TOWARDS A COMMON GOAL

Exploring an Interdisciplinary Design Method for Sustainable Building

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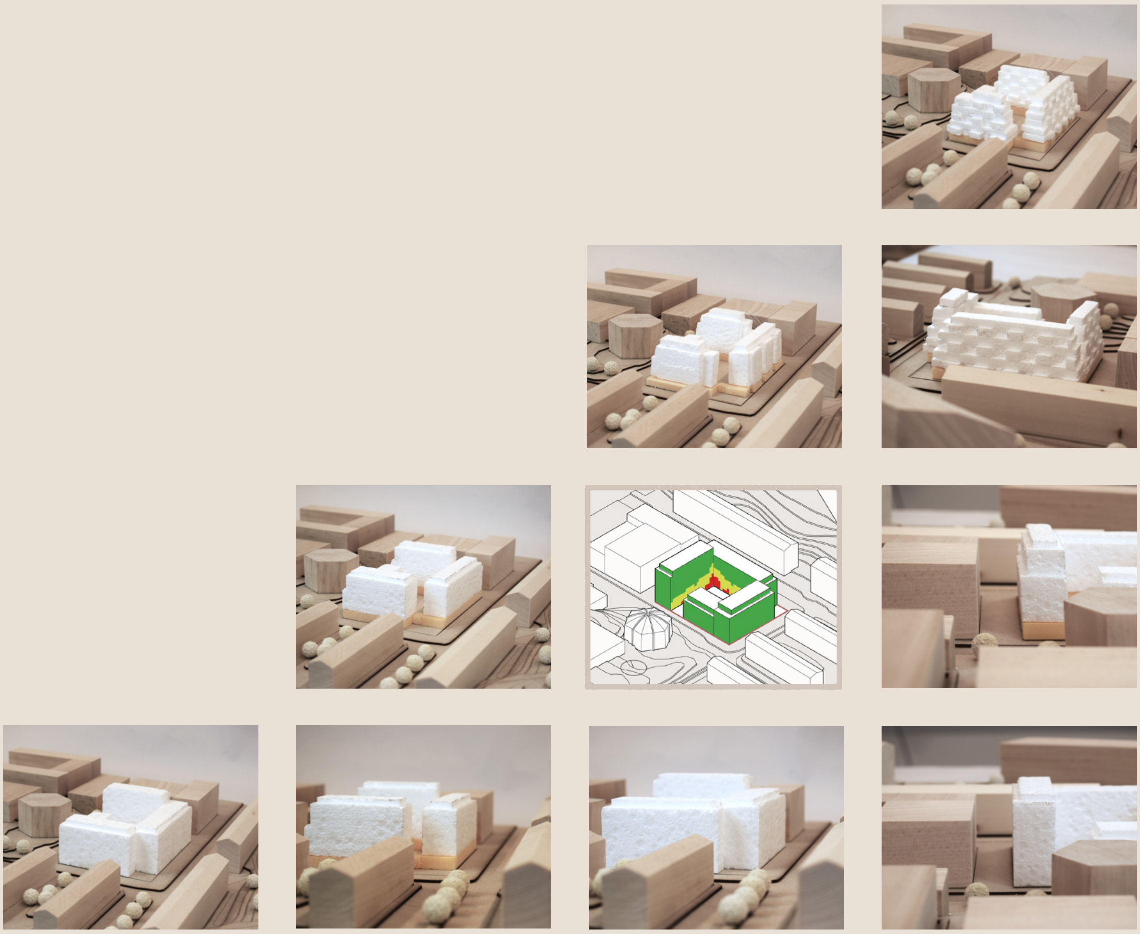
Master thesis
Chalmers University of Technology
Department of Architecture and Civil Engineering

Examiner: Joaquim Tarraso
Supervisor: Emilio Da Cruz Brandao

Ona Forss



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ABSTRACT

Decisions made in the architectural conceptual design process have a profound impact on the final performance of buildings. With increasing demands for energy efficiency and daylight access, the need to solve these issues in early stages becomes more important.

Today there is a gap in the industry in the collaboration between architects and building performance engineers, two professions that possess the knowledge needed in making high-quality, sustainable and aesthetically strong buildings. This is especially the case in Sweden, where architects and engineers work mostly in different parts of the process, whereas collaboration between the two takes place a lot earlier in other parts of Europe.

This thesis is carried out in close collaboration with engineering student Linda Wäppling, and the department of Energy and Environmental Assessment at the Gothenburg-based engineering office Bengt Dahlgren AB. In the architecture faculty the thesis will be located in Urban Challenges, a direction that welcomes interdisciplinary projects. The purpose of the thesis is to explore how architects and building performance engineers can collaborate in early stages to design more well-performing buildings. An interdisciplinary design method is defined as a possible solution for early-stage collaboration. The focus here is to identify how the process looks like for both professions in early stages and defining indicators that could help both architects and engineers in multi-objective decision making.

A previously developed building performance tool BeDOT (Building early-stage Design Optimization Tool), is further developed as a possible solution for this kind of early-stage collaboration. The method and the tool are tested through prototyping a design process, with a housing project in wood located in Gibraltarvallen in Gothenburg as a case study. The building design and tool are then developed in a parallel process.

The expected results are threefold: developed design tool for architects and engineers, a collaboration method between the two professions and a completed exploration in an early-stage building design case study. When working to create buildings that perform strongly in technical aspects as well aesthetic ones, we need both architects and engineers, in order to reach that common goal.

Examiner: Joaquim Tarrasó
Supervisor: Emilio Da Cruz Brandao

Key words: *sustainable building design, early-stage building design, interdisciplinary collaboration, multi-objective decision making, building performance tool, integrated design process*

Collaboration method — *Building performance tool* — *Case Study*

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STUDENT BACKGROUND

ACADEMIC BACKGROUND

Architecture and Civil Engineering, Chalmers University of Technology
Gothenburg, September 2018 - June 2019

MSc in Architecture and Urban Design. Studio Matter, Space, Structure and master thesis in the direction Urban Challenges.

Escuela Técnica Superior de Arquitectura de Vallés, UPC
Barcelona, September 2017 - June 2018

Erasmus exchange year at ETSAV in Barcelona. Studios in urban design, restaurant design, and alternative housing solutions.

Architecture and Engineering program, Chalmers University of Technology
Gothenburg, September 2013 - June 2016

BSc in Architecture and Engineering. The courses included the theories, methods and tools of both architecture and engineering at a bachelor level.

PROFESSIONAL BACKGROUND

Architectural intern at HENN Architekten
Berlin, February 2017 - July 2017

Architecture internship at HENN Architekten, in the design studio and model workshop, participating in four competition projects.

Structural engineering intern at Schlaich Bergermann Partner
Berlin, July 2016 - January 2017

Engineering internship at sbp in Berlin.

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PREFACE

This project stems from my background in the bachelor program Architecture and Engineering (AT) at Chalmers University of Technology. This thesis is written in collaboration with Linda Wäppling, a fellow student from AT, who is writing her master thesis at the department of Building technology. After AT, Linda and I went on to intern at both engineering and architecture offices, and have experienced first hand the difficulties in collaboration between these two professions.

Having for a long time felt quite split between the two professions, and finally choosing to go for a master's degree in architecture, it has been wonderful, albeit challenging, to get to work with a thesis exploring how these two disciplines can learn from each other and consequently grow and evolve.

A big thank you to my examiner Joaquim Tarraso, my supervisor Emilio Da Cruz Brandao and Linda Wäppling's examiner Angela Sasic Kalagasidis. Our discussions, and your welcoming attitude of an interdisciplinary master thesis has been a great support.

Thank you to the hard-wired engineer Max Tillberg at Bengt Dahlgren AB for your willingness to understand (and relentless aim to figure out) how we architects think. Also a big thanks to the whole 1022 team at BDAB, for reminding us to take our fika breaks.

A massive thank you to my fellow students at the Urban Challenges direction and all the interviewees who contributed to this thesis.

Finally, a massive thanks to my thesis partner and friend Linda for making this master thesis process so indescribably great!

Göteborg, 2019

1. INTRODUCTION

BACKGROUND

Decisions made in the architectural conceptual design process have a profound impact on the final performance of buildings. With increasing demands for energy efficiency and daylight access, the need to solve these issues in early stages becomes more important.

Today there is a gap in the industry in the collaboration between architects and building performance engineers. This is especially the case in Sweden, where architects and engineers work mostly in different parts of the process. A lack of synergy between architects and engineers was illustrated by Le Corbusier already in 1960 (Figure 1).

This thesis is carried out in close collaboration with engineering student Linda Wäppling, and the department of Energy and Environmental Assessment at the Gothenburg-based engineering office Bengt Dahlgren AB (BDAB). In the architecture faculty the thesis is located in Urban Challenges, a direction that welcomes interdisciplinary projects.

BDAB has in previous master thesis projects developed a tool called BeDOT, short for Building Early-stage Design Optimization Tool. The purpose of this tool is to conduct building performance simulations that are accurate and quick, to be used in early stages of the design process. This tool is a suggestion for bettering the collaboration in early stages, and is further developed in this master thesis, in collaboration with the engineering student.

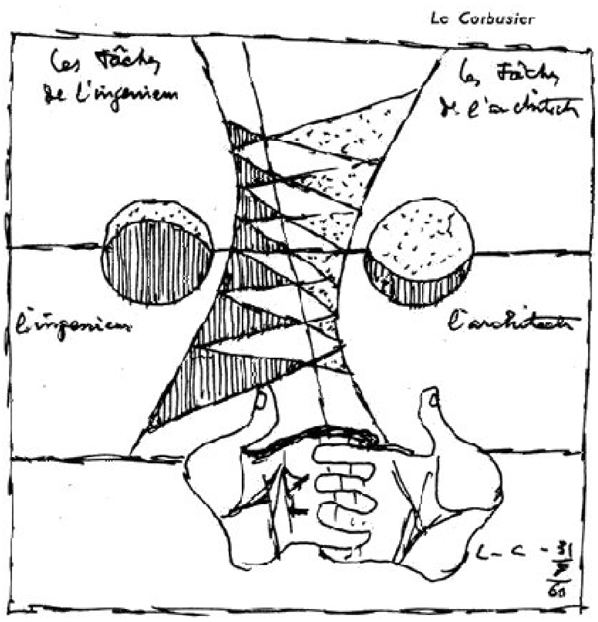


Figure 1. *The relation between architects and engineers (Le Corbusier, 1960)*

PURPOSE AND OBJECTIVE

The purpose of the thesis is to promote a more integrated design process as a whole, with a stronger back-and forth interaction between architects and engineers. This thesis aims to shine light on the issues in collaboration in the industry, especially in Sweden, while suggesting a new way of working, to encourage collaboration in a very practical way.

The objective of the thesis is to explore that collaboration, by creating an alternative design workflow, and further developing a building performance tool, in this case BeDOT, as a suggested solution among many. The issues do not merely reside in lack of tools and workflows, but in mindsets. However, by suggesting a new workflow, the goal is to change mindsets by first changing behaviours, and this thesis in an exploration in what that change might look like (Figure 2).

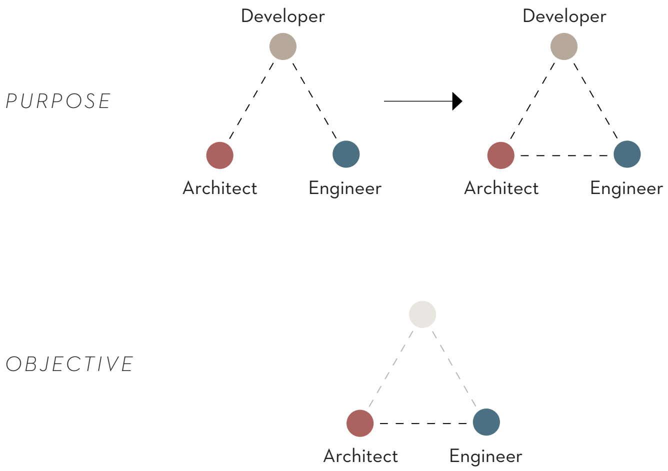


Figure 2. *The purpose of the thesis is to strengthen the overall integration in building design projects. The objective of the thesis is to explore the collaboration between architects and engineers.*

RESEARCH QUESTIONS

The research questions are divided into two categories: this thesis focuses on what the process looks like today, and how it can be improved with a new suggested design method.

PROCESS TODAY

1. What is preventing the early-stage collaboration between architects and engineers in Sweden?
   - How can an interdisciplinary design method support sustainability in early-stage building design?

DESIGN METHOD

2. What information is needed for architects to make well-informed decisions in the practice of early stage building design?
   - Which building performance indicators are important?
   - How can the process of early-stage building design be supported with building performance simulations?

DELIMITATIONS

The thesis has quite a few delimitations, the most important ones illustrated in the figure below (Figure 3). The topics are in order of relevance, the most important at the top and the less important at the bottom.

RELEVANCE

EARLY STAGES	INTERDISCIPLINARY DESIGN	BUILDING PERFORMANCE SIMULATIONS	SUSTAINABILITY	STAKEHOLDERS
Early investigations	**Performance-driven design process**	**Energy demand**	**Environmental sustainability**	**Architects**
Early stages of the building design process	**Multi-criteria decision making**	**Daylight in buildings**	Social sustainability	**Building performance engineers**
Detail planning process	**Communication of analysis results**	**Direct sunlight**	Economical sustainability	Developers
Urban planning	Translation of models	**Outlook from building**		Structural engineers
		Acoustic analysis		Contractors
		Wind analysis		Users
		Structural analysis		
		People flow		
		Embodied energy		
		BIM		

Figure 3. *Thesis delimitations*

THESIS STRUCTURE

The thesis is structured into six chapters, that all have different methods (Figure 4). Chapter 1: Introduction, presents a general background and the scope of the project. Chapter 2: Overview of Area, presents what was learned from literature and interviews, in order to understand the process today. Chapter 3: Potential Gaps, identifies what's lacking in the process today, where the gaps are and how this thesis aims to close those gaps. Chapter 4: Interdisciplinary Design Method, presents a new method and workflow, as well as the BPS tool BeDOT, as solutions for collaboration. Chapter 5: Case Study, presents a testing of the workflow and tool in a design project. Chapter 6: Discussion, presents a review of the method and a discussion about the topic in general.

COMMON ABBREVIATIONS

BDAB	Bengt Dahlgren AB
BPS	Building performance simulation
BTA	Building gross area (Bruttoarea)
DF	Daylight factor
EP_{pet}	Primary energy demand (Primärenergital)
E_{uppv}	Heating energy demand
SHL	Solar heat load

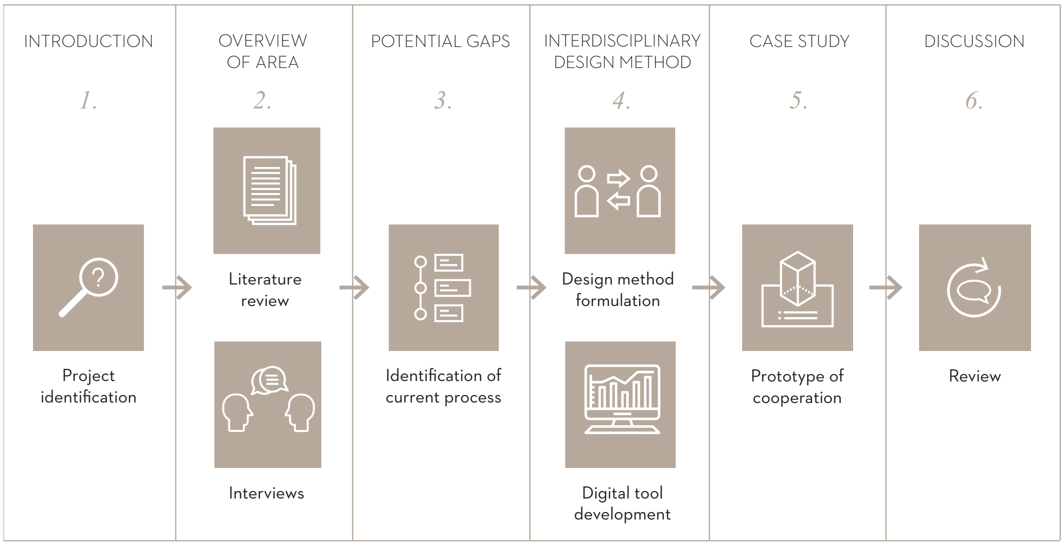


Figure 4. *Diagram of thesis structure with methodology and correlating chapters*

2. OVERVIEW OF AREA

A TOOL AS A SOLUTION AMONG MANY

This thesis suggests an interdisciplinary design tool as a solution among many to the identified problem in collaboration. There are countless of collaboration strategies in architecture, meaning this method and tools are not the only ones. This mapping of other strategies is not meant as an extensive review of all other collaboration methods, rather a way of acknowledging existing strategies in the field (Figure 5).

> *"Collaboration is a collective intellectual function that can be a force multiplier in an intended objective".*
>
> *(Pressman, 2014)*

Figure 5. *Diagram showing a mapping of collaboration strategies. Adopted from Designing Relationships (Pressman, 2014) and The Designer's Field Guide to Collaboration (Brause, 2017).*

INTEGRATION OF DOMAINS

Today in Sweden, architects and engineers have very distinct roles and responsibilities. According to Negendahl you can divide the work flow into three different domains: user domain, tool domain and model domain. Negendahl claims that in order to achieve and integrated process, the integration must happen in more than one domain. Due to architects and engineers using different design tools that results in different models, there's a discrepancy in the work flow. The architect sends over drawings from the geometric design model to the engineers, who converts it into a model that works for calculations. In this case, the engineer works as an assistant to the architect. With a design team that incorporates both architects and engineers, there's a feedback loop in both directions (Figure 6).

In this thesis the focus is to integrate the users (architects and engineers) and the design tool, by suggesting a new cooperative design method together with an interdisciplinary design tool (Figure 7). A vision for the future would be to create a tool that could house both the geometric design model and a calculation model, or for one model to be able to perform for both spatial design and for calculations, however that is not the focus in this thesis.

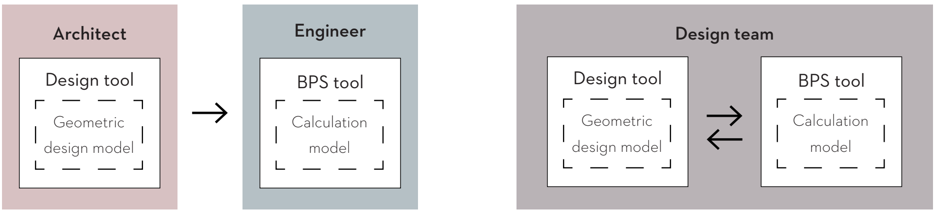


Figure 6. *Left: Example of a traditional design process, where the engineer is an assistant to the architect. Right: Example of an integrated design process . (Adopted from Negendahl, 2004.)*

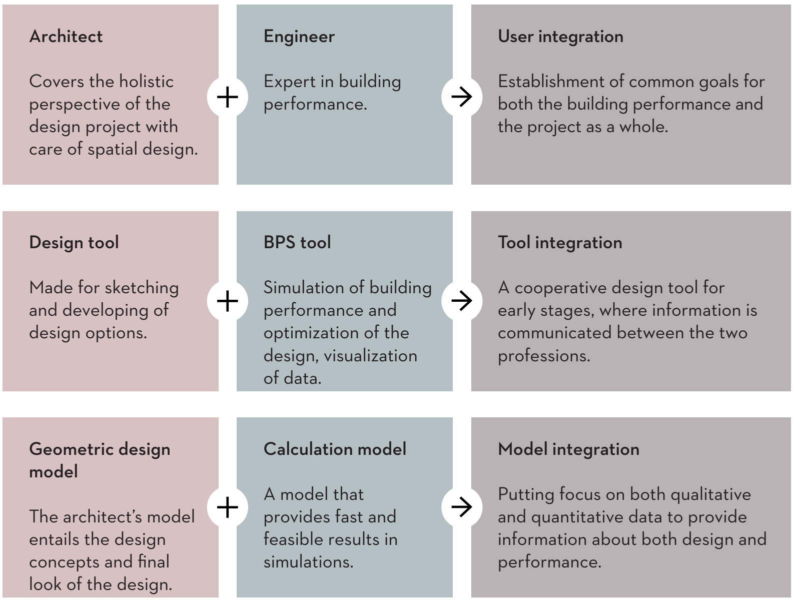


Figure 7. *Diagram showing integration of different domains, marking the focus of the thesis: user integration and tool integration. (Adopted from Negendahl, 2004.)*

INTERVIEWS

Interviews were conducted in order to understand the architects' and engineers' roles in the building process in Sweden, and the existing collaboration between the two professions. A total of ten interviews were conducted, with architects, engineers, developers and researchers. Some interviews were conducted from representatives from abroad. The aim was to identify the problems in the workflow to then suggest an improved collaboration method for multi-criteria decision making. Specifically the use of building simulation tools in the early stages was of interest. The interviews were semi-structured, and are in this chapter summarized from the interview notes that were taken. They dealt with topics about what the current work flow looks like, identifying problems in the design process and understanding what could be improved and how. The qualitative results from the interviews are then translated into qualitative and quantitative input for the thesis, in the shape of indicators to use in the building performance simulation, and designing a suggested improved interdisciplinary work flow.

INTERVIEW QUESTIONS

The following types of questions were generally asked from stakeholders within the industry (architects, engineers, developers):

- What does early-stage collaboration between architects and engineers look like today?
- What kind of building performance analyses are made in early stages? Which indicators are of importance?
- What do you think needs to change in the process in order to reach increasing demands of energy and daylight in our citites?

The following types of questions were generally asked from researchers:

- What are your thoughts about using building performance simulations in early-stage building design?
- What do you consider to be the most important qualities of such tools?

ARCHITECTS

Collaboration between architects and engineers varies strongly between projects. Architects are generally mostly incorporated in the design process in early stages, when defining the program and main design principles. It is up to the developer or project leader to incorporate input from other consultants. A problem identified in Sweden is that there is an avoidance to incorporate a more integrated design process from the start, although it has been shown to be more financially viable to conduct such simulations in earlier stages. In large architecture firms, building performance information can be acquired in-house, however this is often not in the form of simulation, rather as knowledge from previous experience and approximations. Lots of architects feel like when the project moves on to a detailing phase, they have to "hand over" their influence to engineers and other consultants, not anymore having a say over their developed designs. One interviewer stated that architects need to be comfortable in their own role and invite the input from engineers, consequently designing better performing buildings, enabling it to go throug less changes later on. Another issue can be identified in the detail planning section, where for example daylight analyses are made only after the grids of neighborhoods have been set.

Indoor climate indicators such as daylight, energy demand and overheating were mentioned to be important for early-stage design. Geometric indicators such as floor space index, shape coefficient and window/wall ratio can directly help the architect make decision about the design. Life cycle analysis and indicators for choosing the right materials are of increasing importance.

ENGINEERS

Incorporating collaboration between architects and building performance engineers vary highly, and depend on the ambitions of the developer and architect. The greater the ambition, for example for certifying the building for environmental indicators, the more important it is to incorporate building performance simulations from the start. However, in most cases engineers are not part of the design team when the main decisions are made in early stages, the most common time to be incorporated is in the system phase. One example in England showed a workshop between stakeholders where apartment modules from the architect was tested in a parametric study to see what window placement, room orientation and layout configuration would work best from a building performance stand-point. All stakeholders were able to understand the goals of the project, and the architect was able to walk away from the workshop with a set of drawings for further development of the design. According to the interviewees it is not common to have workshops in the beginning, but that it would be beneficial for all parties. Although no data was shown, it was a common belief that incorporating building performance simulations in early stages would reduce the overall cost of a project in the long run. The McLeamy curve was mentioned in several interviews, both by engineers and architects (see Figure 8).

The most important indicators according to the interviewees are the ones used in certifications, such as BREEAM or Miljöbyggnad.

DEVELOPERS

The developer and architect are the common stakeholders to be involved in the early stages of the design process, whereas other consultants, such as building performance engineers are included later in the process. Ultimately, it is up to the developer to decide who is involved and to gather the team for all stages in the process. There is a wish to get more input about building performance earlier, however unfortunately, economy is a key factor. A project might be a competition where there is no use in allocating time money to simulations if the competition is lost. Despite this, there is a wish to balance conflicting and multi-criteria demands, such as daylight, energy, solar heat load, view from buildings, materials etc.

RESEARCHERS

A key factor in the Swedish industry is that the design process is performance-based, meaning there is one final design that is then simulated in order to understand the performance. There is an incentive to move from a performance-based process to a performance-driven one. Performance-driven means letting performance indicators help making decision about the design. However, there should still be room for the designers to tweak the process and cherry-pick among the suitable options. An identified problem among the tools available today is that they are too slow, fast results are required in order for simulations to be useful in early stages.

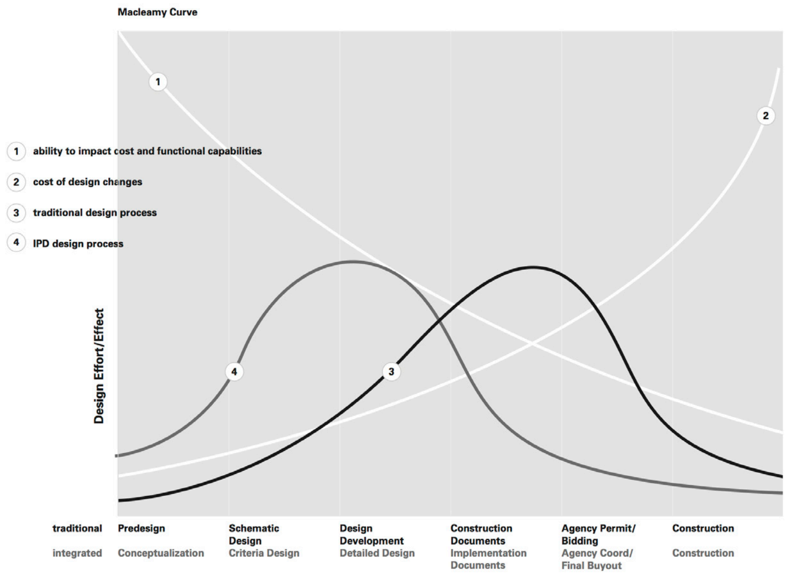


Figure 8. *The MacLeamy Curve, illustrates the benefits of Integrated project delivery (IPD). The graph, illustrated here by the American Institute of Architects, shows a comparison of Integrated Process Delivery (IPD) process with traditional design process in architecture.*

CONCLUSION FROM INTERVIEWS

The Workflow Today

- Architects and engineers are often separated, working in different stages of the design process
- Usually when an engineer is asked to contribute to a project's building performance, the design has already been set
- Usually the process is performance-based, meaning building performance analyses are made on one final proposal
- There are successful examples where the engineer was included from the start, and one important part of a specific project was a workshop with all actors where a multi-parameter analysis was made on different designs
- Including the engineer's expertise in early stages will reduce longterm costs and improve the quality of the final product

Problem Identification

- In Sweden there's an avoidance of cost and time expenditures in early stages
- Architects feel like they have less control over their design when engineers "take over"
- There's a complexity of meeting multiple conflicting demands
- Current simulation technology have a high computational power and accuracy, but are not able to perform analysis fast

Visions for the Future

- To start earlier with daylight and shading analysis is suggested
- If the engineers are able to partake in the design phase, they can support the architects ideas and the clients requests in a better way
- Going from performance-based to a performance-driven design process

CONCLUSIONS FROM OVERVIEW OF AREA

Conclusions that can be drawn from both literature and interviews are that there is a lack of collaboration in the common practice of building design in Sweden. Four important issues, and thus reasons for the lack of collaboration are: 1. Project budget, 2. Distribution of Resposibilities, 3. No common praxis, 4. Usability of BPS tools (see figure 9). The way this thesis tries to solve these problems is to suggest a new interdisciplinary collaboration method for architects and building performance engineers, creating a start for a common praxis, and by further developing BeDOT, a building performance tool to be used by several stakeholders in order to get input in early stages

Project Budget

The project budget does not always allow implementing building performance simulations in early stages.

Distribution of Responsibilites

Engineers, who ultimately are resposible for building performance, are generally not included in early stages of the design process when important decisions about the design are made.

No Common Praxis

There is no common praxis for how and when building performance simulations are implemented in the building design process.

Usability of BPS Tools

The usage of BPS tools requires specialist knowledge and many of the available tools lack in usability.

Figure 9. *Identified main issues causing the lack of collaboration in early stages.*

overview of area

3. POTENTIAL GAPS

BUILDING DESIGN PROCESS IN SWEDEN

Today there is a gap in the industry in the collaboration between architects and building performance engineers. This is especially the case in Sweden, where architects and engineers work mostly in different parts of the process (see figure 10).

Today, you have a developer, or a similar representative who is responsible for the whole process. They then include architects in the beginning, especially in the design phase of the project, whereas engineers are included from the system phase onwards. This means that when engineers are asked to contribute, they will be presented with an almost completed design. When architects are then stepping away from the project in the system and detail phase, they have no control over what will happen to their design. What we suggest is inviting input from the engineer to the early stages of the design process. This would then consequently provide architects with the opportunity to a more well-informed design process, safeguarding the architect's influence in later stages. Our suggested building performance tool is to be used in early stages, providing a platform for collaboration.

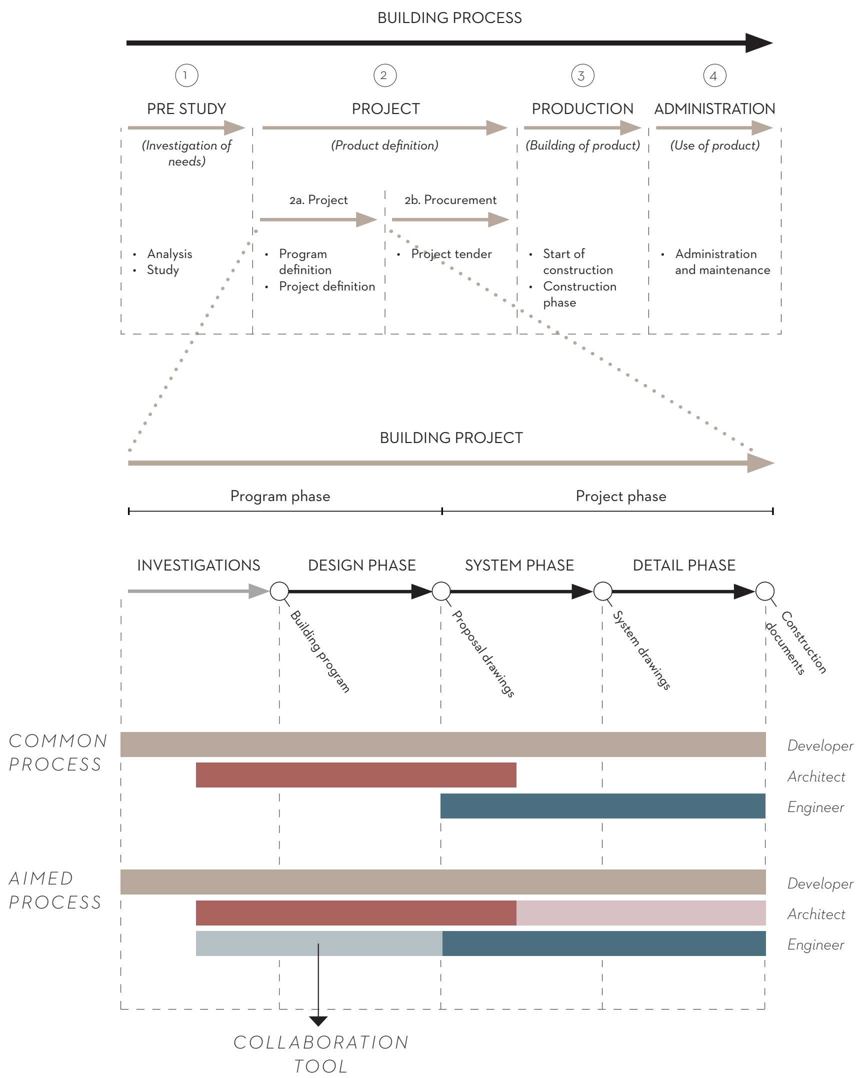


Figure 10. *Timeline of building process in Sweden (Eringstam, Sandahl, 2018), with added diagrams of where different stakeholders are usually incorporated.*

BUILDING PERFORMANCE INPUT

Today, building performance input is usually wanted at the end of the stages, to provide "proof" that the building will work according to regulations. This then causes extra effort and changes, because these aspects were not addressed earlier (Figure 11).

What we propose in stead is an integrated process where building performance input is given continuously, giving the engineers a more even workload, and provide information so that the building is designed using infromation about building performance. The thesis focus is in the beginning of this suggested process.

Figure 11. *Illustration of building performance input in different stages of the building design process*

BUILDING DESIGN PROCESS ABROAD

This thesis focuses on early-stage building design in Sweden. From the interviews we've had some input about these processes abroad, namely from Spain, Germany and the UK. As an example we lift the certification for RIBA in the UK. Each Riba stage has sustainability checkpoints, from the early stages. Meaning that sustainability indicators must be taken into account from the beginning. Meanwhile, in Sweden simulations must only be made when actually certifying the building for BBR or other certification, much later in the process.

WHY A NEW TOOL?

LIMITATIONS OF EXISTING SOFTWARE

This thesis suggests a tool for improving collaboration in early stages. BeDOT has been developed in previous master thesis projects at BDAB. The main idea of BeDOT is to provide fast and feasible simulations, in order to cater for the early stages. The most common tool used today, IDA, is a very accurate building performance tool. However, it needs a detailed design and takes a long time to perform calculations. BeDOT is not suggested to replace the use of IDA, but to compliment the use of BPS tools in early stages.

4. INTERDISCIPLINARY DESIGN METHOD

DESIGN METHOD FORMULATION

A new design method is formulated for early-stage collaboration between architects and building performance engineers. The formulation is in the form of an improved BPS tool, which is a development of the existing tool BeDOT, the choosing of suitable indicators that are important for both professions, a suggested workflow showing where in the architect's design process the tool can provide information, and finally, how these results will be communicated in order for all stakeholders to understand the results.

DIGITAL TOOL: BeDOT

Building Early-stage Design Optimization Tool, BeDOT for short, has been developed at Bengt Dahlgren offices for a few years through several master thesis projects, finally getting its name after the master thesis of Giovana Fantin Do Amaral Silva and Ramón Bergel Gómez in 2018. During the master thesis, BeDOT is further developed by the engineering student Linda Wäppling to accommodate the suggested interdisciplinary design process, where it is used for the back-end simulations of building performance. In order to understand BeDOT on a deeper level, it is recommended to read Linda Wäppling's thesis titled Multi-Objective Building Performance Simulation.

The workflow of the design tool is explained in the following steps (Figure 12)

Input

Input can be given by the developer, architect and the engineer. The idea is for all stakeholders to have a clear view of the project goals. This can be achieved through an initial workshop or other exchange of information. Input information in the shape of sketches, reference project images, the brief of the project and accurate 3D models etc. is added to a common database as a way to log the interdisciplinary process.

Database

The database is where the input data is managed. Form here, the engineer can take the uploaded 3D model from the architect to conduct the building performance simulation. The results from the simulation is entered back into the database, which has an output to the interface.

Back-end Simulations

The building performance is calculated in a back-end simulation that today is represented by BeDOT. Results are entered back to the database for visualizations. A desired future development is to lift out BeDOT from Grasshopper into a cloud simulation tool that is directly connected to the interface.

Interface

The interface is for visualizing the results from the simulation analysis and for comparing options with one another. A wish is for the visualization of the results to be visible in a 3D model similar to the geometric model designed by the architect, to enable all parties to understand the results. A possible future development is to let the interface have its own simple design tool for both simulations and visualizations.

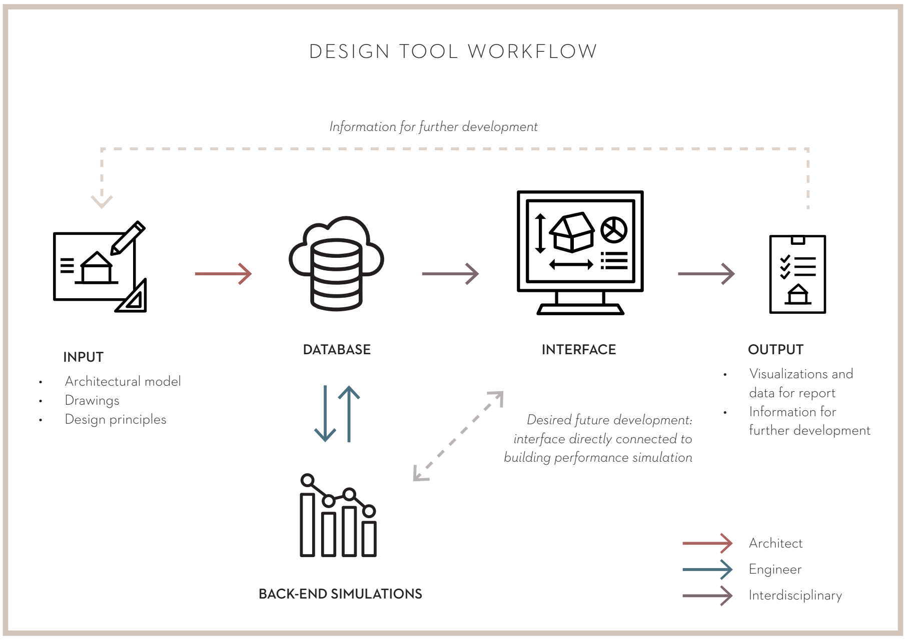


Figure 12. *Diagram of data flow chart in the digital design tool BeDOT*

BeDOT MODELING ENVIRONMENT

BeDOT has been developed at Bengt Dahlgren AB, with a last master thesis giving it its name in 2018. Currently BeDOT is tied to grasshopper, with components of Ladybug, Honeybee, Dayism and self written components in Python (Figure 13). The vision is to one day lift BeDOT out of Grasshopper, possibly into a cloud service, making it more available and adaptable with other modeling environments than just Rhino. For the sake of this master thesis, both the architect and the engineer will be working in Rhino and using BeDOT as a backend simulation in Grasshopper.

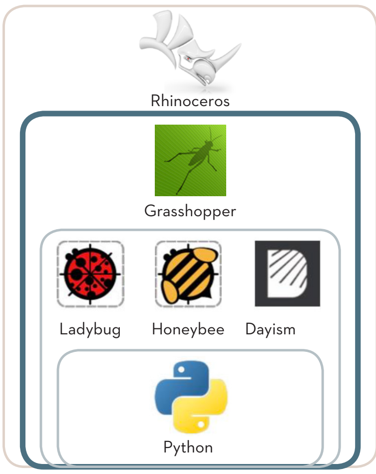


Figure 13. *Diagram of BeDOT modeling environment, used by the building performance engineer.*

DISCREPANCY IN MODELS

Architects and engineers use different modeling tools and methods. What means one thing in the geometry model, might mean something completely different in the calculation model (Figure 14). Therefore, it is vital that the modeling is clearly communicated between the stakeholders. The thesis does not focus on the translation of these models, but it is something that would ideally be further developed in the future. For now, the architect is expected to follow a checklist given by the engineer considering the calculation model (Figure 15). The reason for this is to save time so that the engineer does not have to redraw each model sent by the architect.

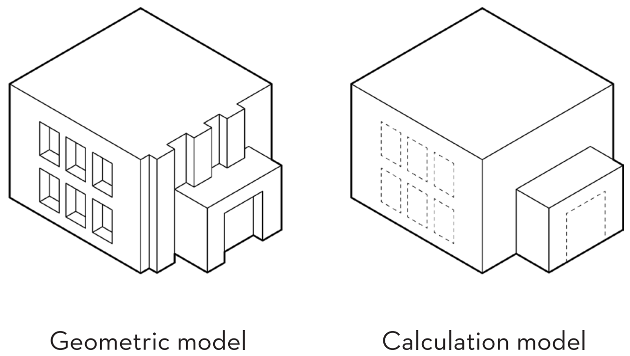


Figure 14. *Diagram of a geometric model in a design tool (left) and a calculation model in a BPS tool (right)*

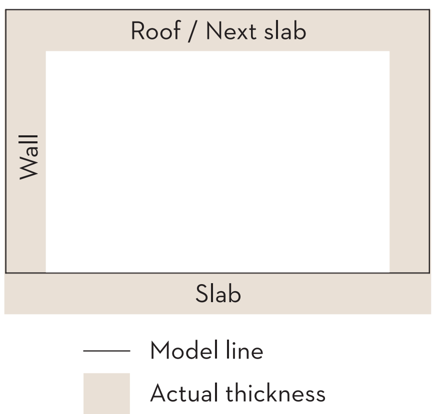


Figure 15. *Possible modeling dilemma considering line representation.*

INDICATORS FOR BPS

Indicators for building performance simulations are chosen with information from the interviews, demands by regulations and input from Bengt Dahlgren. Previous master thesis work has been an influence in choosing these indicators (Jacobsson, Eriksson, 2017). Other indicators are chosen as help-indicators for the design process. The following indicators were considered to be the most important (Figure 16).

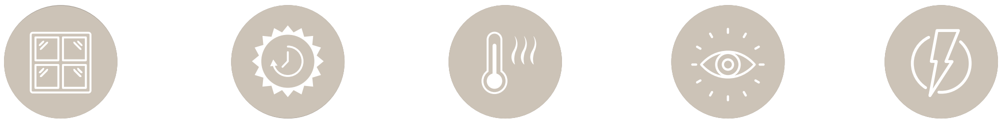


Figure 16. *Main indicators chosen for building performance simulations*

DAYLIGHT FACTOR

Natural light in residential architecture

Humans are profoundly affected by daylight, because light is experienced through the sense of sight, the a predominant human sense (Erwine, 2017). Daylight is a vital factor for human wellbeing, its importance can't be quantified in engineering terms alone. Before the development of artificial light at the end of the 19th century, designing for access to natural light was vital for indoor living and working. In the middle of the 20th century, however, when artificial light and air conditioning were becoming more popular, natural light and air were seen as uncertain sources for a healthy indoor climate. Fortunately, there has been a movement back to natural light. When given the choice, workers will far more often choose to work in spaces with natural light when given the opportunity. Lack of natural light has been shown to decrease productivity, while increasing stress and ailments related to mental and physical health (Phillips, 2004).

Natural light is also an important component in architectural design. The amount, and the way natural light reaches a room defines its identity. Daylight emphasises the surroundings, the materials and atmospheres created in the building. Light can then be seen as a building component in itself. (Zumthor, 2006). As Steven Holl said: "Someone asked me what my favorite material was and I said: 'Light.' I really believe in a certain sense you can sculpt with light." (Erwine, 2017) (Figure 20).

Daylight factor is a regulated demand, where a 1% DF is a minimum for housing in Sweden (Figure 17). Simply put, Daylight Factor is the proportion between the light available outside, and the daylight available inside. With increasingly dense cities it is important to make sure adequate daylight is provided in buildings, and that simulations are made in early stages. Daylight is variable through the year, so the calculations are made in the vernal equinox to give an appropriate middle-ground for the simulations.

Regulation	Daylight factor [%]
BBR	> 1
Miljöbyggnad silver	> 1.2
Miljöbyggnad guld	> 1.5

Figure 17. *Daylight factor demands by different regulations (Boverket, 2015, Swedish Green Building Council, 2017)*

SUNLIGHT HOURS

Access to direct sunlight in the home

Sunlight has for long been considered to have health-promoting benefits. For example, Alvar Aalto's Tuberculosis Sanatorium at Paimio, completed in 1933, was fundamentally a building of large windows and terraces, back when tuberculosis was treated mainly with fresh air and sunlight exposure (Fleig, Aalto, 2014). "Light, air, sun" was a prevailing statement for healthy living, especially in cities where the working class were crammed into small, dark apartments in dense neighbourhoods. "Light, air, sun" were also perfectly suited for the Modernist Movement and its design- and aesthetic principles (Corrodi, Spechtenhauser, 2014). (Figure 21).

When talking about sunlight in architecture, it is often spoken as a factor to be welcomed or to be excluded (Phillips, 2004). In Sweden, a country which is considered far too dark for a large part of the year, it is mainly a question of welcoming the sun. This can also be seen in the new Swedish daylight standard from 2018: ISO SE-EN 17037:2018, which defines a minimum for direct sunlight in apartments. 1.5 hours is defined as minimum and 4.0 hours as high (See figure 18). Sunlight hours measures direct sunlight that reaches the facade without first being reflected. For example northern facades will always struggle to meet the demands due to orientation, but knowing where the facade has good access to sunlight exposure, helps making decisions about how to orientate apartments and other functions in the building, ensuring sufficient sunlight in at least one part of the home.

Level of recommendation	Sunlight exposure [h]
Minimum	1.5
Medium	3.0
High	4.0

Figure 18. *Sunlight hours according to the new Swedish daylight standard (ISO SE-EN 17037:2018)*

SOLAR HEAT LOAD

Assessing overheating

Solar heat load is not a regulated demand in apartment buildings in Sweden. The reason for this is there are no cooling systems in multi-family housing projects that would require energy use. However, it is regulated in Miljöbyggnad, a certification system by Swedish Green Building Council (Figure 19). The reason for choosing Solar Heat Load as an indicator in this thesis, is that it shows risk areas for overheating. By having large windows and lots of sunlight access, you run the risk of having apartments that are too hot from a thermal comfort aspect. Therefore, by knowing where the building risks overheating, the architect has the opportunity to add shading elements (like balconies or shutters) or change the massing in a way that protects the apartments, while still letting in sufficient amounts of natural light (Figure 24).

Regulation	Solar heat load [W/m^2]
Miljöbyggnad brons	< 38
Miljöbyggnad silver	< 29
Miljöbyggnad guld	< 18

Figure 19. *Limits for solar heat load (Swedish Green Building Council, 2017)*

Figure 20. *Daylight: Yi Architects, Stuttgart City Library, Stuttgart, Germany, 2011. Direct and indirect natural light reaching the reading room. Author's own image.*

Figure 21. *Sunlight: Morning sun shining through a window of an apartment in Västra Frölunda, Göteborg. Author's own image.*

OUTLOOK / VIEW

The provider of information and well-being

The view from buildings is the visual connection to the world outside. A view is of significant importance to our mental and physical wellbeing. Having a view from a hospital room for instance, has been proven to help patients recuperate quicker (Phillips, 2004). Outlook and view are defined as the possibility to follow daily and seasonal variations (Boverket, 2014). Views of natural elements, such as forests, water, and cultural and historic elements have a positive impact on human wellbeing (WELL, 2018). A good quality-view does not have to be a vast panorama of a natural landscape, even a glimpse through a small window of the sky, a natural element or the children playing outside, provides us with the information needed about the world outside (Corrodi, Spechtenhauser, 2014) (Figure 25).

Because of its importance to design and final quality of the interior, the view indicator was chosen as a new addition to be simulated in BeDOT. It's defined by how much sky and how much of the quality views are exposed to the building facade (Figure 22). High-quality views are defined by the architect on different sides of the building, by setting up surfaces for the view analysis in the simulation tool (Figure 23).

Level of demand	View access [%]
Low	< 10
Medium	in between
High	> 25

Figure 22. *Levels for view access, defined by the author and engineering student.*

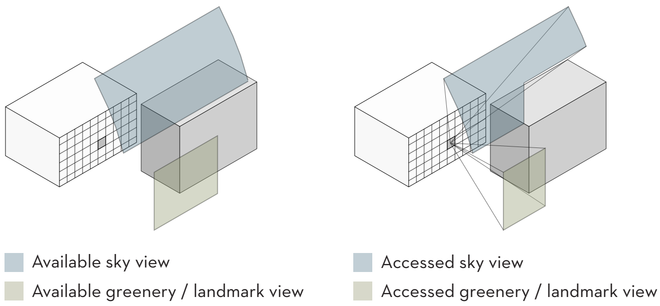


Figure 23. *Illustration showing how the view indicator is defined in the tool*

Figure 24. *Solar heat load: Nieto Sobejano Arquitectos, Castillo De La Luz Museum, Las Palmas de Gran Canaria, Spain, 2013. A concrete slab protecting the fully glazed entrance hall from the sun, with an opening to let light in. Author's own image.*

Figure 25. *View: Ricardo Bofill, Walden 7, Sant Just Desvern, Spain, 1975. View from a courtyard bridge through the building to an olive tree outside the building. Author's own image.*

ENERGY DEMAND

Increasing demands for the environment

Buildings stand for 40% of total energy use, and 36% of CO_2 emissions in the EU (European Commission, 2019). This alone makes Energy demand an important indicator to investigate, and it's always calculated due to regulations. However, not addressing energy in early stages may lead to issues later on. With increasing demands on energy, taking this indicator into account in earlier stages is vital. Energy used for artificial lighting is a large part of the total energy use in buildings. Therefore, by providing more access to natural light, less energy will be needed for lighting systems in the buildings (Phillips, 2004). However, having multiple large windows also come at a cost for energy demand due to heat losses through the windows. There needs to be a balance between daylight and energy, in designing well performing buildings.

Main energy indicators used are EP_{pet} (primary energy demand) and E_{uppv} (energy heating demand). E_{uppv}, which is a part of EP_{pet}, is a good indicator for understanding how much energy is needed only for heating, which is what is mostly affected by the building design. In BeDOT, different modeling methods are used: single-zone and five-zone calculations, depending on the level of detail in the design. The results for energy demand is communicated through a number, which is compared to the demand (Figure 26).

Regulation	EP_{pet} [kWh/m²· year]
BBR	< 80
Miljöbyggnad silver	< 64
Miljöbyggnad guld	< 56
Göteborgs program för miljöanpassat byggande	< 60

Figure 26. *Certification levels of BBR and Miljöbyggnad (Boverket, 2015, Swedish Green Building Council, 2017)*

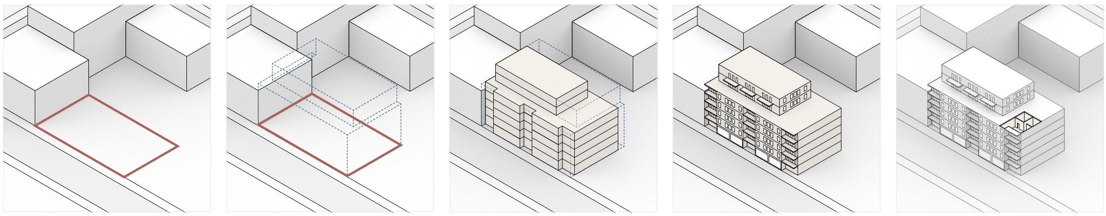
QUALITATIVE INDICATORS

After presenting the five most important indicators, it is important to note that not everything in architecture is, nor should be measurable. There always need to be room for hand-picking design options, merely on the grounds that they're inspiring, poetic, appealing. The point of these indicators is to simply provide information to all parties, to understand where the project is strong considering some indicators, and where it will struggle to reach given demands.

SUGGESTED WORKFLOW

What information can we get and when?

The suggested workflow is a result form discussions about what information the BPS results can provide in which stages in the design process. The stages correlate with levels of detail, or LOD for short. (Lantmäteriet, 2018). The order of the steps is suggestive, the reason for the numbering is the correlation with existing definitions of LOD. A conclusion is that the architect can get answers on all indicators in all stages of the workflow, but as the design gets more detailed, so do the results get more accurate. In this thesis, steps 1-3 of the suggested workflow will be tested in a case study.



0. Site study | *1. Building Envelope study* | *2. Massing study* | *3. Facade study* | *4. Interior study*

0. SITE STUDY

Analysis level 0 is comparable with LOD0, where the outline of the site is analyzed with regards to its placement and surrounding buildings (Figure 27).

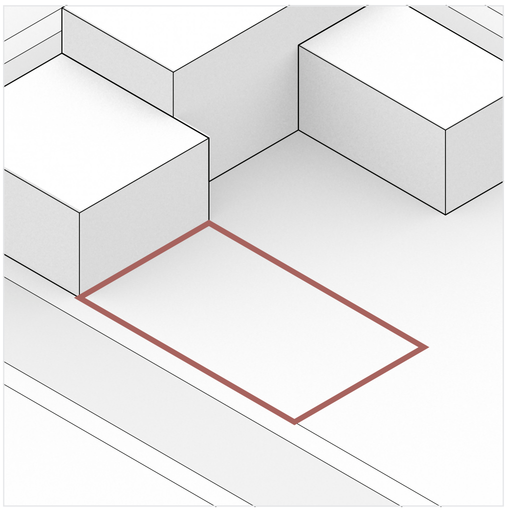


Figure 27. *Example image: Site study*

GEOMETRIC INPUT

- Site outline
- Site building lines
- Surrounding buildings and objects
- Planned surrounding buildings

INFORMATION INPUT

- Geographic conditions
- U-value for windows and walls

ANALYSIS

- Shades on the site
- Shades around the site

USE OF ANALYSIS

- Understanding the interior and exterior solar conditions of the site

1. BUILDING ENVELOPE STUDY

The building envelope study is comparable with LOD1, where the maximum volume of the building, retrieved from the developed detail plan, is analyzed together with its surroundings. The analysis focuses on the outside of the building, before the architect makes their own design (Figure 28).

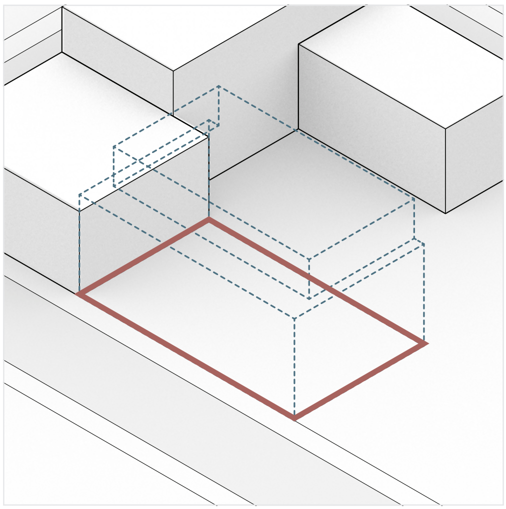


Figure 28. *Example image: Building envelope study*

GEOMETRIC INPUT

- Building envelope from developed detail plan
- Max building volume and height

INFORMATION INPUT

- Initial approximated floor heights
- Aimed gross floor area (BTA)
- Approximative window/wall ratio and room depth
- Definition of attractive views around the site

SIMULATION RESULTS

- Daylight factor on facade [%]
- Sunlight hours on facade [h]
- Solar heat load [W/m^2]
- View/Outlook [%]
- Initial energy use calculation [kWh/m^2]

USE OF RESULTS

- DF on facade is shown as a DF_{mean} value, which can tell where the building might have issues from a daylight perspective
- Base for architect's massing models
- Comparison of results with regulations and demands

2. MASSING STUDIES

The massing studies are comparable with LOD2, however also floor height is taken into account. The idea is to analyze several options. Here the architect can come with first ideas of placement of balconies and window ratios. Knowing the floor height enables comparison of gross floor area and degree of exploitation (Figure 29).

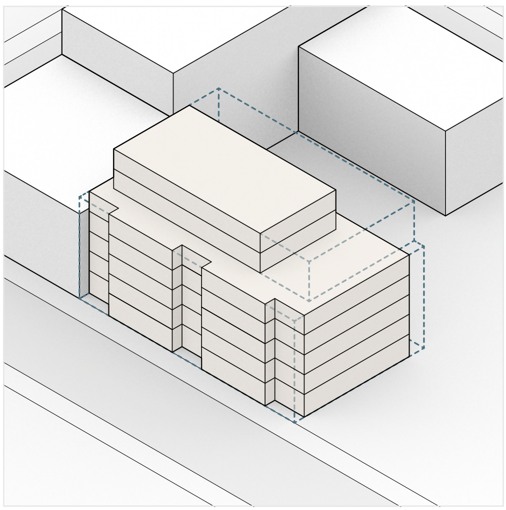


Figure 29. *Example image: Massing study*

GEOMETRIC INPUT

- Several massing options
- Building volume
- Floor heights

INFORMATION INPUT

- Preferred location for balconies or exterior corridors

SIMULATION RESULTS

- Same as in LOD1
- More accurate energy use in a five-zone-model, thermal zones produced by the building performance engineer

USE OF RESULTS

- Compare massing options with one another
- Seeing critical areas of the building that struggle to meet regulations and project goals
- Information for choosing or altering the massing
- Information for facade design: placement of balconies and windows

3. FACADE STUDY

The interior daylight study is comparable with LOD3. In this model the building performance engineer can create virtual rooms to analyze energy and daylight inside the building together with the balconies and windows, if the architect has not yet developed a final floor plan (Figure 30).

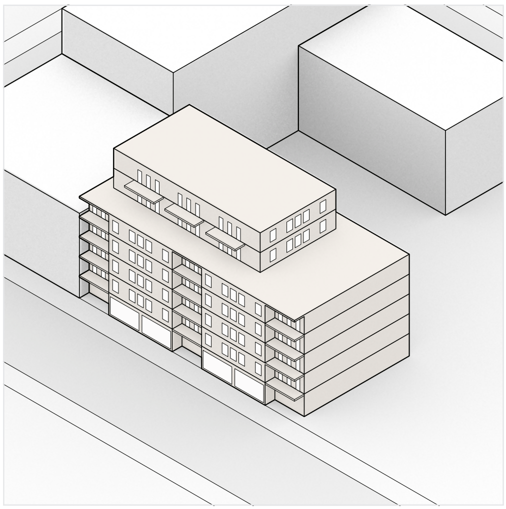


Figure 30. *Example image: Facade study*

GEOMETRIC INPUT

- One or several massing options
- Placement of balconies and windows
- Virtual rooms in critical places in the building, created by the building performance engineer

INFORMATION INPUT

- Room depth from facade
- Room width for virtual rooms
- What kind of rooms will be analysed

SIMULATION RESULTS

- Same as in LOD1 and LOD 2
- More accurate energy use
- More accurate DF, using virtual rooms to understand the inside of the building
- Optimizing the facade related to daylight and energy use

USE OF RESULTS

- Further development of facade design
- For development of floor plan (understanding if the facade design works from an interior perspective)

4. INTERIOR STUDY

The detail study is comparable with LOD4. With a floor plan in place, analyses are made with inner walls taken into account and zoning of the building is in correlation with the floor plan (Figure 31).

Figure 31. *Example image: Interior study*

GEOMETRIC INPUT

- Interior walls
- Light and dark areas in the building (room depth)
- Placement stairwells

INFORMATION INPUT

- Developed floor plans
- Final building volume

SIMULATION RESULTS

- Energy use, detailed calculations
- Daylight, detailed calculations

USE OF RESULTS

- Certification of building
- Final proposal drawings

RESULTS VISUALIZATION

All the BPS results, except for energy demand, are visualized as a coloured mesh on the facade. The mesh is chosen to show traffic light colours - red, yellow and green - in order to easily understand where the building is performing well, where it struggles and where larger alterations need to be made in order to reach building performance demands (Figure 32). If this was in an interface, it would be an interactive model to spin around in, however in the thesis, the results are presented from four different directions of the building site. The limits for the colours are 20% above and below a given demand, while yellow is a buffer zone. When choosing the demands from an early stage, all the stakeholders are in agreement of the project's ambitions: if the wish is to simply meet regulations, or certify the building to a higher standard.

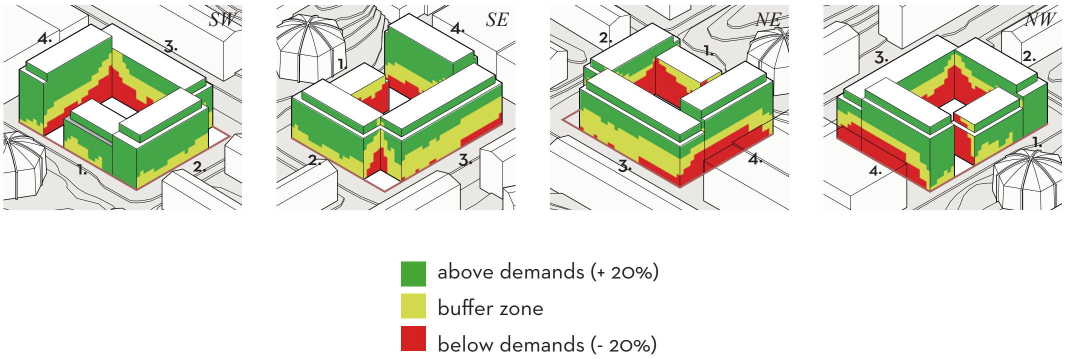


Figure 32. *Example of results visualization showing the building from four different directions*

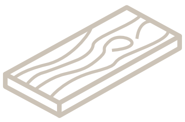
5. CASE STUDY

HOUSING COMPETITION: GIBRALTARVALLEN

The chosen case study is a competition for land allocation in Gibraltarvallen in Gothenburg, that was conducted in 2017. Gibraltarvallen is located at Chalmers University of Technology, 2.5 kilometres south of Gothenburg city centre (Figure 34). The competition ended with two winning proposals, one for each plot. The case study was chosen because its focus on early-stage design, and because BDAB was allocated as a building performance consultant in one of the winning proposals.

There is a developed detail plan in place, which is currently under its last revision (Figure 35). The brief asks for apartments larger than studios, and public activities in the ground floors to contribute to the urban life in the area. The competition specifies a residential building in wood, to encourage more wooden building in Gothenburg. Another important point is naturally sustainability, and the brief mentions that all proposals are to follow Gothenburg's program för sustainable building (Göteborgs program för miljöanpassat byggande), which specifies quite high regulations, for example for energy demand. The main points taken from the brief can be read in Figure 33.

The point of the case study is to explore the developed design workflow and building performance tool. The idea then, is not to fill all the requirements of the competition brief or arrive at a proposal for the competition, rather it is used as a base for the development of the massing and facade iterations in the case study.



BUILDING IN WOOD

- Housing in wood
- Wood as structure and as cladding
- Awareness of site and surroundings
- Advocate for building with wood in Gothenburg

GOOD QUALITY HOUSING

- Apartments for families with children and adolescents
- Shared outdoor areas: patios, entryways, playground
- Common areas for waste management, yard management, laundry room and bike storage
- Smart, efficient apartments
- 2 plots, with 60-80 apartments in each
- Larger apartments are of interest
- Only 5% studios or one bedroom apartments
- 14 000 m^2 gross floor area (BTA)

SUSTAINABLE BUILDING

- Innovative ideas for energy use and material choices
- Ease for sustainable living for the residents
- Seeing the building as a system
- Following Gothenburg's program for sustainable building

Figure 33. *Main points retrieved from the competition brief in Gibraltarvallen*

Figure 34. *Aerial photo of Gibraltarvallen, Gothenburg, 1:2000. Base image retrieved from Google Earth Pro.*

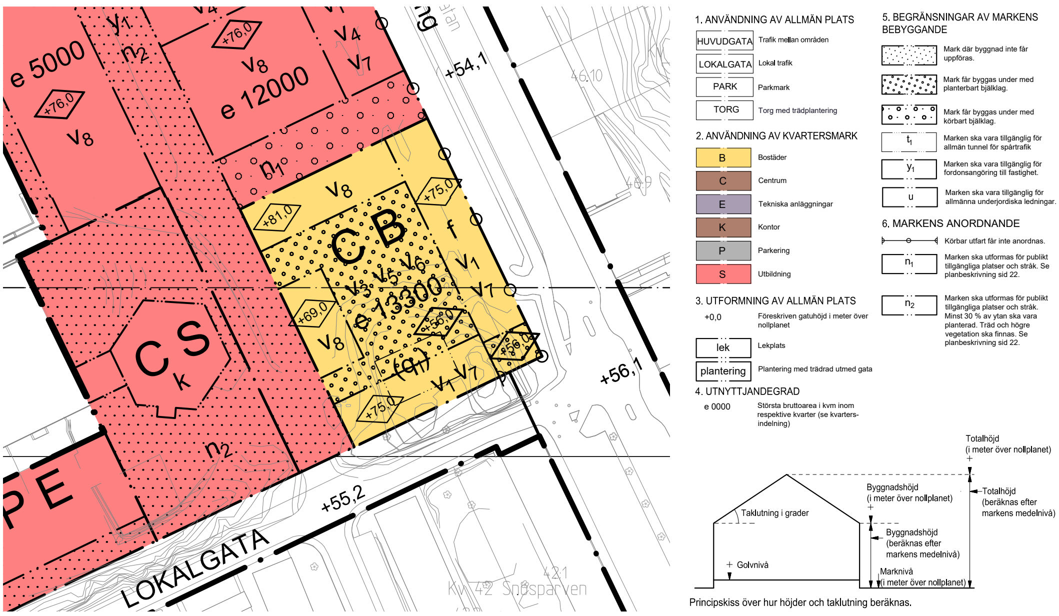


Figure 35. *Developed detail plan Gibraltarvallen 1:2000. (Göteborgs Stad, 2018).*

EARLY INVESTIGATIONS

The case study started with some early investigations about the design problem at hand. I was found to be important to leave room for more traditional design methods used by architects. Therefore in the early investigations, the project concept was explored through sketches and models (Figures 37-39).

MASSING

A decision was made to include the building to the north of the site in all building performance simulations (Figure 35). There is already a developed detail plan in place, and a decision was made to follow this detail plan in the massing studies (Figure 36). Massing options have a large effect on the final design and performance of the building. Making several massing options is a common practice in early-stage design for architects. Adding then building performance to those options in order to compare them with one another, can provide architects with vital information about which option will work best for the design problem at hand.

FACADE DESIGN

Equally important as the massing, facade design affects the building performance and final aesthetic qualities of the building. Considering facade design, here we are mainly talking about size and placement of windows and balconies, as well as window/wall ratio. The impact on building performance indicators, as explained in the last chapter, are strongly affected by the final design of the facade. Large windows bring good outlook, daylight and sunlight access, however impact negatively on solar heat load and energy demand, due to energy losses from windows. Therefore, it's important to conduct calculations on the different facade options, to find an ideal balance for windows, light access and shading.

Figure 36. *Site model, built in scale 1:500*

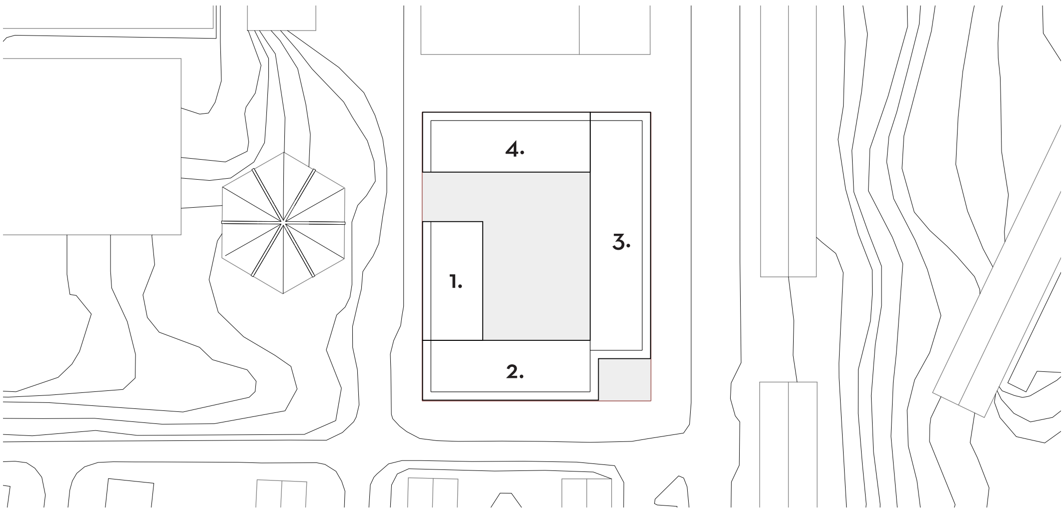


Figure 36. *All building volumes according to the developed detail plan.*

Figure 37. *Variation in the facade through use of materials, going from dark to light, private to public.*

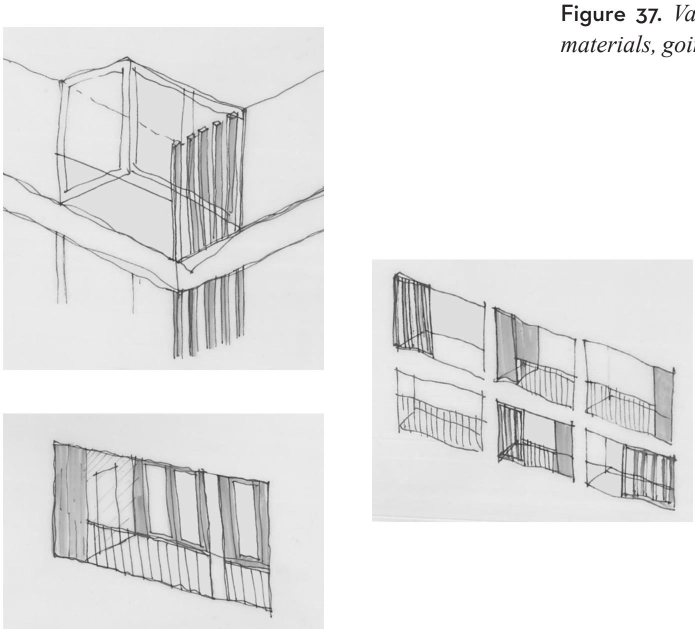


Figure 38. *Sketches for balcony design*

Figure 39. *Collage of images from facade models: Bottom floor dedicated to different public or semi-public functions, whereas upper floors are dedicated to housing.*

ITERATION SETUP

The objective of the iterations is to explore changes in building performance through design options. The idea is not to come to an optimal design solution, but to evaluate the suggested workflow and tool through a case study. Four building volumes are designed in different massing options, according to the developed detail plan. The numbering of the building volumes can be seen in Figure 36. Building 1: facing Gibraltarvallen and "Kopparbunken", Building 2: facing Engdahlgsgatan and "Barnahemmen", Building 3: facing Gibraltargatan and Johanneberg, Building 4: facing the suggested building from the developed detail plan, where there today is a parking lot.

The options in one iteration stage are not results of one another, therefore there is no optimization taking place. Multiple options were delivered to the engineer to be simulated for the given indicators. Results were then discussed together with the engineer, comparing the options with one another.

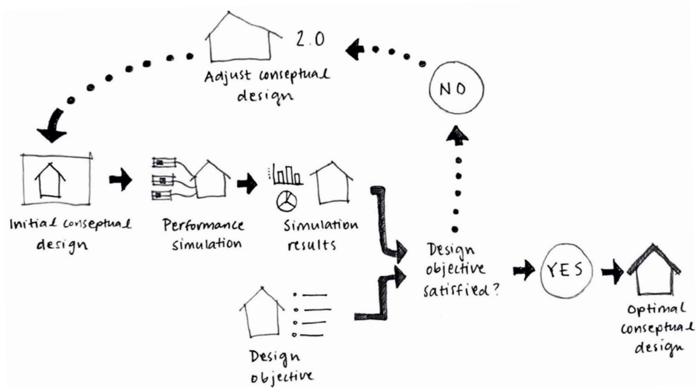


Figure 40. *A sketch showing what an iterative process could look like, if continued in further research*

1. ***Building Envelope Study***

Iteration 1.0	Building envelope

2. ***Massing Studies***

Iteration 2.1	Massing option 1
Iteration 2.2	Massing option 2
Iteration 2.3	Massing option 3

3. ***Facade Studies***

Iteration 3.1.0	Facade option 1.0
Iteration 3.1.1	Facade option 1.1
Iteration 3.1.2	Facade option 1.2
Iteration 3.2.0	Facade option 2.0
Iteration 3.2.1	Facade option 2.1

Figure 41. *All iterations conducted in the case study*

ITERATION 1.0

Building Envelope Study

The first building performance simulations are made for the building envelope - the biggest allowed building volume according to the developed detail plan. Geometric input comes from the detail plan, while information input (U-values, G-value and window/wall ratio) comes from the building performance engineer. At this stage, the idea is to identify how well the building performs with a completely filled building envelope, with a standard facade design and room depth.

Information input:
- Floor to ceiling-height: 3.2 m
- Slab thickness: 0.3 m
- Window/wall ratio: 30%

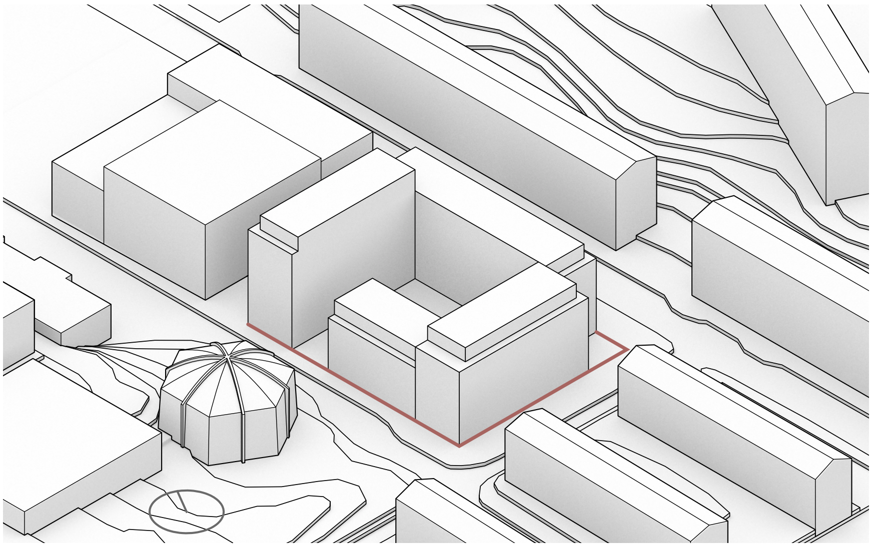


Figure 42. *Axonometric view of building envelope from South-East*

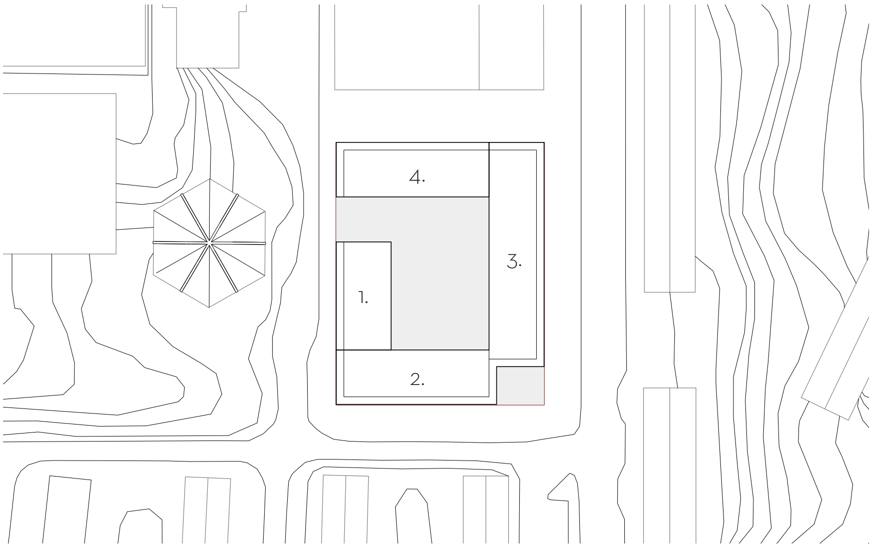
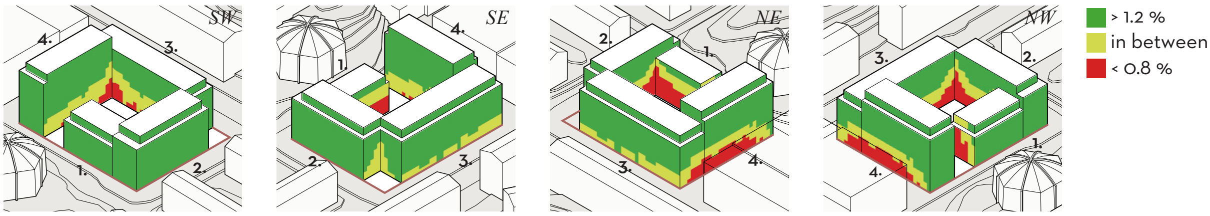


Figure 43. *Site plan, 1:2000*

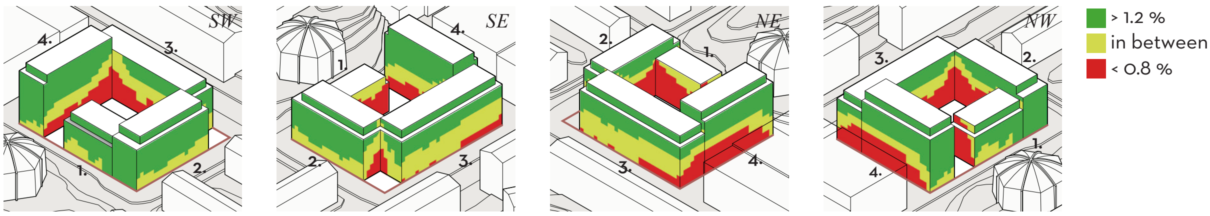
Figure 44. *Massing model images, building envelope*

RESULTS ITERATION 1.0: BUILDING ENVELOPE

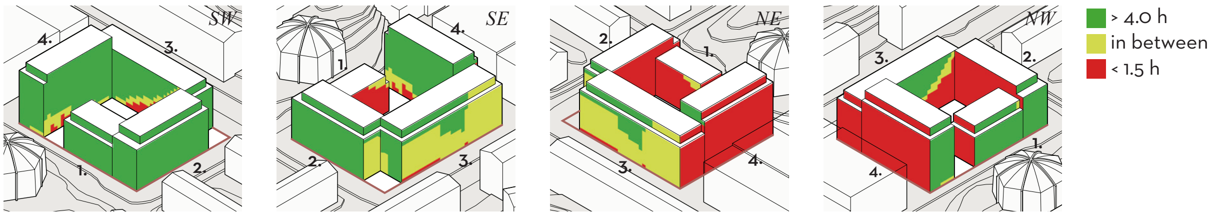
DAYLIGHT FACTOR (Room depth: 5 meters)



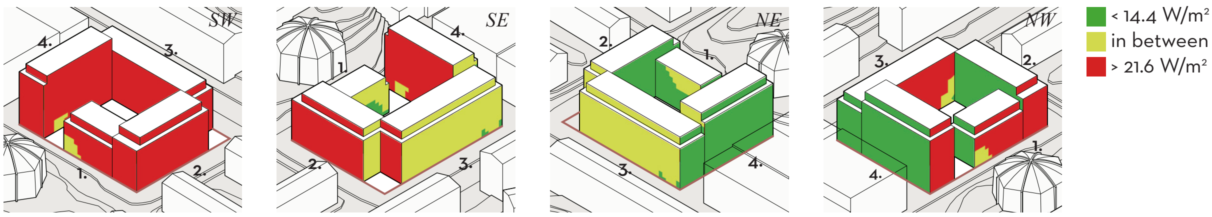
DAYLIGHT FACTOR (Room depth: 7 meters)



SUNLIGHT HOURS



SOLAR HEAT LOAD



VIEW ACCESS

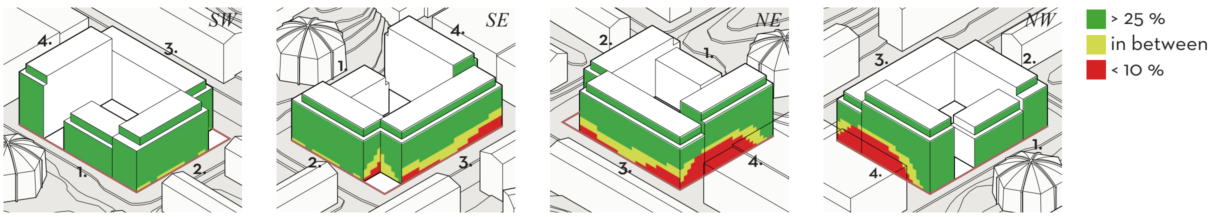


Figure 45. *Result visualization from BPS analysis, iteration 1.0*

DAYLIGHT FACTOR

The reason for poor daylight conditions is the density of the site and proximity to surrounding buildings, especially in the north where a new building is planned according to the detail plan. Inner corners in the courtyard have bad daylight conditions, as do some lower parts of the facade.

SUNLIGHT HOURS

Northern facades will always struggle to meet the demands due to orientation. High buildings along Gibraltargatan block some direct sun from the east, but the facade still attains medium to high sunlight exposure. Facades facing the courtyard (except toward south and partly to the west) will struggle to reach direct sunlight.

SOLAR HEAT LOAD

Solar heat load looks like it would be an issue, however the limits chosen for the building performance simulation is to miljöbyggnad guld, a very high demand. Facades towards south and west struggle the most to reach demands, showing a risk for overheating. Street facade toward the east might face some difficulties, but should be able to be mended with minor alterations.

VIEW ACCESS

The lower part of the street facade of building 3 struggles with view, this is due to the low placement and struggle to exposure to the sky. However, the northern facade of building 4 is the one with the most red. This is due to the obscuring building to the north, and the narrow street that the two buildings create.

ENERGY DEMAND

The calculated energy demand, EPpet is 73.7 kWh/m^2, of which E_{uppv} is 18.7 kWh/m^2. Meaning that, even if we would lower E_{uppv} a bit, it would still be hard to reach the goal of Gothenburg's assigned Energy demnand of 60 kWh/m^2, which is a high demand to begin with.

CONCLUSIONS

Generally a good exposure to sunlight, especially towards south and west. The massing will have to be modified to attain a suitable DF in all parts of the building. Lowering some of the buildings and/or making apertures in the building volume might give better daylight conditions. Double-aspect apartments could be a solution for having satisfactory daylight in at least one side of the apartment, since most buildings vary strongly between their longest facades. Alternatively to make the entire building more shallow, decreasing the room depth and through that enabling more daylight to reach further into the building. Balconies are most suitable in the facades toward south and west since most sunlight exposure is located there.

REVIEW

The building envelope study showed clearly where in the building there might be issues with reaching set demands in chosen indicators. Getting these kinds of answers already for the building envelope, without having to first design something themselves, gives great insight both for the architect and the building performance engineer about the conditions of the site and the project at hand. Granted, these calculations were made using standard values and the results might change if there were different input data. The decision to take into account the planned building in the north, has a strong impact on all indicators for that facade.

MASSING STUDIES

ITERATION 2.1

Massing Study: Option 1

The main concept of massing 1 is opening up the courtyard volume from the building envelope, by making building 3 it's own volume. All building volumes are also stepped, to bring more light into the street and simultaneously creating long terraces on the upper floors.

BTA: 14 426 m^2

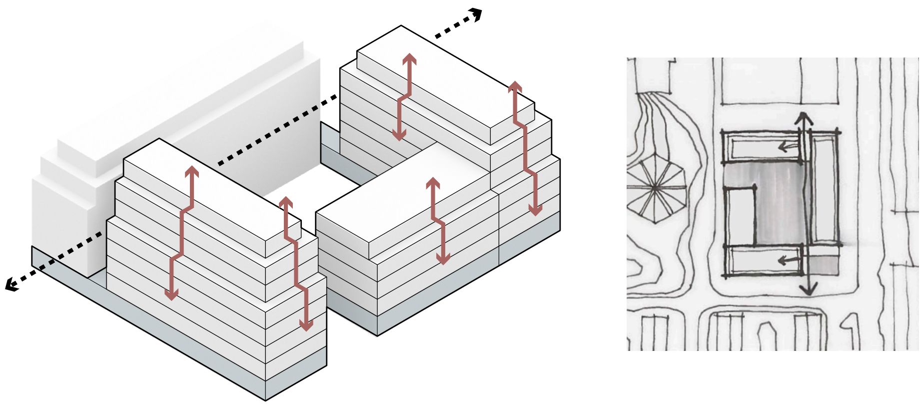


Figure 46. *Concept diagrams of Massing option 1*

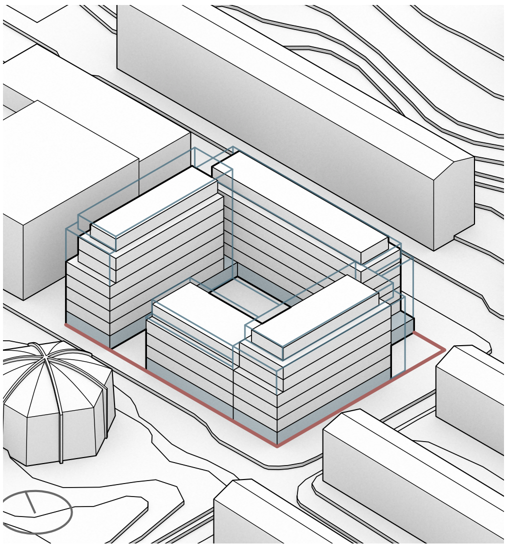


Figure 47. *Axonometric view of Massing 1 from South-East*

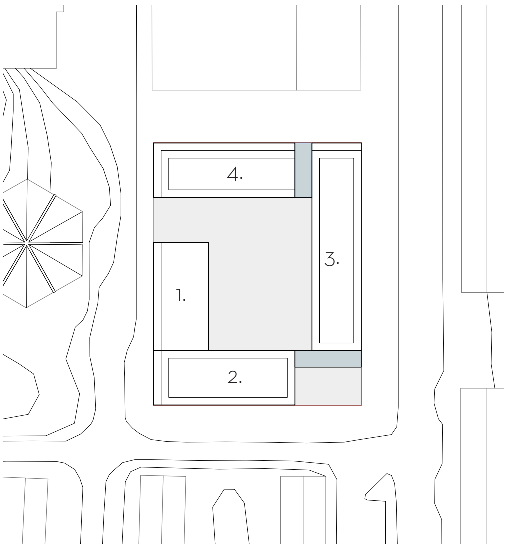


Figure 48. *Site plan, 1:2000.*

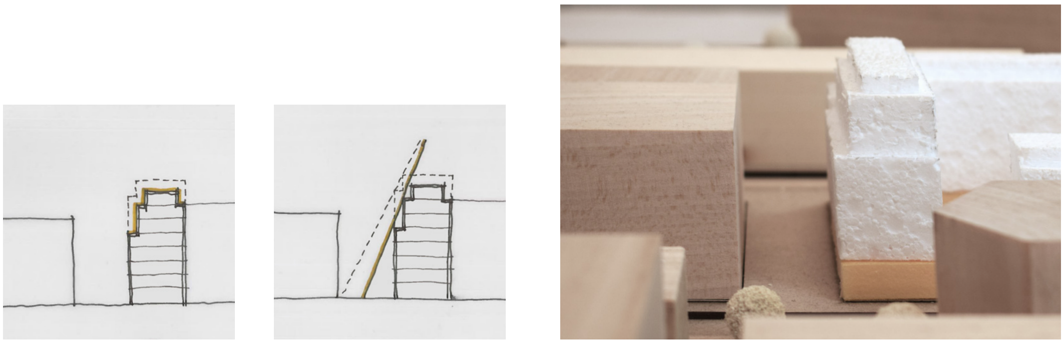
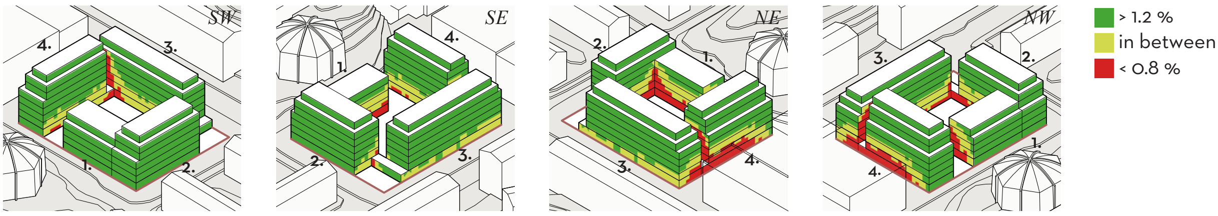


Figure 49. *Section sketch showing how lowering the building and stepping the volume provides more light in the narrow street to the north*

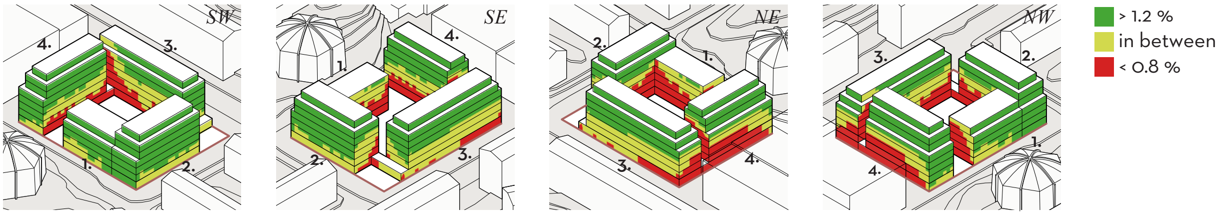
Figure 50. *Opening a gap between building 2 and 3, and between building 3 and 4, provides some light and insight to the courtyard, while the translucent bottom floor keeps the courtyard private. What is visible in the physical model is that these gaps are actually quite narrow and might not have such a strong impact.*

RESULTS ITERATION 2.1: MASSING 1

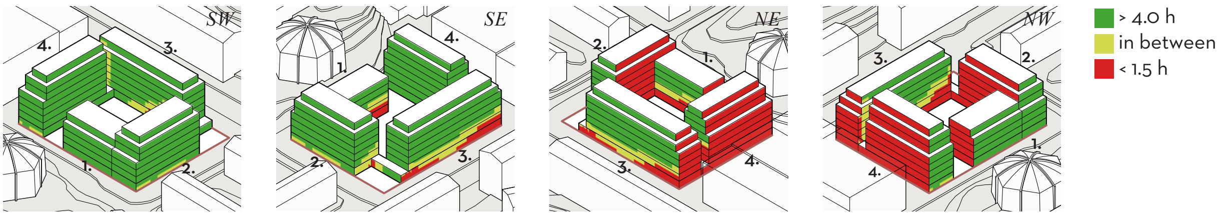
DAYLIGHT FACTOR (Room depth: 5 meters)



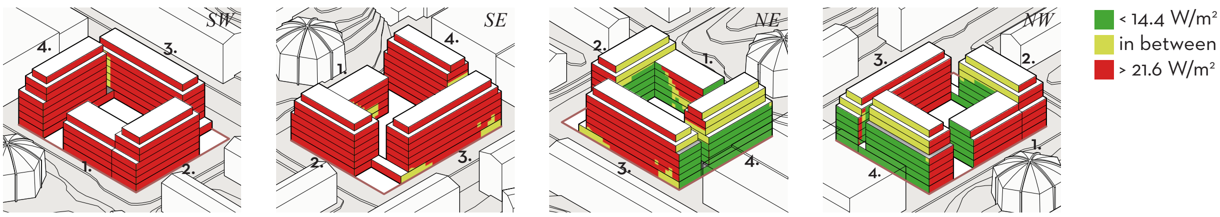
DAYLIGHT FACTOR (Room depth: 7 meters)



SUNLIGHT HOURS



SOLAR HEAT LOAD



VIEW ACCESS

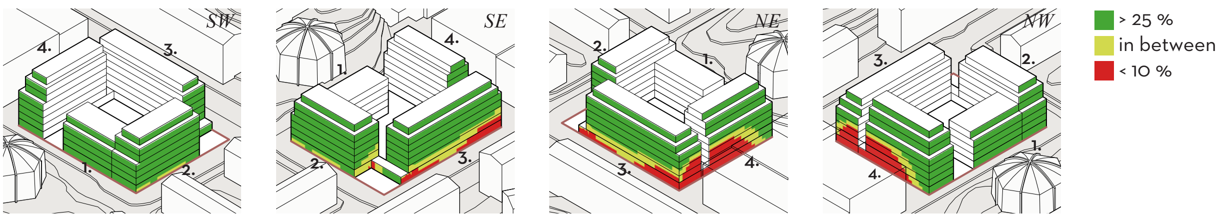


Figure 51. *BPS results from iteration 2.1: Massing option 1*

DAYLIGHT FACTOR

There's clearly more daylight after splitting the geometries, by letting building 3 stand on it's own. The hoped affect with lowering and stepping the building volume to the facade to the north is not that clear. However, had there been a sunlight study for that street it might show that there's more access to daylight after all. The best daylight conditions are of course at the top of the buildings.

SUNLIGHT HOURS

Sunlight hours has improved because of the openings between the buildings, specifically in the western courtyard facade of building 3. The terracing shape of the buildings makes so that it does not shade itself as much, for instance in the courtyard.

SOLAR HEAT LOAD

The results from solar heat load seem inconsequential and hard to compare. A reason might be the high demand set for the building performance simulation, which in this case is miljöbyggnad guld. Solar heat load is supposed to show areas in the facade that risk overheating, since there is no cooling used in housing in Sweden. This indicator might need to be reviewed in the further development of BeDOT.

VIEW ACCESS

View access has not changed a lot, in the building envelope study and massing studies there were no measures made for the courtyard facades. However, this might have been a good indicator for seeing how much sky can be seen from each facade, which would be an attractive quality for the residents.

ENERGY DEMAND

The results from the energy demand in massing 1 compared to the building envelope are more pessimistic. In the massing studies, a more accurate calculation model is used. Another reason for the weaker results is the massing itself, since it has a more complex geometry and more facade area.

Building	EP_{pet} [kWh/m², year]	E_{uppv} [kWh/m², year]	E_{kyl} [kWh/m², year]	A_{temp} [m²]	Solar heat load [W/m²]
1.	87.3	30.8	6.1	1 911	18.4
2.	86.3	30.0	7.4	3 317	30.7
3.	84.4	28.2	6.9	4 503	29.3
4.	85.8	29.6	7.7	3 691	30.6
All	85.7			13 422	

ITERATION 2.2

Massing Study: Option 2

The main concept of massing 2 is vertical slits going up and down the exterior facade. The massing is very similar to option 2, however with added interest, especially on the long facade to the east facing Gibraltargatan, where the slits now break up the volume.

BTA: 12 183 m²

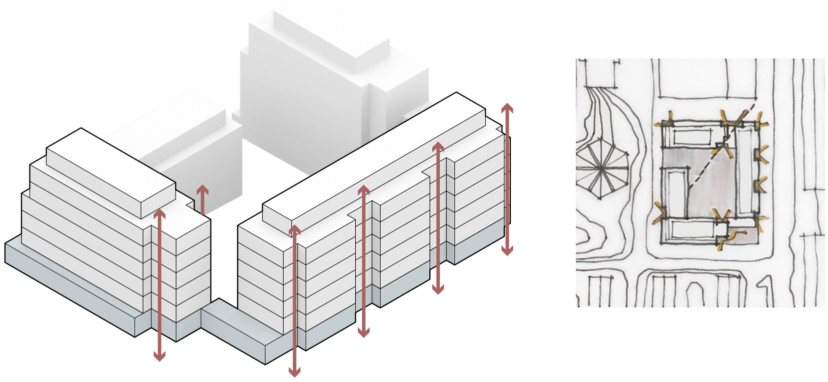


Figure 52. *Concept diagrams of Massing option 2.*

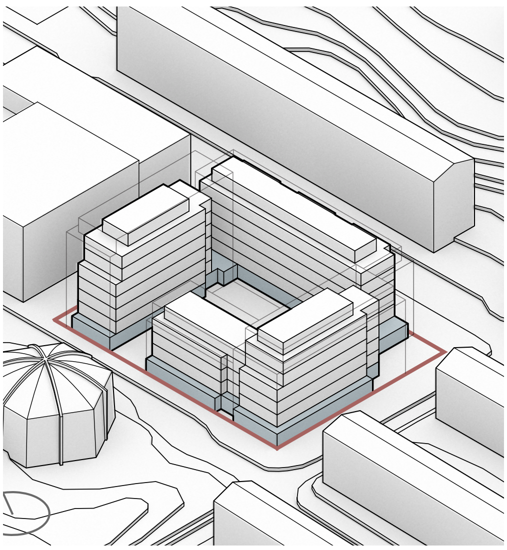


Figure 53. *Axonometric view of Massing 2 from South-East*

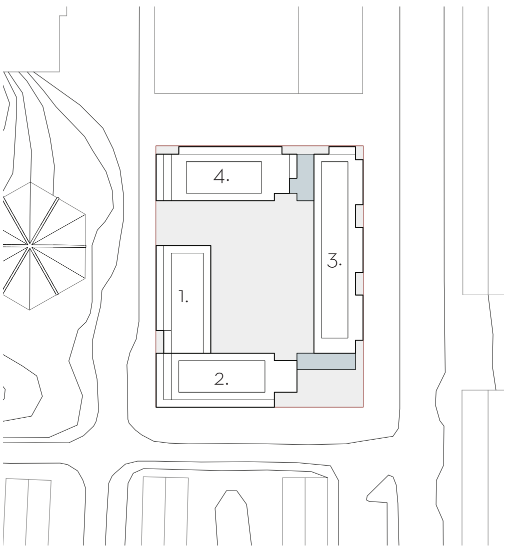


Figure 54. *Site plan, 1:2000.*

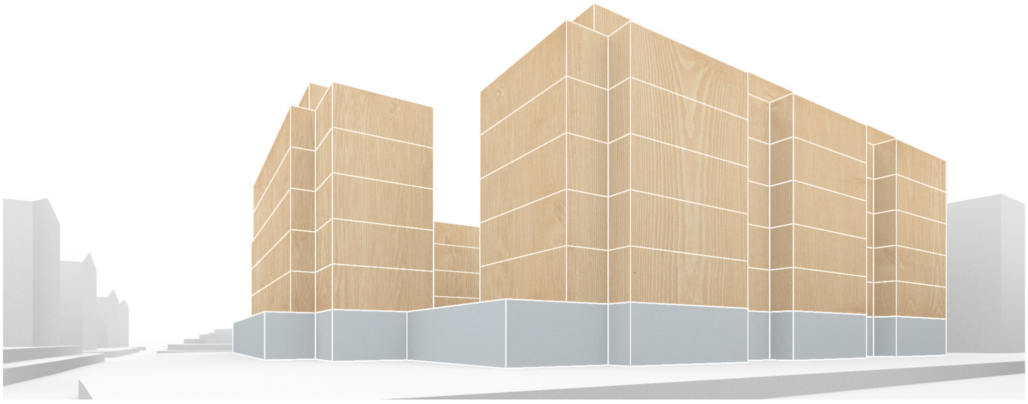


Figure 55. *Collage-diagram of massing option 2*

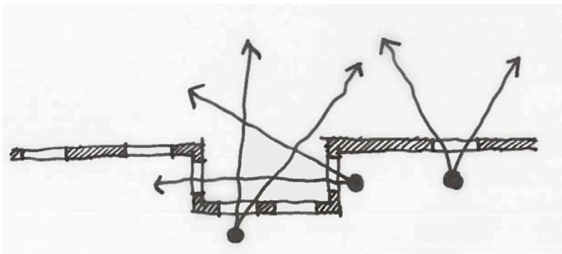
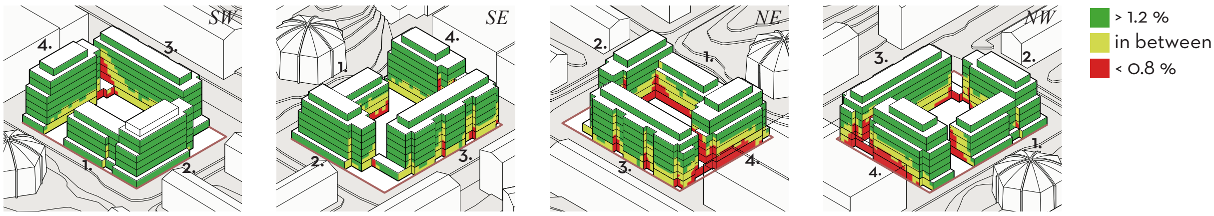


Figure 56. *The vertical slits offer corners to add windows, welcoming views from several directions.*

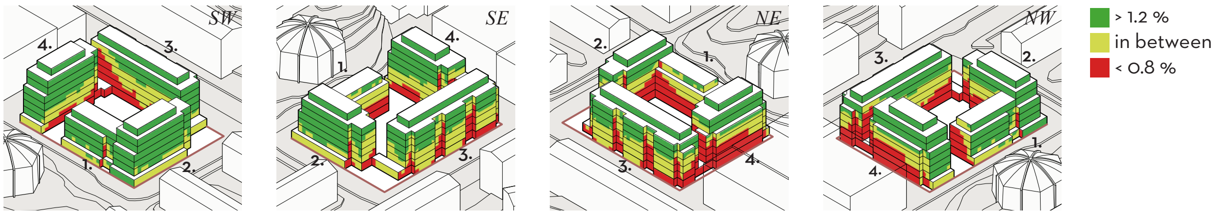
Figure 57. *The stepping volume together with the slits add more interest to the overall massing.*

RESULTS ITERATION 2.2: MASSING 2

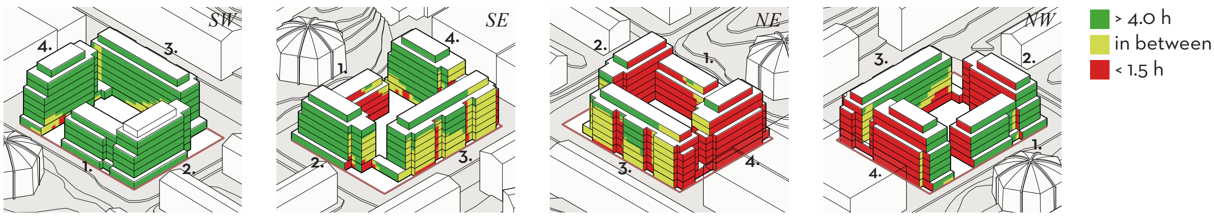
DAYLIGHT FACTOR (Room depth: 5 meters)



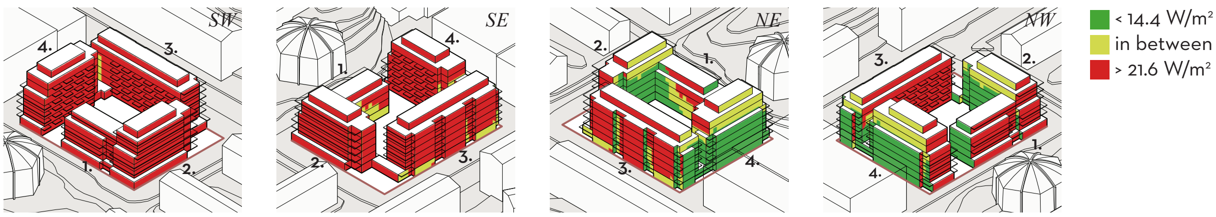
DAYLIGHT FACTOR (Room depth: 7 meters)



SUNLIGHT HOURS



SOLAR HEAT LOAD



VIEW ACCESS

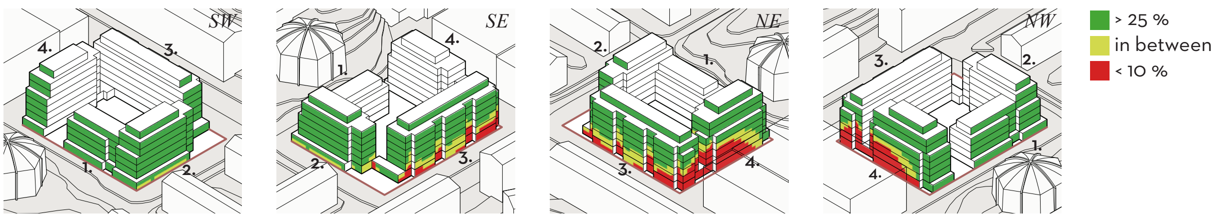


Figure 58. *BPS results from iteration 2.2: Massing option 2*

DAYLIGHT FACTOR

The massing is very similar to option 1, with added vertical slits in the facade. What this ends up affecting is the building shadowing itself in those slits. These slits could be possible placements for balconies, however from these studies it would be hard to tell exactly how this options would work.

SUNLIGHT HOURS

Sunlight hours differ quite a lot between option 1 and two, especially in the southern, eastern and western facades. It seems in the eastern facade it's the morning sun that doesn't get to access the building with direct sunlight. The slits in the eastern facade won't have any access to sunlight in the facades, but might work as places for balconies with morning sun.

SOLAR HEAT LOAD

Solar heat load in massing 2 very similar to massing 1, where the conclusion was made that the demand was set quite high. However we can see areas where shading might be needed in the facade.

VIEW ACCESS

The eastern facade has worse view results due to the cutouts, however the niches that are created might be attractive in other ways. However, if the vertical slits are seen as an attractive attribute the design would be stronger if they were more frequent in the facade, creating a stronger grid and design concept.

ENERGY DEMAND

Energy results from massing 2 are worse compared to massing 1. The adding of facade are by having a more broken facade creates a higher energy demand, quite far from 60 kWh/m^2 as recommended by the program for green building in Gothenburg.

Building	EP_{pet} [kWh/m², year]	E_{uppv} [kWh/m², year]	E_{kyl} [kWh/m², year]	A_{temp} [m²]	Solar heat load [W/m²]
1.	93.5	36.5	6.3	1 543	25.4
2.	88.6	32.1	7.1	2 538	29.6
3.	88.3	31.8	6.6	4 069	43.3
4.	89.1	32.5	7.1	3 166	32.1
All	89.3			11 316	

ITERATION 2.3

Massing Study: Option 3

The main concept of massing 3 is a modular structure pushing in and out of the building volume, creating a stepping shape toward the top for better daylight, and offering terraces and balconies in the massing itself for all apartments. The third massing options offers more variation than the first two options. A concept would be that all apartments are offered corner windows in the extruded parts, balconies and lost of daylight. The BTA is significantly smaller than in the other options, but the hoped better values for daylight and the quality of balconies might be a selling point.

BTA: 11 286 m^2

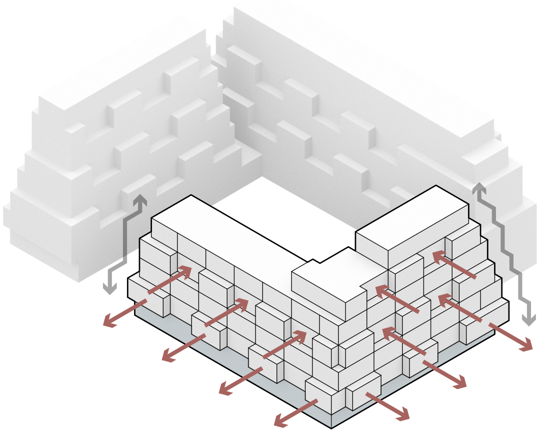


Figure 59. *Concept diagram of Massing option 3*

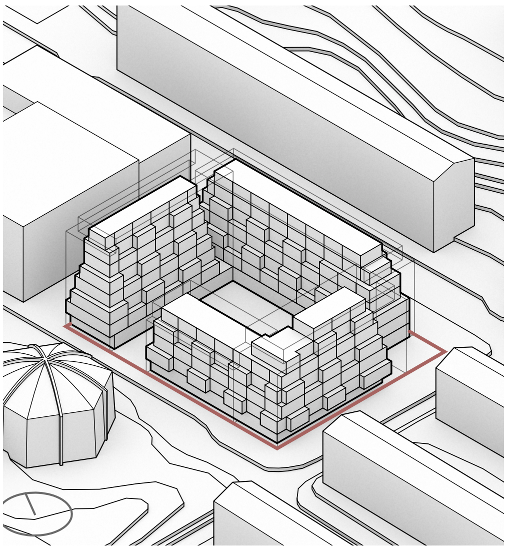


Figure 60. *Axonometric view of Massing 3 from South-East*

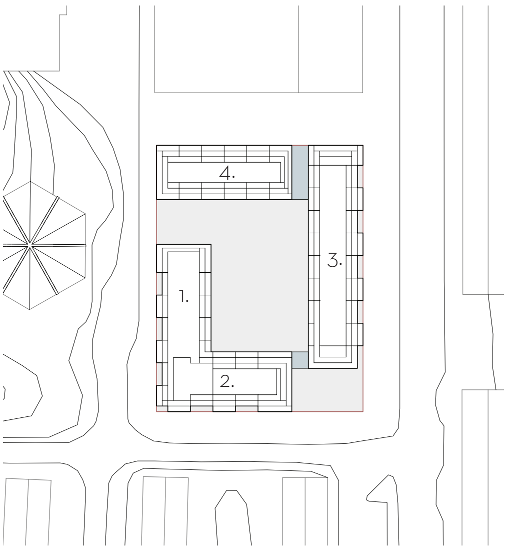


Figure 61. *Site plan, 1:2000.*

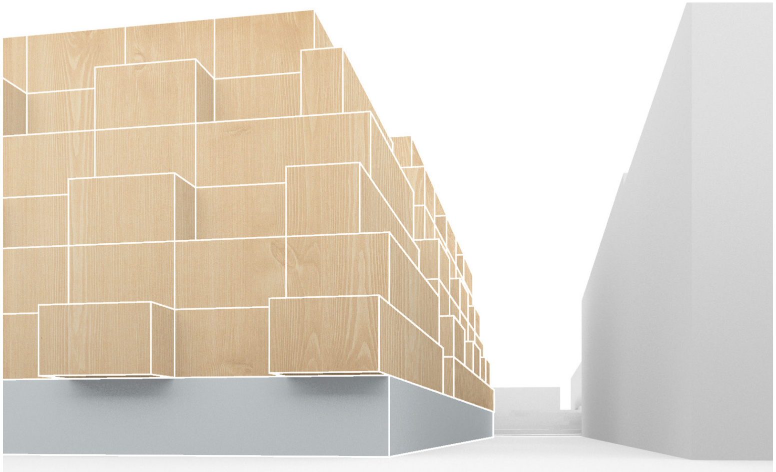
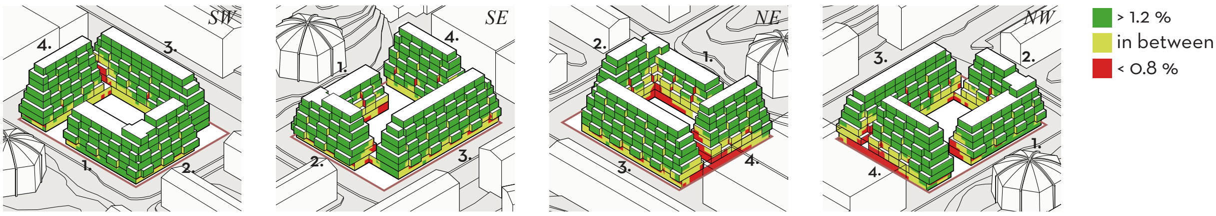


Figure 62. *Collage-diagram of massing option 3*

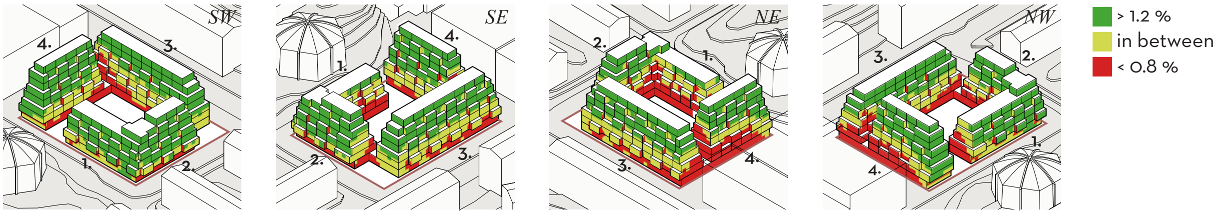
Figure 63. *The stepping volume together with the slits add more interest to the overall massing.*

RESULTS ITERATION 2.3: MASSING 3

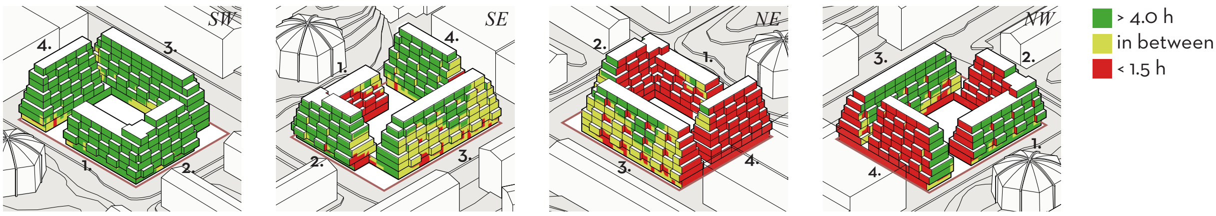
DAYLIGHT FACTOR (Room depth: 5 meters)



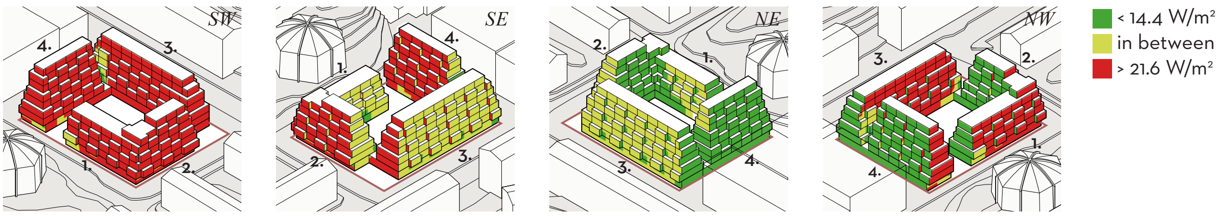
DAYLIGHT FACTOR (Room depth: 7 meters)



SUNLIGHT HOURS



SOLAR HEAT LOAD



VIEW ACCESS

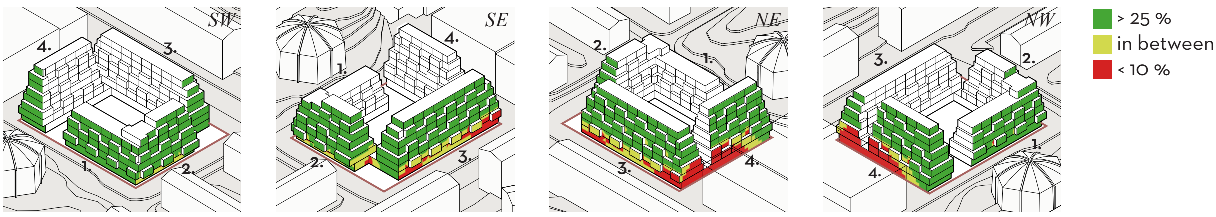


Figure 64. *BPS results from iteration 2.3: Massing option 3*

DAYLIGHT FACTOR

Daylight factor looks strong in option 3, however there's always a trade-off. The option slopes to the top, meaning there's less floor space in the top floors where the conditions are better for daylight. The massing makes for less BTA, however all apartments get terraces.

SUNLIGHT HOURS

Sunlight hours are similar to options 1 and two, yet slightly better in some areas. The attractive things about this design is that it offers balconies already in the massing itself, without the need of adding additional balconies that might shadow from sunlight.

SOLAR HEAT LOAD

Results looks more like the building envelope results, and better than in option 1 and two, which is unclear why, most likely there should be a larger solar heat load because of this massing. The indicator of solar heat load has shown to be challenging, although the idea of it could have a great impact for the design process.

VIEW ACCESS

View indicators still look very similar to the other massing options.

ENERGY DEMAND

Energy results are, as expected, the worst in this massing option. The intricate building volume and facade solution makes for a much higher form factor, which consequently gives a higher energy demand. E_{uppv} is higher which shows that the reason for this demand lies in the massing and design of the building.

Building	EP_{pet} [kWh/m^2, year]	E_{uppv} [kWh/m^2, year]	E_{kyl} [kWh/m^2, year]	A_{temp} [m^2]	
1.	99.1	41.5	5.0	1546	
2.	94.0	36.9	6.3	2275	
3.	94.6	37.4	6.3		
4.	100.2	42.5	6.4	2666	
All					

CONCLUSION FROM MASSING STUDIES

The decision of sticking of the developed detail plan led there to not be large differences in building performance indicators between the different massing options. Ultimately, the BPS made for the building envelope already provided lots of information for the development of the massing, facade and interior desgn of the building.

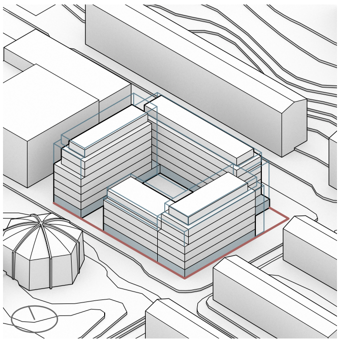
Energy demands got higher for each option, as the facade area got higher as well. The options were not results from one another, they were delivered to the engineer as equal design solutions. Therefore, no optimization of the massing models took place.

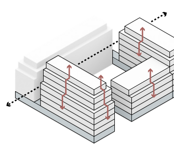
Some limitations of BeDOT were defined, for example there is no option for simulating double-shell facades, which would have been an interesting design element to explore for the architecture.

Seeing all the struggles already in the building envelope study, gives an incentive to use this suggested process in an earlier stage, for example while developing a detail plan, before locking the given grid and building volume. There is a lot of input to be given in earlier stages from building performance.

The challenge lies in how to make decisions between multiple objectives, which will of course vary between projects. Howevery, the ways the results were shown as a colored 3D-mesh was a clear and strong communication tool, that enabled the users to compare options with one another, and look at several indicators simultaneously.

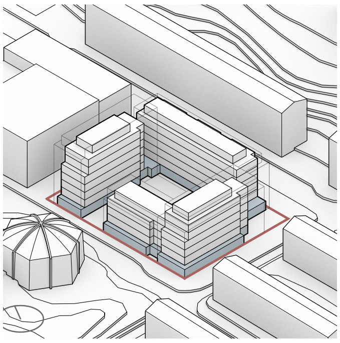
MASSING OPTION 1

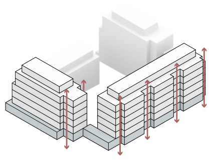




- BTA: 14 426 m2
- Energy demand: 85.7 kWh/m²

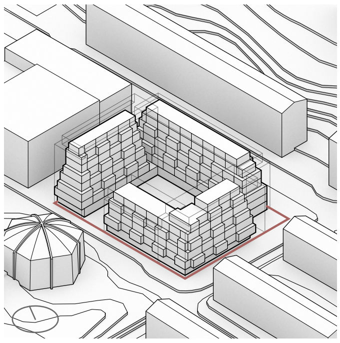
MASSING OPTION 2

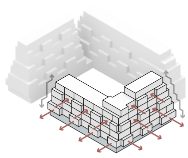




- BTA: 12 183 m²
- Energy demand: 89.3 kWh/m²

MASSING OPTION 3





- BTA: 11 286 m²
- Energy demand: 96.5 kWh/m²

FACADE STUDIES

For the facade study only one building would be calculated to see the affects of the decisions in glazing and balcony configurations. Most potential for different design ideas was seen in massing option 3, albeit it was the worst performing from an energy-perspective. From massing 3, more specifically building 3 was chosen for further development. The reason being the two long facades towards east and west, and not performing specifically bad or well in either one of those directions.

ITERATIONS 3.1.0 - 3.1.2

Facade study: Options 1.0, 1.1 and 1.2

Investigating how placement, shape and size of windows and balconies have an effect on building performance for a given massing. The facade studies are made on Massing 3, building 3. The chosen window/wall ratio, is 25%, which is lower than the numerical 30% ratio chosen in the massing studies. All three facade options in iterations 3.1.0-3.1.2 have the same glazing, but different solutions for balconies. Facade option 1.0 has balconies created just from the terraces in the massing, 1.1 has added balconies all around and along the facade. 1.2 is an in between solution, with added balcony slabs in some places in the facade, while leaving gaps between the modules.

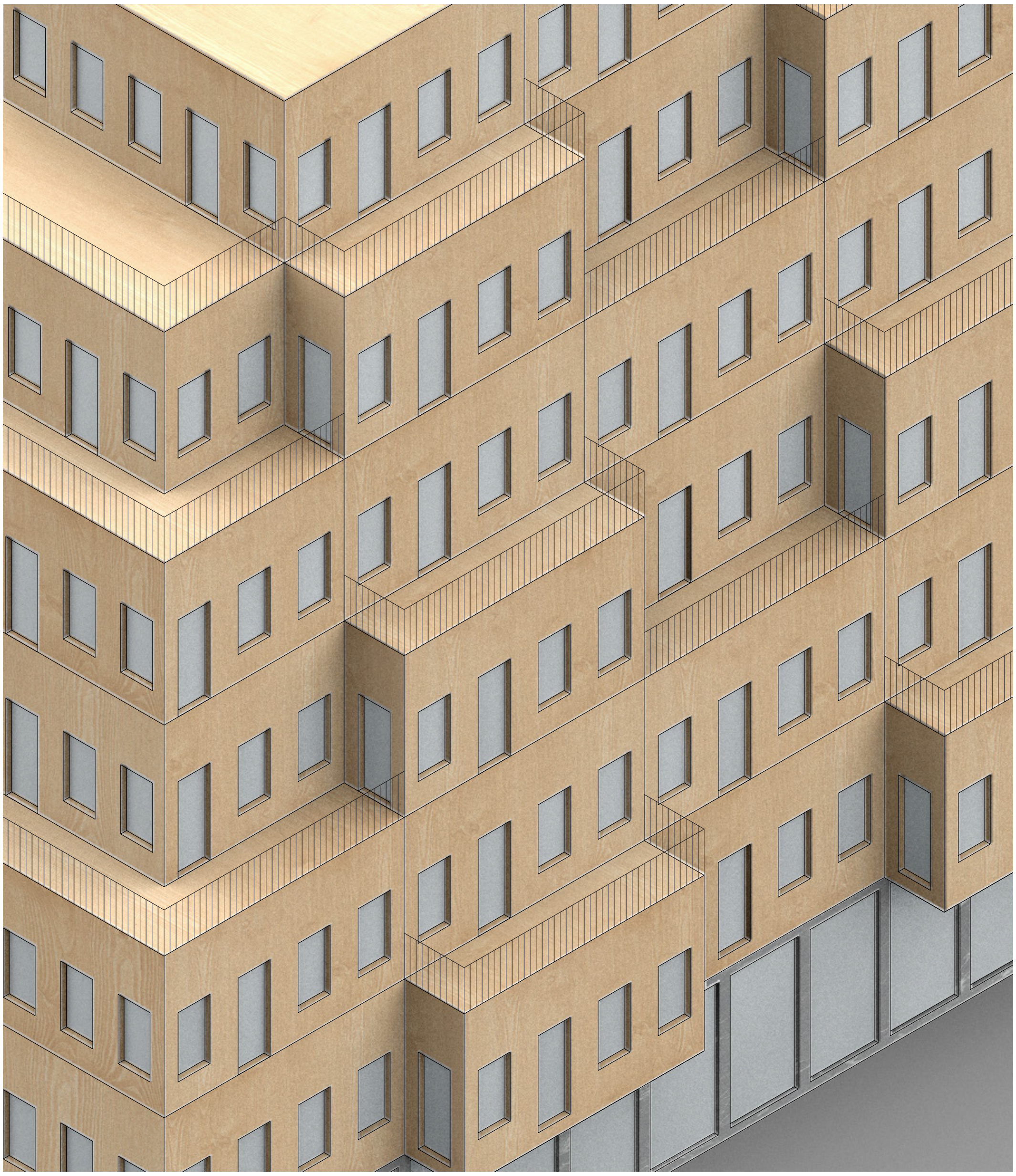


Figure 65. *Facade option 1.0*

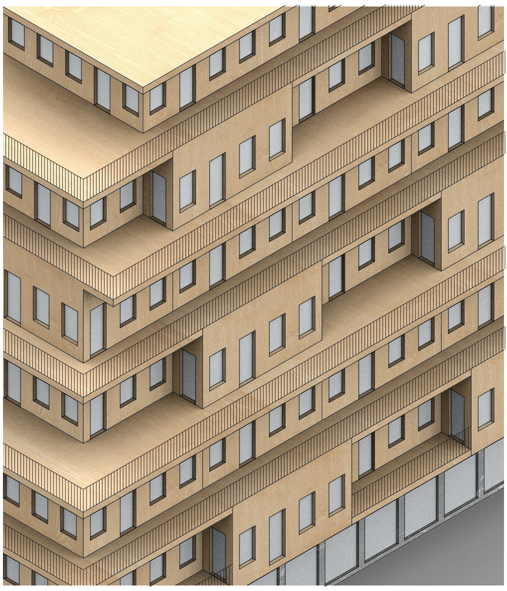


Figure 66. *Facade option 1.1*

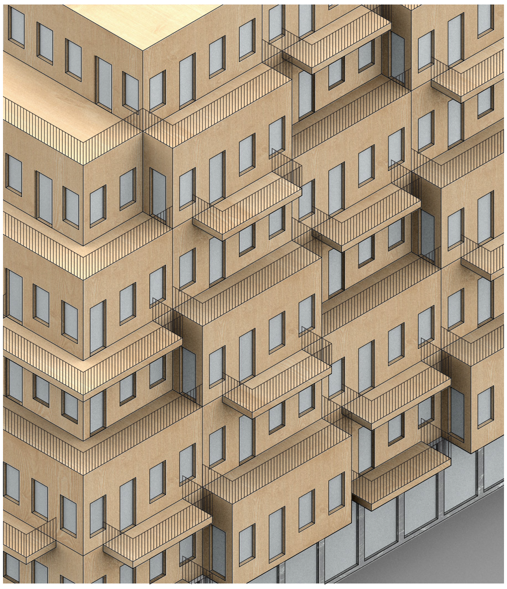


Figure 67. *Facade option 1.2*

Figure 68. *Facade option 1*

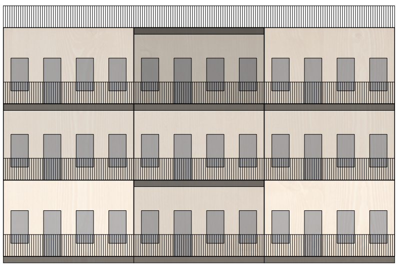


Figure 69. *Facade option 1.1*

Figure 70. *Facade option 1.2*

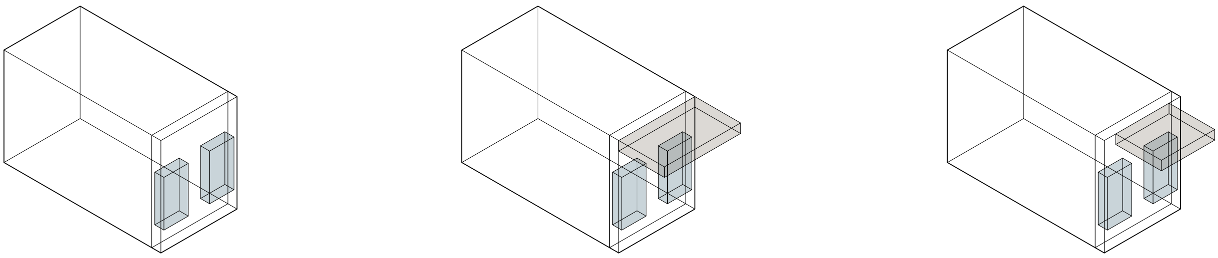


Figure 71. *Virtual rooms for options 1.0, 1.1 and 1.2*

RESULTS ITERATION 3.1.0: FACADE OPTION 1.0

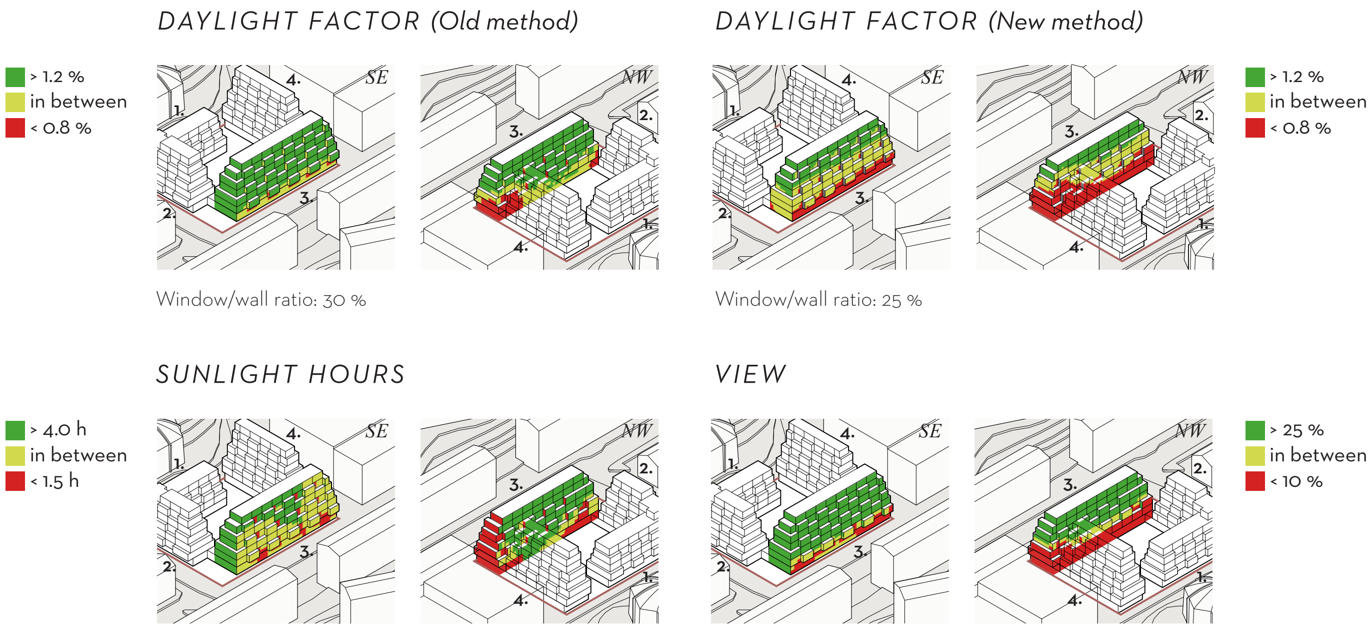


Figure 72. *BPS results from iteration 3.1.1: Facade option 1.1*

RESULTS ITERATION 3.1.1: FACADE OPTION 1.1

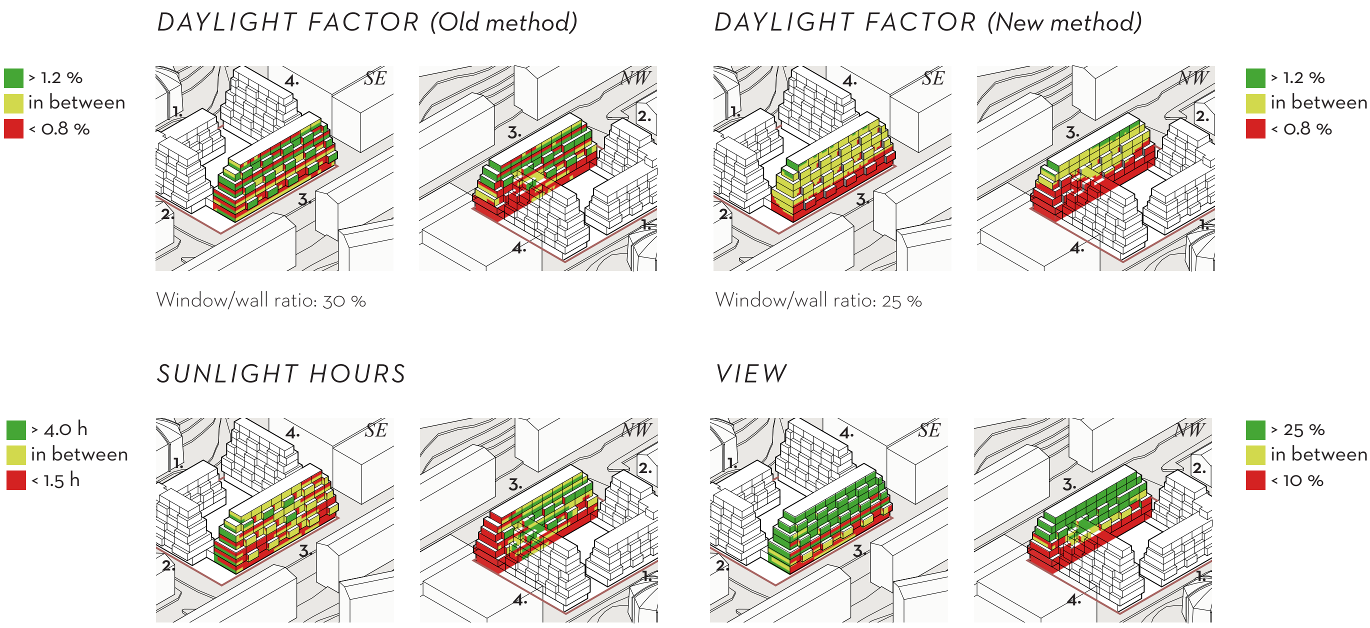


Figure 73. *BPS results from iteration 3.1.1: Facade option 1.1*

RESULTS ITERATION 3.1.2: FACADE OPTION 1.2

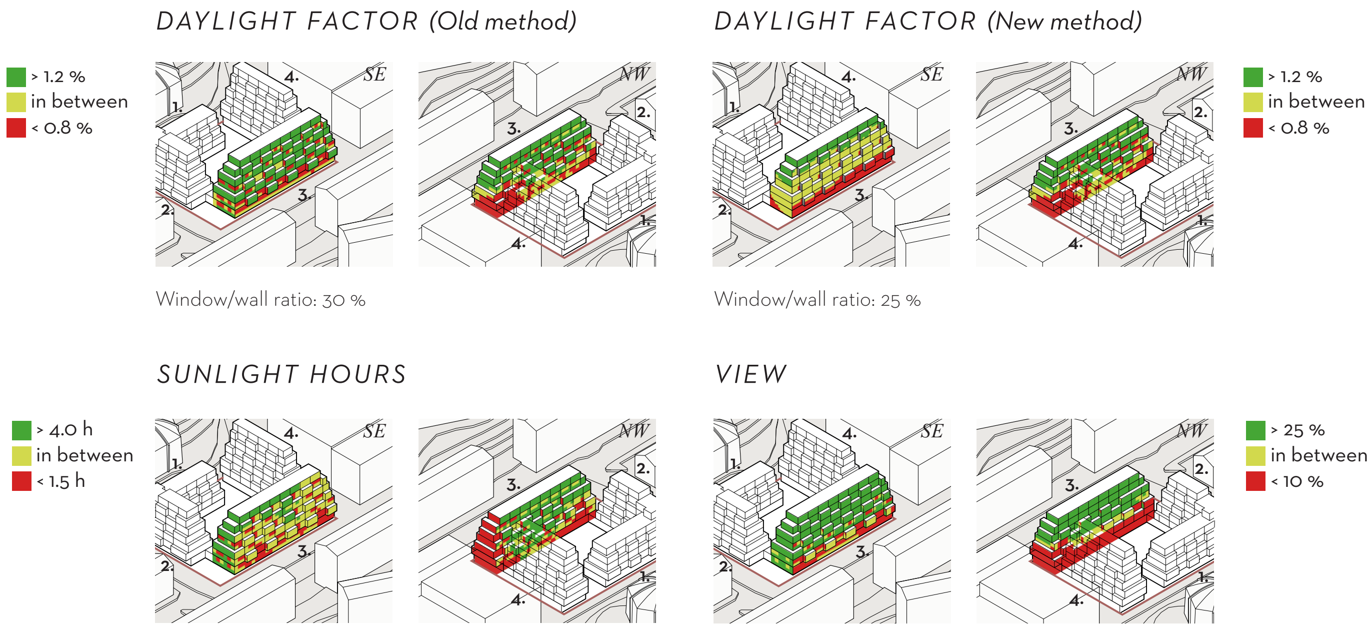


Figure 74. *BPS results from iteration 3.1.2: Facade option 1.2*

CONCLUSIONS ITERATIONS 3.1.0-3.1.2

DAYLIGHT FACTOR

It's clear to see how the new method for calculating daylight factor gives more pessimistic results compared to the old method, this is however most likely because of the decrease in window/wall ratio from 30% to 25%. We can also see that balconies have a large effect on window/wall ratio, where option 1.2 performs a bit better than 1.1 due to the gaps in the balconies in option 1.2. One thing that's notable is the stripy mesh for DF in options 1.1 and 1.2 using the old method, however similar stripes are not visible when using the new method, although the method for simulating are similar. A possible reason is that the old method measures DF on facade, whereas the new method focuses on DF inside, which is less affected by direct shadows. A conclusion from the DF simulations is that lowering the window/wall ratio by 5% units gives a rater large disadvantage to daylight in the building.

SUNLIGHT HOURS

Looking at options 1.1 and 1.2, it's visible that adding balconies puts more of the facade in the buffer zone of attaining enough direct sunlight. Conditions of sunlight exposure are not affected as much in the western facade towards the courtyard, that has access to a low evening sun and therefore not as strongly affected by balconies. The eastern facade, however, might struggle because of Johanneberg and surrounding buildings blocking the access of morning sun. A viable conclusion for the design might be to have large balconies in the west, while only having French balconies or no balconies at all to the east to attain more sunlight. If the apartments are double-aspect this would still give each apartment an attractive balcony with beautiful sunlight in the evenings.

VIEW ACCESS

Balconies won't affect view a lot, as long as they're not too deep. The largest affect balconies have on the view is blocking the facade from the sky, however this is mainly in the facade straight below the balcony, where no eyes will be located. A reflection on the view indicator in the facade studies is that it does not take windows into account, since it only measures view from the facade. An idea for further development would be to measure view form inside the building, with eye-heights in standing and seated positions. This way the design of the windows would actually be taken into account, which is a far more better indicator for how much view is accessed from the building.

ENERGY DEMAND

The differences in energy demand are the result of different balcony configurations. The differences are not very high, but it is noticeable that option 1.1 with the most covering balconies obstruct the sun from reaching the facade, resulting in the larget E_{uppv} of the options, and the lowest E_{kyl}.

Option	EP_{pet} [kWh/m², year]	E_{uppv} [kWh/m², year]	E_{kyl} [kWh/m², year]
1.0	96.7	39.4	4.3
1.1	97.7	40.3	2.9
1.2	97.2	39.7	3.5

ITERATIONS 3.2.0 - 3.2.1

Facade study: options 2.0 and 2.1

Facade options 2.0 and 2.1 are similar to 1.0 and 1.1, with identical balcony solution but changes in the window design. Here, there are glazed double-doors as windows, which give a larger window/wall ratio of 30.5 %, almost the same as in the massing studies (30%). The simulations of the two options 2.0 and 2.1, are for understanding how changing the glazing affects the results for the new DF method using virtual rooms.

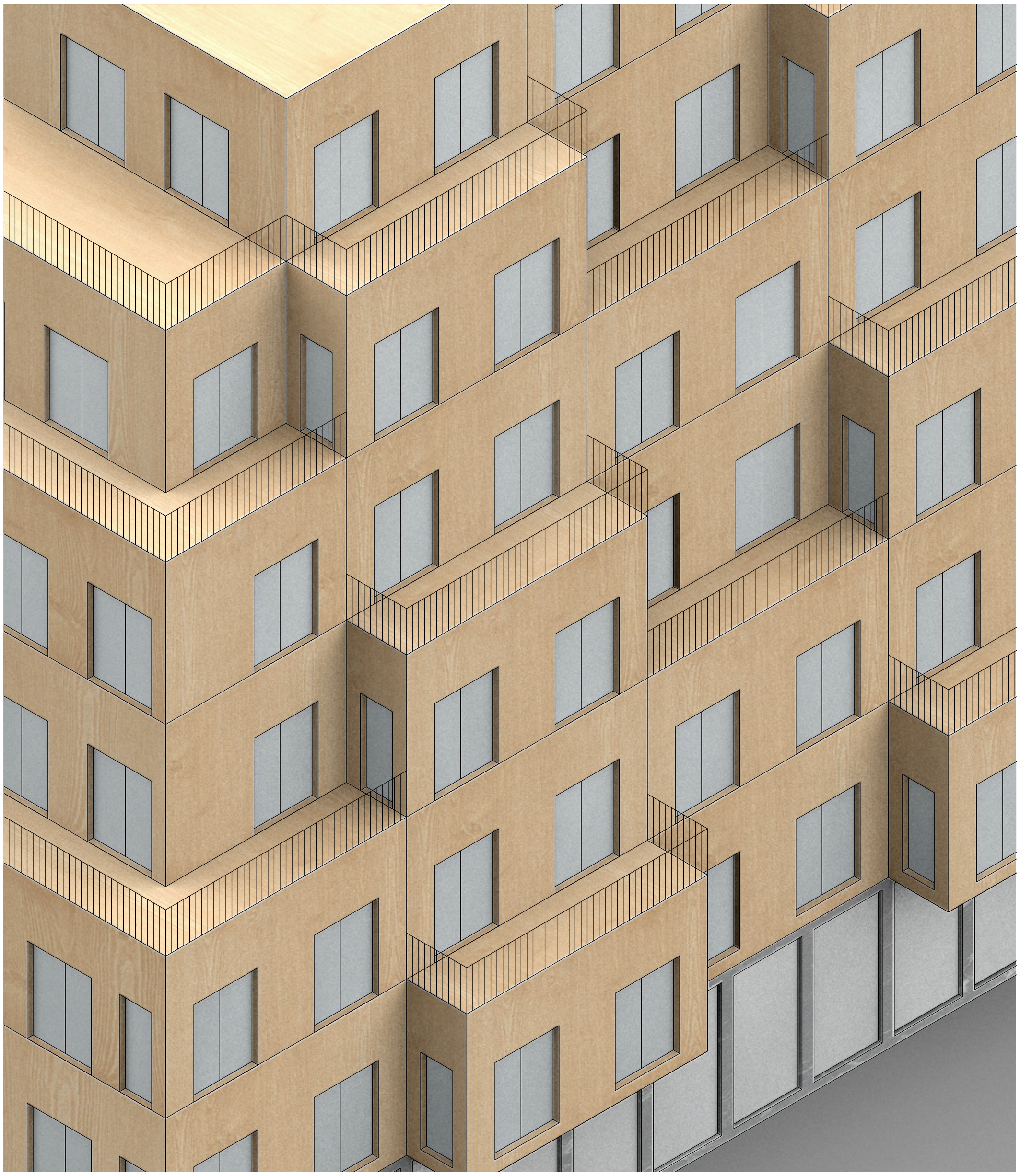


Figure 75. *Facade option 2.0*

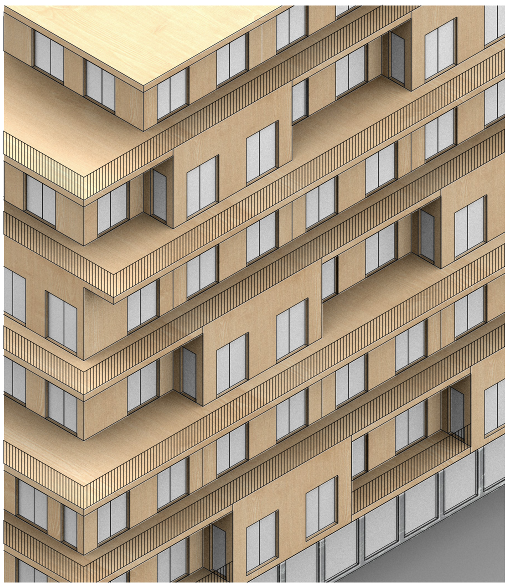


Figure 76. *Facade option 2.1*

Figure 77. *Facade option 2.0*

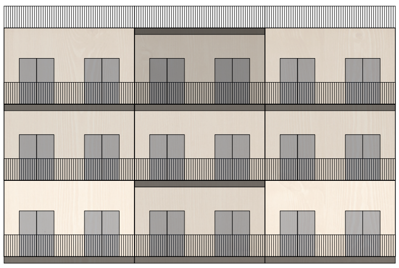


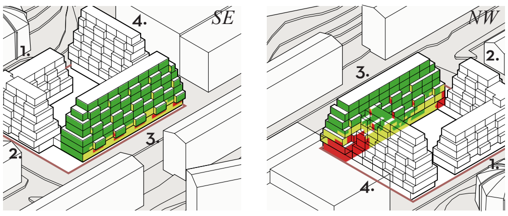
Figure 78. *Facade option 2.1*

Figure 79. *Virtual rooms for options 2.0 and 2.1*

RESULTS ITERATION 3.2: FACADE OPTION 2.0

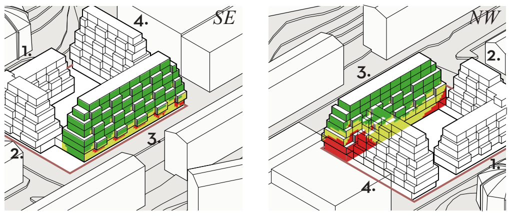
DAYLIGHT FACTOR (Old method)

> 1.2 %
in between
< 0.8 %



Window/wall ratio: 30 %

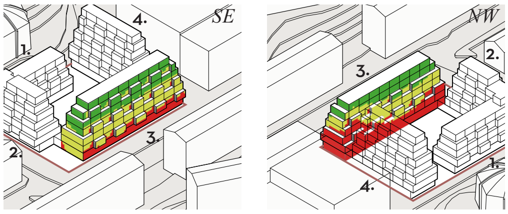
DAYLIGHT FACTOR (New method)



> 1.2 %
in between
< 0.8 %

Window/wall ratio: 33 %

COMPARISON: DAYLIGHT FACTOR (New method, option 1.0)



> 1.2 %
in between
< 0.8 %

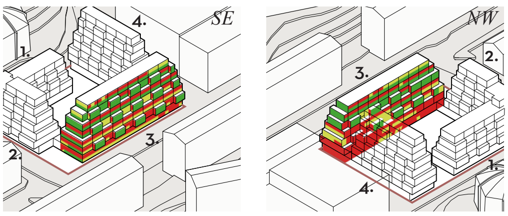
Window/wall ratio: 33 %

Figure 80. *BPS results from iteration 3.2: Facade option 2*

RESULTS ITERATION 3.2.1: FACADE OPTION 2.1

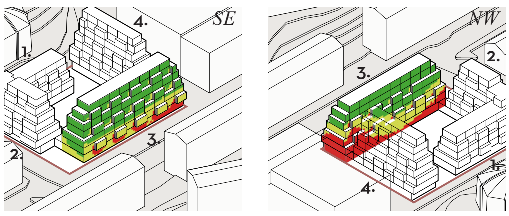
DAYLIGHT FACTOR (Old method)

> 1.2 %
in between
< 0.8 %



Window/wall ratio: 30 %

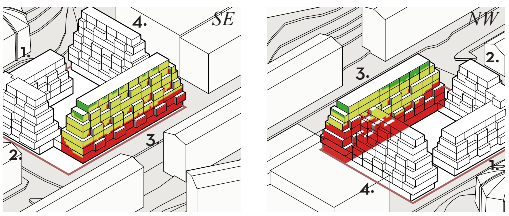
DAYLIGHT FACTOR (New method)



> 1.2 %
in between
< 0.8 %

Window/wall ratio: 33 %

COMPARISON: DAYLIGHT FACTOR (New method, option 1.1)



> 1.2 %
in between
< 0.8 %

Window/wall ratio: 25 %

Figure 81. *BPS results from iteration 3.2.1: Facade option 2.1*

CONCLUSIONS ITERATIONS 3.2.0-3.2.1

Since the only indicators changing due to the changes in glazing are daylight factor and energy demand, these are the only indicators presented in these iterations.

DAYLIGHT FACTOR

In options 2.0 and 2.1 the window/wall ratio is 30.5 %, therefore showing much better results för DF than options 1.0 and 1.1. The window/wall ratio is slight higher, yet near the one used in the old method for DF, but still the new method gives more pessimistic results than the old one. The room depth is the same, so what is probably the reason is the room shape used in the different simulations. An options for further development would be to parametrically mimic the rooms drawn by the architect, for example following the modular measure of 6 meters used in this massing. The simulations take quite a long time, which negates the point of having quick results in early stages. The results between options 1 and 2 are quite tricky to compare because of the difference in window/wall ratio, therefore the results won't tell a lot about the specific shape of the windows. A further iteration might be to have an identical window/wall ratio but use different shapes for windows, to see how it affects DF inside the building.

ENERGY DEMAND

The larger windows in options 2.0 and 2.1 lead to a higher E_{uppv} than in the previous options with same balconies. Seemingly, the transmission losses through the windows are larger than the solar heat gain from the windows. E_{kyl} is also higher in facades 2.0 and 2.1 because of the larger windows. This leads to a conflicting demand between daylight and energy.

Option	EP_{pet} [kWh/m², year]	E_{uppv} [kWh/m², year]	E_{kyl} [kWh/m², year]
2.0	98.4	40.9	5.8
2.1	99.3	41.6	4.1
1.0	96.7	39.4	4.3
1.1	97.7	40.3	2.9

CONCLUSIONS FROM FACADE STUDIES

The facade studies mainly gave results depending on the placement of balconies for the external indicators: DF on facade, sunlight hours and view. Here it was quite clear to see how the balconies affect the facade. However, it would also be interesting to see how the placement of balconies would affect the interior conditions of the building, not only the external effects on the facade.

The new method used in the facade studies, the virtual rooms for a calculation of DF inside the building, was the only one that took into account the design of the windows.

FUTURE DEVELOPMENT

An idea for development would be a new way to measure view and outlook from the inside, from eye-heights for standing and seated positions. This way the window design would alos be taken into account, which is an important aspect for view access. For example, the relationship between horizontal and vertical windows, where horizontal windows have more view access to different landscape in similar heights - possibly preferred in a rural setting - and vertical windows have more view access to sky, surrounding buildings and ground - possibly more suitable in an urban environment (Figure X).

A possible help indicator would also be how much balcony area the building offers, since this might be an attractive selling point for residents.

An interesting optimization would be to design facade options with different window settings and balcony configurations, and let BeDOT optimize the best option for different cardinal directions of the facade according to different indicators. This would show what would be ideal for different indicators, after which all stakeholders could more easily decide what is most important in a specific project and how this could be solved in the design of the building, already in the early concept phases.

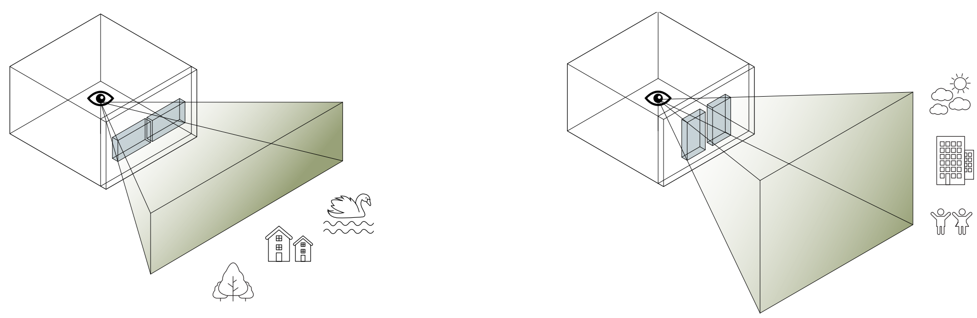


Figure 82. *Diagram of relationship between horizontal and vertical windows.*

6. DISCUSSION

INTERDISCIPLINARITY LEADING TO TRANSDISCIPLINARITY

I would like to start the discussion by telling the most disheartening comments we heard when doing research. One was an engineer stating “Who needs architects anyway?” and another, was an architect saying that the ideal solution would be to get this input without including engineers.

This clearly shows that this is not only a problem of processes and lack of tools, but one of attitudes. However, we know that through changing processes and behaviors, we also change attitudes and mindsets, meaning that this thesis is contributing to an overall integration of the professions. Our take is that we recognize the competence in the two professions but we want them to collaborate through a process, and our suggestion is a tool supporting that process.

We suggest an interdisciplinary process, that might lead to a transdisciplinary one, meaning that in collaboration, architects and engineers still identify themselves in their own roles, but that the interaction might broaden these roles, as the collaboration goes on (Figures 83-84). Trust between stakeholders is a vital factor for collaboration. Everyone contributing their part, knowing who is responsible of what, and an open mind to input from different professions is what is needed for a successful integration.

When exploring the tool we noticed that although the idea is to use the tool in early stages of the design process, it would be valuable also for when developing a detail plan, to ensure that the grids that are laid out work from a building performance perspective. Considering early stages, it is believed that implementing performance indicators in early stages, also has an effect on the later stages of the design process.

It’s important to state that not everything in design has to be quantifiable with a number, and that’s not the aim of the thesis either. There is an opportunity the take advantage of optimization tools, but we are not suggesting a completely machine-driven design process. There still needs to be room for the sketching and exploring process that architects need as designers. However, sustainability is a vital part of building in our cities, and increasingly high demands on sustainability indicators makes them important to include in the early architectural design process.

We believe that our proposed tool and design method are viable options for architects and engineers, when working in collaboration, towards a common goal.

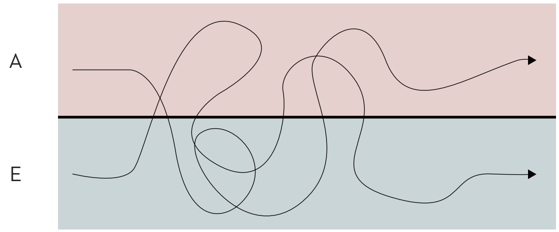


Figure 83. *Interdisciplinary collaboration: Professionals mix in collaboration, they end up in their own domain and the fields don't change.*

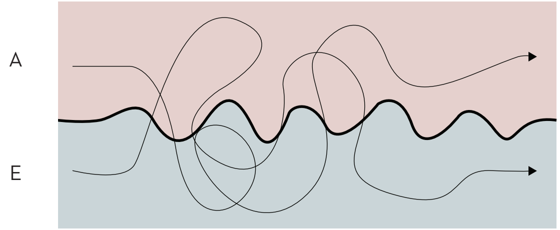


Figure 84. *Transdisciplinary collaboration: Professionals mix in collaboration, they end up in their own domain and the lines of the fields might change due to the collaboration.*

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