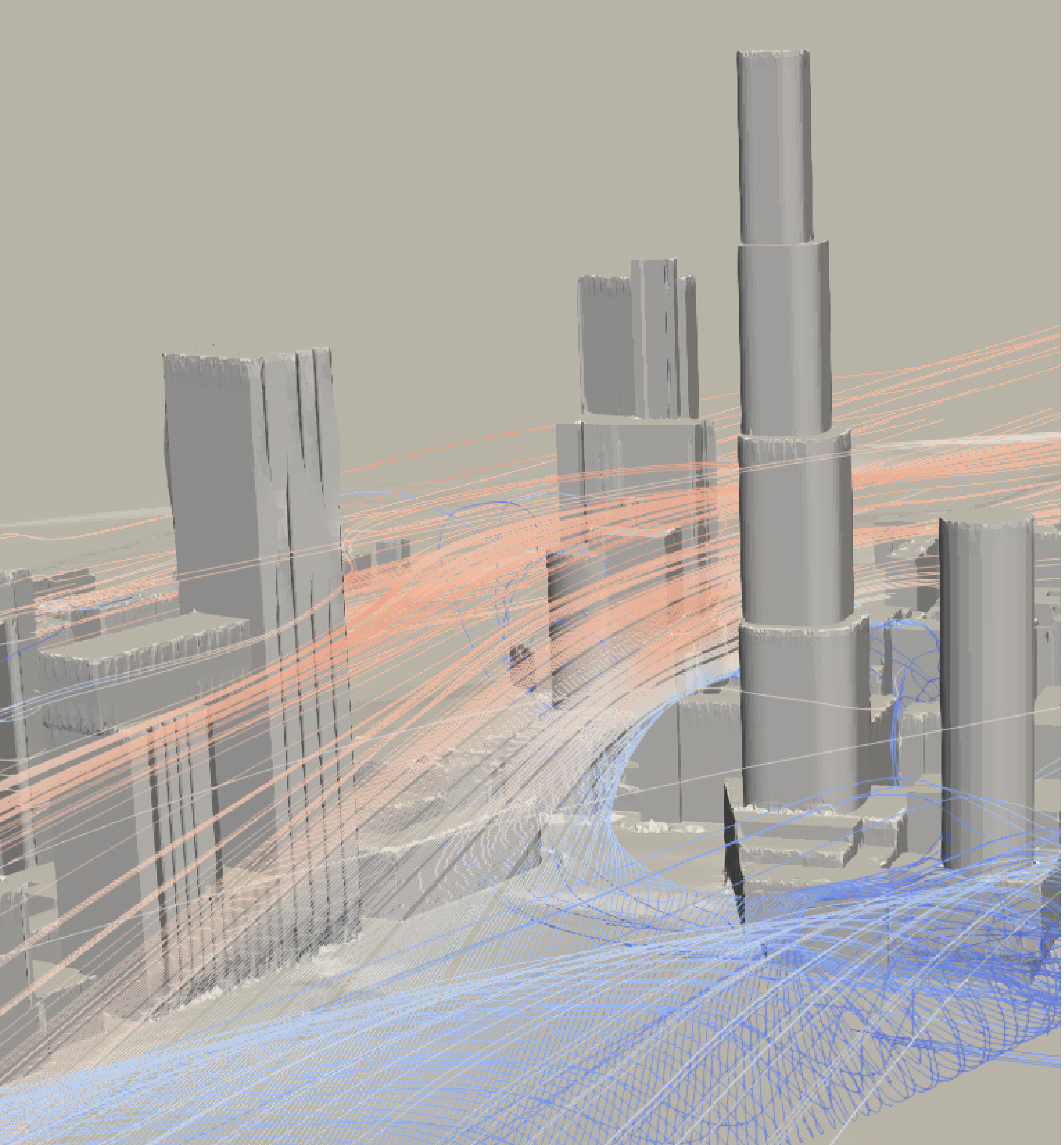


Wind Driven Design

How bringing wind into the design process can positively impact the design process of high-rise buildings

Research Plan

Faculty of Architecture and the built environment
Track: Architecture
Studio: Architectural Engineering, Flow

Candidate

Thijs Kroft (5078644)

Tutors

Research Tutor: Clara Garcia-Sanchez
Design Tutor: Mauro Parravicini

Contents

Choice of Studio

I chose the architectural engineering studio for its emphasis on technological innovation and the freedom it offers, all while maintaining a structured schedule. Throughout my education, technical requirements have consistently inspired my designs, making the studio's technological focus a perfect fit for my approach. Additionally, the opportunity to select a mentor from outside the studio is invaluable to me, as it allows me to work with an experienced supervisor in the field of aerodynamics—essential for achieving success in this field where I have very limited experience.

Key Words

Urban Air System

This concept was minted by Simone Tax, who wrote her graduation thesis on the relation between human-scaled urbanism and urban physics. The term is used for the system of air flows through a system.

Computational Fluid Dynamics (CFD)

A simulation method that is used to simulate any fluid behaviour with the use of a computer. It is based on the governing equations of the fluid flow (Navier-Stokes). These simulations are used for different types of fluids, including liquid and gas states, in fields such as aerospace engineering, Formula 1 and the built environment.

High-Rise

A high-rise building is a building that is significantly taller than the average surrounding buildings. In this paper, high-rise buildings are taller than 70 meters. This height is chosen as buildings that are taller than 70m are required to run wind simulations in the municipality of Rotterdam.

Wind Danger

Danger caused by high wind speeds. When the windspeed is higher then 15 m/s, a healthy human can be blown of their feet. This situation should be prevented.

Powerhouse/Shop - The Codrico Terrain

Problem Statement

Origin

The evolution of high-rise buildings in the Netherlands began in the late 20th century as urban centres sought to accommodate population growth and economic development within limited space. Initially concentrated in cities such as Rotterdam and The Hague, high-rise construction has since become a prominent feature of many Dutch urban landscapes. While these developments have contributed to urban densification and skyline transformations, they have also introduced new challenges related to urban comfortability. One of the key concerns is the impact of high-rise structures on local wind conditions.

Focus

High-rise buildings can significantly alter local wind patterns, resulting in unsafe wind conditions for pedestrians and cyclists. This issue is particularly relevant in Dutch cities, where strong prevailing winds are common, and public spaces are extensively used for various urban activities. Despite the rapidly advancing field of aerodynamics, urban designers as well as architects still have a very limited understanding of the impact their designs have on local wind patterns. This lack of understanding, combined with regulations that require wind-tunnel testing or CFD simulations, frequently results in less than ideal last-minute efforts to mitigate wind dangers. These last-minute efforts are often not very effective at mitigating the problem nor very visually appealing.

Urgency

Now that buildings are rising to ever increasing heights, understanding wind in an urban environment is more crucial than ever. If we do not take wind into account with these new high-rises, we are stuck with a terrible wind environment for a long time. Therefore, we must take action now and make sure that architects and urban designers take this topic into account while designing. A short and understandable workflow relating to wind for architects and urban designers is missing. This thesis will be a starting point towards a more widespread understanding of wind behaviour in the architectural profession.

Shop – Atlassian

Objective

Goal

The goal of this project is to assist architectural designers in incorporating wind into the earlier stages of their design. In practice, architectural designers often do not understand the impact of their buildings on the local wind climate. Often, this leads to undesirable outcomes. The outcome of this research is a workflow that can help architectural designers prevent these undesirable outcome.

Research

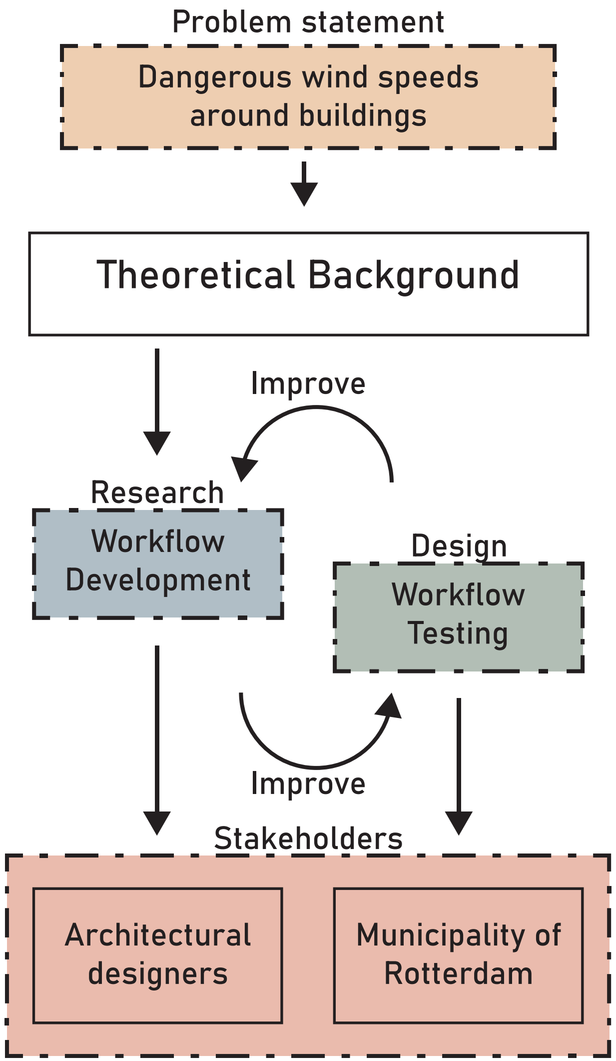
Due to the complexity the task at hand, the scope of this research will be limited to a specific location; Rijnhaven in Rotterdam. The urban plan for this location has recently been finalized and includes requirements for wind speeds in the surrounding area. These requirements are challenging to meet, due to the unique situation of high-rise buildings situated next to the water front. This research paper aims to provide a workflow for architects to help incorporate wind behaviour into their early design concepts and therefore create a better and more integrated design. This results into the following research question:

How can an improved understanding of wind behaviour be integrated into high-rise design strategies to enhance pedestrian comfort and safety in Rijnhaven, Rotterdam?

Design

The resulting workflow provides a practical guide for architectural designers in Rijnhaven who aim to incorporate wind considerations into their designs. It will feature several design strategies to enhance local wind conditions around their structures, along with methods for testing these strategies' effectiveness. The masterplan for Rijnhaven is notably ambitious, envisioning multiple multifunctional towers reaching around 200 meters in height, complemented by extensive new greenery. Social aspirations for the area are equally high; the development aims to create a vibrant urban center that serves as a meeting place for residents from nearby neighborhoods Kop van Zuid, Katendrecht, and the Afrikaanderwijk—each with its distinct identity and character. Integrating these diverse ambitions with the wind-driven design approach brings us to the following design question:

How does the incorporation of a wind-based design workflow impact the design process of a multifunctional highrise building in the the urban context of Rijnhaven, Rotterdam?



Hypothesis

By using a wind-oriented workflow in the design process for highrise buildings, the pedestrian comfort at streat level will increase by creating a more favourable wind climate. Furthermore, by taking wind into account at an earlier stage, the final design will be more in line with the original architectural vision.

Method

In order to answer the research and design questions, this project is devided into three main parts:

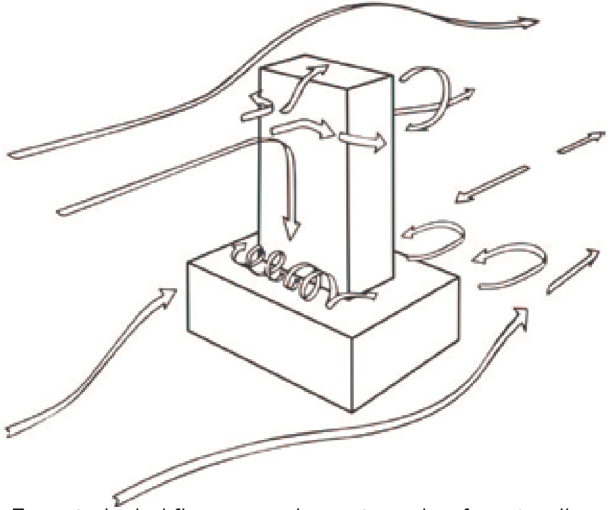
Theoretical Background
In this chapter, a general explanatation of wind behaviour is given. This chapter includes characteristics of a desirable wind climate as well as an exploration of several design strategies that could help reach this target.

Workflow Development
The design strategies that are found in the previous chapter will be tested in this chapter in order to reach a workflow that architects can use to create a better wind climate around their buildings as well as maximize their creative freedom.

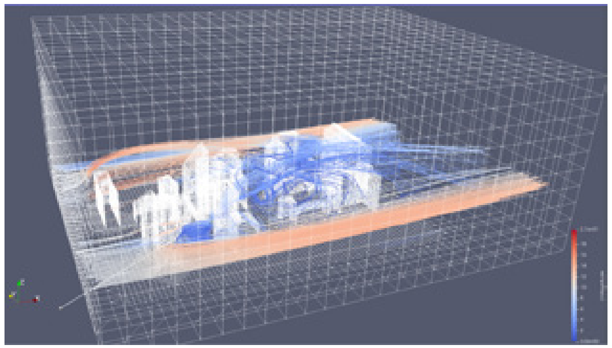
Workflow Implementation
In this third chapter, the workflow will be implemented for a test case in Rijnhaven, Rotterdam. The test case includes the design of a multifunctional highrise structure with a height around 200 metres.

Success

The workflow can be seen as successful when it leads to a design that leeds to a comfortable wind climate as well as sufficient freedom in the designprocess. For the determination of what a “comfortable” wind climate is, the NEN 8100 will be used. The NEN 8100 sees different wind conditions as comfortable for different activities. The workflow should help architects deal with wind comfort while improving on design quality.



Expected wind flow around a rectangular, freestanding building (S. Tax 2021)



CFD analysis of a testcase in OpenFOAM (personal work)

Theoretical Background

Comfort

The first part of this chapter focuses on defining the characteristics of a desirable wind climate, which vary according to season and intended activities. For instance, summer and winter wind conditions may require different considerations, as do distinct urban functions. These variations should inform any wind study, guiding the choice of recommended research methods.

Behaviour

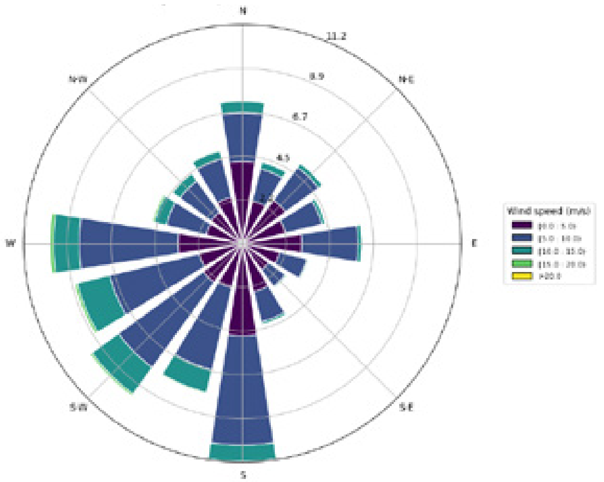
The second part explains wind behavior in an urban context and provides an overview of Computational Fluid Dynamics (CFD) technology, highlighting its role in understanding and predicting wind patterns around high-rise buildings.

In the third part, the chapter revisits the insights from the previous sections to identify design interventions that can positively impact wind behavior. These recommended interventions will form a key component of the proposed workflow.

Sources

The sources referenced in this chapter include, but are not limited to:

- Blocken, B. (2015). Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. Elsevier
- Lenzholzer, S. (2015). Weather in the City - How Design Shapes the Urban Climate. Nai 010 Uitgevers/Publishers.
- NEN. “8100:2006.” 2006.
- Tax, S. People centred + climate oriented Urbanism. Eindhoven: Eindhoven University of Technology, 2021.
- Tax, S., Arends, E. Handleiding Windhinder & Windgevaar. Rotterdam: Gemeente Rotterdam, 2023.



Expected wind frequency and strength for Rijnhaven, Rotterdam (based on data from KNMI)

N	4.83 m/s
NE	4,82 m/s
E	4,81 m/s
SE	4,39 m/s
S	5,57 m/s
SW	6,90 m/s
W	6,39 m/s
NW	5,65 m/s

Expected average wind strength for Rijnhaven, Rotterdam (based on data from KNMI)

Workflow Development

Goal

The second part of the thesis will focus on creating a workflow for architects to help incorporate wind behaviour into early stages of their design process. Design strategies that are aquired in the first part will be tested using the theoretical framework that Blocken, B et al. provided in their paper *“CFD simulation for pedestrian wind comfort and wind safety in urban areas: General decision framework and case study for the Eindhoven University campus”* will be employed (Blocken 2011). This framework provides an overview of the best practice guidelines relating computational fluid dynamics, a method that is used to simulate wind and fluid behaviour with an iterative process that solves mathematical equations for every cell in a large mesh.

Boundary Conditions

The required geometry for this simulation is constructed using city4cfd. This model will be constructed with geometrical data from pdok as well as pointclouds from GeoTiles.nl. When this is completed, a mesh will be constructed. This will be done using blockMesh and nappyHexMesh. The simulation is run while keeping ABL conditions as well as turbulence in mind. Wind statistics are aquired by combining data from KNMI weather stations near Rotterdam Airport, Rotterdam Geulhaven, Hoek van Holland and Voorschoten (KNMI sd). Combining this data tells us that the dominant wind direction for Rijnhaven is likely south. However, the wind from the southwest is often faster. Due to time limitations, this research is limited to one wind direction. Southwest is chosen as this wind direction, as it is expected to be the most problematic for wind comfort at pedestrian level. As a wind speed, the mean wind speed from the southwest is chosen, at 6,9 m/s.

Simulation

The simulations for this research are run in Openfoam V7. For this project, the SIMPLE algorithm is used. This particular solver is based on the incompressible Reynolds Averaged Navier Stokes (RANS) equations and is capable of taking turbulent flow into account. The simulations will run locally on a computer that is located in the VR-Lab at the faculty of architecture and the built environment. A convergence factor in the magnitude of 1e-5 is desired to call the simulation reliable. The results of the simulations will be visualized using paraview. This is a tool in OpenFOAM which allows for several methods of visualizing. This is important as CFD simulations are complicated and require simplification in order to fully grasp the contents.

MVRDV - The Sax

Workflow Implemenation

Case

In the third phase of this research, the workflow manual developed in the second phase will be applied to design a building block in Rijnhaven, Rotterdam. Recently finalized, the ambitious urban masterplan for Rijnhaven envisions numerous high-rise structures interwoven with green spaces and recreational areas. Given the site's south-west orientation and its proximity to a large water surface, wind considerations are essential due to the potential for challenging wind conditions that could impact safety and comfort. While the overall plan is nearing completion, individual plots are yet to be allocated. One of these plots will serve as the location for this project, a multifunctional high-rise building reaching approximately 200 meters. The height presents unique wind-related challenges, as high winds at these elevations must be carefully managed to avoid being redirected to pedestrian levels.

Challenges

Situated in Rotterdam, the Rijnhaven site is part of a rapidly developing area at the intersection of several diverse neighborhoods: the office- and hotel-oriented Kop van Zuid, and the residential neighborhoods of Afrikaanderwijk and Katendrecht, all with completely seperate and unique identities. This development aims to create a central urban hub for these communities, with a welcoming climate that promotes comfort and accessibility, specifically extending to wind conditions.

Ambition

The current development includes extensive public spaces, a floating garden, and new cafés and restaurants, along with high-rise projects such as The Sax by MVRDV and the Codricotower by SHoP. The design for the building block and its surrounding area aim to foster:

-Establish an urban community that supports residents in making a “housing career.”

-Suitable and sufficient space for local entrepreneurs.

-A comfortable space that allows for the other two goals, with a pleasant climate.


OMA - The Rotterdam

Bibliography

- Blocken, B., Janssen, W.D., Van Hooff, T. CFD simulation for pedestrian wind comfort and wind safety in urban areas: General decision framework and case study for the Eindhoven University campus. Elsevier, 2011.
- NEN. “8100:2006.” 2006.
- Tax, S. People centred + climate oriented Urbanism. Eindhoven: Eindhoven University of Technology, 2021.
- Tax, S., Arends, E. Handleiding Windhinder & Windgevaar. Rotterdam: Gemeente Rotterdam, 2023.
- Lenzholzer, s. Weather in the City - How Design Shapes the Urban Climate. NAI 010 Uitgevers/Publishers, 2015.

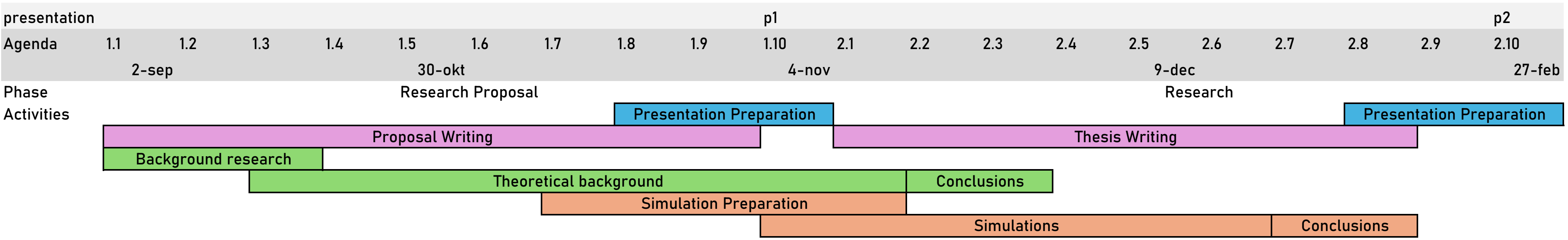
Software

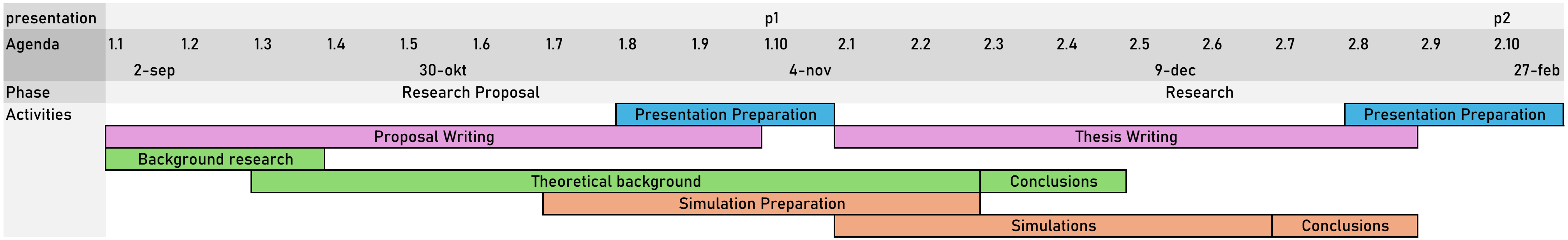
- OpenFOAM Foundation. OpenFOAM. V.7. Ubuntu. 2019.
- 3D geoinformation research group at TU Delft. City4CFD. V.1. Ubuntu. 2022.
- Ivan Pađen, Ravi Peters, Clara García-Sánchez, and Hugo Ledoux (2024). Automatic high-detailed building reconstruction workflow for urban microscale simulations. Building and Environment, 265, 2024
- Ivan Pađen, Clara García-Sánchez, and Hugo Ledoux (2022). Towards Automatic Reconstruction of 3D City Models Tailored for Urban Flow Simulations. Frontiers in Built Environment, 8, 202

Data

- KNMI. Uurgegevens Van Het Weer in Nederland. n.d. https://www.knmi.nl/nederland-nu/klimatologie/uurgegevens.
- van Natijne et al. (geotiles.citg.tudelft.nl). “GeoTiles: Readymade Geodata With a Focus on the Netherlands,” October 12, 2020. https://geotiles.citg.tudelft.nl/.

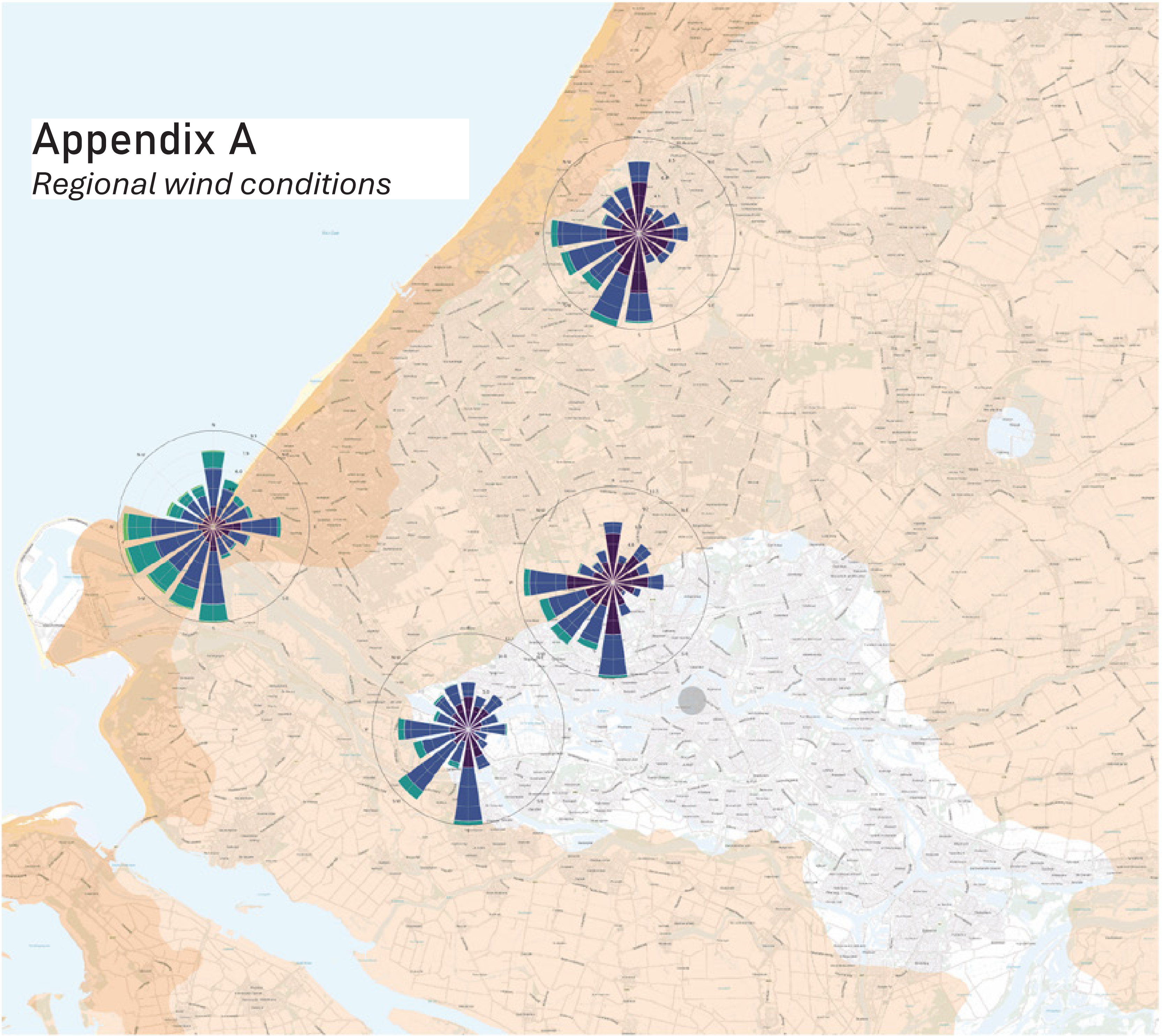
Graduation Timeline





Appendix A

Regional wind conditions



Wind Driven Design

Location: Rotterdam Rijnhaven
Date: 2024-10-24
Author: Thijs Kroft
Student number: 5078644

regional Wind

Wind speeds at height of 100m

- 5.5 - 6.0 m/sec
- 6.0 - 6.5 m/sec
- 6.5 - 7.0 m/sec
- 7.0 - 7.5 m/sec
- 7.5 - 8.0 m/sec
- 8.0 - 8.5 m/sec
- 8.5 - 9.0 m/sec
- 9.0 - 9.5 m/sec

Wind speed (m/s)

- [0.0 : 5.0)
- [5.0 : 10.0)
- [10.0 : 15.0)
- [15.0 : 20.0)
- >20.0

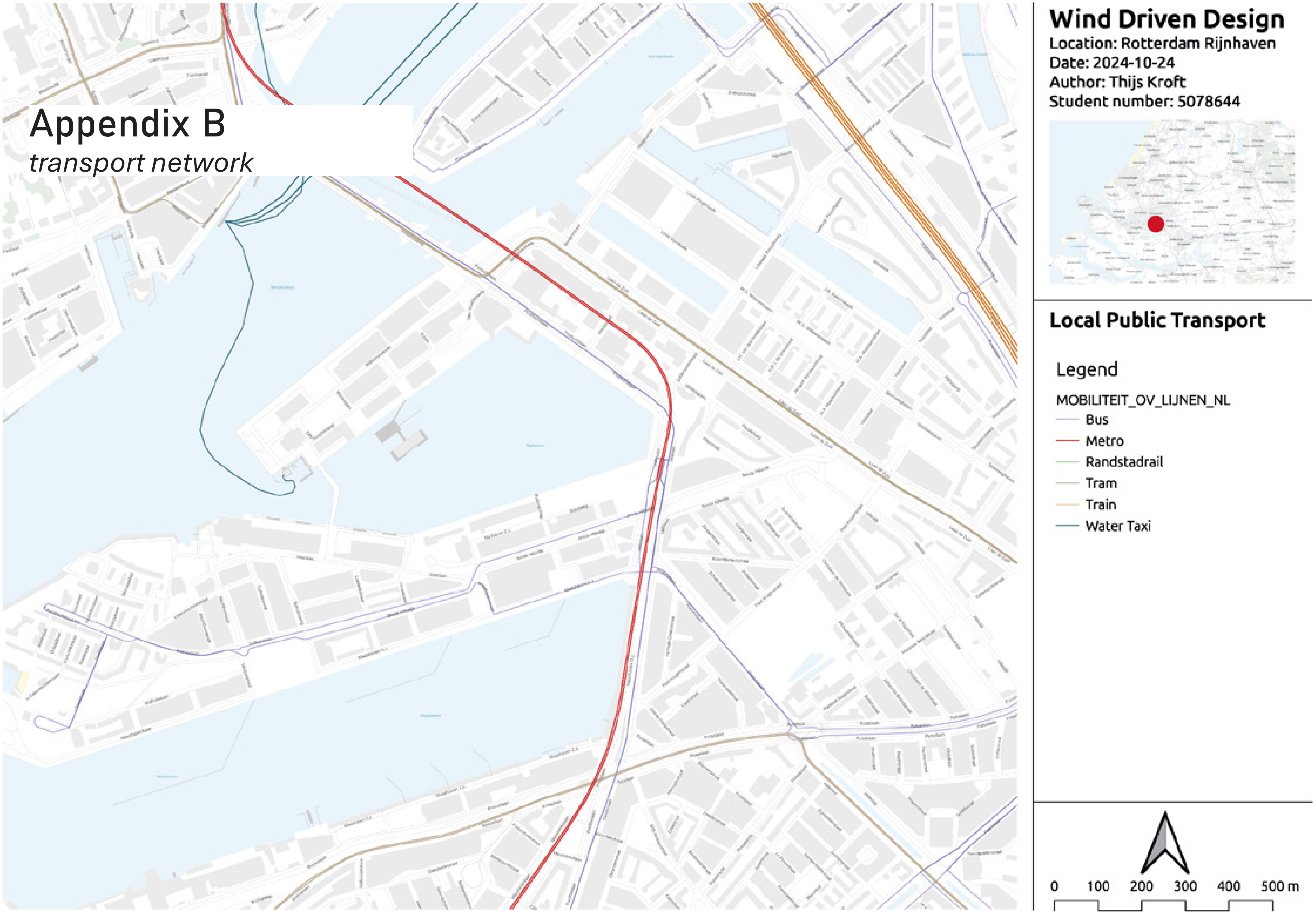
Wind Analysis Domain

- domainBnd

0 5,000 10,000 15,000 m

Appendix B

transport network

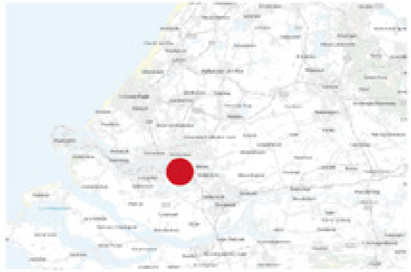


Appendix C

current situation

Wind Driven Design

Location: Rotterdam Rijnhaven
Date: 2024-10-24
Author: Thijs Kroft
Student number: 5078644



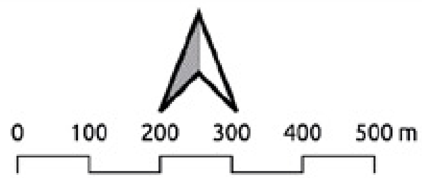
Local Buildings

Legend

- road
- Buildings
- waterlots
- Greenery

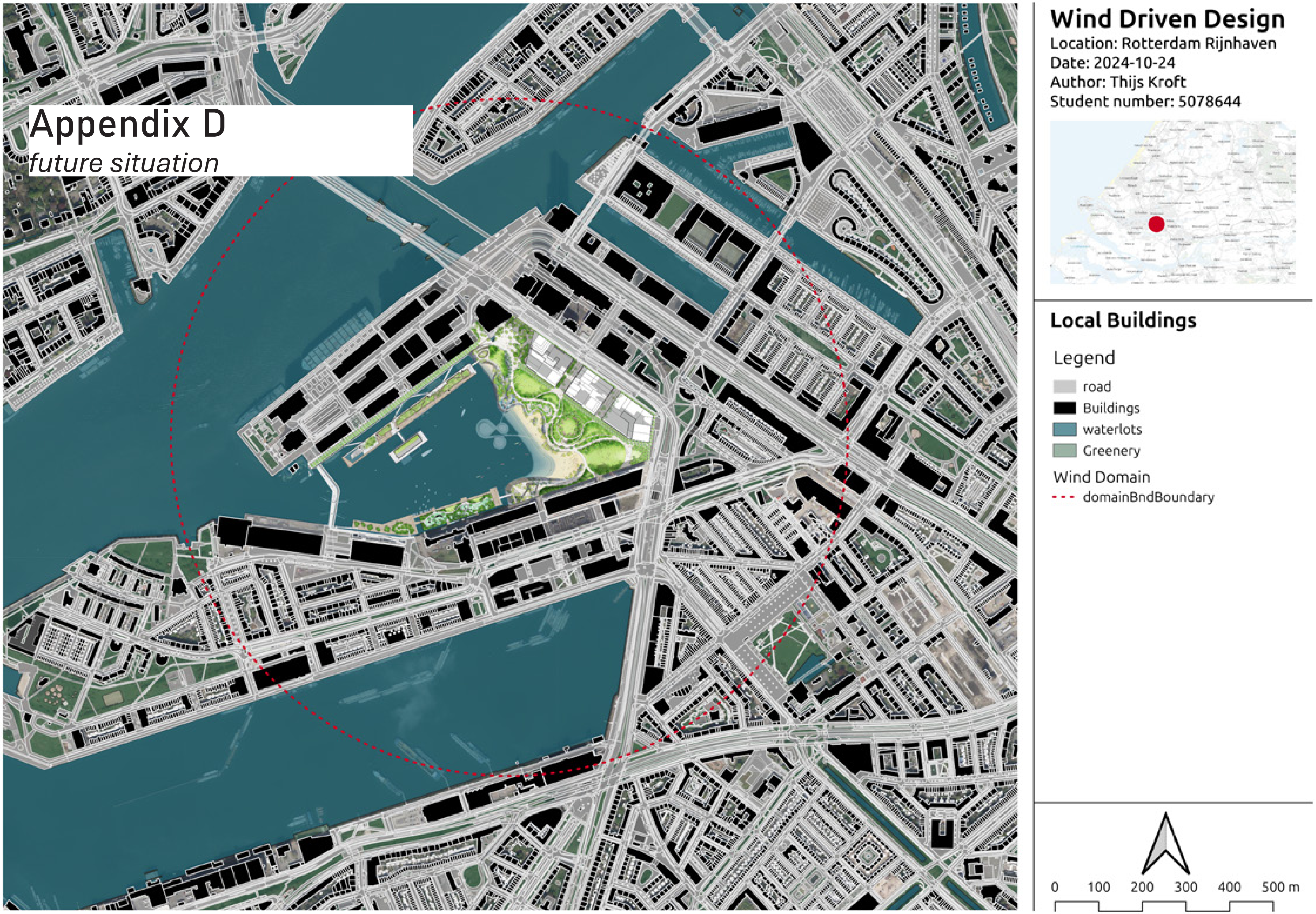
Wind Domain

- domainBndBoundary



Appendix D

future situation



Appendix E
Simulation domain