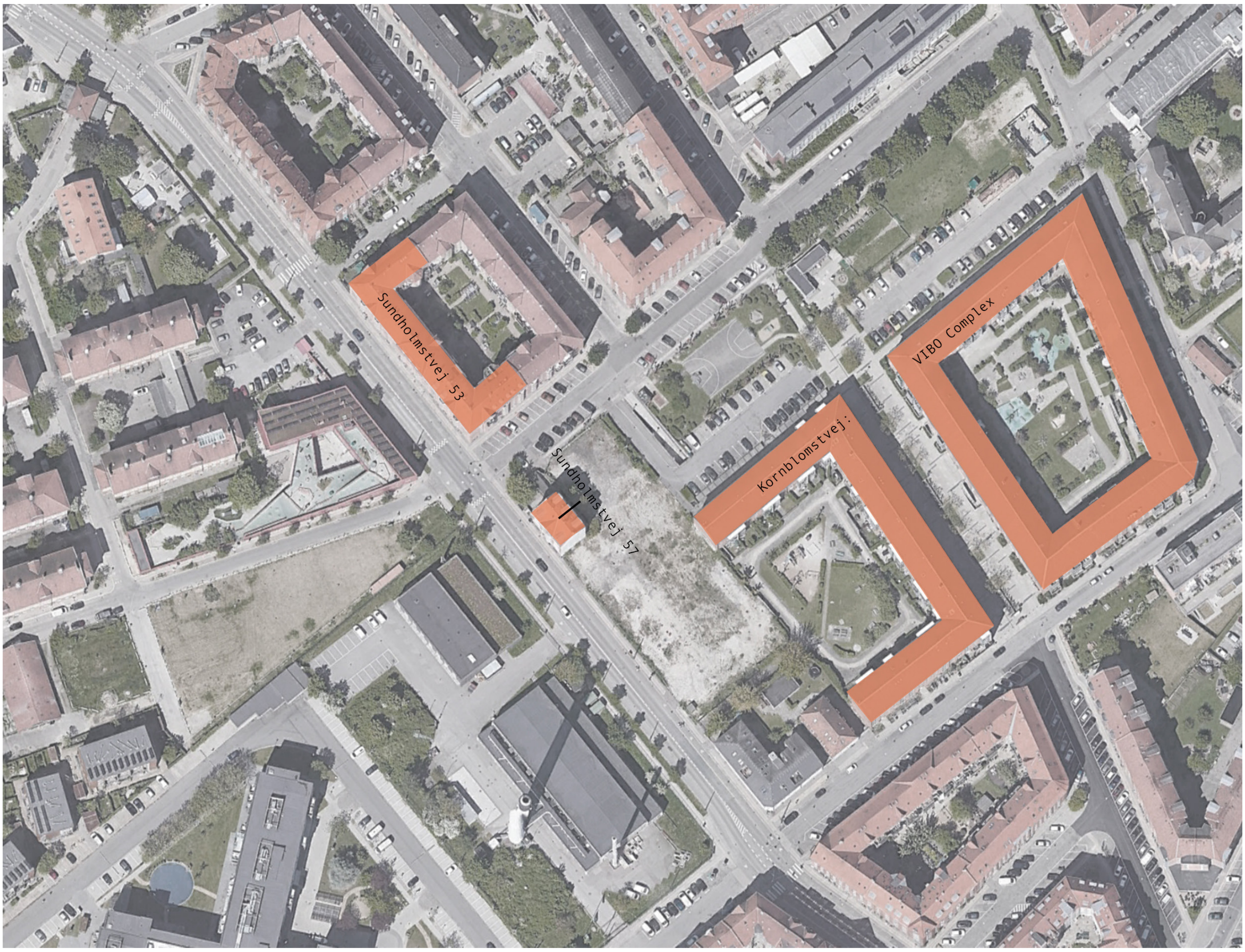
Closeness to public transportation:
Essential -12,5%
I wouldn't mind -87,5

Private outside space:
I wouldn't mind -87,5%
I could live without it -12,5%

Public outside space:
Essential -25%
I wouldn't mind -75%

Is there something specific you would like to have in your future home?

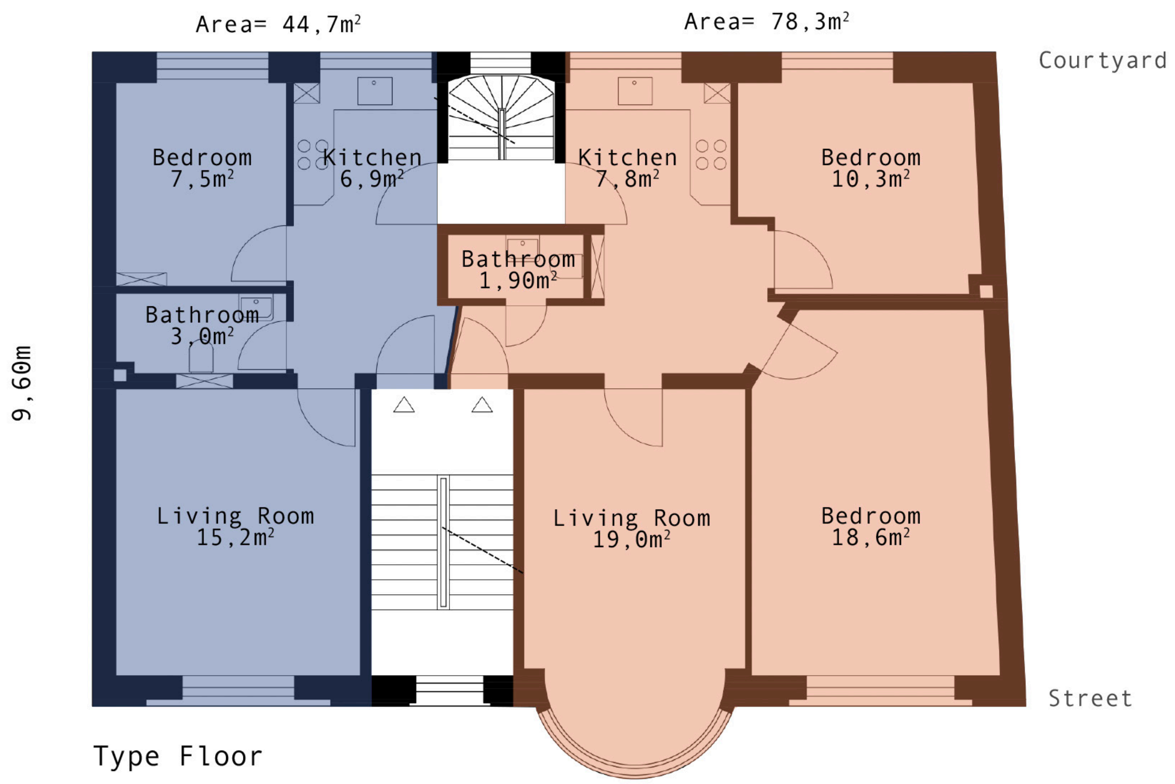
-Space to have friends over and host parties
-Balcony/ Sun room



To know the most common areas and layouts for a building in the area of study, a analysis of the sorrounding buildings was conducted. In this analysis, three different buidlings will be looked at, the areas of each compartiment and how the bulding functions will be discussed. The information was taken from the Dingeo website, a danish website where it is possible to obtain all the information about a certain plot.

The buildings that were analyzed were: Sundholmstvej 53, Sundhomlstvej 57 and Kornblomstvej - The VIBO Complex

Sundholmsvej 57



Sundholmsvej 57 is a six-storey housing building from 1907 that as underwent a renovation in 2012.

There are two apartments on each floor except on the loft where there is only one apartment. these apartments all consist of T1 and T2 apartments. The apartments are acessed though the staircase that organizes them through a left-right scheme. This also happens on the ground-floor, where the privacy to the street is achieve through a different to the street level of the floor of three steps and there is no obvious moment of entrance to the building as the staircase occupies the whole entrance.

Inside the apartments, there isn't a obvious distributive element, like a corridor. Instead all of the rooms have direct acess to the kitchen that connects to a service staircase that leads not only to the back outside part of building but also, it is the only way to access the underground floor. The bigger rooms of the houses are on the front facade facing the main street, while the kitchen and the smaller rooms face the back facade while the small bathrooms have no windows to the outside.

Kornblomstvej (Two apartments sample)

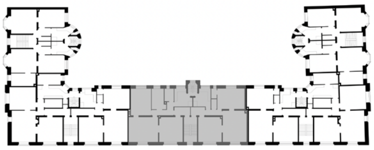
Half of the two building complex

Kornblomstvej is five-storey building that is part of VIBO (a non profit housing company) this project that was built in 1982, is a two complex building, each with an interior courtyard.

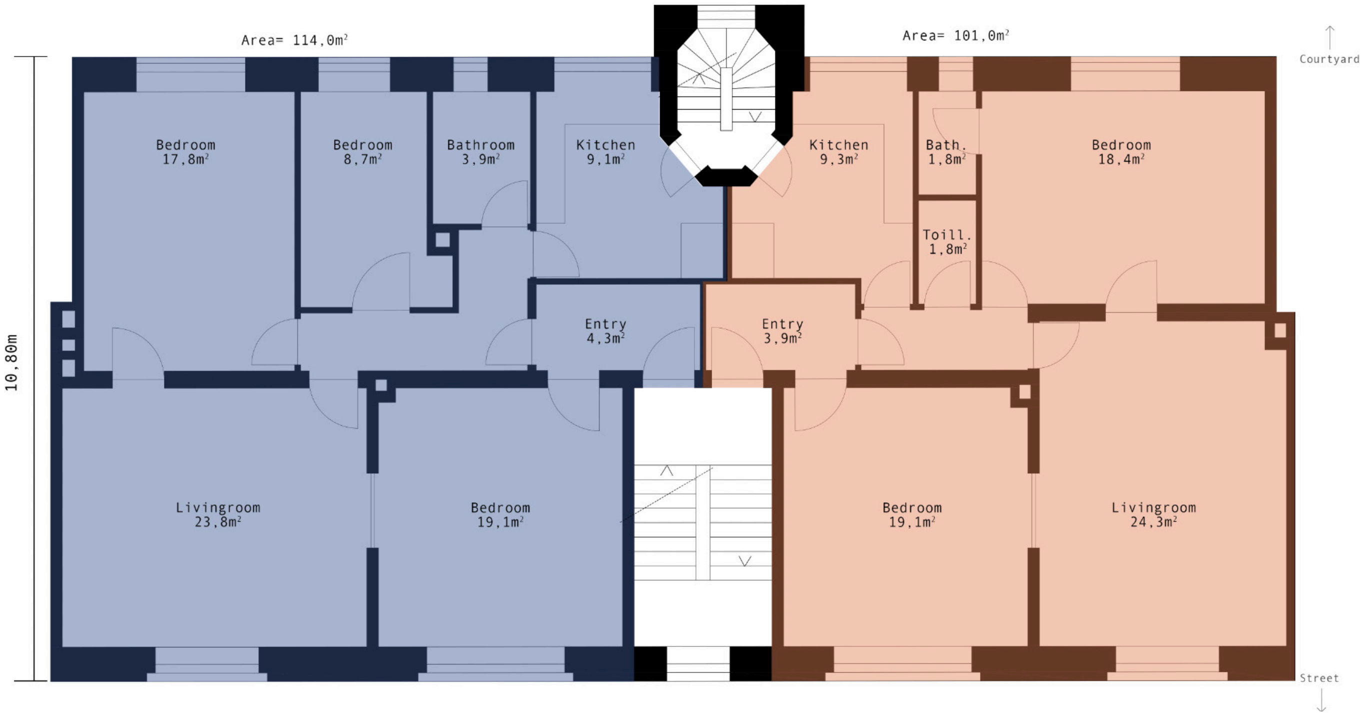
Much like Sundhomlsvej 57, this building is also organized though a "left-right" scheme, with each staircase serving two apartments, except on the corners of the building, where the staircase leads to three different apartments. Almost all of the apartments are T2's with the occasional T1's and T3's on the corners of the buildings.
Once more, the ground floor also consists of housing, however there is no height difference of the floor and every apartment (on the ground-loor) as a direct connection with a small private space for each apartment on the inside of the courtyard. The main difference to Sundholmsvejon on the organization of the building is the fact that exists a moment of entrance separated from the staircase.

Inside the apartments, all of the rooms connect to an entry hallway. Besides this there is also a connection between the living rooms and the adjacent rooms (kitchen or bedroom) . In this case, the bigger rooms of the house connect to the inside of the courtyard, while the smaller rooms are connected to the outside of the block.

Sundholmsvej 53 (Two apartments sample)



Building



Sundholmsvej 53 is a six-storey building built in 1915. It is one half of two building complexes that make up a closed block with an inner courtyard.

Once more, the staircase serves two apartments in each floor, with a “left-right”scheme organization. There are three different types of houses in this building, T1’s, located on the “upper legs” as it can be seen in the miniature and T2’s and T3’s, that make up the rest of the houses in the building. The ground floor is also housing, with the same technique of elevating the floor to give it more privacy. There is also no“moment of entrance” in the building, with the staircase occupying the whole space.

The apartments have an entry space that leads to a corridor where all the rooms are connected to, there is also a passage way between the living room and the room adjacent to it. The bigger rooms are located on the main facade, while the smaller rooms and kitchen connect to the inside of the courtyard. The kitchen connects to a service staircase that also connect to the inside of the courtyard.

To understand better the types of apartments and the areas corresponding to each type of compartment and apartment typology, a table of areas was made.

	Sundholmsvej 57		Kornblomstvej			Sundholmsvej 53		
	T1	T2	T1	T2	T3	T1	T2	T3
Entry Space/Corridor	2,3	4,7	10,1	9,7	7,3	4,2	7	9,9
Living Room	15,2	19	18,9	18,2	19,8	21,2	24,3	24
Kitchen	6,9	7,8	12,4	10,7	10,5	8	9,3	11,1
Bedroom	7,5	14,45	4,2	10,8	9,5	15,5	18,8	15,8
Bathroom	3	1,9	9,6	4,3	4	1,7	3,6	4,7
Total Area	44,7	78,3	64,7	77,3	90,5	65,8	101	116

	T1	T2	T3
Average Area	58,4	85,5	103,2

Quantity	Sundholmsvej 57	Kornblomstvej (Whole Block)	Sundholmsvej 53	Total
T1	10 (50%)	114 (~40%)	12 (20%)	136 (38%)
T2	10 (50%)	119 (~40%)	30 (50%)	159 (44%)
T3	0	45 (~20%)	18 (30%)	63 (18%)

-The areas of each typology vary through the buildings:

T1 go from 44,7 m2 to 65,8 m2;

T2 go from 77,3 m2 to 101 m2;

T3 go from 90,5 m2 to 116 m2.

-Most of the houses are T2 and T3 which means that, even though this is a school area, there isn't a lot of big families living here/wanting to buy a house around the area, or maybe there is lack of offer.

It is now possible to conclude that :

-All of the buildings are organized through a "left-right" scheme;

-The smaller rooms are always located to where it seems to be the least important view of the apartments. In the Sundholmsvej buildings being the back of the building/inside of the courtyard and, on the Kornblomstvej the view to the street;

-Housing on the ground-floor is very common in the area;

-Each house is connected to both facades of the building, allowing for cross ventilation and access to more daylight, as most of the houses studied are part of "Perimeter Blocks".

-The distribution inside the apartments varies: circulation through space (kitchen); circulation trough atriums; circulation through atrium + corridor.

To meet the goals of the city, the Copenhagen commune worked in collaboration ELF Ejendomme A/S to elaborate a plan for the Sundholmsvej 59 plot. The plan consists of a housing building mixed with public-oriented services. The plan has as an objective to complete the block structure existing along Sundholmsvej with Kornblomstvej and tie the existing buildings.

Local Proposal for the Site

The plan is to design a building with approximately 7,900m^2. Of them, 3,000m^2 is designated to correspond to public housing for the public housing association VIBO and 175m^2 correspond to public-oriented services. Along with the construction of the new building, it is also required to upgrade and reorganize the road area (sidewalks, road conditions). On the ground floor, the VIBO association (in collaboration with the city of Copenhagen) intends to build a playground of 340m^2. The new construction must assure that the visual and physical connection between the streets and the courtyard.

Regarding parking, 175 m^2 corresponds to the area designated for parking cars and the parking is located underground. For bicycles it is determined that 100m^2 should be used for parking them., 50% of those places must be located on the terrain, while 50% of those places should be in the ground-floor to ensure accessible and safe bicycle parking.

The expression and location of the new construction derives from its surroundings, the main purpose is to complete the existing residential building on Sundholmsvej, the height of the building should be the same as the existing one, with the saddle roof having the same dimension and inclination, the use of brownish-red brick is used to give a continuous look to the block.

The only place of the building where the height is different is when it connects to the VIBO's residential complex, where the height of the new building corresponds to the height of the sloping boundary plane.

My considerations

Regarding the brief, I believe that there should be more area dedicated to services/ public-orientated, as it would be an opportunity to bring a different dynamic to the area. These services should communicate with the courtyard, greenspaces, and playground, while creating new job opportunities for the people living in the area. There should also be some type of acknoledgemnt of the existing bus stop, this could be an opportunity to relate to the "lack of life" and activitie the area has. On the other hand, I agree with having a **visual and physical communication between the outside and the inside of the courtyard** and with the main intention of giving a **continuous look to the residential block that the existing Sundholmsvej 57 asks for.** However, I do think it is a lost opportunity to not resolve the existing blank façade of the VIBO's residential complex that is directly connected to the terrain

Regarding the car parking situation, I believe the access proposed by the local plan is not the most rational as there is an existing access to the underground floor near the terrain, which in my opinion, is also not the best solution for the underground access, so a new entrance to the underground park should be proposed on another part of the unused adjacent garden. The bicycle parking takes a lot of space and I believe it could be solved in a different way.

Finally, I do believe the look of a continuous expression between the new building and the existing ones should be preserved, as it will bring a consistent look to the neighborhood.

As previsouly stated, there was an area reserved to install photovoltaic panels on the flat roof of block B. This area was around 320 $m^{2,}$ which makes it possible to install 160 panels, as each panel occupies $2m^2$ and has an installed potential of 4.5kWP. To calculate how much energy would be produced by the photovoltaic panels, the Photovoltaic Geographic Information System tool (PV-GIS: https://re.jrc.ec.europa.eu/pvg_tools/en/) was used.

In the system, it was only necessary to input:

- The location: Copenhagen, Denmark;
- The installed peak PV power (kWP): which is the result of the amount of panels by the installed potential = 160 x 4.5 kWP = 720 kWP;
- To define the mounting position: Free-standing;
- The slope: 40º

The result was an yearly PV energy production of 749 654 ,89 kWP.

European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

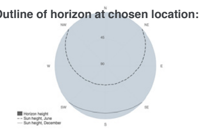
Provided inputs:

Latitude/Longitude:	55.660,12.600
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	720 kWp
System loss:	14 %

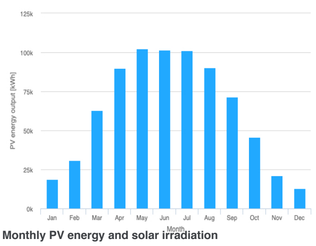
Simulation outputs

Slope angle:	40 °
Azimuth angle:	0 °
Yearly PV energy production:	749645.89 kWh
Yearly in-plane irradiation:	1253.69 kWh/m²
Year-to-year variability:	29532.28 kWh
Changes in output due to:	
Angle of incidence:	-2.96 %
Spectral effects:	1.39 %
Temperature and low irradiance:	-1.85 %
Total loss:	-16.95 %

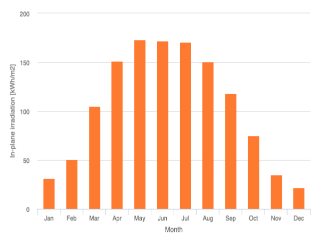
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	18869.0	31.2	4394.0
February	30869.9	50.5	6552.2
March	62992.8	104.8	10045.8
April	89957.2	151.1	14523.7
May	102527.4	173.1	12675.3
June	101688.3	171.7	7758.6
July	101146.0	170.4	13829.1
August	90331.3	150.8	7519.5
September	71589.9	118.3	8013.7
October	45808.3	74.8	8850.7
November	21118.6	34.8	4924.4
December	12747.3	22.1	2847.2

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Report generated on 2022/09/15

However, this result was related to the energy produced for the entire building complex. To understand what this result meant, it was necessary to related it to the the energy simulation (made in Appendix VIII) to see if the energy produced would cover the electricity needs of the simulated apartments and, in consequence the overall electricity needs of the whole complex.

Data

Yearly PV energy production (kWP) = 749 645, 89 kWP

Total area of the complex (m^2) = 6 434,20 m^2

Gross area simulated (m^2) = 161, 91 m^2

Energy consumption by square meter (kWP/m^2a) = 123, 04 kWP/m^2a
(according to the energy simulation report made in Appendix VIII)

Calculations

Energy consumed by the simulated area:
Gross area simulated x Energy consumption by square meter = 19 921, 40 kWP

Energy produced for the simulated area:

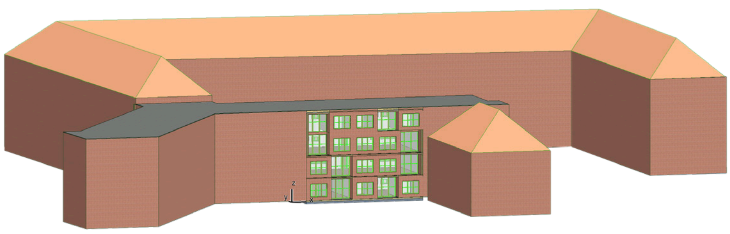
$$\frac{\text{Gross area simulated} \times \text{Yearly PV energy production}}{\text{Total area of the complex}} =$$

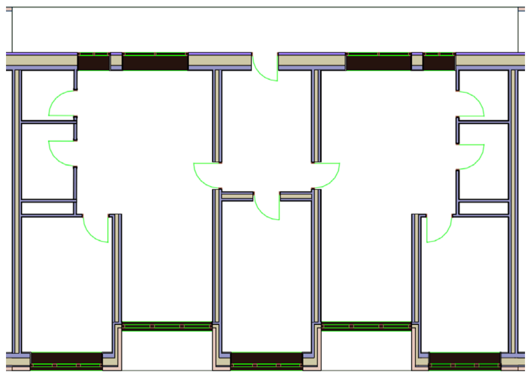
$$= \frac{161{,}91 \times 749\,645{,}89}{6\,434{,}20} = 18\,864{,}06\ kWP$$

This means that the energy produced by the PV panels covers up to 94% of the energy needs of the simulated area and, as it can be assumed, 94% of the electricity needed for the whole complex, with the rest of the electricity needs being covered by the connection to the district net.

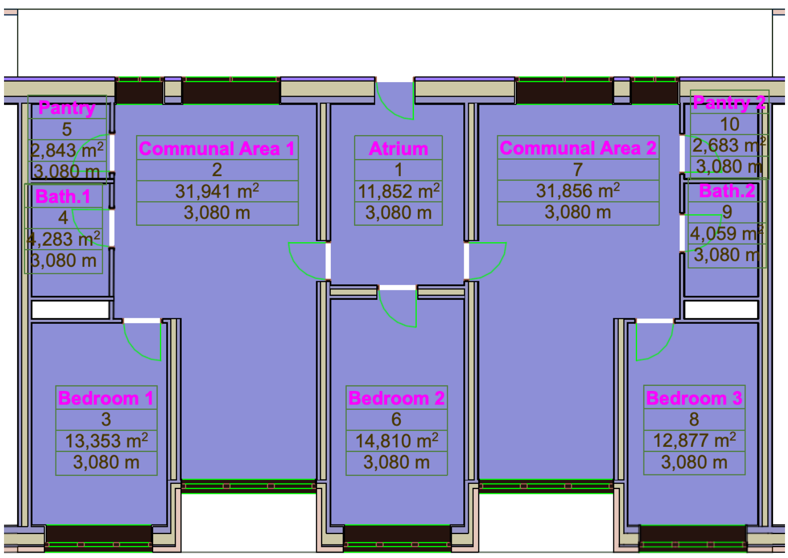
As previously said, the simulation in ArchiCAD, was made on two apartments located in Block B. These two apartments were considered the most critical apartments in the whole complex, because of their orientation (North-East to South-West) and the adjacent building (Block C) overshadowing.

To perform the energy simulation in these two apartments, it was first needed to model the interior and exterior of the apartments as well as the sorrounding buildings. All of the geometries were simplified to avoid geometry problems in the program. The buildign elements (walls, slabs, doors and windows) were also defined according to the intended design (constructive system and energy performance).

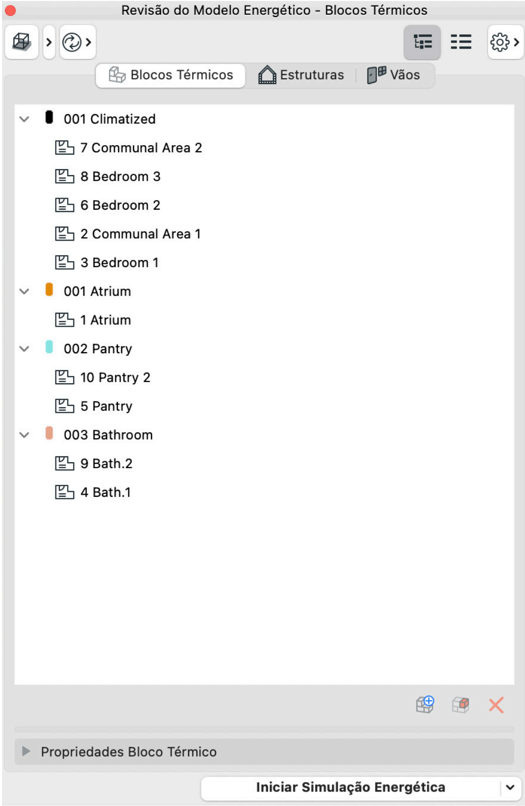




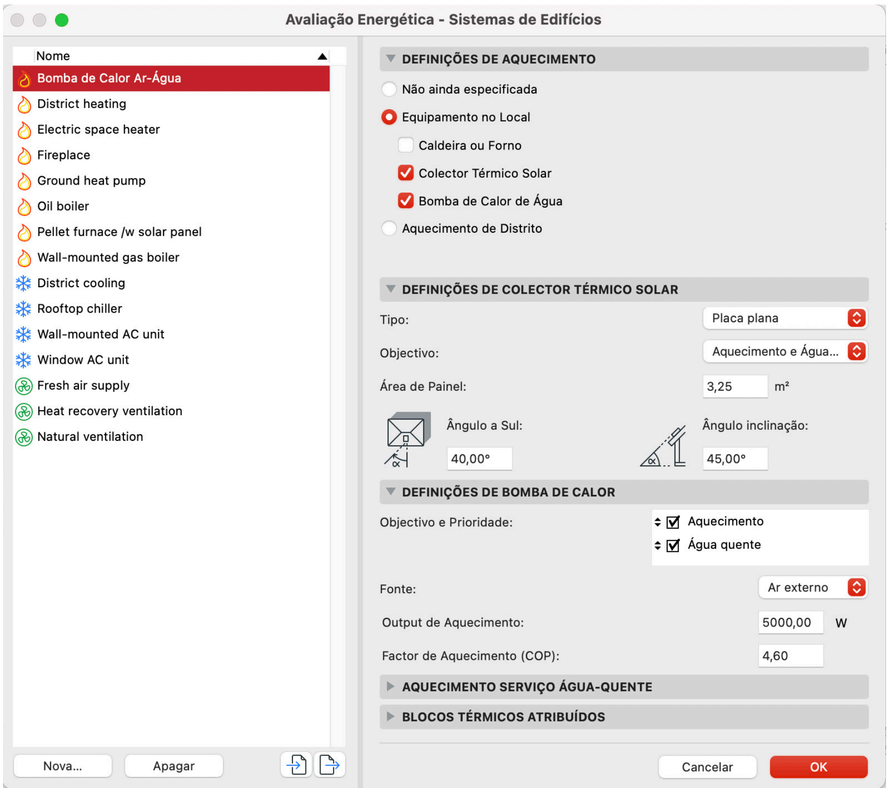
Afterwards, it was necessary to divide each apartment division into zones to, then, atributte each zone to a zone category and thermic block. The category attribute to each zone was Residential and Recreation.



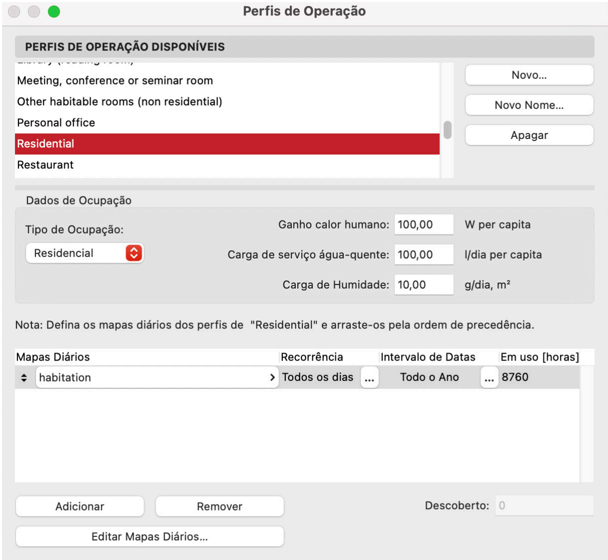
Four different thermic blocks, were created: 1- Climatized; 2- Atrium; 3- Pantry; 4- Bathroom. All the blocks had different building systems associated.

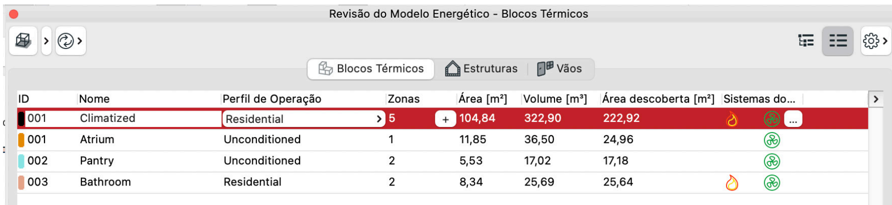


It was necessary to add the heat-pump to the building systems with the solar thermic collectors.

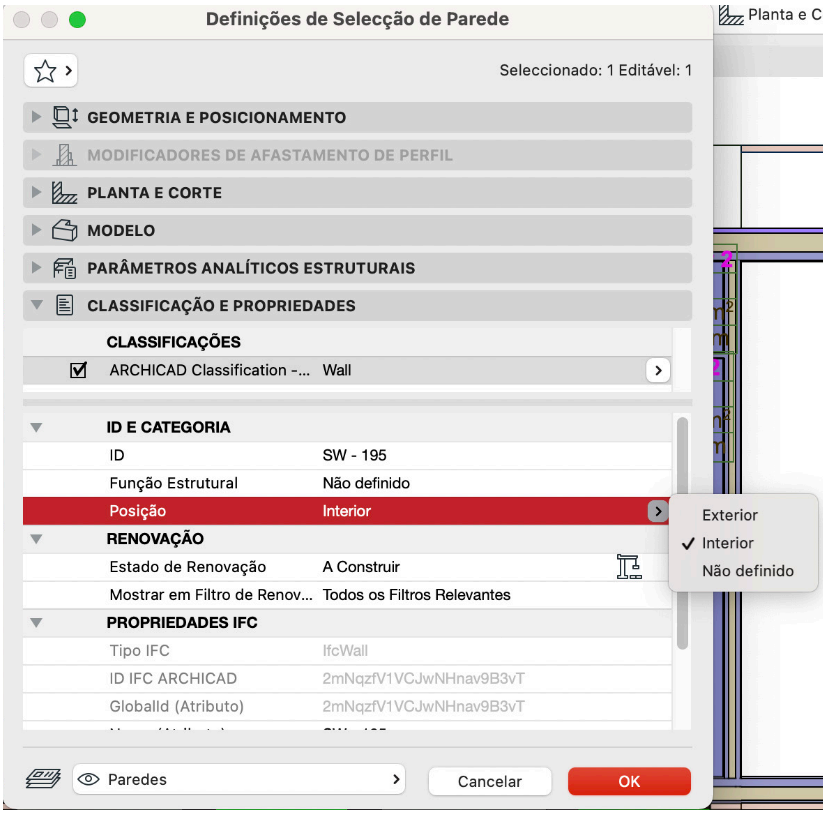


It was also necessary to chose the operation profile for each type of thermic block: climatized and bathrooms - Residential; pantry and atrium - Unconditioned.

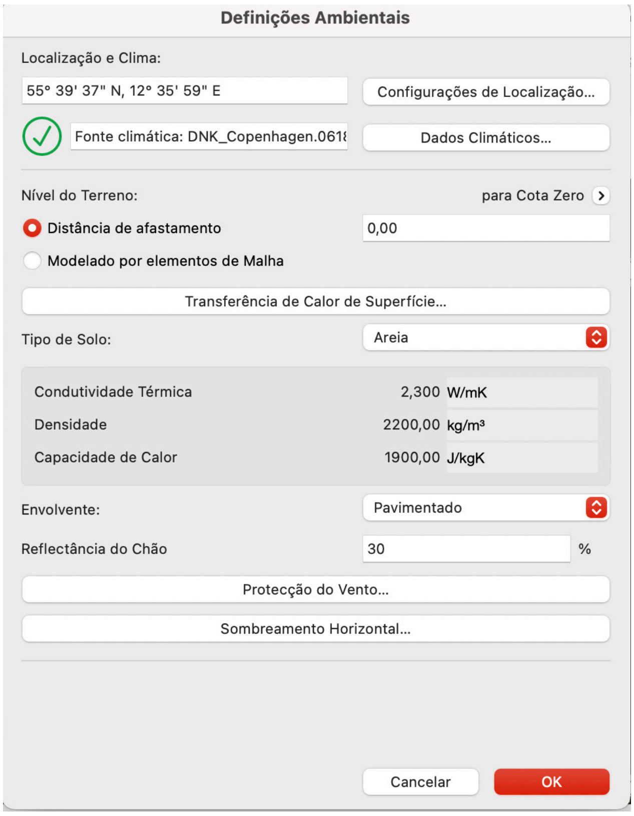




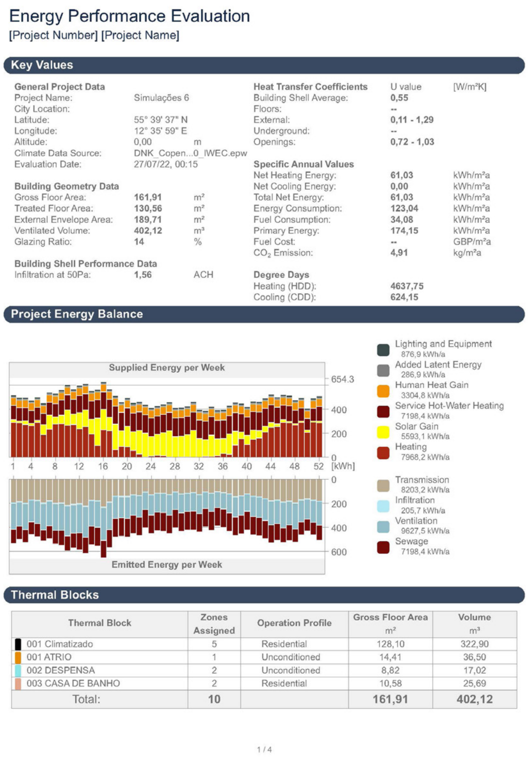
Then, it was necessary to define the position of each building element adjacent to all of the zones.

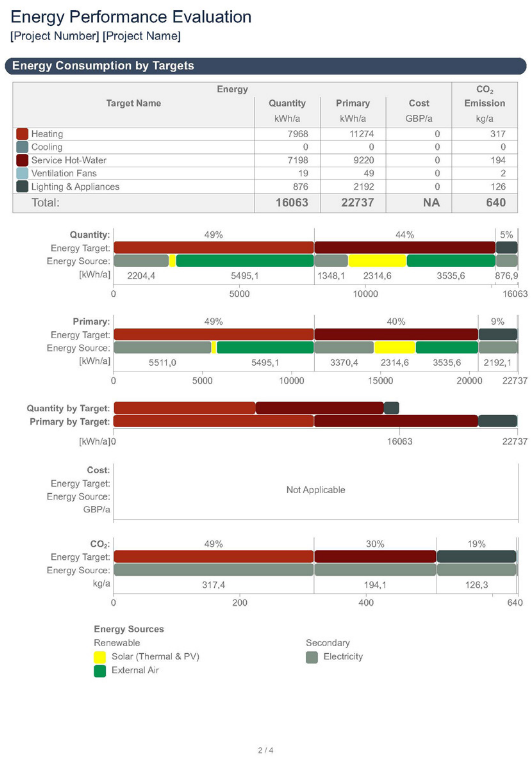


Then, the location of the project was defined.



At last, the model is ready for the energy simulation and the report is the product of the simulation that is given to us by the software.



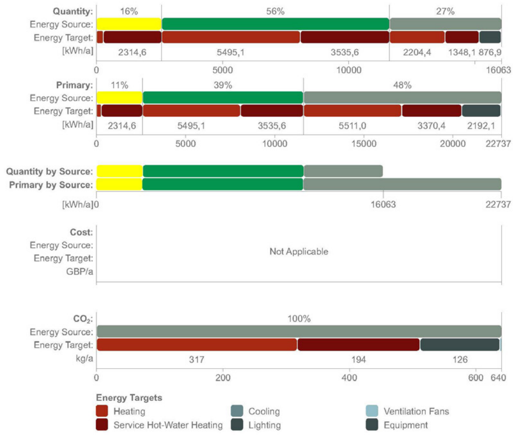


Energy Performance Evaluation

[Project Number] [Project Name]

Energy Consumption by Sources

Source Type	Source Name	Energy: Quantity kWh/a	Energy: Primary kWh/a	Energy: Cost GBP/a	CO_2 Emission kg/a
Renewable	Solar (Thermal & PV)	2583	2583	NA	0
	External Air	9030	9030		0
Secondary	Electricity	4449	11123	--	640
	Total:	**16063**	**22737**	Not Applicable	**640**



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Energy Performance Evaluation

[Project Number] [Project Name]

Environmental Impact

Source Type	Source Name	Primary Energy kWh/a	CO_2 emission kg/a
Renewable	Solar (Thermal & PV)	2583	0
	External Air	9030	0
Secondary	Electricity	11123	640
	Total:	**22736**	**640**

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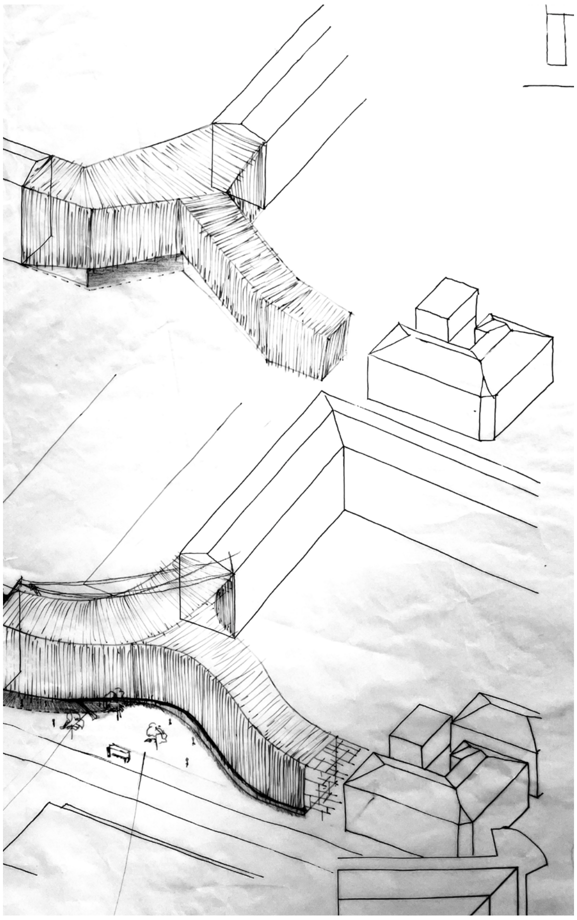
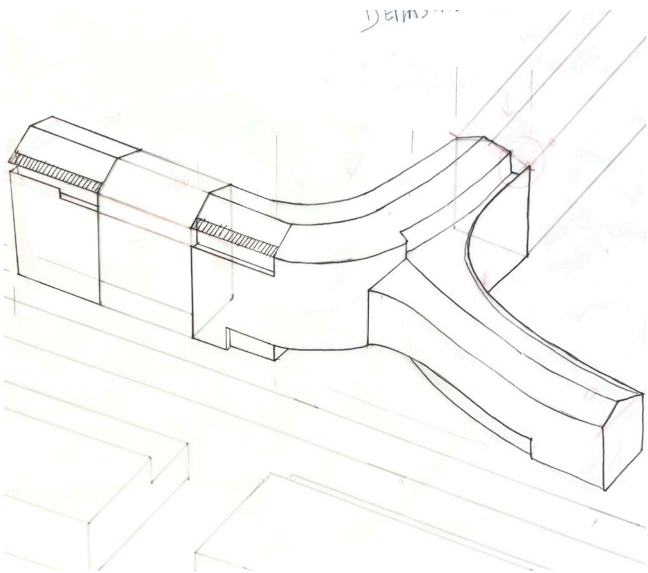
These results combined with the result of the PV potential (Appendix VII) allows to denominate the building as an NZEB, as more than 90% of the energy needs of the whole building complex si covered by renewable sources.

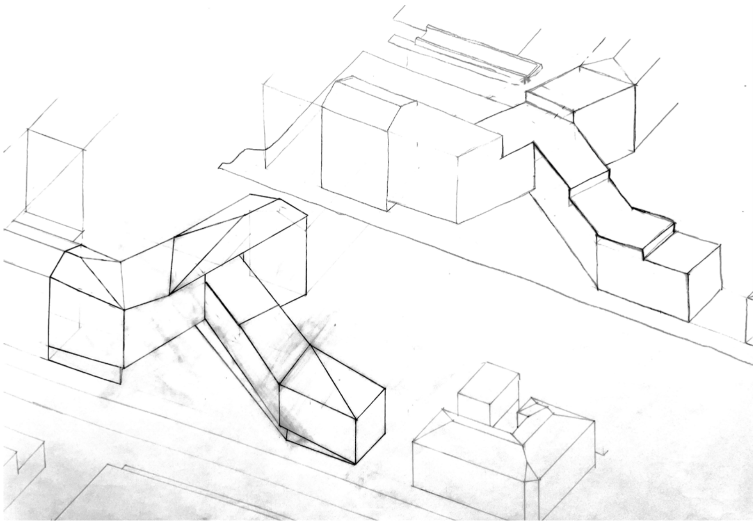
Appendix IX- Design Process

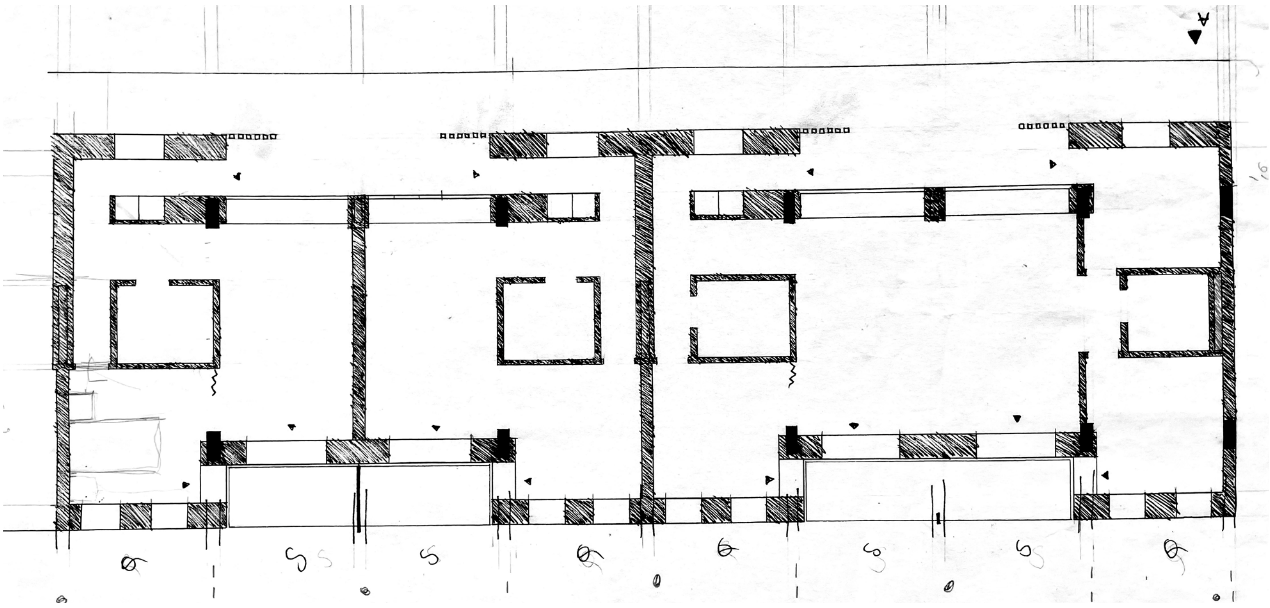
Process Drawings



First volumetric iterations.

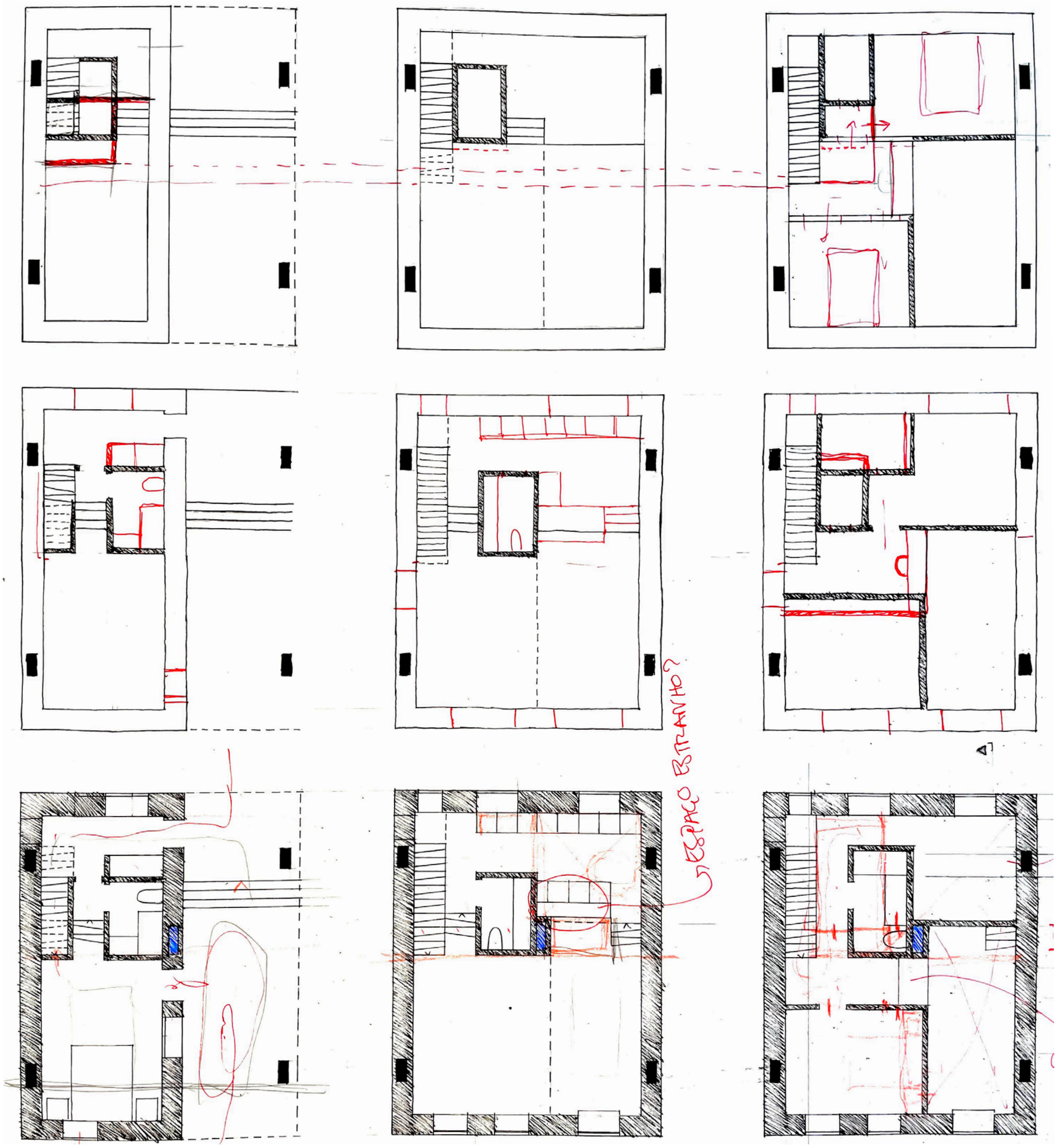




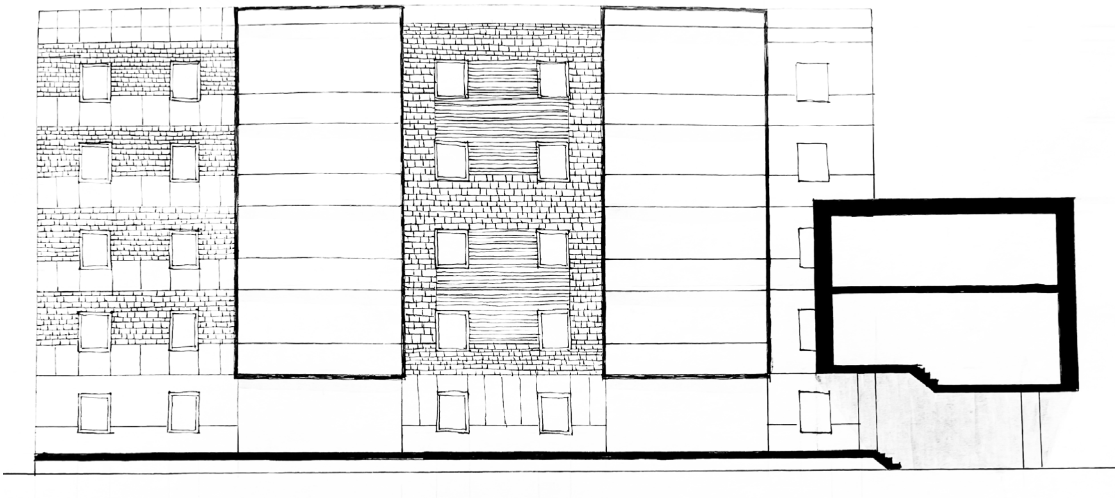


First apartment iterations.

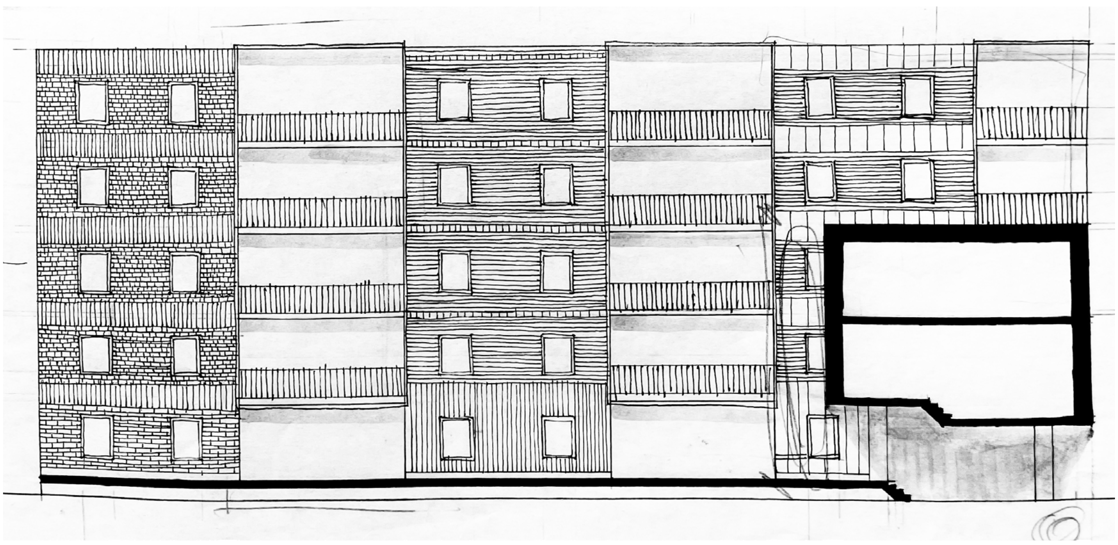
First facade iterations.



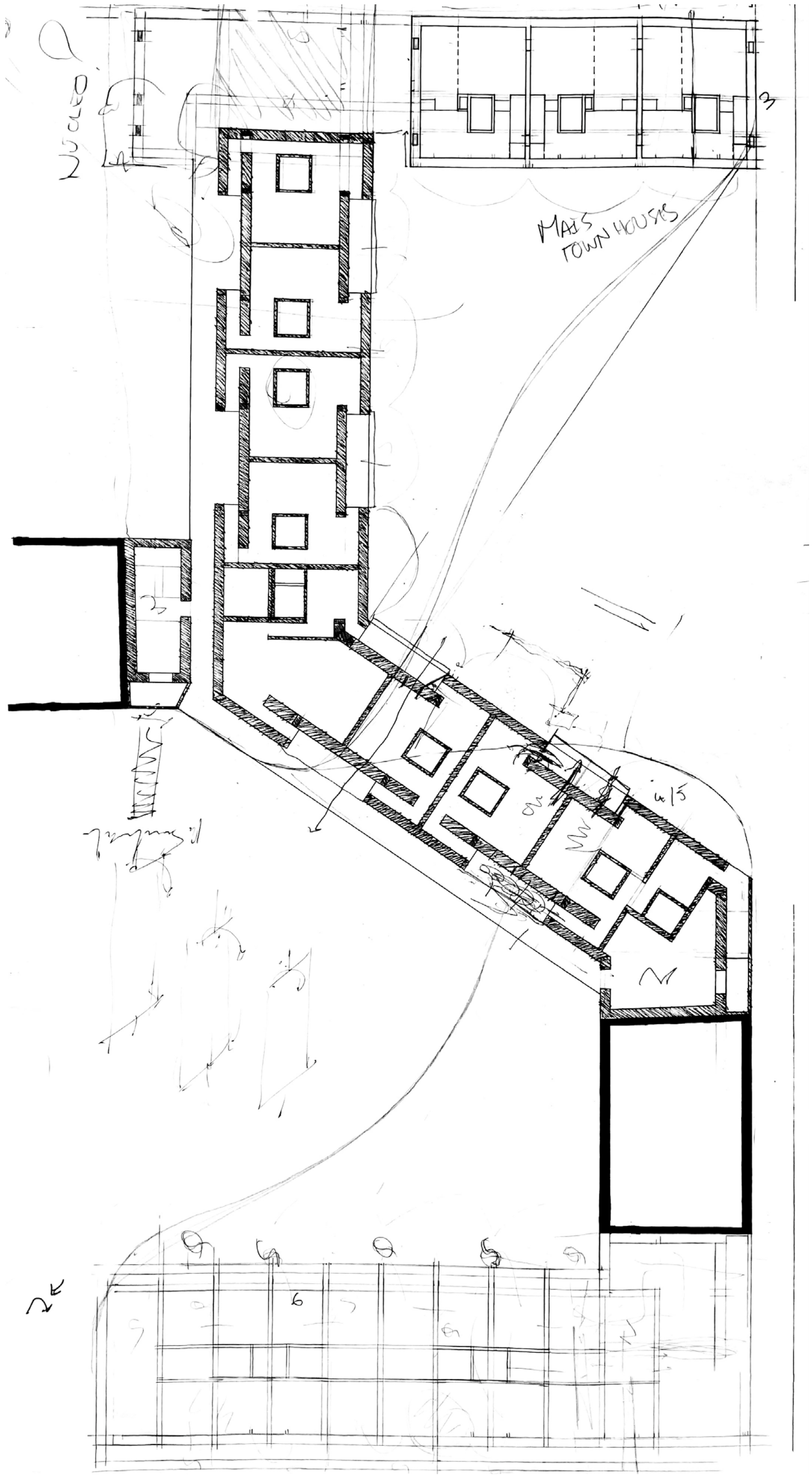
First “town house” iterations - Block C.



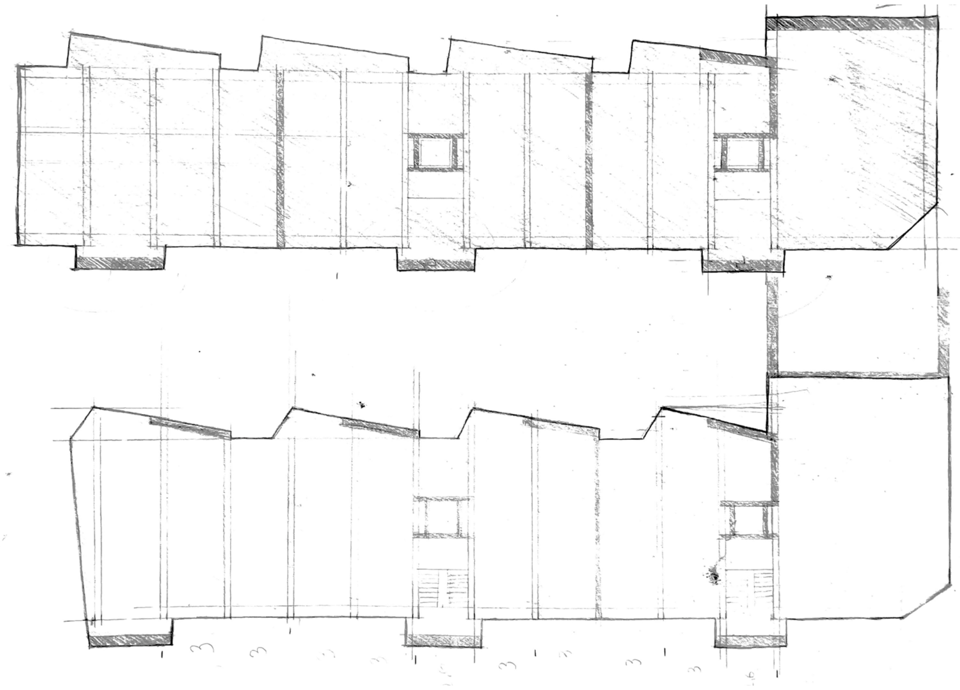
Block B South-west facade compositions options.



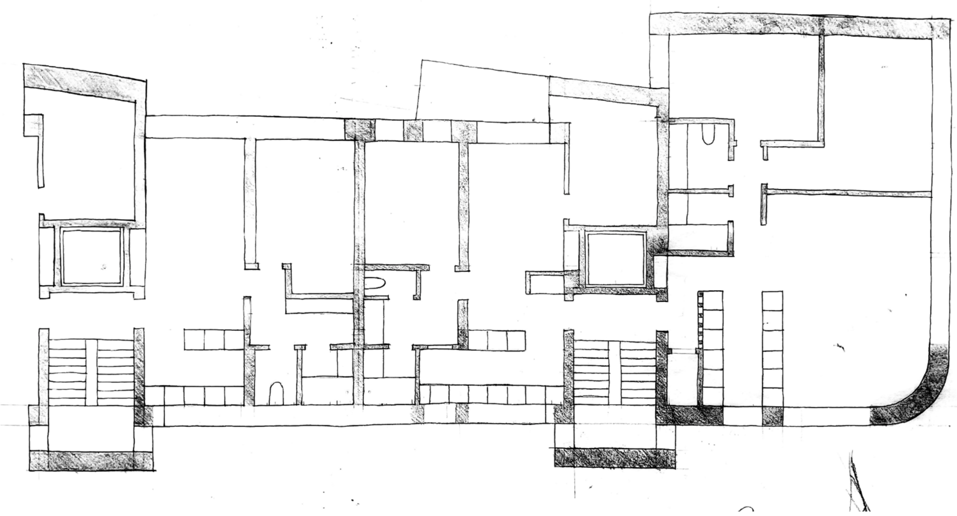
Block B South-west facade compositions options.



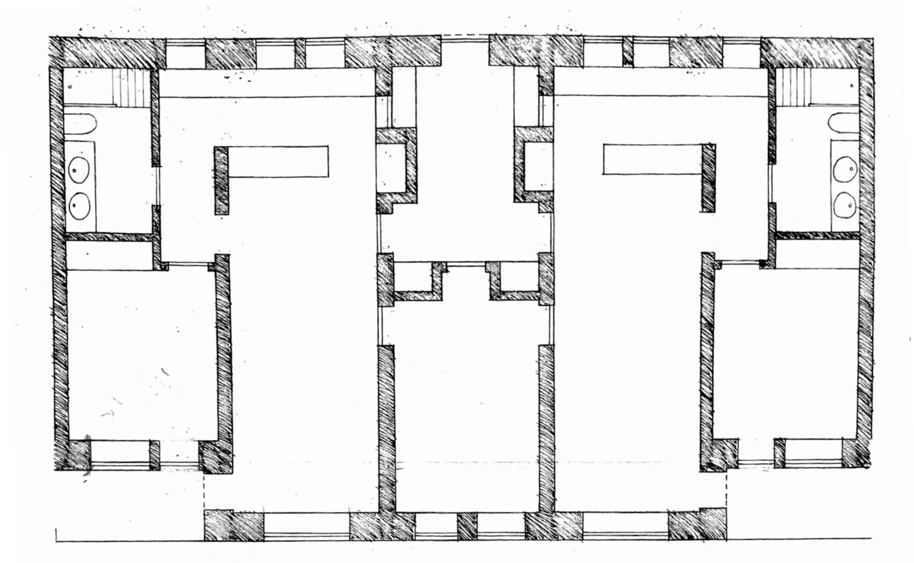
First floor layout studies.



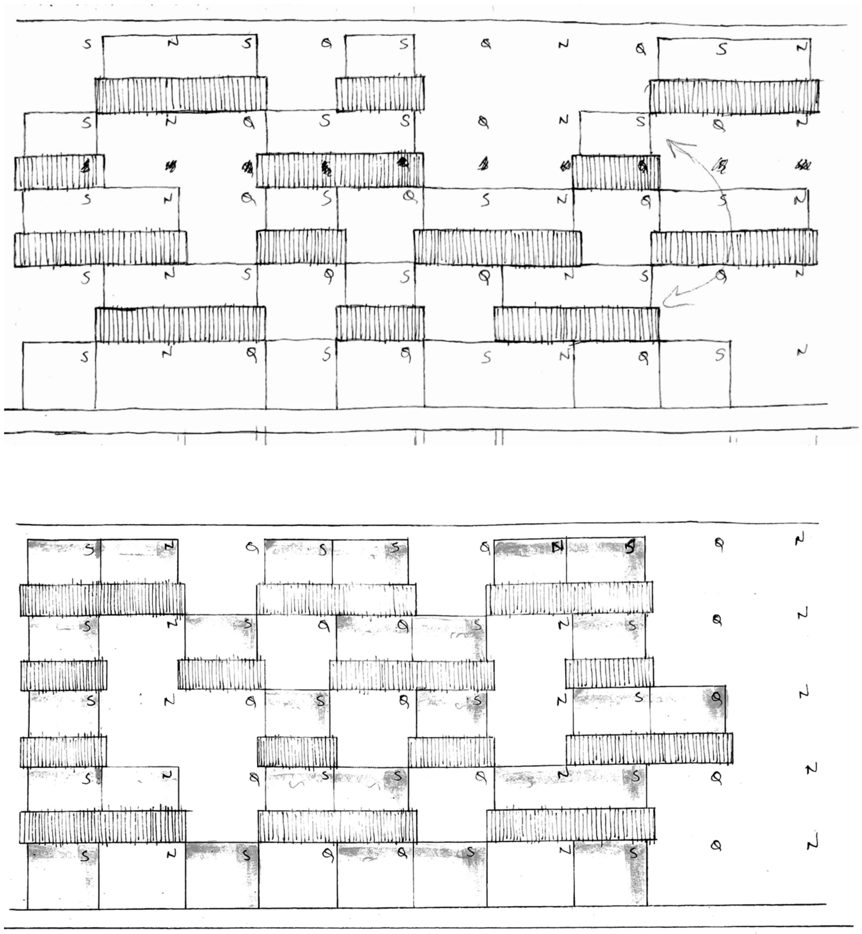
Block A layout composition studies.



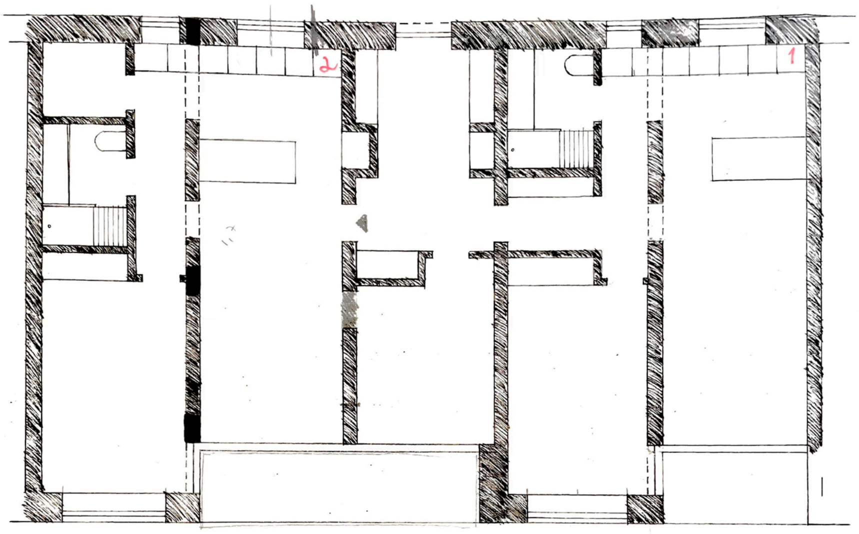
Block A corner, apartment layout composition study.

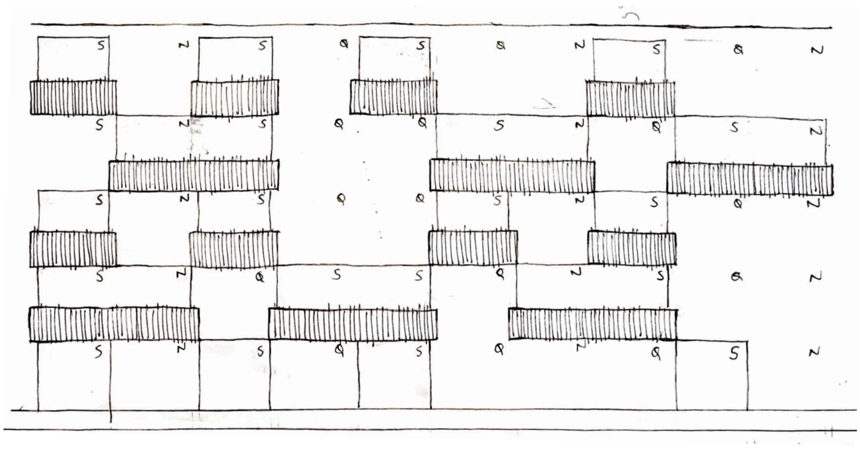


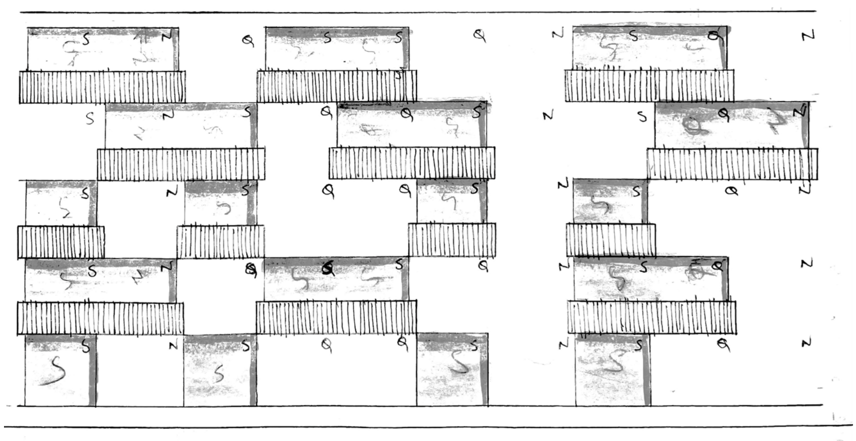
Apartment layout studies and how it affects the facades.

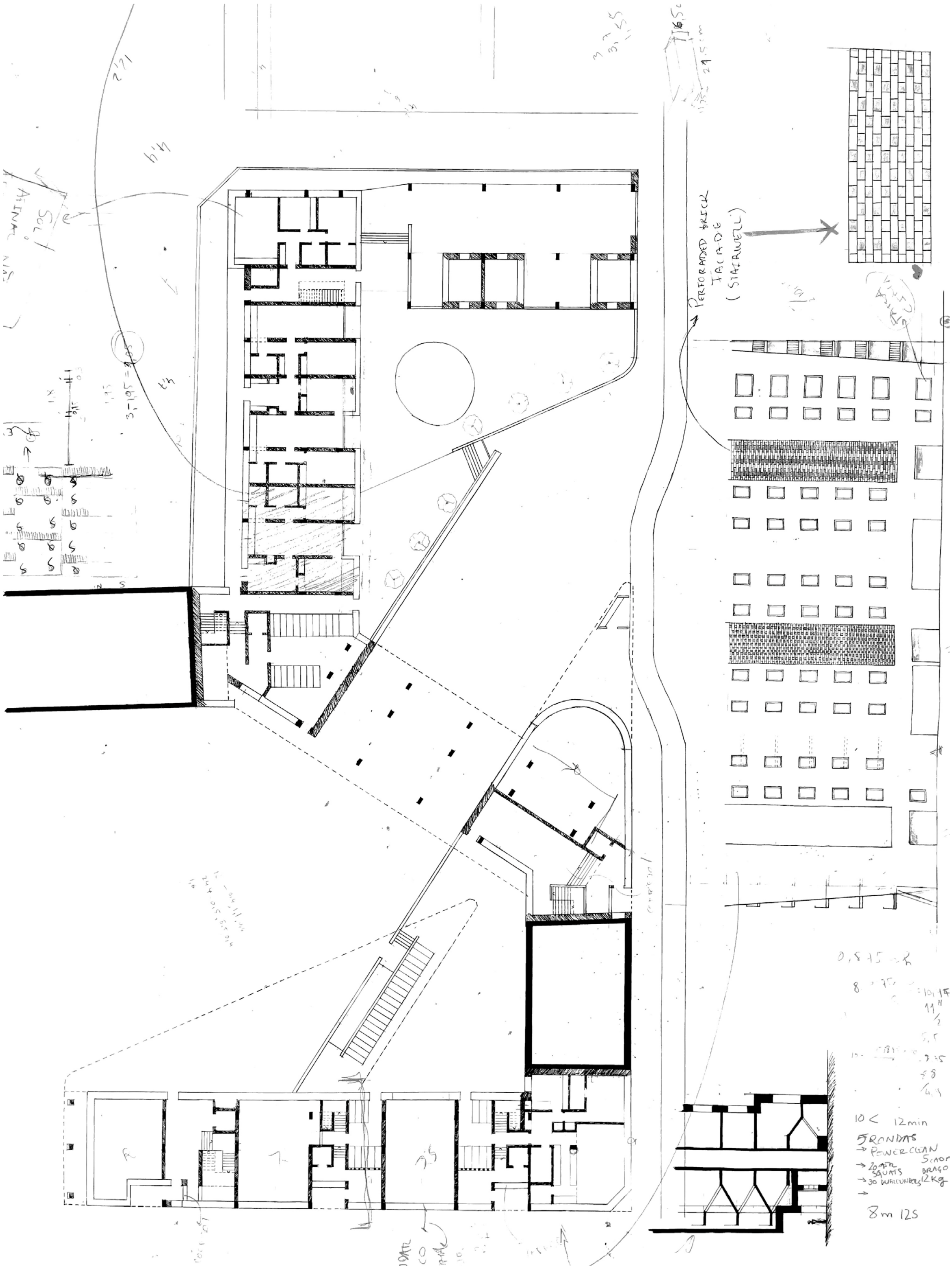


Schematic Block B facade studies according to the apartment layout studies.

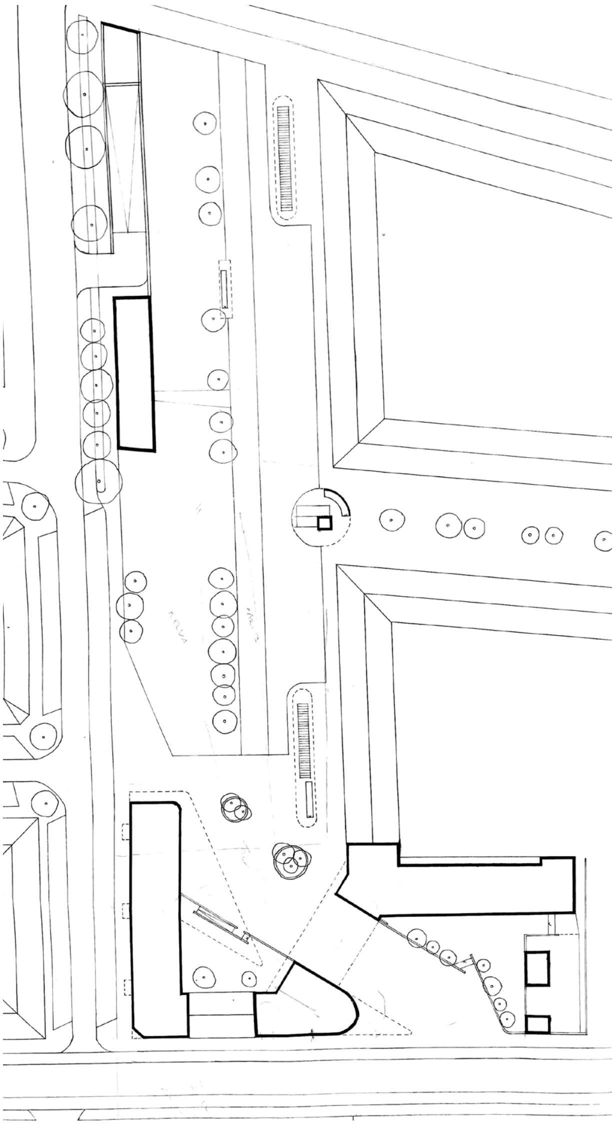




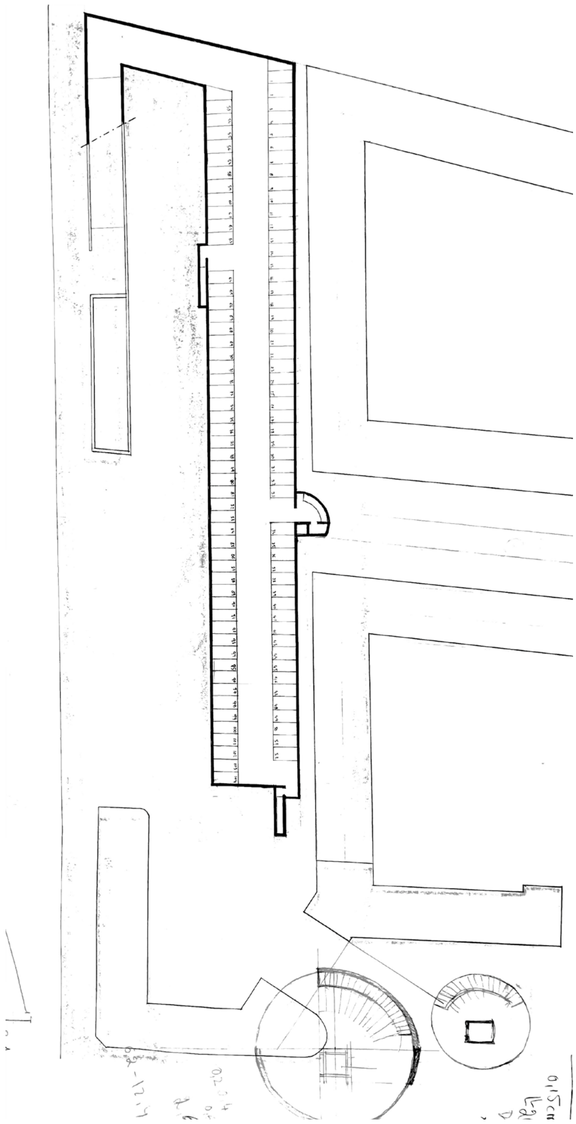




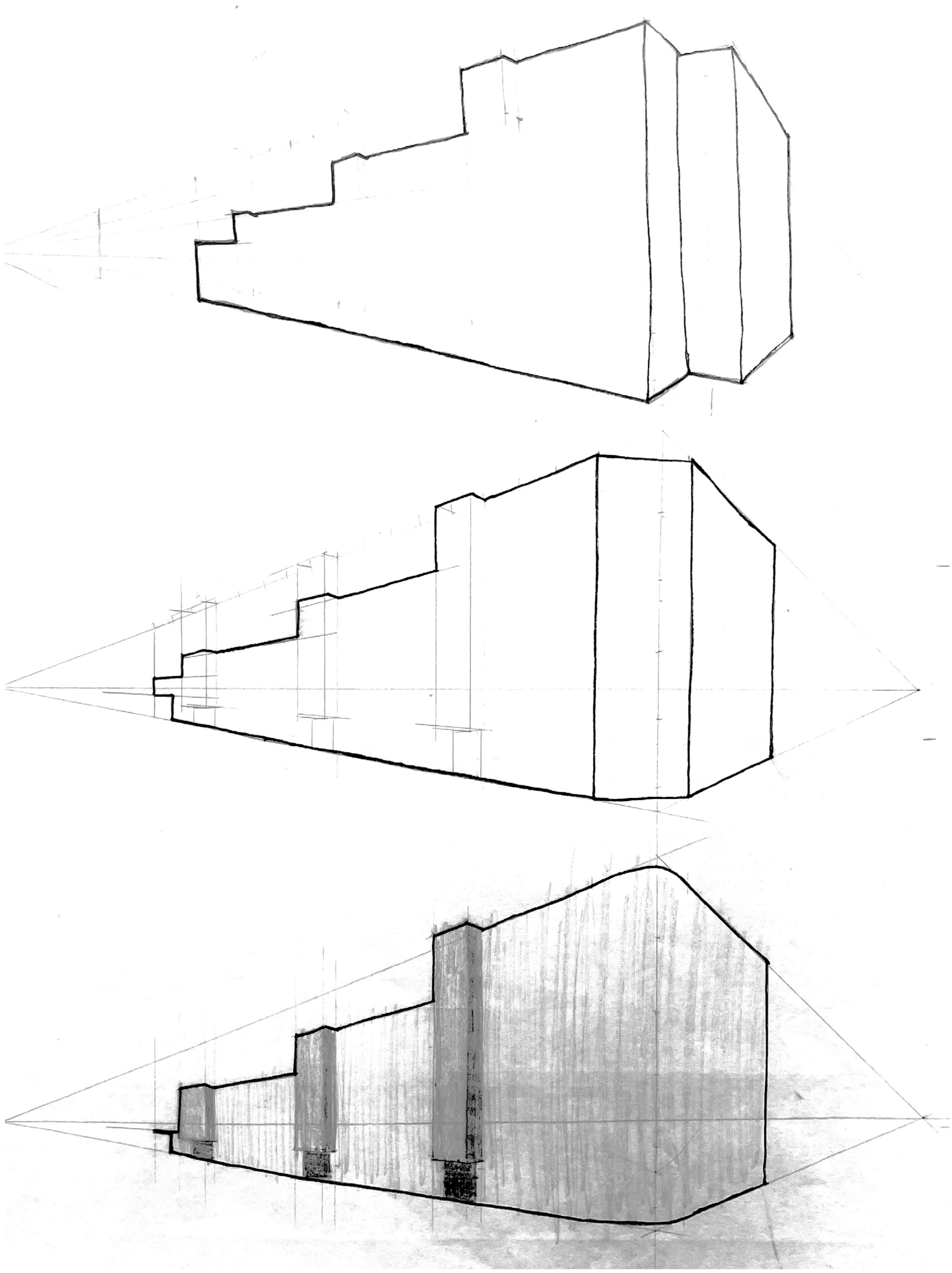
Ground-floor layout study. | North facade of Block A study.



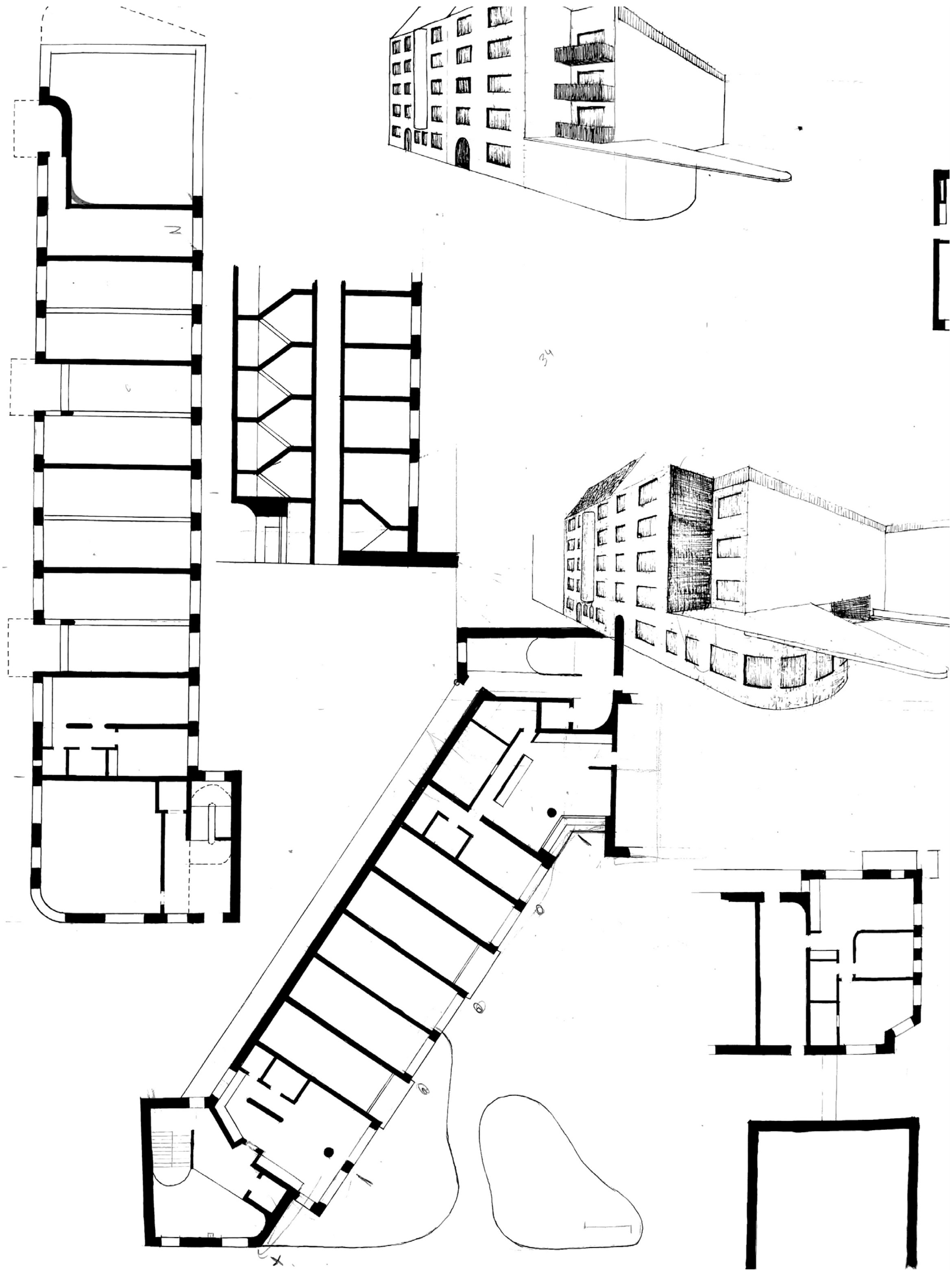
Overview of Ground-floor organization study.



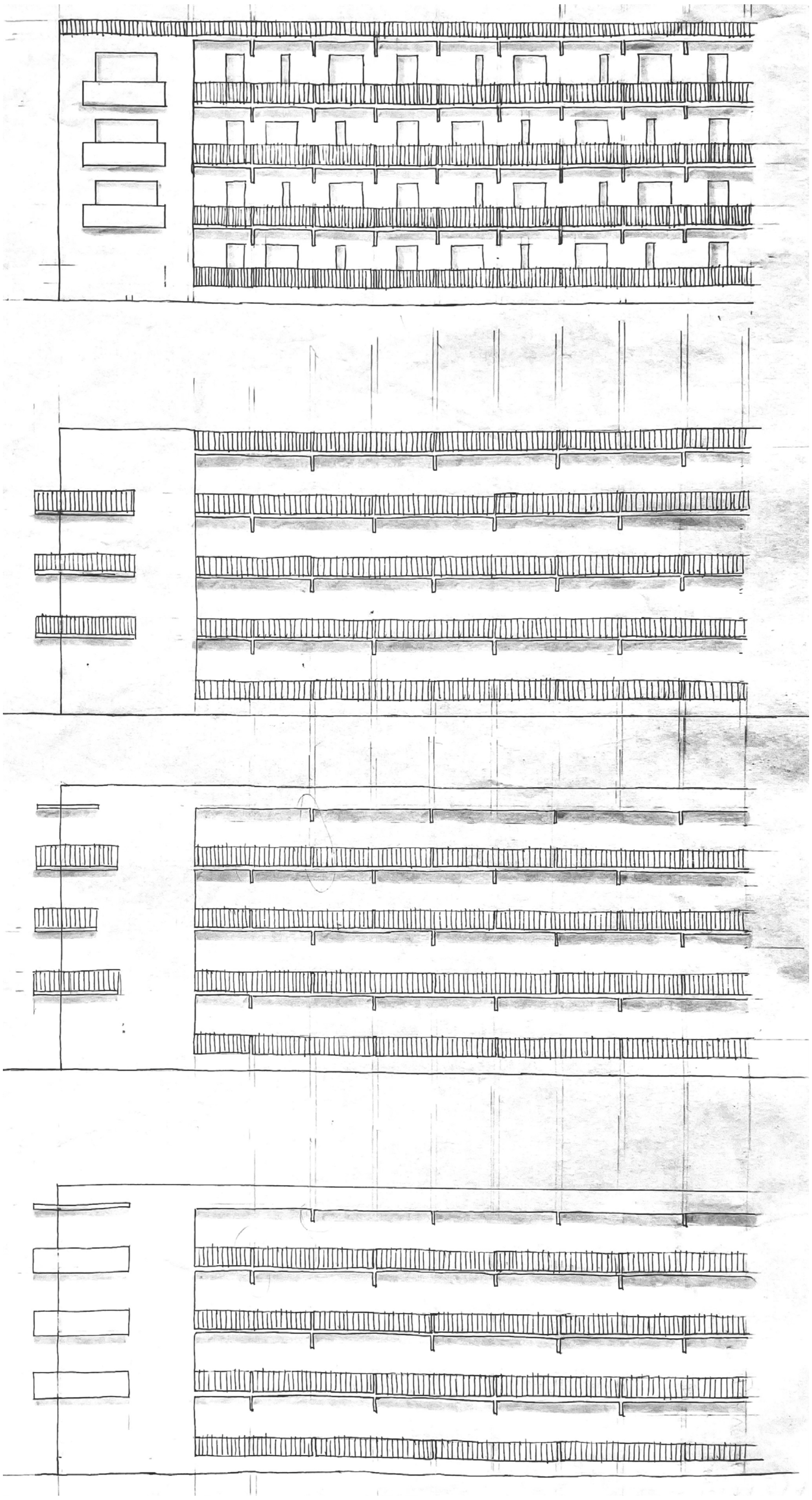
Under-ground parking lot organization.



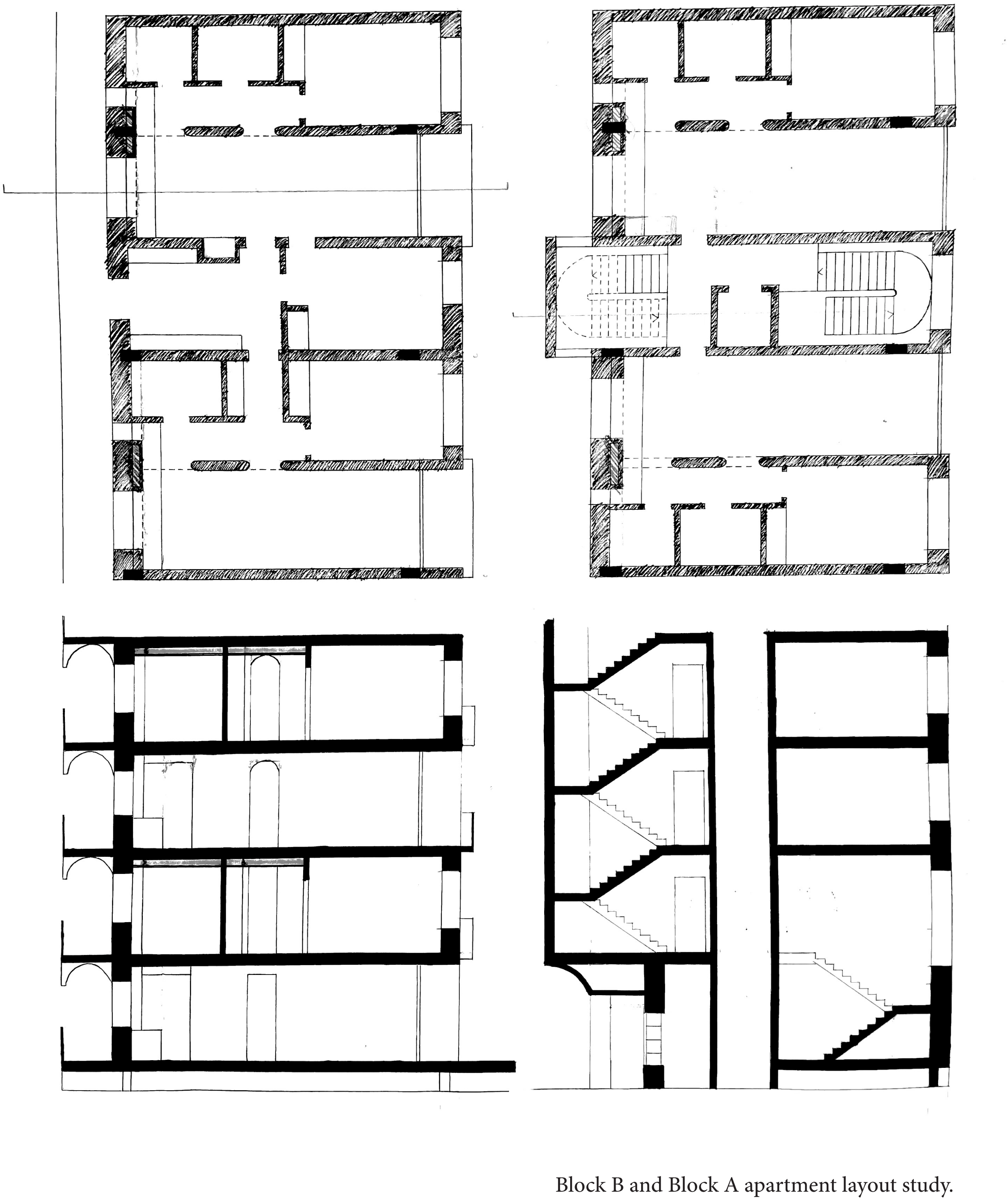
Block A corner volumetric studies.



Layout studies possibility of the different conners of the complex .

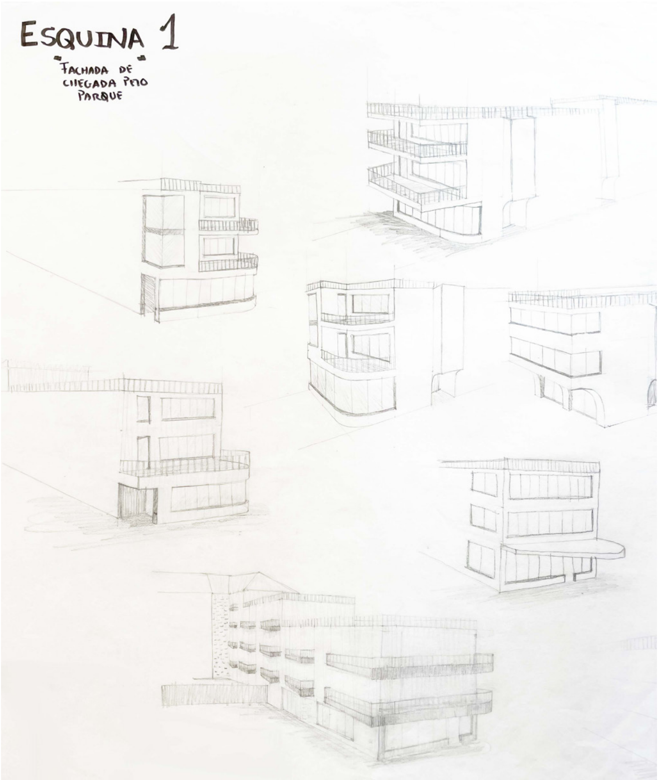


Block B north-east facade studies.

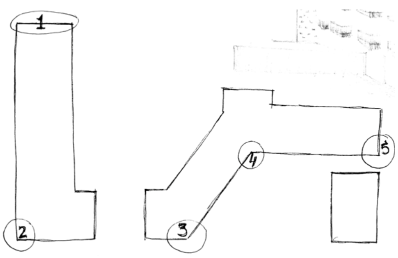


Block B and Block A apartment layout study.

Vertical / Horizontal distribution section studies.


ESQUINA 1
"FACHADA DE CHEGADA PELO PARQUE"


ESQUINA 2
"EM REDOR DO EDIFICIO"


1
2
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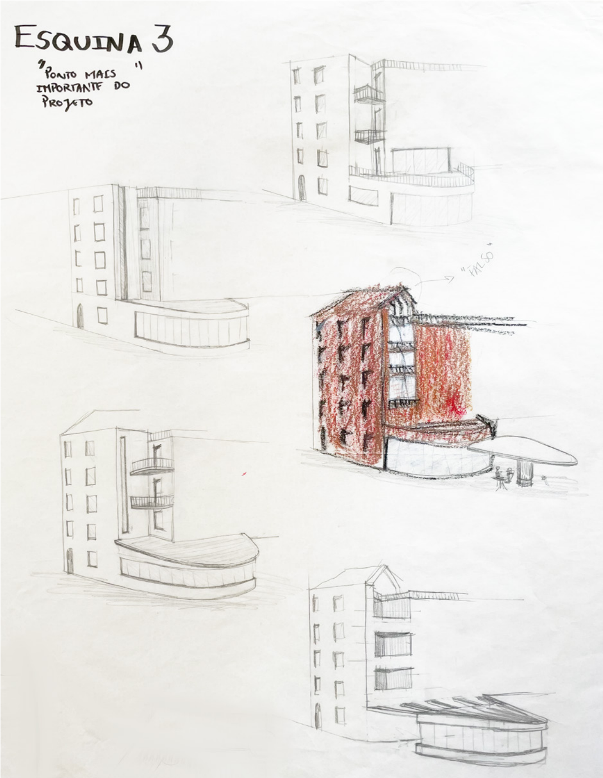
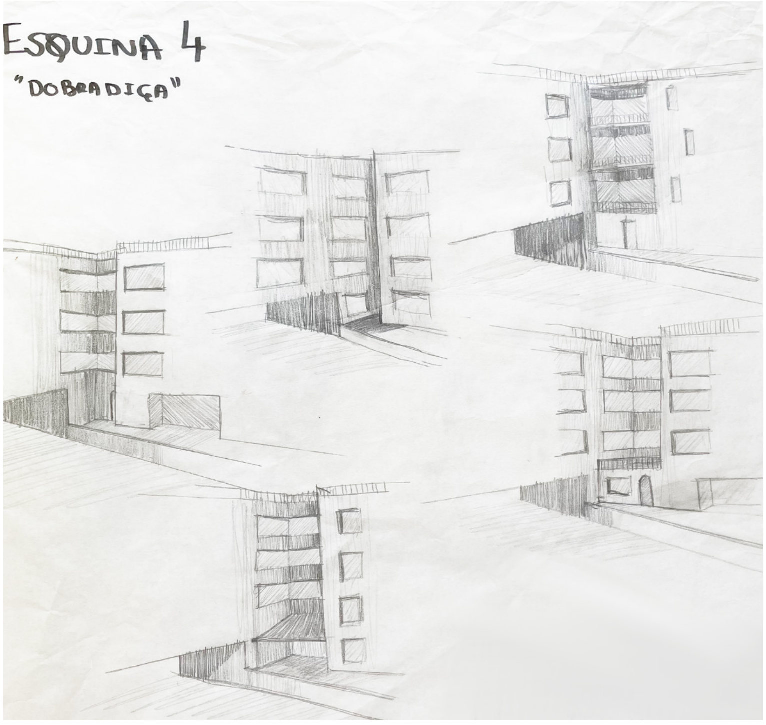
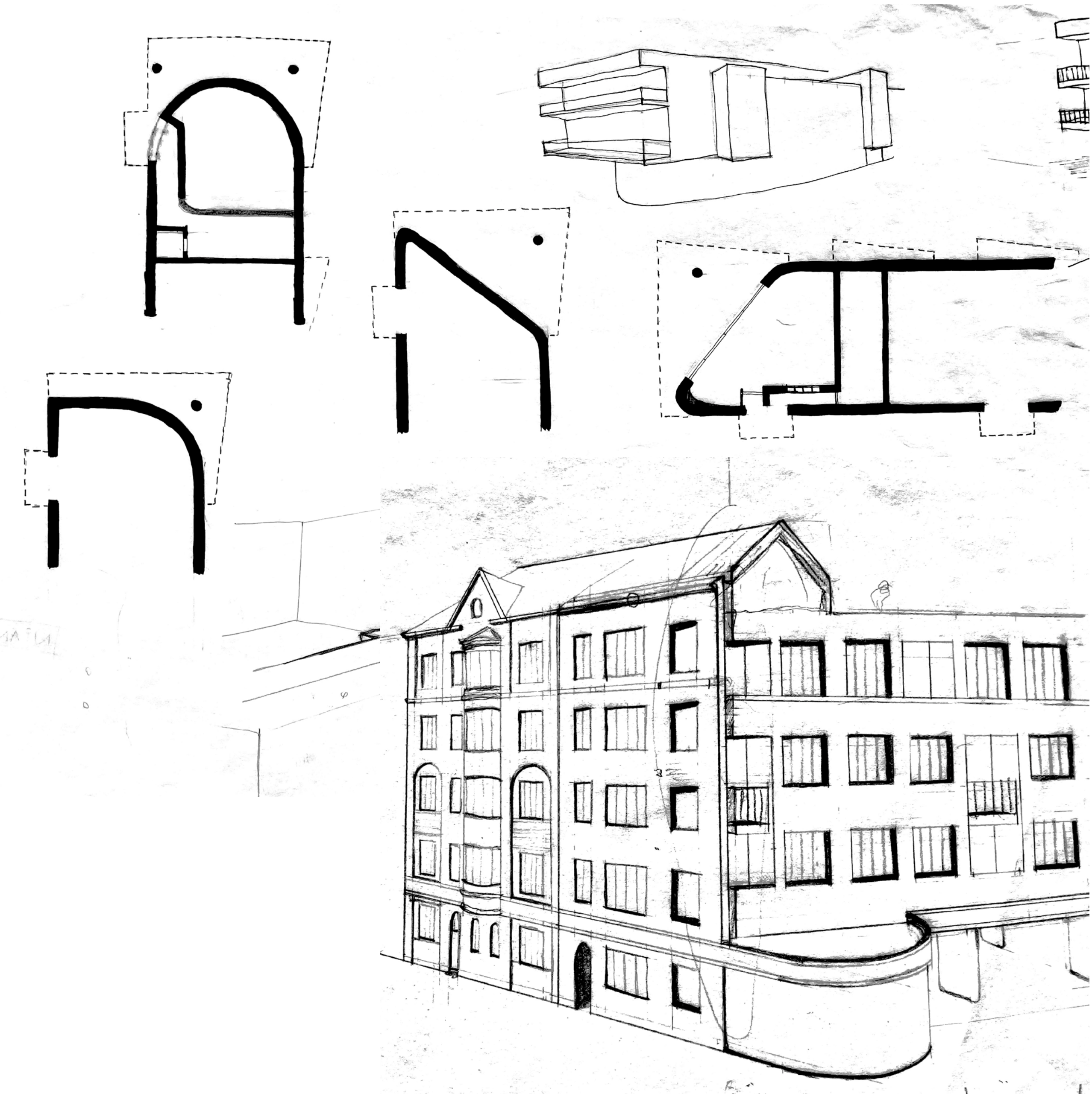

ESQUINA 3
"PONTO MAIS IMPORTANTE DO PROJETO"

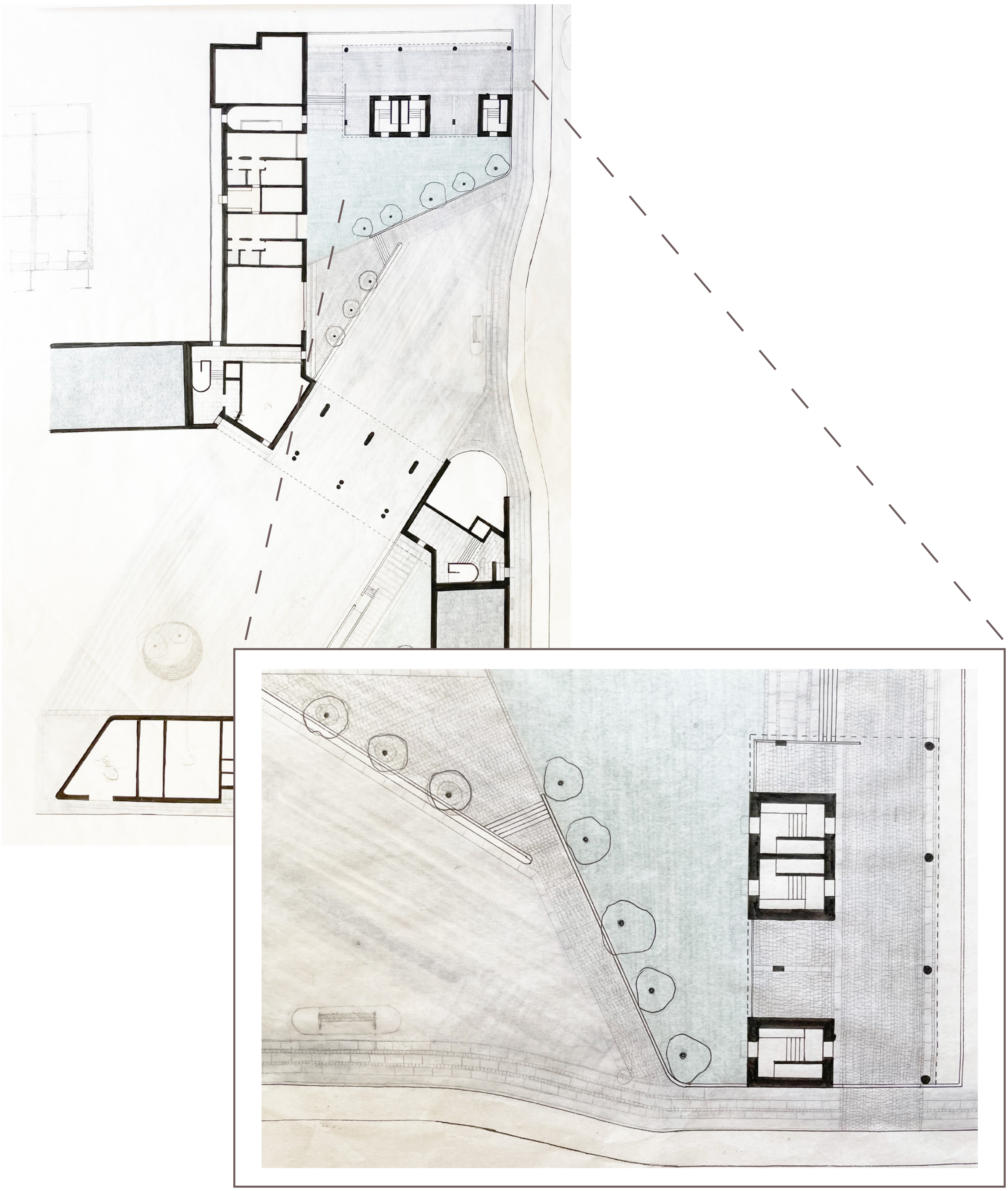

ESQUINA 4
"DOBRADIÇA"



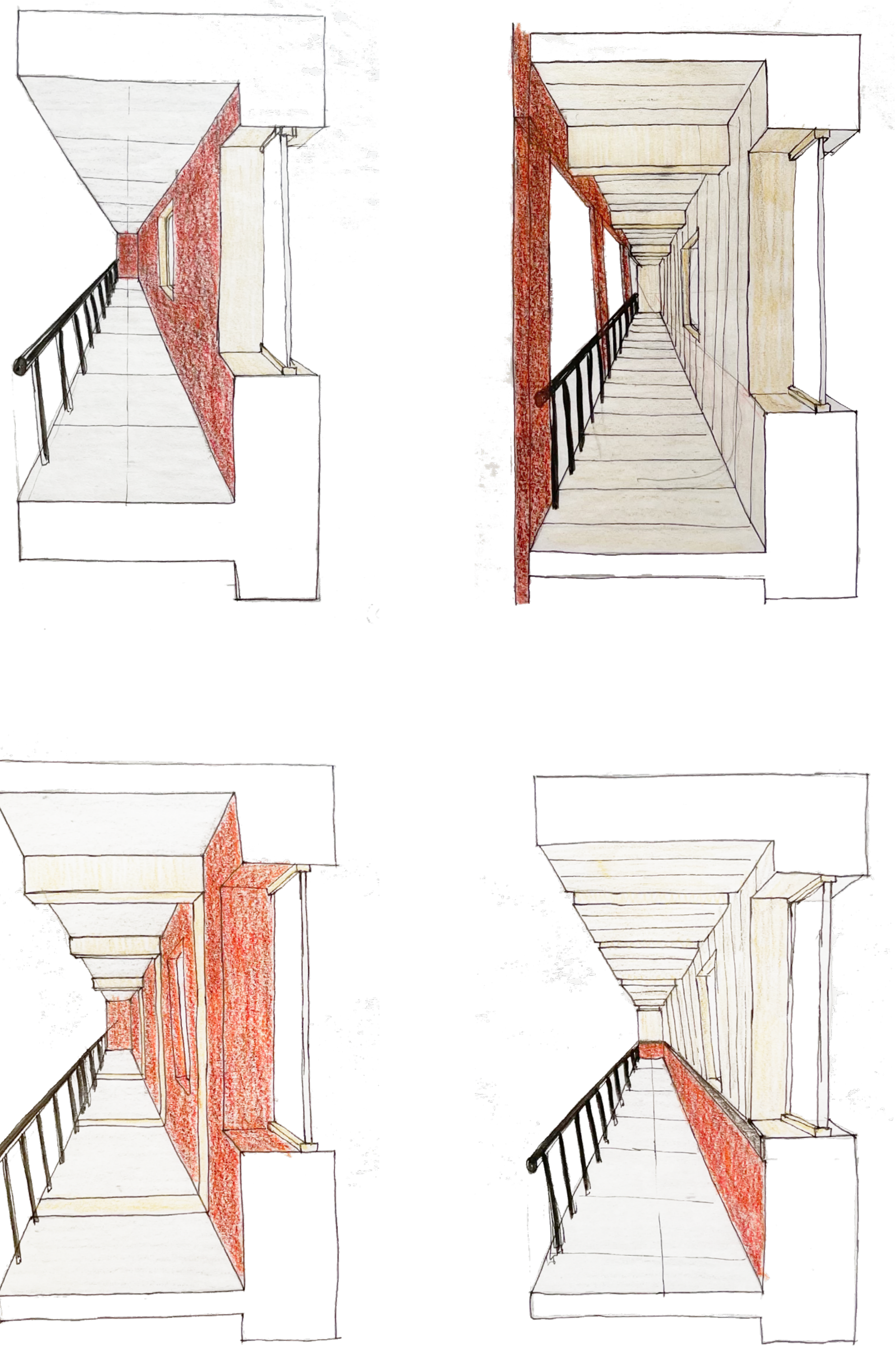
Block A garden facing corner, studies.

Block B corner study.

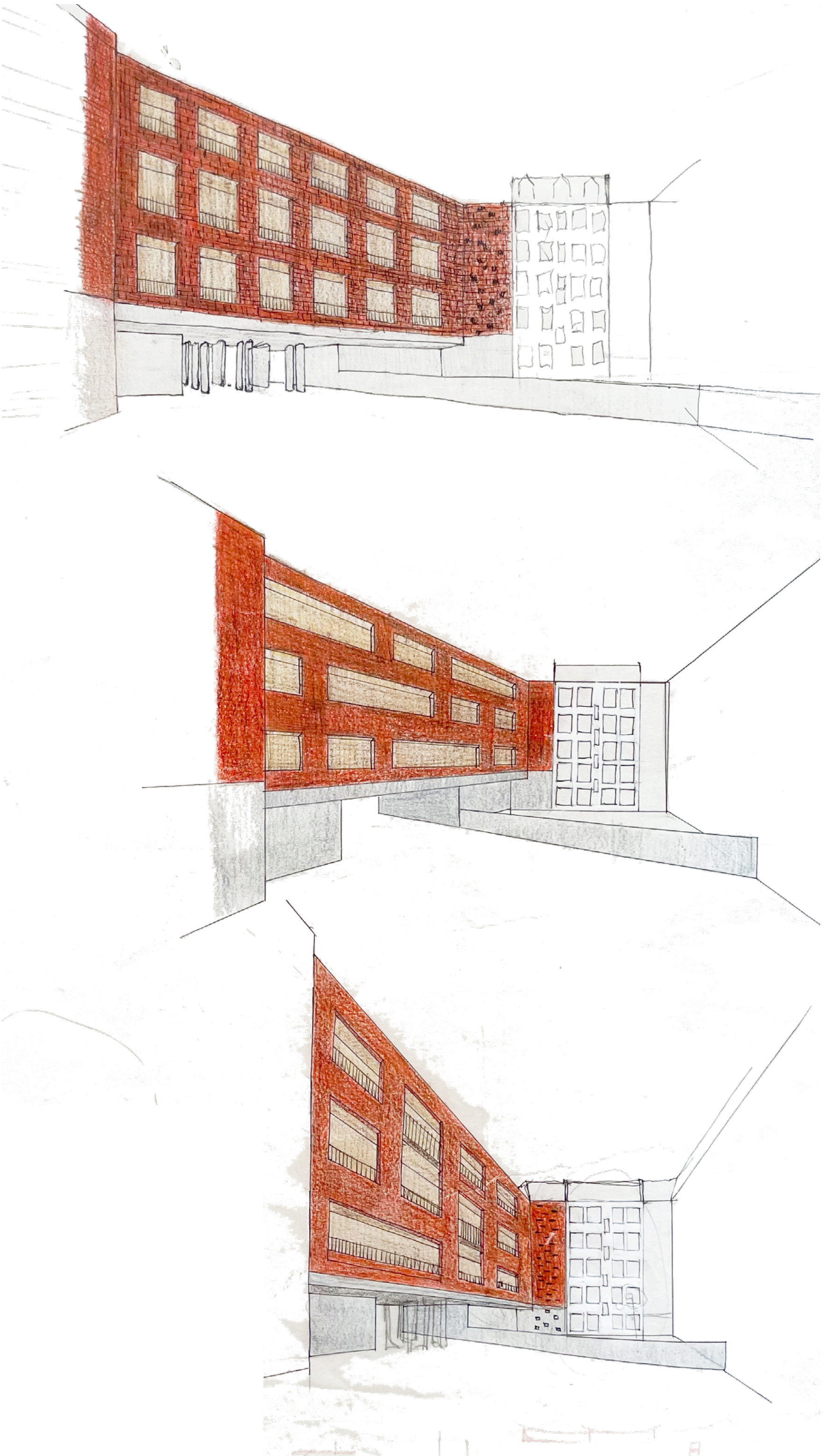
Block B facade studies.



Ground-floor pavement design.

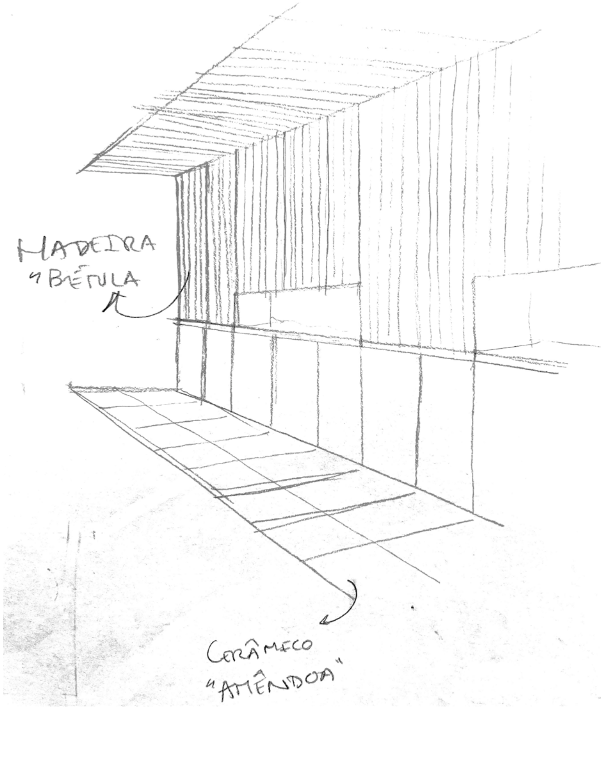


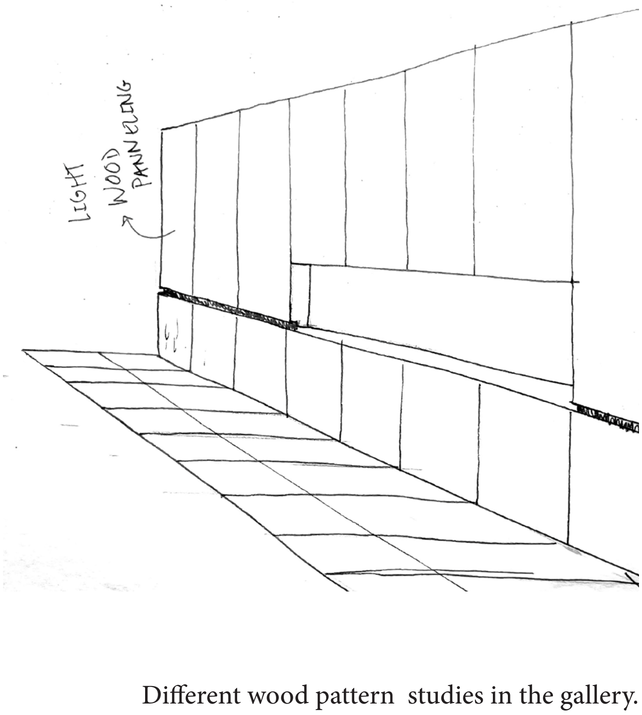
Different gallery materialization studies.



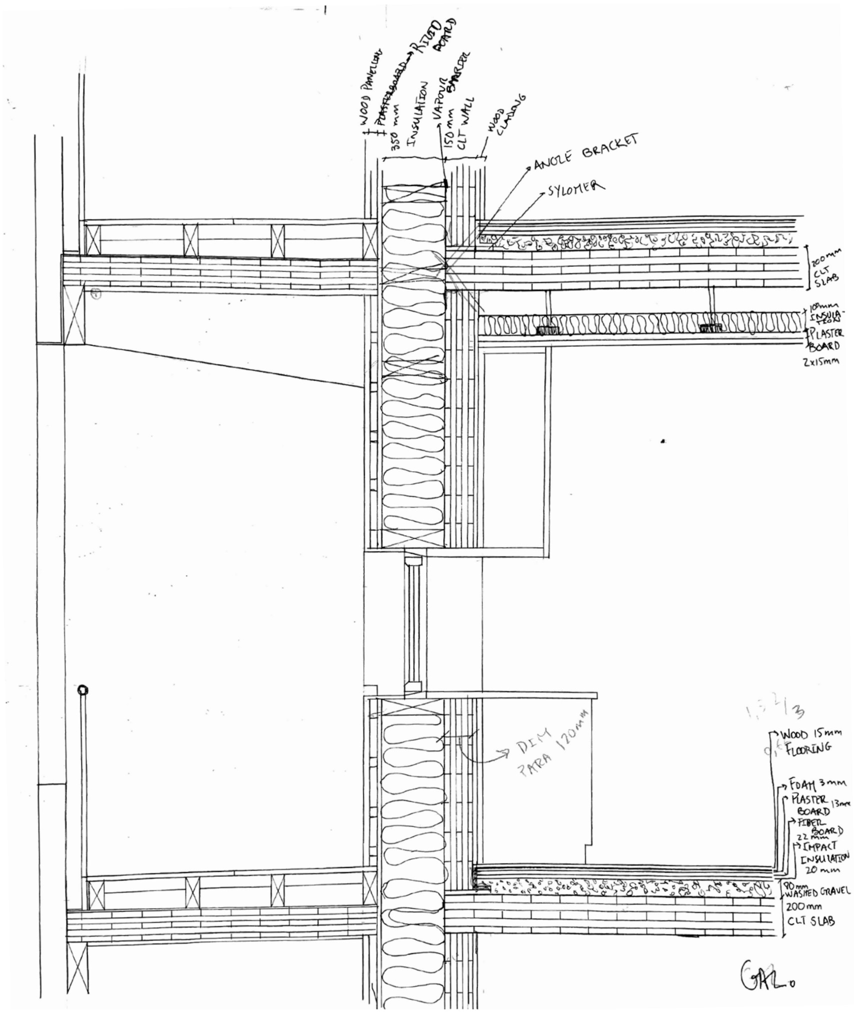
Block B north facade studies.

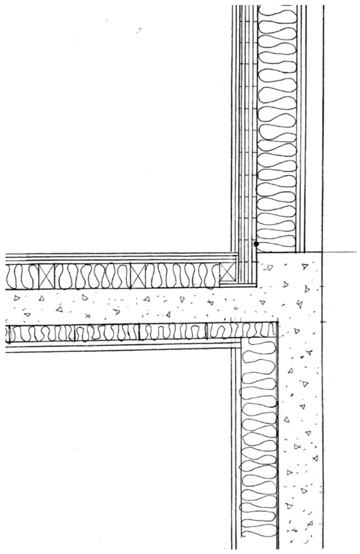
Perspective view from the adjacent garden of the complex.





Different wood pattern studies in the gallery.



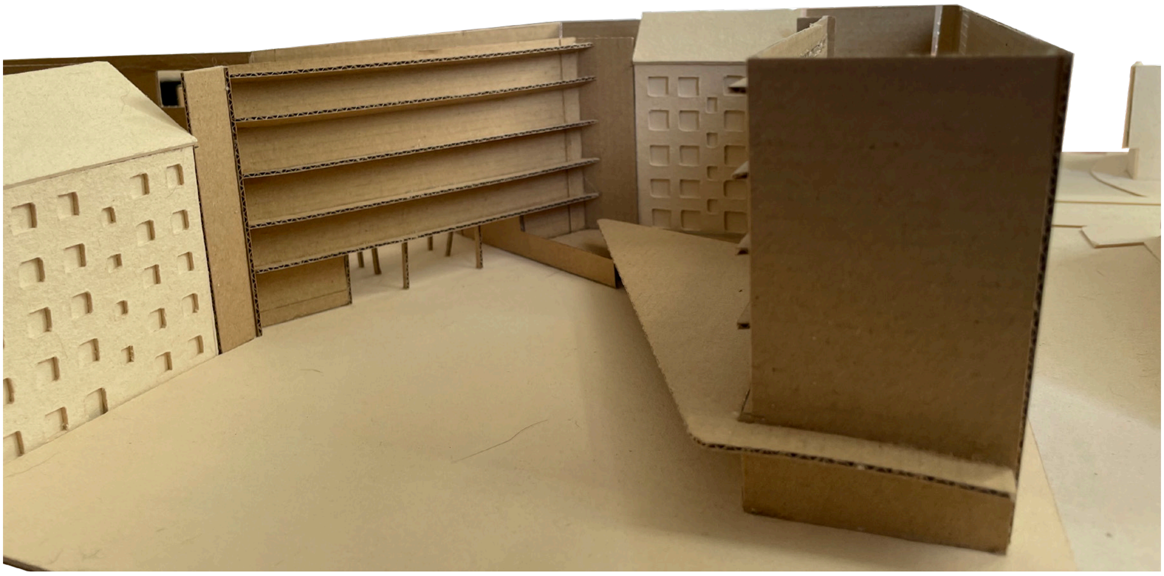


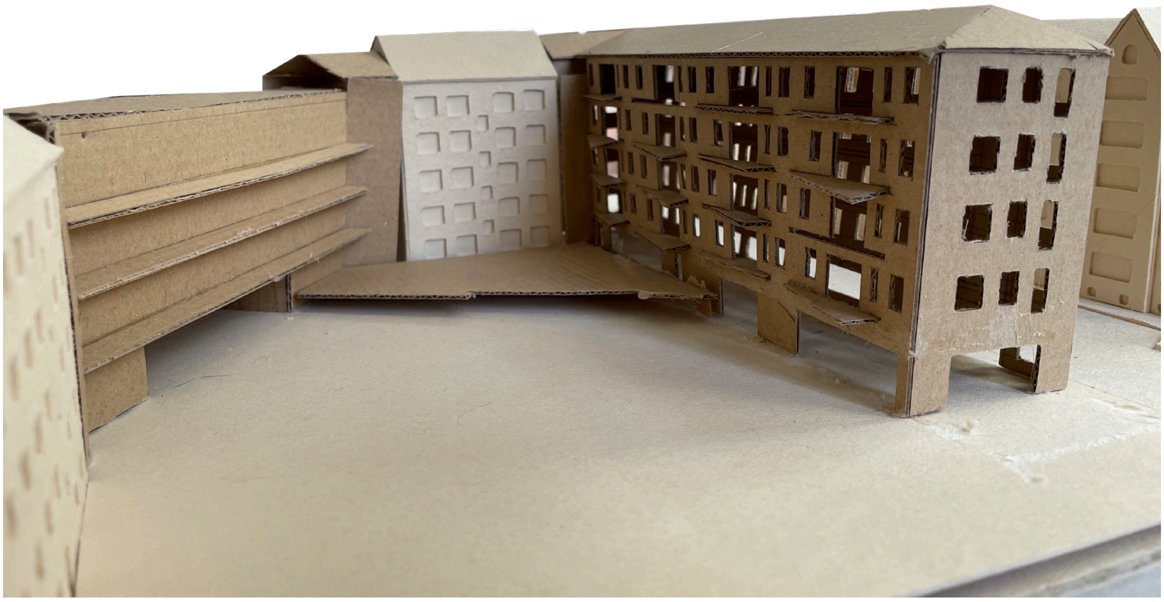
Constructive system studies: Gallery with apartments (top);

Concrete facade with wood structure and brick facade (bottom).

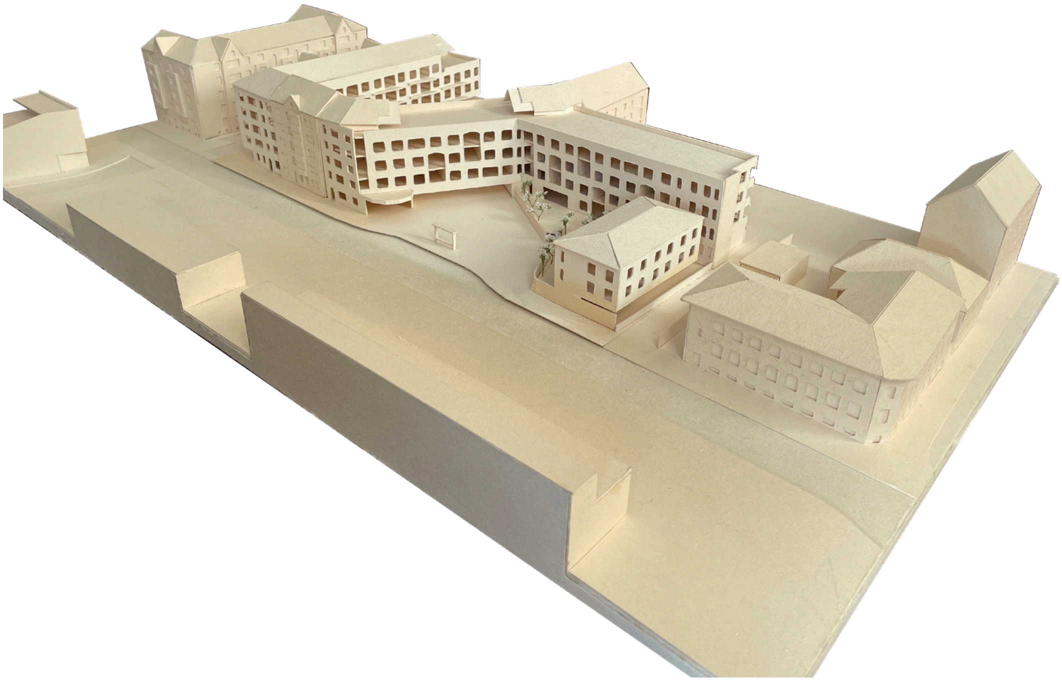
Studies made on the different facades of the complex.

Process Models





Appendix X- Final Design

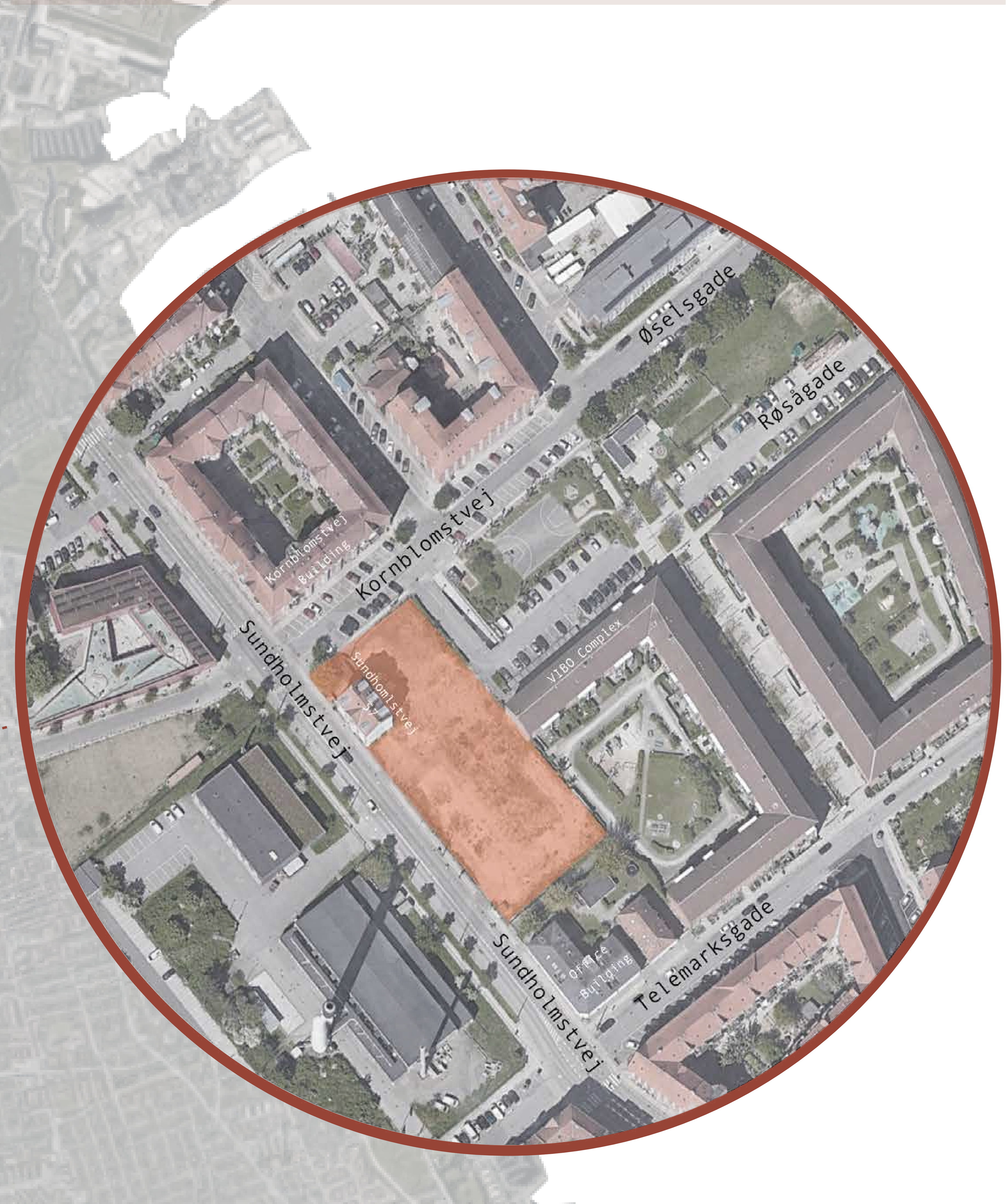


Organization of the Posters in the Document

(All posters are standart A1 size, in the horizontal position)

Organization of the Posters for Presentation

Location of the Project 01	Characterization of the Project 02	Ground-Floor Plan 1:200 05	First-Floor Plan 1:200 07	Third-Floor Plan 1:200 09	Schematic Apartment Organization 12	The Building Design for NZEB 13
Urban Strategy 1:500 03	The Brief 04	Sections: AA'; BB'; CC' 1:200 06	Sections: DD'; EE'; FF' 1:200 08	Sections: GG'; HH' 1:200 10	Materialization of the Apartments 1:50 11	



THE PROPOSAL

This work presents a proposal for a housing complex "Near Zero Energy Building" (NZEB) performance in a consolidated city block in Copenhagen. The aim was to have a sensible approach to the NZEB buildings, focusing not only on the energy performance of building but also on the connection with the surrounding city.

The aim of the project was to understand what a near zero energy building (NZEB) was. It was then necessary to define which of the possible directions (associated with the main concept) would be taken and applied to the project, considering that the project strives to give an answer to the city's and the user's needs.

It was then necessary to understand the dynamics of a "typical" Danish block so that the choice of the exact location could be made. The goal was to choose a site (within the traditional city) where the building would solve existing problems and bring benefits to the location.

A brief research was conducted to understand the "Danish way of living", so that the design could correspond to the needs of the users, and correlate the design of the houses to the strategic building characteristics of a net zero energy building.

Then, it is essential to develop a proposal that strives to surpass the resolution of practical issues and searches for a poetic response to what the chosen site needs and its possible to accomplish.

And lastly, the use of digital tools and software's to analyze and evaluate the performance of the building, it was crucial to make sure that the building was as close as it could be to the qualification of a net zero energy building.

2021 | Front view of Sundholmvej 57

2021 | Vibo complex (left); Back view of Sundholmsvej 57 (Front)

2021 | Office Building

2021 | Kornblomstvej building (Left); Sundholmsvej 57 (right)

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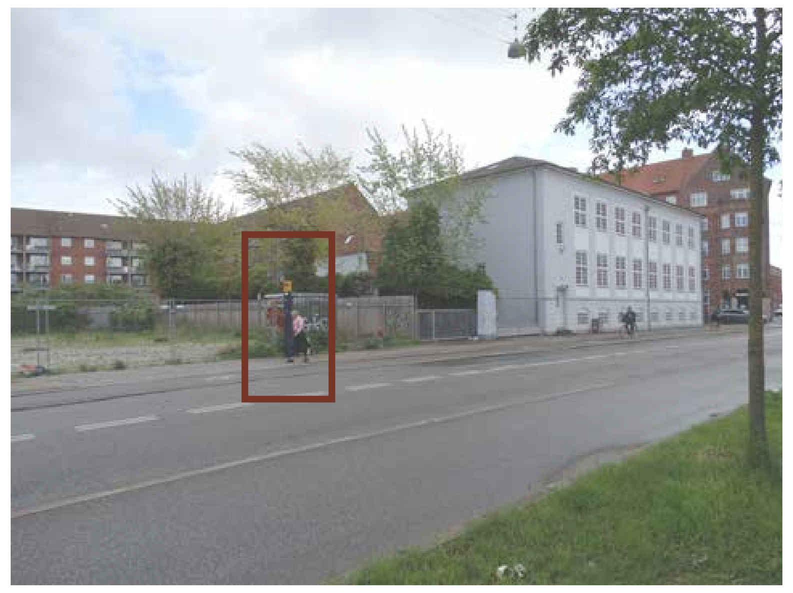
2021 | Unresolved facade of Sundholmsvej 57, facing Kornblomstvej Building



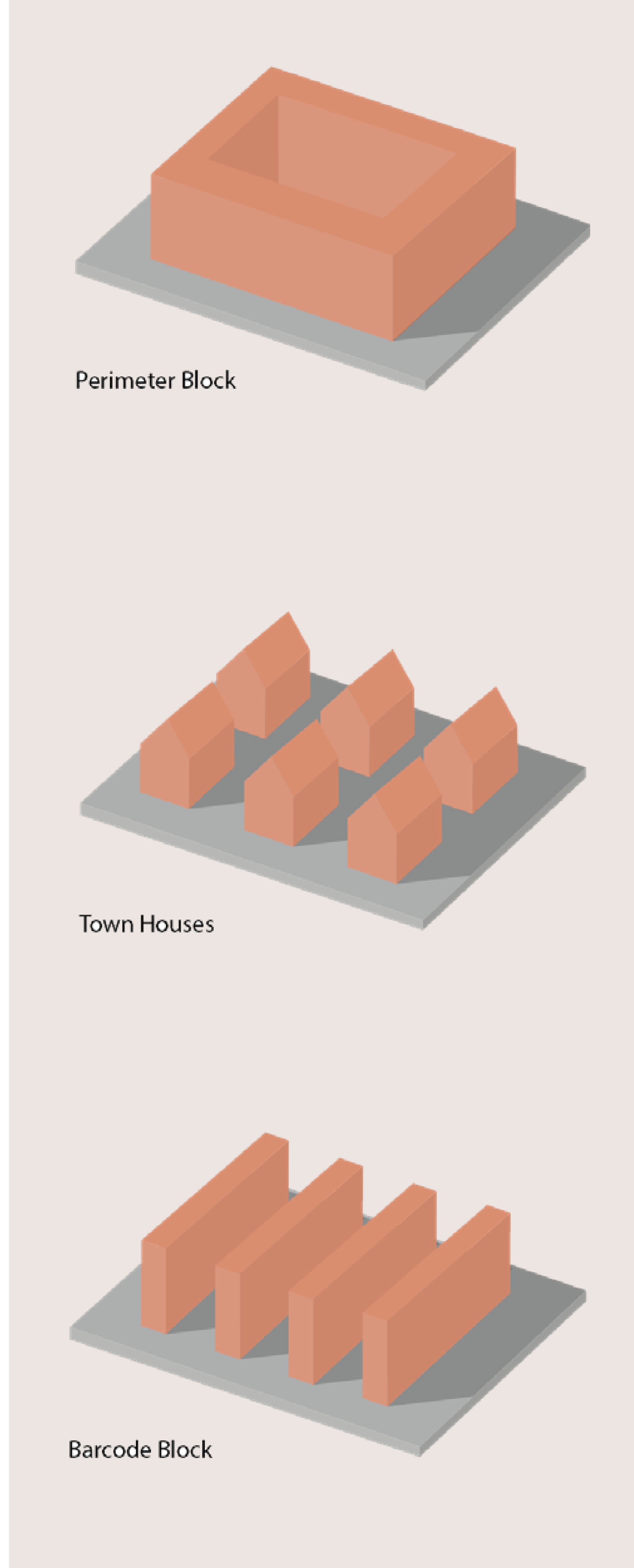
2021 | Bus stop existing in the site

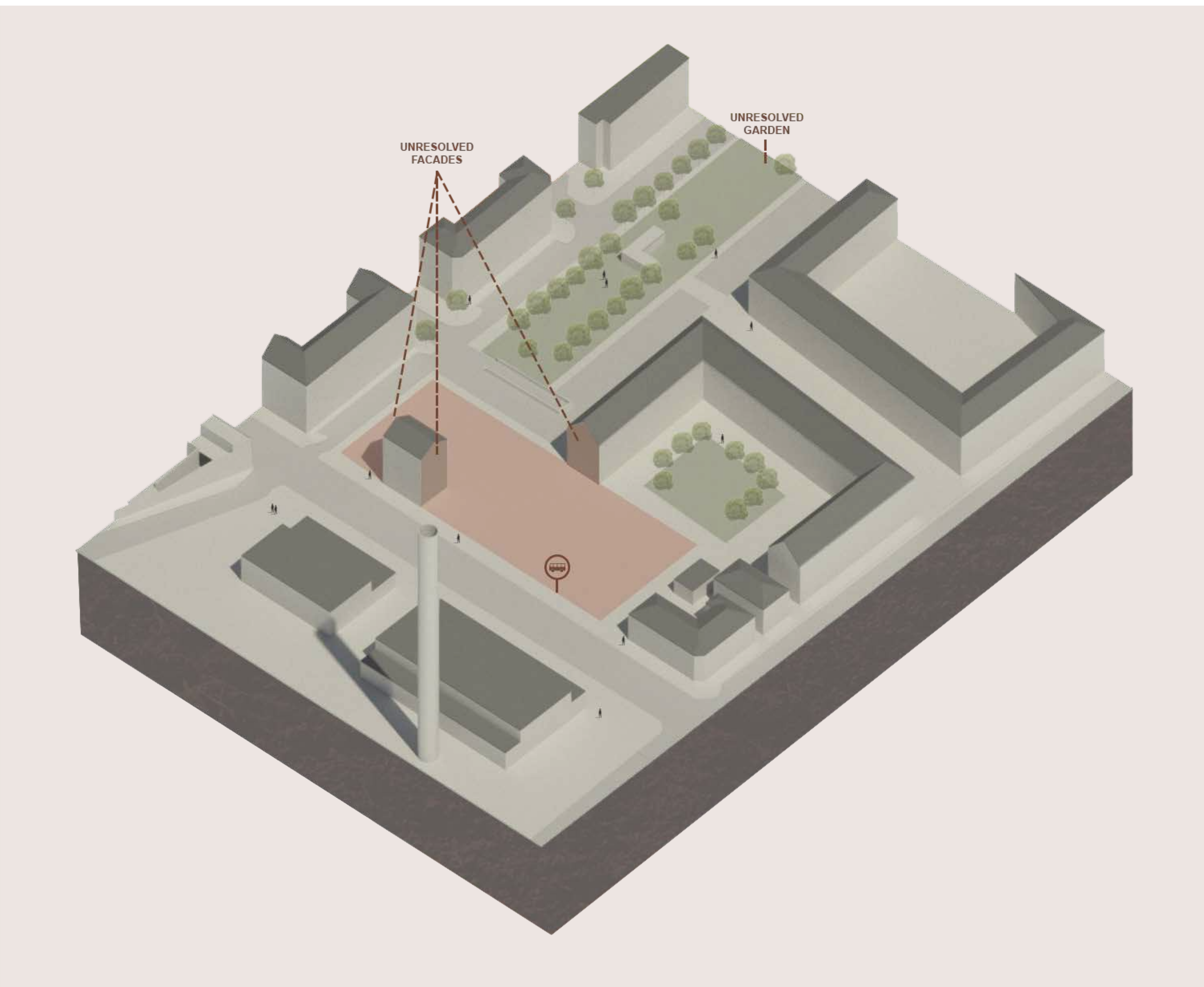
2021 | Unresolved facade of Sundholmsvej 57 and unresolved facade of Vibo's Complex

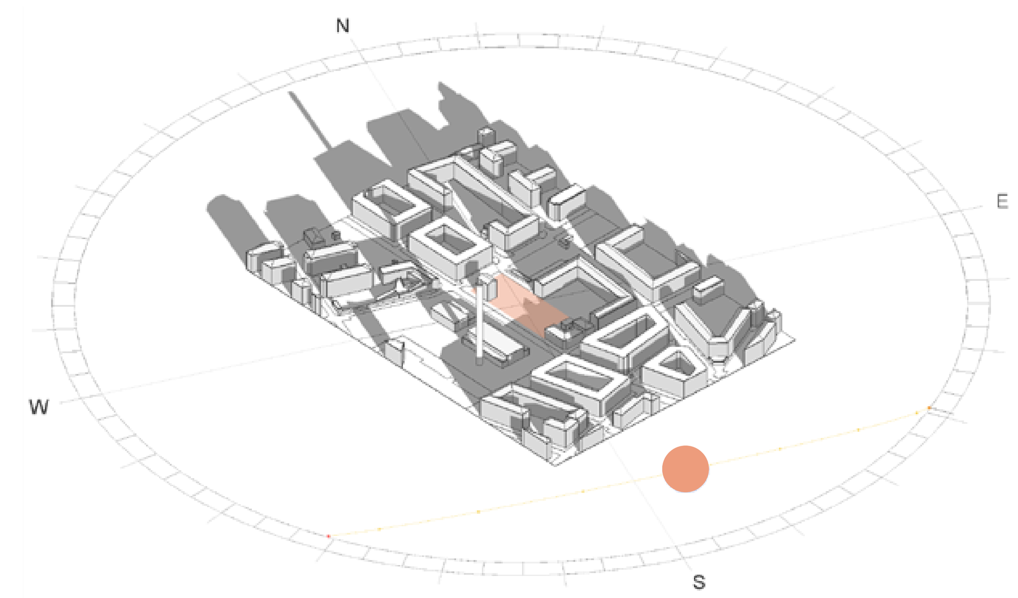
2021 | Parking entrance behind Sundholmsvej 57; Vibo's complex in front

2021 | Unresolved garden behind Sundholmsvej 57

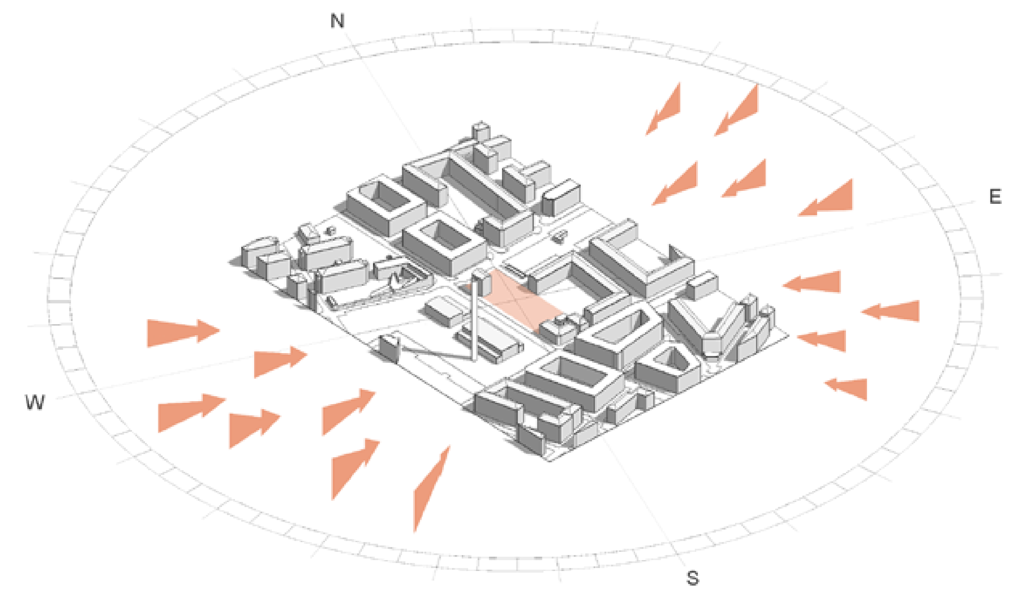
2021 | Children's day care on the unresolved garden behind Sundholmsvej 57





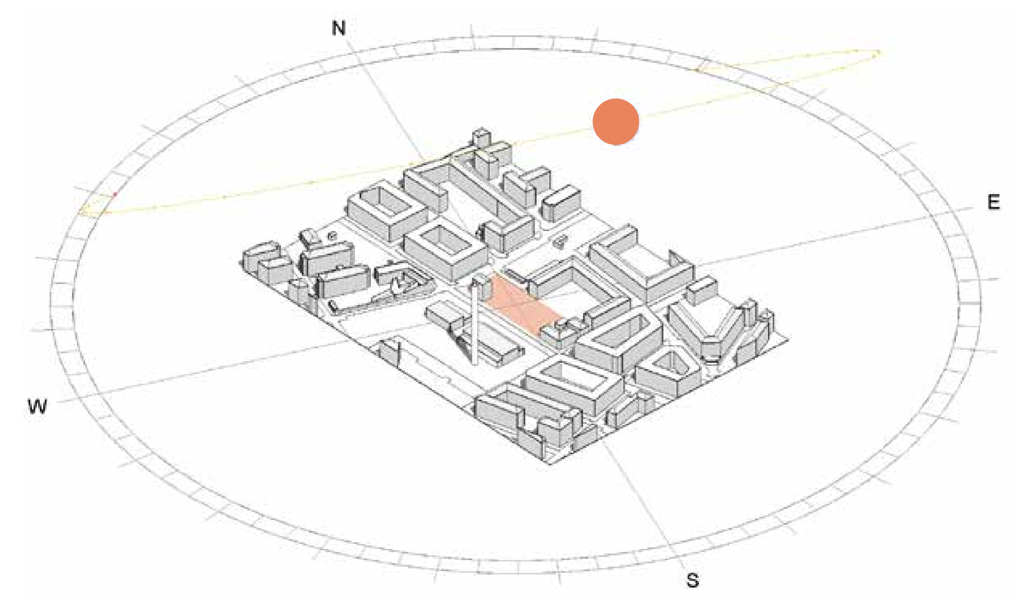


2021 | Shadows caused by the sorrounding buildings in the terrain, during the winter solstice, 21st of December at 13:00 h.

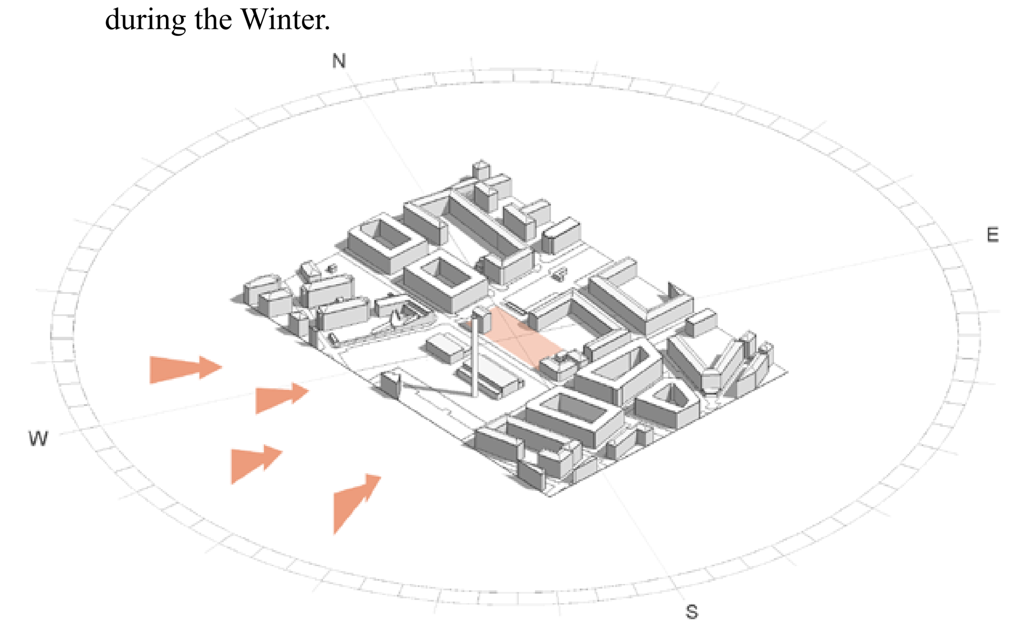


2021 | West, Southwest, and East winds representation affecting the terrain during the Winter.

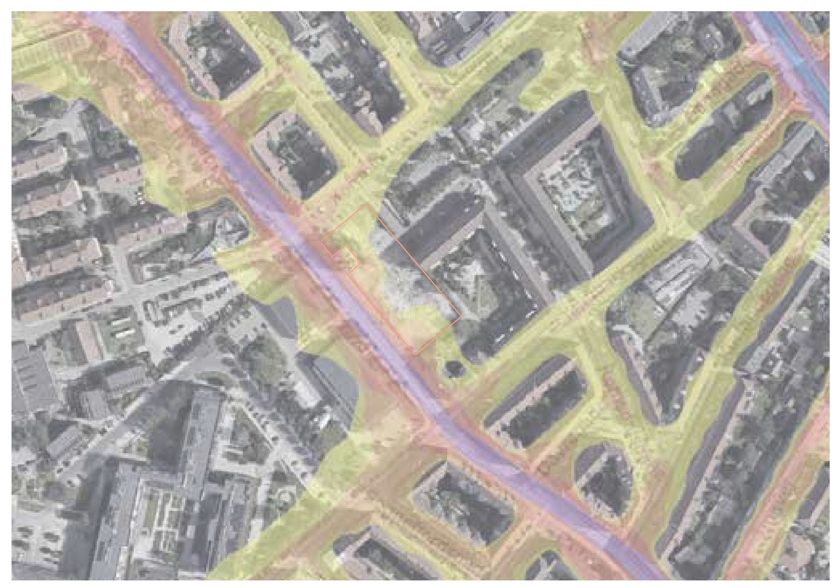
2021 | 2 meter water level rise representation affecting the terrain.



2021 | Shadows caused by the sorrounding buildings in the terrain, during the summer solstice, 21st of June at 13:00 h.



2021 | West and Southwest wind representation affecting the terrain during the Summer.



2021 | Noise representation on the streets surrounding the terrain.

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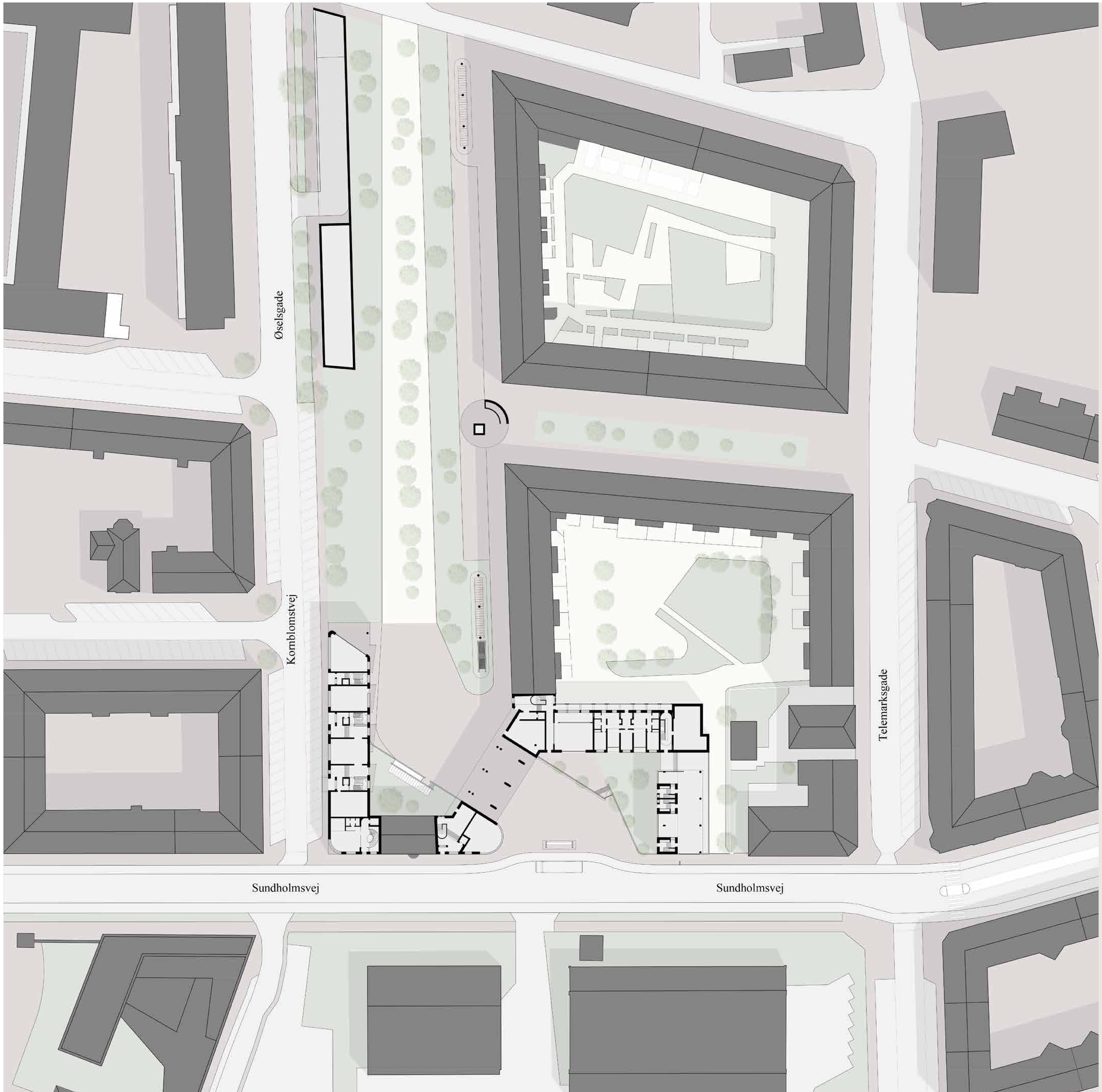
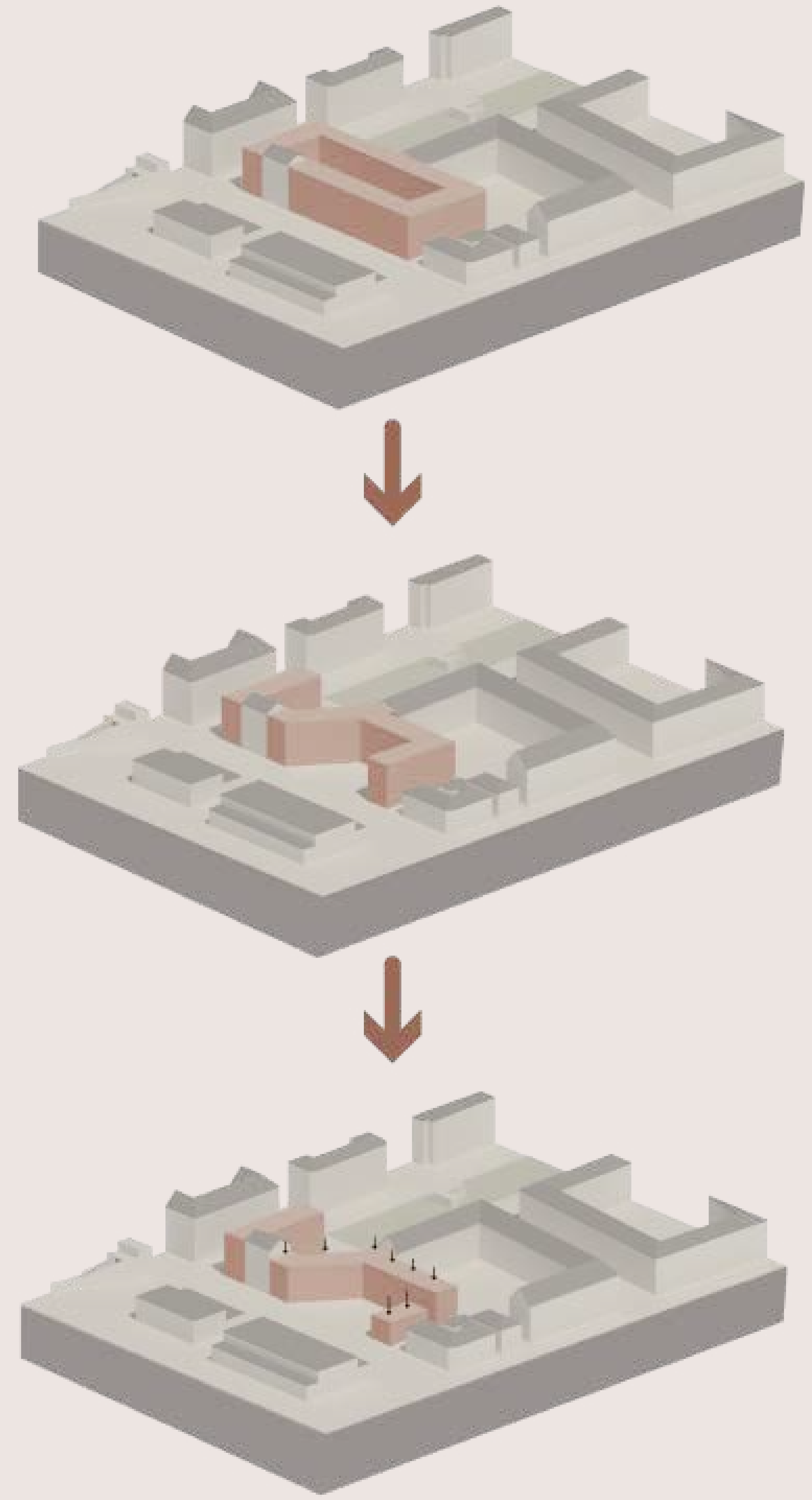
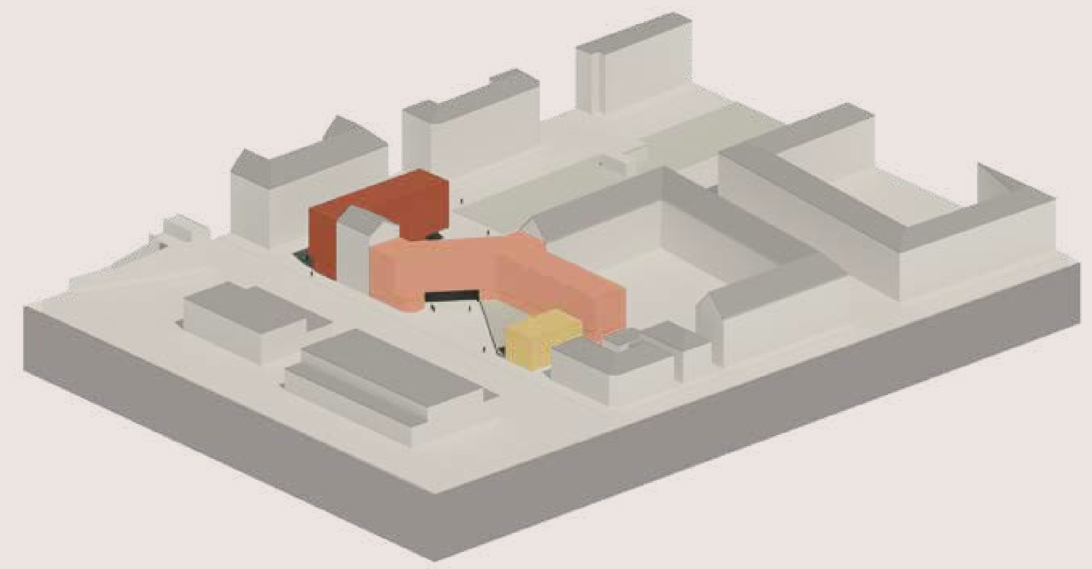




Form Progression of the Building Complex



The Building Complex:
- Complex A
- Complex B
- Complex C

Anchor Points of the Project

The project anchors it self onto different aspects:

- The connnection between the existing Bus stop and the unresolved garden;
- The three unresolved facades that face the terrain;
- The need to bring a different dynamic to the site;
- To relate to the sorrounding buildings;

The Brief

The program for this project results from the analysis of the existing urban plan for this location and on the study of the residential buildings surrounding the terrain.

The existing official urban plan proposes a residential building for the site, as this site is part of city's plan to increase the number of "beds" in the city (Copenhagen Municipal plan 2015).

The site is in a residential area, where houses are mostly of T1s and T2s typologies.

The terrain is a 10min walk away from the IT University of Copenhagen.

It was relevant to consider the existing bus stop and public garden adjacent to the site.

These two elements justified the choice to have the ground floor dedicated to the public, with the purpose of reactivating the unused garden to the north, connecting it to the bus stop through a commercial area in order to bring more life and activity to this part of the city. The public garden had to be reorganized for the connection to the building to be stronger.

My proposal considered that the parking lots that used to exist in the entrance of the VIBO's complex were deactivated and included in the extend underground parking lot. The access to the underground parking, had to be relocated so that it wouldn't break the connection between the garden and the building. The existing day care center was also relocated. This and the new entrance to the parking lot were aggregated in the same polygon and relocated to the side of the garden closest to the road, so that the space in-front of the VIBO's complex also would become more pleasant.

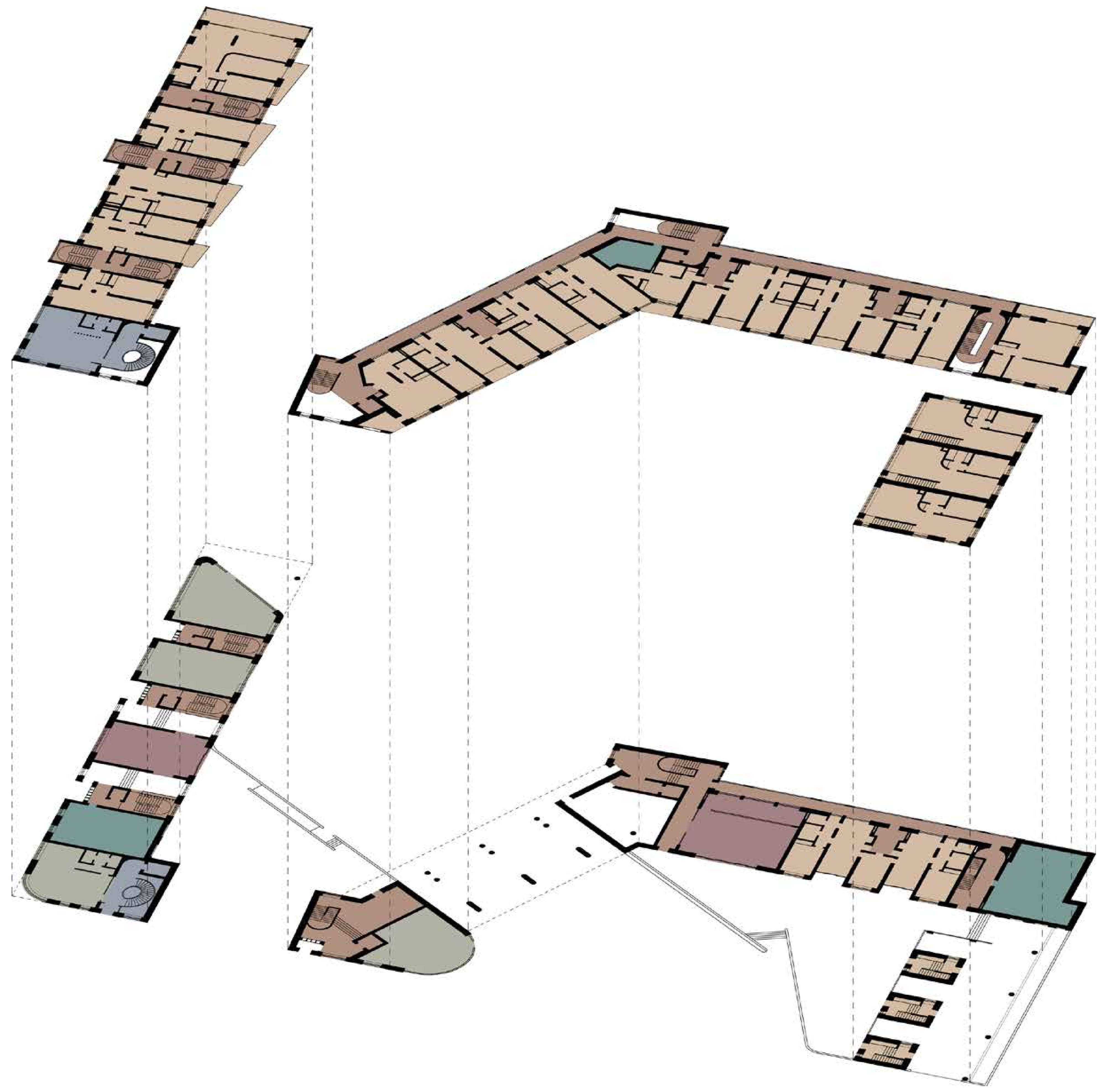
Part of the proposed complex was dedicated to office space. It is also seen as one more way to bring people to visit and enjoy the site.

3D Representation of the Existing Local Plan

Some of the Buildings studied to formulate the Brief

Programmatic

- Residential Programme:
  The houses proposed are mostly of a T1 typology with a possibility of turning some of the T1's into T2's. There are also houses of T2 and T3 typologies.
- Distributive System:
  Complex A - Left/right System;
  Complex B - Gallery distribution with entry atriums;
  Complex C - Autonomous entry for each house.
- Office Programme:
  In Complex A
- Stores/ Restaurants/ Cafe zones;
- Communal Areas for Residents;
- Storage/ Technical Rooms.



Programmatic Axonometry of the Building Complex

GROUND FLOOR PLAN | 1:200
THE TERRAIN IN THIS AREA IS MOSTLY FLAT, NO COUNTOR LINES ARE PRESENT

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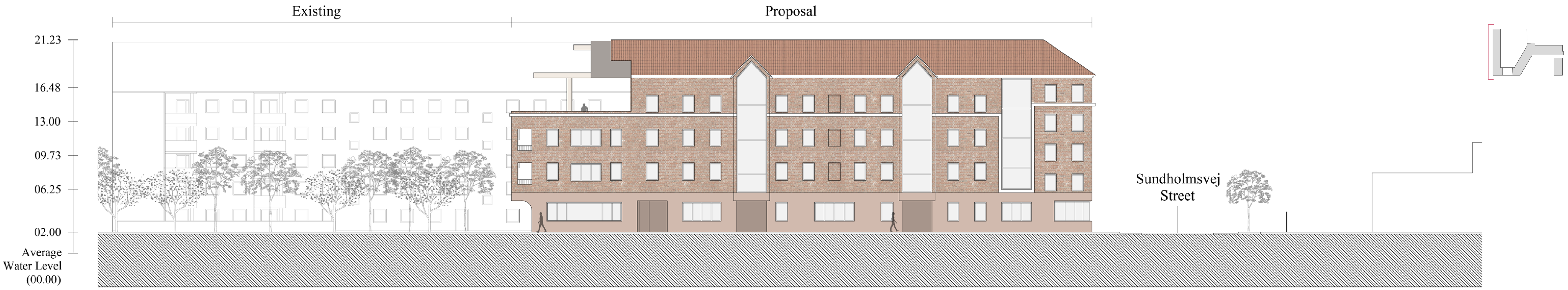
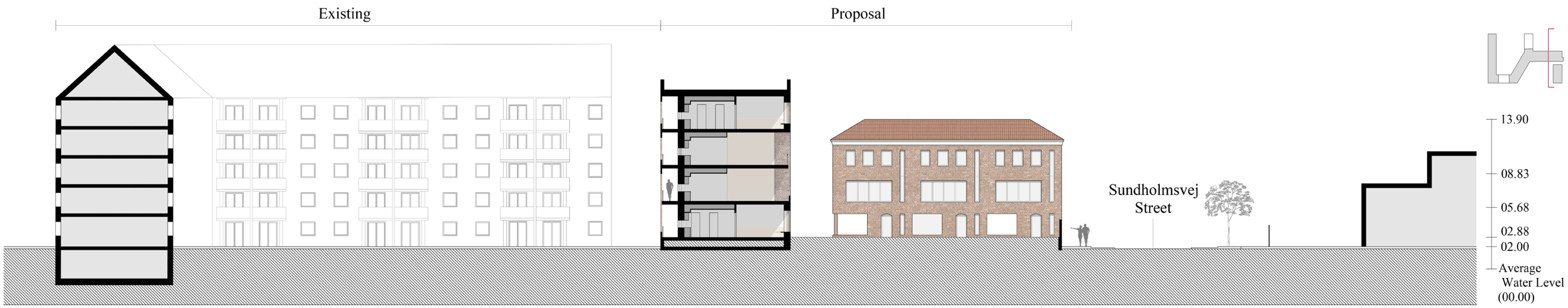
SECTION AA’



SECTION BB’



SECTION CC’

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FIRST FLOOR PLAN | 1:200

THE TERRAIN IN THIS AREA IS MOSTLY FLAT, NO COUNTOR LINES ARE PRESENT

AN NZEB APPROACH TO A PROPOSED COLLECTIVE HOUSING COMPLEX IN A CONSOLIDATED CITY BLOCK IN COPENHAGEN

FINAL MASTER PROJECT TO OBTAIN THE MASTER'S DEGREE IN ARCHITECTURE

FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA

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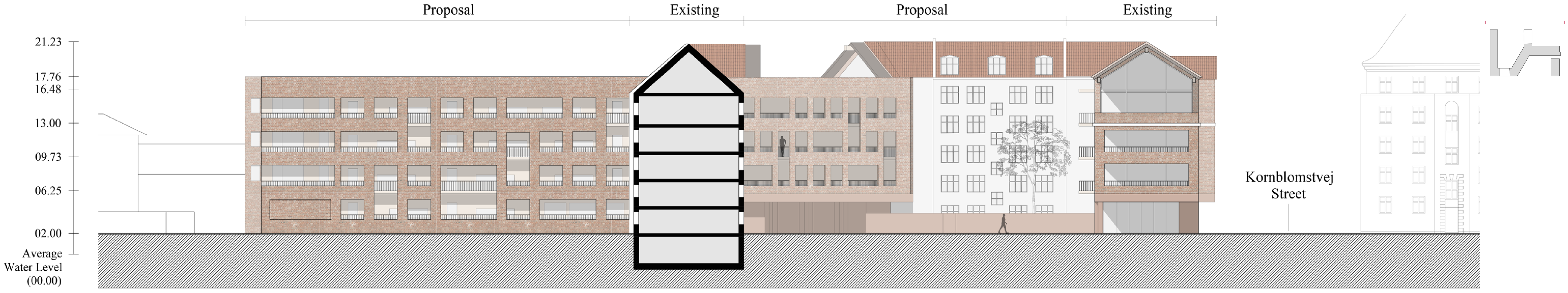

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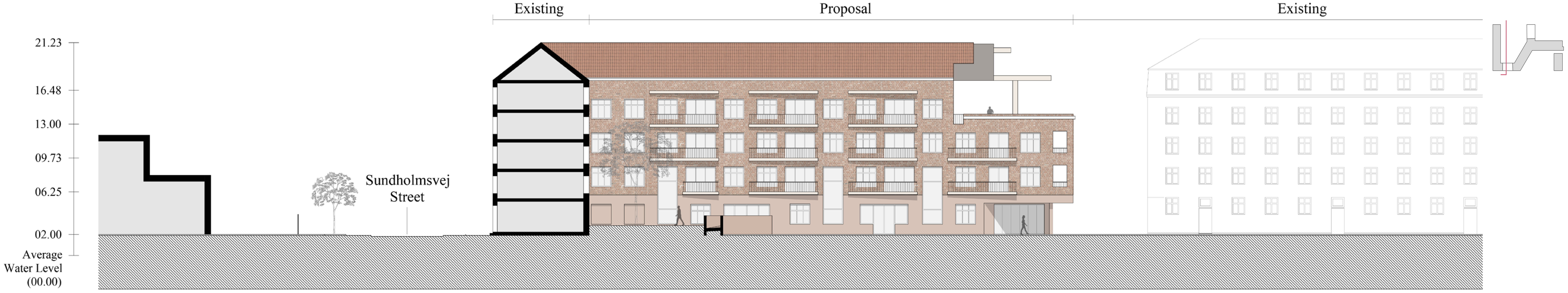

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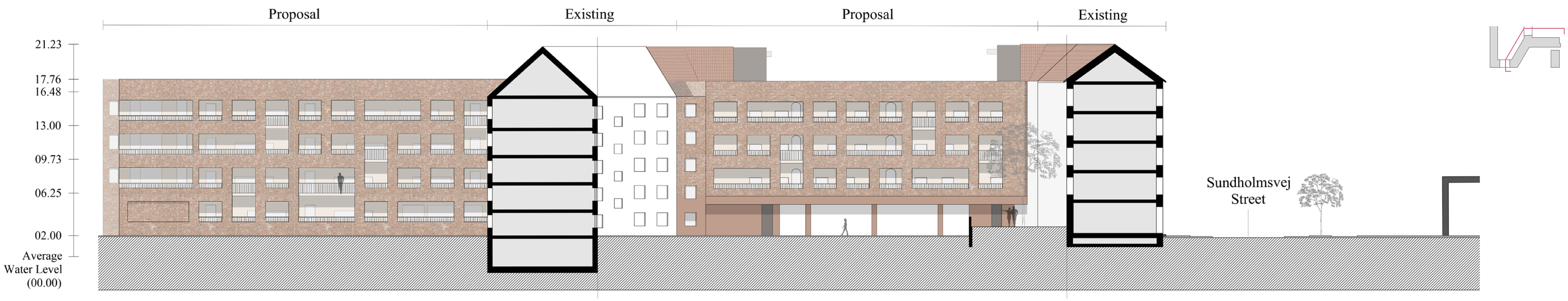

SECTION FF’

THIRD FLOOR PLAN | 1:200
THE TERRAIN IN THIS AREA IS MOSTLY FLAT, NO COUNTOR LINES ARE PRESENT

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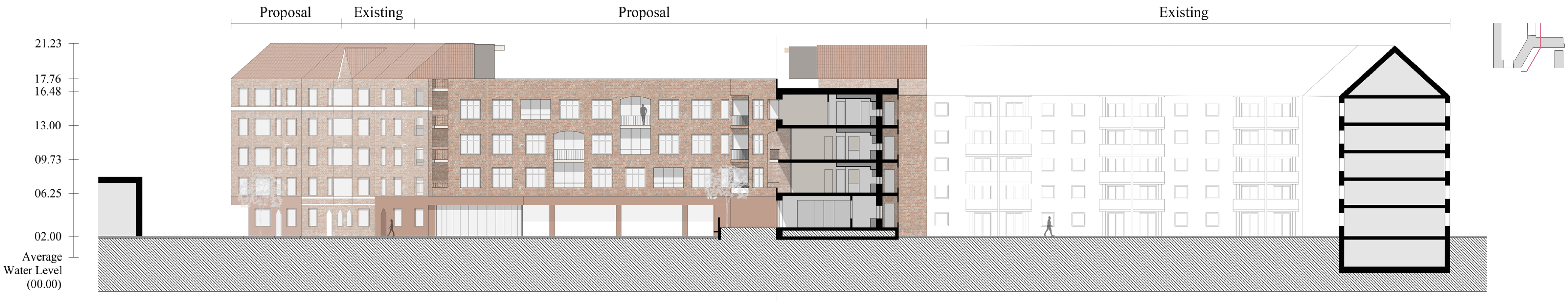

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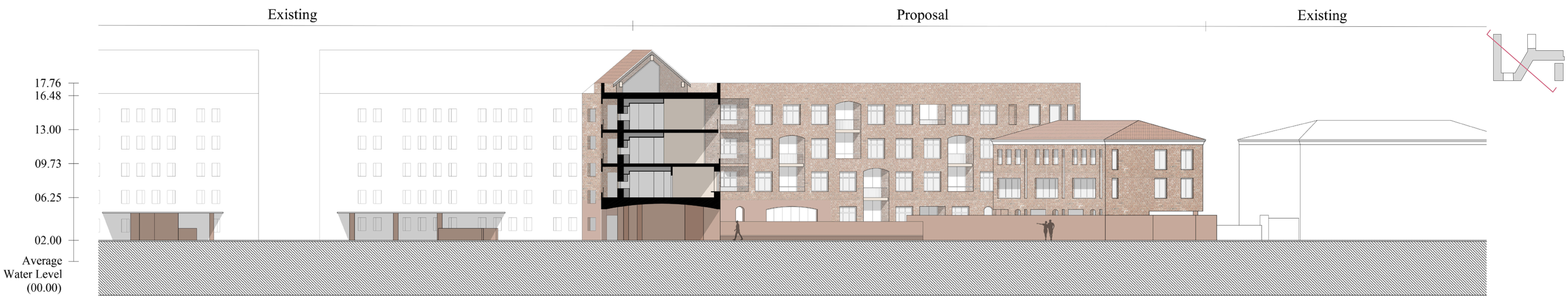
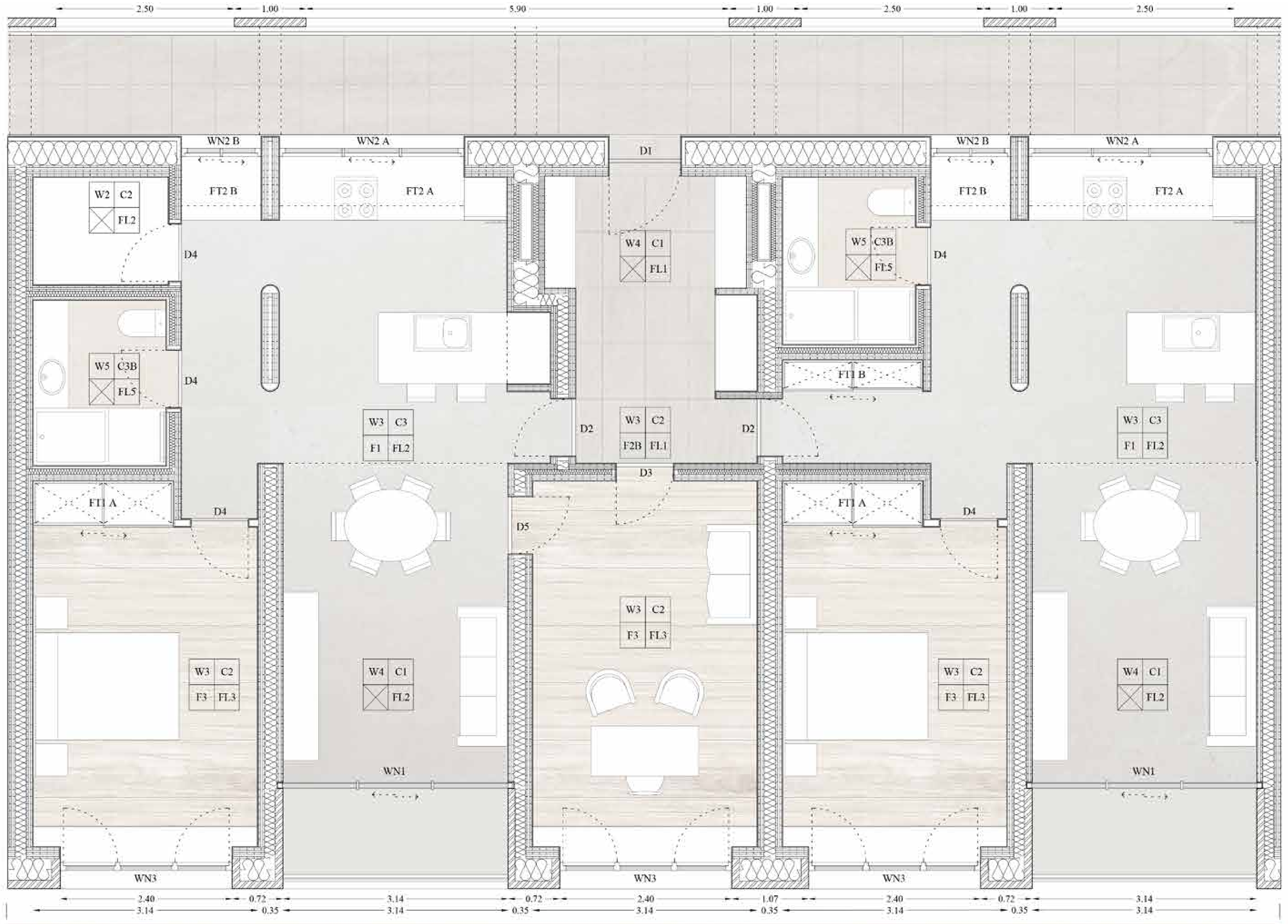


SECTION HH’



CLT

Concrete

Thermal and Acoustic Insulation

Gravel

Interior Finishes:

Walls (W)

W1	Birch Wood Paneling
W2	Painted Brick | color - NCS S 1505-Y70R
W3	Painted Plaster | color - NCS S 0603-Y80R
W4	Exposed CLT
W5	Ceramic Tiles | color - NCS 1002 - R

Ceilings (C):

C1	Exposed CLT
C2	Painted Plaster | color - NCS S 0603-Y80R
C3A	Painted Suspended Ceiling | color - NCS S 0603-Y80R
C3B	Painted Suspended Ceiling | color - NCS 1002 - R

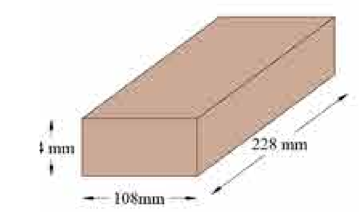
Footers (F)

F1	90 cm; Ceramic Tiles | color NCS S 2002-Y50R
F2A	90 cm; Ceramic Tiles | color NCS S 1502-R
F2B	50 cm; Ceramic Tiles | color NCS S 1502-R
F3	90 cm; Birch Wood Paneling

Flooring (FL)

FL1	Exterior Ceramic Tiles | color NCS S 1502-R
FL2	Linoleum Flooring | color NCS S 2002-Y50R
FL3	Birch Wood Flooring
FL4	Exterior Ceramic Tiles | color NCS S 2002-Y50R
FL5	Interior Ceramic Tiles | color NCS S 1502-R

Standard Danish Bricks Dimensions

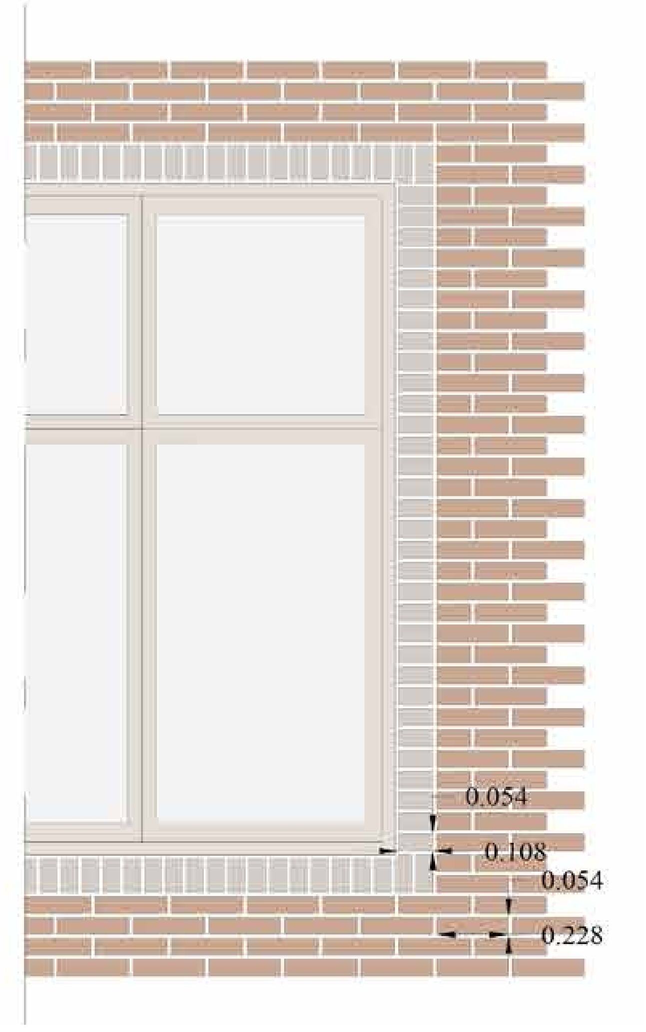


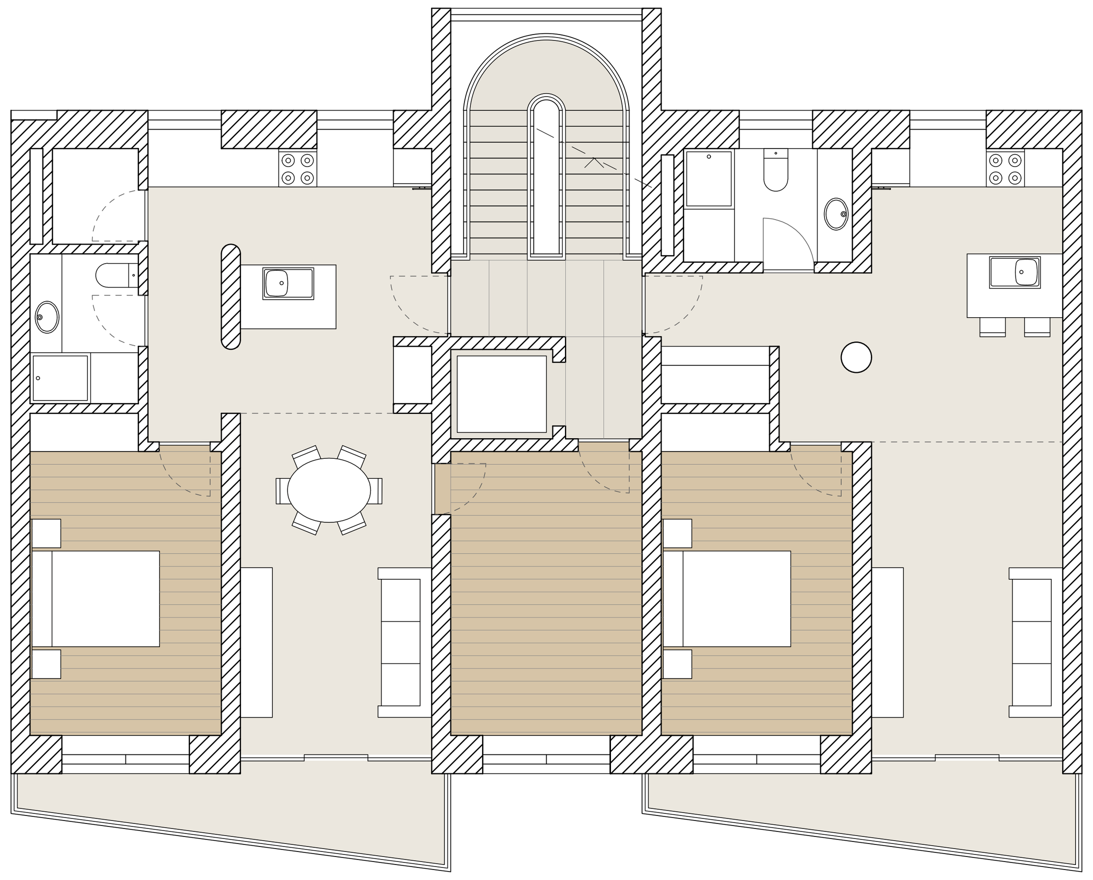
Joint size: 12 mm

Horizontal Width
Brick + Joint: 240 mm

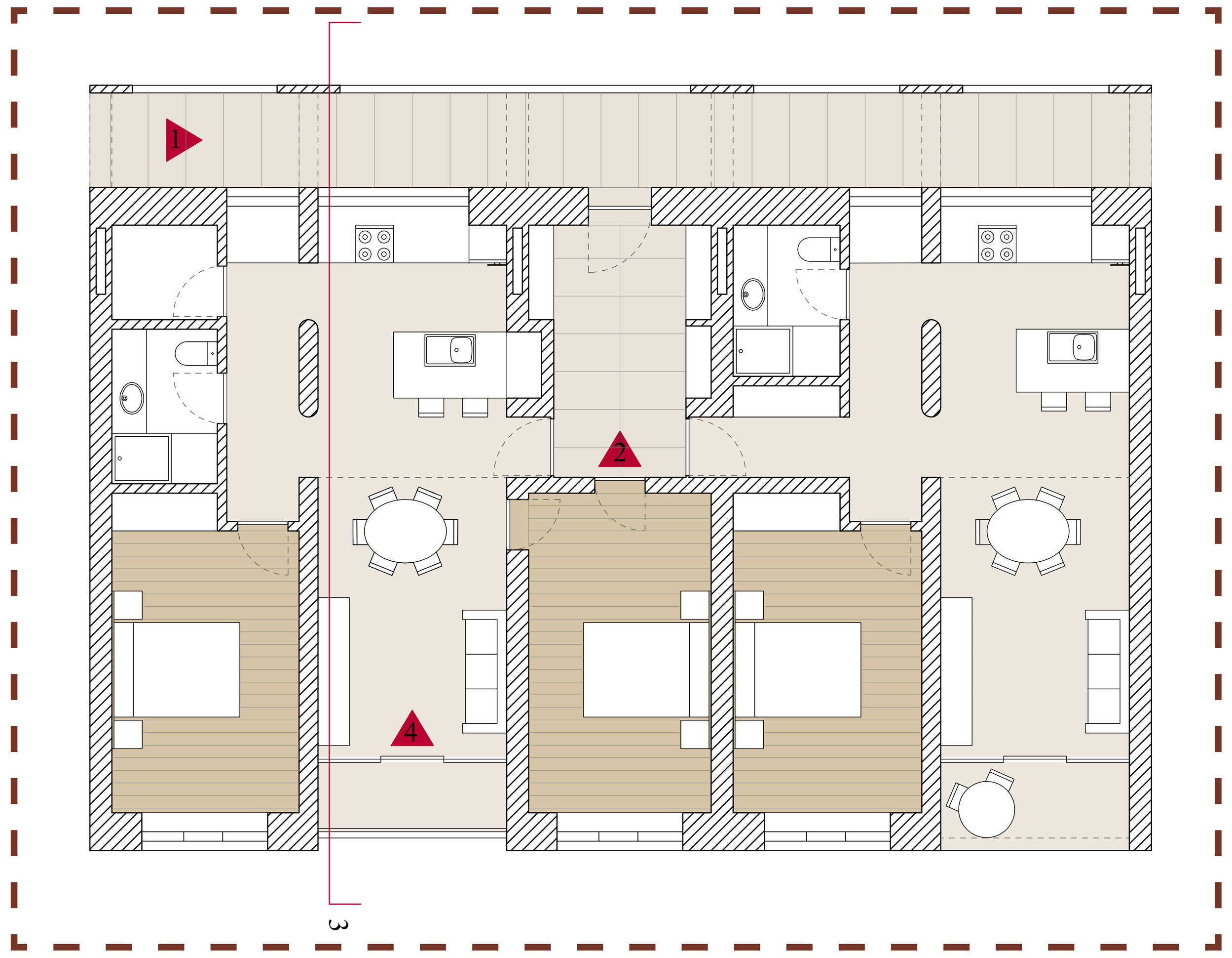
Horizontal Depth
Brick + Joint: 120 mm

Vertical
Brick + Joint: 62 mm

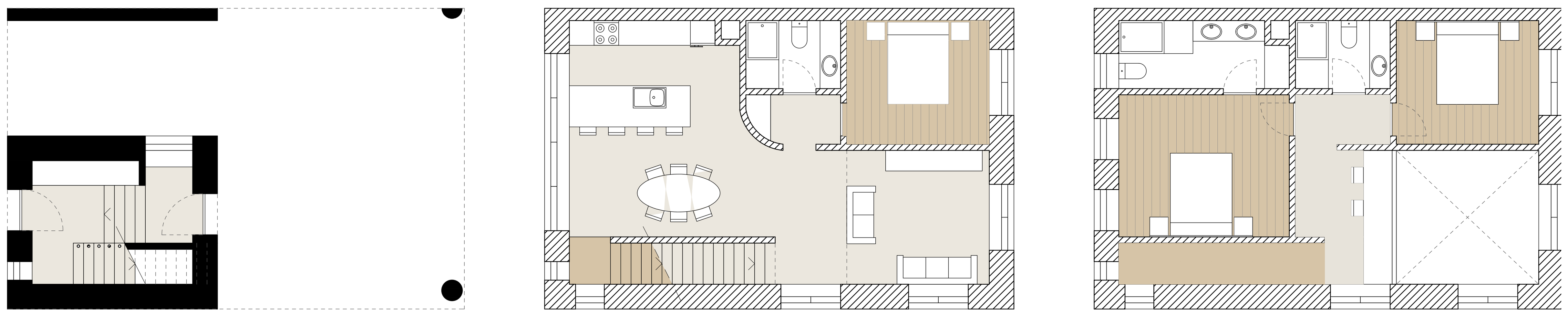




Complex A - Apartments | T1 Typology with T2 possibility



Complex B - Apartments | T1 Typology with T2 possibility



Complex C - Town Houses | T3 Typology

1. Gallery

2. Atrium

4. Frontal view from the balcony

3. Longitudinal view of a type 1 apartment from complex B

Typologies and Amount of Apartments

The building complex has different types of typologies.

T0	T1	T2	T3	TOTAL
3	32	5	3	43

There is the possibility for 13 of the T1 apartments to transform into T2's. There is a room anexed to the apartments that can be used for external use (example: as an office) or to be used an extra room to the house.

Average areas of the Apartments

T0	T1	T2	T3
49, 50 m²	58, 85 m²	86, 74 m²	130 m²

Average areas of the Existing Apartments

T1	T2	T3
58, 40 m²	85, 50 m²	103, 20 m²

The areas of the apartments can be compared to the areas of the apartments in the sorrounding buildings. T3's, however are not apartments, but Town Houses, so they are bigger than the existing T3's.

Organization of the Modules influencing the Facades:

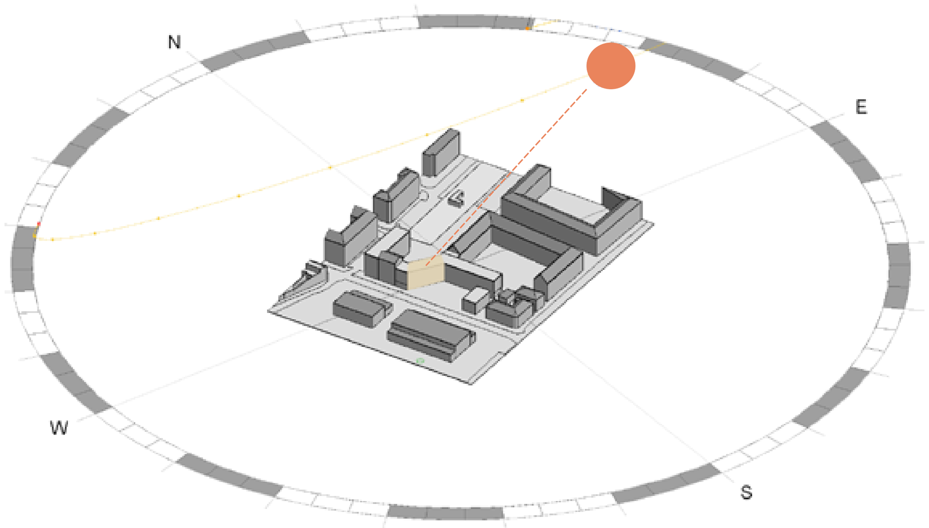
- Atrium Module
- Living room Module
- Bedroom Module

Orientation Relating to Climate

The preferred orientation when designing a good performance building would be North-South, to take advantage of the sun path.

However, the site was orientated North-west – South--east and there were buildings that were already built, affecting the space.

The solution was to rotate parts of the complex to face this direction, while the rest of the facades would respect the terrain and street layout.



Rotation of the central block to face the exact direction of South.

The organization of the house is a response to the prefereable orientation of the building. The places of stay should be facing South to receive the most sunlight and to be gradually heated by the sun.

The kitchen and bathroom should be on the colder parts of the apartment has they don't need to be as confortable as the places of stay.

Organization of the Modules influencing the Facades:

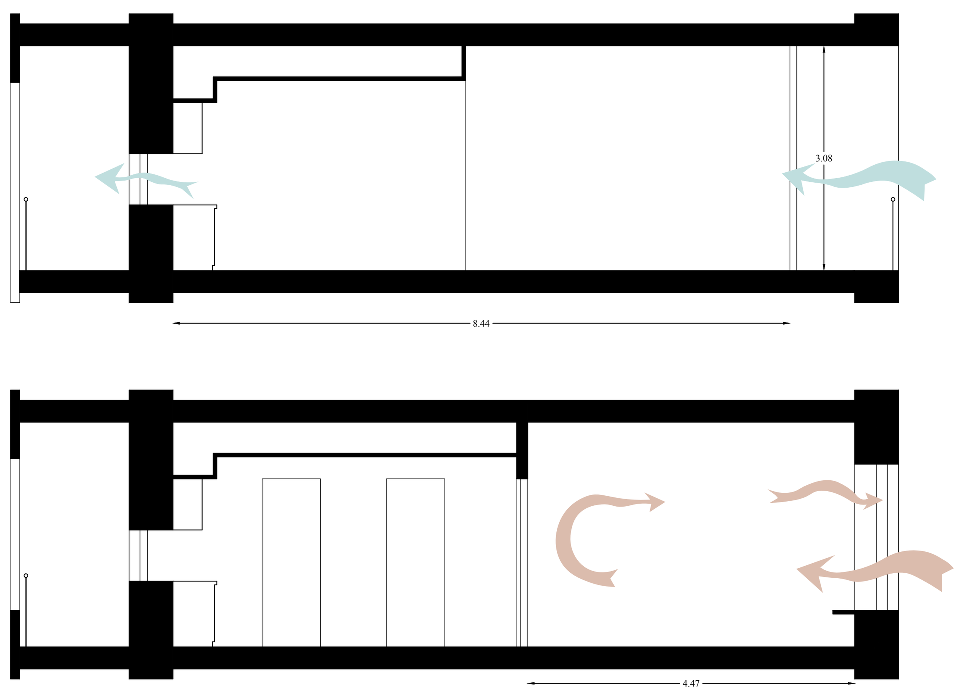
- Rest Spaces
-Circulation
- "Water Spaces"

Natural Ventilation

It was assured that the rooms where most of the time would be spent (living room, kitchen, and bedroom) could have cross-ventilation and when this wasn't possible (when the door to the bedroom is closed) one sided-ventilation should be possible.

The unobstructed connection between the living room and kitchen allows for cross-ventilation, as the distance between the windows is less than five times the height of the spaces.

In the bedroom, when the door is closed, the one-sided ventilation is granted through the apportioned windows used, so that the air could circulate through the room and have a different way out. The room is smaller than 6 meters to allow for one-sided ventilation. When the bedroom door is open, it can cross-ventilate with the corridor/kitchen windows.



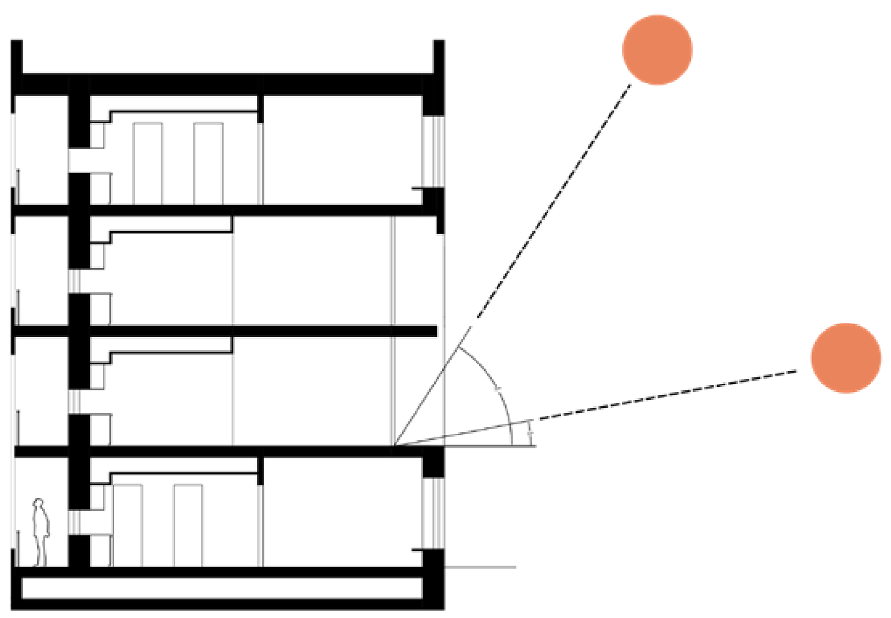
Cross-ventilation in the living room/kitchen (top); One sided ventilation in the bedroom (bottom).

Passive Solar

The orientation of the complex, the dimension and type of windows used contribute to control the passive solar (heating) gains the building has. It was necessary to maximize these gains in the winter minimizing them during the summer. This can be achieved through the positioning of the window in the envelope and balconies.

The dimension of the windows to the south were maximized to be almost the size of the wall. The curtains used should be of a translucid material to allow the daylight to penetrate but still give some privacy to the users.

During the sun the sun's highest is 57ºC. During the winter the sun's lowest angle is 11ºC.



Balconies allow to receive the most amount of sun in block B.

Thermal Optimized Envelope

This was determined by the structural and building systems used in the external walls, the roof, the ground-floor slab, and the windows/doors used. The construction elements were chosen to respect the parameters required by the Danish Building Regulations (BR18) - "Building Class 2020".

It was also necessary to have a continuous layer of insulation throughout the whole complex to prevent any thermal bridges and maintain the indoor temperatures at a comfortable level.

Construction Elements	Materiality	U-Value of the Element (W/m²K)	U-Value "Building Class2020" (W/m²K)
Brick Exterior Wall	Brick 12mm Air Space 3mm Wood Fiber Insulation 27mm CLT Panel 15mm Plaster Cladding 1,5mm	0,12	0,30
Wood Exterior Wall	Wood Cladding 1,5mm Air Space 3mm Wood Fiber Insulation 34mm CLT Panel 15mm Plaster Cladding 1,5mm	0,11	0,30
Flat Roof	Paving Stone 3mm Air Space 3mm Hard Wood Fiber Insulation 6mm Wood Fiber Insulation 16,5mm Gravel 12mm CLT Panel 20 mm	0,19	0,20
Ground-floor Slab	Linoleum Flooring 1,5mm Plywood 1,5mm Air Space 3mm Hard Wood Fiber Insulation 6mm Wood Fiber Insulation 14mm Concrete 30 mm	0,18	0,20
Triple Glazed Wood Windows	U_g = 0,53	0,80	0,80
Glazed Doors	U_g = 0,53	0,9	1,00

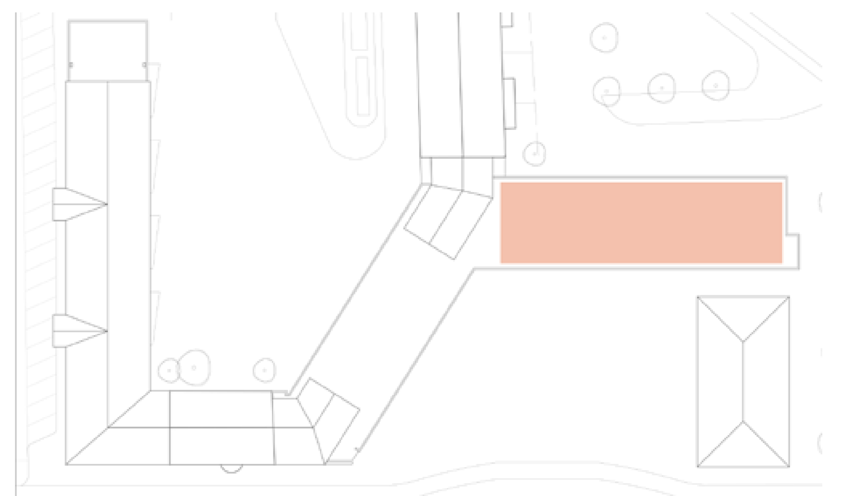
Active Strategies

To heat the air and the water inside the apartments, an air-to-water heat pump system would be used. This system is powered by photovoltaic panels installed in the roof of the complex (72m2 of photovoltaic panels were estimated to be necessary to power the heat pumps in the complex), and then it heats up the rooms through radiators: The radiators were placed in the bedroom and in the living room the closest possible to the windows, as this is the coldest part of the room and can help counteract the possible drafts. In the bathroom, the radiators appear as a towel heater.

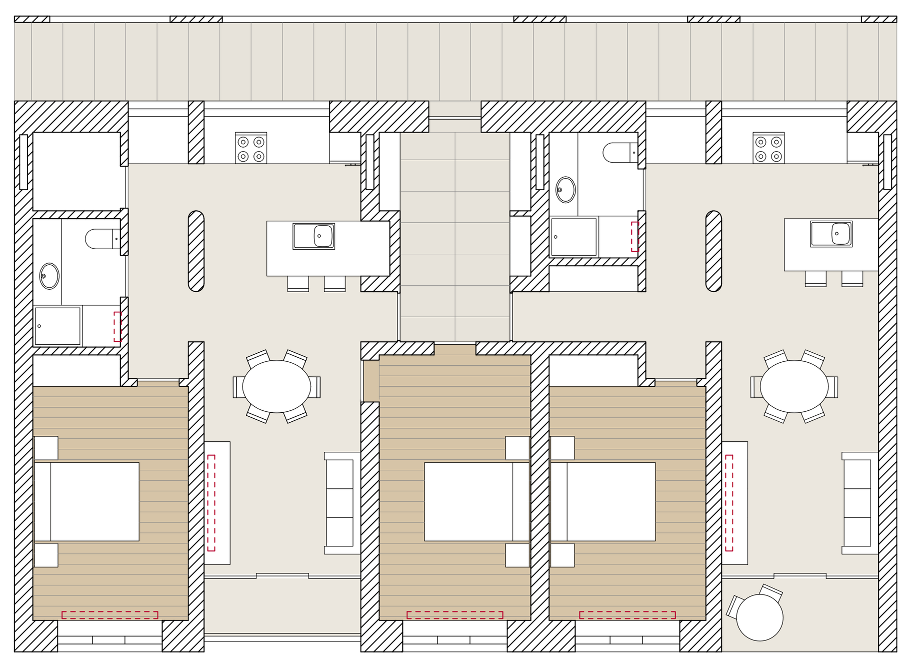
The hot water heated up by the heat pumps is stored in centralized boilers in the designated technical spaces on the ground-floor, that is then distributed to each apartment.

The electricity required to meet the needs of the building is produced through solar panels that are also located on the roof of the building. There wasn't a calculation made on how much square meters of solar panels would be needed to sustain the whole complex, however the space reserved for this panels is around 400 m2 and, if needed they can also be placed on the angled roofs.

The photovoltaic panels and solar panels would be placed of the flat part of the roof so that they can be set to the most desirable angle (perpendicular to the sun), in Copenhagen it would be around 40º.



Space on the flat roof reserved for the solar and photovoltaic panels, around 400 m2.



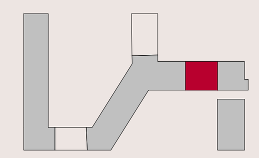
Location of the radiators in the apartments.

Energy Performance Evaluation

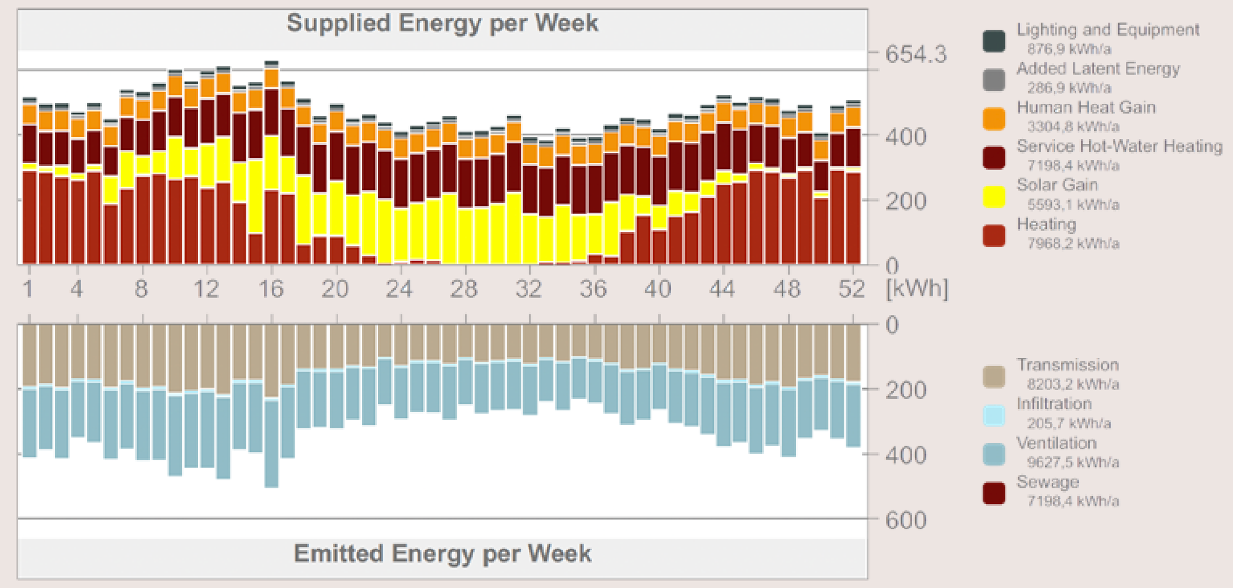
To understand how the building would behave in terms of its energy performance, some evaluations were made in ArchiCAD.

The evaluation was made to two apartments located in the ground floor of Block B, with a gross floor area of 161,91 m². This was assume to be the most critical part of the project.

Some key values of this evaluation are:



Building Shell Performance data - 1,56 ACH
Energy Consumption - 123,04 kWh/m²a
Primary Energy - 174,15 kWh/m²a



This graphic shows the thermic gains and losses along the 52 weeks of the year.

On top, It is possible to see that during the summer (week 20-36) there are more solar gains than during the winter (week 48-52). During this time there are almost no solar gains, due to the shadowing of Block C and the orientation of this part of Block B.

Energy Consumption by Targets

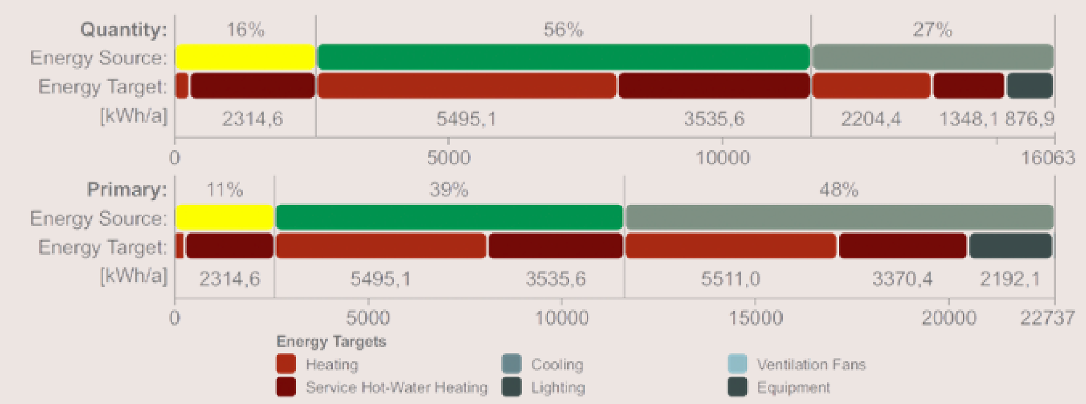
Target Name	Energy Quantity kWh/a	Primary kWh/a	Cost GBP/a	CO_2 Emission kg/a
Heating	7968	11274	0	317
Cooling	0	0	0	0
Service Hot-Water	7198	9220	0	194
Ventilation Fans	19	49	0	2
Lighting & Appliances	876	2192	0	126
Total:	16063	22737	NA	640

In these graphics it is possible to understand that 49% of energy consumed is for heating and 44% of energy consumed is for the heating of water, the source is mainly from the heat pump installed. However, in the energy needed to heat the water, the Solar (Thermal and PV) panels installed are a big contributer.

Only 5% of the energy consumed is for electricity.

Energy Consumption by Source

Source Type	Source Name	Energy Quantity kWh/a	Primary kWh/a	Cost GBP/a	CO_2 Emission kg/a
Renewable	Solar (Thermal & PV)	2583	2583	NA	0
	External Air	9030	9030		0
Secondary	Electricity	4449	11123	--	640
	Total:	16063	22737	Not Applicable	640



In this graphic it is possible to see that the 72% (16% + 56%) of the energy consumed by the building is renewable energy.

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