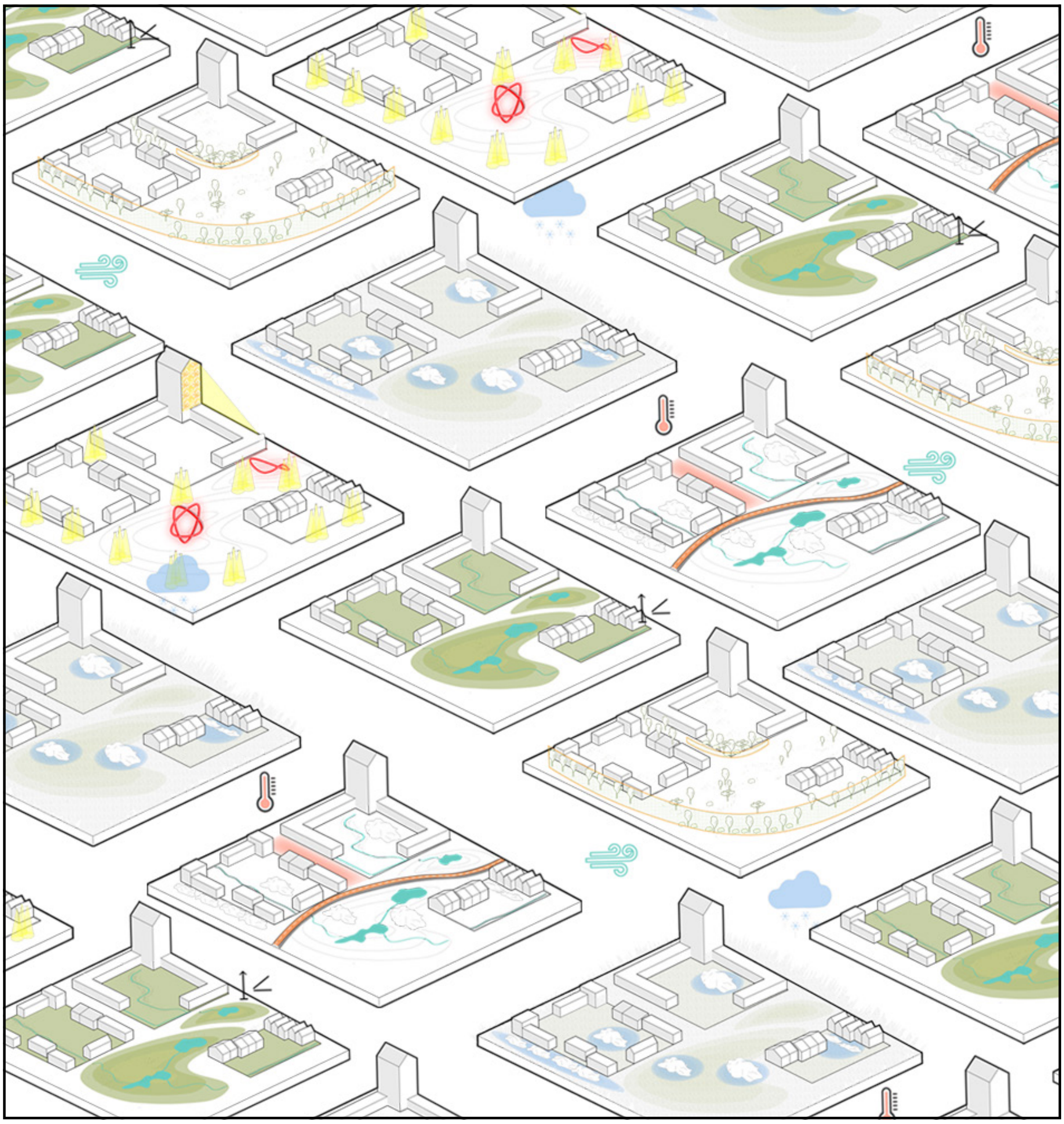
Comfort in the Cold

Mitigating Evolving Winter Barriers to Outdoor Use in the Arctic Town of Piteå

Zerham Shahd | Spring 2025



Chalmers School of Architecture | Department of Architecture and Civil Engineering | Examiner: Jorge Gil | Supervisor: Job van Eldijk

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Zerham Shahd

Chalmers School of Architecture
Department of Architecture and Civil Engineering
Master’s Program in Architecture and Planning Beyond Sustainability

Examiner: Jorge Gil
Supervisor: Job van Eldijk

Student Background

Education

Master of Science in Architecture & Planning

Chalmers University of Technology

2023 - 2025

Bachelor of Science in Spatial Planning

Blekinge Institute of Technology

2020-2023

Glossary

Climate-sensitive Design

Climate-sensitive design is an approach to architecture and urban planning that considers local climate conditions and built-form to enhance comfort and manage the surrounding microclimate.

Soft Mobility

Soft mobility refers to human-powered, non-motorized modes of transportation. This includes walking, cycling, kicks-leading, skiing, among others.

Winter Design

Design principles that consider wind protection, sun exposure, color, lighting, and urban infrastructure to support winter life.

Abstract

This thesis explores how urban design and planning can improve conditions for outdoor stay and soft mobility during winter in the changing Arctic climate of Piteå, Sweden, where residents face both climatic and mental barriers to outdoor activity.

To address this challenge, the study adopts a mixed-method approach, combining inductive qualitative methods, such as a literature review and case study, with quantitative analysis through computational simulations. A master plan proposal for Piteå's Sörfjärden area serves as the basis for a microclimatic study. The research draws on winter planning literature, municipal documents, and the work of contemporary architects and planners.

The findings led to the development of a framework of design principles and a hierarchical design strategy, both of which were applied in the microclimatic analysis and in the improvement of the study area. In conclusion, this combined method suggests the potential of integrating design intuition, principles, and strategies with data-driven tools to assess and improve outdoor environments and offers insights for designing more resilient and liveable urban spaces in the arctic.

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Introduction

This chapter introduces the thesis covering, background, aim, methodology, delimitation, structure, and a framing of the Arctic context.

Figure 1. *Piteå, Timmerleden pedestrian crossing.* Photo by author.

1.1 Problem

Piteå, located in Sweden's arctic north, faces significant climatic challenges that impact soft mobility and urban life. Long, cold winters with heavy snowfall, sub-zero temperatures, and limited daylight significantly influence mobility habits and the use of public spaces. Research suggests that cold climates play a critical role in shaping mobility choices, often reinforcing car dependency (Böcker et al., 2019). This is evident in Piteå, where car usage is high and car ownership per 1,000 residents has steadily increased over the past decade (Norconsult AB, 2022).

Climate change is expected to further complicate mobility patterns in Arctic cities. Rising temperatures may lead to more frequent freeze-thaw cycles, increased ice formation, and unpredictable winter conditions, making walking and cycling even more challenging, making it an unattractive mobility choice during winter. Studies indicate that as Arctic cities experience warmer, wetter winters, physical inactivity tends to increase, exacerbating health and sustainability concerns (Chapman et al., 2018).

Despite these growing challenges, winter adaptation strategies in urban planning remain limited, particularly in the municipality of Piteå, which, while proudly identifying as a summer town, overlooks aspects of winter design and the influence of climate change on future design requirements in its policy documents and planning.

As Piteå undergoes urban transformations, including the development of a new railway line and urban expansion, there is an opportunity to integrate winter-sensitive design principles that support soft mobility and the use of outdoor public spaces.

To fully realize this potential, a deeper understanding is required of how urban design can address the challenges of Arctic winters and the escalating impact of climate change on Arctic living. This thesis explores these issues, examining how Piteå's new development can integrate winter-adaptive design strategies into its planning to create a more livable, accessible, and climate-resilient city throughout the year.

1.2 Aim

This thesis examines the Solander Ring master plan for Piteå's new Sörfjärden development area, with the objective of integrating a winter perspective and exploring climate adaptation strategies. The thesis focuses on climate sensitive urban design that responds to Piteå's climatic conditions and the evolving challenges of Arctic climate change. The goal is to propose improvements to outdoor environments that support year-round outdoor stay and facilitate soft mobility during winter.

Thesis question:

How can urban design and planning improve conditions for soft mobility and promote people's use of public spaces in Piteå's changing Arctic climate?

1.3 Delimitation

The thematic scope of this thesis includes winter soft mobility, winter city planning, climate-sensitive design, and urban design. The literature study is limited to sources relevant to these themes, with a focus on Arctic and Subarctic regions. The geographic scope of the thesis is limited to the municipality of Piteå.

The case study focuses on general municipal planning documents and specific materials related to the overall design, layout, and structure of the Solander Ring master plan. It also includes an analysis of Piteå's current climate and projected future climate, with the projection period limited to the year 2100.

The spatial interventions and simulation-based analysis are confined to the area covered by the Solander Ring master plan. The design scope is limited to the urban scale; aspects such as architectural detailing, materials, and construction methods are excluded from this study.

1.4 Methodology

Literature study

The thesis research is primarily conducted through a literature study that is based on an inductive qualitative text analysis where data was categorically coded connected to their thematic subject. The literature collection process consisted of searches in various databases where a selection of texts was found, with databases such as Chalmers Library, Z-Library, Scopus, and BTH summon having been instrumental in the literature collection.

Searches were conducted in the databases using, among others, the keywords Winter City, Subarctic City, Northern climate, Urban planning, Winter planning, Soft mobility, Outdoor, Urban design, Arctic, and Climate change in various combinations.

Further literature was found through references in scientific articles, dissertations, and works whose content was relevant to the subject area. Additionally, tools such as Research Rabbit and Scopus AI were used to collect more literature. The data includes all kinds of publications, such as journals and conference proceedings, research reports, government guidelines and books.

Case study

In addition to the literature study, this thesis incorporated a case study to examine how principles of winter city planning and climate-sensitive urban design were addressed within Piteå's municipal planning, with a particular focus on the Solander Ring master plan. The case study drew on municipal planning documents, existing and projected climate data, and site-specific urban plans to understand the planning context and design framework.

To complement the text analysis, a semi-structured interview was conducted with a representative from Piteå Municipality to gain insight into local planning intentions and priorities. The purpose of the case study was to assess how winter conditions and climate adaptation were, or could be, integrated into the design of public spaces and soft mobility infrastructure within the Solander Ring master plan.

Development of design principles

The literature review and case study provided valuable insights into contemporary winter design and the anticipated impact of climate change on Arctic cities, particularly in Piteå. These informed the development of key design principles, which were then translated into a strategy and together applied to improve the Solander Ring master plan.

Computer simulations

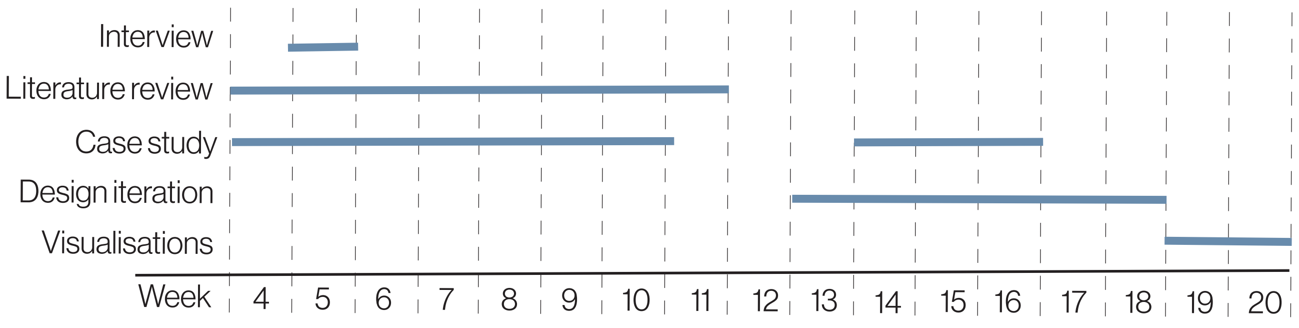
This thesis employed a quantitative method using computational simulations to analyze outdoor thermal comfort and solar access in the Solander Ring master plan. The purpose was to evaluate the impact of different design options and support improvements aimed at enhancing soft mobility and the usability of outdoor public spaces during winter.

The simulations were conducted using Rhino and Grasshopper, together with the Ladybug plugin. The results were interpreted through graphical outputs generated by the simulations. A more detailed explanation of the simulation process, input data, and interpretation is provided later in the Method chapter.

AI usage

ChatGPT was used during the writing process of this thesis to assist with grammar and spelling correction. These tools were also used to rephrase complex sentences, improve structure, and maintain consistency in tone and style. This support was limited to enhancing the expression of ideas and did not influence the research design, analysis, or findings. For further details, see the AI Appendix.

Project timeline



1.5 Structure of the Thesis

Chapter 1 – Introduction
Introduces the thesis topic, including background, research aim, methodology, delimitations, and structure. It also frames the Arctic context and its relevance to the study.

Chapter 2 – Theory
Examines how Arctic conditions affect urban life, reviews current winter planning practices, and considers the future impact of climate change.

Chapter 3 – Method
The chapter is introduced by identifying key planning principles and proposes a design strategy. Describes the computational simulations and design iteration methods used in the thesis to explore and evaluate improvements to Solander Ring.

Chapter 4 – Case Study
Analyzes the local planning conditions in Piteå, focusing on environmental factors such as temperature, snowfall, and rainfall. Reviews key planning documents and the Solander Ring master plan to assess opportunities for enhancing winter soft mobility and outdoor comfort.

Chapter 5 – Results
Presents the design process, including each iteration, key decisions, and final design outcomes. Evaluates how the proposed changes could improve the existing Solander Ring master plan with a stronger winter adaptation focus.

Chapter 6 – Discussion
Reflects on the findings, discussing their implications in the context of Arctic urban planning, climate adaptation, and design practice. Summarizes the main insights of the thesis.

1.6 Contextualizing the Arctic & Winter Cities

In this thesis, the Arctic is defined following the Arctic Council's classification, as outlined in the Arctic Human Development Report Boundary (see Figure 2). Arctic cities are identified as settlements located within or near the Arctic Circle. These areas are typically characterized by low population density, an abundance of natural resources, and relatively small, widely spaced cities. Additionally, in contradiction to popular belief, they experience distinct seasonal variations in climate (Chapman et al., 2024).

Winter cities, Subarctic, and Arctic cities will be used interchangeably within this thesis, as they share many common determinants. According to Pressman (as cited in Chapman et al., 2024), these cities typically experience notable seasonal climate variations, with temperatures frequently dropping below 0°C, and where precipitation is predominantly in the form of snow, and where daylight hours are significantly limited during winter months. Moreover, these conditions persist for an extended period of the year, shaping the urban environment and daily life.

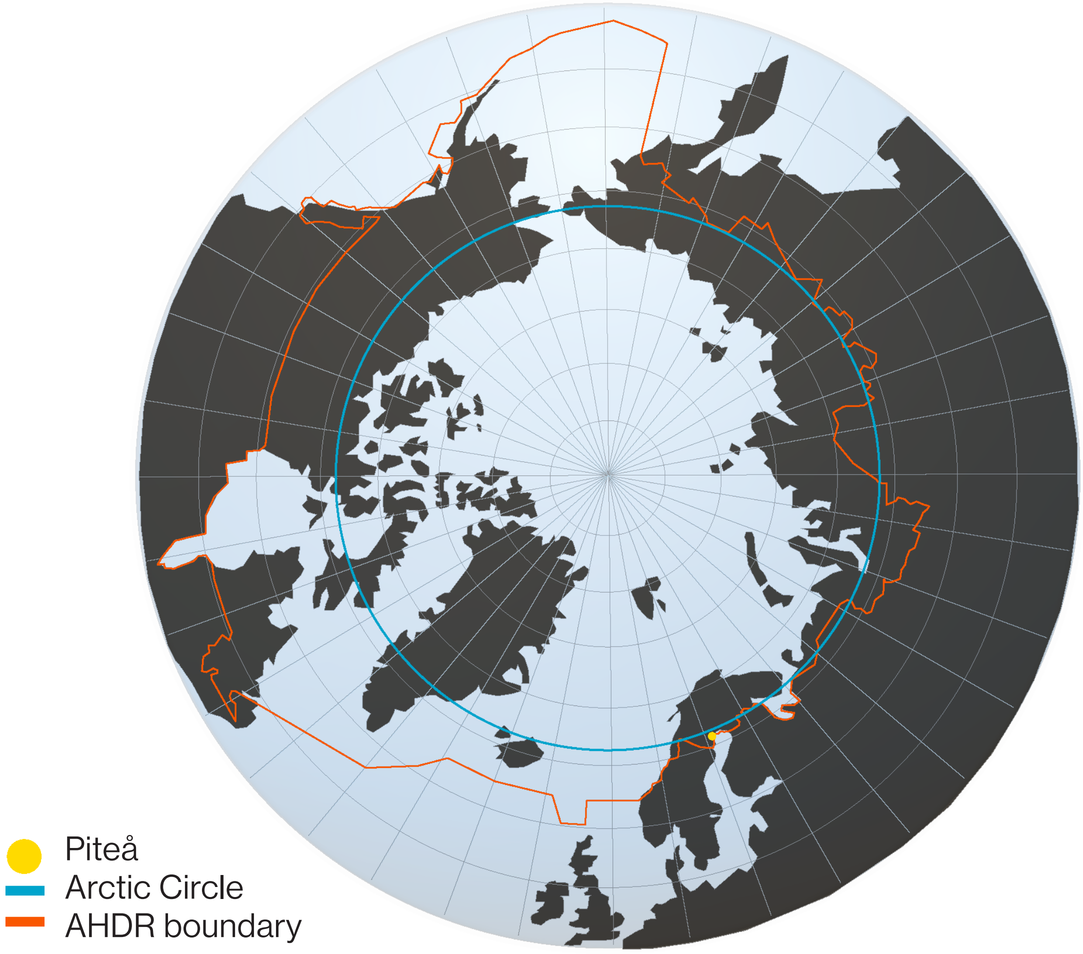


Figure 2. *Map showing the Arctic Circle in blue, Arctic Human Development Report boundary in red, and Piteå in yellow.*

2

Theory

This chapter examines the impact of Arctic conditions on people and urban life, and offers an overview of contemporary winter planning, and considers the future impact of climate change.

Figure 3. *Piteå midday walking amongs snow piles* . Photo by author.

2.1 The Impact of Arctic Climate on People

In Arctic cities, both the built environment and climate significantly influence how residents utilize outdoor spaces. Understanding the importance of Arctic urbanism and climate-sensitive design in facilitating soft mobility and outdoor activities requires recognizing the impact of Arctic winter conditions on residents.

Winter depression, or Seasonal Affective Disorder (SAD), is a common mental health problem whose prevalence rises significantly at higher latitudes. The disorder is caused by extended periods of darkness during winter months which negatively influences the psychological well-being among residents of northern cities. SAD is characterized by depressive episodes linked directly to limited daylight exposure during fall and winter. The disorder disproportionately affects young adults and women, with studies showing women experiencing the disorder at rates nine times higher than men. SAD also occurs in children and adolescents (Roecklein & Rohan, 2005).

When discussing the impact of winter on people, it is important to note that this thesis does not suggest that winter-oriented or climate-sensitive urban design cures or treats any seasonal depressive disorders. However, spaces that offer ample natural daylight and are attractive and safe for outdoor activities encourage physical activity and social interaction. Such spaces provide significant psychosocial benefits, enhance social engagement, and contribute to community cohesion and improved mental health (Chapman et al., 2024).

Studies have found that darkness is one of the most detrimental atmospheric conditions to trips such as walking and biking (Böcker et al., 2019). Additionally, Cold outdoor temperatures discourage physical activity and increases social isolation, which leads to physical and mental health risks (8 80 Cities & AARP, 2021).

Studies conducted in various Arctic countries report a notable decline in outdoor physical activity during winter months, with some people spending up to 90% of their time indoors. For instance, Finnish studies suggest that residents spend only around 4% of their time exposed to cold climates, primarily during leisure activities (Chapman et al., 2018). Furthermore, the severe winter conditions characteristic of Arctic regions limits the feasibility of year-round outdoor activities, frequently forcing individuals to depend on cars for transportation (Chapman et al., 2024).

This reliance on cars can be seen in the increase in car ownership statistics in Piteå. Over the past decade, the number of privately owned cars per 1,000 residents in Piteå has increased by 5%. Additionally, the proportion of Piteå residents commuting by car is higher than both the national and Norrbotten County averages (Norconsult AB, 2022).

Given these findings, implementing climate-sensitive design to support soft mobility and outdoor activity is essential. It is argued that such designs can reduce discomfort caused by cold climates by, for instance, minimizing wind chill and maximizing sunlight exposure are measures that can increase the number of comfortable days for outdoor activities (Chapman et al., 2017).

2.2 Contemporary Winter design principles

Founded in 2008, the Winter Cities Institute emerged out of Pressman's research, and the Winter Cities Movement established to serve as a central hub for winter city studies, policy development, and global advocacy (Winter Cities Institute, 2025). "Winter cities" Is defined by the Institute as northern cities that emphasizes the design of buildings, infrastructure, and city planning to ensure livability throughout all four seasons (Petryshyn, 2022).

Since the early 2000s, many municipalities have introduced design guidelines and policies to enhance the winter season, echoing the ethos of the Winter Cities Institute. Among them, Edmonton municipality stands out for its dedication to creating public spaces that remain lively and accessible in all seasons, especially during winter (Petryshyn, 2022).

The guidelines of Edmonton have since been internationally recognized and have become a model for other municipalities seeking to enhance winter city livability (Winter Cities Institute, 2025). The municipality has formulated its winter design guidelines by outlining several principles addressing the challenges shared by Northern and Arctic settlements.

The guidelines of Edmonton municipality (2016) can be summarized into five key principles:

1. Implement design solutions that mitigate wind effects, especially prevailing winds and downdrafts.
2. Optimize building orientation and layout to maximize sunlight exposure.

3. Introduce color to enhance the vibrancy of winter landscapes.
4. Utilize lighting to create visual appeal, considering factors such as intensity, distribution, and color.
5. Develop infrastructure that enhances winter livability and ensures comfort in cold climates.

These winter design guidelines are not exclusive to Edmonton, as many other northern cities implement comparable principles and strategies in their own planning efforts most notably by North American cities like Anchorage, Calgary, and Fort St. John.

Furthermore, Edmonton’s winter design guidelines place a strong emphasis on creating comfortable micro-climatic conditions and ensuring outdoor thermal comfort during winter, something that is shared with the broader profession in practice and in research and, as mentioned earlier in the chapter, has been a long-standing focus in winter city planning.

For example, In the research of Ebrahimabadi (2015) he states that the most crucial determinants for improved outdoor comfort in subarctic climates are providing shelter from the wind, maximizing solar access, and managing snow in the outdoor environment.

Arctic architecture and urbanism are broad subjects and encompass both outdoor and indoor environments. This thesis focuses on soft mobility and the utilization of outdoor public spaces in winter cities. Outdoor thermal comfort is an essential factor in facilitating pedestrian movement and ensuring the usability of public spaces during the colder months.

However, it is only one of many interrelated aspects of winter design. Other elements such as color, lighting, urban furniture, and public art also play a significant role in shaping the experience of outdoor winter environments by enhancing wayfinding, safety, and overall engagement with public spaces.

The subsequent sections of this chapter will explore the principles and strategies of winter design, focusing on the various factors that enhance the usability and appeal of outdoor spaces in cold climates.

Daylight

When planning and designing for northern environments, it is essential to consider the limited daylight hours during winter, a seasonal phenomenon that significantly impacts populations in the Arctic. In some of Sweden's northernmost areas, the sun does not rise above the horizon for several weeks.

However, even when the sun is above the horizon during winter, its low position presents an additional challenge, as the low sun casts long shadows limiting daylight penetration in urban environments and only exacerbates the issue with dens and taller building heights, complicating efforts to facilitate adequate daylight access in planning (Sundborg, 2010).

One way of letting daylight into the streets of the urban environment is in many ways mirroring the old the planning ideals of grid structures of the 1600s settlements of Piteå and Luleå. The strategy coined "Light paths" by Sundborg (2010) is the design of street networks with straight, continuous paths that facilitate sunlight penetration into dense urban areas, even when the sun remains low on the horizon. The street needs in this case to be straight because beams of sunlight remain inherently straight, as they do not bend.

The orientation of these light paths significantly influences the timing and duration of sunlight exposure. Streets aligned east-west receive sunlight in the morning and evening, while those oriented north-south are illuminated primarily around noon (Sundborg 2010; Edmonton, 2016).

Sundborg (2010) argues that a grid network oriented in both directions maximize light distribution, as the intersecting streets create key points where daylight is most effective. Additionally, straight pathways enhance visibility and create sightlines, making an otherwise compact cityscape feel brighter and more open.

Furthermore, the street section plays also a role in facilitating good light exposure to the street level. In designing well-lit streets and courtyards, the ideal angle can be determined using the formula:

$$H < W \times \tan(A)$$

To ensure adequate sunlight, the width of a street (W) should be at least 1.2 times the height of adjacent buildings (H) multiplied by (A) the solar altitude angle of any given place and time, which varies during the day and decreases the further north you go.

For instance, In Stockholm, located at a latitude of 60°, the solar altitude angle would be 40° during the summer when the sun is facing south, the recommended building height would be three stories if the street, including sidewalks, would be approximately ten meters wide (Sundborg, 2010).

This formula is recommended as a general guideline for bright street environments across different latitudes. However, it's important to note that this formula may not be as effective for calculating winter daylight, particularly in Arctic latitudes. In winter, the sun's altitude angle is much lower, meaning the required street width for adequate sunlight can be significantly larger, as the solar altitude angle (A) is smaller.

This may result in impractically wide streets in the Arctic. For example, in Piteå, which has the of latitude 65°, during winter noon, has a solar altitude angle of 10°, the formula suggests that the street width should be at least 68 meters for adequate sunlight to reach the street.

Moreover, the position of buildings in the urban environment is also something that needs to be considered when planning in the north. The Edmonton municipality guidelines highlight the importance of placing taller buildings to the north of shorter structures, patios, and other outdoor spaces to minimize casting shadows on public spaces. This strategy is also adopted by other Canadian cities, such as Fort St. John and Calgary (Edmonton, 2016; Petryshyn, 2022; Urban Systems, 2000).

However, as mentioned earlier facilitating adequate daylight during arctic winters is somewhat of a hard objective to reach even if there is strategies that can minimize shadowing in urban environments, Chapman et al. (2018) argues that maximizing direct solar access in high-latitudes cities is a complex and impractical design goal due to the significant issue of long shadows cast by the low-angled winter sun.

While increasing the distance between buildings could theoretically solve this, it's argued that this solution is impractical because it would require excessive spacing that is not feasible in central urban areas. Therefore, prioritizing solar access as a major design objective may not be realistic.

Micro-climate & Wind Mitigation

The microclimate is essential for pedestrian comfort and contributes to the overall quality of public spaces. Wind, in particular, greatly affects pedestrians, with impacts ranging from gentle breezes to strong gusts that can create discomfort (Ebrahimabadi, 2015). Moreover, Wind is often regarded as one of the most disruptive weather conditions for outdoor comfort (Chapman et al. 2018).

The urban micro-climate is shaped by the built environment a zone that extends from the ground up to the height of buildings and trees, where individual structures and objects play a significant role in influencing atmospheric conditions (Ebrahimabadi, 2015) in research it is generally agreed that built forms and vegetation can either reduce or compound the effects of wind (Chapman et al. 2018).

During winter buildings disrupt wind patterns leading to turbulence and vortex formations. These disturbances may cause increased wind speeds and localized wind effects, often resulting in snowdrift accumulation on the sheltered side of structures (Sterten, 1988).

Snow accumulates in areas where wind speeds are lower, meaning its distribution can be influenced by understanding how wind interacts with the layout of buildings, streets, and open spaces. For instance, a street that aligns with the dominant wind direction can experience natural snow removal (Chapman et al. 2018).

However, streets oriented in the direction of dominant winds can act as wind tunnels as well, further amplifying airflow along urban corridors (Ebrahimabadi, 2015). This can create a colder streetscape as the wind creates wind chill effects during the colder winter months.

Furthermore, tall buildings significantly affect local climate conditions and can be problematic in cold climates like the Arctic. Pedestrians near high-rise structures face stronger winds due to the redirection of upper-level air currents downward, creating a “downdraft effect”, intensifying wind force at street level (Edmonton, 2016).

To mitigate this effect, limiting buildings to no more than twice the area’s average height can help reduce wind intensity by approximately 50%, preventing strong downdrafts (Chapman et al. 2018). When taller structures are necessary, incorporating stepped or terraced designs can help minimize downdraft effects, enhancing pedestrian comfort by reducing wind impact at ground level (Edmonton, 2016).

Moreover, Natural elements like trees, bushes and earth walls as well as man-made wind protection structures can be used to protect pedestrians and outdoor public spaces against wind and snowdrifts in winter (Sterten, 1988). Furthermore, areas of dense evergreen vegetation is seen as most effective in public spaces (Edmonton, 2016; Chapman et al., 2024).

A strategy that undermines the concept of “Light paths” in the previous segment of daylight, Chapman (2018) argues that irregular and broken facades, as well as curved streets, can help counteract the wind’s cooling effect, thereby improving pedestrian comfort.

However, this conflict underscores the need to carefully evaluate urban design strategies, as they may sometimes be at odds with one another. While certain approaches prioritize one aspect of pedestrian comfort, such as wind protection, others, like the Light paths strategy, emphasize maximizing daylight penetration through straight, continuous streets. However, these strategies are not necessarily mutually exclusive. When thoughtfully integrated, they can complement each other, mitigating the effects of wind and snow while also enhancing daylight conditions.

Snow Management

In northern regions, effective snow management is essential, as it directly impacts the mobility of pedestrians and cyclists. Studies indicate that during winter, accumulations of snow, ice, slush, and water limit the usable space within the public realm for soft mobility (Chapman, 2018).

During the melting period, lingering snow and accumulated snow cover can create challenges by causing streets to become flooded with water and slush, making outdoor conditions uncomfortable and difficult to navigate (Chapman et al. 2018).

In the winter design guidelines of Edmonton municipality multiple small snow storage areas is favoured over large snow storage zones, streets and parks are designed with consideration for small snow storage areas, placing them in sunlit locations rather than large, shaded zones. This approach accelerates snowmelt while balancing the need for local snow storage with other considerations (Edmonton, 2016). Furthermore, its recommended that storage areas should be incorporated into street designs (Chapman et al., 2024).

This will of course need wider streetscapes in comparison with urban environments that only experience bare ground conditions year-round.

In the green, blue, and white structure plan of Gällivare municipality also mirror the strategies of Edmonton, and in addition they emphasize that extensive green spaces are needed to store the large amounts of snow that fall during winter within the city, and that snow storage areas should not be placed directly next to residential buildings, as they can create a colder microclimate, attract mosquitoes, and cause other inconveniences for residents (Gällivare, 2016).

Larger green areas are also effective in managing meltwater when the snow thaws in spring. Proper stormwater management is essential in connection with snow storage. Stormwater ponds, drainage pathways, and infiltration areas should be incorporated into each snow storage site, enhancing both functionality and aesthetics year-round. Additionally, smaller spaces such as pocket parks or plazas can serve as temporary snow storage areas during winter if the ground material allows for infiltration and purification of stormwater.

To manage snow and ice accumulation at building entrances, Edmonton's guidelines recommend steep and angled roof designs with varying slopes to divert falling snow and ice away from entryways. When combined with smooth materials like metal, this allows snow to slide off easily (Edmonton, 2016).

However, Chapman (2018) argues that steep roof angles can create hazardous conditions for pedestrians walking below. Instead, it's recommended to design flatter roofs with integrated arcades or overhangs along streets which can enhance safety while also reducing downdraft effects, thereby lessening the impact of winter weather on pedestrians.

The City of Edmonton also emphasizes the importance of various architectural elements, such as arcades, awnings, roof overhangs, and entrance canopies, particularly at the main entrances of multi-family residential buildings (Edmonton, 2016).

Color and Illumination

As highlighted earlier in this chapter, residents of the Arctic experience extended periods of limited or no daylight during winter, it is therefore important that planners and architects design ample lighting. This is not only important for wayfinding and security concerns but also makes the urban environment an attractive place and mitigates the psychological effects of extended periods of darkness, moreover color also helps to liven the city during the dark winter months of the Arctic.

Adding color to buildings is an effective way to break the monotony of the urban winter landscape. One approach to integrating color into building façades is through the use of contrasting or saturated color palettes, particularly around entrances, to create focal points and enhance the overall streetscape (Edmonton, 2016).

Additionally, a strategy that is also emphasized by Sundborg (2010) is the use of reflective and light-colored south-facing façades to direct passive light onto streets, parks, and nearby structures (Edmonton, 2016).

Beyond the use of color, artificial lighting plays a crucial role in shaping urban spaces during winter. This principle is emphasized by the City of Edmonton and echoed in Anchorage's downtown comprehensive plan. Recommended strategies include installing lighting fixtures on façades, incorporating seasonal decorative lighting, and illuminating key urban elements such as bridges, parks, and walkways (Anchorage Municipality, n.d.).

Lighting not only enhances the visual appeal of a city but also contributes to safety by improving visibility and fostering a sense of security for residents and pedestrians. The winter design guidelines in Edmonton advocate for a thoughtful approach to lighting, where darkness itself is strategically used as a design element rather than simply increasing the number of light sources.

The guidelines further promote reducing overall ambient lighting levels, both for aesthetic reasons and to enhance contrast. Additionally, they suggest integrating materials in streets and sidewalks that can modify light through diffusion, direction, aggregation, or refraction, capitalizing on the reflective properties of snow to maintain lower ambient light levels (Edmonton, 2016).

Similarly, Fort St. John's design principles emphasize the role of illuminated buildings and infrastructure, such as sculptures, in creating focal points throughout the city. Strategic lighting can be used to highlight significant buildings and public spaces, contributing to a well-defined and visually engaging urban identity (Urban Systems, 2000).

Navigating public space during the harsh winter conditions of the Arctic presents significant challenges, as snow and ice can obscure essential wayfinding. For instance, painted markings on cycling and walking paths may remain hidden beneath snow for months, making them ineffective for guiding pedestrians and cyclists.

To mitigate this issue and ensure that key information about networks and designations remains visible and accessible, it is beneficial to elevate these details above ground level (Chapman et al., 2024). A notable example can be found in the Municipality of Oulu, where the city has implemented projection lighting to display lane designations for pedestrians and cyclists directly onto the snow (City of Oulu, n.d.).

Urban furniture & Winter Recreation

In Arctic cities, engagement in outdoor social activities is often limited during the winter months. An advantage of ice and snow is that it can be used for temporary architectural interventions like snow and ice sculptures that celebrate the season or to support winter activities cross-country skiing, sledding and ice skating (Chapman et al. 2024).

Creative furnishings, public art, and thoughtful lighting enhance visual appeal while offering weather protection. A welcoming public space not only stimulates the city but also promotes social interaction and community engagement. By supporting both physical and social activities, these spaces contribute to mental health and well-being (Edmonton, 2016).

To encourage year-round engagement, the design of urban spaces should have multifunctionality in mind, ensuring they accommodate activities in both winter and summer. For instance, a lake or water feature can serve as an ice rink during winter and transform into a pond in the warmer months (Akgül & Toy, 2021).

Incorporating semi-open and semi-enclosed spaces within the urban environment can help mitigate the harsh effects of winter by creating inviting, sheltered areas for residents. These spaces should offer various social activities and services, fostering a sense of community even in colder months (Akgül & Toy, 2021).

In line with the above, The City of Edmonton implemented a strategy of a four-season patio, promoting a vibrant, year-round outdoor space the key elements of solar access, shelter, snow management, decorative lighting amenities, and aesthetics enhances comfort and usability during winter. The establishment of these winter patios has grown since the introduction of the city's winter design guidelines and has gained a positive reputation (Edmonton, n.d.; Edmonton, 2024).

To further enhance comfort, urban design should integrate sheltered seating areas and frequently incorporate overhead coverings, helping to shield pedestrians from the elements while maintaining accessibility and usability throughout the year (Akgül & Toy, 2021).

2.3 Climate change Impact on Urban Life

Climate change will, over time, either intensify or alleviate many of the challenges facing urban life in the Arctic. Given that northern regions are experiencing some of the most rapid and pronounced effects of climate change, it is essential to incorporate these evolving environmental conditions into future planning and development strategies. These changes will have consequences not only for the natural environment, but also for cultural traditions, patterns of physical activity, and everyday mobility among local inhabitants.

Earlier in this chapter this thesis suggested that cold outdoor climates discourage physical activity and negatively impact physical health. However, this claim is contested by research and institutions such as Boverket, the Swedish National Board of Housing, Building, and Planning (Chapman et al., 2024). Studies conducted by Larsson and Chapman (2020) demonstrate that the greater barriers to soft mobility and public space usage are slush-covered and icy surfaces, rainfall, and darkness.

Even more, their research indicates that sunshine, snowfall, and snow-covered surfaces encourage public space usage and are generally viewed positively by inhabitants. However, projections from the Finnish Environmental Administration suggest climate change could result in cloudier winters (Chapman et al., 2024) which will further reduce the appeal of outdoor stay. Larsson and Chapman (2020) further suggest that warmer winters may present greater challenges for outdoor activities in Arctic regions than traditionally colder winters.

Increased icy and wet conditions around 0°C not only reduce the appeal of public spaces but also pose significant safety risks. Moreover, this shift may disrupt winter-specific cultural and recreational practices that depend on permanent ice and snow conditions during winter.

Furthermore, reduced snow cover due to warmer winters may intensify the experience of darkness in Arctic cities, as snow significantly contributes to light reflection during the polar night period. Increased rainfall, which absorbs rather than reflects light, may also amplify the perceived dimness of the urban environment during winter.

Current studies indicate that rain is currently perceived as a significant barrier to soft mobility in Arctic communities, especially during winter. However, these perceptions may evolve alongside changing climate conditions. Chapman et al. (2017) argue that traditional winter city planning historically viewed extreme cold and heavy snowfall as the primary barrier. Now, rising temperatures are reshaping perceptions of barriers to soft mobility.

While rain presents the primary challenge today, future climatic shifts may introduce new barriers to outdoor activity in winter, indicating that urban design in winter cities must continually adapt to emerging weather-related challenges.

2.4 Summary of Literature Study

The aim of this thesis is to explore strategies that improve and promote conditions for soft mobility, outdoor activity, and the use of public spaces in the future Arctic climate of Piteå.

Previous chapters have outlined how architects and planners currently manage climatic conditions to create attractive outdoor environments through climate-sensitive winter design. Additionally, these chapters have discussed the current and anticipated future climatic impacts on people and urban life.

While this thesis bases itself upon existing research in the field of Arctic urbanism, prevalent literature has yet to adequately formulate concrete and detailed design solutions for future Arctic cities impacted by climate change. Instead, existing studies fall short of only recognizing that it will require innovation without offering practical solutions.

This limitation may stem from limited interest in the subject, resulting in current winter city design principles being insufficient to meet future challenges of creating attractive and functional urban environments during the winter season. Chapman et al. (2018) argues that the core principles of urban design in winter cities remain focused on solar access, wind protection, and snow management, emphasizing that past efforts have lacked an awareness of climate change impacts on human well-being into Arctic urbanism.

However, conclusions can be drawn from anticipated climatic impacts making it possible to develop design strategies that mitigate the negative effects climate change will have on outdoor stay and soft mobility. Many of the traditional winter design principles remain relevant in the future Arctic climate of Piteå, particularly solar access and wind protection strategies. Additionally, there is an argument that snow management design strategies will likely remain relevant in the future, although with reduced significance compared to today.

Moreover, the limited daylight hours of the Arctic is one climatic condition that is not affected by climate change. Consequently, the principles of lighting and decorative illumination remain a relevant design strategy.

For example, the five key principles of winter design formulated by Edmonton municipality (Edmonton, 2016) can be argued to remain highly relevant for future Arctic cities:

1. Implement design solutions that mitigate wind effects, particularly prevailing winds and downdrafts.
2. Optimize building orientation and layout to maximize sunlight exposure.
3. Introduce color to enhance the vibrancy of winter landscapes.
4. Utilize lighting to create visual appeal, carefully considering factors such as intensity, distribution, and color.
5. Develop infrastructure that enhances winter livability and ensures comfort in cold climates.

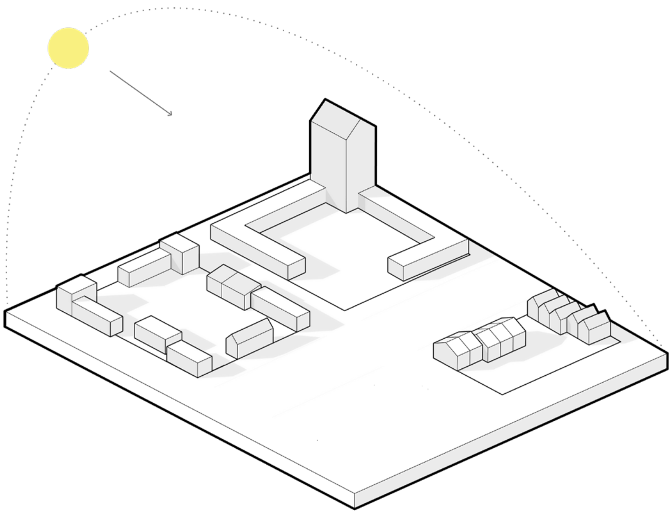
3

Method

This chapter Introduces key principles from the literature, viewed through the lens of what is most relevant for future Arctic planning, and presents a corresponding design strategy. The chapter also describes the computational simulations and design iteration method used in the thesis to explore and evaluate improvements to the Solander Ring master plan.

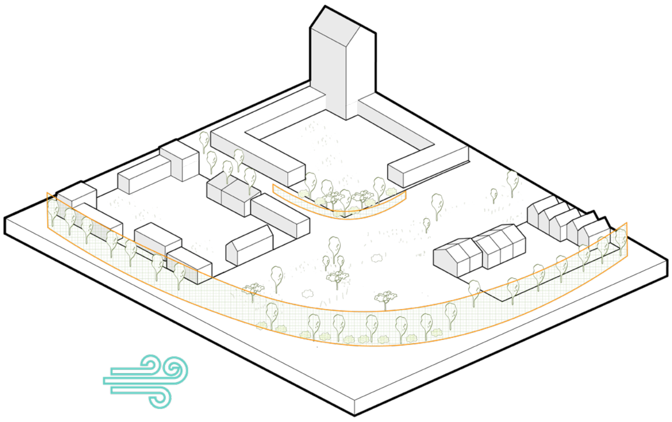
Figure 4. December *Winter day at Smurfitt west rock, Piteå* . Photo by author.

3.1 Design Principles



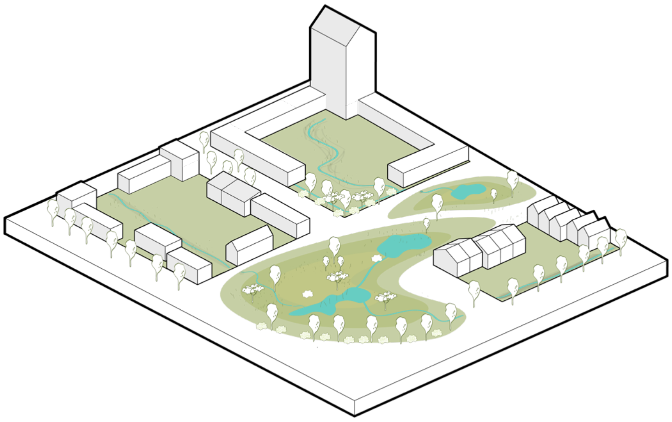
Daylight Maximization

The short daylight hours and low sun position in the Arctic make it even more important to design public spaces that maximize access to natural light.



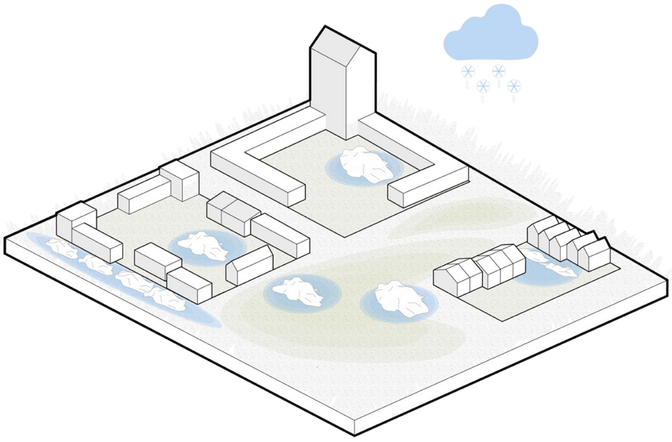
Wind Mitigation

The wind is one of the greater barriers to soft mobility in the Arctic and will only increase with the diminishing sea ice.



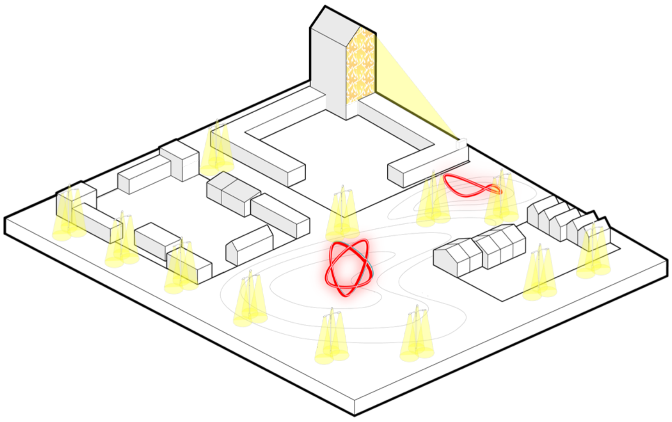
Stormwater Consideration

Precipitation will only increase In the future, which will need consideration when planning the future physical environment to counteract flooding especially as freeze-thaw cycles become more frequent.



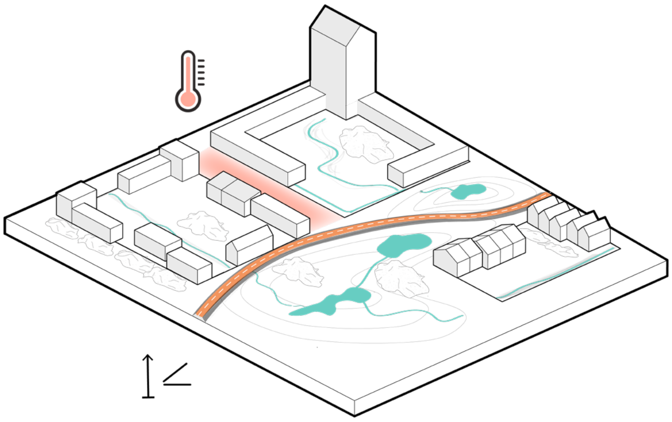
Snow managment

Even with warmer winters, snowfall will still occur, making it essential to continue applying winter design principles, planning for snow removal, and design infrastructure with snowy conditions in mind.



Artificial Lighting

As global warming leads to reduced snow cover, winter will feel even darker, increasing the need for artificial lighting that is both functional and visually appealing.



Slip Prevention

Climate change will impact ground conditions by increasing the number of winter days with temperatures around 0°C, leading to more frequent slippery surfaces due to melting and refreezing.

3.2 Design strategy

The principles outlined in this chapter are essential for creating outdoor environments that support outdoor activities and soft mobility. They also align closely with the core principles of urban design in winter cities, which include solar access, wind protection, and snow management, with the additional climate change induced concerns of increased participation that requires the accommodation of storm water management.

These design principles apply at both large and small scales. As with most urban design it involves a wide range of interventions. However, this thesis places an greater emphasis on climate-sensitive elements, particularly large-scale design strategies.

When designing for winter cities, certain principles must take priority, and some may conflict with others. For example, wind protection and solar access often contradict each other: solar access requires open, unshaded spaces, while wind protection involves creating barriers that can block sunlight. This conflict is especially significant when the sun and wind come from the same direction, requiring a careful balance between allowing sunlight and blocking wind.

Additionally, some design elements can only be addressed after others have been established. For instance, planning for snow storage can only occur once sun exposure and wind protection strategies have been finalized.

With these considerations in mind, this thesis follows a hierarchical approach to the design process, structuring the analysis and subsequent improvements based on the priority and interdependence of each principle.

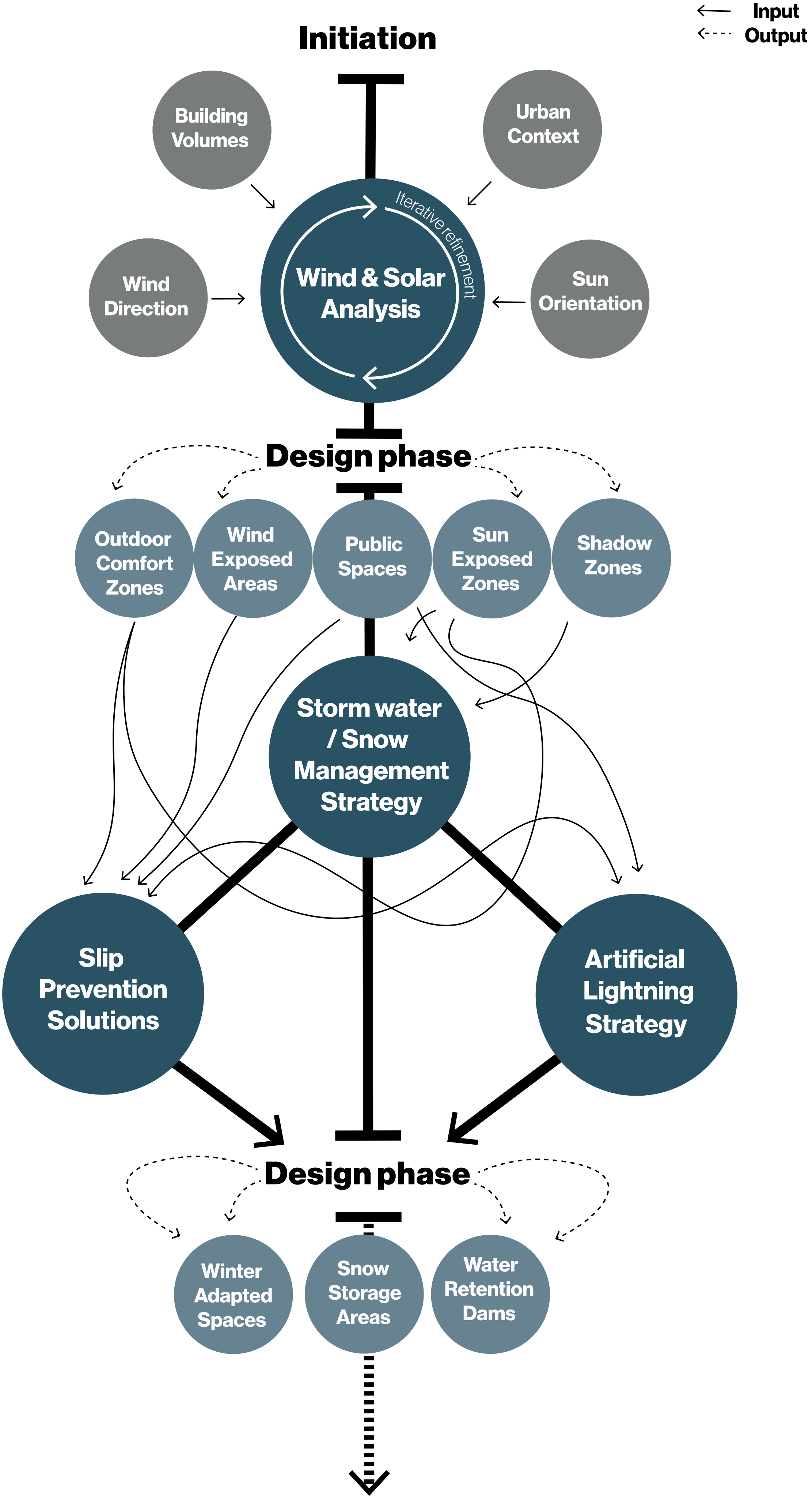


Figure 5. *Conceptual representation of a hierarchical design strategy.*

3.3 Computational Simulation Setup

Introduction

Following a hierarchical design approach, this thesis aims to create outdoor environments that support outdoor stay and soft mobility during winter. To achieve this, the project analyzes the site's microclimatic conditions and guides design decisions based on environmental data. These decisions are refined through a series of design iterations, each evaluated using the Universal Thermal Climate Index (UTCI) and Direct Sun Hours analysis.

Simulation Approach

By using computational simulations to analyze outdoor thermal comfort and solar access in the Solander Ring master plan, the objective of this process is to evaluate the impact of the different design iterations in relation to soft mobility and the usability of outdoor public spaces during winter.

Tools and Data Sources

The simulations are conducted using Rhino 8 and Grasshopper, together with the Ladybug plugin. The environmental data used in the Grasshopper script comes from real-world EPW weather files sourced from the Piteå Rönnskär Lighthouse, the closest active weather station to the Sörfjärden area where the simulations take place. The Grasshopper scripts can be found in Appendix A and Appendix B. Appendix A contains the script used for the UTCI calculations, while Appendix B includes the script for the direct sun hours calculations.

The 3D model used for simulations is provided by the New Environment architecture firm, the authors of the Solander Ring proposal. It represents the master plan proposal for the Sörfjärden development and includes the volumes of proposed and existing buildings, along with a simplified surface representing the flat topography of the site. The model does not include any topographical variations, which reflects fairly to the relatively even terrain of the area.

Site Analysis and Delineation

The delineation of the study area and the resulting design inputs for the masterplan are guided by the identification of key zones for improvement, specifically, areas significant for public outdoor use and mobility connectivity derived from the Initial analysis. Additionally, the scope of the analysis is shaped by the practical limitations of the thesis, particularly in terms of time, scale, and the size of the new design proposal.

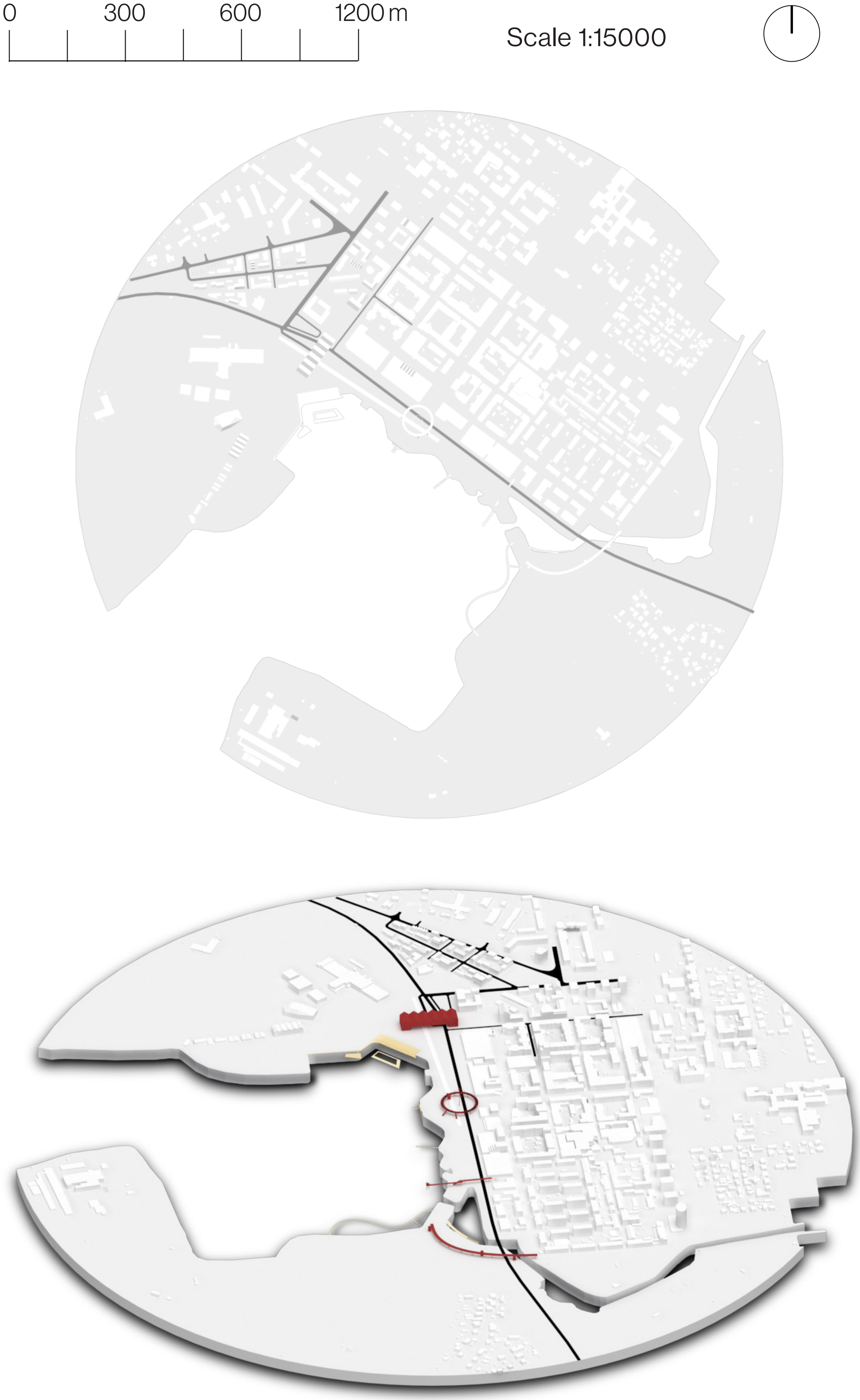


Figure 6. *3d model and scaled map of simulation area.*

3.4 Environmental Analysis & Design Process

Universal Thermal Climate Index (UTCI)

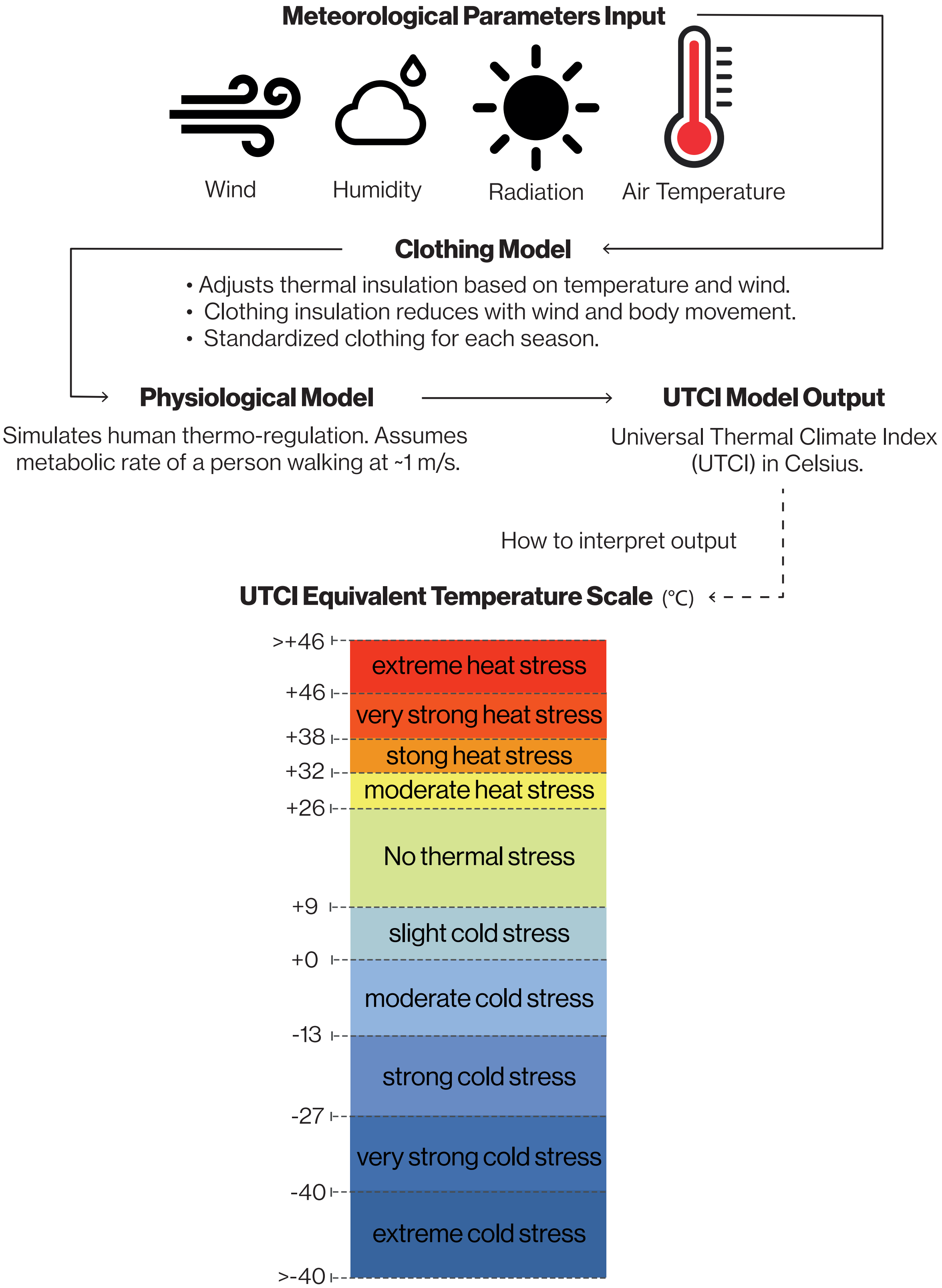
The UTCI is a standard metric in human biometeorology used to assess how outdoor environmental conditions affect human comfort and well-being. It represents the “feels-like” temperature and is applicable across all climates, seasons, and spatial scales. UTCI calculations take into account key atmospheric variables such as air temperature, humidity, wind speed, and mean radiant temperature at a specific time and date (European Environment Agency, n.d.).

The UTCI results are explained using ten thermal stress categories that show how the body reacts to different levels of heat or cold. These categories are linked to corresponding UTCI values measured in degrees Celsius (European Environment Agency, n.d.).

The index is based on the assumption of a person walking at a moderate pace, wearing weather-appropriate clothing. This means there are certain limitations when using UTCI to assess comfort for sedentary activities like sitting, standing, or for individual variation in thermal experience. For practical reasons, the UTCI calculations in this thesis are based on current climate conditions rather than future climate projections, as such atmospheric data is not available for Piteå.

Despite these limitations, the UTCI remains a valuable tool. Although it assumes a moving subject, it still reflects the overall thermal environment—air temperature, humidity, solar radiation, and wind, all of which also affect comfort for sedentary users. A more cautious interpretation of UTCI results can therefore be used when evaluating comfort for activities like sitting or lingering.

The date selected for UTCI analysis is January 15th. This date was chosen because January typically has the lowest average temperatures of the year, and the 15th closely aligns with the midpoint of the winter daylight arc. As such, it serves as a useful reference point for assessing thermal comfort throughout the winter period.



Meteorological Parameters Input

Wind

Humidity

Radiation

Air Temperature

Clothing Model

- Adjusts thermal insulation based on temperature and wind.
- Clothing insulation reduces with wind and body movement.
- Standardized clothing for each season.

Physiological Model

Simulates human thermo-regulation. Assumes metabolic rate of a person walking at ~1 m/s.

UTCI Model Output

Universal Thermal Climate Index (UTCI) in Celsius.

How to interpret output

UTCI Equivalent Temperature Scale (°C)

Figure 7. *Conceptual diagram of the Universal Thermal Climate Index (UTCI),* adapted from Bröde, Krüger, & Rossi (2011).

Direct Solar Access Analysis

Direct solar access is also evaluated to guide decisions related to snow storage and other design elements that influence outdoor stay. A series of representative dates were selected to capture the seasonal variation in sunlight during the winter months: November 15th, December 21st (Winter Solstice), February 15th, March 20th (Spring Equinox), April 15th.

These dates provide a broad overview of solar conditions across the winter season. December 21st marks the lowest point of solar altitude and daylight duration, while March 20th represents a return to more balanced daylight conditions. The intermediate dates offer representative snapshots of solar progression across the winter season.

Additionally, the dates November 15th and April 15th are particularly relevant for analyzing snow-related factors. In November, early shadowing affects areas where snow and ice begin to accumulate, while in April, solar-exposed areas have the potential to accelerate snowmelt.

Design Iteration Process

The design decisions made are shaped by findings from the UTCI and solar access simulations. Through multiple iterations, adjustments are made to improve outdoor thermal comfort and sun exposure in key public areas, particularly those related to soft mobility and year-round usability. These iterations respond directly to environmental performance outputs generated from the simulation tools.

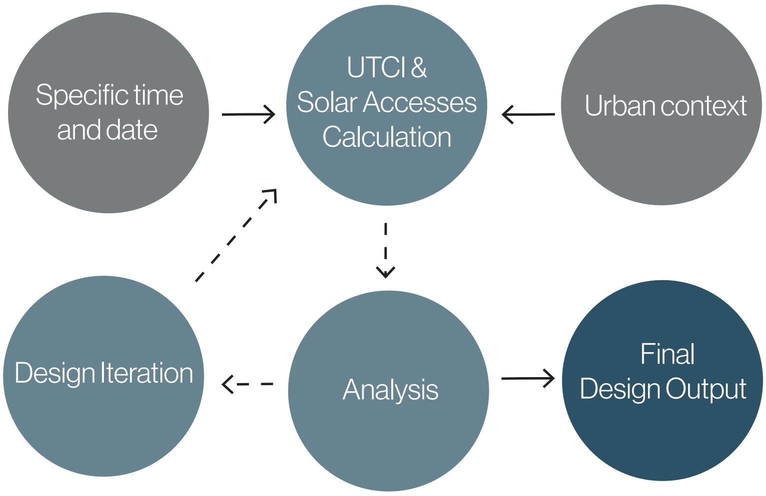


Figure 8. *Workflow diagram for evaluating and iterating design based on environmental factors.*

Interpretation of Simulation Results

The simulation outputs are interpreted using both graphical and numerical data generated in Grasshopper.

UTCI results are read through the UTCI equivalent temperature scale, which categorizes thermal comfort levels (e.g., no thermal stress, moderate cold stress, strong cold stress). This allows an evaluation of whether certain outdoor spaces support comfortable human use in winter conditions.

Direct Sun Hours are evaluated by analyzing how many hours each surface receives direct sunlight on the selected dates. Results are displayed as both color-coded surfaces and numerical values using a legend scale.

Simulations in Relation to Design Strategy and Principles

The simulations used in this thesis are directly connected to two key design principles: wind mitigation and daylight maximization. The UTCI simulation, which incorporates wind data to assess thermal comfort, is used to support the principle of wind mitigation, as wind exposure significantly affects perceived outdoor comfort.

The direct solar access simulation is applied to achieve the goal of daylight maximization in selected public spaces. It also helps identify suitable locations for snow storage, specifically areas with high sun exposure, which supports the design principle of snow management.

In this way, the simulations are not separate tools but are integrated into the design process, reinforcing the overall design strategy. The results from these simulations directly inform spatial strategies and programming decisions, ensuring that the design aligns with and responds to the guiding principles.

Limitations

The 3D model uses a simplified terrain surface, not accounting for detailed topographic features such as dikes. However, since the area is relatively flat, this simplification is considered reasonable.

UTCI assumes a moving person with appropriate winter clothing, which may not fully capture the comfort levels for sedentary activities or variations in individual sensitivity like height, age and sex.

Future climate scenarios are not included due to the unavailability of localized predictive data for Piteå from EPW weather files. All analysis is based on current climate conditions.

4

Case study

This chapter examines planning conditions in Piteå, focusing on environmental factors such as temperature shifts, snowfall, and rainfall, as well as the impacts of climate change on urban life. It reviews the Solander Ring master plan, and related documents to explore how the masterplan can support winter soft mobility and enhance outdoor comfort in line with the local context and future climate projections.

Figure 9. A*erial view of central Piteå.* Photo by Jens Wennerberg, n.d. Provided by Piteå Municipality.

4.1 Current Climate of Piteå

Climate Characteristics of Piteå

Following the Köppen classification, Piteå experiences a Dfc subarctic climate, a winter-humid arctic climate characterized by cold winters and mild summers. Symbols within these classifications have specific meanings: “f” indicates a humid climate without a distinct dry season, “c” denotes a short and cool summer lasting fewer than four months, during which average temperatures exceed +10°C, and “d” signifies a very cold winter, with the coldest month’s average temperature above -38°C (Mattson, 1970).

The average annual temperature in Piteå is approximately 3.9 °C. July is the warmest month, with an average temperature of 16.8 °C, whereas January is the coldest, averaging -12.3 °C (SMHI, 2025).

Annual precipitation in Piteå totals around 603 mm. July is typically the wettest month, receiving approximately 125 mm of rainfall, while March is the driest, with around 52 mm. Snow is common from October through April. January usually has the highest snowfall, averaging 156 mm, closely followed by March, with 154 mm (SMHI, 2025).

Daylight Variations

Daylight hours vary significantly throughout the year in Piteå. During the summer solstice in June, days can extend up to 22 hours and 32 minutes. In contrast, December days are considerably shorter, averaging approximately 3.7 hours of daylight. The shortest day is about 3 hours and 21 minutes long (Weather Spark, 2025).

Polar night is a climatic phenomenon occurring during the shortest days of the year, where the sun does not rise at all north of the Arctic Circle. In parts of northern Sweden, this results in several weeks of complete darkness (SMHI, 2023).

Conversely, during the longest day of the year, areas north of the Arctic Circle experience the midnight sun, meaning the sun does not set and remains visible even at midnight. This phenomenon can continue for extended periods. For example, Kiruna experiences approximately 47 continuous days of daylight (SMHI, 2023).

Although cities like Piteå do not explicitly experience polar nights or the midnight sun, factors such as atmospheric refraction and the method of calculating sunrise and sunset times, using the sun's top edge rather than its center, influence the actual perception of these phenomena. Consequently, even when the sun technically rises in winter in a city like Piteå, it often barely clears the horizon and remains low. This results in limited daylight hours and creates a twilight-like environment rather than bright daylight (SMHI, 2023).

Moreover, the limited daylight hours of the Arctic is one climatic condition that is not affected by climate change and is something that greatly affects the populations living in the North.

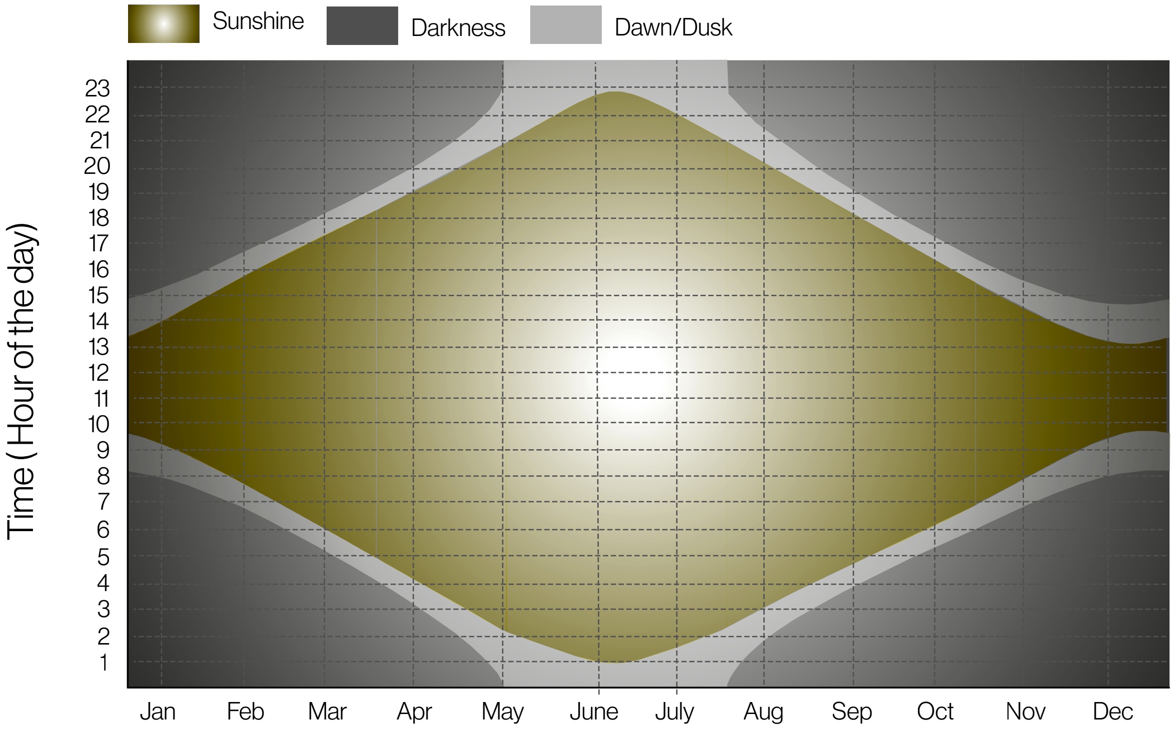


Figure 10. *Solar exposure diagram of Piteå showing seasonal variations in daylight hours.* The golden area represents sunlight, while dark gray shading indicates the sun is below the horizon.

4.2 Climate Change Projection for Piteå

This thesis examines the potential impacts of climate change on Piteå, with a specific focus on its future winter climate. To assess future climate scenarios, the study will utilize Representative Concentration Pathway (RCP) models made for Piteå by the Swedish Meteorological and Hydrological Institute (SMHI). This will help identify the key urban design challenges that could emerge in response to these climate changes.

Based on an understanding of the Arctic climate of Piteå from the previous section of this chapter, it is possible to examine potential future changes of this climate. However, to do so, it is essential to understand how these projections are calculated, and which future scenarios are considered in this study.

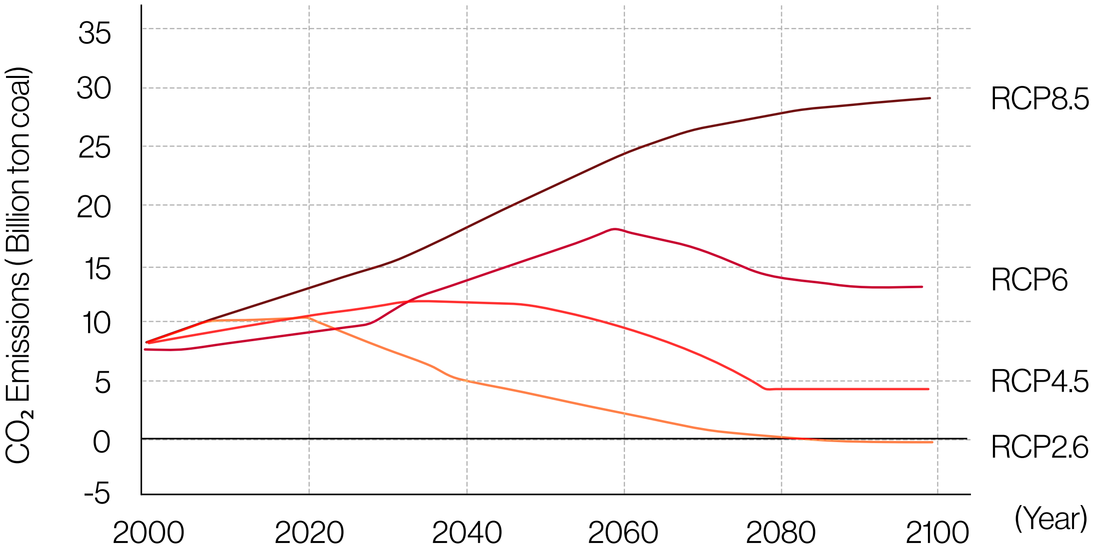


Figure 11. *Example of possible carbon dioxide emission trajectories under different RCP scenarios.*

RCP scenarios consist of four climate development scenarios developed by the United Nations Intergovernmental Panel on Climate Change (IPCC). These scenarios aim to explore how different concentrations of greenhouse gases in the atmosphere affect the climate. The RCP scenarios are based on assumptions regarding future development and serve as a foundation for understanding potential climate changes under various future conditions projected up to the year 2100 (Sjökvist et al., 2020).

For this study, the RCP8.5 climate scenario has been chosen. This projection assumes that carbon dioxide emissions will be three times higher than today's levels by the year 2100, and methane emissions will increase significantly.

This choice is based on the current global situation. Recent research from the Global Carbon Project indicates that carbon emissions from fossil fuels reached an all-time high in 2024, pushing global temperatures 1.5°C above pre-industrial levels (WMO, 2024).

However, it is important to note that there are also signs of a decrease on a regional scale. According to the latest climate action progress report from the European Commission, EU greenhouse gas emissions decreased by 8.3% in 2023 compared to the previous year. The report also highlights that net emissions are now 37% lower than in 1990 (Directorate-General for Communication, 2024).

Moreover, the outcomes of climate scenarios depend on various economic, technological, demographic, and political developments, leading to significant uncertainty of future outcomes (Sjökvist et al., 2020).

Findings from the report

In the report, data from the period 1961–1990 serve as a reference period and comparative tool. Future climate projections are provided for two key time frames 2021-2051 and 2069–2098, with a primary focus on the later period, which offers the most comprehensive insight into the long-term effects of the scenarios (Sjökvist et al., 2020).

The SMHI climate scenario report for Piteå shows us that one of the most notable consequences of the RCP8.5 scenario is the significant increase in temperature.

The annual average temperature in Piteå during the reference period was 0.7°C. By the end of the 21st century, under the RCP8.5 scenario, this is projected to rise to 6.4°C. Furthermore, the greatest increase in temperature is during the winter period were in this report is set between December and February.

During the reference period the average winter temperature was -11.3°C. Projections indicate that winter temperatures will increase by approximately 7.6°C, reaching an average of -3.8°C (Sjökvist et al., 2020).

This increase in average winter temperatures will increase the frequency of temperatures approaching 0°C which will result in more rain on snow events and freeze-thaw cycles and will decrease snow coverage and precipitation in form of snow fall.

Under the RCP8.5 scenario, the duration and extent of snow cover in Piteå are expected to decline sharply. During the reference period Piteå experienced between 140 and 180 days per year with a snow cover of at least 20 mm water equivalent.

By the end of the 21st century, the period of snow coverage is projected to decrease dramatically were the days of snow coverage span between 14 to 21 near the coast and up to 100 days per year inland.

Similarly, the number of days with snow cover of at least 60 mm water equivalent, which historically ranged between 100 and 160 days, is projected to decline drastically. By the end of the century, coastal regions are expected to experience a near-total loss of such snow cover, while eastern parts of the municipality may see it disappear entirely (Sjökvist et al., 2020).

Accompanying the rise in temperature, annual precipitation levels are also expected to increase significantly. The historical average annual precipitation for Piteå was approximately 620 mm. Under RCP8.5, precipitation is projected to increase by roughly 35%, reaching an estimated 837 mm per year (Sjökvist et al., 2020).

Winter precipitation patterns are also expected to shift. Historically, winter precipitation predominantly fell as snow, with an average of 124 mm of water-equivalent snowfall.

Under the RCP8.5 scenario, winter precipitation is projected to increase by up to 42%. However, rising temperatures will result in a greater proportion of this precipitation falling as rain rather than snow, significantly altering winter hydrology and potentially increasing the risk of mid-winter flooding and ice accumulation (Sjökvist et al., 2020).

4.3 Effects of a Warmer Winter in Piteå

Projected Winter Temperature Increase and Consequences

As cited earlier, projections indicate that winter temperatures will increase by approximately 7.6°C, reaching an average of -3.8°C in Piteå. This rise in temperature will increase the frequency of days with temperatures around 0°C, resulting in more frequent “rain-on-snow” events and freeze-thaw cycles. These conditions will have detrimental consequences for outdoor activities.

Additionally, research shows that climate change contributes to volatile and unpredictable weather conditions, resulting in drastic temperature fluctuations, leading to days of -20°C closely followed by +3°C the next (Chapman et al., 2024).

Changes to Coastal Sea Conditions

Moreover, the rising temperatures will dramatically alter Piteå’s coastal sea, which currently remains frozen for most of the winter. Climate change is predicted to cause the sea to remain unfrozen during winter, exposing coastal communities to increased wind levels. Combined with an average winter temperature of -3.8°C, this will negatively impact outdoor activities.

In addition, this change will affect the entire winter season, undermining traditional social activities and mobility patterns associated with ice-covered seas, such as ice fishing and the use of ice roads for transport and recreation (Chapman et al., 2024).

Figure 12. *Snowmobile tracks on the frozen sea in Piteå during a warm December day. The tracks lead to the horizon, highlighting how the coastal sea serve as routes for winter recreation and movement.* Photo by author.

Declining Snow Cover and Increased Darkness

According to the RCP8.5 scenario projections, the duration and extent of snow cover in Piteå are expected to decline significantly, decreasing from 140–180 days per year to only 14–21 days with at least 20 mm water-equivalent snow cover, and a near-total loss of 60 mm water-equivalent snow cover.

This reduction in snow cover will only exacerbate the effects of limited daylight hours in cities like Piteå. Snow plays a crucial role in mitigating the impact of polar nights by reflecting a substantial portion of incoming light, freshly fallen snow can reflect between 75% and 95% of incoming light, while older snow reflects approximately 55%. In contrast, bare soil reflects only 5–15%, and grass reflects between 15–20%.

Given the significantly higher albedo of snow and ice compared to bare ground, reduced snowfall and a shorter snow seasons could lead to longer and more intense periods of perceived darkness among residents (Bernes, 2016).

Increased Winter Precipitation and Flooding Risks

Additionally, the RCP8.5 scenario predicts an increase in winter precipitation by up to 42%, predominantly in the form of rain or cold rain near 0°C. Combined with frequent freeze-thaw cycles, this trend will heighten the risks of mid-winter flooding and ice accumulation.

Rainy winters will also amplify the perceived darkness since water absorbs light, creating visually darker environments (Chapman et al., 2018).

The annual precipitation in Piteå is projected to rise by approximately 35%, reaching an estimated 837 mm per year. This increase necessitates enhanced stormwater management strategies to mitigate year-round flood risks.

Planning for Current and Future Climate Conditions

Despite the significant anticipated climate changes in Piteå, it remains important to consider current climatic conditions while simultaneously designing for future climate scenarios. The projected impacts of climate change will unfold over a 75-year period, with the most substantial effects expected by mid-century (Sjökvist et al., 2020).

4.4 Winter Perspectives in Piteå's municipal Planning

Piteå is regarded as a "summer town" that thrives and comes alive during summer, prompting the municipality to place greater emphasis on summer activities and tourism.

Currently, there are no specific winter design guidelines for the city, unlike municipalities such as Edmonton or Gällivare, which indicates a lack of emphasis and conscious approach toward winter-specific planning. However, the municipality's existing planning documents implicitly address winter conditions through broad development goals, though they fall short of explicitly incorporating winter-specific measures.

Piteå's municipal planning documents reveal limited references to snow management strategies or detailed winter accessibility measures. Nevertheless, some considerations appear in its comprehensive plan, where winter cycling is supported by ensuring cycling paths remain accessible throughout winter, thereby encouraging year-round use (Piteå Kommun, 2021).

Moreover, the municipal guidelines for development in Piteå's city center acknowledge challenges associated with designing urban spaces at northern latitudes. These challenges include risks like creating shaded, less attractive environments due to denser construction, as well as considerations related to sunlight, lighting, and snow management in the design of businesses (Piteå Kommun, 2022).

Seasonal lighting strategies specifically addressing extended darkness during winter are not prominently featured in Piteå's municipal documents. However, general design guidelines recognize that Piteå's northern location necessitates designs that consistently aim to create a comfortable climate and optimal lighting conditions (Piteå Kommun, 2021).

Urban design measures specifically targeting winter usability, such as sheltered walkways, heated outdoor spaces, or adaptive winter furniture, are also largely absent. However, general urban development goals emphasize creating attractive environments year-round.

Piteå's snow management strategy involves collecting snow and transporting large quantities from the city to designated snow storage sites and landfills located on the outskirts.

Gällivare (2016) argues that such transport methods are costly for both municipalities and the environment, advocating instead for a more efficient local strategy.

Implementing local snow storage strategies could significantly reduce transportation needs, thus saving money and lowering emissions. Additionally, as cited in Chapter 2, multiple smaller snow storage areas placed in sunlit locations accelerate snowmelt integrated into parks and street designs for efficient snow management and serves a dual purpose as the snow can be used for play and recreation (Chapman et al., 2024; Gällivare, 2016).

Despite limited emphasis on winter-specific urban design in Piteå's municipal planning documents, the city has incorporated several features enhancing winter activities and aesthetics.

Notably, Storgatan, a central pedestrian street, is heated to remain free of snow and ice during winter months, facilitating comfortable pedestrian movement. Furthermore, decorative lighting adorns Storgatan during the winter season.

The city also hosts innovative structures such as Stadsberget, a parking garage designed with a sloped roof doubling as a sledding hill in winter, exemplifying multifunctional urban design catering to seasonal recreational activities.

In celebration of Piteå's 400th anniversary, the city hosted the "Air 4x400" snow sculpture event, showcasing large-scale snow art created by local artists.

According to the Winter Placemaking Guide by 8 80 Cities & AARP (2021), winter placemaking can significantly support rural and small-town economies traditionally reliant on summer tourism. However, many communities have yet to fully embrace outdoor, public winter activities. An effective strategy to overcome this is adopting an asset-based approach that leverages existing community infrastructure and resources.

Winter placemaking is defined as a strategic approach aimed at developing vibrant, inclusive, and sustainable winter spaces that enhance community well-being, cultural identity, and tourism sustainability. The approach is based on active engagement with local communities to create public spaces tailored to their winter-specific needs and preferences (8 80 Cities & AARP, 2021).

The Air 4x400 event exemplifies winter placemaking by utilizing local artistic resources to strengthen community pride, creativity, and cultural identity. This event also establishes a potential foundation for future annual winter celebrations.

According to 8 80 Cities & AARP (2021), there are many benefits for municipalities to integrate winter placemaking initiatives into their planning strategies. Such initiatives offer numerous benefits, categorized broadly into three pillars: health, economic, and social outcomes.

Additionally, active participation in winter activities among Piteå's residents is evident in a community group dedicated to cold-water bathing at Sörfjärden. While this group currently represents a minority, expanding and integrating niche activities like this into municipal planning aligns with inclusive winter placemaking strategies. This approach empowers residents to play a significant role in the identity, creation, and maintenance of winter spaces, thereby fostering broader community engagement and promoting year-round usage (8 80 Cities & AARP, 2021).

The city also maintains winter recreational paths on its outskirts, providing cross-country skiing trails and recreational ice roads at Norrfjärden, thus promoting outdoor activities and leveraging the natural winter landscape.

4.5 Solander Ring Master Plan Proposal

Introduction

The Municipality of Piteå is in the early stages of planning a new railway and central station as part of the broader Sörfjärden development. This initiative seeks to expand the city core by introducing new residential and commercial areas, while integrating the Norrbotniabanan rail line into a comprehensive urban renewal strategy. A central component of the plan is the creation of a transportation hub that connects multiple modes of travel, including trains, buses, bicycles, and pedestrian routes (Piteå kommun, 2024).

The plan also involves the redesign of Timmerleden, a heavily trafficked road along the city's waterfront, through the construction of a bypass bridge aimed at reducing congestion and enhancing urban livability. Additional goals include preserving and improving green spaces and maintaining open sightlines to the waterfront, thereby strengthening the city's relationship with its natural surroundings.

The Solander Ring proposal, selected through the Europan 17 Living Cities competition initiated by Piteå Municipality in collaboration with Trafikverket, serves as the guiding vision for the Sörfjärden development. This master plan forms the subject of this thesis, which will assess its adaptability to Piteå's harsh winter climate and its alignment with climate-sensitive urban design principles, first through an initial overview of plans and later through computational simulations in chapter 5.

The master plan

The Solander Ring master plan, authored by a Amsterdam-based urban design agency New Environments, positions itself as forward-thinking that seeks to improve human well-being by fostering a dynamic and balanced relationship between people and their environment (New Environments, 2024).

The proposal emphasizes slow mobility, climate adaptation, and biodiversity, envisioning a seamless integration of parks and urban infrastructure into a continuous ecosystem that promotes harmony between urban life and nature.

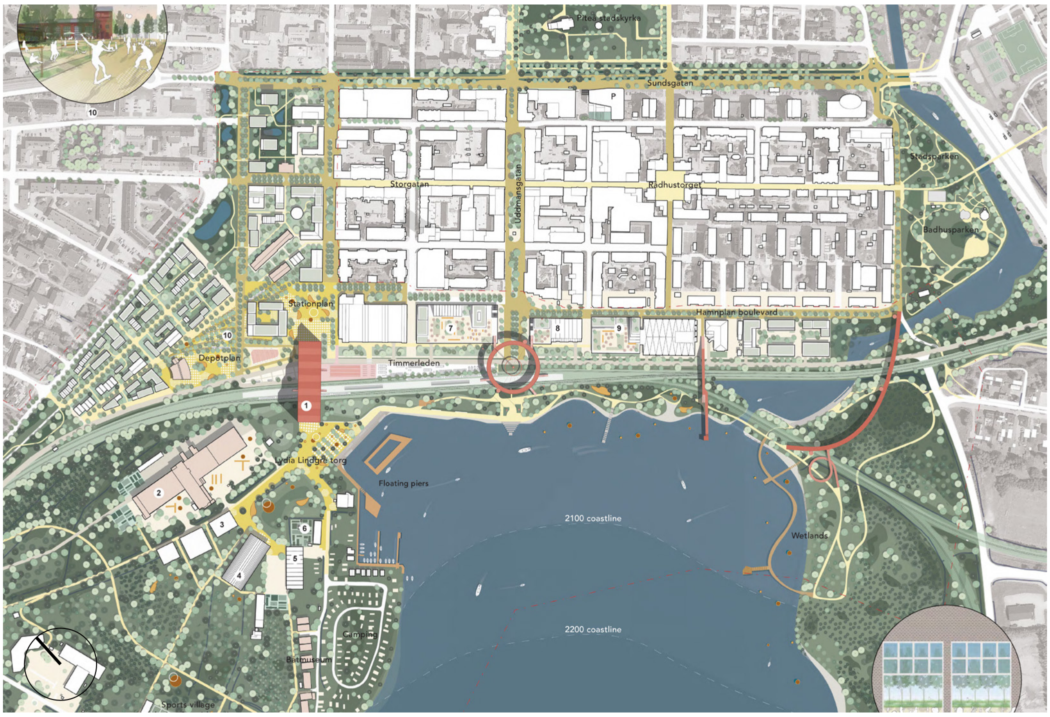


Figure 13. Solander Ring *Master plan for Sörfjärden, Piteå, designed by New Environments.* Reprinted from arkitektbidrag-solander-ring-2.pdf, by Piteå Kommun, 2024. © New Environments.

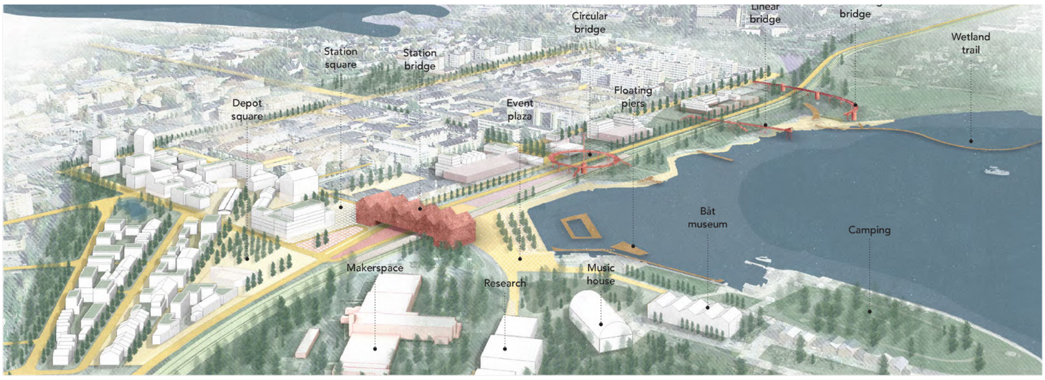


Figure 14. Birds eye vievw of the *Solander Ring master plan, designed by New Environments.* Reprinted from arkitektbidrag-solander-ring-1.pdf, by Piteå Kommun, 2024. © New Environments.

While the concept is ambitious and rooted in commendable values, several concerns arise when the plan is assessed through the lens of climate-sensitive design, particularly in relation to winter conditions specific to Piteå.

One notable issue is the design of the pedestrian and cyclist bridges connecting the new development to the waterfront. These structures are fully exposed to the elements and elevated at significant heights, leaving them vulnerable to harsh winter conditions.

With projections indicating warmer, wetter winters and increased precipitation, combined with frequent freeze-thaw cycles, the open design could lead to the accumulation of snow and the formation of ice due to the prevailing northbound winds that expose all the bridges.

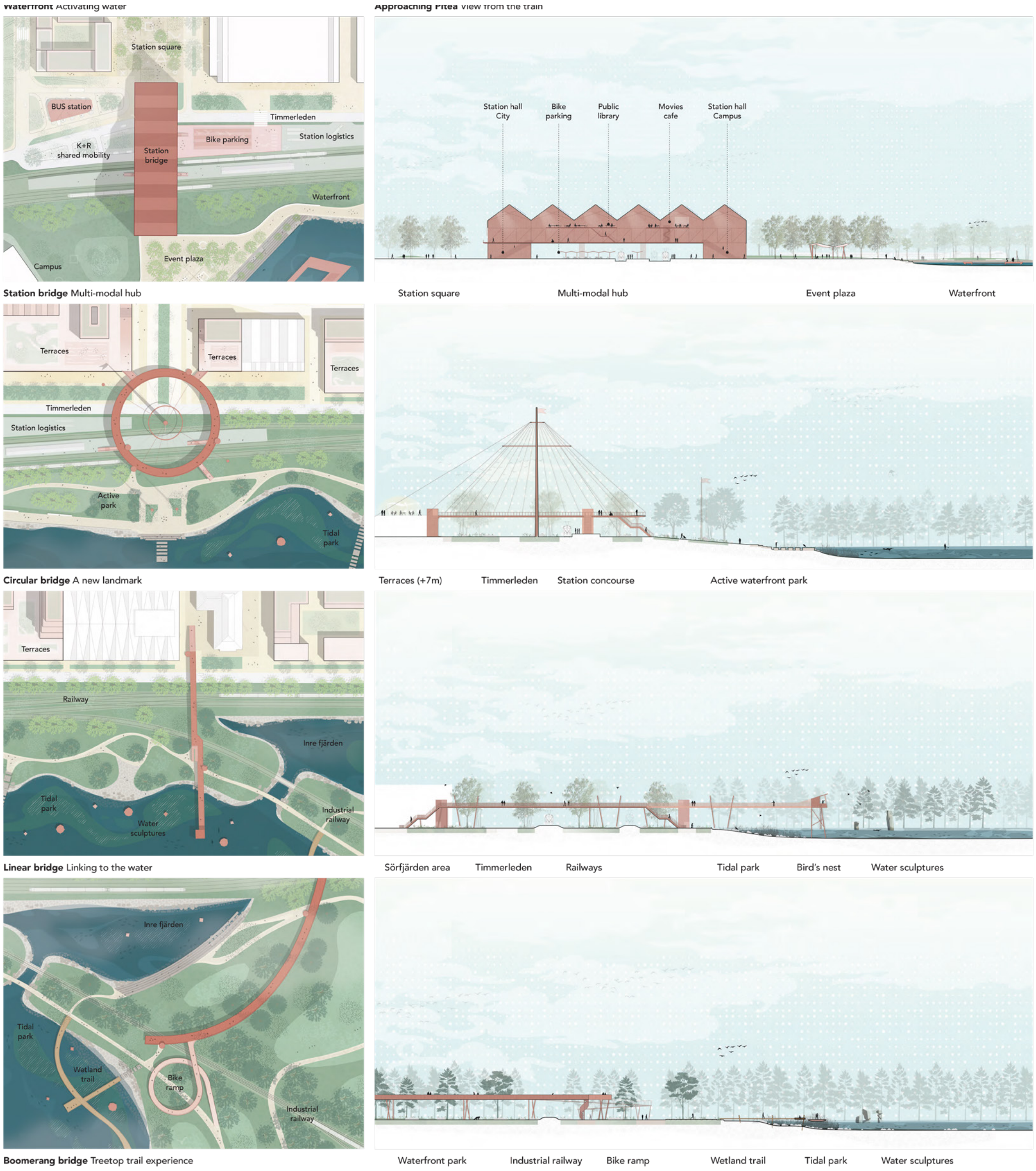


Figure 15. *Sections of the multiple bridges of Solander Ring master plan, designed by New Environments.* Reprinted from arkitektbidrag-solander-ring-3.pdf, by Piteå Kommun, 2024. © New Environments.

These factors pose safety risks for people and complicate snow removal operations. The lack of wind protection may also result in discomfort for pedestrians and cyclists, potentially deterring use during winter months.

In contrast, the proposed train station, also serving as a bridge to the waterfront, addresses these climatic challenges more effectively, being an enclosed structure that offers protection from weather exposure, but is not accessible to other soft mobility modes such as cyclists.

Additionally, certain public spaces, such as the Event Plaza, are situated in areas with minimal wind protection. This is particularly problematic given their intended function as venues for sedentary and social activities. Exposure to cold, persistent winds may limit usability and diminish the overall experience of these spaces during much of the year.

5

Results

The purpose of this chapter is to present the design process, including each iteration, key decisions, and final design outcomes and the potential improvments. As well as to evaluate how the proposed changes could improve the existing Solander Ring master plan with a stronger winter adaptation focus.

Figure 16. *Piteå, cyclist captured biking, Midday* . Photo by author.

5.1 Initial Site Analysis

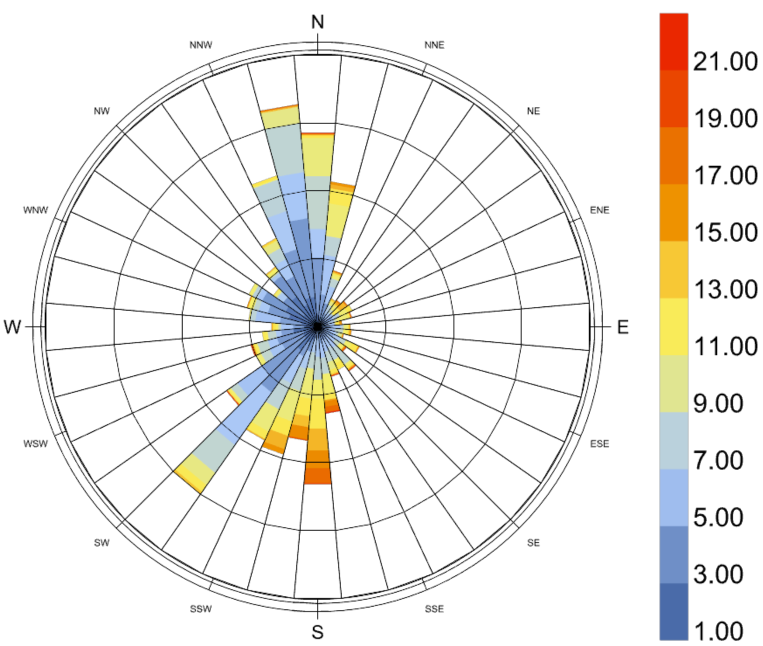


Figure 17. *Winter wind rose (Period Dec 1 to Feb 28).*

Prevailing Winds

To assess how wind might affect the urban environment, a Wind Rose was created to show the typical wind patterns during the winter months. The Wind Rose indicates that the most common and dominant wind direction is from the north/ northwest.

Wind Force (on land)	Wind Speed (m/s)
Calm	0–0.2
Light air	0.3–1.5
Light breeze	1.6–3.3
Gentle breeze	3.4–5.4
Moderate breeze	5.5–7.9
Fresh breeze	8.0–10.7
Strong breeze	10.8–13.8
Near gale	13.9–17.1
Gale	17.2–20.7
Strong gale	20.8–24.4
Storm	24.5–28.4
Violent storm	28.5–32.6
Hurricane	≥ 32.7

Figure 18. *Beaufort wind force scale on land, in m/s.* Adapted and translated from SMHI (n.d.).

Wind Force

The Wind Rose shows that wind speeds are generally low, averaging around 3–5 m/s. According to the Beaufort wind scale, this falls under the category of a gentle breeze. At this level, the wind typically causes leaves and small twigs to move continuously.

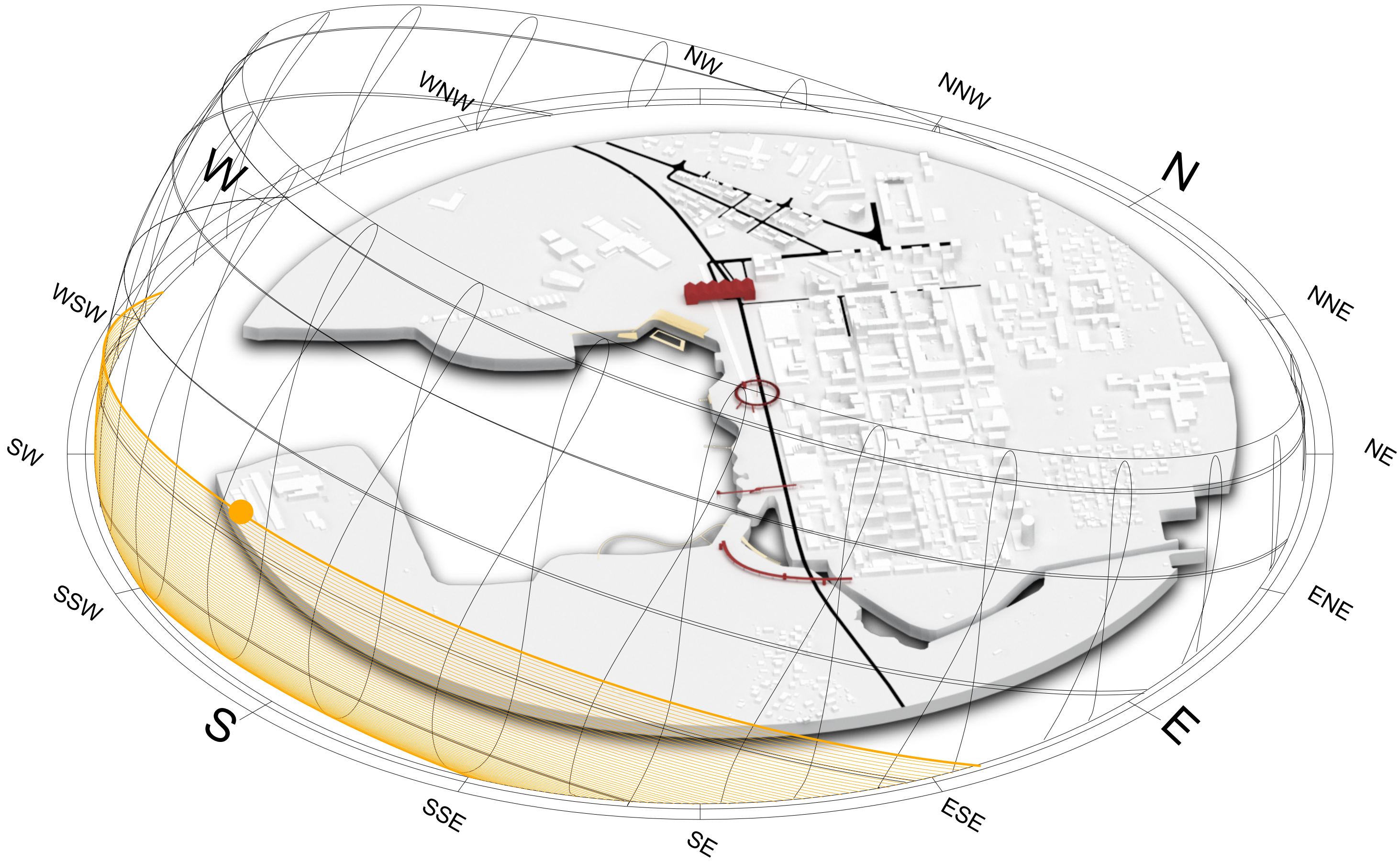
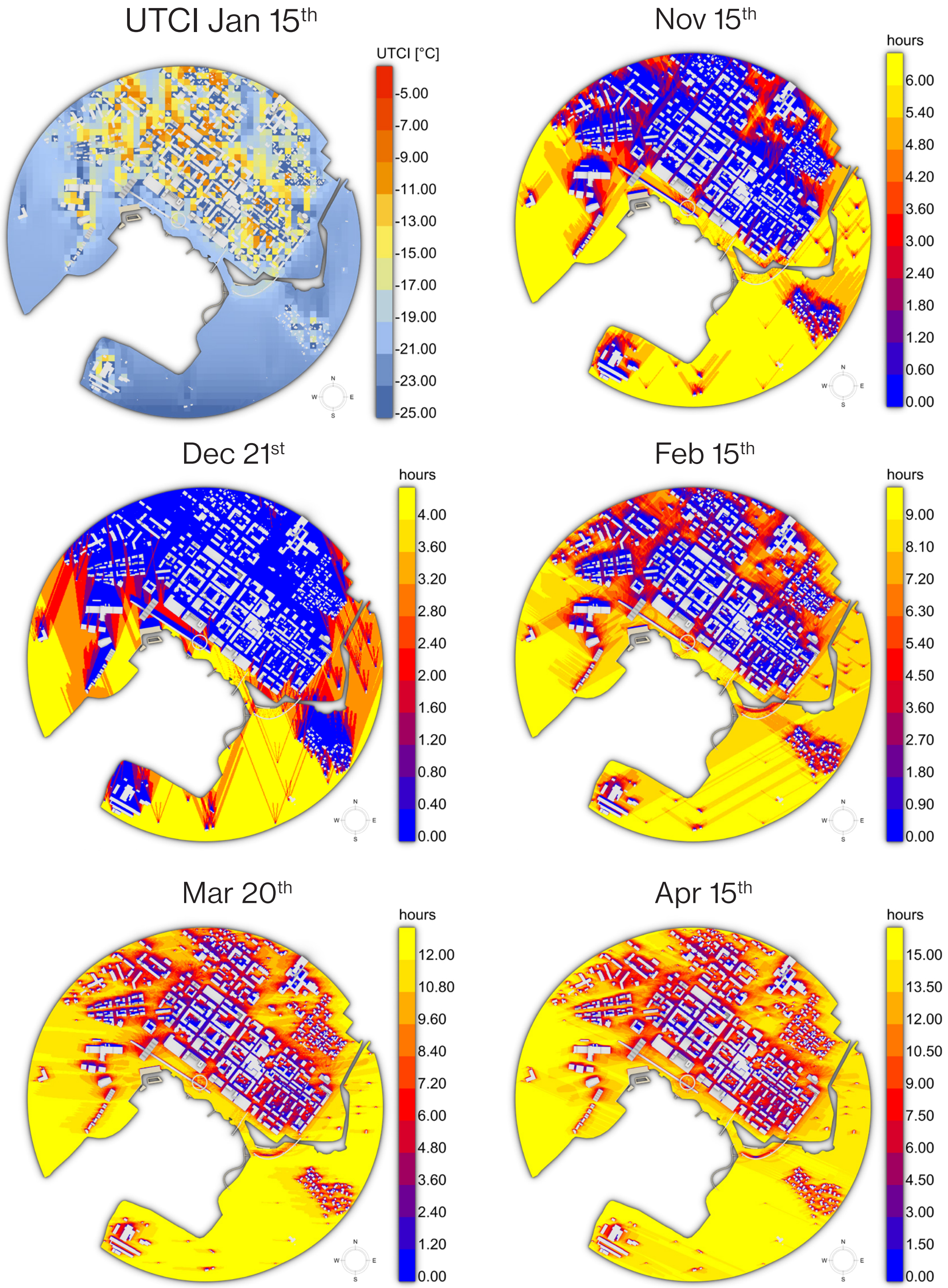


Figure 19. *The area of analysis showing the Solander Ring proposal and the solar path during winter between the dates 1st of December to 28th of February.*


UTCI Jan 15th

Nov 15th

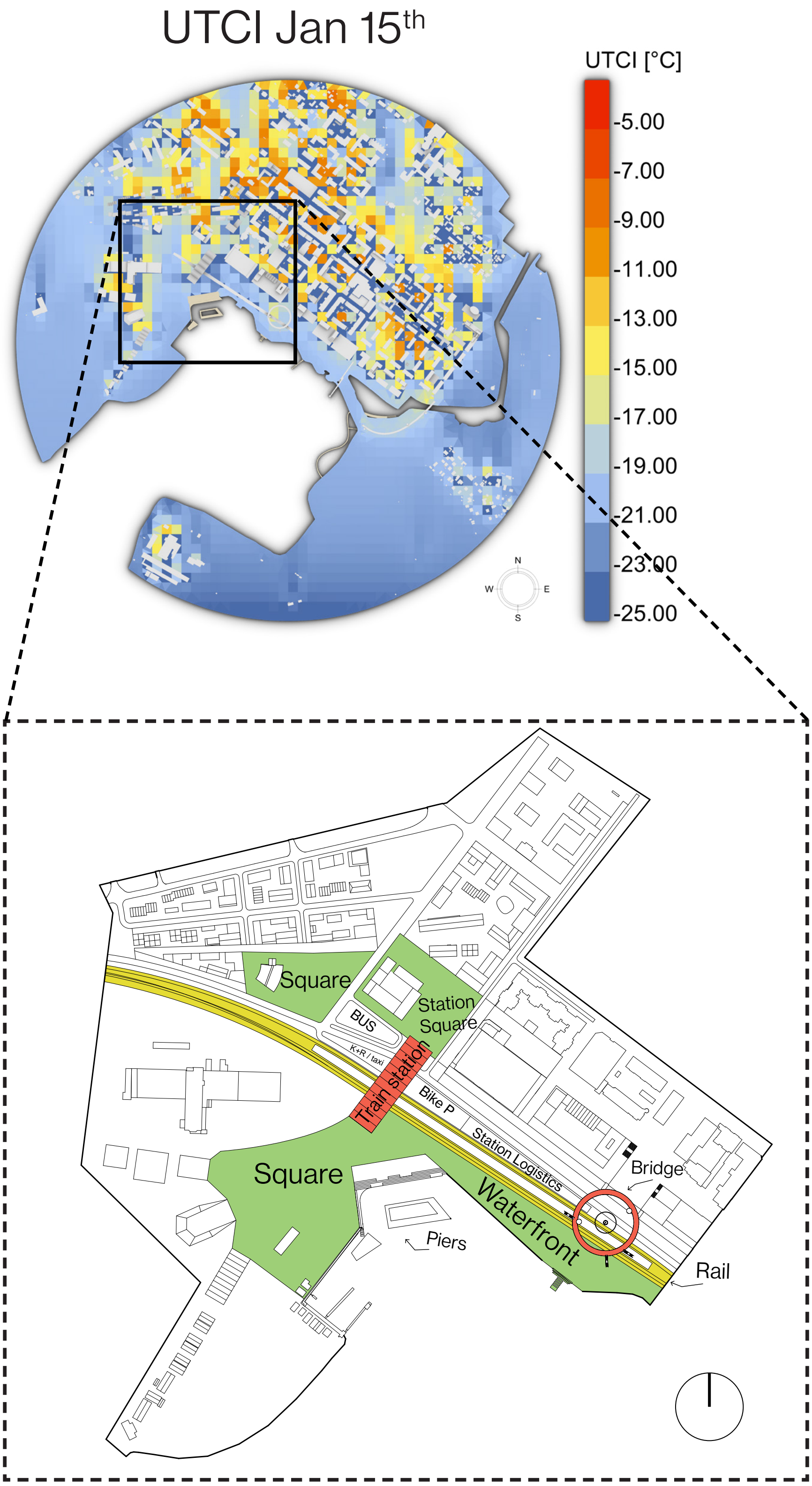
Dec 21st

Feb 15th

Mar 20th

Apr 15th

Figure 20. *Graphical representations from the initial simulations of the whole study area of Solander Ring, showing UTCI results and hours of direct sunlight.*



The delineated study area, shown in the diagram above, was chosen based on the UTCI results, solar access analysis, and wind rose data showing the area is exposed to harsh microclimatic conditions. Despite the area appointed with many public spaces with piers and dock seating, it lacks wind protection and lies directly in the path of prevailing winter winds from the north/northwest (340°). Interpreting the UTCI data it shows that this area experiences “strong cold stress,” with apparent temperatures between –19°C and –21°C, highlighting the need for microclimatic improvement.

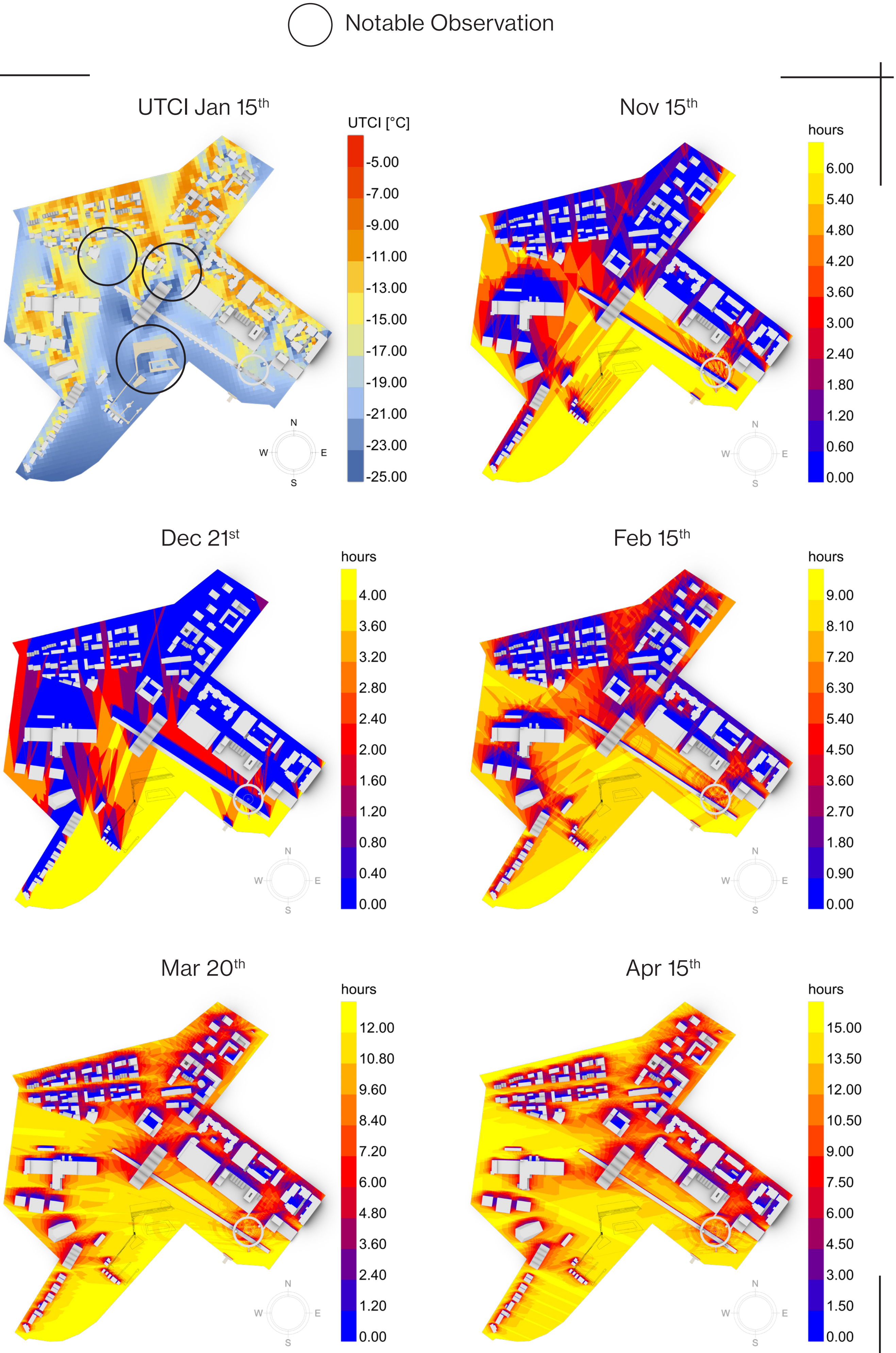
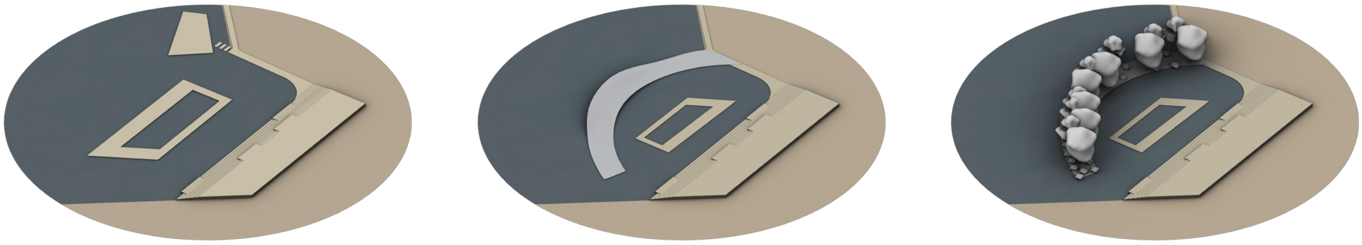


Figure 20. *Graphical representations from the initial simulations, showing UTCI results and hours of direct sunlight.*

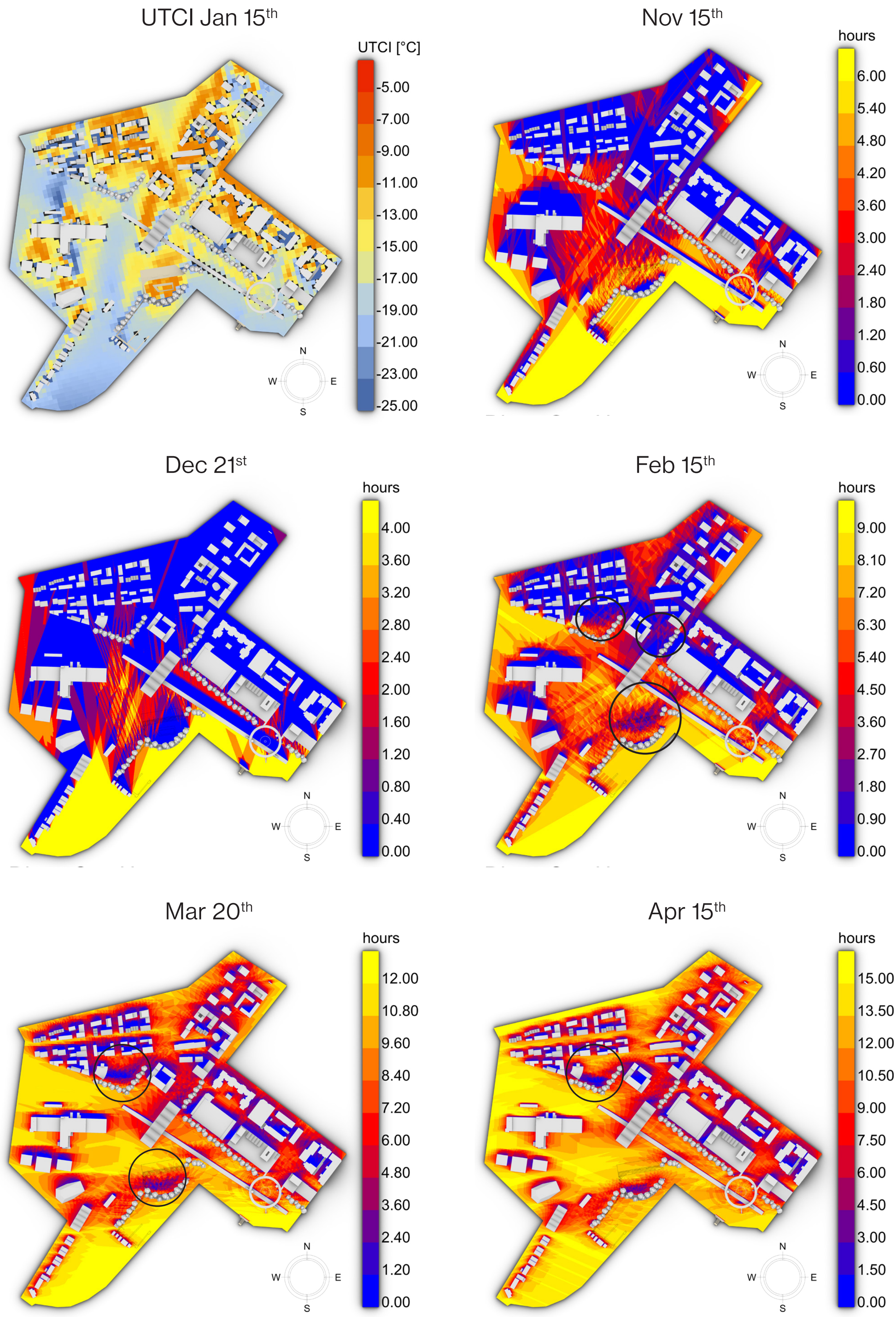
5.2 First Design Iteration



Original proposal → 5m high mound + Trees and bushes

In the first phase, the initial intervention involved creating a windbreak to protect public spaces and outdoor areas, reinforcing the design principle of wind mitigation. This was done using trees and earth mounds. Special attention was given to the outdoor dock seating and pier, as these were among the most exposed parts of the site. Pine trees and pine bushes, also known as evergreens, were selected based on research suggesting that vegetation can improve local microclimatic conditions.

○ Notable Observation → Tall pine trees casting too much shade over the public spaces.


UTCI Jan 15th

Nov 15th

Dec 21st

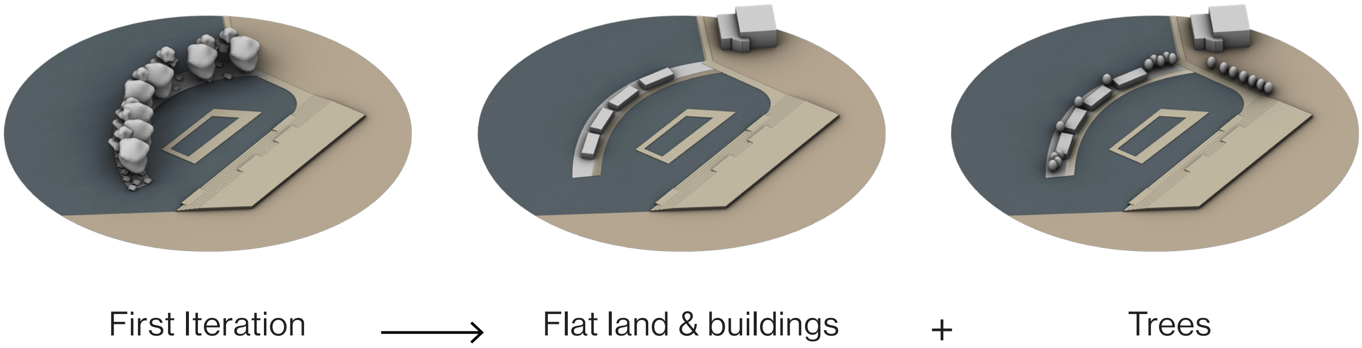
Feb 15th

Mar 20th

Apr 15th

Figure 21. *Graphical representations from the first iteration, showing UTCI results and hours of direct sunlight.*

5.3 Second Design Iteration



After analyzing the first phase, it became clear that the tall pine trees were casting too much shade over the public spaces, particularly during the spring months ,which conflicted with the design principle of daylight maximization. As a result, the plan was adjusted to use smaller pine tree species throughout the site. Despite this issue, the original combination of tall pine trees and earth mounds had significantly improved thermal comfort in the dock seating area and the nearby land and water.

Temperatures increased from around -25 to -19 degrees Celsius to a warmer range of -15 to -9 degrees Celsius. According to the UTCI equivalent temperature scale, this shift represented an improvement from strong cold stress to moderate cold stress.

To achieve similar results in UTCI measurements, single-story buildings were placed along a flat stretch of land directly in front of the dock seating area. Additionally, a larger two-story building was added nearby to provide further wind protection. These structures were introduced to evaluate their effectiveness in combination with the smaller pine trees.

○ Notable Observation → Small pine trees not enough to significantly improve thermal comfort in the public spaces.

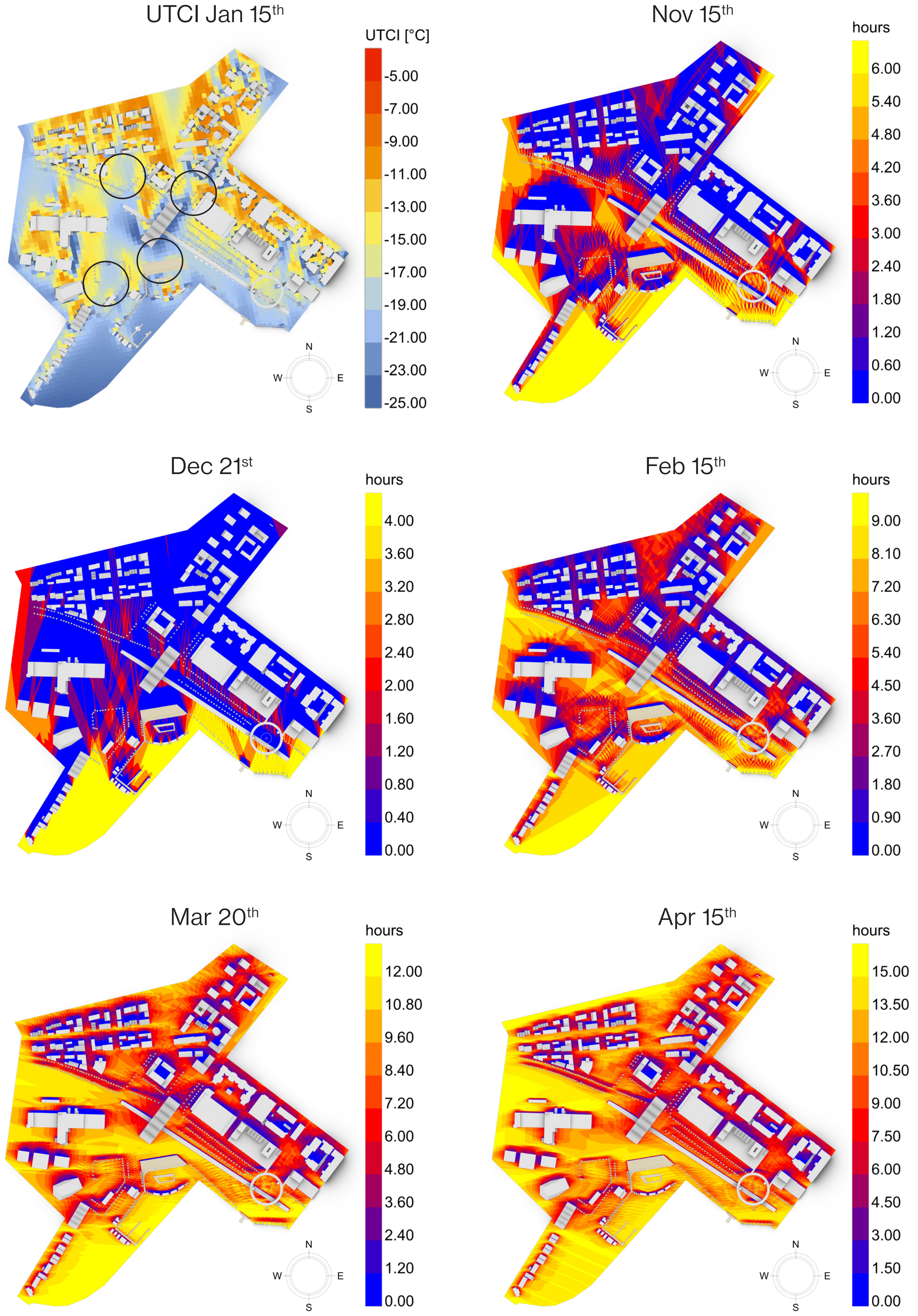
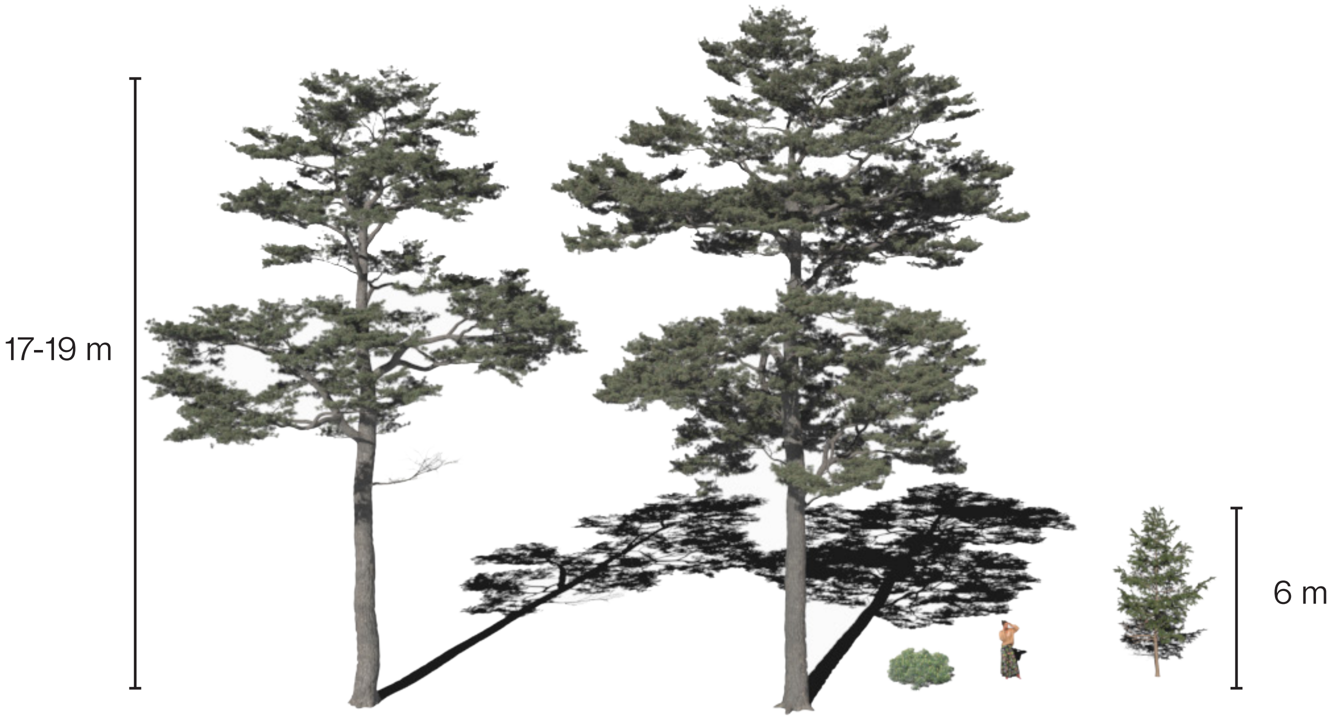
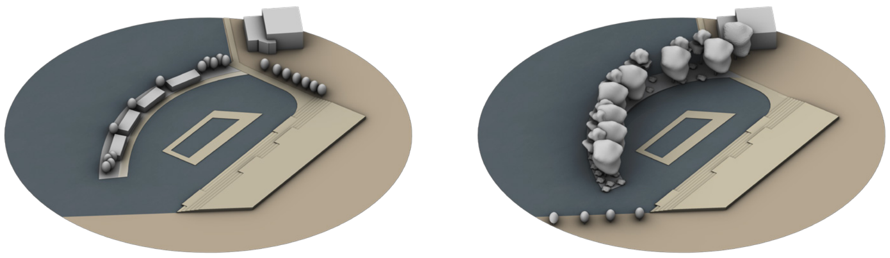


Figure 22. *Graphical representations from the second iteration, showing UTCI results and hours of direct sunlight.*

5.4 Third Design Iteration





Second iteration ⟶ Revision

The analysis of the second phase showed that the small pine trees used were not enough to significantly improve thermal comfort in the public spaces, according to UTCI readings. However, they did allow for better sunlight exposure in these areas. Based on these findings, the decision was made to use both large and small trees in a more strategic way. The larger trees would serve as windbreaks placed further away from the public spaces, while the smaller trees would be positioned directly around the spaces.

The aim of this combination is to create a more comfortable outdoor environment by balancing thermal comfort and sunlight, effectively addressing the sometimes conflicting principles of daylight maximization and wind mitigation. The tall trees were positioned just before the rail line to block most of the wind, while the smaller trees were placed closer to the public areas to shield against any remaining wind that might pass through the larger ones.

○ Notable Observation → Improved stress range of -13 to -9 degrees Celsius. Acceptable sun exposure.

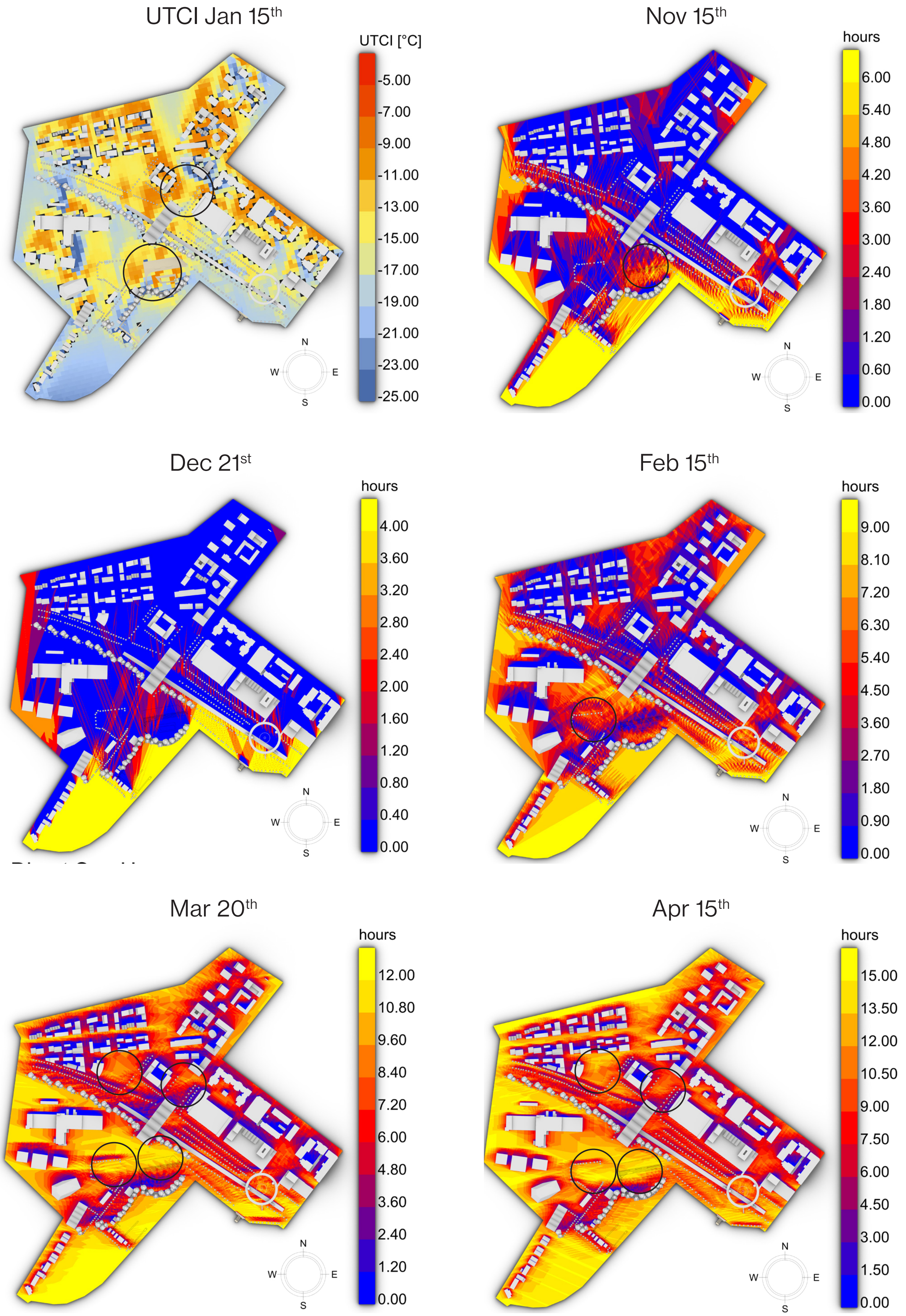
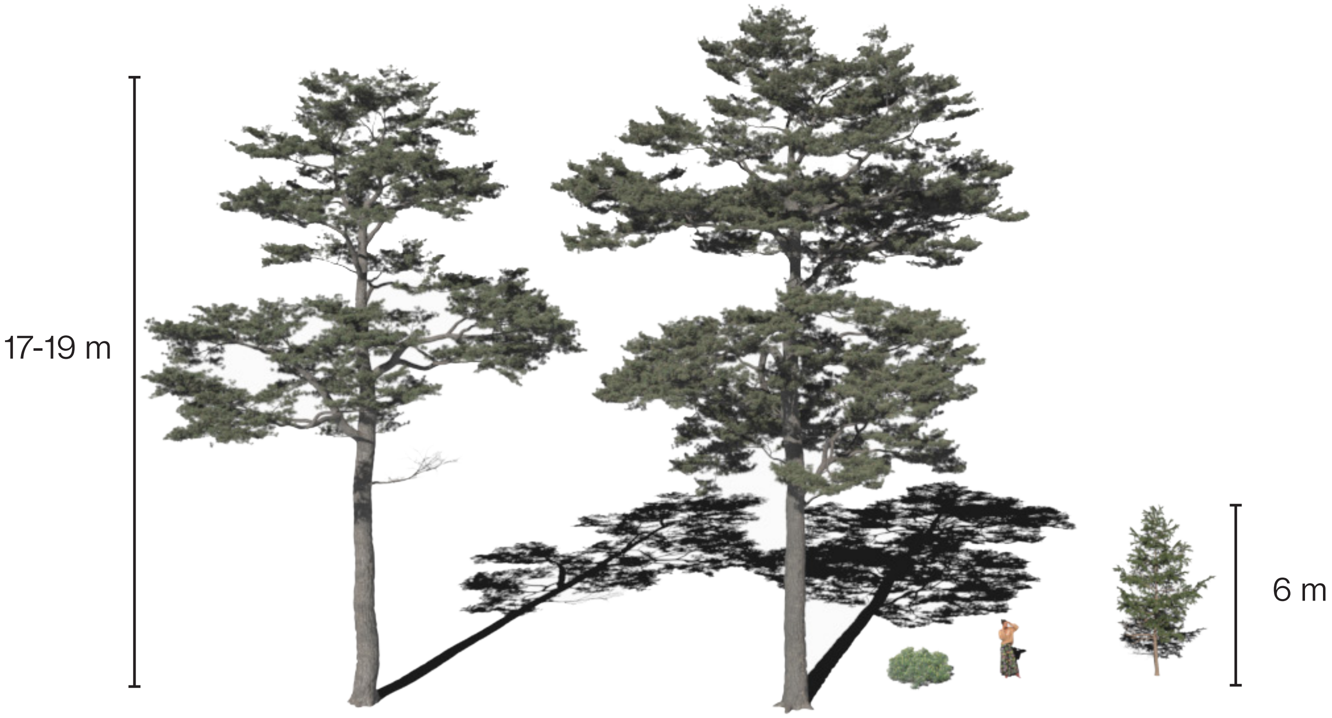
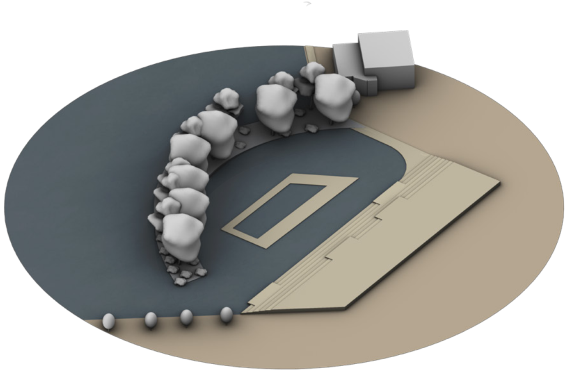


Figure 23. *Graphical representations from the third iteration, showing UTCI results and hours of direct sunlight.*

5.5 Fourth Design Iteration





Final Output

The analysis of the third iteration showed that it successfully created outdoor environments suitable for outdoor stay and activity. According to UTCI results, most public spaces fell within the moderate cold stress range of -13 to -9 degrees Celsius. These values are considered reasonable given the cold Arctic climate, and further improvements on the chosen date, January 15 in Piteå, are unlikely.

Minor adjustments were made by removing and adding some tree lines to allow for more direct sunlight. These changes did not reduce thermal comfort in the public squares. In particular, removing tree lines near Timmerleden increased sun exposure in that area, especially in spring, and created potential space for snow storage.

○ Notable Observation → Improved Sun exposure.

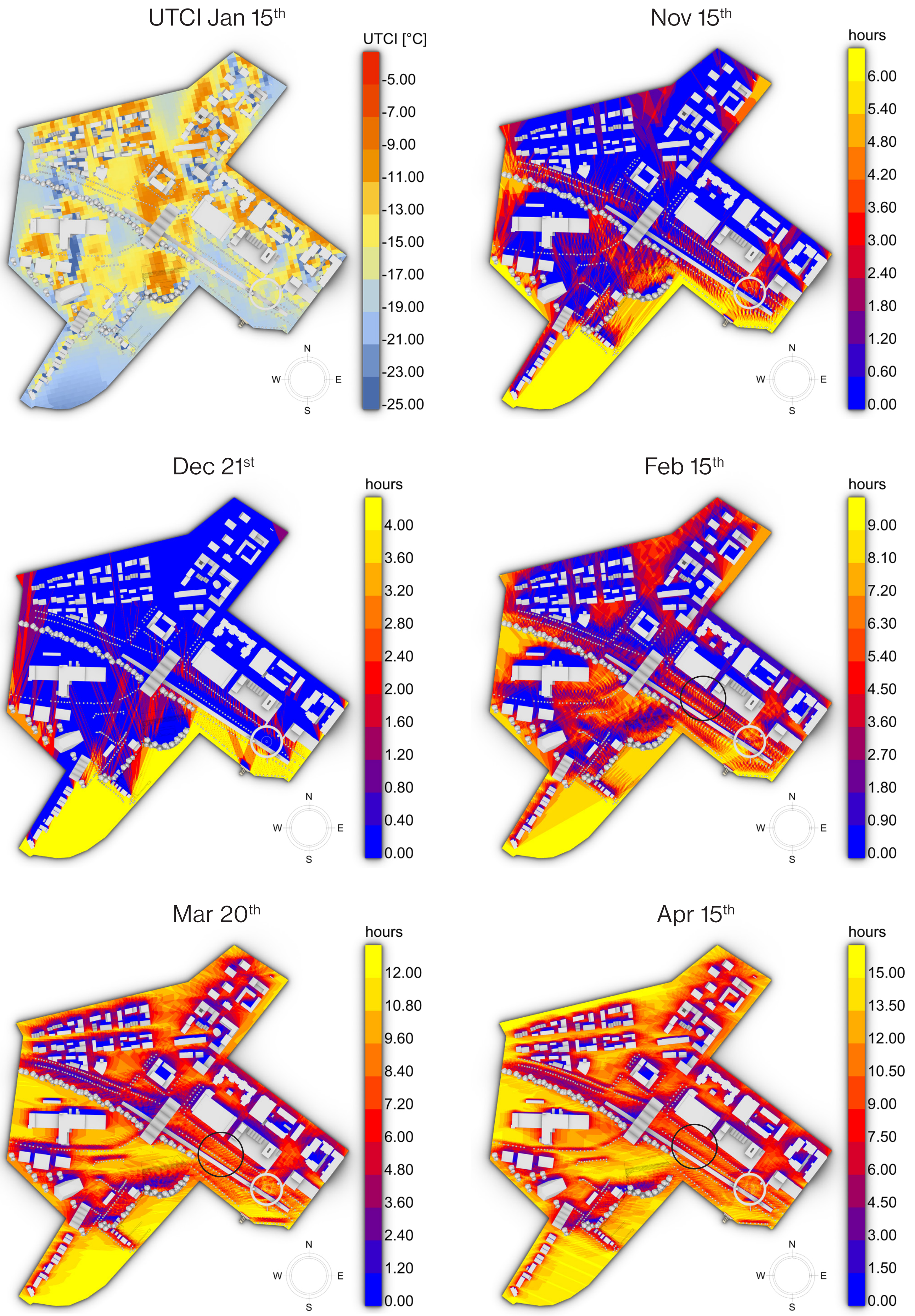


Figure 24. *Graphical representations from the fourth iteration, showing UTCI results and hours of direct sunlight.*

5.6 UTCI-Informed Redesign

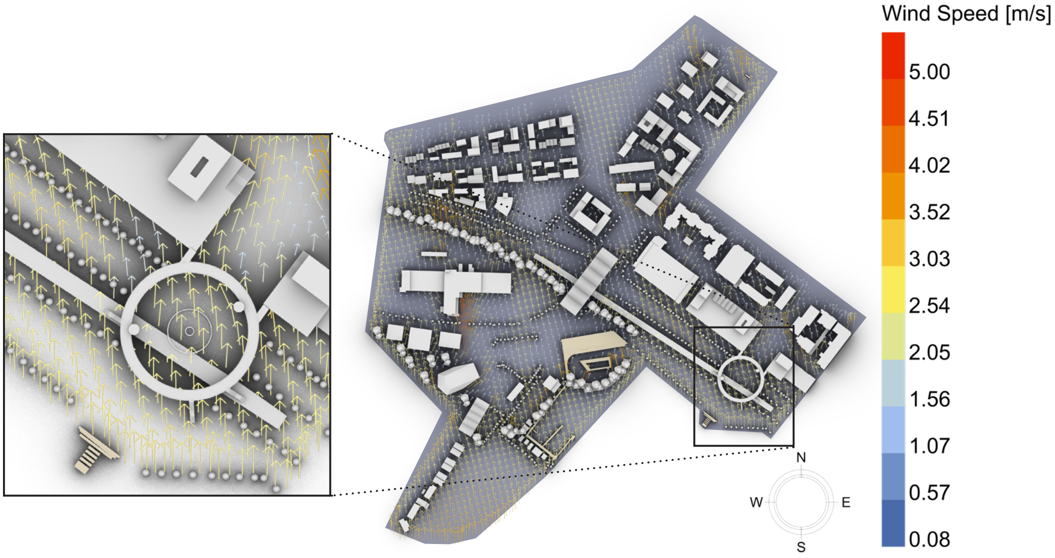


Figure 25. *Graphical representation of wind direction and speed based on wind vector data from the UTCI simulation.*

An analysis of the pedestrian bridge in the study area, using wind vector data from the final UTCI output, supports initial observations made during the case study. The data confirms that the bridge is directly exposed to prevailing winds. Its design, open to the elements and elevated near the waterfront, leaves it highly vulnerable to environmental stressors, especially during the winter season.

Current climate projections indicate a trend toward warmer, wetter winters, with increased precipitation and more frequent freeze-thaw cycles. In such conditions, the bridge's exposure to strong winds could lead to significant snow accumulation and ice formation on walking surfaces. This not only creates safety hazards for pedestrians but also presents operational challenges for snow and ice removal.

In addition to safety concerns, the open and unprotected nature of the bridge may cause discomfort for users during colder months, potentially reducing its use during winter.

To address these issues, the bridge was redesigned to fully enclose the pedestrian walkway, providing protection from wind and weather. A skylight was incorporated into the new design to ensure that the enclosed space still benefits from natural daylight. This solution is supported by the literature and the design principles formulated, specifically principles of maximizing daylight exposure and wind mitigation. The intervention aims to improve pedestrian comfort and safety, encouraging year-round use of the bridge despite seasonal challenges.

Original proposal

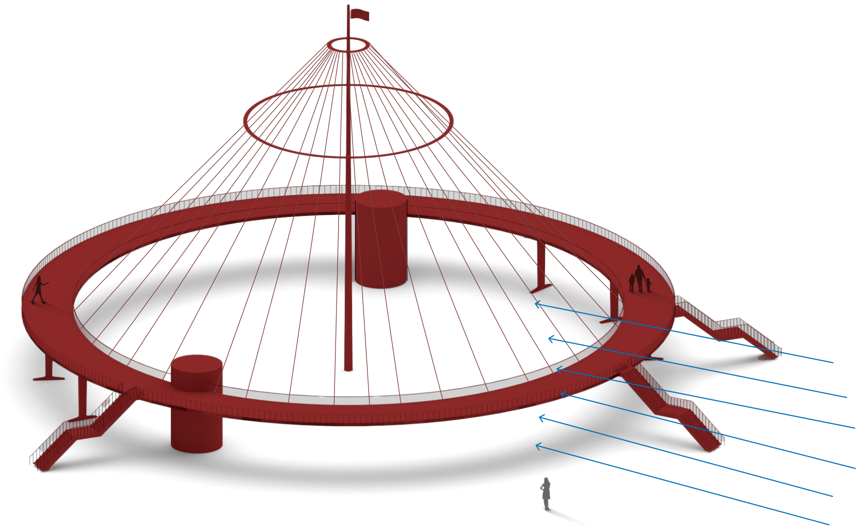


Figure 26. *Original design proposal for the pedestrian bridge in the study area.*

Redesign

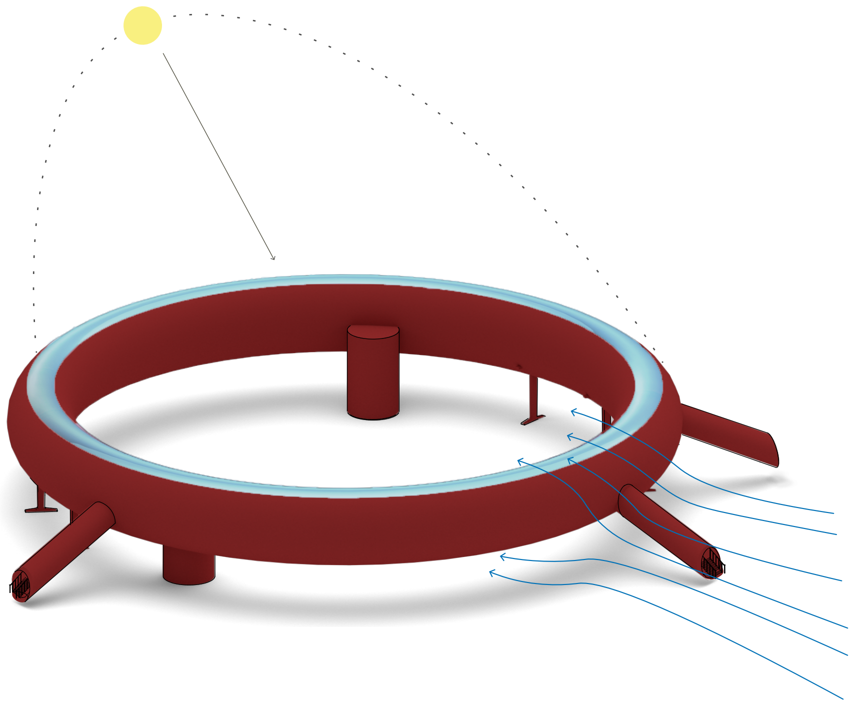


Figure 27. *Redesigned proposal for the pedestrian bridge in the study area, featuring a fully enclosed walkway and a skylight to enhance wind protection and natural lighting.*

5.7 Spatial Strategies

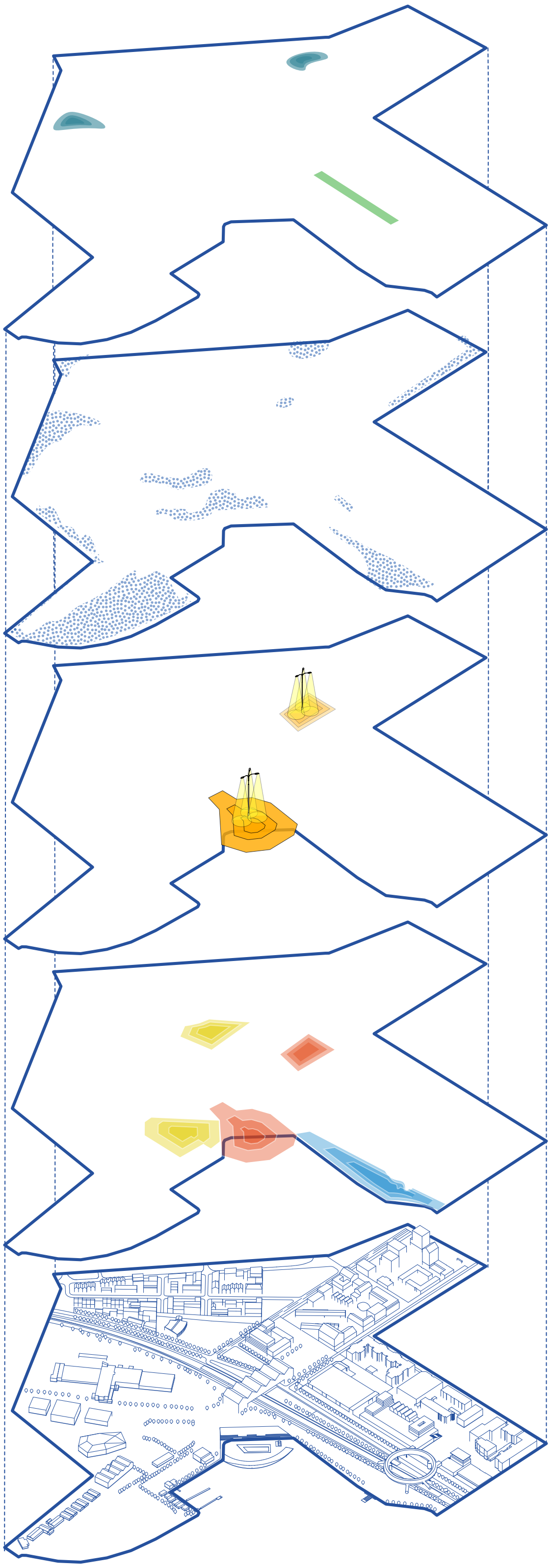
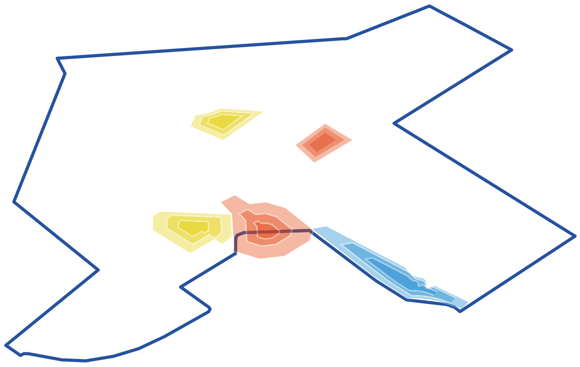


Figure 28. *Diagram showing Spatial strategies based on Final output of UTCI results and direct sunlight hours, as well as 100 year flooding simulations.*

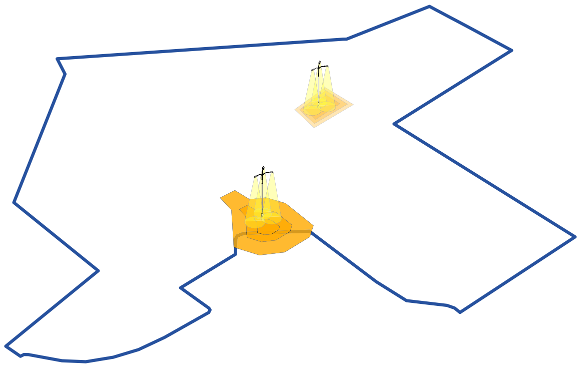


🟥 Sedentary use 🟨 Active use 🟦 Sun Bathing

Potential functions of the public spaces

The analysis of the final iteration using UTCI results shows that public spaces offer varying levels of thermal comfort, which should guide how these areas are used. For example, yellow zones, with temperatures around -15 to -13°C, indicate strong to moderate cold stresses on the UTCI scale. These areas are better suited for active, non-sedentary uses such as ice skating or playgrounds.

In contrast, red zones offer a better thermal comfort, where the temperatures sit comfortably within the moderate cold stress category, and may be more appropriate for sedentary activities like markets, outdoor cafés, or public events. The blue zone, while not offering ideal thermal comfort, receive abundant sunlight and could be used for sunbathing. This approach supports a mix of uses across the waterfront, balancing sun exposure and thermal comfort.



🟧 Focus area for artificial lightning

Areas of focus for decorative artificial lightning

When it comes to areas that should be well lit, it is evident that every space used by pedestrians and cyclists should be well lit, but special attention should be given to areas for sedentary use and high foot-traffic areas. When it comes to decorative artificial lighting, the areas for sedentary use outlined in the previous diagram overlap with the areas of potential focus for decorative lighting.

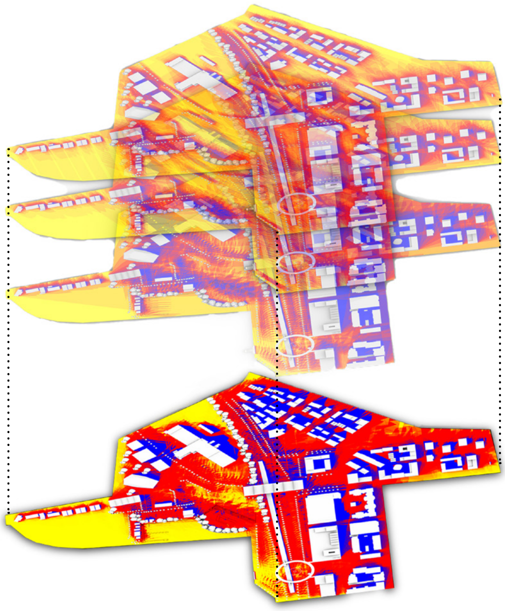
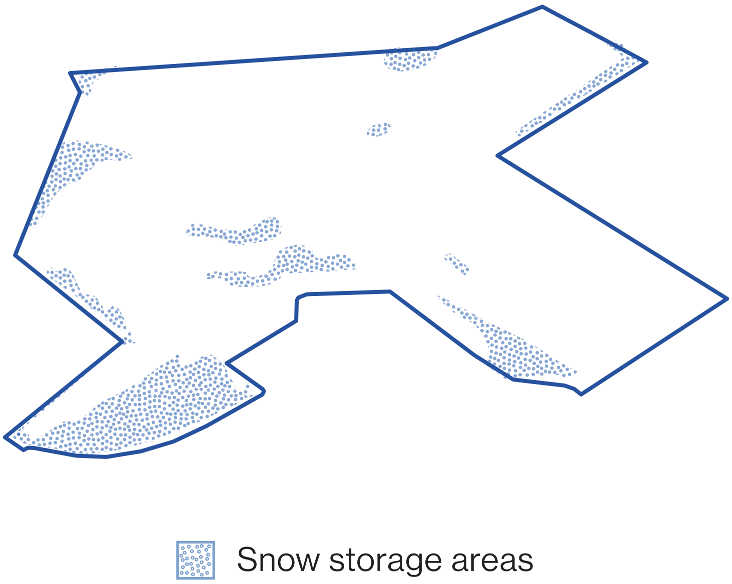


Figure 29. *Superimposed diagram of direct sun hours analyses for February, March, and April, illustrating areas with the highest cumulative solar exposure across late winter and early spring.*

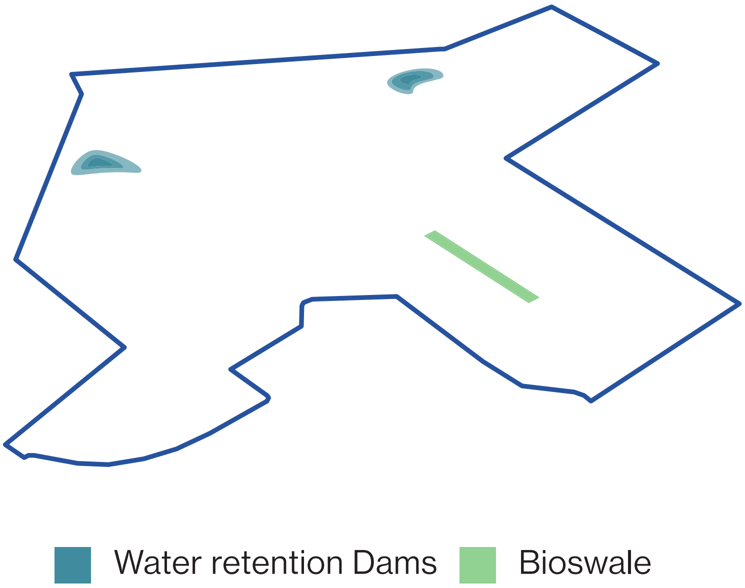


Potential areas for snow storage

By analyzing the final iteration of the study area and comparing and superimposing the direct sunlight hours of the selected dates February 15th, March 20th, April 15th, one can identify the most suitable locations for snow storage, areas that receive the most sunlight during winter and spring.

Nevertheless, these locations need further delineation, especially in relation to snowplow access and potential conflicts of interest within the study area and planning of the spaces. This means that not all the highlighted areas are necessarily suitable for snow storage.

Figure 30. *Flood risk map of central Piteå showing projected flooding areas during a 100-year flood event. Areas in red indicate zones of highest flood vulnerability.*



Areas for storm water management

Following the design strategy developed in this thesis, the areas for stormwater management, although not directly identified through computational simulations, can now be determined based on several guiding factors. Features such as bioswales and stormwater dams can be placed by considering the location of wind protection measures, identified sun-exposed areas, and zones expected to flood during a 100-year rain event.

In addition, overlaps with potential snow storage areas should be considered, as they can function together effectively. Taken together, these factors help inform planners in selecting stormwater management areas that provide the most benefit throughout the year.

5.8 Spatial programming

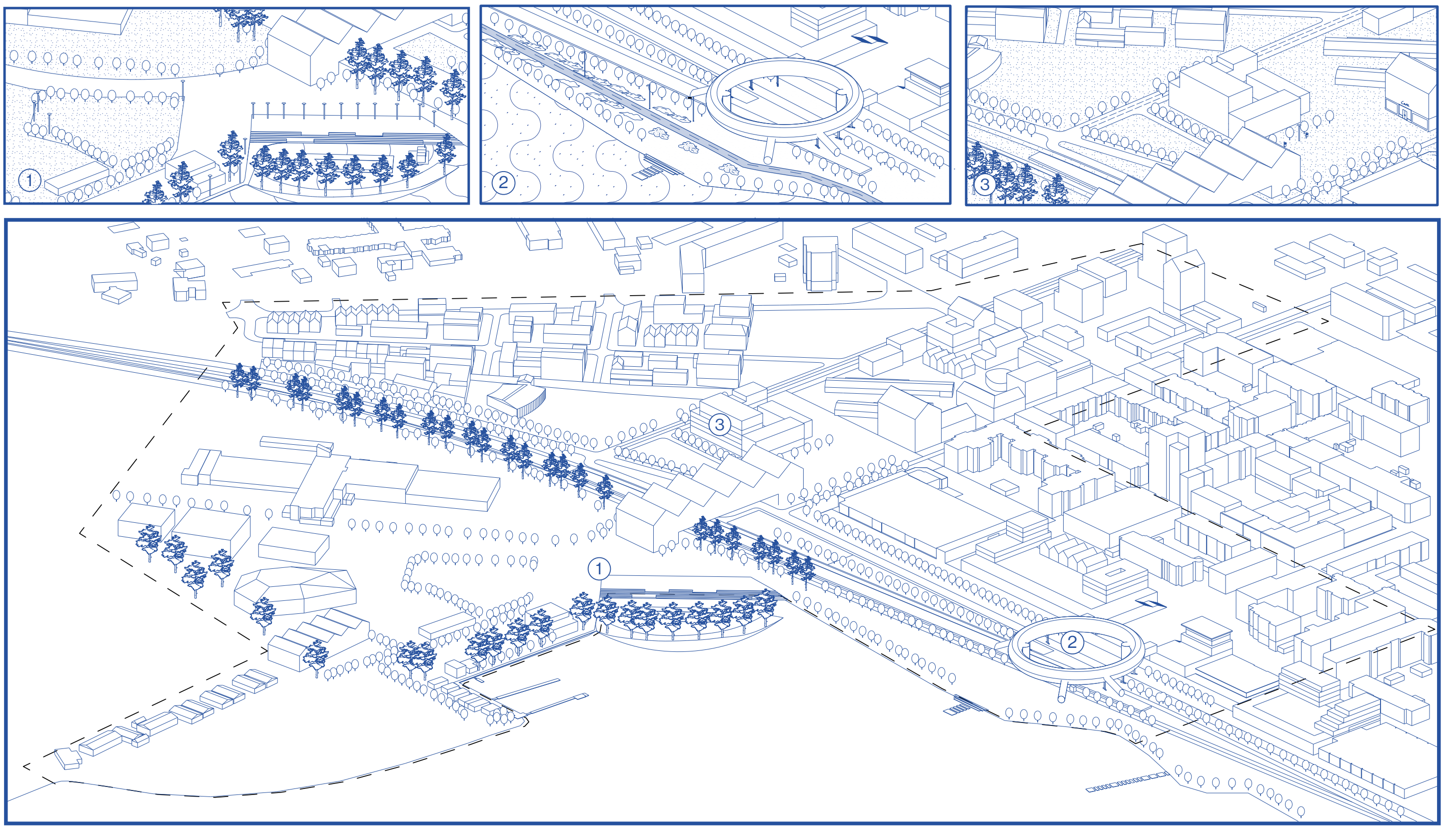
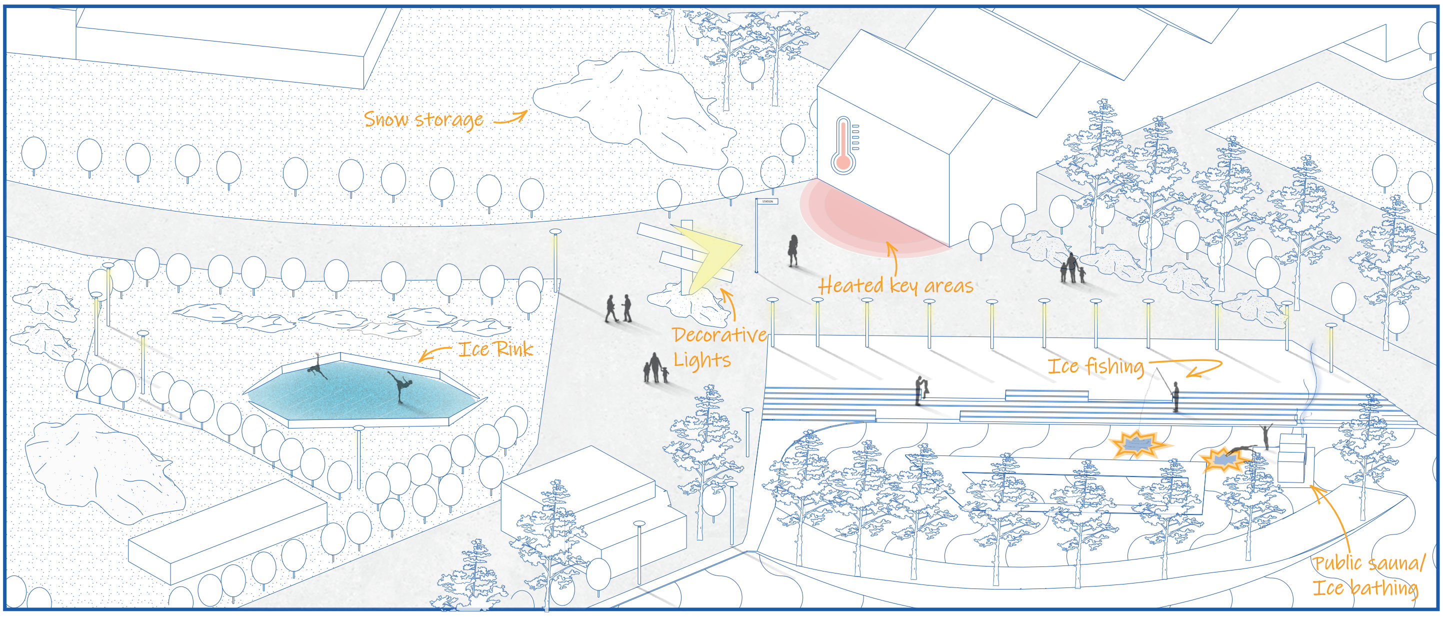


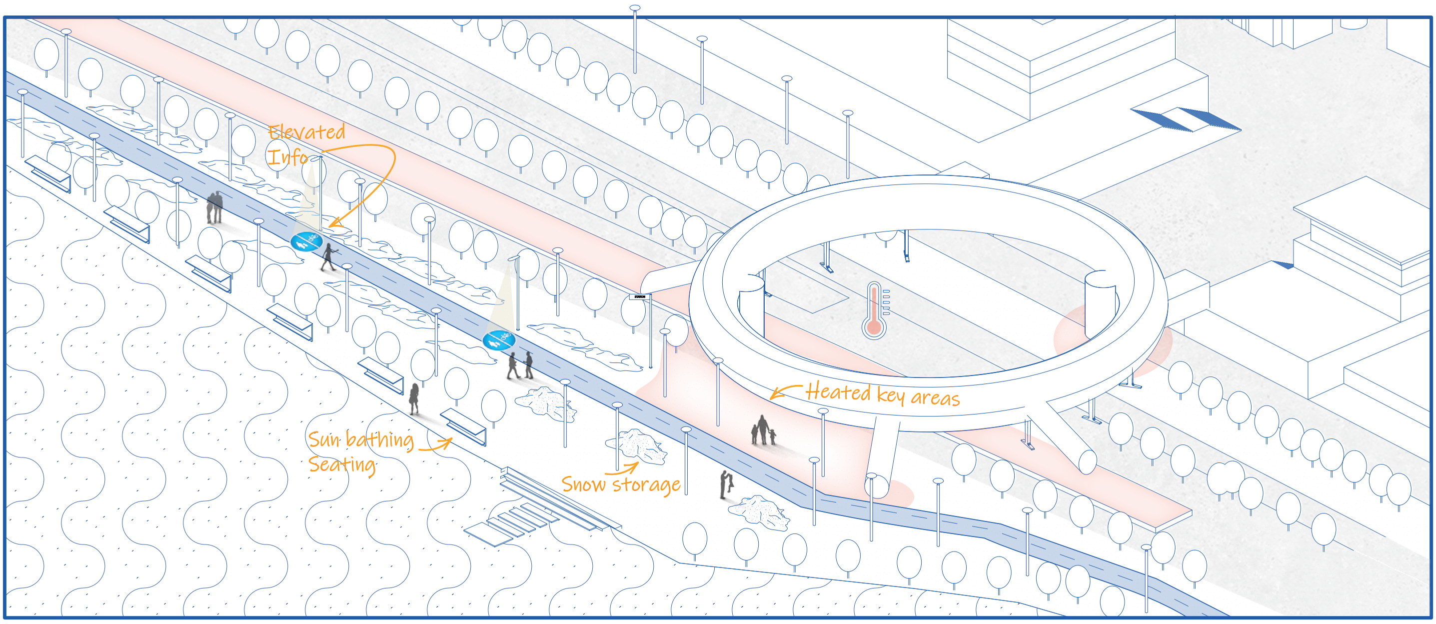
Figure 31. *Axonometric overview and detail views of three key intervention zones along the study area.*

Building on the spatial strategies developed for the study area, the design process can now focus on bringing public spaces to life by introducing specific functions and features that align with those strategies. These additions are guided by the design principles outlined in this thesis, supported by findings from the literature review and case study, and based on contemporary winter design practices. Altogether, the spatial programming illustrates how urban design in Arctic contexts can move beyond mitigation and actively celebrate winter, encouraging soft mobility and outdoor stay throughout the cold season.

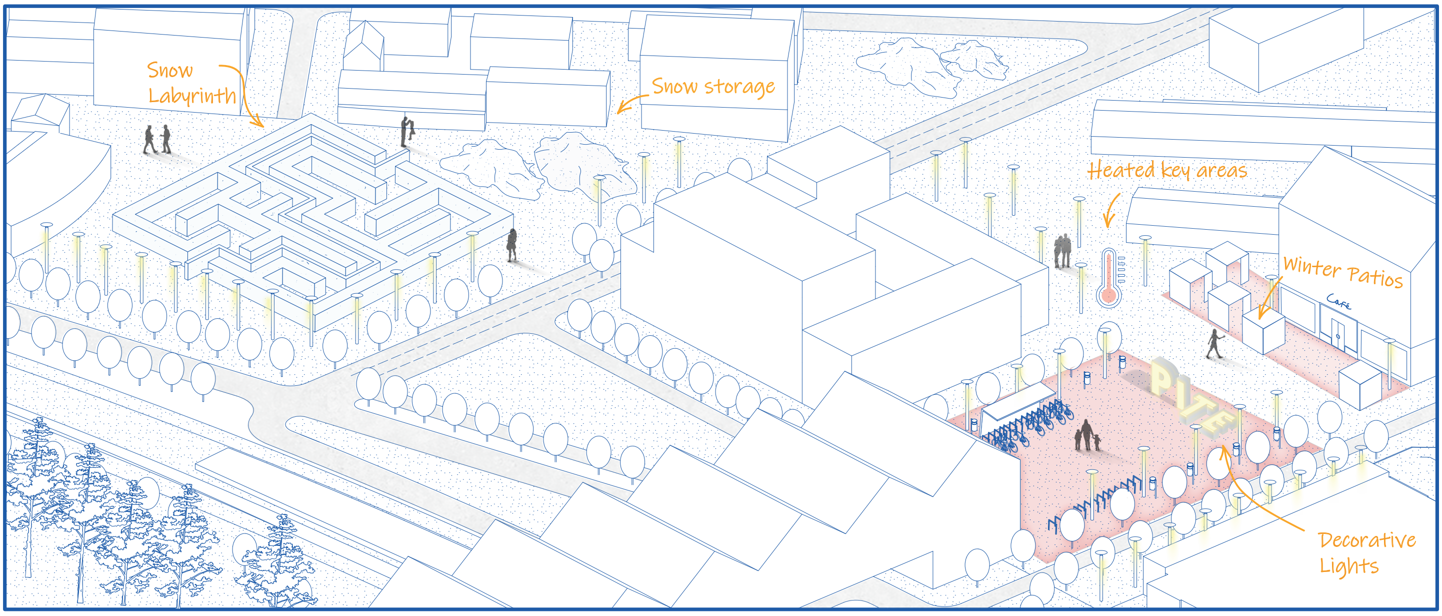


For the dock seating area and the adjacent green space, the spatial proposal offers insight into how the design process can be further refined to create a winter-adapted public space. The area integrates a variety of seasonal and climate adaptive features. These include designated snow storage zones strategically placed to receive optimal sunlight, and seasonal use of the green space as an ice rink, framed by vegetation to provide wind buffering. Heated zones are also introduced to mitigate slippery surfaces, particularly near the entrance of the train station.

Additional elements such as decorative lighting enhance visibility and atmosphere during the dark winter months, especially in areas intended for sitting and lingering. Furthermore, amenities like public saunas and designated cold water ice bathing areas activate the space with culturally rooted, winter-specific activities, a design choice informed by the case study , which indicate that cold water bathing is a common practice in Piteå and in the Sörfjärden area.



Heated zones are placed at key locations such as the train platform and in front of the bridge staircases and lifts to reduce the risk of slippery surfaces in areas expected to have high foot traffic. Sun-oriented seating is positioned along the waterfront to encourage sunbathing during winter-spring. Snow storage areas are carefully located in spots with good sun exposure to promote efficient melting, while avoiding interference with pedestrian and cycling routes. Elevated signage is introduced to improve wayfinding and maintain visibility during heavy snow accumulation, using projected lighting to display lane designations for pedestrians and cyclists directly onto the snow.



Programmed to support outdoor activity and social engagement, the design introduces a snow labyrinth as a playful and interactive seasonal feature that encourages movement and exploration during the colder months. Given the temporary nature of snow, this space can also accommodate various snow-related activities, such as snow sculpture exhibitions and other play-focused events. Adjacent areas are designated for snow storage, strategically placed to benefit from sun exposure and ensure efficient melting.

The station square incorporates heated zones in key locations to reduce slippery surfaces, promoting longer stays and greater usability during harsh winter conditions. Decorative lighting adds visual interest and improves safety during periods of limited daylight. Additionally, winter patios are proposed to extend urban life into the colder season, creating an active street edge even in winter.

6

Discussion and Conclusions

This chapter reflects on the findings, discussing their implications in the context of Arctic urban planning, climate adaptation, and design practice. and summarizes the main insights of the thesis.

Figure 32. *Piteå, pedestian captured walking, Midday* . Photo by author.

6.1 Discussion

Reflection

This thesis explored how urban design and planning can improve conditions for soft mobility and promote the public use of outdoor spaces in Piteå's changing Arctic climate.

To address the research question, the study focused on the application of both computational simulations and climate-sensitive design principles. The simulations generated quantifiable data indicating whether an outdoor space is comfortable, supported by analysis and comfort indices. These tools informed critical planning elements, such as the placement of snow storage and the functions of public spaces.

The data-driven nature of these simulations offers a clear and objective perspective, which underscores the importance of integrating analytical methods when designing outdoor environments in extreme climates. However, revisiting the design principles outlined in Chapter 3. These principles, drawn from the literature, offer detailed strategies for creating resilient winter environments, strategies that have been employed long before the advent of computational tools. Given this fact, what unique value does computational simulations provide that established design principles do not?

Ebrahimabadi (2015) addresses this question directly. He argues that in Arctic regions, failure to account for microclimatic conditions during the planning process can lead to more severe consequences than in milder climates. He notes that many practitioners rely on generalized climate principles without employing analytical tools, which often results in vague and potentially ineffective design solutions. Sole reliance on such principles, therefore, may yield uncertain or unintended outcomes.

Moreover, Ebrahimabadi emphasizes the interdependence of these general principles and warns that applying them in isolation can produce undesirable effects. He advocates for a design process that is analysis-led rather than solution-led, where decisions are driven by evidence rather than preconceived ideas. Analytical methods allow for a more comprehensive understanding of the environmental context and its complexities.

From this perspective, simulations should be viewed as enhancing the use of climate-sensitive winter design principles. They make microclimatic variations visible and quantifiable, providing planners and architects with concrete information, such as optimal locations for specific functions or snow storage areas.

Moreover, the combination of the design principles and strategy outlined in Chapter 3 with computational simulations can be seen as a foundation for more thoughtful and responsive outdoor environments that support both outdoor stay and soft mobility, The methodology could be taken further to develop more advanced and detailed design proposals in future work.

Limitations

Several limitations affect the reliability and applicability of the results presented in this thesis. The simulations were based on a 3D model with a simplified terrain, which does not account for detailed topographic features. Additionally, the Universal Thermal Climate Index (UTCI) used assumes a moving person dressed in appropriate winter clothing. This model may not accurately reflect comfort levels for sedentary activities or account for individual variations in sensitivity due to factors such as age, sex, or body size.

Another limitation is that the simulations reflect current climate conditions and do not consider projected future climate scenarios for Piteå. Further constraints relate to the tools employed, such as Rhino, Ladybug, and the calibration of the Grasshopper script. These tools require specialized knowledge that many practitioners may lack. While some automated simulation tools exist, they are often too simplistic or restrictive to be fully effective in professional practice.

Finally, a specific limitation of the UTCI model is its inapplicability to suspended walkways, such as the bridges proposed in the Solander Ring master plan. As of now, additional or alternative simulation methods are required to evaluate microclimatic conditions in these elevated contexts.

6.2 Conclusions

This thesis set out to investigate how urban design and planning could improve conditions for soft mobility and promote public use of outdoor spaces in Piteå's changing Arctic climate. The findings indicate that computational simulations, when used in conjunction with climate-sensitive winter design principles, can offer valuable methods for assessing existing conditions and informing design proposals. This combined approach could be useful for assessing and informing design for outdoor stay and soft mobility in Arctic conditions.

The thesis outlines a method for integrating analytical tools with established design principles through a hierarchical design strategy. This process could support more climate-resilient planning in cold regions by providing a structured framework for addressing both environmental and functional aspects of public space. While the study was limited by the simplified terrain modelling and the assumptions built into the UTCI model, the approach offers a basis for further development and refinement.

Future work could expand the scope of this strategy to include projected climate scenarios, more complex urban topographies, and design processes that span from conceptual planning to more detailed designs. The method presented here may also be applicable to other Arctic or sub-Arctic contexts facing similar climatic and urban challenges.

Overall, this research highlights the potential of combining design intuition, principles, and strategies with data-driven tools to create outdoor environments that are not only functional, but also adaptive, and better suited to the realities of Arctic living. Such an approach could contribute to improving conditions for soft mobility and encouraging greater public use of outdoor spaces in Piteå's evolving Arctic climate.

Reference list

Academic Sources

Akgül, B. K., & Toy, S. (2021, September 21). The designed examples for optimal use of urban furniture in winter cities. ResearchGate. 5th International Conference on Advances in Natural & Applied Science Engineering, Ağrı, Turkey. Retrieved from https://www.researchgate.net/publication/356206648_The_Designed_Examples_for_Optimal_Use_of_Urban_Furniture_in_Winter_Cities

Bernes, C. (2016). *En varmare värld: Växthuseffekten och klimatets förändringar (3rd ed.).* Naturvårdsverket.

Bröde, P., Krüger, E., & Rossi, F. A. (2011). Assessment of urban outdoor thermal comfort by the Universal Thermal Climate Index (UTCI). In S. Kounalakis & M. Koskolou (Eds.), *Proceedings of the XIV International Conference on Environmental Ergonomics* (pp. 338–341). https://www.researchgate.net/publication/265227362_ASSESSMENT_OF_URBAN_OUTDOOR_THERMAL_COMFORT_BY_THE_UNIVERSAL_THERMAL_CLIMATE_INDEX_UTCI

Böcker, L., Priya Uteng, T., Liu, C., & Dijst, M. (2019). Weather and daily mobility in international perspective: A cross-comparison of Dutch, Norwegian and Swedish city regions. *Transportation Research Part D: Transport and Environment, 77, 491–505.* https://doi.org/10.1016/j.trd.2019.07.012

Chapman, D., Nilsson, K., Larsson, A., & Rizzo, A. (2017). Climatic barriers to soft-mobility in winter: Luleå, Sweden as a case study. *Sustainable Cities and Society, 35, 574–580.* https://doi.org/10.1016/j.scs.2017.09.003

Chapman, D., Nilsson, K., Rizzo, A., & Larsson, A. (2018). Updating winter: The importance of climate-sensitive urban design for winter settlements. *Arctic Yearbook, 16(19), 3669.*

Chapman, D., Nilsson, K. L., & Sjöholm, J. (2024). *Planning and urban design for attractive Arctic cities.* Taylor & Francis.

Ebrahimabadi, S. (2015). *Outdoor comfort in cold climates: Integrating microclimate factors in urban design.* DIVA; Luleå tekniska universitet. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-26319

Hemmersam, P. (2021). *Making the Arctic city.* Bloomsbury Publishing.

Larsson, A., & Chapman, D. (2020). Perceived impact of meteorological conditions on the use of public space in winter settlements. *International Journal of Biometeorology, 64(4), 631–642.* https://doi.org/10.1007/s00484-019-01852-5

Mattsson, J. (1970). *Väderlekslära och klimatologi.* CWK Gleerup.

Petryshyn, N. (2022). A City for All Seasons: Winter City Planning for Toronto's Parks and Public Spaces (Version 1). Toronto Metropolitan University. https://doi.org/10.32920/19083320.v1

Roecklein, K. A., & Rohan, K. J. (2005). Psychiatry 2005 [J A N U A R Y] 20 Seasonal Af f Disorder An Overview and Update [R E V I E W]. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3004726/pdf/PE_2_1_20.pdf

Sterten, A. K. (1988). Climate and weather protection systems in settlement planning in the Arctic regions of Northern Norway. *Energy and Buildings, 11(1-3), 23–32.* https://doi.org/10.1016/0378-7788(88)90020-5

Sundborg, B. (2010). *Ljus i bebyggelsen.* Svenskbyggtjänst.

Sjökvist, E., Eriksson, A., Johnell, A., & Vallot, D. (2020). *Framtidsklimat i Piteå kommun (pp. 1–64).* SMHI.

Municipal Documents

Anchorage Municipality. (n.d.). *Anchorage downtown comprehensive plan.* Retrieved from https://www.muni.org/Departments/OCPD/Planning/Documents/Chapter_6_Final.pdf

Edmonton. (2016). *Winter design guidelines: Transforming Edmonton into a great winter city.* WinterCity Edmonton. Retrieved from https://www.edmonton.ca/city_government/documents/PDF/WinterCityDesignGuidelines_draft.pdf

Edmonton. (n.d.). *All-season patio design tips.* Retrieved from https://www.edmonton.ca/public-files/assets/document?path=PDF/all-season-patio-design-tips.pdf

Edmonton. (2024). *Tip of the iceberg: WinterCity strategy 10-year report.* Retrieved from https://www.edmonton.ca/sites/default/files/public-files/assets/PDF/Tip-of-the-Iceberg-WinterCity-Strategy-10Year-Report-Sept-2024.pdf

City of Oulu. (n.d.). *Oulu is the unofficial capital of year-round cycling. Retrieved from https://oulu.com/en/living/mobility/cycling/*

Gällivare. (2016). *Grön-, blå- och vitstrukturplan.* Gällivare kommun, Samhällsbyggnadsförvaltningen. Retrieved from https://gallivare.se/download/18.4e20a890188bda337d16238c/1687718683989/GBV_slutlig_20160321.pdf

Norconsult AB. (2022). *Trafikutredning luftmiljö Piteå.* Piteå Kommun. Retrieved from https://www.pitea.se/contentassets/1be9e27e12ab4f6dbe67e0d6e6d7eebb/220531-trafikutredning-luftmiljo-pitea.pdf

Piteå kommun. (2024). *Planprogram Sörfjärden.* Piteå kommun.

Piteå kommun. (2021). *Översiktsplan planstrategi.* Kommunfullmäktige, Piteå kommun.

Piteå kommun. (n.d.). *Planeringsunderlag ÖP2030 Bilaga.* Piteå kommun.

Piteå Kommun. (2022). *Riktlinjer för bebyggelse Piteå centrum.* Kommunfullmäktige, Piteå kommun.

Other Sources

8 80 Cities & AARP. (2021). *Winter placemaking guide.* Retrieved from https://www.880cities.org/subscribe/

Directorate-General for Communication. (2024, November 5). *Climate report shows the largest annual drop in EU greenhouse gas emissions for decades.* European Commission. Retrieved from https://commission.europa.eu/news/climate-report-shows-largest-annual-drop-eu-greenhouse-gas-emissions-decades-2024-11-05_en

European Environment Agency. (n.d.). *Thermal comfort indices: Universal Thermal Climate Index (1979–2019).* Climate-ADAPT. https://climate-adapt.eea.europa.eu/en/metadata/indicators/thermal-comfort-indices-universal-thermal-climate-index-1979-2019

NEW ENVIRONMENTS (2024) . *“NEW ENVIRONMENTS.” Newenvironments.eu, 2024, newenvironments.eu/info.* Accessed 1 May 2025.

SMHI. (n.d.). *Skalor för vindhastighet* [Scales for wind speed]. Swedish Meteorological and Hydrological Institute. https://www.smhi.se/kunskapsbanken/meteorologi/vind/skalor-for-vindhastighet

SMHI. (2025, Feburary 28). *Hur var vädret?* SMHI. https://www.smhi.se/klimat/klimatet-da-och-nu/hur-var-vadret/Pite%C3%A5/precipitation

SMHI. (2023). *Jordens bana runt solen.* SMHI. https://www.smhi.se/kunskapsbanken/meteorologi/solens-upp--och-nedgang/sommarsolstand-och-vintersolstand

Winter Cities Institute. (2025, February 20). *About the Winter Cities Institute.* Retrieved from https://www.wintercities.com/about-page/

WMO. (2024, November 19). *Record carbon emissions highlight urgency of global greenhouse gas watch.* World Meteorological Organization. Retrieved from https://wmo.int/media/news/record-carbon-emissions-highlight-urgency-of-global-greenhouse-gas-watch

Appendix A

UTCI Grasshopper Script

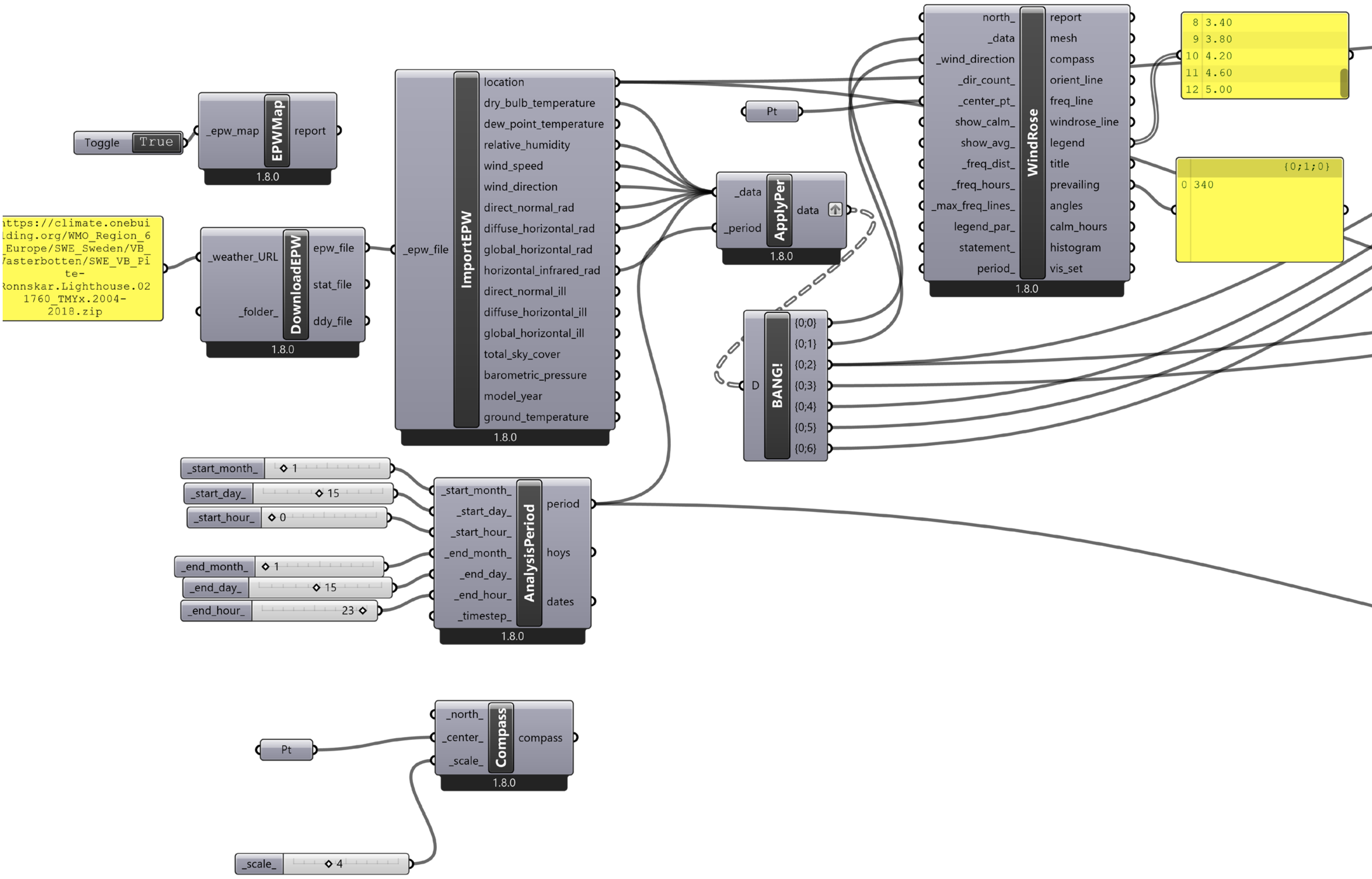


Figure 1. Grasshopper script for UTCI calculations climate data input. Imports EPW weather file and location data.

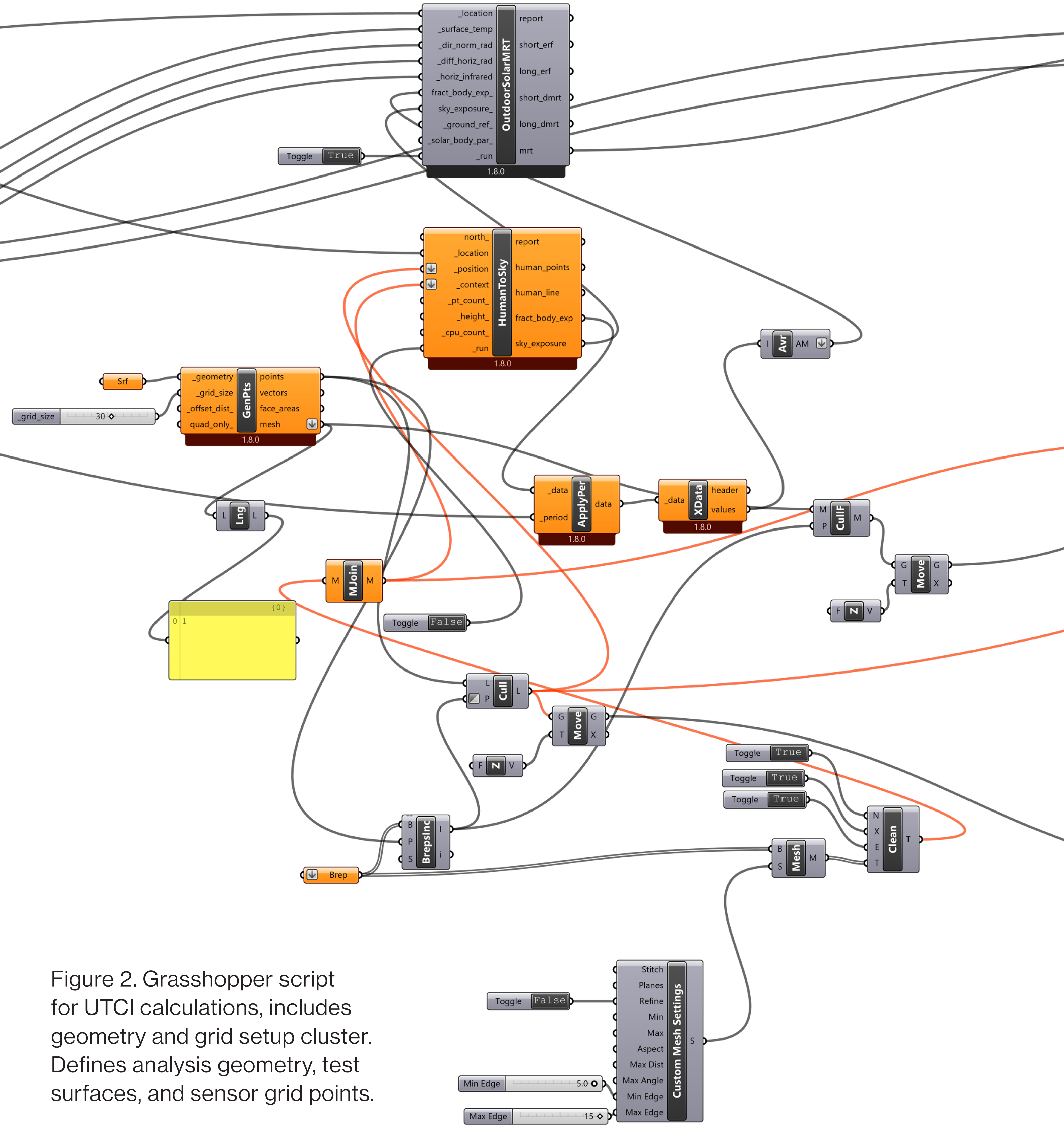


Figure 2. Grasshopper script for UTCI calculations, includes geometry and grid setup cluster. Defines analysis geometry, test surfaces, and sensor grid points.

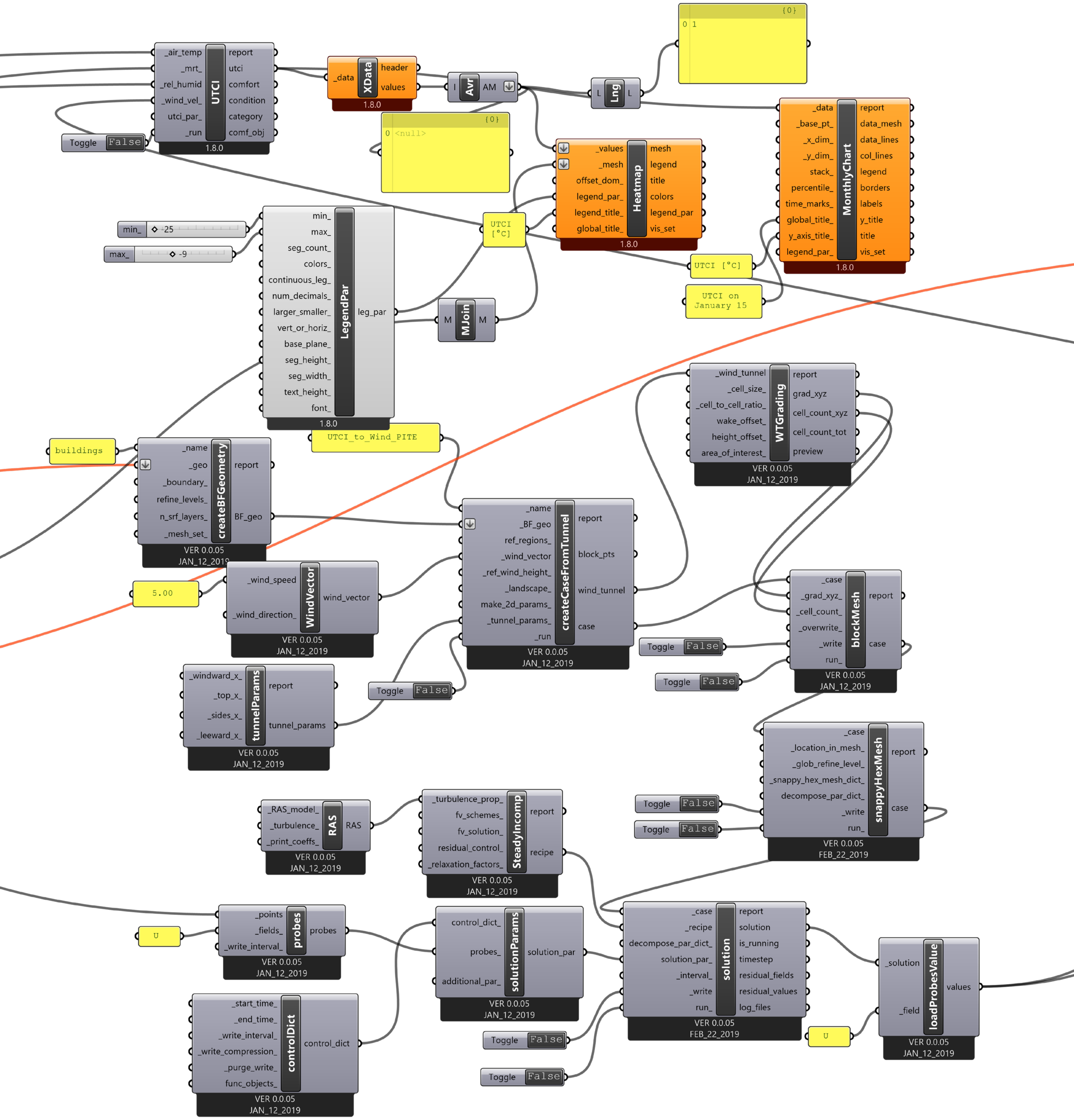


Figure 3. Grasshopper script for UTCI calculations, Environmental data cluster. Includes many things.

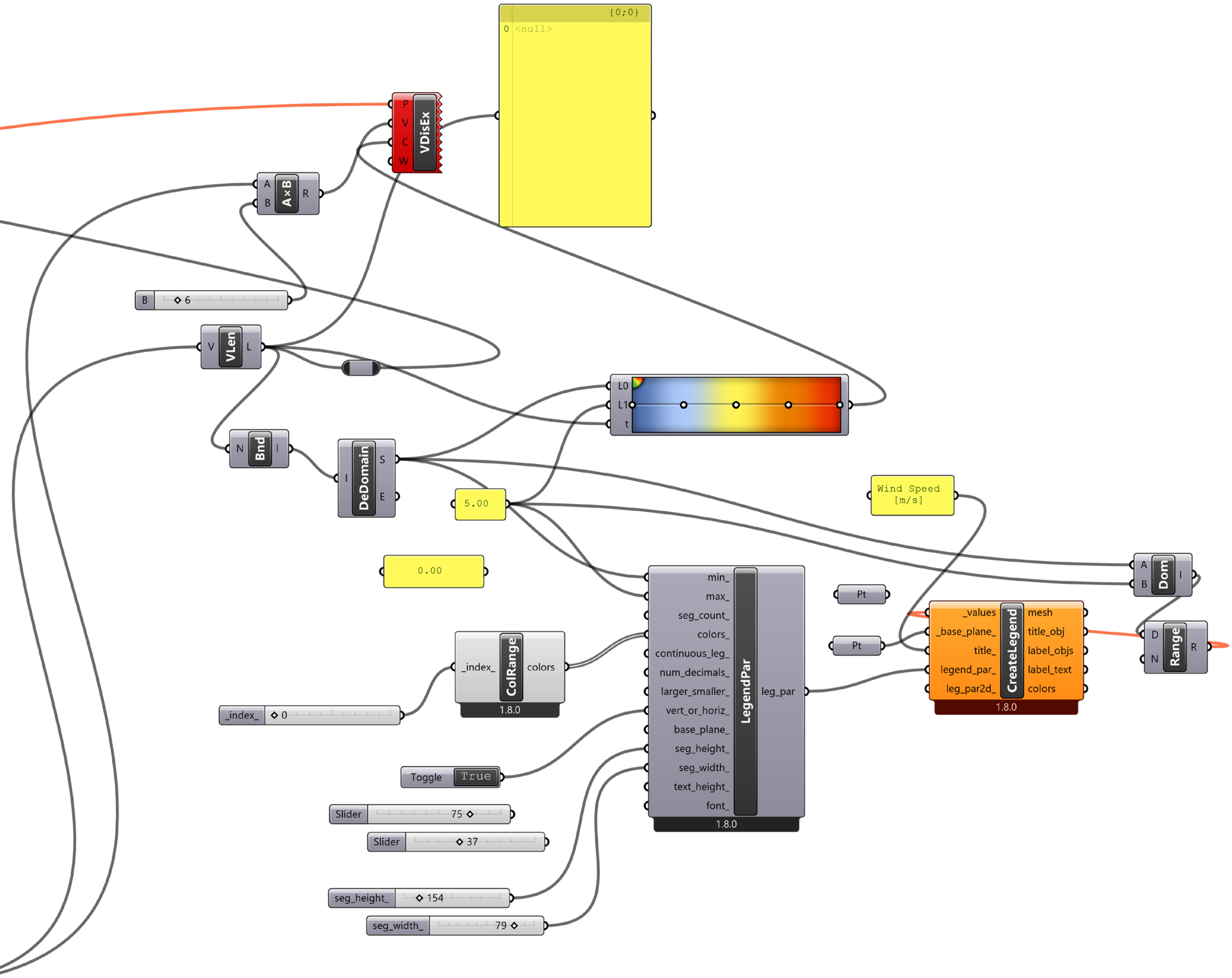


Figure 4. Grasshopper script for UTCI calculations, wind direction vector visualisation.

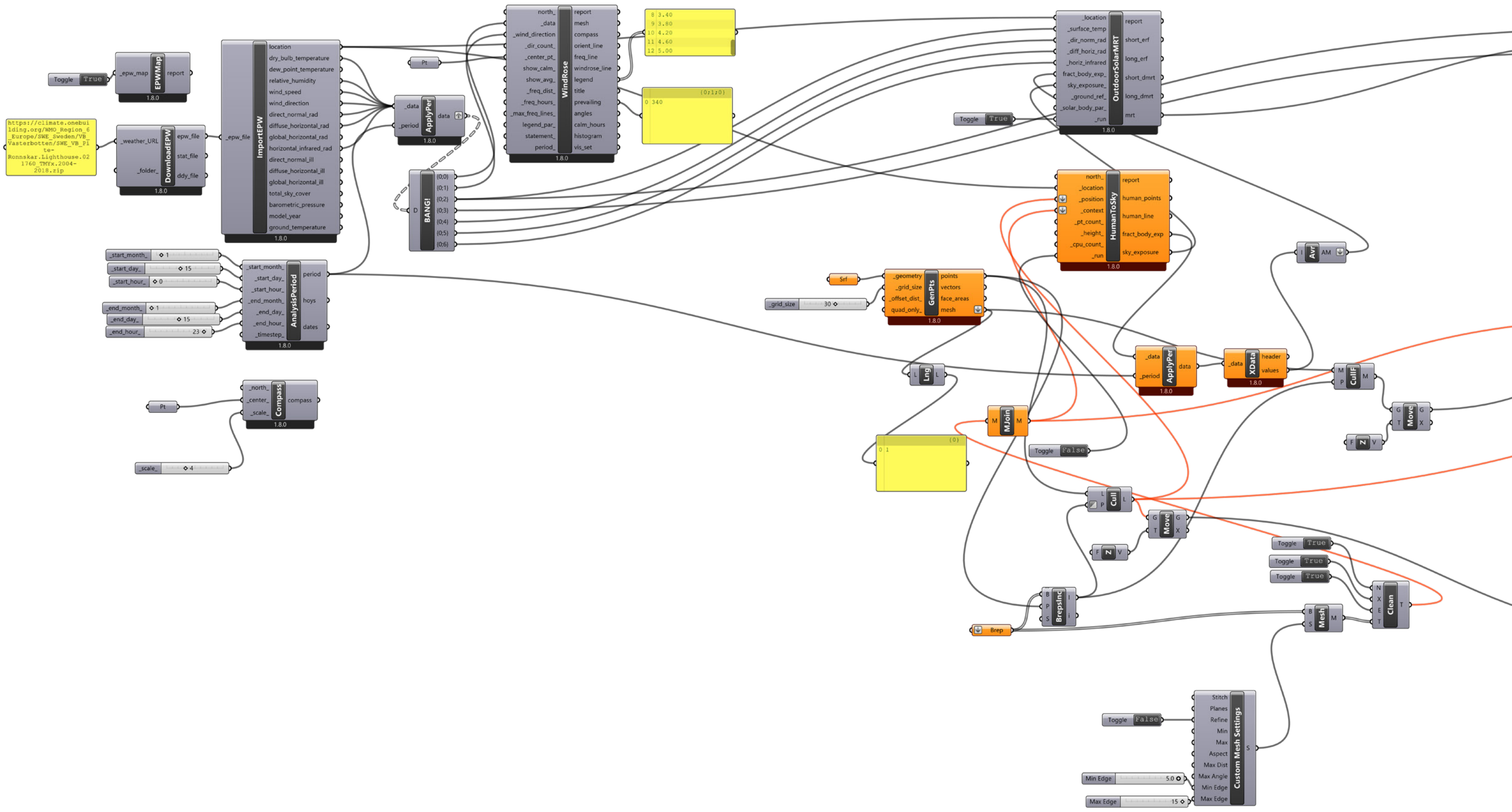
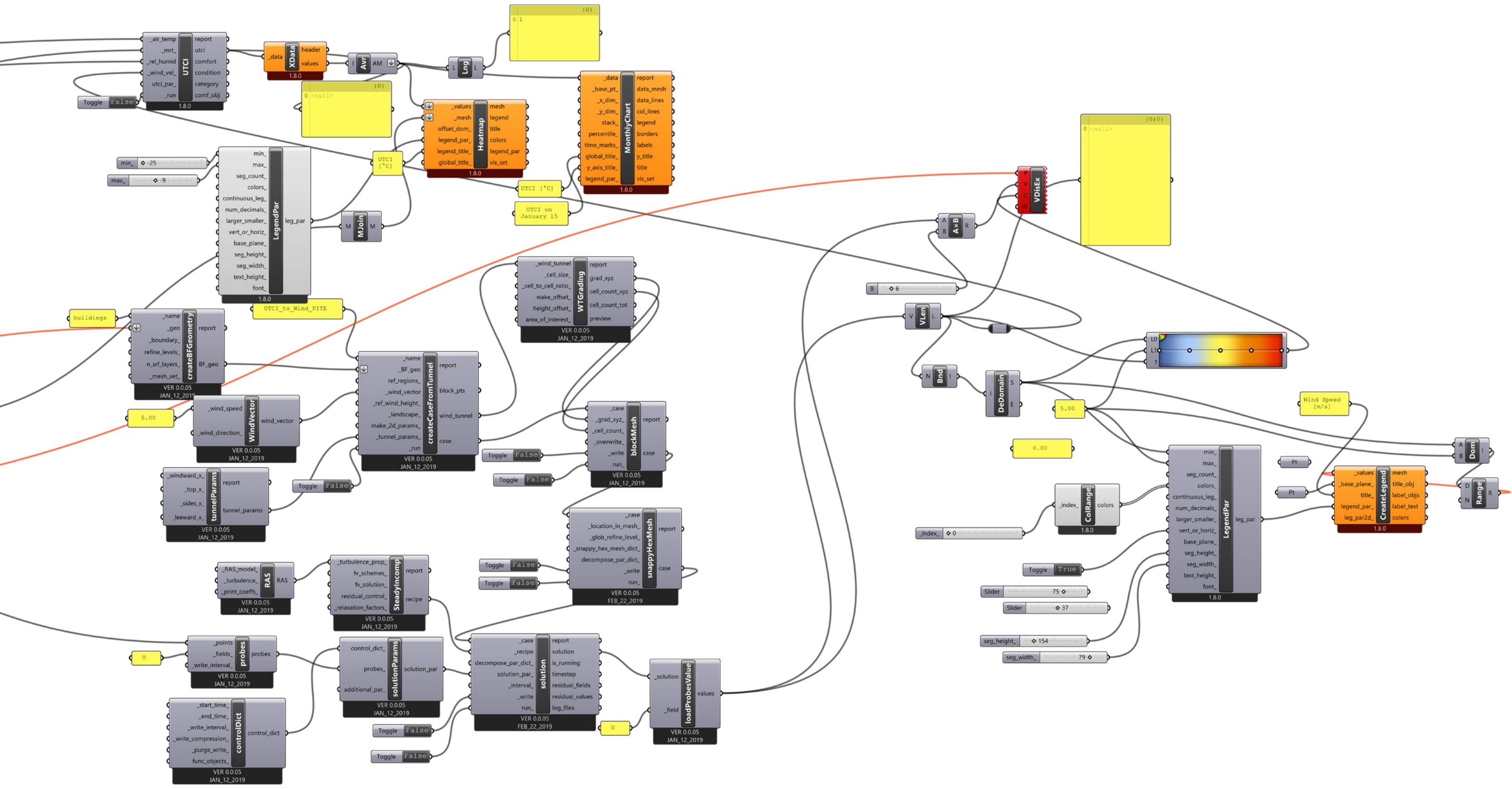
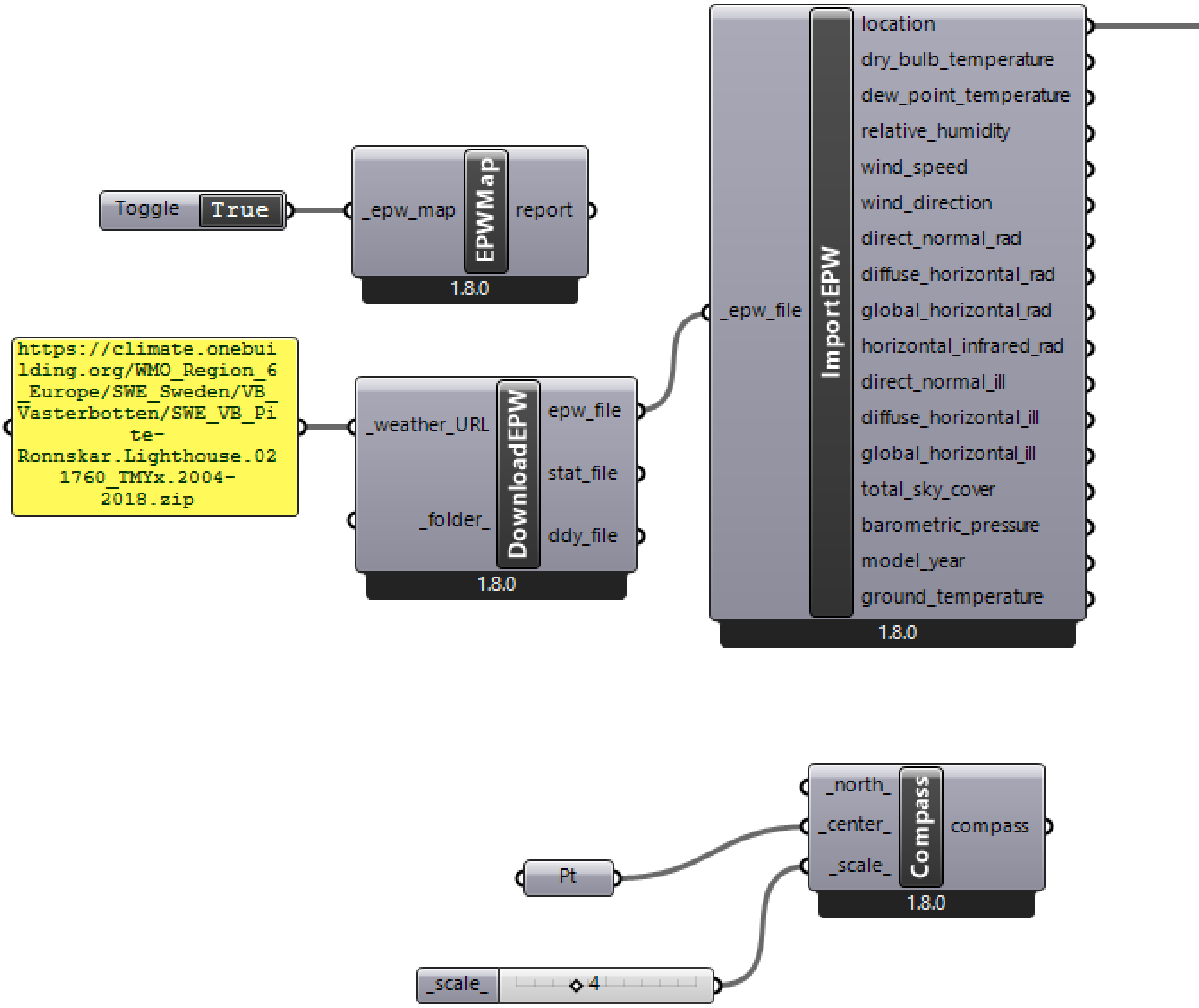


Figure 5 Grasshopper script for UTCI calculations. Full Script.


UTCI
Toggle False
XData
1.8.0
Avr
AM
Lng
{0}
<null>
Heatmap
MonthlyChart
UTCI [°C]
UTCI on January 15
VDisEx
{0;0}
LegendPar
min_ -25
max_ -9
MJoin
UTCI_to_Wind_PITE
buildings
createBFGeometry
VER 0.0.05
JAN_12_2019
createCaseFromTunnel
WTGrading
blockMesh
WindVector
5.00
tunnelParams
snappyHexMesh
RAS
SteadyIncomp
probes
solutionParams
solution
loadProbesValue
controlDict
U
FEB_22_2019
AxB
VLen
Bnd
DeDomain
ColRange
Wind Speed [m/s]
0.00
CreateLegend
Dom
Range
Pt
index 0
Toggle True
Slider 75
Slider 37
seg_height_ 154
seg_width_ 79

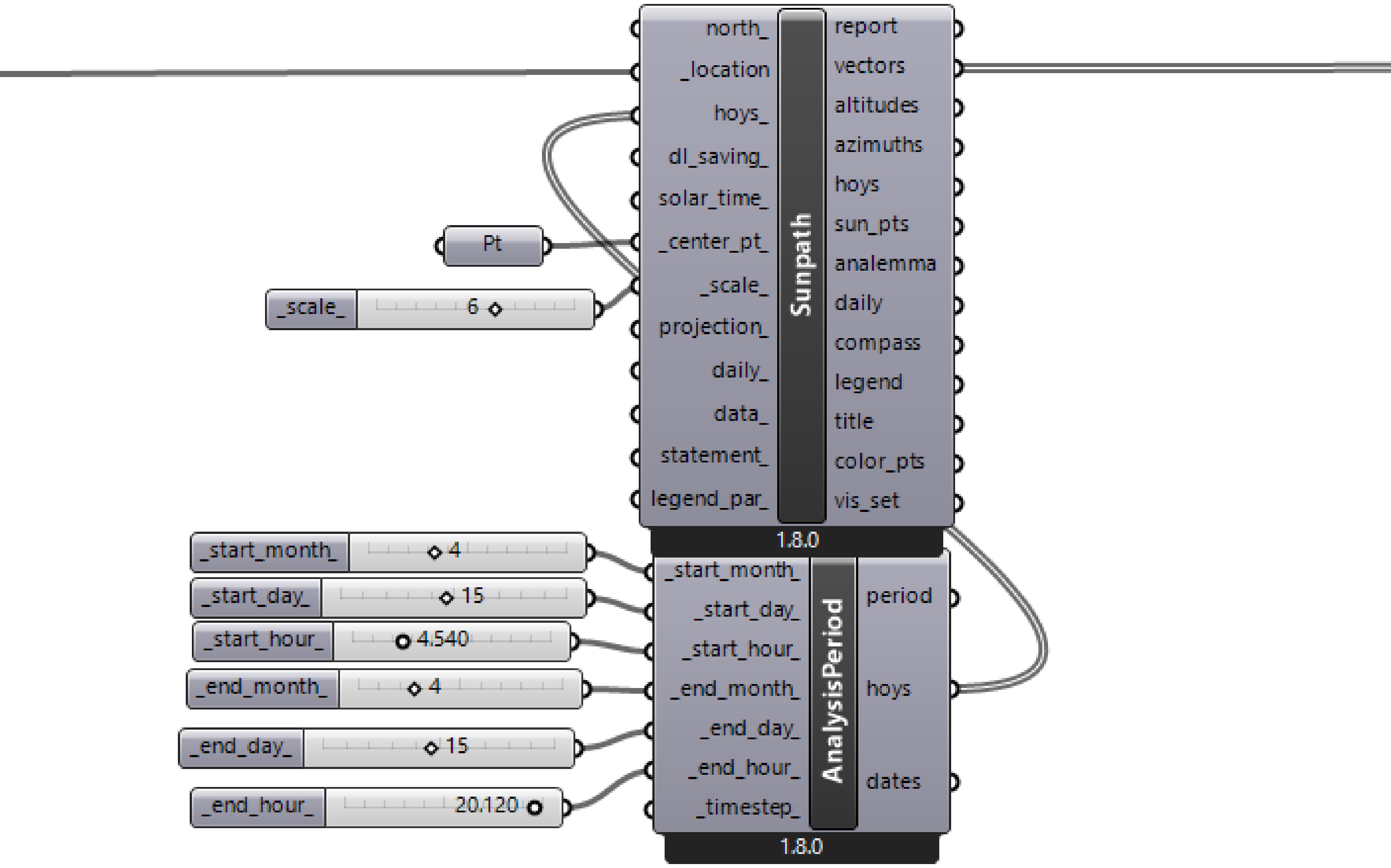
Appendix B

Direct Sun Hours Grasshopper Script



https://climate.onebuilding.org/WMO_Region_6_Europe/SWE_Sweden/VB_Vasterbotten/SWE_VB_Pite-Ronnskar.Lighthouse.021760_TMYx.2004-2018.zip

Figure 1. Grasshopper script for direct sun hours calculations. Input cluster, downloads and imports EPW climate data and location.



scale 6

_start_month_ 4

_start_day_ 15

_start_hour_ 4.540

_end_month_ 4

_end_day_ 15

_end_hour_ 20.120

Figure 2. Grasshopper script for direct sun hours calculations. Time and location setup cluster, sets analysis period, location, and sun path.

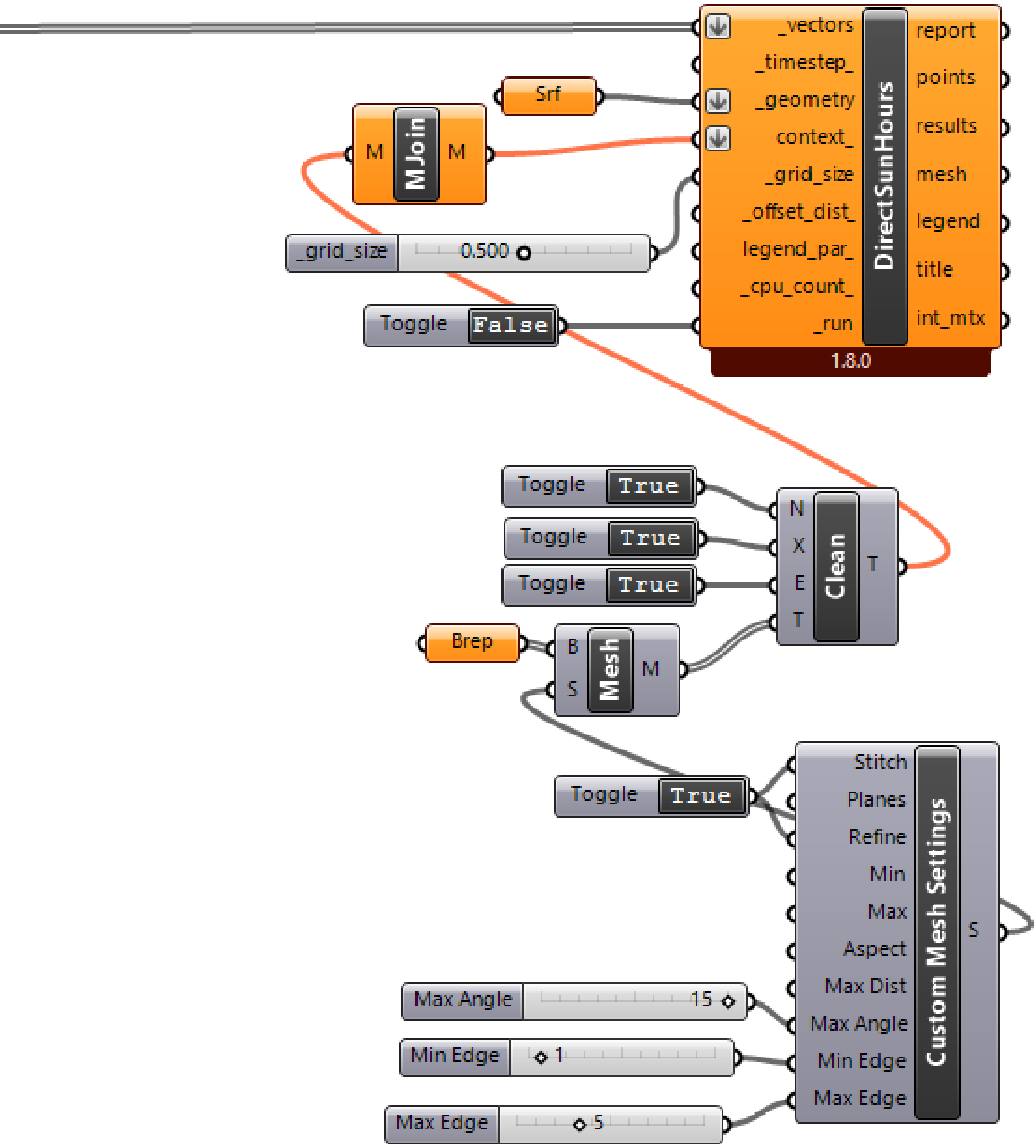


Figure 3. Grasshopper script for direct sun hours calculations. sun analysis cluster, calculates direct sun hours using solar vectors and displays results.

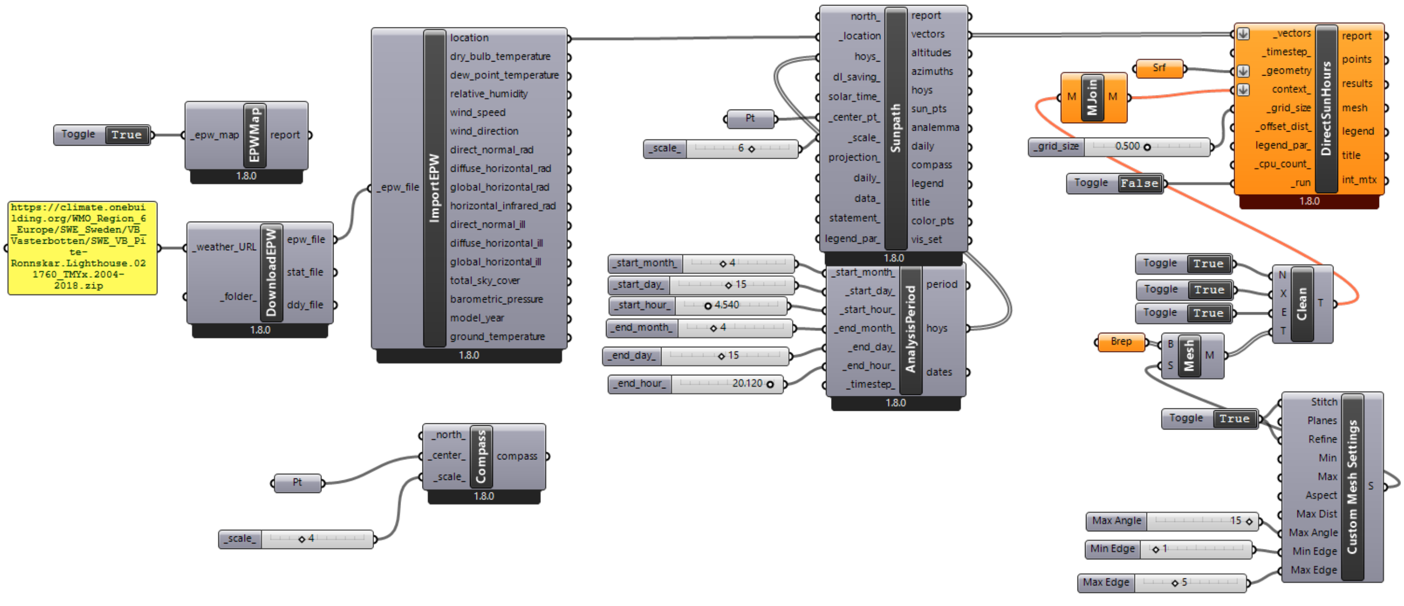


Figure 4. Grasshopper script for direct sun hours calculations. Full script.

AI Apendix

ChatGPT was used throughout the writing process of this thesis to assist with grammar and spelling correction. It was guided by a set of specific criteria aimed at rephrasing complex sentences, improving structure, and maintaining a consistent tone and style. These criteria were provided in an instruction box within a project folder named “Text Booklet,” which was used in conjunction with the ChatGPT tool.

The typical process involved copying and pasting sections of text into the ChatGPT chat box, where the content was rewritten based on the set criteria. This output was then further refined and rewritten by me. Usually, one to three iterations of this process were carried out for each section of text promted.

The criteria:

1. Simplify Complex Information

Act as a rewriting expert, your task is to rewrite the provided complex text, making it easier to understand for a general audience. The rewritten text should maintain the original meaning but should be written in simpler, more accessible language. The goal is to ensure that anyone, regardless of their background or level of education, can understand the information. Please ensure that the text is free from jargon and complicated terms. The tone should remain professional, but friendly and approachable.

2. Improve Clarity and Conciseness

As a rewriting expert, your task is to improve the clarity and conciseness of the provided text. This will involve assessing the existing content, identifying areas that can be simplified or clarified, and restructuring sentences where necessary. Make sure you maintain the original meaning while reducing verbosity and ensuring the text is easy to understand. The final product should be a clear, concise, and coherent version of the original text.

3. Formalize Informal Text

As a rewriting expert, you are to take the provided informal text and transform it into a formal composition. Ensure that the tone is professional and appropriate for a formal setting. Replace any slang or colloquial language with more sophisticated vocabulary, while maintaining the original message and intent of the text. The rewritten text should be grammatically correct and free of any informal abbreviations or contractions. Pay attention to sentence structure and punctuation as well to ensure that the text flows smoothly and logically.

4. Make Professional Text Sound Casual

As a rewriting expert, your task is to take the given text and rewrite it in a casual, conversational tone. The text should still convey the same message and information, but it should sound like it's being spoken by a friend in a casual setting. Use informal language and contractions where appropriate and aim to make the text engaging and easy to read. Be sure to maintain accuracy and clarity while transforming the tone and style of the text.

5. Tailor Content for Specific Audience

As a rewriting expert, your task is to modify the provided text to make it more appealing and relevant to the specified audience. The text must maintain its original intent and meaning, but the tone, style, and vocabulary should be adjusted to suit the audience's preferences, understanding, and interest. Ensure the rewritten text is engaging, easy to understand, and evokes the desired reaction or emotion from the audience.

6. No Em Dashes (—), En Dashes (–) , and Hyphens (-) when rewriting.

Example of one iteration of prompts and answers:

Prompt:

“To try to get similar results from the UTCI calculation, it was decided to add single-story buildings along a flat stretch of land directly Infront of the dock seating area as well as a larger two story building right next to the area to offer additional wind protection and to assess their effectiveness when used alongside the smaller pine trees.”

Answer from ChatGPT:

“To achieve similar results in UTCI measurements, single-story buildings were placed along a flat stretch of land directly in front of the dock seating area. Additionally, a larger two-story building was added nearby to provide further wind protection. These structures were introduced to evaluate their effectiveness in combination with the smaller pine trees.”

Example of two iterations of prompts and answers:

First Prompt:

“This chapter explores the the specific planning conditions of the case study, It explores environmental factors such as temperature fluctuations, snowfall patterns, rainfall. As well as the challenges that climate change presents for urban life and people in Piteå. Th chapter aims to provide insights into how the city can adapt to support year-round soft mobility and enhance the comfort of outdoor environments. including the Piteå’s Sörfjärden development plan and accompanying planning documents as well as the Solander ring master plan proposal, with the aim of creating a winter design proposal rooted in the local context and in line with the current pans. the current and projected climate of Piteå,”

First answer from ChatGPT:

“This chapter examines the specific planning conditions of the case study, focusing on environmental factors such as temperature changes, snowfall patterns, and rainfall. It also addresses the challenges that climate change poses for urban living in Piteå. The chapter aims to offer insights into how the city can adapt to support soft mobility throughout the year and improve the comfort of outdoor spaces. It reviews Piteå’s Sörfjärden development plan, related planning documents, and the Solander Ring master plan proposal, with the goal of developing a winter design strategy that reflects the local context and aligns with current plans and climate projections.”

Second Prompt:

“Can you make it more concise?”

Second answer from ChatGPT:

“This chapter examines the planning conditions in Piteå, focusing on climate factors like temperature shifts, snowfall, and rainfall, as well as the impacts of climate change on urban life. It explores how the city can adapt to support year-round soft mobility and improve outdoor comfort. The analysis includes the Sörfjärden development plan and the Solander Ring master plan, aiming to create a locally grounded winter design aligned with current and future climate conditions.”