Master Thesis

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Socially and environmentally sustainable transformation of existing buildings

Frederiksberg Hospital

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Abstract

The following report presents and illustrates a design proposal for a socially and environmentally sustainable transformation of the existing buildings at Frederiksberg Hospital - from hospital to a new open and welcoming neighborhood. The proposal serves as the Thesis Project, written in relation to the masters programme in Architecture, MSc in Engineering at the Department of Architecture, Design and Media Technology at Aalborg University. The thesis investigates through theoretical studies, site analysis and other studies, how to transform buildings with respect for history, qualities and atmosphere. The thesis is developed with the *Integrated Design Process (IDP)* (Knudstrup. 2004) and *Transformation of Architecture - Five Methods* (Andersen. 2015) as the design approach and underlying structure of the thesis. The methods are approached simultaneously where IDP contributes to that the project has progressed through an iterative process, where research has been conducted through interdisciplinary investigations and design solutions have been developed and evaluated due to functional, technical and aesthetical aspects. Along the iterative process the methodology of Transformation of Architecture has been used to collect and develop knowledge on the site of Frederiksberg Hospital as well as the buildings to transform and further which disciplines to use hereof.

The aim with the thesis is to discover a framework for restoration and energy-optimization of existing structures with an extended intention of preserving existing values. The design proposal thereby consists of a general master plan of the hospital site and a detailed transformation of three selected buildings and the surrounding area.

Den følgende specialerapport præsenterer og illustrerer et designforslag til en social og miljømæssig bæredygtig transformation af eksisterende bygninger ved Frederiksberg Hospital - fra hospital til en ny, åben og imødekommende bydel. Designforslaget er et specialeprojekt, skrevet i forbindelse med kandidatuddannelsen i Arkitektur, civilingeniør ved Institut for Arkitektur og Medieteknologi på Aalborg Universitet. Gennem teoretiske studier, site analyser og andre studier, undersøger rapporten, hvordan bygninger transformeres med respekt for deres historie, kvaliteter og atmosfære. Designforslaget er udviklet med *Den Integrerede Design Proces (IDP)* (Knudstrup. 2004) og *Arkitekturens transformation - fem metoder* (Andersen. 2015) som fremgangsmåde og underliggende struktur for projektet. Metoderne er bearbejdet samtidigt, hvor IDP bidrager til at projektet har udviklet sig iterativt, hvor analyser er udført gennem interdisciplinære undersøgelser, og hvor designløsninger er udviklet og evalueret på baggrund af funktionelle, tekniske og æstetiske aspekter. I forlængelse af den iterative proces er metoden Arkitekturens transformation - fem metoder brugt til at samle og benytte data om hospitalsgrunden og bygningerne som skal transformeres, og yderligere hvilke discipliner der skal bruges herunder.

Formålet med specialet er at finde en ramme for restaurering og energioptimering af eksisterende strukturer med en udvidet intention om at bevare de eksisterende værdier. Designforslaget præsenterer derfor en overordnet situationsplan over hospitalsgrunden samt en detaljeret transformation af tre udvalgte bygninger og det omkringliggende område.

Reading guide

The following master thesis report is a collection and presentation of conducted methods, theoretical studies, analysis, and appurtenant studies which together shape the framework of the project and constraints its focus. Selected material from the underlying process of design is presented lastly to give an understanding of the development of the project from initial ideas towards a final design.
The project has taken its point of departure in tender material from Frederiksberg municipality. The following link will guide the reader to the webpage, where all material given for the competition is uploaded:
https://www.frederiksberg.dk/frederiksberghospital

The report is divided into eight chapters; Prologue, Theoretical Studies, Analysis and Studies, Delimitation, Presentation, Process, Epilogue and Appendix. All the chapters are presented with metatexts, so the reader gets an idea of what's to come and is reflected upon in the end of the report. In addition to the report, a drawing folder is made with additional illustrations on a bigger scale.

All literature and illustrations not created by the group is quoted and referenced due to the Harvard reference method. The sources used are collected and divided into reference-, literature-, and illustration lists and can be found in the Epilogue, where illustrations produced by the group are not mentioned here. Maps and illustrations with north arrow will have an arrow next to the illustration number and text.

The following scales, interventions, and keywords are presented to give the reader an intentional understanding of the report. The scales describe the scales used and developed throughout the project to create a broader understanding of the prepared material, where the key words give an indication of important key subjects used throughout the project. The interventions are connected to the optimization of the selected buildings where different ranges of interventions is used to develop the design

Ill. 1.

Scales

Big scale	*The city of Frederiksberg and masterplan of the hospital ground*
Medium scale	*The project site and the buildings nearby*
Small scale	*The buildings to transform*

Interventions

Original	*Original elements are used as they are without changes*
Careful	*Few elements are optimized with the same aesthetics as the existing*
Medium	*Elements are optimized more with the same aesthetics as the existing*
Radical	*The section is optimized with less or no focus on the existing aesthetics*

Keywords

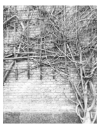
Original buildings	*The building is described as it was when it was built without changes*
Existing buildings	*The buildings as they are used and look today*

01 Prologue

02 Theoretical Studies

03 Analysis and Studies

04 Deliminations



Ill. 2.

01. CHAPTER

This chapter serves as an introduction for the rapport as it presents and specifies the focus. Furthermore, it presents the general aspects of the project, such as location and stakeholders. Moreover, the methodologies and project approach is identified.

PROLOGUE

Ill. 3.

Ill. 4.

Motivation

The past is more accessible than ever before. Knowledge within historical research, scientific analysis, object collections, and pictures are put together in large 'memory machines' as museums, books, in cities and landscapes. Today, not only the individual buildings are preserved, but even parts of cities, historical town centers, and cultural landscapes as the criteria for preservation-worthy buildings increase and include a longer list of developments (Braae & Hansen. 2007). Prognoses predicts that 70% of architectural assignments in the future will have to do with transforming existing facilities. Therefore, instead of creating new buildings the focus will be on converting or adding to buildings that others have put in this world (Harlang. 2011). This raises the need for a system or a way of working with transformation of buildings to ensure the qualities, the historic and unique details and the general feeling and atmosphere of the places are preserved. The thesis therefore investigates this issue and proposes a system, a method for transforming buildings while preserving the unique qualities of the atmosphere. The increased demand and wish for preservering older buildings might be a response to the present architecture, where individuality, richness in details and character in many ways is missing. A lot of the architecture built today and in the later years all look the same, they all use the same varied materials, look-alike windows and similar shapes and forms. The architecture today is missing some of the qualities that are so prominent in older buildings; tactility, rhythm and hierarchy. Though, preservation of old buildings should not just be for preservation-sake because the buildings are part of history but because the buildings, in their architecture, their character still brings something unique to the built environment. Old historic buildings are not only beautiful but also filled with atmosphere and memories as well as being embedded in the local understanding of an area. Cultural recycling is a term explaining the reuse of the cultural heritage when transforming buildings into new functions and uses. The term focuses on continuity, appreciation for history and acknowledgement of its value (Braae & Hansen. 2007). Cultural recycling is everywhere today, from closed down industrial-architecture turned into culture centers to old courtyard farms transformed into dwellings. It operates with a dialog between new and old and ensures a continued appreciation for the former life and functions of the buildings and other developments.

Methodology

Arkitekturens transformation handler om at foretage indgreb i en eksisterende fysisk situation. [Transformation in architecture is about making architectural interventions in an existing physical situation.]

Nicolai Bo Andersen (Andersen. 2015. p. 82)

This thesis builds its methodological basis on a combination of two methods that respectively describe different working methods as well as an overall work structure. This is used to relate the project to a definitive goal of developing a transformation matrix where technical, functional and aesthetic values are processed equally, and shows which position this thesis takes when working with transformation. The methods are *The Integrated Design Process* and *Transformation of Architecture - Five Methods* and together the two will be used as an underlying structure of the thesis and be approached simultaneously.

Mary-Ann Knudstrups' design method The Integrated Design Process (IDP) is used as a design approach to develop the transformation of the buildings at Frederiksberg Hospital. The method helps ensure a balance between both architectural and engineering elements throughout a process which leads to a final design. The phases, divided into five, overlap throughout the process and can be implemented in different stages of the thesis as a tool to enhance the iterative work (Knudstrup. 2004). This method overall describes the work structure of the thesis whereas the following is an in depth method working with all the facets of transformation. The methodology of Transformation of Architecture - Five Methods by Nicolai Bo Andersen describes the work with transformation and cultural heritage by using five individual methods to collect and develop knowledge on buildings to transform. With the use of the method, studies of materiality, existing buildings structure, and history of the architecture will cover important architectural characteristics and by that ensure that the cities and buildings qualities of preservation are preserved and not demolished (Andersen. 2015). The work structure and phases of IDP ensure the possibility of working iteratively with the methods of transformation. Furthermore, will a holistic design be achieved with this approach and result in a design with a clear connection between technical, aesthetical, and functional elements.

The methods combined:

Problem: The problem for the thesis is stated
Technique: Registration, analysis, and setting the technical value of the existing conditions
History: Description of the existing and its connection to the architectural and cultural history
Phenomenon: Registration, analysis, and valuation of the buildings qualities

Analysis: Analysis of buildings, site and context and other information is conducted
Technique - History - Phenomenon
Landscape: The relationship between the near and distant - scale 1:500
Still Life: The connection in-between the buildings relations to each other - scale 1:50
Portrait: Specific characteristics and details described as tactility, tectonic, and joint elements- scale 1:5

Sketching: The problem and conducted knowledge is converted into initial design ideas
Landscape - Still Life - Portrait
Skin: Separates in- and outdoors and is the first part of a building the human react to - elevation
Meat: The volume and organization of the rooms / spaces - plan
Bone: The construction, structure, and framework of the building - section

Synthesis: Combines all information from earlier phases and evaluate
Look: See and analyze the building
Throw: The knowledge gained is put away while other aspects are developed
Project: Knowledge from the ‘look’ and ‘throw’ is used to design the project

Presentation: Combine the design and process to a presentation of the final outcome

Disciplines of Transformation: These leads to the position and concept of the thesis
Subtraction - Reconstruction - Reparation - Rephrasing - Addition

The New Neighborhood

På hospitalsområdet skaber vi et åbent, imødekommende, grønt og blandet byområde, hvor liv og ro forenes i et bykvarter med bæredygtige fremtidsløsninger og sin egen identitet.
[On the hospital site, we will create an open, welcoming, green and diverse urban area, where life and tranquility are unified in a neighborhood with sustainable solutions and its own identity.
Frederiksberg Kommune. 2019 a. s. 2

Since June 2018, the citizens of Frederiksberg and other stakeholders have participated in workshops, thematic tours around the hospital site, and public meetings, where ideas, comments and other relevant data have been collected (Frederiksberg Kommune. n. d. a). The questions asked were ***'What will happen when the hospital moves out?'***, ***'What is important to take care of?'***, and ***'What will be good to add?'***. The general feedback was that the area should develop into a diverse and inviting neighborhood, *'a city within the city'* with an assortment of functions, activities and meetings between different people. Moreover, many consider the atmosphere of the place to be unique and an asset to the rest of Frederiksberg and therefore important to preserve as much as possible when transforming the hospital site. Therefore, when creating the new area and designing new developments, the historic and preservation-worthy buildings should be the point of departure and as the center for the different extensions and transformations (Frederiksberg Kommune. 2019 b). In addition to the knowledge collected by Frederiksberg municipality from workshops and public meetings, this thesis strives to direct the new functions of the area to the citizens of Frederiksberg and people who on a daily basis use the functions offered at Frederiksberg. The added functions should help tie the new neighborhood and the surrounding context together where missing elements in the context will be considered a part of the transformed area.

Furthermore, the answers and other information gathered from the citizens and stakeholder has been converted into a joint vision for the transformation of Frederiksberg Hospital, that takes everyones comments and ideas into consideration (Frederiksberg Kommune. n. d. a). The vision should be seen as a guide for transforming the unique area of Frederiksberg Hospital to an area with a new identity. The vision consists of an overall vision for the area and eight sub-visions that cover the different relevant themes (Frederiksberg Kommune. 2019 a). Sub-visions with relevance for the thesis are conducted to help delimit the most important aspects of a future design.

Location

The project site is located in Frederiksberg, located in Greater Copenhagen, Denmark. The project takes inspiration from a tender invitation by the Frederiksberg Municipality to transform Frederiksberg Hospital. As part of the extension and opening of Ny Bispebjerg Hospital, the Hospital of Frederiksberg is planned to close by the end of 2026. The transformation from hospital to a new neighborhood is desired by the citizens to make the area become an integrated part of the City of Frederiksberg (Frederiksberg Kommune. n. d. a). The thesis focuses on transforming three selected buildings and as well design an overall idea of what the area should become.

Adress

Nordre Fasanvej 59
2000 Frederiksberg
Denmark

Sub-visions

Based on the history of the hospital, the historic buildings and green features are preserved and space is made for new developments in a accomodating scale, activities and climate-adapted urban spaces.

Varied types of housing and ownership, close health and leisure facilities, culture environments with small businesses, including creative entrepreneurship should become accessible to every citizen and create life in the area.

The traffic should be arranged on the premises of cyclists and pedestrians in a predominantly car-free area, though with limited necessary access for cars that should primarily be parked underground.

New developments and preserved buildings, trees and green areas should in interaction with the choice of materials and architecture create a varied and eventful expression in interaction.

Ill. 5. Birdview map of project area

Problem

Through the past couple of years the building industry has had a focus upon sustainability in terms of technical and measurable parameters, in order to secure fundamental economical and environmental frameworks. This development has influenced how we design new buildings, and how we restore existing structures, but not about how we preserve existing values of significant buildings and spaces. In order to maintain a high quality of social sustainability where the provision of spatio-temporal values are applauded to initiate wellbeing among humans. This thesis aims to discover a framework for restoration of existing structures where the framework will pivot on developing methods with the purpose of energy-optimizing existing buildings with an extended intention of preserving and manifesting existing values of social and historical means.

Vision

The city of Frederiksberg is known for its green structures, historically significant buildings, and calm ambiences - the diverse ground of the old Frederiksberg Hospital is a big part of this exact identity. The following thesis' intention is to develop upon values of the existing structures of particular buildings and the cohesive urban area. The thesis delves into the purpose of restoring and transforming the existing buildings into optimized functionalities, with a program that secures social values for the citizens in the city of Frederiksberg as well as for future residents of the hospital ground. New additions, both attached and detached structures, are to be developed in order of maintaining the spatio-temporal values and at the same time evolve the area with a new narrative added to the existing ones. The final transformation and design of the chosen buildings and urban area, therefore both pivot the integration between creating sustainable and optimized solutions that secures both the historical and new narrative, and at the same time acts as a frontrunner for future architectural developments which includes existing structures.

Keywords;

Transformation
Spatio-temporal values
Cultural heritage
Impact on people's wellbeing

Theme;

Socially
and environmentally
sustainable transformation
of existing buildings

Ill. 6.

02. CHAPTER

This chapter introduces the themes and theoretical approach of the project. The chapter is divided into three parts and identifies the aesthetics, technical and functional topics important for the project.

THEORETICAL STUDIES

Ill. 7.Koldinghus restoration, Kolding, Denmark

Transform or Demolish?

“Historic places connect us to the striving and struggles of earlier generations and of generations to come. They tell us who we are . And they help us understand that, though we ourselves may be mortal, our actions will echo on after we are gone, just as those of previous generations inform our world today”
Stephanie Meeks, CEO of National Trust for historic Preservation Mayes. 2018. p. xvii

The quote states that the ethics of preserving existing architectural structures, art, monuments, and books are that they are the witness of the story that we as humans left behind. It is difficult to measure why old places matter, and furthermore how they influence people’s wellbeing. The following will go in depth with the theorem of preservation and try to build the case of why we as architects and engineers should support the movement of preservation of existing and historic structures. It is fundamental in a world where sustainability is important, to remember the importance in that sustainability is not only environmental, which most in the profession are familiar with, but also socially defined, where physical and psychological needs of humans are featured.

One man’s work published in 1943 which is still relevant to today is important in order to build arguments whether or not old buildings influence people’s well-being - psychologist Abraham Maslow’s hierarchy of human needs. The hierarchy is a pyramid that diverges between basic needs, psychological needs, and self-fulfillment needs (Mayes. 2018. p. xvii). The psychological needs are especially interesting in the social sustainability subject since it contains the need of belonging - which nevertheless can be related to the relationship between humans and buildings, and therefore how buildings can affect one’s well-being.

Belongingness, noun. “the human state of being an essential part of something”
Collins dictionary. n.d.

We humans have a need to be a part of something greater, one’ life has to have a purpose, and one has a need to identify oneself with matter in the surroundings. Existing buildings, especially old or historic buildings are influenced by its many layers of history and by the century it was built or renovated in. New buildings are in contrast a part of one’s own century, in the near continuum which one has experienced. By comparing the two spectrum of building categories one’s connection to the two could be highlighted. When experiencing new buildings in the everyday one usually takes their characteristics for granted, but the moment we move away and get deattached we find the sense of belonging when visiting the place again. When this happens one begins to discover nostalgic feelings and familiarity in the context which is influenced by the collected and constructed memories and stories experienced in the specific place. The sense of belonging and the argument for preservation followed by this is explained in the book *“Why Old Places Matter - How Historic Places Affect Our Identity and Well-Being”* by Thompson M. Mayes, Vice President and Senior Counsel, National Trust for Historic Preservation. The theorem of the book is based on various interviews, experiences, and extensive research which Mayes have reflected upon in order to figure out why old places matter.
As Mayer, Frank Peter Jäger in *“Old and new - Design manual for revitalizing existing buildings”* describes that old buildings have a tendency to relate to humans because of sociopolitical backgrounds that are preserved in their fabrics, whereas new buildings express the cultural development and re-cultivation of obsolete structures (Jäger. 2010. p. 10). The social and political factors are results of developments over time controlled by political fluctuations and changing social needs which buildings in parallel change with. Because of the changing needs and legislations in politics, buildings are restored, transformed, and

rehabilitated in order to follow the development, and to ensure that a building's purpose can last in decades and not become obsolete. Because of these changes old buildings consist in a continuum of layered spatiality, expressed in the structures and fabric of a building (Jäger. 2010. p. 10).

To ensure that the continuity of belonging utilized by buildings is not fragmented by restoration it is important to develop a design which juxtaposes to the existing in a manner that prevails and somehow stands in contrast. Charles Bloszies describes, in his book *"Old Buildings, New Designs : Architectural Transformations"*, different ways of developing solutions and designs that facilitates preservation and framing of existing which contributes to the understanding of the continuum (Bloszies. 2011). When adding, transforming, or developing solutions of buildings in a historical context, new attributions should be designed with a careful approach to the connectedness between new and old which in the architectural manner can be utilized by implementing solutions of prevailing materials, proportions, and styles, in a balance with contrasting elements which highlights both the existing and the new. An example of the use of contrasting elements is vivid in the restoration of the castle Koldinghus made by the architects Inger and Johannes Exner. Here the remaining ruin was preserved as it was while new and modern materials were added in the restored parts to emphasize the contrast between old and new (Dansk Arkitektur Center. 2022).

When we as architects consider to restore existing structures it can therefore be concluded that a vital part of developing a concept of restoring is to consider the story that concerns the specific building, the adjacent structure, and lastly the surrounding context. Thoughtfulness, clarity of purpose, and identity should guide the design process as the building's fabric should guide the people around it with finding their sense of purpose and contributing to the development of one's identity.

When developing an understanding of the original purpose of an existing building interesting issues are considered. One issue as an example is that old buildings are usually not built to meet the needs and legislations of today - which in the end can have an influence upon the scope of preservation. However, as it is stated earlier, it is important to preserve existing structures because of belongingness. So, which criteria is weighted the highest in the case of preservation. Continuous changing legislations or the historic layers, which both help secure people's wellbeing?

Both ways are vital for the experience of architecture. Nevertheless, during the design process there should be executed different studies and developed a series of conclusions on different parameters in order to find the perfect mid-way solution which fits both sides of the spectrum. It can be discussed whether we should be locked on the current legislations - as an example, the buildings energy performance are a constant changing factor that is influenced by local climate conditions, and when considering the current progression of outdoor mean temperature affected by global warming the energy consumption will be affected over time, because the warmer the climate the higher amount of ventilation is needed and thereby more energy is used. The same question can be asked when considering the other part of the spectrum. This part can be outdated when compared to the needs of today, and therefore not contribute to the surrounding environment. Numerous contradicting examples can be highlighted in order to find the climax in the discussion. Nevertheless, we as architects should assess a given existing building and its conditions in both technical, social, and aesthetic terms. Pros and cons which can influence a conclusion before the actual design process are listed as an example below.

It is difficult to wrap up a conclusion on the discussion, but it can be concluded that there are numerous theories that suggest that the preservation of existing structures is a vital part of preserving our history and our identity. As a successor to the written section, it will be suggested that every architectural project before the design process and a possible demolition should be assessed in a matrix considering both soft and measurable values wrapped up in an assessment of its conditions. Such a matrix could be inspired by other certification matrices, such as DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) and LCA (Life Cycle Assessment), where the focus instead should concern the assessment of whether or not to preserve existing structures.

Cons for preserving existing structures

- Technical limitations; ventilation systems and construction
- Ineffective location of structures, in terms of flow and views
- Fire security limitations
- Energy inefficiency; inefficient building envelope
- Inefficient strength of existing load bearing structures
- Accessibility limitations
- The structure no longer serves its intended purpose
- Economical forces

Pros for preserving existing structures

- Desirable attributes, hereas high ceilings, operable windows, natural light, distinctive facades
- Financial feasibility, whether the tenants invest upgrades and maintaining
- Efficient structural load bearing system, which enables repurpose
- Historical value
- Social forces

(Bloszies. 2011)

The Method of Preserving, Transforming, and Develop

Designing solutions for transformation projects is different from designing solutions for new buildings. When considering the integrated design process there will be additional and different analysis needed in the initial analysis- and sketching phases, in order of implementing transformational variables. These variables, when identified, can be defined as early delimitations of the design process, which is important to consider from the start to interpret and find solutions which can lead to a grant of expectations defined by legislation. Potential grant is given to ensure the qualification of renovation and conservation of existing substances' special features (Jäger. 2010. p. 185). Before defining the method of preservation it is important to state, as Jäger also describes it, that successful developments usually are based on a recognition of existing attributes and a heightening of these. A renovation or transformation project should not compromise the existing but juxtapose to it in different scales which nevertheless fits the relevant substance (Jäger. 2010. p. 183).

The method of developing existing structures is based on an understanding of the existing attributes, its history and therefore purpose of use, and thorough assessment of the existing substance and structure. It should furthermore be a process of careful consideration where one should contemplate about the scale of interference, the possibilities of the existing, and the execution of the development. When developing the suitable method of transformation or renovation the attributions of the existing original materials, construction and craft is to be defined (Jäger. 2010). To fulfill transformation projects that consist of the mentioned qualities, the considerations on the right should be explored in the design process. It is important to state that every transformation project utilizes different scales of focal points of the method.

Det bør være målet med enhver ombygning og nyindretning at få huset til at fremtræde i harmoni med sin alder, historie og arkitektur - både overordnet, i detaljen og i byggeskikken.
[It should be the goal of every alteration and refurbishing to get the house to appear in harmony with its age, history, and architecture - both overall, in the detail, and in the architectural tradition.]
Vadstrup. 2004. p. 341

This master thesis will therefore in relation to building the case regarding preservation, investigate a conceptual construction of an assessment matrix which should discover a working method of renovation and optimization of existing buildings, and furthermore attempt to execute it as part of the thesis' design process of the given structures of the Frederiksberg Hospital.

Preservation of buildings, from the perspective of the cheapest overall economy

Preserve original materials, the time's patina, characteristics and execution.

- Execute assessment of the building's condition and performance and develop strategies of the need for repair, where repair signals are not read as replacement needs.
- Execute building-historical examinations of original framework and transformation concepts utilized in the course of years.

Develop and modernize the purpose and use of the building and secure a connection to historic qualities.

- Evaluation of the functional programming, and whether the new purpose can be implemented in the existent.
- Execute assessment of original plan solutions etc. for reconstruction and whether these can be used again and at the same time gain some historicism and identity.

Secure consistency in the quality of materials, construction and craft

- Define materials and construction types, and how they should be processes in order of possible conservation.
- Execute repair and preventative maintenance with historic defined materials and craftsmanship, where quality is applaud instead of quantity, and lastly the design of the whole is consistent in both the whole and in the detail.

Vadstrup. 2004. p. 41-42+129

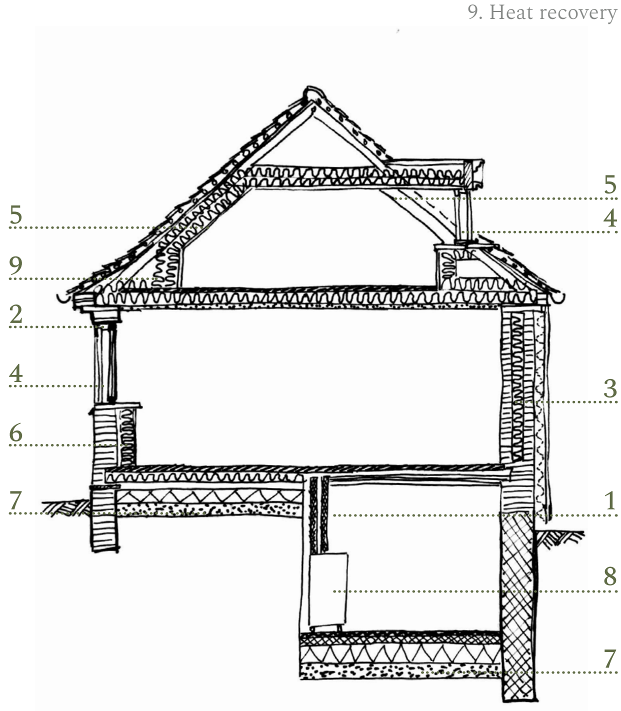
Energy Optimization of Existing Buildings

A present problem in the building industry is that many constructions have reached the end of their service life and no longer reach the high demands for energy standards that are seen these days. Therefore, it is necessary to optimize these buildings and constructions, so they live up to today's requirements for indoor comfort and remove all materials that are no longer acceptable to use in the building industry (Rexroth. 2010). The society has high demands for the future environment and plans on how to decrease the climate impact. In 2030 it is required that the CO2 emission is reduced with 70 pct. which means that the consumption will be downgraded with 20 million ton of the emission (Klima-, Energi- og Forsyningsministeriet. 2021). At present the energy consumption in buildings constitute almost 40 pct. of Denmark's total energy consumption where the energy is used primarily on heating, ventilation, and lighting (Energistyrelsen. 2022).

With an increased focus on climate in all its facets and with knowledge of the total energy consumption from buildings, it testifies that new trends in recycling, reusing, and optimization of existing construction have come to stay. Not only do old buildings get new life by incorporation of new functions or other use, but it is also required that the buildings live up to the present standards according to energy and indoor climate. By reusing the building's materials, the materials embodied energy is maintained and thus remains part of the circular system. However, one must investigate how best to upgrade and transform the buildings to the new conditions and still preserve the original architectural expression as it has environmental, technical, and cultural historical qualities (Vadstrup. 2014). What initiatives are needed to optimize the energy of old buildings will here be discussed and developed through various principles and strategies.

The dramatic, non rectilinear forms designed for the most conspicuous consumers were inefficient by many yardsticks of sustainability, while the most efficient buildings tended to be architecturally timid.
Bloszies. 2011. p. 39

1. Insulation of heat pipes
2. Proofing of doors, windows etc.
3. Cavity wall insulation
4. Double window
5. Insulation of roof and twig
6. Insulation of window parapet
7. Insulation of floor against terrain
8. New, effective boiler
9. Heat recovery



Ill. 8.

on selected buildings at the site of Frederiksberg Hospital with different preservation, the optimization concerns the building envelope and windows to be able to live up to the current building standards of indoor climate, air quality, and daylight. It is for that reason relevant to develop several concepts for an optimization of the building envelope which strives to retain facade components as a part of the energy conservation while improving the use of the buildings.

In Tempered Transparency - Renovating Modern Movement Facades in Line with Landmark Preservation Principles by Pottgiesser, U. and Kirch, J., different possibilities in terms of revitalization strategies according to today's many preserved buildings are described and how it is needed to distinguish between historical buildings with landmarks preservations and those without and further different functions and states of repair. From the description four fundamental refurbishment strategies are to be approached when optimizing preserved buildings retaining the existing facade construction; *Preserving and repairing profiles, Reconstructing the original profiles, Replacing the original glazing with insulating glazing. Replacing or improving sealing profiles* (Kirch & Pottgiesser. 2010).

Using these principles, the overall energy consumption can to a certain level be reduced by supporting ventilation systems whereas the improvement in the thermal insulation is minor. Kirch and Pottgiesser further describe another common approach in preservation of landmarks as a supplement to the existing facade construction where current standards to thermal insulation and indoor comfort are achieved, though no reduction in the energy consumption is achieved; *Installing an additional interior glazing or insulation layer to fenestration or walls, Installing an additional exterior glazing or insulation layer to fenestration or walls, or as facade or fenestration bands which have a significant impact on the exterior design of the building* (Kirch & Pottgiesser. 2010).

However, technical and architectural limitations indicate that it can be difficult to make energy improvements in old buildings which follow the given standards. In preserved buildings and others with conservation values there are several additional factors to consider, including the architectural expression, technical conditions in increasing the wall thickness, the indoor climate in relation to daylight and air exchange and considerations about passive energy. Although the process does not seem easier the old buildings have advantages according to climate and CO2 emission compared to new constructions, which is seen in the materials' durability and good climate properties, the use of natural ventilation, and the division of individual rooms. to some rooms in the winter, while others can be unheated.
In Byhuset, by Søren Vadstrup, three principles describe which are important to adhere to if an energy optimization is to be successful without the building losing value.

The dimension of time is an important indicator in the process of transformation - it is important to be thorough and sensitive to the existing to be able to implement new functions with thoughts on sustainability (Vinterakadami. 2016). Therefore, it is important to follow the mentioned strategies, categories, and principles when preserved buildings go through energy optimizations. Furthermore, it is necessary to understand and contemplate the buildings from a historical, architectural, and construction technology holistic perspective. Strategies and principles can hieratically be composed and developed due to the function and by that strive to reach a goal that fulfills the present standards for energy demands and indoor climate. It is a necessity to decrease the climate impact from the building industry combined with the several unused square meters, a growing need of housing, and the possibility to decrease the production of new construction materials. Together with this, enhancement of the social and architectural qualities will make it possible to develop how transformation, and hereof energy optimization of preserved buildings, can contribute to transition of a sustainable low emission society (Noldus. 2014).

Principles of energy improvement

Keep the buildings values | Preserve the original architectural expression as it has environmental, cultural-historical, and technical values and by that do not change the old windows of wood or cast iron.

Change form of heating | Combined heating and ventilation systems which fit the old buildings.

Create energy and indoor climate improvement | The buildings preservation values, energy improvements with respect to the preservation values, the buildings indoor climate before and after re-insulation, construction technical knowledge about moisture in re-insulation buildings and the economic consequences of the interventions.

The improvements can furthermore be divided into three overall categories according to the architectural expression whereas the third will make unacceptable changes.

- Category 1 | interventions that does not influence the preservation values
- Category 2 | visible interventions, but architectural acceptable
- Category 3 | interventions which in terms of architectural and preservation is unacceptable.

(Vadstrup. 2014)

Demands and Building Codes

The renovation and optimization of the selected builfings will strive to meet the following demands in the Danish Building Code.

§ 274 - § 279 Energy demand in relation to conversions and replacement of building parts
§ 274 In conversions, energy savings must be carried out to the extent that they are financially viable and do not involve a risk of moisture damage. The energy demands in conversions may either be observed by fulfilling the requirements for all building parts affected in § 279 or by observing the renovation classes for existing buildings in § 280 - § 282.
§ 278 (3) Buildings worthy of preservation which are included in a local preservation planning regulation or a registered preservation declaration or buildings appointed in the municipal plan as being worthy of preservation und er s. 19(1) of the Danish Act on Listed Buildings are also exempt from the provisions in § 274 - § 282 if observation of the requirement would be contrary to the plan or appointment in question.
§ 279 Conversion or other changes to the building must be in accordance with the requirements for U values and linear thermal transmittance stated in Appendix 2, Table 3. Windows, glass outer walls, glass roofs and skylights must fulfil the requirements stated in § 257 - § 258.

§ 280 - § 282 Renovation class for exsisting buildings
§ 280 The following provisions apply for the use of renovation classes for existing buildings:

- The need for energy supply must be reduced by minimum 30.0 kWh/sq. metre per year.
- Evidence must be provided in accordance with the instructions of the Danish Building Research Institute 213 Energy demand in buildings.
- The total energy supply to buildings must be composed party by renewable energy.

§ 281 Residential units, halls of residence, hotels, etc. may be classified as: Renovation class 2, when the total need for supplied energy for heating, ventilation, cooling and domestic hot water per. m^2 heated floor area does not exceed 70.0 kWh / m^2 per. year added 2,200 kWh per. years divided by the heated floor area.
§ 282 Offices, schools, institutions and other buildings not subject to § 281 may be classified as: Renovation class 2, when the total need for supplied energy for heating, ventilation, cooling, domestic hot water and lighting per. m^2 heated floor area does not exceed 95 kWh / m^2 per. year added 2,200 kWh per. years divided by the heated floor area.

Table 3

Minimum requirements for climate screen for conversions and other changes in the building.

Thermal transmittance	
Exterior walls and basement walls against the ground	0.18 W/m^2K
Floor partitions and partition walls towards rooms where the temperature difference between the rooms is 5 ° C or more	0.40 W/m^2K
Terrain deck, basement floors to the ground and floor separations above the open or ventilated crawl space	0.10 W/m^2K
Ceiling and roof constructions, including skunk walls, flat roofs and sloping walls directly against the roof	0.12 W/m^2K

Linear thermal transmittance	
Foundations	0.12 W/m^2K
Joint between exterior wall, windows or exterior doors, gates and hatches	0.03 W/m^2K
Joint between roof structure and skylights or skylight domes	0.10 W/m^2K

(§ 274 - § 279. Bolig- og Planstyrelsen. 2022a)

Ill. 9. Rooftop community space, Østergro, Copenhagen. Photo: Søren Rud/Life Exhibitions

How to develop new neighborhoods?

Cities expand and change constantly. Some districts change character, new areas develop, and others are demolished. When planning new areas or changing existing areas it depends on the existing conditions, former and future functions as well as the surrounding context. Therefore, the planning of cities and neighborhoods needs to differ and adjust to the specific type and identity of the place. The planning of new areas or changes of others cannot just be systematic and standardized, as no area is the same (Pålsson. 2016). Cities and neighborhoods are more than just the physical elements and the spatial character but also the social character and coherence between residents, visitors, and other users. So, how are all these elements considered and how are well-functioning neighborhoods and cities created?

The tendency in urban planning today is the concept of mixed neighborhoods. The concept is seen as the solution to create lively and functional spaces. It is a notion that emerged as a response to previous tendencies of a geographical division of dwellings, trade, and other urban functions, an increased monotony of the physical expression of the city and increased segregation of different population groups. The concept of mixed neighborhoods solves this, by blending different functions within a city and using multifunctional buildings with active ground floors. This activates the buildings, the streets and thereby the neighborhood and city making them functional (Andersen & Møller. 2021).

This idea by mixing functions and having active ground floors is not new, as Jane Jacobs prosed this in 1961 in '*The Life and Death of Great American Cities*'. To have successful cities and nice atmospheres it is important that people use the area at different times throughout the day. Jacobs highlights that it is not just about mixing different functions, but the importance of the functions complimenting each other. This is in order to ensure the flow through the site is fluent and the mixture and amount of people are reasonably proportionate to people there at other times (Jacobs. 1961).

When cities develop, new pieces are added to the existing cities. It is not only a physical development of buildings and urban spaces but also of existing communities and the formation of new ones (Andersen & Møller. 2021). Therefore, it calls for a holistic approach when planning cities and neighborhoods.

It is not enough just to mix different functions there is also a need for ensuring space and places for the community to meet and prosper. Community is a value that is in demand, even in the big cities, though numerous new cities do not take this into account when designing new neighborhoods, meaning a shortage of rooms and other settings for people to meet and gather. As communities exist on multiple levels, a building is part of the different networks of the city which needs to be considered in the planning phase. This ensures the formation and coherence of the small and big communities as no can exist without the other (Andersen. 2019).

To create coherence between functions, the spaces in-between, and the activities across the different user groups, a strategic approach to organization, design, and planning is needed. If multiple activities are gathered under one roof or in one area of a neighborhood, it entails different user groups and places where kids, grown-ups, elderly etc. can meet on equal terms. These areas will be the nodes that generate life, meeting places and coherence (Andersen. 2019).

This thesis will consider these aspects when designing and planning the new neighborhood of Frederiksberg Hospital as it is important to create a neighborhood which ties to the rest of the city. It is important not just to focus on the buildings and their functions but also on the area in-between and the possibility for activities and an active city life.

Ill. 10.

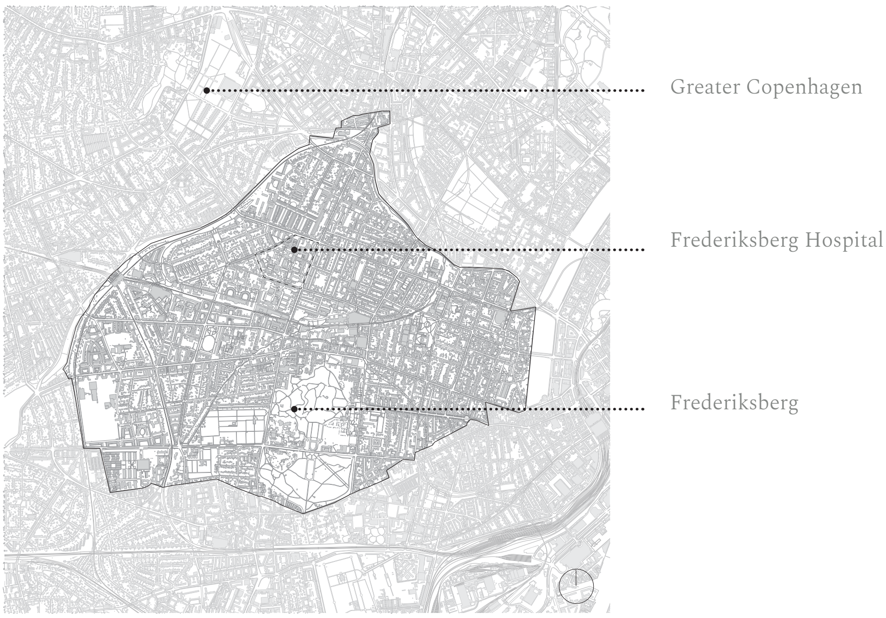
03. CHAPTER

This chapter introduces and analyzes the project site and its context. The chapter is divided into three; Big Scale, Medium Scale, and Small Scale in order to understand the project site and context on different levels. Moreover, simple studies have been carried out to connect the analysis with possible design solutions. These serve as guidelines for the further design process and development of the final project.

ANALYSIS & STUDIES

Big Scale

The Big Scale analysis focuses on the City of Frederiksberg. These are carried out in order to understand the bigger context, the project site is a part of but does not have a direct share in the design. The analysis consists of thematic mappings of aspects important to the site and Frederiksberg.



Ill. 11.

Introducing the Context - The City of Frederiksberg

Frederiksberg is located in the Capital Region of Denmark and with 8.7 square kilometers it is the smallest municipality in Denmark (Danmarks Statistik. n.d. a). However, with just under 104.000 inhabitants (Danmark Statistik. n.d. b) it is also the most populated one per square meter. Frederiksberg is placed in between the areas of Vanløse, Nørrebro, the Inner city and Vesterbro. Therefore, extensions and further development of the municipality rely on urban conversion, conversion of functions and transformation of individual buildings, infill buildings, and utilization of attics (Frederiksberg Kommune. 2021 a).

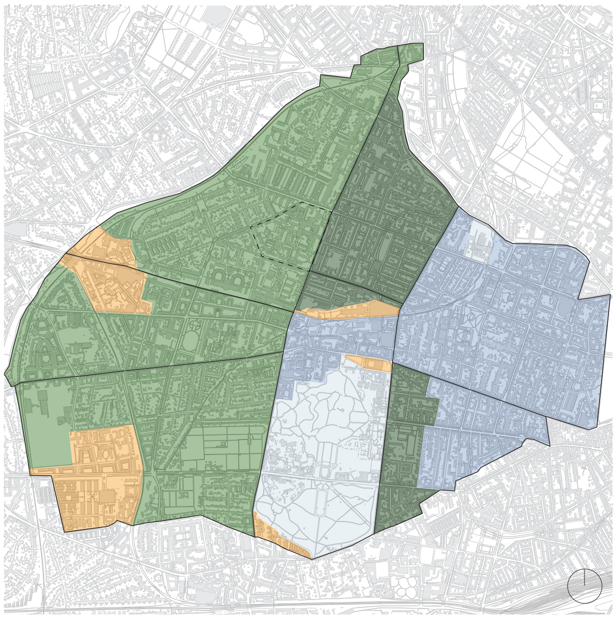
Ill. 12.

Green structures

The municipality of Frederiksberg is seen as the green heart of Copenhagen, with trees, green boltholes, and parks intertwined between the buildings, roads and squares. Throughout Frederiksberg, the green structures are connected through avenue trees, green front- and courtyards. In addition, the many cemeteries are parklike, making them an addition to the other parks and recreation areas (Frederiksberg Kommune. 2021 b). The mix of green structures ensures great conditions for animals and insects as well as being important qualities for city and human life.

The knowledge conducted can be utilized in the further work where the green structures from the city of Frederiksberg will be implemented on the site. This to create an extension and continuum which is known for the citizens and the new neighborhood will be a more integrated part of the city.

Cemeteries
Parks
Sports facilities



Ill. 13.

Characteristics in Architecture

Frederiksberg is divided into seven main districts, and the architectural character differs from district to district which shows the development from village to city. The mix of typologies, detached houses, patrician villas, multistory buildings, and big institutions from the eighteenth to the twentieth century tells of the architectural heritage (Frederiksberg Kommune. 2017). The architectural identity of Frederiksberg is highly valued, therefore when building new and transforming existing buildings, the developments should consider the architectural heritage and tradition of Frederiksberg.
Frederiksberg Hospital is located in district four; an area that is characterized by neighborhoods of villas and row-houses from the beginning of the twentieth century and multistory buildings along the big roads.

When transforming the site of Frederiksberg Hospital and the associated selected buildings, emphasis will be placed in the design on preserving the architectural and cultural, as well as new initiatives for the changed functions of the buildings. The existing architecture of Frederiksberg invites mixed urban spaces and typologies whereas this should be developed for the new neighborhood.

1945/1950 -
1914 - 1945/1950
1890 - 1914
1850 - 1890
Before 1850

Ill. 14.

Culture and Education

The culture- and leisure life of Frederiksberg is a broad list that includes museums, theaters, historic buildings etc. and it is based on a strong local presence and engagement. The cultural as well as the educational institutions are placed throughout Frederiksberg and ensures a diverse city with different cultural destination points that draws people to the area each day (Frederiksberg Kommune. 2021 b). Frederiksberg Hospital is placed in an area with less cultural institutions making the area suitable for different culture and leisure activities and ensure Frederiksberg as a cultural destination point.

As the area, where the site of Frederiksberg Hospital is located, does not have predominantly cultural offerings, this function will be developed throughout the transformation of the selected buildings, thereby creating more cultural coherence in the city.

Ill. 15.

Accessibility

Even though Frederiksberg is its own area, the connection to the city of Copenhagen is strong, as multiple train- and metro stations connect the cities. The infrastructure enables fast and easy transportation within Frederiksberg as well as to and from the municipality. In addition, the size of Frederiksberg ensures the possibility of getting around on a bike from one place to another within fifthteen minutes.

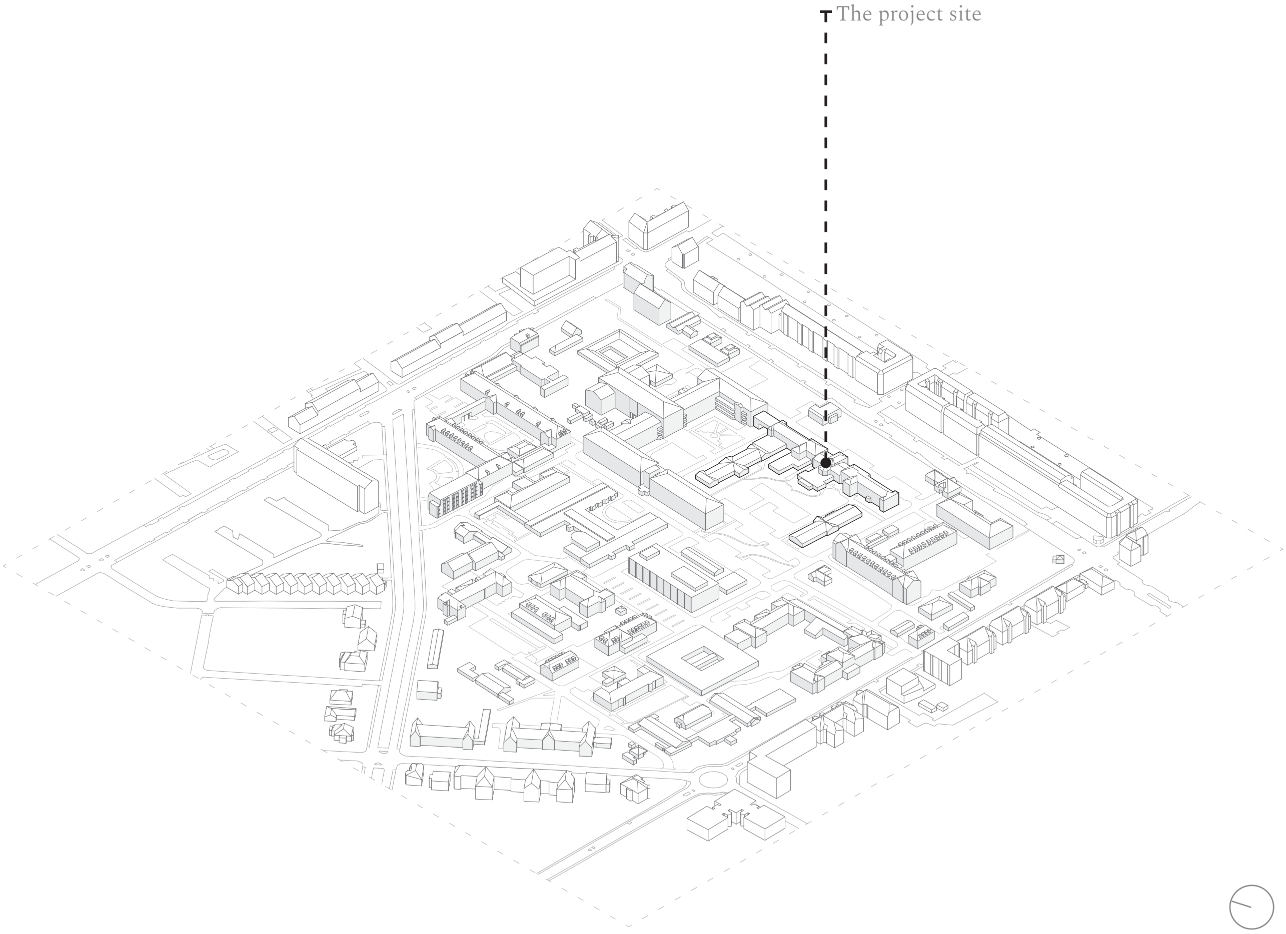
Frederiksberg Hospital is located with access to both metro lines in walking distance of ten minutes and a train station with walking distance of fifteen minutes. Therefore, Frederiksberg Hospital connects easily with the whole city of Copenhagen.

Train
Metro

4 km.
Education
Culture

Medium Scale

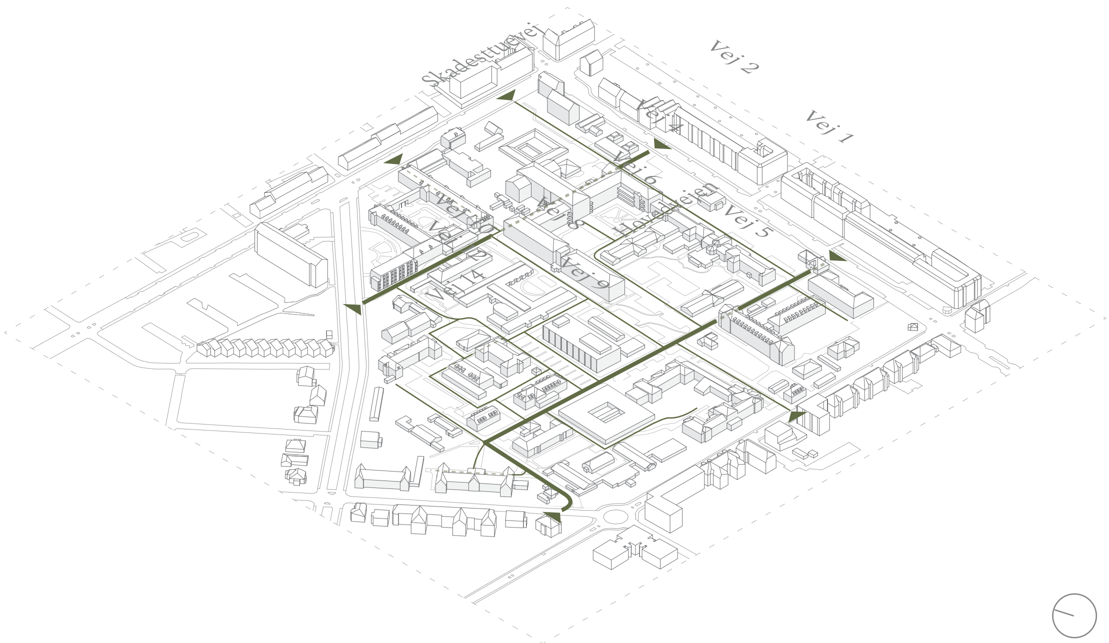
The Medium Scale analysis focuses on the site of Frederiksberg Hospital, hereof the characteristics of the buildings and urban spaces. These are carried out in order to understand the structures and organization of the area. Analysis and studies further develop knowledge upon the identity of the area, varying typologies and characteristics, as well as atmosphere.



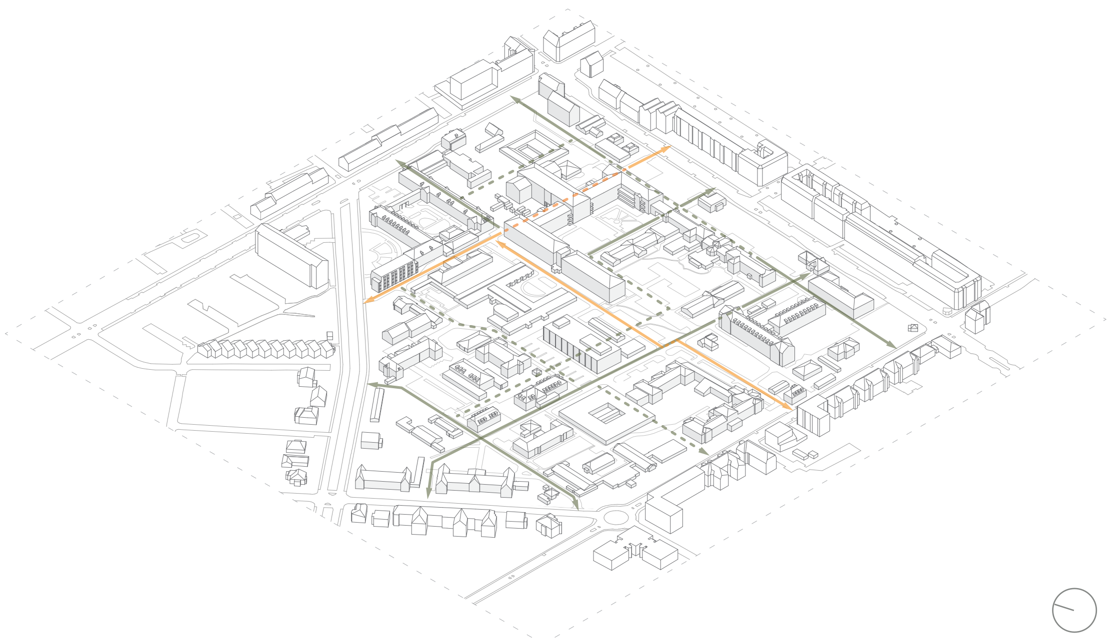
Ill. 16.

Introducing the Context - Frederiksberg Hospital

The official inauguration of Frederiksberg Hospital was present in 1903, but had its beginning around 1850, and through time it became the size seen today (Hansen. 2003). The hospital is located in the northern part of Frederiksberg on the border of Nordre Fasanvej and Godthåbsvej. Today the hospital ground has an area of 141.000 square meters which contains approximately 37 different buildings with functions from dialysis and aids center to heart and blood test outpatient departments. Frederiksberg Hospital was built over different decades and this is also seen in the architecture, which is characterized by the needs of the time and thoughts on how a new hospital should contribute to society.



Ill. 17.



Ill. 18.

Connections

The hospital site is analyzed according to different connections in order to understand how the site connects within and to its surroundings as well as how the buildings connect to each other. The site has seven connections towards the surroundings, where five is for cars, bikes, and the bus line that goes through the area. Furthermore two connections are accessible by bike or as pedestrians. From the outgoing connections roads overlap and cross within the boundaries. The routes within the site tell the history of the hospital where the names of these are known to the citizens of Frederiksberg should be preserved in a new master plan in order to preserve the identity and wayfinding of the site.

Today, the workings of the hospital ensures flow from building to building and connects the different buildings and functions together. The flow of road users share the same routes which indicate that the outside spaces seem safe as people are moving through the area. Connections such as these should be considered and somewhat preserved when transforming the area. New connections between the site and the city as well as between the buildings will be developed.

Study

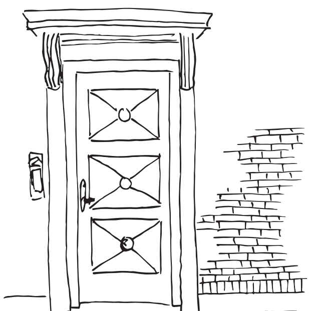
Connections within the area, towards the city, and between the selected buildings are conducted. Development of green avenues for soft road users and less possibilities for cars to use the area is arranged. Furthermore, new openings towards the city gives the area a sense of the desired neighborhood. Another study shows the flow between the selected buildings as well connecting to the overall flow on site - here the future functions of the buildings will direct the flow in the area.

Ill. 21.

Ill. 19.

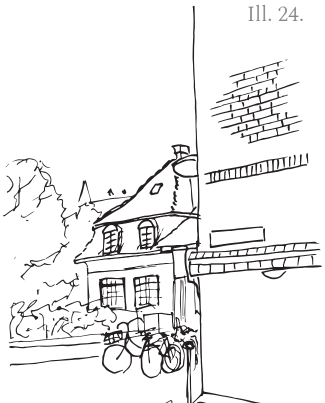
Ill. 22.

Ill. 24.



Ill. 20.

Ill. 23.



Ill. 25.

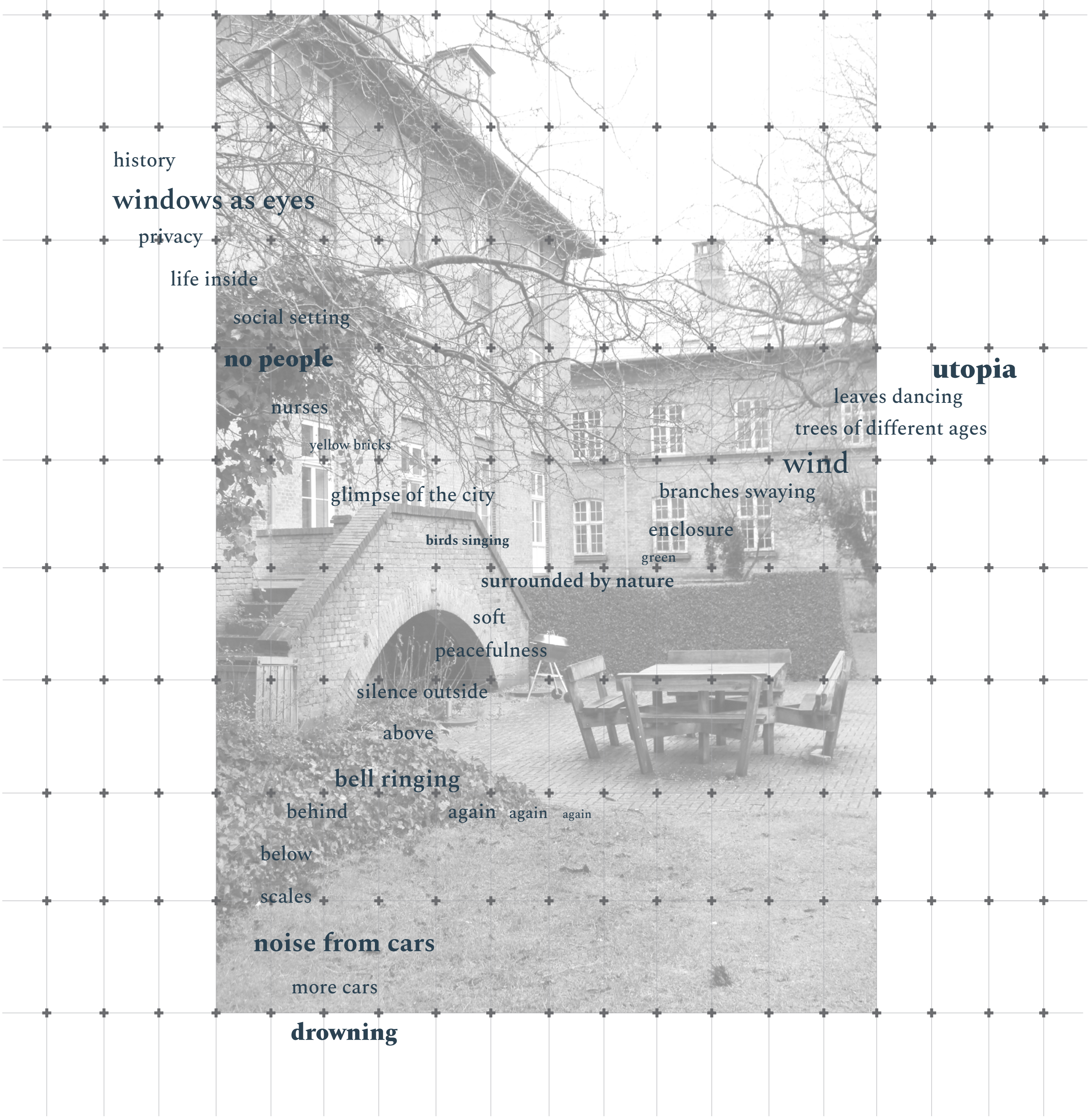
Ill. 26.

Buildings and Spaces

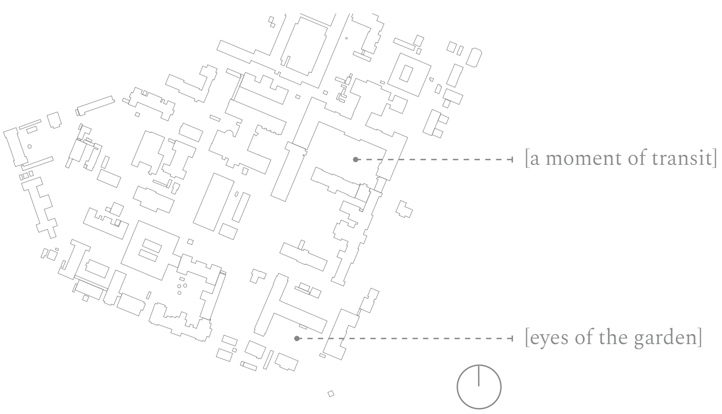
The analysis is directed to what is interesting in the area and the outcome of the analysis will thereby become an alternative mapped itinerary where a subjective representation of the everyday life describes the area drifted. Both spaces in between buildings and buildings themselves represent interesting elements of the site of Frederiksberg Hospital. Some of the drifted routes overlap each other - either because of interest or the necessity to pass by experienced areas or buildings to get to others and get the experience from other angles. The site of Frederiksberg Hospital has a lot to offer for new initiatives in all its different buildings and spaces. The place exudes history that provides a special atmosphere to the area.

It can be concluded that the site varies a lot in expressions of building shapes, heights, typologies, and level of details. Furthermore, the buildings help ensure different layers of spatialities in between them by having many corners and indentations. The site is not characterized by a grid structure or any other tight structure and therefore it is concluded that the thesis will develop the existing structure in the further work as it already creates interesting views. In addition to the structure the diversity in typologies will be developed in the design as new and old elements easier complement each other within the area which range widely in a field of different scales and wealth of detail.

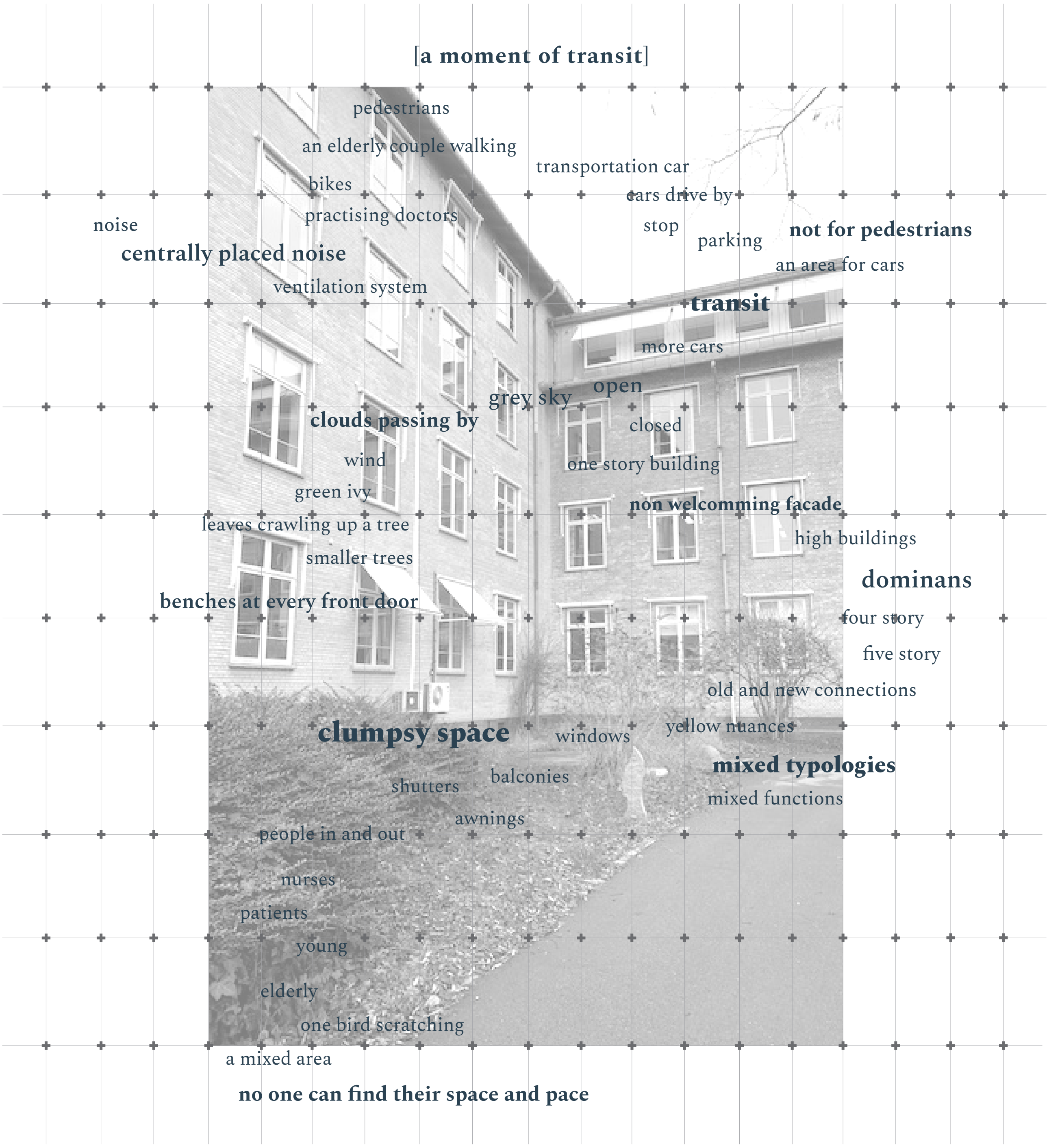
[eyes of the garden]



Ill. 28.



Ill. 27.



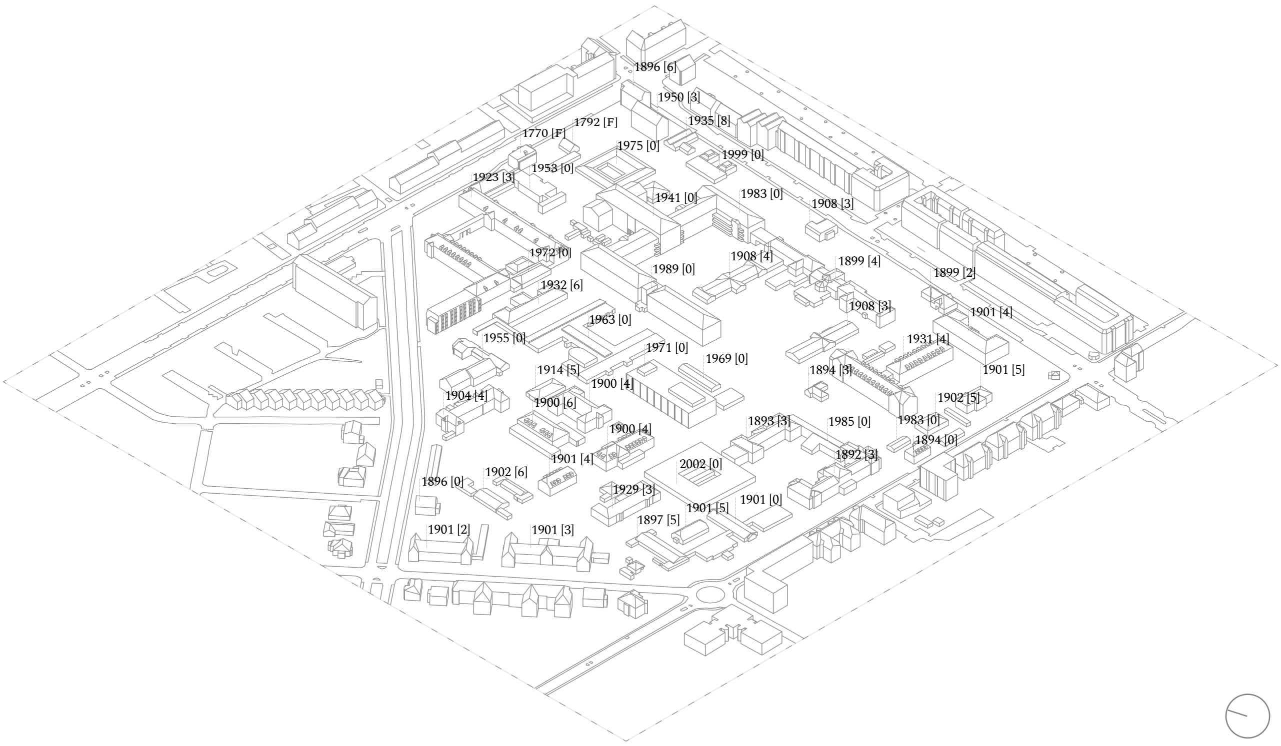
Ill. 29.

Selected Spaces

A phenomenological study of different urban spaces at Frederiksberg Hospital has been conducted. The purpose is to experience the different atmospheres and understand how it is influenced by the buildings and other surrounding elements. The analysis is conducted in two defined urban areas with different characteristics; one which functions as a garden and one used for transit. The atmosphere is illustrated through pictures and highlighted words. The analysis serves as a momentary and subjective impression of the two spaces. It is meant as an example of the experienced atmosphere and not as a holistic picture of Frederiksberg Hospital.

Study

The atmosphere of the project site should have; the feeling of being surrounded by nature, birds singing and leaves on trees swaying in the subtle wind. A mix of people walking past, using the area as transit or for a small break, activating the space and creating a lively urban area. There are kids playing on the grass, an old man sitting on a bench enjoying the sun, a pair of friends meeting up for a coffee. All understanding the history of the buildings.


1896 [6]
1950 [3]
1935 [8]
1770 [F]
1792 [F]
1975 [0]
1999 [0]
1953 [0]
1923 [3]
1941 [0]
1983 [0]
1908 [3]
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1955 [0]
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1971 [0]
1969 [0]
1914 [5]
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1893 [3]
1985 [0]
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1892 [3]
2002 [0]
1902 [6]
1896 [0]
1929 [3]
1901 [0]
1901 [5]
1897 [5]
1901 [2]
1901 [3]

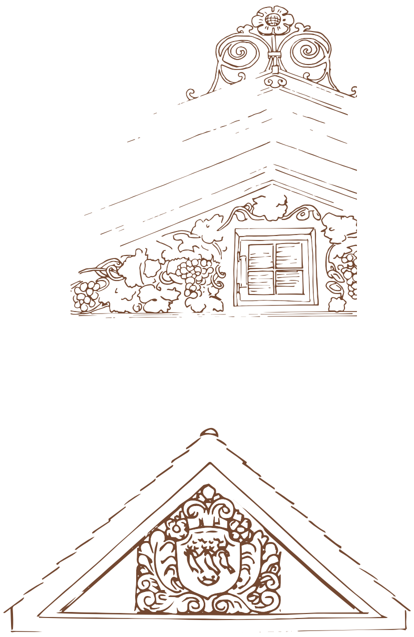
Ill. 30.

Ill. 31.

Level of Details

To get an understanding of the timeline of the existing structure both building's origin year, SAVE factor and characteristics are analyzed. The buildings span in origin from the year of 1770 to 2002, whereas most buildings are built between the early 1900's till early 2000's. The building cluster, consisting three buildings, which the design process will focus upon, were built between 1899 and 1908 and have the SAVE-rate from 3 to 4. In relation to the years of origin the site is divided into areas which have the same characteristics in the architecture. It can be concluded that the exterior mainly consists of red or yellow brickwork in different qualities.

The site of Frederiksberg Hospital is therefore an area with great diversity in architectural characteristics, which overall is rooted in the anchored historicism of the place. To ensure restoration, concepts which respect historicism are therefore important to integrate so the values are preserved or heightened.



Details on gables

Ill. 32.

Signs on facades

Ill. 33.

Coat of arms

Ill. 34.

Ornaments

The ornaments of the buildings and other historical elements of Frederiksberg Hospital have been investigated and categorized in order to gain an understanding of their historic relation to the architecture. Ornamental detailing and guiding elements can be found throughout the buildings enhancing the atmosphere and unique feeling of the site. When one notices one of the small details one experiences the variety of details and other small elements scattered all round.

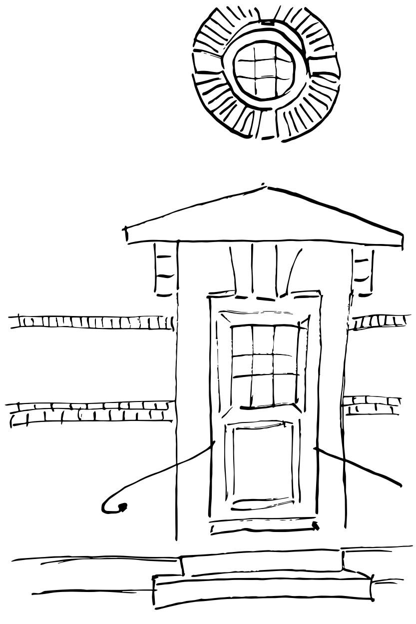
One of the main categories are the pediments on the gables of the buildings. These are rarely left untouched but instead decorated with various patterns of blooming wine branches, coat-of-arms, historic scripts etc. The pediments create a transition between the facade and the roof, finishing off the gable and thereby enhancing the ends of the building. In addition, the pediments enhance the history of the buildings and illustrate the period of the buildings. Another main category is the guiding elements that are rooted in the use and history of the hospital. These elements not only guide patients, employees and visitors but also indicate a certain way of displaying signs on historic buildings. The signs adapt to the character of the facades and submit to the other elements and the symmetry of the facade.

The way ornaments and other historic elements are used throughout Frederiksberg Hospital indicates a specific method for enhancing certain elements. Therefore, the transformation of the area should be rooted in this to ensure the historic atmosphere and maintain the unique qualities the site offers.

Study

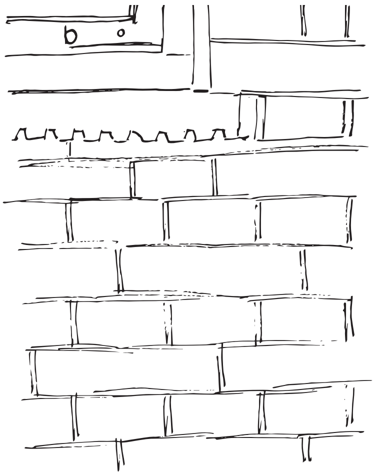
Different concepts on how to respect the characteristics of the buildings are developed throughout simple studies. This gives an initial idea of how it is possible to work further with the selected buildings. According to the given SAVE-rate changes in the facade are possible within different categories. These describe changes as facade color, windows and doors, roof surface, and shop fronts, which will be investigated.

It is concluded that if changes of different elements must happen in the facade it is important to differ between the types of details according to where these are placed in the exterior. Thereby details and elements of the selected buildings should be seen as valuable to preserve or gently replaced with new and similar elements.



Ill. 35.Details around entrance

Ill. 37.Facade division



Ill. 36.Details around windows

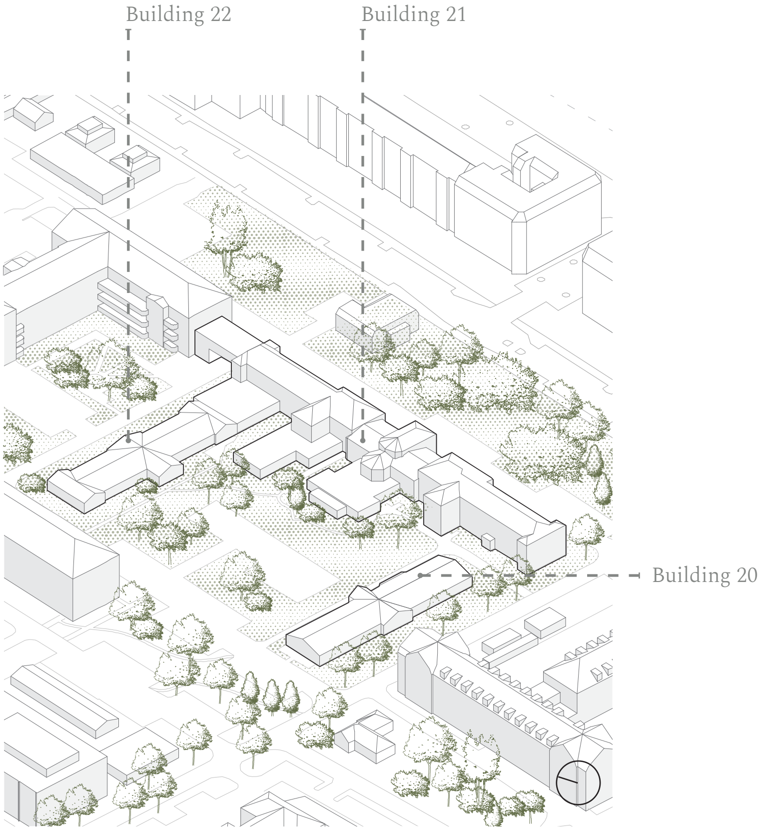
Ill. 38.Colors and ornamentation

Ill. 39.Window placement

Ill. 40.Roof surface

Small Scale

The following section will present the Small Scale analysis of the project site with a focus on a selected cluster of buildings and intermediary urban spaces. The architecture of the buildings are in the following section analyzed with a focus on their former use, potential and limitations for transformation and which characteristics define them.

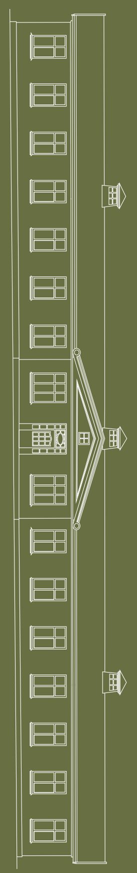


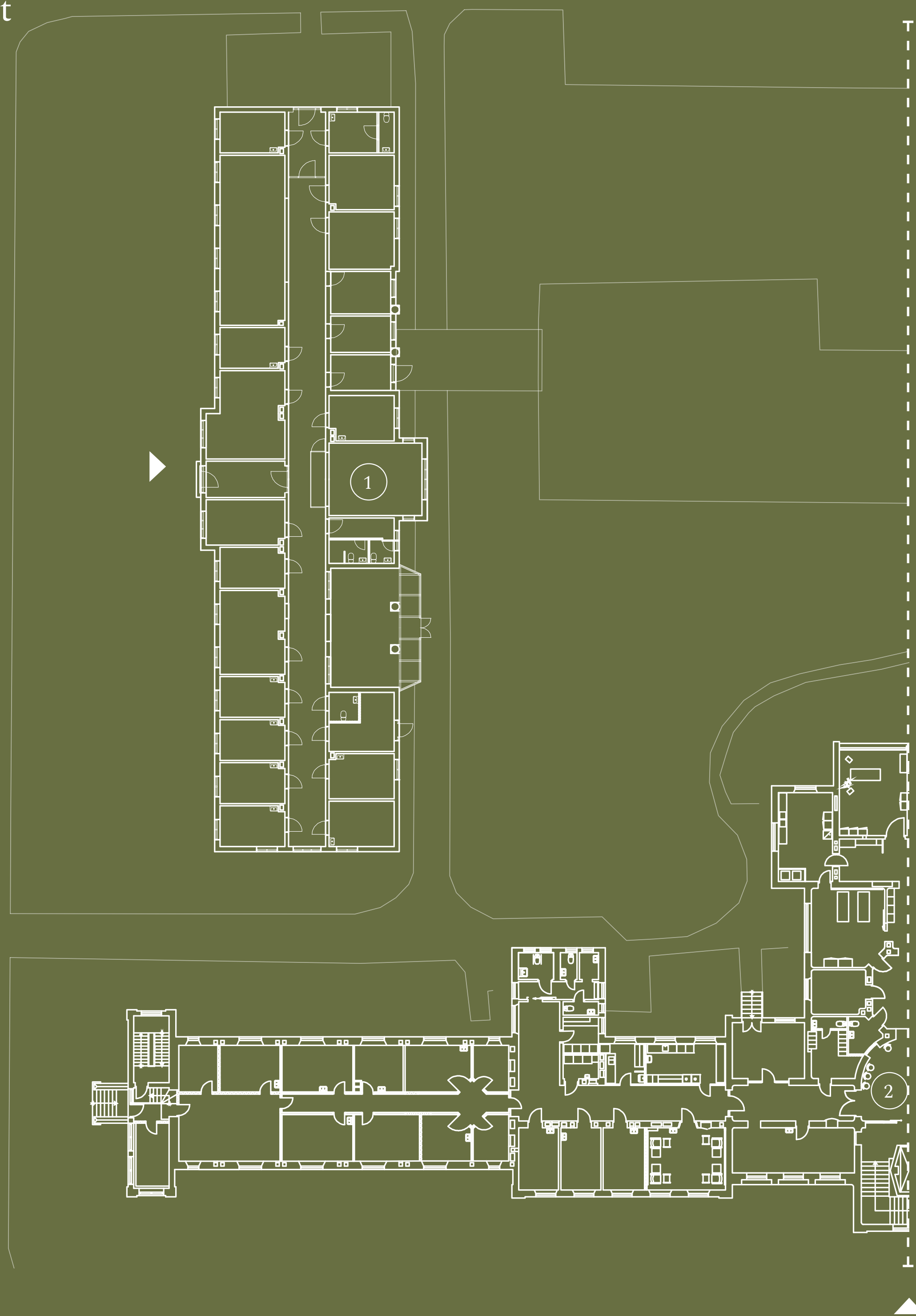
Ill. 41.

Introducing the Project Site - The Selected Buildings

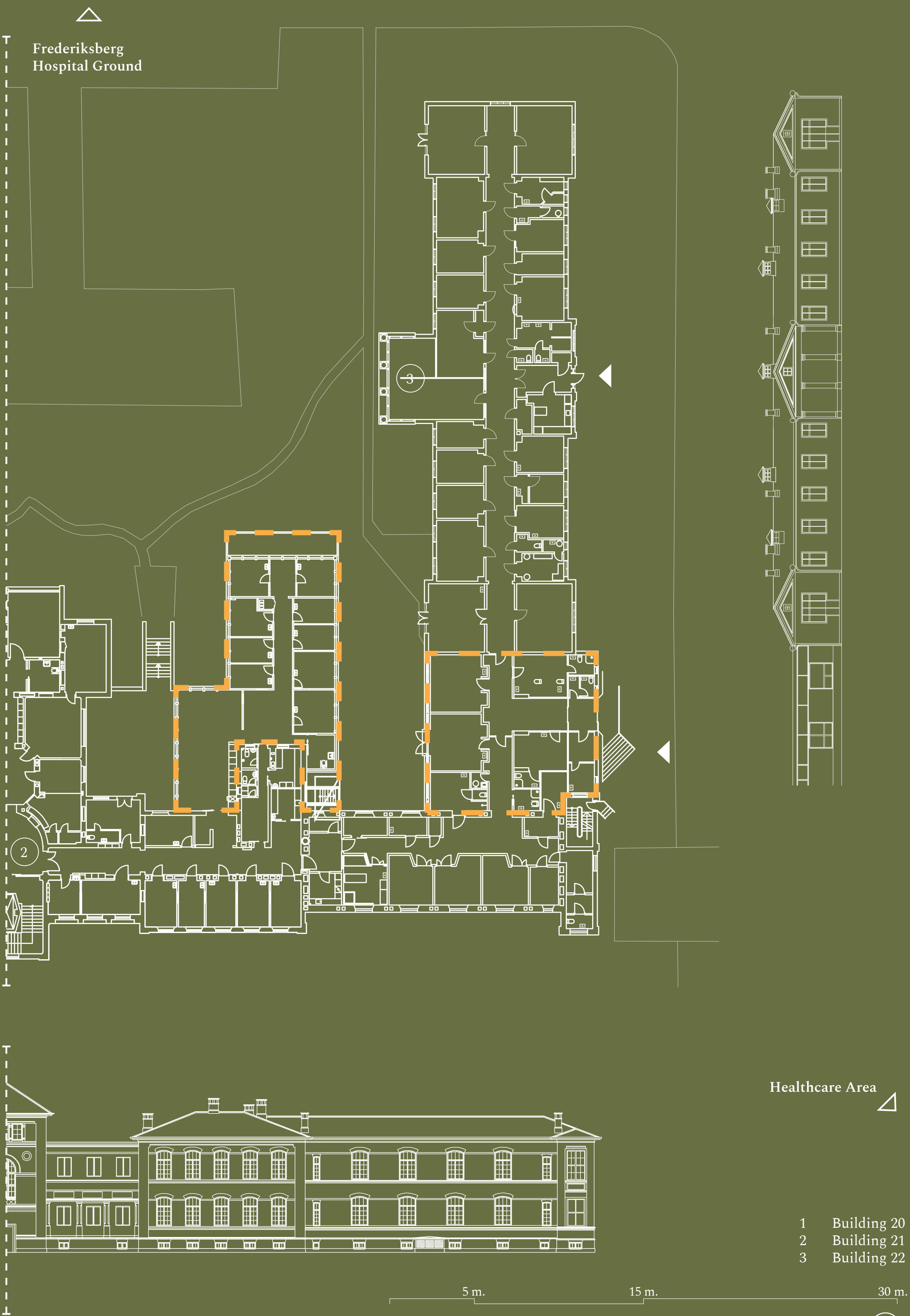
The project site consists of three buildings which encircle a green courtyard. The three buildings are defined as Building 20, 21 and 22. Building 20 and 22 are low pavilions from 1908. They have similar aesthetics and compliment each other in volume, details and materials. They are built in a small scale to relate to the human scale and the greenery in between to ensure the connection from inside to outside. These buildings are former bedwards for paying patients and children (Frederiksberg Kommune. n.d. b) and today they are outpatient departments for patients with heart diseases (Region Hovedstaden & Frederiksberg Hospital. n.d.). Building 21 is a bigger pavilion from 1899 and has a more scattered volume and scale. Therefore the building is diverse and seems like multiple buildings in one. Building 21 is a former surgical unit with bigger and smaller patient wards. The different functionalities and departments were built in separate annexes to ensure a high standard of hygiene (Frederiksberg Kommune. n.d. b). Today, the building is geriatric outpatient department for patients that have suffered a fall or experienced memory loss (Region Hovedstaden and Frederiksberg Hospital. n.d.).

The Building Plot





Main Entrance to
the City of Frederiksberg


Frederiksberg
Hospital Ground
2
3
Healthcare Area
1 Building 20
2 Building 21
3 Building 22
5 m.
15 m.
30 m.

Ill. 42.

Building 20

Hovedvejen 12 (Vej 4 number 2)
Nordre Fasanvej 59
2000 Frederiksberg
Denmark

Gross area: 693 square meters
Net area: 647 square meters
Basement: 647 square meters

Historical Changes

Since the building's original framework, different small adjustments have changed the expression and plan organization seen today. The small changes have been reorganization of the non-load-bearing structures of the interior to create smaller or bigger open spaces. In addition, some adjustments in the load-bearing structure have been made with an overlaying beam instead of load-bearing columns. This is interpreted from different historical plan drawings.

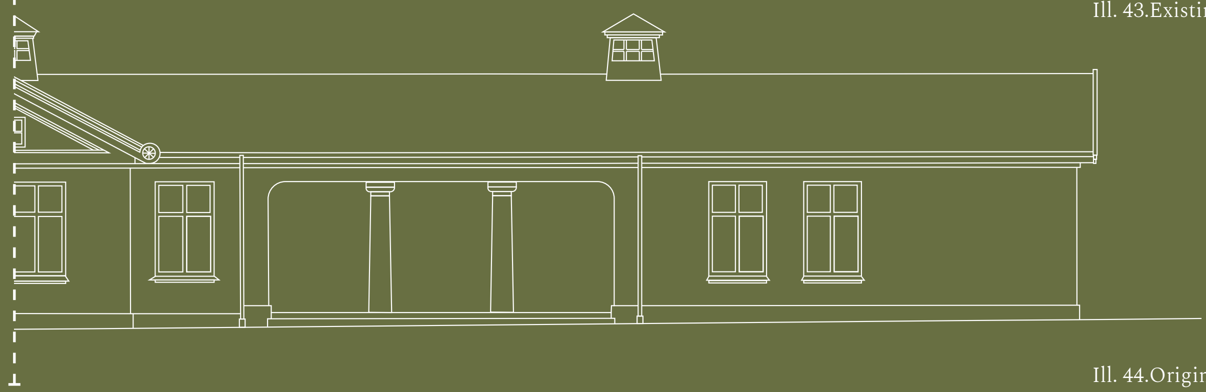
Architectural Characteristics

Building 20 is built after the architectural style Historicism which has its references to the historical styles of Classicism and Neo-Baroque.

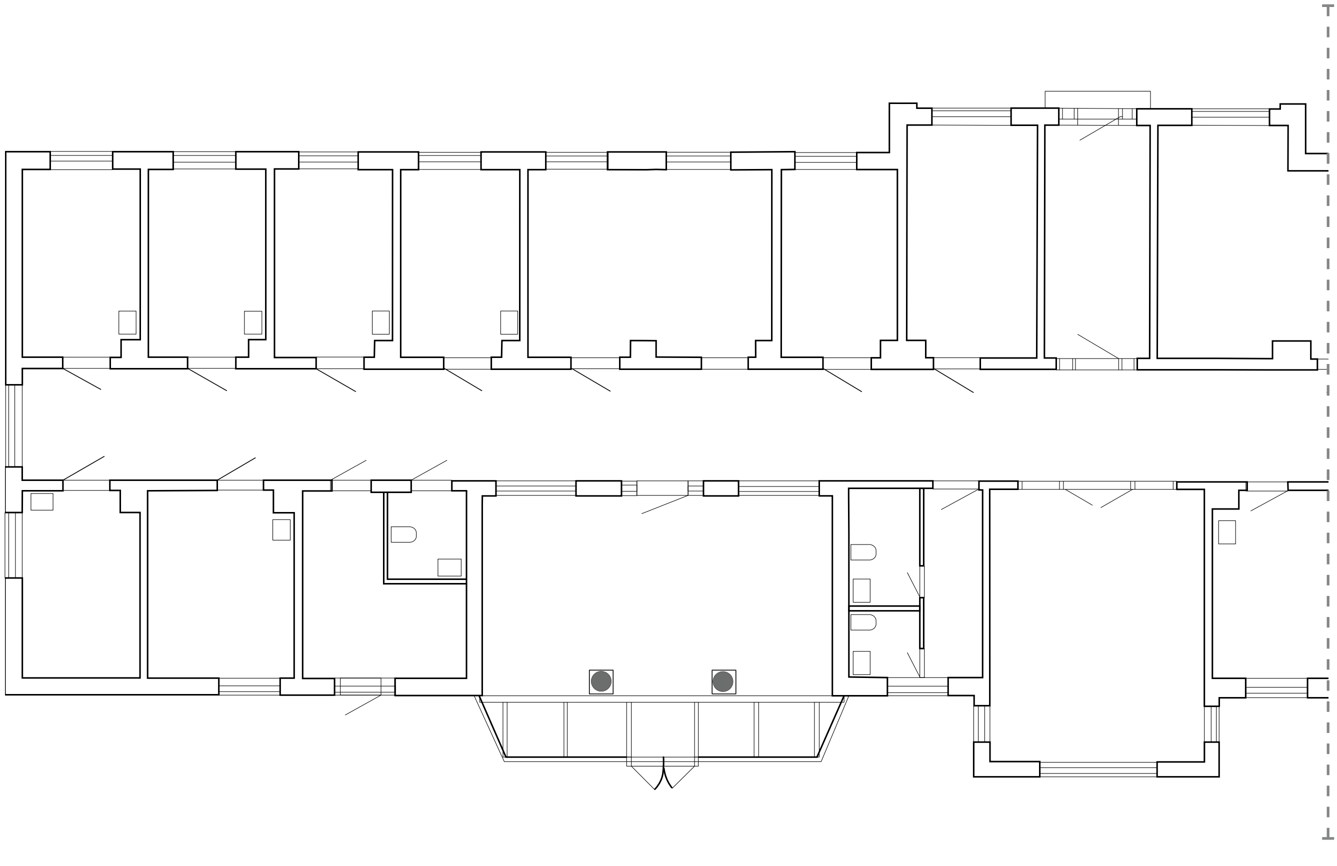
The building's fabric entails a high quality of detailing, from the window's joints to small details applied and integrated on various building elements. Nevertheless, it is characterized by its very orange plaster facade and its low relief framed by a triangular-shaped frontispiece.

The building is inspired by classicisme blended with historical architectural style. The classicisme measurements are identified in the symmetrical framework of the building's upright projection and overall plan distribution.

Ill. 43.Existing conditions



Ill. 44.Original conditions



Structural System

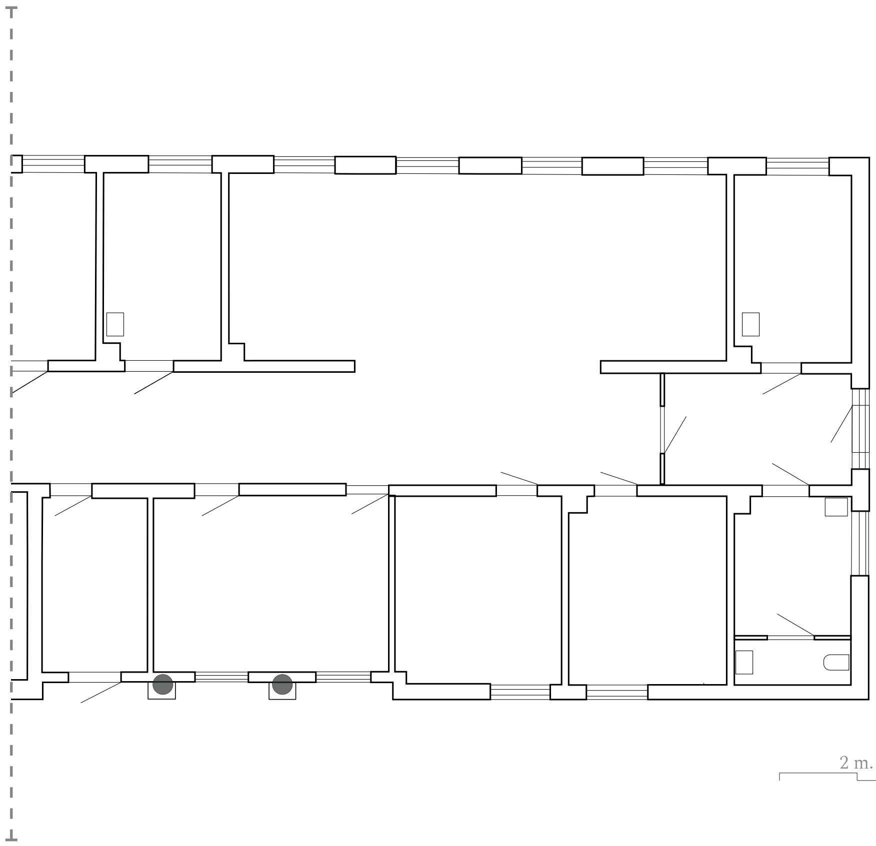
Load-bearing timber-frame and brickwork system. The structural system is defined by a truss system placed with 1 meter distance. The truss system is divided in three elements with the middle over the hallway and the two others on either side.

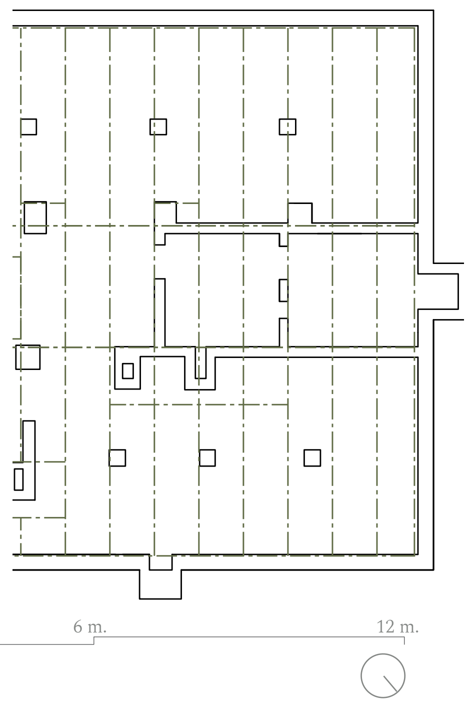
Potentials

The building's load bearing system, which entitles repetitive placed columns that allows free spans of varying lengths from 2.5 to 6.4 meters, allows functionalities which both need strict structural division or open plan solutions.
The fabric of the building has a high potential for preservation. The many high quality details, the orange facade expression, and the historic low reliefs are statements of the past and therefore brings the users attention to former building styles and past history.

Limitations

Building 20 is centrally located near the main entrance to Frederiksberg Hospital. Potential functionalities could therefore be limited from sensitive functionalities, as private one-plan residential units with direct connection to the public surroundings.





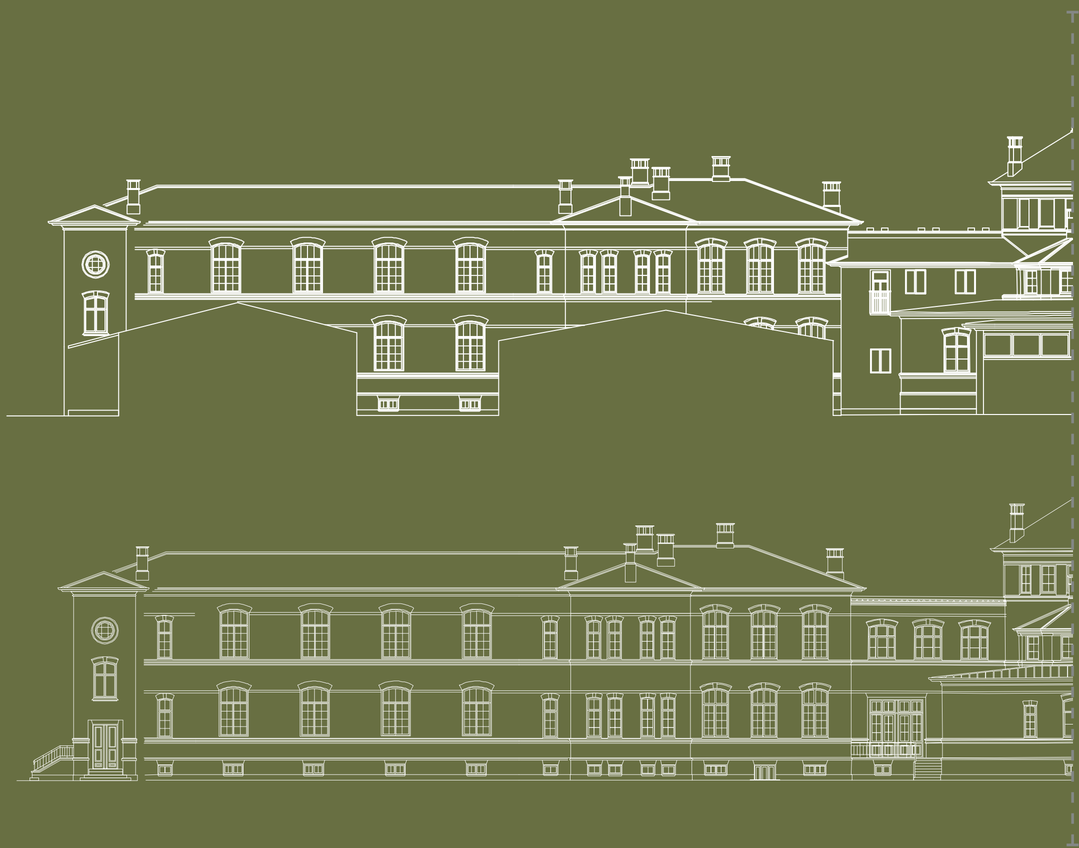
Ill. 45.Floor plan

Ill. 46.Ceiling plan

Building 21

Vej 2, number 1
Nordre Fasanvej 59
2000 Frederiksberg
Denmark

Gross area: 1804 square meters
Net area: 3413 square meters
Basement: 1619 square meters



Historical Changes

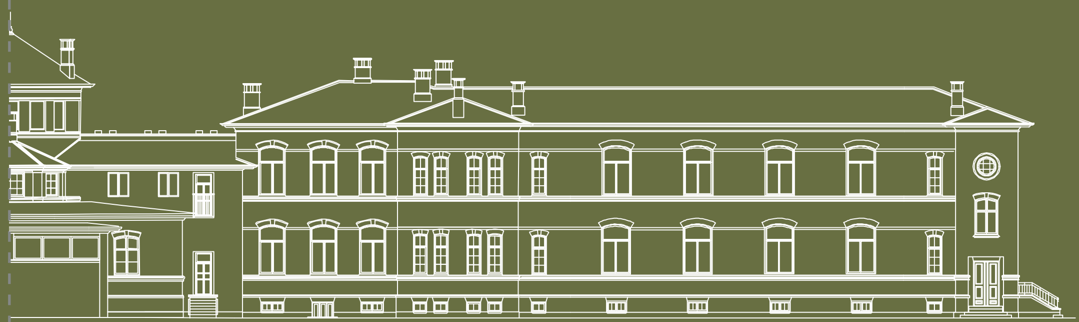
When analyzing different historic plan- and facade drawings, bigger changes have happened through time in the organization, when considering flow patterns and entrances. Two former main entrances on both sides of the south-east facade's middle-ressaut have been removed and integrated into the center of the ressaut as one main entrance. This symmetrical concept of entrances have been implemented on the north-western facade - shaping the framework of a hall-like atmosphere joining the east and west urban scape of the building.

Nevertheless, by connecting the building's historical typology, facade drawings and by a careful on-site investigation concerning the condition of the different building parts, it has been made clear that the whole middle section, which historically only consisted of cross-over bridges dividing the building in three parts, have undergone a significant change. The change concerns a pronounced expansion of the building in this area by an increase in size to the north-west. The expansion somehow rests in the historical building, and by first eyesight this is not noticed. Furthermore, fire exits have been reorganized from having direct exit to the outdoor to only having outdoor access through a number of intermediary rooms. Other smaller changes in the inside organization have happened as well with the biggest change being an open plan bed ward transformed into smaller examination rooms. Though, all the interior reorganizations have been fitted to the original structural system.

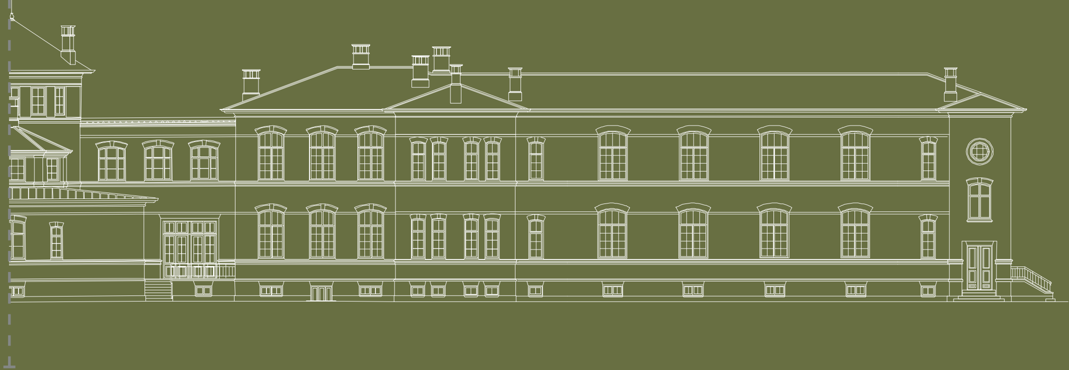
Architectural Characteristics

Building 21 is also built after the architectural style Historicism with references to Classicism and Neo-Baroque. Especially the use of architectural references to the baroque style characterizes the voluminous building. Details such as cornices, forward drawn pilasters in the facade, and the before mentioned middle-ressaut especially gives a clear reference to baroque architecture. The building therefore states a theatrical front piece of the historic hospital. When considering the composition of the two main facades they are very different but still alike in its symmetry. The south-east facade is mounting equally to two storeys high whereas the north-eastern facade is divided into multiple heights, and therefore meets the human scale of the corresponding buildings and intermediary urban space.

Considering the characteristics of the indoor environment it is to mention that the house is built with high ceiling heights with complimenting high windows, which allows natural daylight and ventilation to happen. Different patterns in the ceiling are utilized by different structural frameworks, which creates architecturally shaped artworks.

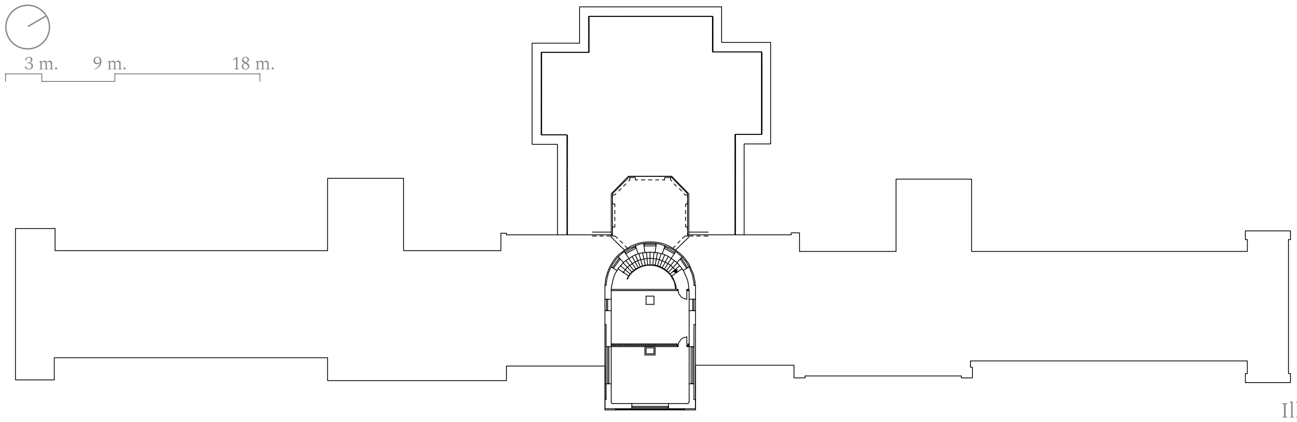


Ill. 47.Existing conditions



Ill. 48.Original conditions

2 m. 6 m. 12 m.



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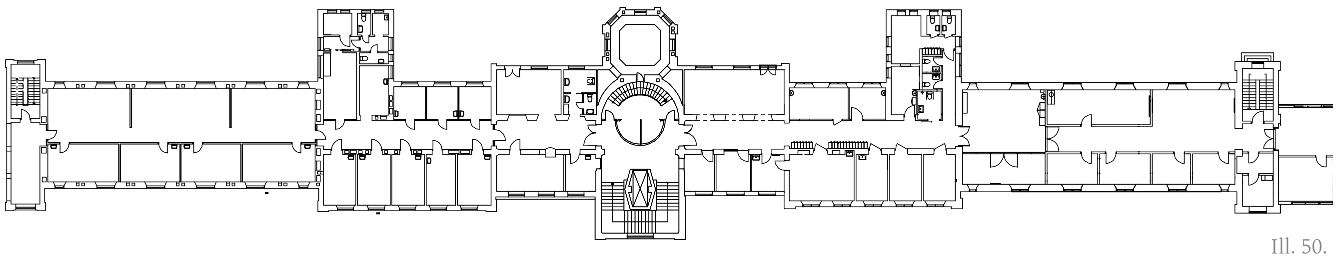

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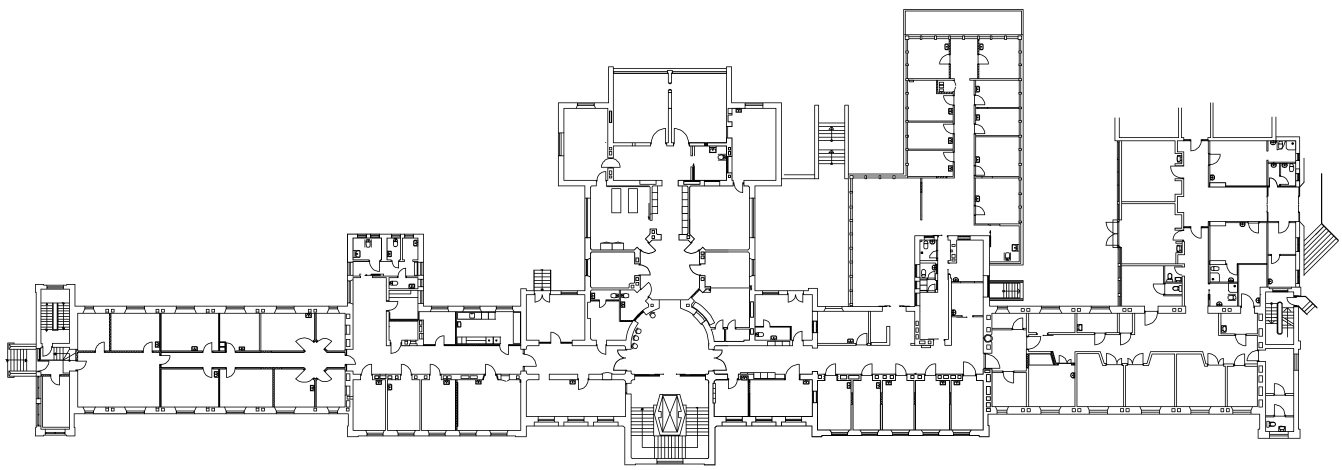

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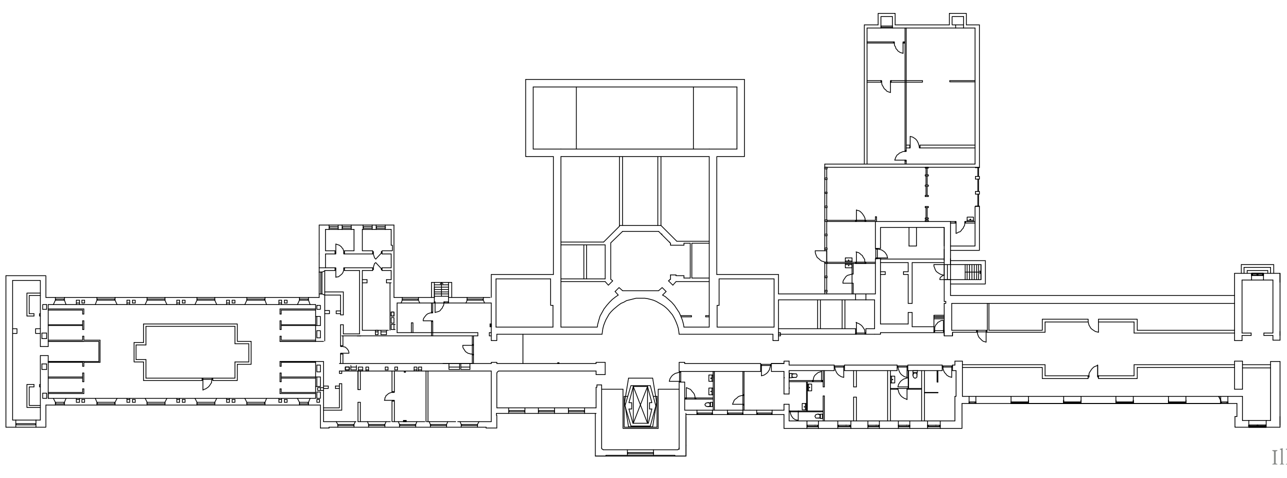

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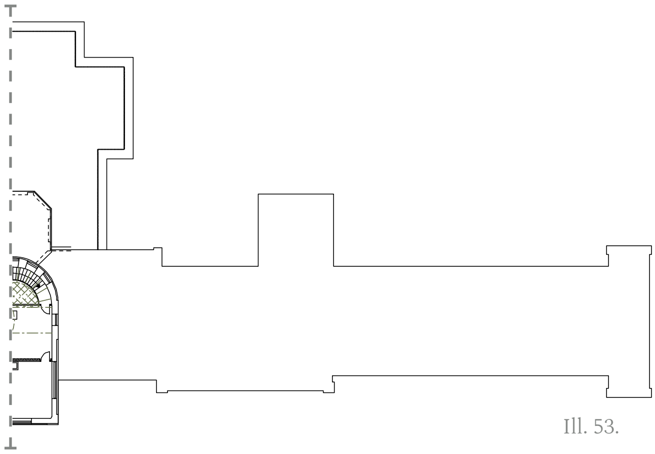

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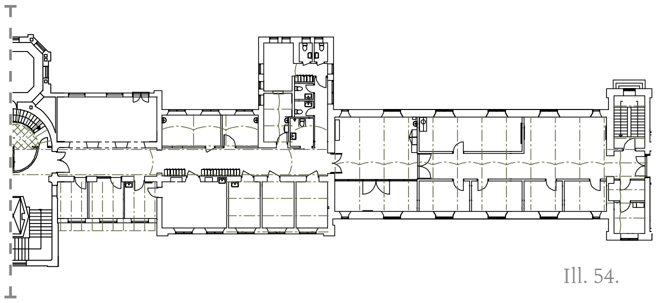
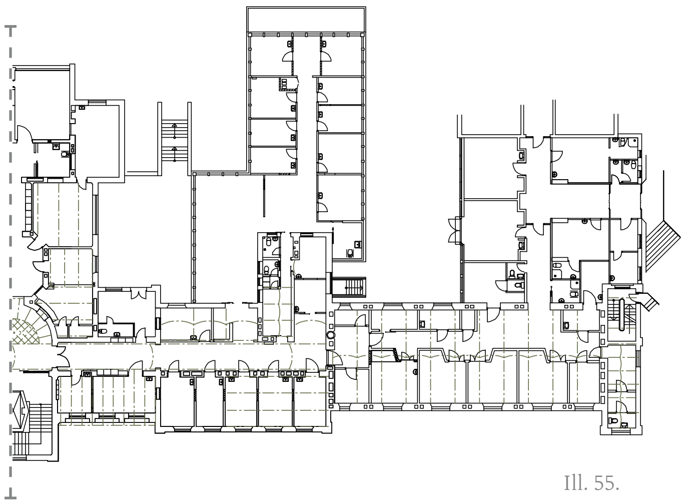
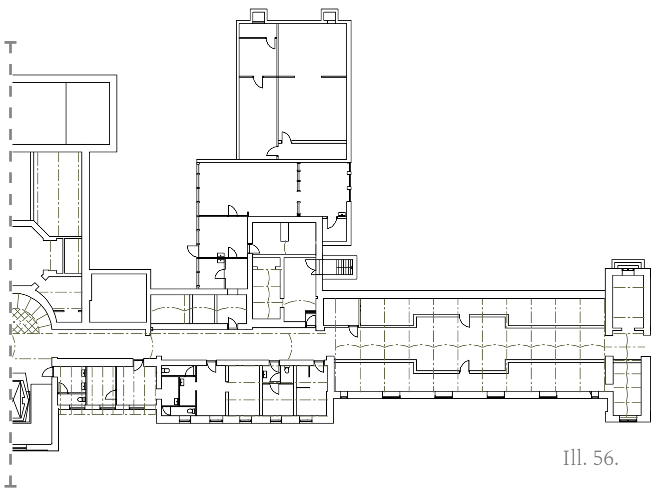


Ill. 54.



Ill. 55.



Ill. 56.

Structural System

Load-bearing beam and brickwork system. The structural system of the building is diverse in the use of different systems - defining variating atmospheric qualities. One system which has been used in many areas of the building is arches in the ceiling structure with complimenting beam structures, to ensure the capability of open-plan areas. The different arches vary from one room to another, and are considered to be defined by the specific rooms' dimensions.
In addition to the use of curved ceilings divided by beams, flat ceilings with beams are integrated in some areas. These two systems are somehow interconnected in the center of the building, at all floors, where a small ceiling area consists of a coffered ceiling.

Potentials

The symmetry, the clear use of simple tectonic instruments, and the transition over time shapes great potentials for discovery and transformation or re-purpose. The greatest potential of them all is how careful new extensions have been added to the existing historical buildings - so careful that it is not noticed, but read as a natural and original part of the exitsing.
The building's shape creates potential in matters of mixed use transformation, whereas smaller apartment units, bigger common areas, and recreational spaces can be integrated under one collected roof - utilizing a framework of a social house, with green areas right in front of one's window.

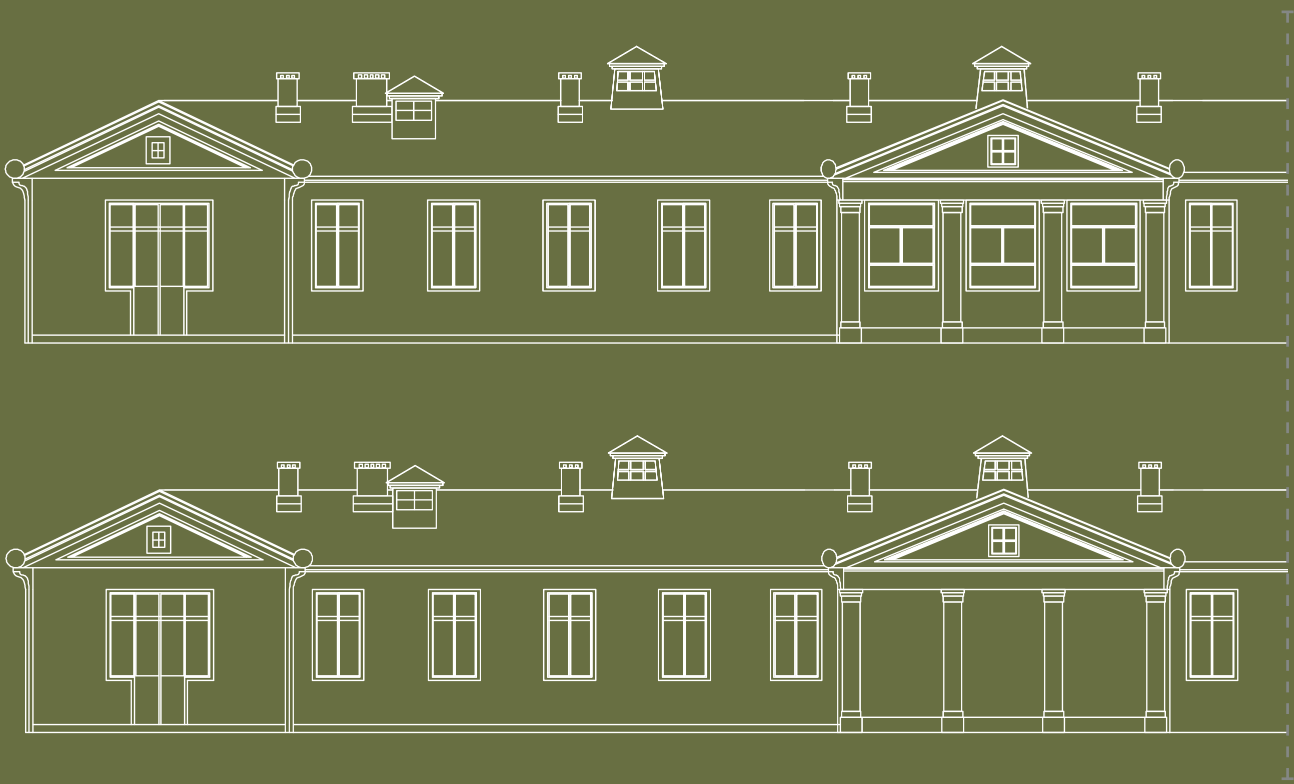
Limitations

The building acts as a wall against the city towards the east, and therefore has a negative influence on the flow in the area. It should be discussed whether it is a potential or a limitation to open into the courtyard surrounded by the three selected buildings, to ensure that the atmosphere of this space is not lost.
The greatest limitation of the building is its many architectural qualities, both the building's fabric and the organization. Additions, extensions, and such must be considered with careful thought to the existing qualities, to ensure that a neglect of the existing does not happen in the final proposal of transformation. A preservation and careful approach to scale, hierarchy, symmetry, and connection are a vital part to ensure to keep up with the limitations.

Building 22

Vej 4 number 14
Nordre Fasanvej 59
2000 Frederiksberg
Denmark

Gross area: 907 square meters
Net area: 844 square meters
Basement: 637 square meters



Historical Changes

Not much has happened with the building's original framework. The biggest change is the closure of the historic entrance at the building's northern facade's middle-ressaut which is replaced with an added building that connects to Building 21. The new addition acts as the new entrance of Building 22 and seems as an unnatural addition to the two buildings.

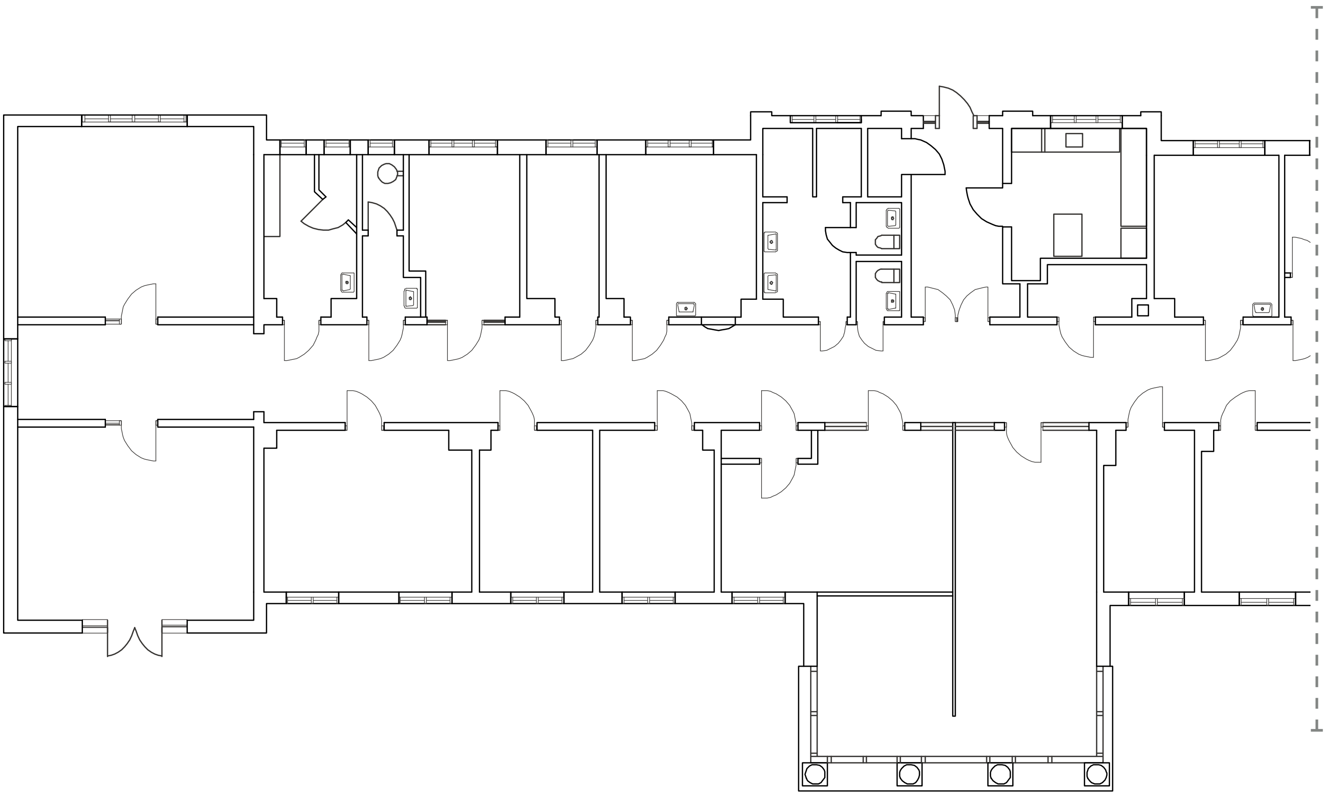
Architectural Characteristics

Building 22 is likewise built after the architectural style Historicism which references the historical styles of Classicism and Neo-Baroque. The building has similar details as Building 20, though the outer fabric seems more neglected.

Ill. 57.Existing conditions

Ill. 58.Original conditions

2 m. 6 m. 12 m.



Structural System

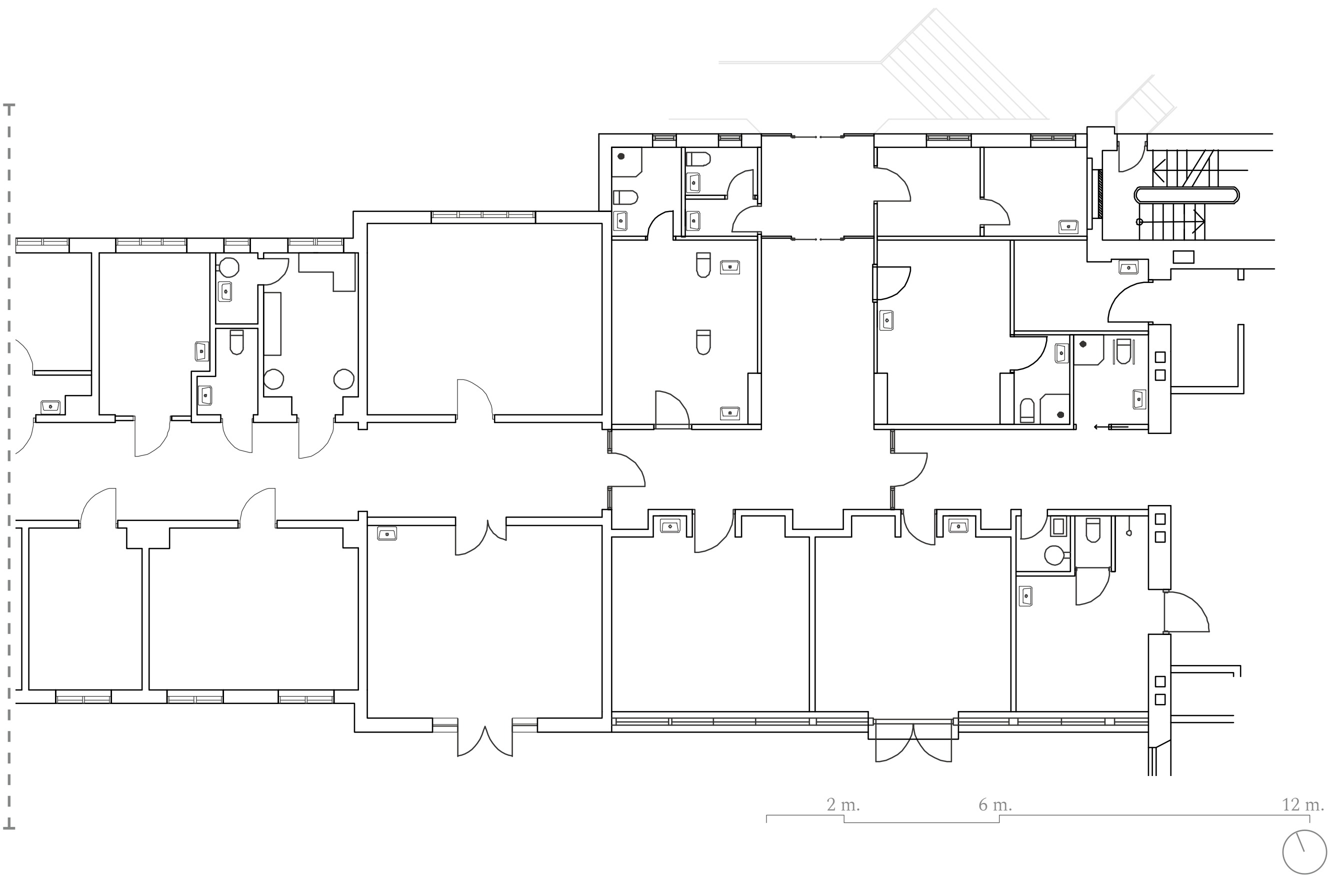
It is assumed that the building has a similar structural system as Building 20, consisting of a load-bearing timber-frame and brickwork system.

Potentials

This building has a great potential for restoration of neglected qualities. The qualities are similar to Building 20 and should be the first to be restored.
Moreover, it should be considered whether the added building and its function as a connecting element between Building 21 and 22 is needed and fits the architectural expression of the area. As it is designed now, it can be concluded to have a negative effect on the surrounding architectural scape because of its shed-like expression which is not seen elsewhere at the site. There is therefore a hidden potential of exploring what this tiny space should be in the future, whether it should still be a connecting part but designed differently, or demolished to secure better flow patterns in the area.

Limitations

Building 22 is located near the buildings maintained for healthcare functions and placed in a very public space. Therefore it has similar limitations as Building 20, which is limited from sensitive and more private functions.



Ill. 59.

Ill. 60.

04. CHAPTER

In this chapter, the theory and analysis are summed up and concluded upon. The thesis' position on transformation is presented as well as the design criteria which clarify the focus of the project and are acting as a guide throughout the design process.

DELIMITATIONS

The Position

The position of the thesis is to work with and not against the heritage and the existing structures of the buildings to be transformed. To be in dialogue with the present situation of the buildings and let them evolve around their own logic and valuation is the essence of the design. Therefore, the question arises; What does the building prefer?, which asked for the processed buildings to promote the development and supply of new functions without imposing the buildings to become something that was not meant for it.

The stated question acts as the guideline and concept of the thesis. The position's approach is likewise to combine the architectural and engineering field. This has evolved into a Renovation Matrix (see page 96), which balances the two. Nevertheless, the thesis' position leads to two general disciplines within transformation in general, which can be described as;

Subtraction | The original shape is valuable and additions will be considered

Rephrasing | Rooms and building parts should be transformed and rephrased due to new functions and energy optimization

The concept and the two above mentioned disciplines have formed the basis of this thesis and the transformation of Frederiksberg Hospital.

Design Criteria

Masterplan

The historic buildings, green areas, and trees of Frederiksberg Hospital should predominantly be preserved, as new developments are adapted to the existing structures.

The aesthetics of Frederiksberg Hospital, hereof the architecture, green features, and materials, should articulate a varied appearance by interplay between existing and new elements.

The transformed neighborhood should enable activity and be inviting to all kinds of citizens by having varied types of housing, cultural environments, leisure facilities, and diverse urban areas.

The green structures of the surrounding city should be reinforced in the transformed neighborhood by the implementation of avenues that establish spatiality and smaller paths, as urban spaces ensure recreational areas in-between buildings.

Project Site

The buildings should ensure an accommodating scale and utilize climate-adapted urban spaces, that consider the sun, wind and shadows.

Cultural and residential coherence should be ensured by an implementation of diverse functionalities when transforming and reorganizing the buildings.

The relation between the buildings should encourage flow and coherence between the buildings and users.

Buildings

Details and ornamentation of the buildings should be preserved to uphold the identity of the area.

New added architecture must relate to the existing buildings by implementation of elements from the existing architecture, such as similar volumes, dimensions and scales, windows, details on facades etc.

The transformation of existing buildings should consider the original thoughts and ideas of the buildings and its functionality by reinventing them into a new design.

The existing load-bearing structures should be utilized and reinvented when transforming and reorganizing the buildings, in order to highlight the historicism of the place.

The existing buildings should undergo an optimization of the building envelope in order to meet the energy requirements of Renovation Class 2 and to ensure thermal comfort throughout the year.

Ill. 61.

05. CHAPTER

This chapter presents the final design proposal through a variety of different illustrations and diagrams. The aesthetic, technical and functional intent and solutions are presented throughout the chapter. The Small Scale is presented first, and is then followed by the Medium Scale and then the Big Scale. This order is reversed compared to the Program and the Design Process.

PRESENTATION

Building 20 & 22

General Presentation

At first glance, the two smaller pavilions appear as a reflection of each other. Building 20 and 22 are similar in structure and details, yet they differ from each other. Elements such as columns in the facade and different use of cover for the division between outside and inside to appear invisible. The trees that have grown tall over time cast shadows on the small buildings and tell the story of a long life - the story before the new transformation. The low building heights ensure a human scale in the area and embrace the outdoor area with their horizontal building bodies. This creates life between the buildings in the area's and the buildings' niches.

Technical Interventions

As a part of the optimization of the building's technical intervention of Building 20 and 22 is made to optimize the energy consumption and indoor climate to the new functions of the buildings. The intervention is made with the building's preservation and historical values as the main design drivers. The Renovation Matrix has been used to compare careful, medium, and radical intervention with the original architectural aesthetics. The buildings therefore have remained the same exterior expression to keep their recognizability in the area which predict the interventions to be in the interior - here especially the insulation of the external walls, as this contributed to preserve the external fabric of the buildings. The buildings are insulated from the inside both in the floor against the basement, the ground deck, roof, and windows, where the windows are replaced with new and better to keep the aesthetics in the exterior. As the roof is insulated from the inside the ceiling is removed to expose the construction of the roof and by that tell the story of how constructions were made in 1908. The basement in Building 20 is made usable for the future functions with the insulation of the ground deck and the external insulation of the walls which prevent humidity of the basement.

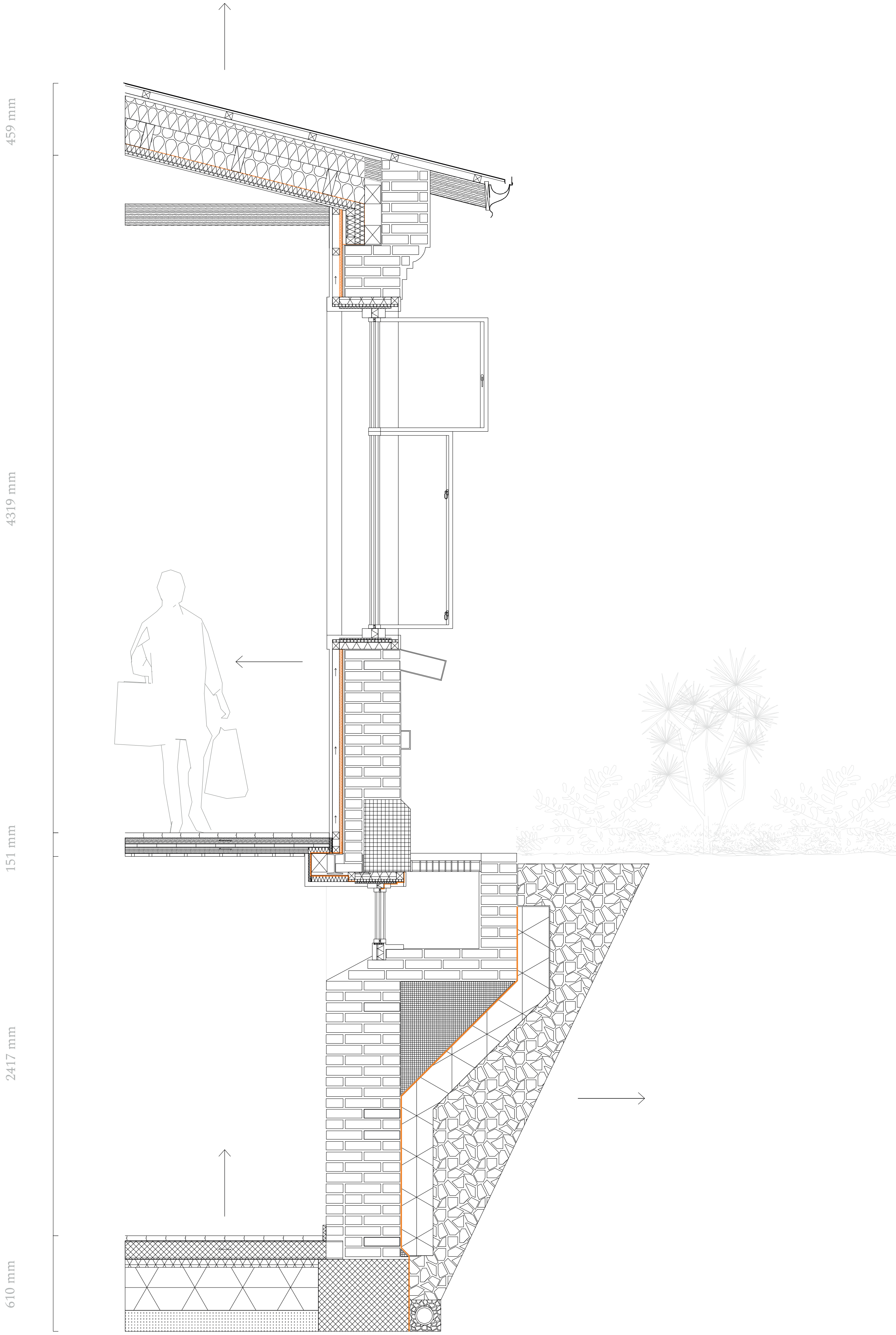
Ceiling beneath rear-ventilated attic roof, from the inside
12 mm wooden boards
60 mm rockwool between 60x45 mm battens
Vapour barrier
160 mm rockwool between 160x60 mm battens
120 mm rockwool + 20 mm rear ventilated space between 140x120 mm trusses
45 mm rear ventilated space between 45x45 mm battens
12 mm wooden planks
Roofing felt

Exterior wall construction, from the inside
10 mm render
35 mm vacupor NT-B2-S insulation
10 mm mortar
360 mm solid brick
10 mm render

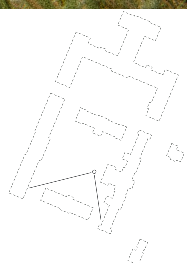
Windows
3 layer energy glass
Basement floor where no terrain deck is constructed, from the top
32 mm wooden flooring
120 mm concrete and steel beam
50 mm polystyrene
1.5 radon and moisture protection foil
275 mm polystyrene
133 mm sand

Basement footing / wall, from the outside
1 mm covering
100 mm porous panel S80
0,2 mm Moisture barrier
5 mm basement wall cover
Footing mortar
470 mm brick wall

Floor deck, from the top
32 mm wooden flooring
45 mm air layer with transverse beam
20 mm wooden boards
45 mm air layer with transverse beam
20 mm wooden boards



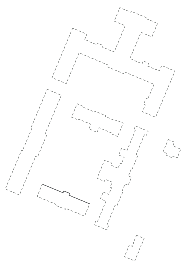
Ill. 62.Building fabric interventions



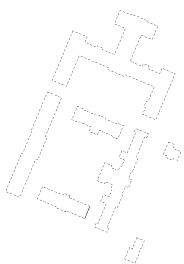
Ill. 63.Vizualisation of Building 20 and concept of new added building, in relation to the urban park area in-between buildings

The Fabric of the Buildings

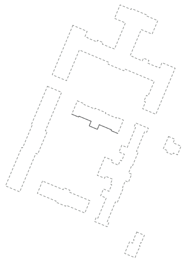
The two small pavilions from 1908 stand with their original facade expression to ensure the identity and recognizability of the area. All details and ornaments on the facades and roof constructions are preserved and kept as is. The level of original detail gives a depth and an extra layer to the buildings that tell they were built in another time. The facades towards the courtyard are opened up, so the main entrances are defined and lead the way inside. Moreover, it gives shade from the sun and rain when needed. Even though the facades are opened up, the tactility and rhythm of the facade is kept as the original.
The wooden extension on Building 22, that connected to Building 21 is removed and replaced with an entrance that visualizes the connection between the two buildings.



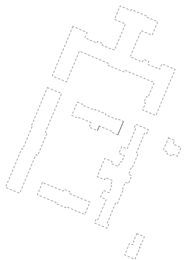
Ill. 64.North-east elevation of Building 20 showing the opening of the facade which create a sheltered space on both sides of the middle-axis



Ill. 65.South-west elevation of Building 20 where the original fabric is preserved



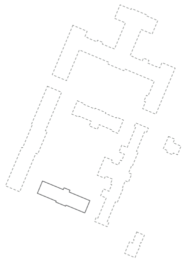
Ill. 66.South-west elevation of Building 22 illustrating the re-opening of the middle frontispiece



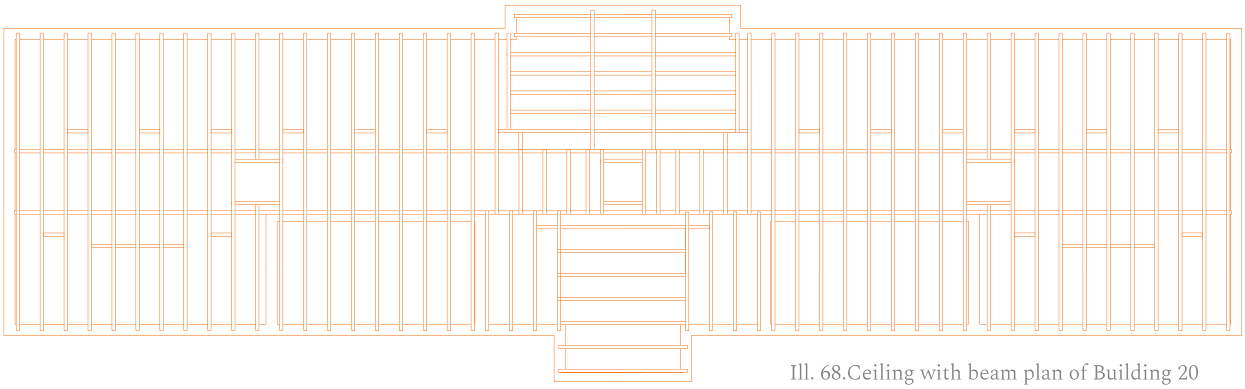
Ill. 67.South-east elevation of Building 22 which shows the extension of a glass entrance pavillion

1 m. 3 m. 7 m.

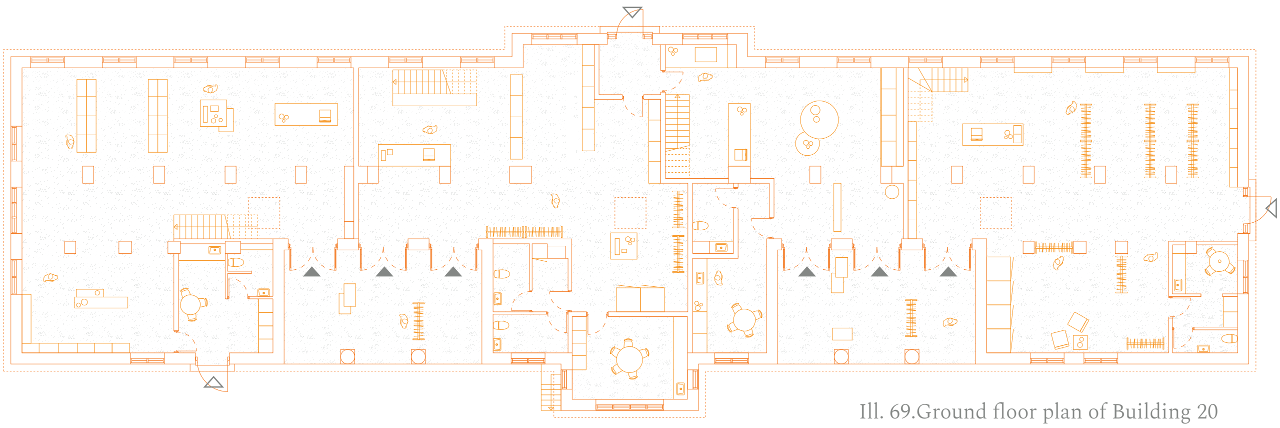
The Interior Organization of the Buildings



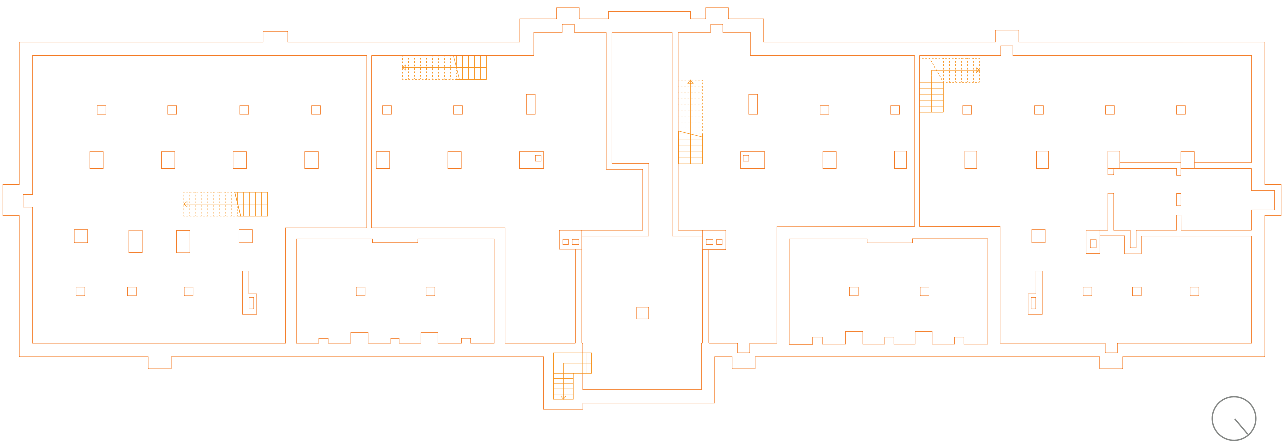
To create a lively courtyard and area, Building 20 and 22 is divided into different functions. Building 20 consists of small local shops and Building 22 is a creative space.
Building 20 is organized with four shops with individual entrances. Every store is equipped with a staircase to the basement with space for storage.
Building 22 is organized with one main entrance that contains toilets and a wardrobe with space for bags and jackets. The space is then divided into two directions. On one side there is room with space for different workshops, this can be divided into two seperate if needed. On the other side there is a library space for chil-



Ill. 68.Ceiling with beam plan of Building 20

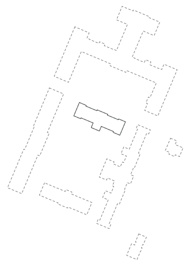


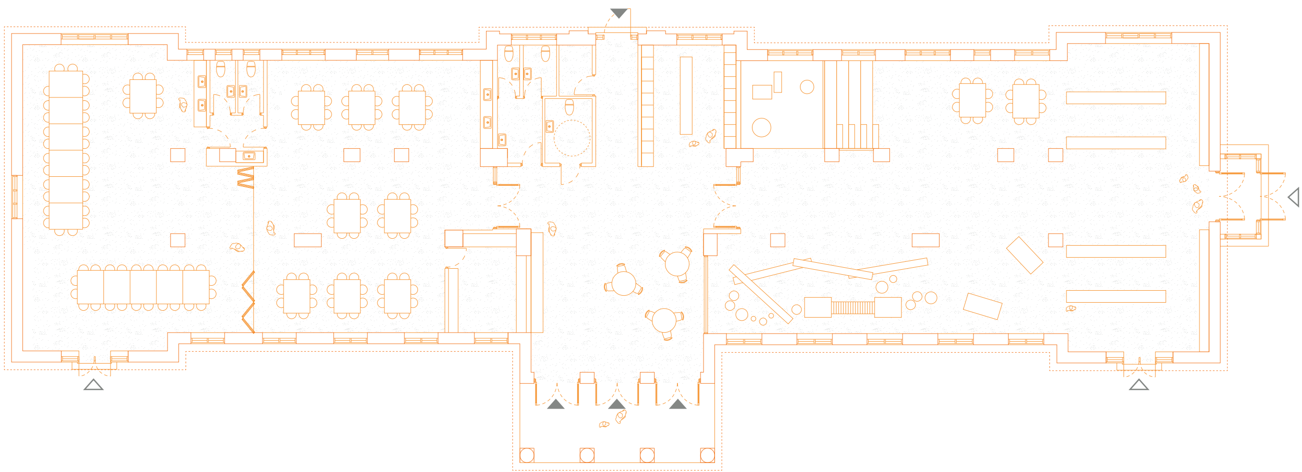
Ill. 69.Ground floor plan of Building 20



Ill. 70.Basement floor plan of Building 20

dren. The door at the gable connects to the rest of the library in Building 21.
The interior is organized with respect for the load bearing construction which is kept as is. However, it is assumed that the ceiling plan for Building 22 is similar to the one shown for Building 20. Moreover, The basement under Building 22 has not been utilized and therefore, it is not presented.





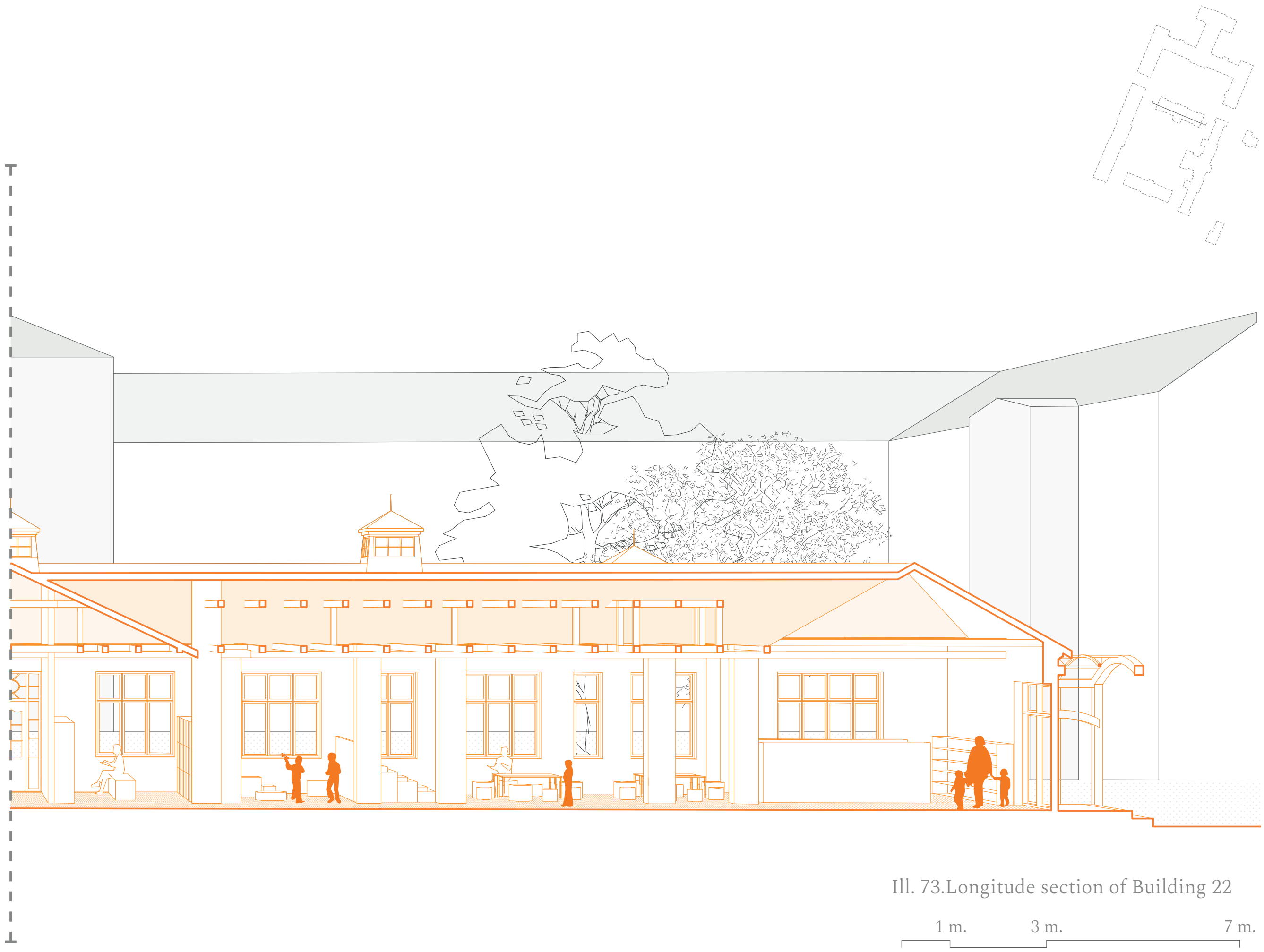
Ill. 71.Ground floor plan of Building 22

1 m. 3 m. 7 m.

The Interior Spatiality of the Buildings

The ceiling of Building 20 and 22 are opened up to enhance the interior space and create light and airy rooms. The initiative exhibits the extensive roof construction of beams placed every meter. Even though it is a vaulted ceiling, the dense roof construction brings down the ceiling height.
In both buildings a skylight guides the light into the middle of the building. The skylights are original elements, designed to get light inside the hospital hallways. Today, the interior rooms are placed across the buildings as seen in illustration 72, this allows the visitor to experience the spatiality of the building in its entirety.

Ill. 72.Cross section of Building 20



Ill. 73.Longitude section of Building 22

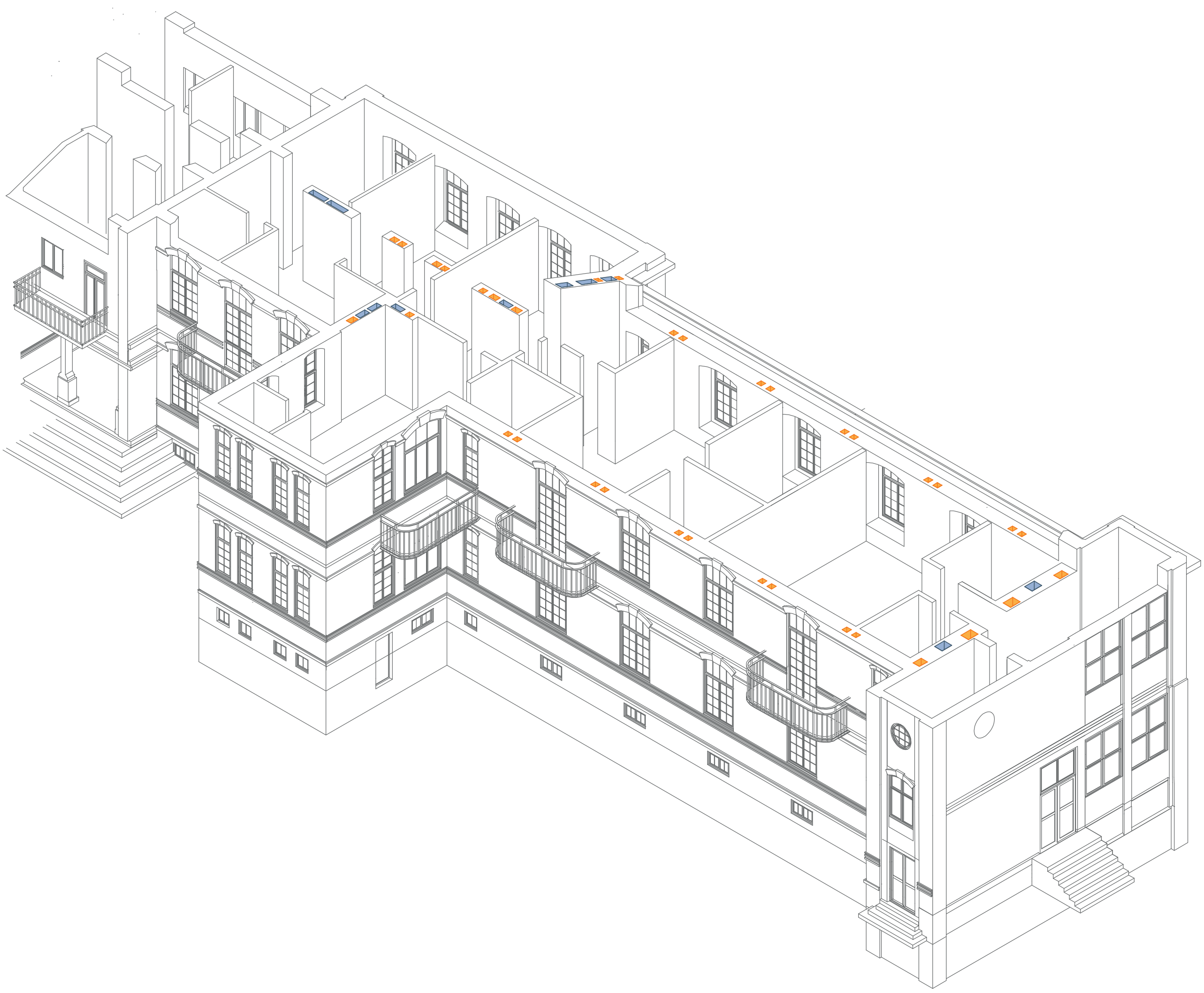
Building 21

General Presentation

As a magnificent monument to the former Frederiksberg Hospital, Building 21 appears as the entrance portal to a new area within the city, where diversity in users and functions creates a synergy for the area. The building, with its continuous opening from the city towards the park, shows new connections for the area's other buildings. With its luminous eyes looking down on the park's wild areas, the building in synergy with the park creates an idyllic oasis in the middle of the busy city. The building is accompanied by a luminous public conservatory by breaking with an otherwise tight rhythm and building structure. The center of the building meets the human scale and thereby addresses the surrounding buildings towards the rest of the old hospital ground. The building does not violate its history but has been transformed to house new functions that complement the existing building structure.

Technical Interventions

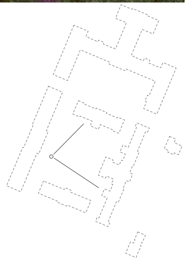
The technical intervention of the building is somewhat a copy of the interventions made in Building 20, but some elements are changed specifically according to the building construction - hereof the floor structure and ceiling towards the roof. In Building 20 the roof is insulated, and the ceiling is removed to increase the room height and expose the load-bearing system of the roof. This is not possible to do in Building 21 as all the ceilings are detailed with arches in the interior. The insulation of the floor structure is therefore made on top of the floor - this takes a few centimeters of the room height but preserves the details which the building is enriched with. Furthermore, the building has integrated ducts for exhaust in the load-bearing walls. Illustration 74 shows the existing duct and how they are used for exhaust and heated air. All ducts are connected to the ground and first floor by small grids which are placed high in the external walls. It is presumed that these can be reused for the new functions of the building as it is known that the sizes of the duct can extract the air.



Heated air ducts

Exhaust ducts

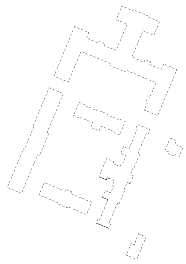
Ill. 74.Technical potentials in the ex-
itsing strusture of Building 21



Ill. 75.Vizualisation of Building 21 with attention to the activity be-hind windows by nightfall, caused by the new functionities

The Fabric of the Building

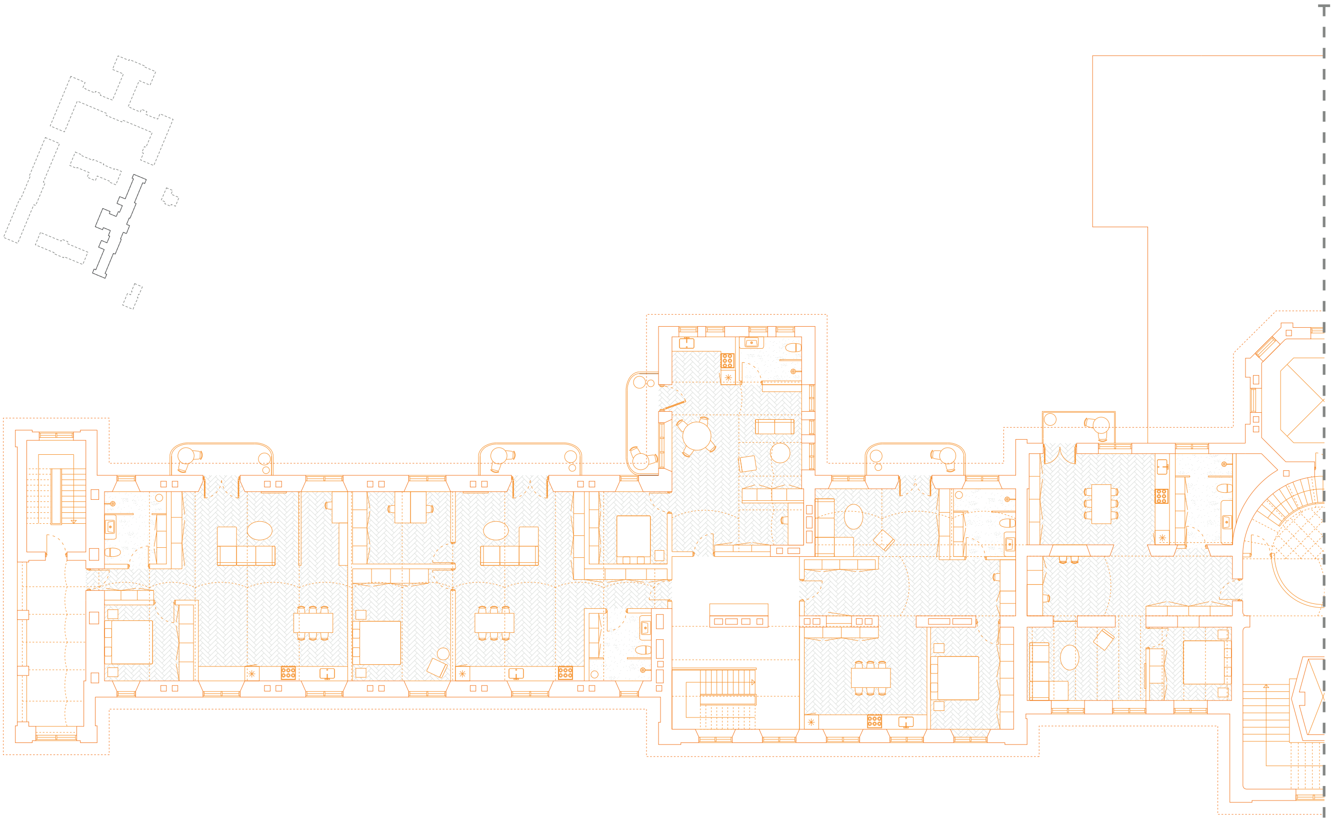
The old hospital building, originally from 1899, stands with its original façade expression with the main material - yellow bricks. The details and ornaments of the old façade are preserved and divide the façade horizontally and thereby indicate the height of the building. The level of details and structure also state that the building once was meant for other purposes and the history of the building is kept. The big, white mullioned windows as well gives the façade a majestic expression as it rises towards the street and rest of Frederiksberg. Openings around the middle of the building invites visitors to go through and thereby use the green areas behind. From the street the building seems as one complete unit, but by entering the park behind the expression shows the functions of the inside. Balconies on the first floor show that the building is divided into several functions - divided horizontally as the details in brick insinuated. The middle part of the building meets the outdoor space in a scale aimed at humans by its different shapes and heights.



Ill. 76.South-west elevation showing the gable of the build-ing

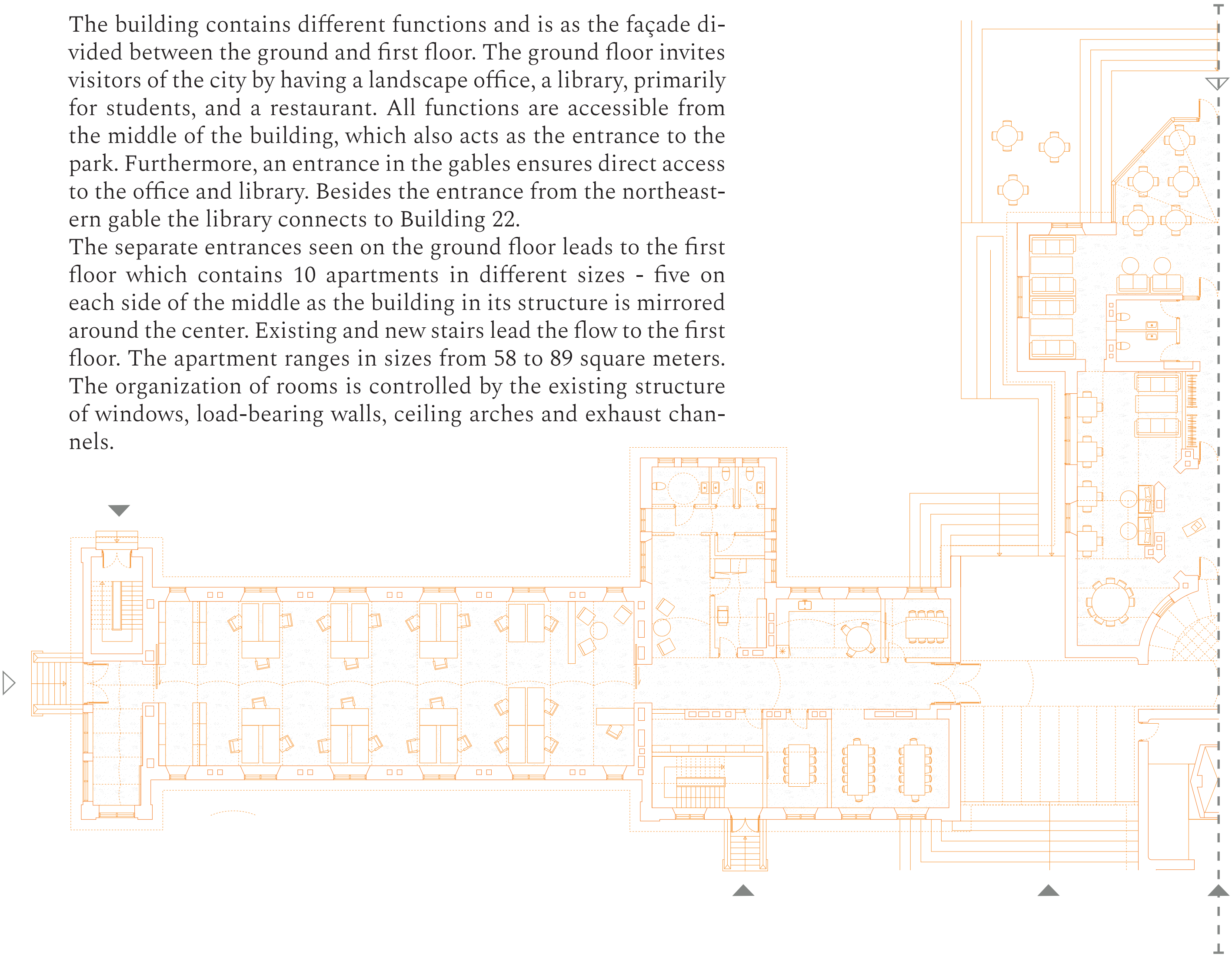
Ill. 77.North-east elevation of Building 21, showing the intervention of opening up the facade as a maingate to the urban space behind the building, and the new entrances to appartments units on first floor

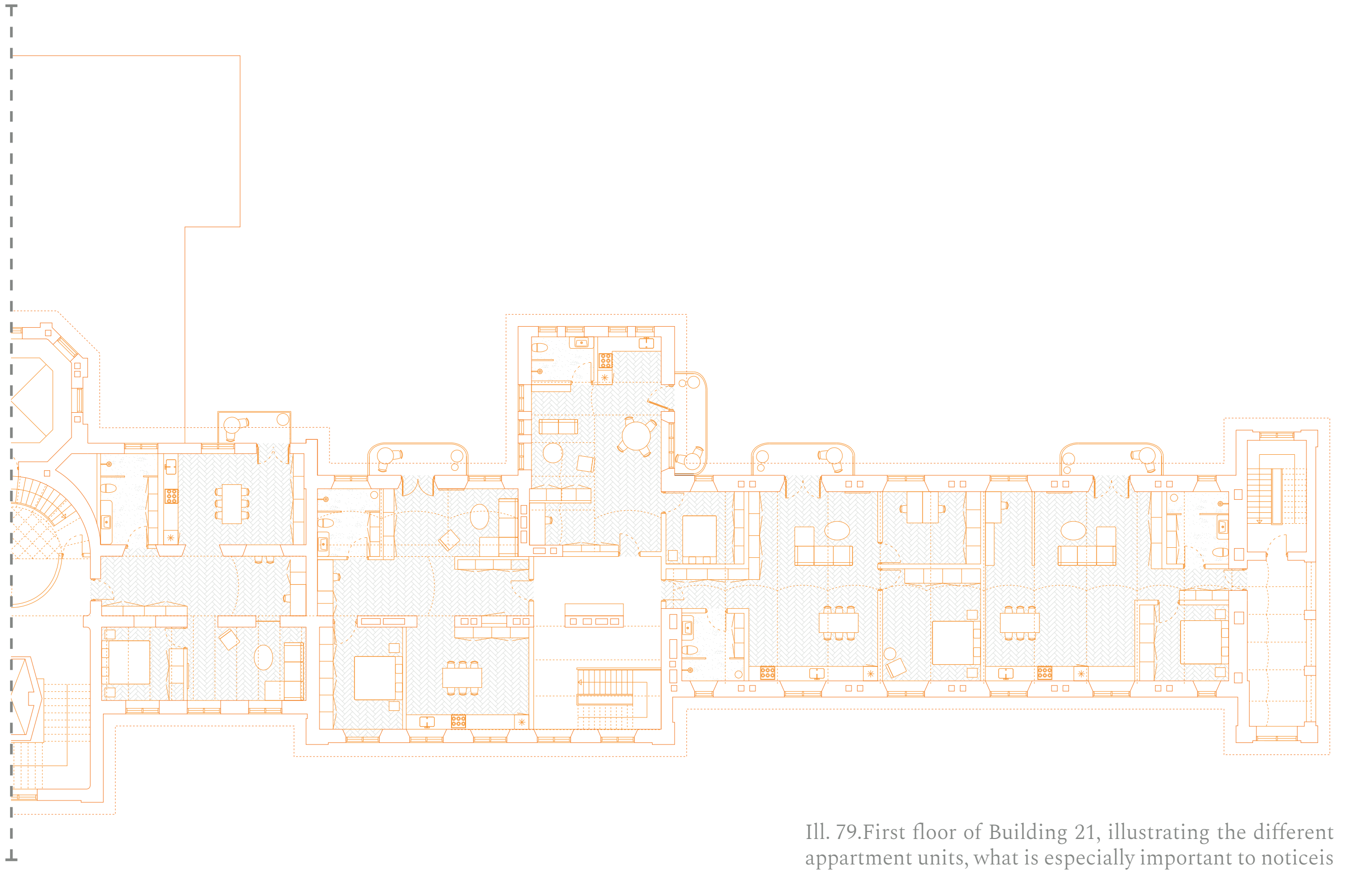
Ill. 78.North-west elevation of Building 21, showing the intervention of extending some windows into glass doors, the pavillion extending th glass extention to indicate the entrance between library functionalities



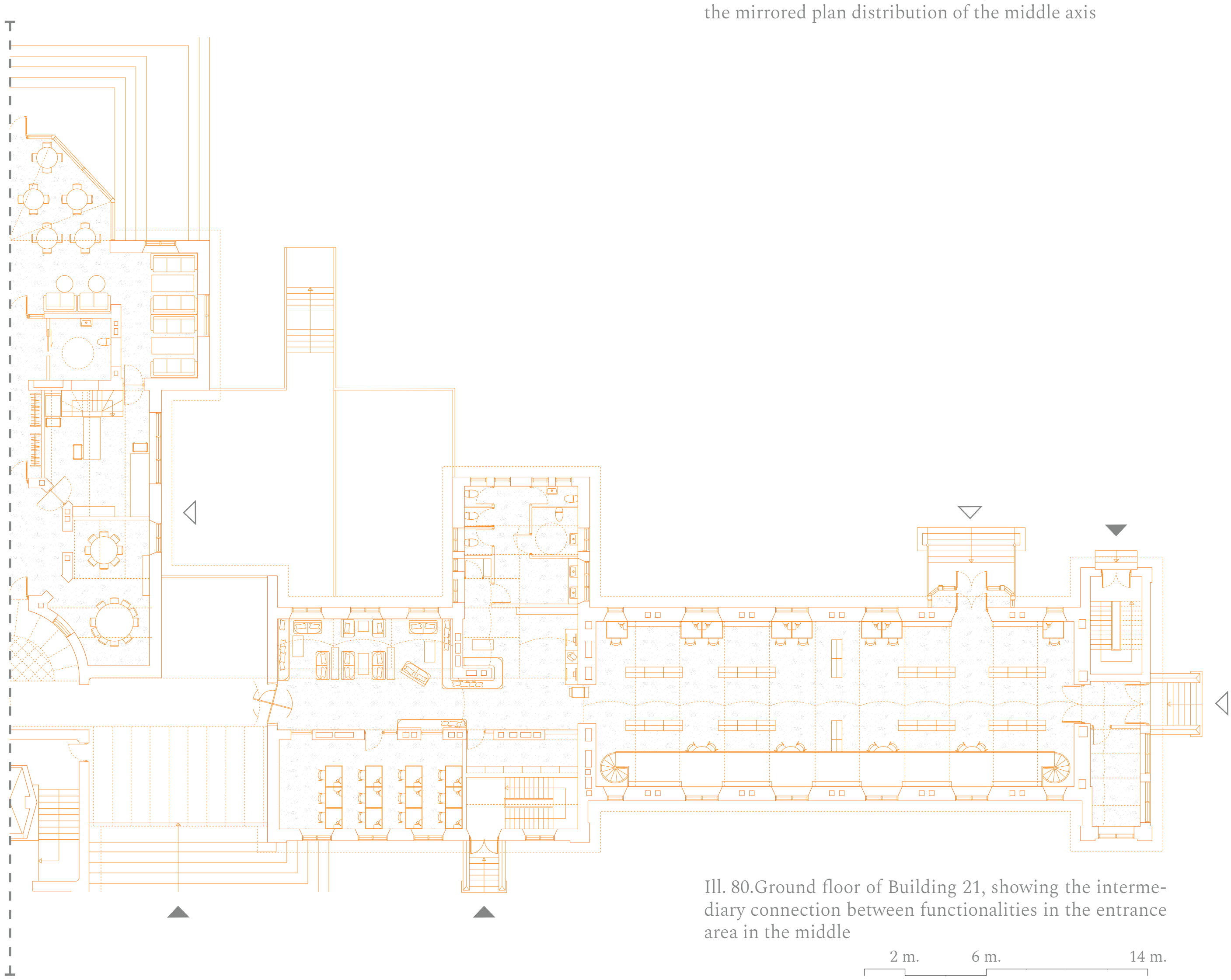
The Interior Organization of the Building

The building contains different functions and is as the façade divided between the ground and first floor. The ground floor invites visitors of the city by having a landscape office, a library, primarily for students, and a restaurant. All functions are accessible from the middle of the building, which also acts as the entrance to the park. Furthermore, an entrance in the gables ensures direct access to the office and library. Besides the entrance from the northeastern gable the library connects to Building 22.
The separate entrances seen on the ground floor leads to the first floor which contains 10 apartments in different sizes - five on each side of the middle as the building in its structure is mirrored around the center. Existing and new stairs lead the flow to the first floor. The apartment ranges in sizes from 58 to 89 square meters. The organization of rooms is controlled by the existing structure of windows, load-bearing walls, ceiling arches and exhaust channels.

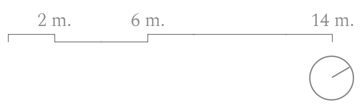


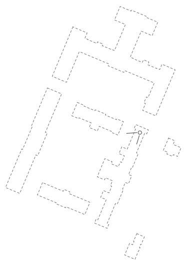


Ill. 79.First floor of Building 21, illustrating the different appartment units, what is especially important to noticeis the mirrored plan distribution of the middle axis



Ill. 80.Ground floor of Building 21, showing the intermediary connection between functionalities in the entrance area in the middle

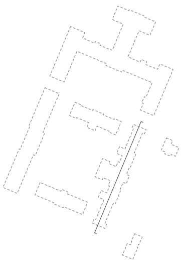


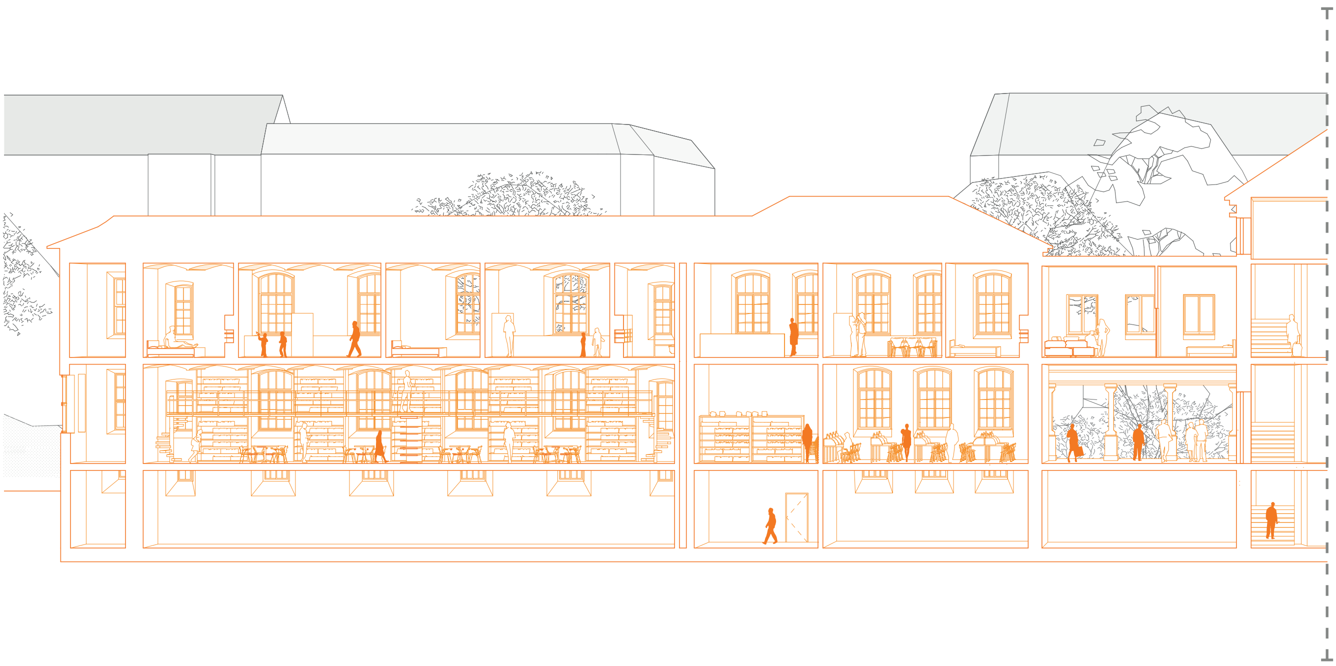


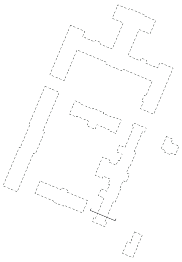
Ill. 81.Vizualisation inside Building 21 which tells the conncetion between indoor and outdoor as a result of the extented window into a palcony door

The Interior Spatiality of the Building

By cutting through the building, the originally designed spaces are seen on the two floors, where the building's interior details communicate the former history. The ceiling is designed with arches and thus makes the space experience more interesting. In the time when the building was constructed, large windows and high floor heights were a design factor for the good spaciousness. The large windows also help to create a visual connection to both sides of the building and allow for the use of naturally ventilated spaces. The circulation in and around the building is furthermore ensured by the stair towers that connect the building across the floors.



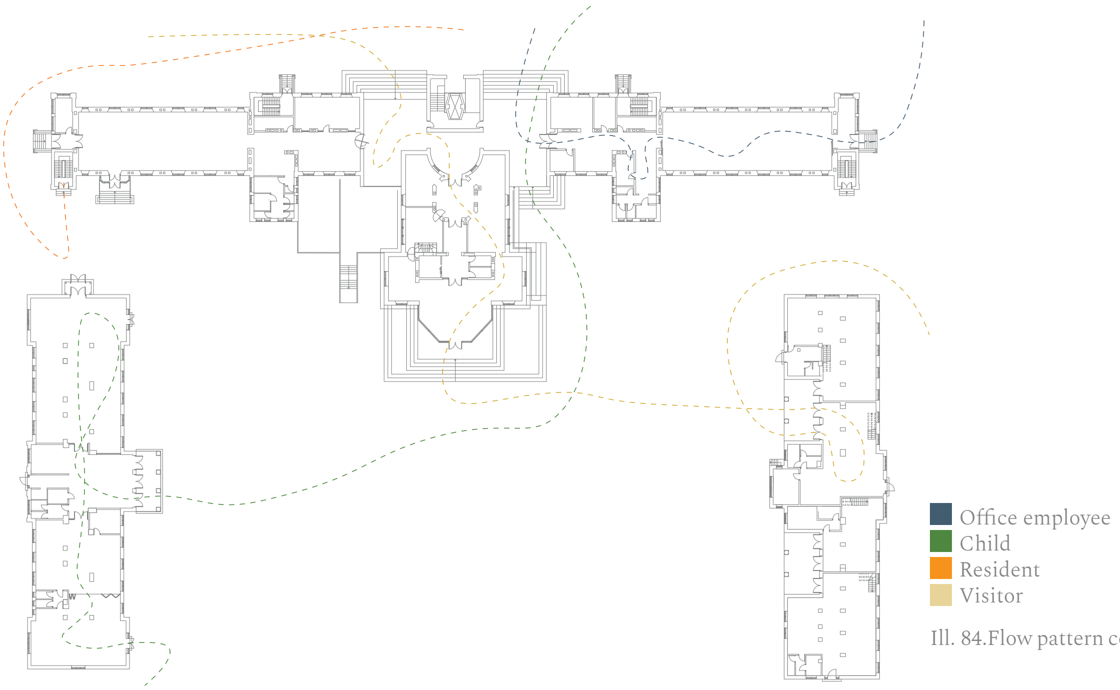




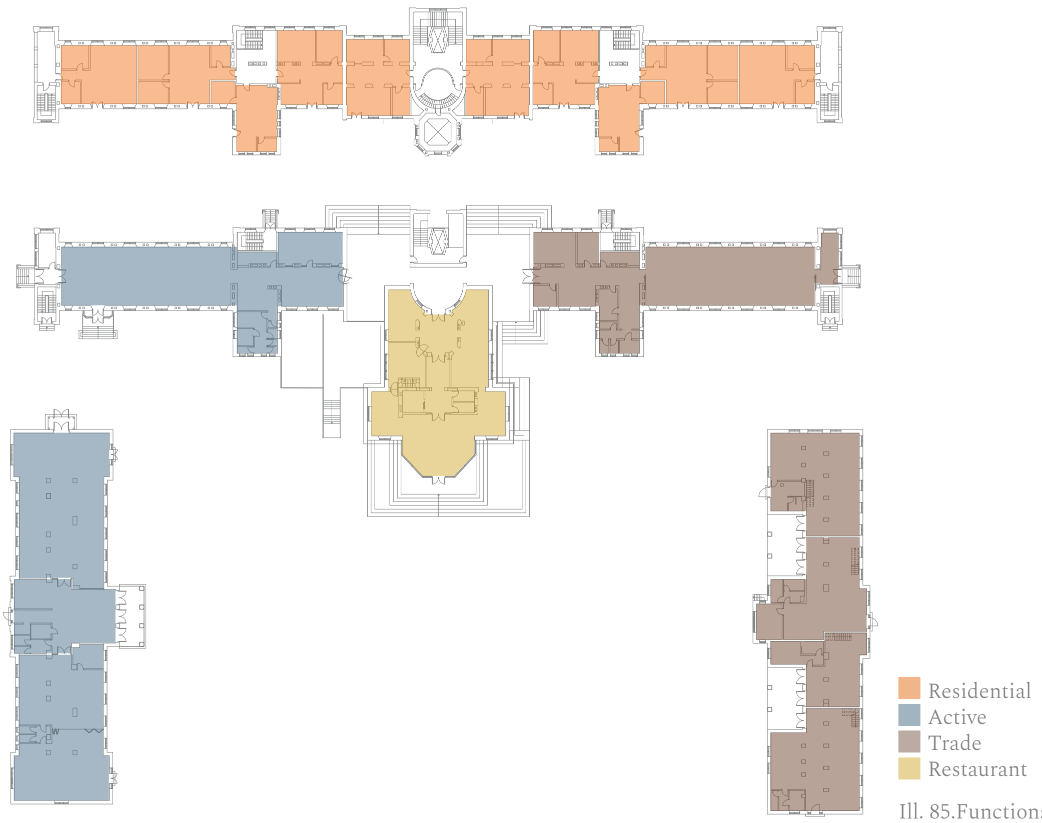
Ill. 82.First floor of Building 21, illustrating the different appartment units, what is especially important to noticeis the mirrored plan distribution of the middle axis

Ill. 83.Ground floor of Building 21, showing the intermediary connection between functionalities in the entrance area in the middle

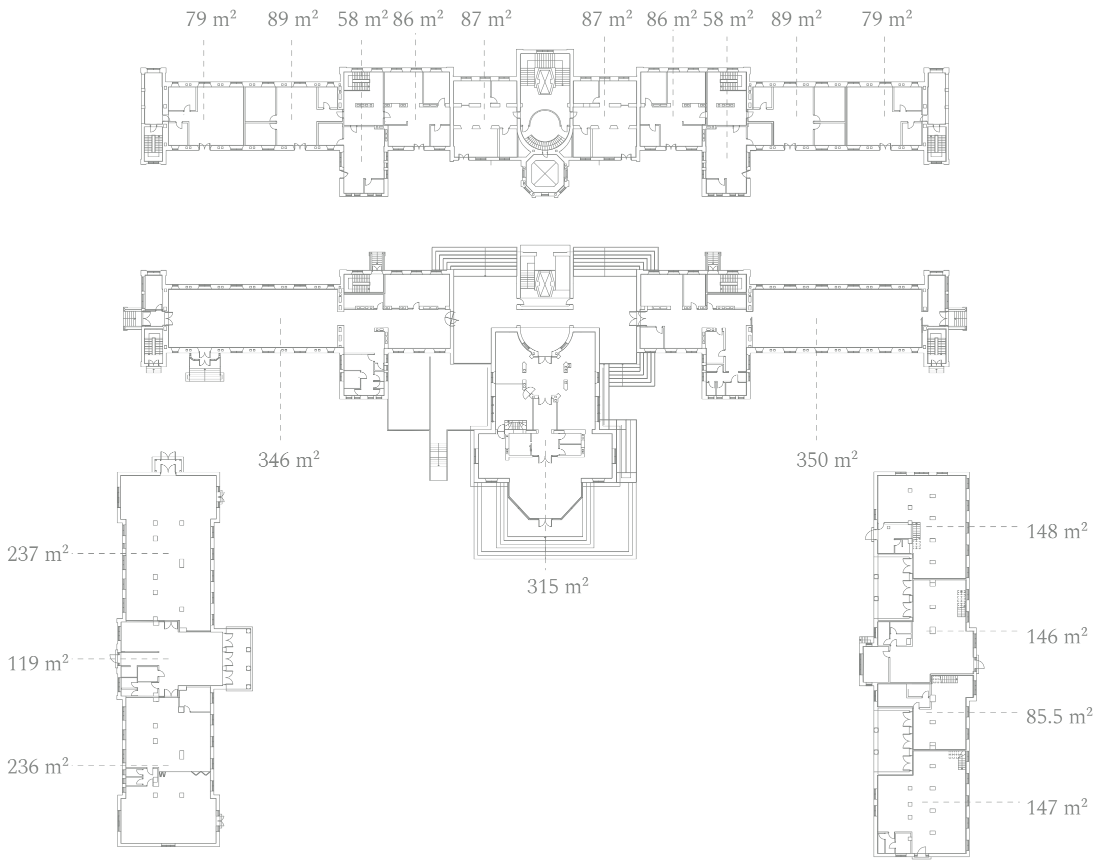
2 m. 6 m. 14 m.



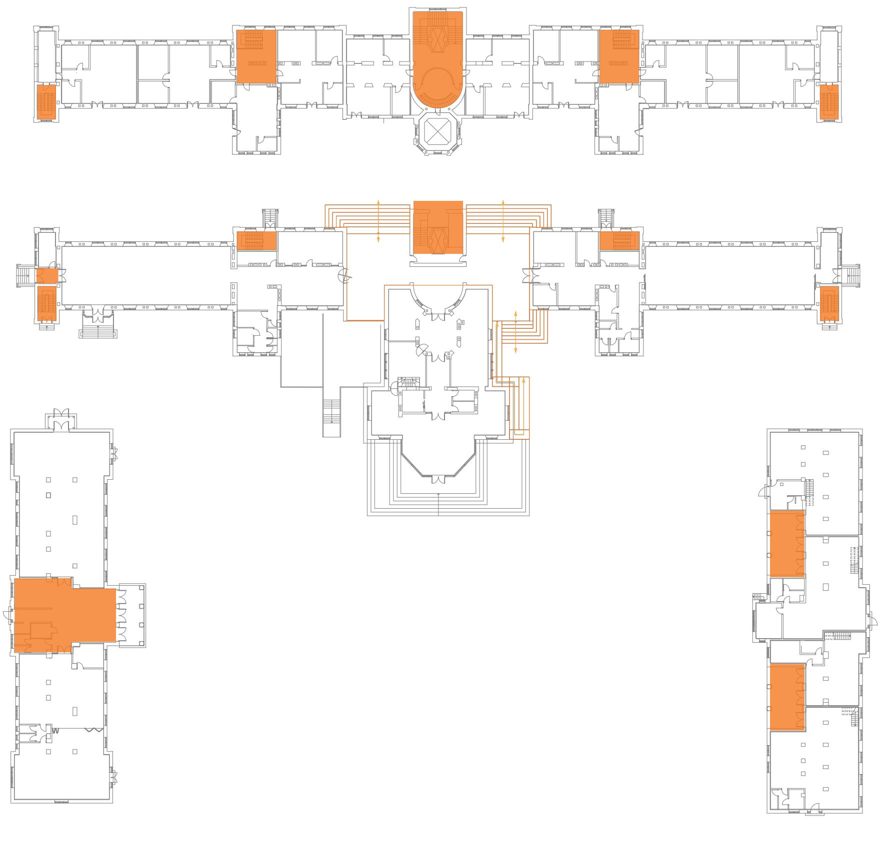
Ill. 84.Flow pattern concepts



Ill. 85.Functions



Ill. 86.Areas



Ill. 87.Accessibility

Relations Between Buildings

The transformed buildings are laying on the edge of the old hospital ground and act as the main entrance to the new neighborhood of Frederiksberg. The history of the former use is seen in the symmetry of the buildings placement that with new functions encircle a park with connections to the rest of the hospital ground and the city of Frederiksberg. By the opening of Building 21 the construction invites all its residents and visitors to the area and connect the park structure to the preserved greenery. The openings between and in the buildings indicate a natural flow through the area where both bigger avenues and smaller pathways ensure diversity in the flows. Furthermore, the diversity in function activates the site and buildings at different hours of the day and encourages users of all ages to the site.

1	Direction to new metro station
2	Health building
3	Sun park area
4	Blue spot park area
5	Creative space building
6	Intermediary connection between library functionalities
7	Library on groundfloor, appartments on first floor
8	Intermediary connection between thesis site and the rest of the historic hospital area
9	Open park area
10	Indoor and outdoor restaurant
11	Main entrance
12	Wild greenery area
13	Office on ground floor, appartments on first floor
14	Entrance to trade building
15	Trade building
16	Main green street
17	Landmark funtion of the gate to the historic hospital ground

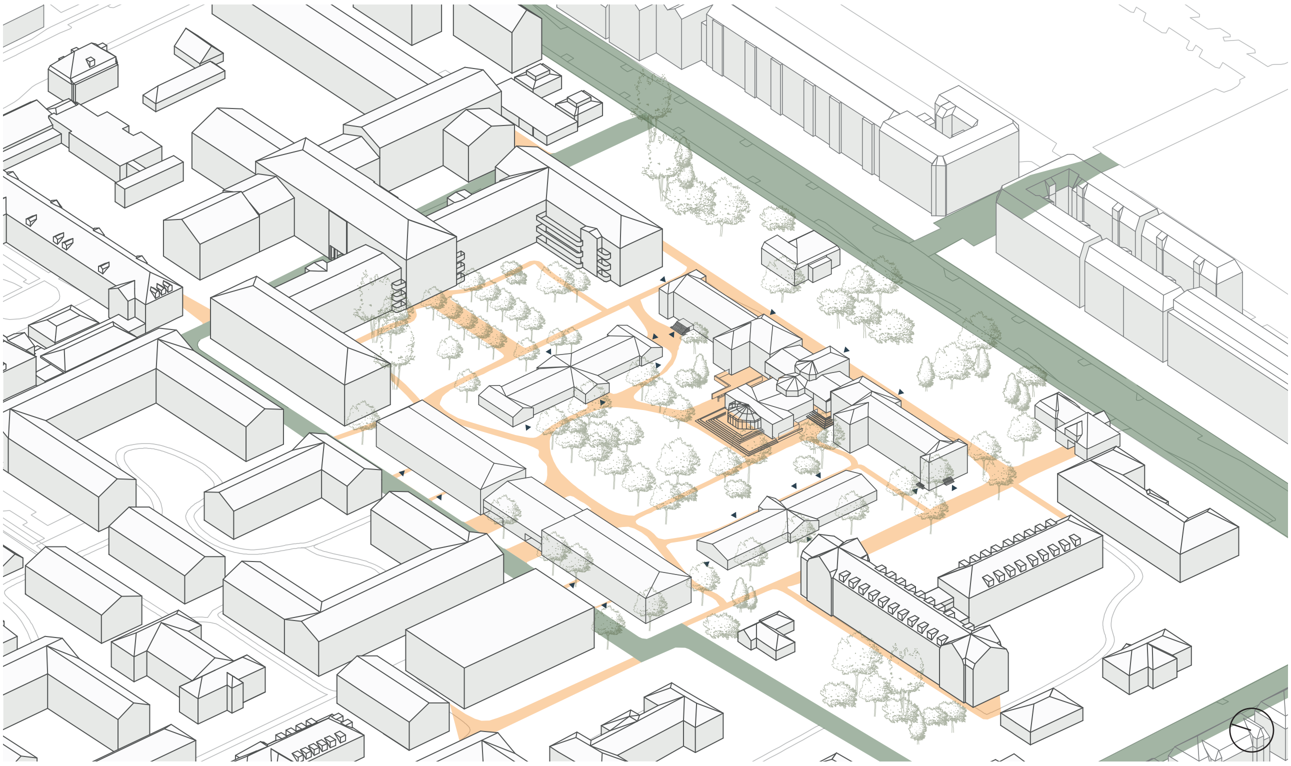
Ill. 88 Siteplan

Different functionalities are present at the project site where three buildings are transformed. Illustration 92 shows the new functions which primarily consist of residence, trade, and culture. The functions are divided into the transformed buildings and are thereby placed in relation to each other to create coherence between the building cluster. Furthermore, pathways between and through the buildings are illustrated in illustration 91. These indicate the flow in the park and further where to entrance the buildings.

Ill. 89.Longitude section

Ill. 90.Cross section

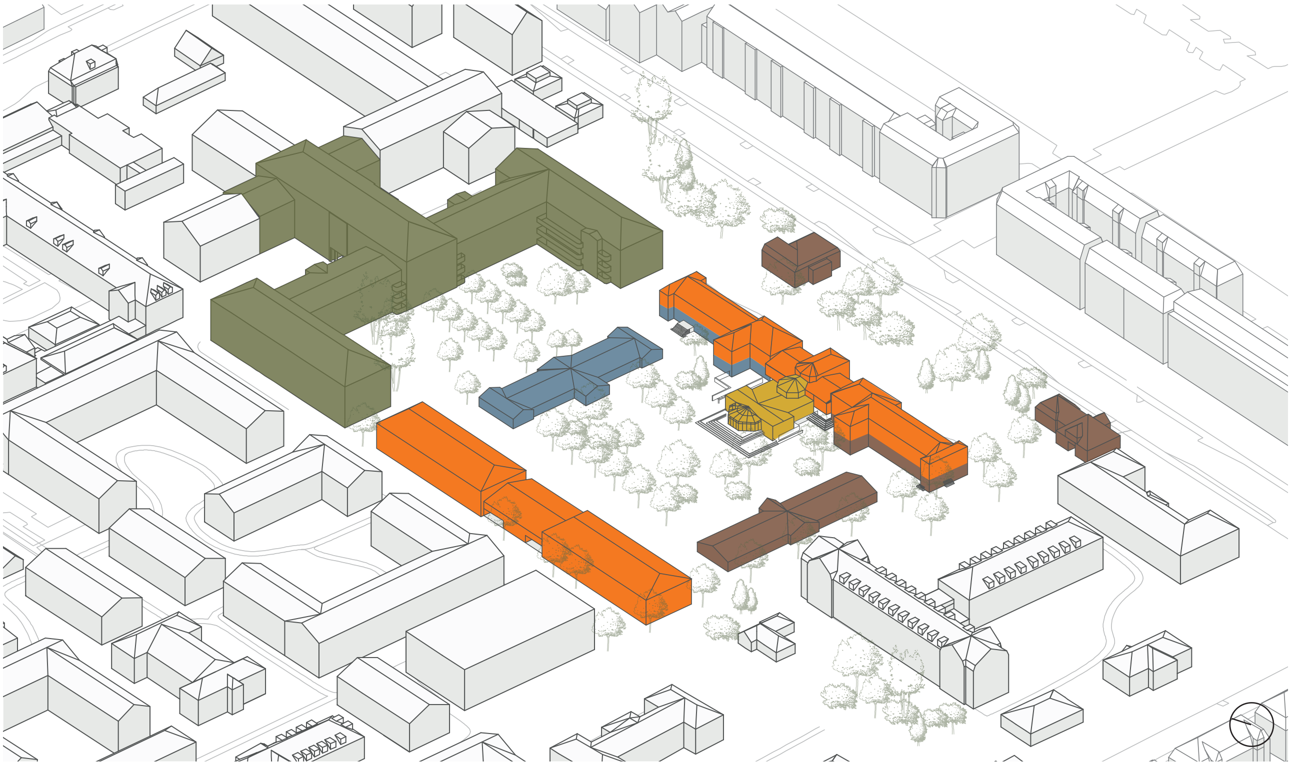
10 m. 30 m. 70 m.



Access roats

Building entrances

Ill. 91.Access roads and building entrances

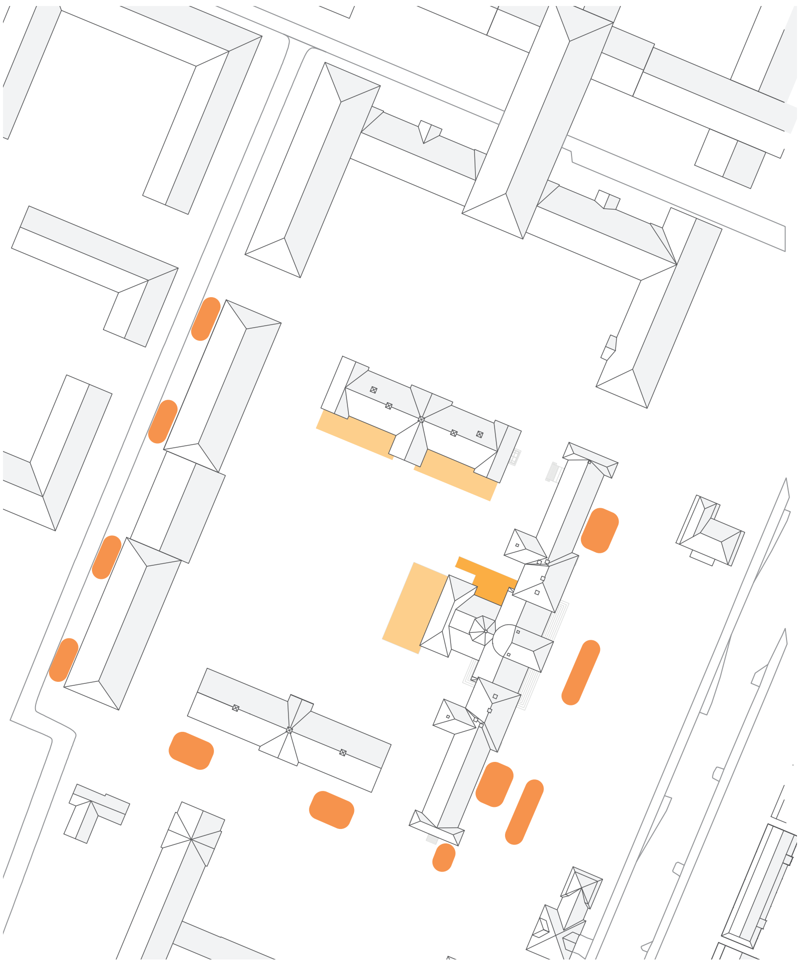


Trade | Health | Restaurant

Residential | Active

Ill. 92.Functions of the thesis site

Ill. 93.Green structures



Ill. 94.Pavement areas

Ill. 95.Preserved trees

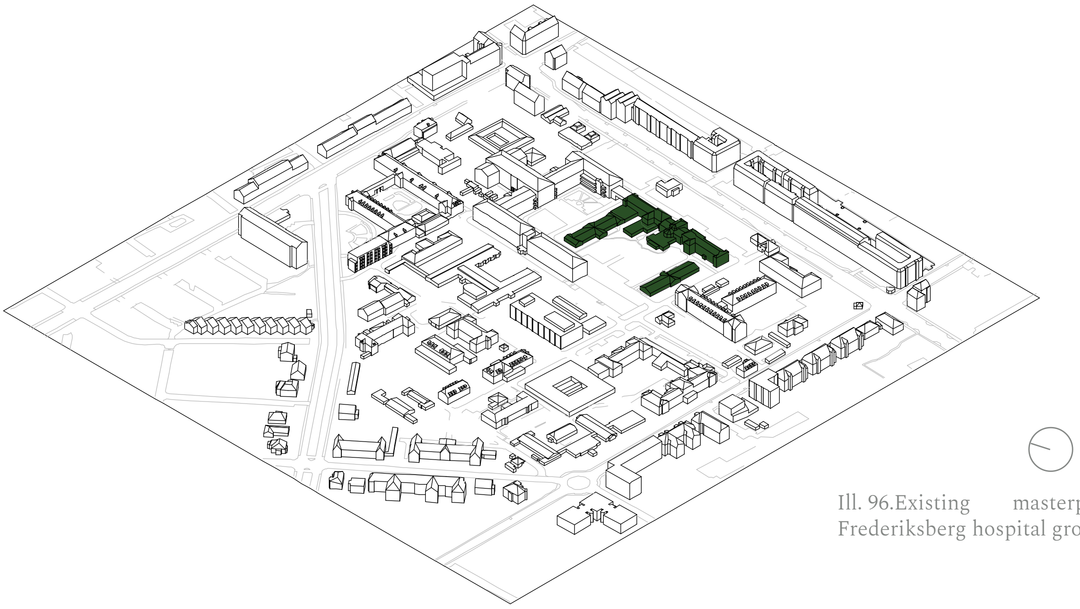
Relations to Frederiksberg Hospital Area

The new neighborhood of Frederiksberg Hospital is developed at a conceptual level to create cohesion between existing and new buildings, building height and scales, functions, and green structures. The development plan is designed to provide an insight into what the area can be used for in the future. Over time, new functions and buildings will come to the area and, together with the existing buildings, will create a synergy in the area that indicates the area's previous history.

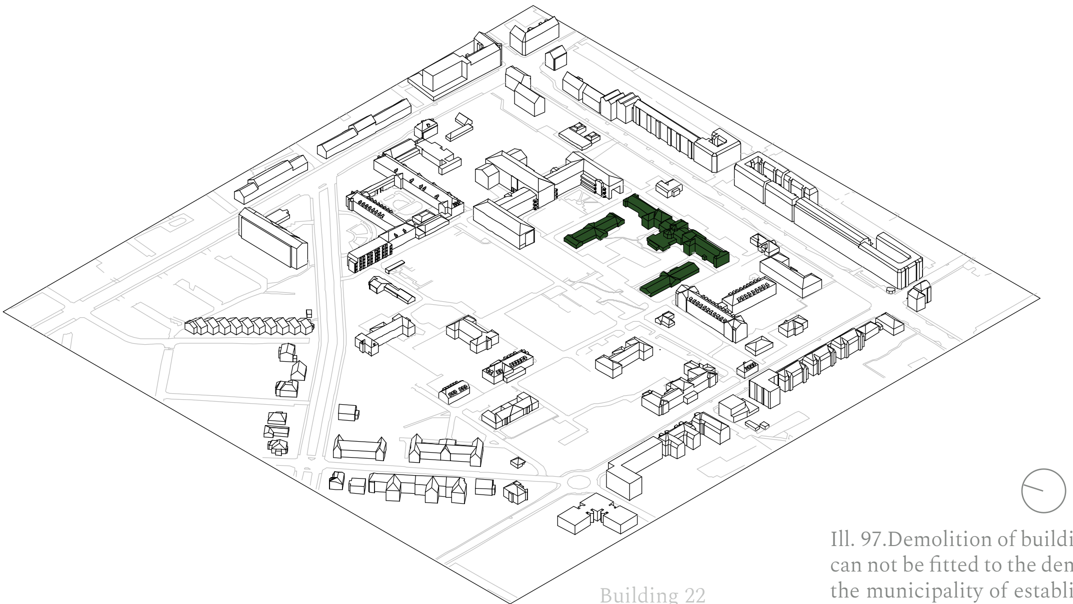
Illustration 99, on the next page, shows the relation between existing and new buildings. The new buildings are added between the preservation worthy buildings which stand as the existing foundation of the history of the area. The future neighborhood should appear as an area where the primary traffic consists of pedestrians and cyclists. Different access roads and pathways around the hospital ground thus guide visitors and residents' movement.

In continuation of the mix between new and existing buildings illustration 102 shows the varying building height on the ground. The added buildings attempt to follow the near surroundings, whereas a plot ratio at 100% is reached. Furthermore, illustration 100 shows the future functions of the buildings which create a balance between residence, trade, and cultural institutions.

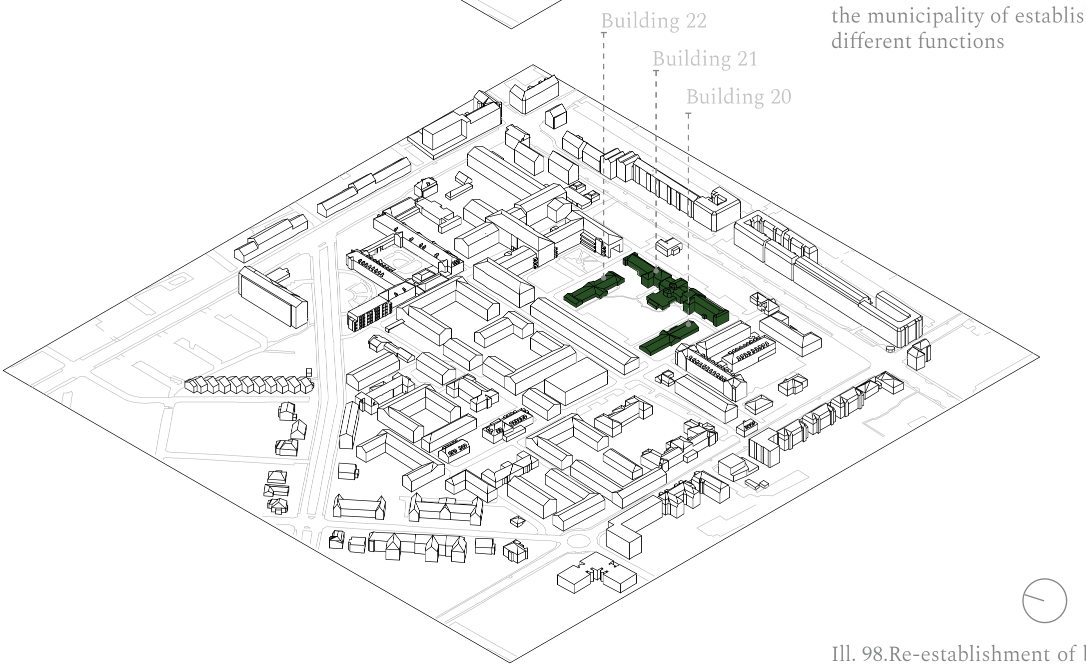
Between the buildings it is possible to enjoy green courtyards and parks which gives the area a sense of belonging to the rest of the green structures of Frederiksberg. Illustration 101 presents the new neighborhood with its green areas which also function as green avenues between the buildings.



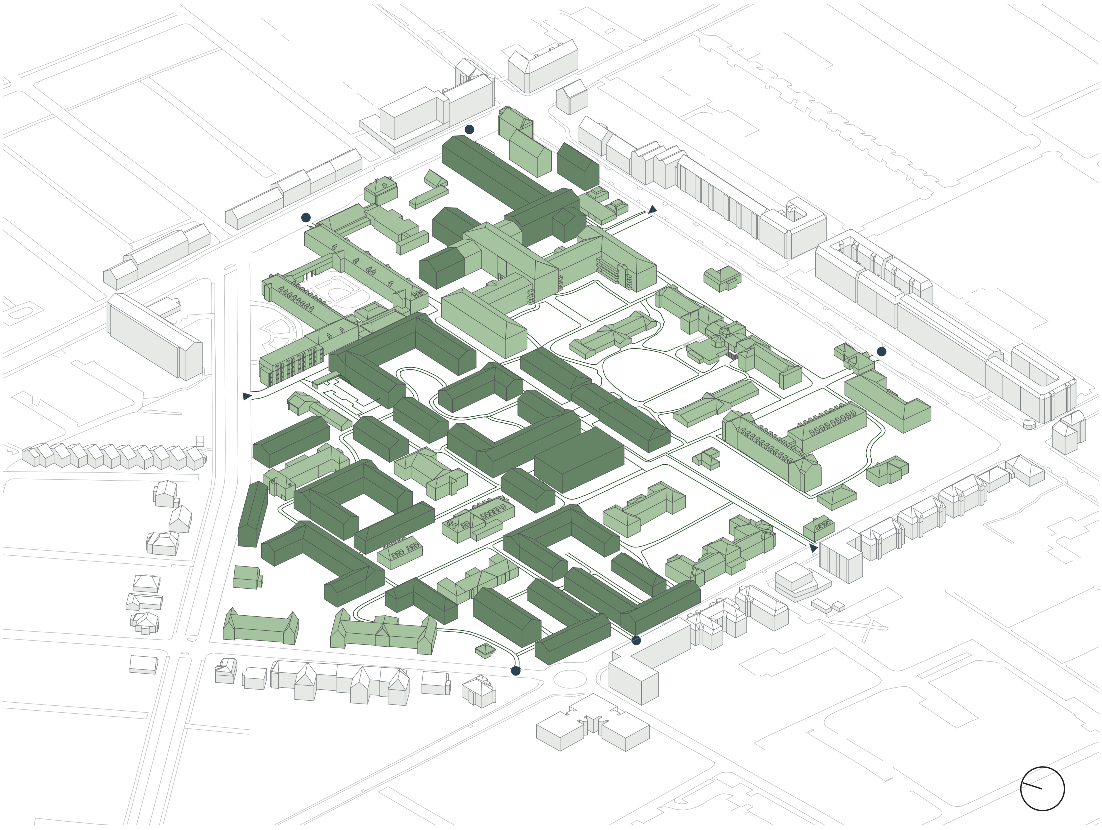
Ill. 96.Existing masterplan of Frederiksberg hospital ground



Ill. 97.Demolition of buildings which can not be fitted to the demand from the municipality of establishment of different functions

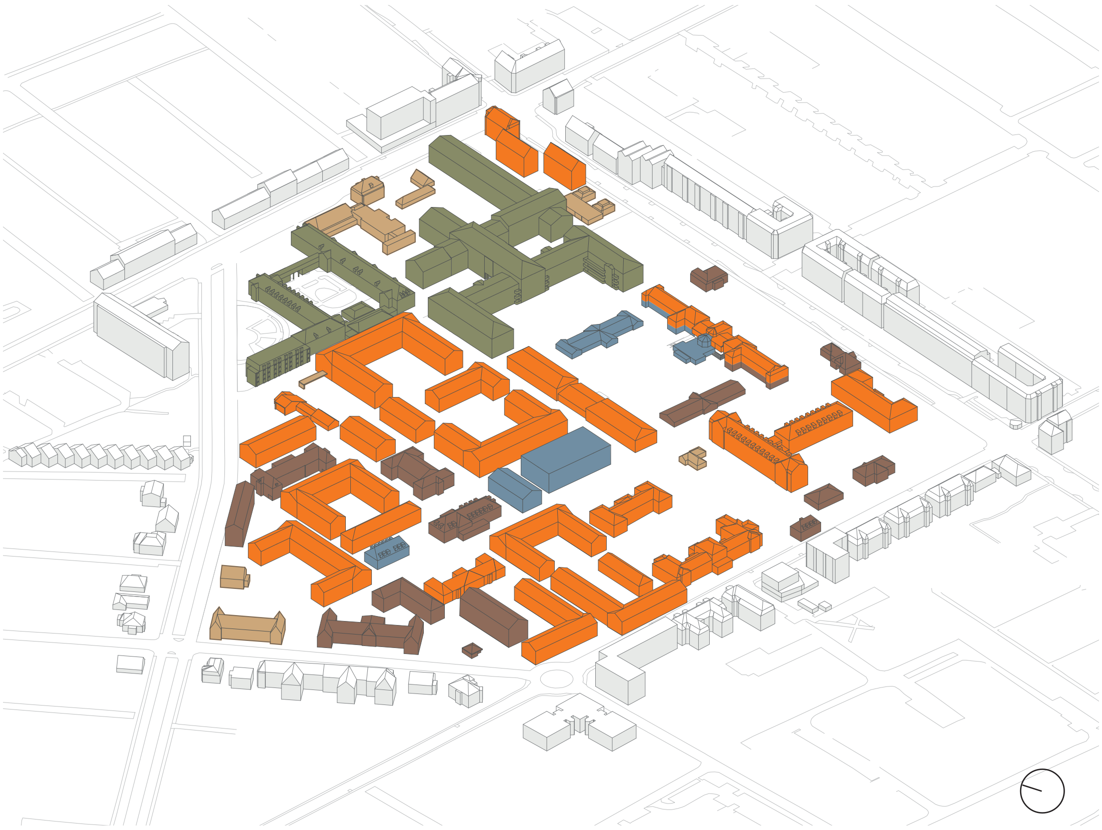


Ill. 98.Re-establishment of buildings which together fit the demand of the municipality



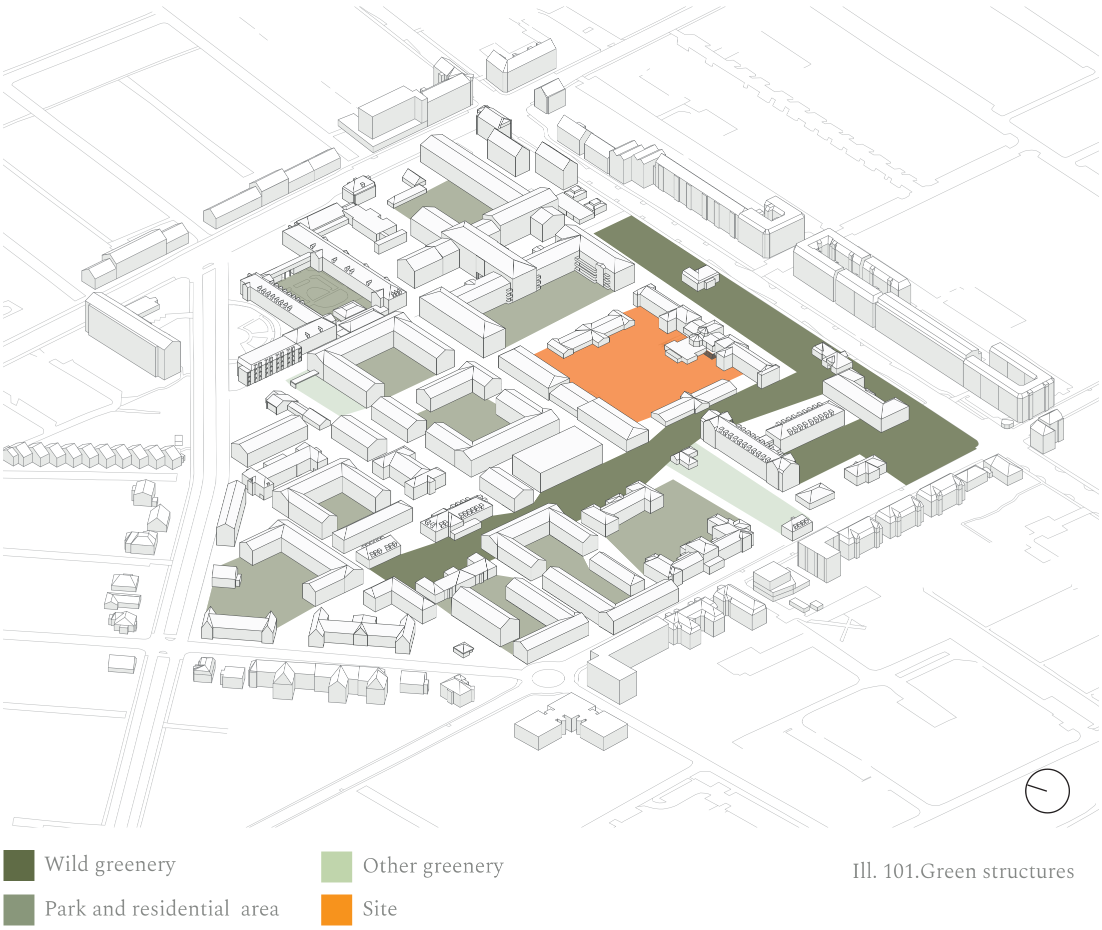
New buildings
Preserved buildings

Ill. 99.Buildings and access roads

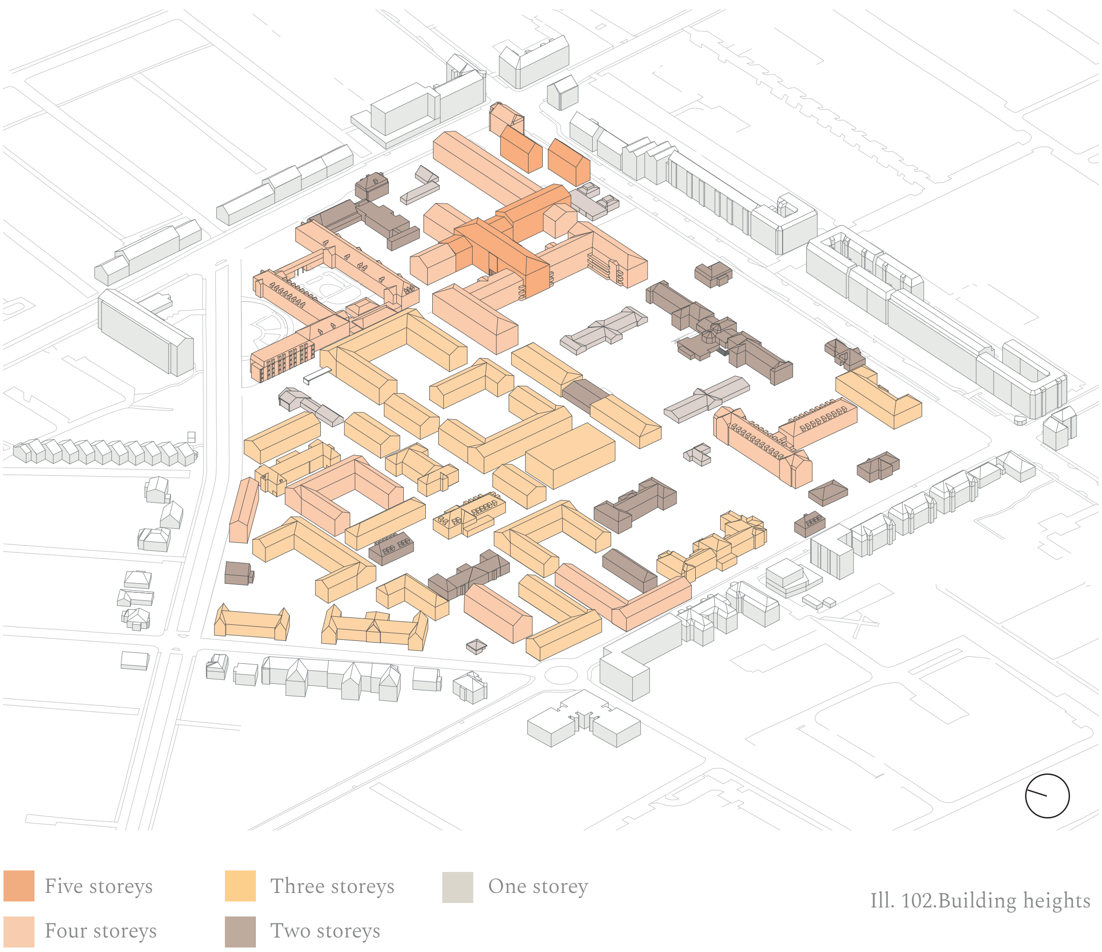


Trade
Health
Other
Residential
Active

Ill. 100.Functionalities



Ill. 101.Green structures



Ill. 102.Building heights

Ill. 103.

06. CHAPTER

This chapter presents the design process through themes. The themes represent the important aspects of the process in a systematic way, though as the project is developed through an iterative process, the different themes overlap and are dependent on each other. Firstly, the Technical Discoverings is presented, where The Renovation Matrix is introduced and outlines its use and importance. Secondly Big Scale Discoverings, Medium Scale Discoverings and lastly Small Scale Discoverings.

DESIGN PROCESS

Technical Discoverings

Renovation and Optimization

As this thesis strives to discover a method for renovation and optimization of existing buildings, it is essential to approach the design process in a structured manner. This is in order to assess qualitative and quantitative measures and make well-argued decisions.

Previous projects throughout the bachelor's and master's programme have only considered the development of new buildings and have mainly been influenced by the Integrated Design Process (IDP). Unlike the previous projects, this thesis works with existing buildings. Therefore, the framework of the buildings are given in advance, why the design process will take its point of departure in the existing framework and develop design solutions from this. This thesis presents the idea of an Extended Integrated Design Process method (EIDP), which is developed with the intention to accommodate the method of optimizing existing building structures. IDP acts as the framework for EIDP, utilizing the scattered loops between its five phases. In EIDP, which considers the development of existing buildings, initial design studies consider existing qualities and issues in terms of both qualitative and quantitative parameters to ensure the best possible solution.
EIDP is made legible in the so-called "The Renovation Matrix" which is further explained and explored in the following section.

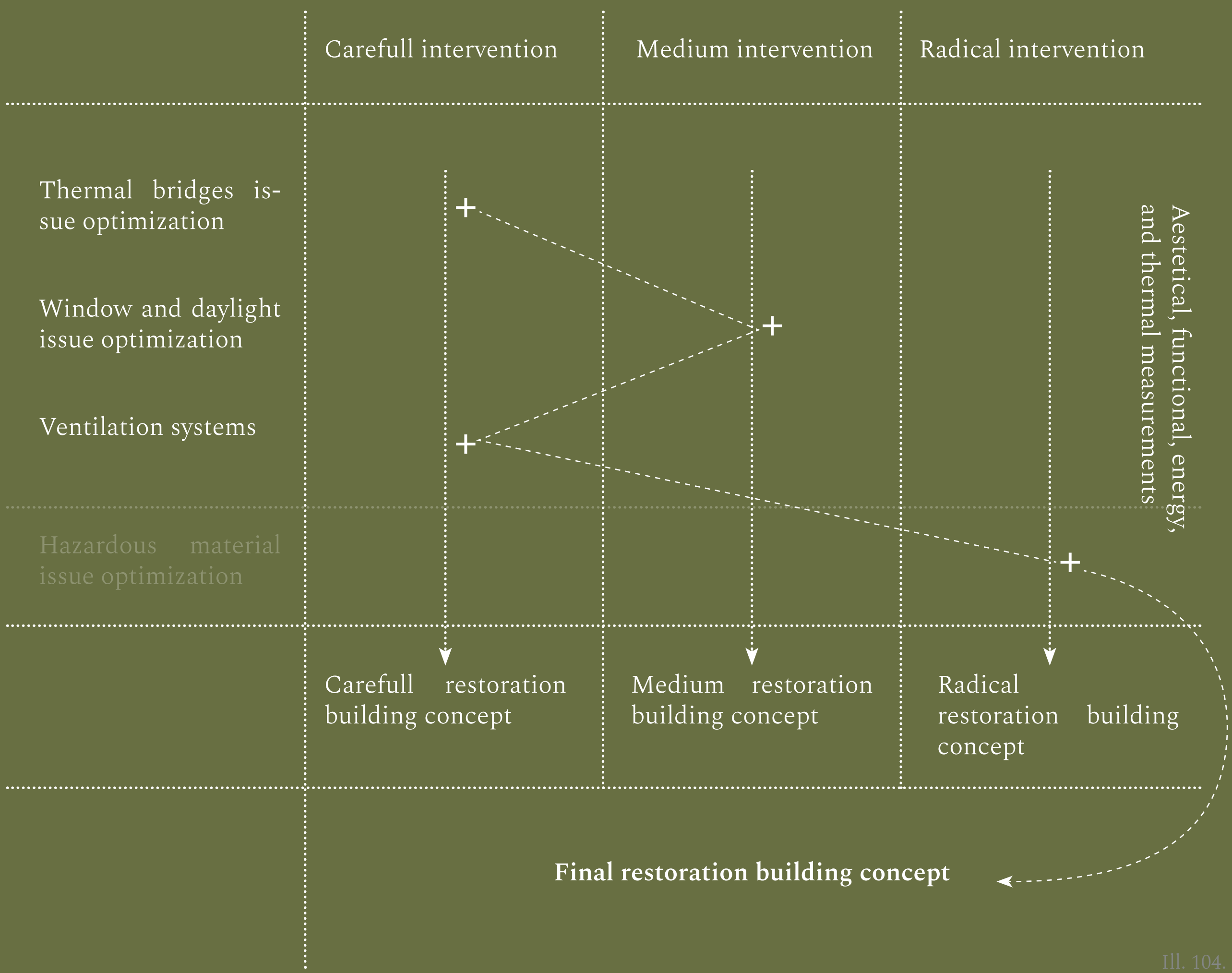
The Renovation Matrix

EIDP is facilitated through a structured approach where both careful, medium, and radical interventions are considered. The importance of exploring the different interventions is made clear in the 'Position section', where different architectural stand-points and opinions of intervention are explained.
This thesis does not consider an opinion on the type of intervention. The process of the design is therefore not influenced by a certain standpoint to the scale of intervention in order to facilitate an argument based approach, where only quantitative and qualitative qualities count.

The steps of EIDP

1. Discovering issues and potentials in building components.
2. Discovering plausible and implausible interventions in the building structure.
3. As a result of the discoveries in step one and two, optimizing solutions are developed.
4. The optimizing solutions are combined in three initial concepts of interventions where the aesthetical qualities of the building intervention framework are assessed.
5. The final intervention concept is assembled from appointed optimizing solutions with consideration to both qualitative and quantitative measures.

The final design solution of the optimization will in the subsequent design process be implemented in the existing building framework, which will be presented in this thesis. Nevertheless, the design process conducted with the EIDP Renovation Matrix Method will be presented in the following section.


Carefull intervention
Medium intervention
Radical intervention
Thermal bridges issue optimization
Window and daylight issue optimization
Ventilation systems
Hazardous material issue optimization
Aestetical, functional, energy, and thermal measurements
Carefull restoration building concept
Medium restoration building concept
Radical restoration building concept
Final restoration building concept

Ill. 104.

Optimization of Building 20

The renovation and energy optimization of the three selected buildings will be based on Building 20, and then transferred to the other two buildings.

The initial studies of the next presented part of the design process concerned a derivation of the existing building's envelope and its different structural compositions. These studies were conducted with the assessment of drawing material and pictures from different decades in the building's lifespan, review of historical building codes, and architectural styles whereas descriptions and the tender material were evaluated in order to conclude which elements from the history was part of the existing architectural style and therefore the composition of the different structural elements.

The Building Envelope

The optimization of building envelope optimization is divided into separate subjects concerning the exterior wall, roof, ceiling, and basement. In each section different solutions are presented where different parameters are assessed and evaluated. The presented solutions are based on underlying initial discoverings developed in the intermediary work with transmission loss calculations in relation to different building materials. The underlying process strived to facilitate material compositions, which through manual calculations did not indicate an accumulation of moisture in the affected envelope element. Furthermore, to meet the demands of the building regulation described earlier in 'Demands and Building Codes', with regard to the maximum transmission coefficient of each building envelope structure.

Composition of Building Envelope

Ceiling beneath rear-ventilated attic roof
12 mm wooden boards
45 mm air layer with transverse beam
12 mm wooden boards
45 mm air layer with transverse beam
12 mm wooden boards
Structural timber beams in rear-ventilated attic

Exterior wall construction
White spackled mortar
360 mm solid brick (1+0.5 brick system)
Orange spackled mortar
Windows
2 layer glass

Floor deck, from the top
32 mm wooden flooring
45 mm air layer with transverse beam
20 mm wooden boards
45 mm layer with transverse beam

Basement floor, from the top
32 mm wooden flooring
45 mm air layer with transverse beam
130 mm concrete slab with transverse steel beam
770 mm high columns of brick between un-ventilated and un-heated air

Basement wall
470 mm solid brick (1+1 brick system)

The renovation studies and solutions strive to meet the energy demands in section 274-279, 'Energy Demands by Modification and Replacement of Building Elements' (§ 274 - § 279 Bolig- og Planstyrelsen. 2022) in the Danish Building Code which is stated in the program of the thesis, 'Demands and Building Codes'.


Ill. 105.

Outer Wall

The building component of exterior walls, especially solid brick walls, is crucial when it comes to the potential of damaging moisture accumulation which in severe cases can result in frost damage in the bricks or dry rot in wooden structures and organic materials (Jensen & Bjarløv. 2019). There are multiple sources which outline the problem of implementing interior insulation in renovation methods and therefore prescribes the values of exterior implemented insulation - nevertheless a wave of researchers exploring and optimizing the method of interior insulation in renovation concepts have been developed in the previous years. Studies to mention, which have been carefully read and analyzed for the execution of the thesis' wall study, are (Nickolaj Feldt Jensen et al. 2021; N. F. Jensen, Rode, & Møller. 2021) and (Johansson 2014; Johansson et al. 2014).

To understand the issues and potentials by either renovation method preliminary values are to be mentioned, which is elementary in the contradicting discussion. Environmental, physical balance, and economical measures are what researchers determine their results and arguments from. These measures will therefore be highlighted in the different solutions in this thesis to facilitate an augmented discussion of the final choice of intervention.

The Physical Balance

The measure of a wall structure's physical balance, especially the boundaries of an exterior wall, should be considered with extended attention. It is vital to ensure that the exterior wall's physical balance makes it possible to intervene with a new layer of insulation (Realdania By & Byg A/S & Bendtsen 2021), if the case, it is important to ensure that moisture accumulation is not a risk as a result of colder and more fluctuating temperature gradients in the wall structure (Jensen et al. 2021).

Preservation Values

One parameter which can influence the choice of insulation method is the preservation value of a given existing building. The buildings detailed in this thesis are influenced by such value which makes the renovation of such exterior walls especially difficult, which is explained in 'Level of Details'.
In order to counterbalance the potentials of the existing buildings, studies of the building fabric have been executed. Outer- and inner- fabrics are in these studies divided.

When exploring the inner fabric, only a few elements are worthy to mention, which have value to preserve the building's architectural history. Doors, windows, and roof window coffers are footprints of architectural history. They are marked by previous optimization interventions but are kept in their original appearance. The fabric of the inner walls are cleaned for architectural qualities, why an inner implementation of insulation is suitable.

When looking at the exterior fabric of the building one is met by the opposite. The exterior fabric's appearance is an eye-catcher in its environment because of the use of orange colored plaster, detailed low relief framed by a triangular-shaped frontispiece, pillars, and cornices. The exterior fabric has therefore many qualities to preserve, which would be negatively influenced if a new layer of insulation has to be implemented on the cold side of the wall. If such a measure is necessary a careful approach to preserving the mentioned elements is indispensable.

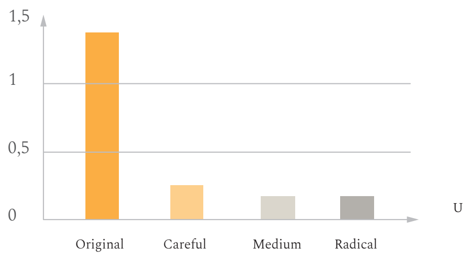
Wall Intervention

Therefore different wall intervention proposals are utilized with care to the above mentioned preservation problem. The concepts are as following:

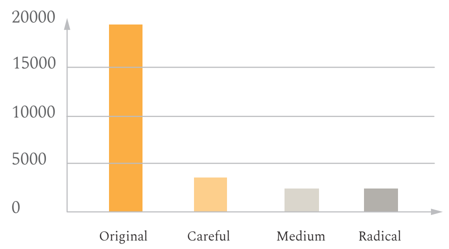
Careful intervention: The outer fabric is kept as it is. On the warm side a 10 millimeter mortar layer is added as a middle-layer between brick and insulation. 20 millimeter Vacupor-NT-B2-S insulation is placed hereafter which is furthermore protected by the next and last layer of wood panels. No vapor barrier is needed.

Medium intervention: The outer fabric is kept as it is. On the warm side a 30 millimeter rear ventilated layer acts as a ventilated layer between the solid brick layer and the insulation. Hereafter a cellulose insulation layer is built up by first 130 millimeters and then 100 millimeter. To ensure moisture- and air-tightness against the indoor climate a vapor barrier is placed as the second last layer, with a layer of mortar as the last.

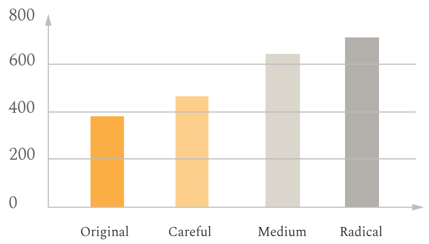
Radical intervention: The inner fabric is kept as it is. On the cold side a new layer of 180 and 45 millimeter stone wool insulation is implemented, whereafter a 50 milimeter rear ventilated level secures against moisture accumulation on the insulation. The last layer is a 60 millimeter new solid mortar layer.



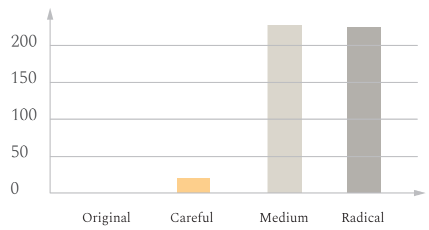
Ill. 106.U-value [W/m²*K]



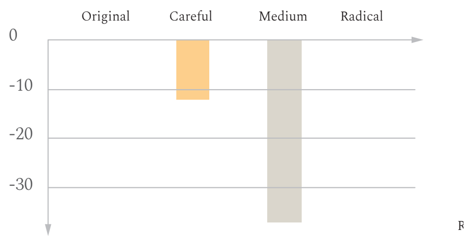
Ill. 109.Heat loss [W]



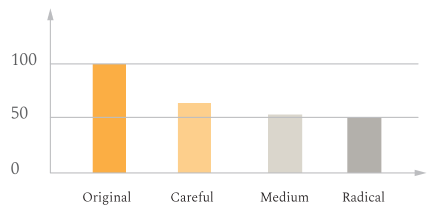
Ill. 107.Total thickness [mm]



Ill. 110.Insulation thickness [mm]



Ill. 108.Rental area loss [m²]



Ill. 111.Maximum relative humidity [%]

Basement

The following section describes the basement floor optimization. Furthermore, a conceptual framework for the joining basement wall is composed. Calculations are therefore only executed for the basement floor optimization.

Basement Wall

In order to utilize the preconditions for the interventions of optimizing the basement floor it is vital to secure the insulation method of the basement wall (Baltzer & Videncentret Bolius. 2021).

In relation to the basement wall, the study of the external wall is transferred. Nevertheless, there will be different moisture accumulation risks because of changed boundary conditions of both different moisture and temperature margins inside- and outdoor which is to the ground. When considering this in the process of finding interventions for the basement wall, the transferred wall systems need to be fitted to the new boundary conditions.
There have been detected existing moisture damages in the basement wall construction joint with the upper external walls. Before implementing insulation a fully dry basement should be secured in order to decrease the risk of moisture accumulation from the inside. The indoor climate should therefore be heated to 20 degrees all summer and all organic materials should be removed (Baltzer and Videncentret Bolius. 2021). Because of the existing moisture damage a perimeter drain is needed to secure a dry basement. In continuation to the implementation of a perimeter drain it is prescribed that the basement wall should be insulated on the cold side of the wall (Baltzer and Videncentret Bolius. 2021.;Energistyrelsen and Videnscenter for Energibesparelser i Bygninger 2015).
Different guides have been read in order to utilize the best conceptual construction of the basement wall. The best placement of insulation is on the cold side in order to utilize a warm construction (Videnscenter for Energibesparelser i Bygninger. 2021). A rule of thumb in this case is ⅓ of insulation on the outside of the wall, and ⅔ on the inside with inorganic and diffusion open insulation materials (BYGGE.DK n.d.; Baltzer & Videncentret Bolius. 2021).

Basement Floor

There are multiple methods to optimize the division between heated and unheated areas - in relation to this it is to be considered whether the existing basement is to be optimized for normal use with room temperature of approximately 20 degrees or non-heated, which decreases the potential of free use.

Noteworthy methods to mention are implementation of insulation in the existing tier of beams in the basement floor above crawl space, executed from below or above. The existing tier of beam layer of the basement floor can be transformed to a new terrain deck, which abolishes the crawl space. Lastly, the floor division between ground floor and basement can be insulated with a new tier layer of beams; .

Basement Floor Intervention

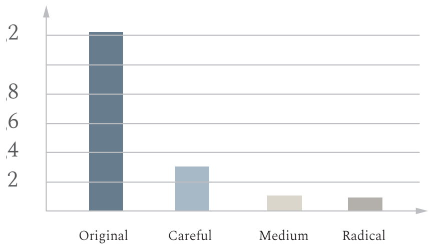
The concept of the optimization of the basement floor is as following:

Careful intervention: The deck between the ground floor and basement is insulated, making the basement an unheated space (Vadstrup. 2014)

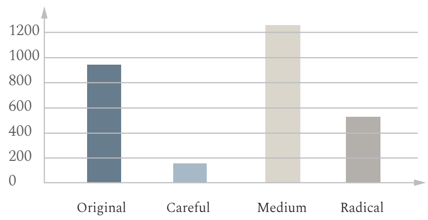
Medium intervention: The basement floor is insulated above the existing structure, making the basement a heated space. Though by doing this it decreases the height of the basement. (Videncenter for Energibesparelser i Bygninger. 2021 a)

Radical intervention: The existing basement floor is removed, the crawl space is demolished and a new terrain deck is built up, making the basement a heated space (PAROC DANMARK. 2013).

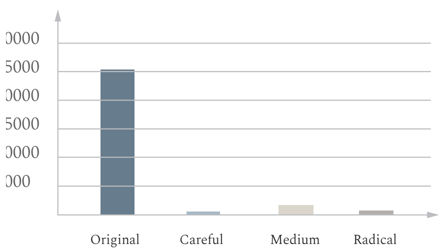
Later discovery showed that the basement floor rested on a concrete beam instead of a wooden beam, as the calculations shown here are made on. This change causes the buildup of moisture in the medium intervention.



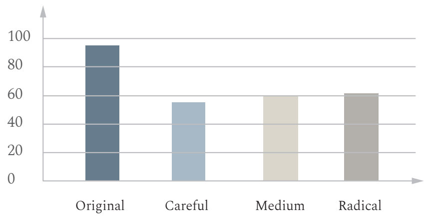
Ill. 112.U-value [W/m²*K]



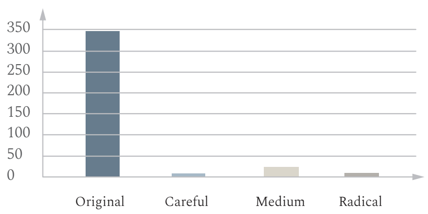
Ill. 115.Total thickness [mm]



Ill. 113.Heat loss [W]



Ill. 116.Maximum relative humidity [%]



Ill. 114.Insulation thickness [mm]

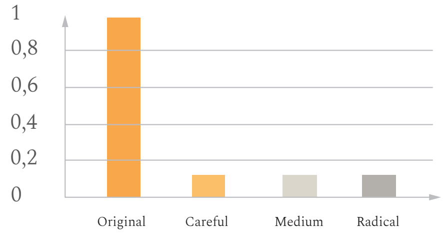
Roof

The roof and ceiling is original in the layout and materials and is as mentioned non-insulated. The renovation will therefore consist of adding insulation to either the roof or the ceiling.
The recommendations from the Energimærkerapport (Energistyrelsen. 2016) is to add 300 millimeter insulation to the top of the ceiling to eliminate the thermal bridges through the roof construction. This is the most typical and easiest choice when re-insulating a roof. Though, a re-insulation of the trusses will instead entail the possibility of opening the ceiling construction allowing for a higher ceiling height within the rooms.
Therefore, it is investigated how different constructions of the roof and ceiling act when the minimum u-value is reached.

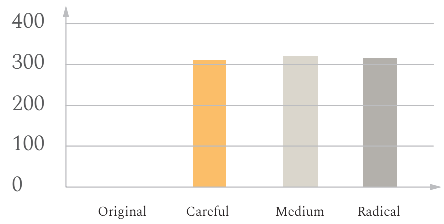
Careful intervention: The construction of the roof and ceiling is kept as is. The ceiling is insulated with 310 millimeter cellulose, that is blown-in between the beams. As cellulose absorb and release moisture, the construction is without a vapor barrier. Instead a space between the insulation and roof-construction ensures ventilation of the roof.

Medium intervention: The construction of the roof is kept as it is and insulated with 320 millimeter rockwool between the trusses and inbetween new battens. A distance between the outer roof and insulation is kept to ensure ventilation of the roof. The ceiling is opened with visible beams to enhance the interior space.

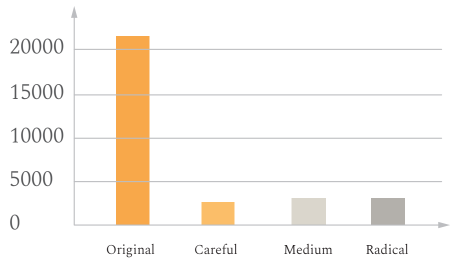
Radical intervention: The roof and ceiling is built up as the medium intervention. The only change is the outer roof material, that is changed to zinc as it has a longer durability than roofing felt and needs no maintenance.



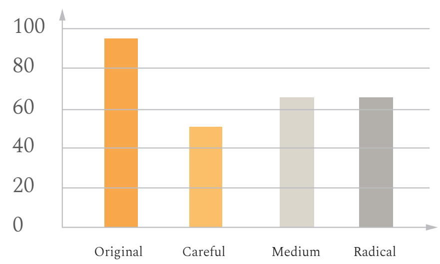
Ill. 117.U-value [W/m²*K]



Ill. 118.Insulationthickness[mm]



Ill. 119.Heat loss [W]



Ill. 120.Maximum relative humidity [%]

Window

As part of the renovation and energy optimization of Building 20, the windows need to be optimized to ensure better indoor climate and energy consumption. As stated in the previous section concerning the wall, 'Outer Wall', the windows have footprints of architectural history.
By further investigation it is figured that the windows are not original from when the building was built but have been changed to a sealed double pane. The aesthetics of the windows have been kept from the original and as part of the exterior of the buildings they are deemed preservation worthy. Therefore, in a renovation or replacement of the windows the aesthetics needs to be in line with the existing.

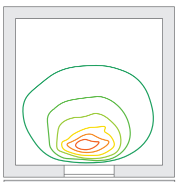
The recommendations from the Energimærkerapport (Energistyrelsen. 2016) is to change out the old windows to a three-layer energy window. Though historical, old windows are often renovated or optimized by adding a storm window on the interior or by changing the glass to better ones as this is deemed the preferable choice, both energy-wise and in terms of heat recovery (Raadvad-centret. 2002). Though, this has a considerable impact on the daylight in the interior rooms.

Therefore, it is investigated how different window compositions act in terms of daylight and heat loss through the windows.

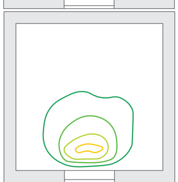
Careful intervention: The original windows are preserved and a storm window is added on the interior. This intervention requires the storm window to be tightly sealed to prevent the warm air from the interior to create moisture in the gap between the windows.

Medium intervention: The original window is replaced with a new three-layer energy-window in the same aesthetics as the original dannebrog window.

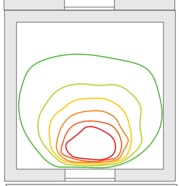
Radical intervention: The window hole is extended to the floor and a new three-layer energy-window in the same aesthetics as the original dannebrog window is placed.



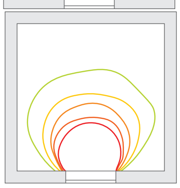
Ill. 127.Original two-layer window
301.5 W



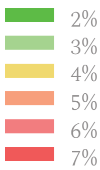
Ill. 124.Interior storm window
105.8 W

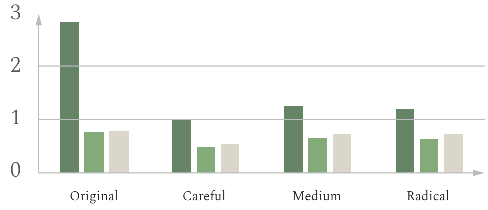


Ill. 126.New energy-window
132.2 W



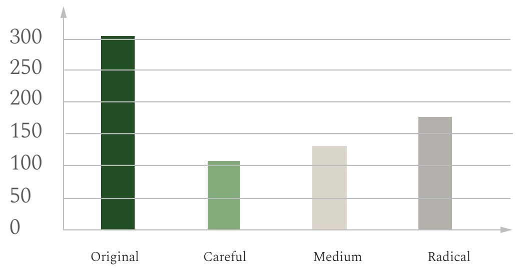
Ill. 125.Window hole extension
176 W



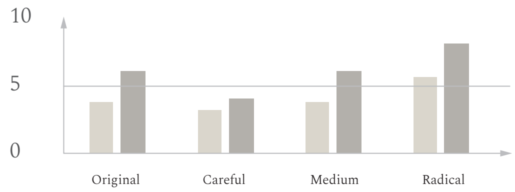


Ill. 121.Window characteristics

U-value [W/m²*K]
g-value
LT_g-value



Ill. 122.Heat loss



2% Daylight factor
Maximum daylight factor

Ill. 123.Daylight factor

The Process of Selection

From the abovementioned iterations of the different types of interventions, four different renovation concepts have been examined and compared with the original structures of walls, windows, roof and ceiling, and basement. Furthermore, all concepts are compared in their total energy consumption. Besides the development of concepts pros and cons is conducted to choose which concept to design upon, these can be seen in Appendix 10.

The Process of Selection

The two concepts look alike, only with a difference between the choice of windows and walls. As it was decided that it made most sense to replace the basement floor with a new terrain deck in order to utilize the basement for storage. Moreover, it was decided to open up the ceiling to the visible beam structure (see for further process in 'Development of Cultural Functions and Trade'). The choice of concept ended on concept 4 to utilize the building's full potential of an extended area and spatialities. The wall here is thin and prevents damage from humidity - if the demand from the building regulation should be met, humidity in the construction would have been a problem as the thickness of the insulation was not profitable. The wall was further picked because of the temperature of the surfaces. Instead of having only 10 degrees on the walls it was seen as profitable to insulate the walls and thereby have 18 degrees because of a better indoor climate.
By the use of the The Renovation Matrix, the final design solution of the optimization is a combination of different scales of interventions from careful to radical. The final solution ensures a better indoor climate and a decreased heat loss through the building elements.

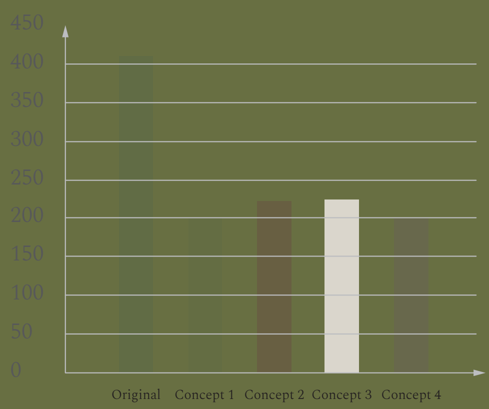
The Intervention Concepts

Concept 1
Windows: Medium intervention
Wall: Careful intervention
Roof: Careful intervention
Basement: Careful intervention

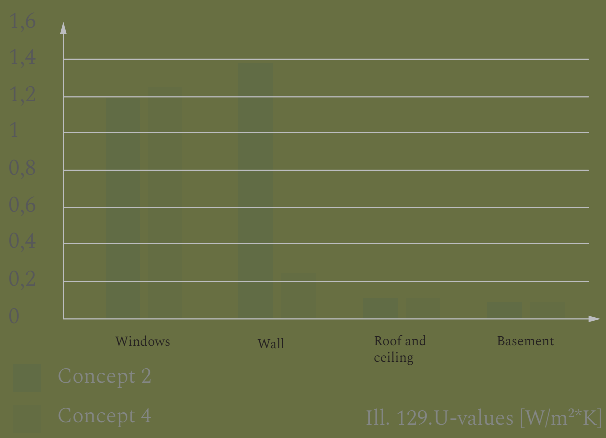
Concept 2
Windows: Radical intervention
Wall: Original
Roof: Medium intervention
Basement: Radical intervention

Concept 3
Windows: Medium intervention
Wall: Original
Roof: Careful intervention
Basement: Radical

Concept 4
Windows: Medium intervention
Wall: Careful intervention
Roof: Medium intervention
Basement: Radical intervention



Ill. 130.Renovation Concepts

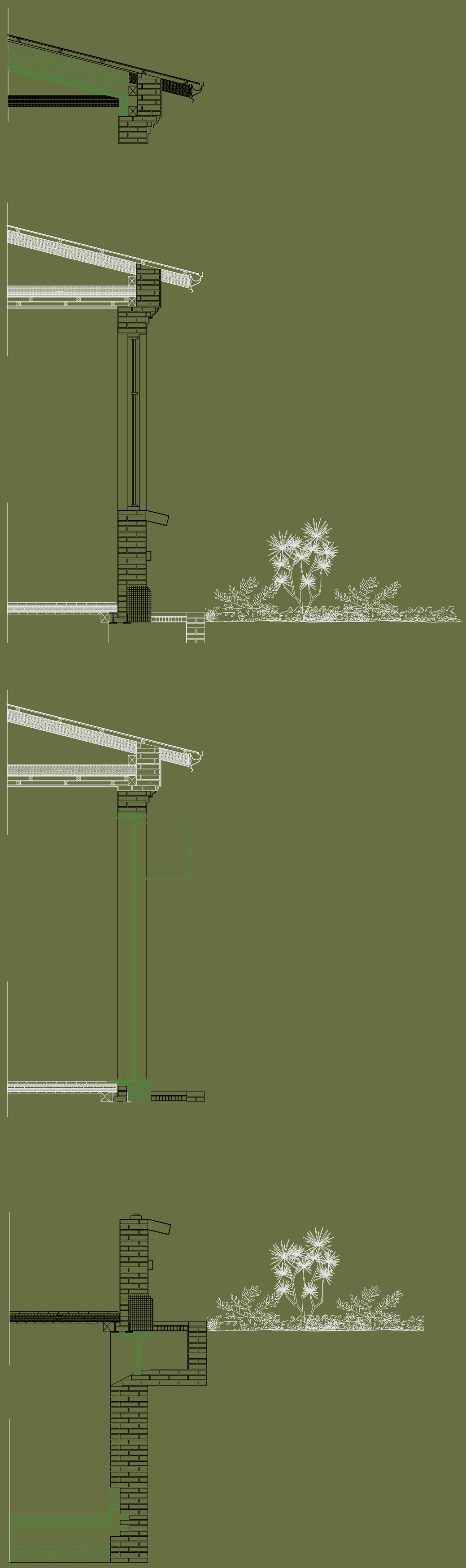


Ill. 129.U-values [W/m²*K]

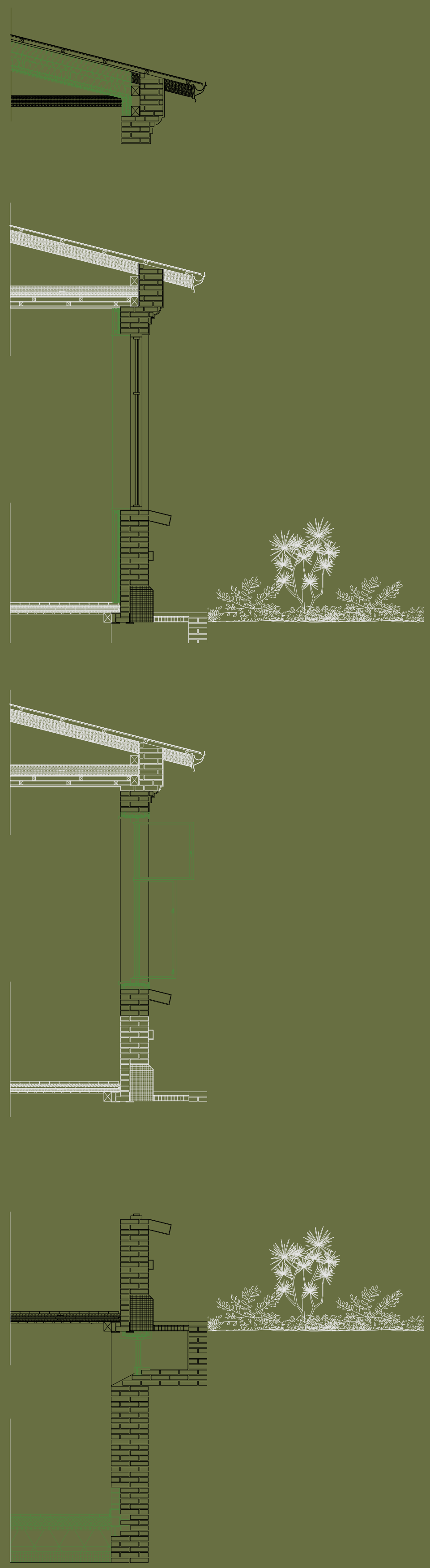
Ill. 128.

The Renovation Concepts

Concept 2



Concept 4



Ill. 131.

Ventilation

As a part of the optimization of the indoor climate of Building 20, the ventilation needs to be optimized according to the future functions. Today the selected buildings are primarily ventilated by natural ventilation with mechanical ventilation exhausts in toilets and bathrooms. Historical sources and plan drawings of Building 21 show that the hospital's bedrooms in the past were ventilated by hidden ducts in the walls where in- and outlet grids were placed in the walls. As the ducts are already installed in the external walls, it is estimated that they can be used for natural or mechanical ventilation in the building where trade, cultural and residential functions are placed.

As mentioned above, the thesis strives to have different functionalities in the buildings. Therefore, the initial calculations of the ventilation handle the three functions: trade, culture, and residential housing. The ventilation is calculated according to the atmospheric comfort where the building is considered as category II, which has a maximum percentage of dissatisfied of 20% (Dansk Standard. 2013). Further the room's dimensions are calculated to check if natural ventilation is a possibility.

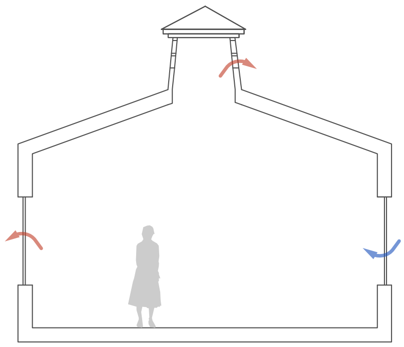
Therefore, different kinds of ventilation strategies are investigated to meet the requirements for the indoor environment from the Building Regulations (BR18).

Careful intervention: The use of natural ventilation is kept and optimized to fit the new functions of the building. Bigger spaces will be ventilated by cross ventilation and thermal buoyancy as the building's existing chimney stacks and 'light boxes' on the roof can be opened as outlets.

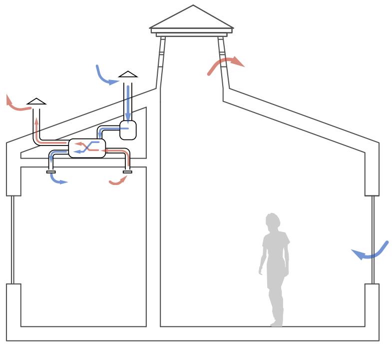
Medium intervention: The ventilation strategy is a hybrid ventilation system. Both natural and mechanical ventilation is used in the building. Rooms with higher demands to the air change and need for mechanical ventilation should be arranged close to each other to minimize the pipe work.

Radical intervention: The building is ventilated by mechanical ventilation. All rooms will be installed with in- and outlets and the ventilation will be fully automatic.

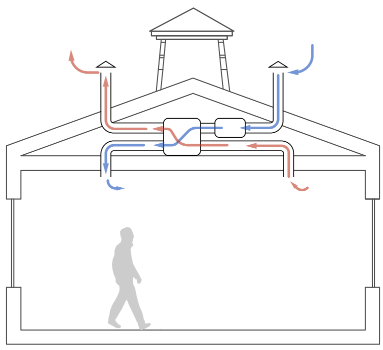
Based on the investigation of the ventilation of the different functionalities, none are overloaded seen in the percentages of dissatisfied. It is concluded that one of the functions will be taken to further investigations and development of the optimization of energy and indoor environment.



Ill. 132.Naturalventilation



Ill. 133.Dividedventilation



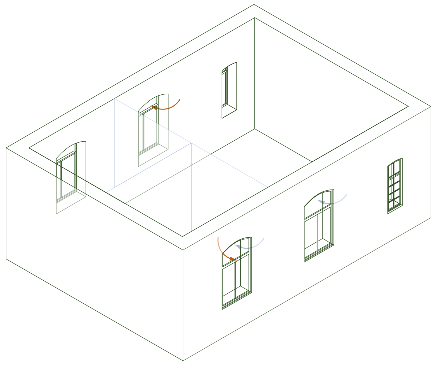
Ill. 134.Mechanical ventilation

Natural Ventilation

Building 20 is today designed with hospital functions. Therefore, the building has a long hallway in the middle connecting to smaller rooms facing the external walls to get in daylight. As the building is naturally ventilated it is estimated that the smaller rooms are ventilated by 'single-sided' ventilation.

Iterations of different room sizes are set to check if the natural ventilation still is usable when the functions and room sizes change for the future needs. As the abovementioned values on ventilation of residential housing, trade, and culture, natural ventilation is calculated by different rules of thumb for these functionalities.

Based on the calculations it is estimated that the buildings can be ventilated by natural ventilation. The values will in further iterations be used to simulate the indoor climate of Building 20. As well thermal buoyancy is calculated, though the calculations showed that it is not possible to theoretically use it as a part of the ventilation (Appendix 04). Nevertheless, thermal buoyancy is seen as possible to use on a practical level as the windows have the possibility to open the top part.



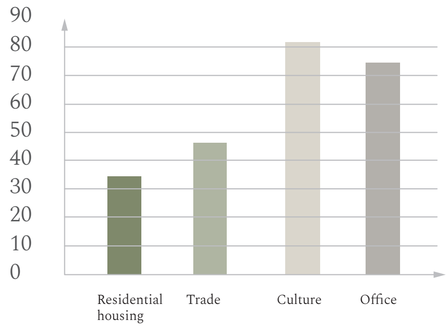
Ill. 137. Bigger rooms as living rooms, study hall, library, and shop can be ventilated by cross ventilation whereas smaller rooms as bedrooms, bathrooms, and individual group rooms can be ventilated by single-sided ventilation

Existing Ducts

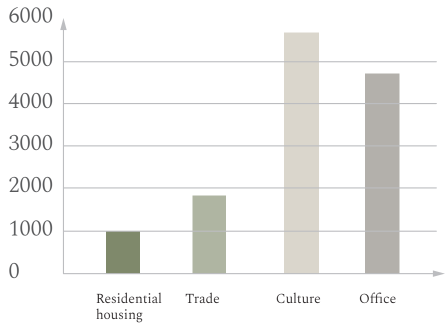
A further part of the ventilation is development of the existing ducts seen in Building 21. The ducts run from the basement towards the first floor and end as smaller chimneys in the roof. The ducts are seen as useful as they already exist and it is therefore possible to investigate if the amount of existing ducts are enough to help ventilate the building or if new ducts should be added. The renovation can be done by 'strømpeforing', where a soft impregnated polyester sock is led through the pipes. The sock, which hardens in a very short time, lies as a new lining in the old ventilation duct and the renovated ducts now have a lifespan of 100 years. Furthermore, the renovation ensures unnecessary energy consumption due to leaky pipes which draw in false air (Aarsleff. 2022).

To prove that the ducts can handle the necessary flow rate from the different functionalities a cross section of the existing ducts is made to measure the diameter, which is measured to be 24 centimeters. The duct size is compared to the needed sizes for the different functionalities as the design wants to utilize the existing.

As the existing ducts have a diameter of 24 centimeters one duct is not enough to handle the flow rate needed to ventilate the rooms. Therefore it is necessary to have more than two ducts per room, if the case is a culture or office situation. An example could be that each apartment needs two outlets to handle the flow rate from the used air and will be a design guide when the plan is developed.



Ill. 135.Duct size [diameter, cm]



Ill. 136.Flow rate [m³/h]

Indoor Environment

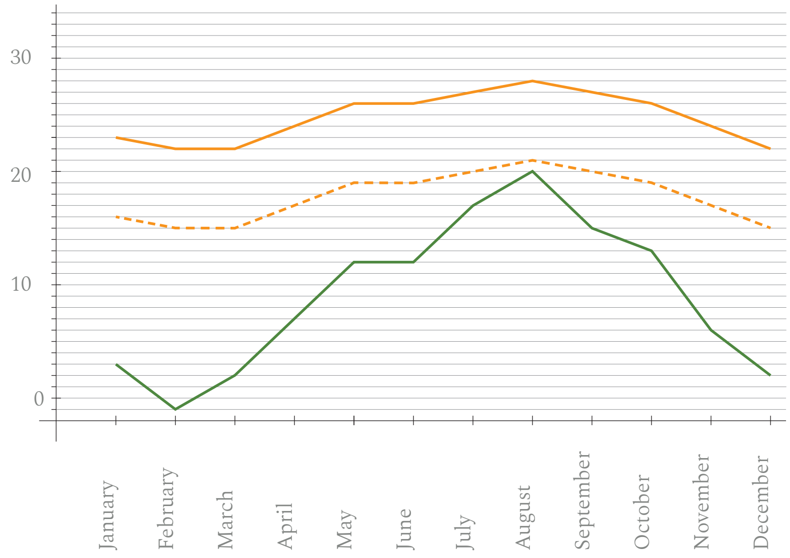
In order to ensure a satisfactory thermal indoor climate, the maximum and minimum indoor temperatures are investigated due to adaptive comfort. The idea with adaptive comfort is that the comfort temperatures differ from person to person as well as the type of buildings. Therefore, there is an interval between the lowest and highest temperatures that are recommended depending on the outdoor temperature. Moreover, the adaptive comfort temperatures fits better with the use of natural ventilation as lower temperatures than 21 degrees are acceptable in the winter.
As the ventilation and atmospheric comfort is calculated due to building category II, this investigation takes the point of departure in the same category. The running mean outdoor temperature and its related lower and upper limit temperatures is calculated for each month in illustration 138 (see calculations in Appendix 08).

By comparing the original with the renovated building (see illustration 139), it is clear that the renovated building is better than the original when looking at the minimum temperatures. Though, as the construction is better sealed, it does not work better with the maksimum temperatures as warm hot air can not escape as easily as before the renovation.
As there is no problem with sub-temperatures, the further investigation will focus on decreasing the maximum temperatures with solar shading.

The addition of solar shading on its own is not enough to decrease the maximum temperatures to acceptable values. Therefore the natural ventilation is increased to 5 h^{-1} to allow for a higher ventilation rate in the summer. The idea is, that if it is warm inside you open the windows wide and accept the little wind that might appear in order to decrease the temperature. Moreover, the people load is detailed for a more realistic input (see Appendix 07) than having 20 people in the room at all times.
Illustration 140 shows the maximum values for three different types of solar shading.

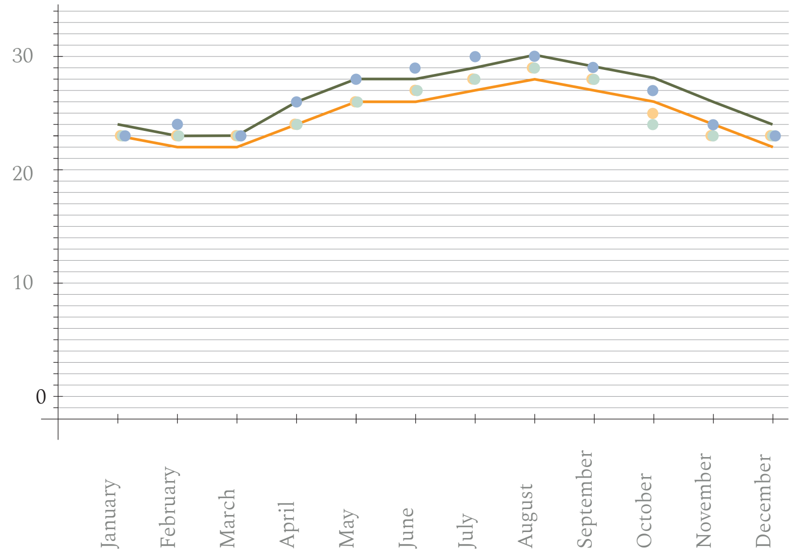
1. A retractable awning: This relates to the awnings that are already in use today on the buildings.
2. An external curtain: This is not as visible on the facade when not in use.
3. Box around window: This creates shade while enhancing the windows.

As illustrated, none of the solutions are under the upper limit of category II, though both solution 1 and 2 are under the upper limit of category III. Where category II is for new buildings and renovations, category III is for existing buildings (DS/EN 16798-1:2019 DK NA:2021). Therefore, it can be argued that this is the category to follow instead.
This allows us to choose between sun shading solution 1 and 2. As the sun shading in solution 1 is one seen on the buildings today, it is the one chosen.



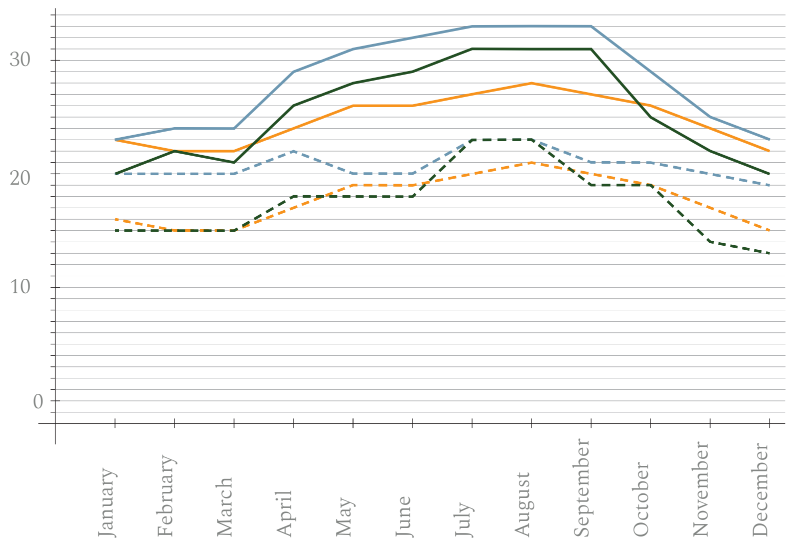
Ill. 138. Category II of adaptive comfort

Upper limit
Lower limit
Running mean outdoor temperature



Ill. 139. Original versus renovated building

Solution 3, maksimum temperature
Solution 2, maksimum temperature
Solution 1, maksimum temperature
Upper limit, cat. III
Upper limit, cat. II



Ill. 140. Test of solar shading intervention

Renovated, maks. temperature
Renovated, min. temperature
Original, maks. temperature
Original, min. temperature
Upper limit
Lower limit

Big Scale Discoverings

The Masterplan

This thesis' process of design embraces all architectural scales of a building project in a development area. Since the area is in the state of a future planned revitalization, as presented by the municipality in 'The New Neighborhood', it has been vital to perform a conceptual master's plan of Frederiksberg Hospital which the defined buildings, as presented in 'Relation to Frederiksberg Hospital Area', are located in. The thesis therefore stresses the importance of the entity of the large scale urban plan, the medium scaled area plan, and the small scale on building level.

The development of the conceptual framework of the master's plan of the area was developed with point of departure from the sub-visions presented by the municipality, and the municipality's architectural and urban possibility study which was handed in the tender material. An extract of the entitled is given in Appendix 09.

Low or High Plot Ratio?

When developing a master's plan of an area many drivers are important to consider. Nevertheless, the process has had a broadened focus upon building ratio in relation to the manifestation of larger and therefore open green structures. The discussion of building plot ratio and its economical, social, and environmental factors has therefore been explored in terms of different scenarios.

Regarding the discussion of the contradicting arguments for demolishing or preserving existing build structures in terms of environmental and social factors, as presented in 'Transform or Demolish?, one instance is where the existing structures and footprints are favored and expanded upwards. Another instance is of keeping preservation worthy structures only and adding new buildings on the building plot in order to meet the building ratio demands. In the presented scenarios the area of green structures has been an additional layer to explore in terms of securing high quality urban green scapes, in the middle of a great city.

The initiary concept as presented in illustration 141-145 is a mixture of above mentioned but with the focus of ordering the building volumes in terms of developing large green areas in between buildings, which the residents of Frederiksberg wished for in the future development of the area, described in 'The New Neighborhood'.

The Development of the Master's Plan

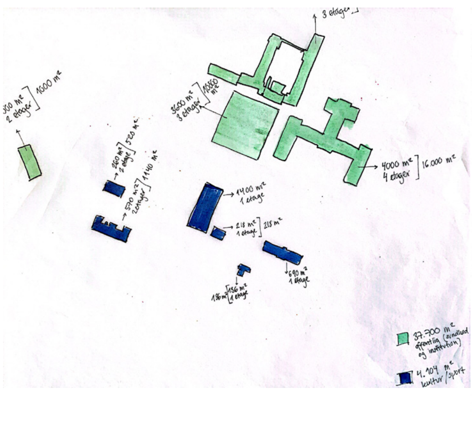
The process gave rise to reflecting upon the actual evolution of the large scale building plot concept, and as presented it has been boiled down to the following process of design. The first intervention dealt with the development of knowledge upon the plot's buildings to facilitate the selection process. The second phase selected which buildings to preserve and which to not. The final two steps constitute the implementation of new building volumes and the functionalities of these.

Preserving buildings with value only

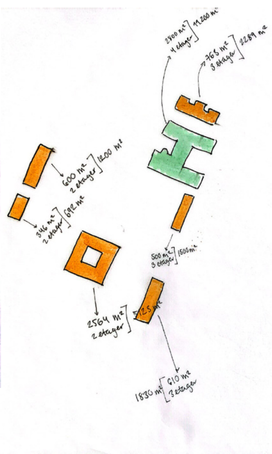
Ill. 141.

Developing an area with plot ratio of 100 precentage

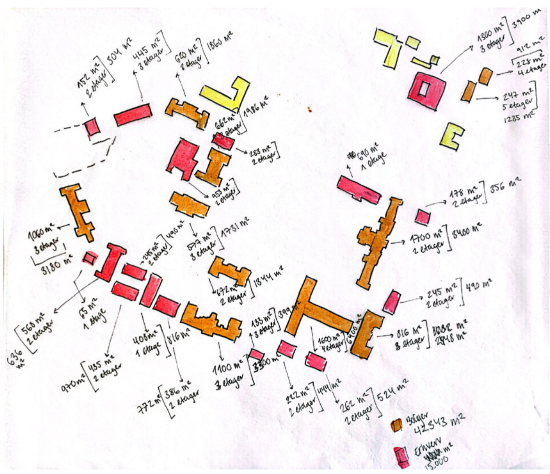
Ill. 143.



Ill. 142.



Ill. 144.



Ill. 145.

Adding on existing structures and footprints

Medium Scale Discoverings

The Functions of the Buildings

Caused by the development of the conceptual master's plan, and with point of departure in the neighboring functionalities in the conceptual buildings manifested by this, different solutions of functionality locations have been tested in the chosen buildings of this thesis.
Because of the building's very characteristic and magnificent architecture, as described in 'Small Scale', there was an initial idea of these buildings becoming some kind of a cultural shared hub, where visitors would be introduced to the history and atmosphere of the area. This was an outcome of the discoverings of the analysis' 'Culture and Education' and 'Green Structures', where it was discovered that Frederiksberg city is lacking a place where culture and green urban areas are connected as a unity. The analysis highlighting education structures in the area of Frederiksberg city concludes as well a large number of education structures that could facilitate the need for a public library targeting students.

In relation to the municipality's tender material, they also manifest a percentile division of housing, trade, culture and health which should be accommodated on the overall Frederiksberg Hospital plot, which also the thesis' building plot should correspond with.

The Development of the Funtional Organization

With care to the parallel process of the development of the master's plan, the presented different proposals of the functional organization were explored.

Illustration 149 facilitates the idea of a public community center accommodating all age groups, here only the ground floor is considered.

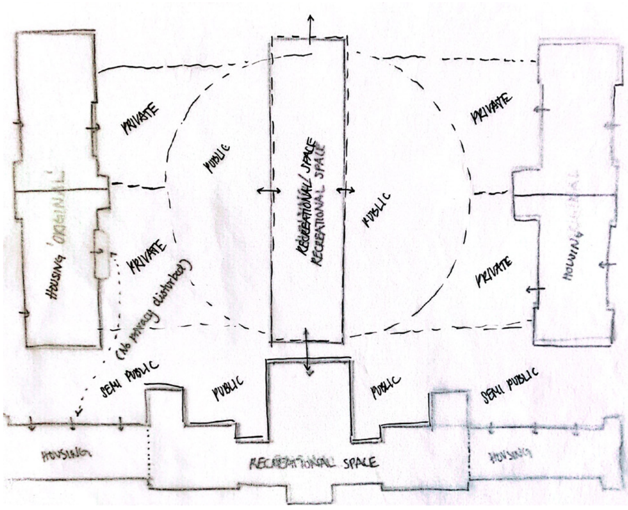
Illustration 147 is a mixture where the culture institution is accommodated by functionalities which correspond with the health area to the right and the city to the left.

In the scenarios presented in illustration 149-151 the first floor is implemented in the solutions to explore both vertical and horizontal connections.

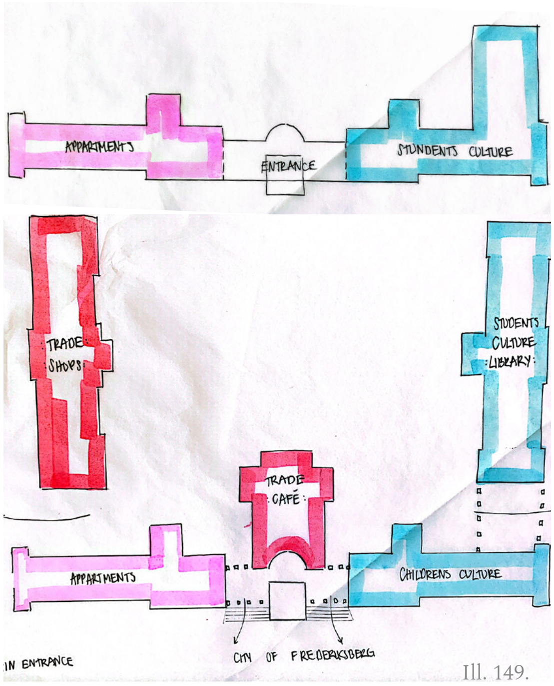
Creating a Public but Intimate Area

The building plot of the thesis acts, because of its pavilion structure, presented in illustration 146-151, as a quiet and slow pocket in the city. The buildings are located around a large flat green structure which acts as the pocket. Furthermore, the buildings face the open green space with an accommodating human scale. This corresponds with the above mentioned need for cultural functionalities, that invites visitors for a stay. This pocket in the city therefore utilizes an intimate area, which should be designed to be and perceived as publicly available.

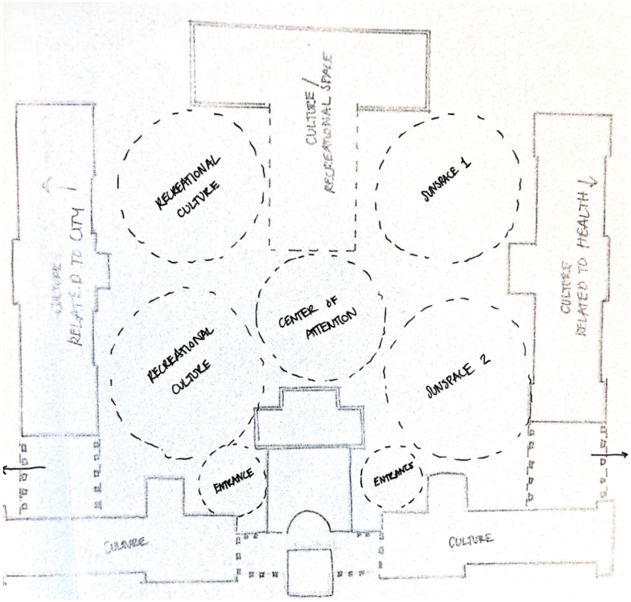
As seen on the illustrations given in this section, it was clear from the start that a kind of main entrance should be implemented in the middle of Building 21 in order to relate to the flow surrounding the building plot, whereas one is from a future metro station and the other from the gateway path of Frederiksberg Hospital.



Ill. 146.



Ill. 149.



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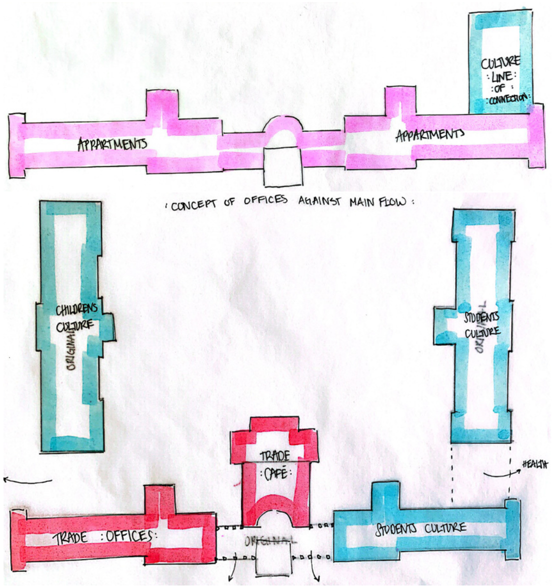

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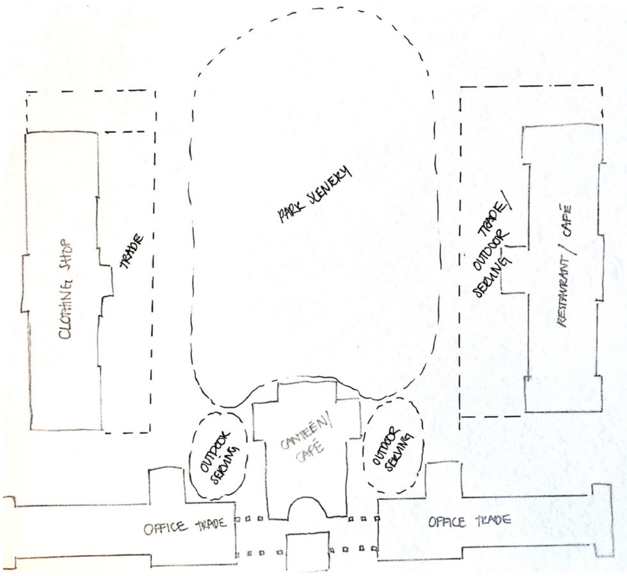

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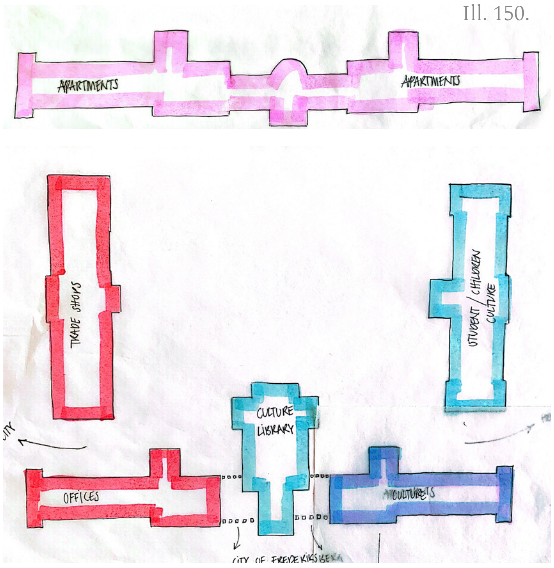


Ill. 151.

Organization of Multifunctional Area

Creating Intermediary Public Spaces

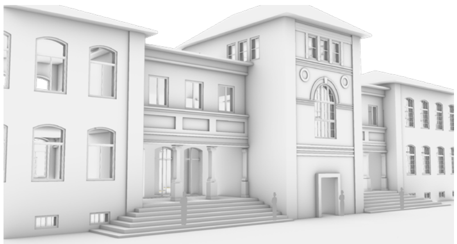
As stated above, the need for a main entrance in the structure of Building 21 is vital to utilize the perceived public available area. The following illustrations therefore accompany the design process and development of such principles. This process encircles the concept of having a fully transparent entrance hall, with iterations with care to room dimensions, inviting architecture, and use of the entrance hall.
Illustration 152-159 presents the iterations of such divided on the scale defined by careful to radical interventions.

Ill. 152.

Ill. 153.

Ill. 154.

Ill. 155.



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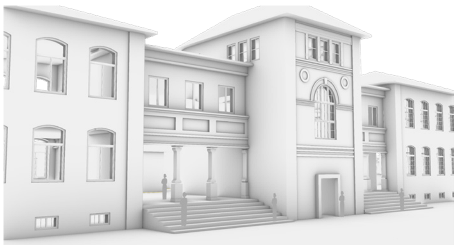

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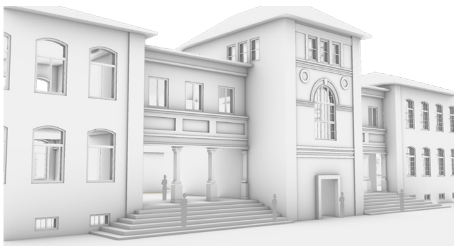

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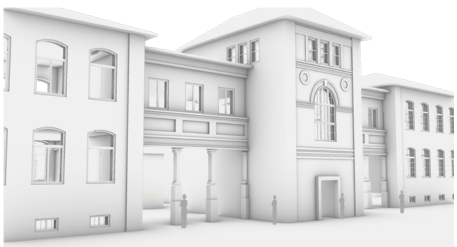
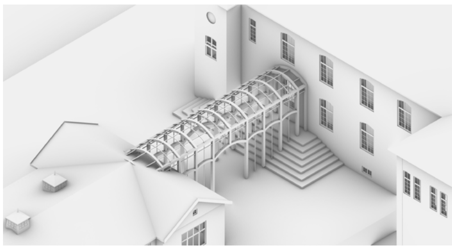


Ill. 159.

Inviting Main Entrance

As a result of the evolution of the functional organization, presented in 'Presentation', the corresponding library functionalities located in Building 21 and 22 give rise to a need for an intermediary connection. This to utilize the perception among visitors that the functionalities, in the separated buildings, are interconnected. This area of the design process accumulated questions regarding the relevance of the addition. Would a flow between the buildings actually occur, when the user groups are different and therefore not in relation to each other? Is the argument for enhancing the corresponding functionalities in the architecture strong enough to facilitate a sculptural new structure? These questions were raised many times in the process of design. Nevertheless, a small opening in the facade to fascilitate a connection between the two buildings was needed.

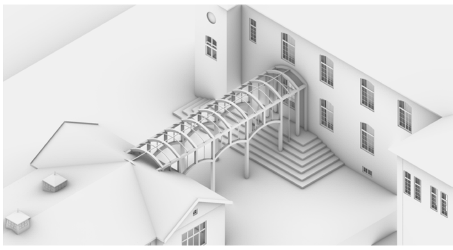
Ill. 160.



Ill. 163.

Ill. 161.

Ill. 164.



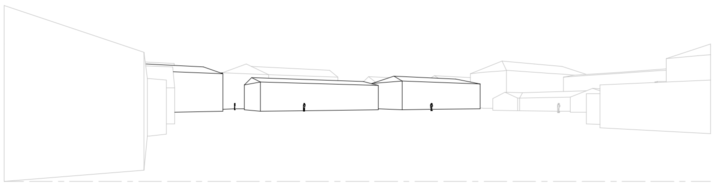
Ill. 162.

Ill. 165.

Framing Interconnections

Creating New Buildings with Care to Existing

To thoroughly investigate the new volume's features in relation to existing building volume's , the following process takes its point of departure in the development of the conceptual masterplan presented in 'Relations to Frederiksberg Hospital Area'. This part of the process is on the contrary from the medium scale perspective, where the transition between building volumes heights are in focus. The studies explore both an intermediary division of the building volume (see illustration 166-168), which neighbors the urban area, and different proportions in the facade in order to gain harmony (see illustration 169 and 170).



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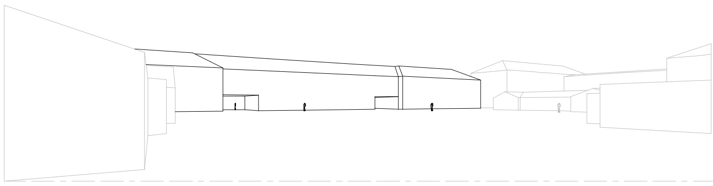

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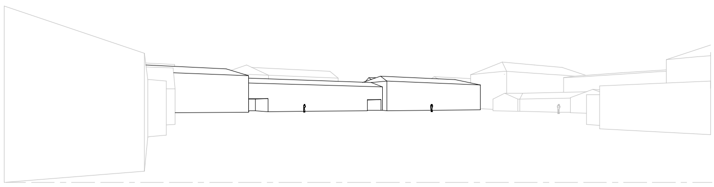

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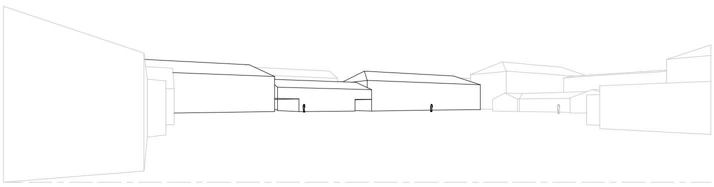

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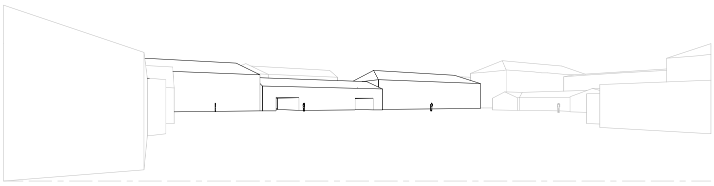
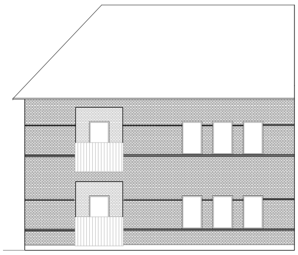
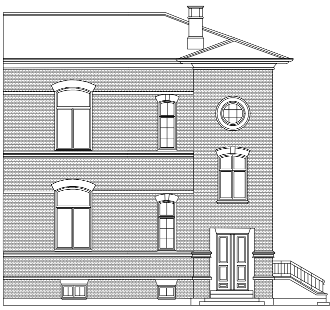
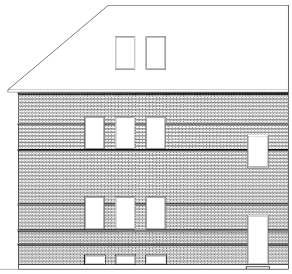


Ill. 170.

New Building Volume in a Historic Context

In relation to the volume study of added buildings in historic contexts, it is vital to explore how the outer fabric of such new buildings should respond to the existing architecture. Through readings explaining how to relate new architecture to existing, it is concluded that a chosen number of stylistic devices should be translated from the existing to the new.
The presented part of the design process, which has been conducted simultaneously with the interventions on the existing structures, illustrates the method of extracting different stylistic devices and compounding it in a new building's facade concept. The studies are kept very conceptual to enhance the conceptual design process regarding the added new building.

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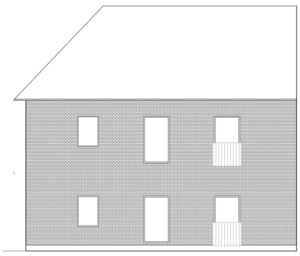
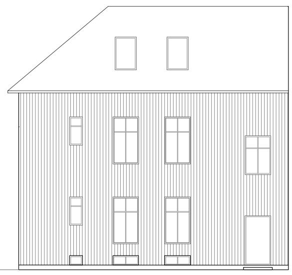
Ill. 174.





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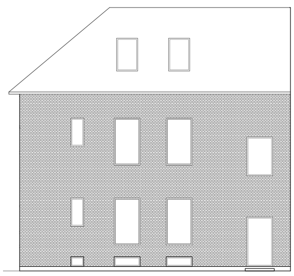
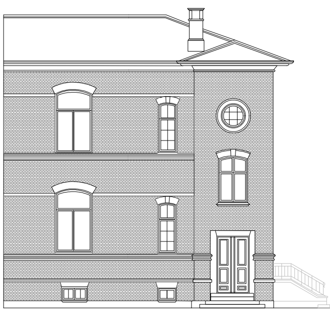
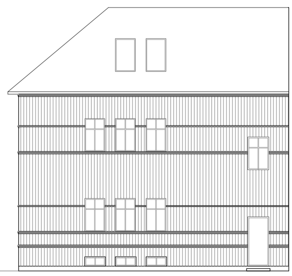




Ill. 173.

Ill. 176.

Materials in Relation to Existing

It was concluded that the implementation of brickworks as a stylistic device on new buildings created a clear link to the existing buildings. A study regarding different brick bonds was therefore conducted to explore different solutions to also ensure that it was clear that these buildings would be from a more recent time than the existing.

Ill. 177.

Ill. 178.

Ill. 179.

Ill. 180.

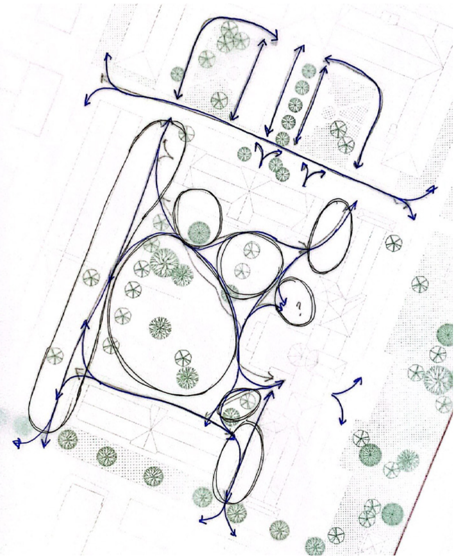
Ill. 181.

Ill. 182.

Brickwork Bonds

Creating Diverse Outdoor Experiences

As stated in the 'Green Structures' Frederiksberg city is known for its manifold and rich green structures, which characterizes the overall area. The thesis has had an overall desire to maintain and promote this exact city strategy, which is also described in 'Characteristics in Architecture'.
The process of the urban greenery plan is developed with focus to flow patterns and functional division between buildings, this is exemplified in illustration 183 and 184. Furthermore, framing natural happening blue spot, sun- and shadow spots as illustrated on the next page (see Appendix 11).



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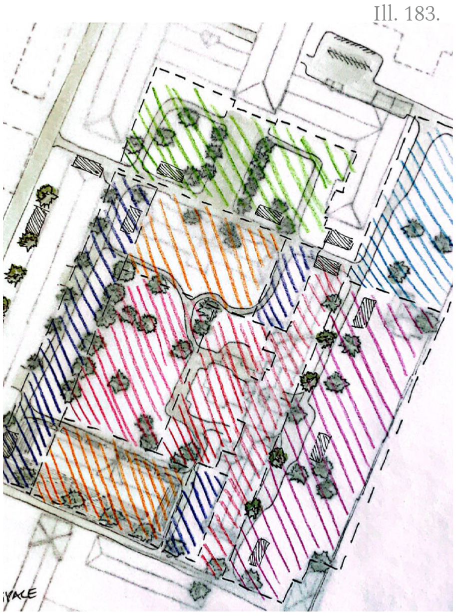
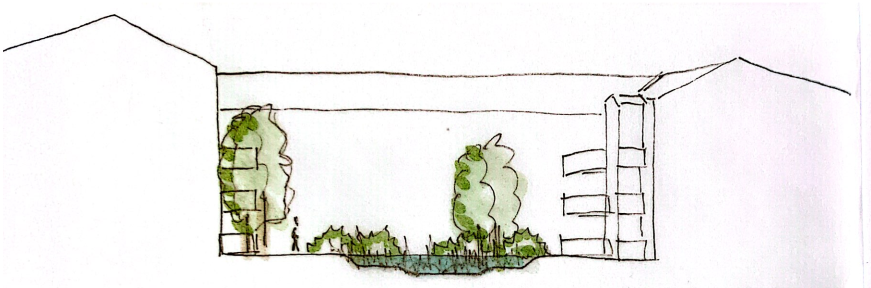


Ill. 184.

Ill. 185.

In continuation to the above described, some of the urban spaces have undergone a more thorough process. Especially existing recreational and green structures have been explored and transformed in order to develop the area but with care to the historic stylistic devices. The presented design process on these pages show the method of careful to radical interventions translated to urban sceneries. The solutions are developed with focus to creating an area, with care to existing urban structures, which naturally accumulates rainwater in heavy rain squall.



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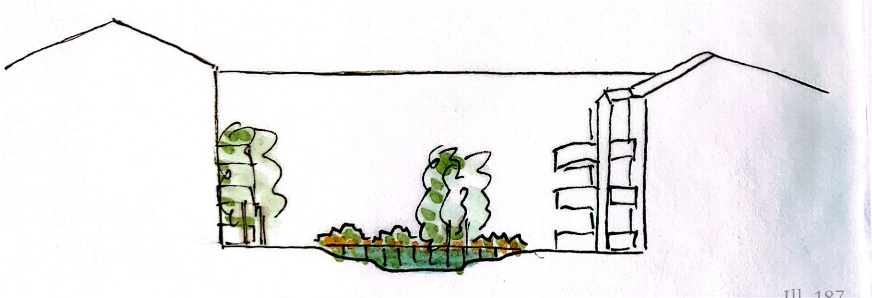

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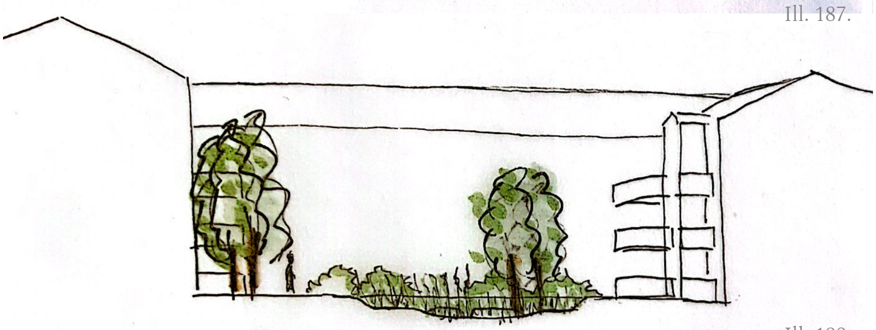

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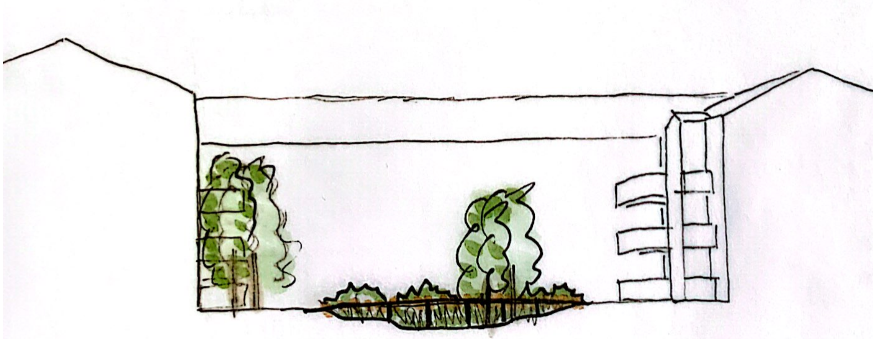

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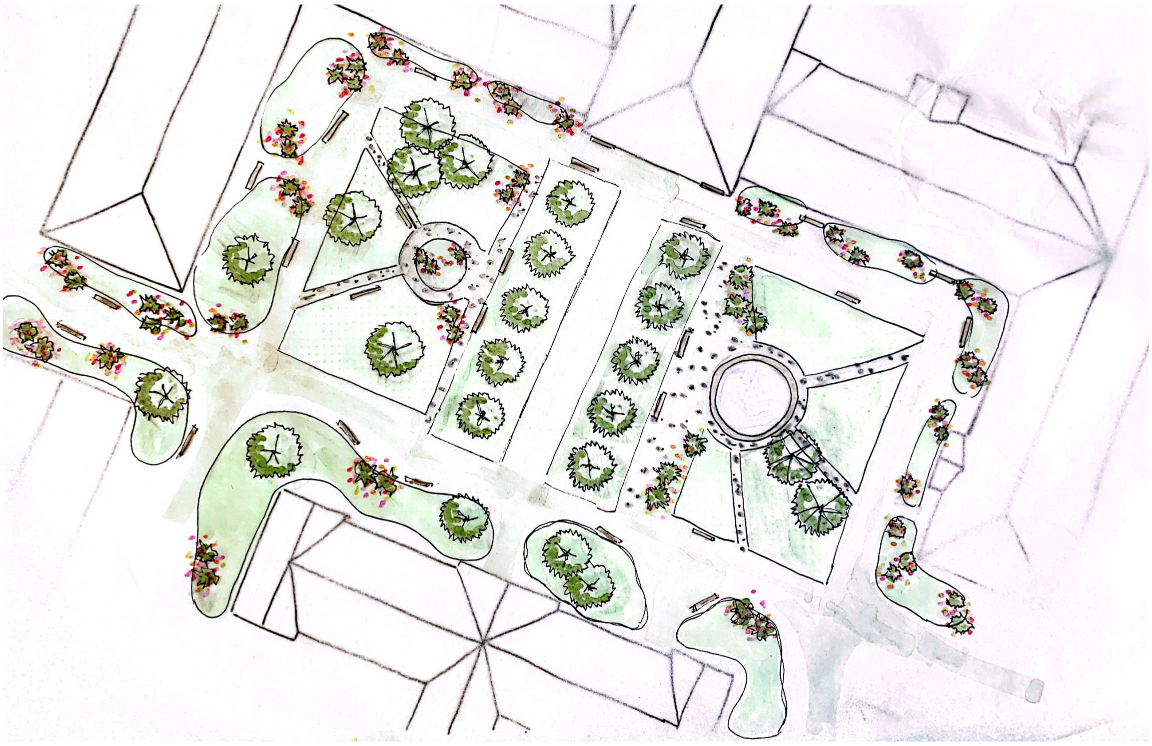


Ill. 190.

Ill. 191.

Small Scale Discoverings

Organization and Strategies

Parallel with the development and final decision regarding the functional division in between the thesis' buildings, organizational principles on building scale have been executed. This level of detailing is with care to the history of the building, more precisely the building's original and existing use and enclosed organization, which should generate the concept of future use and organization. The brief extract of such analysis conducted throughout the design process described in 'Levels of Details', gives clarification of historic changes in the built structure, and furthermore possibilities of revivision of former organizations.

Obligated to Existing Potentials

In the development of strategies for the inner organization of the buildings the point of departure facilitated a study of the buildings structural properties and the extraction of important performance related components in the structure, as described in 'Building 21 - Technical Interventions'. The findings generated possibilities and limitations of the existing structures, which have been implemented in the process from an early stage - this to ensure that the inner organizational revitalization obliged vital structures of the existing buildings.

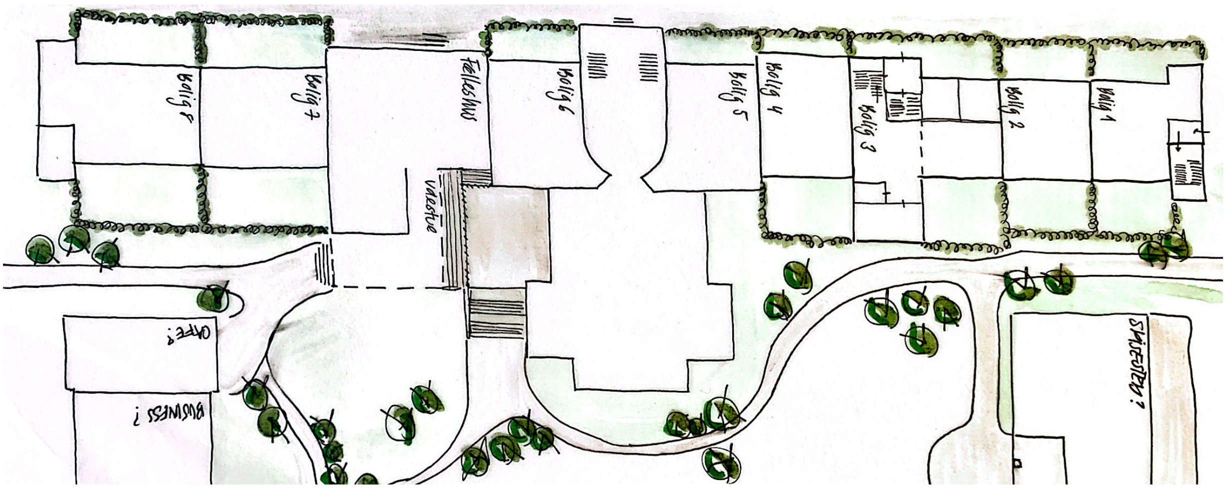
In phases in the design process dealing with small scale discoverings, a careful approach to existing qualities and detailing have been vital in terms of upholding a strategy of maintaining and furthermore framing the existing architectural qualities. Findings of the analysis presented in 'Level of Details', the historical knowledge of the building's use, and the technical iterations presented in 'Small Scale', have therefore been the superior catalysts in the development of the following small scale discoverings.

The following section will illustrate a variety of considerations regarding the different typologies of functions in the different buildings, which takes its point of departure in the final decision of the functional organization in the medium scale section. The section is divided into the different typologies in order to give a clear understanding to the reader of the individual area's development. Nevertheless, in order to understand the process, it is important to state that the process has not been linear but parallel to each other - wherefore each typology has had an influence on one another.

Initiary Concepts

In the early design stage of figuring out which type of architectural interventions that was needed in order to revitalize the buildings used in the future, different initial concepts were explored. The presented initiary concepts are conducted parallel with the evolution of the functional division between this thesis focussed buildings, for which reason a widened range of possible internal strategies of organization is presented in order to introduce the reader to underlying design potentials which dictated the subsequent process of small scale design explorations.

The underlying design potentials which have been presented covers different ways of internal division between functionalities, flow patterns, and extension of existing structures. These potentials in some ways oblige the existing structure and at the same time develop the existing matter.



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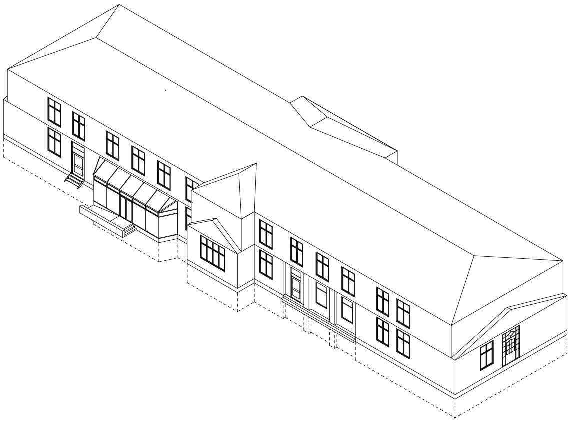

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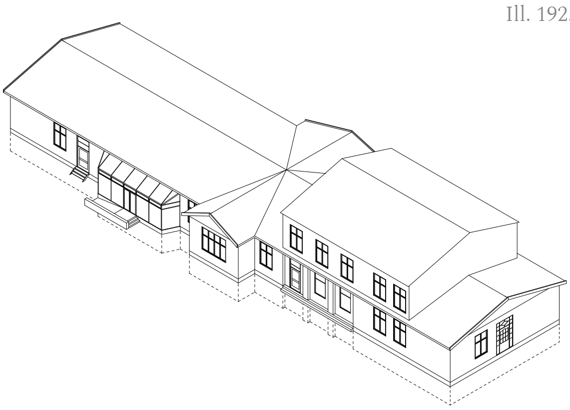

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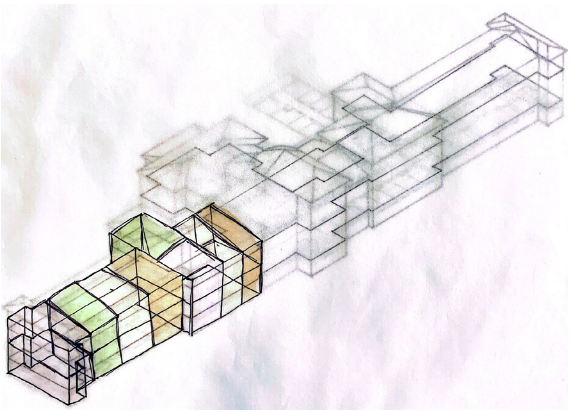

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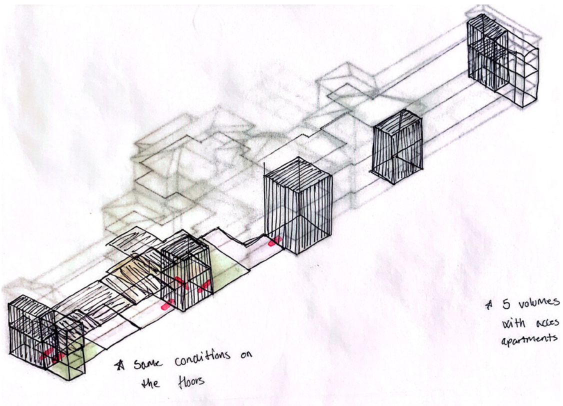

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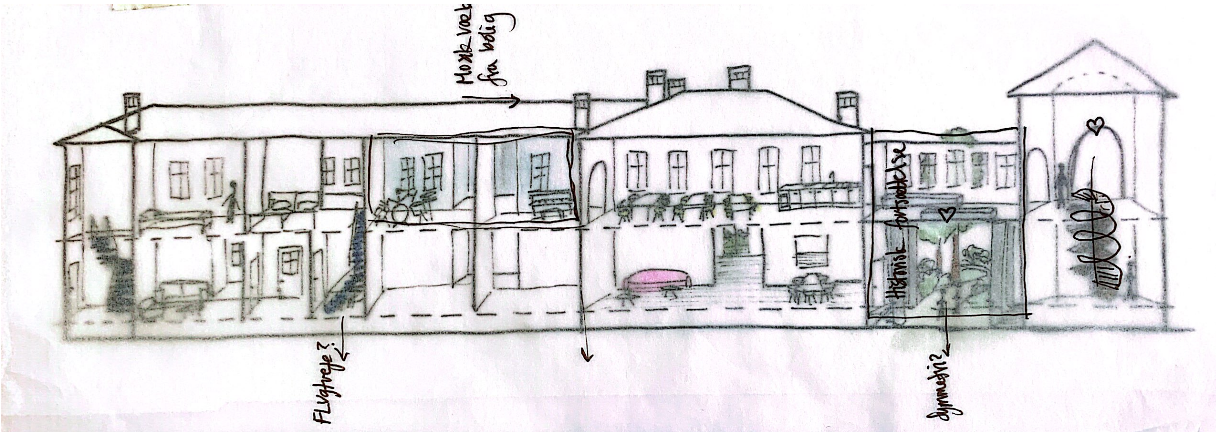


Ill. 197.

Division of Building Volume into Smaller Parts

Development of Cultural Functions and Trade

Qualities of the existing structures were from the start considered to be framed in the public areas of the buildings. The development of such have therefore been with a focus upon how the organization of volumes could be an instrument to raise the visitors' awareness of the qualities of such historic architecture.
Qualities which have been catalysts in the small-scale design process are the building's characteristic high ceiling heights, transverse ceiling vaults, large vaulted windows, and octagon shapes which are repeated numerous times in the fabric of the building.

Ill. 198.

Ill. 199.

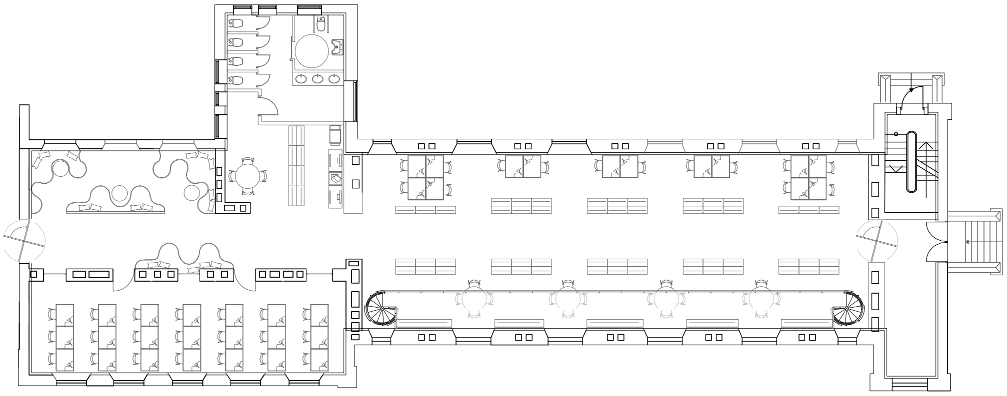
Ill. 200.

Ill. 201.

Ill. 202.

Ill. 203.

Manifesting the High Ceiling Height



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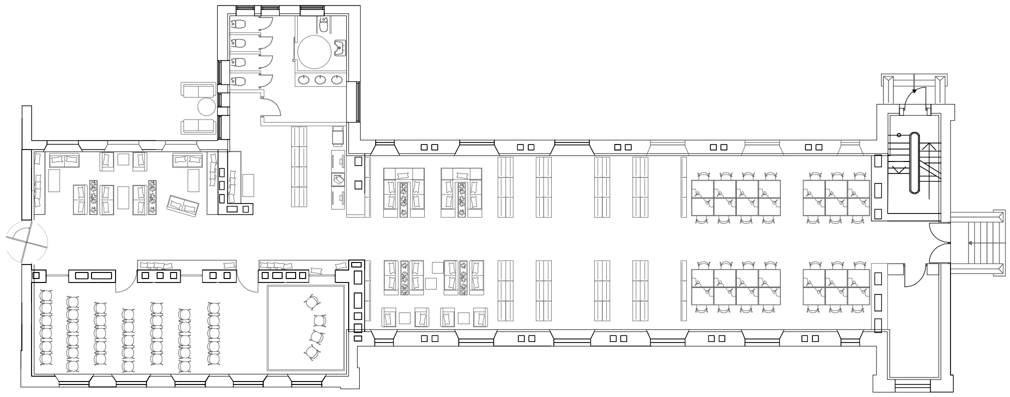

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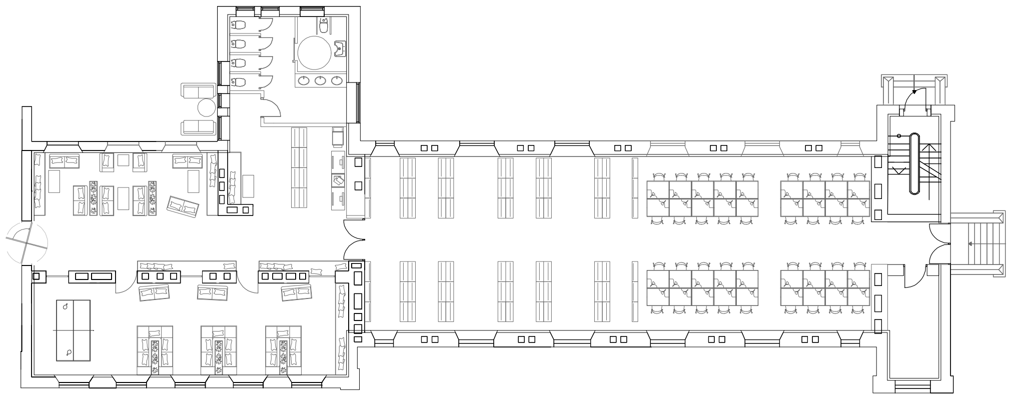

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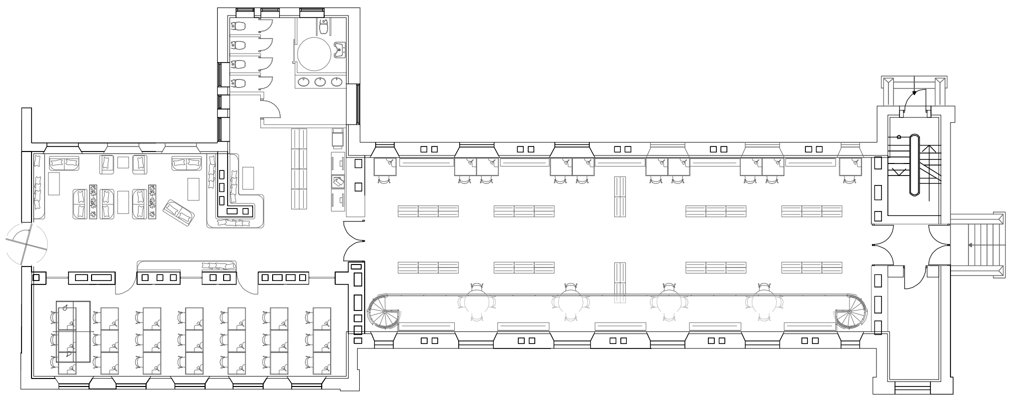


Ill. 207.

Multipurpose Interior Organization

The development of different organization strategies regarding the different functional typologies have been executed with the use of scenarios in order to methodologically consider different parameters which are related to potential user's needs.

Transparency and the embodiment of creating spaces that give rise to a perceived public space have as well been considered in the development of the presented public spaces, this to ensure that one will be met by an inviting structure and organization, which again refers back to the wished outcome of the publicly available functions.

Ill. 208.

Ill. 211.

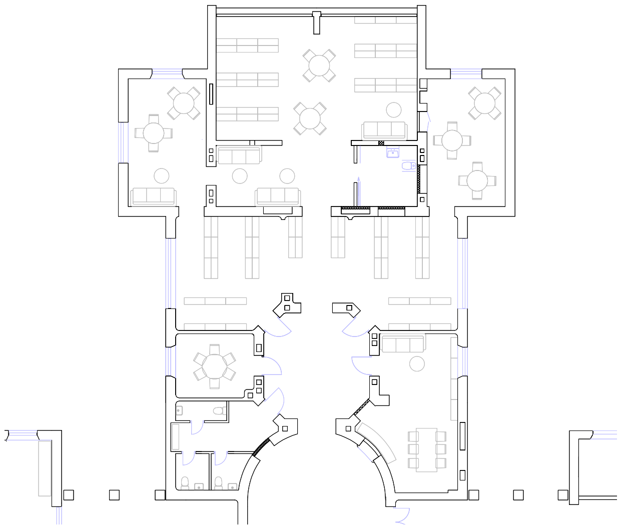
Ill. 209.

Ill. 212.

Ill. 210.

Ill. 213.

Manifesting the Octagon



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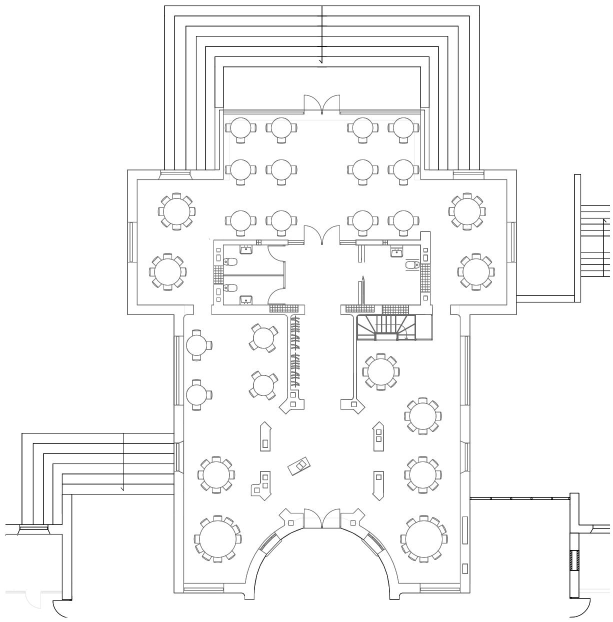

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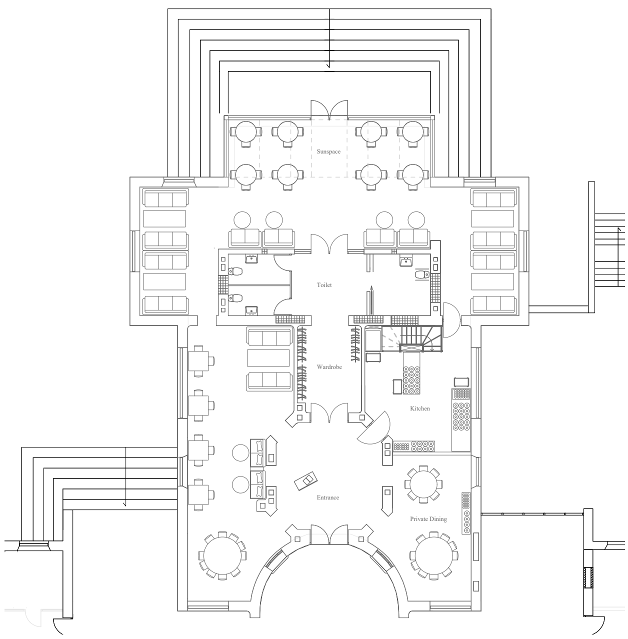

Ill. 216.

Variating Spatial Spaces

Another catalyzation of the small scale design process, is the potential of re-vitalizing and framing the different building's load-bearing and stabilizing structures. This to facilitate a varying experience of the built environment and the utilization of a general acknowledgement and appreciation of former building techniques.

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Ill. 221.

Ill. 218.

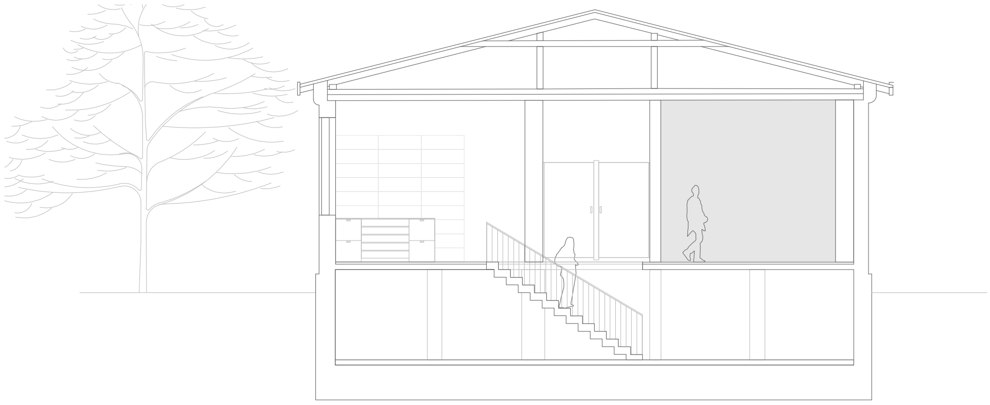
Ill. 222.

Ill. 219.

Ill. 220.

Ill. 223.

The Experience of Building Structures



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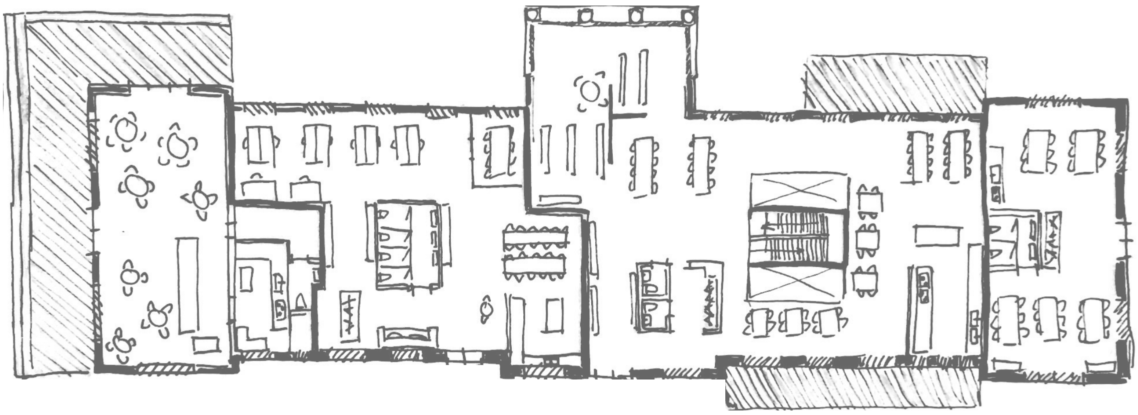

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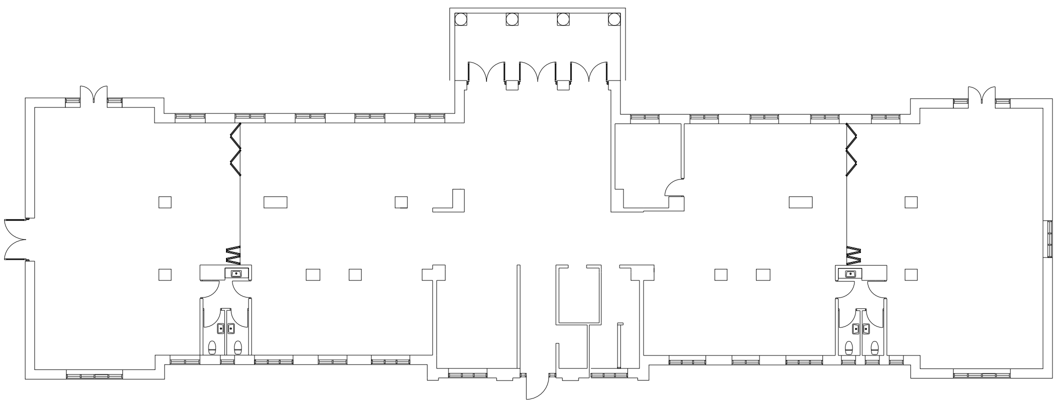

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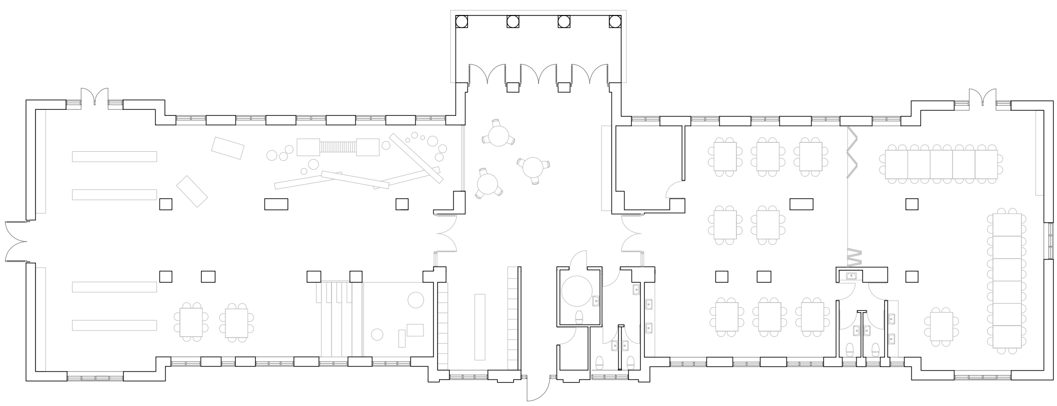
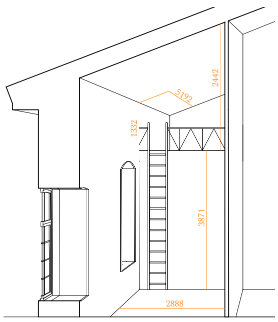


Ill. 227.

Creative & Multifunctional Spaces

Development of Residential Units

Parallel with the discoveries in the technical section of the design process, explained in 'Optimization of Building 20', and with different degrees to the above mentioned catalyzts different proposals of plan organization of residential apartment units have been developed. The different proposals take their point of departure in a variety of residential and therefore user-types wherefore the process again has been executed methodologically.



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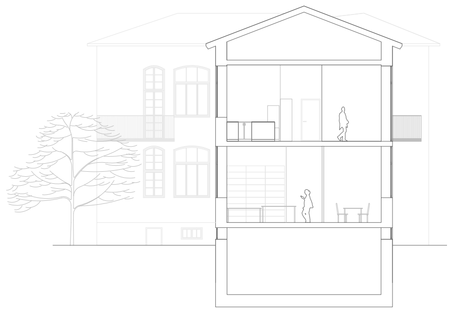

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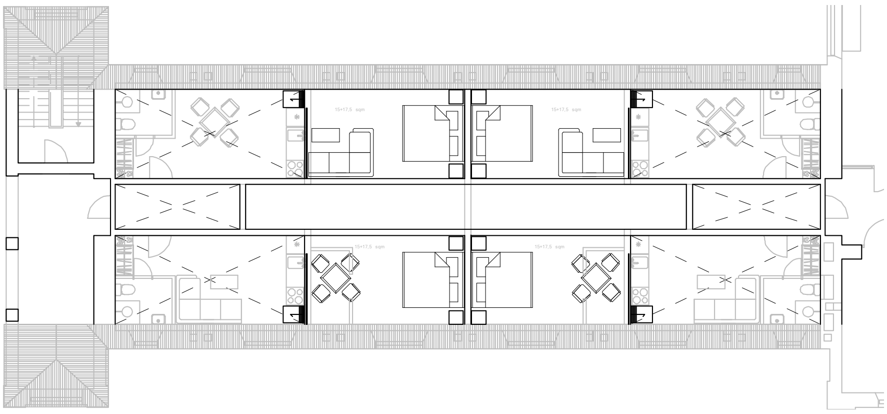

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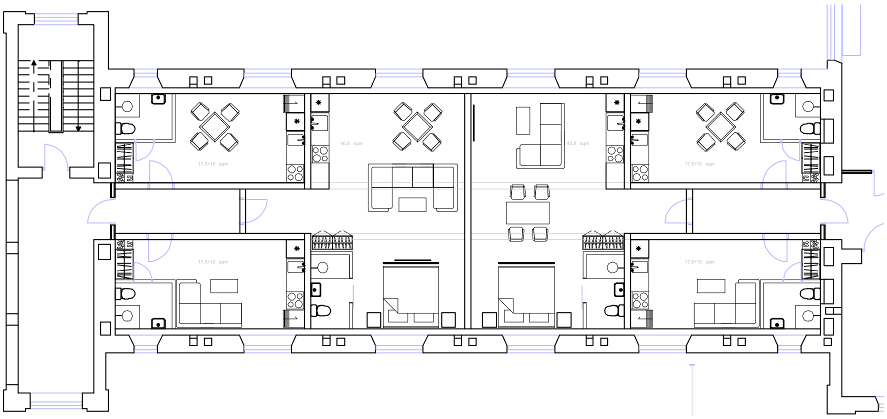
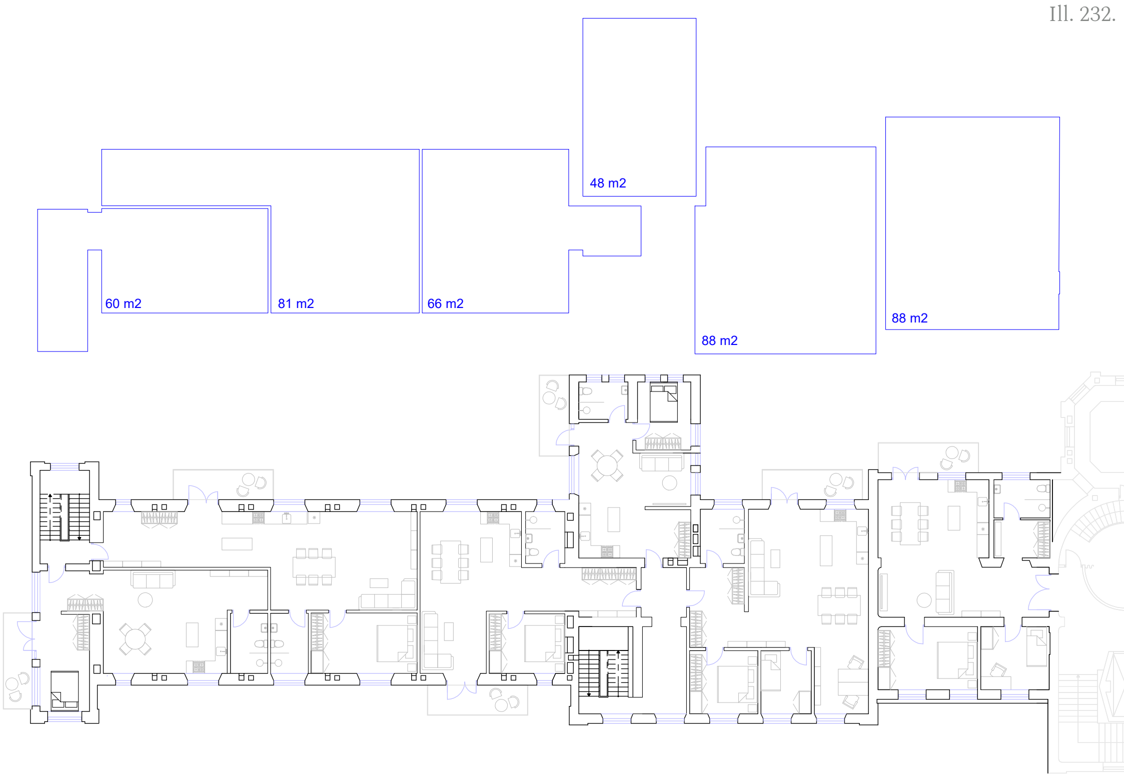


Ill. 231.

Studio Appartments

Ill. 232.



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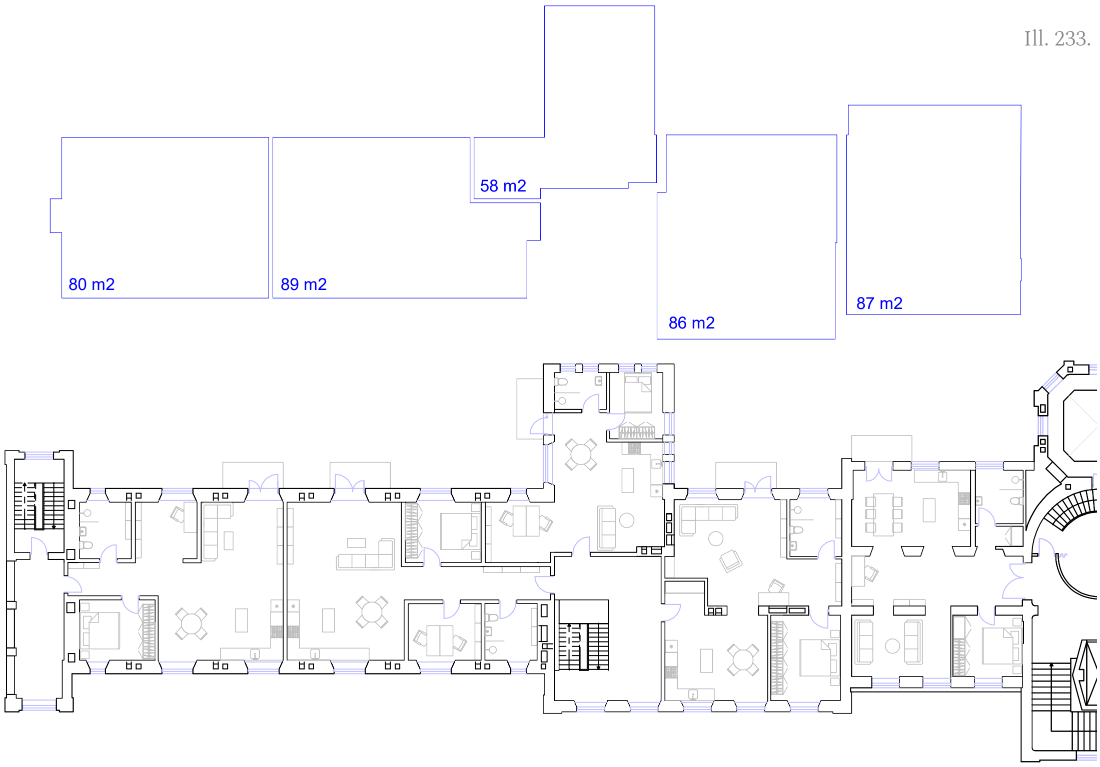
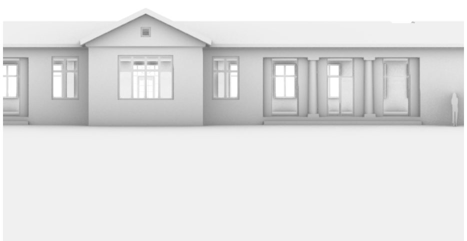


Ill. 234.

Ordinary Appartments

Development Intermediary Spaces

In continuum to the study of 'manifesting the octagon' and the study of 'creating intermediary public spaces', different proposals to revitalization of intermediary outdoor spaces were explored. On the contrary, this study explores the smaller scale intermediary space between the inside and outside, and how such openings should be designed in order to oblige to the existing architecture.



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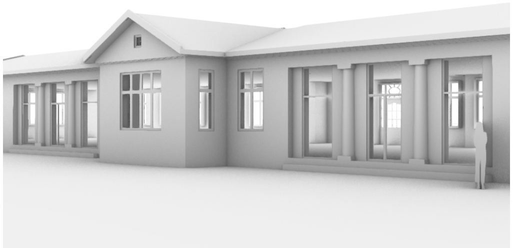

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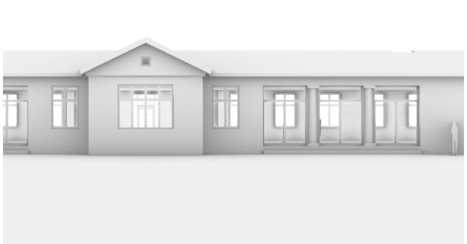

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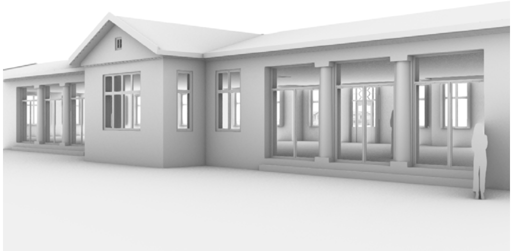

Ill. 239.

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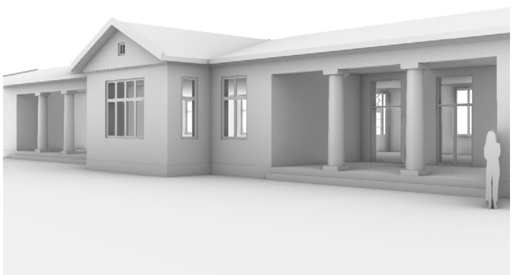
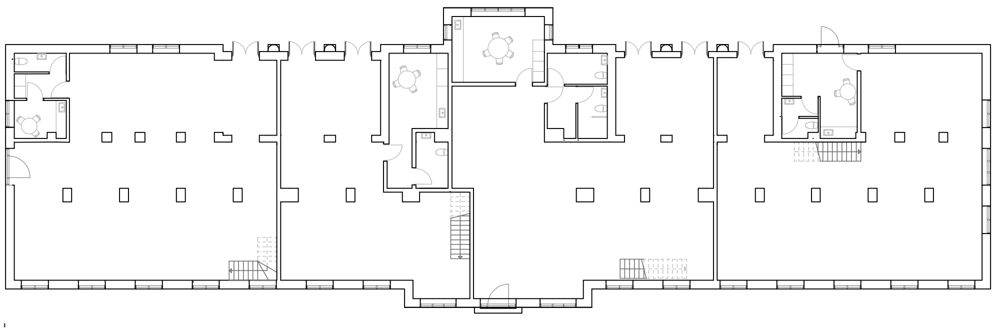


Ill. 240.

Opening of Facade



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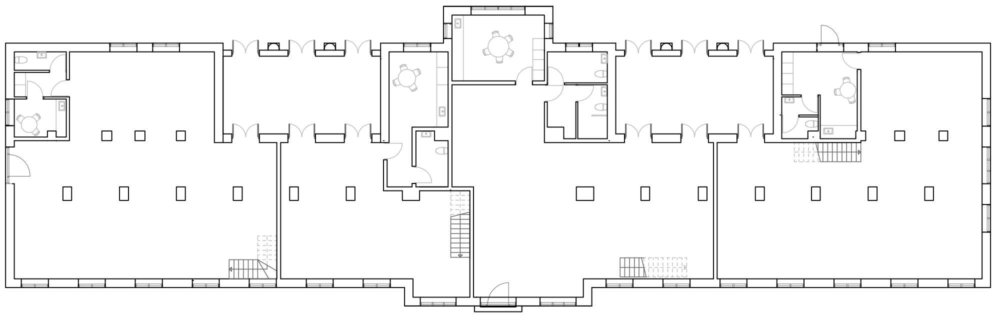
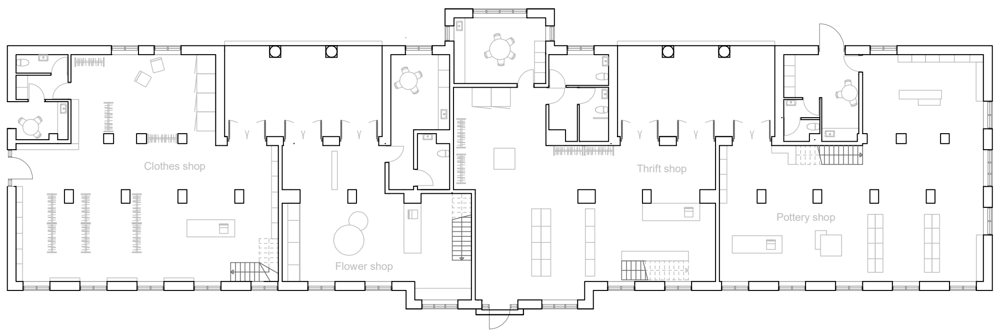
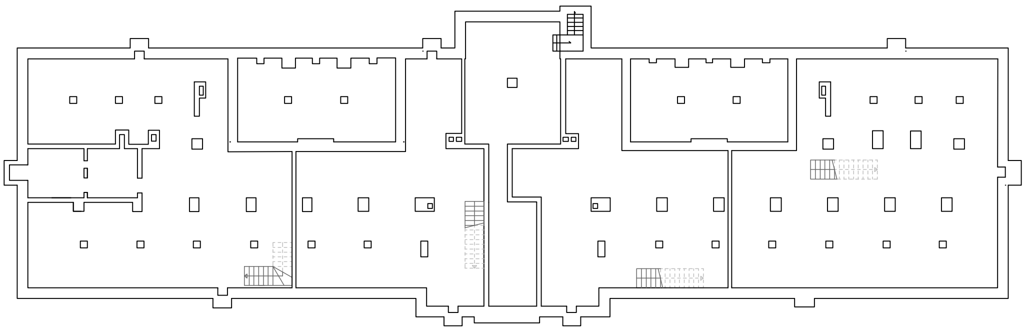


Ill. 242.



Ill. 243.



Ill. 244.

Integration of Intermediary Outdoor Space

Ill. 245.

07. CHAPTER

This chapter concludes on the project with a conclusion and a reflection.

EPILOGUE

Conclusion

The aim of the thesis was to *discover a framework for restoration and energy-optimization of existing structures with an extended intention of preserving and manifesting existing values of social and historical means*, as the architectural profession will soon be at a point where an extensive percentage of all projects will be connected to transformation and/or preservation of existing buildings and structures.

The thesis proposes a framework; The Renovation Matrix, in which technical and aesthetic values and qualities are combined and balanced in functional buildings and urban developments – transformation of buildings are more than the beautiful spaces and historic atmosphere, it is also about creating a great indoor climate and a decreased energy consumption to optimize the past for the future.
The developed framework is based on a principle of an iterative process and method, divided into five steps, that combine potentials and challenges into possible technical solutions that are assessed aesthetically and functionally. The framework divides the technical solutions into three categories; careful, medium, and radical interventions with consideration for the historical values and memories. This division ensures a systematic understanding and assessment of the positive and negative consequences of the different solutions. Hereby, it is possible to choose the better solution for the particular building element and building.
The framework is exemplified by a project site at Frederiksberg Hospital, where The Renovation Matrix is used to energy optimize the buildings with respect for the historical values and identity.

The thesis has been developed through empirical studies of theory, documents from others' experience of renovations and optimization, and research papers on building materials. Throughout the project, it was intricate to find comprehensive cases that considered both the technical, aesthetical, and functional needs and demands. The cases either focus on selected building elements, selected materials or on the preservation of selected historic elements, though with scarce consideration for the functional aspects. However, there is an increased focus on research on technical and functional aspects of materials and selected building elements, it has simply not developed into the building industry yet. Though, this will happen over the next couple of years as the building industry evolves.

With the framework, the thesis proposes an approach to combine the beautiful transformation of existing buildings into functional buildings with consideration for the indoor climate and the energy consumption. By combining the knowledge from both perspectives it is possible to create well functioning buildings with respect for the historical identity. This ensures a transformation of old buildings that will be operable in the future as well. With the framework, the thesis proposes a method for future transformations projects as well as further development of cities and other urban areas.

Reflection

Our Position

This thesis has dealt with the transformation of existing buildings and structures. This entails the question - What is our position on how to transform and preserve buildings? Throughout the project, this has been difficult to answer as it necessitates a more complex answer. Two prominent transformation- and preservation architects in Denmark are Johannes Exner and Søren Vadstrup. They are on opposite sides of the spectrum; Exner works with transforming buildings that creates contrast between new and old elements, whereas Vadstrup is conservative and will preserve the original expression at all costs.
Our position can be said to be both but at the same time it is neither, as our approach is based on the specific building and not a method where all buildings are transformed in the same way. Our approach relies on the question of What the building prefers? as it is the building that decides what happens - should it be kept in its original expression or should the new elements stand in contrast to the original. Additionally, the approach also considers the qualities of the indoor climate and the energy consumption as an important factor to ensure a well functioning building on multiple levels.
Transformation projects today, either have focus on the historic or the energy- and indoor climate aspects - there are few if any projects that focus on both. Our approach is the combination that balances the architectural field with engineering. Therefore, the answer to the question would be, that our position is neither as Exner or Vadstrup, it is our own.

The Act of Transformation

Transformation of existing buildings and structures, needs to be considered as a natural part of the architectural practice. Today, it is often a separate aspect and a subject on its own, though transformation of existing buildings will play a greater role in the industry in the coming years as the built environment increases. Cultural identity, site understanding, and material science are central aspects in any projects, including transformations. These aspects stem from existing surrounding structures and the understanding hereof. Additionally, in transformations there is also an existing volume and some original thoughts and ideas to be considered.
The act of transformation consists of different methods to address the existing structures, whereas two are chosen for this project; Subtraction and Rephasing. The methods are chosen based on the project site and the selected buildings. If it would have been any other project, it might have been one or two of the other methods; Reconstruction, Reparation, and Addition that were used. Therefore, the right methods to approach the existing building will vary from project to project, as it would differ what the buildings prefer to be transformed into. Transformation of buildings is a complex act, where the right direction and method will vary from project to project - underlining the importance of understanding the existing structures in depth.

The Collection of Empirical Knowledge

Transformation of existing buildings entails the need for original and existing drawings and illustrations, which require a preliminary work of obtaining all the relevant drawings. With older buildings the preliminary work becomes even more complex, as most of the drawing material is not digitized but stored in boxes in the local city archives. This was the case with most of the drawing material of Frederiksberg Hospital, which altogether consist of 75 boxes. As time was limited, the understanding of the buildings has relied on the few digitized plan drawings, sections and elevations that were available. This has not been ideal as every information needed has not been obtainable, and therefore some aspects have been assumed throughout the project. The assumptions are based on examples and theory on how buildings were built at that time as well as photos and other documents about the hospital.
An example is the small detail of the ventilation ducts in Building 21, these are visible on the different plan drawings and on photos of the interior, but no other information has been available. Though, it is assumed that they still can be used for extraction as well as where they start and end.
As arguments and results about the indoor climate and energy consumption rely on these assumptions it is far from ideal but it has been a way to work around the complexity of the project.

Therefore, a successful transformation entails an understanding of the existing and the potentials and limitations that are present.

Reference List

Aarsleff. 2022. ‘Renovering Af Ventilationskanaler’.

Andersen, Mette Lis, and Jes Møller. 2021. Bedre Byskik - Demokratisering, Fællesskab, Bæredygtighed. Bogværket.

Andersen, Nicolai Bo. 2015. ‘Arkitekturens Transformation - fem metoder’. Pp. 72–87 in Om bygningskulturens transformation. Gekko Publishing.

Andersen, Rasmus B. 2019. ‘Debat: Vi Må Ikke Glemme de Store Fællesskaber i Byudviklingen’. Byrummonitor. Retrieved (https://byrummonitor.dk/Debat/art7503411/Vi-må-ikke-glemme-de-store-fællesskaber-i-byudviklingen).

Baltzer, Ulrik, and Videncentret Bolius. 2021. ‘Isolering Af Kælderen - Sådan Gør Du’. Retrieved 18 April 2022 (https://www.bolius.dk/isolering-af-kaelderen-saadan-goer-du-16366).

Bloszies, Charles, and Hugh Hardy. 2011. Old Buildings, New Designs: Architectural Transformations. New York, UNITED STATES: Princeton Architectural Press.

Bolig- og Planstyrelsen. 2022 a. § 274 - § 279 Energikrav ved ombygninger og udskiftning af bygningsdele.

Bolig- og Planstyrelsen. 2022b. § 280 - § 282 Renoveringsklasser for Eksisterende Bygninger.

Braae, Ellen, and Maria Fabricius Hansen. 2007. Fortiden for tiden: Genbrugskultur og kulturgenbrug i dag. 1. edition. Arkitektskolens Forlag.

BYGGE.DK. n.d. ‘Isolering af kælder: En komplet guide (pris, regler, tips)’. Retrieved 18 April 2022 (https://www.bygge.dk/guide/isolering-af-kaelder).

Collins. 2022. ‘Belongingness Definition and Meaning | Collins English Dictionary’. Retrieved 15 February 2022 (https://www.collinsdictionary.com/dictionary/english/belongingness).

Danmarks Statistik. n.d. a. ‘Areal 1. Januar Efter Område Og Tid’. Danmarks Statistik. Retrieved (https://www.statistikbanken.dk/statbank5a/selectvarval/saveselections.asp).

Danmarks Statistik. n.d. b. ‘Folketal Den 1. i Kvartalet Efter Køn, Alder, Civilstand, Område Og Tid’. Danmarks Statistik. Retrieved (https://www.statistikbanken.dk/statbank5a/selectvarval/saveselections.asp).

Dansk Arkitektur Center. 2022. ‘Koldinghus’. Retrieved (https://dac.dk/viden/arkitektur/koldinghus/).

Energistyrelsen. 2022. ‘Byggeri og renovering’. Retrieved (https://ens.dk/ansvarsomraader/energibesparelser/byggeri-og-renovering).

Energistyrelsen. n.d. ‘Inddata for Forskellige Vinduestyper (HB2016 - Historisk)’. Håndbog for Energikonsulenter. Retrieved (https://hbemo.dk/haandbog-for-energikonsulenter-hb2016-2018/vejledende-tekniske-anvisninger-i-tabelform/vinduer-og-yderdoere/inddata-for-forskellige-vinduestyper).

Energistyrelsen, and Videnscenter for Energibesparelser i Bygninger. 2015. ‘Isolering af kældervæg, udefra’. Energistyrelsen. Retrieved 15 May 2022 (https://sparenergi.dk/forbruger/vaerktoejer/energiloesninger/isolering-af-kaeldervaeg-udefra).

Frederiksberg Kommune. 2017. ‘Arkitekturpolitik for Frederiksberg’.

Frederiksberg Kommune. 2019 a. ‘Frederiksberg Hospital - Hele Byens Nye Kvarter’.

Frederiksberg Kommune. 2019 b. ‘Hele Byens Nye Kvarter! Frederiksberg Hospital. Idékatalog’.

Frederiksberg Kommune. 2021 a. ‘Kommuneplan 2021: Frederiksbergs Plan for En Bæredygtig Byudvikling - Hovedstruktur’.

Frederiksberg Kommune. 2021 b. ‘Kommuneplan 2021: Frederiksbergs Plan for En Bæredygtig Byudvikling - Rammer Og Retningslinjer’.

Frederiksberg Kommune. n. d. a. ‘Frederiksberg Hospital - Hele Byens Nye Kvarter!’ Frederiksberg. Retrieved (https://www.frederiksberg.dk/frederiksberghospital).

Frederiksberg Kommune. n.d. b ‘Bilag 13 - Beskrivelse Af Bygninger’.

Hansen, Søren Høgh. 2003. ‘Frederiksberg Hospital 100 År’.
Harlang, Christoffer. 2011. ‘1+1>2’. in Transformation. Arkitektens Forlag.

Jacobs, Jane. 1961. The Death and Life of Great American Citiies. Vintage books, december 1992. Random house.

Jensen, N. F., C. Rode, and E. B. Møller. 2021. ‘Hygrothermal Assessment of Internally Insulated Historic Solid Masonry Walls with Focus on the Thermal Bridge Due to Internal Partition Walls: 8th International Building Physics Conference, IBPC 2021’. Journal of Physics: Conference Series (Online) 2069(1). doi: 10.1088/1742-6596/2069/1/012079.

Jensen, Nickolaj Feldt, Søren Peter Bjarløv, Carsten Rode, Birgitte Andersen, and Eva B. Møller. 2021. ‘Hygrothermal Performance of Six Insulation Systems for Internal Retrofitting Solid Masonry Walls’. Journal of Building Physics 44(6):539–73. doi: 10.1177/1744259120988745.

Johansson, Pär. 2014. ‘Building Retrofit Using Vacuum Insulation Panels: Hygrothermal Performance and Durability’.

Johansson, Pär, Stig Geving, Carl-Eric Hagentoft, Bjørn Petter Jelle, Egil Rognvik, Angela Sasic Kalagasidis, and Berit Time. 2014. ‘Interior Insulation Retrofit of a Historical Brick Wall Using Vacuum Insulation Panels: Hygrothermal Numerical Simulations and Laboratory Investigations’. Building and Environment 79:31–45. doi: 10.1016/j.buildenv.2014.04.014.

Kirch, Julia, and Uta Pottgiesser. 2010. ‘Tempered Transparency - Renovating Modern Movement Facades in Line with Landmark Preservation Principles’. Pp. 119–31 in Old & New - Design Manual for Revitalizing Existing Buildings. Germany: Birkhäuser GmbH.

Klima-, Energi- og Forsyningsministeriet. 2021. 'Regeringen fremskynder klimaindsatsen med køreplan til ny 2025-deadline'. Retrieved (https://kefm.dk/aktuelt/nyheder/2021/sep/regeringen-fremskynder-klimaindsatsen-med-koereplan-til-ny-2025-deadline).

Knudstrup, Mary-Ann. 2004. 'Integrated Design Process in Problem-Based Learning'.

Noldus, Vera. 2014. Grøn Genanvendelse. CONCITO.
Pålsson, Karsten. 2016. Humane Byer: Byrum Og Bebyggelse. Forlaget Bogværket.

PAROC DANMARK. 2013. 'Byg Sådan 5 Merisolering Af Bjælkelag over Krybekælder'.

Preservation, Thompson M. Mayes, Vice President and Senior Counsel, National Trust for Historic. 2018. Why Old Places Matter: How Historic Places Affect Our Identity and Well-Being. Rowman & Littlefield.

Raadvad-centret. 2002. 'Vinduers Varmetab: Energi-, Kondens- Og Lydforhold for Nye Og Gamle Vinduer i Ældre Bygninger Før 1950'.

Realdania By & Byg A/S, and Dorthe Bendtsen. 2021. Energiforbedring i Historiske Bygninger - Erfaringer Og Læringer Fra Realdania By & Byg.

Region Hovedstaden, and Frederiksberg Hospital. n.d. 'Kort over Frederiksberg Hospital'. Retrieved 3 March 2022 (https://www.frederiksberghospital.dk/ckff/Kontaktoplysninger/Documents/kort-over-frederiksberg-hospital.pdf).

Rexroth, Susanne. 2010. 'Top Marks for Energy Conservation - Refurbishing School and University Buildings'. Pp. 101–7 in Old & New - Design Manual for Revitalizing Existing Buildings. Germany: Birkhäuser GmbH.

Vadstrup, Søren. 2014. Byhuset - historie, bevaring, istandsættelse. 1. edition. Lindhardt og Ringhof.

Videnscenter for Energibesparelser i Bygninger. 2021. 'Indvendig Efterisolering Af Kældervæg'. Retrieved 18 April 2022 (https://byggeriogenergi.dk/media/1671/indvendig-efterisolering-af-k-lderv-g-ok.pdf).

Videnscenter for Energibesparelser i Bygninger. 2021. 'Indvendig Efterisolering Af Kældervæg'. Retrieved 18 April 2022 (https://byggeriogenergi.dk/media/1671/indvendig-efterisolering-af-k-lderv-g-ok.pdf).

Videncenter for Energibesparelser i Bygninger. 2021 a. 'Dæk over krybekælder ændres til nyt terrændæk'. Dæk over krybekælder ændres til nyt terrændæk. Retrieved 18 April 2022 (https://byggeriogenergi.dk/enfamiliehuse/klimaskaerm/gulv-terraendaek-kaelder-og-sokkel/daek-over-krybekaelder-aendres-til-nyt-terraendaek/).

Vinterakadami. 2016. 'Transformation er vigtigt for bæredygtighed i byggeriet'. Retrieved (http://vinterakademi.dk/transformation-af-byggeriet-vinterakademiet/).

Illustration List

Illustration 5: Developed with inspiration retrieved from: https://www.google.dk/maps/place/Frederiksberg+Hospital/@55.6853698,12.5230154,17z/data=!3m1!4b1!4m5!3m4!1s0x465253b86bad535f:0xd743632447e892ff!8m2!3d55.6853698!4d12.5252041?hl=da&authuser=0

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Illustration 9: Borrowed picture. Photo: Søren Rud/Life Exhibitions. Retrieved from: (https://naturibyen.com/steder/ostergro/).

Litterature List

Andersen, Nicolai Bo. 2015. 'Transformation og restaurering'. Pp. 30–39 in Om bygningskulturens transformation. Gekko Publishing.

Bloszies, Charles, and Hugh Hardy. 2011. Old Buildings, New Designs: Architectural Transformations. New York, UNITED STATES: Princeton Architectural Press.

Byggeskadefonden, and Jens V. Nielsen. 2020. GUIDE TIL KVALITET VED BYGNINGSRENOVERING.

Cabeza, Luisa F., Alvaro de Gracia, and Anna Laura Pisello. 2018. 'Integration of Renewable Technologies in Historical and Heritage Buildings: A Review'. Energy and Buildings 177:96–111. doi: 10.1016/j.enbuild.2018.07.058.

Collins. 2022. 'Belongingness Definition and Meaning | Collins English Dictionary'. Retrieved 15 February 2022 (https://www.collinsdictionary.com/dictionary/english/belongingness).

Department of the Environment and Heritage. 2004. Adaptive Reuse - Preserving Our Past, Building Our Future. Pirion.

Energistyrelsen. 2019. 'Når du renoverer gulv eller gulvkonstruktion'. Energistyrelsen. Retrieved 11 April 2022 (https://sparenergi.dk/forbruger/boligen/bygningsreglementets-energikrav/renovering-gulv).

Fredede Bygninger, Center for Kulturarv i Slots- og Kulturstyrelsen. 2020. 'GULVE OG DÆKKONSTRUKTIONER Faglige Retningslinjer for Byggesager Om Restaurering Og Udskiftning Af Gulve Og Dækkonstruktioner'. Retrieved 21 April 2022 (https://slks.dk/fileadmin/user_upload/SLKS/Omraader/Kulturarv/Bygningsfredning/Faglige_retningslinjer/10_Indvendige_konstruktioner_og_beklaedninger/10.1_Gulve_og_daekkonstruktioner.pdf).

Grundejernes Investeringsfond, and - Bedre Boliger og Realdania. n.d. 'Danske Bygningsmodeller, Fundament'. Retrieved 6 April 2022 (https://www.danskebygningsmodeller.dk/pages/type-2-original-fundament.html).

Hansen, Tessa Kvist, Nickolaj Feldt Jensen, Britt Haker Høegh, and Eva B. Møller. n.d. 'Indvendig efterisolering af murværk | BYG-ERFA'. Retrieved 6 April 2022 (https://byg-erfa.dk/indvendig-efterisolering-af-murvaerk).

Jensen, Caroline Drost. 2020. Weather Statistics for Danish Airports 2009-2018 DMI Report 20-17. Danish Meteorological Institute.

Jensen, N. F., C. Rode, and E. B. Møller. 2021a. 'Hygrothermal Assessment of Internally Insulated Historic Solid Masonry Walls with Focus on the Thermal Bridge Due to Internal Partition Walls'. Journal of Physics: Conference Series 2069(1):012079. doi: 10.1088/1742-6596/2069/1/012079.

Jensen, N. F., C. Rode, and E. B. Møller. 2021b. 'Hygrothermal Assessment of Internally Insulated Historic Solid Masonry Walls with Focus on the Thermal Bridge Due to Internal Partition Walls: 8th International Building Physics Conference, IBPC 2021'. Journal of Physics: Conference Series (Online) 2069(1). doi: 10.1088/1742-6596/2069/1/012079.

Jensen, Nickolaj Feldt, and Søren Peter Bjarløv. 2019. 'INDVENDIG ISOLERING AF MUREDE FACADEVÆGGE - DTU Byg'. https://www.byg.dtu.dk. Retrieved 31 March 2022 (https://www.byg.dtu.dk/forskning/byganalyse/dtu-byganalyse-nr-2).

Jensen, Nickolaj Feldt, Søren Peter Bjarløv, Carsten Rode, Birgitte Andersen, and Eva B. Møller. 2021a. 'Hygrothermal Performance of Six Insulation Systems for Internal Retrofitting Solid Masonry Walls'. Journal of Building Physics 44(6):539–73. doi: 10.1177/1744259120988745.

Jensen, Nickolaj Feldt, Søren Peter Bjarløv, Carsten Rode, Birgitte Andersen, and Eva B. Møller. 2021b. 'Supplementary Data for "Hygrothermal Performance of Six Insulation Systems for Internal Retrofitting Solid Masonry Walls"'.

Krieger, Martin H., Moo-Ryong Ra, Jeongyeup Paek, Ramesh Govindan, and Jennifer Evans-Cowley. 2010. 'Urban Tomography'. Journal of Urban Technology 17(2):21–36. doi: 10.1080/10630732.2010.515087.

Kulturstyrelsen, and Kulturministeriet. 2012. 'INFORMATION OM BYGNINGSBEVARING - Tagpap'.

LCA Center. 2022. 'Hvad er LCA'. Retrieved (https://lca-center.dk/hvad-er-lca/).

Matthes, Erich Hatala. 2016. 'The Ethics of Historic Preservation'. Philosophy Compass 11(12):786–94. doi: 10.1111/phc3.12379.

MEMBRAN-ERFA, Fonden BYG-ERFA. n.d. 'Kælderydervæg Med Grundmursplade Og EPS- Eller XPS-Plade | MEMBRAN-ERFA'. Retrieved 15 May 2022 (https://membran-erfa.dk/Isolering-af-kaelderydervaeg-med-EPS-og-eller-XPS-draenplade-og-grundmursplade).

Osborne, Christopher M. 2021. 'How to Identify Baroque Architecture'. WikiHow. Retrieved 4 March 2022 (https://www.wikihow.com/Identify-Baroque-Architecture).

PAROC DANMARK. 2013. 'Byg Sådan 5 Merisolering Af Bjælkelag over Krybekælder'.

Patursso, Tue. n.d. 'Generelt Om Efterisolering'. Bolius.Dk. Retrieved 14 April 2022 (https://www.bolius.dk/generelt-om-efterisolering-17526).

Thompson, M. Mayes, Vice President and Senior Counsel, National Trust for Historic. 2018. Why Old Places Matter: How Historic Places Affect Our Identity and Well-Being. Rowman & Littlefield.

Realdania By & Byg A/S, and Dorthe Bendtsen. 2021. Energiforbedring i Historiske Bygninger - Erfaringer Og Læringer Fra Realdania By & Byg.

Realdania, and Grundejernes Investeringsfond. n.d. 'Kap. 3 Funderingsmetoder (Foundation Methods)'. Retrieved 6 April 2022 (https://danskbyggeskik.dk/bygningsdel/fundamenter/funderingsmetoder).

ROCKWOOL Danmark A/S. 2022a. 'Energirenovering og efterisolering - Efterisolering af kælder'. Retrieved 15 May

2022 (https://info.rockwool.dk/da/den-lille-lune/energirenovering-og-efterisolering/efterisolering-af-kaelder/).

ROCKWOOL Danmark A/S. 2022b. ‘Energirenovering og efterisolering - Efterisolering af ydervæg’. Retrieved 31 March 2022 (https://info.rockwool.dk/da/den-lille-lune/energirenovering-og-efterisolering/efterisolering-af-ydervaeg/).

SKANACID. 2017. ‘Vacupor - Vakuum isolering’. Skanacid A/S. Retrieved 6 April 2022 (https://www.skanacid.dk/isoleringsteknik-markedets-stoerste-udvalg-af-specialisolering/produkter/vacupor-vakuum-isolering/).

Slots- og Kulturstyrelsen, and Kulturministeriet. n.d. ‘Fredede Og Bevaringsværdige Bygninger’. Retrieved 16 February 2022 (https://www.kulturarv.dk/fbb/index.htm).

Teknologisk Institut. n.d. ‘Mur & Tag Densitet’. Mur & Tag. Retrieved 31 March 2022 (https://www.mur-tag.dk/materialer/byggesten-mursten-og-blokke/egenskaber-byggesten/densitet/).

Videncenter for Energibesparelser i Bygninger. 2021. ‘Efterisolering Af Gulv over Uopvarmet Kælder’. Retrieved 11 April 2022 (https://byggeriogenergi.dk/media/1661/efterisolering-af-gulv-over-uopvarmet-k-lder_ok.pdf).

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08. CHAPTER

Voluptae volorep turem. At eatemodis eostrum repudam, eos esequiscitis aligend ipiende sendis mo conet, is as con pliqui dolor solorpos as consediam et fuga. Et quassit quos eos qui te eum quas saecabo reptas aut ratur milisqu oditate ctecea delestiate sent aliqui dolupti con reperume illam soluptatis di ni soluptatius ea corrorem. Ibus reiunt et ma nis rerepud antio. Ceat optaectas esto eius et abo. Dem est harissinum lab in core nos ma dunt reperero enimo

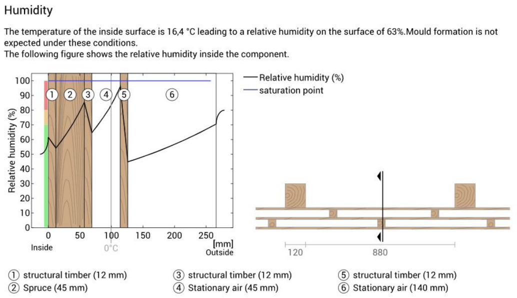
APPENDIX

Appendix 01

Humidity Profiles

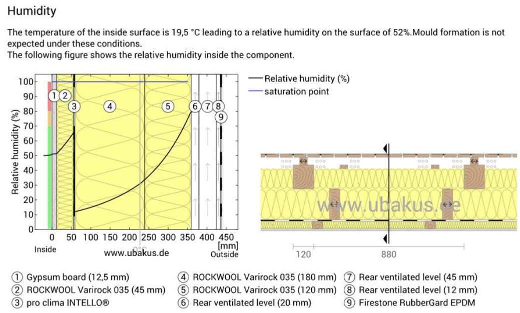
Roof Interventions

Original



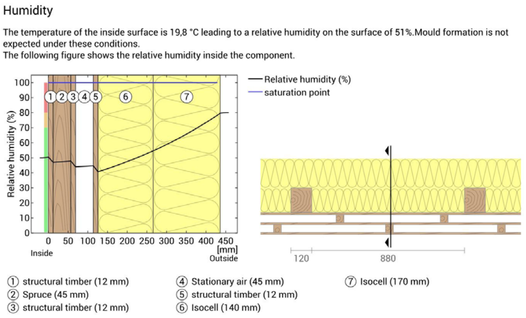
Ill. 2.

Medium Intervention



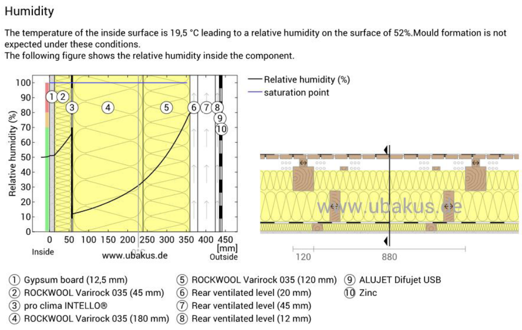
Ill. 4.

Careful Intervention



Ill. 3.

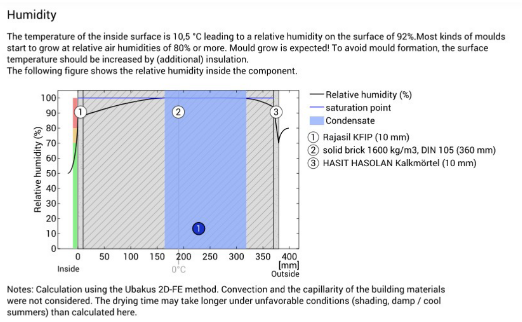
Radical Intervention



Ill. 5.

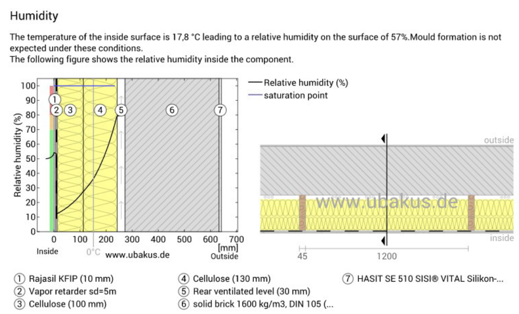
Wall Interventions

Original



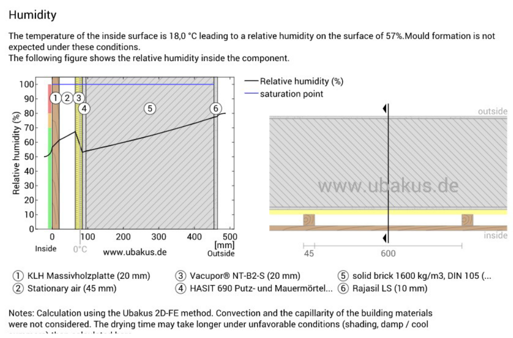
Ill. 6.

Medium Intervention



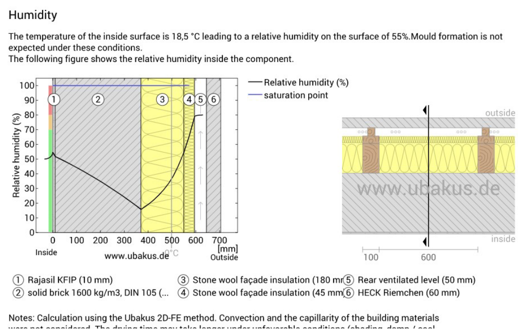
Ill. 7.

Careful Intervention



Ill. 8.

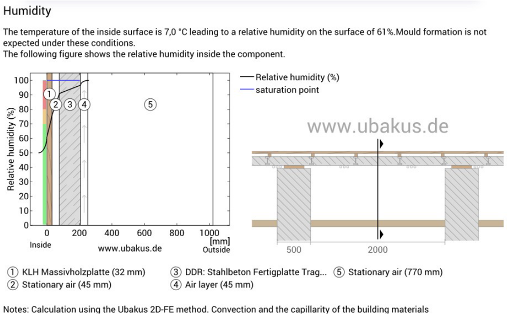
Radical Intervention



Ill. 9.

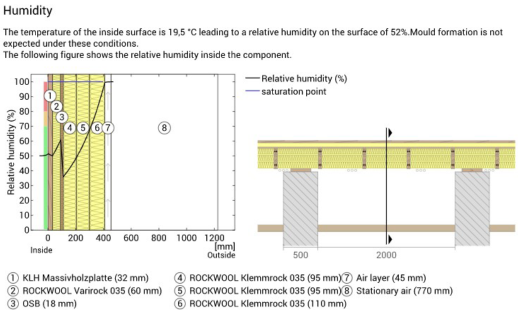
Basement Interventions

Original



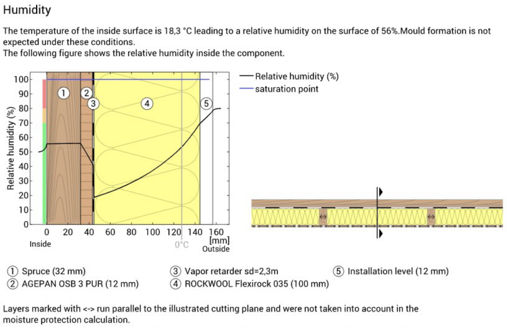
Ill. 10.

Medium Intervention



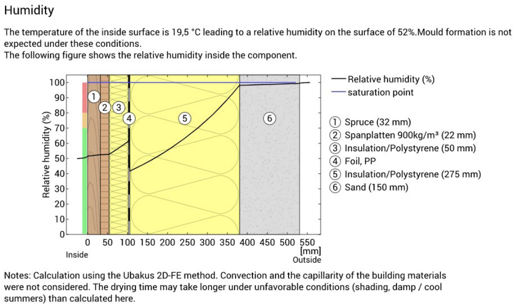
Ill. 12.

Careful Intervention



Ill. 11.

Radical Intervention



Ill. 13.

Appendix 02

U-values and Heat Loss

The calculations of u-values and heat loss are calculated according to DS418:2011. An example of the different calculations are shown for Careful intervention - Storm window.

The calculations of thermal transmittance is made according to the following equation

$$U_W = \frac{A_g * U_g + A_f * U_f + l_g * \Psi_g}{A_g + A_f}$$

U_W = *thermal transmittance of window [W/m²*K]*
U_g = *thermal transmittance of glass [W/m²*K] assumed (Patursson et Blomsterberg 2022)*
U_f = *thermal transmittance of frame [W/m²*K] assumed (DS418:2011)*
Ψ_g = *thermal transmittance of the edge zone (between glass and frame) [W/m*K] (DS 418:2011)*
A_g = *area of glass [m²]*
A_f = *area of frame/mullions [m²]*
l_g = *circumference of glass [m]*

The thermal transmittance for the exterior/original window (sealed double pane)

$$U_{Wex} = \frac{2.2*3+1.1*2+12.4*0.05}{2.2+1.1} = 2.85\ W/m^2*K$$

The thermal transmittance for the interior/storm window (two layer energy glass)

$$U_{Win} = \frac{2.2*1.1+1.1*2+12.4*0.05}{2.2+1.1} = 1.59\ W/m^2*K$$

The total thermal transmittance is calculated with the following equation. For the other options, only one calculation for the thermal transmittance is made.

$$U_{Wt} = \frac{1}{(\frac{1}{U_{Wex}})+(\frac{1}{U_{Win}})} = 1.1\ W/m^2*K$$

The heat loss through the window is calculated through the following equation

$$\Phi_t = U_{Wt} * A_W * (\Theta_{in} - \Theta_{ex})$$

Φ_t = *heat loss [W]*

U_W = *thermal transmittance of window [W/m²*K]*

A_W = *area of window [m²]*

Θ_{in} = *interior design temperature [C°] (DS 418:2011)*

Θ_{ex} = *exterior design temperature [C°] (DS 418:2011)*

The heat loss through the windows

$$\Phi_t = 1.1 * 3.3 * (20 - (-12)) = 105.8\ W$$

Appendix 03

Atmospheric Comfort

The atmospheric comfort is calculated according to DS447:2013

The calculations are done in the following order and lastly a sheet shows all the calculations made for the different rooms. The calculation example is here based on 'Dwelling 1'. The calculation is done for category II where the percentage of dissatisfied maximum can be 20 % (Dansk Standard. 2013).

Emission from people and building

~ Equation from DS447, page 53 (Dansk Standard. 2013)

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

q_{tot} : *Airflow [l/s]*
n : *Number of people*
q_p : *Necessary outdoor air supplied per person [l/s]*
A : *Area [m^2]*
q_b : *Necessary outdoor air supplied to consider emission from building [l/s per m^2]*

$$q_{tot} = 2 \cdot 7.0 + 48 \cdot 0.7$$
$$q_{tot} = 47.6 \ \frac{l}{s}$$

The air change is calculated;

$$n = \frac{q_{tot} \cdot 3.6}{V_R}$$

n : *Air change [h^{-1}]*
q_{tot} : *Airflow [l/s]*
3.6 : *Value to convert the units*
V_R : *Volume [m^3]*

$$n = \frac{47.6 \cdot 3.6}{187.2}$$
$$n = 0.91 \ h^{-1}$$

CO2 concentration

~ Equation from SBi 202, page 53 (Statens Byggeinstitut. 2002)

$$q_{tot} = n \cdot V_R = \frac{q_{CO2}}{c - c_i} \cdot \frac{1}{3600}$$

q_{tot} : *Airflow [l/s]*
$\frac{1}{3600}$: *Value to convert from l/h to l/s [m^3/h]*
q_{CO2} : *Pollution load [l/h]*
M : *Level of activity [Met]*
c : *Concentration of pollution in the room ~ maximum 1000 ppm [1000 ppm $\cdot 10^{-6}$]*
c_i : *Concentration of pollution in the air ~ maximum 350 ppm [350 ppm $\cdot 10^{-6}$]*

$$q_{CO2} = 17 \cdot M$$

$$q_{CO2} = 17 \cdot M \cdot \text{number of people}$$
$$q_{CO2} = 17 \cdot 1.2 \cdot 2$$
$$q_{CO2} = 40.8$$

$$q_{tot} = \frac{40.8}{0.0007 - 0.00035} \cdot \frac{1}{3600}$$
$$q_{tot} = 32.38 \ \frac{l}{s}$$

The air change is calculated;

$$n = \frac{q_{tot} \cdot 3.6}{V_R}$$

n : *Air change [h^{-1}]*
q_{tot} : *Airflow [l/s]*
3.6 : *Value to convert the units*
V_R : *Volume [m^3]*

$$n = \frac{32.38 \cdot 3.6}{187.2}$$
$$n = 0.62 \ h^{-1}$$

Experienced air quality

$$q_{tot} = 10 \cdot \frac{q_{olf}}{c - c_i}$$

q_{tot} : *Airflow [l/s]*
q_{olf} : *Pollution load from persons and building ~ 1 olf per. person and 0,4 olf from the building*
c : *Experienced air quality [1.4 decipol]*
c_i : *Concentration of pollution in the air ~ maximum 350 ppm [350 ppm $\cdot 10^{-6}$]*
10 : *Value to convert the unit*

$$q_{olf} = \text{Number of persons} \cdot 1 + \text{area} \cdot 0.4$$

$$q_{olf} = 2 \cdot 1 + 48 \cdot 0.4$$
$$q_{olf} = 21.2$$

$$q_{tot} = 10 \cdot \frac{21.2}{1.4 - 0.00035}$$
$$q_{tot} = 151.46 \ \frac{l}{s}$$

The air change is calculated;

$$n = \frac{q_{tot} \cdot 3.6}{V_R}$$

n : *Air change* $[h^{-1}]$
q_{tot} : *Airflow [l/s]*
3.6 : *Value to convert the units*
V_R : *Volume* $[m^3]$

$$n = \frac{151.46 \cdot 3.6}{187.2}$$
$$n = 2.91\ h^{-1}$$

The highest air change value will in the further calculations be the dimensioning to make sure the right ventilation of the room.

Flow rate

$$V_L = \frac{q}{(c_0 - c_i)} \cdot 3.6$$

V_L : *Flow rate* $[m^3/h]$
q : *Sensory pollution load*
c_0 : *Experienced air quality [1.4 decipol]*
c_i : *Concentration of pollution in the air ~ maximum 350 ppm* $[350\ ppm \cdot 10^{-6}]$
10 : *Value to convert units*

$$V_L = 10 \cdot \frac{21.2}{1.4 - 0.00035} \cdot 3.6$$
$$V_L = 545.27\ \frac{m^3}{h}$$

Air change outside service life

$$n_{ub} = 0.5 \cdot 0.1 \cdot n_b$$

n_{ub} : Air change outside service life $[h^{-1}]$
n_b : Air change when in service $[h^{-1}]$

$$n_{ub} = 0.5 \cdot 0.1 \cdot 2.91$$
$$n_{ub} = 0.145\ h^{-1}$$

Concentration of pollution

$$c = 10 \cdot \frac{q_{olf}}{n \cdot V_R} \cdot \left(1 - e^{-n \cdot \tau}\right) + (c_0 - c_i) \cdot e^{-n \cdot \tau} + c_i$$

c : *Experienced air quality*
q_{olf} : *Pollution load from persons and building ~ 1 olf per. person and 0,4 olf from the building*
n : *Air change outside the service life* $[h^{-1}]$
V_R : *Volume* $[m^3]$
c_i : *Concentration of pollution in the air ~ maximum 350 ppm* $[350\ ppm \cdot 10^{-6}]$
c_0 : *Initial concentration [1.4 decipol]*
τ : *Hours outside service life [hours]*

$$c = 10 \cdot \left(\frac{21.2}{187.2 \cdot 2.91}\right) \cdot \left(1 - e^{-2.91 \cdot 9}\right) + (1.4 - 0.00035) \cdot e^{-2.91 \cdot 9} + 0.00035$$
$$c = 0.41\ decipol$$

The percentages of dissatisfied is calculated as;

$$PD = 395 \cdot e^{-3.25 \cdot c^{-0.25}}$$

$$PD = 395 \cdot e^{-3.25 \cdot 0.41^{-0.25}}$$
$$PD = 6.8\ \%$$

The percentage of dissatisfied is thereby under the maximum at 20%.

The following pages will showcase all the calculations done for the different rooms in the selected buildings.

Dwelling - Calculations

Emission

Rooms	People	Area [m2]	Room height [m]	Volume [m3]	Necessary outdoor air supplied per person [l/s]	Necessary outdoor air supplied to consider emission from building [l/s per m2]	Airflow [l/s]	Airchange [h-1]
Dwelling 1	2	48	3,9	187,2	7,00	0,7	47,6	0,92
Dwelling 2	3	88	3,9	343,2	7,00	0,7	82,6	0,87

CO2 concentration

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Emission concentration, room [ppm]	Emission concentration, air [ppm]	Level of activity [Met]	Pollution load [l/h]	Airflow [l/s]	Airchange [h-1]
Dwelling 1	2	48	3,9	187,2	0,0007	0,00035	1,2	40,8	32,38	0,62
Dwelling 2	3	88	3,9	343,2	0,0007	0,00035	1,2	61,2	48,57	0,51

Experienced air quality

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Pollution from people: 1 olf and building: 0,4 olf	Pollution from air [ppm]	Experienced air quality [decipol]	Factor	Pollution from people and building [olf]	Airflow [l/s]	Airchange [h-1]
Dwelling 1	2	48	3,9	187,2	0,4	0,00035	1,4	10	21,2	151,43	2,912
Dwelling 2	3	88	3,9	343,2	0,4	0,00035	1,4	10	38,2	272,86	2,862

Flow rate

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Experienced air quality [decipol]	Pollution from air [ppm]	Pollution from people and building [olf]	Factor	Flow rate [m3/h]	Flow rate [m3/s]
Dwelling 1	2	48	3,9	187,2	1,4	350	21,2	10	545,28	0,151
Dwelling 2	3	88	3,9	343,2	1,4	350	38,2	10	982,53	0,273

Air change outside service life

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Airchange [h-1]	Airchange (when not used) [h-1]
Dwelling 1	2	48	3,9	187,2	2,91	0,15
Dwelling 2	3	88	3,9	343,2	2,86	0,14

Concentration of pollution

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Experienced air quality [decipol]	Pollution from air [ppm]	Time [t]	Airchange [h-1]	Pollution from people and building [olf]	Experienced air quality	PD [%]
Dwelling 1	2	48	3,9	187,2	1,4	350	9	2,91	21,2	0,38	6,29
Dwelling 2	3	88	3,7	325,6	1,4	350	9	2,86	38,2	0,71	11,45

Trade & Culture - Calculations

Emission

Rooms	People	Area [m2]	Room height [m]	Volume [m3]	Necessary outdoor air supplied per person [l/s]	Necessary outdoor air supplied to consider emission from building [l/s per m2]	Airflow [l/s]	Airchange [h-1]
Trade	20	129	3,7	477,3	7,00	0,7	230,3	1,74
Culture	40	450	3,7	1665	7,00	0,7	595	1,29

CO2 concentration

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Emission concentration, room [ppm]	Emission concentration, air [ppm]	Level of activity [Met]	Pollution load [l/h]	Airflow [l/s]	Airchange [h-1]
Trade	20	129	3,7	477,3	0,0007	0,00035	1,2	408	323,81	2,44
Culture	40	450	3,7	1665	0,0007	0,00035	1,6	1088	863,49	1,87

Experienced air quality

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Pollution from people: 1 olf and building: 0,4 olf	Pollution from air [ppm]	Experienced air quality [decipol]	Factor	Pollution from people and building [olf]	Airflow [l/s]	Airchange [h-1]
Trade	20	129	3,7	477,3	0,4	0,00035	1,4	10	71,6	511,56	3,86
Culture	40	450	3,7	1665	0,4	0,00035	1,4	10	220	1571,82	3,40

Flow rate

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Experienced air quality [decipol]	Pollution from air [ppm]	Pollution from people and building [olf]	Factor	Flow rate [m3/h]	Flow rate [m3/s]
Trade	20	129	3,7	477,3	1,4	0,00035	71,6	10	1841,60	0,51155646
Culture	40	450	3,7	1665	1,4	0,00035	220	10	5658,56	1,57182153

Air change outside service life

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Airchange [h-1]	Airchange (when not used) [h-1]
Trade	20	129	3,7	477,3	3,86	0,19
Culture	40	450	3,7	1665	3,40	0,17

Concentration of pollution

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Experienced air quality [decipol]	Pollution from air [ppm]	Time [t]	Airchange [h-1]	Pollution from people and building [olf]	Experienced air quality	PD [%]
Trade	20	129	3,7	477,3	1,4	350	15,5	3,86	71,6	0,38	6,29
Culture	40	450	3,7	1665	1,4	350	14	3,40	220	0,38	6,29

Office - Calculations

Emission

Rooms	People	Room area [m2]	Room height [m]	Volume [m3]	Necessary outdoor air supplied per person [l/s]	Necessary outdoor air supplied to consider emission from building [l/s per m2]	Airflow [l/s]	Airchange [h-1]
Meeting room	12	18	3,9	70,2	7,00	0,7	96,6	4,95
Landscape office	22	170	3,9	663	7,00	0,7	273	1,48

CO2 concentration

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Emission concentration, room [ppm]	Emission concentration, air [ppm]	Level of activity [Met]	Pollution load [l/h]	Airflow [l/s]	Airchange [h-1]
Meeting room	12	18	3,9	70,2	0,0007	0,00035	1,2	244,8	194,3	9,96
Landscape office	22	170	3,9	663	0,0007	0,00035	1,2	448,8	356,19	1,93

Experienced air quality

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Pollution from people: 1 olf and building: 0,4 olf	Pollution from air [ppm]	Experienced air quality [decipol]	Factor	Pollution from people and building [olf]	Airflow [l/s]	Airchange [h-1]
Meeting room	12	18	3,9	70,2	0,4	350	1,4	10	19,2	137,18	7,03
Landscape office	22	400	3,9	1560	0,4	350	1,4	10	182	1300,33	3,00

Flow rate

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Experienced air quality [decipol]	Pollution from air [ppm]	Pollution from people and building [olf]	Factor	Flow rate [m3/h]	Flow rate [m3/s]
Meeting room	12	18	3,9	70,2	1,4	350	19,2	10	493,84	0,14
Landscape office	22	170	3,9	663	1,4	350	182	10	4681,17	1,30

Air change outside service life

Room	People	Room area [m2]	Room height [m]	Volume [m3]	Airchange [h-1]	Airchange (when not used) [h-1]
Meeting room	12	18	3,9	70,2	7,03	0,35
Landscape office	22	170	3,9	663	3,00	0,15

Concentration of pollution

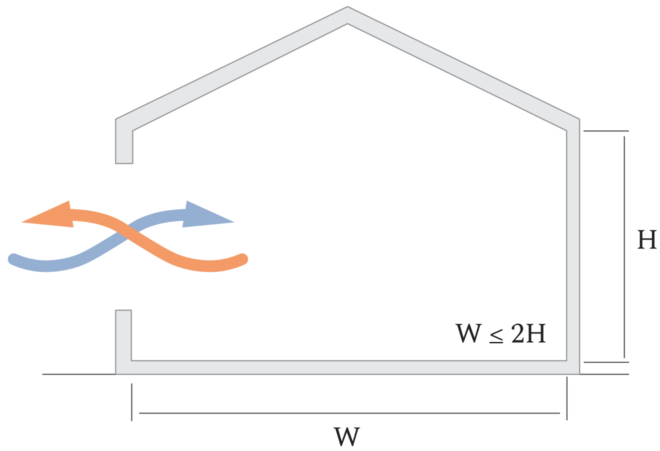
Room	People	Room area [m2]	Room height [m]	Volume [m3]	Experienced air quality [decipol]	Pollution from air [ppm]	Time [t]	Airchange [h-1]	Pollution from people and building [olf]	Experienced air quality	PD [%]
Meeting room	12	18	3,9	70,2	1,4	350	16	7,03	19,2	0,38	6,29
Landscape office	22	400	3,9	1560	1,4	350	16	3,00	182	0,38	6,29

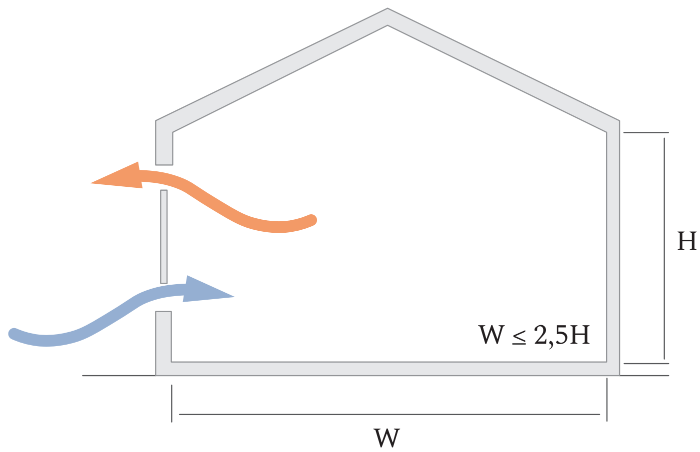
Appendix 04

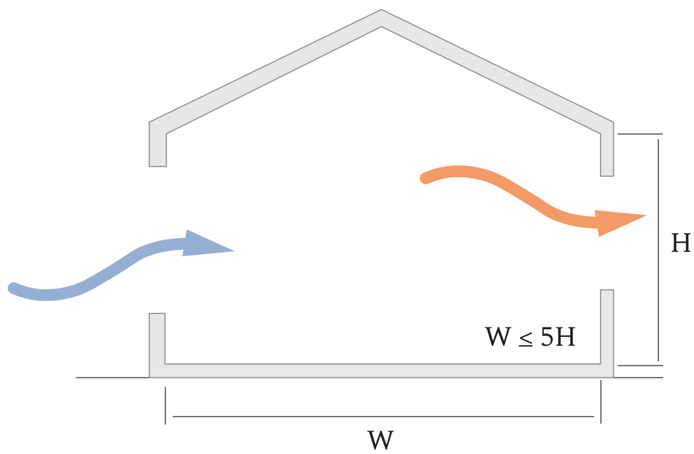
Ventilation

The ventilation is decided to be natural ventilation and thermal buoyancy and is calculated by theoretical rule of thumbs according to SBi 202: Naturlig ventilation i erhvervsbygninger and SBi 301: Dimensionering af naturlig ventilation ved termisk opdrift (Statens Byggeinstitut. 2002 & Statens Byggeinstitut & Andersen. 1998)

Natural ventilation
The theoretical principles for natural ventilation is seen in the following illustrations and the rooms, from the atmospheric comfort, are tested according to single-sided ventilation with one or two openings and cross ventilation.







01: Single-sided ventilation with one opening

02: Single-sided ventilation with two openings

03: Cross ventilation

Dwelling 1

Single sided ventilation | Single opening				
Room	Room height [m]	Room width [m]	Factor	W <
Bedroom	3,9	3,3	2	7,8
Living room	3,9	5,5	2	7,8

Single sided ventilation | Double opening				
Room	Room height [m]	Room width [m]	Factor	W <
Bedroom	3,9	3,3	2,5	9,75
Living room	3,9	5,5	2,5	9,75

Cross ventilation				
Room	Room height [m]	Room width [m]	Factor	W <
Bedroom	3,9	3,3	5	19,5
Living room	3,9	5,5	5	19,5

Dwelling 2

Single sided ventilation | Single opening				
Room	Room height [m]	Room width [m]	Factor	W <
Bedroom	3,9	3,1	2	7,8
Living room	3,9	10,1	2	7,8

Single sided ventilation | Double opening				
Room	Room height [m]	Room width [m]	Factor	W <
Bedroom	3,9	3,1	2,5	9,75
Living room	3,9	10,1	2,5	9,75

Cross ventilation				
Room	Room height [m]	Room width [m]	Factor	W <
Bedroom	3,9	3,1	5	19,5
Living room	3,9	10,1	5	19,5

Trade

Single sided ventilation | Single opening				
Room	Room height [m]	Room width [m]	Factor	W <
Private section	3,7	2,8	2	7,4
Actual shop	3,7	12	2	7,4

Single sided ventilation | Double opening				
Room	Room height [m]	Room width [m]	Factor	W <
Private section	3,7	2,8	2,5	9,25
Actual shop	3,7	12	2,5	9,25

Cross ventilation				
Room	Room height [m]	Room width [m]	Factor	W <
Private section	3,7	2,8	5	18,5
Actual shop	3,7	12	5	18,5

Office

Single sided ventilation | Single opening				
Room	Room height [m]	Room width [m]	Factor	W <
Meeting room	3,9	2,9	2	7,8
Landscape office	3,9	8	2	7,8

Single sided ventilation | Double opening				
Room	Room height [m]	Room width [m]	Factor	W <
Meeting room	3,7	2,9	2,5	9,25
Landscape office	3,7	8	2,5	9,25

Cross ventilation				
Room	Room height [m]	Room width [m]	Factor	W <
Meeting room	3,7	2,9	5	18,5
Landscape office	3,7	8	5	18,5

Culture

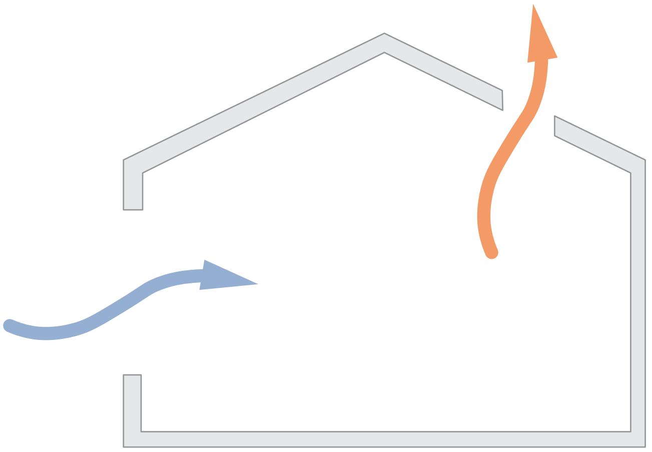
Single sided ventilation | Single opening				
Room	Room height [m]	Room width [m]	Factor	W <
Library / other function	3,7	13	2	7,4
Seperate room	3,7	5,1	2	7,4

Single sided ventilation | Double opening				
Room	Room height [m]	Room width [m]	Factor	W <
Library / other function	3,7	13	2,5	9,25
Seperate room	3,7	5,1	2,5	9,25

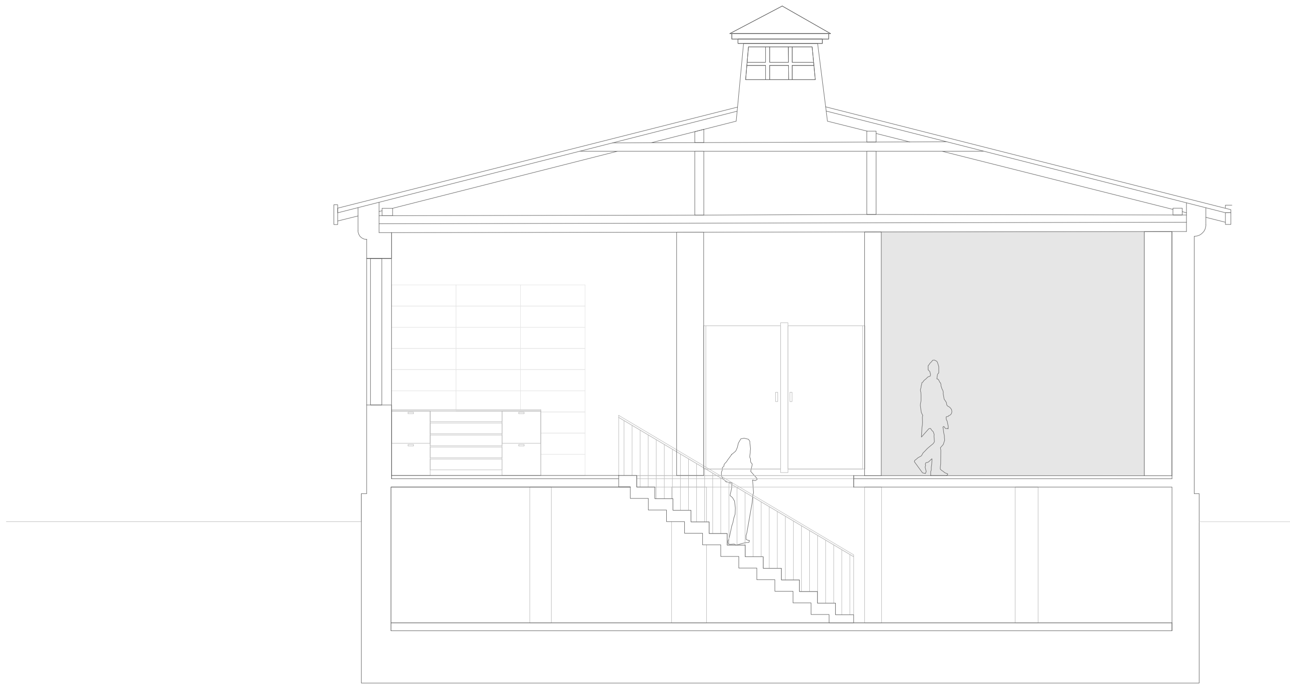
Cross ventilation				
Room	Room height [m]	Room width [m]	Factor	W <
Library / other function	3,7	13	5	18,5
Seperate room	3,7	5,1	5	18,5

Thermal buoyancy
The following calculations showcase the theoretical principles of thermal buoyancy which is calculated for the function; trade. Here the windows, in the external walls, are placed at a height of 1,09 meters and the skylight is placed at a height of 6,4 meters. The calculations will find the neutral plane to make sure the same amount of air that gets inside the building is able to come out again. Further, the results are summed up in a conclusion.

The principle of thermal buoyancy and the room calculated is illustrated.



Principle of thermal buoyancy



Cross section of trade

Calculation of the height of the neutral plan

$$H_1 = \frac{H}{1 + \left(\frac{T_i}{T_u}\right)\cdot\left(\frac{C_{a1}}{C_{a2}}\right)^2\cdot\left(\frac{A_1}{A_2}\right)^2}$$

H : Distance between the openings
T_i & T_u : The absolute indoor and outdoor temperature
C_{a1} & C_{a2} : Opening coefficient
A_1 & A_2 : Opening area for inlet and outlet

$$H_1 = \frac{4.1\ m}{1 + \left(\frac{20}{10}\right)\cdot\left(\frac{0.7}{0.7}\right)^2\cdot\left(\frac{2.4}{2.4}\right)^2}$$
$$H_1 = 1.3\ m$$

The distance between the neutral plane to the middle of the highest placed window is defined as;

$$H_2 = H - H_1$$

$$H_2 = 4.1\ m - 1.36\ m$$
$$H_2 = 2.74\ m$$

Now it is possible to calculate the pressure difference, air velocity, and flow rate

Inlet
The pressure difference is calculated as;

$$\Delta p_1 = \rho_u\cdot\Delta T\cdot g\cdot\left(\frac{H_1}{T_i}\right)\ [Pa]$$

ρ_u : Air desity ~ 1,225 kg/m3
ΔT : The temperature diffenrece between the two opening levels
H_1 : The neutral plan
T_i : The indoor temperature
g : Gravitational acceleration 9,81 m/s^2

$$\Delta p_1 = 1.225\cdot 10\cdot 9.81\cdot\left(\frac{1.36}{20}\right)$$
$$\Delta p_1 = 8.17$$

Now the air velocity can be calculated as;

$$v_{k1} = \frac{2\cdot\Delta T\cdot g\cdot H_1}{\psi_1\cdot T_i}\left[\frac{m}{s}\right]$$

ΔT : The temperature diffenrece between the two opening levels
H_1 : The neutral plan
T_i : The indoor temperature
g : Gravitational acceleration 9,81 m/s^2
ψ_1 : The flow coefficient (calculated)

First the flow coefficient is calculated as;

$$\psi = 1 + \zeta$$

ζ : resistance value ~ 0,6-1,0

$$\psi = 1 + 0.6$$
$$\psi = 1.6$$

The air velocity is then

$$v_{k1} = \frac{2\cdot 10\cdot 9.81\cdot 1.36}{1.6\cdot 20}$$
$$v_{k1} = 8.33\ \frac{m}{s}$$

Outlet
The pressure difference is calculated as;

$$\Delta p_1 = \rho_u\cdot\Delta T\cdot g\cdot\left(\frac{H_1}{T_i}\right)\ [Pa]$$

ρ_u : Air desity ~ 1,225 kg/m3
ΔT : The temperature diffenrece between the two opening levels
H_1 : The middle plane of the highest placed window
T_i : The outdoor temperature
g : Gravitational acceleration 9,81 m/s^2

$$\Delta p_1 = 1.225\cdot 10\cdot 9.81\cdot\left(\frac{1.36}{10}\right)$$
$$\Delta p_1 = 16.34$$

Now the air velocity can be calculated as;

$$v_{k2} = \frac{2 \cdot \Delta T \cdot g \cdot H_2}{\psi_2 \cdot T_u} \left[\frac{m}{s} \right]$$

ΔT : *The temperature diffenrece between the two opening levels*
H_2 : *The middle plane of the highest placed window*
T_u : *The outdoor temperature*
g : *Gravitational acceleration 9,81 m/s²*
ψ_2 : *The flow coefficient (calculated)*

First the flow coefficient is calculated as;

$$\psi = 1 + \zeta$$

ζ : *Resistance value ~ 0,6-1,0*

$$\psi = 1 + 0.6$$
$$\psi = 1.6$$

The air velocity is then

$$v_{k2} = \frac{2 \cdot 10 \cdot 9.81 \cdot 1.36}{1.6 \cdot 10}$$
$$v_{k2} = 16.6 \ \frac{m}{s}$$

The flow rate can now be calculated as;

$$q_v = C_{a1} \cdot A_1 \cdot \left(\frac{2 \cdot \Delta T \cdot g \cdot H_1}{T_i} \right) \left[\frac{m^3}{s} \right]$$

ΔT : *The temperature diffenrece between the two opening levels*
H_1 : *The middle plane of the highest placed window*
T_i : *The outdoor temperature*
g : *Gravitational acceleration 9,81 m/s²*
C_{a1} : *Opening coefficient (calculated)*

The opening coefficient is defined by;

$$C_a = C_v \cdot C_k$$

C_v : *Coefficient of speed*
C_k : *Opening coefficient of contractions ~ 0,65*

The coefficient of speed is calculated as;

$$C_v = \frac{1}{1 + \zeta}$$

ζ : *Resistance value ~ 0,6-1,0*

$$C_v = \frac{1}{1 + 0.6}$$
$$C_v = 0.625$$

$$C_a = 0.62 \cdot 0.65$$
$$C_a = 0.4030$$

The flow rate can now be calculated

$$q_v = 0.4 \cdot 2.4 \cdot \left(\frac{2 \cdot 10 \cdot 9.82 \cdot 1.36}{20} \right)$$
$$q_v = 12.82 \ \frac{m^3}{s}$$

Effective opening area
The effective opening area of the windows is defined as;

$$A_{eff} = A_k = C_k \cdot A$$

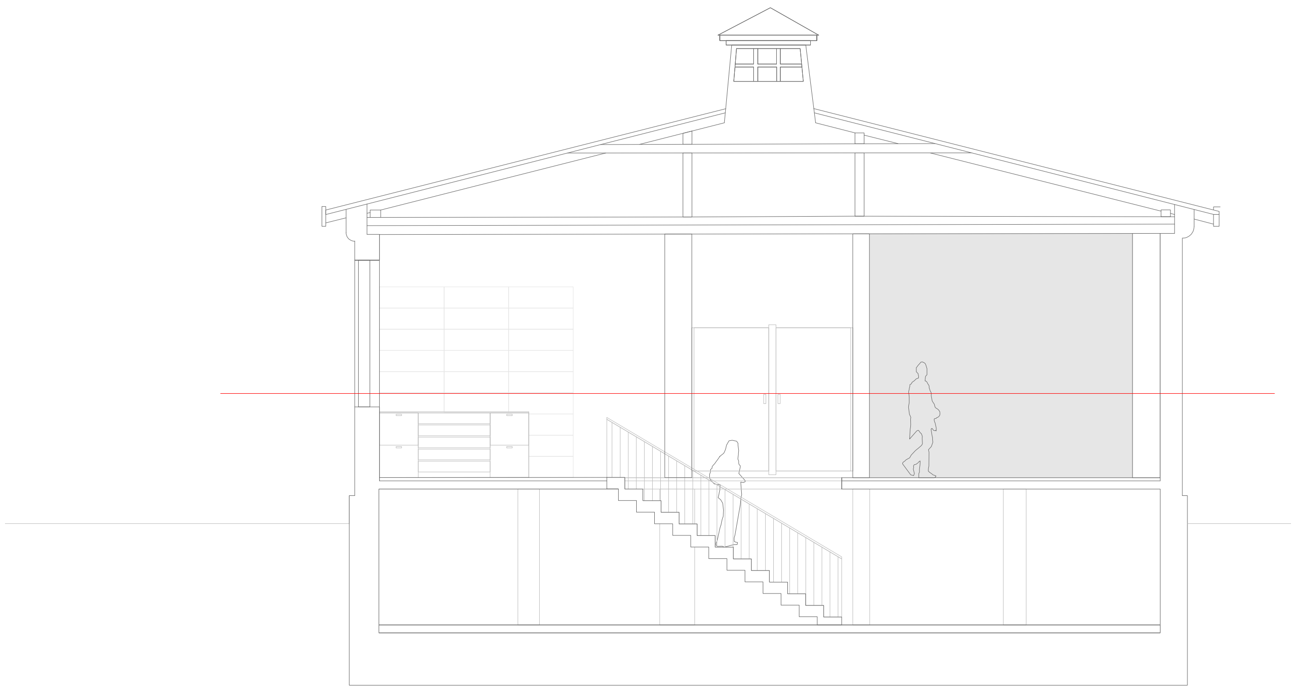
Furthermore the flow rate and the abovementioned areas are connected by;

$$V = A_k \cdot v_k = \left(C_k \cdot A \right) \cdot \left(C_v \cdot v_{teo} \right)$$
$$v_{teo} = \frac{2 \cdot \Delta p}{\rho}$$

The effective opening area can be calculated

$$A_{eff} = 0.65 \cdot 2.4$$
$$A_{eff} = 1.560$$

$$V = 1.560 \cdot 8.3$$
$$V = 12.9$$



The red line showcase the neutral plane of thermal buoyancy.

It can be concluded that the theoretical calculations do not approve the use of thermal buoyancy, because the neutral plane is placed in the opening area of the window in the external wall. Though, it is thought that it will be possible on a practical level as the users of the room can open the windows as they want to and ventilate the room.

Appendix 05

Exsisting Ducts

The existing ducts are seen as possible to use. It is therefore calculated if the existing is enough or if there is need for more in the building.
The ducts are only located in building 21 where the future functions are office, culture, and residential housing. The flow rate for the specific rooms are calculated earlier in the ventilation annex (Appendix 03).

By making a cross section of the existing duct sizes it is seen that these are 24 cm in diameter - this is present for all the ducts in the external walls

Furthermore, the ducts are not present in all the external walls in Building 21. They are only present in the southern section of the building, where they run from basement to first floor. The outlet goes to the roof and ends in smaller chimneys. Since the buildings northern and southern sections have had the same function in the past, it is assumed that both sections have the same ducts in the external walls and that they are usefull for the future functions needs for ventilation.

Illustration of the room with in- and outlets
Plan or section of the building (to see where the ducts are placed)

Dimentions of the existing ducts:
- 24.0 centimeter diameter

The ducts can now be dimentioned by;

$$A = \frac{q_v}{v}$$

A : Area [m^2]

q_v : Flow rate [$\frac{m^3}{h}$]

v : Flow speed [m/s]

3600 : Factor to convert the units from m/s to m/h

The flow speed is assumed to be 2-4 m/s which is the recommended speed in a destribution duct

The flow rate is the following values for the three different functionalities;

Trade: 1841.60 $\frac{m^3}{h}$

Culture: 5658.56 $\frac{m^3}{h}$

Residential housing: 982.53 $\frac{m^3}{h}$

Office: 4681.17 $\frac{m^3}{h}$

The area of the ducts can now be found for the different functionalities

Trade

$$A_{trade} = \frac{1841.60}{3 \cdot 3600}$$
$$A_{trade} = 0.1705\ m^2$$

$$0.1705\ m^2 \cdot 10^4$$
$$1705\ cm^2$$

The diameter of the duct can be found by;

$$d = \sqrt{\frac{A \cdot 4}{\pi}}$$
$$d = \sqrt{\frac{1705 \cdot 4}{\pi}}$$
$$d = 46.59\ cm$$

Culture

$$A_{culture} = \frac{5658.56}{3 \cdot 3600}$$
$$A_{culture} = 0.5239\ m^2$$

$$0.5239\ m^2 \cdot 10^4$$
$$5239\ cm^2$$

The diameter of the duct can be found by;

$$d = \sqrt{\frac{A \cdot 4}{\pi}}$$
$$d = \sqrt{\frac{5239 \cdot 4}{\pi}}$$
$$d = 81.671\ cm$$

Residential housing

$$A_{residential} = \frac{982.53}{3 \cdot 3600}$$
$$A_{residential} = 0.0909\ m^2$$

$$0.0909\ m^2 \cdot 10^4$$
$$909.0\ cm^2$$

The diameter of the duct can be found by;

$$d = \sqrt{\frac{A \cdot 4}{\pi}}$$
$$d = \sqrt{\frac{909 \cdot 4}{\pi}}$$
$$d = 34.01\ cm$$

Office

$$A_{office} = \frac{4681.17}{3 \cdot 3600}$$
$$A_{office} = 0.4334\ m^2$$

$$0.4334\ m^2 \cdot 10^4$$
$$4334\ cm^2$$

The diameter of the duct can be found by;

$$d = \sqrt{\frac{A \cdot 4}{\pi}}$$
$$d = \sqrt{\frac{4334 \cdot 4}{\pi}}$$
$$d = 74.282\ cm$$

Appendix 06

Be18

Be18 has been used as a tool to calculate the expected energy consumption of Building 20. This appendix is an overview over the inputs for the final calculation.

The Building
The building has a heated floor area of 583 m2. The building is constructed as a solid brick wall with interior insulation and a light roof construction. The heat capacity is therefore assumed to be 104 W*h/K * m2. The building is heated by district heating.

Building

Name: Building 20

Other — Detached house (detached single-family house) / Semi-detached and nondetached houses / Multi-storey house, Store etc or Other (non-residential)

1	Number of residential units	0	Rotation, deg.
583	Heated floor area, m²	874,5	Gross area, m²
583	Heated basement, m²	0	Other, m²
690	Developed area, m²		
104	Heat capacity, Wh/K m²	Start at	End at (time)
41	Normal usage time, hours/week	10	17

The Building Envelope

External walls, roofs and floors
The values used for the transmission coefficient is calculated with Ubakus.de (Plag. 2022).

	External walls, roofs and floors	Area (m²)	U (W/m²K)	b	Ht (W/K)	Dim.Inside (C	Dim.Outside (	Loss (W)
		2034,67		CtrlClick	225,302			6371,16
+1	External walls	380,67	0,25	1,00	95,1675	20	-12	3045,36
2	Roof	690	0,12	1,00	82,8	20	-12	2649,6
3	Floor	690	0,098	0,70	47,334	20	10	676,2
4	Basement walls	274	0	0,70	0	20	10	0

Foundations and joints at windows
The line losses around the foundations and the joints at windows and doors is implemented. The values are compliant with the requirements for renovations (BR18).

	Foundations and joints at windows	l (m)	Loss (W/mK)	b	Ht (W/K)	Dim.Inside (C	Dim.Outside (	Loss (W)
		472,625		CtrlClick	27,7302			887,367
+1	Ydervægsfundament	150,572	0,12	1,00	18,0686	20	-12	578,196
2	Samlinger ved vinduer	276,575	0,03	1,00	8,29725	20	-12	265,512
3	Samlinger ved døre	45,478	0,03	1,00	1,36434	20	-12	43,6589

Windows and outer doors
The windows and in the building has in the renovation been changed to three-layer energy glass with a trans-

mission value of 1.25 W/m^2*K and a g-value of 0.62 (se Appendix 02 for the calculations). The doors are assumed to have the same values as the windows. The windows and doors are divided into different orientation and placement and the shadows are calculated according to SBi 213.

	Windows and outer doors	Number	Orient	Inclination	Area (m²)	U (W/m²K)	b	Ht (W/K)	Ff (-)	g (-)	Shading	Fc (-)	Dim.Inside	Dim.Outsi	Loss (W)	Ext
		37			167,59		CtrlClick	209,488			CtrlClick				6567,98	0/1
+1	Flagvindue (2x spros) 01	14	s	90	3,3	1,25	1,00	57,75	0,75	0,62	Udhæng (	1	20	-12	1848	0
2	Flagvindue (3x spros) 01	2	s	90	4,2	1,25	1,00	10,5	0,75	0,62	Udhæng (	1	20	-12	336	0
3	Flagvindue (2x spros) 02	2	n	90	3,3	1,25	1,00	8,25	0,75	0,62	Udhæng (	1	20	-12	264	0
4	Flagvindue (4x spros)	1	n	90	6,3	1,25	1,00	7,875	0,75	0,62	Udhæng (	1	20	-12	252	0
5	Vindue (u. spros)	2	n	90	2,7	1,25	1,00	6,75	0,75	0,62	Udhæng (	1	20	-12	216	0
6	Vindue (stort grønt)	1	n	90	40,44	1,25	1,00	50,55	0,9	0,62	Udhæng (	1	20	-12	1617,6	0
7	Flagvindue (2x spros) 03	2	ø	90	3,3	1,25	1,00	8,25	0,75	0,62	Udhæng (	1	20	-10	247,5	0
8	Flagvindue (3x spros) 02	1	ø	90	4,2	1,25	1,00	5,25	0,75	0,62	Udhæng (	1	20	-10	157,5	0
9	Flagvindue (2x spros) 04	1	v	90	3,3	1,25	1,00	4,125	0,75	0,62	Udhæng (	1	20	-10	123,75	0
10	Dør 1	1	s	90	6	1,25	1,00	7,5	0,75	0,62	Udhæng (	1	20	-10	225	0
11	Dør 2	1	v	90	6,15	1,25	1,00	7,6875	0,75	0,62	Udhæng (	1	20	-10	230,625	0
12	Dør 3	1	n	90	3,8	1,25	1,00	4,75	0,75	0,62	Udhæng (	1	20	-10	142,5	0
13	Dør 4	1	n	90	4,6	1,25	1,00	5,75	0,75	0,62	Udhæng (	1	20	-10	172,5	0
14	Dør 5 (grøn spros)	1	n	90	3	1,25	1,00	3,75	0,9	0,62	Udhæng (	1	20	-10	112,5	0
15	Room 17	1	s	90	3,3	1,25	1,00	4,125	0,75	0,62	Room 17	1	20	-10	123,75	0
16	Room 20	1	s	90	3,3	1,25	1,00	4,125	0,75	0,62	Room 20	1	20	-10	123,75	0
17	Room 7	1	n	90	3,3	1,25	1,00	4,125	0,75	0,62	Room 7	1	20	-10	123,75	0
18	Room 9	1	n	90	3,3	1,25	1,00	4,125	0,75	0,62	Room 9	1	20	-10	123,75	0
19	Flagvindue (1x spros) 01	1	ø	90	1,7	1,25	1,00	2,125	0,75	0,62	Lille vindu	1	20	-10	63,75	0
20	Flagvindue (1x spros) 02	1	v	90	1,7	1,25	1,00	2,125	0,75	0,62	Lille vindu	1	20	-10	63,75	0

Ventilation
Building 20 is ventilated by natural ventilation all year around. There is mechanical extraction in the toilets and small kitchens.

	Ventilation	Area (m²)	Fo, -	qm (l/s m²)	n vgv (-)	ti (°C)	El-HC	qn (l/s m²)	qi,n (l/s m²)	SEL (kJ/m³)	qm,s (l/s m²)	qn,s (l/s m²)	qm,n (l/s m²)	qn,n (l/s m²)
	Zone	1749		Winter			0/1	Winter	Winter		Summer	Summer	Night	Night
+1	All rooms	583	1	0	0	0	0	0,3	0,13	0	0	3,97	0	0,13
2	Infiltrations	1166	1	0	0	0	0	0,13	0,09	0	0	0,13	0	0,09

Natural ventilation
The value for the airflow is calculated due to atmospheric comfort in Appendix 03 and is chosen for the value for natural ventilation in the summer. The value for natural ventilation in the winter follows the minimum requirements of 0,3 l/s pr. m2 in order to minimize the energy used for heating (BR18).

Infiltration
The values are compliant with the recommendations from SBi 213.

Be18

Internal heat supply
The values for persons and equipment are compliant with the recommendations from Sbi 213.

	Internal heat supply	Area (m²)	Persons (W/m²)	App. (W/m²)	App.night (W/m²)
	Zone	583,0	2332,0 W	3498,0 W	0,0 W
+1	All rooms	583	4	6	0

Lighting The values are compliant with the recommendations from SBi 213.

	Lighting	Area (m²)	General (W/	General (W/	Lighting (lux	DF (%)	Control (U, M,	Fo (-)	Work (W/m²	Other (W/m²	Stand-by (W	Night (W/m²
	Lighting zone	1166	Min.	Inst.			U,M,A,K					
+1	All rooms	561,66	2	2	300	3	M	1	1	0	0	0
2	Toilets	21,34	2	2	200	0	M	0,6	0	0	0	0
3	Basement	583	3	2	300	0	M	0,6	0	0	0	0

District heating
The values are based on values from SBi 213.

Heat distribution plant

Composition and temperature

Description	Dimensioning	
District heating	70	Supply pipe temperature, °C (at outdoor temp. of -12 °C)
	40	Return pipe temperature, °C
Anlægstype	2	Type of plant: 1: unified or 2: dual

District heat exchanger
The values are assumed (Larsen. 2019).

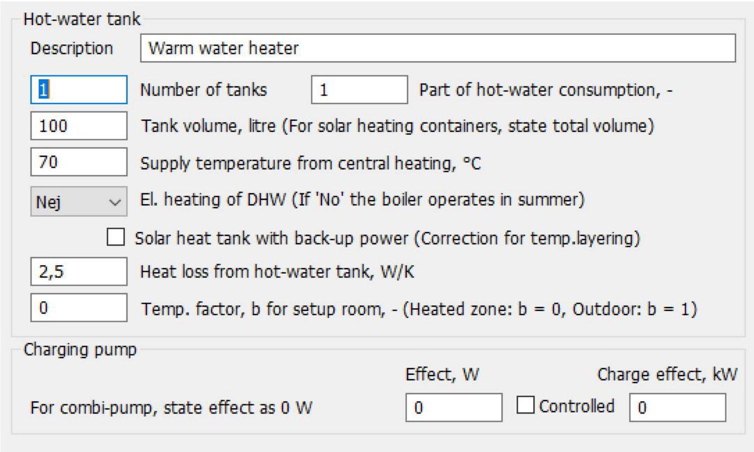
Description: District heating exchanger

District heating exchanger

126	Nominal effect, kW
0,7	Heat loss from exchanger, W/K
☑	DHW heating through exchanger
60	Exchanger temperature, minimum, °C
0	Temp.factor, b for setup room (Heated zone: b = 0, Outdoors: b = 1)
5	Automatics, stand-by, W

Domestic hot water

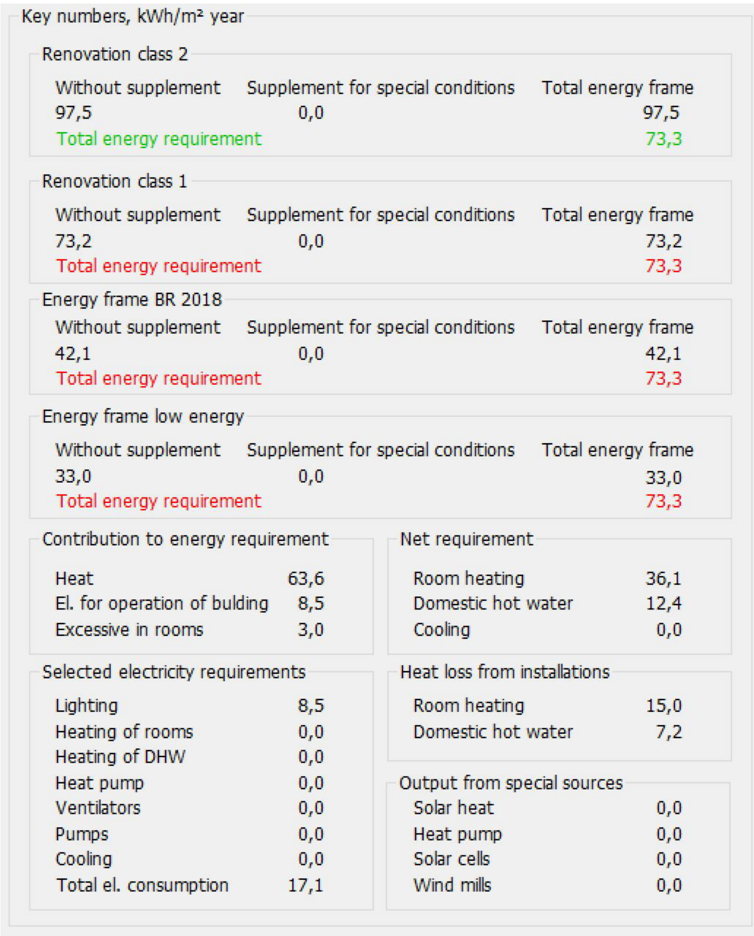
The values are assumed (Larsen. 2019).



Key numbers

Building 20 complies with the requirements of Renovations Class 2. Though, as the indoor temperatures are calculated according to adaptive comfort (See page 25), the over temperatures can be cut from the calculations. Therefore building 20 complies with the requirements of Renovation Class 1.

Heating	64.6	0.85	54.1
Electricity for operation of the building	8.5	1.9	16.2
Total	72.1		70.3



In order to use these calculations for dwellings in building 21 as well. It is tested what the energy requirement would be if the building 20 was dwellings.

The values for usage time is changed to 168 hours pr. week. and the people- and equipment load is changed to comply with the requirements for dwellings.

Heating	67.7	0.85	57.5
Electricity for operation of the building	0.1	1.9	0.2
Total	67.8		57.7

Appendix 07

BSim

BSim has been used as a tool to calculate the expected thermal indoor climate of Building 20. This appendix is an overview over the inputs for the renovated building envelope.

Construction
External wallss: u-value 0.25 W/m2*K
Floor: u-value 1.38 W/m2*K
Roof: u-value 0.12 W/m2*K
Windows: u-value 1.25 W/m2*K
g-value 0.62
Basement floor: u-value 0.098 W/m2*K
Basement wall: u-value 0.17 W/m2*K

Equipment
The values are assumed.

Heating
It is estimated that the building is heated by radiators.
The set point is at 22 C, as this is the temperature to maintain in the building.

Infiltration
Standard values.

Lighting
The values are assumed.

People load
The number of people is set to 20, to test the indoor climate at maksimum capacity. The activity level is set to medium, as people are walking around.

Venting
The needed ventilation rate is calculated by atmospheric comfort (see appendix 03), and is 3.86 1/h. To decrease the maximum temperatures, the ventilation rate is changed to 5 1/h.

The set point for opening the windows is higher in the winter to prevent under temperatures.

Systems	Description	Schedule regulation/control	Time
Equipment	Heat load: 0.3 Part to air: 0.5	100% 100%	Mon-Fri. 10AM-17PM Sat. 10AM-16AM
Heating	MaxPow. 5 Fixed part: 0.05 Part to air. 0.6	HeatCoolCtrl Factor: 1 Set point. 22 Design temp: -12 MinPow. 0 Te Min: 18	Oct-Jan.
Infiltration	Basic AirChange: 0.3 TmpFactor: 0 1 TmpPower: 0.5	100%	Always
Lighting	Task lighting: 2 General lighting: 0.2 Gen. lighting level: 200 Lighting type: Fluorescent Solar limit: 2 Exhaust part: 0	LightCtrl Factor: 1 Lower limit: 0.1 Temp. max: 25 Solar limit: 0.2	Mon-Fri. 10AM-17PM Sat. Kl. 10AM-16PM
People load	Number of people: 20 Medium Activity Heat Gen: 0.12 Moist. Gen. 0.123	100% 60% 30% 60% 100% 30%	Mon-Fri. 10AM-12PM Mon-Fri. 12PM-16PM Mon-Fri. 16PM-17PM Sat. 10AM-12PM Sat. 12PM-14PM Sat. 14PM-16PM
Venting	Basic AirChange: 3 TmpFactor: 0.44 TmpPower: 0.5 WindFactor: 2 Max AirChange: 5 Max Wind: 0	VentingCtrl Set point: 22 SetP Co2: 800 Factor: 1 Set point: 23 SetP Co2: 800 Factor: 1	Apr-Sep. Mon-Fri. 10AM-17PM Sat. 10AM-16PM Oct-Mar. Mon-Fri. 10AM-17PM Sat. 10AM-16PM

Appendix 08

Adaptive Thermal Comfort

The calculations of adaptive thermal comfort are calculated according to DS/ EN 16798-1:2019 DK NA:2021.

The calculations of the running mean outdoor temperature is made according to the following equation and the calculation is made for the 15. day of each month.

$$\Theta_{rm} = \frac{\Theta_{ed-1}+0.8*\Theta_{ed-2}+0.6*\Theta_{ed-3}+0.5*\Theta_{ed-4}+0.4*\Theta_{ed-5}+0.3*\Theta_{ed-6}+0.2*\Theta_{ed-7}}{3,8}$$

Θ_{rm} = outdoor running mean temperature for the considered day [C°]

Θ_{ed-1} = daily mean outdoor air temperature for previous day [C°] (calculated from BSim)

An example is shown for the month of January.

$$\Theta_{rm} = \frac{3.34+0.8*3.8+0.6*3.82+0.5*0.82+0.4*2.33+0.3*3.82+0.2*(-0.55)}{3,8} = 2.9$$

The calculations of the upper and lower limit of temperatures is made according to the following equations for category II.

$$\Theta_{ol} = 3.33 * \Theta_{rm} + 18.8 - 4$$
$$\Theta_{ou} = 3.33 * \Theta_{rm} + 18.8 + 3$$

Θ_{ol} = lower limit

Θ_{ou} = upper limit

The equations for category III is as following.

$$\Theta_{ol} = 3.33 * \Theta_{rm} + 18.8 - 5$$
$$\Theta_{ou} = 3.33 * \Theta_{rm} + 18.8 + 4$$

An example is shown for the month of January for category II

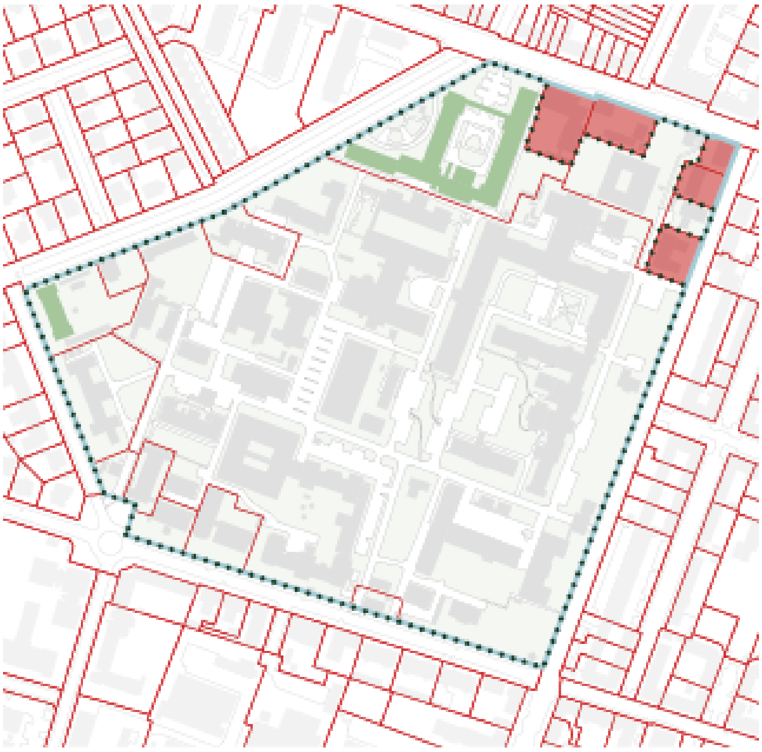
$$\Theta_{ol} = 3.33 * 2.9 + 18.8 - 4 = 16$$
$$\Theta_{ou} = 3.33 * 2.9 + 18.8 + 3 = 23$$

Appendix 09

Tender Material

- Områdeafgrænsning
- Projektområde
- Bygninger forudsat bevaret til eksisterende formål
- Private ejendomme
- Matrikler

Etageareal i udviklingsplan ved bebyggelsesprocent på 100%	
Bygninger forudsat bevaret til eksisterende formål	13.000 m^2
Etageareal der skal fordeles i udviklingsplan	128.000 m^2
Total	141.000 m^2

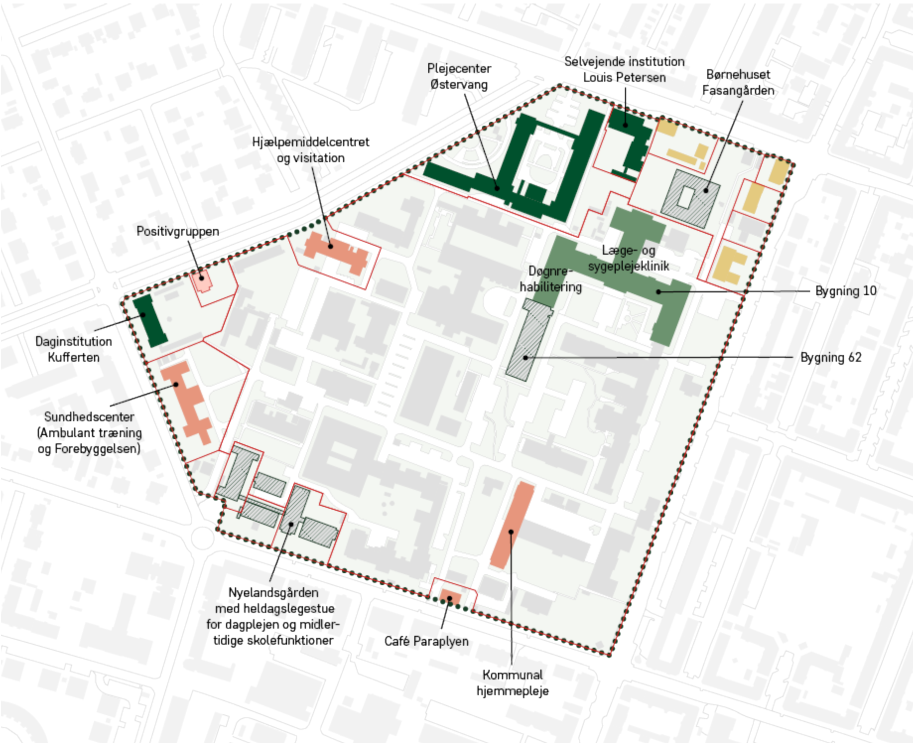


Ill. 14.

BEVARINGSVÆRDIER

- Fredede bygninger
- Bygninger der skal bevares
- Bygninger der anses for bevaringsværdige af generelle bevaringshensyn
- Bygninger der anses for bevaringsværdige af hospitals-historiske hensyn
- Særligt værdifuldt træ der skal bevares
- Bevaringsværdigt træ som så vidt muligt skal bevares
- Mindre værdifuldt træ som evt. kan erstattes
- Bevaringsværdig grøn struktur
- Omkringliggende vejtræer
- Eksisterende karakteristisk mur

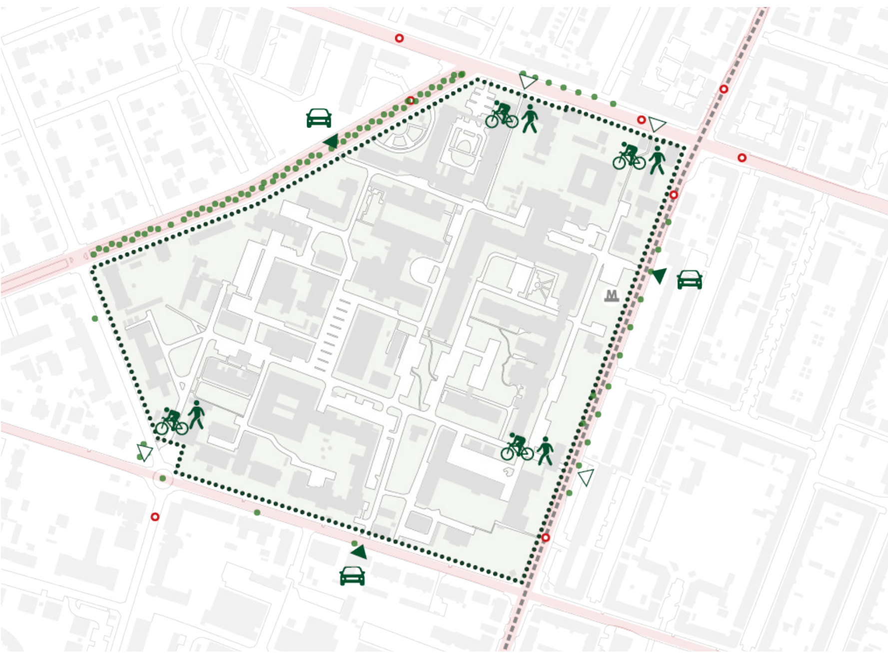
Ill. 15.



FUNKTIONER

- Bygninger der fastholdes med nuværende offentlige funktioner
- Offentlige funktioner der forventes flyttet til et 'sundhedsstrøg'
- Offentlige funktioner der evt. kan flyttes til et 'sundhedsstrøg'
- Bygninger der fastholdes til offentlige funktioner
- Bygninger der fastholdes til andre funktioner
- Bygninger der midlertidigt fastholdes til offentlige funktioner
- Matrikler

Ill. 16.



INFRASTRUKTUR

- Biladgang uden gennemkørsel
- Hovedadgange til området
- Veje med eksisterende cykelstier/baner
- Eksisterende busstop
- Evt. fremtidig metrolinje
- Evt. fremtidig metrostation
- Omkringstående vejtræer

Ill. 17.

Appendix 10

Renovation Concepts Pros & Cons

	Concept 1		*Concept 2*		*Concept 3*		*Concept 4*	
	Pros	Cons	Pros	Cons	Pros	Cons	Pros	Cons
Windows	+original aesthetics		+more light +bigger connection to outdoor	-not an irreversible option	+original aesthetics		+original aesthetics	-less connection towards the outside -require specific functions
Wall	+better u-value +no moisture or condens in the construction		+no risk of damaging the bricks	-risk of cold walls -risk of specific plansolution	+no risk of damaging the bricks		+better u-value +no moisture or condens in the construction	-risk of damaging the bricks -risk of taking too many square meters from the rooms
Roof			+enhancing the interior space	-risk for rooms without human scale			+enhancing the interior space	-risk for rooms without human scale
Basement		-storage/functioning basement	+storage/functioning basement +future proof		+storage/functioning basement +future proof		+storage/functioning basement +future proof	

Appendix 11

Renovation Concepts Pros & Cons

Ill. 18.

Reference List

Aggerholm, Søren, and Kim B. Wittchen. 2018. SBI-Anvisning 213 - Bygningers Energibehov, Beregningsvejledning. Statens Byggeforskningsinstitut, Aalborg Universitet.

Danish Standards Foundation. 2011. 'DS 418:2011 Beregning Af Bygningernes Varmetab'.

Danish Standards Foundation. 2013. 'DS447:2013. Ventilation for Buildings - Mechanical, Natural and Hybrid Ventilation Systems'.

Danish Standards Foundation. 2021. 'DS/EN 16798-1:2019 DK NA:2021. Energy Performance of Buildings - Ventilation for Buildings - Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Adressing Indoor Air Quality, Thermal Environment, Lightning and Acoustics - Module M1-6 - National Annex NA Related to 16798-1'.

Frederiksberg Kommune. 2021. 'Velkommen Til Hele Byens Nye Kvarter - Frederiksberg Hospital - Program for Parallelopdrag Til Udviklingsplan'.

Jensen, Caroline Drost. 2020. Weather Statistics for Danish Airports 2009-2018 DMI Report 20-17. Danish Meteorological Institute.

Larsen, Olena. 2019.'Hygrotermisk Bygningsfysik Og Bygningers Energiforbrug in Lecture 6', Architecture and Design, Aalborg University.

Patursson, Tue, and Ida Blomsterberg. 2022. 'Valg Af Nye Termoruder'. Videncentret Bolius. Retrieved (https://www.bolius.dk/valg-af-nye-termoruder-16770).

Plag, Ralf. 2022. Ubakus.De. u-wert.net GmbH. Retrieved (https://www.ubakus.de/u-wert-rechner/).

Statens Byggeinstitut. 2002. By Og Byg Anvisning 202 - Naturlig Ventilation i Erhvervsbygninger. 1. udgave. By og Byg.

Statens Byggeinstitut, and Karl Terpager Andersen. 1998. By Og Byg Anvisning 301 - Dimensionering Af Naturlig Ventilation Ved Termisk Opdrift. By og Byg.

Illustration List

Ill. 2-13 are screenshots from reports produced in the calculation tool at Anon. n.d. b. 'Ubakus'. Retrieved (https://www.ubakus.de/u-wert-rechner/).

Ill. 14-17 are screenshots from the tender material, publiched by Frederiksberg municipality. Retrieved (https://www.frederiksberg.dk/frederiksberghospital).

Ill. 18 are screenshot retrieved from (https://www.klimatilpasning.dk/vaerktoejer/oversvoemmelseskort/se-oversvoemmelseskortet/).