Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Architecture and Technology

Marit Henriette Mo Sandberg

Parametric analyses of facades in early design phase, to optimise daylight and energy performance

Master's thesis in MSc Sustainable Architecture
Supervisor: Gabriele Lobaccaro
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Abstract

By 2030, there will be 6 million people in Norway. Population growth will mainly take place in big cities. In order to achieve the goals of the Paris Agreement, and to get low-emission cities, planning for the expansion of the cities must include many aspects. One of these aspects is the buildings, buildings account for almost 40% of the total energy consumption in Norway, and the focus should be on reducing the energy needs in both planning and operation of buildings. Solar conditions are a particularly important aspect that allows passive energy to be utilised in the buildings both by reducing electric heating, but also by using electric light. If the planning is done well enough in an early phase, both thermal and visual factors can be optimised for each building.

The goal of this master thesis is to find a method that can be used to optimise the window to wall ratio (WWR) concerning both energy use and daylight in the early design phase. Landbrukskvartalet in Grønland in Oslo is used as a case in this thesis, based on a collaboration between NTNU and Asplan Viak. Landbrukskvartalet is an old dairy area that will be revitalised by the company Landbrukskvartalet Utvikling AS. In this project, there is a significant focus on innovation in both energy and the environment. Today, the project is in a zoning plan, and the background material in this thesis is volume and opportunity studies in the area.

To get an impression of the area and the sun conditions, initial analyses were performed on the whole area. This is also done to show some of the opportunities one has for analysing micro-climate using the ”Ladybug tools” analysis tools. After the initial analyses were completed, a building in the Agricultural Quarter was selected as a case to apply the developed method to optimise the WWR. Octopus in Grasshopper was used as an optimisation tool. The main finding from the developed method in the early design phase is that the WWR was optimised, even if it did not change the performance of the building significantly.

Sammendrag

I 2030 vil det være 6 millioner mennesker i Norge. Populasjonsveksten vil hovedsakelig forgå i de store byene. For å kunne nå målene fra Paris-avtalen og få lavutslippsbyer, må planleggingen av ekspansjonen av byene inneholde mange aspekter. Ett av disse aspektene er bygningene, bygg utgjør nesten 40% av det totale energiforbruket i Norge, og fokuset bør ligge på å redusere energibehovet både i planlegging og drift av bygg.Solforhold er et spesielt viktig aspekt som gjør at passiv energi kan utnyttes i byggene både ved å redusere elektrisk oppvarming, men også bruk av elektrisk lys. Hvis planleggingen er gjort godt nok i en tidligfase kan både termiske og visuelle faktorer bli optimalisert til hvert enkelt bygg.

Målet med denne masteroppgaven er å utvikle en metode som kan bli brukt til å optimalisere vindu til vegg ratioen (WWR) med å ta hensyn til både energibruk og dagslys. Landbrukskvartalet på Grønland i Oslo er brukt som case i denne oppgaven, basert på et samarbeid mellom NTNU og Asplan Viak. Landbrukskvartalet er et gammelt meieriområde som skal revitaliseres av firmaet Landbrukskvartalet Utvikling AS.Det er et stort fokus i dette prosjektet på innovasjon innen både energi og miljø. I dag er prosjektet i reguleringsplan fase, og bakgrunnsmaterialet i denne oppgaven er volum- og mulighetsstudier på området.

For å danne et bilde av området og solforholdene her, ble det utført innledende analyser på hele området. Dette er også gjort for å vise noen av mulighetene man har til å analysere mikroklima ved å bruke analyse-verktøyene "Ladybug tools". Etter de innledende analysene var gjennomført ble et bygg i Landbrukskvartalet valgt som case for å benytte den utviklede metoden for å optimalisere WWR. Octopus i Grasshopper ble benyttet som optimaliserings-verktøy. Hovedfunnet fra den utviklede metoden til bruk i tidlig prosjekteringsfase er at WWR ble optimalisert, selv om det ikke endret bygningens ytelse nevneverdig.

Acknowledgement

I want to thank my supervisor, Gabriele Lobaccaro, for his support through this work, his patience and expertise. I am very grateful for the time he has spent on directing me.

I would also like to thank everyone involved from Asplan Viak for their help answering my questions and sharing information needed for this thesis work. I am also grateful for the information shared by Transborder Studio.

Finally, I want to thank my family and friends who have supported me throughout my studies and have provided good advice along the way. A special thank to my mother for having me back home during the time of Covid-19, and Magnhild for helping me with the perusal of the thesis.

Contents

List of Figures

List of Tables

Abbreviations

ADF	Average Daylight Factor [%]
BIM	Building Information Model
BRA	Heated floor area
DF	Daylight Factor
EU	Energy Use [kWh/m^2]
GHG	Greenhouse gass
HVAC	Heating, Ventilation and Air Conditioning
IDA ICE	IDA Indoor Climate and Energy
LK	Landbrukskvartalet
PV	Photovoltaic
SHGC	Solar Heat Gain Coefficient
SVF	Sky view factor
U-value	Heat transfer coefficient [W/m^{2}K]
UHI	Urban heat island
VT	Visible Transmittance
ZEB	Zero Emission Building
ZEN	Zero Emission Neighbourhood

1 Introduction

In 2030 there will be 6 million people in Norway[1]. The population growth will mainly appear around the big cities. To be able to reach the goal in the Paris-agreement of low emission cities, the planning of infrastructure, residential areas and workplaces must consider a wide range of aspects. In February the Norwegian government decided to increase their goal of reducing greenhouse gas (GHG) emissions from 40% by 2030 compared to 1990 level, to minimum 50& reductions[2]. One of these aspects is the built environment, buildings consume almost 40% of the energy use in Norway, and a focus should be to reduce the energy use in both planning and operation of buildings.

The importance of sustainable development was emphasised already in the Bruntland report of 1987 [3]: *Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.* The sustainable development of cities and buildings is driven by carefully considered solutions and new methods for reducing energy consumption and greenhouse gas emissions.

Oslo is one of the cities with the highest density in Norway, in 2017 the city had 15 000 fewer residences than families. The outskirt of the city facing "marka" is protected from urban development [4]. Thus the city must develop to be denser with higher buildings. In such conditions, shading from surrounding buildings can be a problem for daylight and the opportunity to utilise passive solar energy. It will, therefore, be especially important to do preliminary analyses of the shadow and solar potential in urban areas.

In the development of the city centre of Oslo, former industrial areas have been developed into sustainable areas which contain, among other things commercial, business and residential activity. One of these areas is at Vulkan, sited along the river Akerselva [5]. In this development project, both cultural heritage, with preserving parts of the old industrial buildings, and innovative technological solutions, such as energy-efficient buildings and energy solutions, is implemented.

This thesis project, conducted in the framework of research collaboration between Asplan Viak and NTNU, is a focus in developing energy, climate and environmental assessment on the preliminary design scenario of Landbrukskvartalet in Oslo developed by Aspelin Ramm Eiendom AS.

This thesis is divided into three main parts, first, a literature review and comparison of simulation tools used in micro-climate and energy performance analyses. The second part focus on this case study of Landbrukskvartalet in Oslo, where a proposal of climate analysis that can be included in addition to those carried out today. The last and third part is a more study on how parametric modelling of a facade could be used in an early design phase to increase the daylight factor and to reduce the energy needed in the building.

2 Background

During the design process, several decisions need to be taken. Decisions at earlier phases of the design have a more significant impact on the building performance than measures taken at later design stages or during building operation (see Figure 1[6]). The fundamental decisions in a design, such as building orientation, form and window layout are often made by architects in the early design stage, with little or no support from simulation software [7]. The energy engineer often simulates the building performance too late in the design process and is traditionally used for equipment sizing after the architect has finalised the design [8]. It is assumed that more extensive use of building performance simulations in the early design phase would be beneficial for the result.

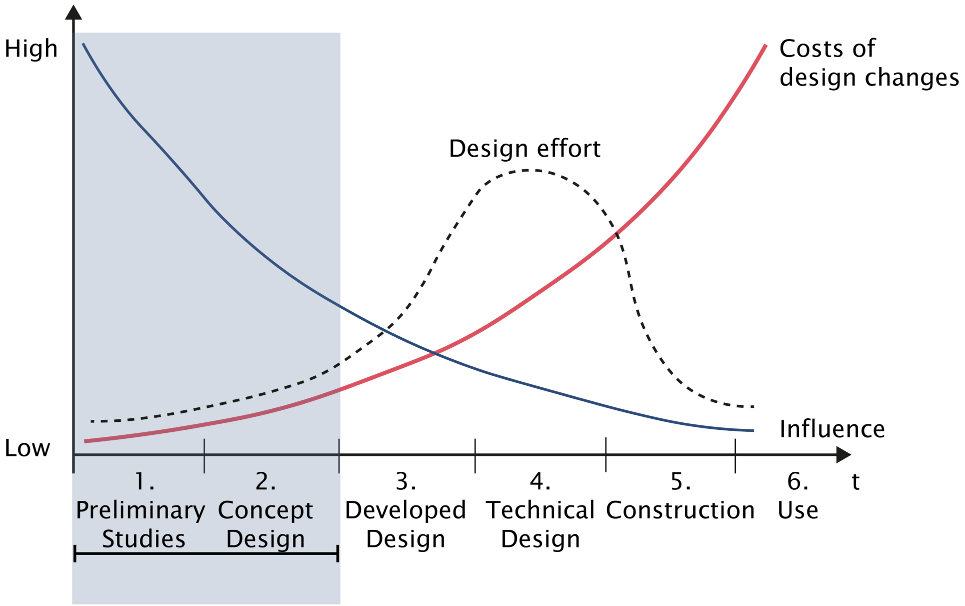


Figure 1: In the early design phases changes has lower costs and make less disruptions.

2.1 State of the art

The last decade a resurgence of different simulation tools has changed the way architects and engineers work during the design. An approach to developing simulation tools is to create many tools that are limited to conduct one type of analysis at a time and can be referred to as a disconnected approach [9]. Separated software for each analysis often limits the amount of analysis in design. Different tools often need different inputs to the simulations; hence it could both be expensive and time-consuming. A literature review of different methodologies for urban analysis and building analysis is performed as a part of this study.

Building Information Modelling (BIM)

is created as an attempt to simplify the workflow between simulation tools. In BIM, all departments in design have their information in one single model in one software. Having a BIM model could be useful to organise and document a final design by reducing the need for physical drawings in a project. Still, the size can make them inflexible and make it difficult to create changes according to simulation results. When more information is added to a BIM model, it becomes harder to test out new ideas or make changes. [9]. Instead of using one all-powerful tool as a BIM or a disjointed set of many tools to conduct the necessary analyses, a third approach is to have a cohesive suite of tools that has an enhanced workflow between different software. In a suite of tools, the flexibility exerts different objectives to be included whenever they become relevant. There is no need for specifying all properties at once. Unlike the disconnected approach, the suite of tools is expected to work together in a continuous process.

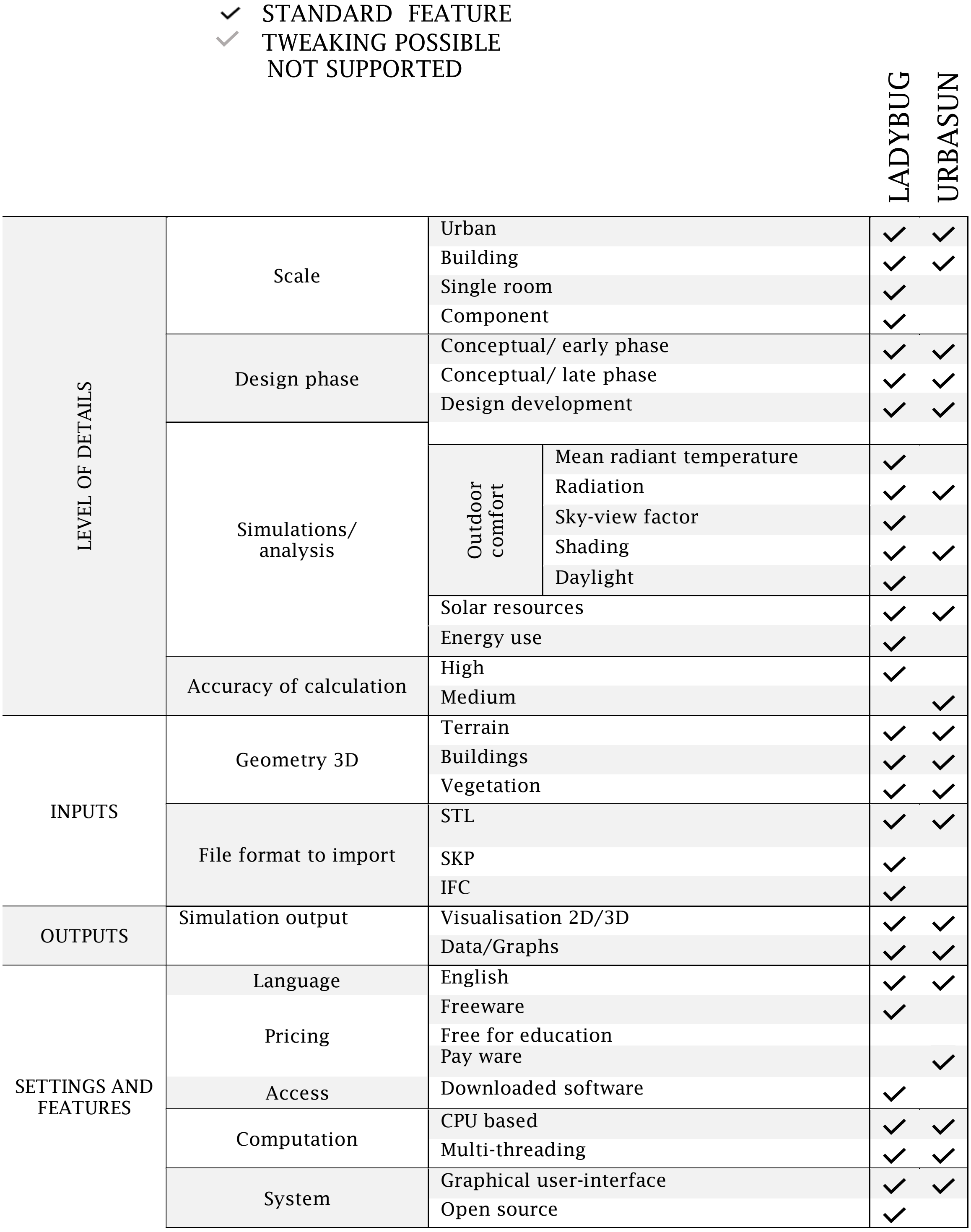
Calibration and validation is a big part of the simulation process since the tools use different techniques and algorithms in the software. However, there are still significant mismatches in the simulated results and the actual energy use in a building. In a study of 121 buildings, a deviation of up to 250% was found between the simulated energy use and the actual energy use; the actual energy use is most often higher than the simulated [10].

A comparison of different tools both at the urban scale and building scale commonly used in Scandinavia is conducted. There is a wide range of tools used around the world, and to limit the literature review, the choice fell on tools used in Scandinavia. The comparison is made to get an overview of the tools and see which features each of them have. A suite of tools, Ladybug, is compared with the findings from the literature review.

Ladybug is a one-suite environmental tool, which is an open-sourced plugin for Grasshopper [11]. Grasshopper is a graphical algorithm editor that is integrated with Rhino's 3D modelling tools. Grasshopper requires no knowledge of the syntax of scripting. Grasshopper uses visual programming, which is a paradigm of computer programming which the user manipulates logic elements graphically instead of textually. Grasshopper is available in Rhinoceros (Rhino), which is a 3D computer graphics and computer-aided design software developed by Robert Mc Neel & Associates [12]. In Rhino the geometry is based on NURBS, a mathematical model that produces a precise representation of curves and surfaces in computer graphics.

In the urban scale comparison, Ladybug and UrbaSun are compared. UrbaSun [13] is a software developed by the French company Meteodyn used to compute the solar radiation in urban areas. Through the literature study, it was noticed that shadow analyses are often conducted directly in 3D drawing programs, such as Revit, Rhino and Sketch-Up, without the use of environmental simulation tools.

The comparison between Ladybug and UrbaSun is shown in Figure2. The two tools are compared on level of details, input, output, settings and features. The analyses that consider solar access and shading are highlighted in this comparison[14].



✓ STANDARD FEATURE
✓ TWEAKING POSSIBLE
NOT SUPPORTED

				LADYBUG	URBASUN
LEVEL OF DETAILS	Scale	Urban		✓	✓
		Building		✓	✓
		Single room		✓	
		Component		✓	
	Design phase	Conceptual/ early phase		✓	✓
		Conceptual/ late phase		✓	✓
		Design development		✓	✓
	Simulations/ analysis				
		Outdoor comfort	Mean radiant temperature	✓	
			Radiation	✓	✓
			Sky-view factor	✓	
			Shading	✓	✓
			Daylight	✓	
		Solar resources		✓	✓
		Energy use		✓	
	Accuracy of calculation	High		✓	
		Medium			✓
INPUTS	Geometry 3D	Terrain		✓	✓
		Buildings		✓	✓
		Vegetation		✓	✓
	File format to import	STL		✓	✓
		SKP		✓	
		IFC		✓	
OUTPUTS	Simulation output	Visualisation 2D/3D		✓	✓
		Data/Graphs		✓	✓
SETTINGS AND FEATURES	Language	English		✓	✓
	Pricing	Freeware		✓	
		Free for education			
		Pay ware			✓
	Access	Downloaded software		✓	
	Computation	CPU based		✓	✓
		Multi-threading		✓	✓
	System	Graphical user-interface		✓	✓
		Open source		✓	

Figure 2: Table review of simulation tools at urban scale, page 1

At the building scale, three different tools are compared; Ladybug, IDA ICE and SIMIEN. All these simulation tools are taught at NTNU and are the most commonly used in Norwegian practising offices. IDA Indoor Climate and Energy (IDA ICE) [15] is a Swedish simulation tool developed by EQUA Simulation AB. IDA ICE is based on dynamic multi-zone simulations for the study of the indoor climate and energy consumption of a building. In IDA ICE there is possible to build up the model inside the tool with the 2D and 3D workspace, but it also allows you to import 2D or 3D models from a building information model (BIM).

SIMIEN [16] is a Norwegian simulation tool that uses the dynamic calculation method explained in NS3031:2014. Climate factors, internal gains and heat storage are calculated for every 15 min over the year. In SIMIEN, you can divide your building into as many zones you want, and for each zone, different heating systems, ventilation systems and internal loads could be added. Schedules for loads could be changed from month to month.

In Figure 3, the table of the comparison of three simulation tools and their features are shown. The level of details, inputs and outputs of the simulation and settings. [14].

At the level of details, the software is compared on which scale of a design they are useful, in which design phases they could be used and which simulations or analysis that could be conducted. They are also compared on how accurate the calculations are, quality and the computational time. The computational time is based on the typical time to run an all-year energy simulation of a building.

The compared inputs are climate file, input data, and how the geometry is fed into the simulation.

✓ *Standard feature*
√ *Tweaking possible*
Not supported

				Ladybug	*IDA ICE*	*SIMIEN*
Level of details	*Scale*		*Urban*	✓		
			Building	✓	✓	✓
			Single room	✓	✓	✓
			Module (façade component)	✓		
	Design phase		Conceptual/ early phase	✓		
			Conceptual/ late phase	✓	✓	
			Design development	✓	✓	
	Simulations/analysis	Solar analysis	Radiation	✓		
			Shading	✓	✓	
		Daylight	Climate based/annual	✓	✓	
			Point-in-time	✓	✓	
			Glare	✓		
			Lighting	✓		
		Regulation reference	TEK, Passive house			✓
			LEED, BREAM	√	✓	
		Energy production	BAPV energy yield	✓		✓
			BIPV energy yield	√		
			Wind turbine yield	✓		
		Energy analysis	Energy balance	✓	✓	✓
			Energy for heating	✓	✓	✓
			Energy for cooling	✓	✓	✓
	Accuracy of calculation		Unbiased (physically based)	✓	✓	
	Calculation quality		High	✓		
			Medium		✓	✓
	Computational time		Seconds to one minute			✓
			Minute to hour	✓		
			Minute to several hours		✓	
	Validation		(CIE 171:2006)	✓	✓	
			(NS-EN 15265:2007)			✓
Inputs	Climate file		EnergyPlus weather file	✓	✓	
			Text based climate file (.doi)			✓
	Data		U-value	✓	✓	✓
			Window specifications	✓	✓	✓
			Specific heat capacity	✓	✓	✓
			Heating system	✓	✓	✓
			Orientation	✓	✓	✓
	Geometry		3D model	✓	✓	
			Numerical			✓
Outputs	Simulation output		Renderings/visualisations	✓		
			Data/ Graphs	✓	✓	✓
	File format					
Setting and features	Language		Norwegian			✓
			English	✓	✓	
	Pricing		Freeware	✓		
			Free for education			✓
			Pay ware		✓	✓

Figure 3: Table review of simulation tools at building scale, page 1

Co-simulation	Design workflow	Real-time simulation/progressive		✓	
		Multiple solutions comparison	✓	✓	
		Integrated optimisation	✓	✓	
		Parametric design (node based)	✓		
	Computation	CPU based	✓	✓	✓
		Multi-threading	✓		
	System	Graphical user-interface	✓	✓	
		Open source	✓		
		Windows	✓	✓	✓
		Mac OSX	✓		
		Unix (Linux)			
	Integration BIM	AECOsim Building Designer	✓		
	Integration CAD/CAM	Rhinoceros 3D	✓		
	General integration	Stand alone		✓	
		CAAD/BIM integrated plugin	✓		
	Interoperability	Live link- dynamic data exchanger	✓		
		CAD interop. (fbx, dwg, sat,obj, IGES)	✓		
		BIM interoperability (gbXML,IFC)		✓	✓

Figure 4: Table review of simulation tools at building scale, page 2

2.2 Parametric design and daylighting

Parametric design is a modelling process that can change the shape and parameters of geometry. Parametric design is implemented trough codes in computer programming design. Before the parametric design was available, changing parameters in a model would be time-consuming. Once an initial model was created, and if the designer wants to make changes to some parameters, the whole process had to be repeated. Using parametric design tools such as Grasshopper, design can be improved by integrating and coordinating the design simultaneously. In addition to changing parameters related to geometry through parametric design, information from environmental studies can also be configured parametrically so that weather and location data can be used to change the design[17].

The aspects that have been investigated in this thesis with the parametric modelling is the window-to-wall ratio (WWR). The balance between the opaque and glazed areas on a building has an impact on many different aspects of the energy balance, the solar heat gains and heat losses but also the daylight availability [18]. The glazed parts of a building are often mainly considered by the architectural and aesthetic aspects, and not the energy performance. The glazing is also often decided early in the design project and is not easily changed later in the design process. Thus, the WWR is a critical aspect to investigate in the early design phase.

In Grasshopper, there are many different plug-ins to run optimisation processes. Octopus is a plug-in made for Multi-objective optimisation, also called

Pareto optimisation, which can search for solutions for several goals at the time and produce a range of optimised trade-off solutions between the extremes of each goal. The theory behind multi-objective evolutionary optimisation is complex and is not explained in this paper. The results from the optimisation are presented as a 3D-visualisation in the Octopus interface with the Pareto optimal solutions.

In a study conducted by F. Goia in 2016 [18], in which he studied the most optimal WWR for different climates in Europe, Oslo was one of the climates in the study. The building used in this case is an office building with cell offices. The external dimensions of the building are 45,9 m (w), 5,4 m (l), 2,7 m (h). The energy use for heating, cooling and artificial lighting was calculated with Energy Plus simulations, and the daylight was calculated with the Split-Flux method in Energy Plus. The E_Tot(WWR) were calculated for five WWR values and turned into a continuous function in the range 0,20-0,80 with spline interpolation with MatLab. By having only five simulated WWR, the computational time was reduced, and Goia stated that the resolution of the E_TOT only would increase slightly with a higher number of simulations. As a result of his investigation, he came up with a proposal on WWR ranges for each orientation that could be used in the preliminary stage of design. The suggested WWR ranges for Oslo is shown in 1.

Table 1: Suggested WWR ranges

[18]	South	North	West	East
Oslo				
Suggested WWR range	0,50-0,60	0,37-0,43	0,37-0,43	0,37-0,43

In a literature review from 2017 [17], 11 different studies used the parametric design on fenestration design, window design and facade design to optimise daylight and minimise the energy use. The studies showed that the daylight could be improved at the same time as the energy use was lowered by using parametric design method. All the studies done in a decided location are in a hot-climate location.

In 2018 A. Toutou, M. Fikry and W. Mohamed did an optimisation on a residential building in the Sixt of October city in Egypt, with the object of increasing daylight and energy performance [19]. In their research, Grasshopper with Honeybee and Ladybug were used to do the analyses related to daylight and energy performance, while the building geometry was created in Rhino. The objective of the study was how the combination of parameters such as WWR, glazing materials, wall construction and shading devices, lead to different performances in daylighting and energy. Spatial Daylight Autonomy "SDA" was used as the indicator for daylight, while Energy Use Intensity "EUI" was used as the indicator for energy performance. The parametric design method leads to the SDA value of 84,11 with nearly 110% increased from the base case design and EUI was 166,01 kWh/m2 with about 3,5% reduction.

3 Research questions and objective of thesis

3.1 Research questions

The research questions of this thesis are:

- Which analyses should be conducted in the preliminary design phases to assure a sustainable neighbourhood and building?
- How could outcomes from climate, energy and environmental analyses be visualised to give a client a better understanding of the neighbourhood and building performance?
- How could parametric based optimisation improve a sustainable building design?

3.2 Objectives of the thesis

The objectives of this thesis are divided into two main goals

- Develop a workflow to present quantitative and qualitative information about the climate analyses on a neighbourhood scale to clients.
- Develop a method to optimise the window to wall ratio (WWR) to minimise the energy use (EU) and maximise the daylight factor (DF) in the early design phase.

The study case that this master thesis deals with, Landbrukskvartalet in Oslo, is still in a phase where the zoning plan is to be determined. The information used in this master's thesis is based on feasibility studies and zoning plan proposals. A model made by the architects at Transborder Studio is used in the neighbourhood analysis. At the building-level, the model is based on sketches from Transborder Studio as well as assumptions from the candidate.

The task is also limited to addressing only some of the analysis options available through Ladybug tools. The main focus has been on solar radiation both in the neighbourhood and on individual buildings. The reason for this choice is that solar radiation on buildings is essential both for daylight and to reduce the heat demand during the cold season. With such a focus, the task is limited to deal with relevant analyses in this field.

4 Methodology

This section describes the methodology of this thesis. The work is divided into two main parts, on two different scales, neighbourhood and building. First, the Case-study of Landbrukskvartalet is presented; this is the base for the analysis in both of the scales. At the neighbourhood scale, climate analyses related to solar are performed. At the building level, an approach to find an optimal WWR-value considering energy use and daylight are developed. When developing the method, it was first applied on a simple box building, both individually and in a simple district. Second, the approach was applied to the Case study building, F2.

4.1 Case-Study Landbrukskvartalet

As mentioned in the introduction, the project located at Grønland in the eastern part of Oslo city centre, Landbrukskvartalet, has been selected as a case study. The project is still in the phase of deciding on the regulation plans in the area. Information about the project is extracted from the insight page of Oslo Kommune, Planning and Building Services [20]. Landbrukskvartalet, which directly translated means the agricultural quarter, is a former dairy factory in Oslo, established in 1912. The site is located in the area between Oslo S, the Old Town, Bjørvika and Grønland (Figure 6). The process of redeveloping Landbrukskvartalet started in 2015. The developer Landbrukskvartalet Utvikling AS consists of Norges Bondelang, Vedal Utvikling and Aspelin Ramm Eiendom AS. Asplan Viak is the primary consultant in developing the regulation plans of the area.

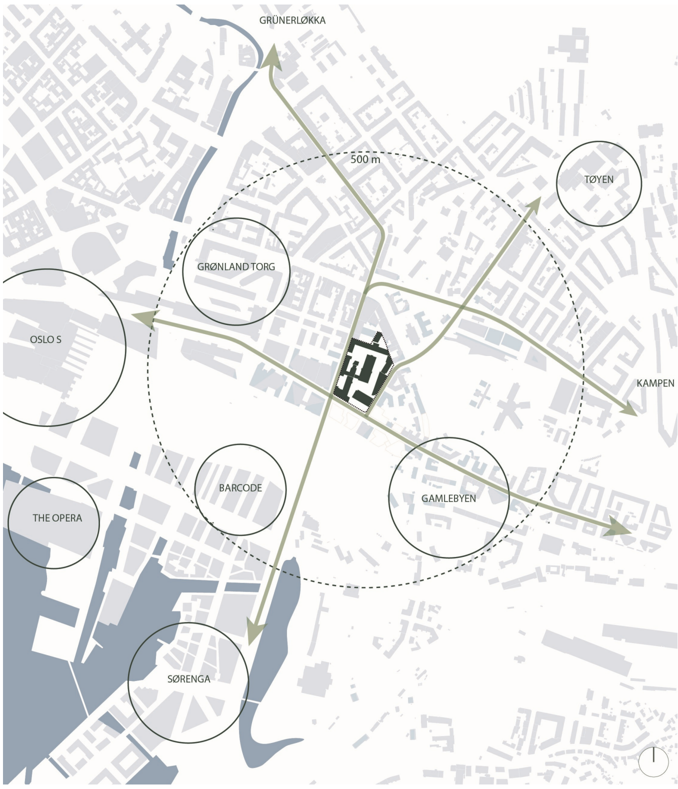


Figure 5: Landbrukskvartalet location map, Transborder Studio 2019

Today the area mainly consists of commercial activities with some residential areas. The main goal of the redevelopment intervention is to create an attractive urban area with commercial, business, services and residential activities. In the early design phases of the project, three ambitions for this area have been set; thus, Landbrukskvartalet is going to be a pilot project in Future Build:

I An open quarter

II A diverse quarter

III A green quarter

The developers have high ambitions to reduce GHG emissions with several different measures. One of the goals is to reduce the GHG emissions from transport, energy and materials by a minimum 50% compared to a reference scenario. One measure is to focus on green mobility; another measure is to have innovative use of wood and other bio-materials. The area should also contain a building that demonstrates new environmental technology in terms of energy and GHG emissions[20].

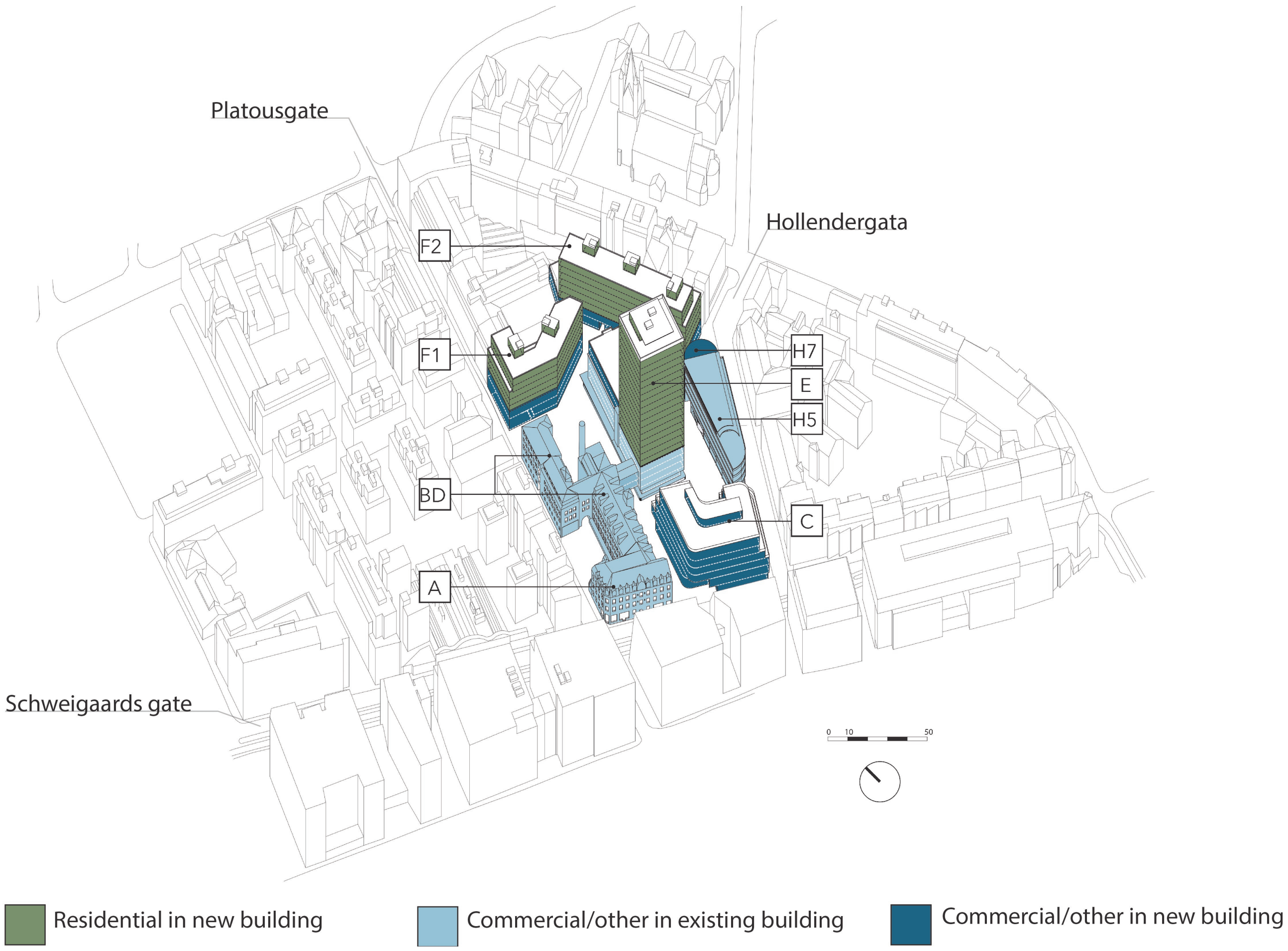


Figure 6: Program proposal, Transborder Studio 2019

The program proposal from 2019 and the revised program proposal from 2020 are the base for the analyses in this thesis[21]. The site consists of 8 buildings, where some of them are kept as they are today, whereas five of them are new buildings or new extensions on the existing buildings. The illustration project for the area shows the following land use:

- Residential , BRA (over terrain) = 18,880 m^2, of which approx. 300 m^2 in existing buildings.
- Business, BRA (over terrain) = approx. 27,575 m^2, of which approx. 13 035 m^2 existing buildings.
- Use area public/private service, BRA (over terrain) = approx. 3,270 m^2, all existing buildings

The urban spaces in Landbrukskvartalet are intended to be open and easily accessible areas. In 2016 the intention was to create seven different urban spaces with different qualities and programs. Figure 7 show the areas and their names that will be used further in this thesis.

Figure 7: Urban spaces in Landbrukskvartalet, Transborder Studio 2016

Figure 8: Illustration of the proposed plan, Transborder Studio

Climate

The project is located in the city centre of Oslo. According to the Köppen Geiger Climate classification [22], the climate in Oslo belongs to the sub-type Dfb (Humid continental climate), which is a cold climate, without any dry season. The cold season is the primary concern of the building design with 4220 heating degree-days. However, the summer outdoor air temperature and solar irradiance could, with the combination of high internal gain, lead to a cooling need. The average temperature in Oslo is 6,7 °C, where the coldest month is January and the warmest month is July. The temperature over the year and the global horizontal radiation is seen in Figure 9. The annual global radiation in Oslo is 879 KWh/m^2.

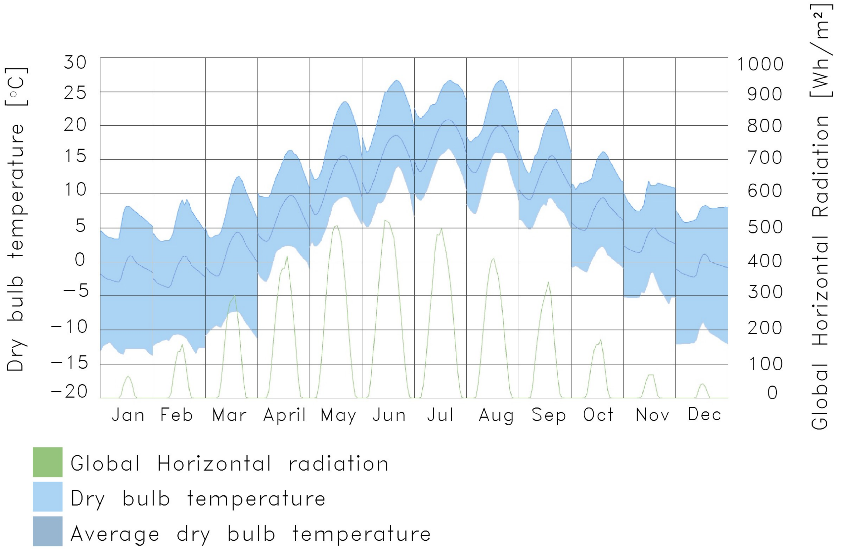


Figure 9: Temperature and radiation over a year in Oslo

Figure 10 show the wind direction and frequency from April to September at the site. In the spring and summer months, the wind is mainly coming from the north. Figure 11 show the wind direction and frequency from October to March, with the wind coming mainly from the south, south-east.

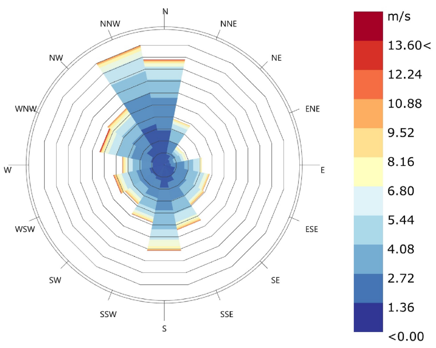


Figure 10: Wind direction and frequency, April to September

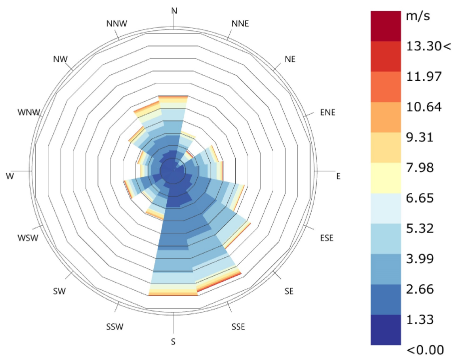


Figure 11: Wind direction and frequency, October to March

4.2 Neighbourhood analyses

In the reports of the preliminary analyses at Landbrukskvartalet, conducted by Transborder Studio and Asplan Viak, the presented analyses are the sun and shading diagrams and view from the sun diagrams. In addition to the shadow studies and the view from the sun study, some qualitative analyses could improve the investigation on solar access and daylight. The results from these analyses are used to decide which buildings to further investigated in the building scale analyses. Following analyses can be conducted to give greater information:

- Radiation analysis, both on vertical and horizontal surfaces
- Outdoor daylight simulations
- Sky view factor (SVF)

Before the analyses were carried out in Rhinoceros and Grasshopper, a 3D model was received from Asplan Viak. The model is a preliminary model from Transborder Studio and received as a sketch-up file. The file was made up of several small surfaces as quite detailed volumes with windows, balconies and other details. The model was simplified in Rhino and reedit as simple volumes, to make it easier to run simulations at the neighbourhood level. Figure 12 show the simplified model, with the buildings in Landbrukskvartalet in blue and the neighbouring buildings in grey.

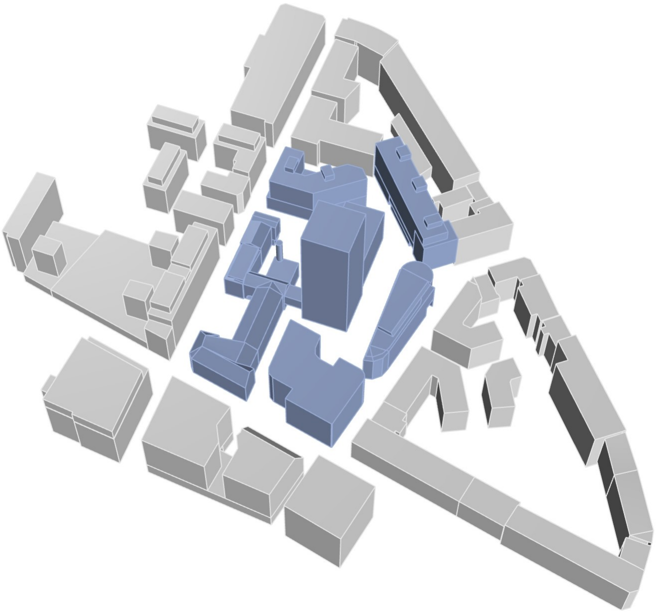


Figure 12: 3D model of Landbrukskvartalet with neighbouring buildings used in the analysis

Preliminary analyses are an essential part of the development of a sustainable building. By analysing the local climate, the effect of the wind and sun on the site makes it is possible to integrate the climate factors in the built form. This may result in a building that utilises the benefits from the sun by increased daylight accessibility and solar heat gains matching the need for heat.

Embedded in the Ladybug Tools are different climate-analyses. Several of these could be interesting to try in this thesis work, however, the analyses on the neighbourhood level has been focused to solar accessibility. The solar accessibility is directly connected to the performance of the building when it comes to energy use and daylight.

The radiation study is conducted with the "Radiation Analysis" component. This component calculates the radiation on the input geometry. This type of radiation study is useful for vertical building surfaces such as windows, to investigate the solar heat gain, or PV panels, to figure out the best location on a facade. The component is also useful to analyse outdoor spaces such as parks or seating areas where the radiation could affect the thermal comfort or vegetation growth. It is important to inform that there is no reflection of sunlight included in the radiation analysis with this component [23].

Radiation analyses are conducted on both the ground and on all the roofs and facades of the neighbourhood. These analyses show which surfaces that could potentially used for solar system installations, but on the other hand, which surfaces that can be overheated and therefore need to be shaded .

The figure 13 shows the script developed in Grasshopper. Buildings and surfaces that are investigated is included by the brep to the geometry input. Surrounding buildings are included by a brep in the context input. The grid size used in the analysis is 1x1 m, with a distance from base at 0,5 m. The selected sky matrix for this analysis is the cumulative sky matrix with a value of the radiation for each hour of the year [23].

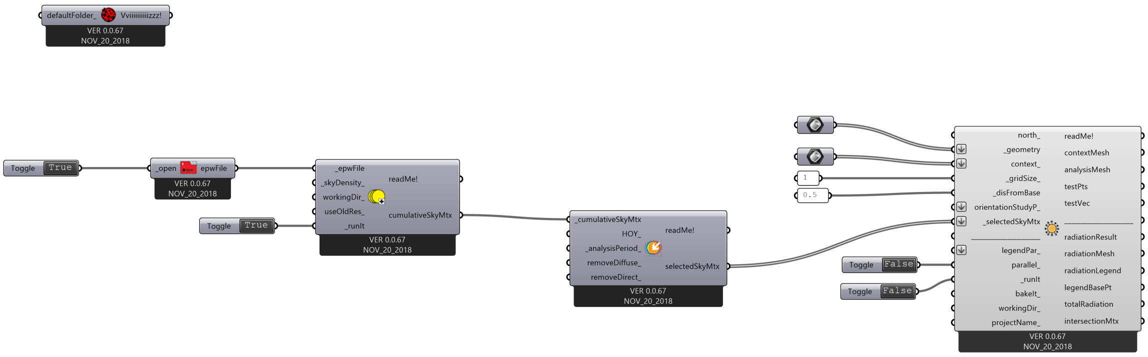
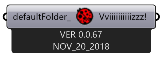


Figure 13: Radiation study on a geometry with surroundings

The SVF was calculated with the "View analyses" component. The figure 14 shows the script developed to conduct the analysis. To generate a SVF analysis, the "viewTypeOrPoints" has to be set at type [4] - Sky view [23]. This component calculate the percentage of the sky that is visible from the surface geometry connected with the input brep. In this analysis the grid size is 0,5x0,5 m and the distance from base is 1,5 m to have the results at the eye height of an average person. The SVF is used as one of the measurements to calculate the urban heat island effect. The SVF is a measurement on how much of the ground in an urban area that are shielded from the sky. [24].



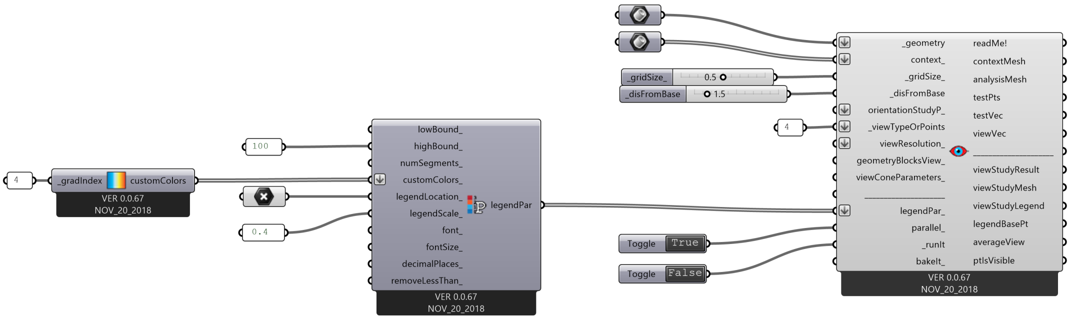


Figure 14: Calculating the sky view factor of an area outside with surroundings

Daylight analyses on the outdoor areas were conducted with the "Run daylight simulation" component and the selected analyse recipe is "Grid-Based Simulation" where the simulation type [0] was selected to do an illuminance analysis, as seen in Figure 15. The grid size of the test points is 0,5x0,5 m and the distance from the base is 0,8 m. The simulation is conducted to study where it could be areas that are uncomfortable because of too much daylight or glare.

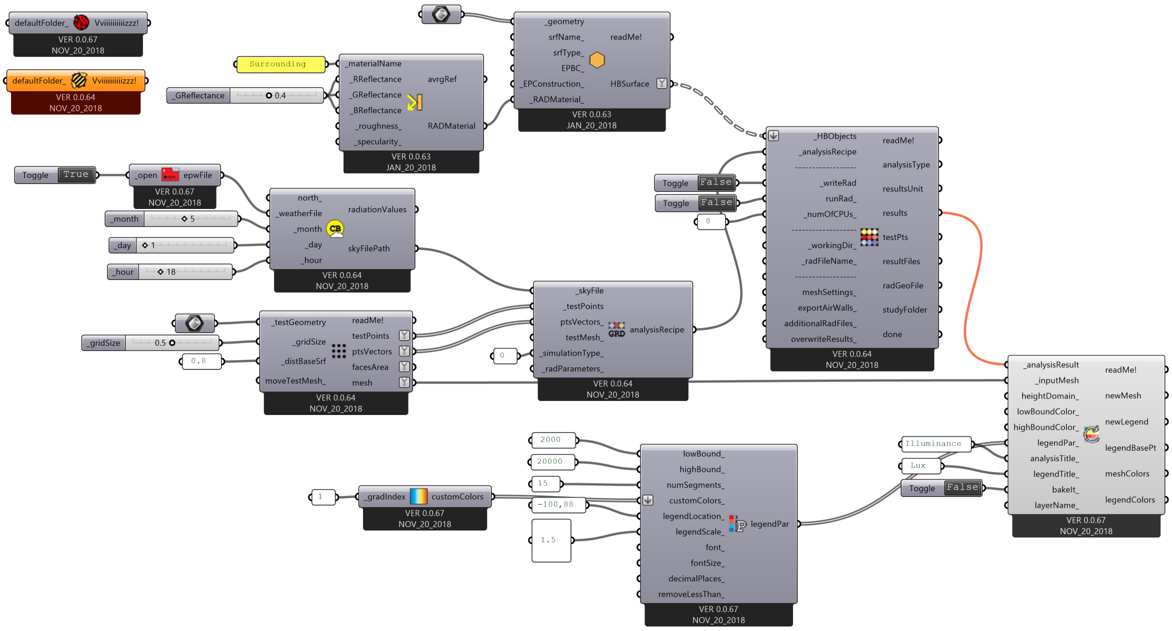


Figure 15: Calculation daylight factor outdoor

The results from the neighbourhood analysis are used to select a building for further analysis at the building level. In city development with dense areas of buildings, the buildings have to be closer evaluated in terms of the daylight and solar heat gains. The thesis narrowed down by selecting one building to focus on for the rest of the analyses. The selected building is the F2-building and the area in front called Stallplassen.

4.3 Parametric modelling of facade

Results from the analyses at the neighbourhood scale are used to choose a building to have a more in-depth analysis. Before the method was applied to analyse the F2 building, several analyses were carried out on a simplified building shapes and on a simple neighbourhood to validate the method.

The optimisation of a facade according to energy performance and daylight is performed with the multi-objective optimiser Octopus in Grasshopper. The parametric modelling is done in Grasshopper while Ladybug and Honeybee are used to perform the energy performance simulation and the daylight simulation. The combination of parameters (WWR for each orientation) lead to the different performance in daylight and energy. For energy, the Energy Use (EU) is used as an energy indicator while Daylight Factor (DF) is used as an indicator for daylight. The maximum total net energy requirement for an apartment building should not exceed the value of 95 kWh/m^2 heated BRA and an office building should not exceed the value of 115 kWh/m^2 [25]. Since the analyses are at an early design phase, it is not expected that these requirements will are met through the optimisation process.

According to TEK17 [26], a non-residential building needs a minimum value of 2% average daylight factor in all rooms for permanent occupation. A residential building could use a more simplified calculation to ensure the daylight inside the building, according to TEK17.
$A_g \geq 0,07 \times A_{BRA}/LT$

A$_g$ = glazed area against the open space which is placed at least 0.8 m above the floor of the room and which is not in a window well.
A$_{BRA}$= heated floor area, including area under an balcony or other similar cantilevered building elements outside window facade.
LT = light transmission through the glazing.
The method assumes that nothing obscures the view of the horizon at an angle of more than 45 degrees measured from the horizontal plane.

Even though sufficient daylight could be assured with this equation in residential; the daylight factor method are used for both non-residential and residential buildings in this thesis.

4.3.1 Simple box study

The method used to determine the optimal WWR value is presented in the following sections. The method drew inspiration from the optimisation framework of A.Toutou [19]. To assure that the method worked as expected, it were first tested on a simple box building. After the results were obtained from the simple box study, the method was applied to the case study building. Figure 6 show the workflow of the optimisation of the WWR value through the optimisation with Octopus. This workflow is applied both on the simple box study and the case study.

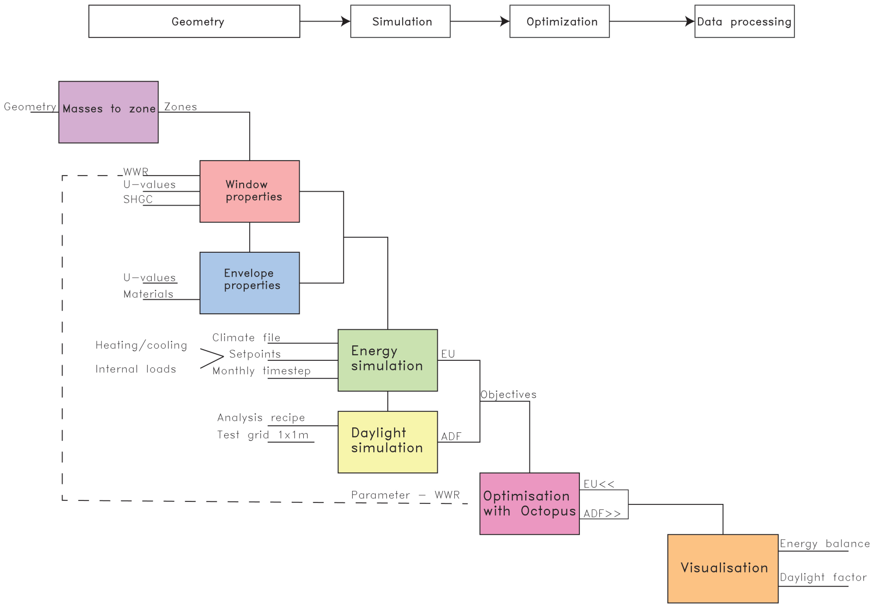
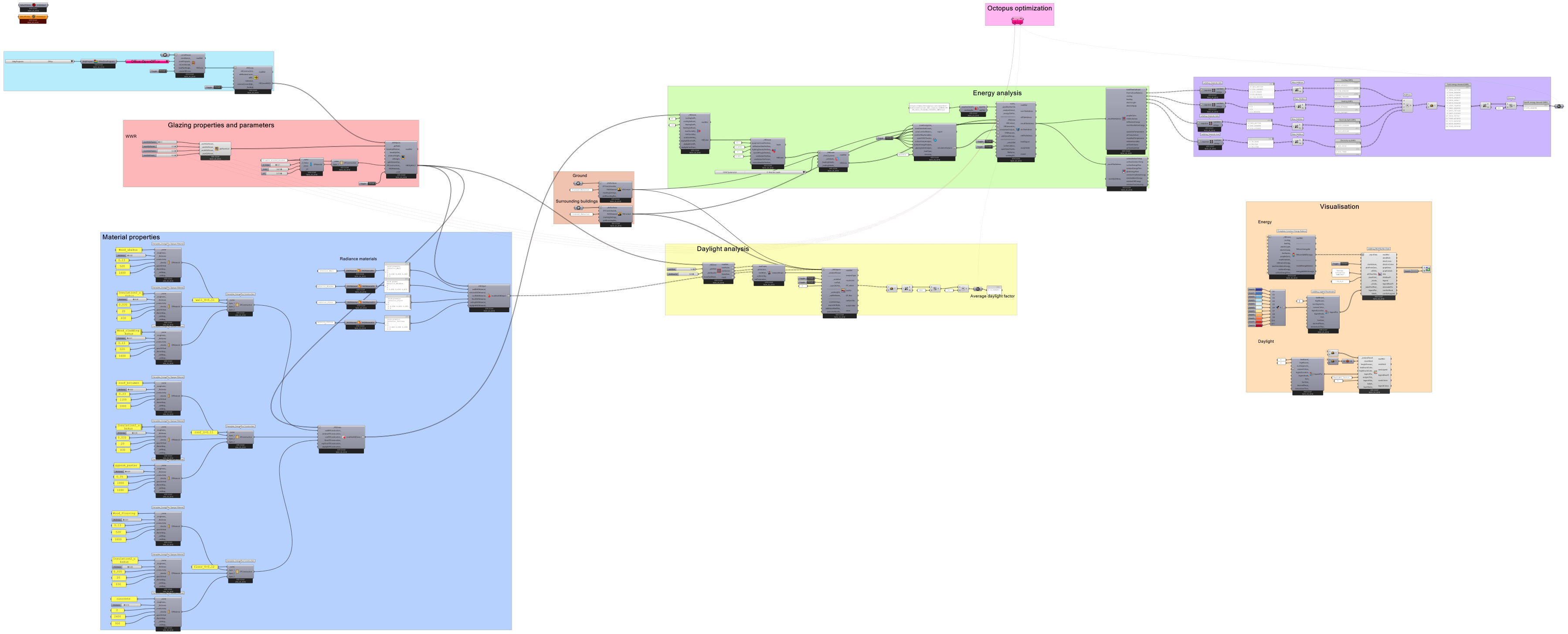


Figure 16: Flow chart explaining the script used in the simulation

In this section the method of the simple box study is explained, and the script developed in Grasshopper is shown **in the next page.** This script is also used in the case study, but with some modifications due to the more complex building geometry. These modifications are presented in section 4.3.2. Each of the different steps in the method is elucidated below for each step in the workflow.


Octopus optimization
Glazing properties and parameters
WWR
Energy analysis
Ground
Surrounding buildings
Material properties
Radiance materials
Daylight analysis
Average daylight factor
Visualisation
Energy
Daylight

Zoning

1. First, the building was created in Rhino, then the geometry was exported to Grasshopper. In Grasshopper the geometry was split into floors with the “Honeybee Split building mass to floor” component. The selected floor height is at 3m.

2. These floors were input to the “Honeybee split floor to thermal zone” component. Here each floor was divided into five zones, four perimeter zones for each orientation and one core zone in the middle.

3. All the zones from the previous component was sent to “Honeybee Masses to zones” component to turn them into Honeybee zones with the right properties to run an energy simulation. The selected zone program for the building is open office from the “Honeybee building programs”.

4. The component “Solve adjacencies” was used to make sure that all adjacent surfaces only make up one interior wall.

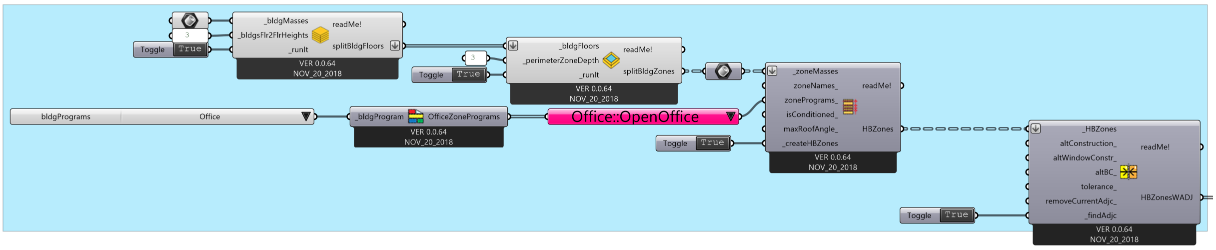


Figure 17: Bringing in the Rhino geometry to Grasshopper and Ladybug tools

Windows

1. The glazing on the zones were created with the “Honeybee Glazing based on ratio”, which generates the window size based on the window to wall ratio (WWR). The WWR is set individually for each orientation, as shown in Figure 18. Parameters for each orientation are set as sliders from 0,1 to 0,5.

2. The Energy Plus material for the window is set in the component with the properties described in Table 2.

Table 2: The window properties applied in the method.

Window properties	
U-value	0,7
SHGC	0,67
VT	0,75

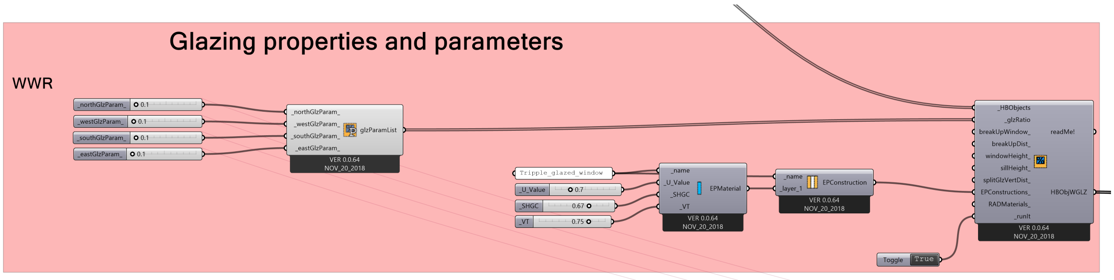


Figure 18: Set window properties and create WWR sliders

Materials

1. All zones were assigned material properties through the “Honeybee set Energy Plus Zone constructions”. This component was used to assign the construction materials to roof, walls and floor as seen in Figure 19. The material properties for each construction is shown in Table 3.

2. The constructions were also assigned the radiance properties through “Honeybee set radiance materials” component, using the materials in the radiance library for interior wall, floor and ceiling , and exterior window.

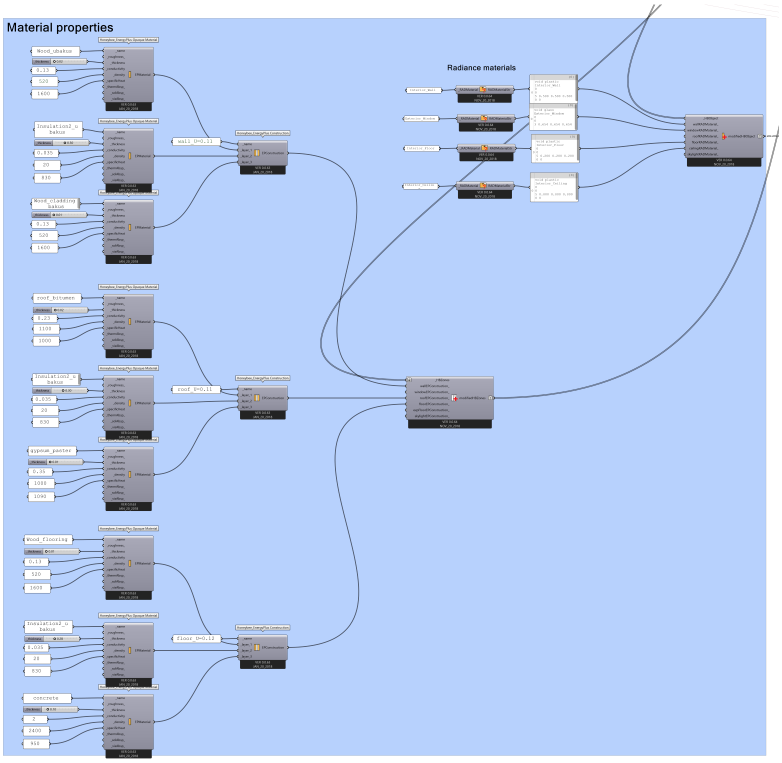


Figure 19: Set energy plus and radiance materials

Table 3: Custom construction

Construction	Material	Thickness (m)	U-value [W/m^{2}K]
Walls			0,11
	Wood cladding	0,01	
	Mineral wool insulation	0,20	
	Wood panels	0,01	
Floor			0,11
	Wooden flooring	0,01	
	Floor insulation	0,28	
	Concrete	0,10	
Roof			0,12
	Gypsum board	0,01	
	Mineral wool insulation	0,30	
	Roof bitumen	0,20	

Surrounding context

Four scenarios of surroundings around the simple box building were created to see how the horizontal shading affect the daylight and the energy use. The horizontal shading is illustrated with three scenarios with different aspect ratio or H/W - ratio,height of building divided by the with of the "street" . The scenarios are listed below:

- Isolated scenario, no surrounding buildings
- Simple district, aspect ratio; H/W=2
- Simple district, aspect ratio; H/W=1
- Simple district, aspect ratio; H/W=0,5

The tree scenarios with simple districts is shown in Figure 20. From literature it is found that the aspect ratio should be as low as possible to get the required daylight in a room. If the aspect ratio is around 1 the daylight is usually sufficient. An analyse of the four scenarios where conducted

The breps of the surrounding buildings and the ground were added in Grasshopper with the “Honeybee energy plus context surface” component. The radiation materials for the surrounding buildings and ground were set as the default radiance context material.

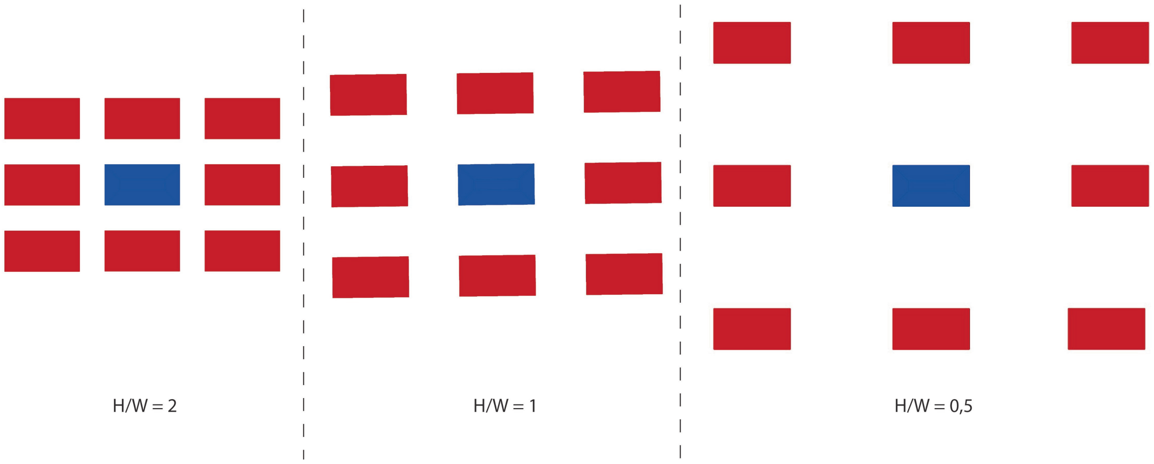


Figure 20: The three scenarios with different aspect ratios.

Energy simulation

1. To assign the zones with heating and cooling set points, they were sent to the “Honeybee set energy plus zone thresholds” component. The heating set-point is set to 19° and the cooling set-point is 22°.
2. The internal loads in the zones are set with the “Honeybee set energy plus zone load” component. As seen in Figure 21 the equipment load per area, infiltration rate per area, lighting density per area and ventilation per area were set to 11 W/m^2, 0,0001 m^3/s per façade, 8 W/m^2 and 0,001 m^3/s- m^2 respectively, other inputs are kept at default.
3. The building were attached to “Honeybee assign HVAC system” component, where the HVAC system was assign to Ideal air loads.
4. To run the energy simulation, the “Honeybee export to open studio”

component is used. This component export the zones into Open studio and run the simulation with Energy Plus. To run this simulation other inputs are needed to assign the component.

- Energy plus weather data file from Fornebu - Oslo, the EPW file closest to the location.
- Simulation outputs are generated with the “Honeybee Generate Energy Plus output” component. In this component the time step is set at monthly.

5. The results from the energy simulation is generated from the “Honeybee read energy plus results”. The total energy use is calculated from the monthly cooling, heating, equipment, and lighting energy. The total energy use is one of the two objectives used in the optimisation process.

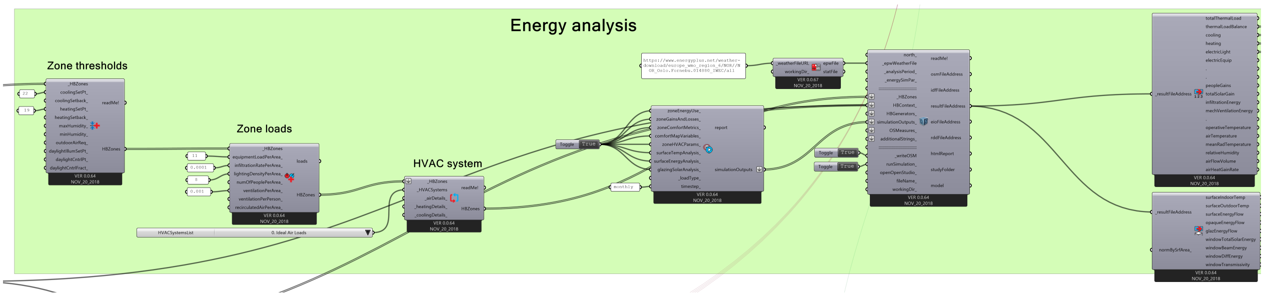


Figure 21: Energy simulation workflow in Grasshopper

Daylight simulation

1. The zones from the “Honeybee set radiance material” are used in the daylight simulation.
2. Test points were generated with the “Honeybee generate test points” component, with a grid size of 1x1 m and a distance from the fllor at 0,8 m.
3. The analyse recipe of daylight factor simulation were chosen. The sky was set to ”cloudy sky” for the simulation and the radiance parameters are kept as default.
4. To run the daylight simulation, the “Honeybee run daylight simulation” component were used. In addition to the information from the analyse recipe, the number of CPUs (8) were set to this component.
5. The average daylight factor were calculated and used as the second objective function in the optimisation process.

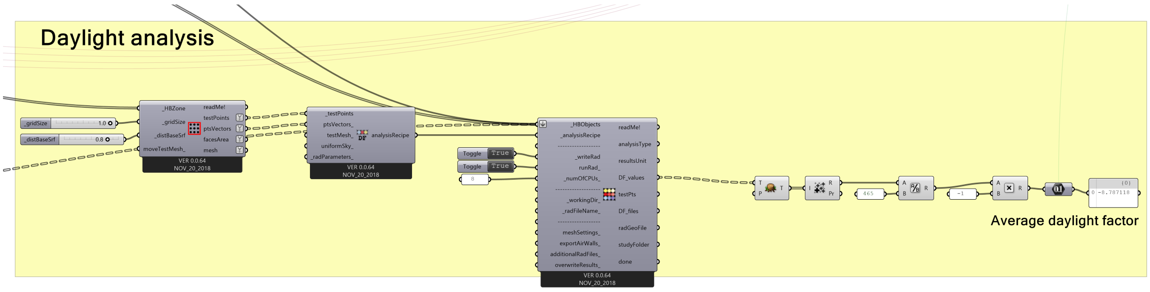


Figure 22: Daylight simulation workflow in Grasshopper

Optimisation

The optimisation of the energy use and the daylight factor is a balancing between two objective functions. The multi objective optimisation tool (MOO), Octopus, was used to try to find the balance.

- Objective functions: total energy use (EU) and average daylight factor (ADF).
- Parameters: 4 sliders (0,1-0,5) with 0,1 increment, to change the WWR for each orientations.
- The optimisation process ran for maximum 10 generations.

The optimised results are extracted from the Pareto front in the Octopus interface. The most optimal solution should be located near the cross point of theoretical best solution of each objective function. The optimisation will create many solutions that could have high performance in one of the objective function, but not give a satisfying results on the other.

4.3.2 Case study

In the case study two different optimisation processes are carried out. The first scenario is with the F2 building individually and second scenario is the F2 building in the urban context of Landbrukskvartalet. The building shape and layout are based on preliminary sketches from Transborder Studio. The preliminary sketches from where facades, plan and section of the building. The WWR from these sketches are used as base-case scenario to compare with the optimisation. Figure 23 and 24 show the 3D model created in Rhino.

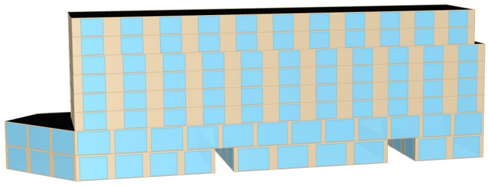


Figure 23: Facade of the building facing south-west

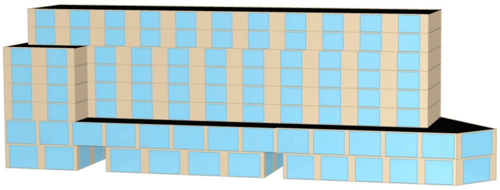


Figure 24: Facade of the building facing north-east

Zoning As mentioned in the previous section, the methodology is mainly the same for the simple box study and the case study. The difference is in the first parts of the script, where the geometry is divided into zones and assigning window properties. The steps used to make the Rhino geometries into zones in Grasshopper is explained below and seen in Figure 25.

1. The geometry was first created in Rhino.
2. The building is made up of parts where the roof of one floor is not the same as the floor on the next one. To overcome the problem when adding the geometry to zones, the geometries was added in different breps and imported with two different methods.

3. 2nd and 6th floor are imported with the "create Honeybee Surface" component and the "Honeybee create HB zones" component.

4. The other floors where imported with the "Honeybee masses to zones" component as in the simple box study.

5. The first and second floor were assigned the building program "Open office", while 3.-8. floor were assigned the building program "Midrise apartment".

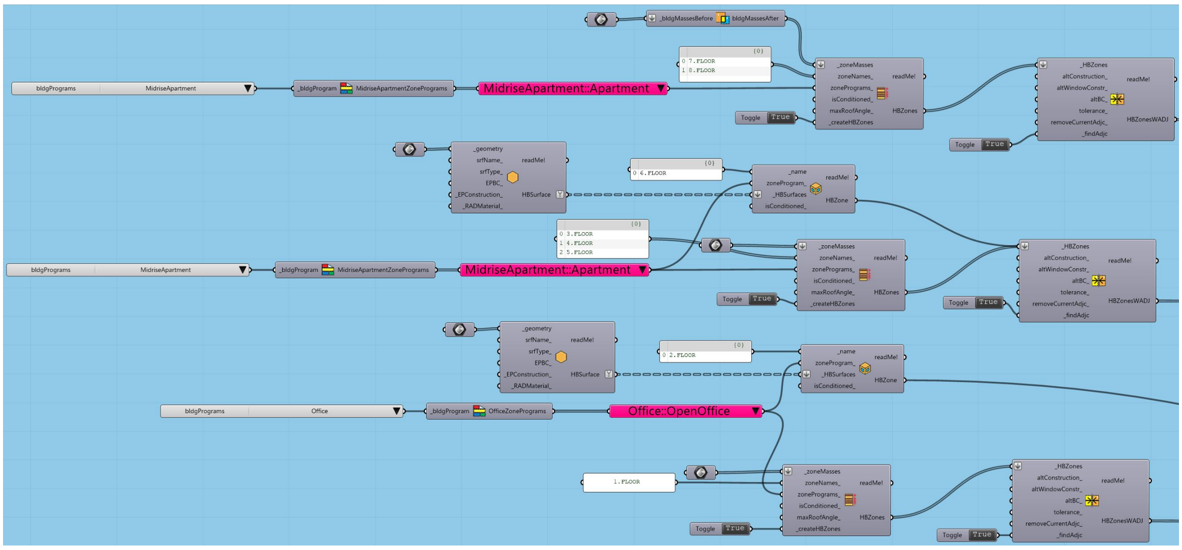


Figure 25: Bringing the different building geometries to Grasshopper and Ladybug tools

Windows

The method of assigning windows to the building is the same as in the simple box study, but instead of having one WWR for the entire building the windows are divided in two different components to be able to have different window heights and break-up distance between the windows on the non-residential floors and the residential floors. Table 4 shows the breakup distance and window height for the two different building programs. Figure 26 shows the two different "Honeybee add glazing by ratio" components used in the method.

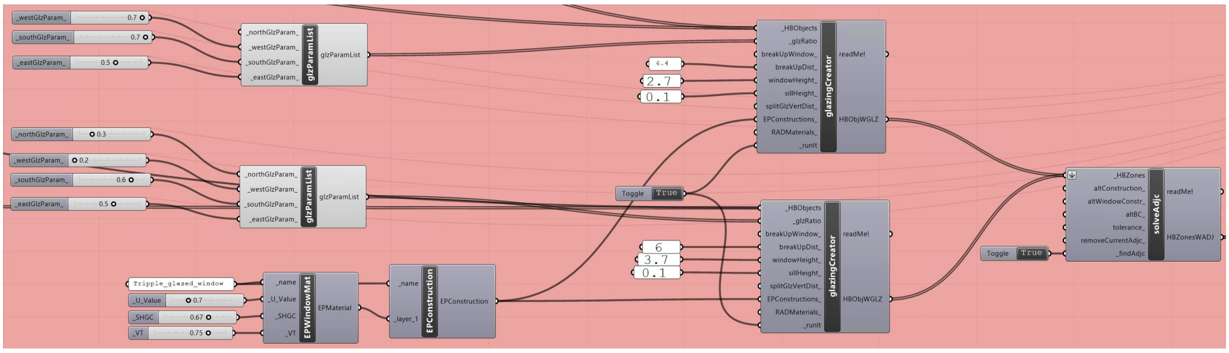


Figure 26: Setting window properties and WWR sliders for three different window categories

Table 4: Height and break-up distance of the windows

Building program	Window height	Break-up distance
Office	3,7	6
Midrise apartment	2,7	6,4

In the F2 building the energy simulation is done by dividing the building in eight different thermal zones according to the eight floors. To take into consideration internal floors in the daylight simulation, the walls separating the apartments are included as shading objects. This makes the energy simulation run faster compared to have each apartment as an one zone, but at the time the daylight simulation is more accurate than without any internal floors.

The typical floor plan used in the simulation is seen in Figure 27. The apartments are in a light blue colour, while the three building cores for circulation and services are visualised with a darker blue colour. The roof of the second floor is visualised with a light grey colour. Floor three to six have this floor plan, while seventh and eight floor has a slightly different floor plan with a indentation in the south-east facade on the seventh floor.

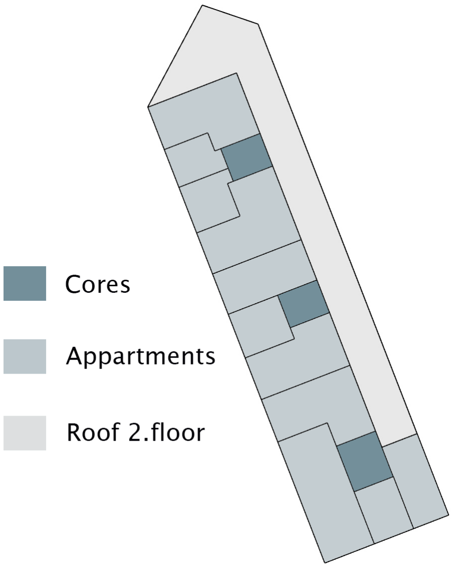


Figure 27: Typical floor plan of the building

Optimisation

Since the windows in the building model is assign to two "Honeybee add glazing by ratio" components, the number of parameters in this optimisation process increased. The objectives are still energy use and average daylight factor, and it is in this case seven sliders which are set form 0.2-0.8 with 0.1 increment. Due to time limitation the Octopus optimisation process where stopped at generation 7.

5 Results and discussion

In this chapter, the results from the two main tasks in the thesis are presented. First, the results from the neighbourhood analysis are presented, followed by the analysis at the building level.

5.1 Results from neighbourhood analysis

5.1.1 Radiation

The results from the radiation analysis show that the roofs of the new buildings, building C, E and F, are most exposed to solar radiation, as seen in Figure 28. These areas could be locations for PV's or urban gardening areas at the rooftop. At the ground level, the highest radiated areas are at "Melkeforsyningen" facing Platous gate and in Schweigårds gate next to building C, as seen in Figure 29. Melkeforsyningen could require extra shading on sunny days to maintain thermal comfort outside. Radiation studies of the facades are seen in Figure 30, seen from the south, and 30, seen from the north. The least irradiated areas are on the south-east part of the F2 buildings facing Grønlandsleiret. In these areas, measures like materials with high reflectance and bright colours could make it appear brighter.

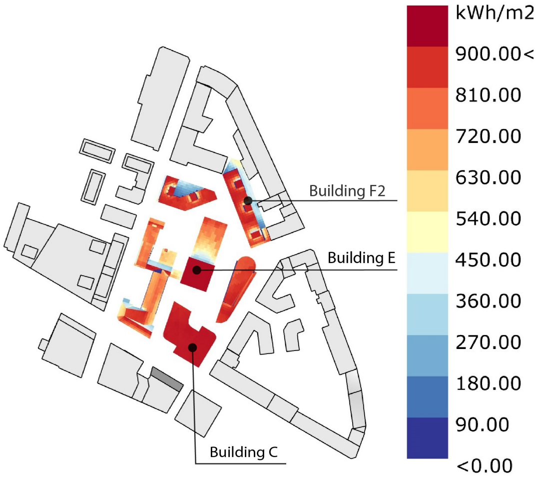


Figure 28: Results from the radiation analysis of the rooftops in LK

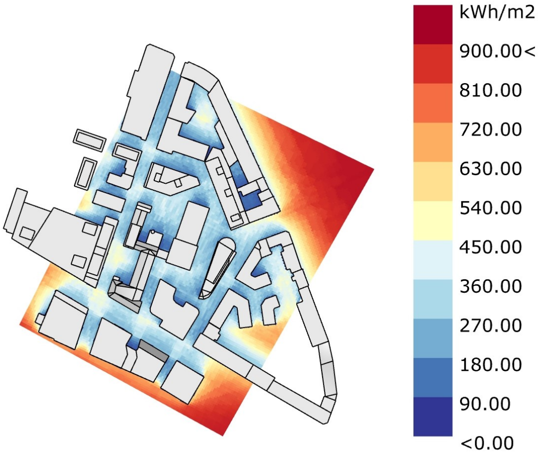


Figure 29: Results form the radiation analysis of the ground in LK

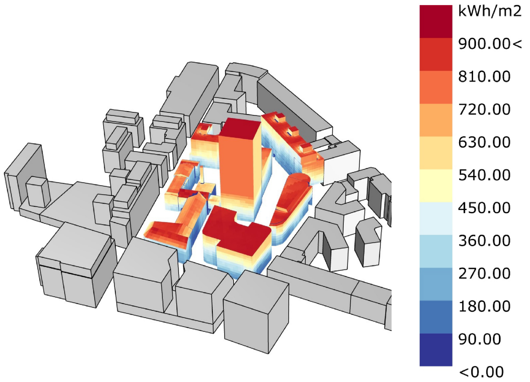


Figure 30: Results from the radiation analysis of the facades facing south in Landbrukskvartalet

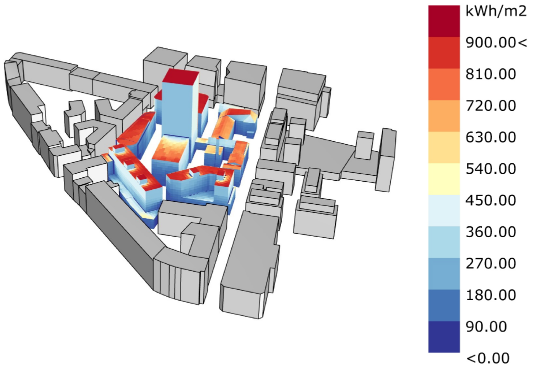


Figure 31: Results form the radiation analysis of the facades facing north in LK

5.1.2 Illumination outside

The illumination [Lux] outside have been analysed at the different urban spaces in Landbrukskvartalet. An explanation of the levels of illumination is seen in Figure 5. The results are shown in Figure 32, 33,34 and 35. From the results, we see that it could be an issue with too high illumination at Stallplassen, in the middle of the summer. The facade facing south-west require shading, either with shading devices or balconies. The central parts of both Meieriplassen and Melkeforsyningen have areas with high irradiation, and these areas could need shading in the summer. These shading installations could be trees or other shading devices. Since the problem only occurs in the summer period, the shading devices should be movable or deciduous trees.

Table 5: Illumination at different levels of daylight

	Lux [27]
Direct sunlight	100 000
Daylight	10 000
Overcast day	1 000
Twilight	10

21. March kl.12 21. June kl.12 21. September kl.12 21. December kl.12

Figure 32: Illumination analysis of Stallplassen, results from Rhino

21. March kl.12 21. June kl.12 21. September kl.12 21. December kl.12

Figure 33: Illumination analysis of Meieriplassen, results from Rhino

21. March kl.12 21. June kl.12 21. September kl.12 21. December kl.12

Figure 34: Illumination analysis of Melkeforsyningen, results from Rhino

21. March kl.12 21. June kl.12 21. September kl.12 21. December kl.12

Figure 35: Illumination analysis of Landbrukets plass, results from Rhino

5.1.3 Sky view factor

The sky view factor is analysed in four different areas at Landbrukskvartalet. As seen from the graphs, the areas have a SVF mainly between 80-50%.

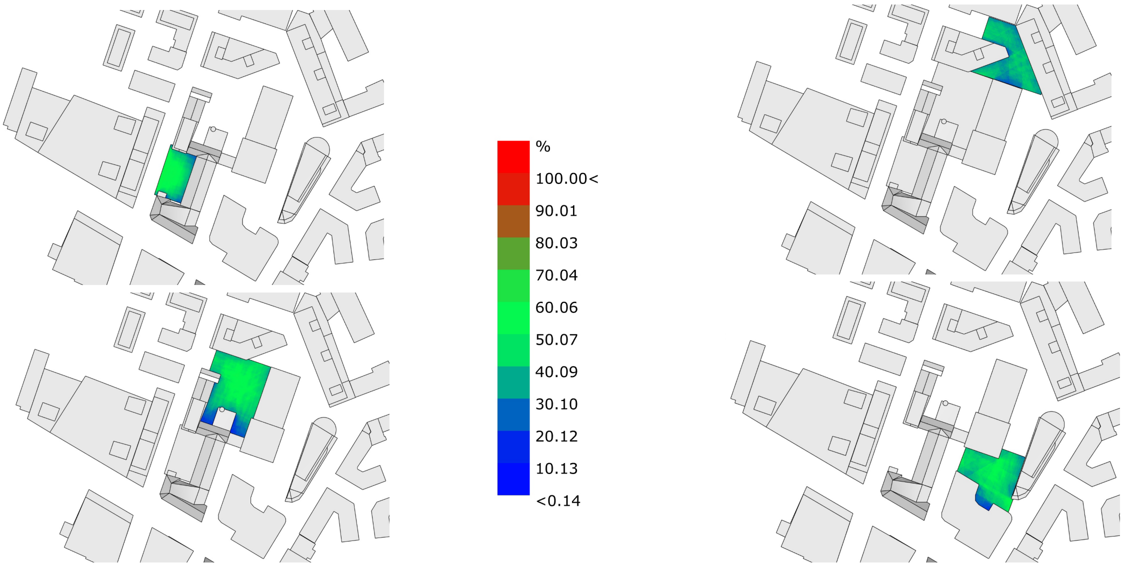


Figure 36: Sky view factor analysis, results from rhino

Many important factors could be investigated and analyses to be conducted to support a sustainable neighbourhood design. The effect of the sun affects both the buildings and the outdoor areas in the neighbourhoods. Having an understanding of which regions are particularly challenging, whether shading is needed or increased awareness of daylight access is essential in order to have a holistic design. The three proposed analyses provide insight into several different aspects. Visualised results may contribute to making it easier to discuss the outcome with someone who is not an expert in the field.

5.2 Results from building/parametric analysis

The outcome of the optimisation process with Octopus is shown in Figure 37,38, 39 and 40 with the Pareto fronts for each of the four scenarios. These optimisations ran for 10 generations, on average the time used to run 10 generations of optimisations were 72 hours with Intel(R) Core(TM) i7-8650U CPU@ 1.90GHz (8 CPUs). The two axes in the Pareto front represent the EU on the Y-axis and the ADF on the X-axis. The most optimised solution is the one closest to the cross point of the two axes.

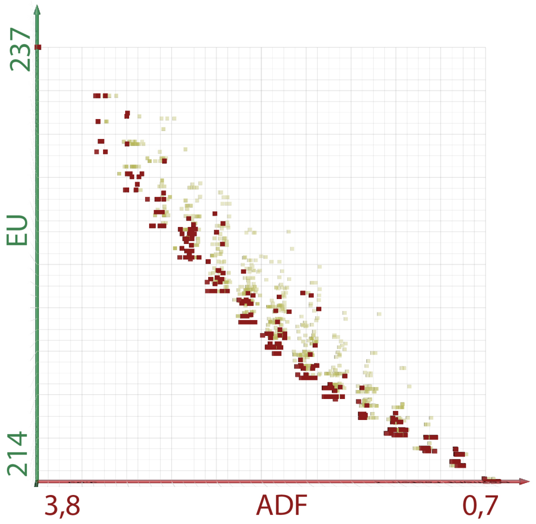


Figure 37: Pareto front of the scenario with aspect ratio 2

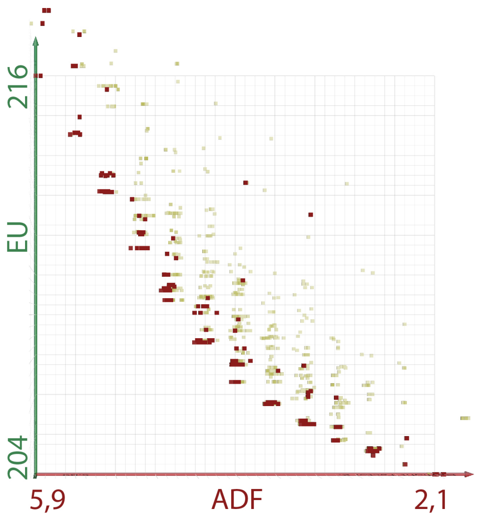


Figure 38: Pareto front of the scenario with aspect ratio 1

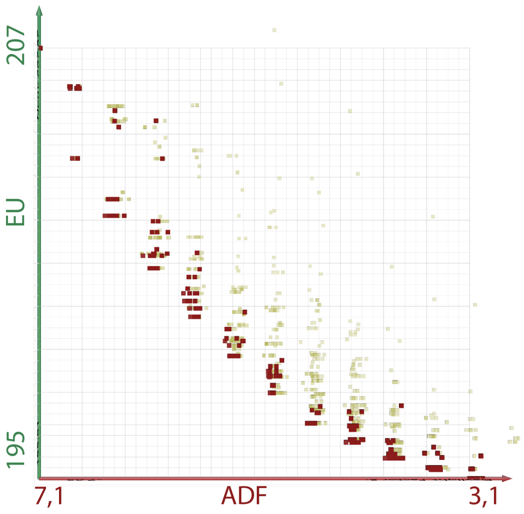


Figure 39: Pareto front of the scenario with aspect ratio 0,5

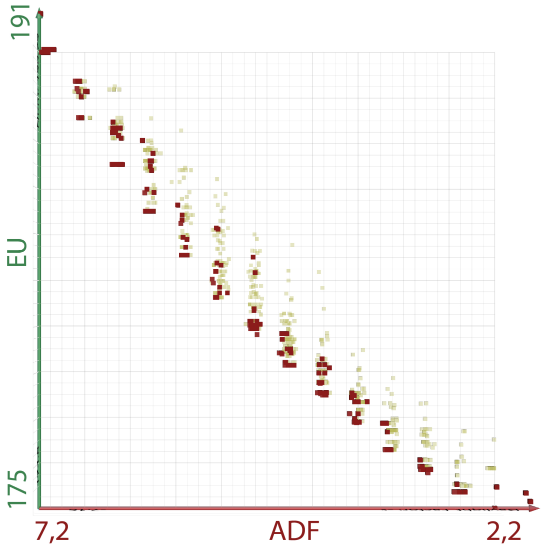


Figure 40: Pareto front of the isolated scenario

For each scenario, the WWR values are pointed out for the maximum value, the optimised value and the minimum value of energy use and daylight (see Table 6). Energy use and the average daylight factor is given for each of the WWR.

Table 6: WWR in four different scenarios after optimisation

Scenario		WWR				Results	
		North	East	South	West	EU [kWh/m^2]	ADF [%]
H/W=2	Max	0,5	0,5	0,5	0,5	237,7	3,8
	Optimised	0,1	0,5	0,2	0,5	221,9	2,5
	Min	0,1	0,2	0,1	0,2	214	0,7
H/W=1	Max	0,4	0,5	0,5	0,5	216,3	5,9
	Optimised	0,1	0,4	0,4	0,5	207,9	4,4
	Min	0,1	0,1	0,4	0,1	203,8	2,1
H/W=0,5	Max	0,5	0,5	0,5	0,5	207	7
	Optimised	0,1	0,5	0,5	0,5	199	5,7
	Min	0,1	0,2	0,4	0,2	195	3,1
Isolated	Max	0,5	0,5	0,4	0,5	190,7	7,2
	Optimised	0,1	0,5	0,2	0,5	181,1	4,8
	Min	0,1	0,2	0,2	0,1	174,8	2,2

The optimisation process simulates random WWR, and this could result in different minimum and maximum values in the WWR-values for the four different scenarios. Because of this randomness, the energy use and average daylight factor from the optimisation in the four different scenarios are not directly comparable for the minimum and maximum WWR-values. The figure 41 shows that all the presented WWR-values give an average daylight factor above 2%, except the minimum values in the scenario with aspect ratio equal 2. It is important to keep in mind that these results are an average of the entire building, which means that some of the rooms could have a higher ADF while other rooms could be below the threshold value of 2%. The EU in these simulations is shown in Figure 42, the energy use decreased as expected with the higher amount of daylight and less shading from the surrounding buildings. The energy use in these scenarios are remarkably higher than the maximum level from TEK17; one of the reasons behind these high values could be because there are no shading devices in the model. The lack of shading devices results in a higher cooling need in the building.

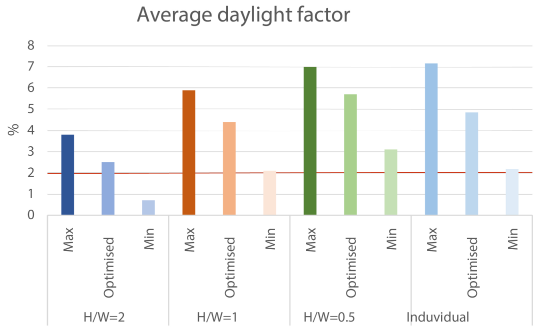


Figure 41: Average daylight results from the four different scenarios

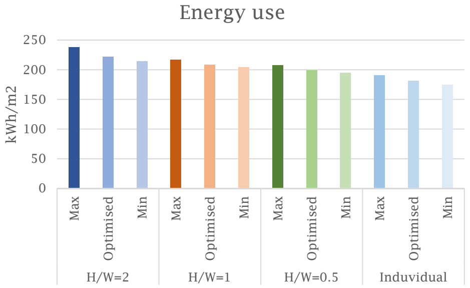


Figure 42: Energy use results from the four different scenarios

5.2.1 F2 building results

In the study of the F2 building to find the optimised WWR-value to balance the daylight factor and energy use, it is carried out analyses of two scenarios. The first scenario is the F2 building in an isolated context, without surrounding buildings. The second scenario is the F2 building in the urban context of Landbrukskvartalet. First, the results form the isolated scenario is presented, then the results from the urban context.

Isolated scenario

First, the F2 building was analysed in an isolated scenario to study the theoretical performance of the building with optimised WWR. The solutions from the optimisation in the Pareto front is seen in Figure 43. These are the results after running seven generations with Octopus. The performance of the building in terms of average daylight factor and energy use is seen in Table 7. The results from the base-case and the optimised solution will be described since these are the most interesting results of the optimisation.

Base-case

The base-case results of EU, ADF and WWR are presented to compare them to the optimised scenario. In the base-case scenario, the EU balance is shown in Figure 44, with a total EU at 144 [kWh/m^2. The floor plan with the DF visualised is seen in Figure 45, with an ADF of 3,8% .

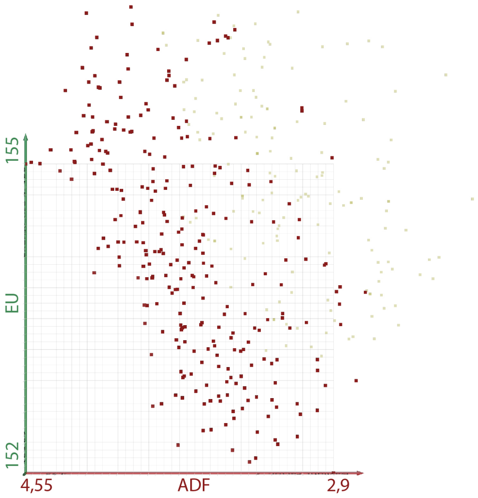


Figure 43: Pareto front of the solution of isolated scenario

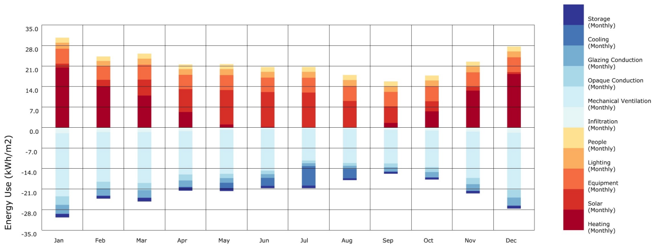


Figure 44: Energy use for the base-case scenario

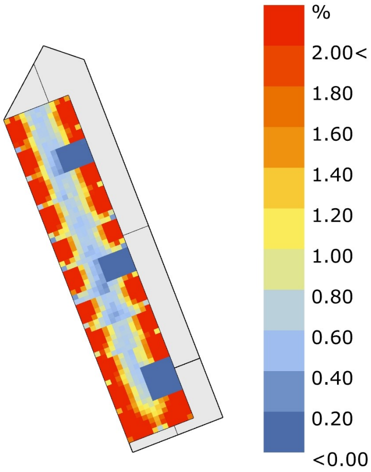


Figure 45: Floor plan with daylight factor in the base-case scenario

The building model with the WWR of the base-case is seen in Figure 46 and 47.

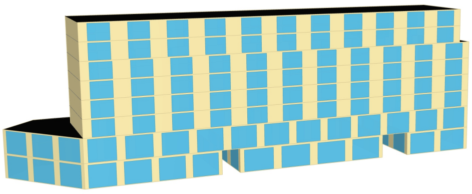


Figure 46: Facade facing south-west with base-case WWR.

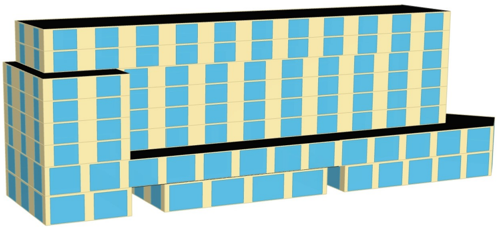


Figure 47: Facade facing north-east with base-case WWR.

Optimised scenario

The solution with the optimum WWR-value was derived from the Pareto front for the optimum solution. The total EU is 143 [kWh/m^2], and EU balance is seen in Figure 48. The floor plan with the daylight distribution is seen in figure 49, the ADF is 3,9%.

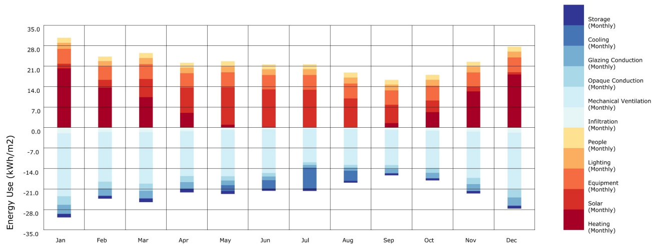


Figure 48: Energy use for the optimised scenario

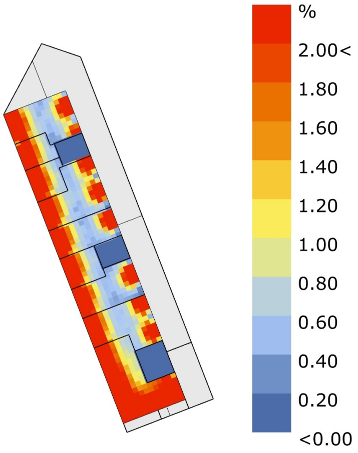


Figure 49: Floor plan with daylight factor in the optimised scenario

The facades with the optimised WWR is seen in figure 50 and 51.

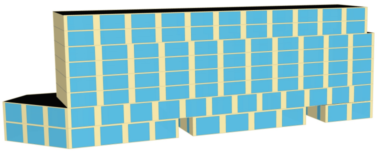


Figure 50: Facade facing south-west with optimised WWR.

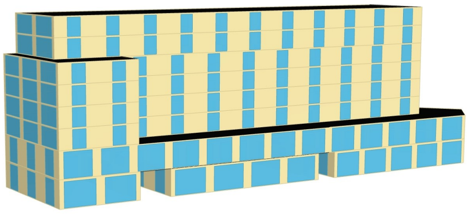


Figure 51: Facade facing north-east with optimised WWR.

Table 7: Results from the isolated scenario of the F2 building

Objective function	Minimum	Optimised	Maximum	Base-case
ADF [%]	2,9	3,9	4,5	3,8
EU [kWh/m^2]	142	143	146	144

Table 8: WWR-values for base-case and optimised scenario

WWR		North	South-West	South	North-East
Base-case	Office	0,6	0,7	0,5	0,7
	Apartment		0,5	0,3	0,5
Optimised	Office	0.2	0,7	0,4	0,7
	Apartment		0,7	0,7	0,3

The WWR-values is seen in Table8. In the optimisation, the daylight increased by 2,6% form the base-case to the optimised scenario. In an isolated scenario, the building will need shading to reduce the solar heat gains and avoid glare inside the building.

The EU decreased by 1,9% from the base-case to the optimised scenario. The results show a slight increase in the total performance of the building from the base-case solution to the optimised solution. Still, the performance of the building did not increase much; the WWR of the different facades changed in the optimisation.

An evaluation of the optimal WWR in an isolated scenario is a way to see if the method works in the way it is expected. However, the WWR-value results from an isolated scenario could not directly be applied to a building in an urban context because the shading from the other buildings is not taken into consideration.

F2 building in urban context

The F2 building is analysed in the urban context of Landbrukskvartalet. The solutions from the optimisation of the WWR-value are seen in the Pareto front in Figure 52. These are the solutions calculated after seven generations.

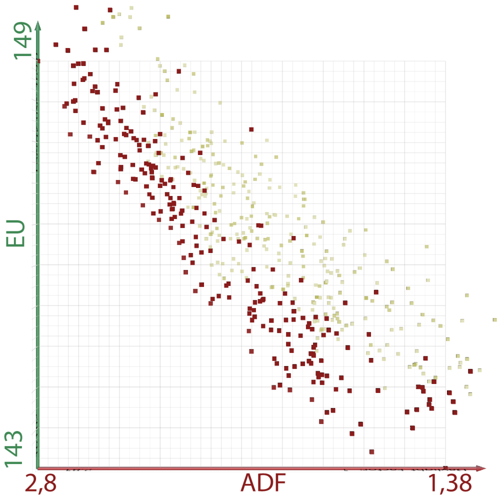


Figure 52: Pareto front of the solutions from the F2 building in urban context

Base-case

The results from the base-case scenario in the urban context of Landbrukskvartalet are presented in this part. The energy use balance is seen in Figure 54, the total energy use is 147 [kWh/m^2]. In Figure 54 the floor plan with the daylight factor is seen, the average daylight factor is 2,2%.

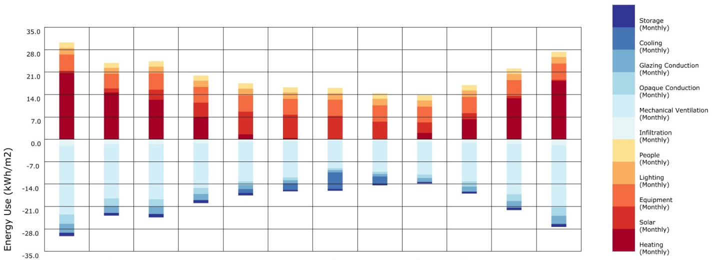


Figure 53: Energy use for the base-case scenario

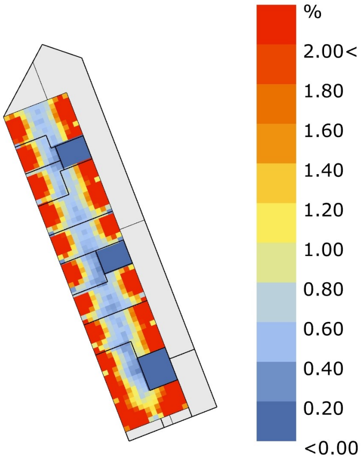


Figure 54: Floor plan with daylight factor in the base-case scenario

The building model With the WWR of the base-case is seen in Figure 55 and 56.

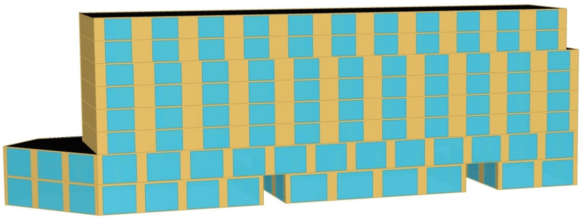


Figure 55: Facade facing south-west with base-case WWR.

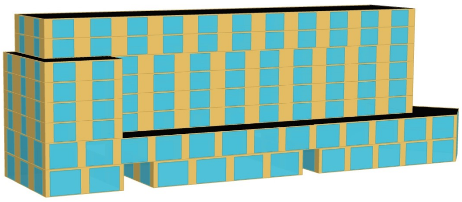


Figure 56: Facade facing noth-east with base-case WWR.

Optimised scenario

The optimal solution is found on the Pareto front; these values for the WWR are used for the optimised scenario. The energy use balance is seen in Figure 57, the total energy use in this scenario was 146 [kWh/m^2]. The average daylight factor was 2,2 %, and the distribution of daylight is seen in Figure 58.

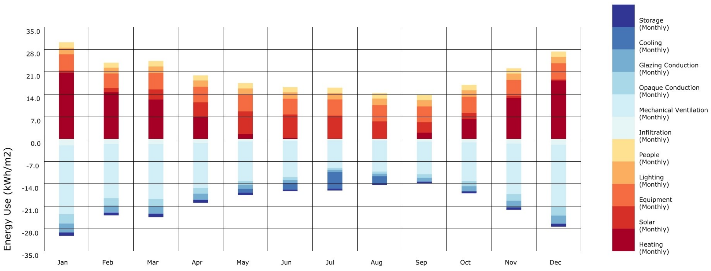


Figure 57: Energy use for the optimised scenario

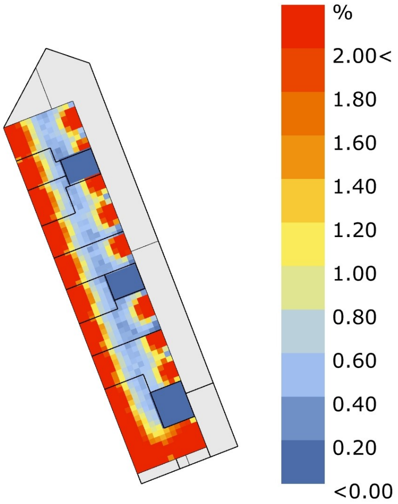


Figure 58: Floor plan with daylight factor in the optimised scenario

The building with the optimised WWR is seen in Figure 59 and 60.

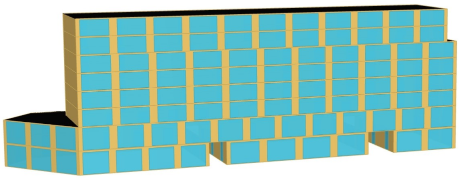


Figure 59: Facade facing south-west with optimised WWR.

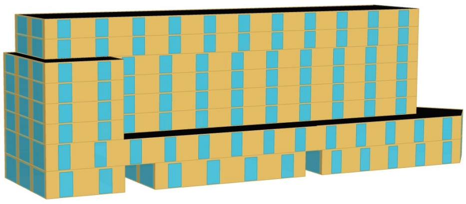


Figure 60: Facade facing north-east with optimised WWR.

Table 9: Results from the urban scenario of the F2 building

Scenario	Minimum	Optimised	Maximum	Base-case
ADF [%]	1,4	2,2	2,8	2,2
EU [kWh/m^2]	143	146	148	147

Table 10: WWR-values for base-case and optimised solution in the urban scenario

WWR		North	South-West	South	North-East
Base-case	Office	0,6	0,7	0,5	0,7
	Apartment		0,5	0,3	0,5
Optimised	Office	0.2	0,7	0,7	0,3
	Apartment		0,7	0,6	0,3

The performance of the building in terms of average daylight factor and energy use is seen in Table 9. In the optimisation, the daylight did not increase form the base-case to the balanced solution but remain the same.

The energy use decreased 0,7% from the base-case to the optimised solution. The improvements in terms of building performance, from the base-case to the optimised solution, is almost negligible.

However, the WWR-values did change from the base-case scenario to the optimised solution; the WWR-values are seen in Table10. These results are also the most interesting results from the optimisation. The WWR in the office part of the building decrease on both the north and the north-east facade, while the WWR on the south facade increased. On the apartment floors, the changes in WWR were slightly lower, the WWR at the south-west and the south facade increased. While on the north-east facade, the WWR decreased. The findings is corresponding to the outcome of F.Goia's work in 2016, even if the facades facing south and south-east is exceeding the WWR range of 0,5-0,6 and the north facade is lower than the WWR range of 0,37-0,43.

Since there is a slight change in WWR, it means that the choices made for the sketches of the building were already well optimised for daylight and energy performance.

Applying the windows with the "Honeybee add glazing by ratio" component, the size of the windows could be changed simultaneously on a facade instead of redrawing each window every time a change appears in a design. It also gives an excellent opportunity to test out different WWR values in the early phase of a design.

If the method of parametric optimisation is applied to a project, many solutions could be investigated without having to do them manually. The results from all simulations are saved in the interface of the optimisation tool, here Octopus, and give a feedback on which solutions are better than others in the Pareto front, in terms of the provided objective functions. However, the optimisation process is time-consuming. The simulation time is strongly connected to the complexity of a model, when a model gets more complex, the time increases.

5.3 Limitations of the thesis

In the thesis work, the study situation, access to the university and computer labs were compromised because of Covid-19. Thus, all simulations had to be conducted with a laptop instead of using the computers at the university. A consequence is, not all the intended analyses were carried out, and the optimisation of the F2 building was quit on the seventh generation of solutions.

One weakness of the thesis is that the results from the energy and daylight simulations are not compared to any of the simulation tools that were introduced early in the thesis, as SIMIEN or IDA ICE. The reason for this is also limited time and access to multiple computers. If the results had been compared, this would have strengthened the method. There are not conducted any sensitivity analyses of the method, and this lowers the reliability of the results.

6 Conclusion and further work

The importance of having a sustainable design of neighbourhoods and buildings is essential for reaching the Paris Agreement and reaching the goal of low-emission cities. By using simulation tools as a step in the design phase, necessary improvements can be made on the design in the early design phase, where the cost of modifications is still relatively low.

Using climate analysis tools, such as Ladybug tools, can get an initial overview of the situation in the analysed area. Analyses such as solar radiation, outdoor daylight and sky view factor provide an insight into which areas need further investigation. It is also a good starting point to start from the outside when a building is to be analysed. It will already be evident in the neighbourhood analyses which areas may have a problem with too high solar gains, have a need of shading or be in an area where it may be difficult to obtain satisfactory daylight.

The developed method of optimising the WWR to increase the daylight factor and reduce the energy use gave satisfying results when it came to optimising the facades, even though it did not provide any significant increase of the building performance. Since this is a method for the early design phase, other measures have to be investigated to improve the total building performance.

Due to time constraints and available computer equipment to run the simulations, it has been chosen only to have the WWR as a parameter in the optimisation. Further work to improve the analysis could be to add shading devices, window material and wall materials as parameters in the optimisation. While this will make the analysis more complete, it will also increase the optimisation process in Octopus, and it will be beneficial to use a high-performance computer. Other work that will improve the developed method is to compare the results with other simulation tools.

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